Eye movements in overall similarity and single-dimension sorting.

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Abstract

A free classification study is presented that uses eye-tracking to better characterize the strategies that are employed in the creation of overall similarity and single-dimension categories. The number of fixations across the dimensions and the proportion of dimensions fixated were significantly greater for overall similarity sorters than for single-dimension sorters. Single-dimension sorters generally fixated a single dimension from the outset, a strategy in line with the principles of SUSTAIN (Love, Medin, & Gureckis, 2004). The pattern of eye movements is consistent with the idea that overall similarity sorting can be a time consuming process that involves greater perceptual processing of the stimuli than single-dimension sorting.

Keywords: free classification; family resemblance; unidimensional; eye tracking; match-to-standards.

Introduction

Categorization is a fundamental cognitive mechanism that enables us to function effectively in our everyday environment. However, in view of the immense number of objects we encounter, this process must necessarily be highly constrained. One reasonable assumption is that the categories we prefer to create would reflect the underlying structure of objects we encounter outside the laboratory. Perhaps the most influential theory of natural categories is the idea that they are organized around a “family resemblance” (overall similarity) structure (e.g., Rosch & Mervis, 1975), in which categories possess a number of characteristic but not defining features. If an item has enough features characteristic of a category it can be considered a member of that category.

Previous work has shown that when people are asked to free classify stimuli (i.e., categorize without feedback) they find it far from natural to sort by overall similarity. In fact, people have a strong tendency to classify on the basis of a single dimension (e.g., Ahn & Medin, 1992; Medin et al., 1987). Whilst manipulations of the method of stimulus presentation (Regehr & Brooks, 1995), the level of spatial integration of the stimuli (Milton & Wills, 2004), time pressure (Milton, Longmore, & Wills, 2008), perceptual difficulty (Milton & Wills, 2008), previous sort strategy (Milton & Wills, 2009), category structure (Pothos & Close, 2008), and background knowledge (Spalding & Murphy, 1996) all influence the extent of family resemblance sorting, such sorting is still far from ubiquitous. It therefore appears important to better understand the processes that are involved in different classification strategies.

Traditionally, single-dimension and overall similarity sorting are thought to be the result of different processes. Single-dimension sorting is believed to be the result of the analytic processing system which requires selective attention and is a relatively effortful and deliberate process whereby stimuli are broken down into their constituent dimensions and categorization is determined on the basis of a subset of these dimensions (E.E. Smith, Patalano, & Jonides, 1998). In contrast, overall similarity sorting is the result of a quick, automatic, non-analytic process, where stimuli are processed as integral wholes (e.g., J.D. Smith & Kemler Nelson, 1984). A number of studies have provided support for this distinction (e.g., Kemler Nelson, 1984; J.D. Smith & Kemler Nelson, 1984; Ward, 1983).

Recently, however, it has been proposed that overall similarity sorting, as well as single-dimension sorting, can be the result of analytic processes. Milton and Wills (2004) argued that an alternative way to sort by overall similarity may be for people to break the stimulus down into its constituent dimensions and then integrate these dimensions into a “majority-features” dimensional summation rule. One prediction of this account is that overall similarity sorting should take more time and require greater use of working memory than single-dimension sorting due to the greater complexity of the categorization rule. These predictions have been supported by Milton et al. (2008) who showed that the introduction of a concurrent task load reduced overall similarity sorting and increased single-dimension sorting. Similarly, they showed that a moderate time constraint reduced overall similarity sorting and increased single-dimension sorting. Such findings challenge a non-analytic account of overall similarity sorting.

Eye-tracking is a technique that could further our understanding of the approaches people employ to spontaneously construct overall similarity and single-dimension categories. To date, relatively few studies have used eye-tracking to investigate categorization (though see Kruschke, Kappenman, & Hetrick, 2005; Rehder & Hoffman, 2005a, 2005b; Wills, Lavric, Croft, & Hodgson, 2007). One important study, however, is that by Rehder and Hoffman (2005a), who used eye-tracking to study a version of Shepard et al.’s (1961) six classic categorization problems to provide evidence for the existence of multiple systems of category learning. They showed that participants learned to fixate dimensions in an optimal manner – at the end of learning, virtually all participants fixated only the dimensions relevant to the solution. That is, the pattern of eye movements was diagnostic of the dimensions participants used to make categorization decisions. Rehder and Hoffman (2005a) concluded that eye movements are highly correlated to the cognitive processes involved in a category learning task.

The present study used eye-tracking to investigate the pattern of eye movements involved in overall similarity and single-dimension sorting. This is, as far as we are aware, the first study to use eye-tracking to investigate the processes of free classification. As such, there is currently little understanding regarding differences in the way stimuli are actively perceived for overall similarity and single-dimension sorting. The present study should therefore be viewed as an interesting first-step in characterizing the pattern of eye movements in free classification. We predicted, based on the theory of Milton and Wills (2004), that overall similarity sorting would involve greater perceptual processing of the stimuli than single-dimension sorting and result in a more even distribution of attention across the stimulus dimensions. In contrast, single-dimension sorting would involve greater selective attention toward the chosen dimension.

Experiment

Method

Participants

31 undergraduates from Exeter University were recruited to take part either for course credits or a small payment.

Apparatus

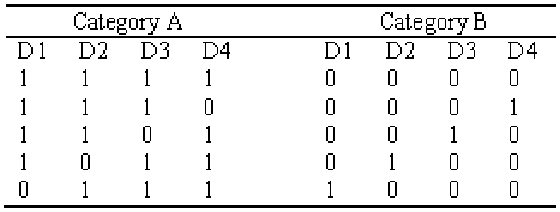
The categorization task was run using E-Prime on a Dell PC with a 22-inch color monitor and a standard computer keyboard. Participants sat approximately 0.5 meters away from the screen.

The Eyelink II system (SR Research Ltd., Osgoode, Canada) recorded movements in the right eye using a video based eye-tracker with a head movement compensation system connected to a Dell PC with a 17-inch TFT monitor. Eye movements were sampled at a rate of 500HZ. Pupil position was monitored via a miniature infrared CCD video camera mounted on an adjustable headband. Participants were asked to minimize head movements and this was sufficient to obtain accurate gaze position recordings.

Stimuli

The stimuli took the same abstract stimulus structure (shown in Table 1) as in Medin et al. (1987). The stimulus set consisted of four binary-valued dimensions (D1-D4) organized around two prototypical stimuli, each representative of a category. These prototypes were constructed by taking all the positive-valued dimensions for one of the stimuli and all the zero-valued dimensions for the other category. The remaining stimuli (one-aways) were mild distortions of the two prototypes in that they had three features characteristic of their category and one atypical feature characteristic of the other category. The stimuli (whose prototypes are shown in Figure 1) were the perceptually simple, spatially separable artificial "lampshades" used in Milton and Wills (2004), shown previously to be amenable to both overall similarity and single-dimensional sorting.

Table 1: Abstract stimulus structure



Category A				Category B			
D1	D2	D3	D4	D1	D2	D3	D4
1	1	1	1	0	0	0	0
1	1	1	0	0	0	0	1
1	1	0	1	0	0	1	0
1	0	1	1	0	1	0	0
0	1	1	1	1	0	0	0

Note. D = dimension: 1 and 0 represent the values of each dimension.

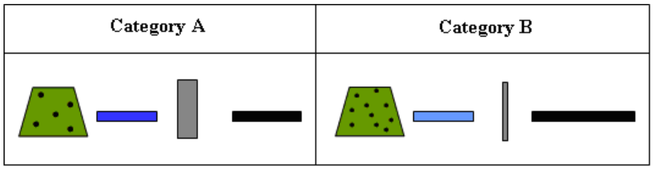


Figure 1: The two category prototypes.

Procedure

Participants were introduced to the stimuli by the matching-pairs task developed by Milton and Wills (2004). Two copies of each of the ten stimuli were spread out randomly in an array. Participants had to match these twenty stimuli into ten matching pairs correctly without feedback. If participants made any mistakes, the pairs had to be matched again. Next, the eye-tracker was fitted to participants who were then calibrated.

The categorization task consisted of 6 blocks of 10 stimuli. In each block, all the stimuli in the set were presented once in a random order. Before each block, experimenter-controlled drift corrections were performed to correct for drift in eye-movement position accuracy. These drift corrections comprised a 2000ms message instructing participants to fixate the cross in the middle of the screen, followed by the fixation cross itself. The offset of this cross was controlled by the experimenter and once the drift correction had been performed by the eye-tracking software, the first trial in the block began immediately.

Participants were asked to categorize the stimuli into two groups in the way that seemed most natural. Participants were informed that there was no one correct answer and that the two groups did not have to be of equal sizes. The method of stimulus presentation was a computer-based version of Regehr and Brooks's (1995) match-to-standards procedure and similar to that used in Milton, Wills, & Hodgson (2009). The category prototypes remained on the screen throughout each block with Category A in the top left portion and Category B in the top right portion of the screen. Labels, sized 5cm wide and 1cm high, marked

"Category A" and "Category B" were presented above their respective prototypes. The target stimulus for each trial was displayed in the lower middle portion of the screen. The prototypes and the target stimuli were all 17cm wide and 6cm high. Each stimulus remained on the screen until a response had been made (pressing either "c" or "m" on the keyboard for categories A and B respectively). The screen then went blank for 1000ms before the next trial began. At the end of each block, participants were asked to describe their sorting behavior in that block.

Eye movement analysis

Eye movements were viewed and analyzed offline using the EyeLink Data Viewer software. The mean position, duration and number of fixations in each stimulus "region of interest" (ROI) on each trial were outputted from the software for further statistical analysis. A rectangular ROI was placed around each stimulus dimension. In total, there were twelve ROIs: one around each of the four stimulus dimensions of the target stimulus (henceforth known as the *target dimensions)*, and one around each of the four dimensions of the two category prototypes. The number of fixations and the dwell time (the total viewing time) for each of these ROIs were calculated for each trial.

Sort type analysis

For each block, two sources of information were used to classify the sort produced: the description the participant used and the categories they constructed. The categories these sorts were placed into were identical to those used in Milton and Wills (2004). The different sort types are summarized below.

An *overall similarity sort* has a structure identical to that shown in Table 1. To receive this classification, the prototypes, along with their derived one-aways, had to be placed into separate categories without error. Sorts that took this structure but which contained a solitary error were classified as *1-away overall similarity* sorts.

A *single-dimensional* sort is based on a single dimension of the stimulus. It does not matter which dimension is used as the basis of sorting, so long as all the positive values for the chosen dimension were in one category and all the zero values for that dimension were in the other category. If participants made a single error in such a sort, it was classified as a *1-away single-dimensional* sort.

Participants had to not only produce a particular sort type but also describe their sort as being based on that particular strategy for it to be classified in that way. All sorts that did not meet this criterion were classified as *other* sorts.

Results and Discussion

For each participant, the sort type for each block was analyzed independently. Each sort was placed into one of three categories: overall similarity, single-dimensional and "other" (the overall similarity and single-dimensional categories were combined with their respective 1-aways). As in Milton and Wills (2004), there was a bias toward overall similarity sorting for this particular stimulus set but single-dimension sorting was sufficiently prevalent to enable informative comparisons between the two strategies. "Other" sorts were of low prevalence (although two participants used an "other" strategy throughout) and are not included in the following analyses.

Table 2: Sort type

	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6
OS	16	14	16	18	17	19
1-D	12	13	10	11	11	9
Other	3	4	5	2	3	3

Note. OS = overall similarity; 1D = single-dimensional.

In Table 2, sorts are classified on a block-by-block basis – each sort is classified independently and placed into the appropriate category. Whilst participants were generally consistent in their sort strategy, some did not sort consistently throughout the entire experiment. This means that, under this particular classification measure, each block must be treated independently of the others, which precludes analysis of block effects which may provide valuable information about the way overall similarity and single-dimensional sorting changes over time. Therefore, as a complement to the block-by-block analysis, participants were also classified by their majority sort type, a measure which permits analysis of block effects. In total, seventeen participants were classified as overall similarity sorters and eleven participants as single-dimensional sorters (two participants who sorted by an "other" strategy throughout, and one who sorted equally by overall similarity and single-dimensionally were excluded from majority sort analyses). Each figure presents the results for both the "by-block" (plot symbols) and the "majority sort" classifications (lines). For conciseness, the statistical analyses will only be presented for the majority sort type classification. Analyses of the "by-block" data resulted in the same conclusions as the "majority sort" data.

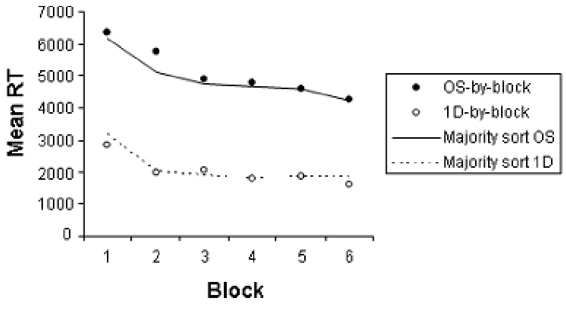


Figure 2: The mean response time on each trial for overall similarity and single-dimensional sorters.

The mean response time for the two conditions is shown in Figure 2. An ANOVA with one within-subject variable (block, 6 levels) and one between-subject variable (sort type, two levels) yielded a significant effect of sort type, F(1,26) = 27.770, p < .0001, with overall similarity sorters taking longer on each response than single-dimensional sorters. There was also a significant effect of block, F(5,130) = 9.691, p < .0001 (the Greenhouse-Geisser correction was applied here and subsequently where appropriate), with response time decreasing across blocks. There was no significant interaction between block and sort type, F(5,130) = .486, p > .4.

The finding that overall similarity sorters take longer to sort the stimuli is contrary to some previous work (e.g., Ward, 1983) but in line with the results of Milton et al. (2008). The present study extends the findings of Milton et al. (2008) by demonstrating that the effect generalizes to a self-paced categorization procedure.

Target dimensions

The mean number of fixations on the target dimensions across blocks by sort type is shown in Figure 3a. There was a significant effect of sort type, F(1,26) = 28.873, p < .0001, with overall similarity sorters fixating the target dimensions to a greater extent than single-dimensional sorters. There was no effect of block, F(5,130) = .341, p > .5, and no interaction between block and sort type, F(5,130) = .723, p > .5. Similar analyses were performed using the dwell time measure and produced identical conclusions to the fixation measure for this and subsequent analyses for which both measures are applicable. For conciseness, dwell time analyses are not reported here.

Figure 3b shows the mean number of target dimensions fixated per trial across blocks by sort type. There was a significant effect of sort type on the number of target dimensions fixated, F(1,26) = 66.165, p < .0001, indicating that overall similarity sorters fixated more of the target dimensions than did single-dimension sorters. There was no effect of block, F(5,130) = .486, p > .7, and no interaction between block and sort type, F(5,130) = 1.608, p > .05.

Figure 3b indicates that participants who sorted single-dimensionally generally fixated only one dimension from the first block onwards. This suggests single-dimensional sorters were disposed from the outset to a one-dimensional solution, rather than fixating all the available information before selecting a single-dimensional rule. Such a strategy is in line with the spirit of models such as RULEX (Nosofsky, Palmeri, & McKinley, 1994) and SUSTAIN (Love, Medin, & Gureckis, 2004), which assume that people are generally inclined to form single-dimension hypotheses.

The pattern of fixations for the overall similarity sorters (Figure 3b) is in line with a dimensional summation account of overall similarity sorting. If participants have perfect knowledge of the category structure and fixate only where necessary, the most efficient possible means of performing a dimensional summation strategy is by fixating an average 2.4 of the target dimensions for each stimulus in a block (assuming participants use a two-out-of-three majority features rule). For instance, if participants use dimensions 1 and 2 from Table 1, the category membership of the top three stimuli in each category can be established on the basis of these two dimensions. The remaining four stimuli require use of a third dimension to consistently sort by a majority features rule. Fixating two dimensions on six of the stimuli and three dimensions on the remaining four stimuli gives an average 2.4 fixations on each stimulus per block. A level of fixation below this figure would be highly problematic to a dimensional summation account. One sample t-tests (using the "by-block" measure) show that the mean number of fixations for overall similarity sorters is significantly above this figure for all six blocks (minimum t = 3.46, all Ps < .005). The number of target dimensions fixated is therefore in line with a dimensional summation account of overall similarity sorting.

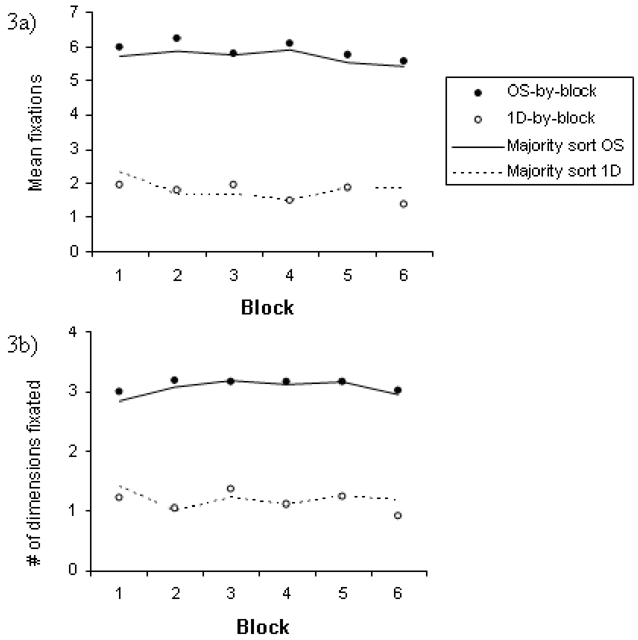


Figure 3: a) The mean number of fixations on the target stimulus; b) the mean number of target dimensions fixated on each trial.

An alternative analytic strategy of overall similarity sorting is the single dimension-plus-exception rule (e.g., Ward & Scott, 1987), in which participants focus upon a single dimension but will memorize stimuli that do not fit this rule. If participants utilize all the information they fixate, then the optimum number of fixations for a single dimension-plus-exception strategy would be 1.6 for each trial (1 dimension fixated on 8 stimuli and 4 dimensions fixated on 2 stimuli). One sample t-tests (using the "by-block" measure) reveal that the level of fixations was significantly greater than this figure for each block (minimum t = 6.672; all Ps < .0001). Whilst one cannot rule out the possibility that participants were fixating dimensions that they did not incorporate into the decision process, the pattern of fixations appear more in line with a dimensional summation account of overall similarity sorting than a single dimension-plus-exception strategy. Furthermore, studies which have produced the most persuasive evidence for a single dimension-plus-exception strategy have all employed a supervised learning procedure (e.g., Ward & Scott, 1987), which provides trial-specific feedback that clearly identifies the exceptions to an adopted single dimension rule. In a free classification study, the challenges faced by a participant adopting a single dimension-plus-exception rule seem greater - they would have to identify for themselves which stimuli were, on an overall similarity basis, an exception to their self-generated single-dimension rule.

In summary, these findings suggest a qualitative difference in the way overall similarity and single-dimension sorters process the stimuli. From the first block onwards, overall similarity sorters focus on a larger proportion of the available information than do single-dimensional sorters. This suggests that differences in sort strategy may be due to the way stimuli are actively perceived rather than to different decisional mechanisms operating on the same set of percepts.

Category Prototypes

Similar analyses to those reported for the target stimuli were performed for the category prototypes. Figure 4a shows the average number of fixations on a prototype stimulus across blocks by sort type. There was a significant effect of sort type, F(1,26) = 17.835, $p < .0001$, indicating that overall similarity sorters fixated the prototypes to a greater extent than did single-dimension sorters. There was also a significant effect of block, F(5,130) = 3.524, $p < .05$, showing that fixations to the category prototypes decreased across blocks. The interaction between block and sort type did not reach significance, F(5,130) = 1.272, $p > .2$.

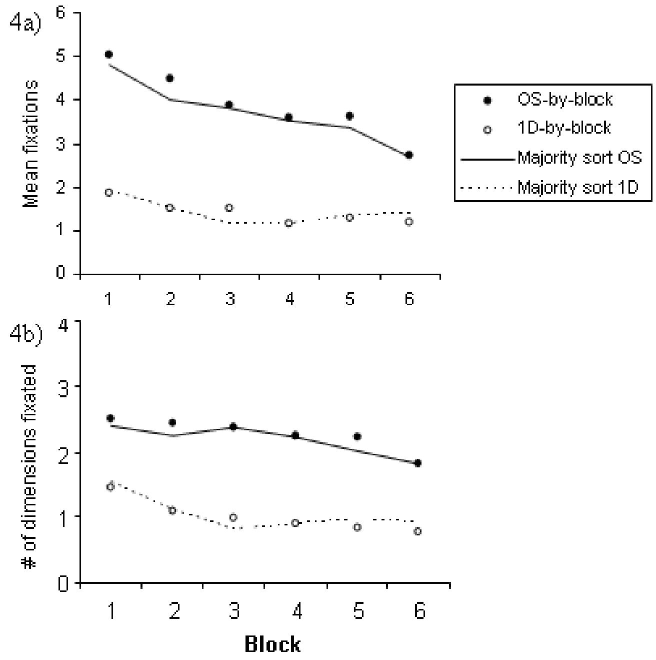


Figure 4: a) The mean number of fixations on each prototype; b) the mean number of dimensions fixated on each prototype.

Figure 4b shows the mean number of dimensions fixated on each prototype for overall similarity and single-dimensional sorters. There was a significant effect of sort type, F(1,26) = 37.222, $p < .0001$, indicating that overall similarity sorters fixated a greater number of the prototype dimensions than did single-dimension sorters. There was also a significant effect of block, F(5,130) = 3.897, $p < .02$, showing that the number of prototype dimensions fixated decreased across blocks. The interaction between block and sort type was not significant, F(5,130) = 1.92, $p > .1$. These results show that overall similarity sorters not only fixate the prototypes to a greater extent but also fixate a larger number of the prototype dimensions. These findings again indicate that overall similarity sorting involves greater perceptual processing of the stimuli than single-dimension sorting.

Taken together, the eye movements to the category prototypes again indicate that overall similarity sorters fixate more and process a greater proportion of the available information than single-dimensional sorters.

General Discussion

The present study investigated the pattern of eye movements associated with overall similarity and single-dimension sorting. In line with the work of Milton et al. (2008), in a self-paced free classification task, we found that overall similarity sorters took significantly longer to classify the stimuli than did single-dimension sorters. This is in line with the idea that overall similarity sorting can be a more time consuming process than single-dimension sorting (Milton et al., 2008), but somewhat contrary to the findings of Ward (1983) and J.D. Smith & Kemler Nelson (1984). A more detailed discussion of the effect time has on free sorting behavior can be found in Milton et al. (2008).

Additionally, overall similarity sorters fixated on the target stimulus to a greater extent and fixated a greater proportion of the target dimensions than did single-dimension sorters. Corresponding results were found for the category prototypes. This pattern of eye movements is consistent with a dimensional summation account of overall similarity sorting (Milton & Wills, 2004). That is, participants selectively attend to each dimension in turn and incorporate these dimensions into a majority features decision rule.

Single-dimension sorters tended to fixate a single-dimension from the outset, rather than fixating all the available information before selecting a single-dimensional rule, which is consistent with the assumption of models such as SUSTAIN (Love et al., 2004) and RULEX (Nosofsky et al., 1994). This finding is, however, somewhat surprising given that Rehder & Hoffman (2005a) showed, in a *supervised* categorization task, that participants who were required to find a single-dimensional rule initially focused on all of the dimensions before selectively attending to the relevant dimension. This suggests that participants approach supervised and unsupervised categorization tasks in a different way. One reason for this may be that, in supervised categorization, participants are initially unaware of the correct rule and it appears adaptive to process more of the dimensions to help the development of subsequent strategies. In contrast, in unsupervised categorization, there is no correct rule so it is less useful to process information not utilized in the chosen categorization strategy.

Taken together, these findings suggest a qualitative difference in the way overall similarity and single-dimensional sorters process the available information – single-dimensional sorters process less information than overall similarity sorters do. It also suggests that differences in sort strategy may be due to the way stimuli are actively perceived rather than to different decisional mechanisms operating on the same set of percepts.

Whilst the use of spatially separable dimensions is prevalent in previous categorization studies, it remains to be seen how the current results generalize to more naturalistic stimuli. Future work should explore the pattern of eye movements to stimuli where the dimensions are integrated into a more coherent unit. In addition, whilst this study provides support for an analytic account of overall similarity sorting, it remains to be seen whether the findings extend to categorization under time pressure which has traditionally been used to distinguish between different processes.

In conclusion, the present study, using a self-paced free classification task, showed that overall similarity sorting is a more time consuming process than single-dimension sorting and involves greater perceptual processing of the stimuli. These findings are in line with an analytical, dimensional summation account of overall similarity sorting.

Acknowledgments

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