Redundant Coding Can Improve Segmentation in Multiclass Displays

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Abstract

Data visualizations allow viewers to compare one dataset to another. The visual marks that represent these datasets, or *classes*, are visually distinguished from one another by salient visual feature differences, such as color or shape. A designer of a graph or map might encode one class of marks as either red, or circular, and another class as either green, or square. One common technique is to combine these cues in a redundant fashion, encoding one class as red *and* circular, and the other as green *and* square, under the assumption that a larger difference (via *multiple* differing features) should help. Despite the ubiquity of this practice, we know of no empirical demonstration that reveals evidence of a potential benefit. Across two experiments, we demonstrate that redundant coding can improve visual segmentation of a simulated dataset in a crowded display (Experiment 1) and that redundant coding also leads to stronger visual grouping of elements (Experiment 2).

Keywords: Perceptual psychology, Information visualization, Visual grouping.

1 Introduction

Graphs and maps often depict multiple datasets, or *classes*, that are important to distinguish quickly and efficiently. Typically, these classes are designated by differences in easily perceived visual features, such as colors (e.g., red and green data points) or shapes (e.g., circular and square data points). But such cues are often used in combination (e.g., shape *and* color, such as a graph with red circles and green squares) as a redundant coding of the class designations. This technique is commonly employed within visual displays of information – for example, it is a default setting for the creation of new graphs created in Microsoft Excel. Redundant coding is assumed to improve a viewer's ability to isolate and compare data points from a given set of classes, or to help link legends to data [1].

However, some might consider redundant coding to be gratuitous, and even inelegant, by violating the rule that data displays should be as simple and unembellished as possible [2-3]. Redundant coding might leave viewers confused – at least temporarily – about which dimension links legend terms to data, or whether the independent dimensions reflect different aspects of the data or data types. Given these potential drawbacks, it is surprising that, to our knowledge, no study has ever demonstrated that redundant coding of visually presented information can improve visual processing of data displays. This fact is particularly striking because of the ubiquity of this technique.

Several studies [4-6] are often cited as showing an advantage for redundant coding, but these studies typically employ tasks that are only distantly related to class segmentation in data displays. Many of these studies require precise categorization of the value (e.g., color, size, or position) of an object along a dimension (e.g., is this the second reddest?), amid closely spaced alternative values from a predefined set of categories (e.g., this object is reddish-orange, not reddish; this object is the second biggest). While these examples are often cited in data visualization textbooks as a best available argument for their use (e.g., [1]), these tasks do not reflect the demands of perceiving visual data displays, because they show an advantage for redundant coding for categorizing single objects among closely spaced alternatives. In contrast, visual data displays require observers to segment an entire collection of objects (pick out the bright ones), among widely spaced alternatives (red, green, or blue).

In fact, when one recent study tested the effectiveness of redundant coding in a set of tasks that better simulated the demands of viewing a data display (deciding which of two classes in a scatterplot had the higher average value), there was no evidence of an advantage for redundantly coded displays [7]. While this single study casts doubt on the usefulness of redundant coding, it relied on an average value estimation task, which we suspect may be too easy and noise-resistant to reveal an advantage of redundant coding.

Here we show that this lack of a benefit for redundant coding does not generalize across all new experimental tasks. Experiment 1 shows that redundant coding improves detection of a spatial pattern in briefly flashed displays, while Experiment 2 shows that redundant coding can strengthen visual grouping among a set of visual objects.

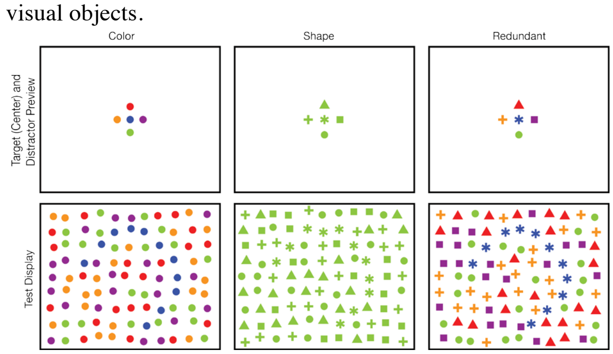

Figure 1: In Experiment 1, participants saw a preview screen (top row; until response), followed by a fixation cross (1000 ms), and test display (bottom row; staircased, beginning at 200 ms (M = 88 ms)). Trials concluded with a colorful mask screen until participants responded with which quadrant of the screen lacked target objects. Target objects differed from distractors either by color (left), shape (center), or color and shape redundantly (right).

2 Experiment 1

We constructed an abstracted task designed to emulate situations in which observers judge the shape of the distribution of the data points that constitute a class (Figure 1). Eleven target objects formed a partial ring embedded among 88 distractor objects. Thirty-six participants were asked to indicate the quadrant of the screen where the target object ring was missing elements. After previewing target and distractor objects, the display was rapidly flashed. We included the target and distractor object preview to

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simulate the experience a viewer should have from previous experience with a specific display (including knowledge of the relevant and irrelevant features within it).

Target objects (e.g., blue circles) were identical to each other, and differed from distractors in color only (*color* trials), shape only (*shape* trials), or in both color and shape dimensions (*redundant* trials). Trials were presented randomly in this within-subject design. Experiments 1a-1c replicated the findings across three target color-shape combinations: blue asterisk, red triangle, and blue circle, respectively. If attending to objects encoded by redundant dimensions yields better visual selection and subsequent global shape detection, then participants should be most accurate in the *redundant* condition.

2.1 Results & Discussion

Confirming a redundancy benefit, we found that performance in the *redundant* condition was approximately 25% more accurate overall (Exp. 1a: M = 92.3%, SD = 4.7%; Exp. 1b: M = 86.5%, SD = 4.3%; Exp. 1c: M = 84.5%, SD = 6.4%), and significantly higher than whichever condition – *color* or *shape* – was better for each participant (average accuracy for participants' best condition (*color* or *shape*) – Exp. 1a: M = 71.4%, SD = 7.1%; Exp. 1b: M = 71.7%, SD = 7.3%; Exp. 1c: M = 71.4%, SD = 8.9%), as indicated by a two-tailed t-test, Exp. 1a: $t(10) = 11.7$, $p < 0.001$; Exp. 1b: $t(11) = 5.5$, $p < 0.001$; Exp. 1c: $t(12) = 5.5$, $p < 0.001$.

We replicated this finding in another experiment (not described due to space limits) in which the preview screen revealed only the target object so that participants could not infer whether the target is redundantly coded via comparison with the distractors. Again, we found an overall 27% advantage for redundant coding.

3 Experiment 2

Experiment 2 (Figure 2) tested whether redundant coding leads to stronger visual grouping, using a common measure from perceptual psychology – the repetition discrimination task [8]. Participants were shown a row of 7 H's and A's that alternated except for one repetition of one of the letters (e.g., H A H A A H A). Fifteen participants indicated the repeated letter as quickly as possible. The letters were contained within objects that alternated in features across either only one dimension (*shape* trials alternated pairs of squares and curved squares, and *luminance* trials alternated pairs of light green and dark green objects) or redundantly across both dimensions. Repeated letters were either on two objects with different features (*between-group* trials; e.g., an A on a dark green square next to an A on a light green square; Figure 2 – 3rd row) or matching features (*within-group* trials; e.g., an A on a dark green square next to another; Figure 2 – 4th row). Trials were presented randomly in this within-subject design. For correctly answered trials, grouping strength is revealed by the reaction time advantage for within-group repetitions over trials with between-group repetitions.

3.1 Results & Discussion

We found a significant interaction between letter repetition location and similarity grouping cue, $F(2,28) = 46.1$, $p < 0.001$. Specifically, the within/between-group reaction time difference was greater for *redundant* trials (M = 582 ms, SD = 254 ms) than for *shape* trials (M = 268 ms, SD = 131 ms), $t(14) = 6.8$, $p < 0.001$, and *luminance* trials (M = 211 ms, SD = 156 ms), $t(14) = 7.9$, $p < 0.001$. This time difference was also significantly greater than whichever single grouping cue (shape or luminance) produced the greatest reaction time difference for each subject (M = 295 ms, SD = 142 ms), $t(14) = -6.6$, $p < 0.001$. Thus, similarity grouping is stronger when objects are redundantly similar than when similar by only a single feature.

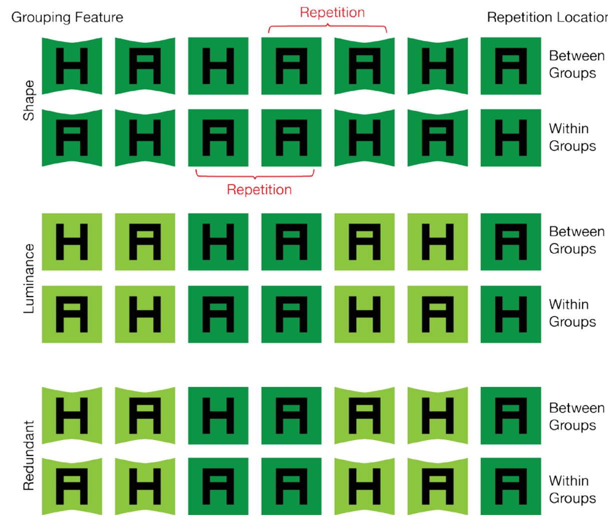

Figure 2: Stimuli for Experiment 2, in which detection of the repeating letter is slower when they are between (vs. within) groups defined by shape (top), luminance (middle), or shape and luminance redundantly (bottom).

4 Conclusion

Redundant coding can improve visual differentiation of classes in a crowded display (Experiment 1) and leads to stronger visual grouping of objects (Experiment 2). While work will be needed to distinguish the conditions under which redundant coding does and does not improve viewer performance, to our knowledge the present results provide the first positive evidence that this technique can improve performance in the types of tasks and displays used in data visualizations.

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