Studying the perception of color components' relative amounts in blended colors

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Abstract
Visualization provides the means for a natural information interpretation with low cognitive loads. In such context, color is a powerful way to convey information properties. One use of color in visualization is color blending, in which distinct colors represent different data properties and one data item which verifies more than one property is represented in a color that consists of blending its properties' colors. Humans are able to perceive the original components that generate particular colors. However, the amount of each color component may not be evident, possibly making it difficult for users to quantify the relative relevance of the each property. We have performed a user-study to verify to which extent people can perceive relative amounts of color components in blended colors. Results of our study have provided a set of guidelines to follow when using color blending for in information visualization.

Author Keywords
Human Perception, Color Blending, Information Visualization, Human-Computer Interfaces

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

Introduction

Visualization is a powerful tool for information representation, easing cognitive load associated with data interpretation [7]. Given the potential of color for highlighting information, the representation of data entities as visual objects, in which colors naturally code their attributes, seems relevant. Hence, depicting data entities which verify more than one property in a color which results from blending the original colors of its attributes seems a natural choice.

Considering human perception of color blending, in particular the extent to which humans are capable of perceiving the original components of a blended color, there are pairs of colors which provide best results when blended together [3, 2]. However, humans can distinguish a limited set of colors [7], which suggests a careful use of color blending so that information is properly perceived by users. Taking into account the aforementioned pairs of colors, we have performed a user study to provide further insight on human perception component ratio in a blended color, allowing us to draw some guidelines on the use of color blending.

This document is organized as follows. We introduce several concepts regarding color representation and present relevant work in the context of our research. Then, we describe our study and analyze its results, drawing some conclusions and design implications on using color blending on information visualization.

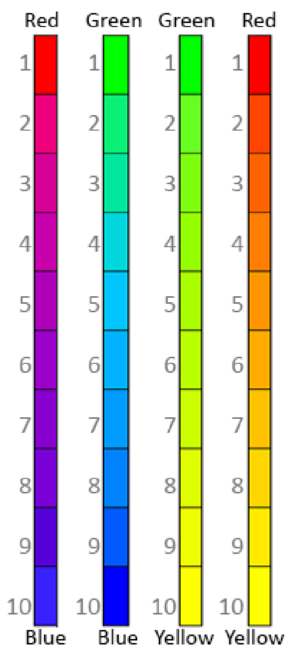

Figure 1: Set of 40 blended colors, 10 for each pair of color components (*(red, blue)*, *(green, blue)*, *(green, yellow)* and *(red, yellow)*, numbered from 1 to 10.

Background

Color has a great potential in visualization, allowing the representation of data entities in a way that alleviates cognitive load associated with information interpretation. One interesting use of color in visualization is color blending. In fact, different color blending techniques have been studied and a number of researchers have also studied color blending for visualization. For instance, Gossett and Baoquan [4] aim at improving visualization using color to convey data properties. A subtractive color space has been adopted which uses red, yellow and blue as primary colors. Noise patterns are procedurally generated to create subregions of easily identifiable colors within a mixed region as a complement to color blending. On a different note, Hagh-Shenas et al. [5] studied information-carrying capacities of color blending and color weaving to encode multivariate information in map-reading. Livingston and Decker [6] have also studied color blending, among other techniques, to represent trends among data layers on a demographic survey. Even though color blending yielded excellent response times, accuracy was not as promising. Although relevant in such particular contexts, previous research has not provided guidelines on how to use color blending in an effective manner. We attempt at overcoming this limitation, by understanding human perception of color blending.

Studying the perception of color components' relative amounts in blended colors

Considering the most appropriate color pairs for blending (*(red, yellow)*, *(green, yellow)*, *(green, blue)* and *(red, blue)*) [3], we attempted at finding out to which extent humans are able to perceive the amount of each component in a particular color. We performed 10-step color interpolation for each color pair, ranging from the first color component to the second, resulting in 40 different colors (Figure 1). We used this set in our study by presenting color individually to find out how human perception of the relative amount of each color component in a blended color.

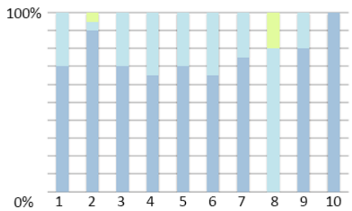

Figure 2: *(red, yellow)* deviation.

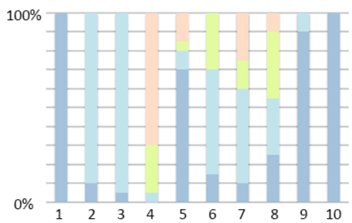

Figure 3: *(green, yellow)* deviation.

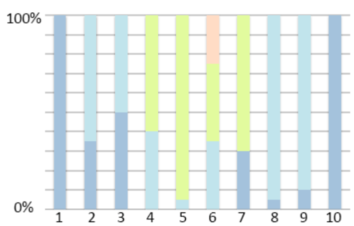

Figure 4: *(green, blue)* deviation.

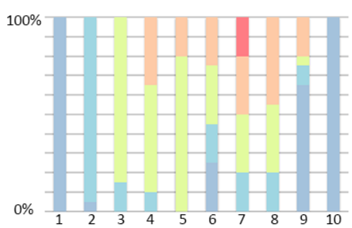

Figure 5: *(red, blue)* deviation.

Designing the user study

The study consisted of a four-stage questionnaire: subjects were asked a small number of profiling questions (age, gender, education, nationality and country of residence), followed by a validated simplified 6-plate Ishihara color blindness test [1]. Then, subjects were presented with each of the 40 blended colors individually, in a random order, and asked to rate these from 1 (only the first color component) to 10 (only the second color component). Finally, subjects were asked to rate, using a 5-point Likert scale (1=completely disagree; 5=completely agree), the following statement: *I found it easy to decide the amount of each color component in the given color.*

Conducting the color study

We performed our study in a laboratory with constant lighting conditions. Subjects were given a brief description of the study and asked to fill in the questionnaire.

Results

Tests were conducted with 20 participants, 13 (65%) between 16 and 25 years of age and 7 (35%) between 26 and 35. Considering gender, 10 (50%) subjects were male and the remaining 10 (50%) female. 14 (70%) currently attend BsC programs and 6 (30%) currently attend MsC programs. All 20 (100%) are european and live in europe. Also, all 20 (100%) participants have normal color vision.

When analyzing results of perception of color component weights in each blended color, besides considering correct answers (in which participants were able to understand the component ratio), we took into into account the deviation between the correct color and the answer provided by users, in terms of points. For instance, if the current sample corresponded to color 2 and the participant labeled it as color 1, the answer is classified with a deviation of 1 point.

Figures 2, 3, 4 and 5 represent, for each color pair, deviation values for each color from 1 through 10. Colors range from dark blue (deviation=0) to red (deviation=4).

Results suggest that participants perceive most colors correctly regarding the pair *(red, yellow)*. Another trend seems to emerge: colors in both extremes are easily perceived by subjects, including the pairs with less encouraging global results (*(green, yellow)*, *(green, blue)* and *(red, blue)*). Regarding such pairs, hit rates for blended colors with similar component quantities relatively low. In fact, if we exclude pure colors, absolute success rates are, in average: $\overline{X_{GY}} = 28\%$, $\sigma = 33\%$, $\overline{X_{GB}} = 16\%$, $\sigma = 19\%$, $\overline{X_{RB}} = 12\%$, $\sigma = 23\%$.

To further investigate these findings, we computed the absolute deviation values for all colors of each pair (Figure 6). *Central colors* are, in general terms, the most problematic. Even though deviation for the *(red, yellow)* color pair is higher than 1 in only one color (8), the remaining blended colors present considerably higher deviations, with 2 points or more in the *central colors* with the exception of the *(green, yellow)* pair for color 5.

Mean global deviations for each color pair are depicted in Figure 7, showing that the *(red, yellow)* pair yields the best global results, $(\overline{X} = 0.34)$ whereas both *(green, yellow)* $(\overline{X} = 0.93)$ and *(green, blue)* $(\overline{X} = 0.99)$ present lower, similar rates and results for the *(red, blue)* $(\overline{X} = 1.44)$ pair are considerably lower.

Computing the average global deviation, we obtain 0.92 points, suggesting that we must consider an approximate deviation of 1 point for each color. This result suggests that the a maximum of 5 colors must be taken into account when blending colors so that the relative amount of each color component is perceivable by humans.

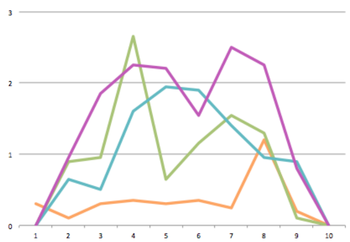

Figure 6: Blended colors' deviation, for all color pairs *(red, yellow): in orange*; *(green, yellow): in lime*; *(green, blue): in cyan*; *(red, blue): in purple*.

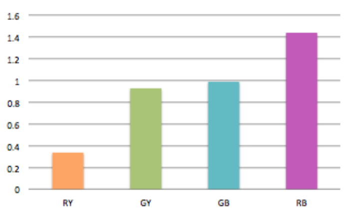

Figure 7: Average mean distance to correct answer by color pair.

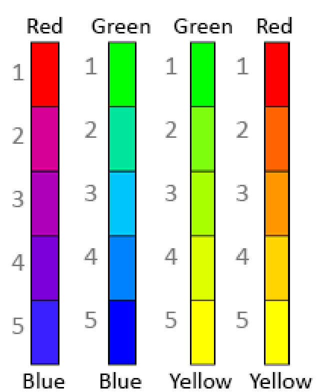

Figure 8: Color blending set.

User satisfaction Results have shown that subjects found it moderately easy to perceive color component weight in blended colors ($\overline{X} = 3.30$, $\sigma = 0.73$).

Discussion and Design Implications

Our study has shown that: (i) For pure colors (colors 1 or 10 of any set), subjects easily understand that only one component is present. (ii) People tend to regard blended colors in which one component is in much a higher ratio as pure colors, consisting of the component with higher weight. (iii) Colors with similar component quantities generate confusion: humans tend to have difficulties in understanding the quantities of each color component (they only perceive that quantities are relatively similar).

The aforementioned results suggest carefully considering color blending to represent relative quantities of any measured data. This method alone will probably fail to communicate all the information being coded through color. Nevertheless, when the idea is to provide rough information of a particular data item, color blending may be successfully used. However, an important restriction must be applied: no more than three intermediate steps must be considered in interpolation, in order not to prevent humans from perceiving component weight. Hence, a set of 5 colors results for each color pair, as depicted in Figure 8: the extremes correspond to pure colors, while the remaining elements correspond to 75%-25%, 50%-50% and 25%-75% component ratios.

Conclusions

Taking into account the potential of color blending for representing information, we conducted a study to determine to which extent can humans perceive the relative weight of different color components in a blended color. The analysis of such results have provided us with a set of design implications to take into account when using color blending in data visualization.

Acknowledgements

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