Explorative Study on Semantically Resonant Colors for Combinations of Categories with Application to Meteorological Data

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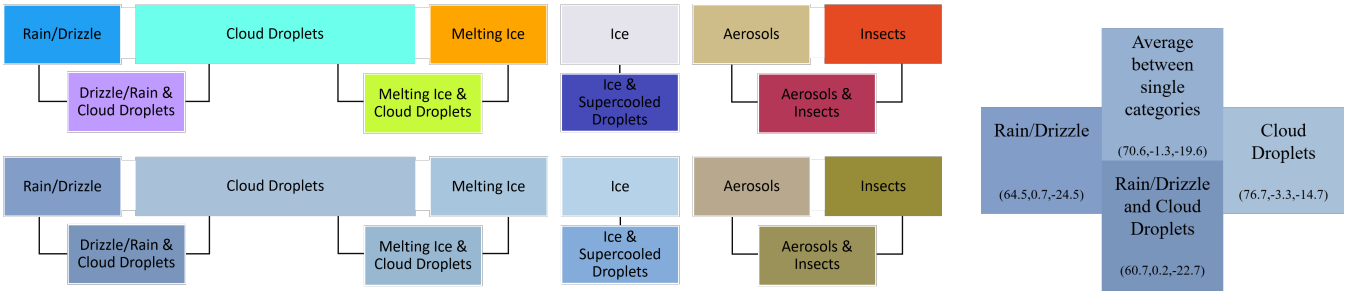

Figure 1: *(a) Shows colors assigned to the meteorological categories [Fin] (top) compared to the average color values resulting from our study (bottom). (b) Shows the two color values chosen for the individual categories, the value of the colors for the combined category (bottom), and the value of the average between the colors for the individual categories, with a standard deviation of 18.29 (top).*

Abstract

We present an exploratory study of semantically resonant colors for combinations of categories. The goal is to support color selection of multi-labeled classes of classified data. We asked participants to assign colors to different categories in the meteorological domain and then to their combinations. Our results show that the colors chosen for the combinations are related to the colors for the individual categories. We also found indications that people tend to prefer darker color values for combinations of categories. Our results can be used to color code meteorological data.

CCS Concepts

• ***Human-centered computing*** → ***Visualization;*** *Scientific visualization; Visualization design and evaluation methods;*

1. Introduction and Related Work

Colors corresponding to the semantics of words play a very important role in the understanding of data visualizations [LFK*13]. They are used to indicate classes of classified data (see Figure 2). In this example, the particles measured in the air were categorized as ice, rain/drizzle, cloud droplets, melting ice, aerosols, and insects, extended by combinations of these categories, namely rain/drizzle & cloud droplets, melting ice & cloud droplets, aerosols & insects, and ice & supercooled droplets [IHO*07, NEL*19]. The current color scheme (see Figure 1a, top) illustrates the challenge of assigning colors to this data. The colors are not semantically resonant [KHMC20], nor do the colors of the combined categories represent the individual category components.

Previous work, such as [ZH16, STWB17, WCG*19, FWD*17, RLLS20, SS16] considers color associations for individual categories only, not combined categories. The closest approach to this problem are categorical hierarchies [TdJ14]. In our case, the color combinations do not form a hierarchy, because category *Cloud Droplets* is combined with two different categories (Figure 1a).

We conducted an exploratory study to answer the following questions *What colors are semantically resonant for combinations of categories? How do the colors of combined categories relate to the colors of individual categories?*

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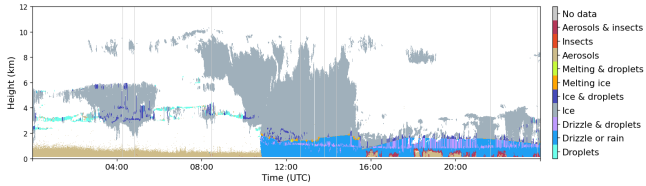

Figure 2: *Time-height plot of categorized cloud data measured on 08/29/2021 at Ny-Ålesund (Svalbard). The categories and their combinations with original color scheme [EMRO22].*

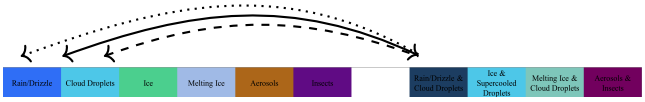

Figure 3: *Shown here is an example of one participants answers and the calculated distances of two example categories.*

2. Study Design and Procedure

The first part of the study asked participants to assign a color to each of the six meteorological categories previously mentioned. Then each of the four combined categories had to be assigned a color. In both parts one of the 58 colors provided could be chosen or individual colors could be generated. The order within both sections was randomized.

Color Selection Interface and Measurement: We provided our participants with a two-dimensional version of the UW-58 color palette presented by Rathore et al. in [RLLS20], which was also used by in [SLL21, MYS*22]. The sample is uniformly distributed ($\Delta E = 25$, using Euclidean Distance) in the CIELAB space, consisting of 58 colors that, cover the entire color space.

Participants: A total of 97 participants completed the study. 32 had a scientific background in computer science/mathematics, 42 in meteorology, and 23 in other fields. 16 participants were excluded from the study because of deficits in color training questions.

3. Results

Color Variation for Individual Categories: On avg. our participants had a mean pairwise distance of 50.39 (min. 20.75, max. 84.31). The distance range of the selected colors was significantly larger for participants with a meteorological background (avg. 55.01) than for participants without a meteorological background (avg. 46.69). We would assume that this is because the participants with a meteorological background were more familiar with both the terminology and the pre-existing color scheme and were therefore able to vary their color choices more easily.

Relation of the Combined Categories to Color Mean: We calculated the distances between the selected color values per category for each participant (see Figure 3). There is a significant dependence between the individual and combined categories (Fischer's exact test, p=0.0026). The color values differ only up to a max. distance of 40.26, and on avg. the colors chosen for the combinations of categories were only between 22.11 and 25.41 away from the mean of the colors of the two individual categories. Thus participants were more oriented toward what they perceived to be an avg. color value between the two individual categories than toward the two colors of the categories themselves.

Darkness of the Combined Color: We found indications that colors chosen for the combined categories were darker than the colors representing the mathematical avg. of the two individual categories. Our participants chose a color for the combined categories that was an avg. of 6.9 darker than the avg. of the two chosen colors for the individual categories (min. 3.32, max. 10.32) (see Figure 1b).

User Feedback: Interestingly, the individual categories of melting ice and cloud droplets were seen as combined categories, and not just the combined categories. This holds true for participants with and without a meteorological background.

4. Discussion and Conclusion

Quantitative Results: Our initial assumption that the color associations for individual categories would be related to those for the combinations was confirmed by the data we measured. Although the division and selection of individual categories makes sense from a meteorologist's point of view, some of the meteorological participants did not perceive the multiword individual categories as such semantically, raising the question of how far this aspect can be explored in further studies; Hall et al. [HKB*22] have explored professional differences in the understanding of visualizations.

Further Indications: Although the two individual categories clearly played a role in the color choice of the combined category, the average of the chosen individual colors was never closer than a distance of 20 to the chosen color for the combination of categories.

Conclusion: Our results show that there is a relationship between the colors for each category and the color for the combination of categories. Since the average of two colors representing individual categories is never a bad choice for the combination of the two individual colors, we can recommend that color choices for such cases actually be based on the average of the colors, including an increase in darkness. It remains to be investigated in further studies what the best choice away from the mean in certain individual cases is. Our results also need to be verified with other colors and thematic directions, but can then be applied to create color scales when needed for visualizations in use cases with combined categories. Other use cases have already been identified, such as in the medical field.

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