International Cartographic Association
Association Cartographique Internationale

Classed or continuous rainbow color scheme? A case study with 2D and 3D permafrost visualizations

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Keywords: rainbow color, visualization, permafrost, color scheme discretization, 3D visualization

Abstract:

Rainbow color (RC) scheme is a controversial choice across various visualization interest groups (data and information visualization, scientific visualization or cartography). Approaching two decades now, there has been critical voices and evidence that spoke against the RC has been presented by various visualisation communities (Borland & Taylor 2007, Silva et al. 2011) e.g., due to multiple limitations in communicating the quantitative data, such as the lack of intuitive order of hues (Gołębiowska & Çöltekin 2022a) or creating false boundaries through implicit discretization (Quinan et al., 2019). On the other hand, empirical studies evaluating the RC showed that it *can* support selected task types in some contexts (Ware et al. 2023), e.g., reading values from the body of the visualization with a use of a legend works well (Gołębiowska & Çöltekin 2022b). This is possibly because of clear discriminability and nameability of hues that support distinguishing categories (Hanley 2016). Interestingly, many user studies concerning the RC have been conducted with the use of a continuous representation of the rainbow colors, possibly due to software defaults which present a continuous RC palette as one of the prominent options (Gołębiowska & Çöltekin 2022a). Classed (also referred to as 'banded') version of the RC appears most often with statistical / thematic maps, and thus it appears to have been tested mainly in the context of cartography (Gołębiowska & Çöltekin 2022b). The effect of introducing banding in quantitative color schemes has been investigated also in other domains, even though this is seldom (Padilla et al. 2017, Ware 2024). Padialla et al. (2017) and Ware (2024) show that the effects of binning might be moderated by additional factors such as the task type or variation in hues, and these factors need to be taken into consideration while formulating conclusions and recommendations. Another factor of potentially important effect on the user performance is the use of spatial dimensions. Precisely exploring these interactions in a scientific visualization context, Borkin et al. (2011) demonstrated that 2D dendrogram visualizations of arteries led to faster and more accurate disease diagnosis and anomaly detection than using 3D visualizations, and using sequential colors yielded much better results than the rainbow colors for this purpose. Essentially, Borkin et al. (2011) paper suggests that using 2D representation with sequential colors should yield higher accuracy in capturing the patterns and anomalies in the data than other combinations (i.e., 2D+rainbow, 3D+sequential, 3D+rainbow).

Given the hypothesis above, we conducted a user study evaluating the effect of rainbow color scheme classification and its interactions with dimensionality (2D vs. 3D representations) in a new context, i.e., visualization of quantitative observations about underground permafrost. The task types were limited to reading values (involving a single value, and involving a series of values) because this task type has been shown to be supported well by the RC . Based on opinions collected from 20 experts in the first phase, we selected three visualization types: 2D, 3D and 'geographic context' (briefly referred to as Context) to test comparing classed vs. continuous rainbow colors (Fig. 1).

To compare the effect of introducing banding (continuous vs. classed) and the dimensionality (2D, 3D, Context) as presented in Fig. 1, we conducted a within-subjects user study with N=184 participants. The outcomes of the study show that, overall, a classed color scheme supports user performance better in terms of response accuracy, response time and user satisfaction for all but one task, i.e., with continuous colors, 2D visualization better supports user performance in reading a single value than 3D. However, interestingly, introducing classes in the tested rainbow color scheme eliminates this difference: 2D and 3D visualizations with a classed rainbow color scheme supports users performance similarly. While it is understood that rainbow colors are not ideal when order needs to be inferred from visualizations, and 3D can hurt user performance (Çöltekin et al., 2016), our results suggest that there is a lesser-known interplay between design decisions regarding the color schemes and dimensionality. In addition, we see that changing implicit banding observed in rainbow colors (Quinan et al. 2029) into an explicit one through classed color scheme the rainbow color scheme where class boundaries limit the search space can better support users. We detail this study further in a recent publication (Gołębiowska et al. 2025).

https://doi.org/10.5194/ica-abs-10-91-2025

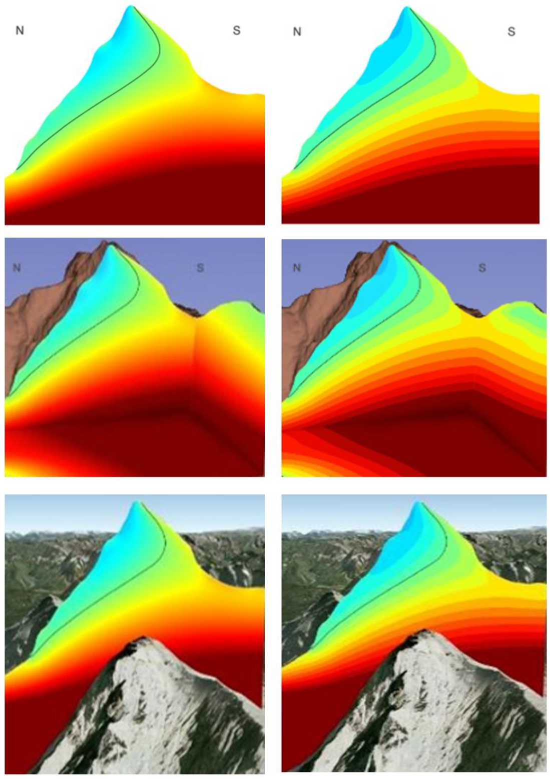

Figure 1. Tested permafrost visualizations featuring Zugspitze mountain in Switzerland (Data source: Noetzli et al., 2010, Gallemann et al., 2017): Continuous (left column) and Classed (right column) of 2D (top), 3D (middle) and Context (bottom).

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Abstracts of the International Cartographic Association, 10, 91, 2025
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada.
https://doi.org/10.5194/ica-abs-10-91-2025