Hue Bands and Human Perception: Revisiting the Rainbow

P. Samuel Quinan* Lace Padilla† Sarah H. Creem-Regehr‡ Miriah Meyer§

University of Utah

ABSTRACT

The visualization literature tells us that rainbow color maps are bad, yet domain experts continue to use them. *Why?* The truth is, we don't know. It turns out that there is a lot we don't know about rainbow color maps. Two of the primary reasons our community argues that rainbow color maps are ineffective can be traced back to the idea that rainbow color maps implicitly discretize the encoded data into hue-based bands; yet there is no research addressing what this discretization looks like or how consistent it is across individuals. This poster discusses an exploratory study designed to test how individuals' perceptual systems discretize widely used spectral schemes and whether this discretization can be modeled by variations in lightness and chroma. We present high-level discussions of the experimental design, our analysis, and the implications of our results.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology;

1 INTRODUCTION

Rainbow color maps continue to be used in a variety of real-world situations, and we still don't know why. As a community, our hypotheses is that the reason is likely some combination of familiarity, aesthetic preference [6], and ease of use (as rainbow colormaps have traditionally been the default colormap in a variety of common visualization toolkits [2]). That said, there is also the possibility that that our own understanding of rainbow colormaps might be flawed or otherwise incomplete [5]. Because of the complexities of human perception, certain aspects of the role of color in visualizations have remained under-studied. Moreover, a growing body of work suggests that conflicts between visualization guidance and domain practice highlight these same ill-understood aspects of color [5, 7].

Our literature contains a number of assertions that rainbow color maps implicitly discretize encoded data into *hue-based bands* [1,2,6]. This discretization appears to drive two of the core reasons we use to argue that rainbow color maps are harmful. In particular, these hue bands *obscure data* through insufficient luminance variation and *actively mislead* users by creating false boundaries [2]. Recent work by Padilla et al., however, has shown that regularly-spaced discretization in grayscale color maps does not negatively impact and can even improve task performance [7]. This raises questions about whether the implicit discretization in the rainbow color maps is actually problematic. At the same time, we have no foundational research showing *that* rainbow color maps implicitly discretize data, *how* they discretize the data, or the extent to which that discretization is consistent across individuals.

In this extended abstract, we discuss an exploratory study focusing on the previously unexplored role of discretization (i.e., hue-banding) in rainbow color maps. The study was designed to assess the consistency of perceived color category boundaries in common spectral schemes across individuals, as well as to explore a hypothesis that these boundaries might be predicted by changes in lightness and chroma. We will talk about the experimental design, our results, and conclude with a brief overview of the implications for our field.

*e-mail: psq@cs.utah.edu
†e-mail:lace.m.k.padilla@gmail.com
‡e-mail:sarah.creem@psych.utah.edu
§e-mail:miriah@cs.utah.edu

2 STUDY OVERVIEW

The primary research question for our study was: assuming that rainbow color maps are being implicitly discretized, what does that discretization look like and how consistent is it across individuals? We explored these questions in tandem with a hypothesis that we could predict color category boundaries by looking at changes in lightness and chroma. *Chroma*, like saturation, is a relative measure of the colorfulness, but one that is measured in relation to a comparably illuminated white [3].

The study employed a mixed design. Participants were assigned to one of two wording conditions, where the wording of the instructions was changed with the goal encouraging different boundary placement strategies (e.g., "delineate the color categories" vs. "mark the color boundaries"). Each participant was provided with 12 stimuli generated by encoding three univariate datasets with four different color maps. The datasets included a 1D linear ramp, a 2D radial gradient, and a complex real-world 2D geo-spatial dataset. The color maps included the default rainbow color map, the jet color map from MATLAB, the Kindlmann color map (a rainbow with monotonically increasing luminance) [4], and a perceptually continuous grayscale color map. For each stimuli, the participants were asked to initially count and then interactively delineate the color categories or color boundaries (according to their assigned wording condition).

The study was conducted in a controlled laboratory setting. Participants were recruited from University of Utah's Psychology participant pool, as well as from the larger campus community. We pre-filtered partipants who were either color blind or who had significant prior exposure to rainbow color maps (e.g., through the nature of their area of study). Before the main study module, participants were walked through a training module, familiarizing them with the definitions and interaction mechanisms used in the study. Similarly, after the main study module, participants were asked to complete a survey in which they both answered questions about the judgments they made and provided demographic information. The survey included explicit checks of the participants color vision along with questions designed to probe other potentially confounding factors, such as prior familiarity with the geographic area used in our complex real-world dataset.

2.1 Results

We analyzed the data from 62 participants across both wording conditions (34 in the boundary condition, 28 in the category condition). We noted strong trends in where individuals placed boundaries for all three spectral schemes, but not for grayscale. The only notable pattern in individuals' boundary placements for the grayscale stimuli was a bunching of responses in the bottom part of the data range for the 1D stimuli. A closer examination of the relevant data and the survey responses, however, suggests that this pattern is due to subtle artifacting present in our 1D grayscale stimuli.

Points of high curvature do appear to be good predictors for a subset of the boundary placement trends in each of the three spectral

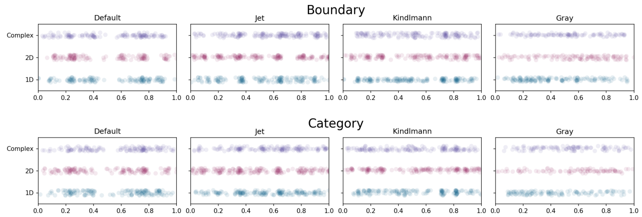

Figure 1: Participant color category boundary placements aggregated according to wording condition, color map, and dataset. Opaque regions highlight strong response trends in all three rainbow color maps but not grayscale.

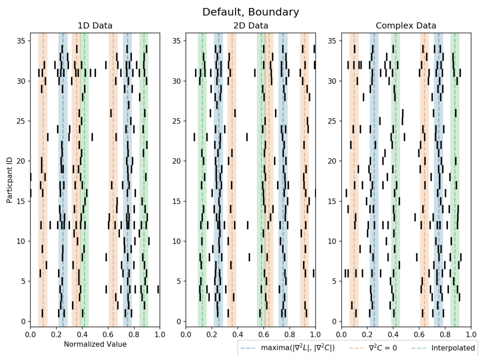

Figure 2: The boundaries placed in the default rainbow color map by each participant in the boundary wording condition are plotted in separate rows as black lines. The colored bands represent the indicators that most closely model the trends across participants. We see major differences in the non-curvature response trends (modeled by the green and orange bands) across the three datasets.

schemes. That said, it is not entirely clear whether luminance or chroma is driving the effect. While the idea that sudden changes luminance can generate color boundaries has already been established in prior work [1], there are no similar statements about sudden changes in a colorfulness metric like chroma (or saturation). In both the default rainbow and jet color maps, however, the points of high curvature in luminance correspond exactly to the points of high curvature in chroma. Moreover, points of high curvature in chroma still predict boundary placement trends in the Kindlmann color map, where the luminance profile smoothly increases. Additional work is needed to better separate the respective roles of luminance and chroma in our perception of color boundaries.

The remaining boundary placement trends in our spectral stimuli can be explained (though not necessarily predicted), by a combination of perceptual and cognitive indicators. A few trends appear to correspond to points of high curvature in hue, others appear to correspond to inflection points in chroma, and still others appear to correspond to purely cognitive strategies, such as interpolating boundaries based on the number of basic color terms between sudden changes in luminance or chroma. These remaining trends, however, shift dramatically depending on the dataset being visualized, and do so consistently across individuals. Fig. 2 illustrates this using the participant responses for the default color map from the boundary wording condition, though similar variation can be found in each rainbow color map across both wording conditions. These results suggest that the real danger with rainbow color maps may have less to do with the fact that they implicitly discretize, and more to do with the unpredictable way in which they implicitly discretize different datasets.

3 Discussion

The results of our study supply initial empirical data about how different individuals perceive color categories in commonly used rainbow color maps. This provides a basis for the idea that rainbow colormaps implicitly discretize beyond just assertions and examples. Additionally, the results suggest that the underlying dataset is a larger source of variance in how we perceive color categories than our individual differences, providing us with a new, unexplored hypothesis about *why* rainbow colormaps are so ineffective.

Having an accurate understanding of what make rainbow color maps ineffective is critical if we want to correct the rainbow or generate effective alternatives. A corrected rainbow might provide advantages by leveraging people's familiarity with, aesthetic preference for, or simply trust in rainbow color maps. Similarly, if we can understand why people keep gravitating to spectral schemes, we might be able to create new color maps that take advantage of this.

Additionally, however, there are new questions we can now investigate, given some understating of how rainbow color maps discretize data. Is it possible people like rainbow color maps, in part, because they simultaneously seem to be both discrete and continuous? How does the implicit discretization occurring in rainbow color maps compare to the explicit discretization tested by Padilla et al. [7]? This exploratory study represents a modest, but necessary first step needed for answering more complex and interesting questions.

4 Conclusions

This work represents an initial step in solidifying our community's foundational understanding of rainbow color maps. We presented an exploratory study that tested how individuals discretize widely used spectral schemes and whether this discretization can be modeled by various perceptual attributes. Our results suggest that rainbow color maps do implicitly discretize data in a consistent way across individuals. We found that high-curvature can predict where people perceive certain color boundaries, though future work is needed to determine whether this effect is primarily driven by luminance or chroma. We also found, however, that many of the perceived color boundaries in rainbow color maps shift depending on the data being visualized. While it is not clear why this happens, it does provide an alternative explanation for the well-documented performance problems with rainbow color maps [1, 2, 6]. Additional work is needed to better understand this phenomenon. While we still have a lot left to learn, this work shows that interrogating conflicts between visualization guidance and domain practice is a meaningful avenue for approaching research. Hopefully this work is one of many steps in improving our understanding of the role of color in visualizations.

References

[1] L. D. Bergman, B. E. Rogowitz, and L. A. Treinish. A Rule-based Tool for Assisting Colormap Selection. In *IEEE Conference on Visualization, 1995. Visualization '95.*, pp. 118–125, 444. IEEE Computer Society, Washington, DC, USA, Oct. 1995. doi: 10.1109/VISUAL.1995.480803

[2] D. Borland and R. M. Taylor. Rainbow Color Map (Still) Considered Harmful. *IEEE Computer Graphics and Applications*, 27(2):14–17, Mar. 2007. doi: 10.1109/MCG.2007.323435

[3] M. D. Fairchild. *Color Appearance Models*. Wiley-IS&T Series in Imaging Science and Technology. John Wiley & Sons, Ltd, 3 ed., 2013.

[4] G. Kindlmann, E. Reinhard, and S. Creem. Face-based Luminance Matching for Perceptual Colormap Generation. In *Visualization, 2002. VIS '02.*, pp. 299–306, Nov. 2002. doi: 10.1109/VISUAL.2002.1183788

[5] R. Kosara. An Empire Built On Sand: Reexamining What We Think We Know About Visualization. In *Proceedings of the Sixth Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization*, BELIV '16, pp. 162–168. ACM, New York, NY, USA, 2016. doi: 10.1145/2993901.2993909

[6] K. Moreland. Diverging Color Maps for Scientific Visualization. In *Advances in Visual Computing*, pp. 92–103. Springer-Verlag, Berlin, Heidelberg, Nov. 2009. doi: 10.1007/978-3-642-10520-3_9

[7] L. Padilla, P. S. Quinan, M. Meyer, and S. H. Creem-Regehr. Evaluating the Impact of Binning 2D Scalar Fields. *IEEE Transactions on Visualization and Computer Graphics*, 23(1):431–440, Jan. 2017. doi: 10.1109/TVCG.2016.2599106