CMasher: Scientific colormaps for making accessible, informative and ‘cmashing’ plots

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Introduction

The use of colors in the visualization of scientific results is a common sight nowadays. Color allows for more (complex) data to be plotted in the same figure without resorting to difficult-to-interpret 3D plots or subplots; online material; or interactive applications. However, an often underappreciated aspect of data visualization, is how color affects the way the visualized data is interpreted, making it crucial to pick the correct colormap. In order to help with picking a scientific colormap, I introduce the CMasher package.

Background summary

A good scientific colormap is often described/characterized as perceptually uniform sequential, which means that the colormap is perceived as uniformly changing in lightness and saturation, mostly at the same hue (Rogowitz, Treinish, & Bryson, 1996; Sharpe, Stockman, Jaegle, & Nathans, 1999). This allows for the data values of a plot to be interpreted correctly by the viewer without giving false information. Such a colormap also often allows for a plot to be converted properly to grey-scale without losing information. A perceptually uniform sequential colormap allows us to properly infer the relative order of the represented numerical values, without requiring a legend or colorbar.

Although there are many works out there that describe the optimal way to do this (Birch, 2012; Brychtová & Çöltekin, 2016; Kindlmann, Reinhard, & Creem, 2002; Rogowitz et al., 1996; Sharpe et al., 1999; Szafir, 2018) and there are tools readily available to test the performance of a colormap (Nuñez, Anderton, & Renslow, 2018; Smith et al., 2018, 2019), bad/misleading colormaps are still very commonly used. The main issue usually is that humans do not perceive every color equally (e.g., small variations in the color green are not perceived as green is a common natural color, while small variations in the colors red and blue are perceived). Here, we use the jet colormap to illustrate this issue:
Figure 1: Output of the viscm package (Smith et al., 2019) showing the statistics and performance of the jet colormap. The various different plots show how the colormap changes in perceived saturation and lightness, as well as how well the colormap converts to different types of color-vision deficiency and grey-scale. In case of a perceptually uniform sequential colormap, the two derivative plots should show a straight horizontal line; the colorspace diagram should be smooth; and the lines in the bottom-right corner plots should be visible up to the same depth across the entire colormap.

In Fig. 1, one can view the performance output of the jet colormap, made with the viscm package (Smith et al., 2019). For perceptually uniform sequential colormaps, the two derivative plots in the top-left should show a straight horizontal line, indicating that the colormap changes uniformly in both perceived saturation and lightness. Consequently, the colorspace diagram in the bottom-left should be smooth. Finally, the lines in the bottom-right plots should be visible up to the same depth across the entire colormap, otherwise it can create artificial features as would be shown by the sample images in the top-right plots. If the colormap is also required to be color-vision deficiency (CVD; color blindness) friendly, the requirements above apply to the deuteranomaly/protanomaly and deuteranopia/protanopia statistics as well.

Using this information, we can check the performance of the jet colormap as shown in Fig. 1. The jet colormap shows the spectrum of visible light, which trivially increases linearly in wavelength. However, in Fig. 1, we can see that this introduces multiple problems, as the color green is perceived as the brightest of the visible colors due to its natural occurrence, and the colormap is absolutely not CVD-friendly. This is an example of a colormap where it would be necessary to have a colorbar/legend, and it is a poor choice for representing numerical values.

Despite all of these shortcomings, jet is still a commonly used colormap in the scientific literature. An often cited reason for this (besides the general “Everyone else uses it.”), is that jet has a high perceptual range, making it easier to distinguish adjacent values (jet has a higher perceptual range than any colormap in CMasher, including the diverging colormaps). Although a high perceptual range can be useful in many different cases, it certainly is not useful in all of them and there are ways to achieve this without giving false information. This is where CMasher comes in.
Figure 2: Overview of all current colormaps in CMasher (v1.2.2).

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CMasher

The CMasher package provides a collection of scientific colormaps to be used by different Python packages and projects, mainly in combination with matplotlib (Hunter, 2007). The colormaps in CMasher are all designed to be perceptually uniform sequential using the viscm package (Smith et al., 2019); most of them are CVD-friendly; and they cover a wide range of different color combinations to accommodate for most applications. It offers several alternatives to commonly used colormaps, like chroma and rainforest for jet; sunburst for hot; neutral for binary; and fusion and redshift for coolwarm. Users are encouraged to request for specific colormaps to be designed if they cannot find the perfect one. An overview of all current colormaps in CMasher (as of v1.2.2) is shown in Fig. 2.

CMasher has already been used in several scientific studies, including model emulations (van der Velden, 2019; van der Velden et al., 2019); galaxy kinematics (Džudžar et al., in prep); and redshift estimations for fast radio bursts (Batten, 2019). Due to the number of different color sequences and the perceptual uniform sequential nature of the colormaps, CMasher is also great for representing qualitative data. The source code for CMasher (including the viscm source files) can be found at https://github.com/1313e/CMasher, whereas the descriptions of all available colormaps can be found at https://cmasher.readthedocs.io with their recommended use-cases.

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References

Batten, A. (2019). Fruitbat: A Python Package for Estimating Redshifts of Fast Radio Bursts. The Journal of Open Source Software, 4(37), 1399. doi:10.21105/joss.01399

Birch, J. (2012). Worldwide prevalence of red-green color deficiency. J. Opt. Soc. Am. A, 29(3), 313–320. doi:10.1364/JOSAA.29.000313

Brychtová, A., & Çöltekin, A. (2016). The effect of spatial distance on the discriminability of colors in maps. Cartography and Geographic Information Science, 44(3), 229–245. doi:10.1080/15230406.2016.1140074

Hunter, J. D. (2007). Matplotlib: A 2D graphics environment. Computing in Science & Engineering, 9(3), 90–95. doi:10.1109/MCSE.2007.55

Kindlmann, G., Reinhard, E., & Creem, S. (2002). Face-based luminance matching for perceptual colormap generation. In Proceedings of the conference on visualization ’02, VIS ’02 (pp. 299–306). Washington, DC, USA: IEEE Computer Society. doi:10.1109/VISUAL.2002.1183788

Nuñez, J. R., Anderton, C. R., & Renslow, R. S. (2018). Optimizing colormaps with consideration for color vision deficiency to enable accurate interpretation of scientific data. PLoS ONE, 13, e0199239. doi:10.1371/journal.pone.0199239

Rogowitz, B. E., Treinish, L. A., & Bryson, S. (1996). How not to lie with visualization. Computers in Physics, 10(3), 268–273. doi:10.1063/1.4822401

van der Velden, (2020). CMasher: Scientific colormaps for making accessible, informative and ‘cmashing’ plots. Journal of Open Source Software, 5(46), 2004. https://doi.org/10.21105/joss.02004
Sharpe, L. T., Stockman, A., Jaegle, H., & Nathans, J. (1999). Opsin genes, cone photopigments, color vision, and color blindness. In Color vision: From genes to perception (pp. 3–51). Cambridge: Cambridge University Press.

Smith, N. J., Futrell, R., Walt, S. van der, Mansencal, T., TFifiE, Betts, E., cghlke, et al. (2018). Njsmith/colorsppacious v1.1.2. Zenodo. doi: 10.5281/zenodo.1214904

Smith, N. J., Futrell, R., Walt, S. van der, Zhao, J., Caswell, T. A., Flyamer, I., Gohlke, C., et al. (2019). Matplotlib/viscm v0.9. Zenodo. doi: 10.5281/zenodo.3378106

Szafir, D. A. (2018). Modeling color difference for visualization design. IEEE Transactions on Visualization and Computer Graphics, 24(1), 392–401. doi: 10.1109/TVCG.2017.2744359

van der Velden, E. (2019). Model dispersion with PRISM; an alternative to MCMC for rapid analysis of models. The Journal of Open Source Software, 4(38), 1229. doi: 10.21105/joss.01229

van der Velden, E., Duffy, A. R., Croton, D., Mutch, S. J., & Sinha, M. (2019). Model dispersion with PRISM; an alternative to MCMC for rapid analysis of models. The Astrophysical Journal Supplement Series, 242(2), 22. doi: 10.3847/1538-4365/ab1f7d

van der Velden, (2020). CMasher: Scientific colormaps for making accessible, informative and ‘cmashing’ plots. Journal of Open Source Software, 5(46), 2004. https://doi.org/10.21105/joss.02004