

cols4all: a color palette analysis tool

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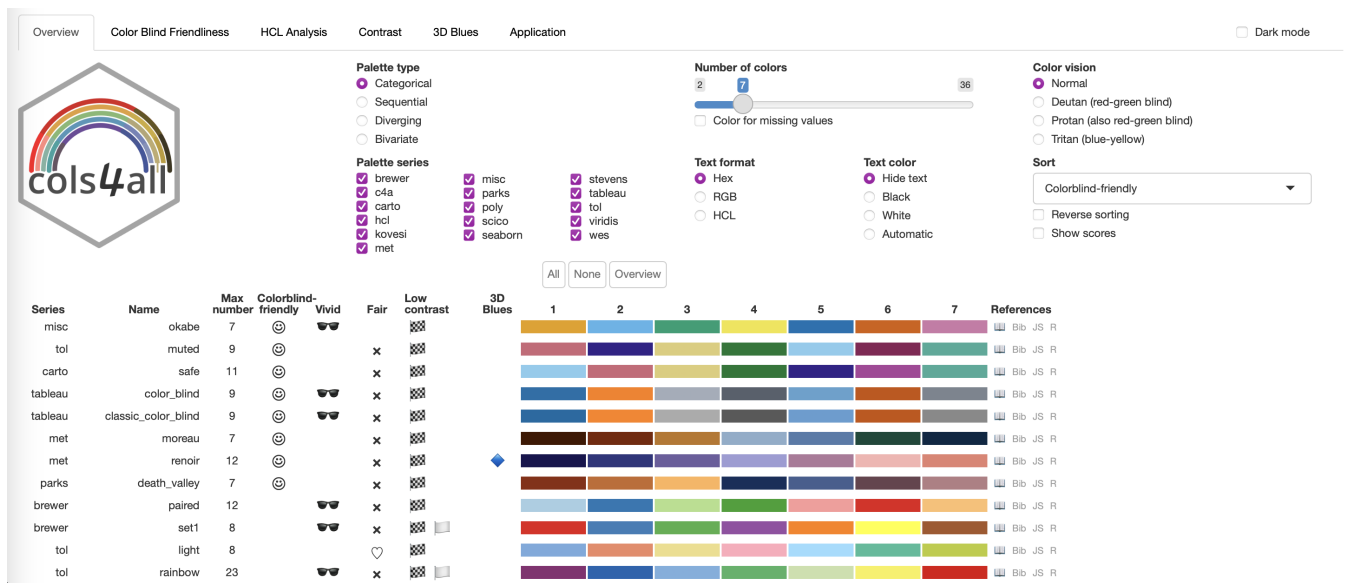


Figure 1: Color palette analysis tool cols4all

Abstract

cols4all is a software tool to analyse and compare color palettes, using several properties, including color blind friendliness and fairness, which checks whether all palette colors stand out about equally.

CCS Concepts

• Human-centered computing → Visualization design and evaluation methods; Visualization toolkits;

1. Introduction

Color is an important aspect of data visualization, because it can be used to highlight data patterns efficiently [Mid20]. Many color palettes have been designed to encode data using various approaches, including linear interpolation in a color space [ZHM09, PC21, Sd15], color blind friendly palette design [OI08, Tol21, Sd15] and color extraction from art [Mil22, RW18] and nature [Bla22]. With the vast amount of models, it is hard to choose the right color palette that suits the problem. In this paper we introduce cols4all, a tool to analyse and compare color palettes, written as a package for the statistical software environment R [Ten23].

To analyse a color palette, it is necessary to examine its characteristics in order to understand how it can be used in a specific visualization. The most important aspect is to examine whether there are potential issues, in particular for people with color vision deficiency. Furthermore, color properties like hue, chroma, and luminance, can be used to analyse whether a color palette is suitable for the application at hand.

These characteristics often have opposite effect; palettes that are extracted from a perceptually uniform color space, for instance the Hue-Chroma-Luminance (HCL) color space [ZHM09, PC21] may not be the most suitable for color blind people. Therefore we intro-

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duce a tool, cols4all, that analysts and graphic designers can use to find proper trade-offs. The tool also allows designers to find colors that suit their personal preferences, match the corporate style, and fit the purpose of the target visualizations.

With this paper we hope to engage the information visualization community in color perception research. With the open source tool cols4all, we hope to reach a broad audience, including researchers and designers, encouraging the sharing of knowledge and best practices, which can lead to the development of more effective and innovative solutions for working with color in data visualization.

2. Related literature

Several interactive tools have been introduced, such as ColorBrewer [HB03] and ColorMoves [SKR18], where users can choose a color palette from a predefined selection and apply it to a specific map or chart. In contrast, the main purpose of cols4all is to compare and analyse existing color palettes from different sources.

The CCC-Tool [NCS*21] is a color palette generation tool for experienced users. Colorgorical [GLS17] is a tool that makes color palette recommendations based on user preferences. Additionally, deep learning has been used to make color palette recommendations [YZZ*22]. Our approach is different because we do generate nor provide recommendations; instead, we only calculate properties that can be used to analyse and select color palettes.

3. Interactive tool

We introduce a tool, called cols4all, that can be used to analyse and compare color palettes. It is written as a package for the R programming language [R C22]. In this paper, we will only describe the interactive graphical user interface. The other features are described in the documentation [Ten23].

3.1. Target users

The tool is intended for data visualization designers to select appropriate color palettes for their data visualizations. Another use case for designers is to test their own (corporate) palettes, and to compare them against other existing palettes. The tool may also be useful for other users, in particular graphic designers and web designers. User studies are required to ensure that the design of the interface is effective, efficient, and easy to use.

3.2. Organisation of palettes

Palettes are organised by series and type. With type we mean either source (e.g. "brewer" stands for ColorBrewer [HB03]) or group of similar palettes (e.g. "poly" includes categorical palettes with many colors [CBAA19, Gre10, GvTG07, Kel65, Wri15]). The palette names in the tool are formatted in snake case, with the series name put in front separated with a dot. E.g. the Color Blind from Tableau [Sto16] is called "tableau.color_blind".

We currently distinguish four types of palettes: *categorical* palettes for nominal data, *sequential* palettes for ordinal or numeric data, *diverging* palettes for ordinal or numeric data with a critical

midpoint, and *bivariate* palettes for bivariate data. The distinction is not always clear. Spectral palettes, for example, can be used as categorical, sequential or even divergent palettes if they have a distinctive middle color.

Two conventions have been applied to make comparison possible. First, black and white colors have been removed from categorical palettes. Second, sequential palettes have been ordered from light to dark, unless there is a special meaning (e.g. terrain colors).

Each color palette is assigned a color for missing values. Most palette series did not include such a color. If that is the case, either a grayscale color from the palette is taken (e.g. the light grey 9th color from ColorBrewer palette "Set3" [HB03] has been used as color for missing values for "brewer.set3"), or a color has been selected that is distinctive for color blind people [Ten23].

3.3. Main table

The screenshot in Figure 1 shows the main tab. The table includes several columns for the properties of the palettes. To aid the analysis and decision making, we have derived a three-point-scale for each property: yes, neutral, no (see software documentation [Ten23]). For advanced users there is a check box "Show scores" that will show the underlying data in the table. Further analysis can be done in the other tabs of the tool, described below.

3.4. Color blindness

For the perceived distance between two colors we use $d(i, j) = \min_x d_x(i, j)$, where $d_x(i, j)$ is the *Delta E 2000* metric [SWD05] between colors i and j that are perceived by (denoted by x): people with 1) normal color vision, 2) deuteranopia, 3) protanopia, and 4) tritanopia, using simulated color vision [MOF09, Now19]. This metric is used in the following way (for bivariate palettes, see software documentation [Ten23]):

Categorical Minimum distance between any two colors in the palette.

Sequential Minimum distance between any two colors in the sequential palette colors. Continuous palettes are discretized.

Diverging Same as sequential, and in addition the minimum distance between any color in the left wing and any color in the right wing of the palette.

Figure 1 shows the overview tab, where the fourth column represents the color-blind-friendliness property. Since this table is sorted in color blind friendliness, we can observe that only 8 of the included 91 palettes have been classified as color blind friendly.

Further analysis of color blind friendliness can be done on the second tab of the tool. Figure 2 shows the analysis of the popular palette "brewer.set2" [HB03]. On the top left the CIE xyY space clipped to sRGB gamut is shown with lines diverging from the defined white point (CIE standard illuminant D65). The bottom left shows the same plot, but using colors simulated for deuteranomaly.

Similarity matrices are shown in the middle column of Figure 2. For similarity we use the distance metric described above, where (configurable) threshold values are used to determine whether two colors are "extremely similar" (large square), "very similar"

(medium sized triangle), "similar" (small dot) or not similar. The top matrix indicates that colors are not similar and therefore easy to tell apart by people with normal color vision. However, bottom matrix indicate that the last two colors are extremely similar to deuteranopes.

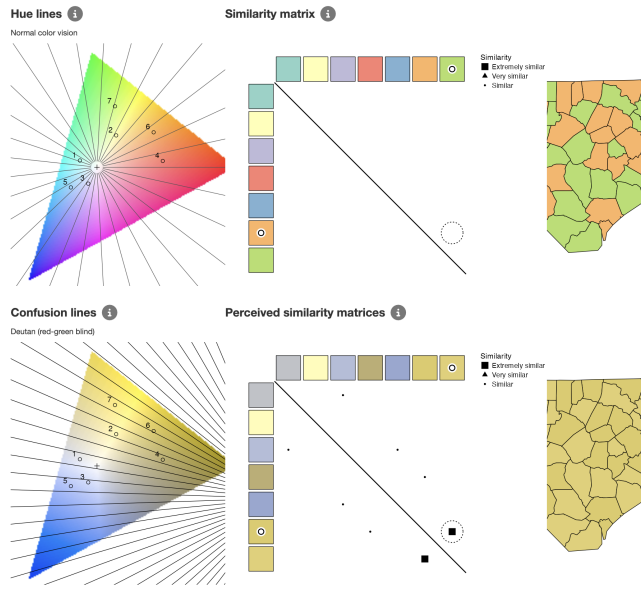


Figure 2: Top: normal color vision, bottom: deuteranomaly. Left: hue lines (top) and confusion lines (bottom), middle: similarity matrices, right: choropleth (as example). The two colors that have been selected are the last two.

3.4.1. HCL analysis

The next tab of the analysis tool studies the properties of the colors, derived from the dimensions of HCL colors space: hue, chroma, and luminance. In order to explain this color space, a sub space is illustrated on the top right of Figure 3.

Since the HCL color space is cylindrical, the hue values are in degrees, as in illustrated in the 'hue necklace' that is shown in Figure 3 (top left). The hue values and especially the range are particularly interesting for sequential and diverging palettes. Spectral palettes (like the "viridis_magma" palette shown and analysed Figure 3) are generally favorable for color distinction and may even be suitable for quantitative analysis [BMPH97], but single hue palettes are a safer choice because they are typically color blind friendlier.

The bottom plot in Figure 3 is a chroma-luminance scatter plot. We use the chroma and luminance values of palette colors to find out whether some colors stand out more than other colors. Ideally, a categorical palette should contain colors that stand out about equally, for otherwise, one color will draw more attention than another, which may bias our perception and interpretation of the shown data. Colors with a high chroma value stand out more than less chromatic colors. Furthermore, dark colors (low luminance) stand out more against a bright background and vice versa. Luminance is only considered for categorical palettes, because sequential and diverging palettes often use luminance to encode data.

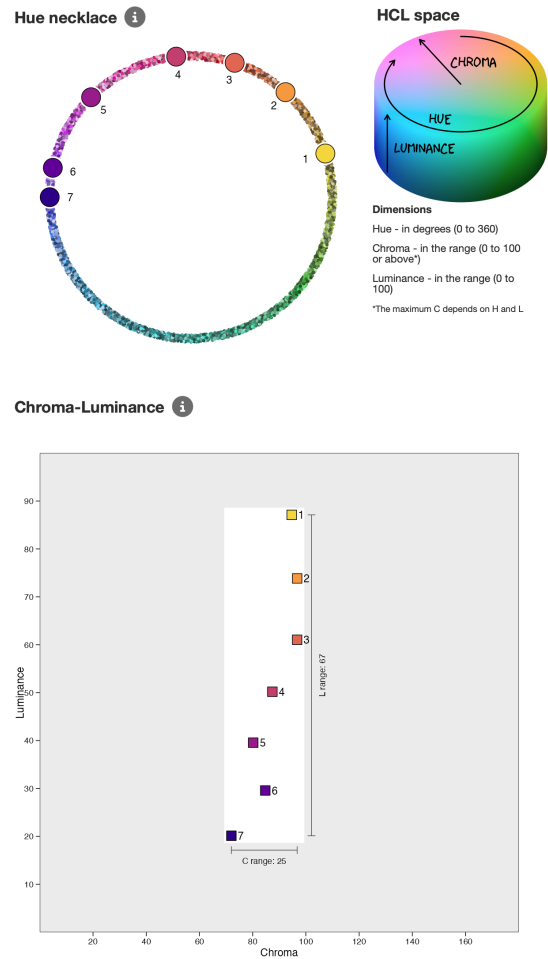


Figure 3: HCL analysis for the Viridis palette magma [Sd15]. Top left: hue necklace with the palette colors, top right: HCL, the used color space (with chroma limited at 100), bottom: luminance-chroma scatter plot.

We call a color palette *fair* if both chroma and luminance ranges are below a certain threshold and *unfair* if one of them is above a certain threshold. For sequential and diverging palettes, only the chroma range is considered. The sequential palette "viridis.magma" illustrated in Figure 3 has a chroma range of 25, which is fair according to the default settings. Fairness is the sixth column of the screenshot displayed in Figure 1: all shown palettes are unfair, except "misc.okabe" [OI08] which falls in the neutral class, and "tol.light" [Tol21] which is fair.

Note that fairness and color blind friendliness have an inverse relationship, because the larger the variance across luminance and chroma, the likelier it is that the colors are easier to discriminate by color blind people. Table 1 shows a cross table between color blind friendliness (rows) and fairness (columns) for categorical palettes of length 5, 7, and 9. Even among the 137 categorical palettes with 5 colors, there is only 1 classified as both color blind friendly and fair (which is "tol.light" [Tol21]). From all 91 palettes of length 7, there is just 1 classified as color blind friendly and not unfair (which is "misc.okabe" [OI08] as can also be seen in Figure 1).

Table 1: Number of palettes by fairness and color blind friendliness

	5 color palettes			7 color palettes			9 color palettes		
	Fair	Neutral	Unfair	Fair	Neutral	Unfair	Fair	Neutral	Unfair
Color blind friendly	1	14	15	0	1	7	0	0	4
Neutral	15	41	29	3	18	28	0	6	16
Color blind unfriendly	11	6	5	13	13	8	13	11	12

3.5. Contrast

Figure 4 shows the tab to analyse the contrast ratio (CR) between two colors, defined as $(L_1 + 0.05)/(L_2 + 0.05)$ where L_1 and L_2 are the luminance values of respectively the light and dark color. The matrix shown at the top left shows the CRs between any two palette colors including black and white, because these are often used for text and background.

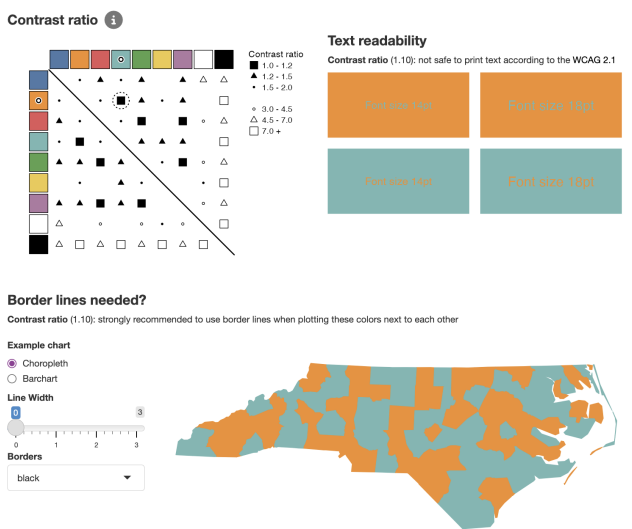


Figure 4: Contrast analysis for the palette "tableau.10" [Sto16]. Top left: contrast ratio matrix, where the second and fourth palette color have been selected. Top right and bottom: examples of low contrast between these colors.

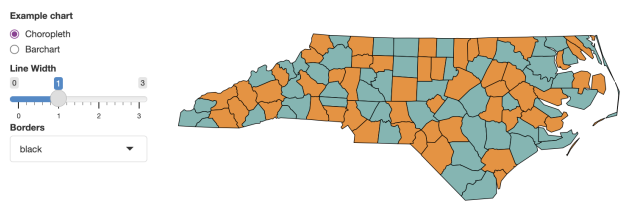


Figure 5: Using borders with sufficient contrast solves this visual illusion.

The closed (black) symbols indicate that colors are (almost) equiluminant. Equiluminance is a condition where two colors have the same luminance. Several parts of the human visual system receive only luminance signals. So some functions, such as form perception and depth perception, are color blind, even in color-normal individuals. For instance, the second (orange) and fourth (cyan) colors illustrated in Figure 4 (right and bottom) are difficult to separate

rate [Cav91]. This can be solved by using border lines (using a high contrast color, in this case black) as can be seen in Figure 5.

Figure 4 top left shows text printing examples where one color is used for the text and the other for the background. According to web accessibility standards WCAG 2.1 [Wor18] a CR of at least 4.5 and 7.0 are recommended for normal sized text at levels AA and AAA respectively.

3.6. 3D Blues

The next tab is dedicated to a visual illusion called chromostereopsis, where two colors are perceived in different depth planes [Bre44]. This illusion is most commonly observed with red and blue against a black background, creating a sense of depth or displacement in the image. This tab is used to find out whether this illusion could appear when using palette colors. Figure 6 shows an example using two colors from "seaborn.bright" [Was21].

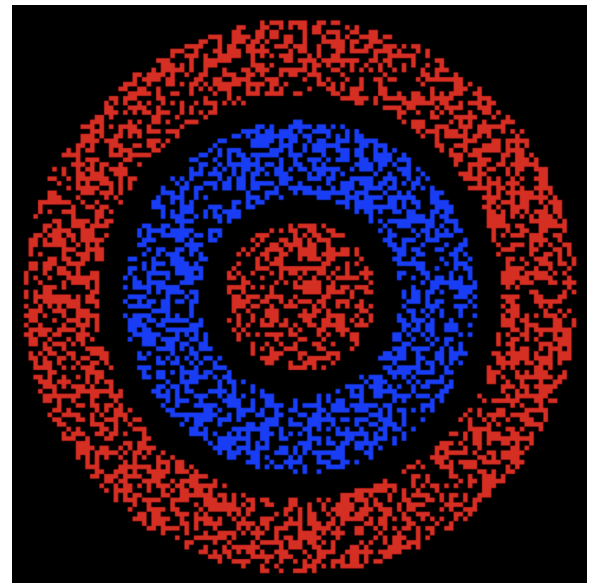


Figure 6: Palettes with a pure blue color, such as "seaborn.bright" [Was21], may suffer from a visual illusion called chromostereopsis [Bre44]. Illustration by Michael Bach.

4. Future research

The properties described in this paper and in more detail in the software documentation [Ten23] are still development. Suggestions for improvement are highly welcome. User studies are recommended to test the interface of the tool as well and the usefulness of the included properties.

A property that could be implemented in cols4all is the nameability of palette colors. Using colors that are easy to name, typically the primary and secondary colors, will benefit the user performance of data visualization tasks [RSGP].

A direction for further research is to use mathematical optimization to find the optimal palettes using criteria based on the properties that we have proposed. An important consideration is to standardise or normalise the properties.

References

- [Bla22] BLAKE K.: *NatParksPalettes: Color Palettes Inspired by National Parks*, 2022. R package version 0.2.0. URL: <https://CRAN.R-project.org/package=NatParksPalettes>. 1
- [BMPH97] BREWER C. A., MACEACHREN A. M., PICKLE L. W., HERRMANN D.: Mapping mortality: Evaluating color schemes for choropleth maps. *Annals of the Association of American Geographers* 87, 3 (1997), 411–438. 3
- [Bre44] BREWSTER D.: On the optical illusion of the conversion of a plane into a concave surface and vice versa. *Transactions of the Royal Society of Edinburgh* 15 (1844), 39–51. 4
- [Cav91] CAVANAGH P.: *Vision and Visual Dysfunction Volume V: Limits of Vision*. CRC Press, Boca Raton, FL, 1991, ch. Vision at equilibrium, pp. 234–250. 4
- [CBAA19] COOMBES K. R., BROCK G., ABRAMS Z. B., ABRUZZO L. V.: Polychrome: Creating and assessing qualitative palettes with many colors. *Journal of Statistical Software, Code Snippets* 90, 1 (2019), 1–23. URL: <https://www.jstatsoft.org/index.php/jss/article/view/v090c01>, doi:10.18637/jss.v090.c01. 2
- [GLS17] GRAMAZIO C. C., LAIDLAW D. H., SCHLOSS K. B.: Colorgical: Creating discriminable and preferable color palettes for information visualization. *IEEE Transactions on Visualization and Computer Graphics* 23, 1 (2017), 521–530. doi:10.1109/TVCG.2016.2598918. 2
- [Gre10] GREEN-ARMYTAGE P.: A colour alphabet and the limits of colour coding. *Color: Design Creativity* 5 (08 2010), 1–23. 2
- [GvTG07] GLASBEY C., VAN DER HEIJDEN G., TOH V. F. K., GRAY A.: Colour displays for categorical images. *Color Research & Application* 32, 4 (2007), 304–309. URL: <https://onlinelibrary.wiley.com/doi/abs/10.1002/col.20327>, doi:https://doi.org/10.1002/col.20327. 2
- [HB03] HARROWER M., BREWER C. A.: Colorbrewer.org: An online tool for selecting colour schemes for maps. *The Cartographic Journal* 40, 1 (jun 2003), 27–37. URL: <http://dx.doi.org/10.1179/000870403235002042>, doi:10.1179/000870403235002042. 2
- [Kel65] KELLY K. L.: A colour alphabet and the limits of colour coding. *Color Engineering* 3, 26 (1965). 2
- [Mid20] MIDWAY S. R.: Principles of effective data visualization. *Patterns* 1, 9 (2020), 100141. 1
- [Mil22] MILLS B. R.: *MetBrewer: Color Palettes Inspired by Works at the Metropolitan Museum of Art*, 2022. R package version 0.2.0. URL: <https://CRAN.R-project.org/package=MetBrewer>. 1
- [MOF09] MACHADO G. M., OLIVEIRA M. M., FERNANDES L. A. F.: A physiologically-based model for simulation of color vision deficiency. *IEEE Transactions on Visualization and Computer Graphics* 15, 6 (2009), 1291–1298. 2
- [NCS*21] NARDINI P., CHEN M., SAMSEL F., BUJACK R., BÖTINGER M., SCHEUERMANN G.: The making of continuous colormaps. *IEEE Transactions on Visualization and Computer Graphics* 27, 6 (2021), 3048–3063. doi:10.1109/TVCG.2019.2961674. 2
- [Now19] NOWOSAD J.: *Check Color Palettes for Problems with Color Vision Deficiency*, 2019. R package version 0.1.0. URL: <https://nowosad.github.io/colorblindcheck/>. 2
- [OI08] OKABE M., ITO K.: Color universal design (cud) - how to make figures and presentations that are friendly to colorblind people -, 2008. Online publication. URL: <https://jfly.uni-koeln.de/color/>. 1, 3
- [PC21] PEDERSEN T. L., CRAMERI F.: *scico: Colour Palettes Based on the Scientific Colour-Maps*, 2021. R package version 1.3.0. URL: <https://CRAN.R-project.org/package=scico>. 1
- [R C22] R CORE TEAM: *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2022. URL: <https://www.R-project.org/>. 2
- [RSGP] REDA K., SALVI A. A., GRAY J., PAPKA M. E.: Color nameability predicts inference accuracy in spatial visualizations. *Computer Graphics Forum* 40, 3. 4
- [RW18] RAM K., WICKHAM H.: *wesanderson: A Wes Anderson Palette Generator*, 2018. R package version 0.3.6. URL: <https://CRAN.R-project.org/package=wesanderson>. 1
- [Sd15] SMITH N., DER WALT S. V.: A better default colormap for matplotlib. SciPy 2015, 2015. URL: <https://www.youtube.com/watch?v=xAoljeRJ31U>. 1, 3
- [SKR18] SAMSEL F., KLAASSEN S., ROGERS D. H.: Colormoves: Real-time interactive colormap construction for scientific visualization. *IEEE Computer Graphics and Applications* 38, 1 (2018), 20–29. doi:10.1109/MCG.2018.011461525. 2
- [Sto16] STONE M.: How we designed the new color palettes in tableau 10, 2016. Online publication. URL: <https://www.tableau.com/about/blog/2016/7/colors-upgrade-tableau-10-56782>. 2, 4
- [SWD05] SHARMA G., WU W., DALAL E. N.: The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. *Color Research & Application* 30, 1 (2005), 21–30. doi:10.1002/col.20070. 2
- [Ten23] TENNEKES M.: *cols4all: Colors for all*, 2023. R package version 0.6. URL: <https://CRAN.R-project.org/package=cols4all>. 1, 2, 4
- [Tol21] TOL P.: Colour schemes and templates, 2021. Online publication. URL: <https://personal.sron.nl/~pault/>. 1, 3
- [Was21] WASKOM M. L.: seaborn: statistical data visualization. *Journal of Open Source Software* 6, 60 (2021), 3021. URL: <https://doi.org/10.21105/joss.03021>, doi:10.21105/joss.03021. 4
- [Wor18] WORLD WIDE WEB CONSORTIUM: Web content accessibility guidelines (wcag) 2.1, 2018. [Online; accessed 26-February-2023]. URL: <https://www.w3.org/TR/WCAG21/>. 4
- [Wri15] WRIGHT K.: R color palettes for many data classes, 2015. StackOverflow answer. URL: <https://stackoverflow.com/a/9568659/1393348>. 2
- [YZZ*22] YUAN L., ZHOU Z., ZHAO J., GUO Y., DU F., QU H.: Infocolorizer: Interactive recommendation of color palettes for infographics. *IEEE Trans. Vis. Comput. Graph.* 28, 12 (2022), 4252–4266. 2
- [ZHM09] ZEILEIS A., HORNİK K., MURRELL P.: Escaping RGBland: Selecting colors for statistical graphics. *Computational Statistics & Data Analysis* 53, 9 (2009), 3259–3270. doi:10.1016/j.csda.2008.11.033. 1