Strategies and Software for Robust Color Palettes in Data Visualizations

Achim Zeileis

https://colorspace.R-Forge.R-project.org/
Motivation

**Figure 2**

EVERY YEAR, DISGRUNTLED SCIENTISTS COMPETE FOR THE PAINBOW AWARD FOR WORST COLOR SCALE.

**Source:** https://xkcd.com/2537/
Motivation

Source: White House (2019-09-04)

Source: U.S. president via Twitter (2019-09-05)
Motivation

**Risk map:** Probability of wind speeds $> 39$ mph ($63 \text{ km h}^{-1}$), 2019-08-30–2019-09-04.

**Source:** National Oceanic and Atmospheric Administration.
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**Need tools for:**
- Construction of palettes with better perceptual properties.
- Assessment of color palettes.
- Manipulation of colors.
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Because Bob Ross would not approve of this!
Motivation

**R package colorspace:**
- Flexible HCL-based color palettes (base graphics, ggplot2, shiny app, ...).
- Color manipulation tools (desaturation, lighten/darken, ...).
- Color vision deficiency emulation.
- Visualization of palette properties.

**Base R:**
- New default color palette for base graphics.
- `hcl.colors()`: HCL-based color palettes (fixed/named).
- `palette.colors()`: Well-established qualitative color palettes.
HCL vs. RGB

**HCL:** Polar coordinates in CIELUV. Captures perceptual dimensions of the human visual system very well.

- **Hue** (Type of color)
- **Chroma** (Colorfulness)
- **Luminance** (Brightness)
HCL vs. RGB

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<table>
<thead>
<tr>
<th>Hue</th>
<th>Chroma</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of color</td>
<td>Colorfulness</td>
<td>Brightness</td>
</tr>
</tbody>
</table>

**RGB:** Motivated by how computers/TVs used to generate and still represent color.
HCL vs. RGB: The End of the Rainbow

RGB Spectrum

HCL Spectrum

Luminance / Chroma

Hue
HCL vs. RGB: The End of the Rainbow

RGB Spectrum

HCL Spectrum

Hue

Luminance / Chroma

Red / Green / Blue

Red
Green
Blue

0 20 40 60 80 100
Index
0

−360 −180 0 180 360
Luminance Chroma Hue

HCL Spectrum

Hue

Luminance / Chroma

Red / Green / Blue

Red
Green
Blue

0.0 0.2 0.4 0.6 0.8 1.0
Index
0

0 90 180 270 360
Luminance Chroma Hue
Color palettes: Somewhere over the Rainbow

<table>
<thead>
<tr>
<th>Qualitative (Set 2)</th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Pink</td>
<td>Yellow</td>
<td>Green</td>
<td>Blue</td>
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<tr>
<td>Desaturated</td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sequential (Blues 3)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
</tr>
<tr>
<td>Desaturated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diverging (Green–Brown)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Green</td>
<td>Brown</td>
<td>Green</td>
<td>Brown</td>
</tr>
<tr>
<td>Desaturated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
Color palettes: Somewhere over the Rainbow

**Qualitative (Set 2)**

- Color
- Desaturated

**Sequential (Blues 3)**

- Color
- Desaturated

**Diverging (Green–Brown)**

- Color
- Desaturated

**Qualitative**: For categorical information with no particular ordering. Luminance differences should be limited.
**Color palettes: Somewhere over the Rainbow**

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**Qualitative:** For categorical information with no particular ordering. Luminance differences should be limited.

**Sequential:** For ordered/numeric information from high to low (or vice versa).
Color palettes: Somewhere over the Rainbow

**Qualitative:** For categorical information with no particular ordering. Luminance differences should be limited.

**Sequential:** For ordered/numeric information from high to low (or vice versa).

**Diverging:** For ordered/numeric information diverging from a central neutral value to two extremes.
Color palettes: Somewhere over the Rainbow

**Sequential:** Luminance contrast is crucial (dark to light or vice versa).

[Blues 2 palette]

[Blues 3 palette]

[Blues palette]
Color palettes: Somewhere over the Rainbow

**Blues 2:** Single hue. Decreasing chroma with increasing luminance.

![Blues 2 palette](image)

![Blues 3 palette](image)

![Blues palette](image)
Color palettes: Somewhere over the Rainbow

**Blues 3:** Single hue. Triangular chroma to achieve higher luminance contrast.
Blues: Multi hue. Triangular chroma. High luminance contrast.
Color palettes: Somewhere over the Rainbow

NOAA original

Luminance / Chroma
HCL Spectrum
Luminance / Chroma
Hue

HCL-based alternative

Luminance / Chroma
HCL Spectrum
Luminance / Chroma
Hue
Color palettes: Somewhere over the Rainbow

NOAA original

HCL–based alternative

Luminance / Chroma

Hue

Luminance

Chroma

Hue

HCL Spectrum

HCL Spectrum
Color palettes: Somewhere over the Rainbow

**Diverging:** Combine two sequential palettes with balanced chroma/luminance.
**Color palettes: Somewhere over the Rainbow**

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Color palettes: Somewhere over the Rainbow

Sequential (hcl.colors)

Diverging (hcl.colors)
Color palettes: Somewhere over the Rainbow

ColorBrewer.org: YlGnBu

Viridis

Luminance / Chroma

Hue

HCL Spectrum

Luminance Chroma Hue

0 20 40 60 80 100

Index

0 90 180 270 360

0 100

13 / 33
Color palettes: Somewhere over the Rainbow

ColorBrewer.org: YlGnBu

Viridis
Color palettes: Somewhere over the Rainbow

**R package colorspace:**
- Flexible HCL-based palettes:
  - `qualitative_hcl()`, `sequential_hcl()`, `diverging_hcl()`.
- Named palettes available, can be easily modified.
- `ggplot2` scales: `scale_<aesthetic>_<datatype>_<colorscale>()`.

**Base R:**
- `hcl.colors()`: Named HCL-based palettes, no modifications.
- `palette.colors()`: Well-established qualitative palettes.
Color palettes: Somewhere over the Rainbow

**Qualitative:** Lack of luminance contrasts critical for color vision deficiencies.

```r
R> hcl.colors(6, palette = "Dark 3") |> 
+     swatchplot(cvd = TRUE)
```

![Color palettes comparison](image-url)
Color palettes: Somewhere over the Rainbow

**Qualitative:** New default base "R4" palette with limited luminance differences.

```
R> palette.colors(7, palette = "R4")[-1] |> 
+   swatchplot(cvd = TRUE)
```
Color palettes: Somewhere over the Rainbow

**Qualitative:** "Okabe-Ito" palette very robust under color vision deficiencies.

R> palette.colors(8, palette = "Okabe-Ito")[-1] |> 
+ swatchplot(cvd = TRUE)
Color palettes: Somewhere over the Rainbow

Qualitative (palette.colors)

- R4
- ggplot2
- Okabe-Ito
- Accent
- Dark 2

Paired
- Pastel 1
- Pastel 2

Set 3
- Tableau 10
- Classic Tableau
- Polychrome 36
- Alphabet
Colors by designers, painters, and directors?

**Movie:** *Todo sobre mi madre* (All About My Mother, 1999)

**Source:** Sony Pictures Classics via MoMA
Colors by designers, painters, and directors?

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**Palette:** Hadley Mendelsohn
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Palette: Todo sobre mi madre
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Palette: OrRd (ColorBrewer.org, HCL version)
Colors by designers, painters, and directors?

Movie: *Tacones lejanos* (High Heels, 1991)

Source: El Deseo S.A. via Twitter
Colors by designers, painters, and directors?

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R package colorspace

Origin of the package: Convert colors between various three-dimensional representations of color.

In particular: From the perceptually-based HCL (Hue-Chroma-Luminance) to standard Red-Green-Blue (sRGB, and corresponding hex codes) space.
Visualization and assessment

Visualizations: Based on vector of colors.

- `swatchplot()`: Color swatches.
- `specplot()`: Spectrum of HCL and/or RGB trajectories.
- `hclplot()`: Trajectories in 2-dimensional HCL space projections.
- `demoplot()`: Illustrations of typical (and simplified) statistical graphics.
Visualization and assessment: `hclplot()`

R> `hclplot(qualitative_hcl(7, palette = "Set 2"))`
R> `hclplot( sequential_hcl(7, palette = "Blues 3"))`
R> `hclplot( diverging_hcl(7, palette = "Blue-Red"))`
Visualization and assessment: `demoplot()`

R> cl <- sequential_hcl(5, palette = "Heat")
R> demoplot(cl, type = "...")
Emulate: Color vision deficiencies.

- \texttt{deutan}(): Deuteranopia (green deficient).
- \texttt{protan}(): Protanopia (red deficient).
- \texttt{tritan}(): Tritanopia (blue deficient).

Example: Maunga Whau volcano data.
Color vision deficiency

rainbow(11, end = 2/3)

sequential_hcl(11, "Blue−Yellow")
Color apps

Facilitate exploration: Graphical user interfaces as shiny apps.

- Palette constructor: choose_palette() or hclwizard() (also in tcltk).
- Color picker: choose_color() or hcl_color_picker().
- Color vision deficiency emulator: cvd_emulator().

Online versions: https://hclwizard.org/
Color apps: choose_palette() / hclwizard()
Color apps: choose_color() / hcl_color_picker()
Color apps: cvd_emulator()

Severity

Different levels of severity for the color vision deficiency can be emulated. A value of 100% means maximum deficiency, a value of 0% no deficiency at all. This value has to be adjusted before uploading the image.

Upload Image

Select an image from your local disc (PNG/JPG/JPEG) for which the color vision deficiency should be emulated. Please note that the file size is limited to 50.0 Megabyte.
Recommendations

Colors and palettes:

• Check whether color is appropriate for coding your information.
• Use appropriate type of palette.
• Don’t reinvent the wheel, start out from well-established palettes.
• For areas use light colors (higher luminance, lower chroma).
• For points/lines darker colors are needed (lower luminance, higher chroma).
• Check robustness of palette.
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R:

- `colorspace` facilitates exploration, manipulation, and assessment.
- HCL approximations of palettes from `RColorBrewer, rcartocolor, scico, . . .`
- Prespecified palettes are also easily available in base R.


