



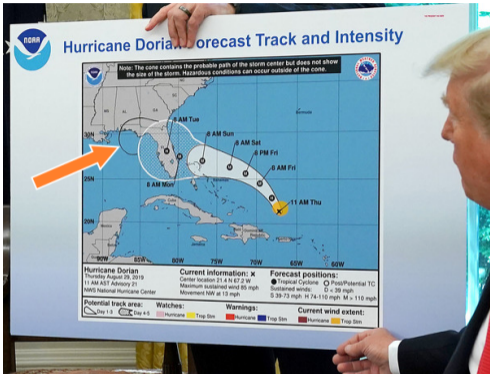
colorspace

Strategies and Software for Robust Color Palettes in Data Visualizations

Achim Zeileis

<https://colorspace.R-Forge.R-project.org/>

Motivation



Source: White House (2019-09-04)

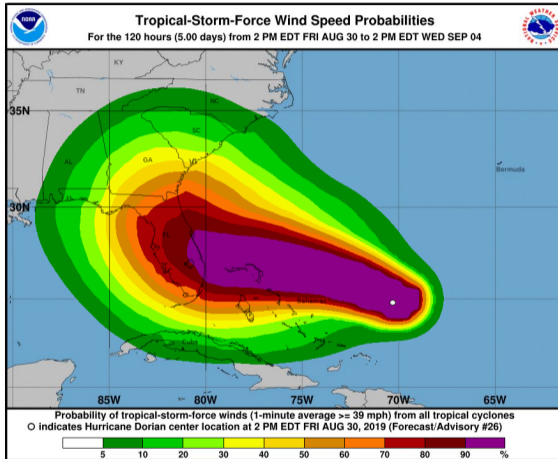
Donald J. Trump @realDonaldTrump · Sep 5, 2019
Just as I said, Alabama was originally projected to be hit. The Fake News denies it!

Four maps showing the earliest reasonable arrival time of tropical-storm-force winds for Hurricane Dorian. The maps show the storm's path and intensity over the Gulf of Mexico and Florida. The maps are arranged in a 2x2 grid.

31.7K 10.8K 46.1K

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

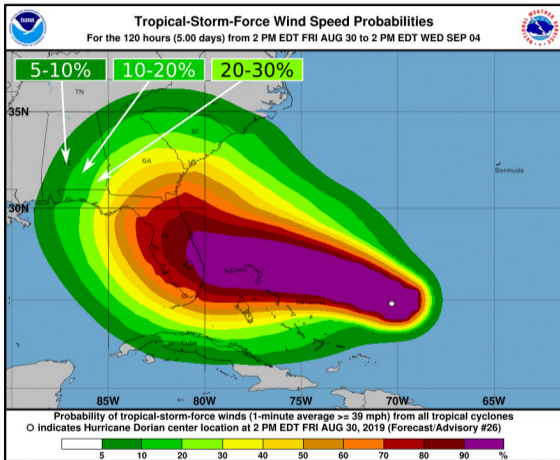
Motivation



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

Source: National Oceanic and Atmospheric Administration.

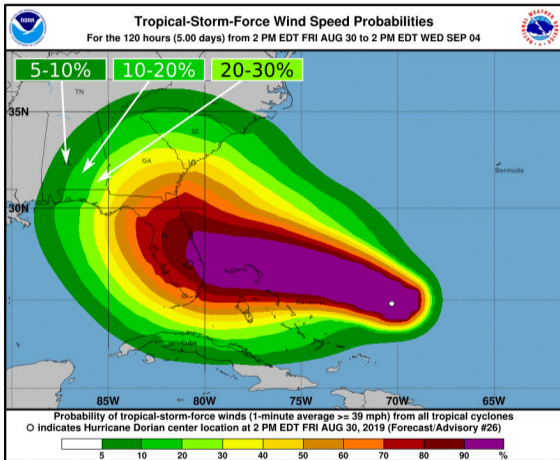
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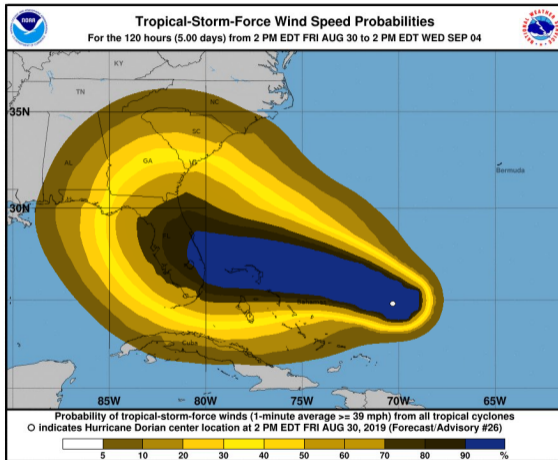


Risk map: Probability of wind speeds > 39 mph (63 km h^{-1}), 2019-08-30–2019-09-04.

Source: National Oceanic and Atmospheric Administration.

Problems: Flashy.

Motivation

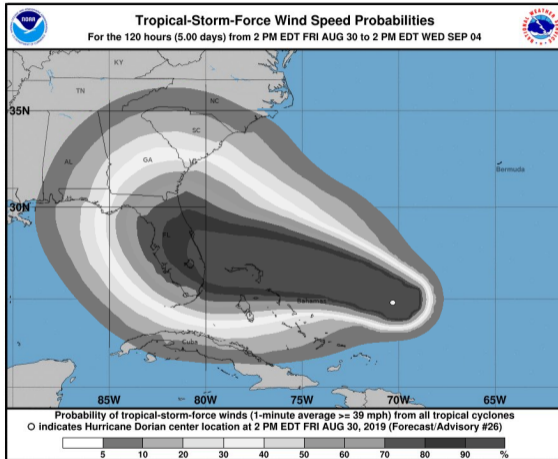


Risk map: Probability of wind speeds > 39 mph (63 km h^{-1}), 2019-08-30–2019-09-04.

Source: National Oceanic and Atmospheric Administration.

Problems: Flashy. Color vision deficiency.

Motivation

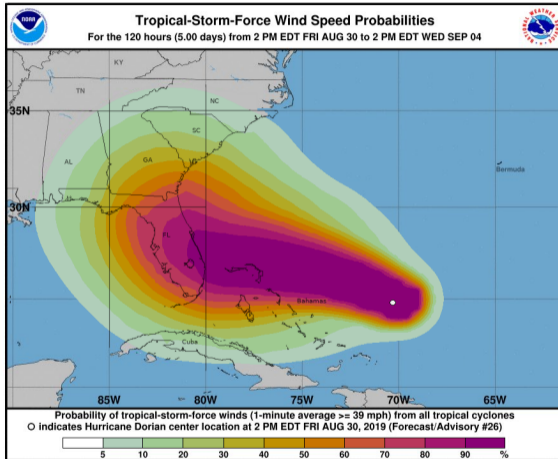


Risk map: Probability of wind speeds > 39 mph (63 km h^{-1}), 2019-08-30–2019-09-04.

Source: National Oceanic and Atmospheric Administration.

Problems: Flashy. Color vision deficiency. Grayscale.

Motivation



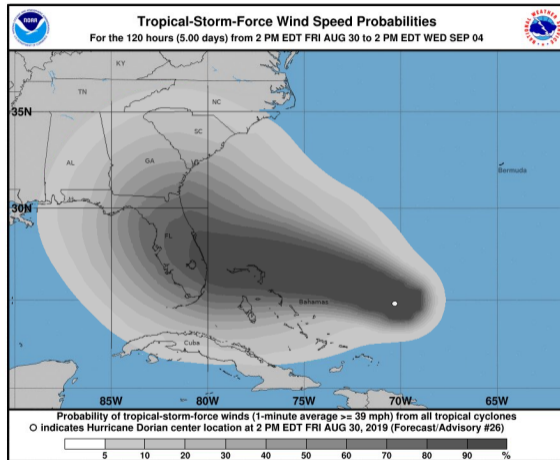
Risk map: Probability of wind speeds > 39 mph (63 km h^{-1}), 2019-08-30–2019-09-04.

Source: National Oceanic and Atmospheric Administration.

Problems: Flashy. Color vision deficiency. Grayscale.

Alternative: HCL-based sequential palette.

Motivation



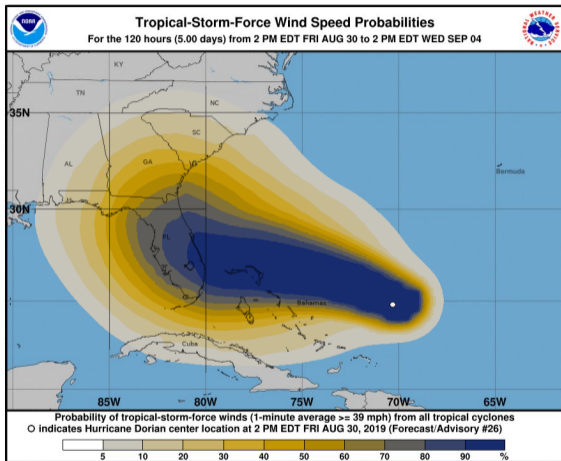
Risk map: Probability of wind speeds > 39 mph (63 km h^{-1}), 2019-08-30–2019-09-04.

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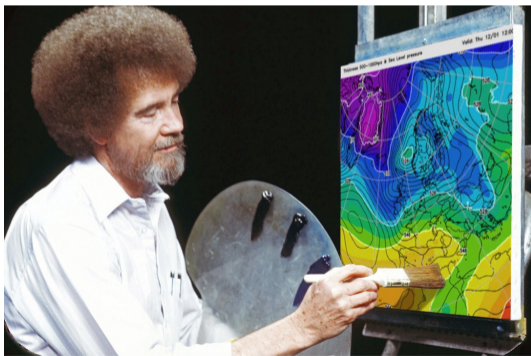
Need tools for:

- Construction of palettes with better perceptual properties.
- Assessment of color palettes.
- Manipulation of colors.

Motivation

Need tools for:

- Construction of palettes with better perceptual properties.
- Assessment of color palettes.
- Manipulation of colors.



Because Bob Ross would not approve of this!

Motivation

R package colorspace:

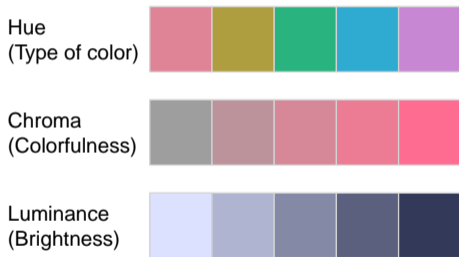
- Flexible HCL-based color palettes (base graphics, ggplot2, shiny app, ...).
- Color manipulation tools (desaturation, lighten/darken, ...).
- Color vision deficiency emulation.
- Visualization of palette properties.

Base R:

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

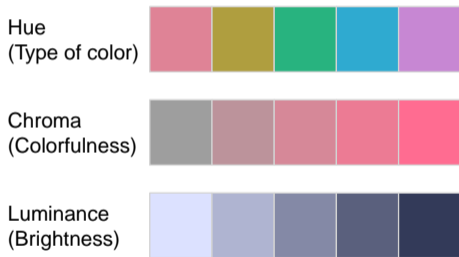
HCL vs. RGB

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

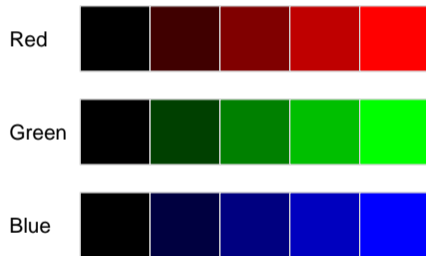


HCL vs. RGB

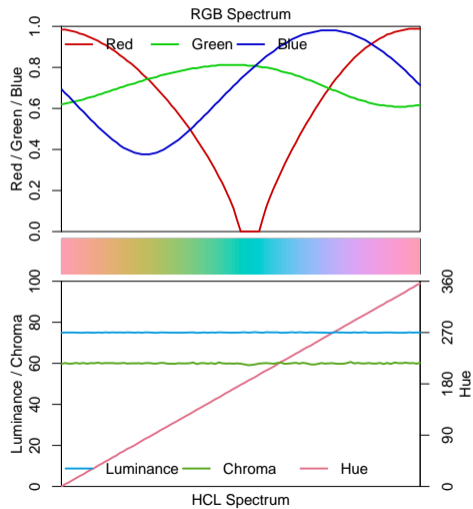
HCL: Polar coordinates in CIELUV. Captures perceptual dimensions of the human visual system very well.



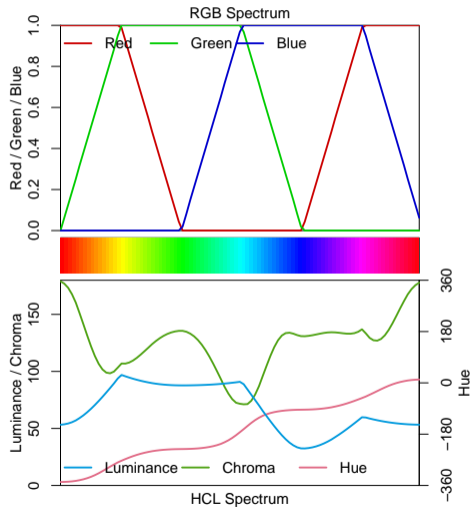
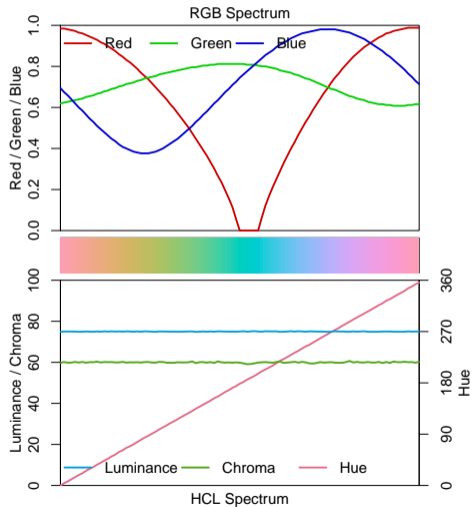
RGB: Motivated by how computers/TVs used to generate and still represent color.



HCL vs. RGB: The End of the Rainbow



HCL vs. RGB: The End of the Rainbow



Color palettes: Somewhere over the Rainbow

Qualitative (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)

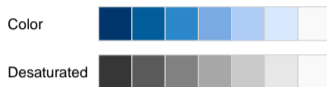


Color palettes: Somewhere over the Rainbow

Qualitative (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)



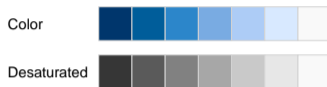
Qualitative: For categorical information with no particular ordering. Luminance differences should be limited.

Color palettes: Somewhere over the Rainbow

Qualitative (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)



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 (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)



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.

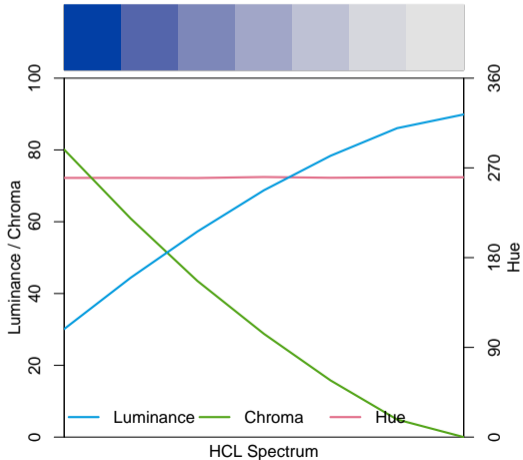
Color palettes: Somewhere over the Rainbow

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



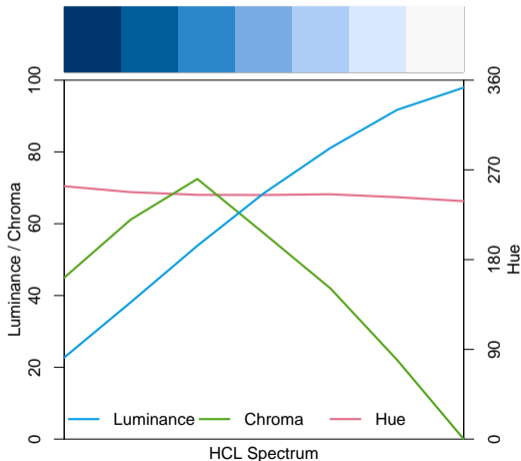
Color palettes: Somewhere over the Rainbow

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



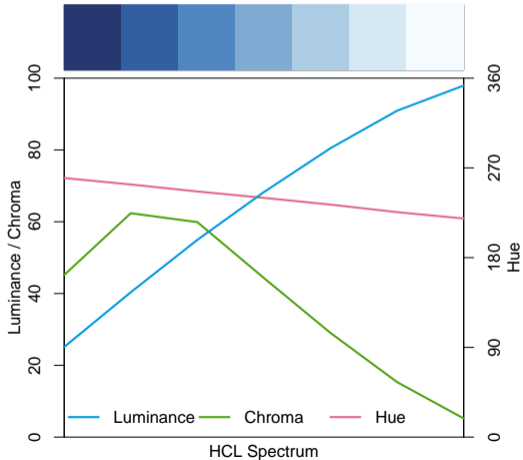
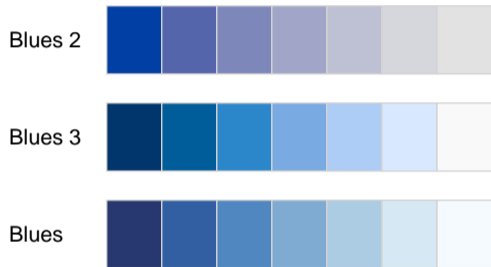
Color palettes: Somewhere over the Rainbow

Blues 3: Single hue. Triangular chroma to achieve higher luminance contrast.

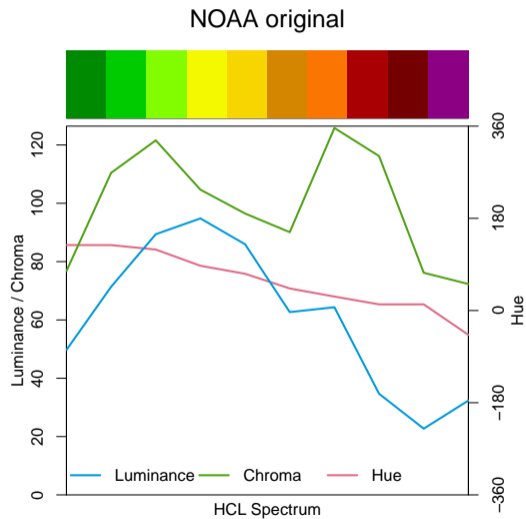


Color palettes: Somewhere over the Rainbow

Blues: Multi hue. Triangular chroma. High luminance contrast.

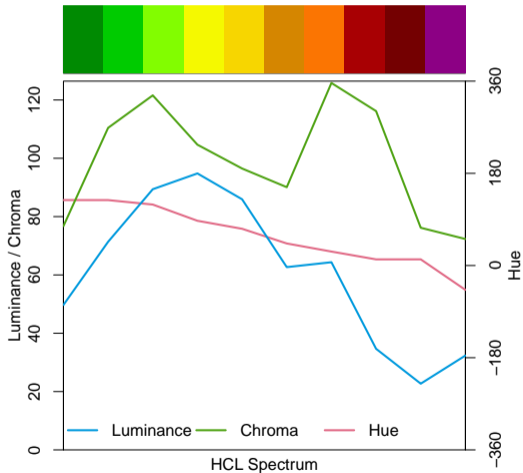


Color palettes: Somewhere over the Rainbow

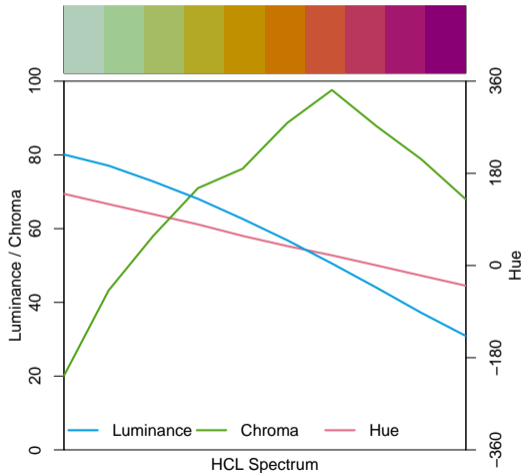


Color palettes: Somewhere over the Rainbow

NOAA original

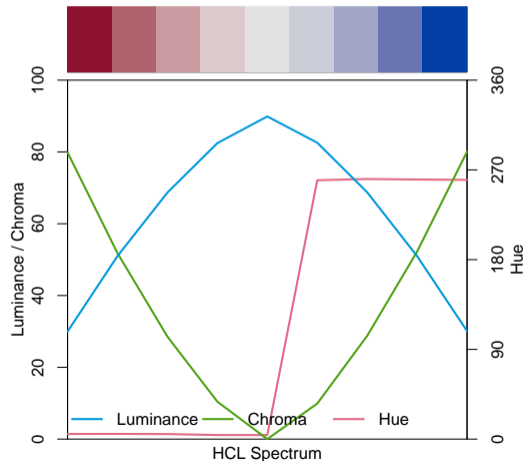


HCL-based alternative



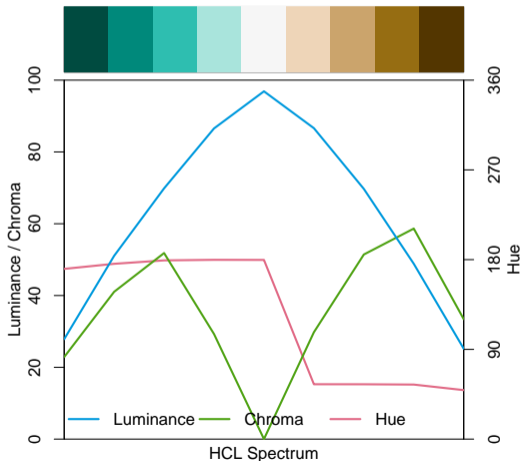
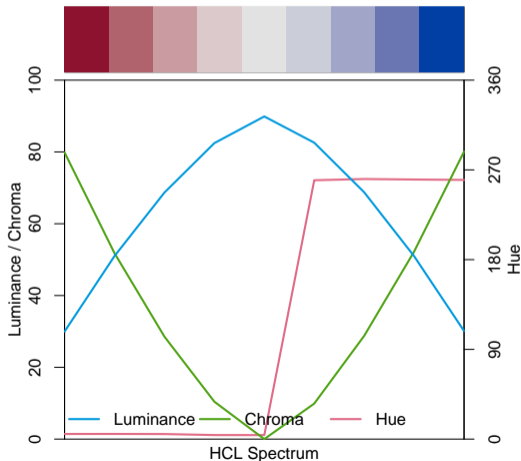
Color palettes: Somewhere over the Rainbow

Diverging: Combine two sequential palettes with balanced chroma/luminance.



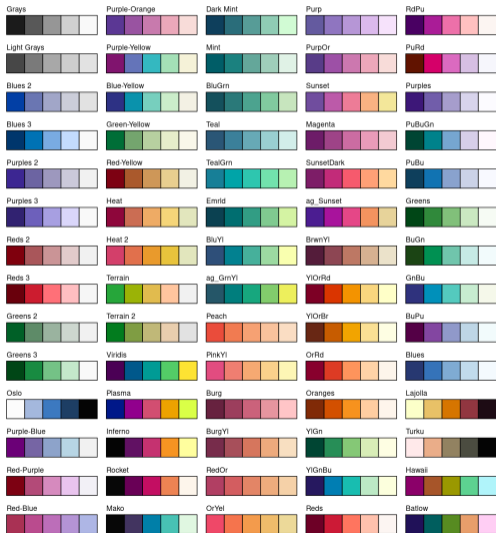
Color palettes: Somewhere over the Rainbow

Diverging: Combine two sequential palettes with balanced chroma/luminance.

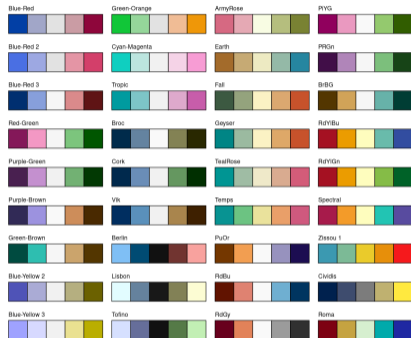


Color palettes: Somewhere over the Rainbow

Sequential (hcl.colors)

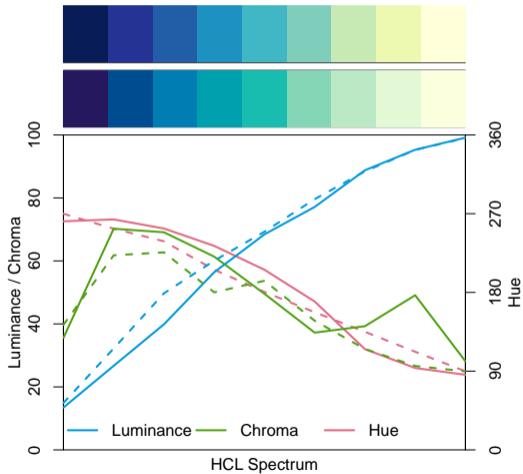


Diverging (hcl.colors)



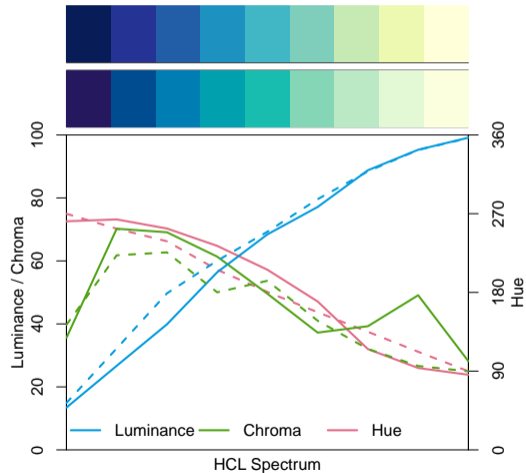
Color palettes: Somewhere over the Rainbow

ColorBrewer.org: YlGnBu

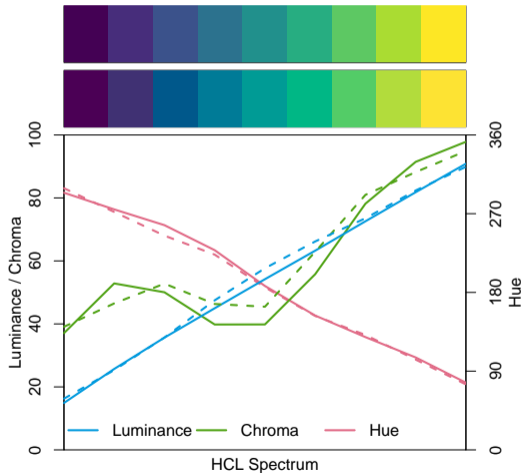


Color palettes: Somewhere over the Rainbow

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>()`.

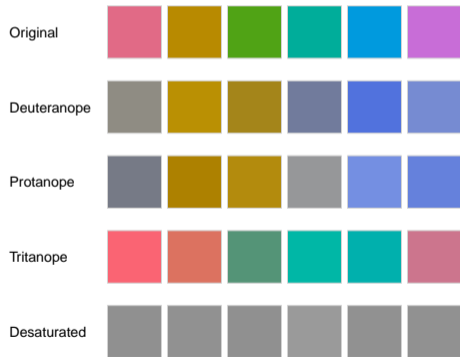
Base R:

- `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.

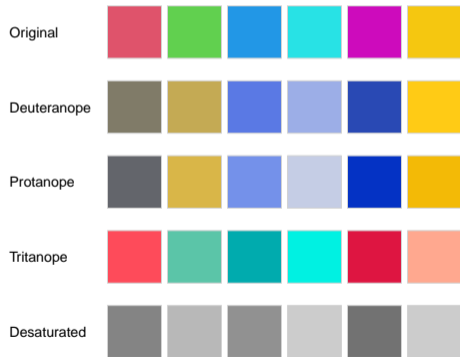
```
R> hcl.colors(6, palette = "Dark 3") |>  
+   swatchplot(cvd = TRUE)
```



Color palettes: Somewhere over the Rainbow

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

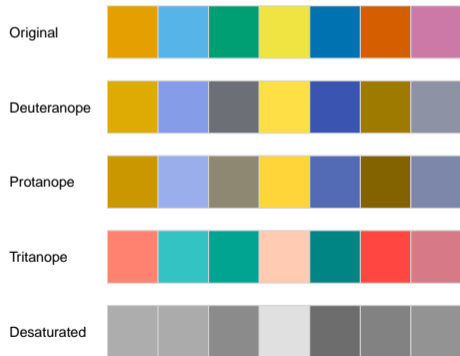
```
R> palette.colors(7, palette = "R4")[-1] |>  
+   swatchplot(cvd = TRUE)
```



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



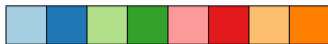
Accent



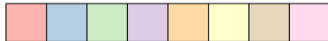
Dark 2



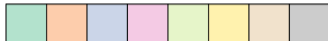
Paired



Pastel 1



Pastel 2



Set 1



Set 2



Set 3

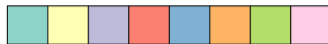


Tableau 10



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?



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

Source: Sony Pictures Classics
via MoMA

Palette: Hadley Mendelsohn

Colors by designers, painters, and directors?



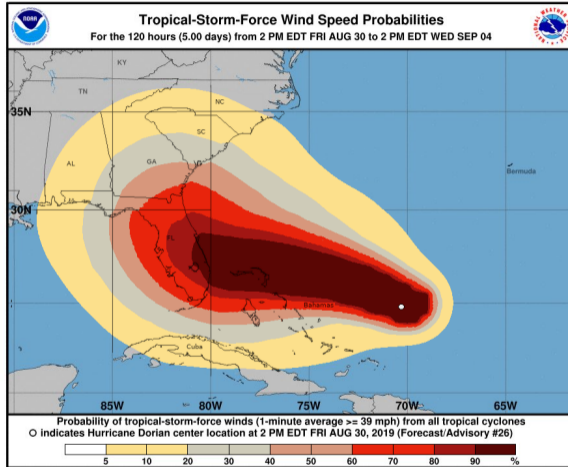
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(*All About My Mother*, 1999)

Source: Sony Pictures Classics
via MoMA

Palette: Hadley Mendelsohn

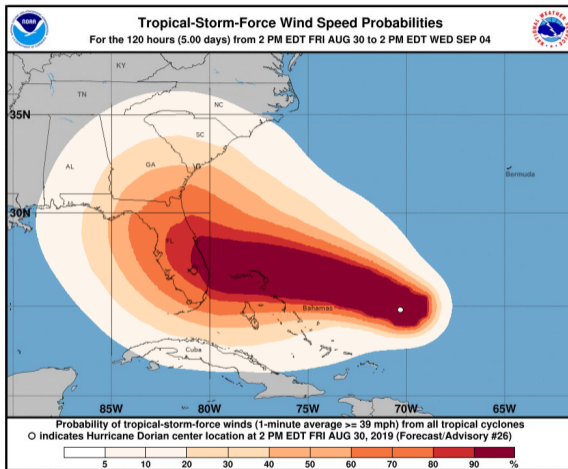


Colors by designers, painters, and directors?



Palette: Todo sobre mi madre

Colors by designers, painters, and directors?



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?



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

Source: El Deseo S.A. via Twitter

Palette: Bibiana Fernandez



Colors by designers, painters, and directors?



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

Source: El Deseo S.A. via Twitter

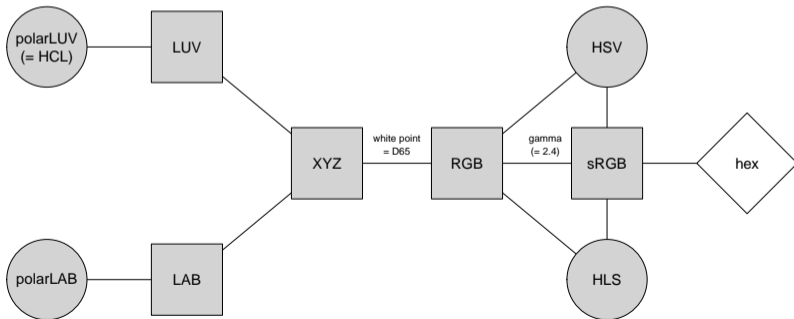
Palette: Bibiana Fernandez



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.



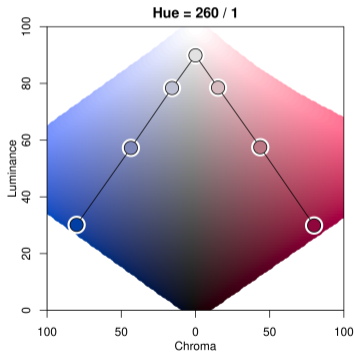
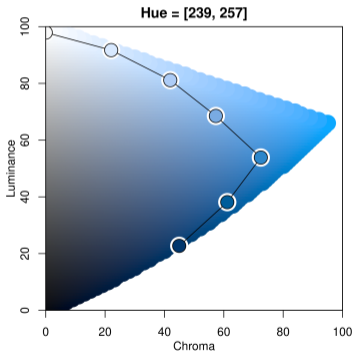
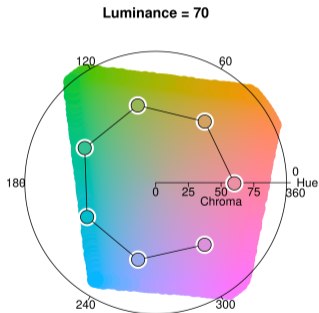
Visualization and assessment

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()

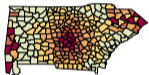
```
R> hclplot(qualitative_hcl(7, palette = "Set 2"))  
R> hclplot(sequential_hcl(7, palette = "Blues 3"))  
R> hclplot(diverging_hcl(7, palette = "Blue-Red"))
```



Visualization and assessment: demoplot()

```
R> cl <- sequential_hcl(5, palette = "Heat")  
R> demoplot(cl, type = "...")
```

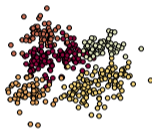
map



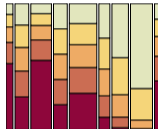
heatmap



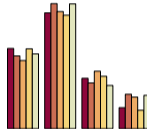
scatter



spine



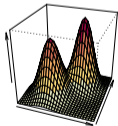
bar



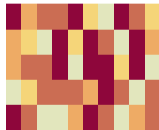
pie



perspective



mosaic



lines

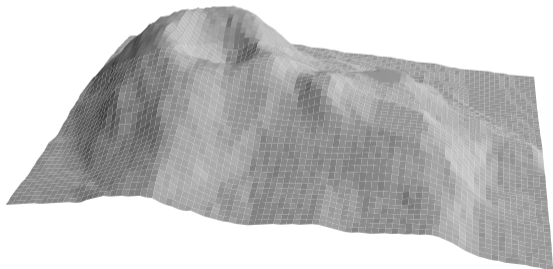


Color vision deficiency

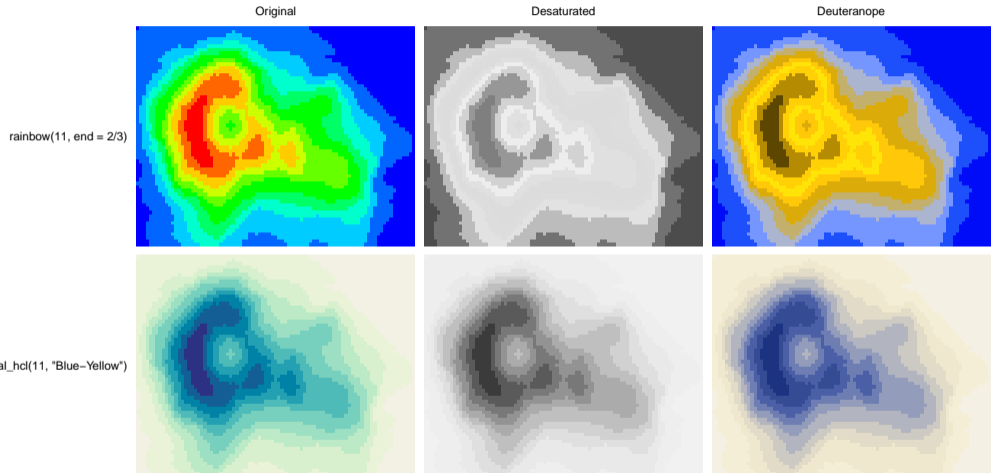
Emulate: Color vision deficiencies.

- `deutan()`: Deuteranopia (green deficient).
- `protan()`: Protanopia (red deficient).
- `tritan()`: Tritanopia (blue deficient).

Example: Maunga Whau volcano data.



Color vision deficiency



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()

Mozilla Firefox

File Edit View History Bookmarks Tools Help

127.0.0.1:5604/ x +

127.0.0.1:5604

Search

Base Options

Type of palette
Advanced: Sequential (single-hue)

Base color scheme
Blues 3

Example
Heatmap

Control Options

Reverse
 Correct colors
 Dark mode
 Desaturated

Vision

Normal
 Deutan
 Protan
 Tritan

Color Settings

HUE 1 240 SET

CHROMA 1 50 SET

MAX CHROMA 50 SET

LUMN. 1 20 SET

LUMN. 2 95 SET

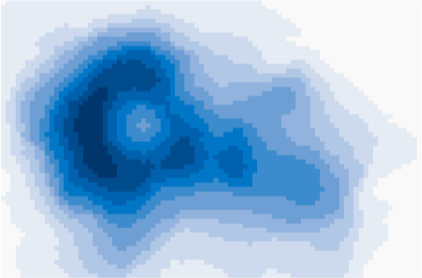
POWER 1 1.2 SET

POWER 2 1.4 SET

NUMBER 11 SET

Return to R

Example Plot Spectrum Color Plane Export Info



R colorspace 1.4.5

Color apps: choose_color() / hcl_color_picker()

The screenshot shows a Mozilla Firefox browser window displaying a color picker application. The browser's address bar shows the URL `127.0.0.1:5604/`. The application interface includes:

- Left Panel:** Three sliders for Hue (set to 270), Chroma (set to 50), and Luminance (set to 60). Below them is an "RGB hex color" input field containing `#9189C7` and a "Set" button. A "Selected color" bar shows the current color. At the bottom are "Actions" buttons: "Pick", "Unpick", "Clear", and "Return to R", along with a "Dark mode" checkbox.
- Main Area:** A "Luminance-Chroma plane" plot with a "Hue-Chroma plane" tab selected. The plot shows a color triangle with a selected point. Below the plot are three horizontal color bars for Hue (0-360), Chroma (0-150), and Luminance (0-100), each with a selected point.
- Bottom:** A "Color palette" with four color swatches: `#E2E2E2`, `#B9B5D5`, `#9189C7`, and `#5F4FB1`.

R colorspace 1.4.0

Color apps: cvd_emulator()

Mozilla Firefox


File Edit View History Bookmarks Tools Help

127.0.0.1:5604/ x +

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All Info



Severity

0 10 20 30 40 50 60 70 80 90 100


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

Browse... No file selected

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.



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Mozilla Firefox

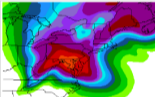
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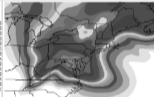
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All Info



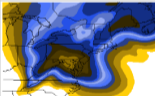
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Original



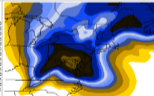
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Desaturated



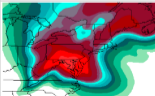
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Deuteranope



Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Protanope



Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Tritanope

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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.

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