



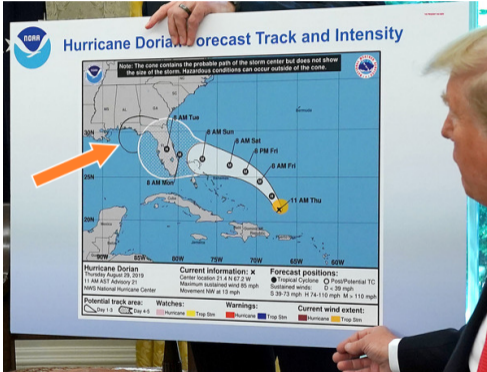
colorspace

Robust Color Maps That Work for Most Audiences
(Including the U.S. President)

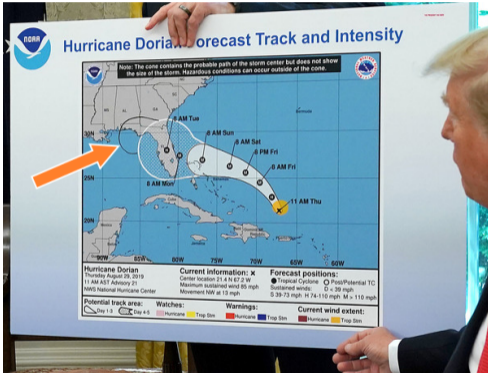
Reto Stauffer, Achim Zeileis

<http://hclwizard.org/>

Motivation



Motivation



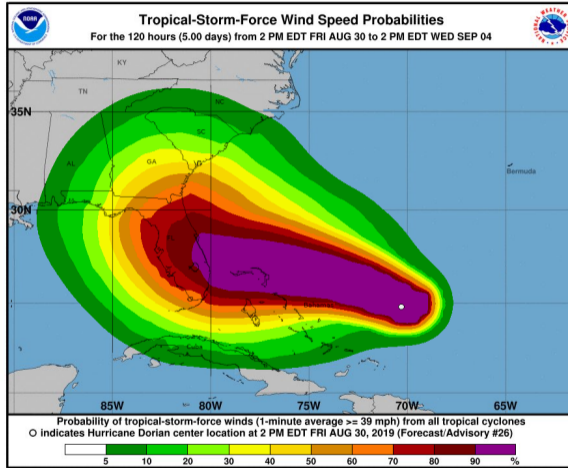
Donald J. Trump @realDonaldTrump · Sep 5, 2019
Just as I said, Alabama was originally projected to be hit. The Fake News denies it!

The tweet includes four meteorological maps from NOAA. The top two maps show the 'Earliest Reasonable Arrival Time of Tropical-Storm-Force Winds' and 'Tropical-Storm Wind Speed Probabilities' for the period from 2 PM EST on August 30 to 2 PM EST on September 01. The bottom two maps show the 'Earliest Reasonable Arrival Time of Tropical-Storm-Force Winds' for a different period. The maps use color gradients to indicate wind speed ranges and probability levels over the Gulf of Mexico and the southeastern United States.

31.7K 10.8K 46.1K

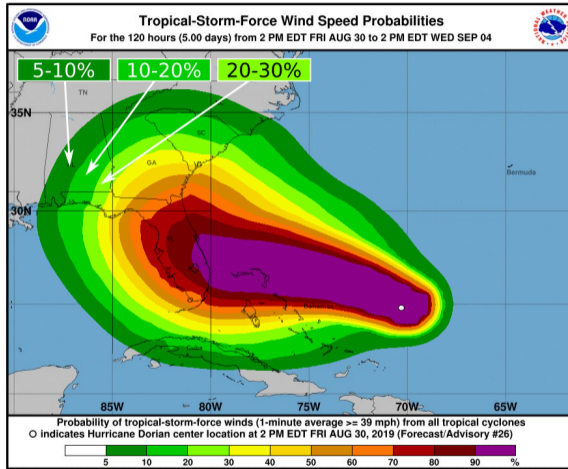
Projected track and wind speed forecast of hurricane Dorian. Screenshot of a video released by the White House (Sep. 4, 2019), tweet by the U.S. president (Sep. 5, 2019).

Problem



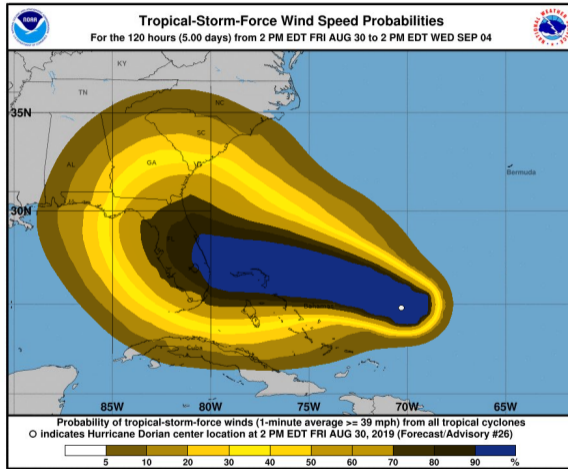
Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

Problem



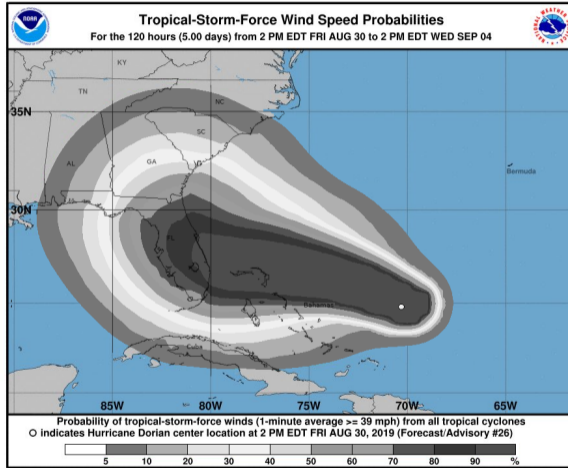
Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

Problem



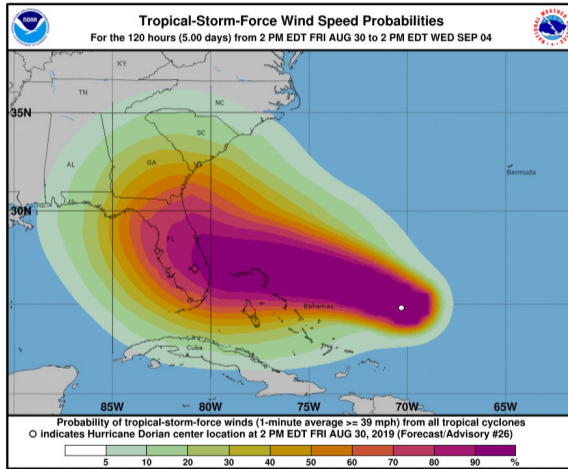
Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

Problem



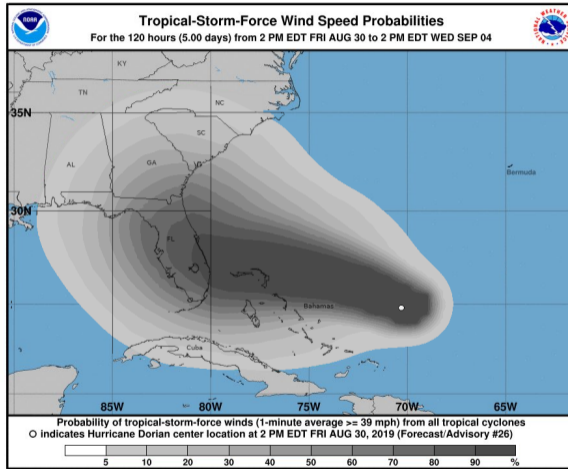
Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

Solution



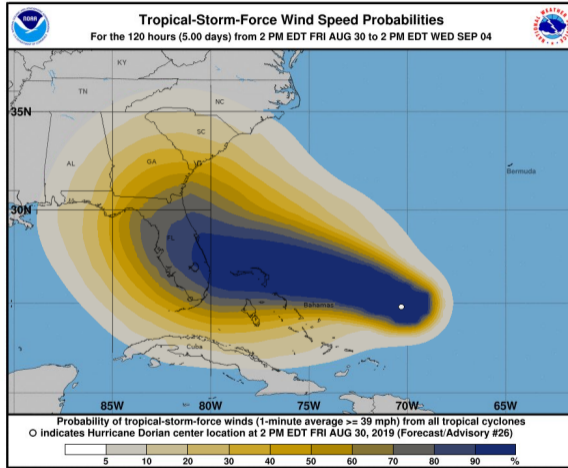
Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

Solution



Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

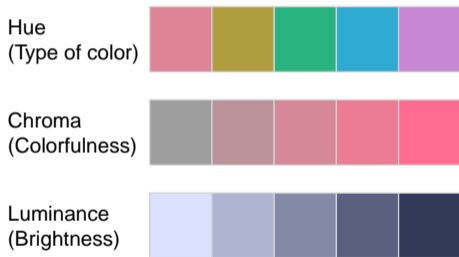
Solution



Probability of exceeding wind speeds of 39 mph (63 km h^{-1}), Aug 30 – Sep 04, 2019 (noaa.gov).

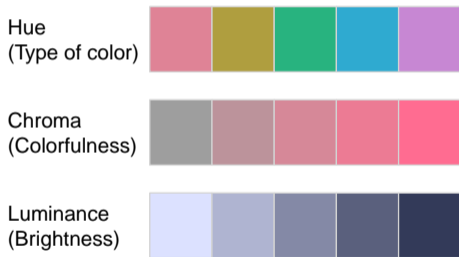
HCL vs. RGB

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

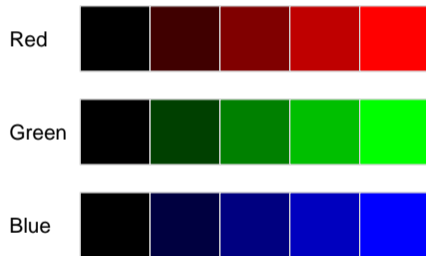


HCL vs. RGB

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

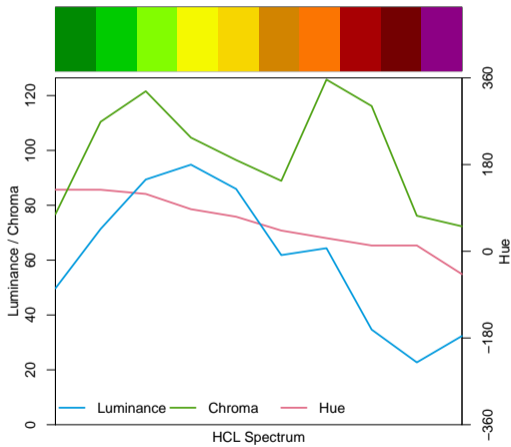


RGB: Motivated by how computers/TVs used to generate and still represent color.

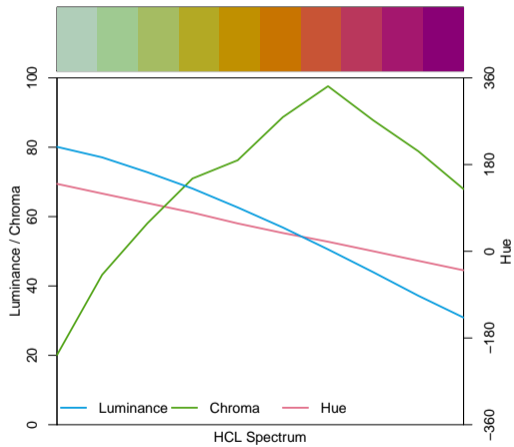


HCL vs. RGB

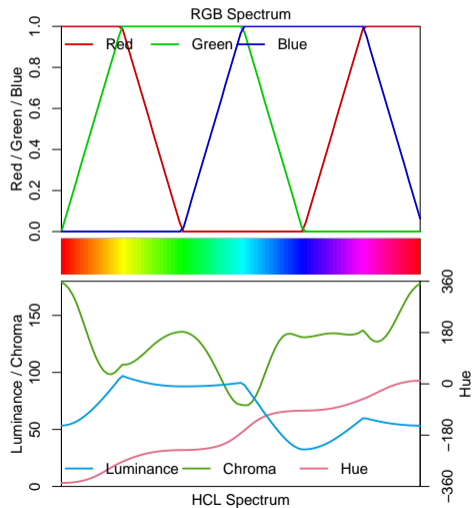
Problem



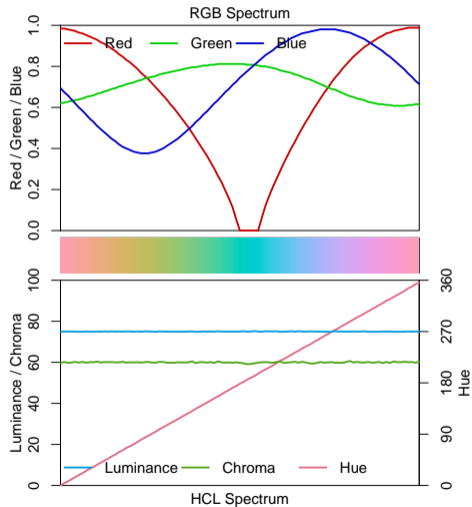
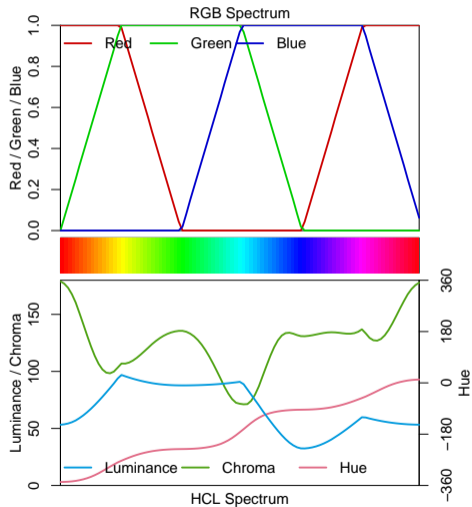
Solution



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, i.e., where no particular ordering of categories is available. Function: `qualitative_hcl()`.

Color palettes: Somewhere over the Rainbow

Qualitative (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)



Qualitative: For categorical information, i.e., where no particular ordering of categories is available. Function: `qualitative_hcl()`.

Sequential: For ordered/numeric information, i.e., where colors go from high to low (or vice versa). Function: `sequential_hcl()`.

Color palettes: Somewhere over the Rainbow

Qualitative (Set 2)



Sequential (Blues 3)



Diverging (Green–Brown)



Qualitative: For categorical information, i.e., where no particular ordering of categories is available. Function: `qualitative_hcl()`.

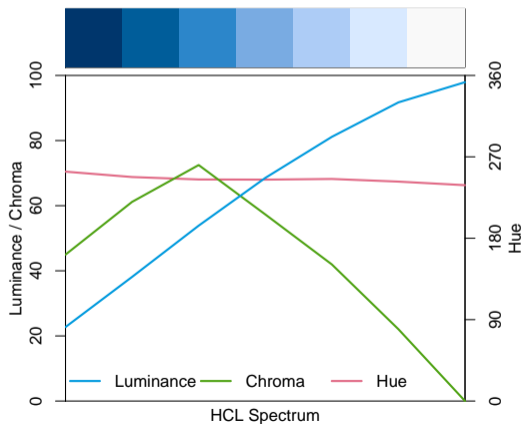
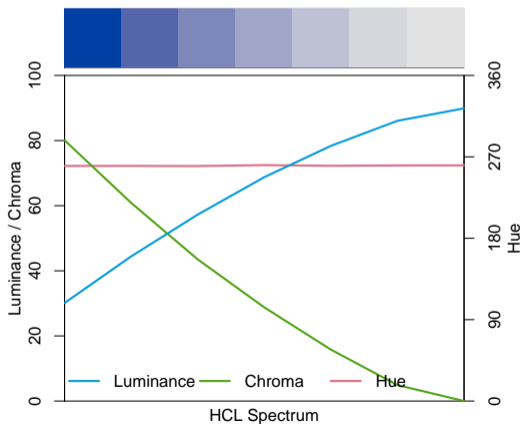
Sequential: For ordered/numeric information, i.e., where colors go from high to low (or vice versa). Function: `sequential_hcl()`.

Diverging: For ordered/numeric information around a central neutral value, i.e., where colors diverge from neutral to two extremes. Function: `diverging_hcl()`.

Color palettes: Somewhere over the Rainbow

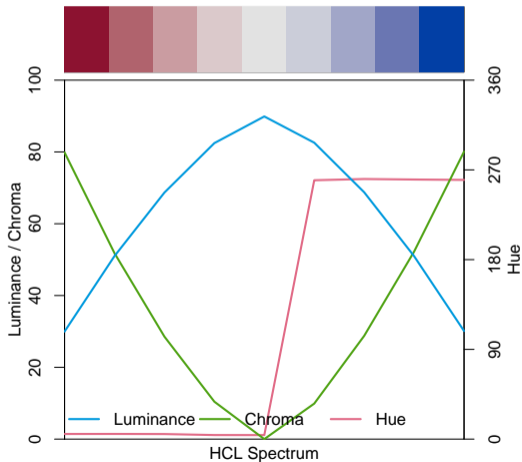
Blues 2: Single hue. Decreasing chroma with increasing luminance.

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



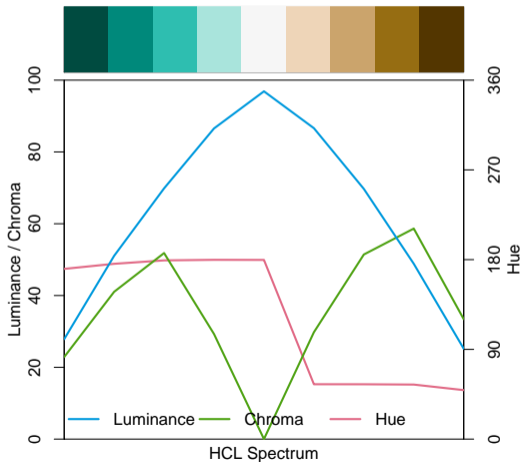
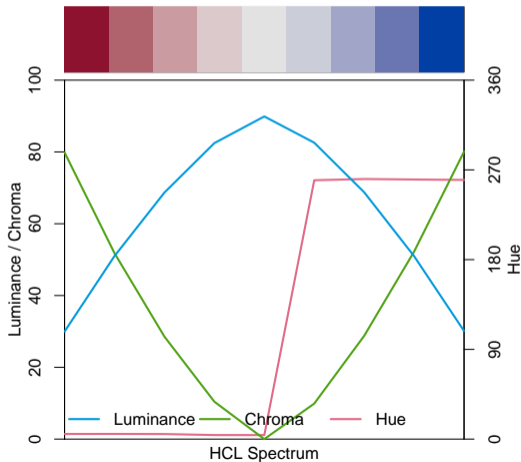
Color palettes: Somewhere over the Rainbow

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



Color palettes: Somewhere over the Rainbow

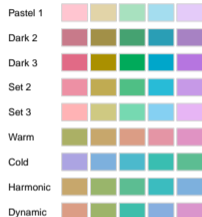
Diverging: Combine two sequential palettes with balanced chroma/luminance.



Color palettes: Somewhere over the Rainbow

```
> hcl_palettes(plot = TRUE)
```

Qualitative



Sequential (single-hue)



Sequential (multi-hue)



BluGnm



YlOrBr



Diverging



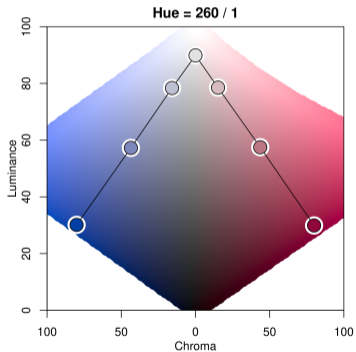
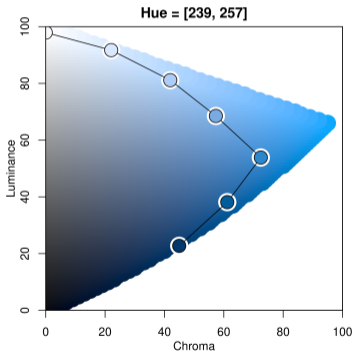
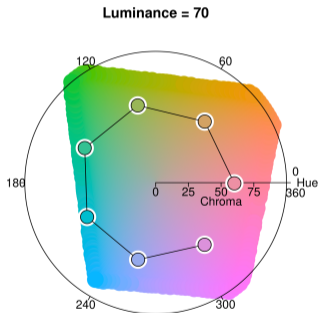
Visualization and assessment

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()

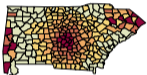
```
> hclplot(qualitative_hcl(7, palette = "Set 2"))  
> hclplot(sequential_hcl(7, palette = "Blues 3"))  
> hclplot(diverging_hcl(7, palette = "Blue-Red"))
```



Visualization and assessment: demoplot()

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

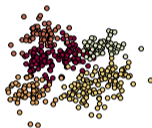
map



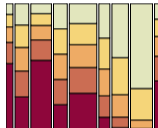
heatmap



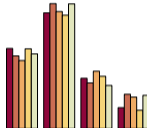
scatter



spine



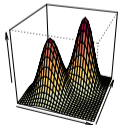
bar



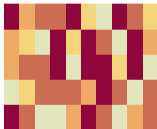
pie



perspective



mosaic



lines

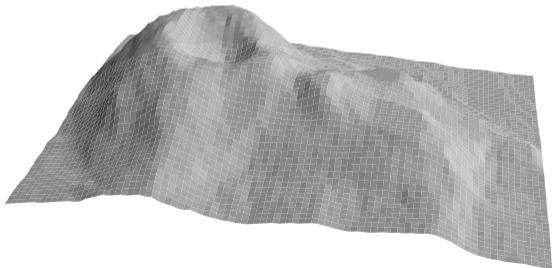


Color vision deficiency

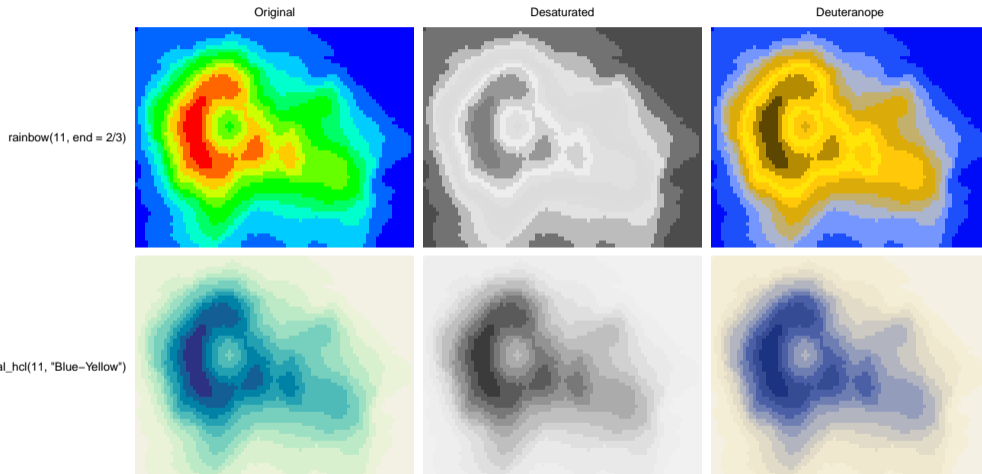
Emulate: Color vision deficiencies.

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

Example: Maunga Whau volcano data.

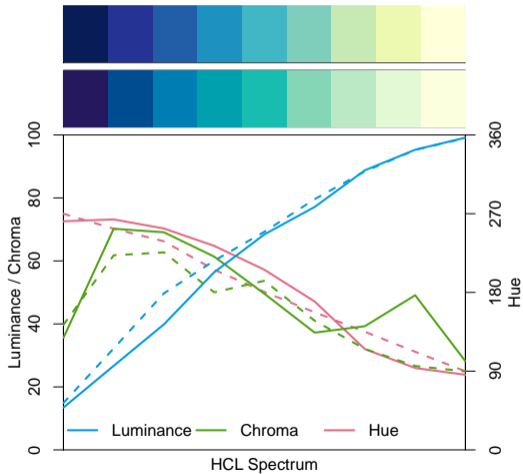


Color vision deficiency



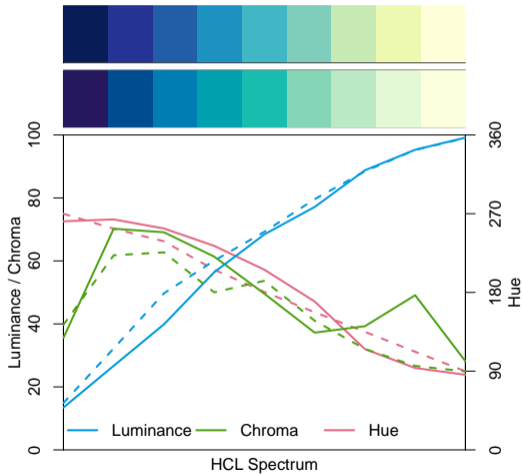
Approximations of other palettes

ColorBrewer.org: YlGnBu

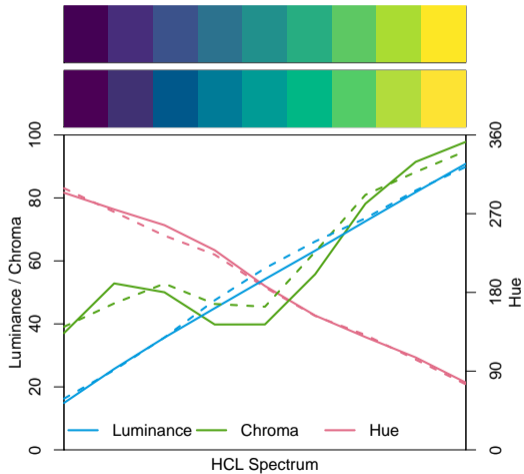


Approximations of other palettes

ColorBrewer.org: YlGnBu



Viridis



Base R

In 3.6.0: All prespecified palettes also via `grDevices::hcl.colors()`.



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: <http://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: 90 SET

LUMN. 1: 20 SET

LUMN. 2: 95 SET

POWER 1: 1.2 SET

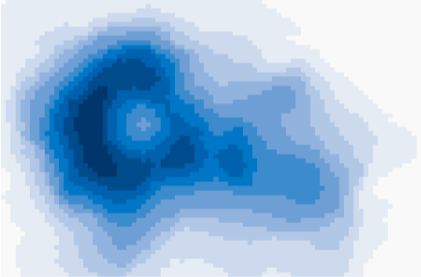
POWER 2: 1.4 SET

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()

Mozilla Firefox

File Edit View History Bookmarks Tools Help

127.0.0.1:5604/

127.0.0.1:5604

Hue: 270

Chroma: 50

Luminance: 60

RGB hex color: #9189C7

Selected color: #9189C7

Actions: Pick Unpick Clear Return to R

Dark mode

Luminance-Chroma plane

Hue-Chroma plane Export Info

H: 0 45 90 135 180 225 270 315 360

C: 0 50 100 150

L: 0 20 40 60 80 100

Color palette

#E2E2E2 #B9B5D5 #9189C7 #5F4FB1

© colorspace 1.4.0

Color apps: cvd_emulator()

Mozilla Firefox


File Edit View History Bookmarks Tools Help

127.0.0.1:5604/ x +

127.0.0.1:5604

Upload Original Desaturated Deuteranope Protanope Tritanope


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% means 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.



© colorspace 1.4.0

Mozilla Firefox

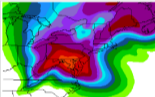
File Edit View History Bookmarks Tools Help

127.0.0.1:5604/ x +

127.0.0.1:5604

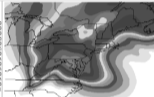
Upload Original Desaturated Deuteranope Protanope Tritanope

All Info



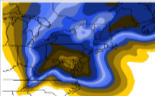
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Original



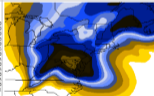
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Desaturated



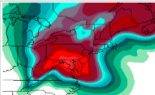
Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Deuteranope



Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Protanope



Hurricane Sandy 120-hour Day 1-5 Rainfall Forecast

Tritanope

© colorspace 1.4.0

Recommendations

Colors and palettes:

- Do not overestimate the effectiveness of color.
- Choose type of palette based on the data to be visualized.
- For areas use light colors (higher luminance, lower chroma).
- For points/lines darker colors are needed (lower luminance, higher chroma).
- For palettes with more colors stronger luminance contrasts are needed.
- Triangular chroma trajectories useful for distinguishing central colors.

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- Triangular chroma trajectories useful for distinguishing central colors.

R packages:

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

Do it yourself

Software: *colorspace*.

- R (mature): <http://colorspace.R-Forge.R-project.org/>.
- Python (beta): <https://github.com/retostauffer/python-colorspace>.
- Web (interactive): <http://www.hclwizard.org/>.

Take-home messages:

- Choose colors carefully.
- Make areas of interest stand out from background.
- Check robustness.
- Software helps you.

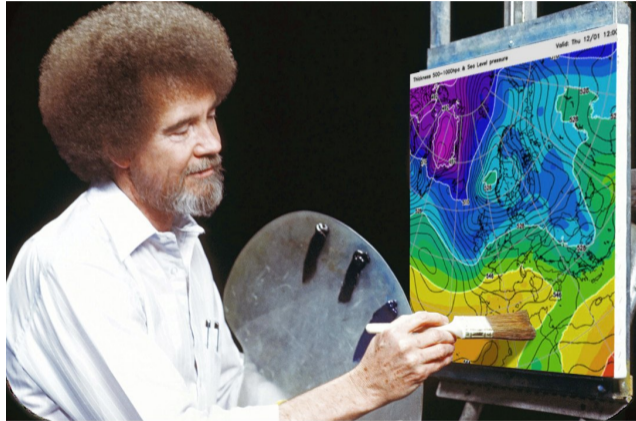
References

Zeileis A, Fisher JC, Hornik K, Ihaka R, McWhite CD, Murrell P, Stauffer R, Wilke CO (2019). “colorspace: A Toolbox for Manipulating and Assessing Colors and Palettes.” arXiv:1903.06490, arXiv.org E-Print Archive. <http://arxiv.org/abs/1903.06490>

Zeileis A, Hornik K, Murrell P (2009). “Escaping RGBland: Selecting Colors for Statistical Graphics.” *Computational Statistics & Data Analysis*, **53**, 3259–3270. doi:10.1016/j.csda.2008.11.033.

Stauffer R, Mayr GJ, Dabernig M, Zeileis A (2015). “Somewhere over the Rainbow: How to Make Effective Use of Colors in Meteorological Visualizations.” *Bulletin of the American Meteorological Society*, **96**(2), 203–216. doi:10.1175/BAMS-D-13-00155.1

Thank you for your interest!



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