Somewhere Over the Rainbow: How to Make Effective Use of Colors in Scientific Visualizations

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http://hclwizard.org
Introduction

Color:

• Integral element in graphical displays.
• Easily available in (statistical) software.
• Omnipresent in (electronic) publications: Technical reports, electronic journal articles, presentation slides.
Introduction

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- Easily available in (statistical) software.

Problem: Little guidance about how to choose appropriate colors for a particular visualization task.

Question: What are useful color palettes for coding qualitative and quantitative variables?
Introduction

Main goal of our work:

• Raise awareness of the issue.
• Introduce Hue-Chroma-Luminance (HCL) model.
  • Based on human perception.
  • Better control for choosing color palettes.
• Provide convenient software for exploring and assessing HCL-based palettes.
Common Sense
Using Red-Green-Blue Based Color Maps
RGB color space: And the (in)famous rainbow color palette.
RGB color space: And the (in)famous rainbow color palette.
RGB Rainbow

RGB rainbow

RGB rainbow spectrum

RGB
Red
Green
Blue
Desaturated

0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0

ZAMG Innsbruck 2017-12-20
• The default color in many software packages.
• Conveniently used by many practitioners.
• Defaults only change slowly (if at all).
RGB Rainbow

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**Question:** Everybody does it – why should it be wrong?
What’s Wrong?

Original figure as published by the NOAA.

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Gradients:  
Very strong

Saturation:  
Highly-saturated colors

Hurricane Sandy  
120-hour Day 1-5 Rainfall Forecast

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What’s Wrong?

Gradients:
Very strong

Saturation
Highly-saturated colors

Discontinuous
Bright, dark, bright, dark, …

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What’s Wrong?

Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated version of the original figure.
What’s Wrong?

Assignment
No longer unique

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Interpretation
Where is the maximum?

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What’s Wrong?

Assignment
No longer unique

Interpretation
Where is the maximum?

Focus
On dark artefacts

Desaturated version of the original figure.
What’s Wrong?

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What’s Wrong?

What color-blind people see (red-green weakness).

About 5% of all Europeans are affected.
What’s Wrong?

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What’s Wrong?

End-user
Who is it?

Consider
Visual constraints?

What color-blind people see (red-green weakness).
About 5% of all Europeans are affected.
Challenges

**Summary:** The colors in a palette should

- be simple and natural,
- not be unappealing,
- highlight the important information,
- not mislead the reader,
- work everywhere and for everyone.

In practice:

- People often do not think about it at all.
- ... and simply use default colors.

Potential problems:

- For end users – reviewers, supervisor, colleague, customer.
- For your own day-to-day work.
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The Hue-Chroma-Luminance Color Space

A perception-based Color Space
Perception-Based Way: HCL

Advantages:

• Hue: Type of color.

• Chroma: Colorfullness.

• Luminance: Brightness.
Perception-Based Way: HCL

- **Hue** (*defines the color*)
- **Chroma** (*defines the colorlessness*) and
- **Luminance** (*defines the brightness*)
HCL Version

Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Same information, changed color scheme.
HCL Version

Colors: Smooth gradients.

Same information, changed color scheme.
HCL Version

Colors:
Smooth gradients.

Information:
Guiding, no hidden information.

Same information, changed color scheme.
HCL Version

Colors:
Smooth gradients.

Information:
Guiding, no hidden information.

Works:
Screen, projector, gray-scaled device.

Same information, changed color scheme.
HCL Version

Hurricane Sandy
120-hour Day 1-5 Rainfall Forecast

Desaturated representation of the HCL-version.
HCL Version

Assignment:
Higher values $\Rightarrow$ lower luminance.

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HCL Version

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Focus:
leads readers to most important areas.

Desaturated representation of the HCL-version.
HCL Version

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leads readers to most important areas.

Summary:
Solved a lot of problems by changing the color palette.

Desaturated representation of the HCL-version.
Warning Map Example

Colorized
Original (left)
HCL idea (right)
Warning Map Example

Colorized
Original (left)
HCL idea (right)

Gray-scale
Warning Map Example

Colorized
Original (left)
HCL idea (right)

Gray-scale

Deuteranopia
Red-Green weakness
Color Palettes: Qualitative

**Goal:** Code quantitative data.
Color Palettes: Qualitative

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- **dynamic [30, 300]**
  - Dynamic color palette with shades of orange, green, and blue.

- **harmonic [60, 240]**
  - Harmonic color palette with shades of brown, green, and blue.

- **cold [270, 150]**
  - Cold color palette with shades of purple, green, and blue.

- **warm [90, –30]**
  - Warm color palette with shades of orange, green, and pink.
Color Palettes: Qualitative

**Goal:** Code quantitative data.

**Solution:** Take colors with different hues, but keep chroma and luminance constant. E.g.: \((H, 50, 70)\)
Color Palettes: Sequential

**Goal:** Code quantitative data (e.g., probabilities) where one side is of main interest.
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**Solution**: Constant hue and changing chroma/luminance. E.g., $(90 - 0, 30 - 100, 90 - 50)$. 

Color Palettes: Sequential
Color Palettes: Diverging

**Goal:** Code quantitative data and highlight both ends of the spectrum (e.g., anomalies, wet/dry, probabilities, ...).
Color Palettes: Diverging

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**Solution:** Diverging color schemes; combine sequential schemes with smooth transition.
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Experiences With Practitioners

In the beginning

• Hesitation of colleagues.
• “Not necessary!”
• “Why should we change existing products?”
• “Everybody does it like this . . .”
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In the beginning

• Hesitation of colleagues.
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• “Why should we change existing products?”
• “Everybody does it like this . . .”

A few days later

• Mainly positive feedback.
• Decrease of misinterpretations in classroom (“Weather & Forecast”).
• “Much easier to interpret . . .”
• “How can I make use of those palettes (in my software)?”
The R colorspace Package
A perception-based Color Space
R colorspace

> library('colorspace')
> # Interactively choosing color palettes
> #
> # Variant A:
> # pal <- choose_palette()
> #
> # Variant B (requires shiny and shinyjs):
> # pal <- hclwizard()
R colorspace

**Figure:** Screenshot of the tikz choose_palette interface.
R colorspace

**Figure:** Screenshot of the hclwizard interface.
R colorspace

Use colorspace package on command-line level
> # choose_palette and hclwizard return a colormap function
> class(pal)
[1] "function"
> # function (n, h = c(12, 265), c = 80, l = c(25, 95), power = 0.7,
> # fixup = TRUE, gamma = NULL, alpha = 1, ...)

```r
> pal(3)
[1] "#7C0607" "#F1F1F1" "#1F28A2"
> pal(9)
[1] "#7C0607" "#953C3D" "#AF6869" "#CA9C9C" "#F1F1F1" "#A3A4C9" 
[8] "#7577B1" "#4D50A1" "#1F28A2"
```
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> class(pal)
[1] "function"
> # function (n, h = c(12, 265), c = 80, l = c(25, 95), power = 0.7,
> #     fixup = TRUE, gamma = NULL, alpha = 1, ...)

Draw a color map with $N$ colors:
> pal(3)
[1] "#7C0607" "#F1F1F1" "#1F28A2"
> pal(9)
[1] "#7C0607" "#953C3D" "#AF6869" "#CA9C9C" "#F1F1F1" "#A3A4C9" "#7577B1" [8] "#4D50A1" "#1F28A2"
R colorspace

Basic colorspace wrapper methods:

```r
> qual <- rainbow_hcl(n=11)
> seq  <- sequential_hcl(n=11, h=0, l=c(90,40), c.=c(0,60))
> heat <- heat_hcl(n=11, h=c(0,-120), l=c(70,40), c.=c(30,60))
> div  <- diverge_hcl(n=11, h=c(270,120), c=60, l=c(50,80))
```
R colorspace

Assess the spectrum of a color map:

```r
> div <- diverge_hcl(n=91, h=c(270,120), c=60, l=c(50,80))
> specplot(div)
```
R colorspace

Assess the spectrum of a color map:

```r
> rainbow <- rainbow(91)
> specplot( rainbow )
```
Use colorspace to convert colors:

```r
> div <- diverge_hcl(n=5, h=c(270,120), c=60, l=c(50,80))
> RGB <- hex2RGB( div ); RGB

R     G     B
[1,] 0.4705882 0.4274510 0.7215686
[2,] 0.6666667 0.6549020 0.7568627
[3,] 0.7764706 0.7764706 0.7764706
[4,] 0.6039216 0.6862745 0.5803922
[5,] 0.2823529 0.5215686 0.1529412

> # Convert to HCL
> HCL <- as(RGB,"polarLUV"); HCL

L       C       H
[1,] 49.96609 60.378199003 270.31045
[2,] 69.49331 20.598091195 270.26623
[3,] 79.88122 0.006140369 94.09931
[4,] 69.23223 21.080046408 119.96933
[5,] 49.85643 59.608000199 119.81271
```
R colorspace

One of the “core functions” is `polarLUV`:

```r
> L <- seq(100, 30, length=12)
> C <- seq(40, 80, length=12)
> H <- rep( c(0,120,240), c(4,4,4) )
> HCL <- polarLUV(H=H, C=C, L=L)
```
R colorspace

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```r
> L <- seq(100, 30, length=12)
> C <- seq(40, 80, length=12)
> H <- rep( c(0,120,240), c(4,4,4) )
> HCL <- polarLUV(H=H, C=C, L=L)
> hexT <- hex( as(HCL,"RGB"), fixup=TRUE)
> hexF <- hex( as(HCL,"RGB"), fixup=FALSE)
```

Convert colors to hexadecimal representation:
R colorspace

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```r
> L <- seq(100, 30, length=12)
> C <- seq(40, 80, length=12)
> H <- rep(c(0,120,240), c(4,4,4))
> HCL <- polarLUV(H=H, C=C, L=L)

What does the `fixup=TRUE`:

```r
> as(HCL,"RGB")
```

R G B
[1,] 1.50358973 0.85466492 0.95620852
[2,] 1.33963389 0.70133126 0.80120053
[3,] 1.18684461 0.56676651 0.66377437
[4,] 1.04495144 0.44977227 0.54287660
[5,] 0.27519179 0.56279146 0.20191278
[6,] 0.19728039 0.46266385 0.12965811
[7,] 0.13385835 0.37503736 0.07240051
[8,] 0.08354332 0.29909188 0.02861425
[9,] -0.01705634 0.20360461 0.48078327
[10,] -0.05184201 0.15500028 0.41481690
[11,] -0.07965869 0.11583956 0.36140338
[12,] -0.10459109 0.08556191 0.32440858
Summary

Choice of colors:

- Use color with care!
- Think about who the readers/users are.
- Avoid large areas of flashy, highly-saturated colors.
- Employ monotonic luminance scale for numerical data.

Try it yourself:

- [http://hclwizard.org](http://hclwizard.org)
- `colorspace` in R.
References


Thank you for your attention!
And Today? (Rampel et al. 2017)

**Figure:** Rempel et al. (2017): MWR 145(8).
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**Figure:** Rempel et al. (2017): MWR 145(8).
And Today? (Rampel et al. 2017)

Figure: Rempel et al. (2017): MWR 145(8).
And Today?
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And Today? (Wang et al. 2017)
And Today? (Wang et al. 2017)
And Today? (Lien et al. 2017)