THE PROCESS OF COLORIZING A DATA VISUALIZATION

• Know your data.
• Select Color Space & Rule.
• Build Color Scheme.
• Check for Color Deficiency & Pre Existing conditions
• Apply Color Scheme to Data & Modify per Review.

• Theresa-Marie Rhyne - Color Maven/Visualization Expert/Author
Know or Identify the Nature of Your Data

- **Nominal** - name/no order - e.g. eye color.
- **Ordinal** - rank - low, medium, high - no info on degree of difference.
- **Interval** - differentiated by degree of difference - numerical values have positive, negative or zero.
- **Ratio** - data distinguished by the degree of difference - Age, Height, Duration
- **Discrete** - only whole numbers & some kind of count
- **Continuous** - data take any value - computational model
- **Binary/Dichotomous** - 2 possible values - Yes or No

Chart prepared by Georges Hattab, see: Ten simple rules to colorize biological data visualization by Hattab, Rhyne & Heider, https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1008259

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<td>Ratio</td>
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For the example I will work through in this talk:

I want to build a set of bar charts using the 5 point Likert scale of Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree.

Magenta is my Key Color.

- Ordinal - categorical attributes of a variable differentiated by order (rank, scale, or position)
- Key Color: Magenta (#FC56FF in Hex Code)
(2A) SELECT COLOR SPACE & RULE: 3 CLASSIC MODELS

RGB adds with lights.

CMYK subtracts for printing.

RYB subtracts to mix paints.

Images Theresa-Marie Rhyne, 2015

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Comparison of the color spectrum (shown as the large oval in the back) with RGB color spaces. This image shows the sRGB, Adobe RGB, and ProPhoto RGB color spaces. The CMYK color space is labeled as Matt Paper.

(2A) OTHER OPTIONS: CYLINDRICAL COORDINATE REPRESENTATIONS OF RGB: HSV & HSL

- Cylindrical Coordinate representations of points in the RGB Color Model:
  - Hue, Saturation & Value (HSV)
  - Hue, Saturation & Lightness (HSL)

- Attempts to be more intuitive and relevant than the cartesian representation of RGB.

- Developed in the 1970s and published in papers at SIGGRAPH 1978.

- Frequently used in color picker and image editing software.
(2A) OR CONSIDER: PERCEPTUAL UNIFORM COLOR SPACES LIKE MUNSELL AND HCL


Screen Capture (as of 2020) by Theresa-Marie Rhyne using Michael Horvath’s 3D Open Source animations by on Wikipedia: https://en.wikipedia.org/wiki/HCL_color_space
For my example in this talk:

My solution works for either the RGB or the Munsell Color Spaces.

Applies to the RGB Classic Color Model and the Munsell Perceptual Uniform Color Space.


Image: Theresa-Marie Rhyne 2015
(2B) DETERMINE YOUR COLOR RULE OR HARMONY

• Color Harmony: based around combinations on the Color Wheel that help to provide common guidelines for how Color hues will work together.

• Color Schemes for Data: classify Color Schemes according to three types of data: Sequential, Diverging and Qualitative.

Harmonic Resolution: See my recent writing on how these two approaches can work together - https://medium.com/nightingale/harmonic-resolution-18202193f5e5
In 1666, Isaac Newton developed the Color Circle as a simplified model of the color spectrum - Red, Green, Blue Color Space. The color wheel starts at red and cycles clockwise through the hues to violet.

Monochromatic: 1 Color with its Tint (White added), Tone (Gray added), and Shade (Black added).

Analogous: 3 or more Colors adjacent to each other on the Color Wheel.

Complementary: 2 Colors opposing each other on the Color Wheel.

For more details see: Ten simple rules to colorize biological data visualization by Hattab, Rhyne & Heider, https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1008259
(2B) COLOR SCHEMES FOR DATA: ORIGIN COLORBREWER

• Sequential Schemes: optimized for ordered data from low to high. (similar to monochromatic & narrow analogous color harmonies)

• Diverging Schemes: places equal emphasis on mid-range critical values as well as extreme values. (some complementary color harmonies used in colormap options.)

• Qualitative Schemes: does not imply magnitude differences and suited for representing nominal or categorical data.

• These Color Schemes for Data are based on the Perceptual Uniform Munsell Color System.

The ColorBrewer tool is a free online tool for color advice for maps and data visualization. It was conceptualized by Cynthia A. Brewer with interface design and software development by Mark Harrower and others (in the Department of Geography at Pennsylvania State University). See: (http://colorbrewer2.org/).

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For my example:
I select the Complementary Color Harmony where Green opposes Magenta on the Color Wheel.

There is also a similar Diverging Color Scheme in ColorBrewer.

- **Key Color:** Magenta (**FC56FF** in Hex Code)
- **Complement:** Green (**97FF54** in Hex Code)

For more details see: Complements that Diverge by T-M. Rhyne [https://medium.com/nightingale/complements-that-diverge-fa487e843674](https://medium.com/nightingale/complements-that-diverge-fa487e843674)
(3) BUILD YOUR COLOR SCHEME

For my example:
I use Adobe Color to build a 5 element Magenta Green Color Scheme with a White neutral element.

Or select the Pink Yellow Green option with 5 data classes in ColorBrewer.

- **Key Color**: Magenta (#FC56FF in Hex Code)
- **Complement**: Green (#97FF54 in Hex Code)

For more details see: Complements that Diverge by T-M. Rhyne
https://medium.com/nightingale/complements-that-diverge-fa487e843674
(4) CHECK FOR COLOR DEFICIENCY

3 Key Types of Color Vision Weaknesses:

- **Protanope**: Red retinal photoreceptors absent.
- **Deuteranope**: Green photoreceptors absent.
- **Tritanope**: only medium and long cones present. Confuse Blue with Green and Yellow with Violet.

- Here, we show the RYB color wheel under color deficiency tests. Individuals with deficiencies cannot easily differentiate between respective hues.

Color Blindness Simulator - Coblis used to evaluate results.

http://www.color-blindness.com/coblis-color-blindness-simulator/#primary
(4) CHECK FOR COLOR DEFICIENCY

For my example:

Adobe Color provides an Accessibility Tools Function.

Similarly, ColorBrewer provides an icon for “color blind friendly”.

For more details see: Complements that Diverge by T-M. Rhyne
https://medium.com/nightingale/complements-that-diverge-fa487e843674
(5) APPLY YOUR COLOR SCHEME TO DATA

The Magenta / Green Complementary/Diverging Color Scheme

Is built for the 5 point Likert scale of

Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree.

Notice the initial color deficiency analysis via Adobe Color.

For more details see: Complements that Diverge by T-M. Rhyne
https://medium.com/nightingale/complements-that-diverge-fa487e843674
(5*) CHECK ACTUAL VIZ FOR COLOR DEFICIENCY

- To be safe, the actual visualization is checked for Color Deficiency.

Color Blindness Simulator - Coblis used to evaluate results.
http://www.color-blindness.com/coblis-color-blindness-simulator/#primary

For more details see: Complements that Diverge by T-M. Rhyne
https://medium.com/nightingale/complements-that-diverge-fa487e843674
The 3D Color Model of a Sphere to describe how humans see color is perceptually incorrect.

The Traditional Rainbow Colormap carries artifacts that influence data analysis when the Colormap is used.

The Traditional Rainbow Colormap carries artifacts when it is used & is non-perceptually uniform.

Albert Munsell in the early 1900s discovered that Human Perception is Geometrically imperfect.

Humans see a wider range of Red Orange hues than Blue Green hues.

So a 3D color space model of a Sphere is perceptually incorrect for humans. Munsell described the 3D color space as an irregular branched Tree.

Today, some prefer the Hue Chroma Luminance (HCL) model for perceptual uniformity.
COMPARING A NON-UNIFORM AND A UNIFORM RAINBOW COLOR SPECTRUM

Non Perceptual Uniform Colormap

Features of the Colormap not of Changes in Data

Perceptual Uniform Colormap

COMPARING RAINBOW & OTHER COLORMAPS

Image from the “Data Visualization: The End of the Rainbow” (2007) paper by Borland & Taylor that compares four data sets visualized with

(a) Rainbow; (b) Gray-Scale; c) Radiation, & d) isoluminant Green-Red Color Maps.

Apparent sharp gradients in the data in (a) appear as Rainbow Color Map artifacts not as data features. This is apparent by comparing this row with the same data viewed using the other Color Maps.

(Image used with permission from Borland and Taylor).
• Effort by Nathaniel J. Smith, Stefan van der Walt, and others to change the default “rainbow” colormap in Matplotlib, 2015/2016. New colormap is entitled “viridis”: https://bids.github.io/colormap/
WHAT IS THE MUNSELL COLOR SYSTEM:
A HUE, VALUE AND CHROMA COLOR SPACE

• A 3D Color Space proposed in the late 1890s and early 1900s by Albert H. Munsell.

• Hue: 5 principal hues of Red, Yellow, Green, Blue and Purple with 5 intermediate hues halfway between each principal.

  Each of these 10 steps is divided into 10 sub-steps to yield 100 hues with integer values.

• Value: black (value 0) at the bottom to white (value 10) at the top.

• Chroma: measured radially from the center of each slice.

• Munsell 2018 - Centennial Color Symposium celebrated 100 years since Munsell’s death: https://munsell2018.org/


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MUNSELL COLOR SYSTEM: A HUE, VALUE AND CHROMA COLOR SPACE

The 1929 Munsell Book of Color described the fundamentals of the color space configuration shown above. Munsell colors can be converted to CIE LAB, RGB, HSV, HSL, and other color spaces. Munsell to CIE Lab reference: https://rdrr.io/cran/munsellinterpol/man/MunsellToLab.html

Wheel & Chroma Scale Illustrations by Theresa-Marie Rhyne, 2015
USE ANDREWWERTH.COM/COLOR AS A DIGITAL REFERENCE FOR THE MUNSELL ATLAS OF COLOR:

The CIE XYZ color space is based on experimental perception studies conducted by W. David Wright and John Guild in the 1920s.

The CIE 1931 XYZ color space is a device independent color space. It is designed for matching calibrated displays or printers.


Note: Black Body Locus or Planckian Locus: the path of an incandescent block body would take as the black body temperature changes in this chromaticity space is also shown.
Observer adjusts Red, Green and Blue lights to match test color.

Color matching functions were then developed to create the CIE 1931 XYZ color space and other later color spaces.

UNDERSTANDING A CHROMATICITY DIAGRAM

- All visible colors to average human eyes are contained inside the diagram.

- The edge of the diagram, called the Spectral Locus, represents most saturated colors or pure monochromatic light.

- The least saturated colors are at the center of the diagram emanating from White.

- Any two colors along a given line between two points are made by mixing the colors at the end points.

- The Line of Purples: Fully saturated colors can only be made by mixing Red and Blue.

A color space is perceptually uniform if a change of length in any direction $X$ of the color space is perceived by a human as the same change.

In 1942, David MacAdam showed this with ellipses defining visual distortions. Circles on the chromaticity plot indicate no distortions.

Open Source Image available at Wikipedia and Data taken from Günter Wyszecki and Walter Stanley Stiles, see: https://commons.wikimedia.org/wiki/File:CIExy1931_MacAdam.png.

Original CIE XYZ color space, based on experimental perception studies conducted in the 1920s.


CIE LUV color space, also known as the CIE 1976 UCS (uniform chromaticity scale) diagram. CIE LUV is useful for Display Devices.


CIE LAB does not have an associated chromaticity diagram. CIE LAB is closely related to Opponent Processing Color Theory.

Diagram of the CIE LAB Opponent Processing Color Space by Theresa-Marie Rhyne, 2015.
TRANSITIONS IN CHROMATICITY DIAGRAMS

CIE x-y Chromaticity Diagram

CIE x-y Chromaticity Diagram Equations:

\[ x = \frac{X}{X+Y+Z} \]
\[ y = \frac{Y}{X+Y+Z} \]
\[ 1 = x + y + z \]

CIE u’v’ Chromaticity Diagram

CIE u’v’ Chromaticity Diagram Equations:

\[ u' = \frac{4X}{X + 15Y + 3Z} \]
\[ v' = \frac{9Y}{X + 15Y + 3Z} \]


Similar to CIE Luv or LAB except that instead of Cartesian Coordinates, Cylindrical Coordinates are used.

Sometimes called “Polarized” CIE Luv or CIE Lab. Consider closest to “Perceptually Uniform”.

HCL Color space packages appearing for D3.js, R and Python.

Some visualization practitioners favor it as a color model of choice.

Not widely used or known of in the digital design communities. (E.G. Pantone, Adobe Photoshop-Color)
WHAT IS THE VISUAL DIFFERENCE BETWEEN RGB AND HCL COLOR SPACES?
• Protanope: Red retinal photoreceptors absent.
• Deuteranope: Green photoreceptors absent.
• Tritanope: only medium and long cones present. Confuse Blue with Green and Yellow with Violet.

Color deficiency tests of the HCL Color Wheel. Used Color Blindness Simulator - Coblis to evaluate results.

http://www.color-blindness.com/coblis-color-blindness-simulator/#primary

Images created by Theresa-Marie Rhyne, 2021.
HCLWIZARD:  
http://hclwizard.org

• Free HCL web app for color suggestion. Palette Creator, Deficiency Emulator, Color Picker

• Palette Creator provides Sequential, Diverging & Qualitative options to create color color schemes. Includes Deficiency checker.

• Color Palette Export option Includes HCL, RGB & #Hex, RGB codes.

• Example Visualization Options provided.

• Writings @ http://hclwizard.org/#hcl-color-space
### 3A: BUILD COLOR SCHEME FOR MY EXAMPLE: USING HCL WIZARD

http://hclwizard.org

**Using Advanced Diverging Red-Green Color Scheme - 5 classes applied to a Bar Chart Example.**

Export Option shows HCL, RGB & Hex codes.
(4B) CHECK FOR COLOR DEFICIENCY

3 Key Types of Color Vision Weaknesses:

- **Protanope**: Red retinal photoreceptors absent.
- **Deuteranope**: Green photoreceptors absent.
- **Tritanope**: only medium and long cones present. Confuse Blue with Green and Yellow with Violet.

- Using HCL Wizard Color Deficiency Tests, the Advanced Diverging Red Green - 5 classes - passes color deficiency tests.
The Red Magenta / Green Diverging Color Scheme Is added to the 5 point Likert scale of Strongly Agree, Agree, Neutral, Disagree and Strongly Disagree. Notice the initial HCL Wizard Red Green Diverging Color Map.
IN THIS TALK, I DISCUSSED 5 COLORIZING STEPS:

- Know your data.
- Select Color Space & Rule.
- Build Color Scheme.
- Check for Color Deficiency & Pre Existing conditions
- Apply Color Scheme to Data & Modify per Review.
AND COLORIZED AN EXAMPLE - 3 WAYS:

- Complementary Color Harmony - Magenta Green - Adobe Color.
- Diverging Color Scheme - Pink Yellow Green - ColorBrewer.
- Advance Diverging Color Scheme - Red Green - HCL Wizard.
THERE ARE MANY MORE COLOR MYSTERIES & I WROTE A BOOK ABOUT SOME OF THEM:


Various Color Apps are covered for building color schemes such as Adobe Color, Pantone Studio, ColorBrewer, & Color Scheme Designer.

ACKNOWLEDGEMENTS:

- I also actively write on Color for Nightingale, the journal of the Data Visualization Society: https://medium.com/@theresamarierhyne.

- Thanks to Georges Hattab and Mary Aviles for thoughtful edits of my Nightingale writings.

- As well as colleagues and family members who have encouraged me to continue exploring color over many years.

  With much gratitude and appreciation.

  Theresa-Marie Rhyne

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