Original Photo Image → **Converted to Monochromatic B&W Photo Image** → **B&W Photo Image colorized with colorize-it.com**
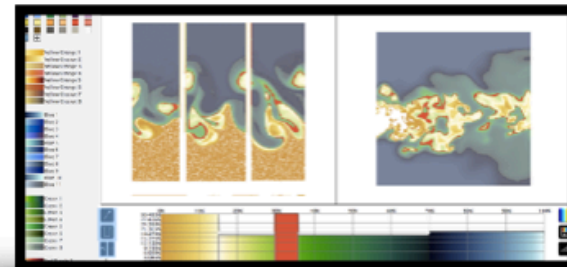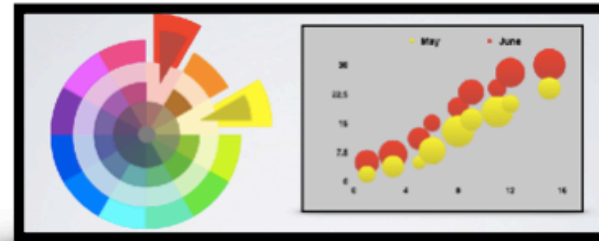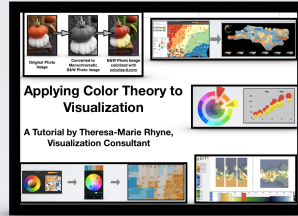
Applying Color Theory to Visualization

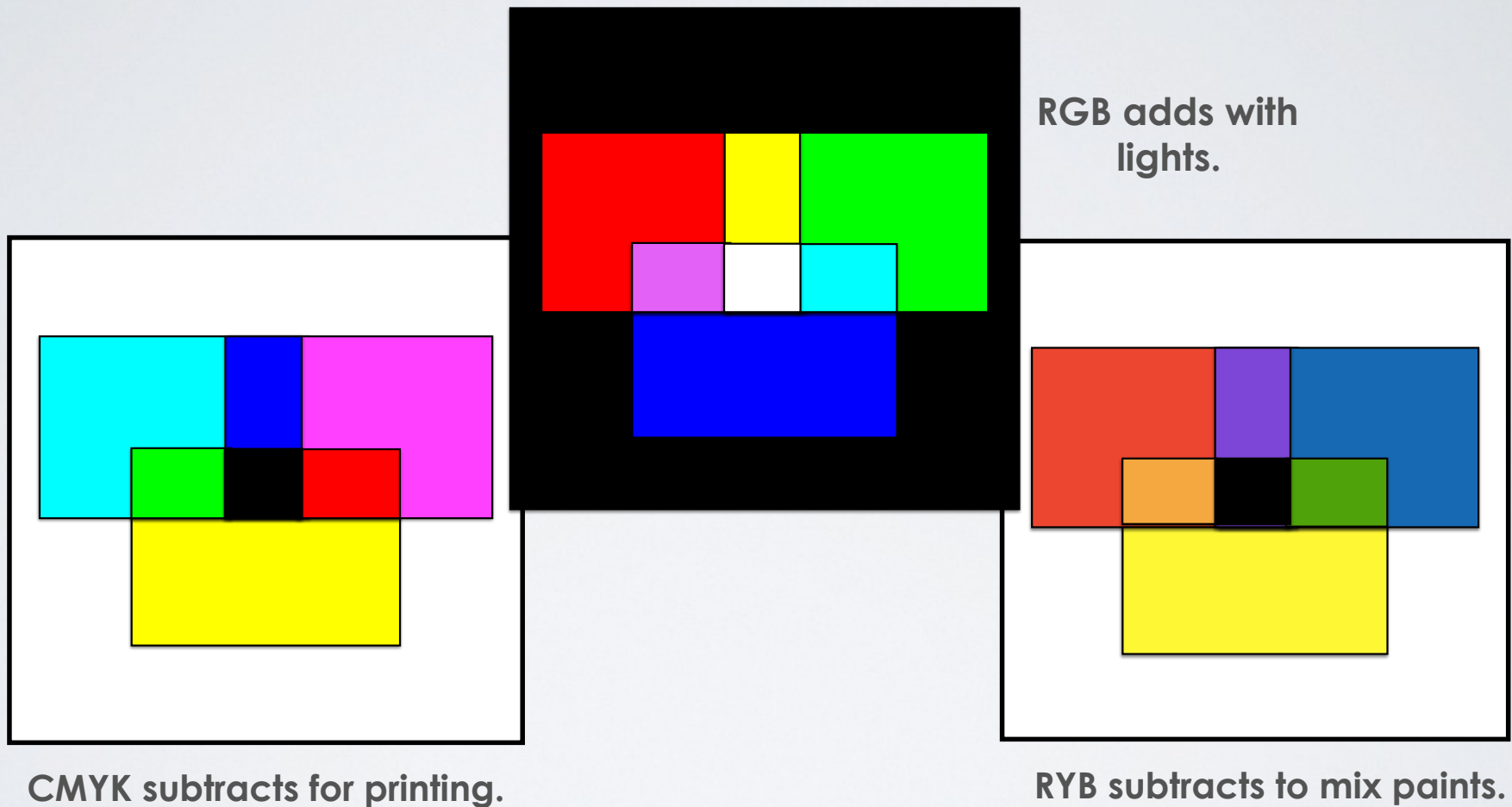## A Tutorial by Theresa-Marie Rhyne, Visualization Consultant
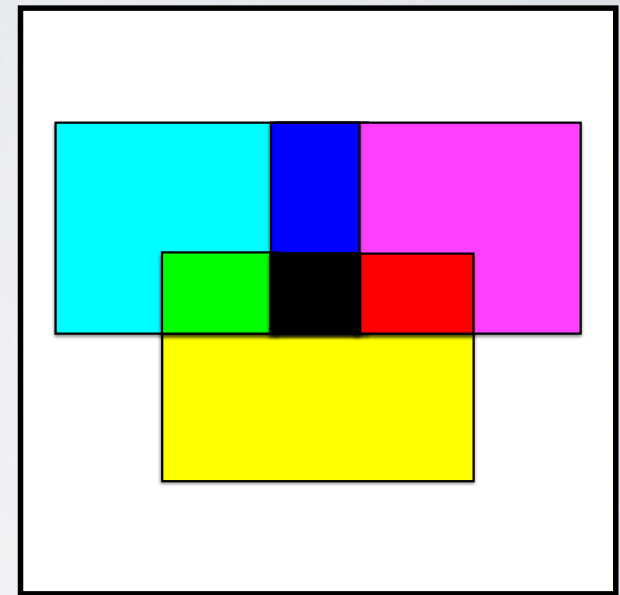
theresamarierhyne@gmail.com

IN THIS LECTURE, WE HIGHLIGHT 5 TOPICS:

- **Introduction to Color Models and Wheels.**

- **Review of Key Color Vision Principals.**

- **Defining Color Gamut, Spaces and Systems.**

- **Exploring Color Harmony.**

- **Tools, Research and Case Studies: Color Analyses of Visualizations.**

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FIRST, A REVIEW OF KEY COLOR MODELS:

RGB adds with lights.

CMYK subtracts for printing.

RYB subtracts to mix paints.

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DEFINING AN INVERSE RELATIONSHIP BETWEEN RGB & CMYK:

Images Theresa-Marie Rhyne, 2015.

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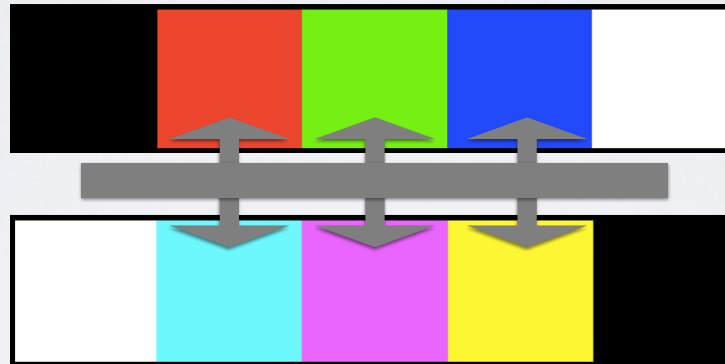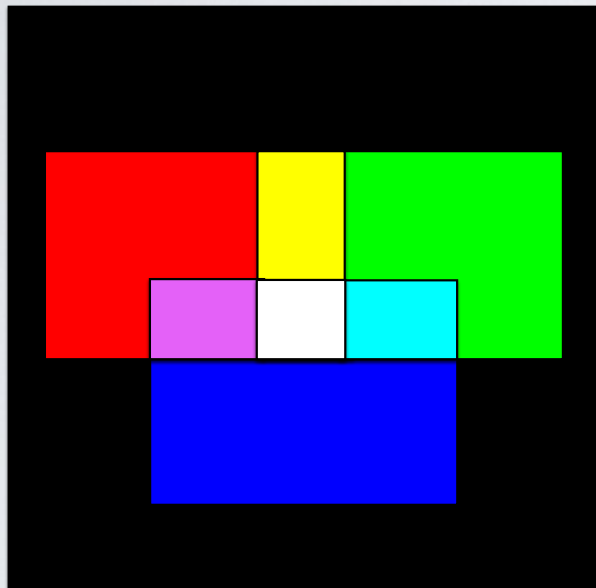
theresamarierhyne@gmail.com

COMPARISON OF RGB & CMYK COLOR SPACES
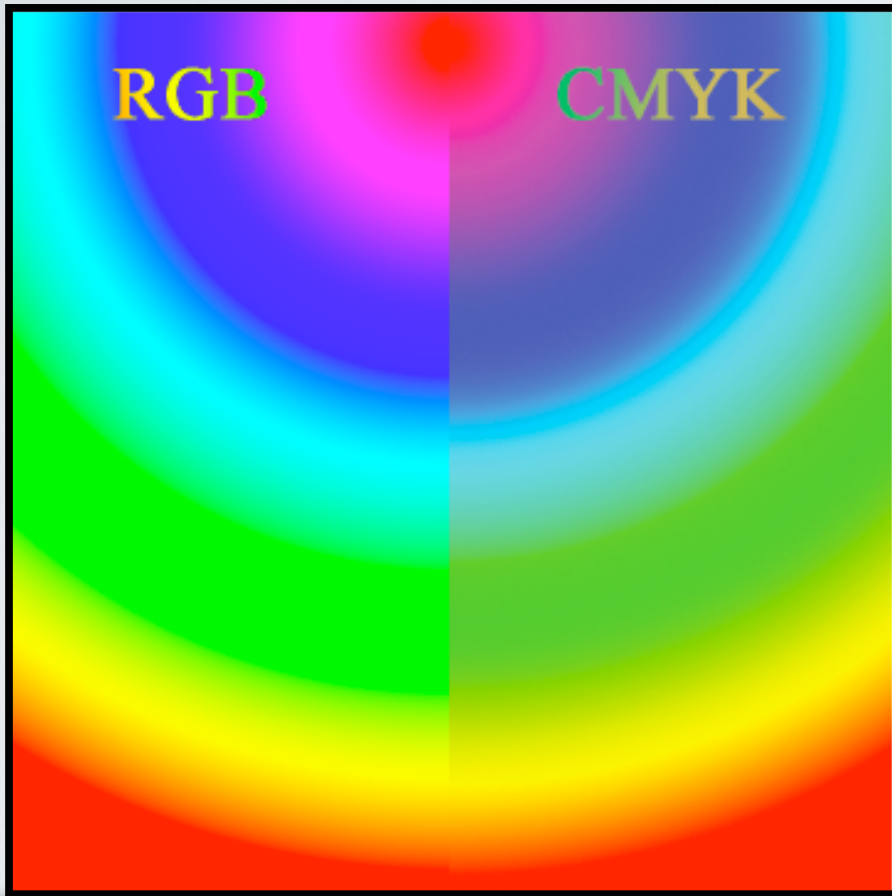
Comparison of the RGB and CMYK colors models. This image depicts the differences between how colors appear on a color display (RGB) compared to how the colors reproduce in the CMYK print process.

Public Domain Image available at WIkipedia and created by Annette Shacklett, see: http://en.wikipedia.org/wiki/File:RGB_and_CMYK_comparison.png.

For more details on RGB & CMYK differences see: http://www.printernational.org/rgb-versus-cmyk.php.

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HISTORICAL VIEWS OF THE COLOR WHEEL:

In 1666, Isaac Newton developed the first Color Circle as a simplified model of the color spectrum.

In 1810, Johan Wolfgang von Goethe defined complementary colors and revised his drawing of the color wheel to include 6 color elements. He also added Magenta as a hue to the wheel.

In 1833 Michel-Eugene Chevreul published "The Law of Simultaneous Color Contrast" that was a compendium of color design principles. 19th Century painters from Delacorix to Matisse attempted to apply these concepts to their art.

Historical Progression of Color Models

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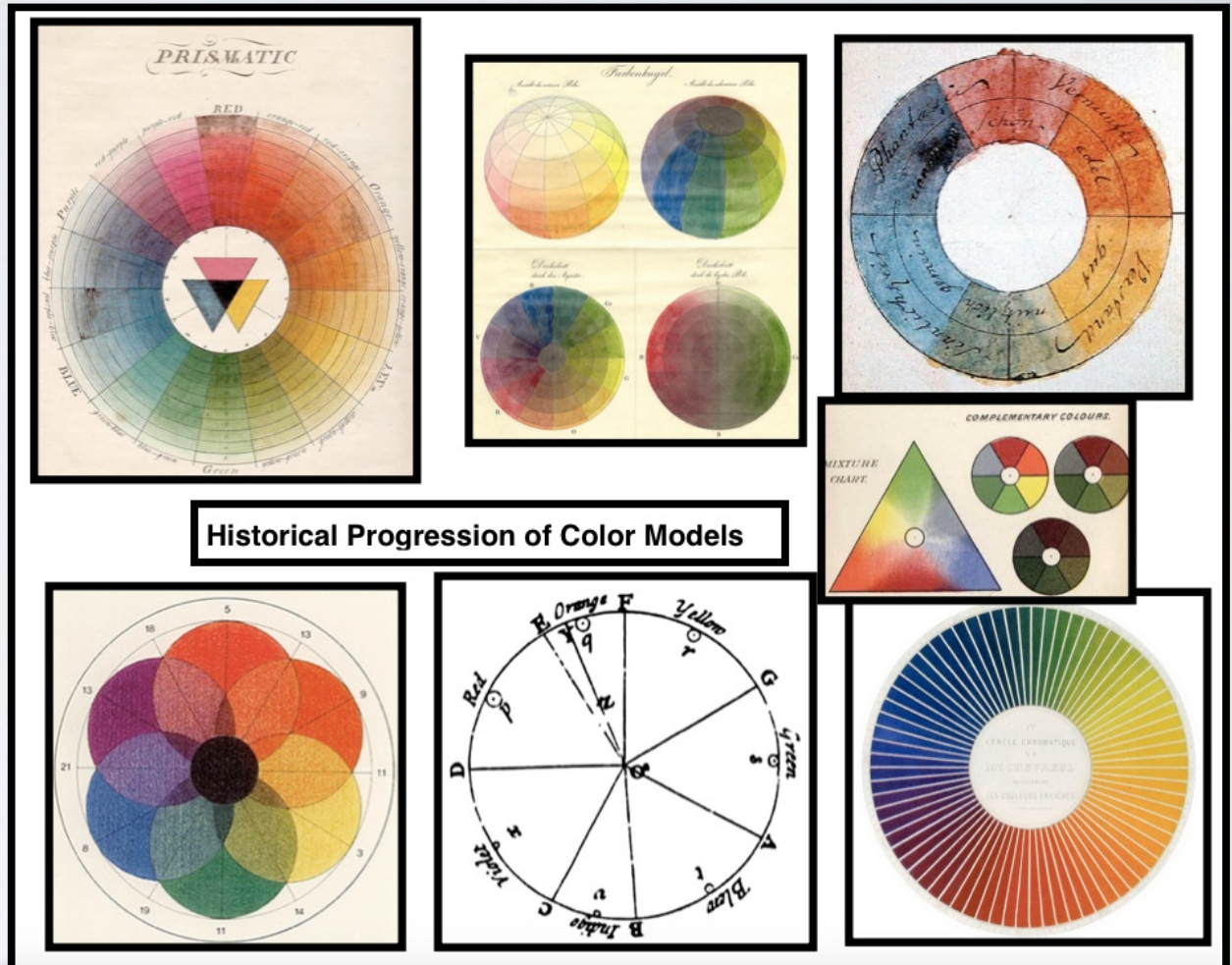
EXAMPLE OF CHEVREUL'S SIMULTANEOUS CONTRAST
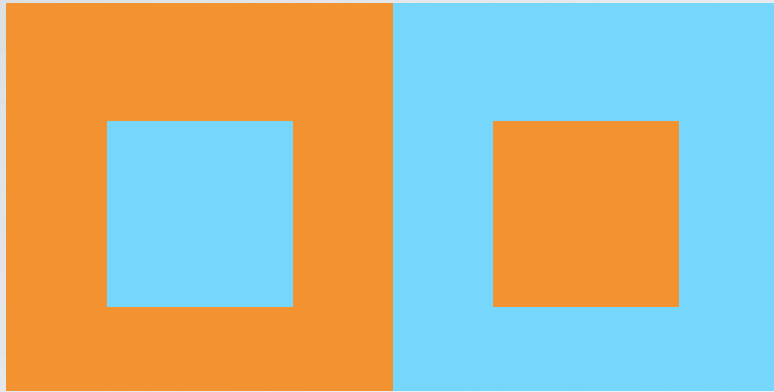
In 1839, Michel-Eugene Chevreul published "The Law of Simultaneous Color Contrast". Here we show an example with Orange and Cyan.
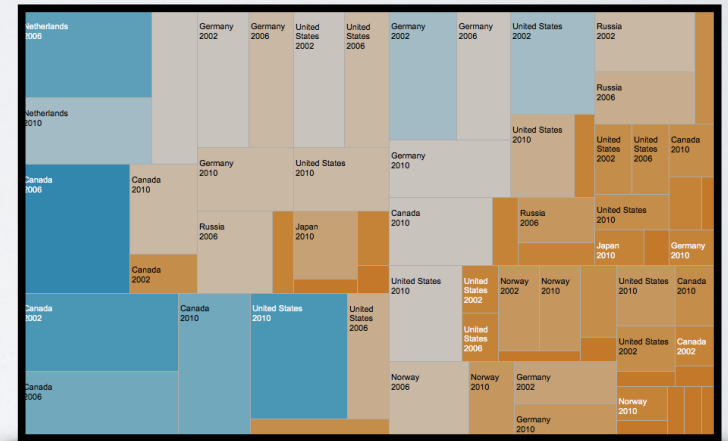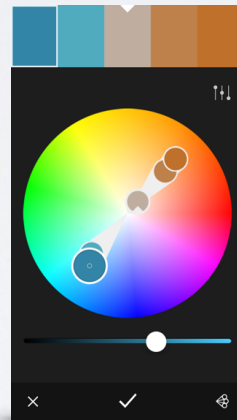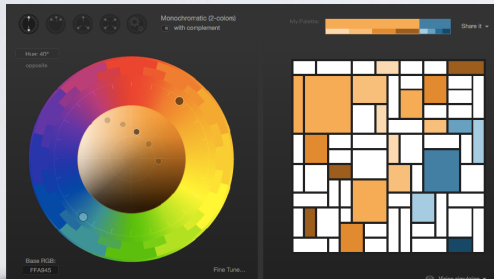
Color Study, Color Analysis and Digital Media Visualization created by Theresa-Marie Rhyne in 2014 & 2015.
The Mosaic uses the Paletton Color Scheme Designer Tool. Adobe Capture was used for the Color Wheel while Tableau Public was used for the Tree Map visualization.

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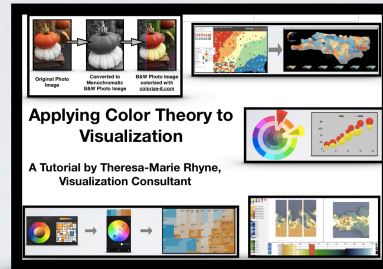
REVIEW OF KEY COLOR VISION PRINCIPLES:

- Trichromatic Theory of Color Vision.

- Opponent Process Visual Perception.

- Coexistence of Trichromatic and Opponent Theories.

- Color Deficiency (Blindness) Overview

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TRICHROMATIC THEORY OF COLOR VISION:

Trichromatic Theory of Color Vision

Blue   Green   Red

Receptors in Retina (Cones)

To the Brain via the Optic Nerve

Spectral Sensitivity Curves of Cones

Blue   Green   Red

Wavelength

V   B   G   Y   O   R
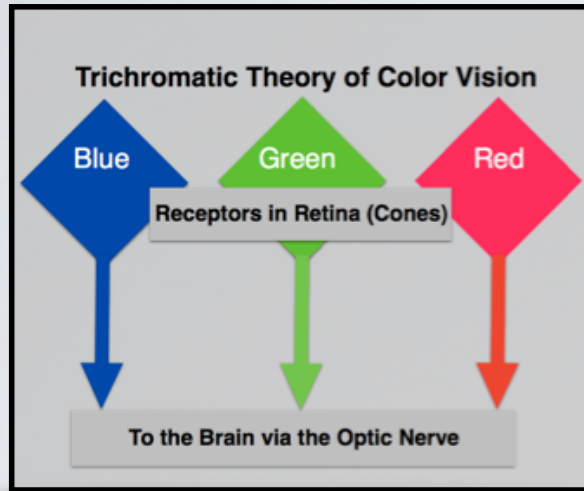
- 1802: Thomas Young postulated 3 types of photoreceptors in our eyes (cone cells).

- 1850: Hermann von Helmholtz classified cone photoreceptors as:
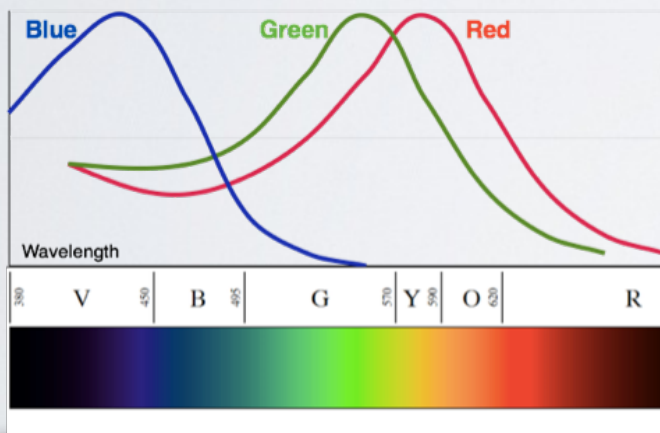
  - Long Preferring (Red),
  - Medium Preferring (Green),
  - Short Preferring (Blue).

Illustrations by Theresa-Marie Rhyne, 2015

WAIT, COLOR VISION IS MORE COMPLICATED: OPPONENT COLOR THEORY

Opponent Color Theory

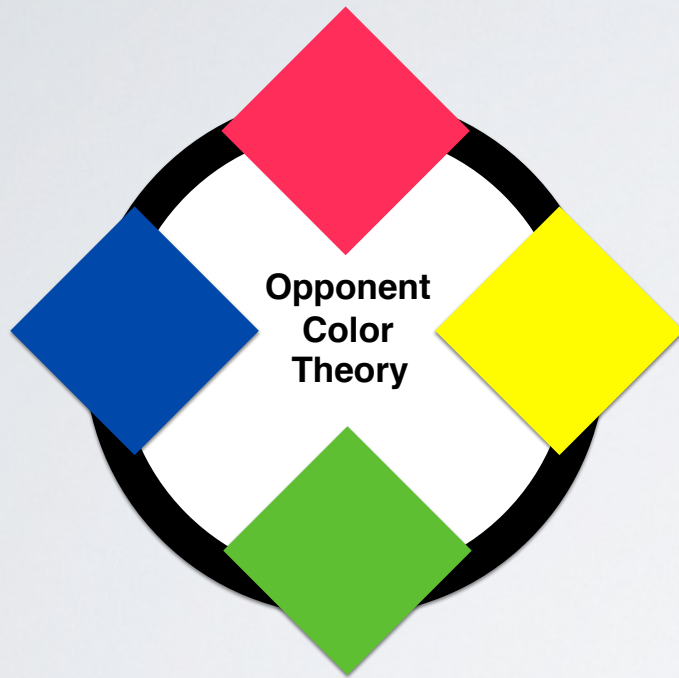In 1878, Ewald Hering published "On the Theory of Sensibility in Light in Vienna" that challenged the purely physical understanding of colors according to the RGB color model. Here we show a diagram of Hering's proposed 4 color opponent color system of Red, Green, Yellow and Blue. Image Theresa-Marie Rhyne, 2015.

• In 1878, Ewald Hering challenged the Young-Helmholtz theory of trichromatic color vision and proposed Opponent Processing.

• Opponent Processing asserts there are 3 opponent color channels in our visual system:

— Red versus Green

— Blue versus Yellow

— Black versus White

• Opponent colors are not perceived together.

• A 4 primary color system of Red, Green, Yellow and Blue was defined to support Opponent Processing.

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HUE CANCELLATION AND OPPONENT COLOR THEORY

• In 1957, in work for Eastman Kodak, Leo Hurvich and Dorothea Jameson provided quantitative data to support Hering's Opponent Color theory.

• In their "An opponent-process for color vision" paper, they defined "hue cancellation methods" and showed that:

— Red and Green lights mixed together produces Yellow, not reddish green.

— Blue and Yellow lights mixed together produces White light not yellowish blue.

— Red & Green cancel each other as do Yellow & Blue.

— Starting with Bluish Green, it is possible to mix Yellow light with the Bluish Green light to cancel out Blue and produce only Green light.

•Hurvich and Jameson also showed that the Young-Helmholtz theory of trichromatic color vision co-existed with Hering's Opponent Processing theory.
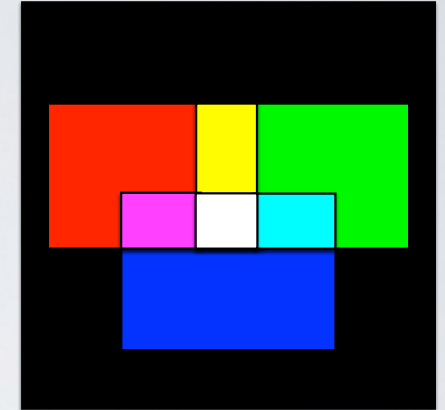
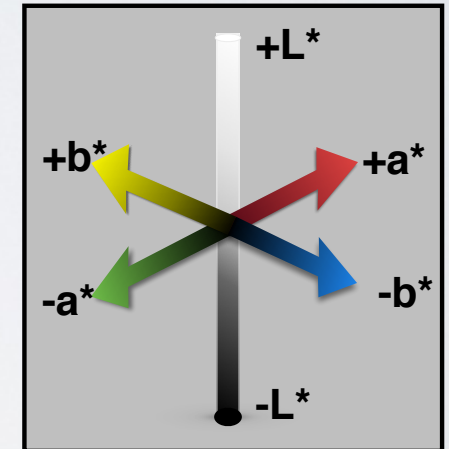Revisiting the RGB Color Model. Diagram created by Theresa-Marie Rhyne, 2015.

Diagram of the CIE LAB Opponent Processing Color Space created by Theresa-Marie Rhyne, 2015.

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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.

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Red, Yellow & Blue primary and secondary color wheel with color deficiency tests.
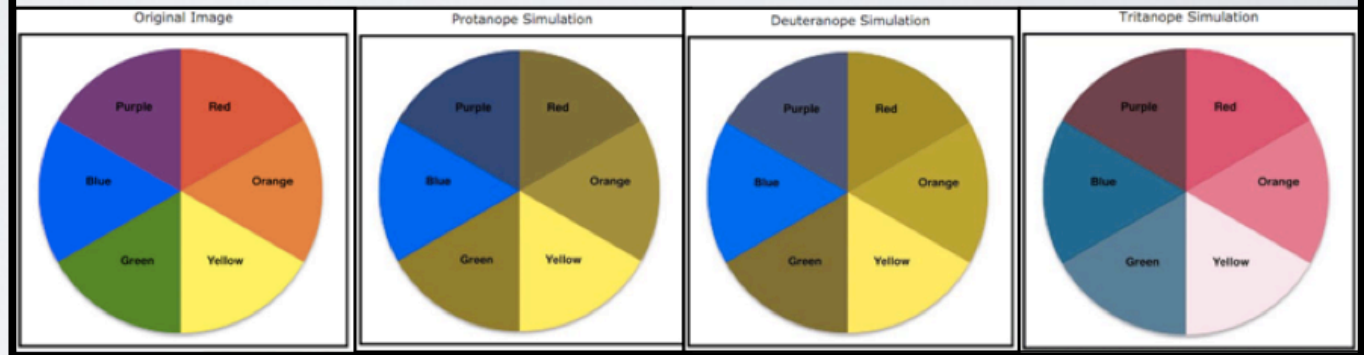
• Here, we show the RYB color wheel under color deficiency tests. Individuals with deficiencies cannot easily differentiate between respective hues.

Vischeck simulations used to evaluate results.
   http://www.vischeck.com/vischeck/vischeckImage.php

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NON-UNIFORM DISTANCES BETWEEN HUES IN RAINBOW COLORMAPS

Red   Orange   Yellow   Green   Blue   Indigo   Purple
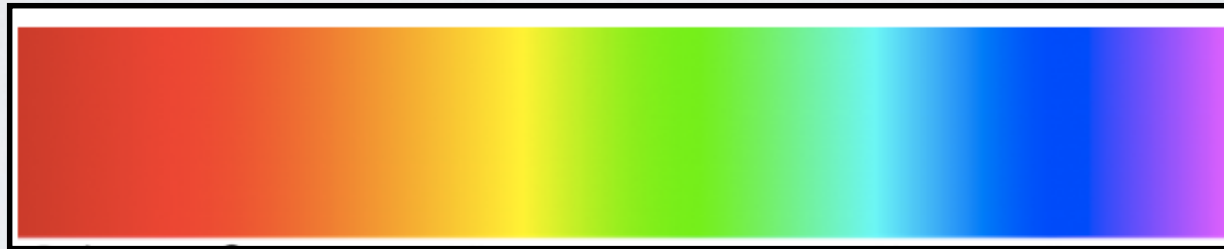
**Typical Rainbow Colormap
used in Visualization tools and analyses.**

Non-Uniform Distances between Hues.

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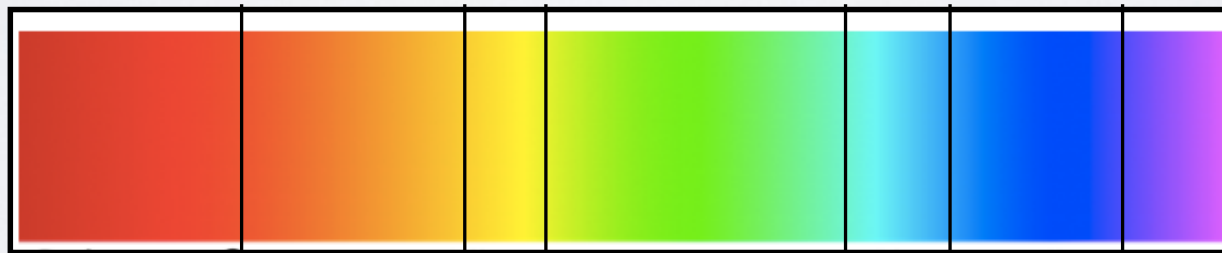
OTHER RECENT: RAINBOW COLOR MAP WORK

MatPlotLib_viridis default colormap

•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/

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REFERENCES: RAINBOW COLOR MAP CONCERNS

• Rogowitz, B.E. and Treinish, L.A. (1998), "Data Visualization: The End of the Rainbow", IEEE Spectrum, 35:12, 52-29.

• Borland, David, and Taylor II, Russell M. (2007), "Rainbow Color Map (Still) Considered Harmful", IEEE Computer Graphics & Applications, 27:2, 14-17.

• Moreland, Kenneth (2016), "Why We Use Bad Color Maps and What You Can Do About It", HVEI 2016 Proceedings of Human Vision and Electronic Imaging, (http://www.kennethmoreland.com/color-advice/BadColorMaps.pdf), online version.

• Ware, Colin, Turton, Terence L., Samsel, Francesca, Bujack, Roxana, and Rogers, David (2017), "Evaluating the Perceptual Uniformity of Color Sequences for Feature Discrimination, EuroRVVV17, https://diglib.eg.org/handle/10.2312/eurorv320171107.

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NEXT, WE DEFINE A FEW COLOR GAMUTS, SPACES AND SYSTEMS:

- Why Does Color Model + Color Gamut = Color Space?

- How Perceptual Uniformity changes Color Spaces: (CIE XYZ) => LAB & LUV.

- What about Hue, Saturation, Value (HSV) ?

- Where did Web Hex Triplets come from?

- How do Designers Match with Pantone?

- Is there an App on my phone for this?

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COLOR GAMUT: THE SUBSET OF COLORS THAT CAN BE ACCURATELY REPRESENTED IN A GIVEN CIRCUMSTANCE.
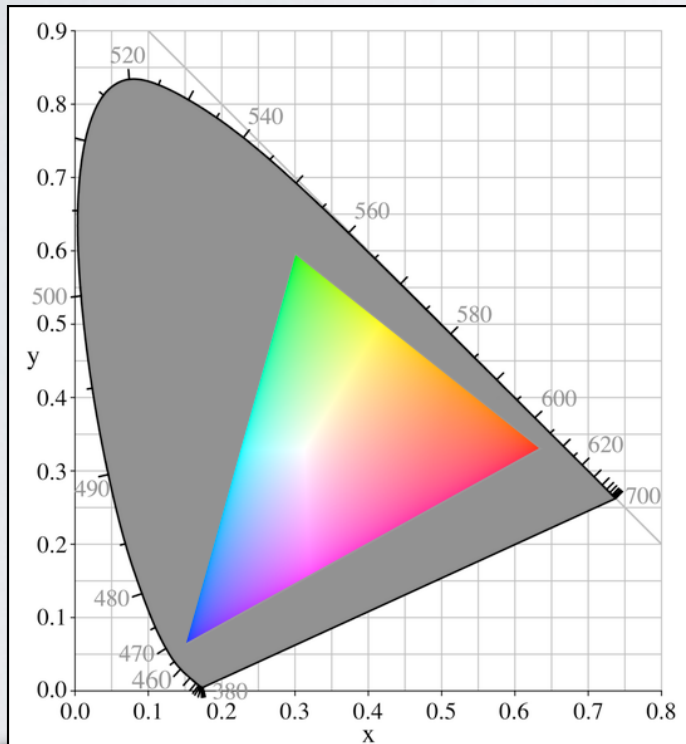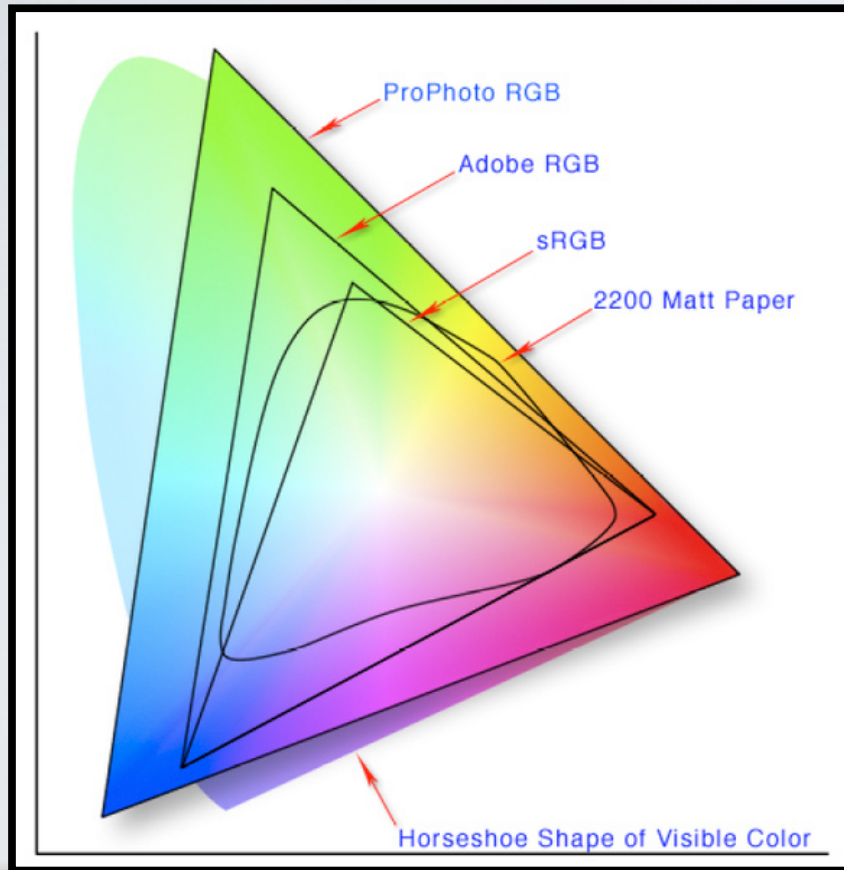

The Color Gamut of a sRGB device such as a mobile phone. The grayed out portion represents the entire color range available.

Open Source Image available at WIkipedia and created by Hankwang, see: http://en.wikipedia.org/wiki/File:CIExy1931_srgb_gamut.png.

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COLOR MODEL + COLOR GAMUT = COLOR SPACE

ProPhoto RGB
Adobe RGB
sRGB
2200 Matt Paper
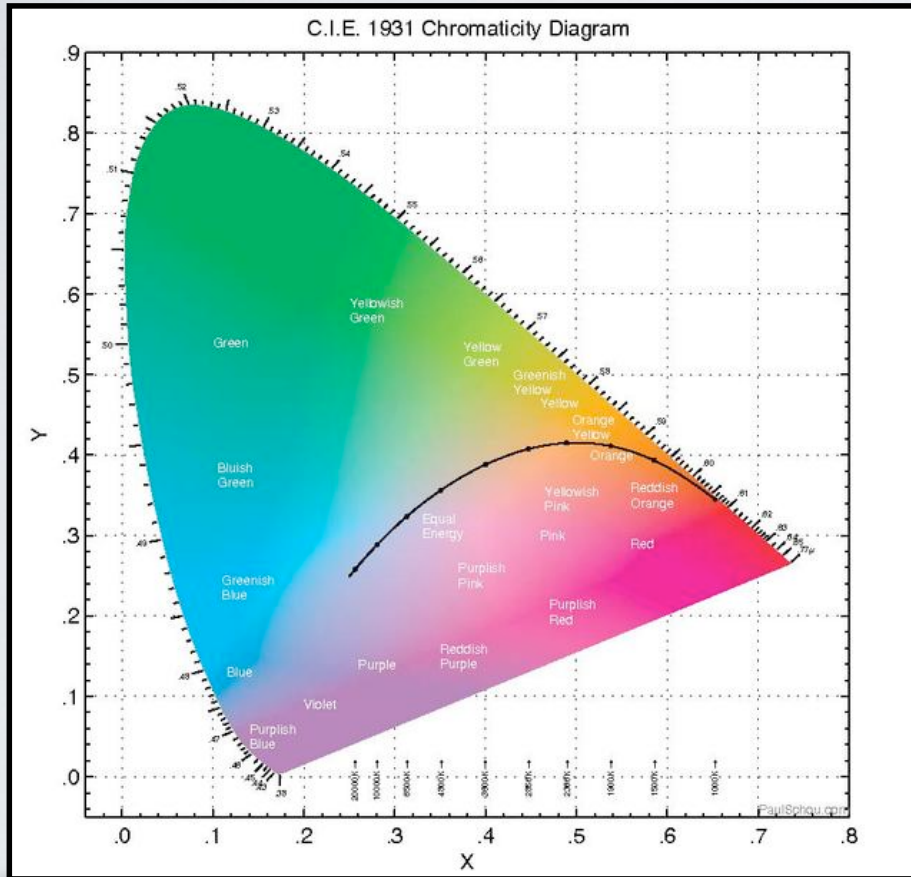Horseshoe Shape of Visible Color

RGB Model + Color Gamut = Color Space

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.

Open Source Image available at WIkipedia and created by Jeff Schewe, see: http://en.wikipedia.org/wiki/File:Colorspace.png and http://www.schewephoto.com/.

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CIE XYZ COLOR SPACE: FROM THE INTERNATIONAL COMMISSION ON ILLUMINATION

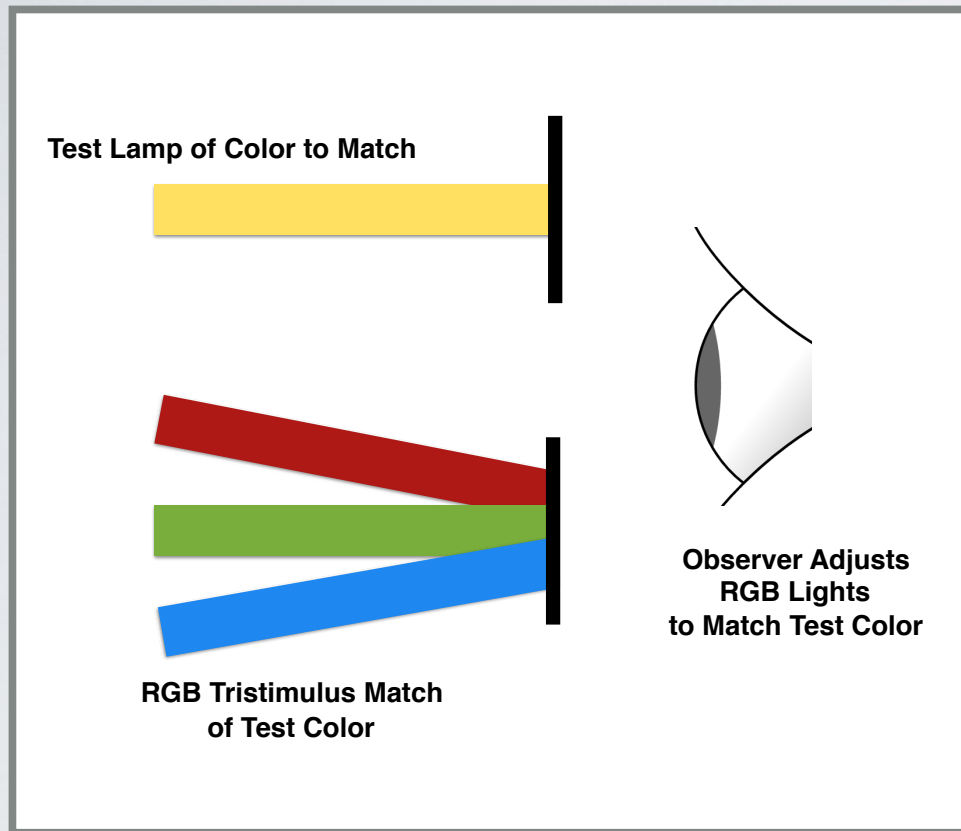C.I.E. 1931 Chromaticity Diagram

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

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

Open Source Image available at WIkipedia and created by Paulschou, see: http://en.wikipedia.org/w/index.php?title=File:Chromaticity_diagram_full.pdf&page=1.

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.

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COLORIMETRY: COLOR MATCHING BY OBSERVERS

Test Lamp of Color to Match

Observer Adjusts RGB Lights to Match Test Color

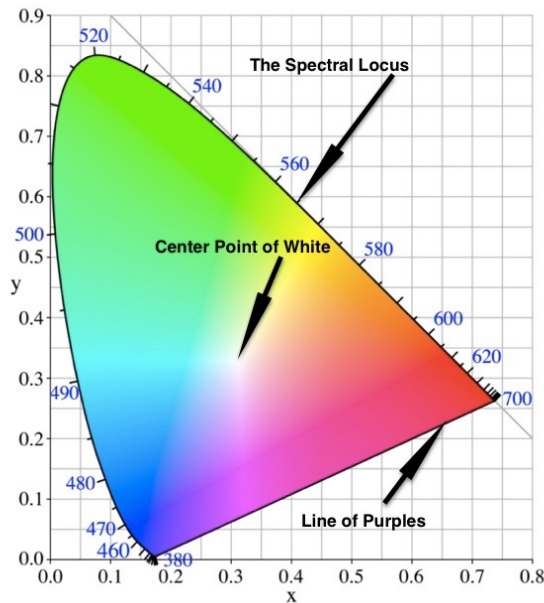**RGB Tristimulus Match of Test Color**

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.

Image by Theresa-Marie Rhyne, 2015: from Chapter 3, pg 42, of her book on "Applying Color Theory to Digital Media and Visualization", CRC Press, 2016.

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UNDERSTANDING A CHROMATICITY DIAGRAM

CIE x-y Chromaticity Diagram

The Spectral Locus

Center Point of White

Line of Purples

CIE x-y Chromaticity Diagram Equations:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$1 = x + y + z$$

Image in public domain: https://en.wikipedia.org/wiki/File:CIExy1931.png#/media/File:CIExy1931.png. Annotations by T-M Rhyne

- 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.
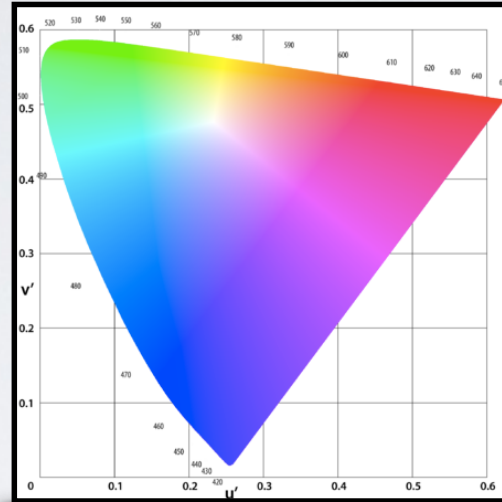
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UPDATES TO CIE XYZ COLOR SPACE
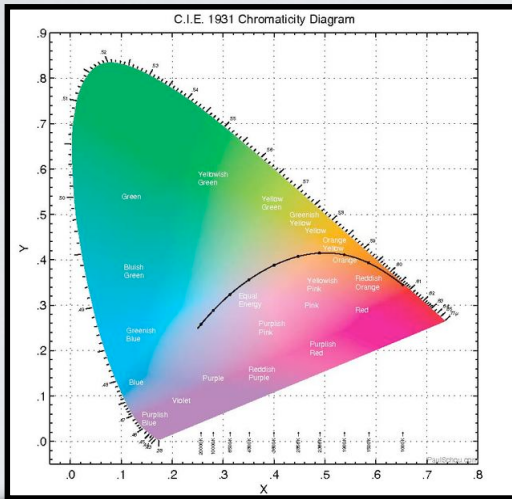
Original CIE XYZ color space, based on experimental perception studies conducted in the 1920s.

Open Source Image available at WIkipedia and created by Paulschou, see: http://en.wikipedia.org/w/index.php?title=File:Chromaticity_diagram_full.pdf&page=1.

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

Open Source Image available at WIkipedia and created by Adoniscki, see: http://en.wikipedia.org/wiki/CIELUV#mediaviewer/File:CIE_1976_UCS.png.
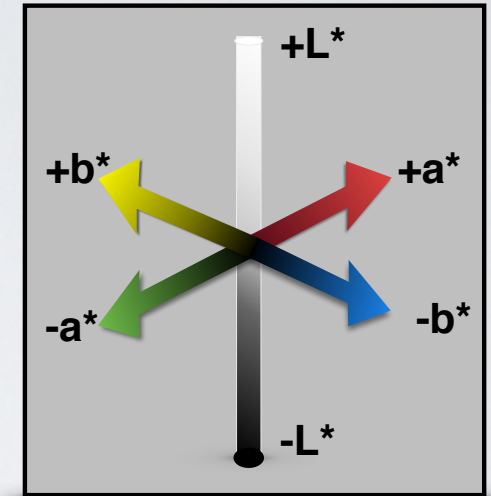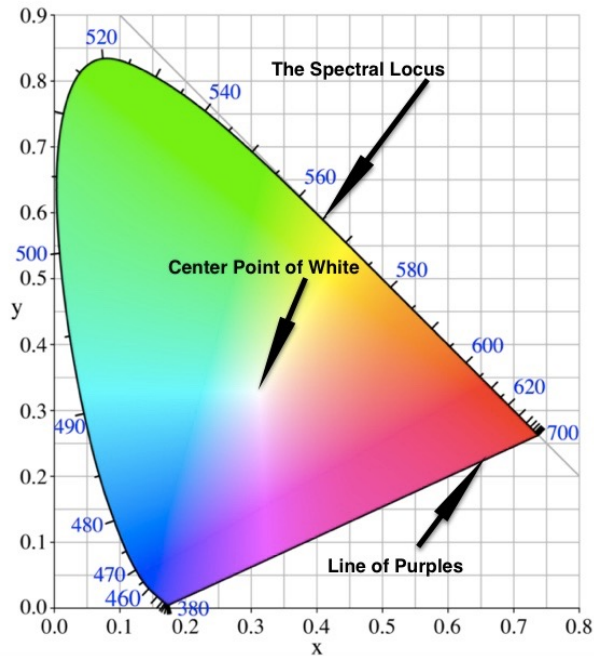
CIE LAB does not have an associated chromaticity diagram. CIE LAB is closely related to Opponent Processing Color Theory.

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

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TRANSITIONS IN CHROMATICITY DIAGRAMS

Image in public domain: https://en.wikipedia.org/wiki/File:CIExy1931.png#/media/File:CIExy1931.png. Annotations by T-M Rhyne

Image in public domain: https://en.wikipedia.org/wiki/CIELUV#/media/File:CIE_1976_UCS.png. Annotations by T-M Rhyne

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UPDATES SINCE CIE LUV & LAB 1976

• In the 1990s, Advance Colorimetry evolved to address Color Appearance models that matched an image on a display with its resulting hard copy reproduction. CIECAM97 was developed as an interim model to address these concerns.

• After academic and industry assessments, the Color Appearance model was revised to CIECAM02 in 2002.

•Presently, CIECAM02 with the CAM02 - UCS (uniform color space) is considered "State of the Art".

Reference: Ming Ronnier Luo and Changjun Li, "Chapter 2: CIECAM02 and Its Recent Developments" in Advanced Color Image Processing and Analysis, C. Fernandez-Maloigne, Editor, Springer, 2013, http://link.springer.com/chapter/10.1007/978-1-4419-6190-7_2.

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WHAT IS APPLE'S WIDE GAMUT COLOR SPACE ?

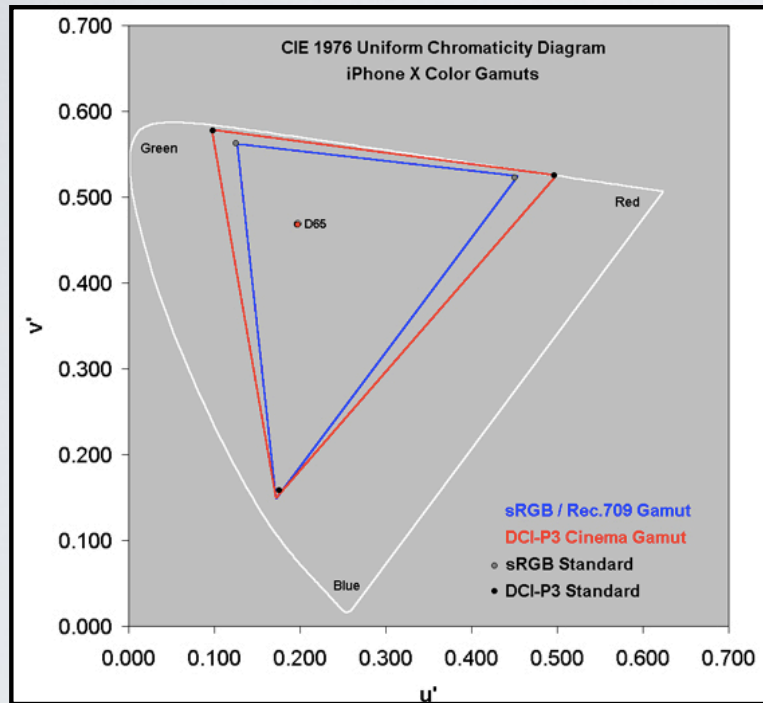## DCI-P3: Frequently used in Digital Movie Projection
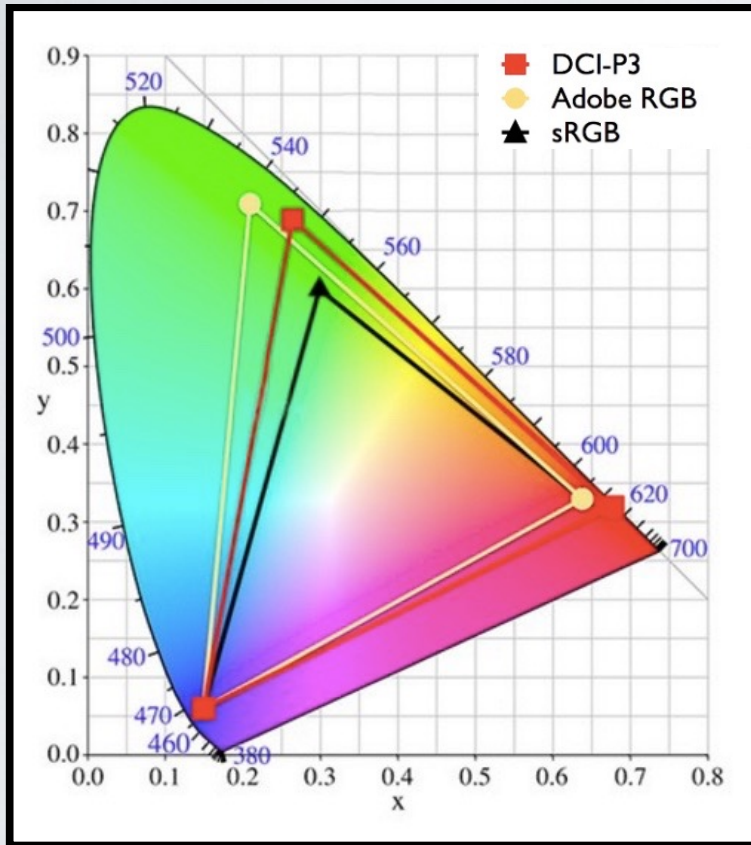
- Wider color gamut than sRGB but different from Adobe RGB.

- Can result in challenges with photography and CMYK printing since DCI-P3 is designed for digital projection devices.

- Adobe RGB extends into Blues & Greens while DCI-P3 extends into Reds and a different set of Greens than Adobe RGB.

Fair use of Image from Thom Hogan's "Another 'new' Color Space" Blog discussion, October 13, 2015, http://www.dslrbodies.com/newsviews/another-new-color-space.html. (shown with author permission)

Note: Diagrammed in CIE XYZ Color Space

Also see: http://www.colourspace.xyz/the-new-apple-imac-and-the-dci-p3-colour-gamut/.

WHAT ARE APPLE'S COLOR SPACES ?
iPhone X: Color Management with 2 Display Modes

CIE 1976 Uniform Chromaticity Diagram
iPhone X Color Gamuts

sRGB / Rec.709 Gamut
DCI-P3 Cinema Gamut
○ sRGB Standard
● DCI-P3 Standard

Note: Diagrammed in CIE 1976 LUV Color Space.
Copyright by DisplayMate Technology Corporation: Used with Permission

With iPhone X, Apple switched from Liquid Crystal Display (LCD) to Organic Light Emitting Diodes (OLED) Display technology.

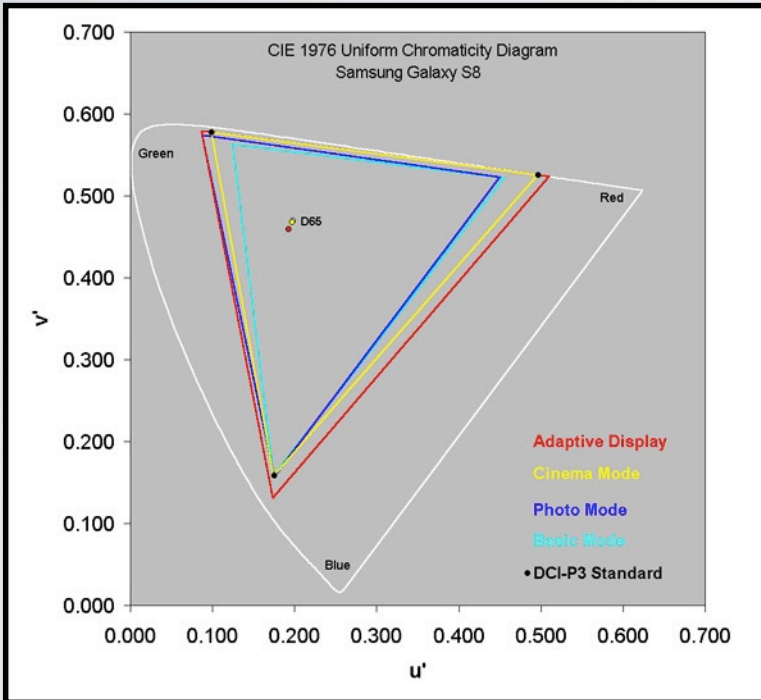OLED Color Gamut: 100% DCI-P3 - Precision Display Calibration technology

OLED Basic Screen Mode: 100% sRGB for Web sites.

Color Management: Precision Display automatically detects DCI-P3 content and switches between 2 display modes so sRGB is accurately reproduced and not displayed with over saturated color.

Image from Raymond Soneira & DisplayMate Technology Corporation's "iPhone X OLED Display Technology Shoot-Out", http://www.displaymate.com/Gamut_41a.html

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WHAT ARE SAMSUNG'S COLOR SPACES ?

Galaxy S8: Color Management with 4 Display Modes

CIE 1976 Uniform Chromaticity Diagram Samsung Galaxy S8

Chart legend: Adaptive Display (red), Cinema Mode (yellow), Photo Mode (blue), Basic Mode (cyan), DCI-P3 Standard (black dots). Axes: v' (vertical) vs u' (horizontal). Points labeled Green, Red, Blue, D65.

Note: Diagrammed in CIE 1976 LUV Color Space.
Copyright by DisplayMate Technology Corporation: Used with Permission

- **Adaptive Display:** Default high end that changes on the fly with phone usage. 142%>sRGB, 113%>DCI-P3

- **AMOLED Cinema:** 100% DCI-P3 for Movie Display. 26%>sRGB

- **AMOLED Photo:** 100% Adobe RGB for Photos. 17% >sRGB

- **Basic Screen Mode:** 101% sRGB for Web sites.

Image from Raymond Soneira & DisplayMate Technology Corporation's "Galaxy S8 OLED Display Technology Shoot-Out: Samsung Galaxy S8 Color Gamuts",
http://www.displaymate.com/Gamut_39.html

Also see: http://www.displaymate.com/ Galaxy_S8_ShootOut_01.htm

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COMPARE GALAXY S8 & IPHONE X COLOR GAMUTS

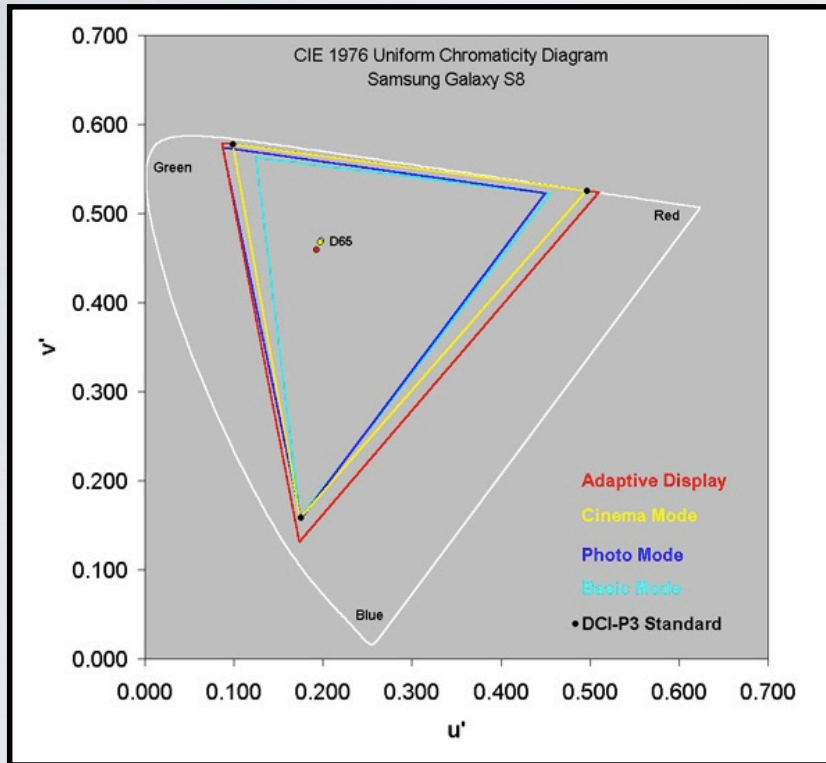Note: Diagrams in CIE 1976 LUV Color Space. Copyright by DisplayMate Technology Corporation, used with Permission

Image from DisplayMate Technology Corporation's "Samsung Galaxy S8 Color Gamuts",
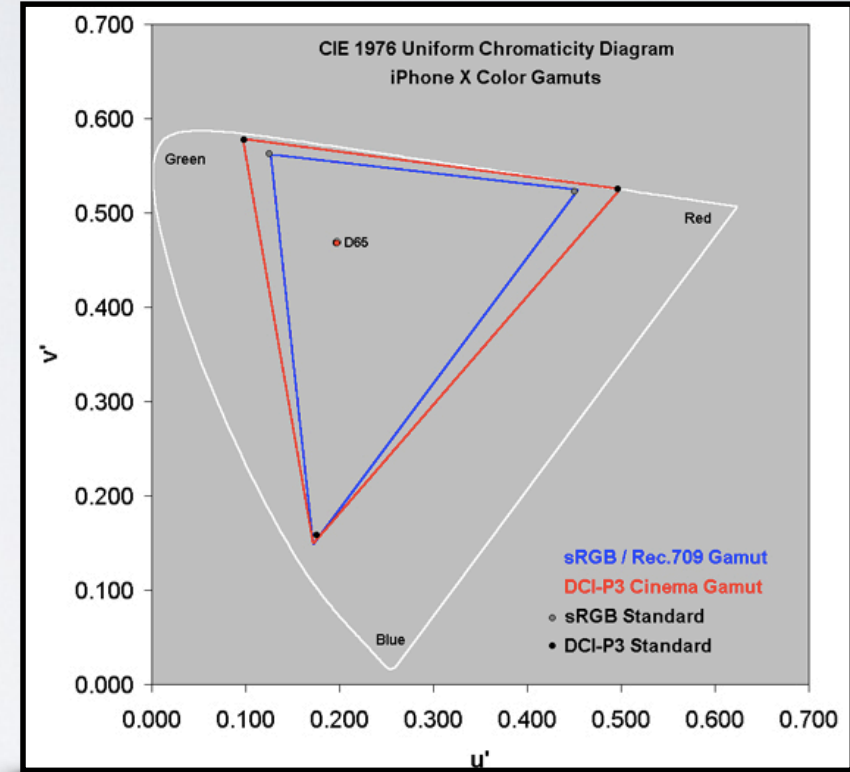**http://www.displaymate.com/ Gamut_39.html**

Image from DisplayMate Technology Corporation's "Apple iPhone X Color Gamuts",
http://www.displaymate.com/ Gamut_41a.html

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HOW ARE COLOR DISPLAYS CALIBRATED?

• Color Calibration Devices are attached to the Display to measure the color response to a given baseline. The baseline is usually the International Color Consortium (ICC)'s color characterization profile.

http://www.color.org/profile.xalter

•2 companies that produce color calibration devices are: Datacolor & X-Rite.

http://www.colourspace.xyz/datacolor-vs-x-rite-best-screen-calibrators/

ColorMunki Display Calibration Device from X-Rite, http://www.xrite.com/categories/calibration-profiling. Image courtesy of X-Rite/Pantone.

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CYLINDRICAL- COORDINATE REPRESENTATIONS OF THE RGB COLOR MODEL: 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.**
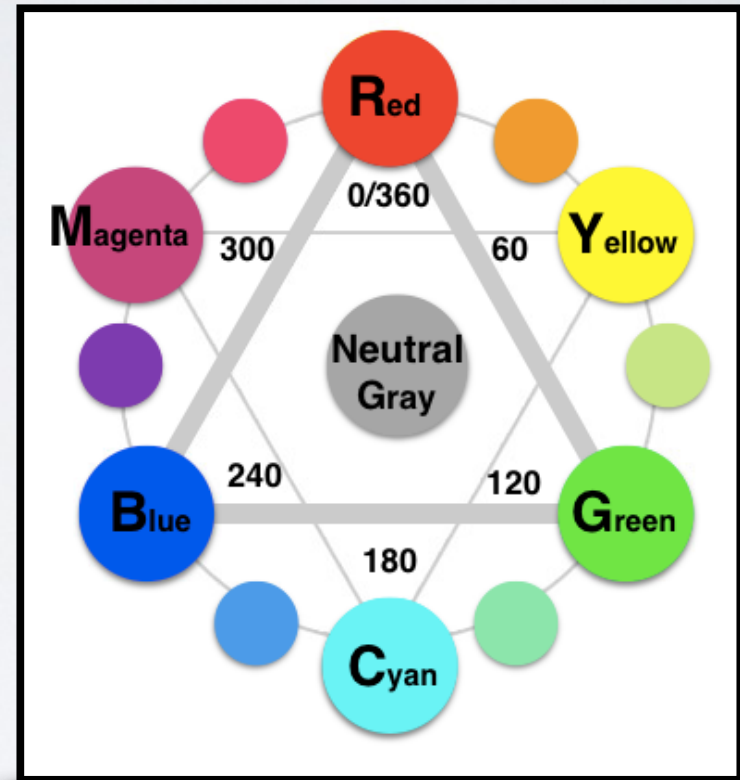
• **Frequently used in color picker and image editing software.**

Diagram of the HSV and HSL Color Wheel. Illustration by Theresa-Marie Rhyne, 2015.

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REDUCING COLORFULNESS IN RGB COLOR SPACE IS NOT ALWAYS LOGICAL
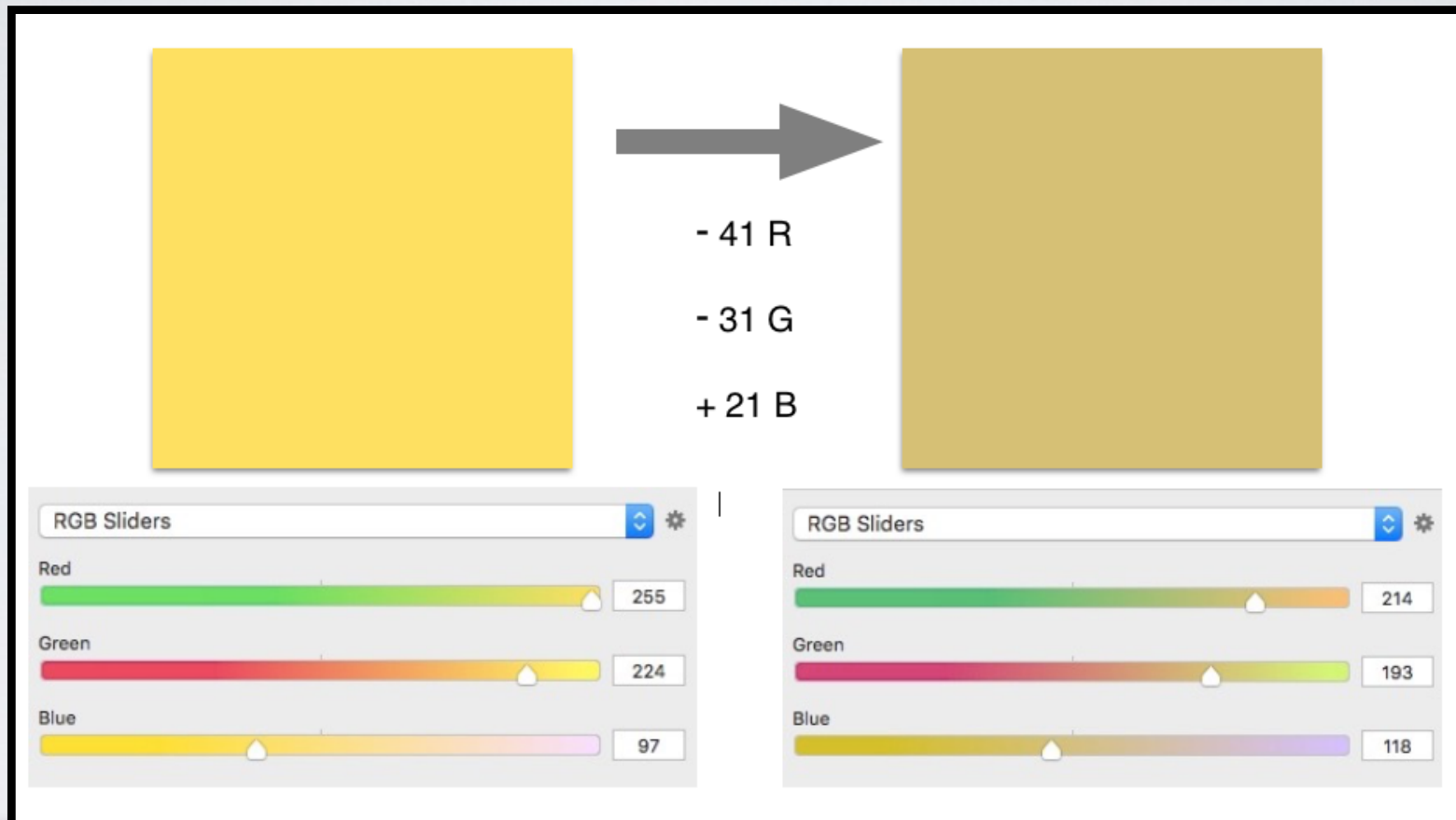
HUE, SATURATION AND VALUE (HSV): IMPROVE RGB COLOR MODEL IN REGARD TO PERCEPTION

- HSV concepts presented by Aly Ray Smith @ SIGGRAPH 1978: "Color Gamut Transform Pairs", (http://alvyray.com/Papers/CG/color78.pdf)

- Hue: defines a particular color selection in terms of wavelengths dimensions.

- Saturation: refers to the dominance of hue in a color, ranges from "pure" to "desaturated".

- Value: expressed in terms of lightness or darkness of a given color, overall intensity of the spectral light.

- HSV is expressed as a 3D cone where hues are strongest at the outer edge and become desaturated when moving toward the central linear axis.
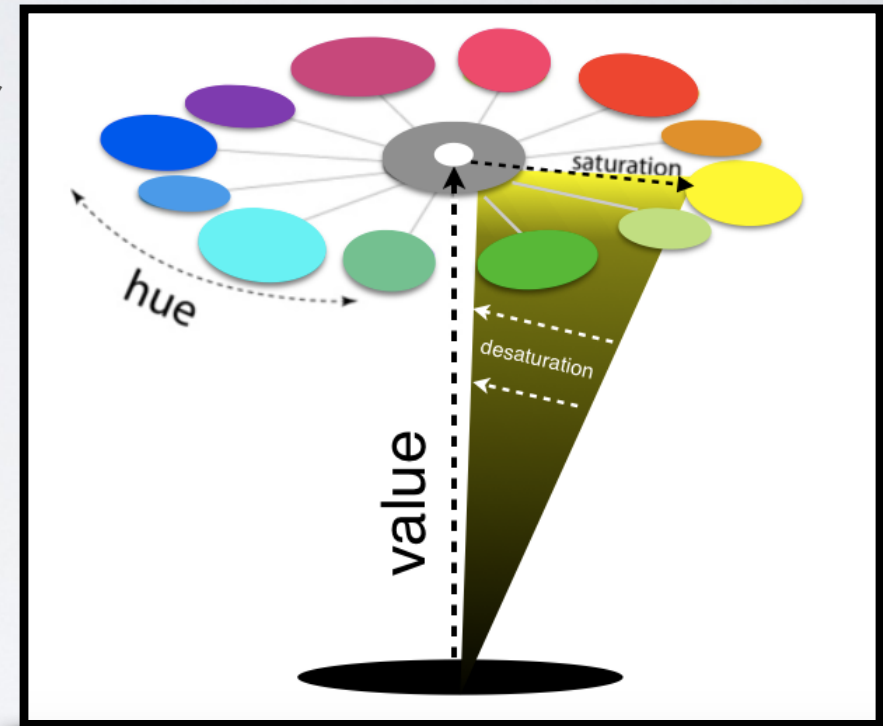
Three dimensional representation of the Hue, Saturation and Value (HSV) color model for color display devices. Illustration by Theresa-Marie Rhyne, 2015.

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HUE, SATURATION & LIGHTNESS: HSL

- HSL concepts presented by George H. Joblove and Donald Greenberg @ SIGGRAPH 1978: "Color Spaces for Computer Graphics", (http://dl.acm.org/citation.cfm?doid=965139.807362)

- Hue: defines a particular color selection in terms of wavelengths dimensions.

- Saturation: refers to the dominance of hue in a color, ranges from "pure" to "desaturated". Full saturation is at the outside edge of a double cone.

- Lightness: represents level of illumination of a given color, overall intensity of the spectral light.

- HSL is expressed as a double 3D cone. HSL notations can be used to specify Web space colors.
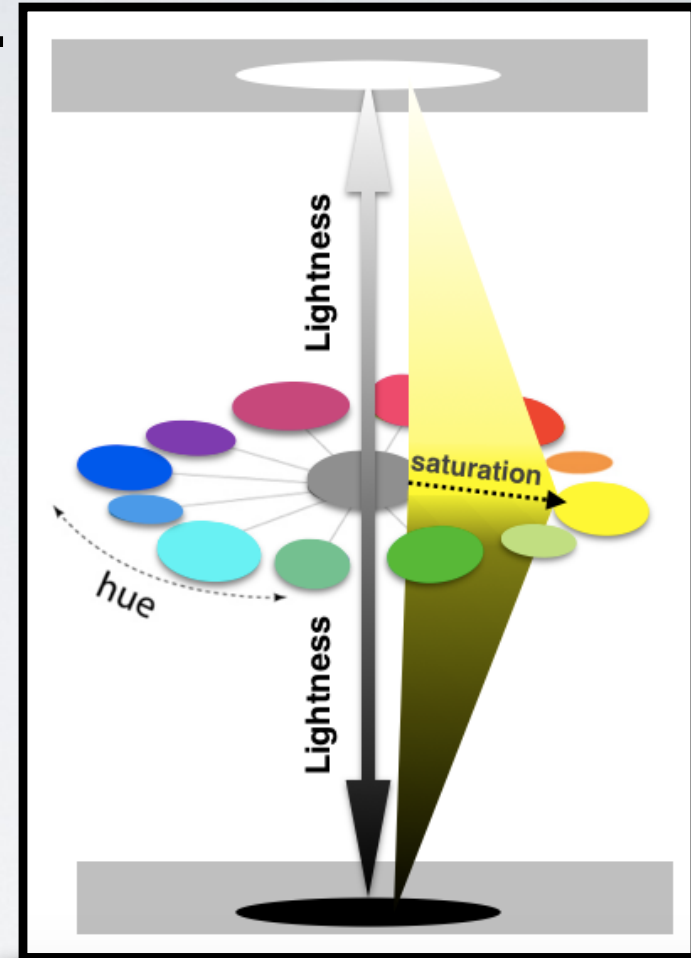
Three dimensional representation of the Hue, Saturation and Lightness (HSL) color model for color display devices. Illustration by Theresa-Marie Rhyne, 2015.

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WEB COLORS: HEX TRIPLETS

• A hex triplet: the 6 digit, 3-byte hexadecimal number used in HTML, CSS, SVG and other web focused applications to represent colors.

• A byte: a number in the range 00 to FF (hexadecimal notation) or 0 to 255 in decimal notation.

The bytes represent red, green, and blue components of color.

Byte 1: red value

Byte 2: green value

Byte 3: blue value

If any one of the 3 color values is less than 10 hex (or 16 decimal), it must be represented with a 0 so that the triplet always has 6 digits.

Hue or Color	English Name	RGB Value	Hex Triplet
	Red	255, 000, 000	#FF0000
	Orange	255, 165, 000	#FFA500
	Yellow	255, 255, 000	#FFFF00
	Yellow Green	154, 205, 050	#9ACD32
	Green	000. 128, 000	#008000
	Aquamarine	127, 255, 212	#7FFFD4
	Cyan	127, 255, 212	#00FFFF
	Deepskyblue	000, 191, 255	#00BFFF
	Blue	000, 000, 255	#0000FF
	Purple	128, 000, 128	#800080
	Magenta	255, 000, 255	#FF00FF
	Deeppink	255, 020, 147	#FF1493
	Gray	128, 128, 128	#808080

Image by Theresa-Marie Rhyne, 2015 using color guidelines from the W3C at (http://www.w3.org/TR/css3-color/).

PANTONE COLOR MATCHING SYSTEM: USED TO STANDARDIZE COLORS

• 1,114 color specified by the allocation number such as "PMS 3527 CP". CP = Coated Paper

• Colors based on 15 pigments (13 base colors along with black & white) that are mixed in specific amounts.

• The CMYK color printing process effectively reproduces a special subset of Pantone colors. Most of the Pantone set cannot be simulated with CMYK and are beyond the CMYK gamut.

• In 2001, Pantone began providing translations of their proprietary system to RGB values. The Pantone Studio app provides sRGB, CMYK, and HEX values for Pantone colors.
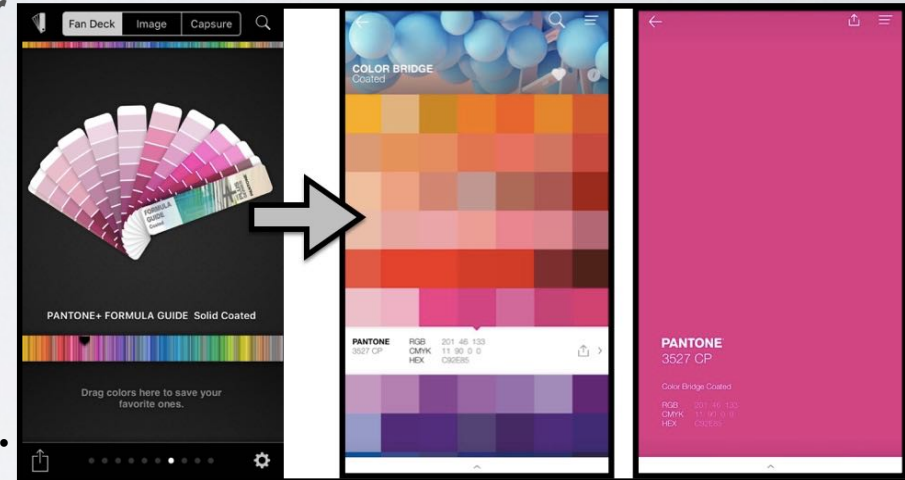
Progression from the virtual fan deck of the older myPantone app to the new digital swatches of the PANTONE Studio app. Illustration by Theresa-Marie Rhyne, 2016.

Pantone online: www.pantone.com

PANTONE Studio app : https://www.pantone.com/studio

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APPLYING COLOR THEORY: PANTONE STUDIO APP
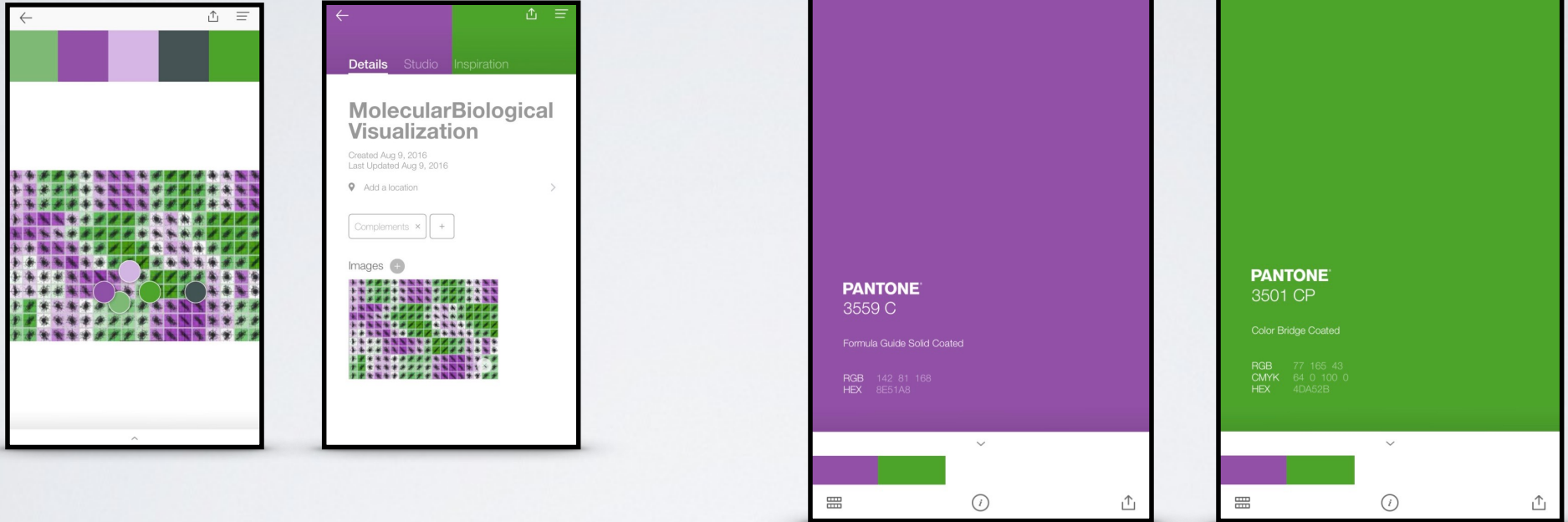
Use the PANTONE Studio Mobile App to examine the color scheme of our digital image for transfer to print media. The basic version of the App is free on iOS platforms while a $7.99 monthly subscription provides access to the complete Pantone library of colors . See: https://www.pantone.com/studio

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Applying Color Theory to Visualization

A Tutorial by Theresa-Marie Rhyne, Visualization Consultant
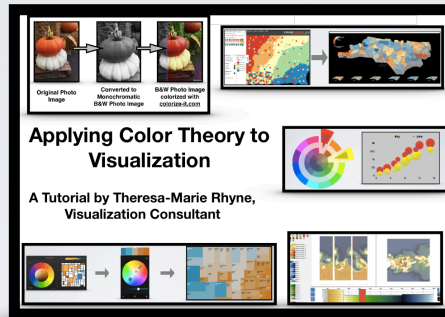
EXPLORING COLOR HARMONY

- Creating a Color Wheel from a Color Model.

- Defining Hues, Tints, Tones & Shades on the Color Wheel.

- Understanding Monochromatic, Analogous, Complementary, Diad, Triad, & Tetrad Harmonies.

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THE COLOR WHEEL:
ARRANGING COLORS AROUND A CIRCLE
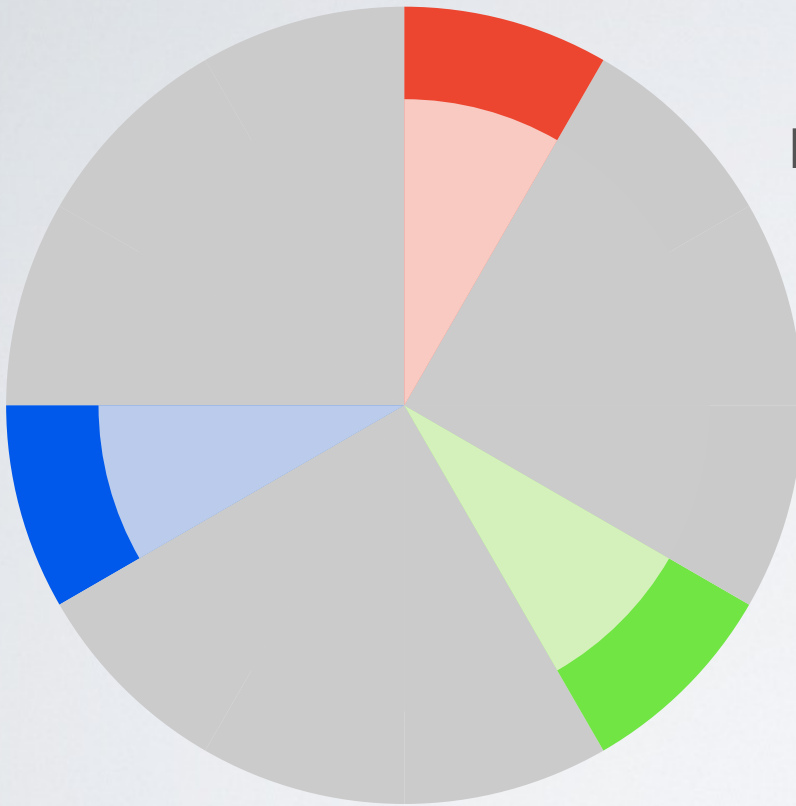
RGB Color Wheel

•1: Define Color Model: place Primaries equidistantly on wheel.
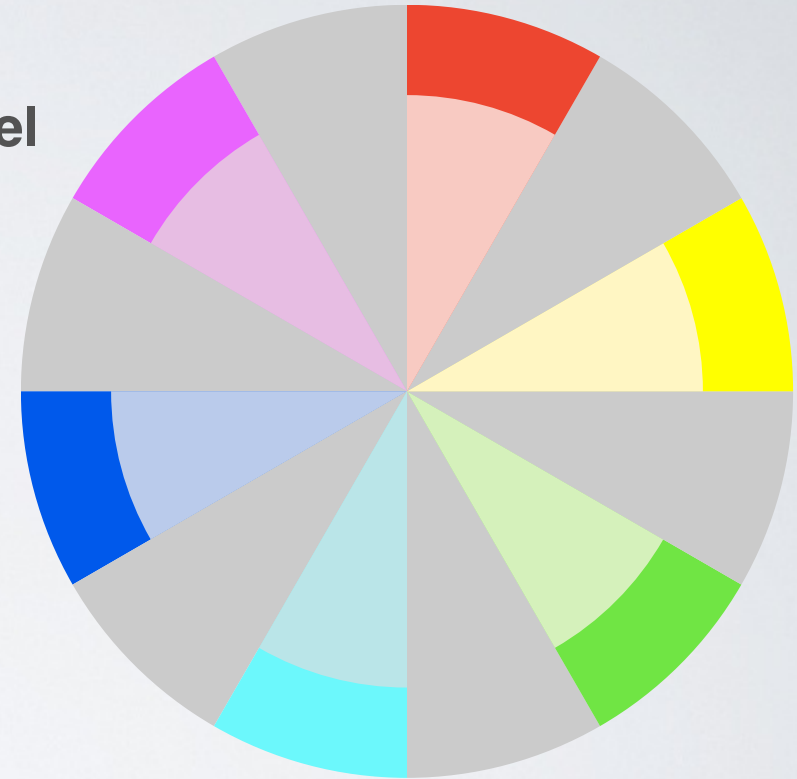
•2: Place Secondary colors equidistantly between primaries.

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THE COLOR WHEEL:
ARRANGING COLORS AROUND A CIRCLE

RGB Color Wheel

•3: Place Tertiary colors: mixtures of primary & secondary colors
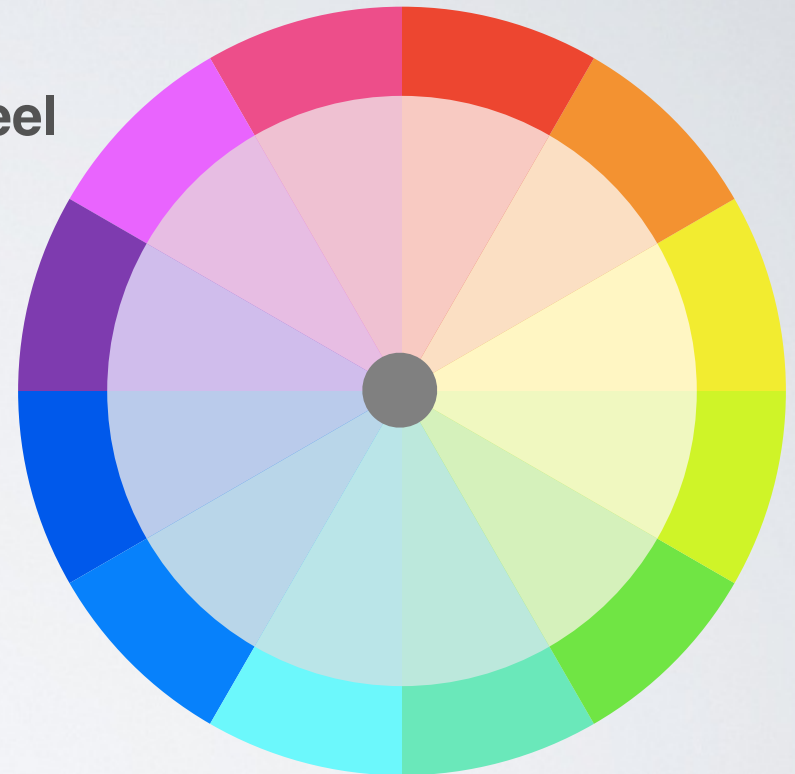
•4: Refine with neutral Gray at center of wheel.

Images created by Theresa-Marie Rhyne, 2016.

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THE COLOR WHEEL:
DEFINING HUES AND TINTS

RGB Color Wheel

•Hue: Purest & Brightest color, resides on rim of color wheel.
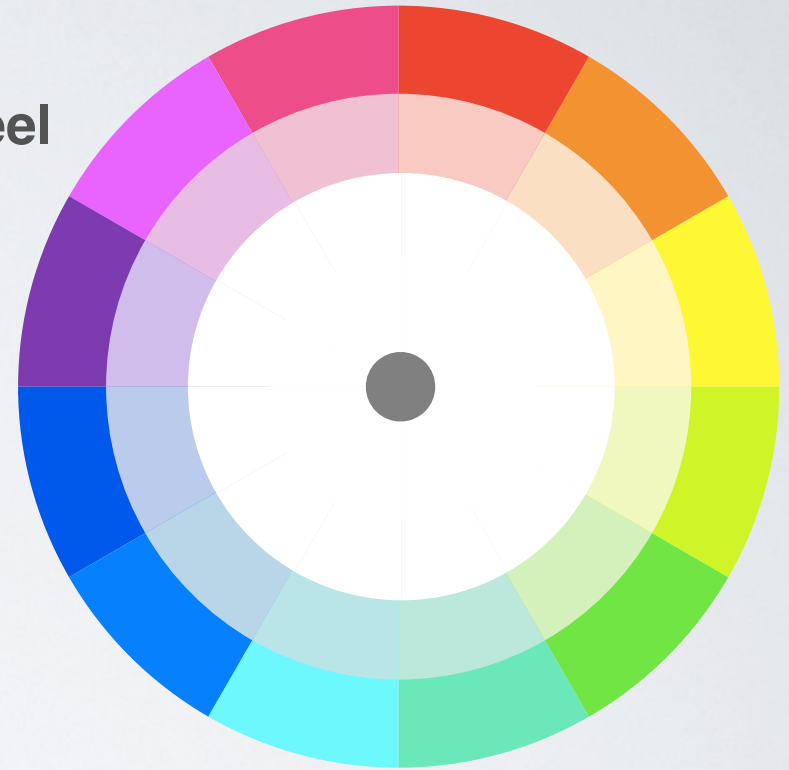
•Tint: A hue mixed with White, resides in 2nd circle next to hues.

Images created by Theresa-Marie Rhyne, 2016.

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THE COLOR WHEEL: DEFINING TONES AND SHADES

RGB Color Wheel

•Tone: A hue mixed with Gray, resides on third concentric ring.
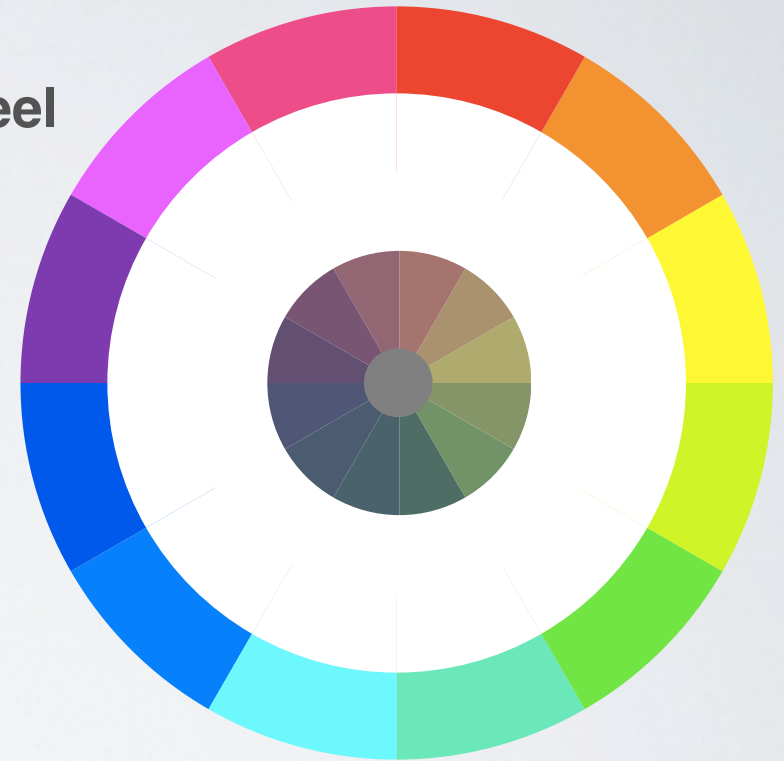
•Shade: A hue mixed with Black, resides in the inner most circle.

Images created by Theresa-Marie Rhyne, 2016.

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USING THE COLOR WHEEL TO BUILD COLOR HARMONIES
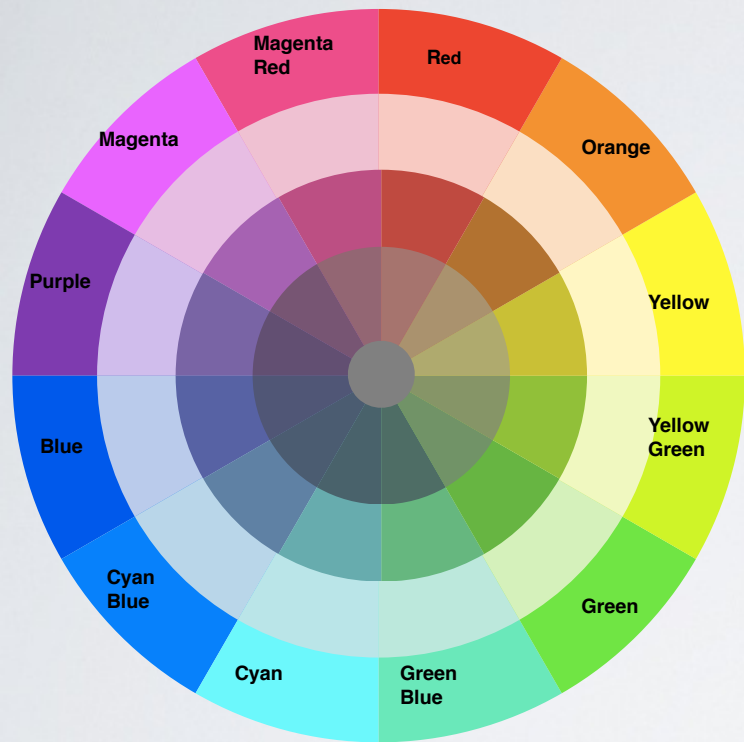
RGB/CMYK Color Wheel

Image created by Theresa-Marie Rhyne, 2016.

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- Monochromatic: Different tints, tones or shades of one color.

- Analogous: colors adjacent to each other on the Color Wheel.

- Complementary: colors opposite each other on the Color Wheel.

- Split Complementary: a main color and two colors on each side of its complementary color.

- Diad: 2 colors that are 2 steps apart on the Color Wheel

- Triadic: 3 colors equally spaced on the Color Wheel.

- Tetradic: Any 4 colors with a logical relationship on the Color Wheel such as 2 complementary pairs.

COLOR HARMONY:
DEFINING & EXAMPLE OF MONOCHROMATIC
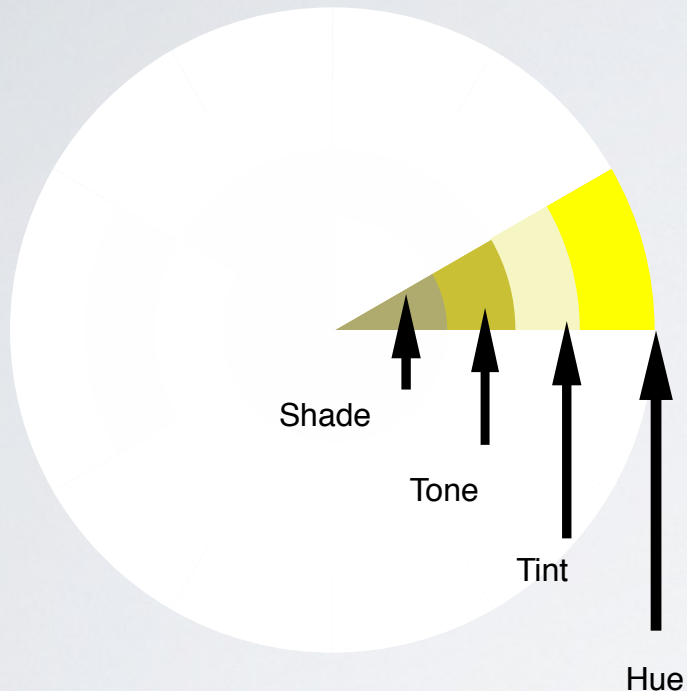
•Monochromatic: Different Tints, Tones of Shades of one Color.

•A Pie Chart with monochromatic colors in the key of Yellow.

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COLOR HARMONY:
DEFINING & EXAMPLE OF ANALOGOUS

- Analogous: 3 Colors adjacent to each other on the color wheel.

Images created by Theresa-Marie Rhyne, 2016.
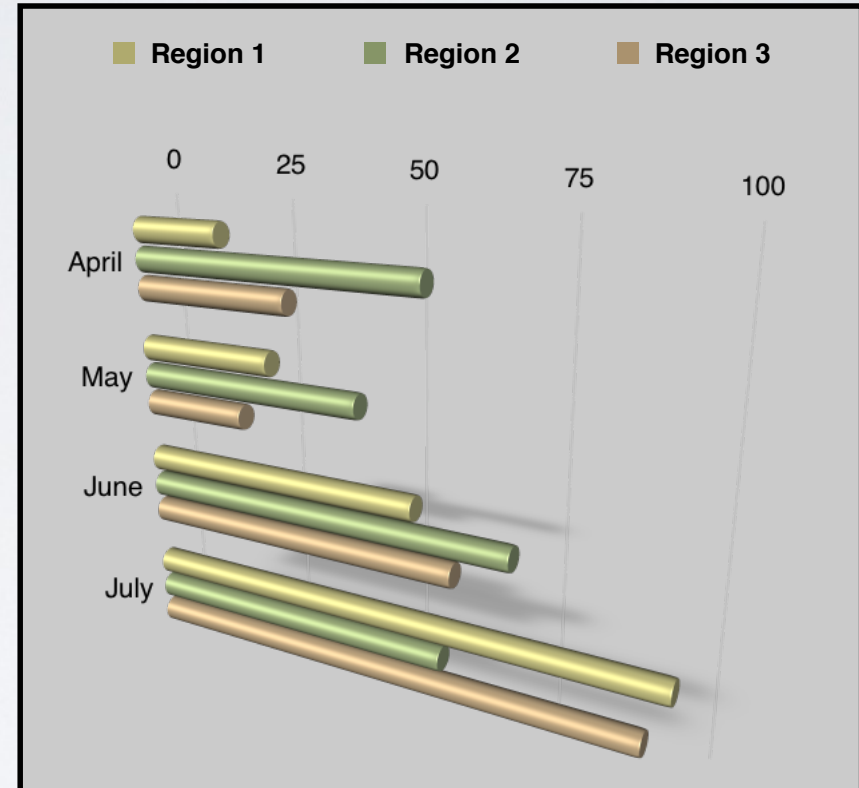
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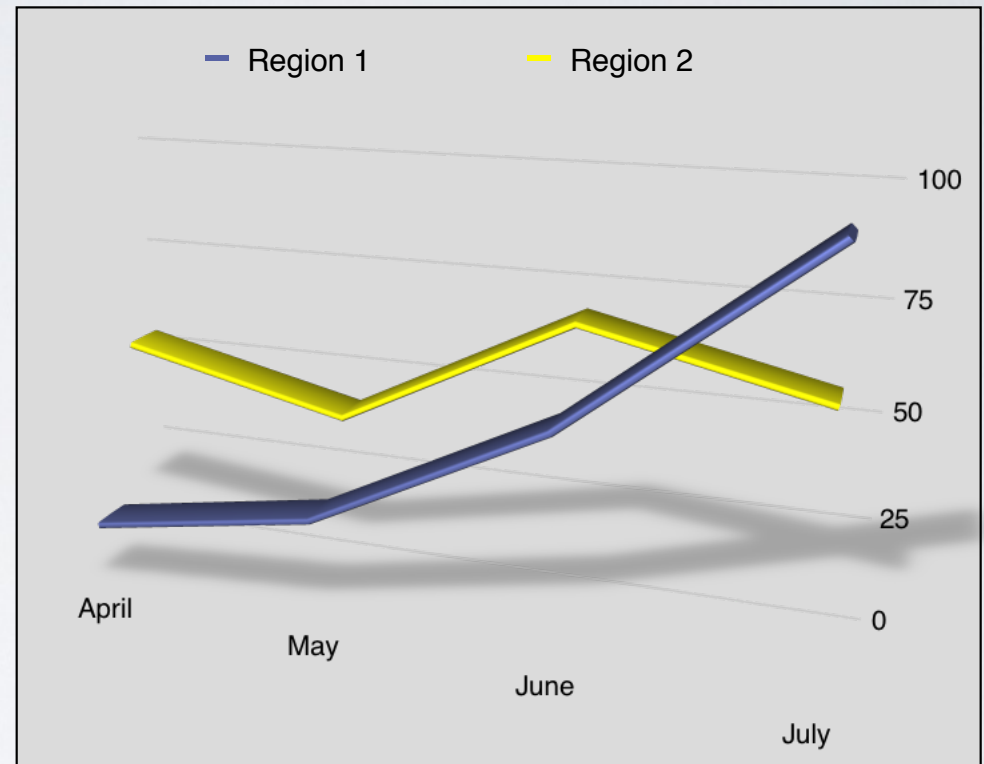- A 3D bar chart with analogous shades in the key of Yellow.

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COLOR HARMONY:
DEFINING & EXAMPLE OF COMPLEMENTARY

•Complementary: Colors opposite each other on the color wheel.

Images created by Theresa-Marie Rhyne, 2016.

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•A 3D plot with complementary tones in the key of Yellow.

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COLOR HARMONY:
DEFINING & EXAMPLE OF DIAD
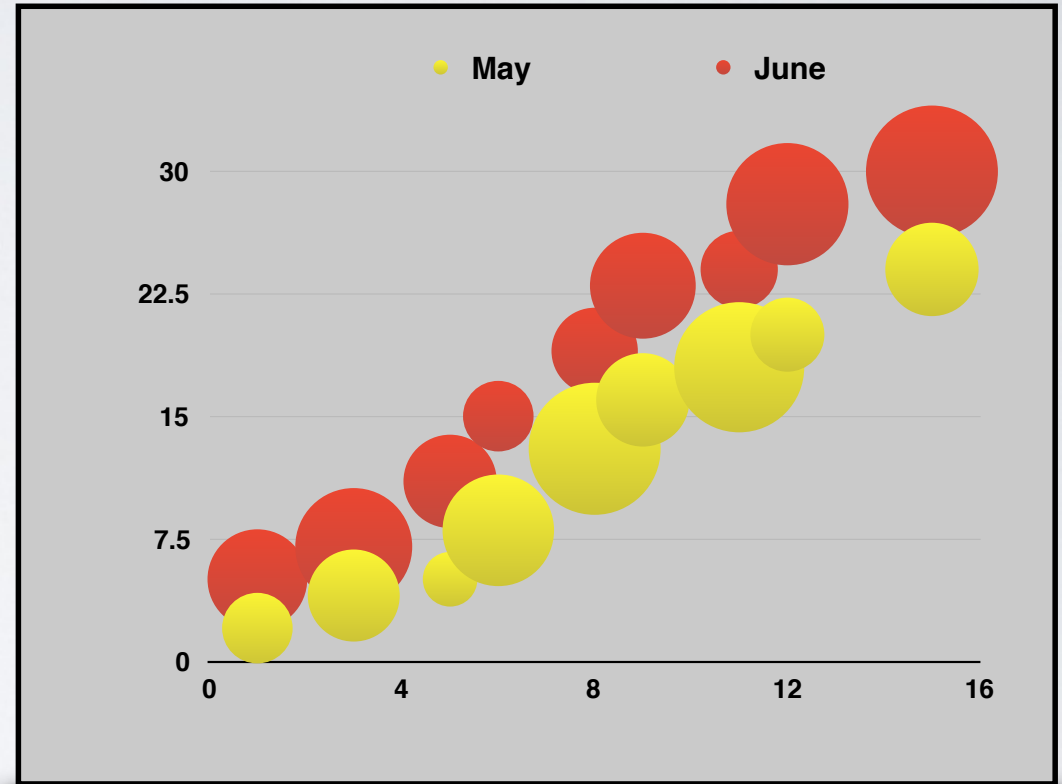
•Diad: 2 Colors that are 2 steps apart on the color wheel.

•A 2D bubble chart with diad hues and tones in the key of Yellow.

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Images created by Theresa-Marie Rhyne, 2016.

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AUTOMATED COLOR ANALYSIS: USING THE ADOBE CAPTURE APP
HTTP://WWW.ADOBE.COM/PRODUCTS/CAPTURE.HTML

Fair Use Image in the USA, Theresa-Marie Rhyne.
"The Seine at Giverny, Morning Mists" painting
created by Claude Monet is on display at the North
Carolina Museum of Art.
http://artnc.org/works-of-art/seine-giverny-
morning-mists
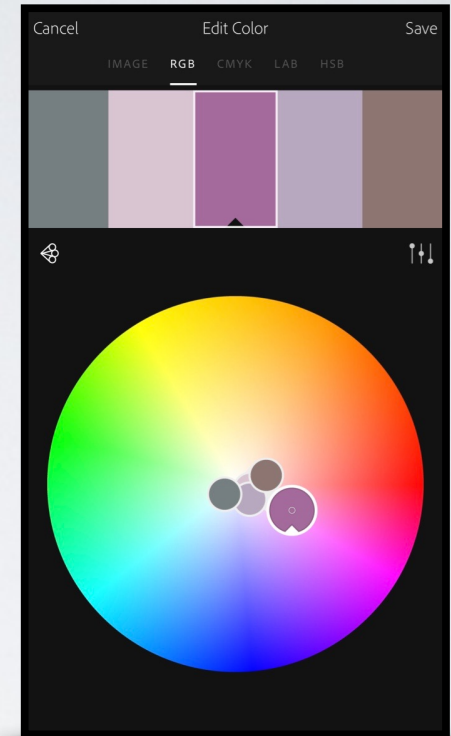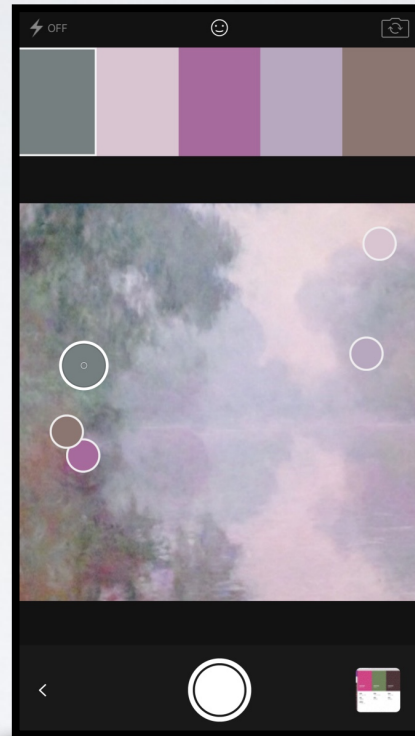
Use the Adobe Capture Mobile App to examine the color scheme of scenes around you.

Here we analyze the 1897 Claude Monet painting: "The Seine at Giverny, Morning Mists".

This painting is in the North Carolina Museum of Art.

The Capture app is available on iPhone-iPad/Android platforms.

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NEXT, WE ADDRESS USING <u>COLORBREWER</u>:

- Free & Online tool for color advice of maps and visualizations.

- Developed by Cynthia Brewer and Mark Harrower - Penn State Univ. Used widely in GIS Community - ESRI ArcGIS software.

- Used as a foundation by Maureen Stone in creating original Tableau Software color maps.

- Sequential, Diverging and Qualitative colormap classifications used in Tamara Munzner's <u>Visualization Analysis and Design</u> textbook: A K Peters Visualization Series, CRC Press, 2014
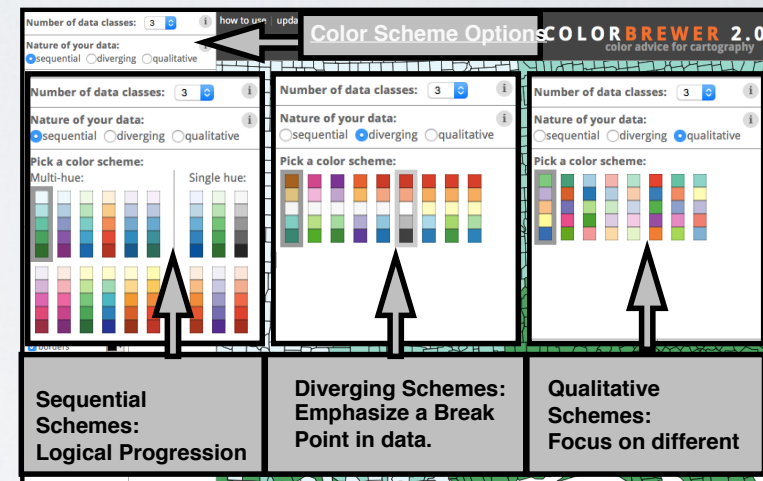

Color Scheme Options — COLORBREWER 2.0 color advice for cartography
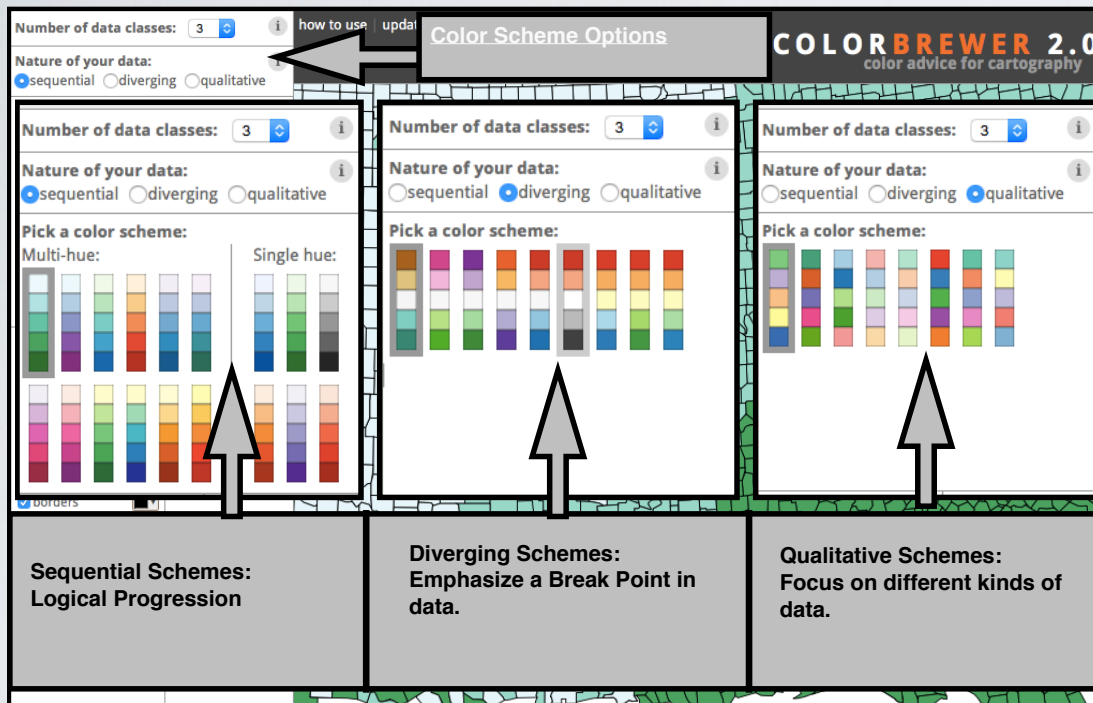
Sequential Schemes: Logical Progression

Diverging Schemes: Emphasize a Break Point in data.

Qualitative Schemes: Focus on different

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COLORBREWER'S COLOR SCHEME CONCEPTS:

Sequential Schemes:
Logical Progression

Diverging Schemes:
Emphasize a Break Point in data.

Qualitative Schemes:
Focus on different kinds of data.

The ColorBrewer tool was conceptualized with color schemes by Cynthia A. Brewer with interface design and software development by Mark Harrower and others (both in the Department of Geography at Pennsylvania State University). See: (http://colorbrewer2.org/).

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- **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 categorial data.**

- **Uses Tints, Tones, & Shades of Hues to achieve various color combinations.**

APPLYING COLORBREWER'S COLOR SCHEME CONCEPTS:
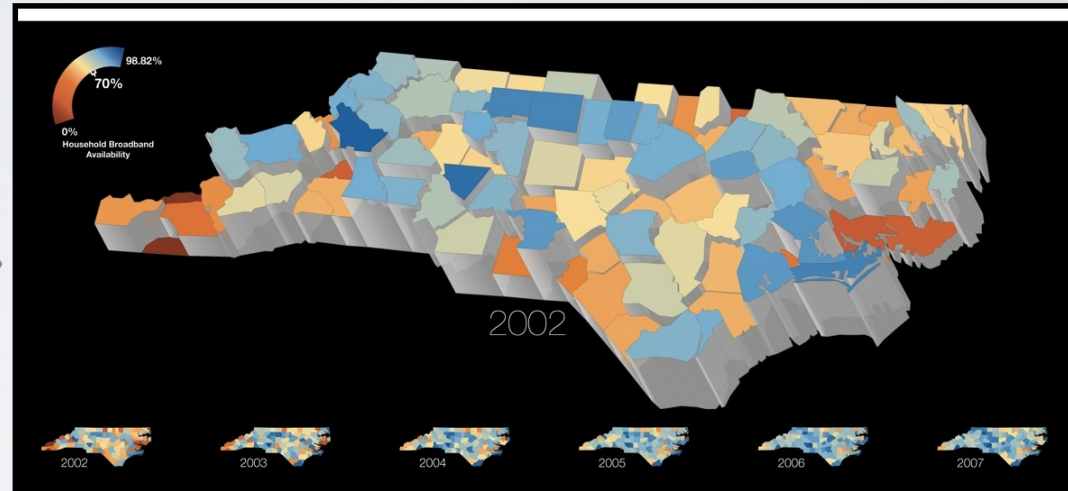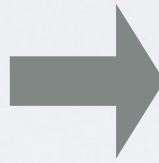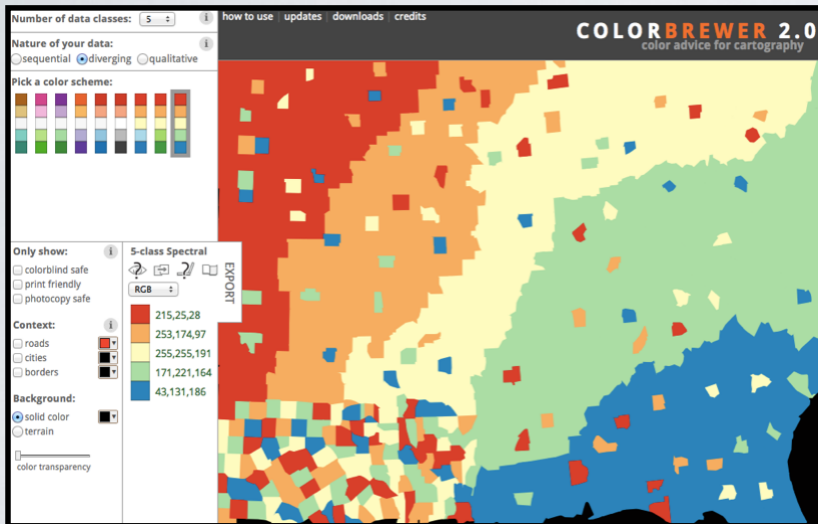
Visualization based on Household Broadband Availability data for the 100 Counties in the State of North Carolina from the years of 2002 through 2007. Information and data provided by the e-NC Authority.
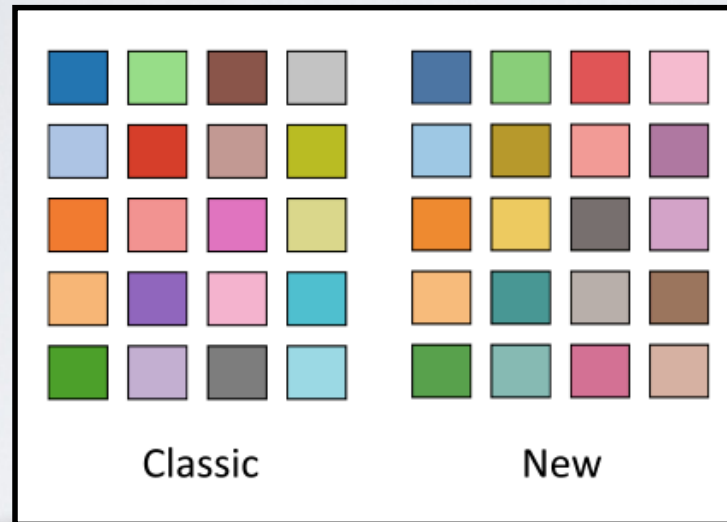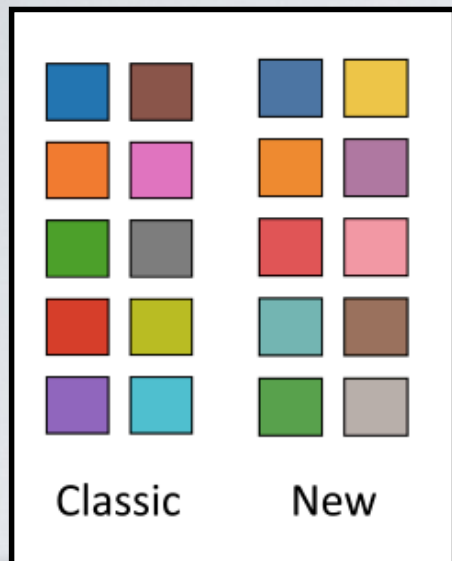
See ColorBrewer online tool at:
(http://colorbrewer2.org).

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COLORIZING INFOGRAPHICS WITH COLORBREWER.
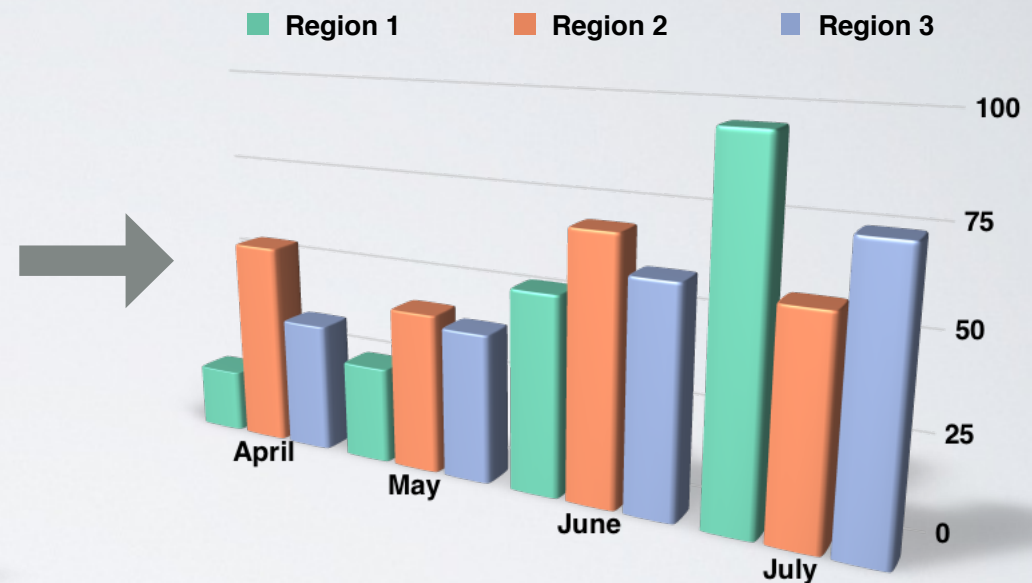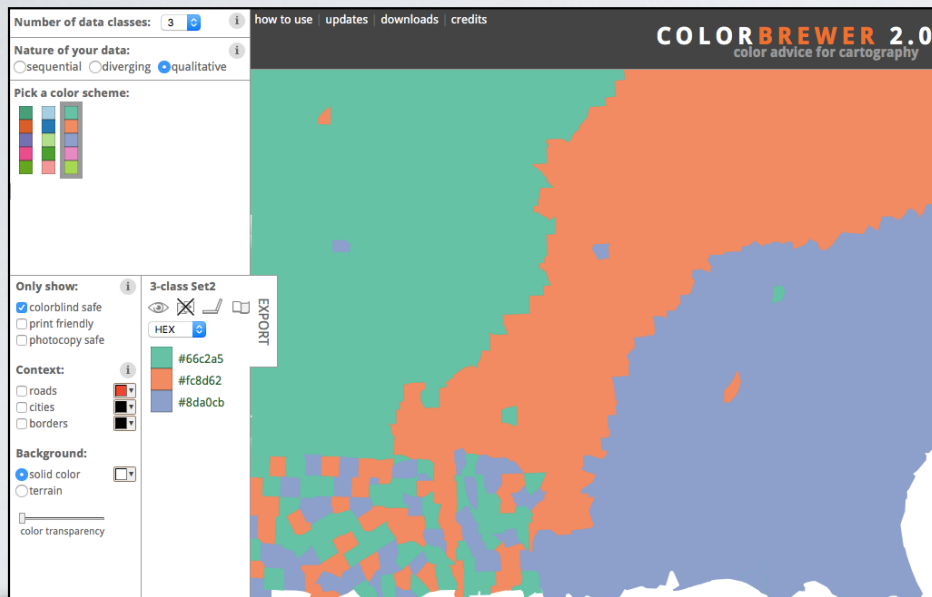
Using ColorBrewer, we select a Qualitative color scheme that is "Color Blind Safe" and apply it to an interactive 3 dimensional bar chart.

Color Study, Color Analysis and Digital Media Visualization created by Theresa-Marie Rhyne in 2016. ColorBrewer and Apple Numbers software were used.

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TABLEAU 10: COLOR PALETTES

Default Tableau Color Palette Redesign for 10 hues & 20 hues.

Images courtesy of Maureen Stone, Tableau Software

• The redesign of the default colors for categorical data in Tableau 10 are shown here.

• Redesigned colors are softer - use tints and tones elements rather than direct hues.

Maureen Stone and Cristy Miller at Tableau re-designed the color palettes in Tableau 10 using concepts from Color Theory. A detailed discussion of their design process can be found at: (https://www.tableau.com/about/blog/2016/7/colors-upgrade-tableau-10-56782).

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TABLEAU 10 DEFAULT COLOR PALETTE CHANGES:

- **Default Sequential Color Palette is now Blue:**

  Previously, it was Green.

- **Default Diverging Color Palette is now Orange-Blue:**

  Previously, it was Red-Green.

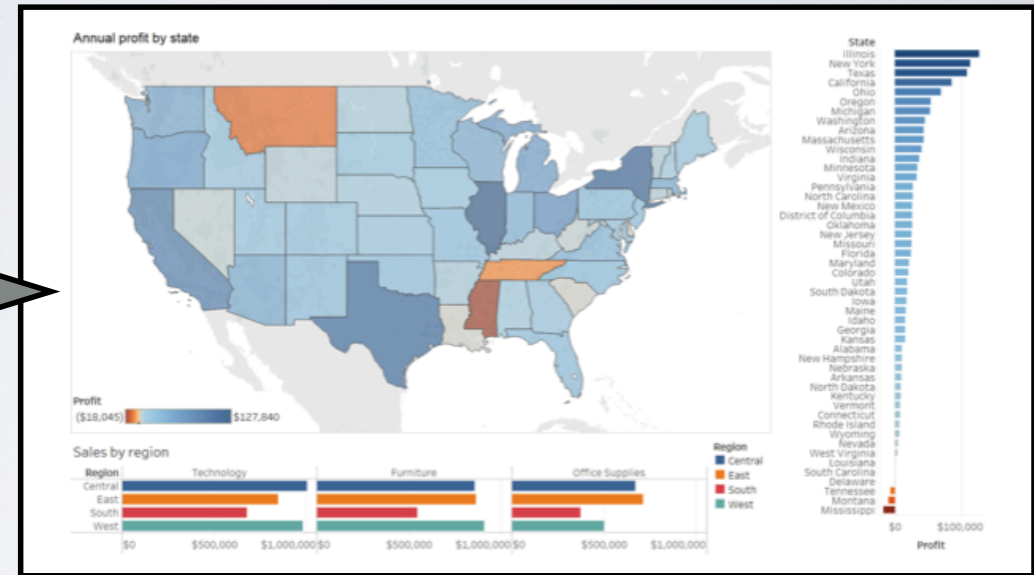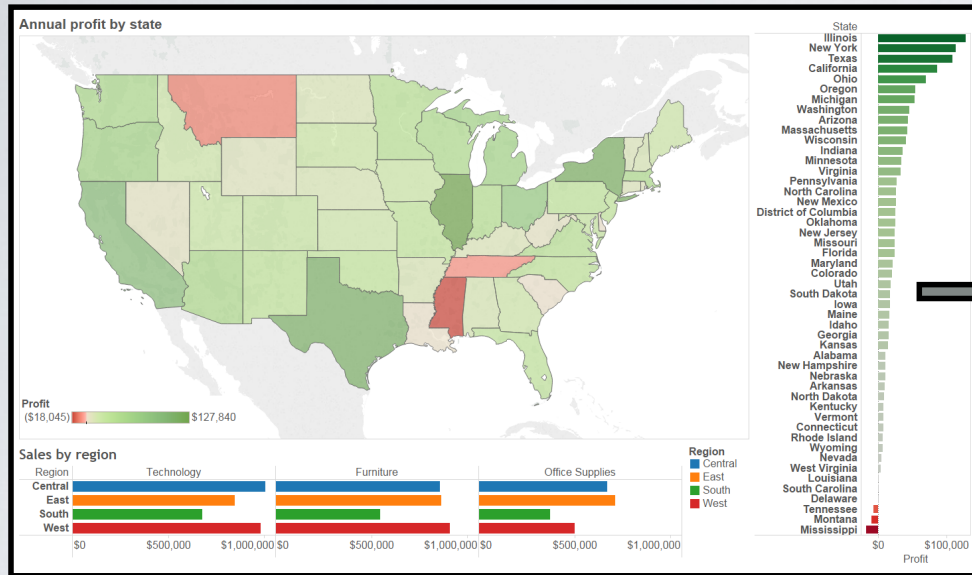- **Design changes intended to aid individuals with color deficiencies.**
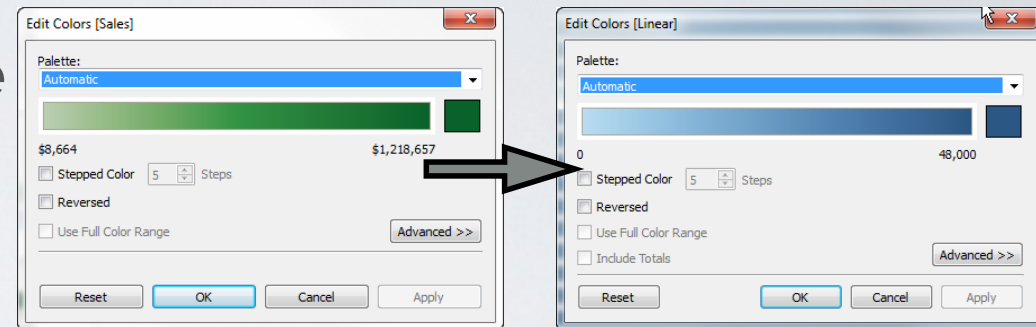
Default Sequential Color Palette for Tableau 10
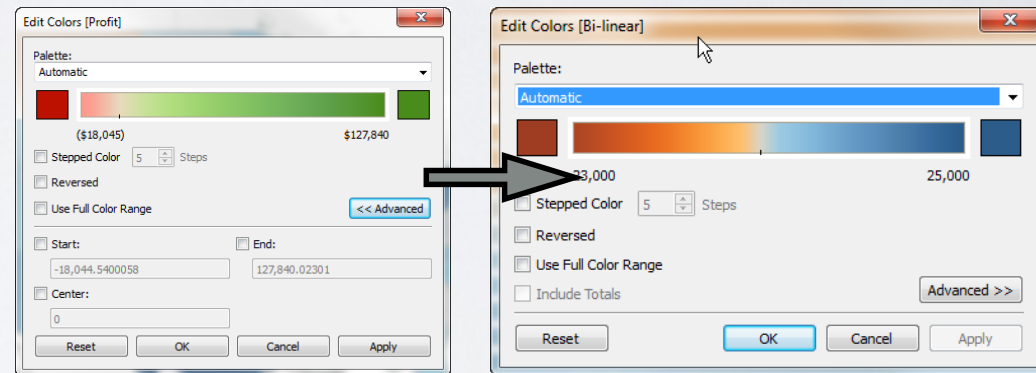
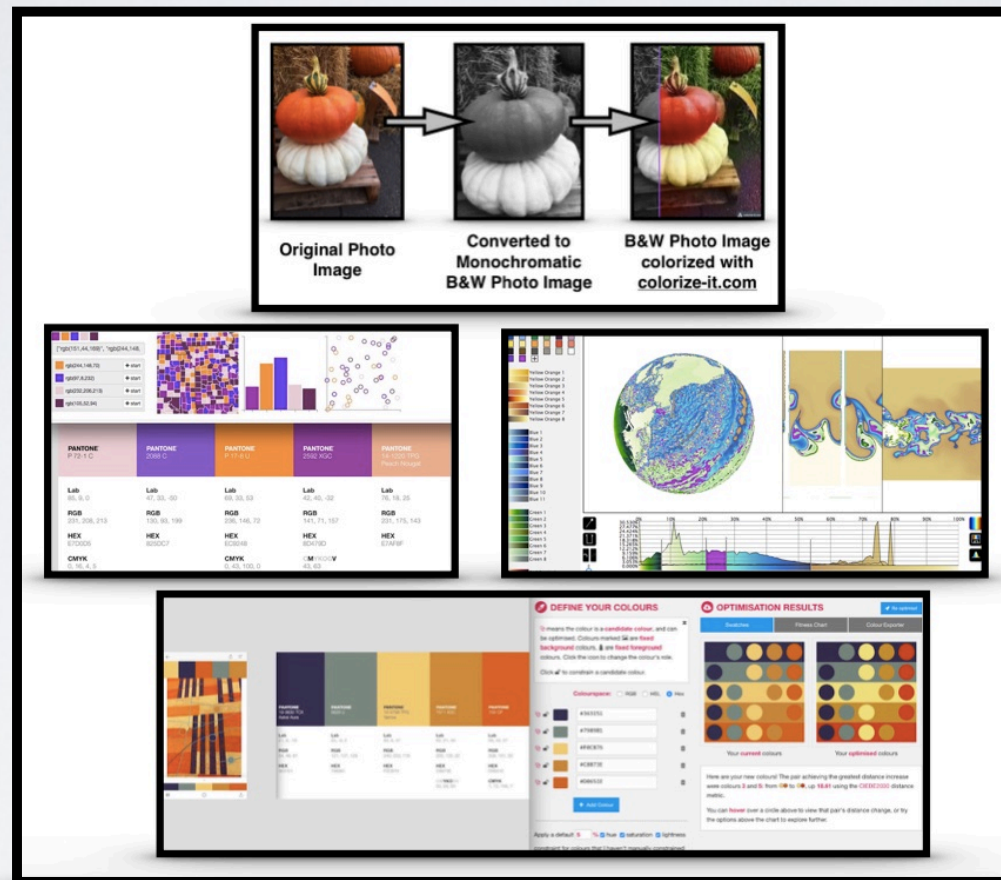Default Diverging Color Palette for Tableau 10

Images courtesy of Maureen Stone, Tableau Software

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TABLEAU 10: COLOR PALETTES

Default Tableau Color Palette Redesign: Visual Analytics Example

Images courtesy of Maureen Stone, Tableau Software

Maureen Stone and Cristy Miller at Tableau re-designed the color palettes in Tableau 10 using concepts from Color Theory. A detailed discussion of their design process can be found at: (https://www.tableau.com/about/blog/2016/7/colors-upgrade-tableau-10-56782).

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RECENT VISUALIZATION & COMPUTER GRAPHICS RESEARCH PERTAINING TO COLOR

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RECENT 2017: COLOR RESEARCH IN VIS & CG

- Danielle Albers Szafir, 2017, Modeling Color Difference for Visualization and Design, InfoVis 2017, IEEE VIS Week 2017, http://danielleszafir.com/colordiff_vis2017.pdf

- Jorge Poco, Angela Mayhua, and Jeffery Heer, 2017, Extracting and Retargeting Color Mappings from Bitmap Images of Visualizations, InfoVis 2017, IEEE VIS Week 2017.

- Roxana Burjack, Terece Turton, Francesca Samsel, David Rogers, James Ahrens, and Colin Ware, 2017, The Good, the Bad and the Ugly: A Theoretical Framework for the Assessment of Continuous Colormaps, SciVis 2017, IEEE VIS Week 2017.

- Maria Shugrina, Jingwan Lu, and Stephen Diverdi, 2017, Playful pallette: an interactive parametric color mixer for artists, In ACM Transactions on Graphics, Vol 36, Issue 4, (SIGGRAPH 2017), Article No. 61: 1-10.

- Lyn Bartram, Abhisekh Patra, and Maureen Stone, 2017, Affective Color in Visualization, In Proc. SIGCHI Conf. Human Factors in Computing Systems (CHI). 1364-1374.

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USING COLORIZE-PHOTOS: ORIGINAL, BLACK & WHITE PHOTO, COLORIZE-PHOTOS VERSION

Original Photo Image → **Converted to Monochromatic B&W Photo Image** → **B&W Photo Image colorized with colorize-it.com**
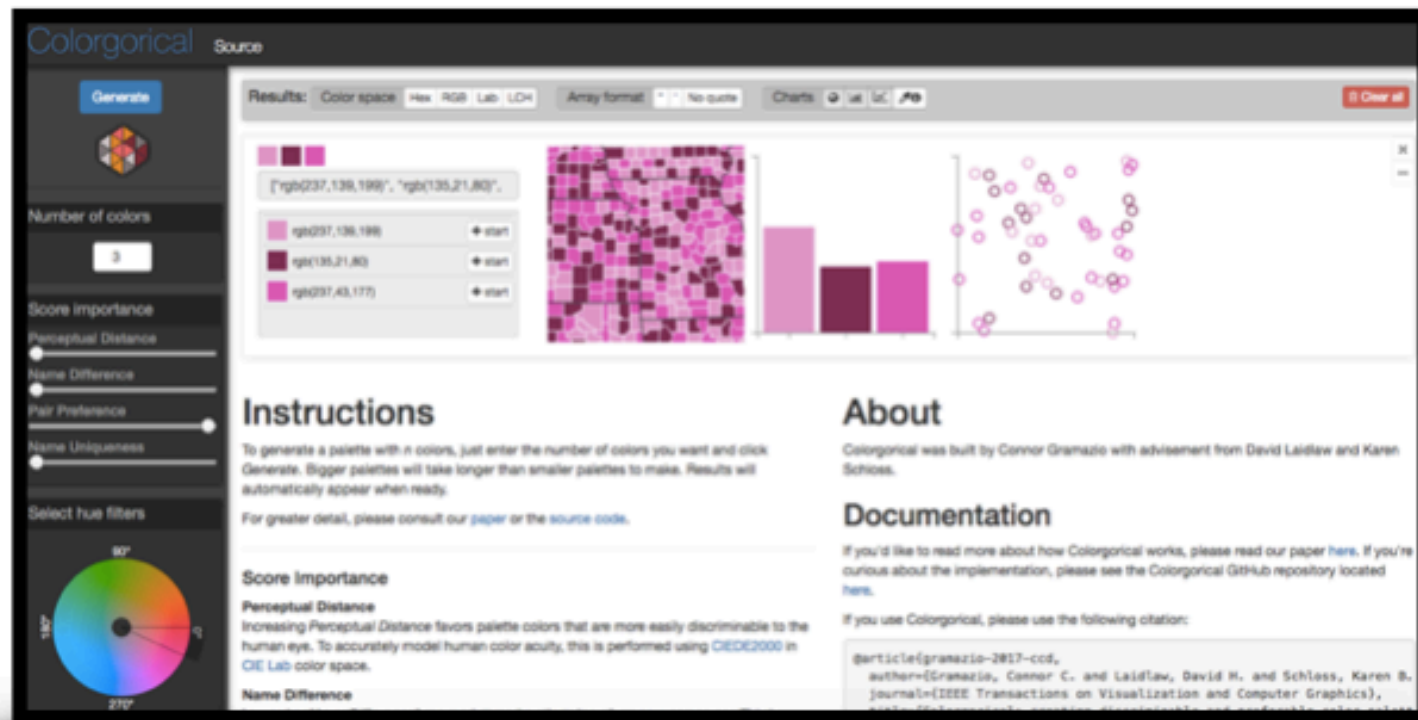
See: http://demos.algorithmia.com/colorize-photos/

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COLORIZE-PHOTOS TOOL:
http://demos.algorithmia.com/colorize-photos/

• "Using Deep Learning to Automatically Colorize Black & White Photos

•Colorful Image Colorization", Richard Zhang, Phillip Isola, & Alexei A. Efros, 2016 European Conference on Computer Vision, https://arxiv.org/pdf/1603.08511.pdf.

•"Real-Time User-Guided Image Colorization with Learned Deep Priors", Richard Zhang, Jun-Yan Zhu, Philip Isola, Xinyang Geng, Angela S. Lin, Tianhe Yu, and Alexei A. Efros, SIGGRAPH 2017 paper, https://richzhang.github.io/ideepcolor/.

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USING COLORGORICAL: ANALOGOUS SCHEME IN THE KEY OF MAGENTA

See: http://vrl.cs.brown.edu/color

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COLORGORICAL:
http://vrl.cs.brown.edu/color

• Web-based tool for generating color palettes, based on a semi-random sampling approach to color selection in CIE Lab Color Space.

• "Colorgorical: Creating discriminable and preferable color palettes for information visualization", Connor C. Gramazio, David H. Laidlaw, and Karen B. Schloss, IEEE Transactions on Visualization and Computer Graphics (Vol. 23, Issue 1, January 2017), pp. 521-530, presented at IEEE VIS 2016 in Baltimore, Maryland, http://ieeexplore.ieee.org/document/7539386/.

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COLORGORICAL & PANTONE STUDIO APP SOLUTIONS COMPARED: IN THE KEYS OF ORANGE AND PURPLE

See: Pantone Studio (https://www.pantone.com/studio) & "Colorgorical" (http://vrl.cs.brown.edu/color)

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USING COLOUR MAP HOSPITAL: COMPLEMENTARY COLOR SCHEME ASSESSMENT
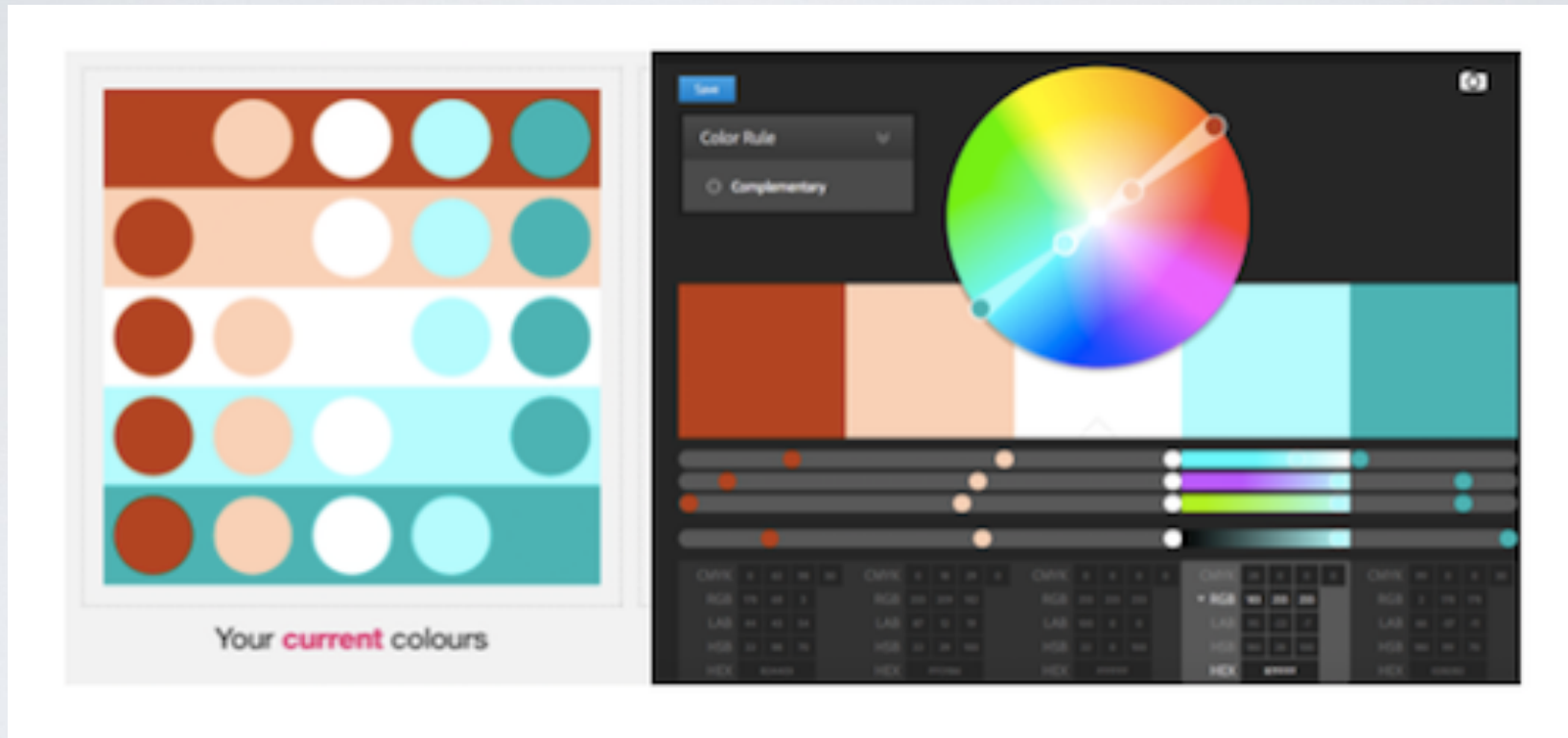
Note: Red Orange & Blue Green Complementary scheme created with Adobe Color (http://color.adobe.com) and entered into Colourmap Hospital (http://simonwalton.me/web-apps/)

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USING COLOUR MAP HOSPITAL: COMPLEMENTARY COLOR SCHEME ASSESSMENT RECOMMENDATIONS

Default 5% Hue Constrained

Default 5% Saturation Constrained

Default 5% Lightness Constrained
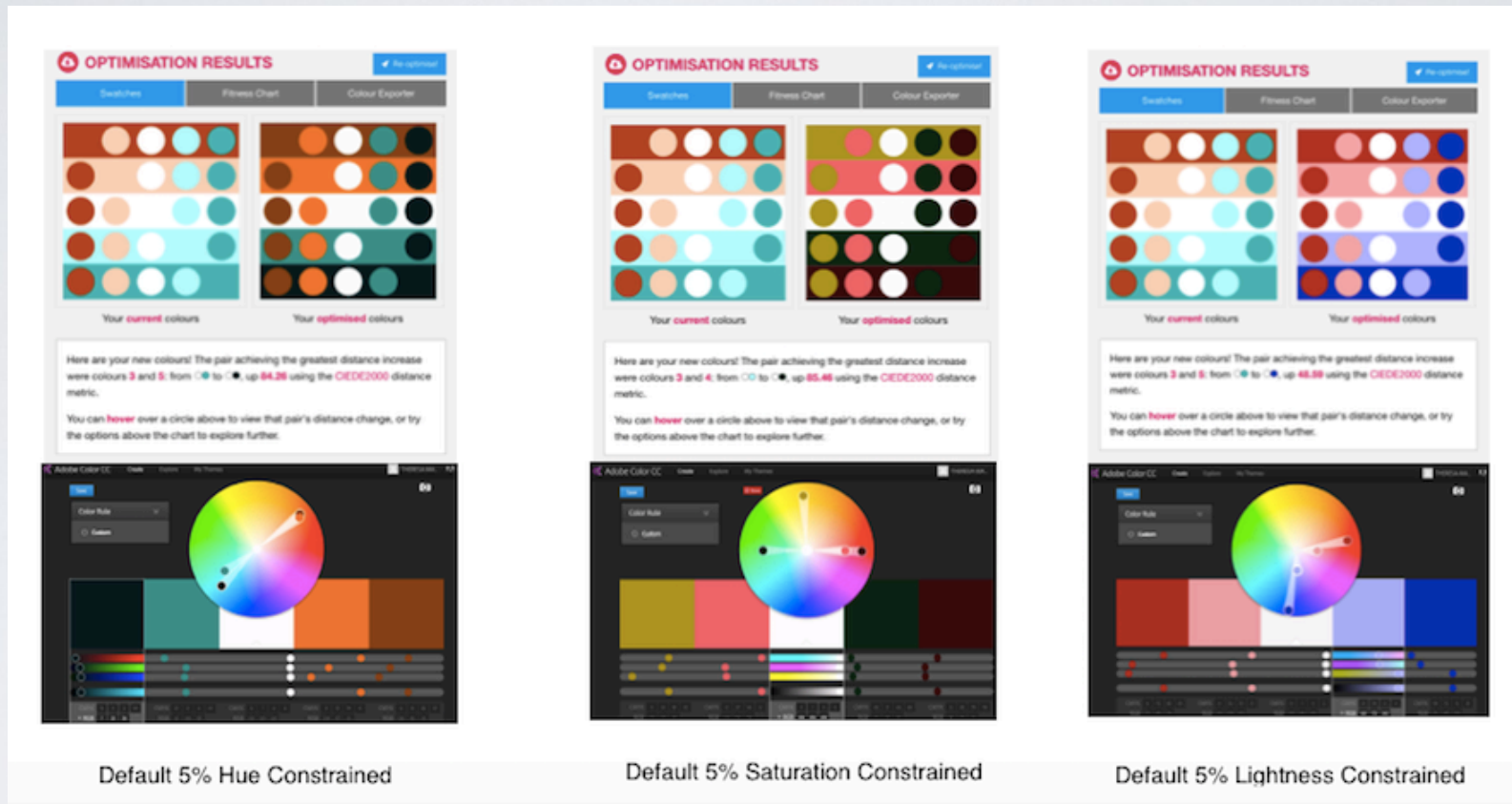
See: Colormap Hospital Video for IEEE VIS 2016 (https://vimeo.com/201772939)

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USING COLOUR MAP HOSPITAL: TO OPTIMIZE A COLOR SCHEME FOR VISUALIZATION

Note: Textile colors captured with <u>Pantone Studio</u> app and entered into Colourmap Hospital (<u>http://simonwalton.me/web-apps/</u>)

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COLOUR MAP HOSPITAL:
## Video from VIS 2016: https://vimeo.com/201772939

• Web-based tool for perceptually optimizing and thus repairing color maps using CIEDE2000 matrix equations that enhance the 1976 CIE Lab color space .

• "Categorical Colormap Optimization with Visualization Case Studies", H. Fang, S. Walton, E. Delahaye, J. Harris, D.A. Storchak, and M. Chen, IEEE Transactions on Visualization and Computer Graphics (Vol. 23, Issue 1, January 2017), pp. 871-880, presented at IEEE VIS 2016 in Baltimore, Maryland, http://ieeexplore.ieee.org/document/7539556/.

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USING COLORMOVES: SCI VIS FLUID FLOW ANALYSIS

See: Colormaps for analyzing Scientific Visualization imagery (http://sciviscolor.org/)

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USING COLORMOVES: SCI VIS FLUID FLOW ANALYSIS

See: Colormaps for analyzing Scientific Visualization imagery (http://sciviscolor.org/)

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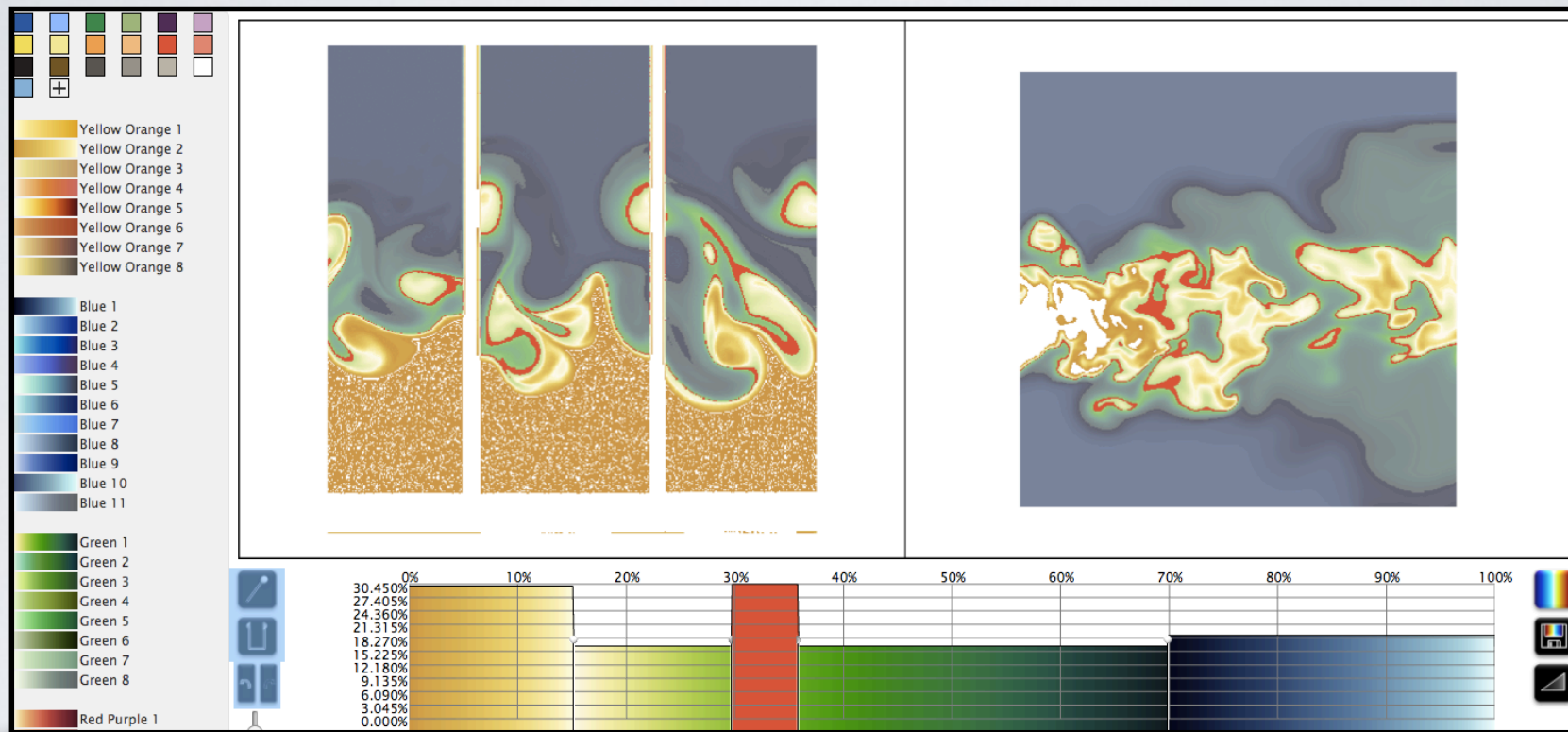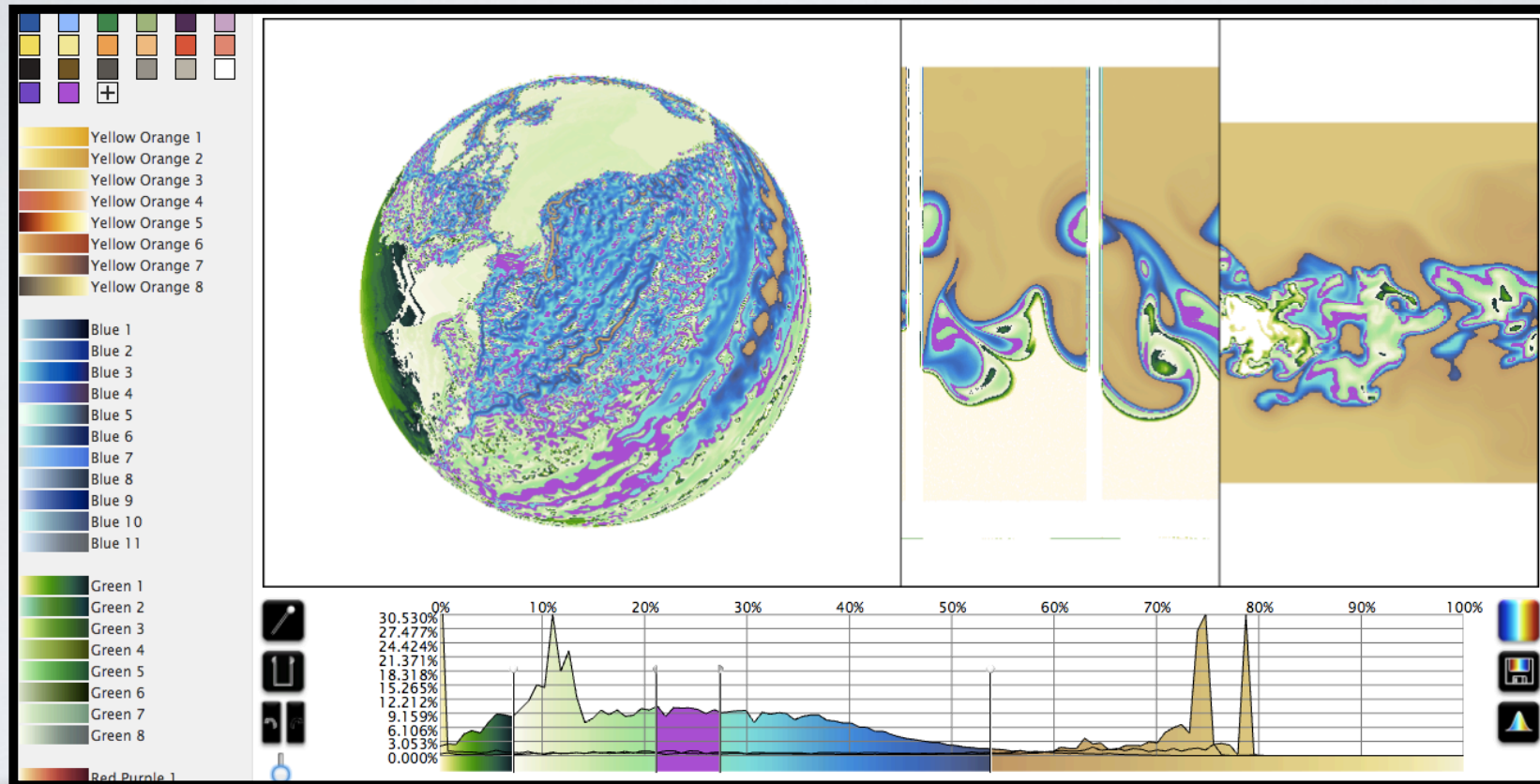
COLORMOVES:
http://sciviscolor.org/

- Web-based tool for interactive exploration and designing of colormaps from scientific visualization imagery (frequently fluid flow) imagery.

- "Interactive Colormapping: Enabling Multiple Data Ranges, Detailed Views of Ocean Salinity", Francesca Samsel, Sebastian Klassen, Mark Petersen, Terence Turton, Greg Abram, David H. Rogers, and James Arenas, 2016, In Proc. SIGCHI Conf. Human Factors in Computing Systems (CHI), pp. 700 - 709. http://sciviscolor.dsscale.org/wp-content/uploads/sites/14/2016/12/InteractiveColormapping.pdf.

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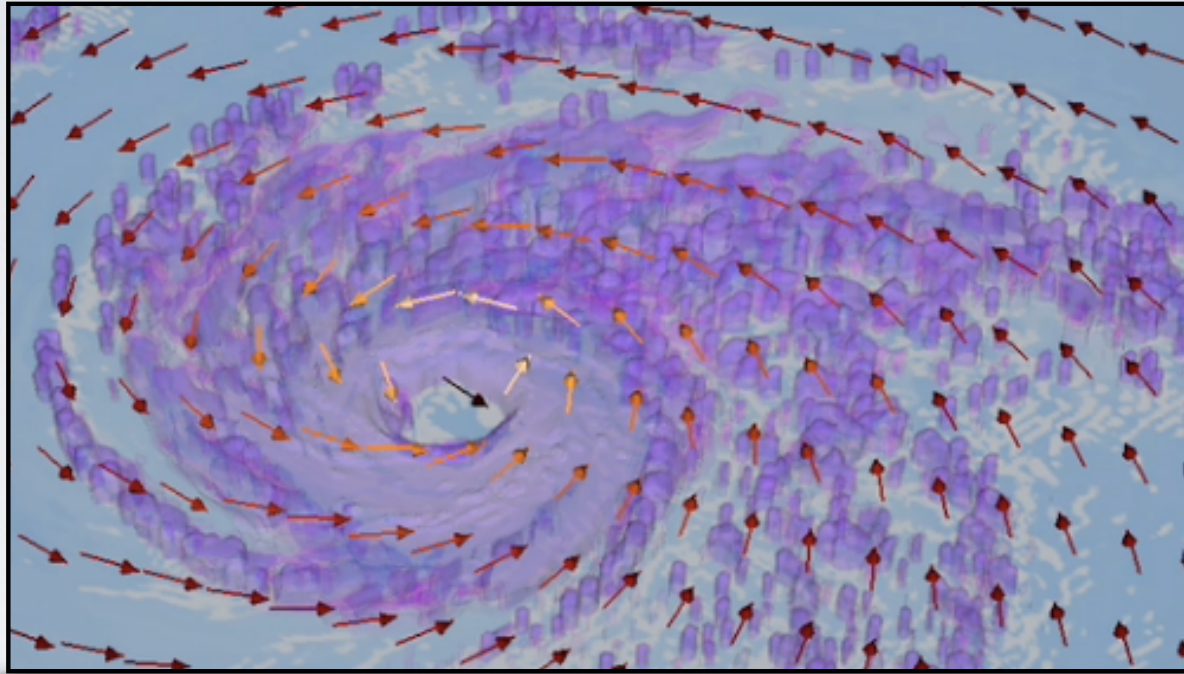# CASE STUDY: COLORIZING A HURRICANE

Image Theresa-Marie Rhyne, 2016.

Visualization based on a Hurricane Katrina model run at 2 kilometer grid resolution using the Weather Research Forecast (WRF) model. The animation shows rain isosurfaces, with the purple areas being locations of heaviest rainfall. Dark blue areas are land masses.

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VISUAL SUMMARY OF STUDY: COLORIZING A HURRICANE
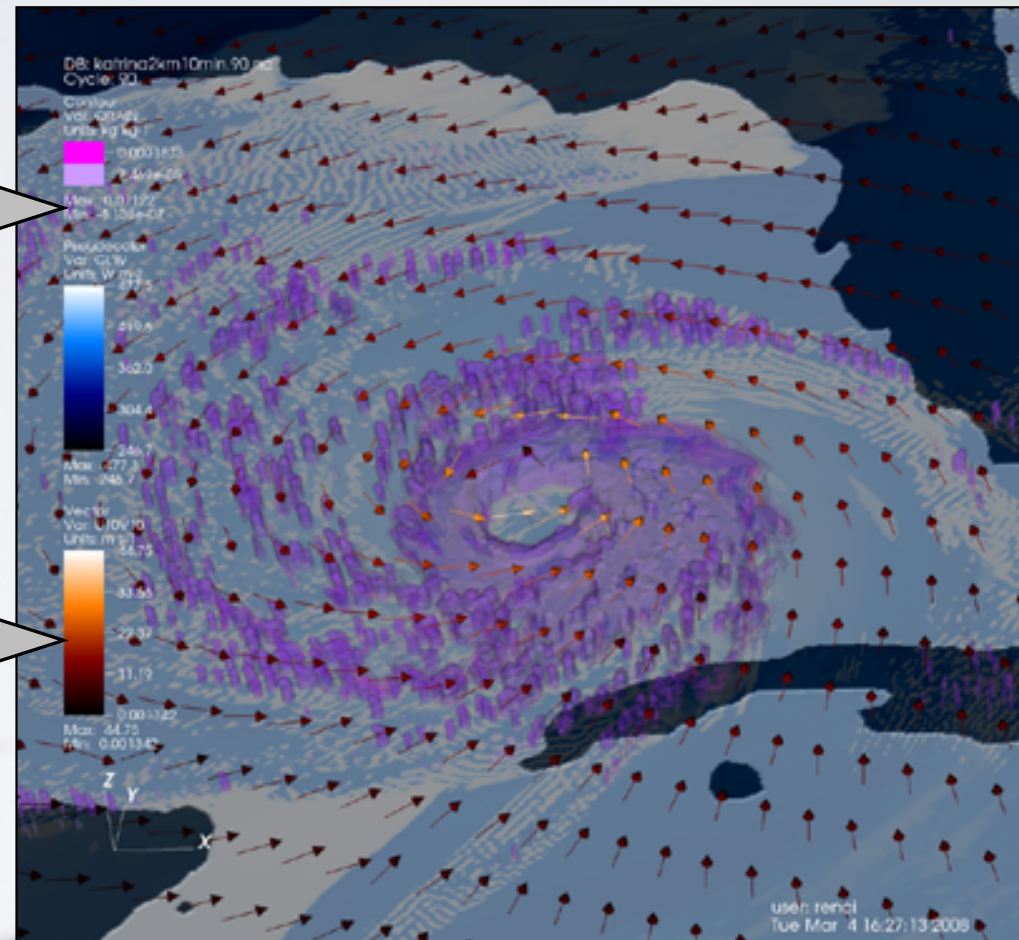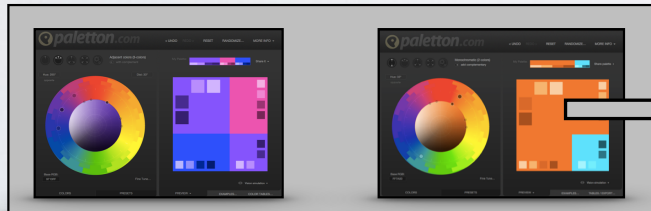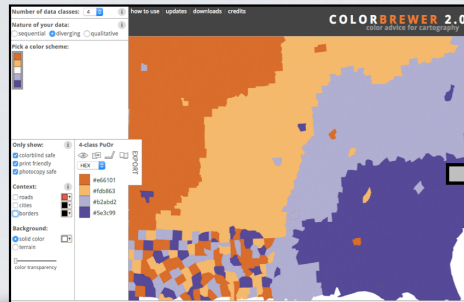
Images Theresa-Marie Rhyne, 2016.

USING COLORBREWER TO DEVELOP COLORMAPS:

Image Theresa-Marie Rhyne, 2016.

Note: Color Vision Deficiency Parameters
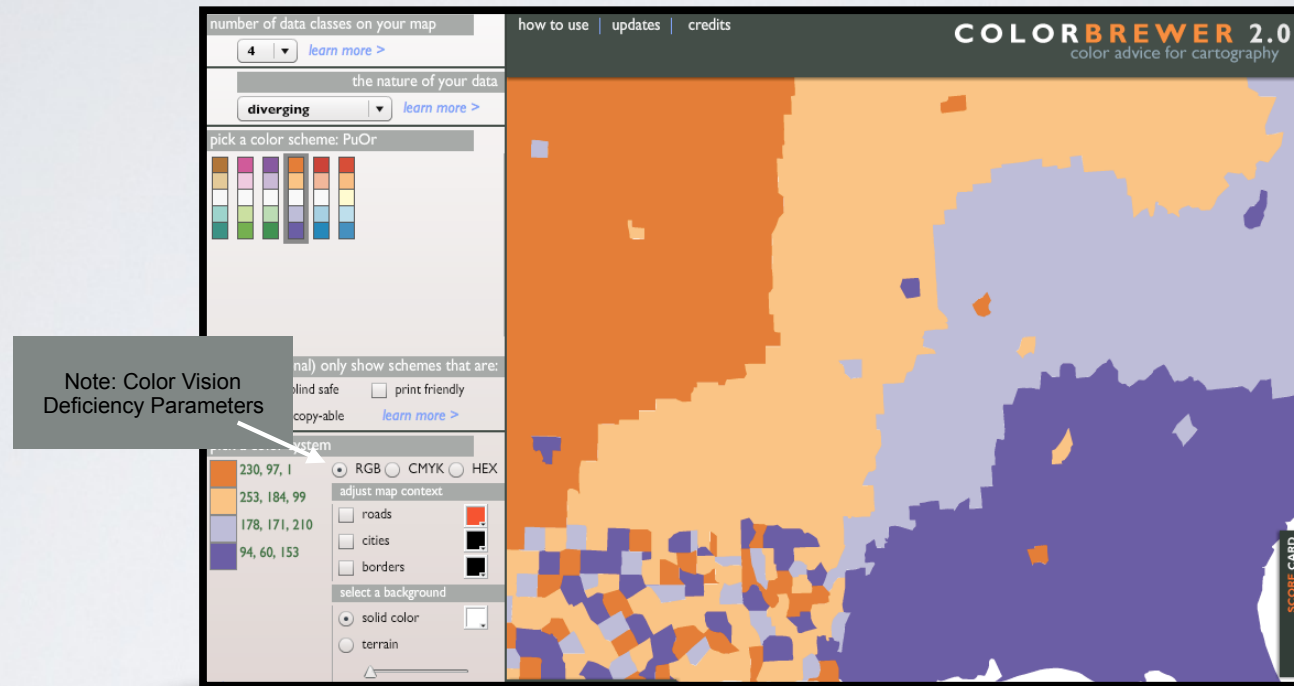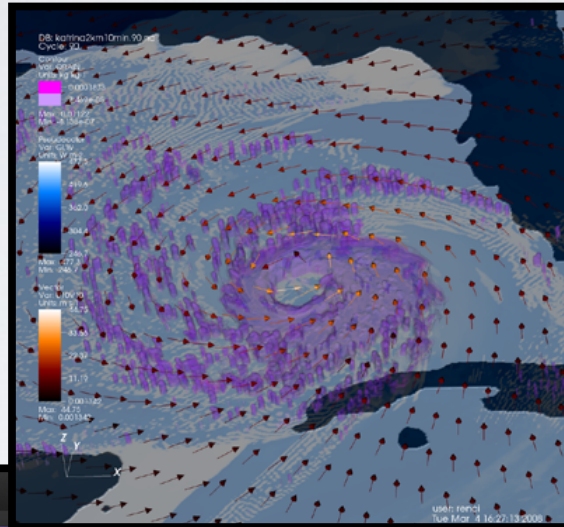
The ColorBrewer tool was conceptualized with color schemes by Cynthia A. Brewer with interface designs by Mark Harrower and software development by Andy Woodruff and Davie Heyman, Department of Geography at Pennsylvania State University.   See: (http://colorbrewer2.org).

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A COLOR SCHEME ANALYSIS OF OUR HURRICANE.

Images Theresa-Marie Rhyne, 2016.
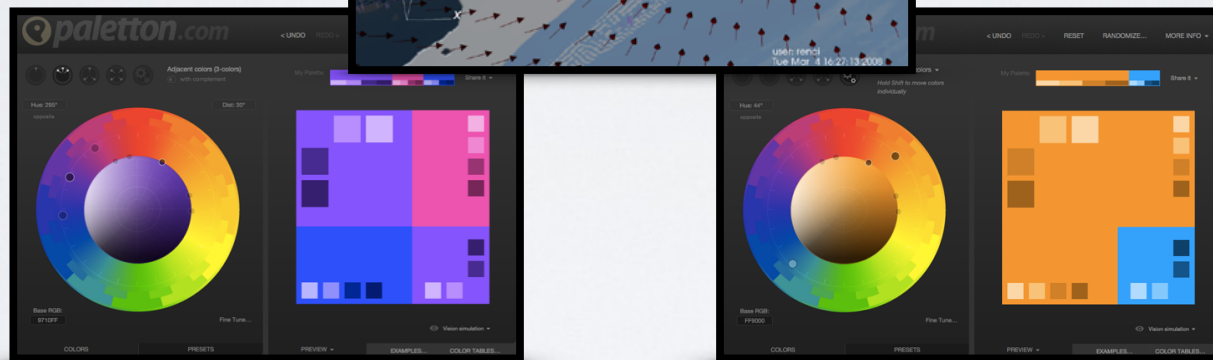
Using Color Scheme Designer, we see that our hurricane colors form an analogous color scheme of Magenta, Purple and Blue. Our wind vectors, in Orange, from a complementary color scheme to our Blue ocean background. The latest version of Color Scheme Designer is now entitled Paletton: Color Schemer Designer, underline.com.

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MY BOOK ON COLOR THEORY:

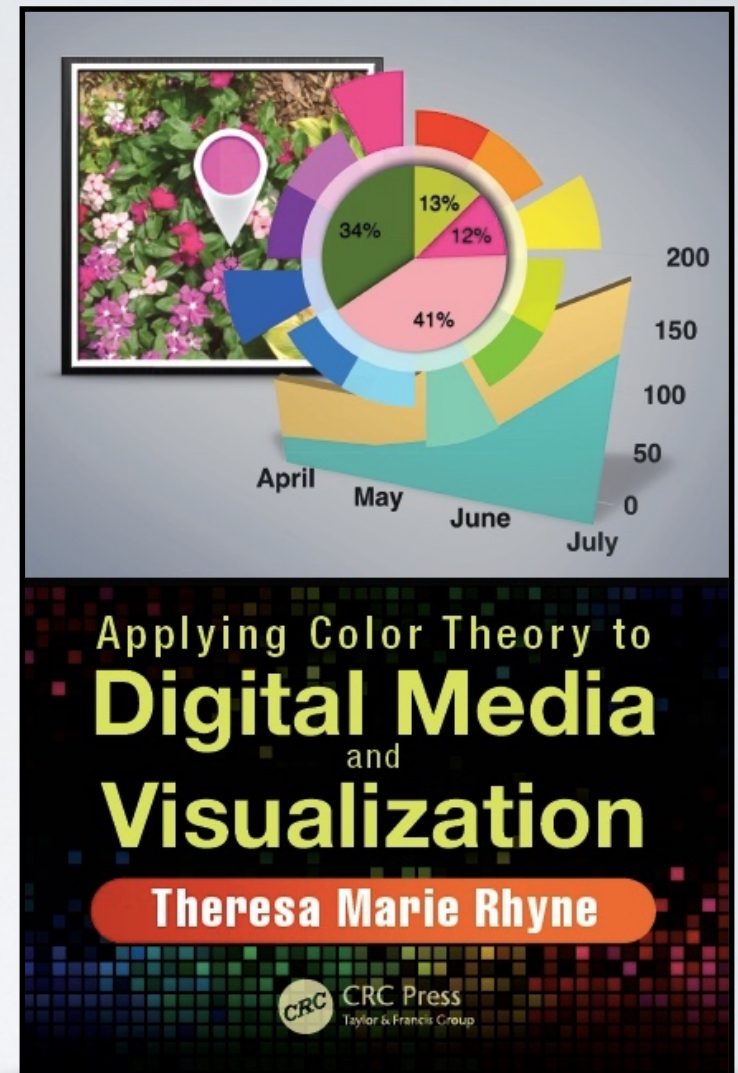"Applying Color Theory to Digital Media and Visualization"

by Theresa-Marie Rhyne, from CRC Press, published in November 2016.

https://www.crcpress.com/Applying-Color-Theory-to-Digital-Media-and-Visualization/Rhyne/p/book/9781498765497

20% promo code for attending this workshop & ordering online: GWR38

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- As well as family members who have encouraged me to continue with these efforts.

With much gratitude and appreciation.

Theresa-Marie Rhyne