CS 571 - Data Visualization & Exploration

Color

Instructor: Hamza Elhamdadi

UMassAmherst

Upcoming Dates

Feb 13: Announce Your Project

Feb 14: ~~Group~~ Activity 1 Due

Feb 14: Homework 1 Due

Some More Details

Office Hours start this week
(see the syllabus for times)

Lectures will be recorded via Echo360
(the first three are already up!)

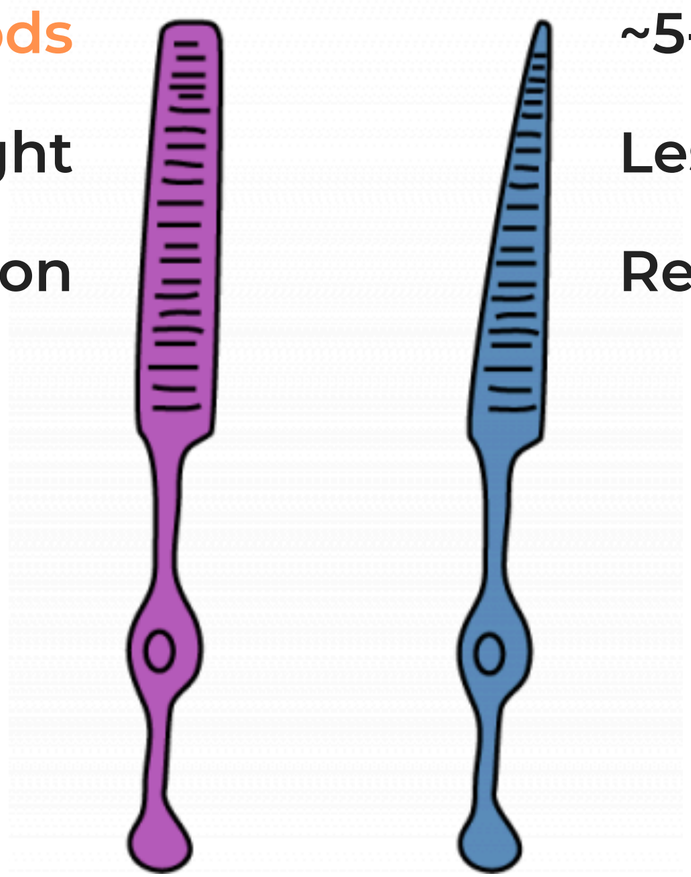
Make sure at least one member from your project team attends class on Feb 13

How do we perceive color?

~120 million rods

More sensitive to light

Responsible for low-light vision

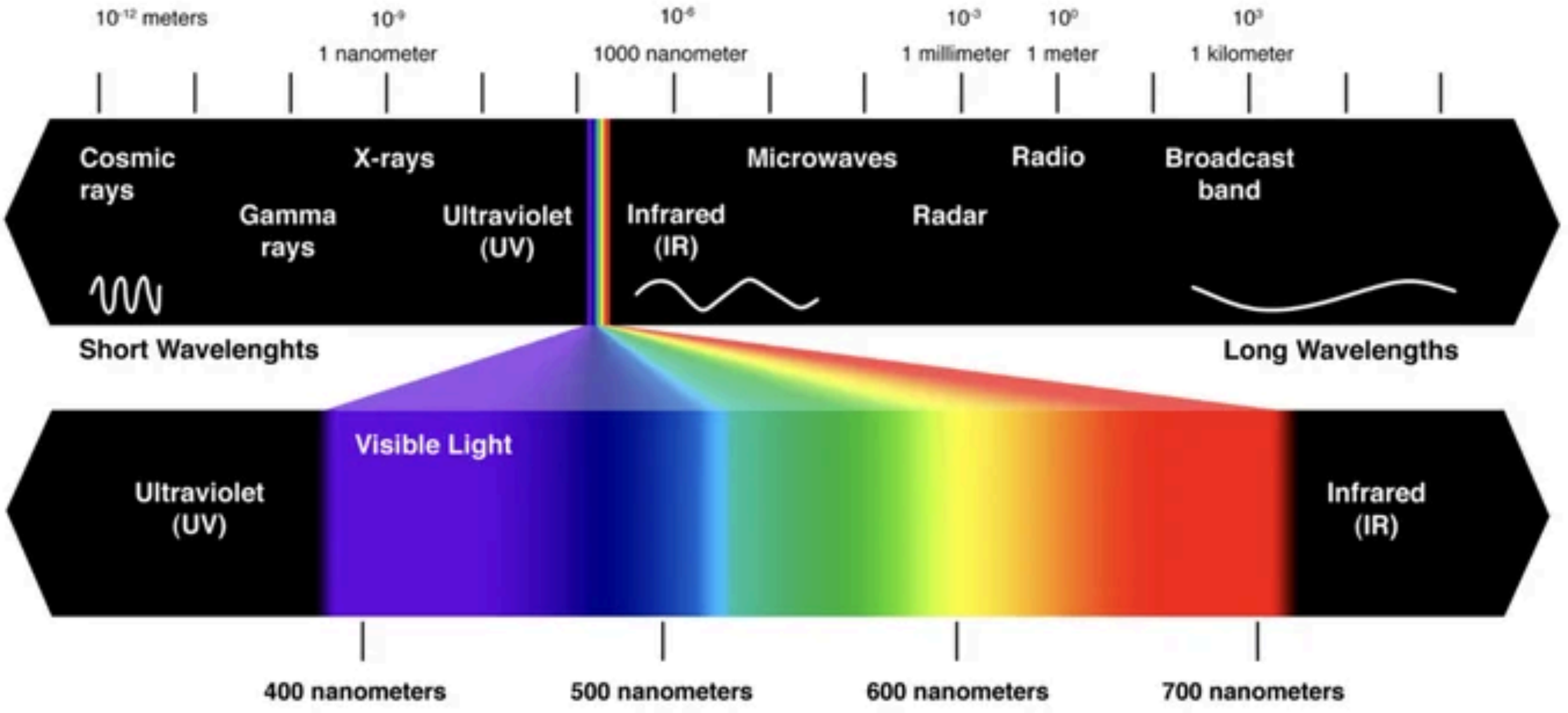


~5-6 million cones

Less sensitive to light

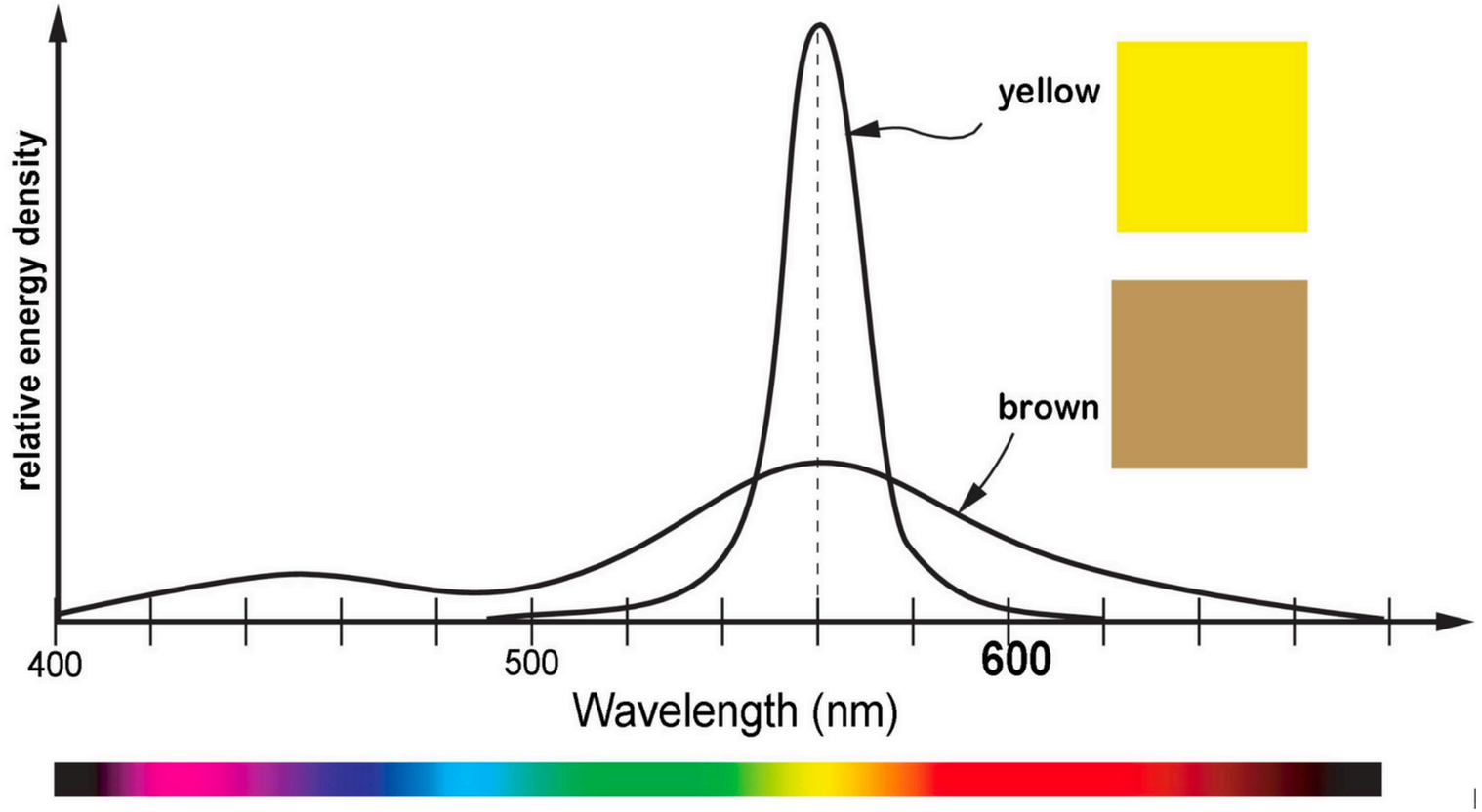
Responsible for color vision

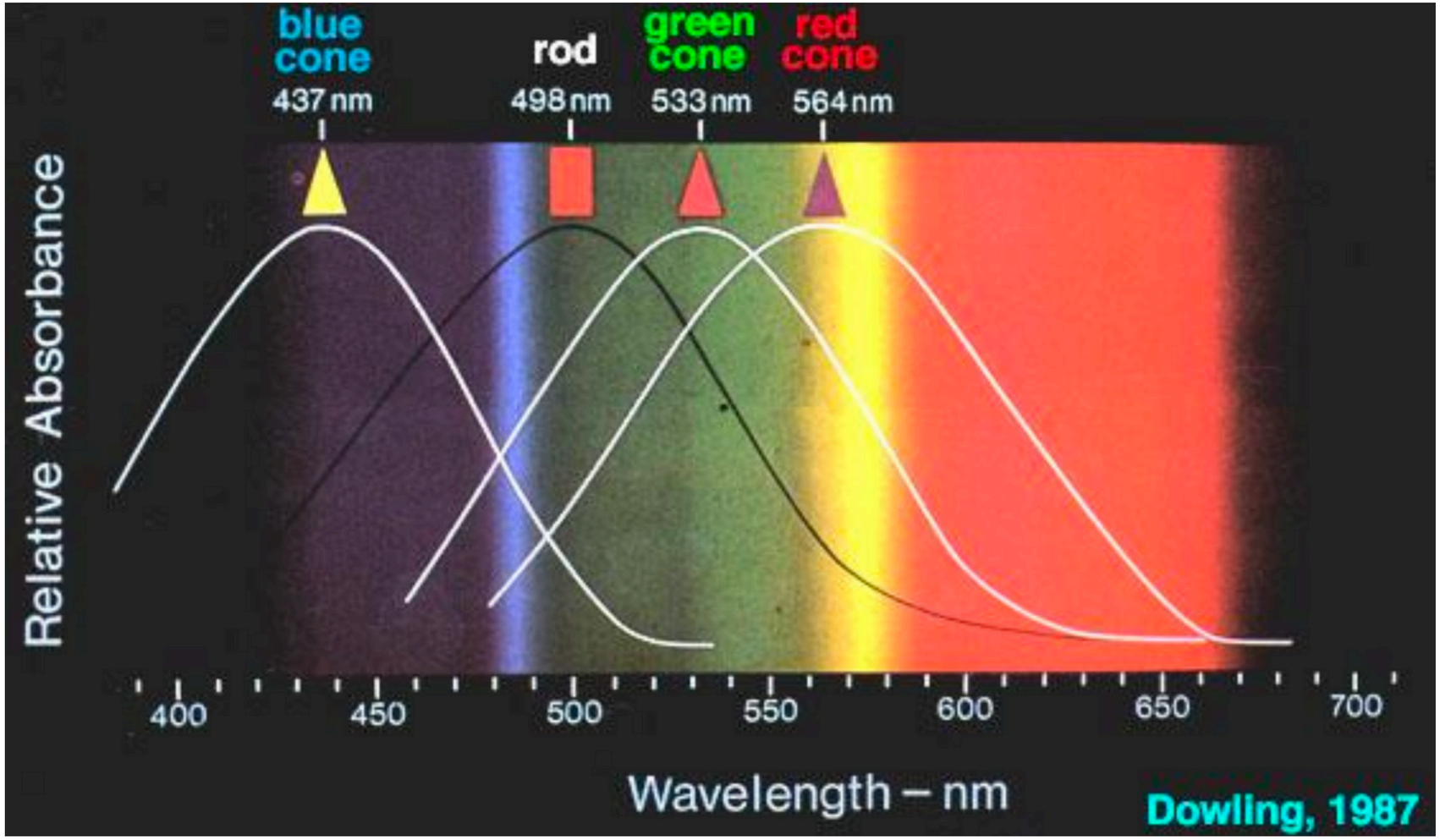
Source: Foundations of Neuroscience (Casey Henley)


10^{-12} meters
10^{-9}
1 nanometer
10^{-6}
1000 nanometer
10^{-3}
1 millimeter
10^{0}
1 meter
10^{3}
1 kilometer
Cosmic rays
Gamma rays
X-rays
Ultraviolet (UV)
Infrared (IR)
Microwaves
Radar
Radio
Broadcast band
Short Wavelenghts
Long Wavelengths
Ultraviolet (UV)
Visible Light
Infrared (IR)
400 nanometers
500 nanometers
600 nanometers
700 nanometers

Color Perception is more than just Wavelength

It’s a combination of wavelength and energy density




blue cone
437 nm
rod
498 nm
green cone
533 nm
red cone
564 nm
Relative Absorbance
400
450
500
550
600
650
700
Wavelength – nm
Dowling, 1987

MAY 21, 2012

Rippin' the Rainbow a New One

Play | Transcript

Image credits: jared

We tear into this show with a dark scene from 1665. A young Isaac Newton, hoping to ride out the plague by heading to the country to puzzle over the deep mysteries of the universe, finds himself wondering about light. And vision. He wants to get to the bottom of where color comes from--is it a physical property in the outside world, or something created back inside your eyeball somewhere? **James Gleick** explains how Newton unlocked the mystery of the rainbow. And, as **Victoria Finlay** tells us, sucked the poetry out of the heavens.

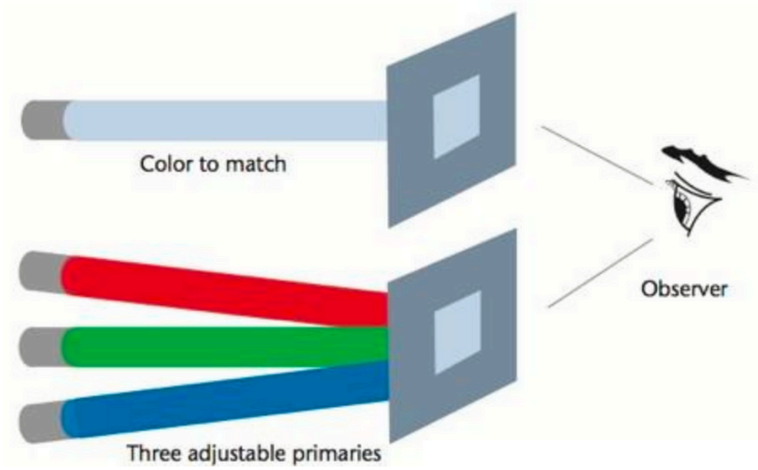
How do we abstract/represent color?

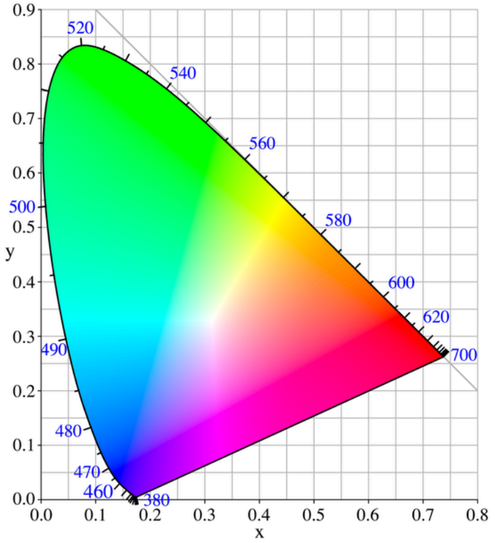
Human Color Perception Space

International Commission on Illumination (CIE)
Commission International de L'éclairage

In the 1920s and 1930s, CIE:

- conducted experiments to understand color perception
- found that humans can mimic any pure (visible) light by addition and subtraction of three primary lights





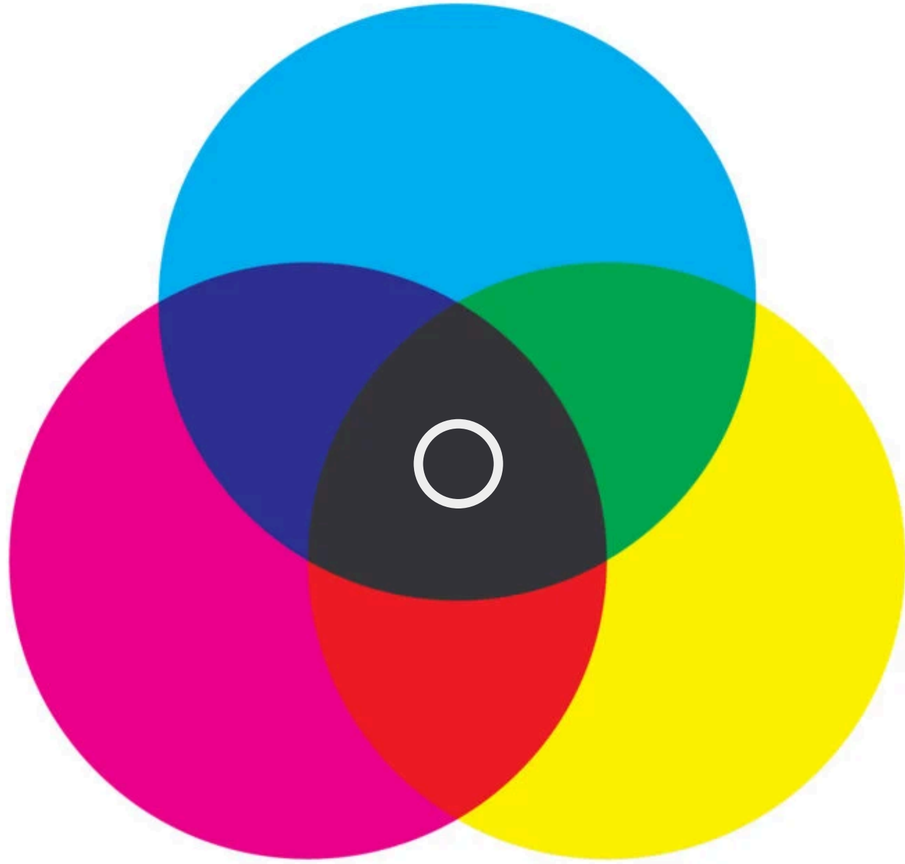
Subtractive Color

Used by color printers

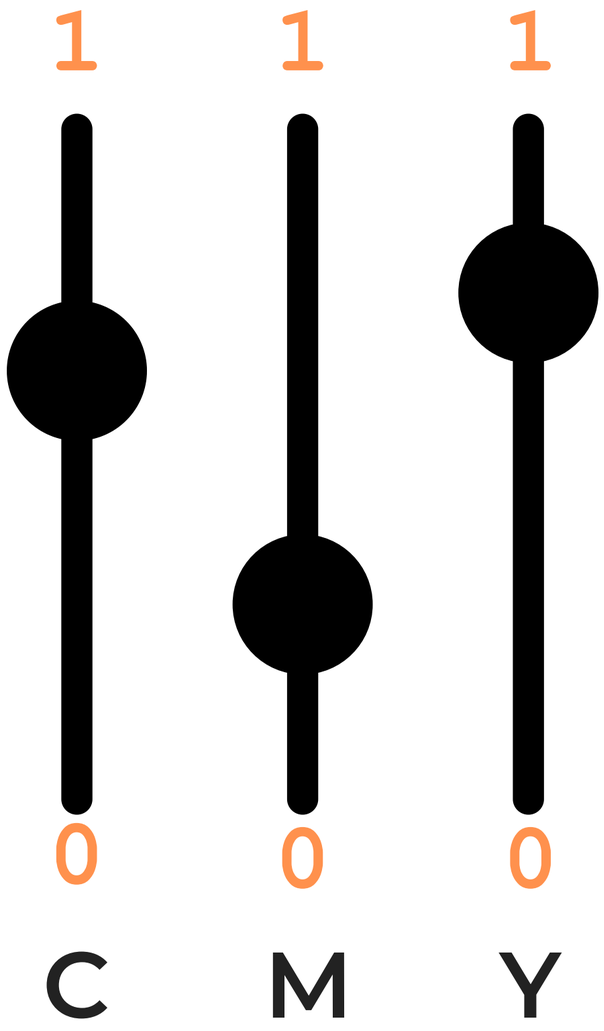
Primary Additive Colors: CMY

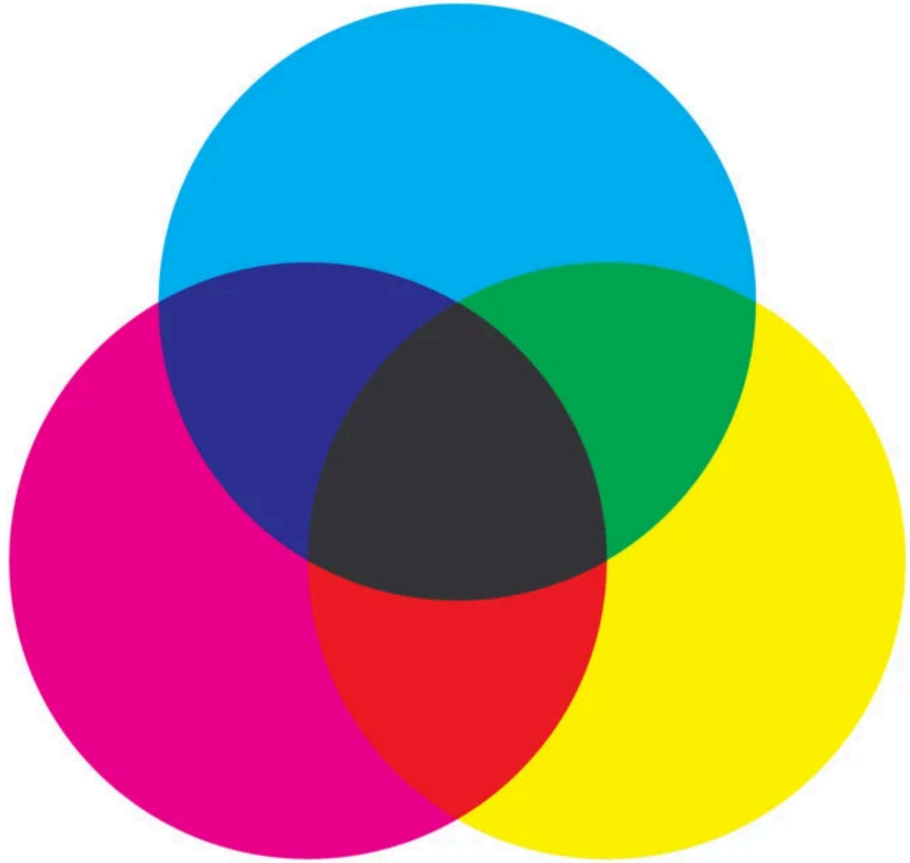
Secondary Additive Colors: RGB

C+M+Y approximates black, but printers will often use CMYK, where K is true black pigment



Subtractive Color



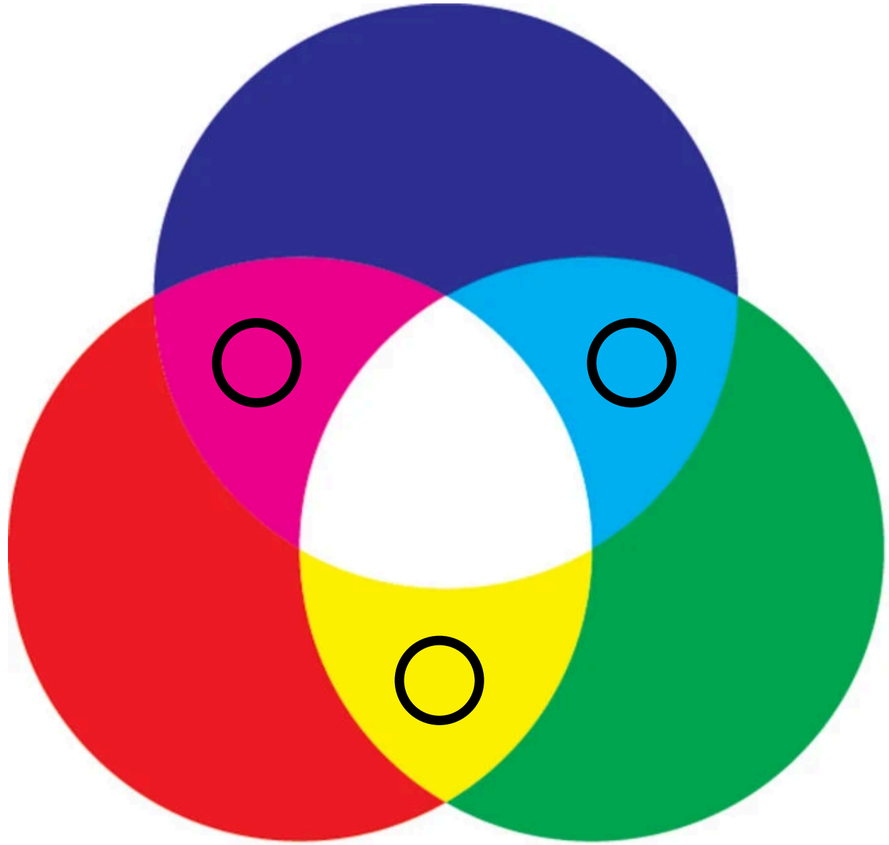


Additive Color

How we see color from light

Primary Additive Colors: RGB

Secondary Additive Colors: CMY

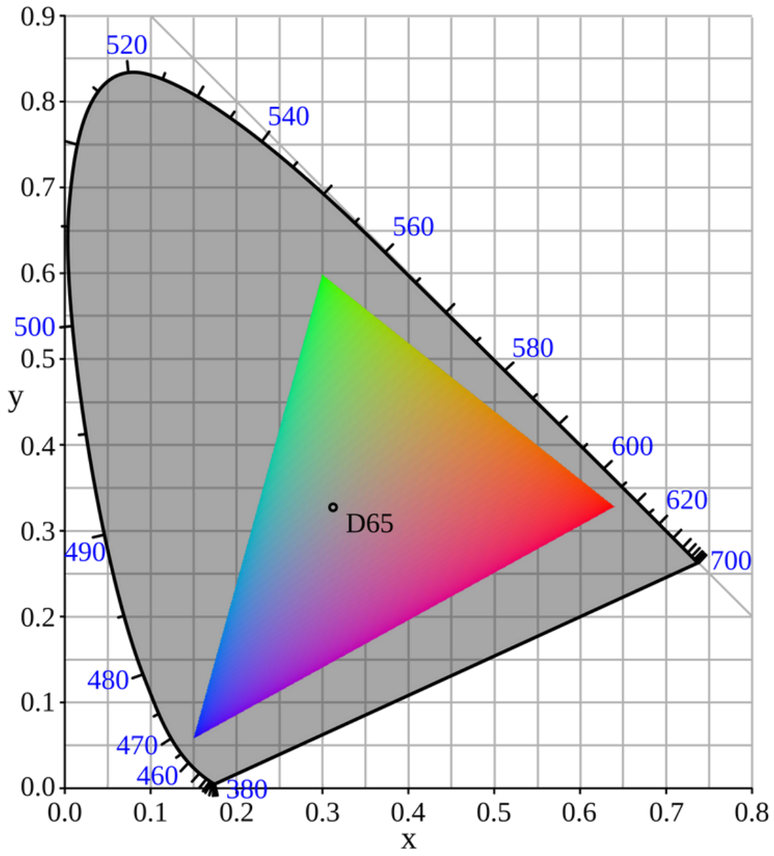


Additive Color: RGB Color Space

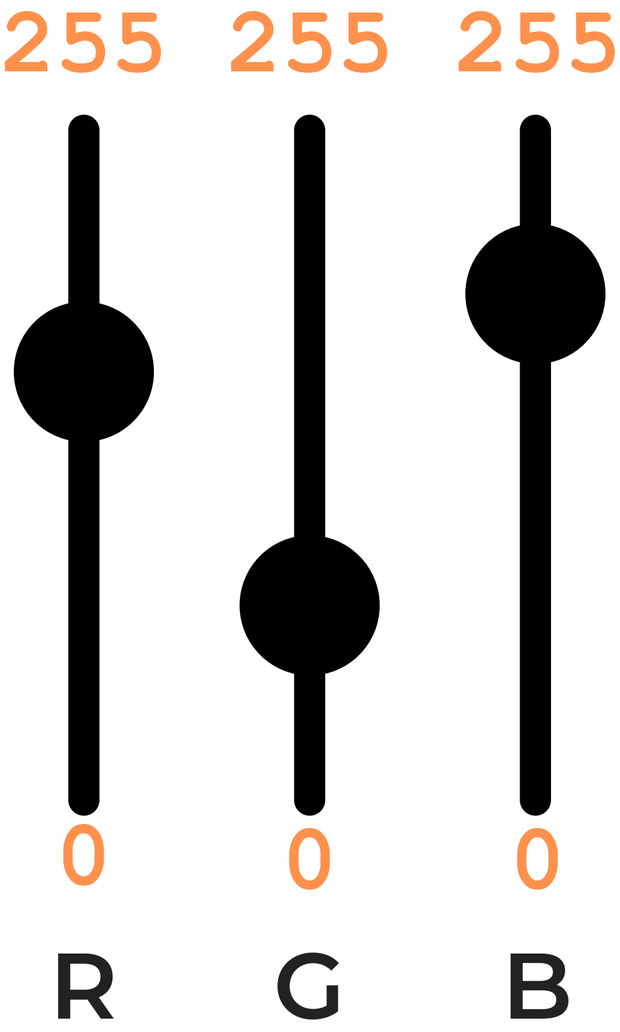
Commonly used color space for monitors

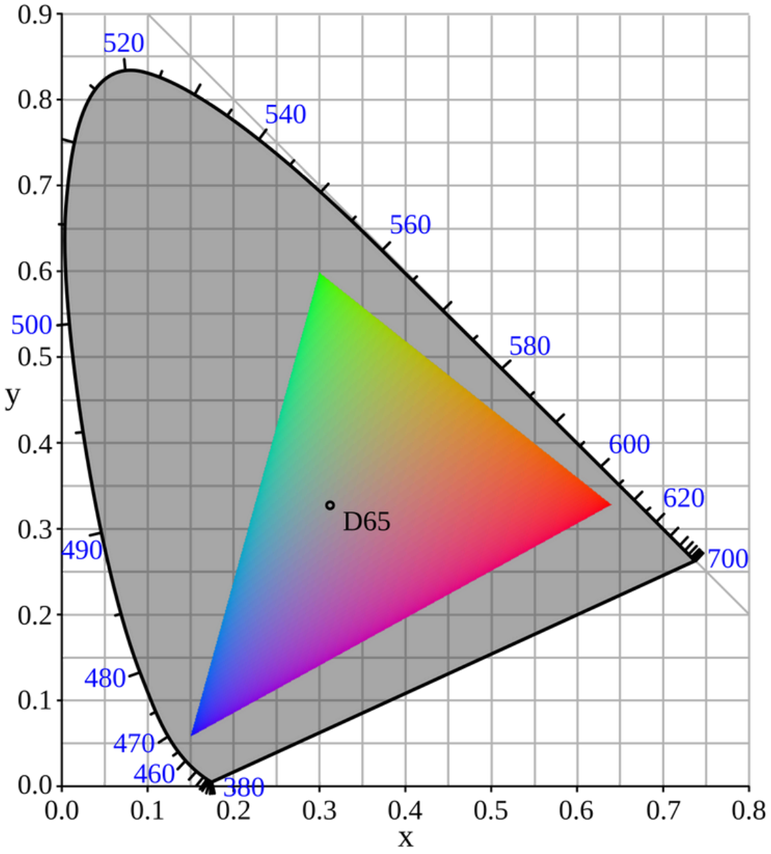
Not perceptually uniform

Actual color is device-dependent



Additive Color: RGB Color Space





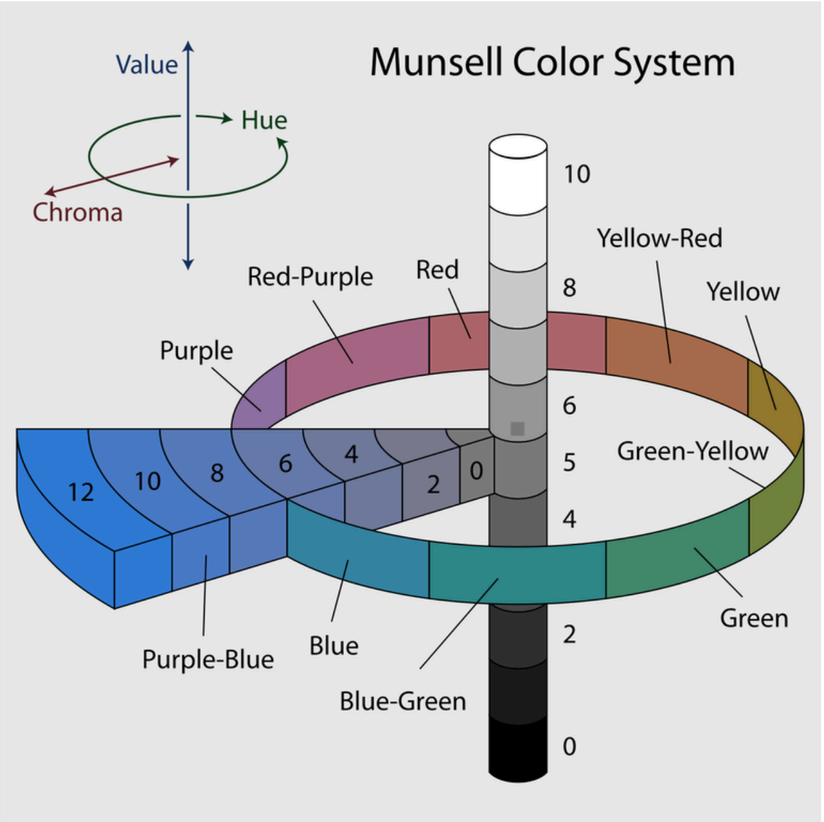
Additive Color: HS[V,B,L,I] Color Space

Hue, Saturation, (Value or Brightness or Luminance or Intensity)

Polar coordinate representation of RGB

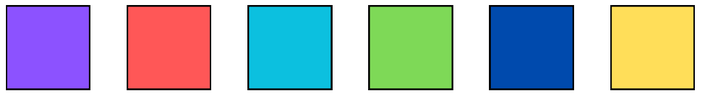
More intuitive than RGB for color tuning

Also not perceptually uniform

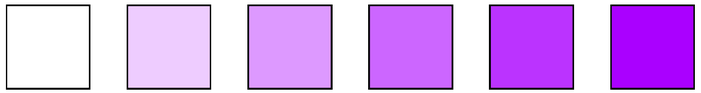


Additive Color: HS[V,B,L,I] Color Space

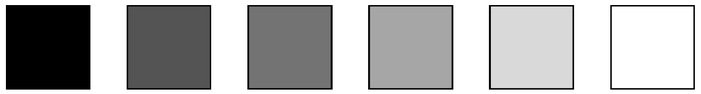
Hue: What you might think of when you hear “color”

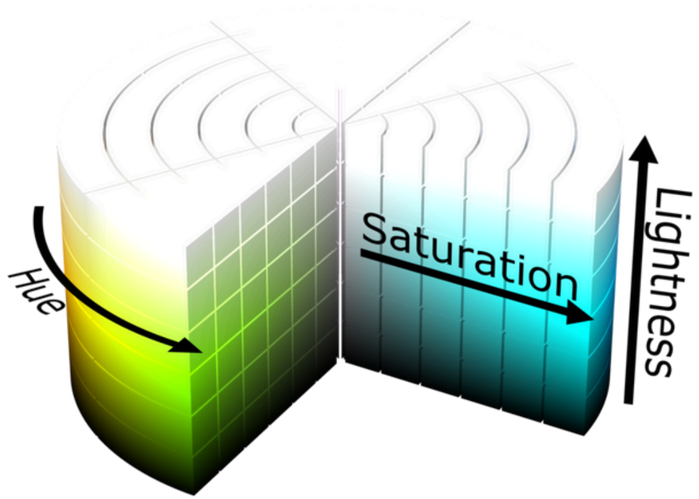


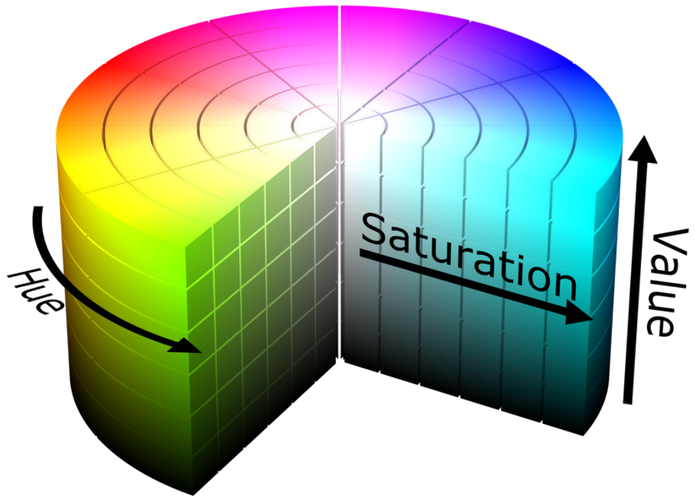
Saturation (or Chroma): Purity of the color compared to white



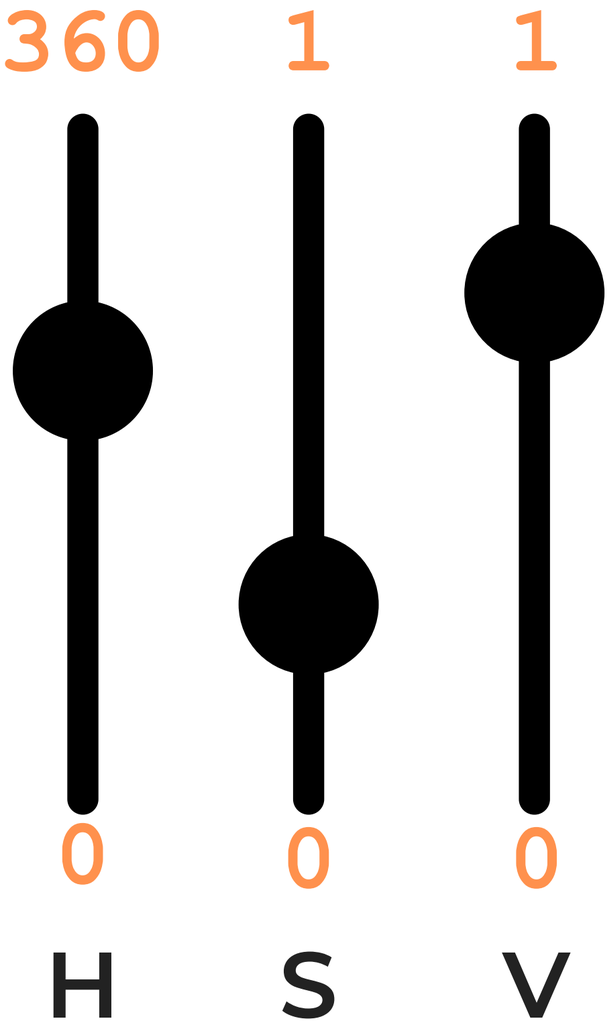
Luminance (or Value): Lightness (or darkness) of the color

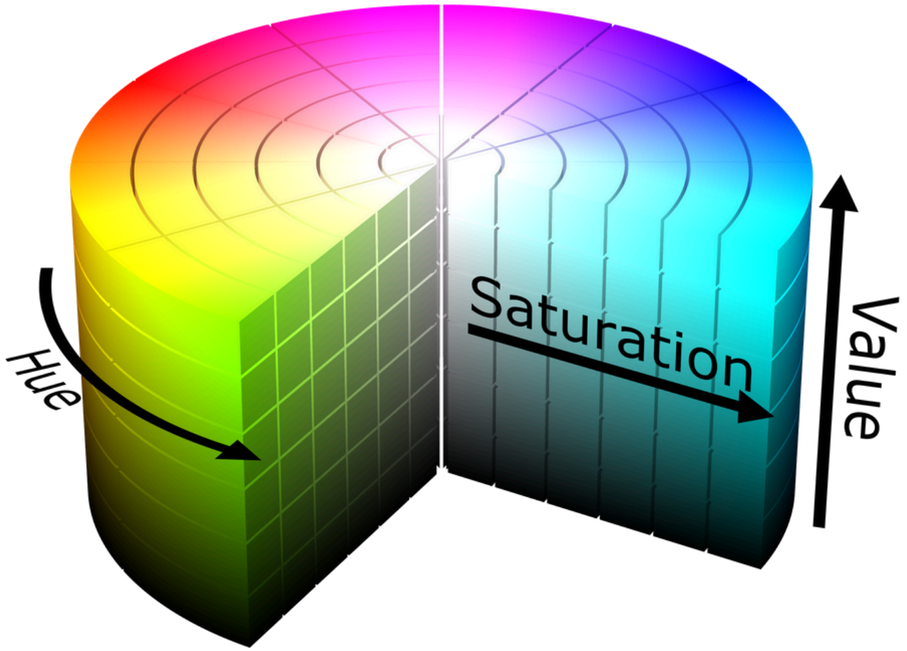




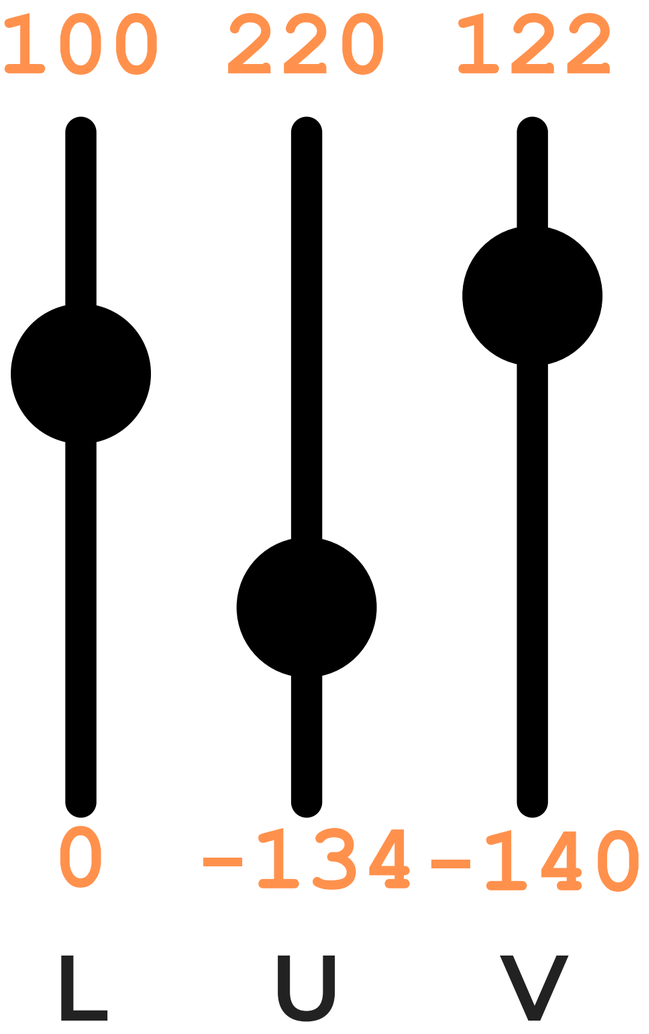


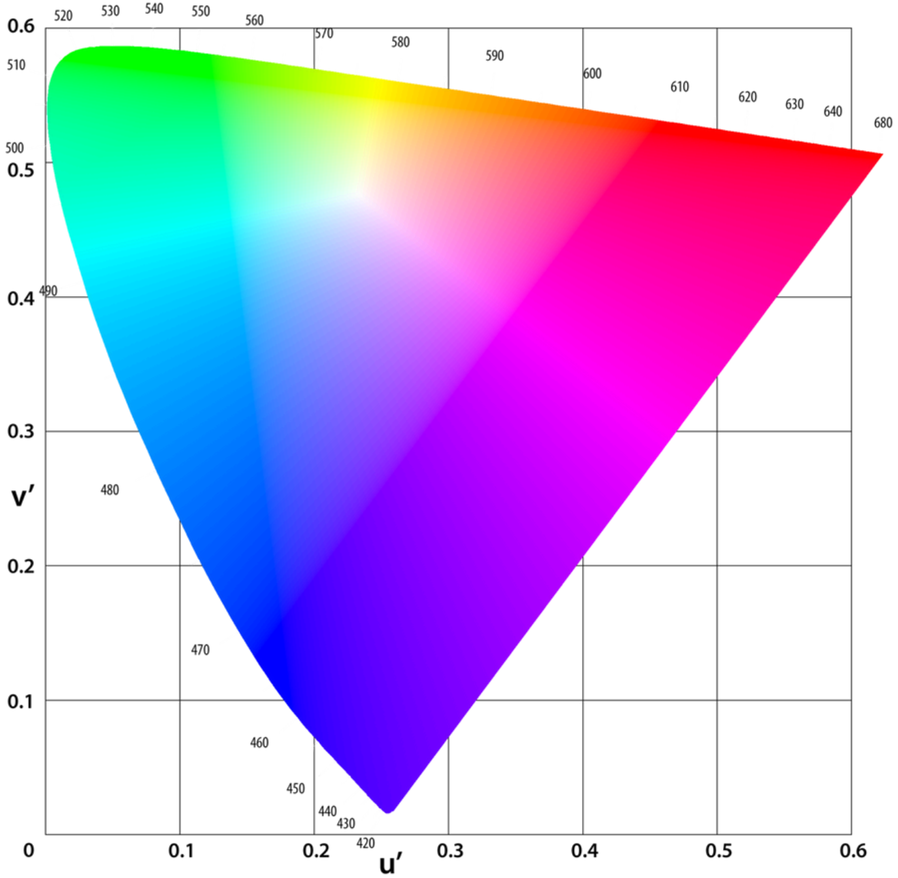
Additive Color: HS[V,B,L,I] Color Space





CIE LUV Color Space

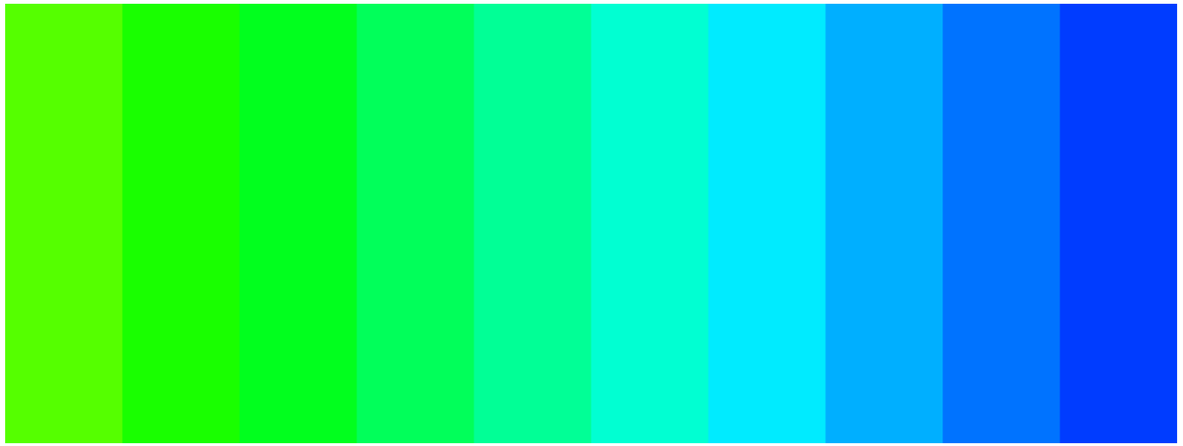




Perceptual Uniformity

HSV color space

Not perceptually uniform



CIELUV color space

Perceptually uniform

Color Blindness

Color Blindness

Deficiency in color vision, typically caused by faulty cone development

Often hereditary, caused by mutations on the OPN1LW, OPN1MW, and OPN1SW genes

These genes provide instructions for making the photopigment called “opsin”

Monochromacy

1-dimensional color vision (total colorblindness)

2 or 3 cone pigments are missing

Two types:

- Rod monochromacy (achromatopsia)
  - All cones are missing or non-functional
- Blue-cone (S-cone) monochromacy
  - Only the blue cones (S-cones) are functional

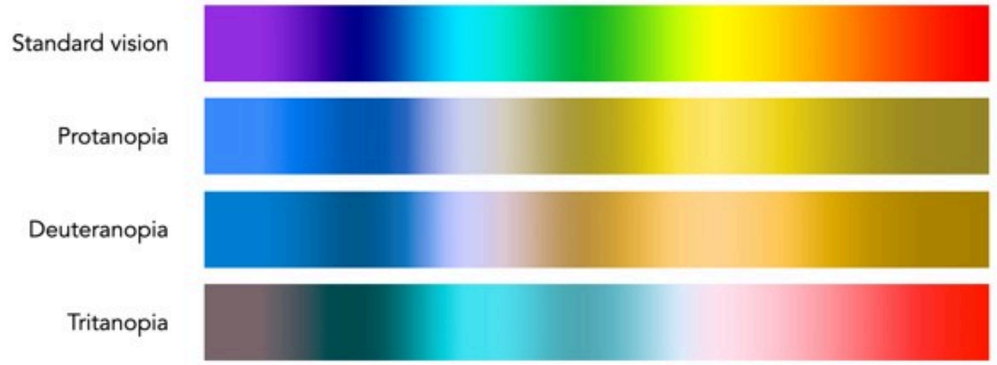
Dichromacy

2-dimensional color vision

1 cone pigment is missing

Three types:

- Protanopia: Absence of Red receptors
- Deuteranopia: Absence of Green receptors
- Tritanopia: Absence of Blue receptors



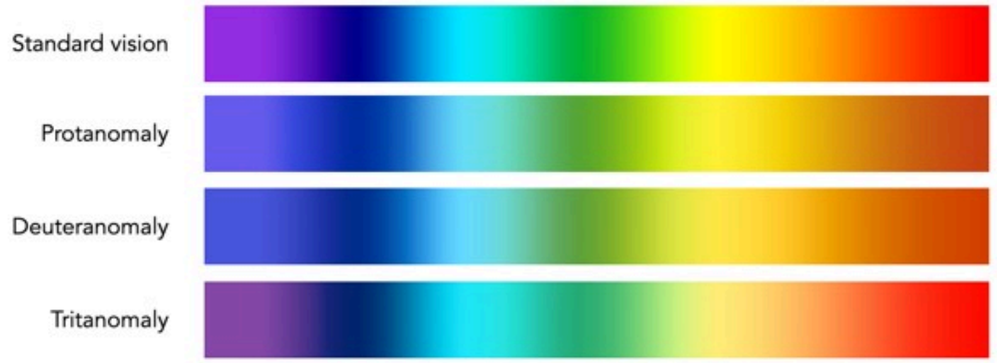
Trichomacy

3-dimensional (typical) color vision

Sometimes, one cone may be altered, causing a slight impairment rather than a loss of color vision

Three types:

- Protanomaly: shift in red receptors
- Deuteranomaly: shift in green receptors (most common)
- Tritanomaly: shift in blue receptors



Colorblind Web Page Filter

What are color blind anomalies?

Please indicate a resource to be viewed, and a color filter to be applied to that resource.

Type a URL:
https://www.toptal.com/designers/colorfilter/exar

Protanopia
red/green color blindness; anomalous red cones

Deuteranopia
red/green color blindness; anomalous green cones

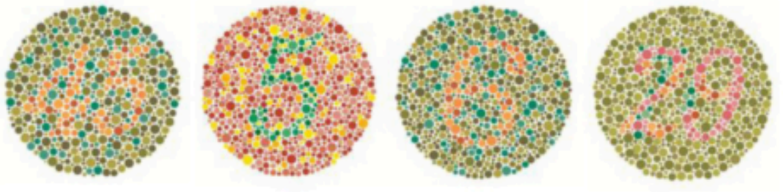
Tritanopia
blue/yellow color blindness; anomalous blue cones

Greyscale/achromatopsia
quick check for all forms of colorblindness

FETCH AND FILTER!

Example page

Type your own URL at the top form to see it color-blind-filtered (at the right side).

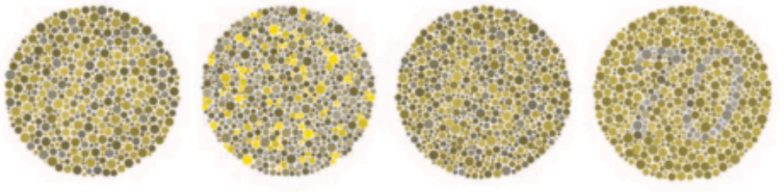


This visual perception test is known as an Ishihara test and has been used since 1917. You can read more at Wikipedia.

Set of colors unambiguous to color vision deficients and to normal sighted persons

Original color	Seen by a... Protan	Deutan	Tritan	HUE	COLOR CODE
				Black, 0°	#000000; RVB 0,0,0 CMJN % 0,0,0,100.
				Orange, 41°	#E69F00; RVB 230,159,0 CMJN % 15,41,93,1.

Type your own URL at the top form to see it color-blind-filtered (at the right side).



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Even if you aren’t colorblind, someone viewing your visualizations may be

Design with colorblindness in mind by varying hue, saturation, and luminance, using monochrome color schemes, and adding visual cues that don’t just rely on color

A Note on Accessible Visualization Design

Color Blindness is NOT the only disability

Data visualization research has historically prioritized designing for color blindness

Approximately 8.4% of white men have some form of color-blindness, compared to significantly lower percentages among various non-white-men (Garth 1933 ***)

Hence, the research has historically prioritized designing for white men

Other disabilities to consider when designing

Low Vision:

- Use high contrast text and marks
- Add options for magnification/zoom
- Use annotations and guides

Functional/Motor Impairment:

- Consider UI alternatives to interactions
- Try Scrollytelling
- Provide keyboard-based interactions

Other disabilities to consider when designing

Cognitive Disabilities:

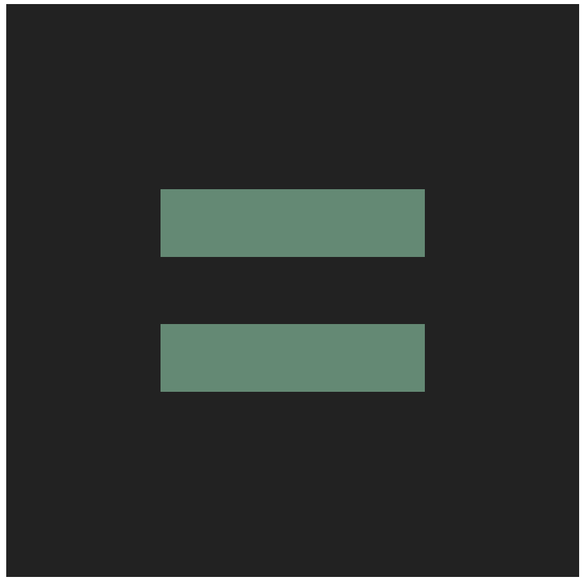
- Use captions, summaries, clear titles, & plaintext alternatives
- Reduce visual complexity
- Use assistive design (how-to-read guides, help)

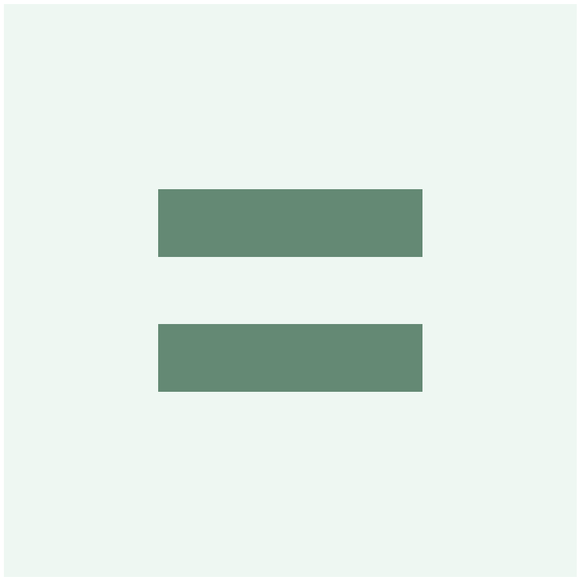
Attentive Deficit-Hyperactive Disorder (ADHD):

- Use clear and concise text summaries
- Consider motion design and animation
- Add interaction history

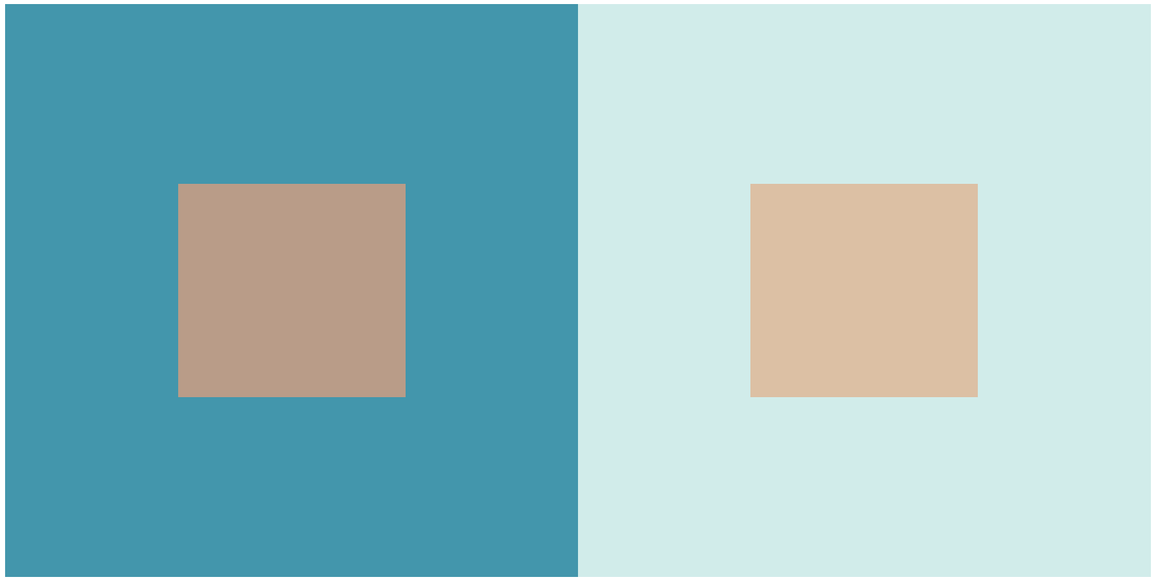
Other Important Features of Color Perception

Color Relativity





Color Relativity



Color Relativity

We have a strong propensity to assume our judgments of color are absolute, when they are actually relative to a specific context

Use color sparingly to avoid weird relative visual effects

Luminance Contrast

Luminance Contrast

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast

Showing small yellow text on a white background is a bad idea.
There is insufficient luminance contrast

Interactions between Color and Size

“the smaller the mark, the less distinguishable the color”

-Jacques Bertin

General Guidelines for Color Usage

Color is a relative medium - Use a solid, neutral background

Text-background luminance ratio - 3:1 minimum (10:1 ideal)

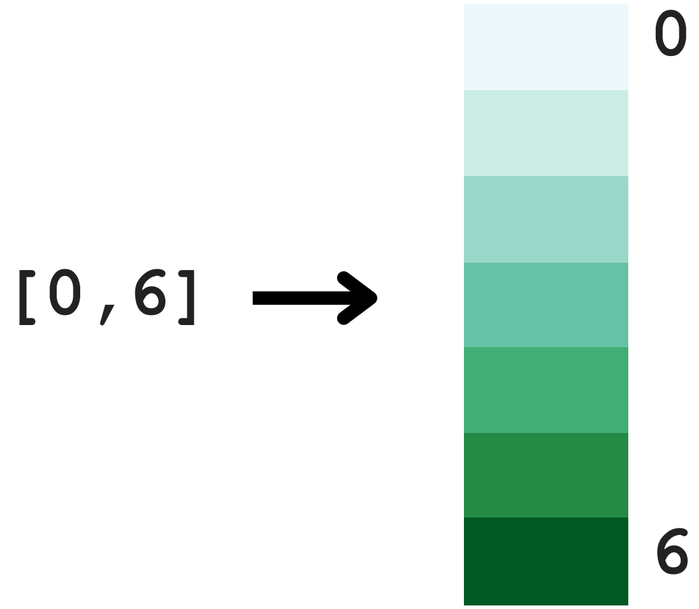
In small regions, use bright, highly-saturated colors

Low saturation, pastel colors can be used in large regions and backgrounds

Colormaps

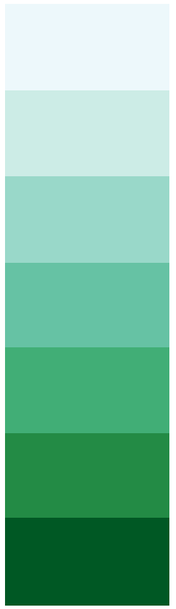
What Is a Colormap?

Specifies a mapping between colors and numerical values (sometimes called a transfer function)



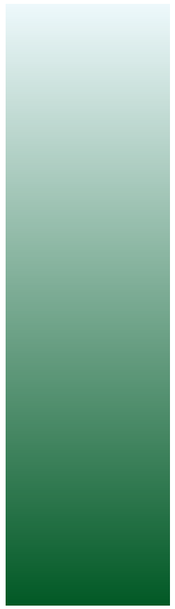
Types of Colormaps

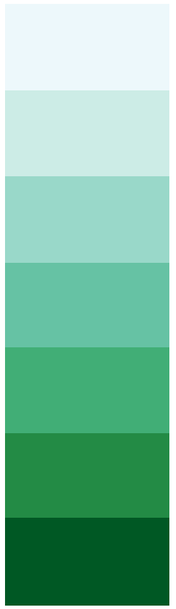
Categorical vs. Ordered



Types of Colormaps

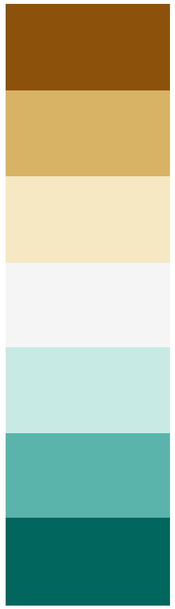
Continuous vs. Segmented

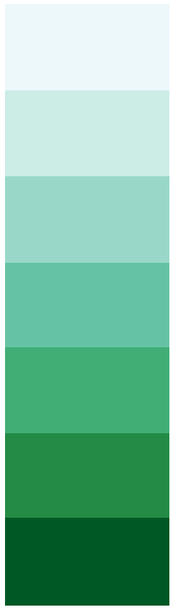




Types of Colormaps

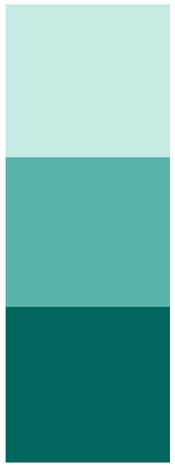
Diverging vs. Sequential

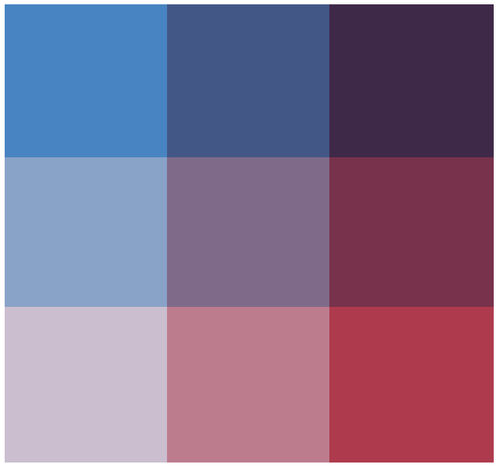




Types of Colormaps

Univariate vs. Bivariate

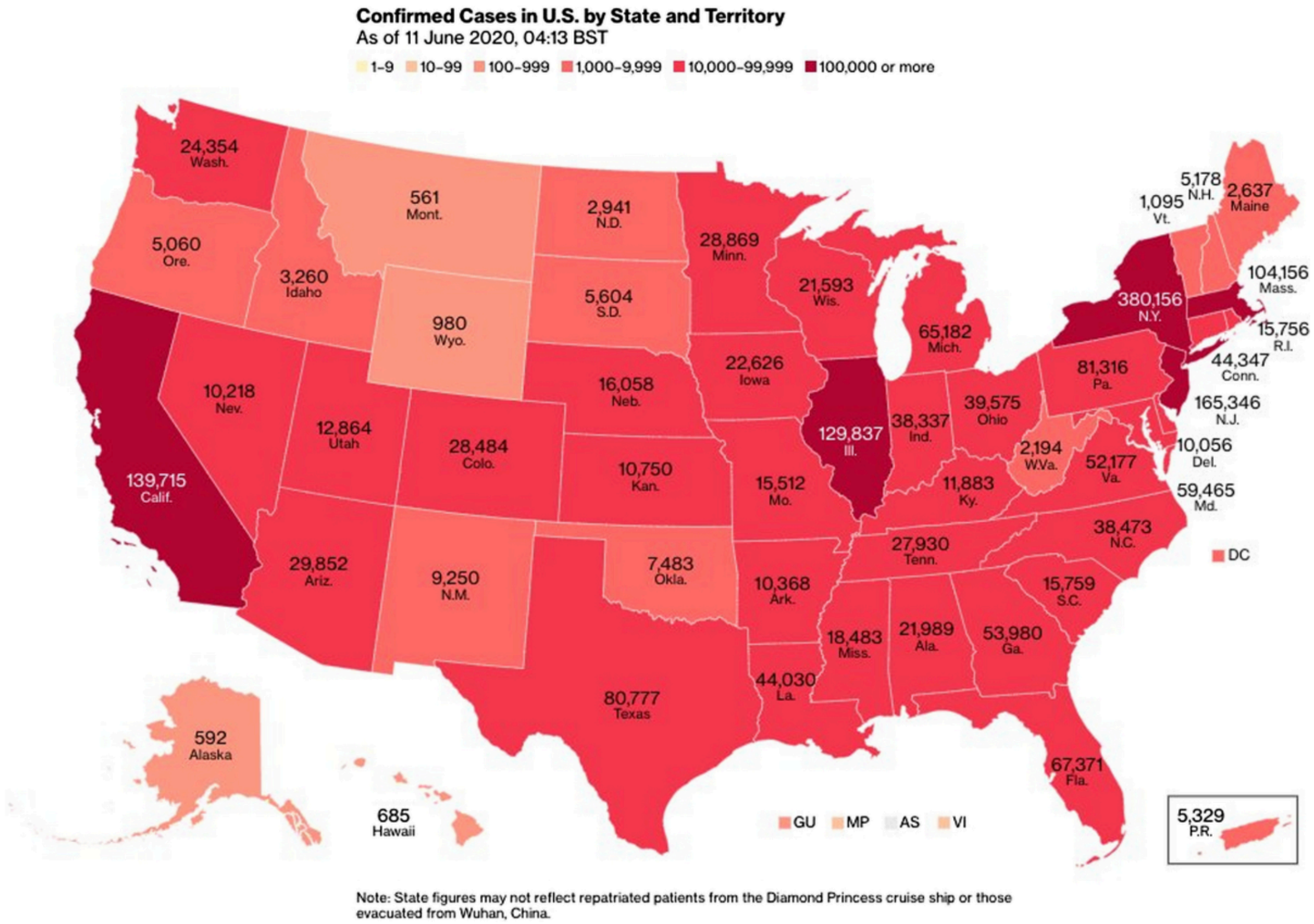




Bivariate colormaps can be difficult to interpret

Colormaps are Expressive

Match your colormap to attribute type characteristics



Note: State figures may not reflect repatriated patients from the Diamond Princess cruise ship or those evacuated from Wuhan, China.

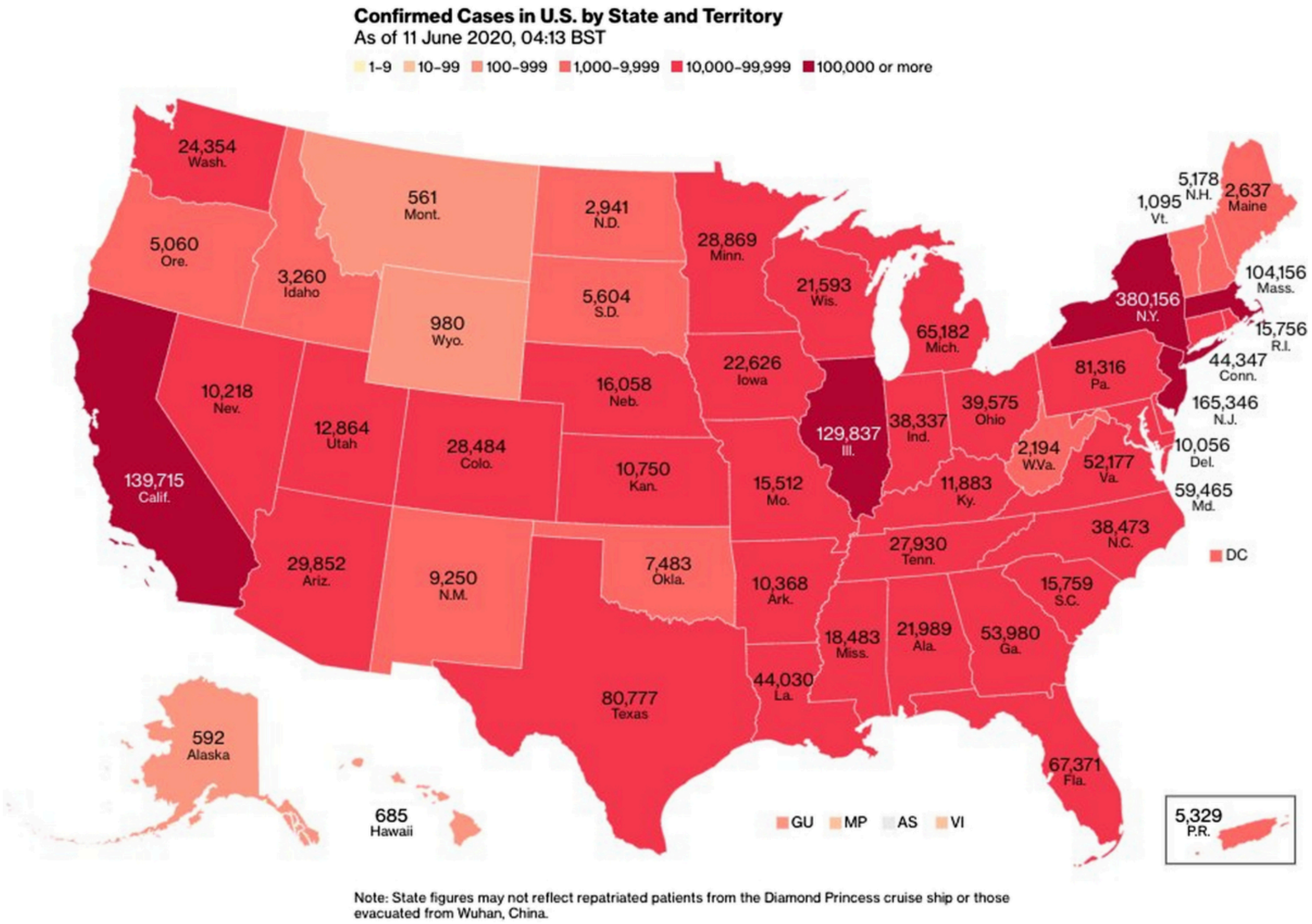
Hues for Categories

Let’s say you have a dataset with carbon dioxide measurements in four different biomes

Mountain Ocean Rainforest Desert

Be careful when you have more categories, we are only good at distinguishing about 6 to 12 colors simultaneously.

Ordinal Data - Use Saturation or Luminance



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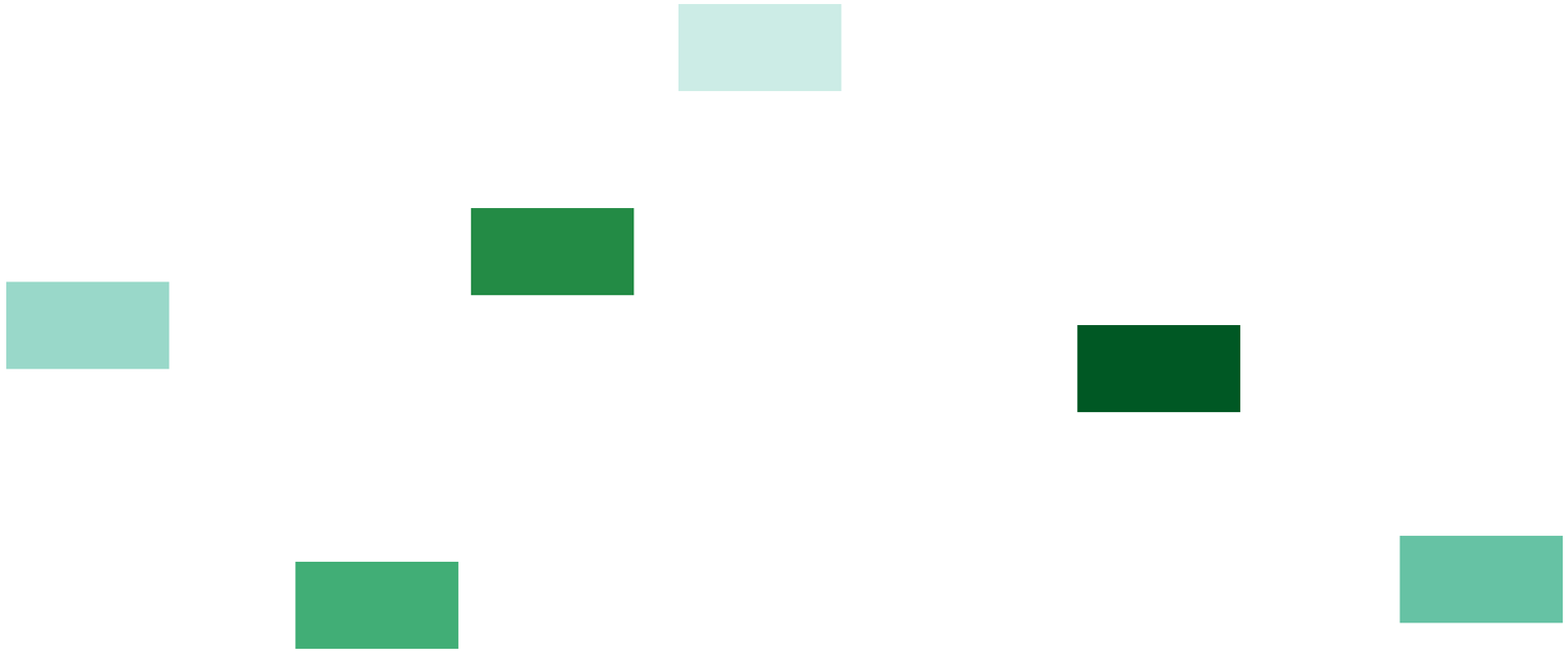
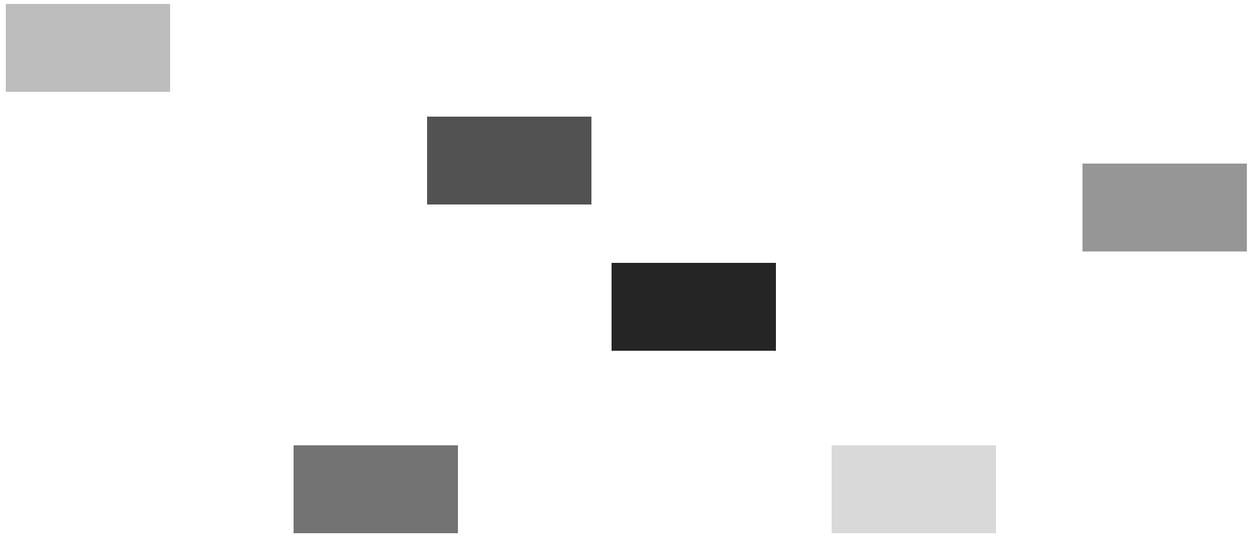
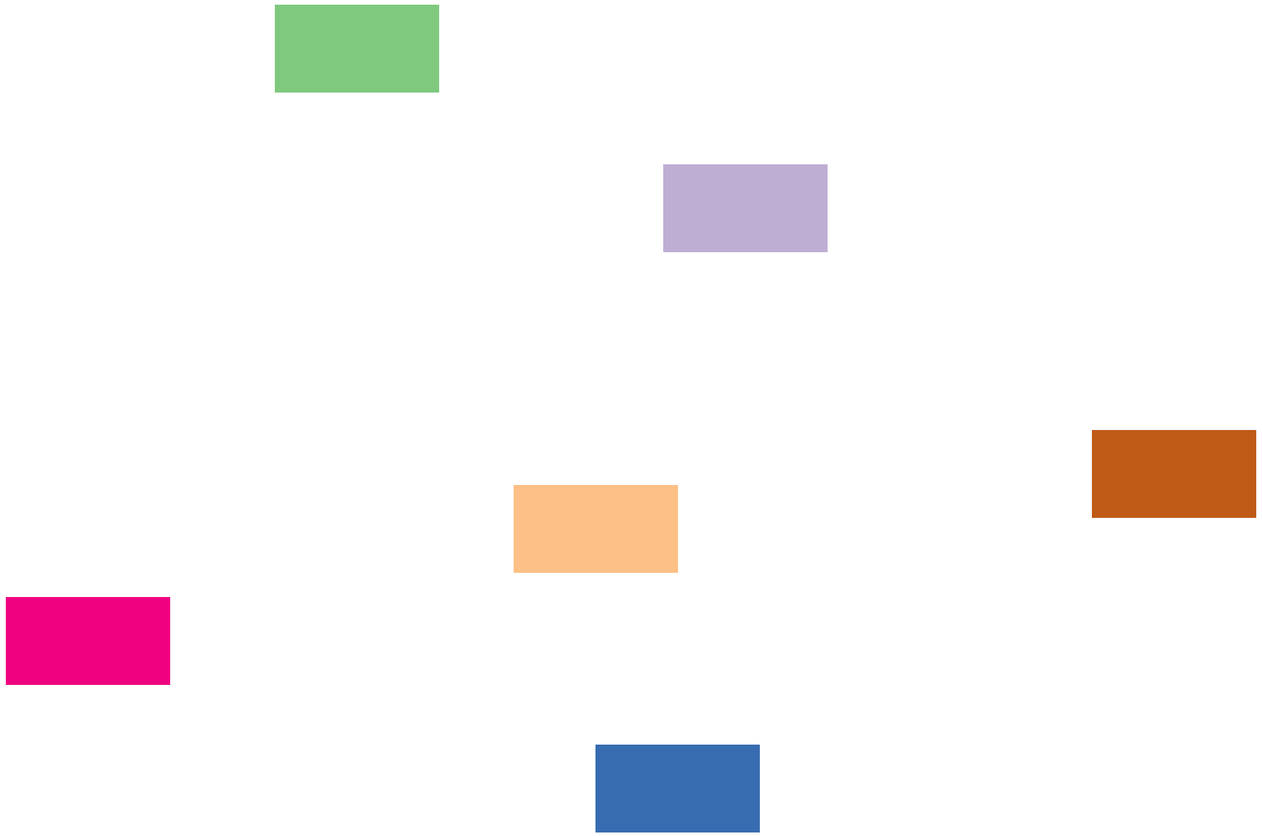
Ordinal Data - Use Saturation or Luminance



Saturation or Luminance for Ordered Data



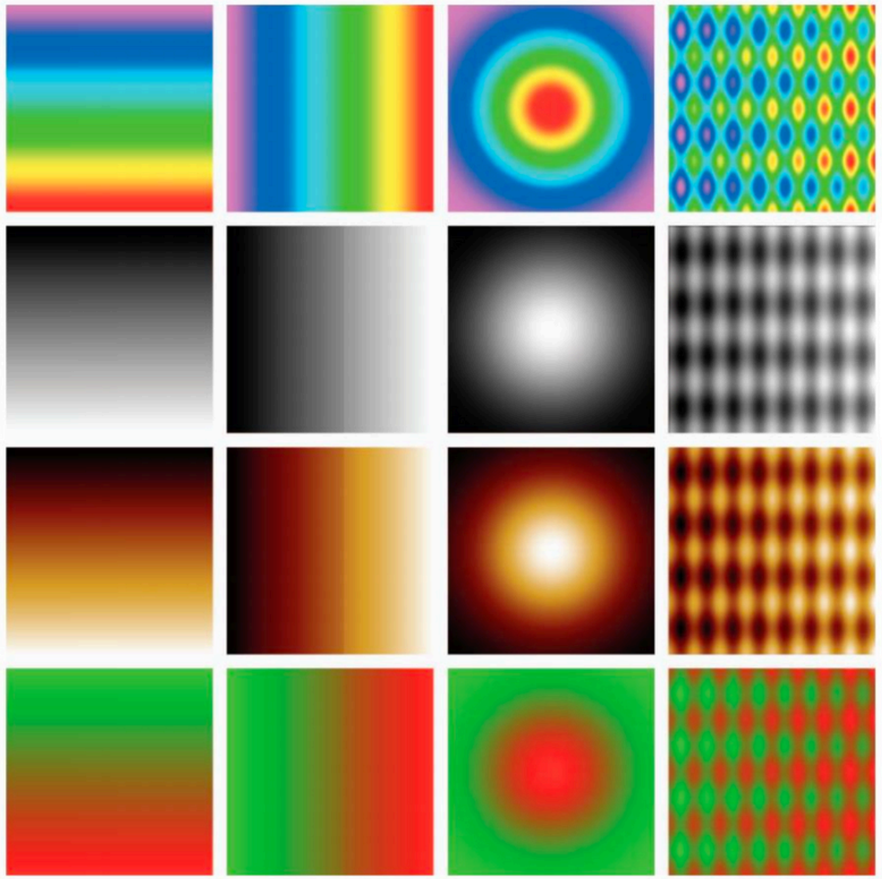
Ordinal Data - Use Saturation or Luminance



Rainbow Colormaps

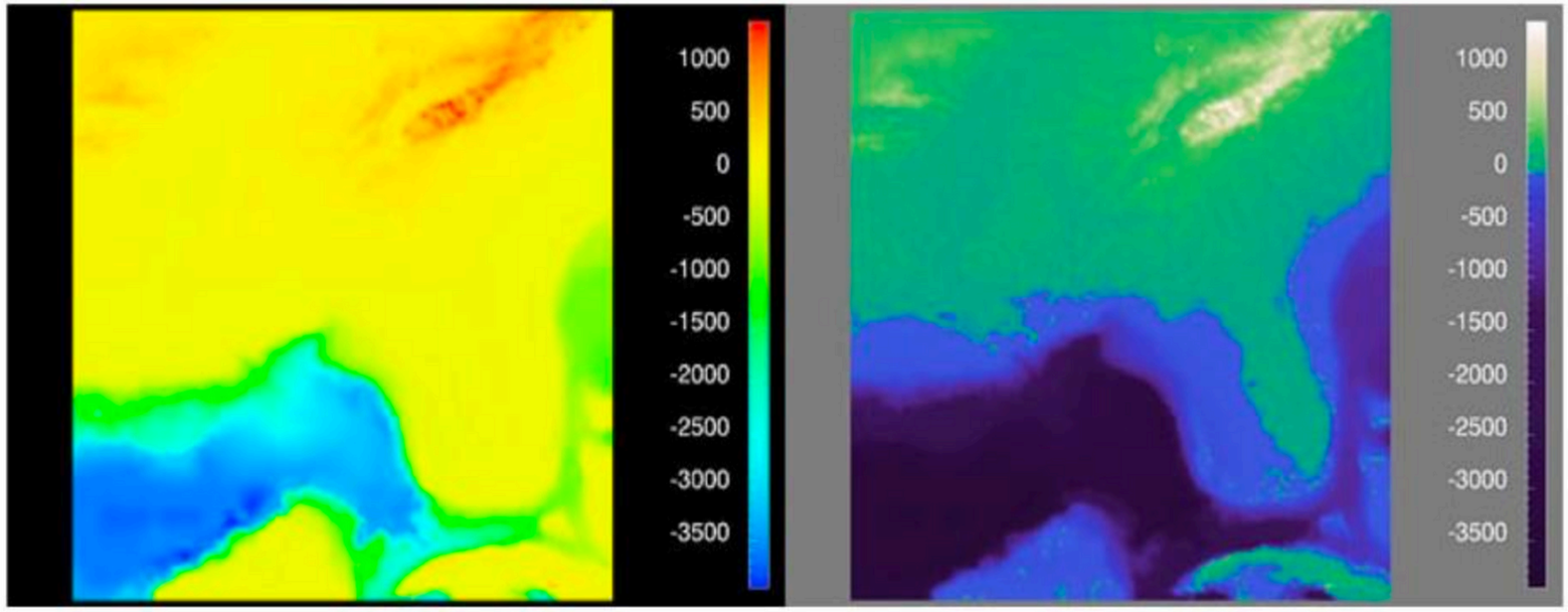
Rainbow Colormaps: Challenges

The luminance of rainbow colormaps is not uniform



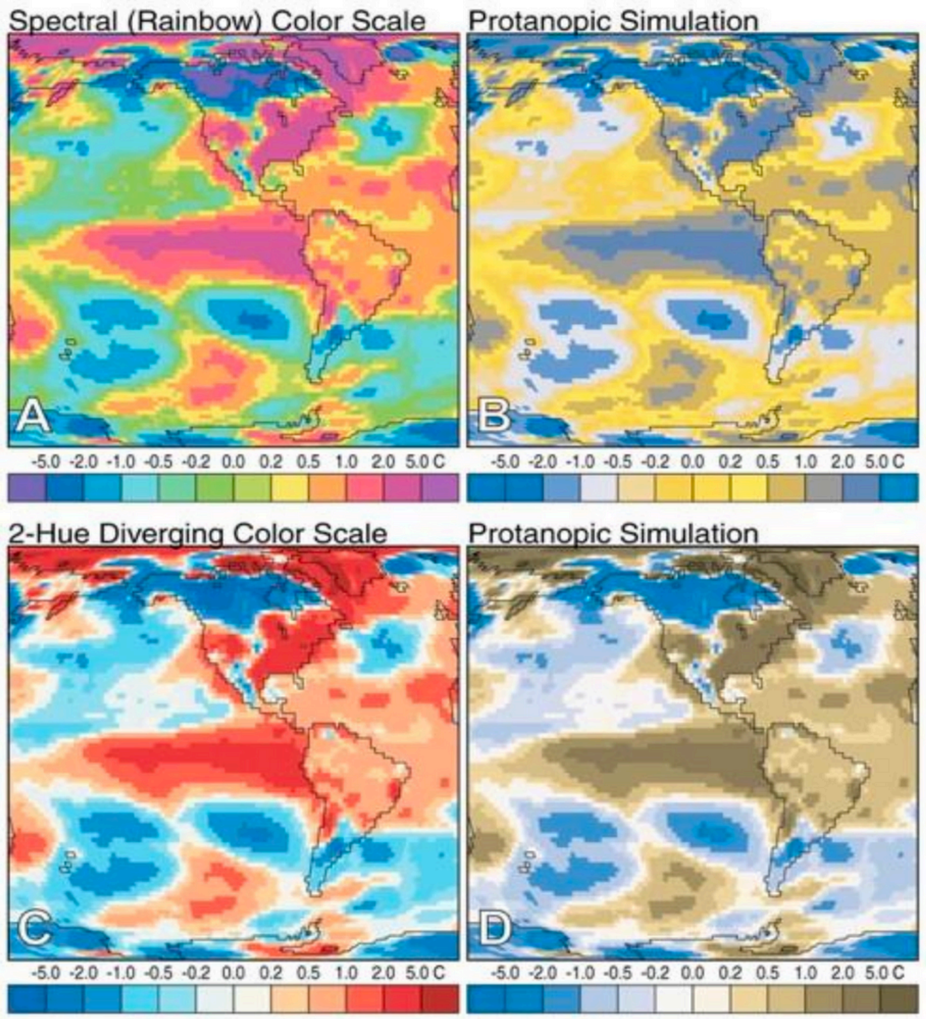
Rainbow Colormaps: Challenges

Since rainbow colormaps are continuous, visual borders can be difficult to distinguish



Rainbow Colormaps: Challenges

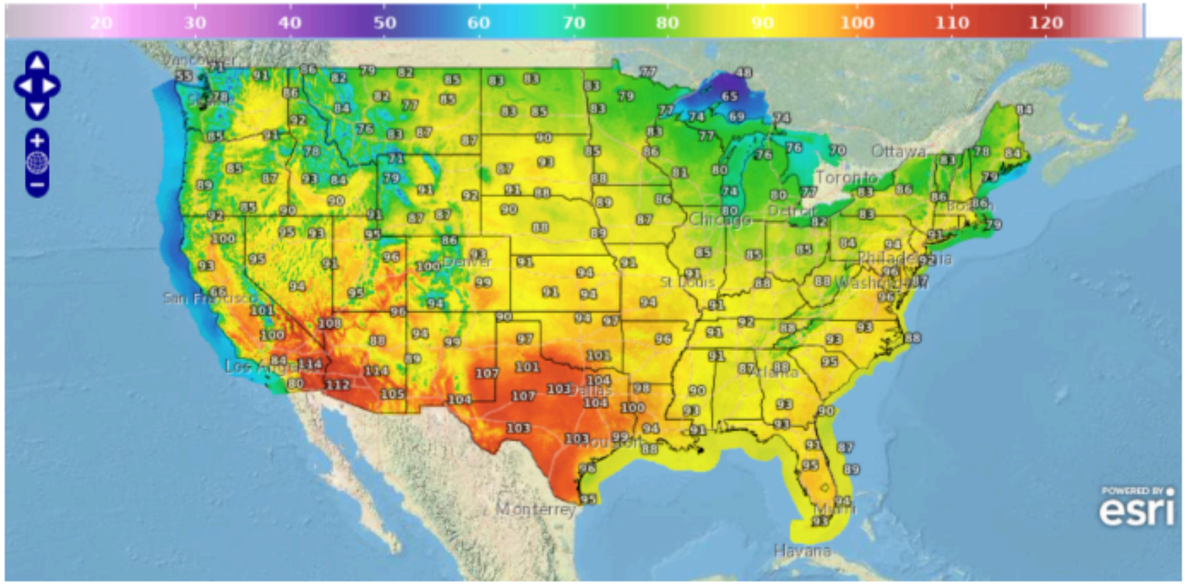
Rainbow colormaps are strongly affected by colorblindness since they use the entire color spectrum



Rainbow Colormaps Are Not All Bad (Paper)

Rainbow colormaps are among the most derided ideas in data visualization, second only to pie charts. And yet, people use them. Why? **A recent paper** looks at some of the reasons why they are so popular and points to research showing that they might not be so bad if used for the right tasks. There's even opportunity for interesting research in rainbow colormaps!

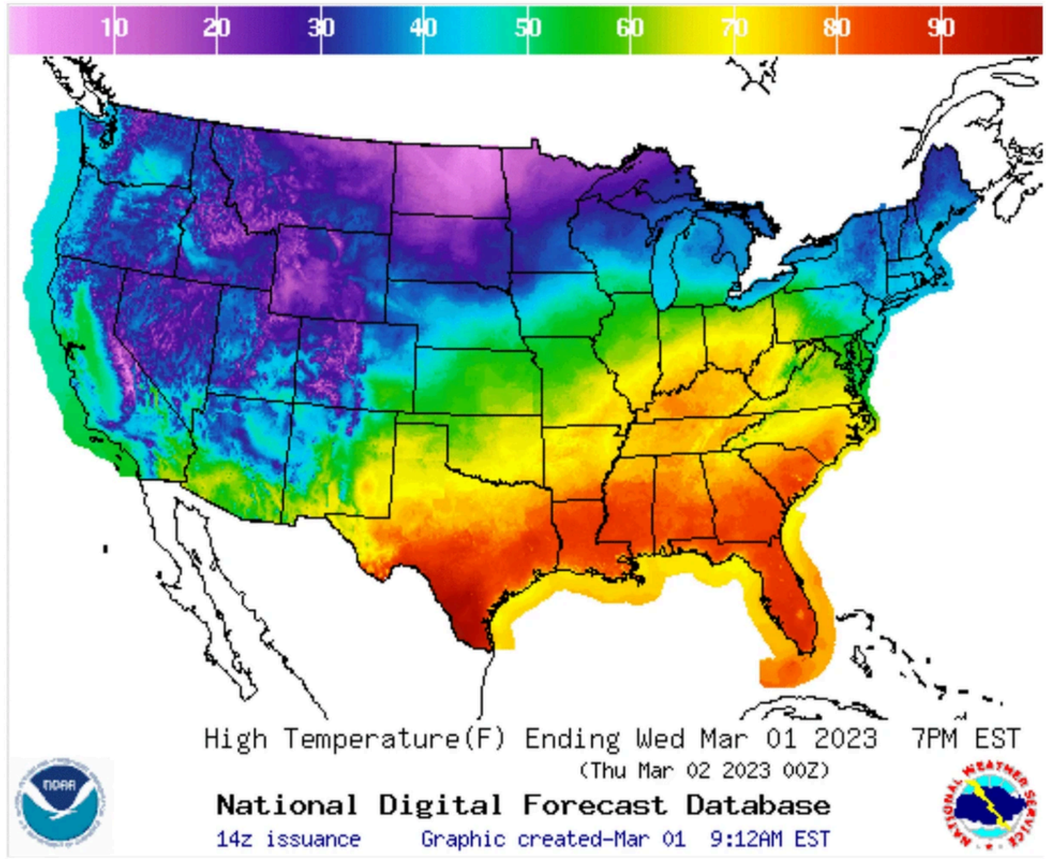
Finger-wagging about rainbow colormaps is a pretty common pastime in visualization, **I've done it too**! And it's not like there aren't good reasons. Look at this map of maximum temperatures in the US, **published by NOAA**, for example:



The rainbow colormap used here has all the usual problems: it's not uniform in its luminance (brightness), different colors cover different ranges of the colormap (though it's usually green that is the worst, here it's purple and red), and of course the ordering is somewhat arbitrary.

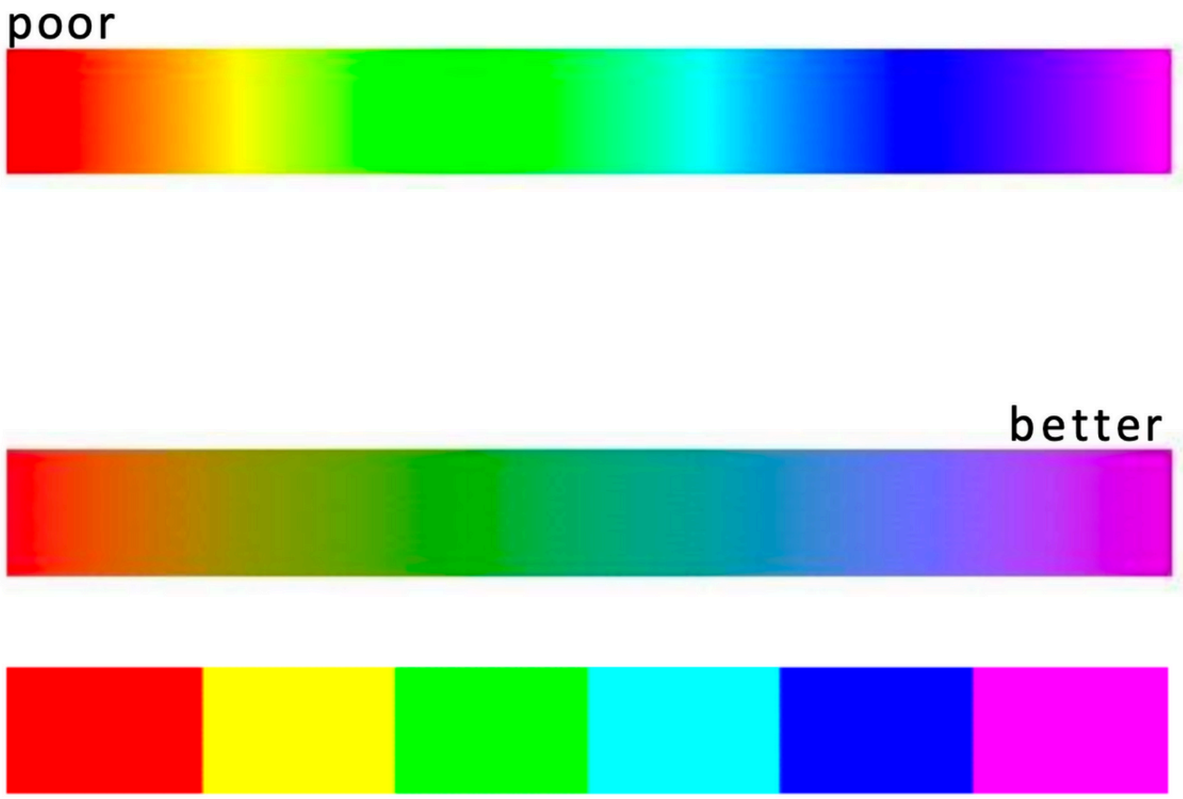
Rainbow Colormaps: Guidelines

Consider your tasks - rainbow color maps are the most accurate when you want users to read a temperature value from a map using a key



Rainbow Colormaps: Guidelines

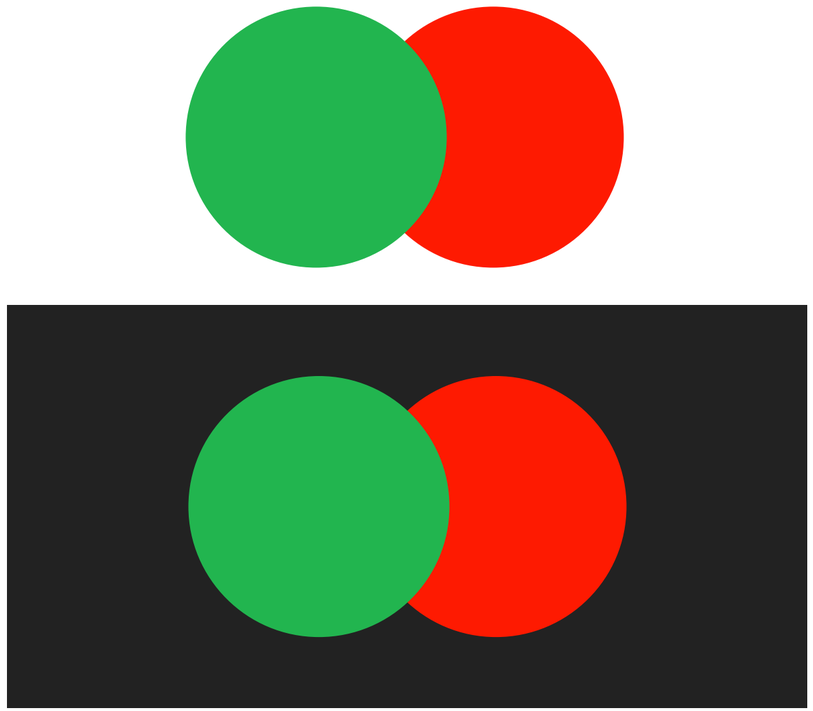
Consider lowering the saturation, or using a segmented rainbow colormap instead



Color Schemes

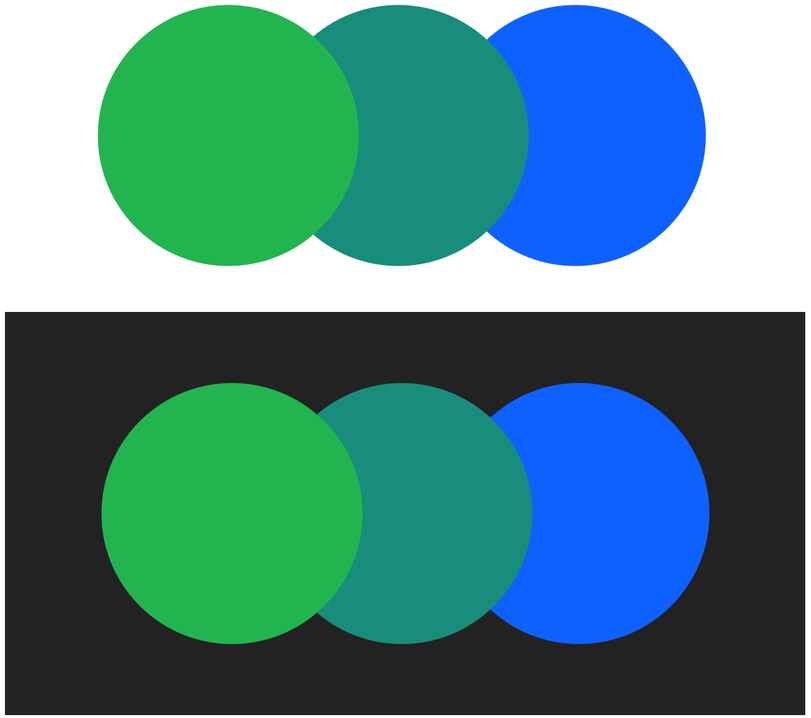
Color Schemes: Complementary

High contrast for vibrant look



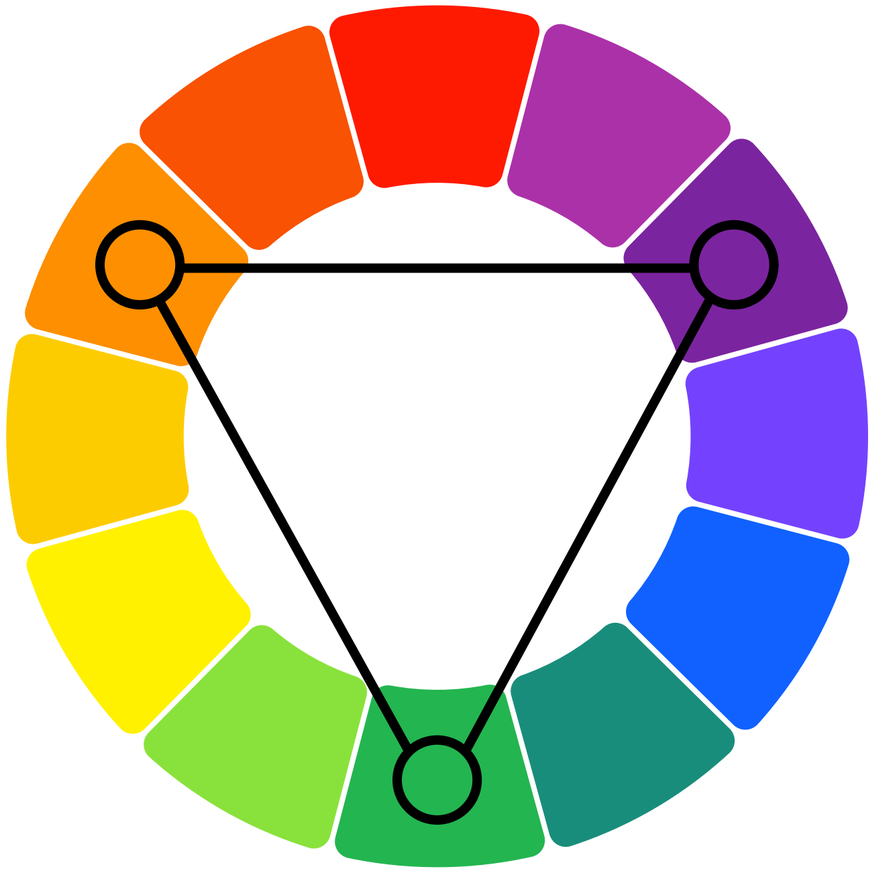
Color Schemes: Analogous

Harmonious and pleasing to the eye - often found in nature



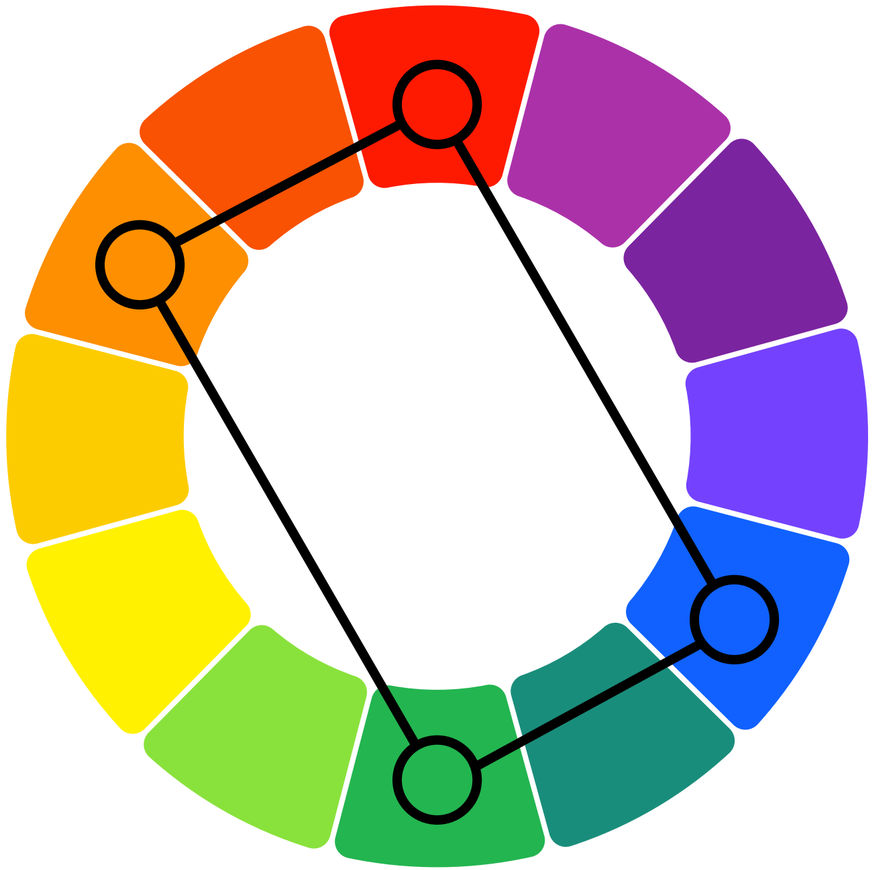
Color Schemes: Triad

vibrant, even if you use pale or unsatured versions of the hues



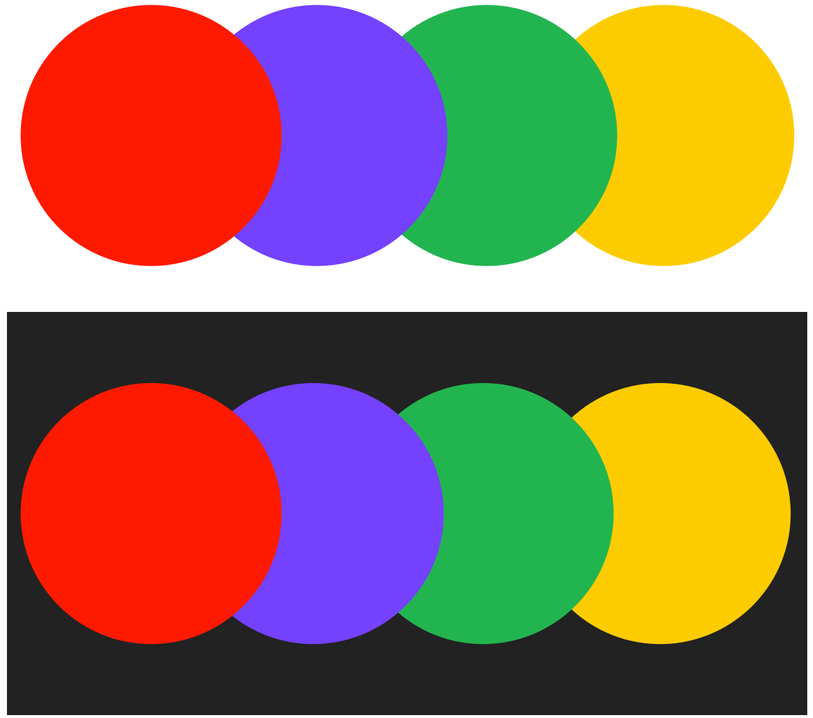
Color Schemes: Split-Complementary

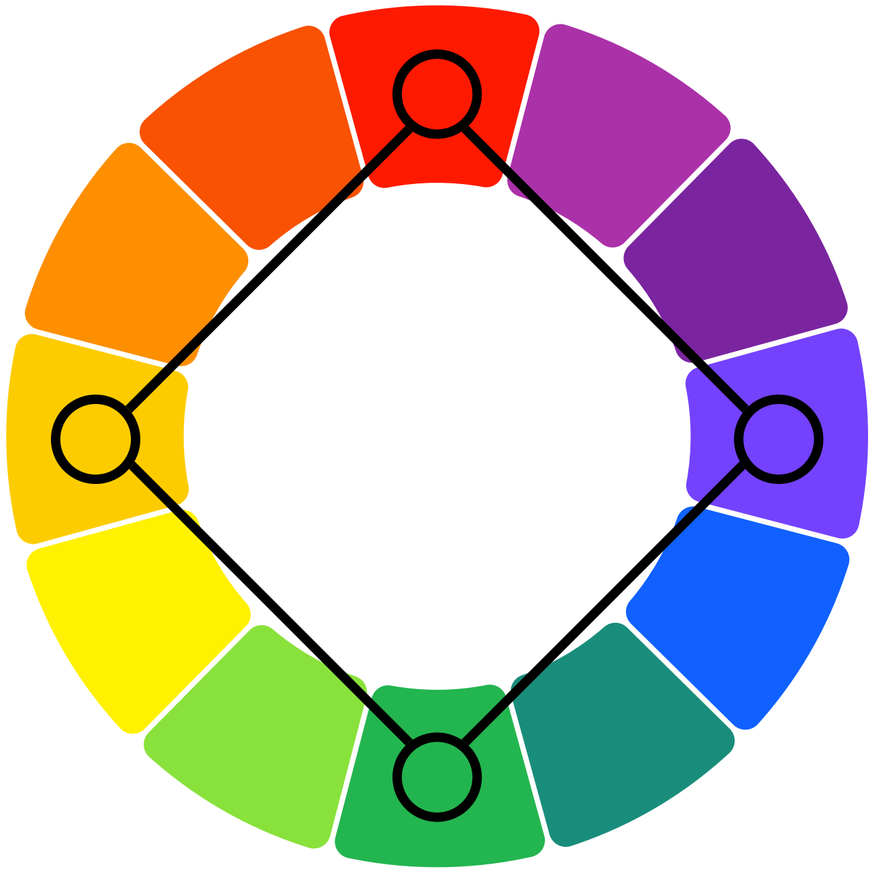
same strong contrast as
complementary, but less tension



Color Schemes: Rectangle

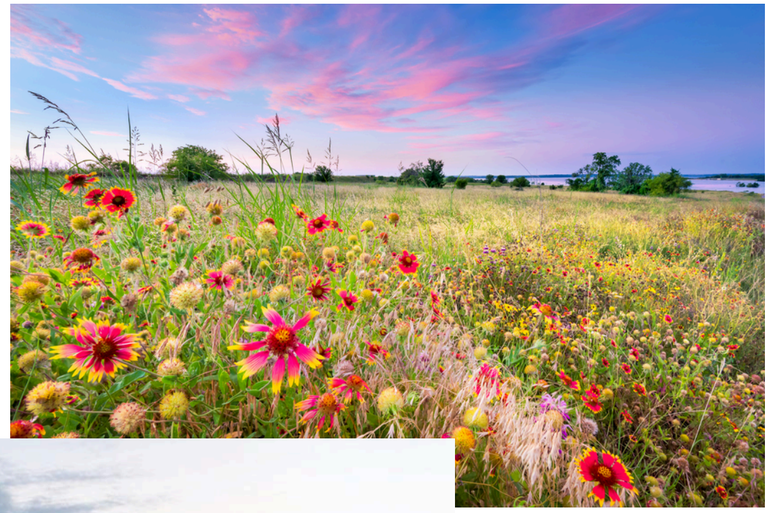
rich color scheme, with plenty of possibilities for variation

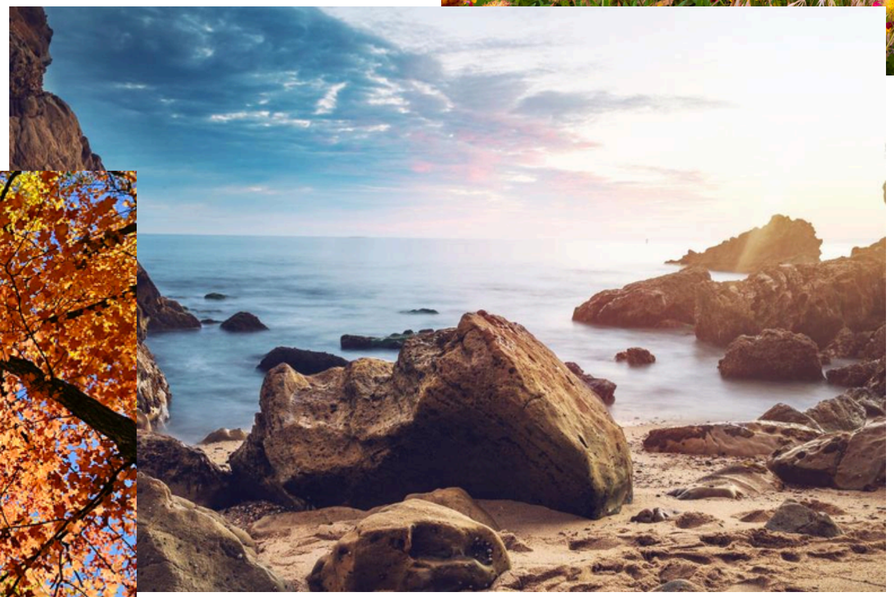




Guidlines: Rules of Thumb

Rule of Thumb: Look to Nature

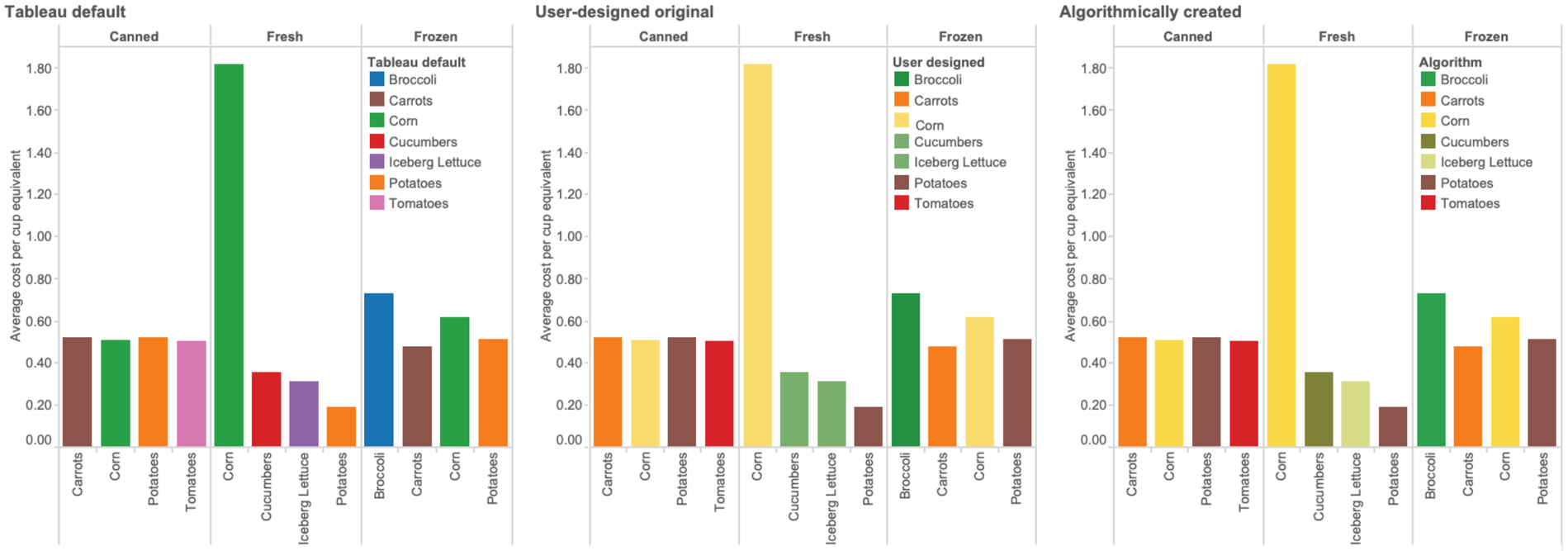




Rule of Thumb: Look to Nature

A Linguistic Approach to Categorical Color Assignment for Data Visualization

Vidya Setlur, *Member, IEEE*, Maureen C. Stone, *Member, IEEE*



Rule of Thumb: Simplicity

Choose a single “accent color” to be used in large amounts

Be selective about the base/background color

Use other colors to add interest

Rule of Thumb: Avoid Using Color

Use neutrals (these work with any color scheme)

- black, white, grey

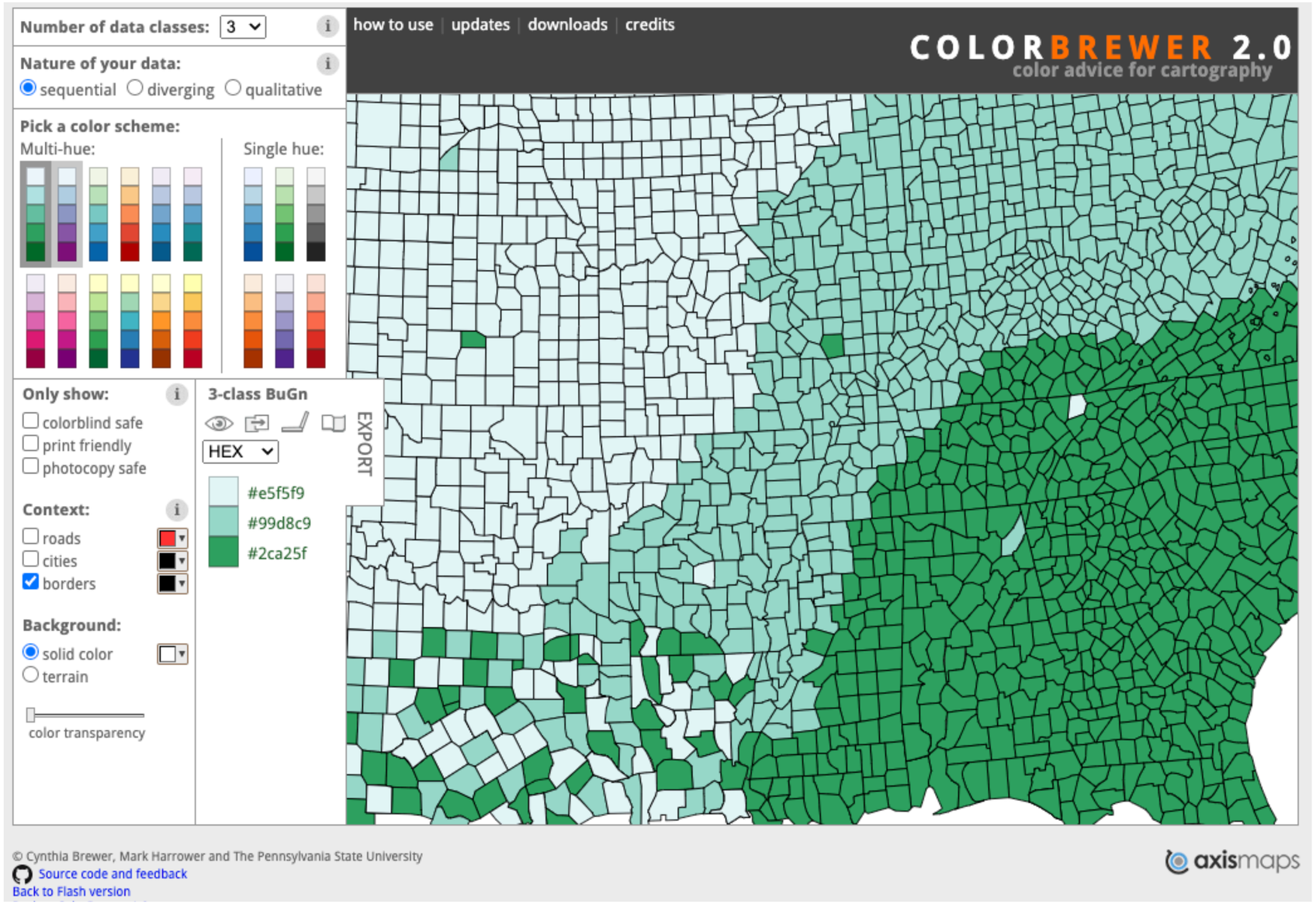
Use other methods than color to encode data:

- size, shape, length, width, orientation

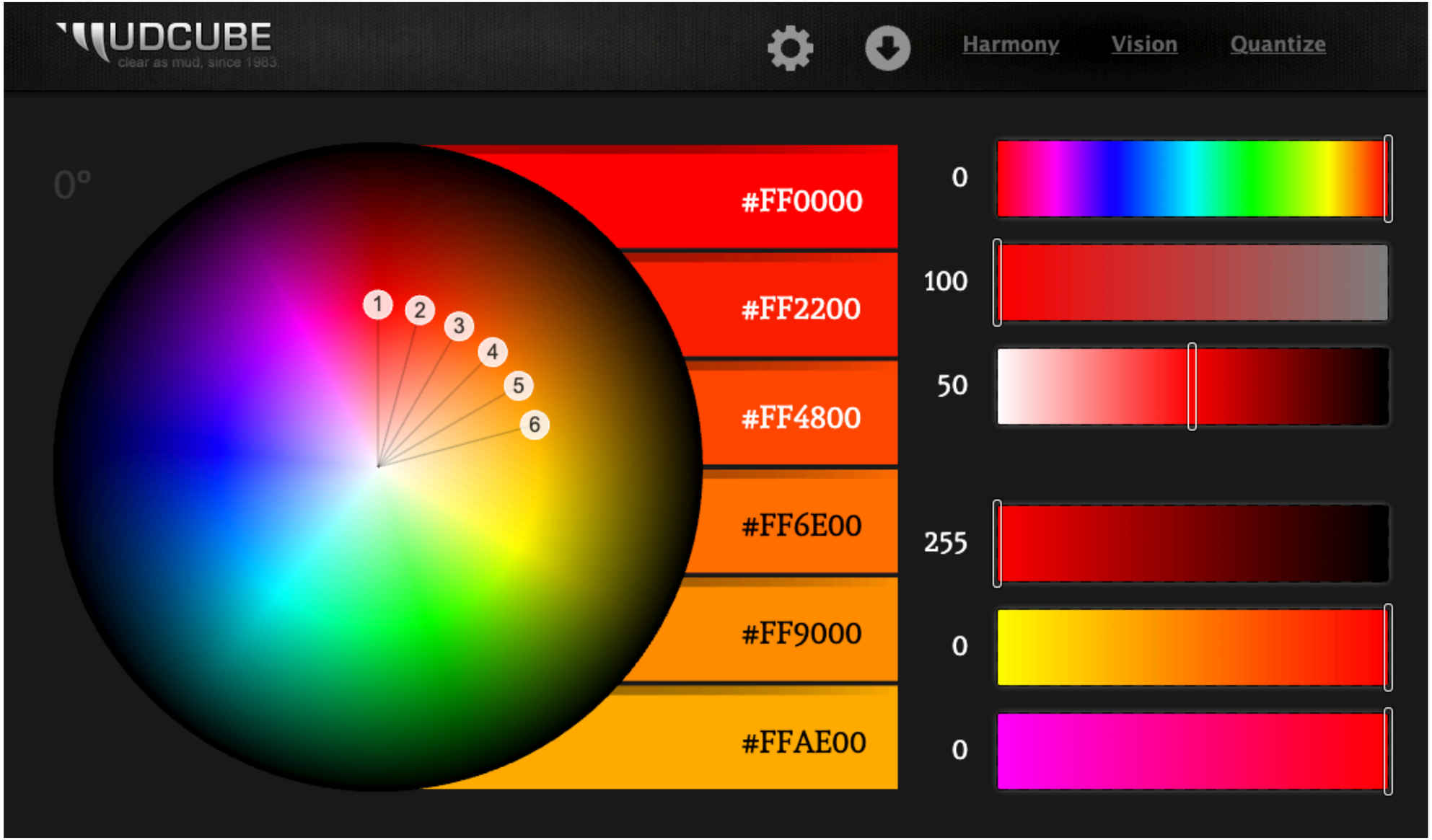
“Get it right in black and white” -Maureen Stone

Tools for Picking Color

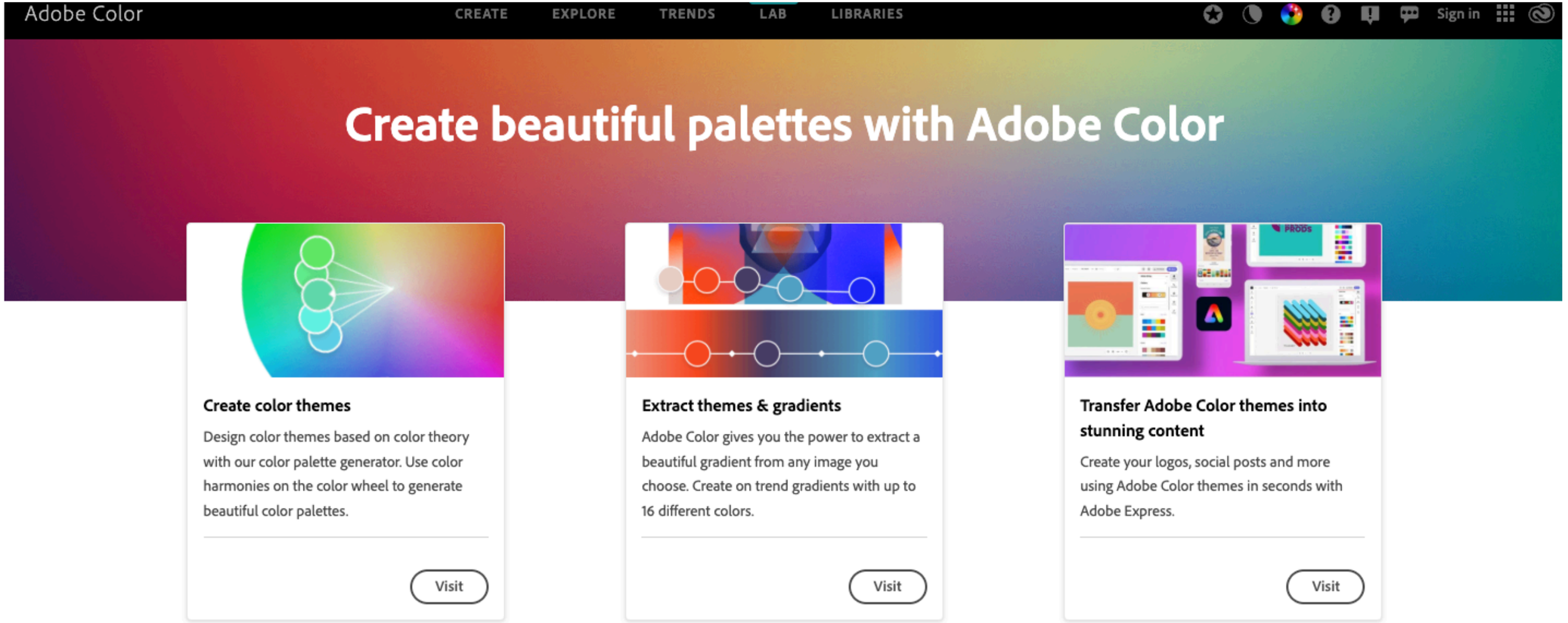
colorbrewer2.org



colorsphere.app



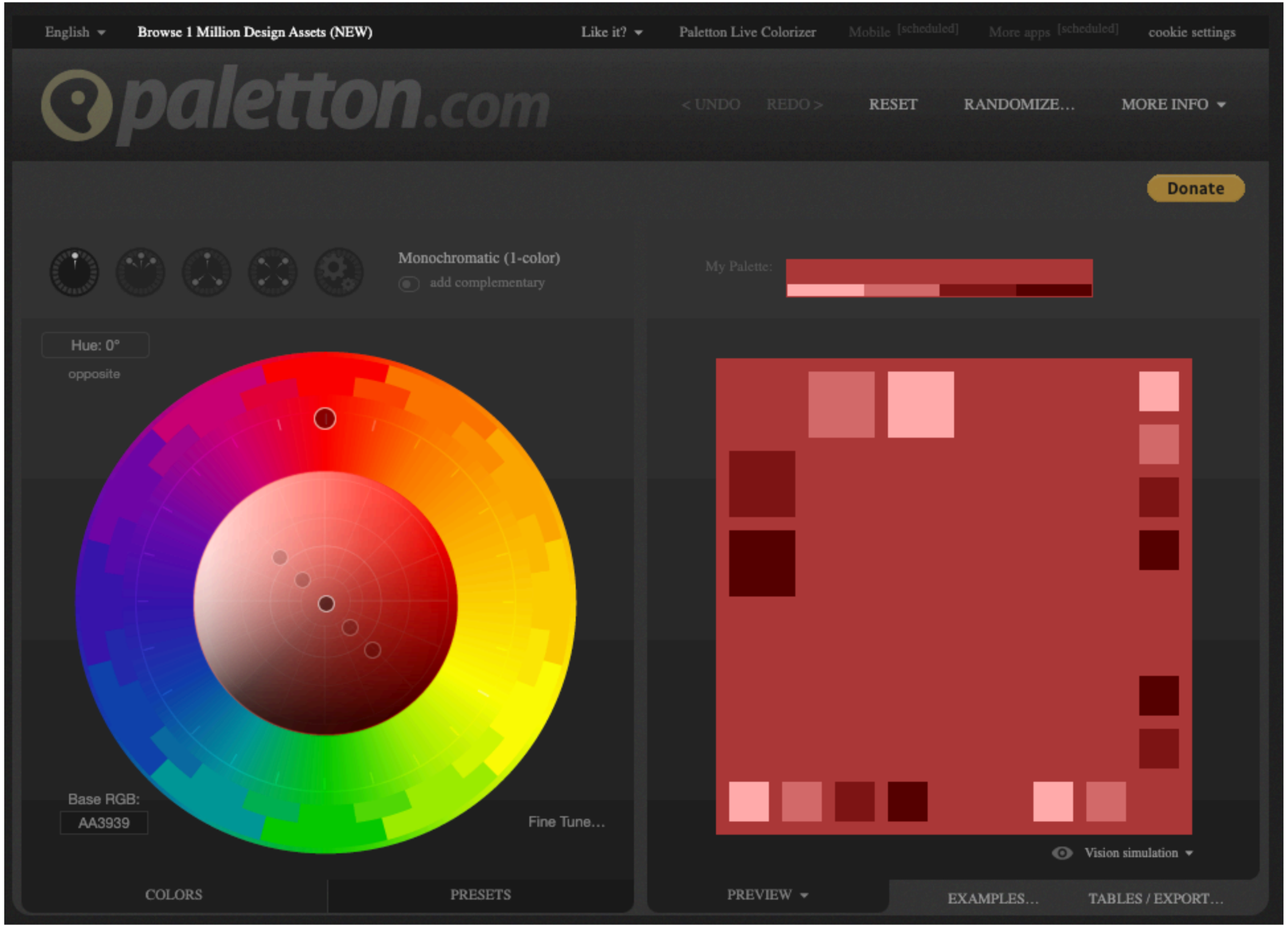
color.adobe.com



Explore color themes

Discover popular color palettes from the Adobe Color community and search for themes by name, mood or keyword using color search. One click any color theme to edit it directly on the color wheel.

paletton.com



colormine.org/color-converter

ColorMine.org Delta-E Calculators Color Converter Colors by Name About

Color Converter

Select a color space and enter your values for accurately convert your selection to Rgb, Cmy, Cmyk, Hsl, Xyz, Lab, Lch and Yxy.

Note: ColorMine uses the sRgb color space. More information on sRgb vs AdobeRgb.

Rgb

We've recently added support for device specific ICC Profiles for conversions to Cmyk based on your feedback. This is a new feature so please let us know if you have any questions or problems with it using the feedback form below.

R 0

G 0

B 0

Color Space

Rgb

Cmyk Profile

No Profile

Convert

Color conversions performed using the open source ColorMine library.

toptal.com/designers/colorfilter

Toptal

Toptal connects the top 3% of **freelance designers** all over the world.

Colorblind Web Page Filter

What are color blind anomalies?

Please indicate a resource to be viewed, and a color filter to be applied to that resource.

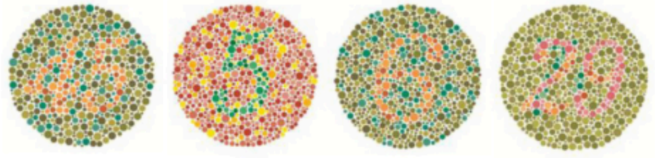
Type a URL:
https://www.toptal.com/designers/colorfilter/exar

- **Protanopia** — red/green color blindness; anomalous red cones
- **Deuteranopia** — red/green color blindness; anomalous green cones
- **Tritanopia** — blue/yellow color blindness; anomalous blue cones
- **Greyscale/achromatopsia** — quick check for all forms of colorblindness

FETCH AND FILTER!

Example page

Type your own URL at the top form to see it color-blind-filtered (at the right side).

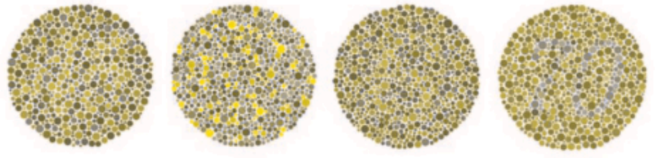


This visual perception test is known as an Ishihara test and has been used since 1917. You can read more at Wikipedia.

Set of colors unambiguous to color vision deficients and to normal sighted persons

Original color	Seen by a... Protan	Deutan	Tritan	HUE	COLOR CODE
				Black, 0°	#000000; RVB 0,0,0 CMJN % 0,0,0,100.
				Orange, 41°	#E69F00; RVB 230,159,0 CMJN % 15,41,93,1.

Type your own URL at the top form to see it color-blind-filtered (at the right side).



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FIN

Upcoming Dates

Feb 13: Announce Your Project

Feb 14: ~~Group~~ Activity 1 Due

Feb 14: Homework 1 Due

Make sure at least one member from your project team attends class on Feb 13