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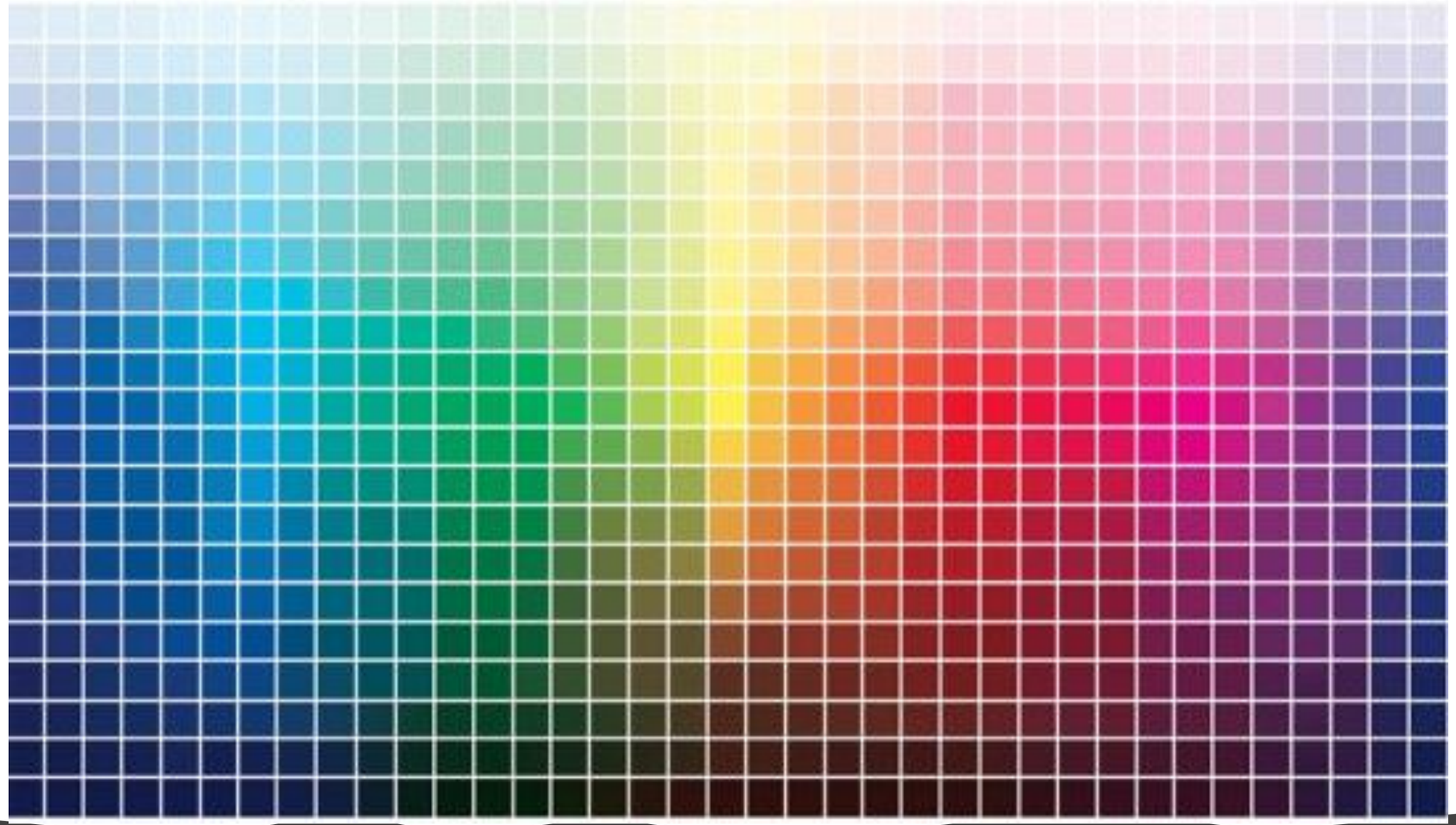
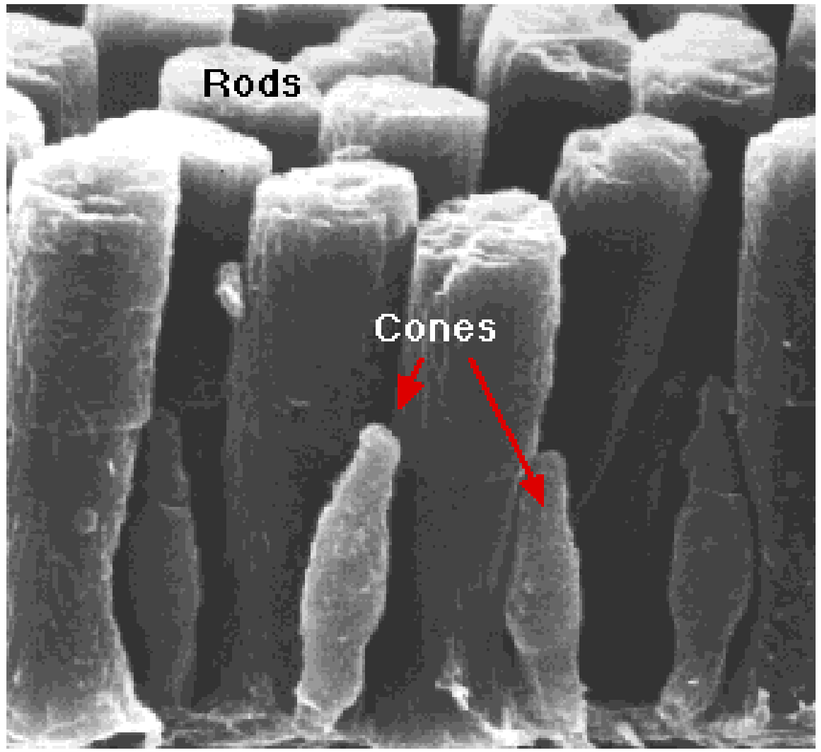
THE UNIVERSITY OF UTAH

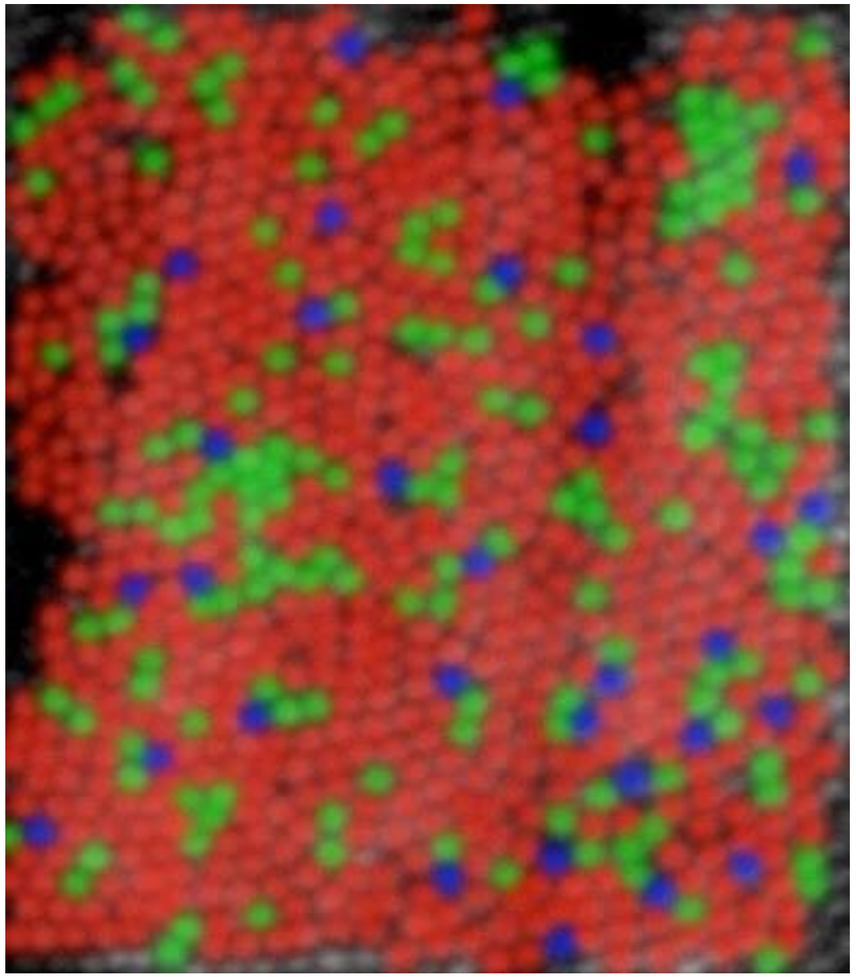
Visualization for Data Science
DS-4630 / CS-5630 / CS-6630

Perception of Color

Color



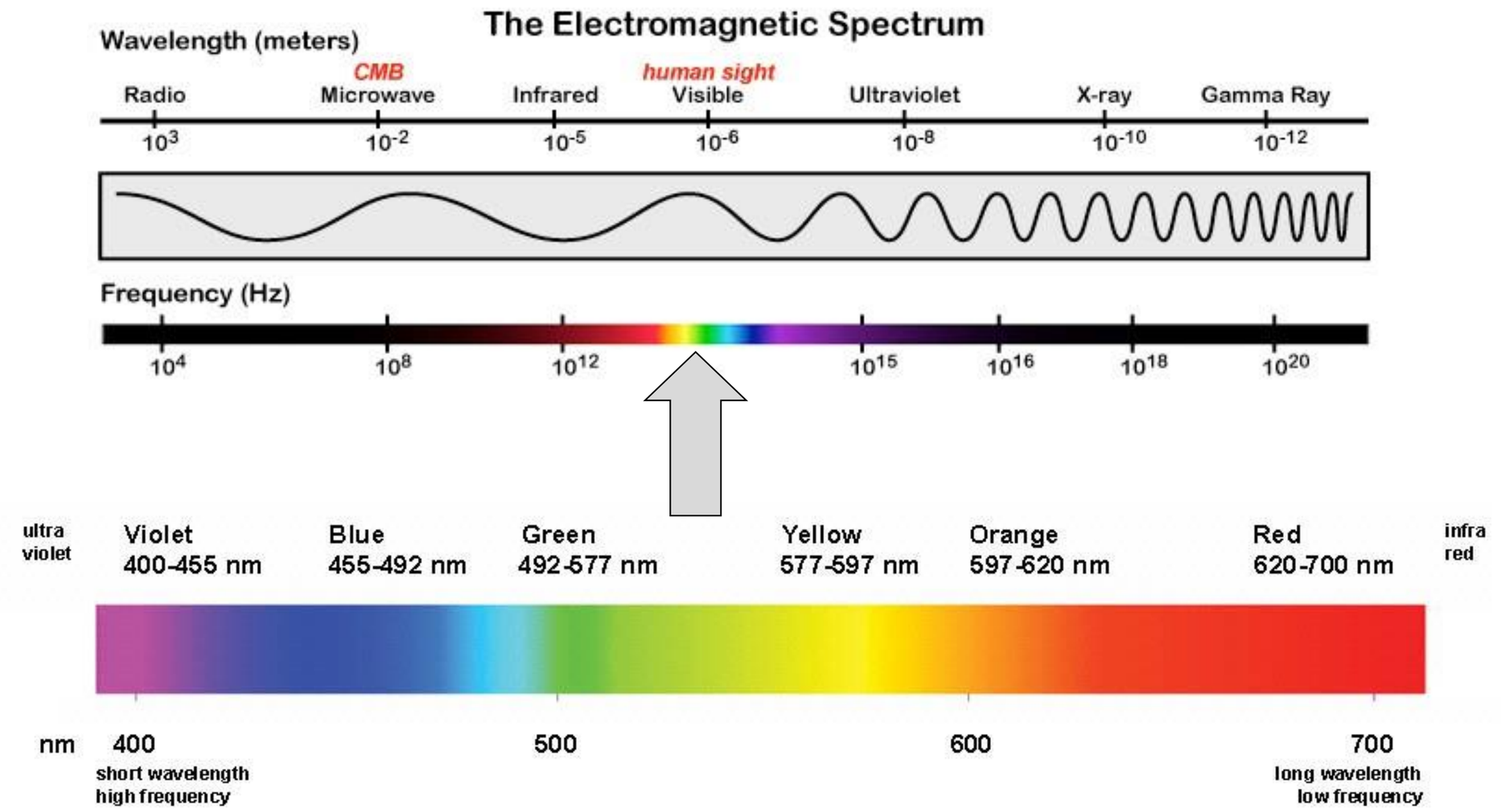




120 million rods

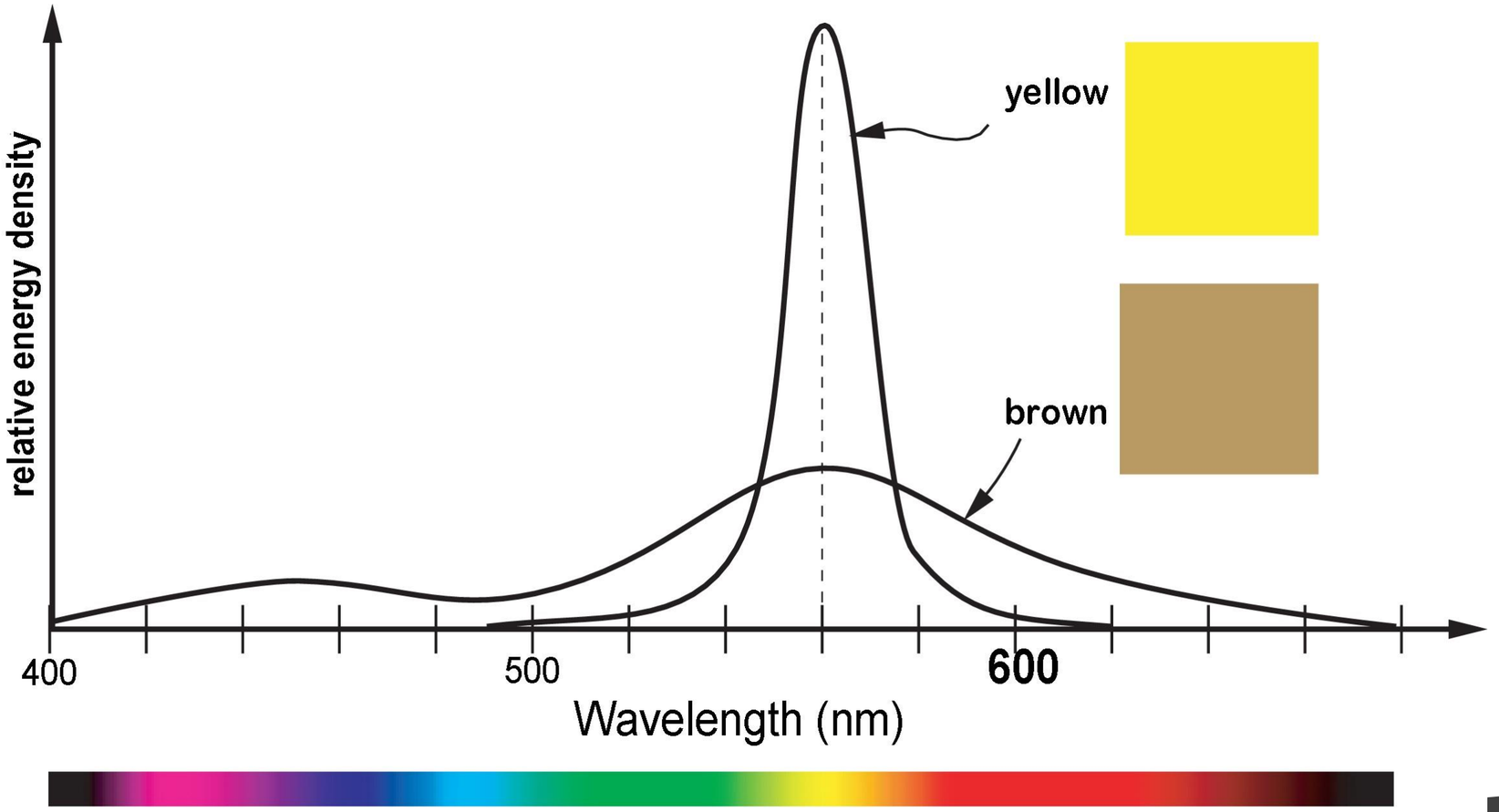
5-6 million cones

light

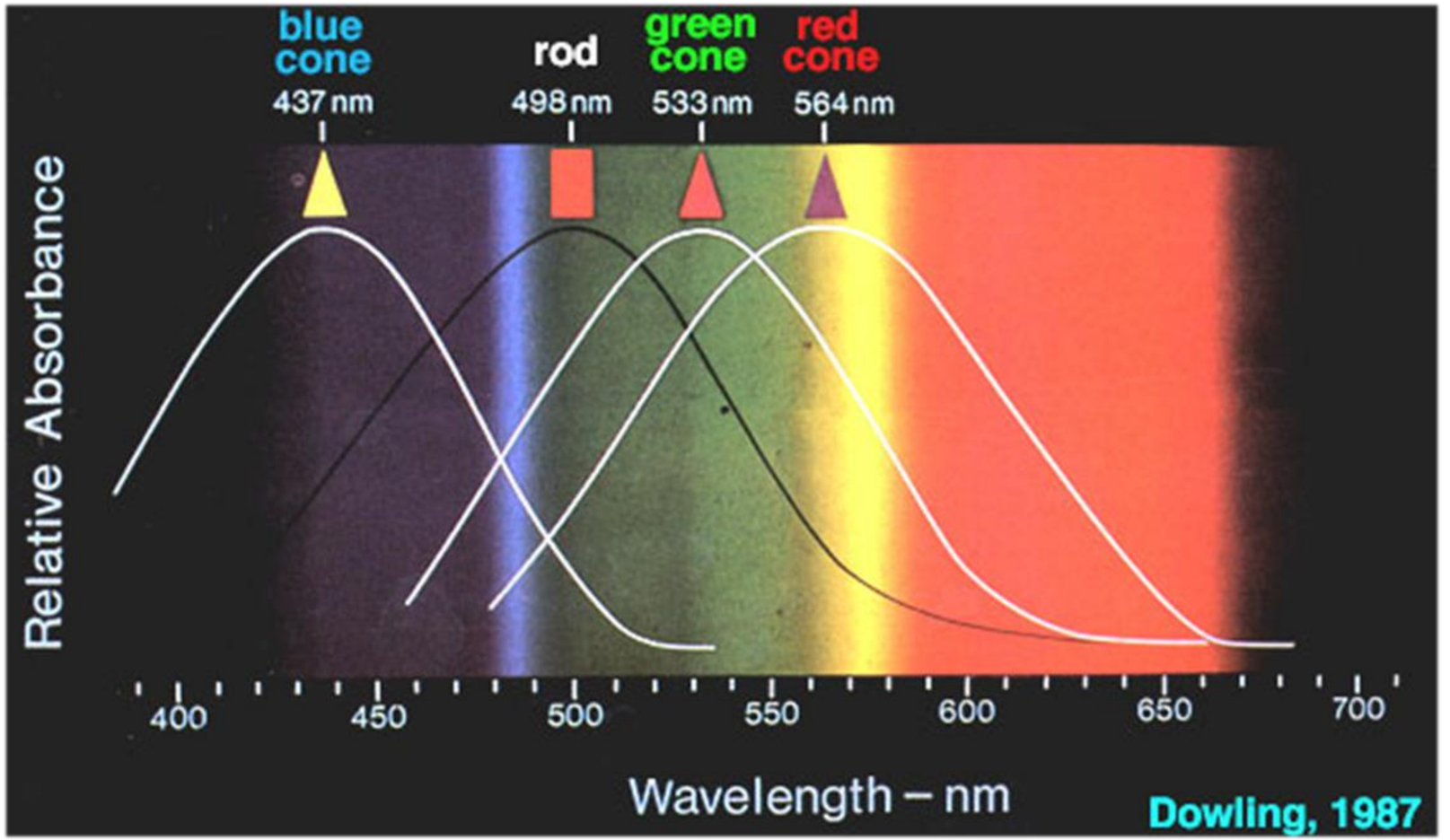

The Electromagnetic Spectrum
Wavelength (meters)
CMB
human sight
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
ultra violet
Violet 400-455 nm
Blue 455-492 nm
Green 492-577 nm
Yellow 577-597 nm
Orange 597-620 nm
Red 620-700 nm
infra red
nm
400
500
600
700
short wavelength high frequency
long wavelength low frequency

Color != Wavelength

- but rather, a combination of wavelengths and energy



Cone Response



RADIOLAB
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Rippin' the Rainbow a New One

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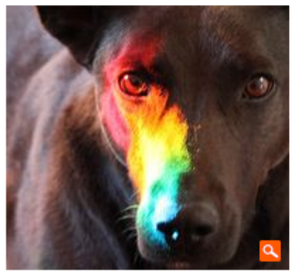

(jared/flickr/CC-BY-2.0)

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.

Jonah Lehrer restores some of the lost magic by way of Goethe--who turned a simple observation into a deep thought: even though color starts in the

PODCAST SUPPORT

Latest Comments

What a fascinating story! I found it interesting as some aspects of it reminded me of the conflict in Gaza ...

Benny
on Fu-Go

The Most Viewed | Listened | Commented

- Remembering Oliver Sacks
- American Football
- The Rhino Hunter
- Elements
- Shrink
- Colors
- Photos: Before and After Carlisle
- Looking Back With Dr. Sacks
- Antibodies Part 1: CRISPR
- The Poetry of "Elements"

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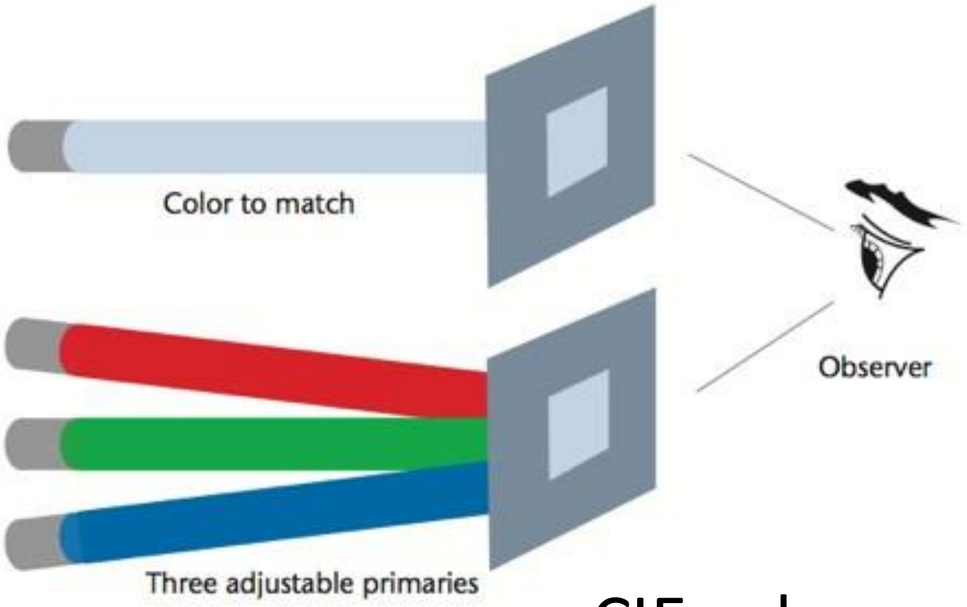
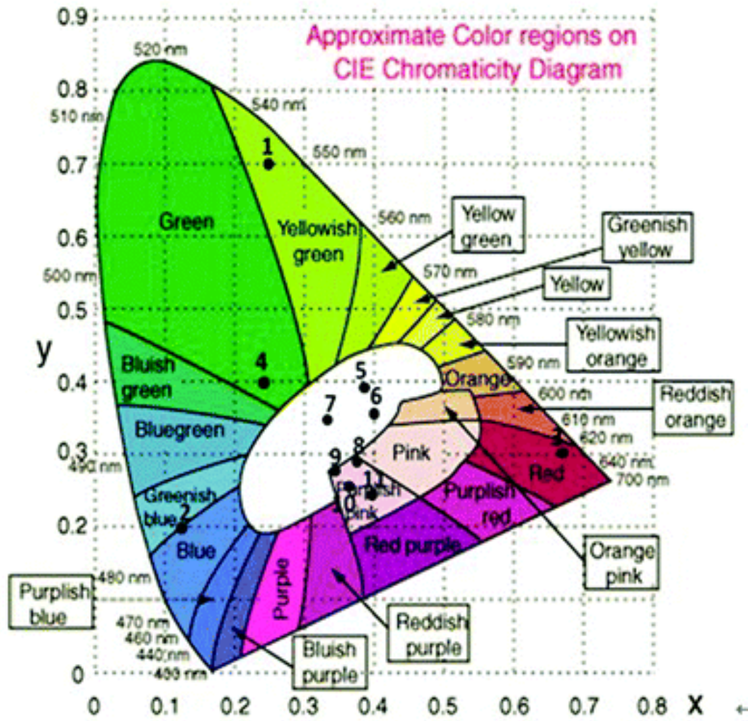
Color abstraction, representation

space of human color perception





CIE color space

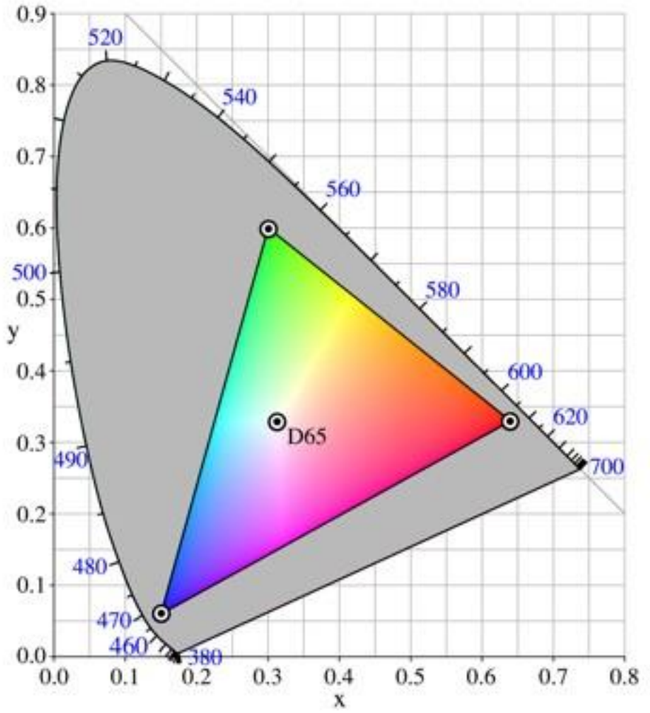
- CIE (International Commission on Illumination)
  - standardized a set of color-matching functions that form the basis for most color measurement instruments
- experiments done in the 1920's and 1930's
- humans can mimic any pure (visible) light by addition and subtraction of three primary lights

ADDITIVE COLOR

- (like we see in light)
- primary: RGB
- secondary: CMY

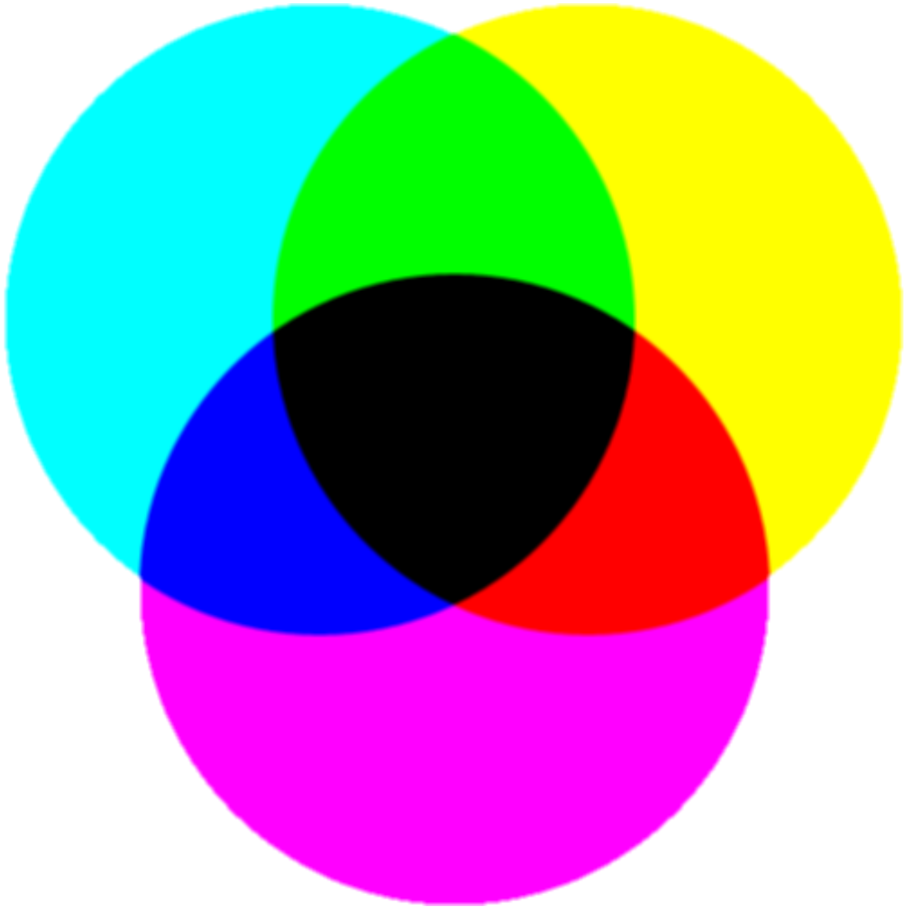
RGB color space

- very commonly used color space
- not perceptually uniform
- actual color is device-dependent



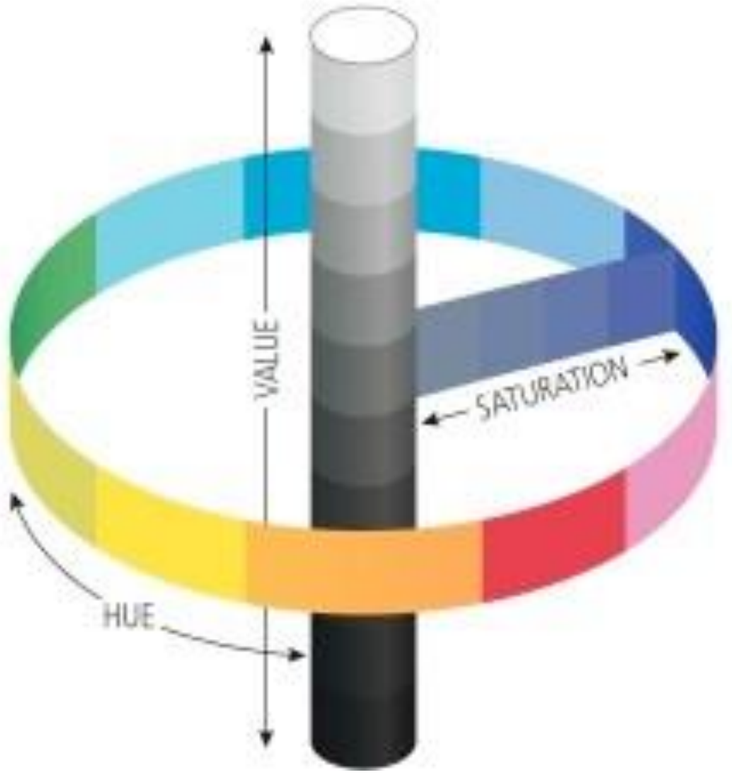
SUBTRACTIVE COLOR

- (used in print ink)
- primary: CMY
- secondary: RGB
- approx black = C+M+Y
- true black = C+M+Y+K
- actual color is device-dependent



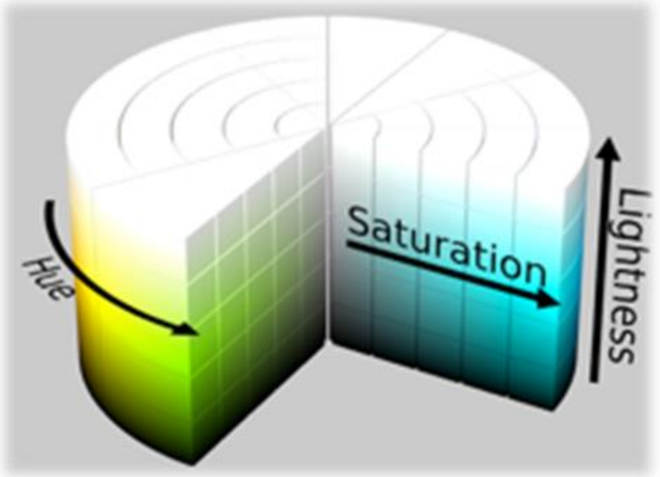
HSV [B, L, I] (additive)

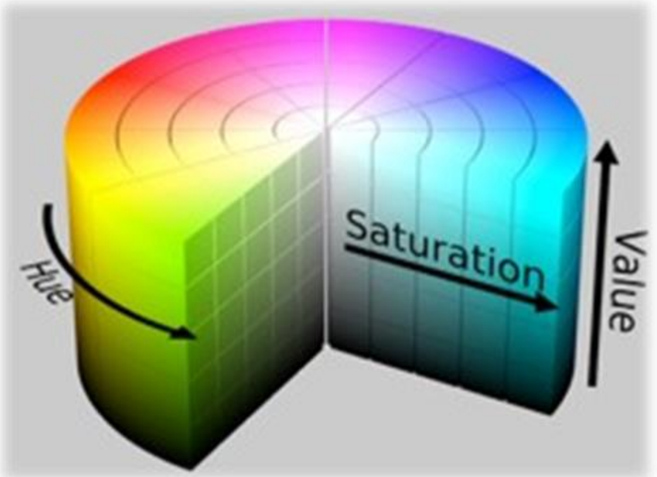
- Hue, Saturation, [Value, Brightness, Lightness, Intensity]
- polar coordinate representations of RGB space
- conical or cylindrical shaped space
- more intuitive than RGB for color tuning



HSV [B, L, I] (additive)

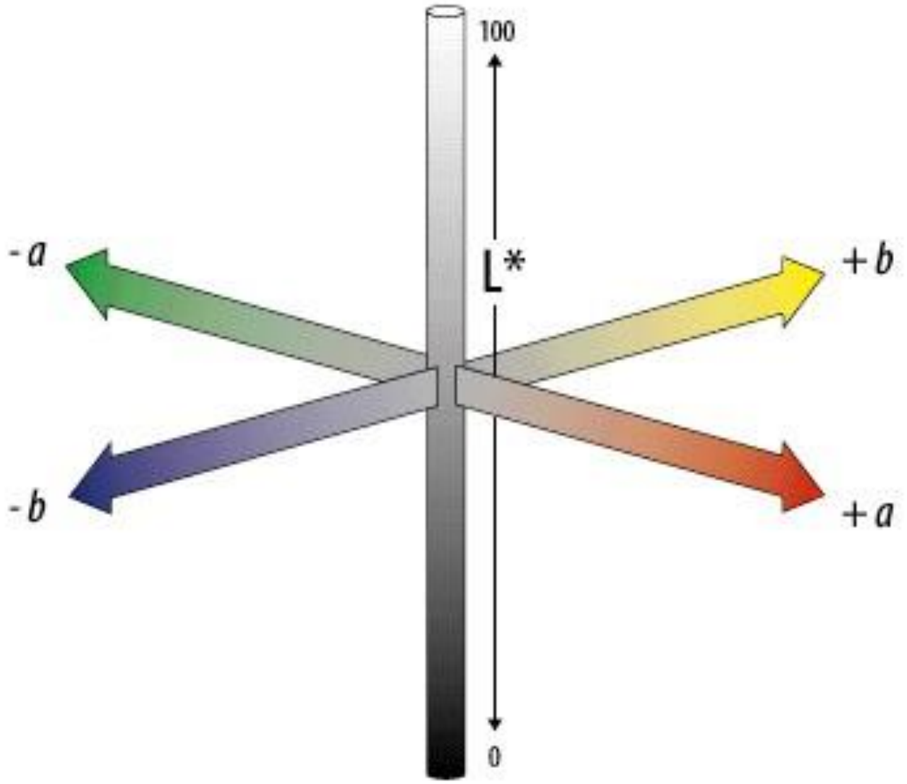
- hue: what people think of as color
- saturation: amount of white mixed in
- luminance: amount of black mixed in
  - lightness vs value (or brightness)
  - intensity, in computer vision applications





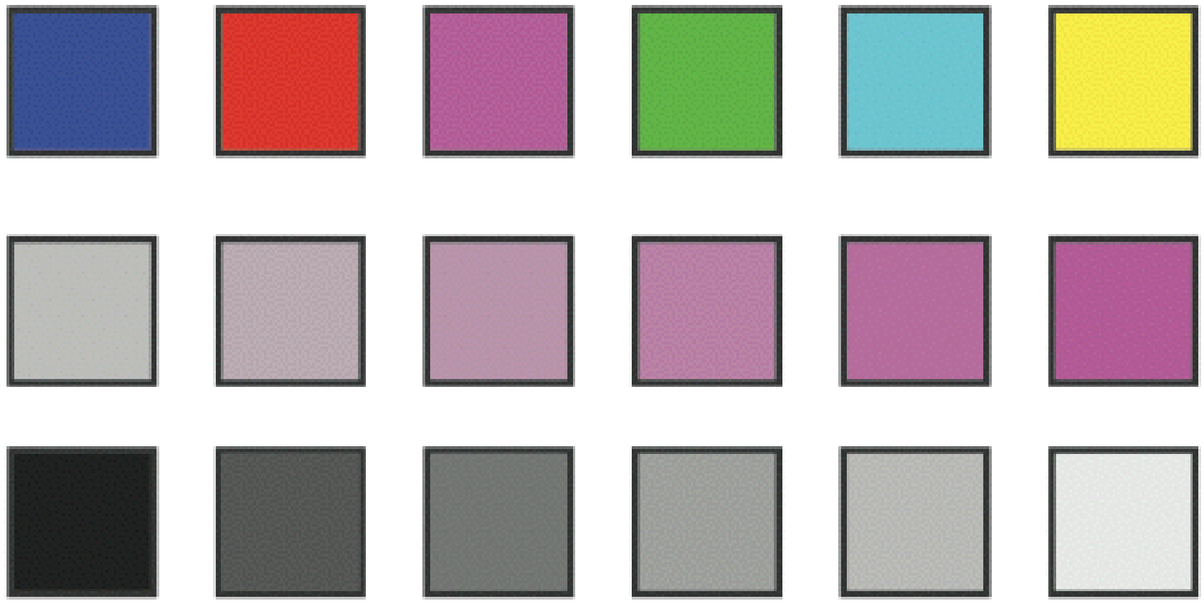
CIE LAB/LUV

- mathematically defined & perceptually based to include all perceivable colors
- a: red to green
- b: yellow to blue
- L*: lightness (black to white)



in this class…

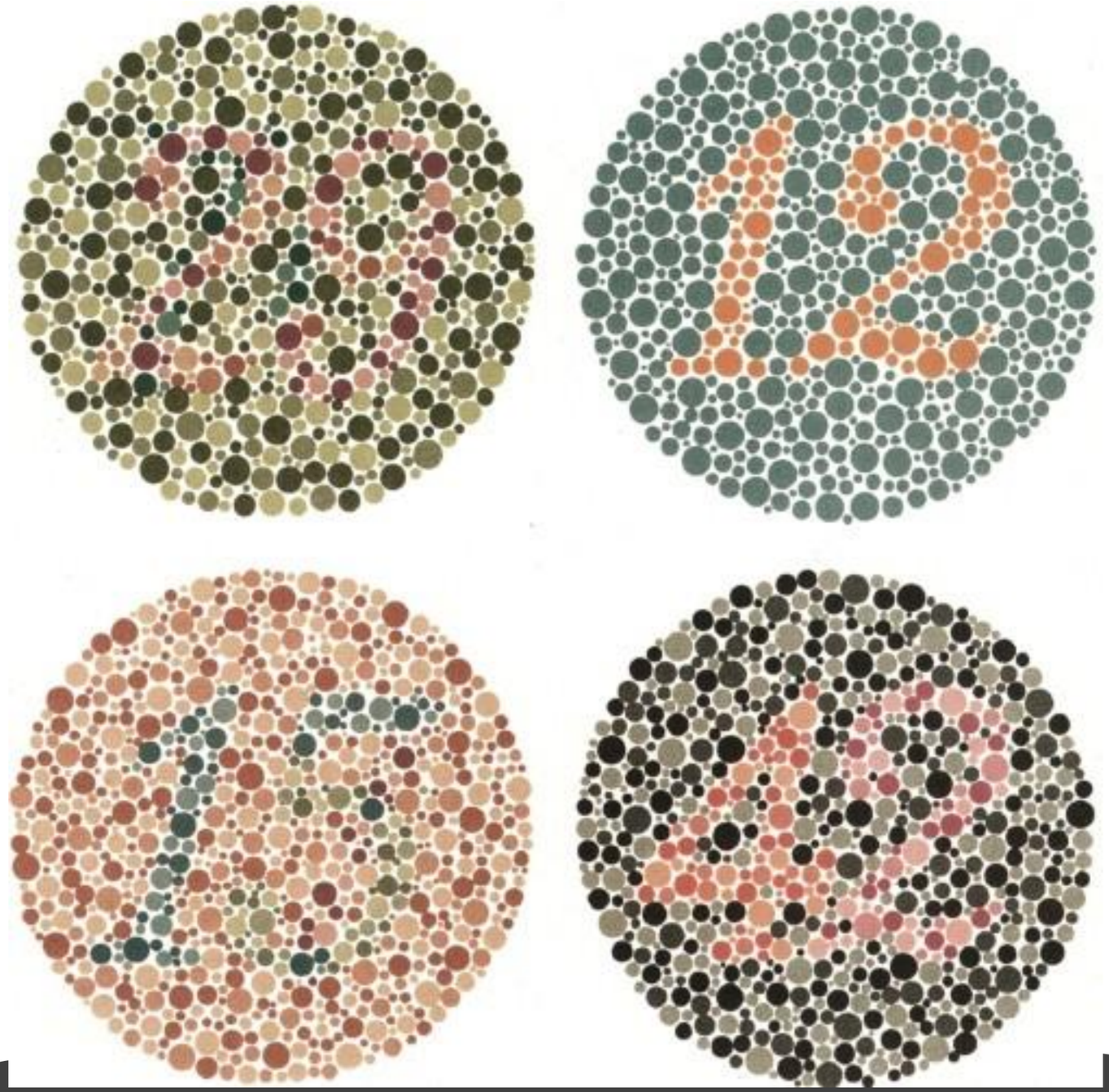
- hue
- saturation
- luminance



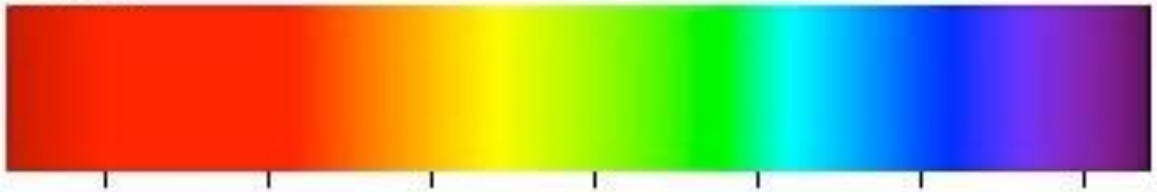
color deficiencies & limitations

COLOR BLINDNESS

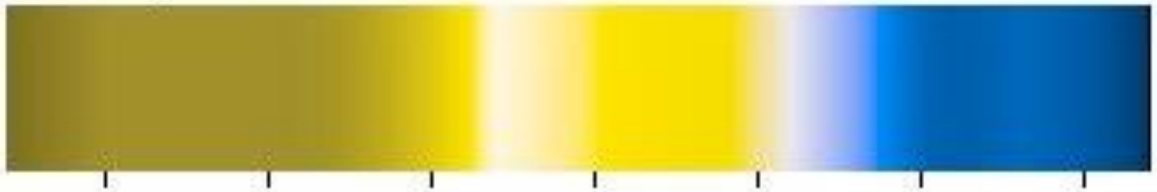
- deficiency in color vision
- typically caused by faulty cone development
- found more in men than women
- photopigment genes carried in x-chromosome
- 5-8% of men and 0.5% of women (of European descent)



Normal

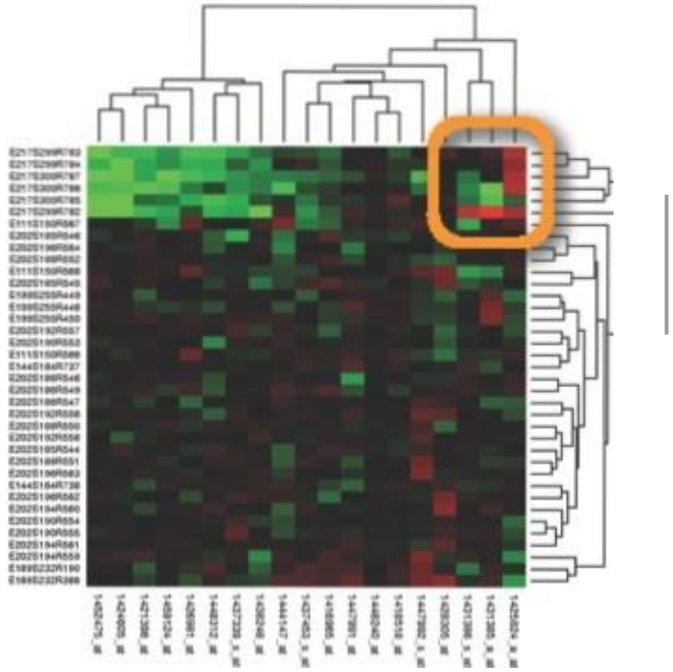


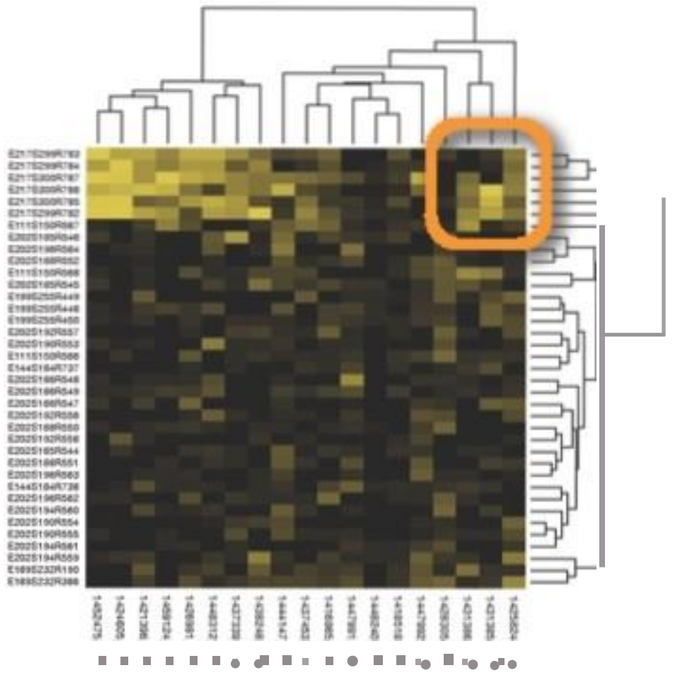
Protanopia



Deuteranopia

Tritanopia





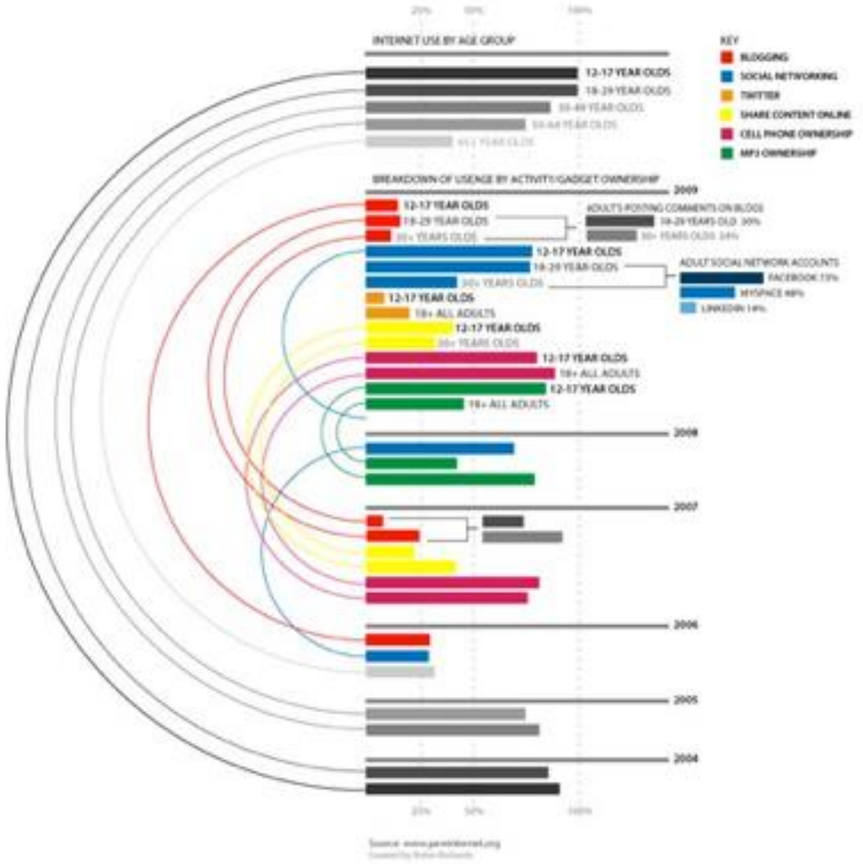
NG

www.ngonlinenews.com

How different age groups are using the internet

With the growth of social media networks such as Facebook and Twitter, traditional blogging has been usurped by micro-blogging quick and short 140 character updates instead of lengthy, in-depth (and sometimes still equally pointless) articles.

However, while teens and young adults seem to be shunning blogging, it is still strong among the over 30s...



Source: www.pewinternet.org

Created by: Robin Richards

NG

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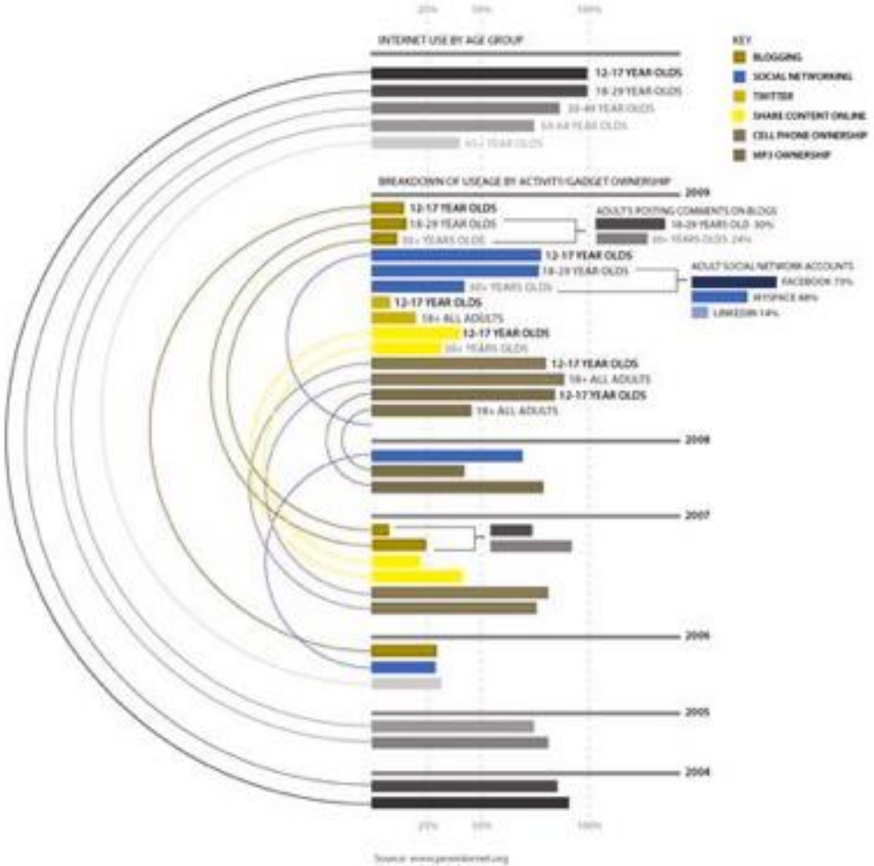
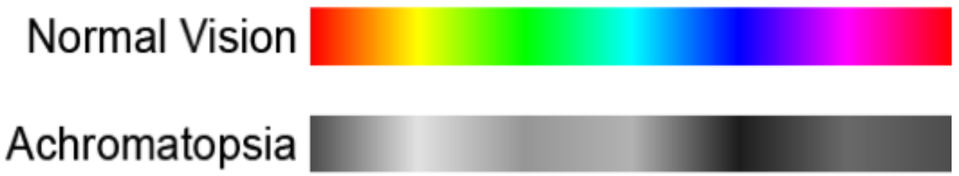


Source: www.pewinternet.org

Created by: Robin Richards

MONOCHROMACY

- total color blindness, very rare
- 1 dimensional color vision
- 2 or 3 cone pigments are missing
- rod monochromacy: non-functioning or missing cones (achromatopsia)
- cone monochromacy: multiple deficient cones

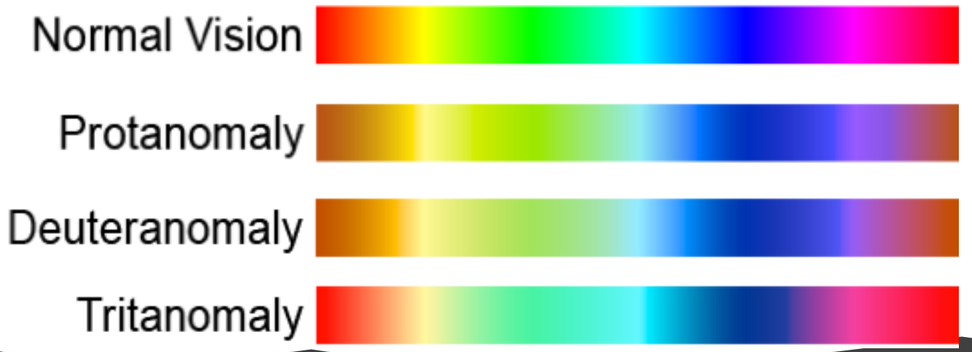


DICHROMACY

- 2 dimensional color vision
- 1 cone pigment is missing
- protanopia: absence of red receptors
- deuteranopia: absence of green receptors
- tritanopia: absence of blue receptors

TYPES: TRICHOMACY

- 3 dimensional color vision
- 1 cone is altered in spectral sensitivity—impairment rather than loss
- protanomaly: shift in red, poor red-green discrimination
- deuteranomaly: shift in green, poor red-green discrimination (most common form of color deficiency)
- tritanomaly: poor blue-yellow discrimination



The X-Rite Color Challenge and Hue Test

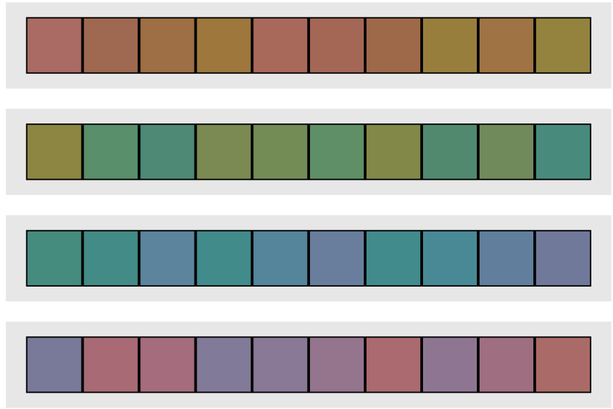
Are you among the 1 in 255 women and 1 in 12 men who have some form of color vision deficiency? If you work in a field where color is important, or you're just curious about your color IQ, take our online challenge to find out. Based on the Farnsworth Munsell 100 Hue Test, this online challenge is a fun, quick way to better understand your color vision acuity.

Just remember, this is not a replacement for the full test!

Directions:

1. The first and last color chips are fixed.
2. Drag and drop the colors in each row to arrange them by hue color.
3. Complete all four color tests.
4. Click 'Score My Test' to review results.

What's My Color IQ?



Score My Test

Takeaway

- Even if you aren't colorblind, someone you're working with could be
  - Be sure to design with colorblindness in mind by:
    - varying hue, saturation, brightness
    - using monochrome color schemes
    - using cues besides/in addition to color
    - software solution, vischeck (http://www.vischeck.com)

A note on accessibility in visualization design

Frank @FrankElavsky · Jan 18

Data visualization cares disproportionately far too much about designing for colorblindness relative to other disabilities that are more common (visual impairments included).

(A thread on disability, race, and patriarchy in data visualization.)

44 1.2K 3.3K

Frank @FrankElavsky · Jan 18

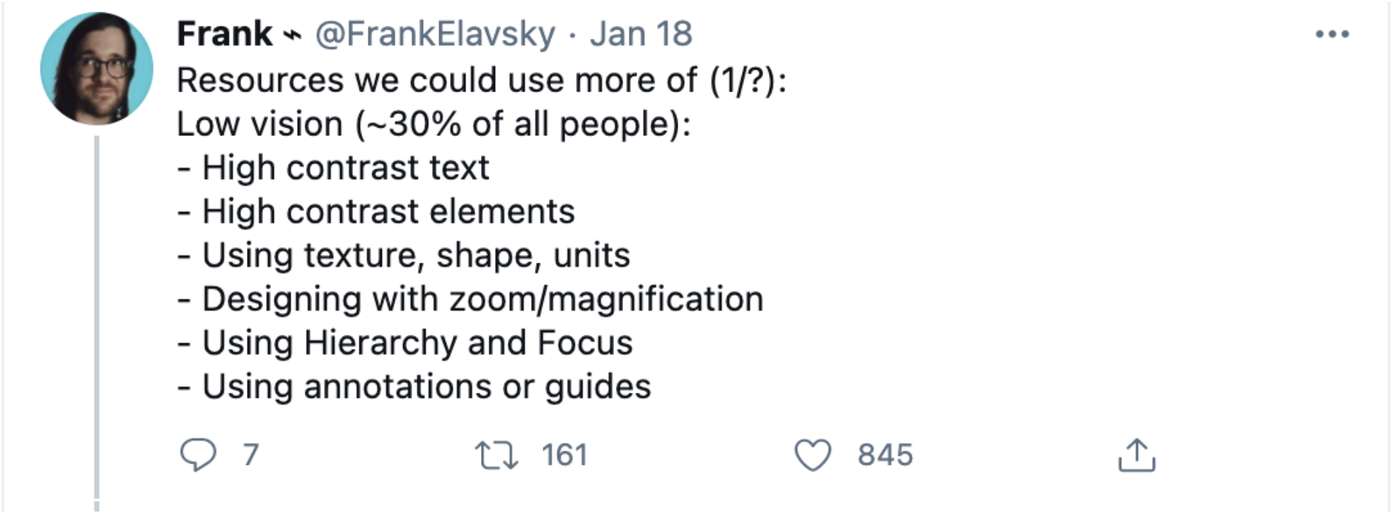
~4.5% of people with northern European ancestry are colorblind. But less than half of a percent of women are.

This means that nearly 8% of men from a northern European background have some form of colorblindness.

Colorblindness affects WHITE MEN the most.

7 14 214

A note on accessibility in visualization design

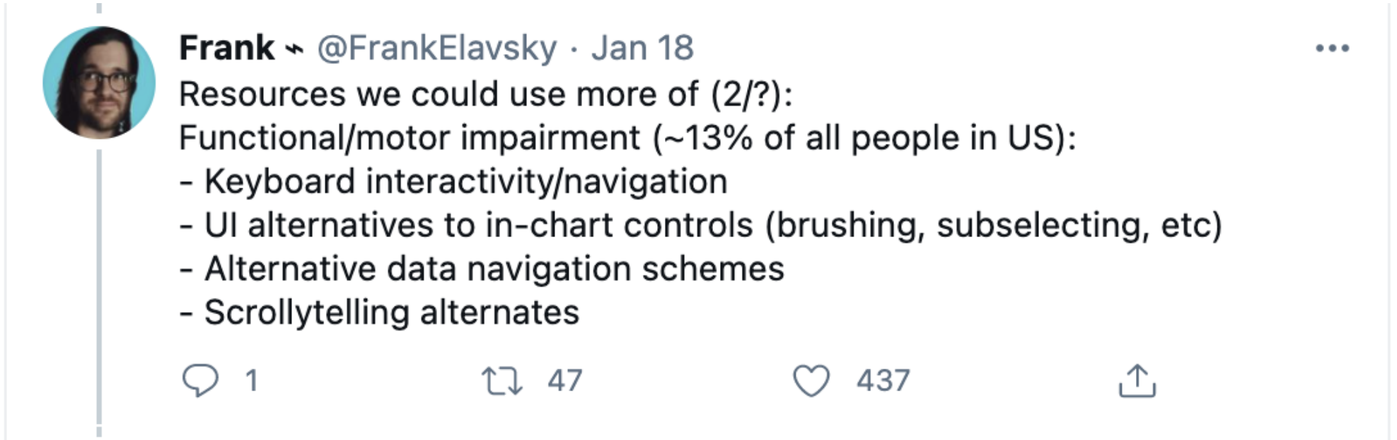


Frank @FrankElavsky · Jan 18

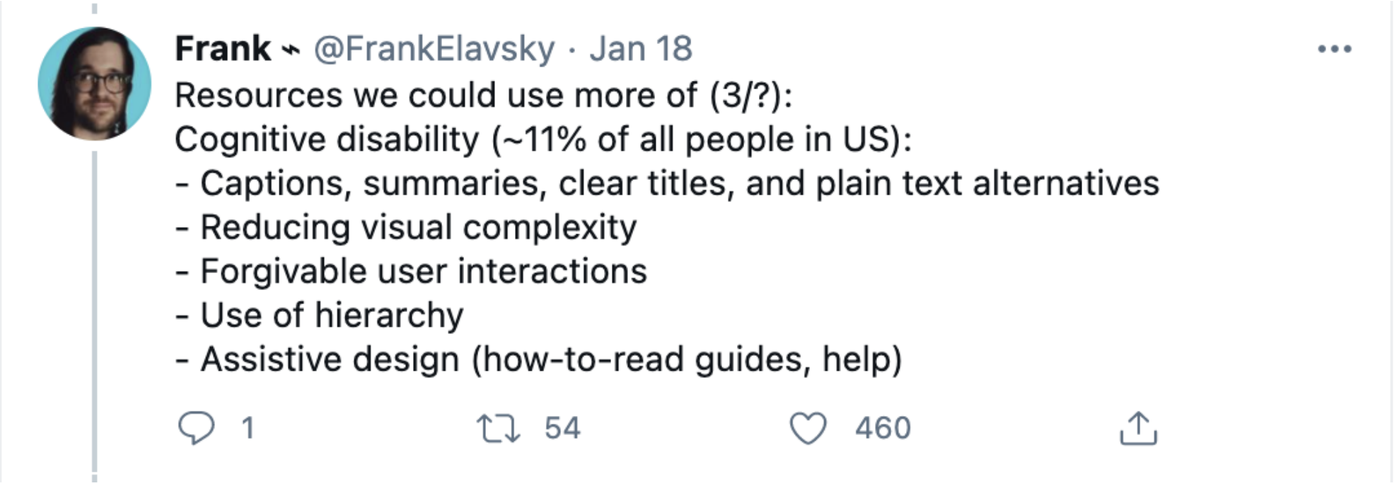
Resources we could use more of (1/?):
Low vision (~30% of all people):
- High contrast text
- High contrast elements
- Using texture, shape, units
- Designing with zoom/magnification
- Using Hierarchy and Focus
- Using annotations or guides

7 161 845

A note on accessibility in visualization design



A note on accessibility in visualization design

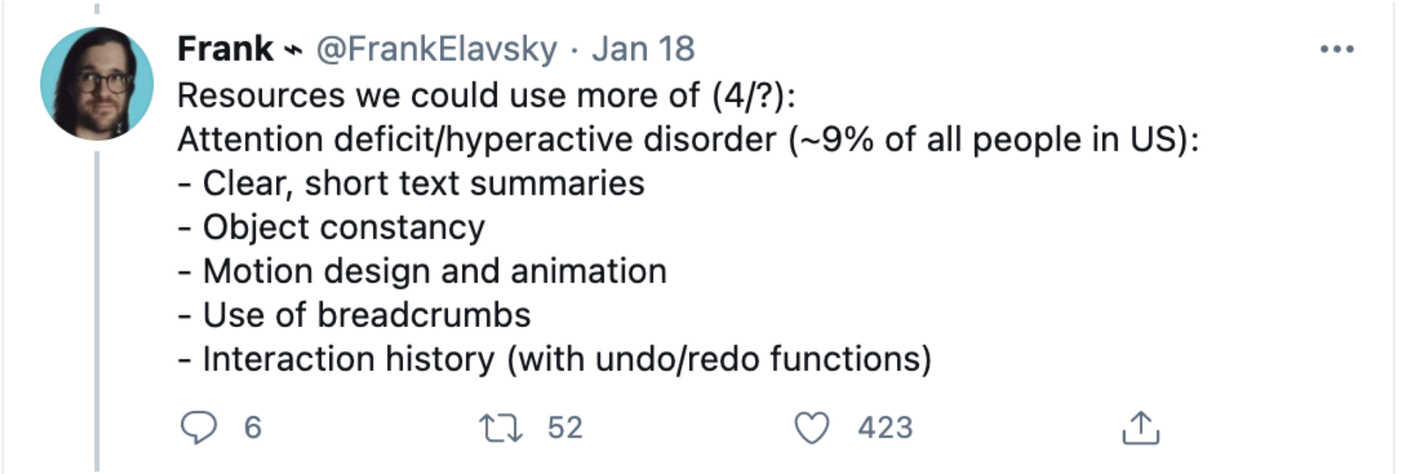


Frank @FrankElavsky · Jan 18

Resources we could use more of (3/?):
Cognitive disability (~11% of all people in US):
- Captions, summaries, clear titles, and plain text alternatives
- Reducing visual complexity
- Forgivable user interactions
- Use of hierarchy
- Assistive design (how-to-read guides, help)

1 54 460

A note on accessibility in visualization design

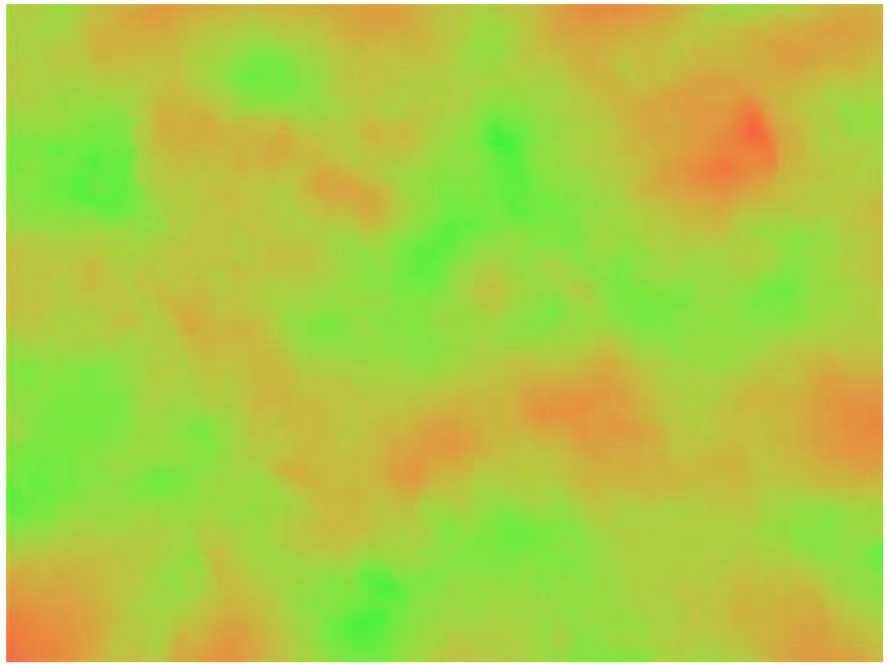


Frank @FrankElavsky · Jan 18

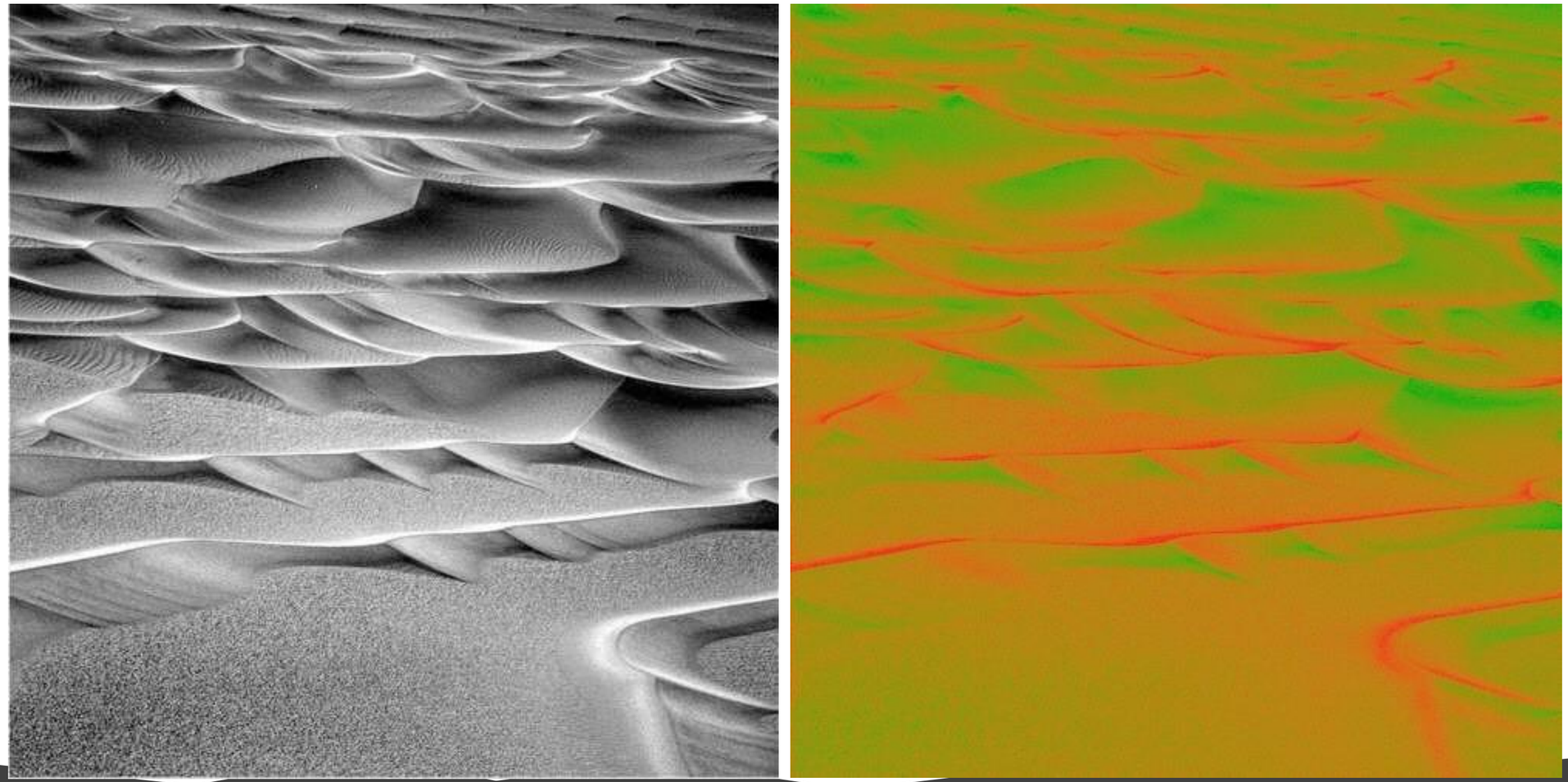
Resources we could use more of (4/?):
Attention deficit/hyperactive disorder (~9% of all people in US):
- Clear, short text summaries
- Object constancy
- Motion design and animation
- Use of breadcrumbs
- Interaction history (with undo/redo functions)

6 52 423

Contrast Sensitivity



Contrast Sensitivity

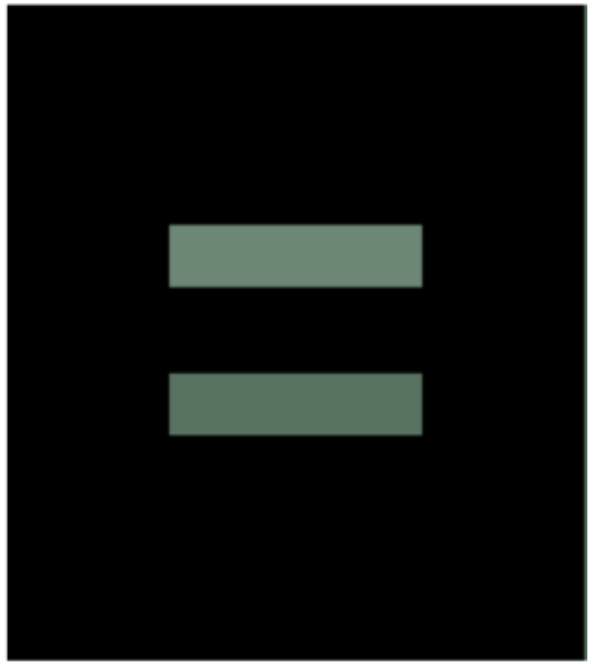


C.Ware, “Visual Thinking for Design”

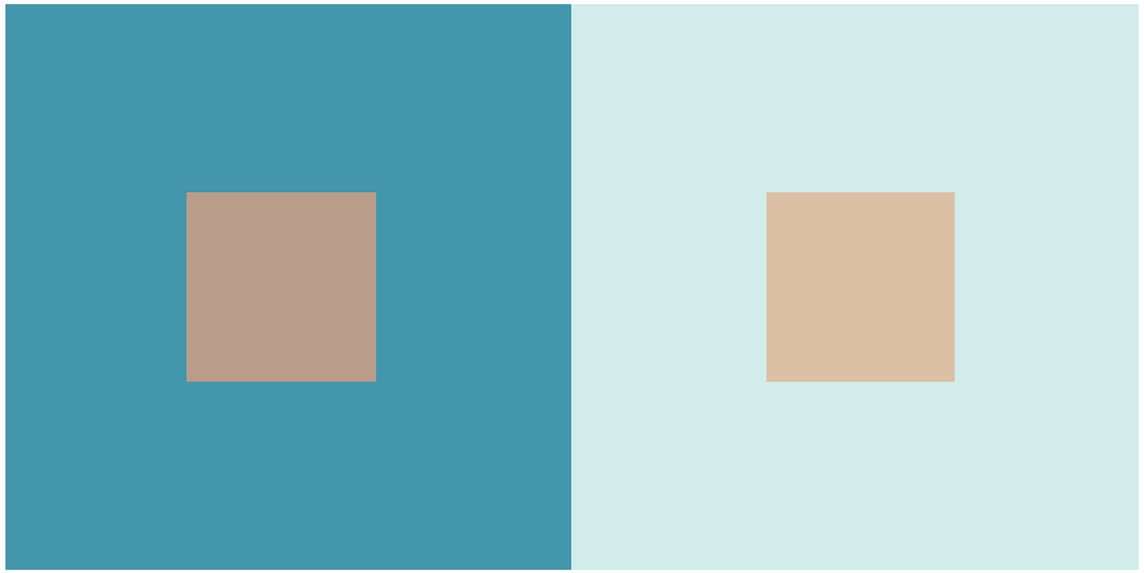
Takeaway

- We have higher contrast sensitivity in the luminance than in the chrominance channel. Show preference to luminance for encoding detail.

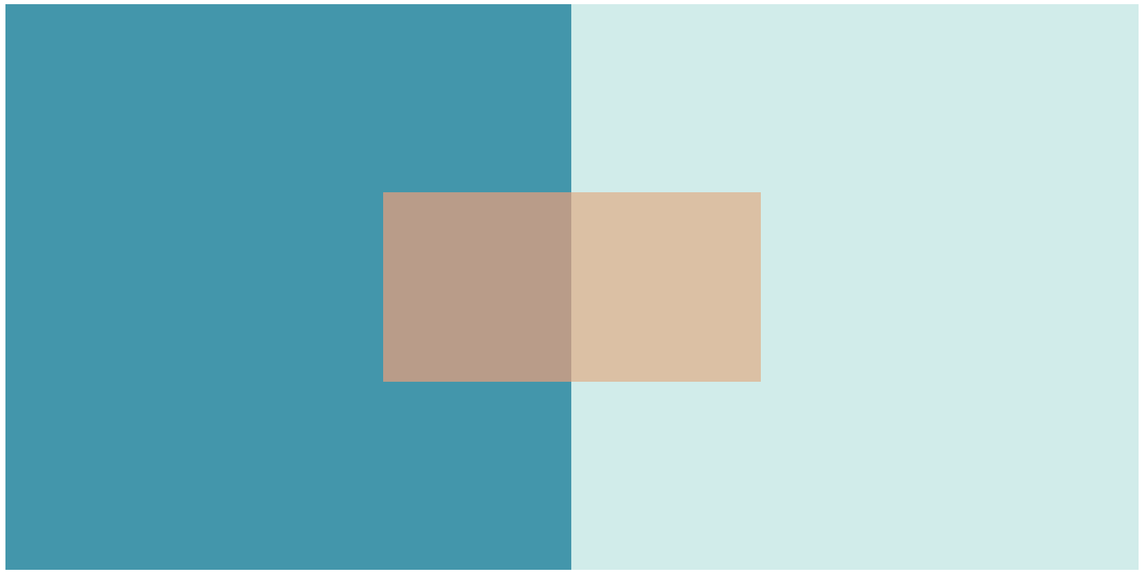
Color Relativity



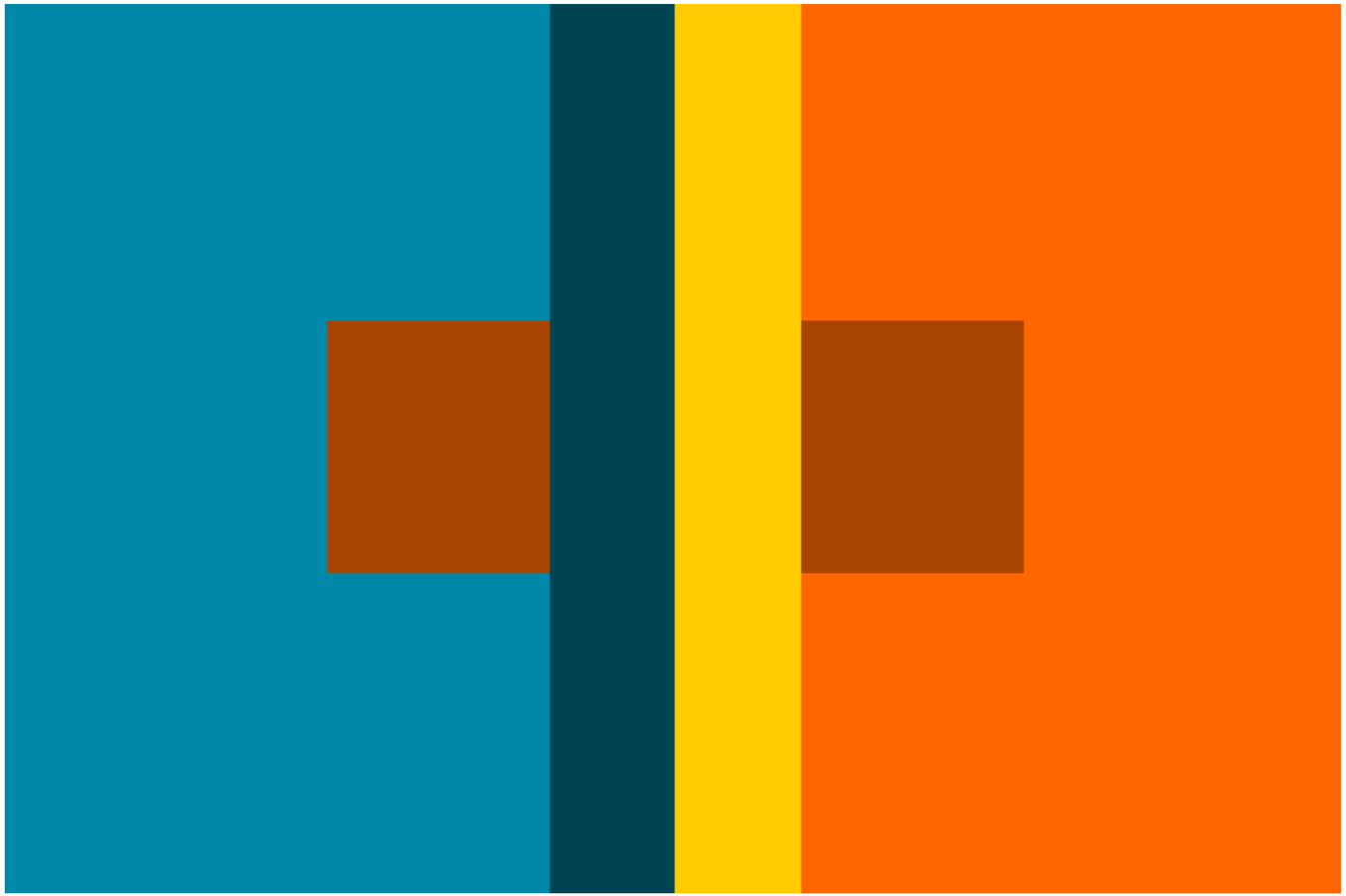
Color Relativity



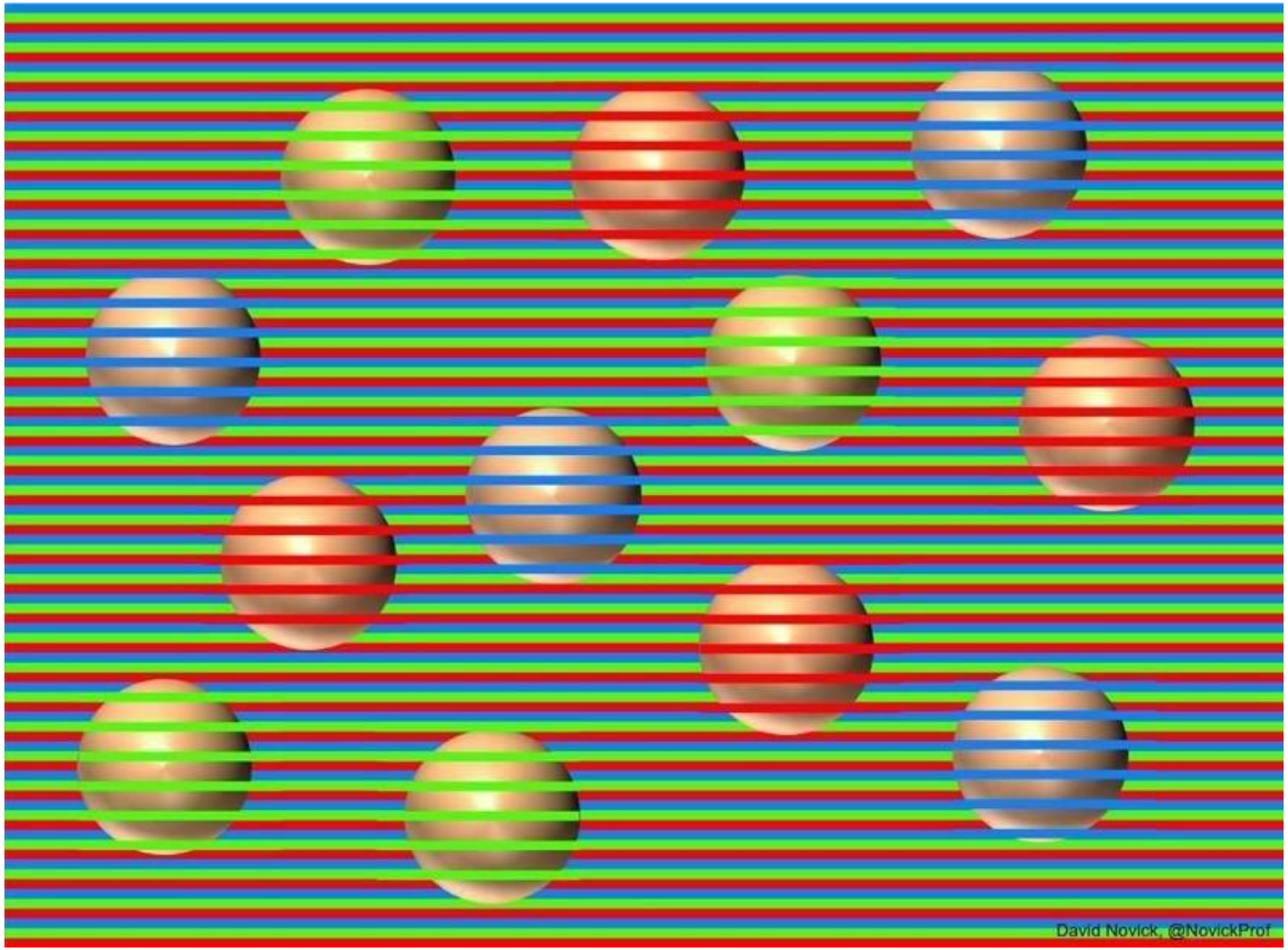
Color Relativity

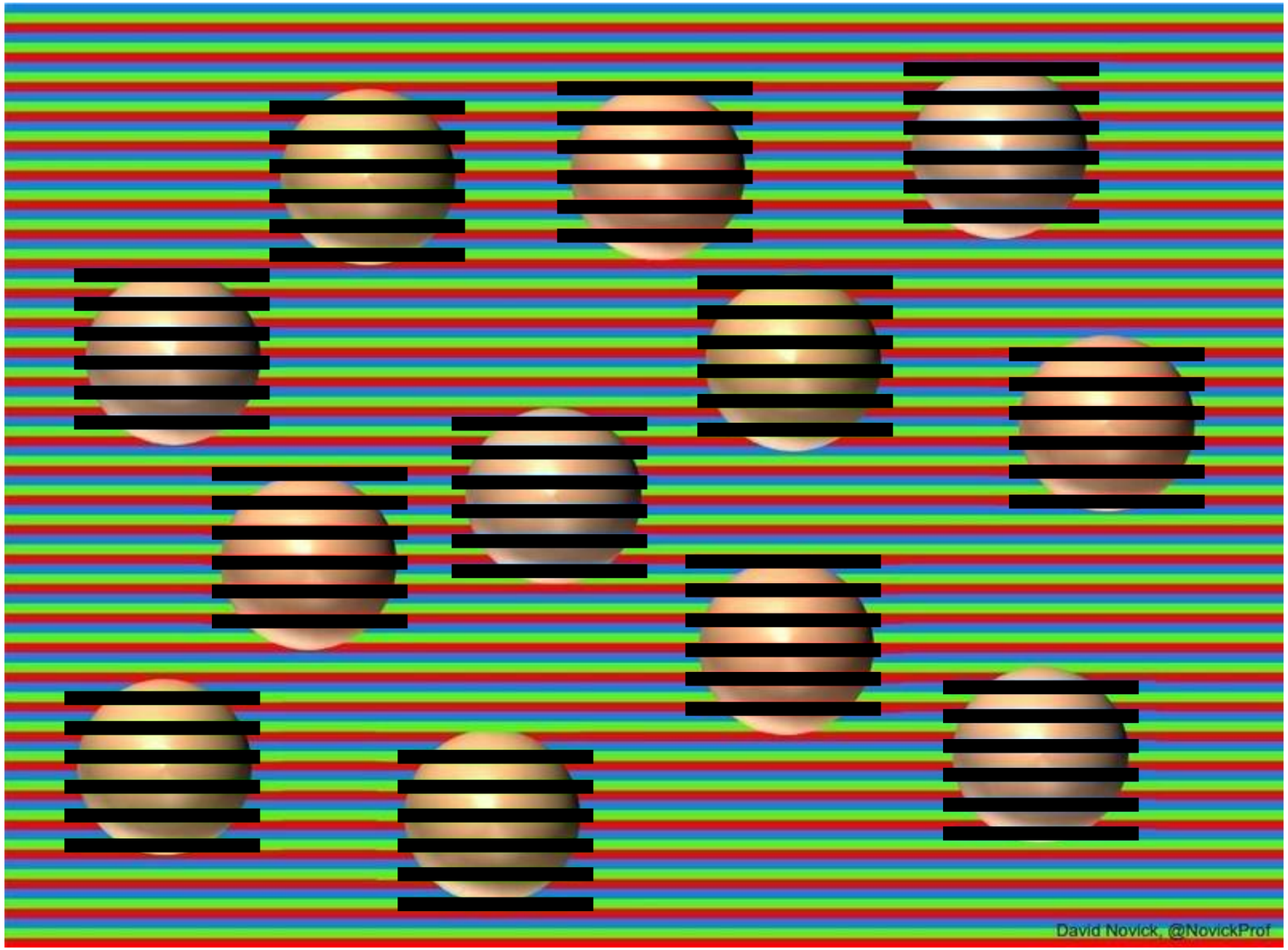


Color Relativity



Color Relativity


David Novick, @NovickProf


David Novick, @NovickProf

Color Relativity

Takeaway

- We have a strong propensity to assume our judgments of color are absolute, when in fact they are extremely relativistic.

- **Do your best to not place data in difficult contexts. Use color sparingly.**

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.

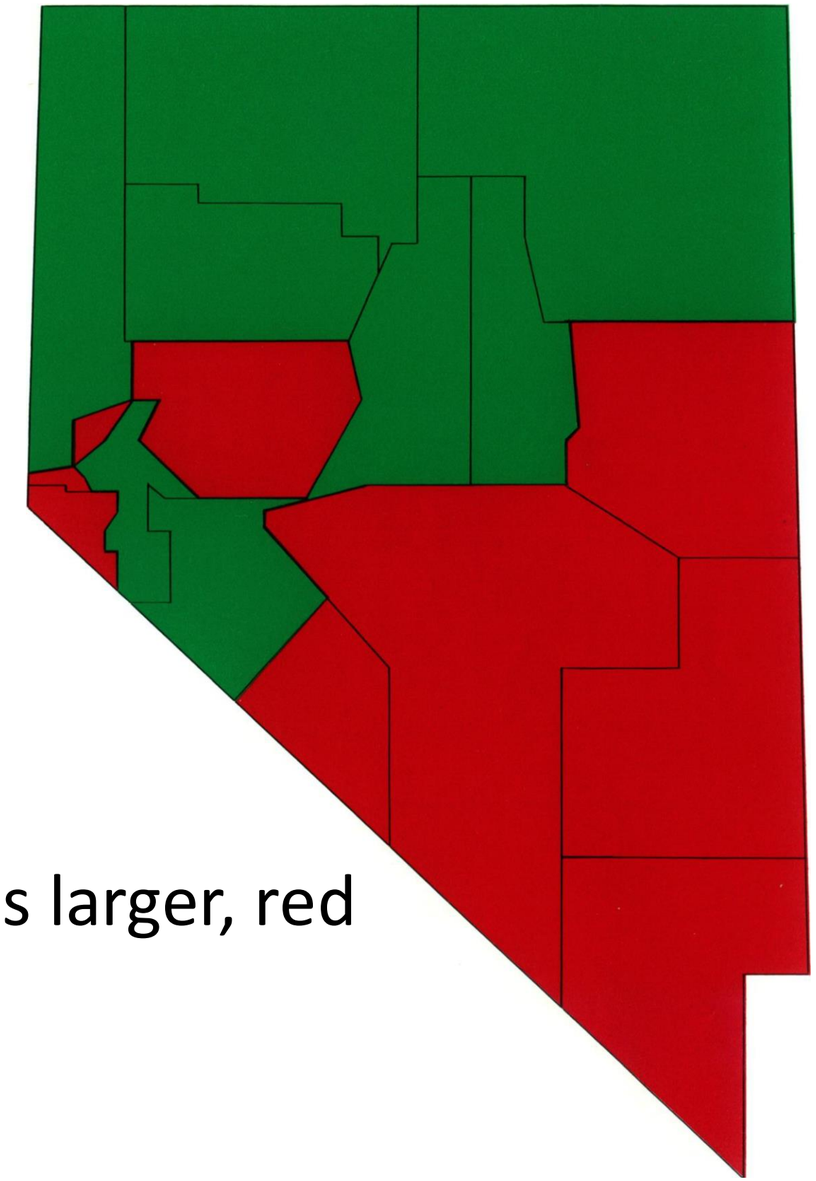
Showing small yellow text on a white background is a bad idea.
There is insufficient luminance contrast.

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

size & color

"the smaller the mark, the less distinguishable are the colors"

-Jacques Bertin



- which area is larger, red or green?

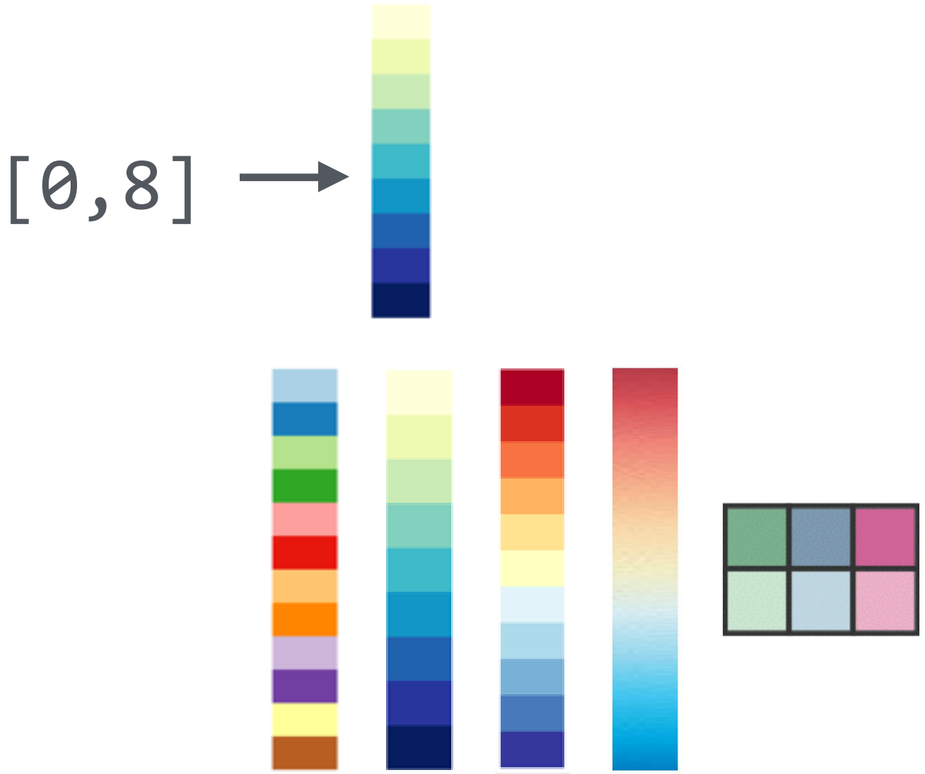
Figure 1. Stimulus From the High-Saturation Group

guidelines

- color is a relative medium—if encoding ordinal data with color, place marks on solid, neutral background
- because of contrast effects, it is difficult to perceive absolute luminance of noncontiguous regions
- for text, ideally use 10:1 ratio, 3:1 minimum

Guidelines

- in small regions use bright, highly saturated colors
- for points and lines use just two saturation levels
- use low saturation pastel colors for large regions and backgrounds

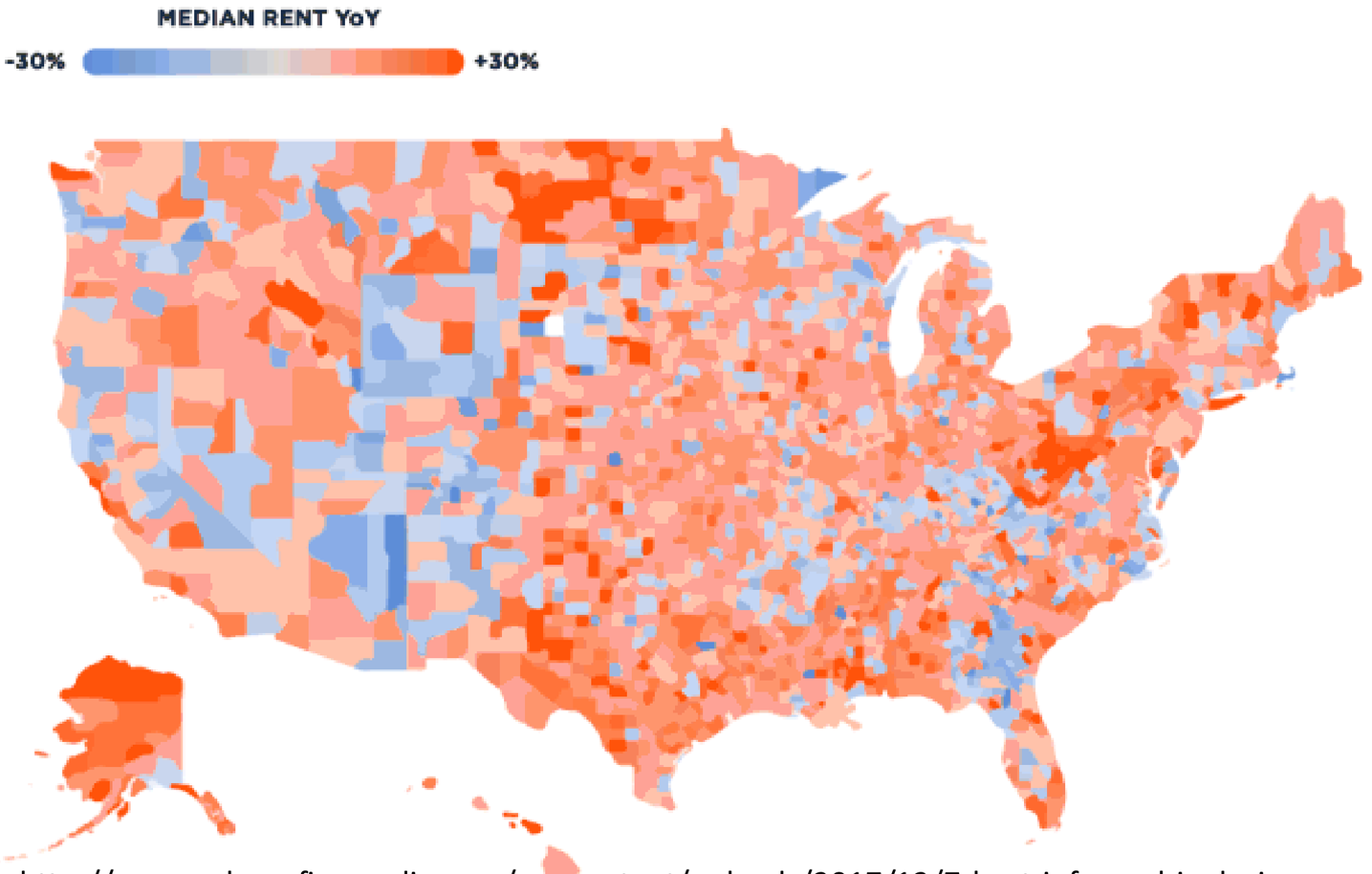


- what is a colormap?
  - specifies a mapping between color and values
    - also called a transfer function

  - categorical vs ordered
  - sequential vs diverging
  - segmented vs continuous
  - univariate vs bivariate

- **expressiveness**: match colormap to attribute type characteristics!

Rents are rising in 78% of counties in the U.S., year-over-year, increasing the urge to buy.[4]



From: http://www.columnfivemedia.com/wp-content/uploads/2017/12/7-best-infographic-design-2017..gif

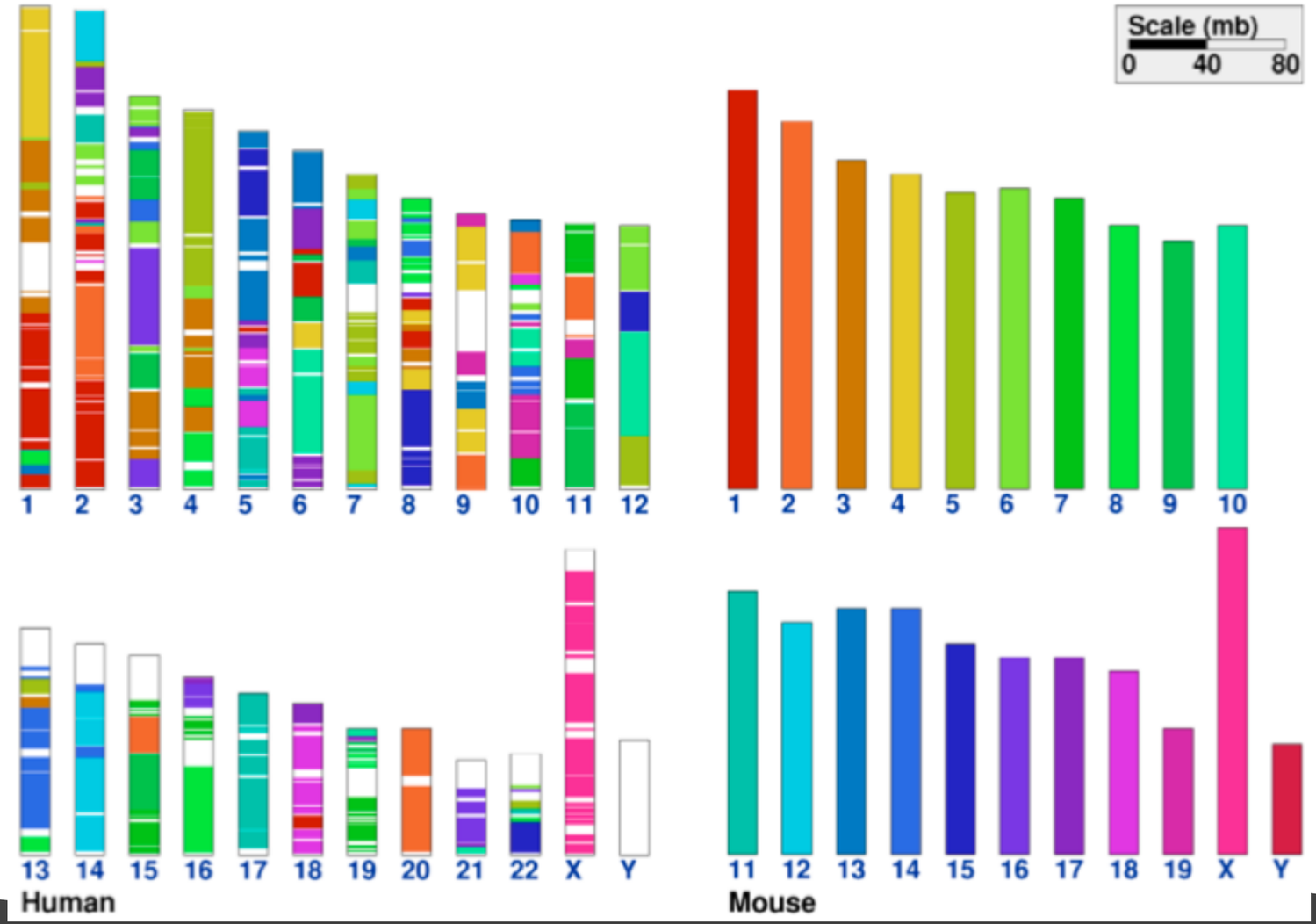
guidelines

- categorical colors are easier to remember if they are nameable
- ordered colormaps should vary along saturation or luminance
- bivariate colormaps are difficult to interpret if at least one variable is not binary

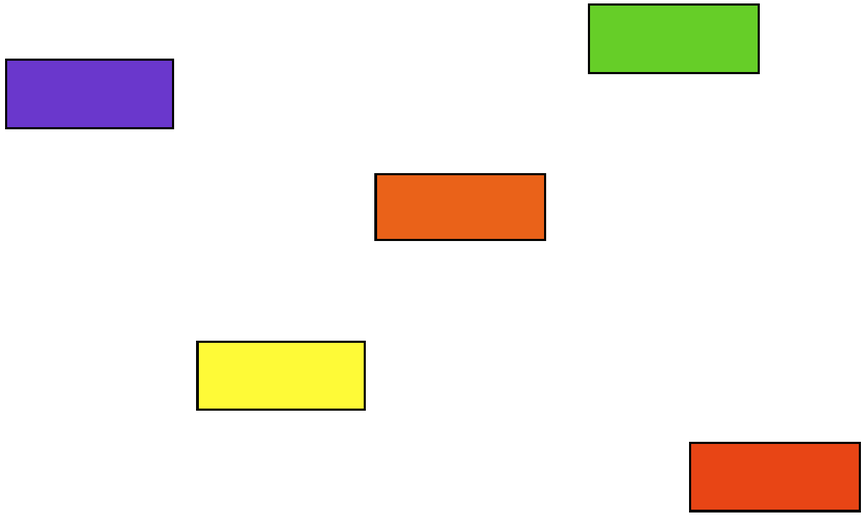
hues for categories

Distinguishability

- only good at distinguishing 6-12 simultaneous colors

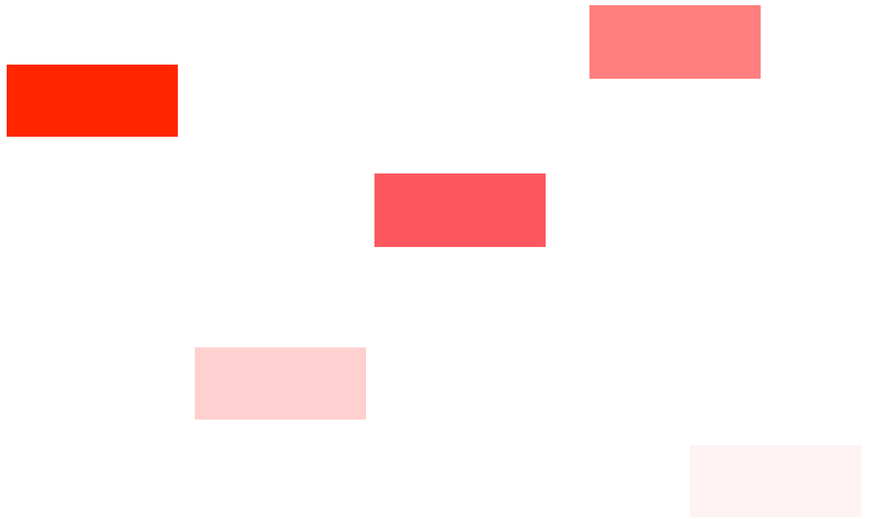


order these colors…



order these colors…

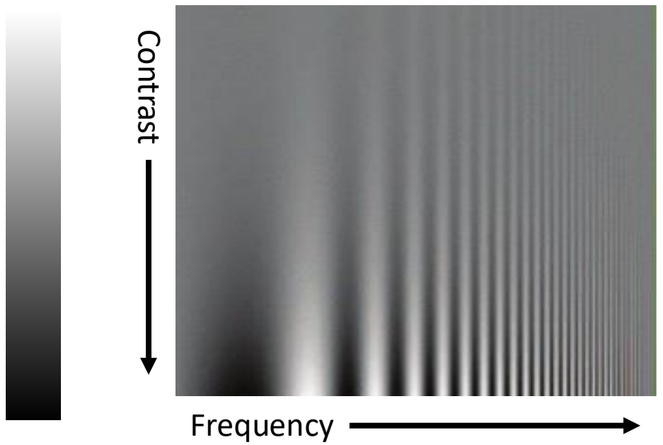
order these colors…

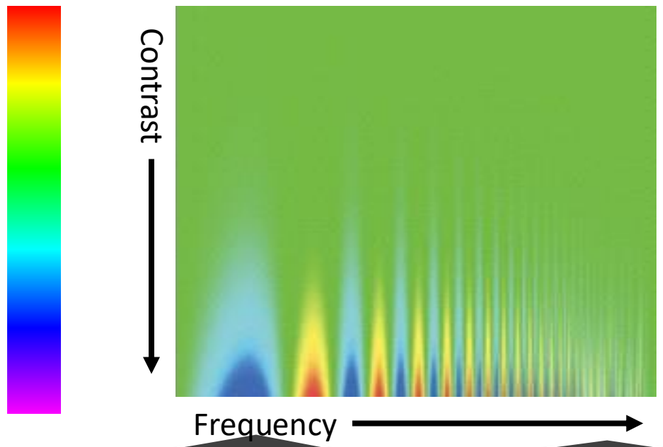


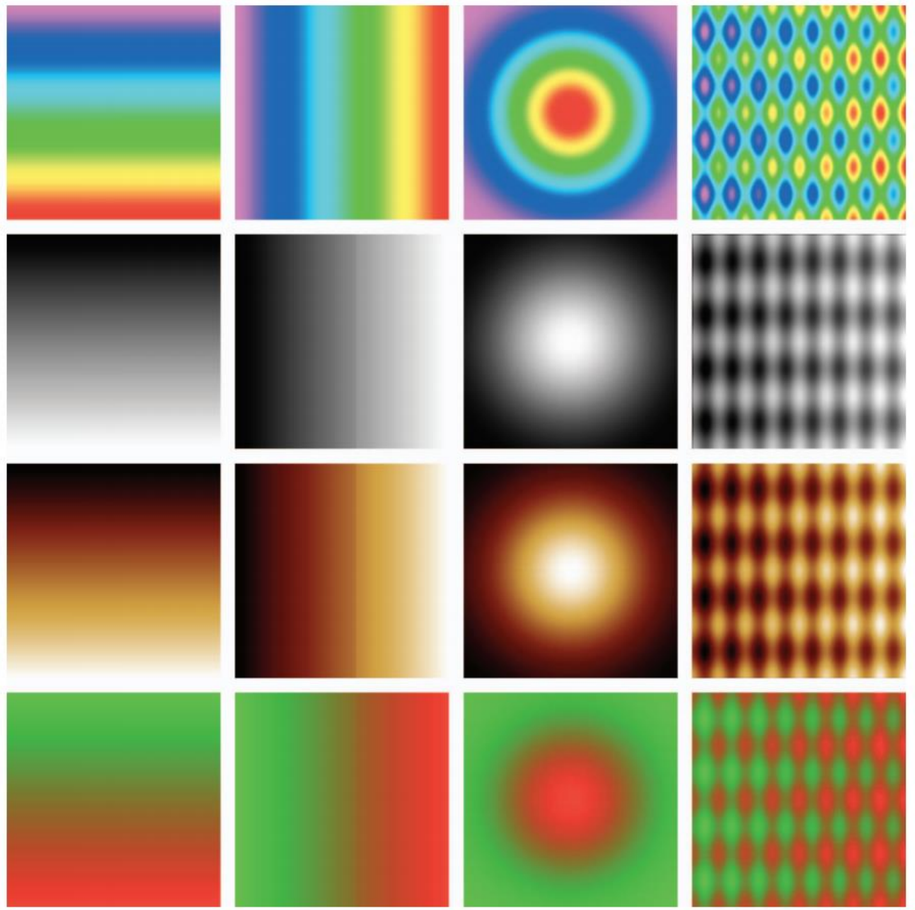
guidelines

- luminance and saturation are most effective for ordinal data because they have an inherent ordering
- hue is great for categorical data because there is no inherent ordering
  - but limit number of hues to 6-12 for distinguishability
- number of hues and distribution on the colormap should be related to which and how many structures in the data to emphasize

rainbow colormaps: challenges

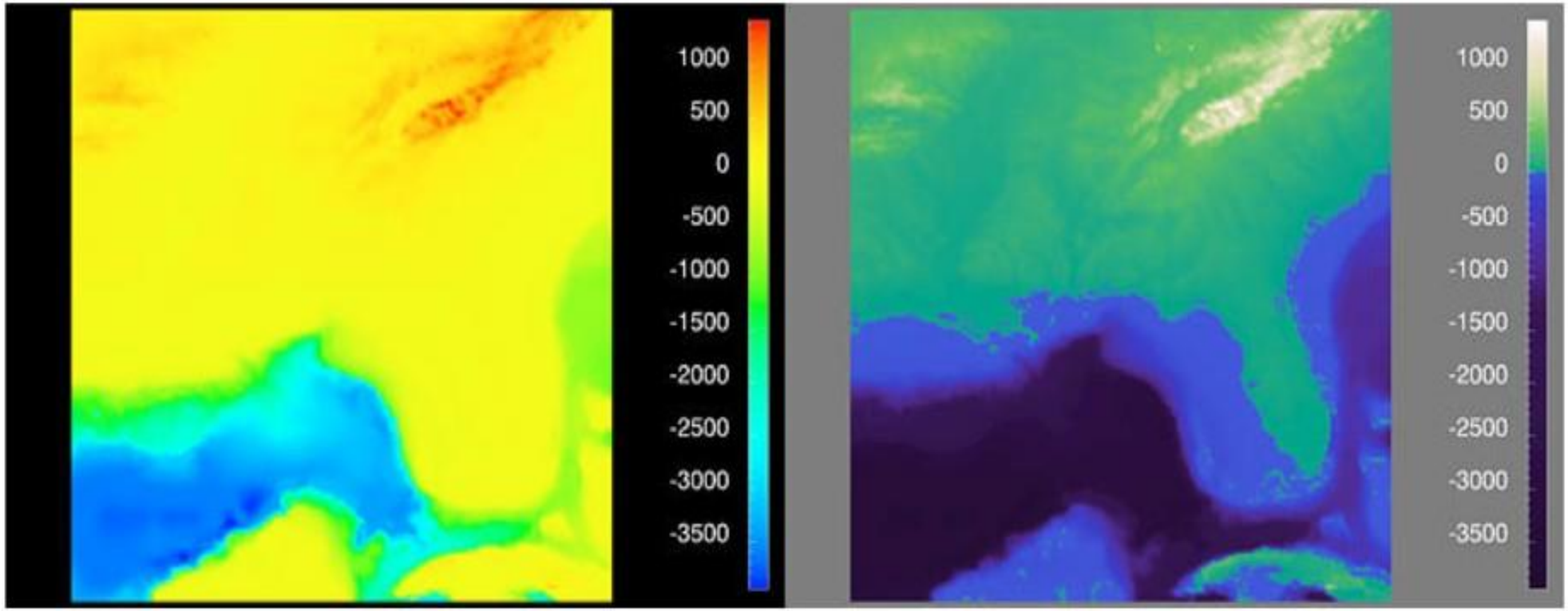






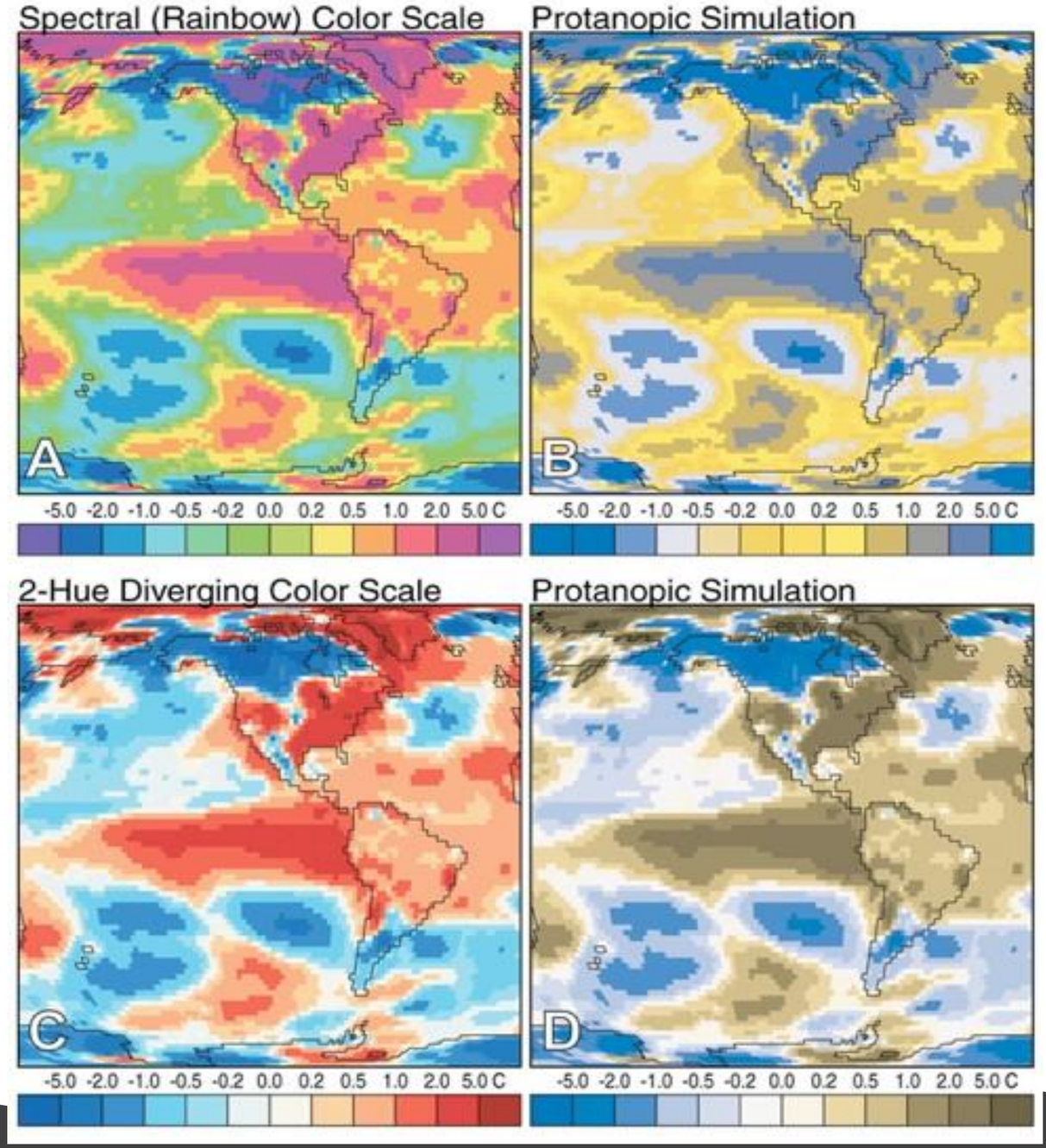
- Borland 2007

rainbow colormaps: challenges



zero crossing not explicit

rainbow colormaps: challenges

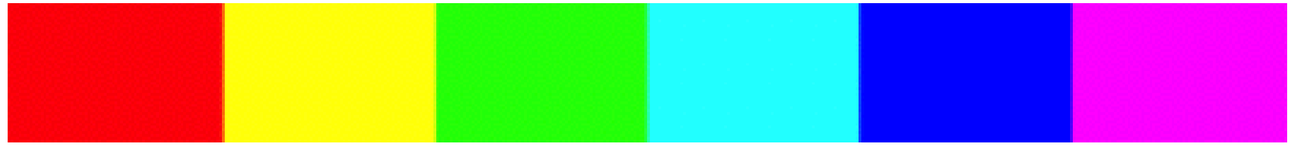


Color section Guidelines

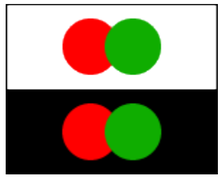
Rainbow guidelines

poor

better

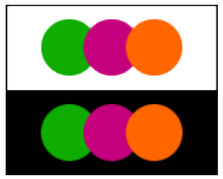


Color Harmonies



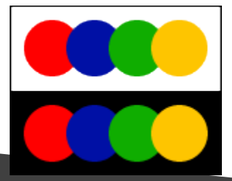
- **Complementary**—high contrast creates a vibrant look

- **Analogous**—often found in nature and are harmonious and pleasing to the eye



- **Triad**—vibrant, even if you use pale or unsaturated versions of your hues

- **Split-complementary**—same strong contrast as the complementary but less tension



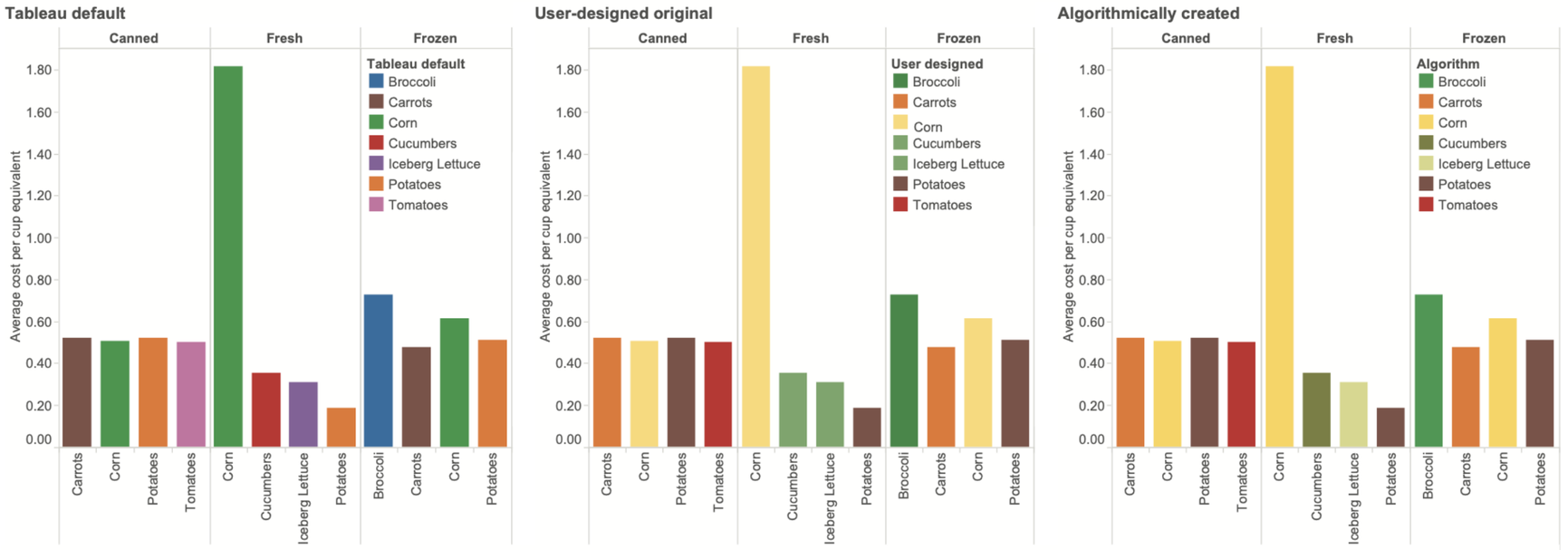
- **Rectangle**—rich color scheme offers plenty of possibilities for variation

http://www.tigercolor.com/color-lab/color-theory/color-harmonies.htm

LOOK TO NATURE

A Linguistic Approach to Categorical Color Assignment for Data Visualization

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



SIMPLICITY

- choose one color to be used in larger amounts
- be selective about the base color
- use other colors to add interest

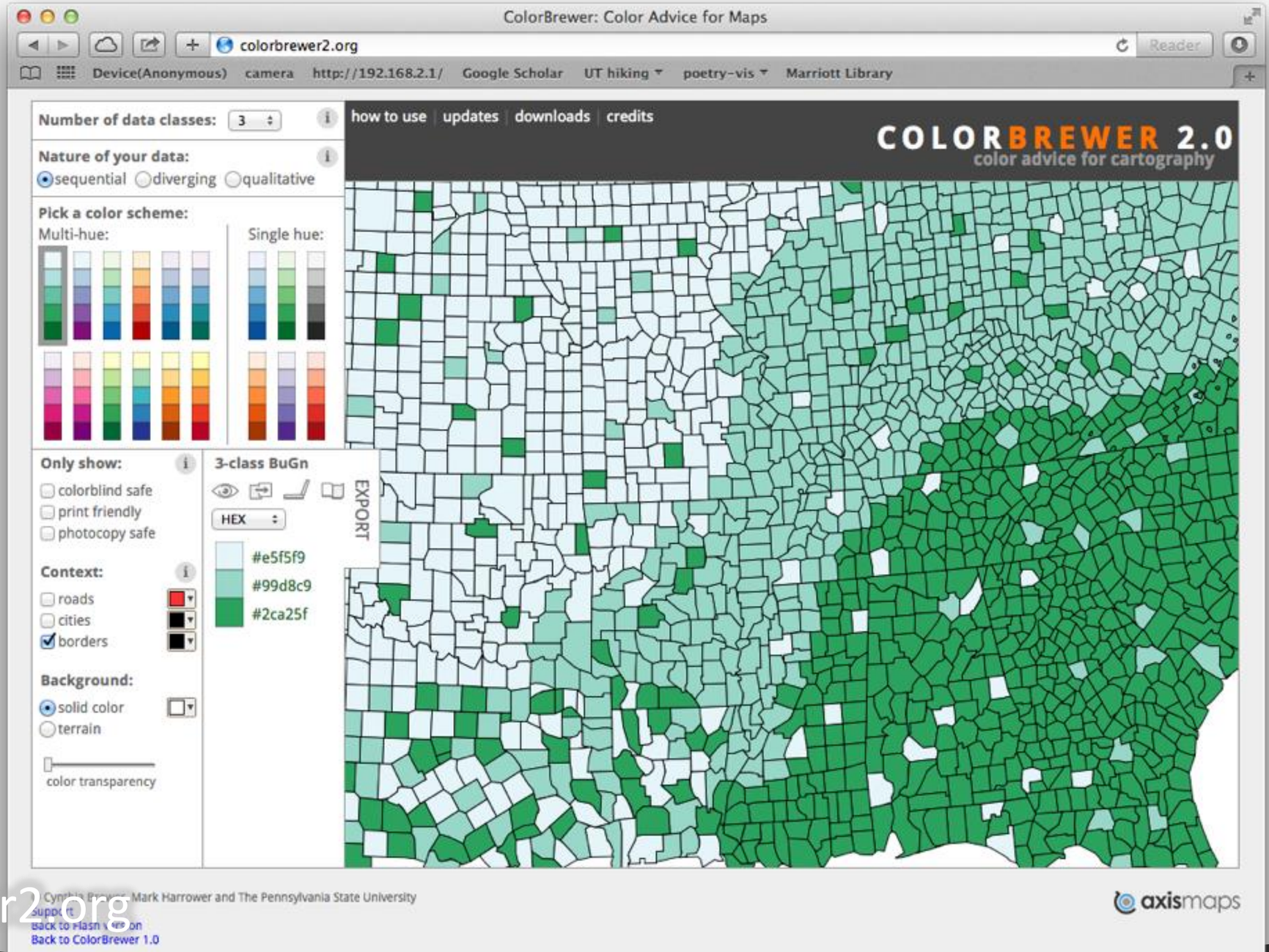
AVOIDANCE OF COLOR

- use neutrals (work with any scheme)
  - black, white, grey
- use diagrammatic marks (may be better encoding channels)
  - size, shape, texture, length, width, orientation, curvature and intensity

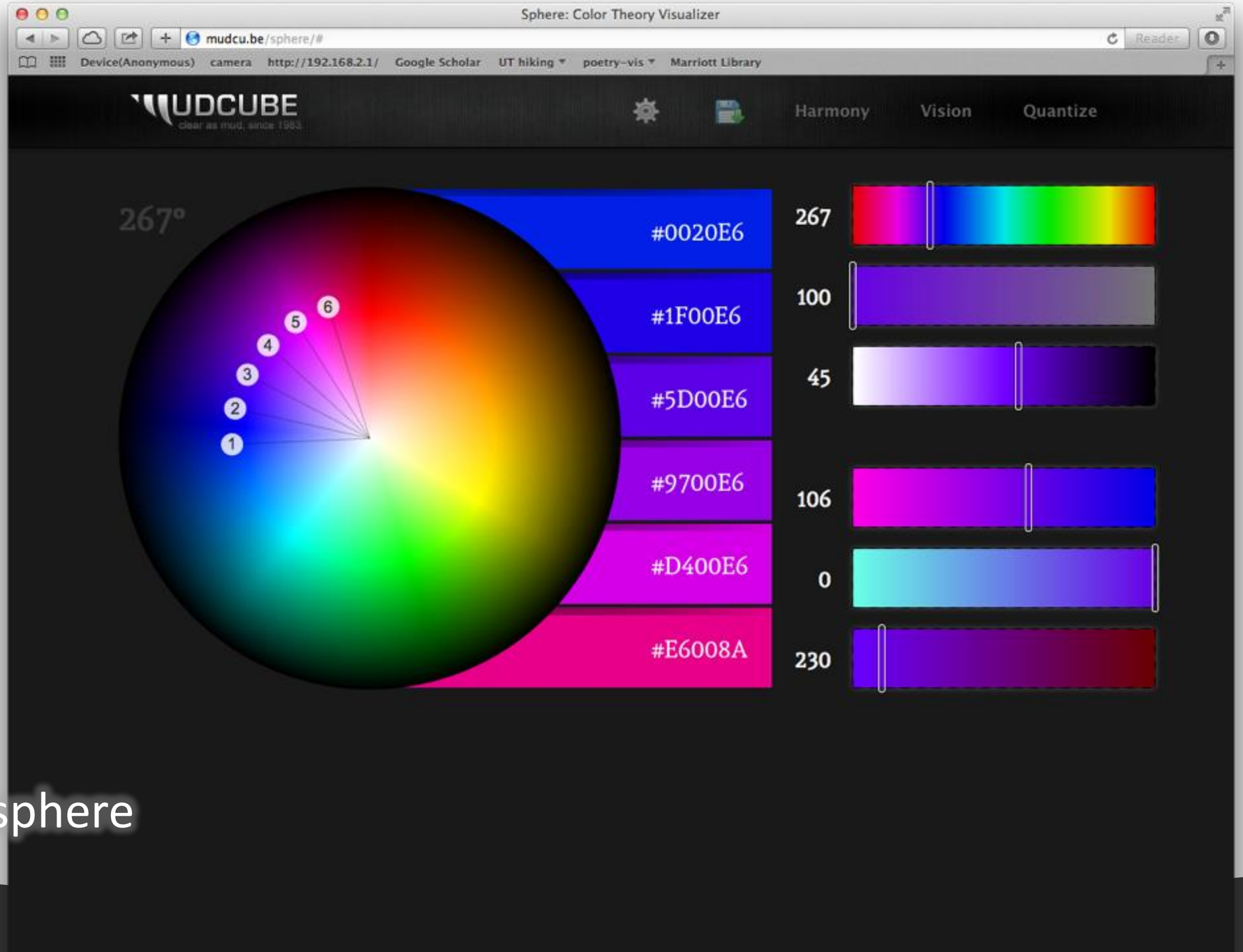
Get it right in black and white

- Maureen Stone

tools for color



- Colorbrewer2.org



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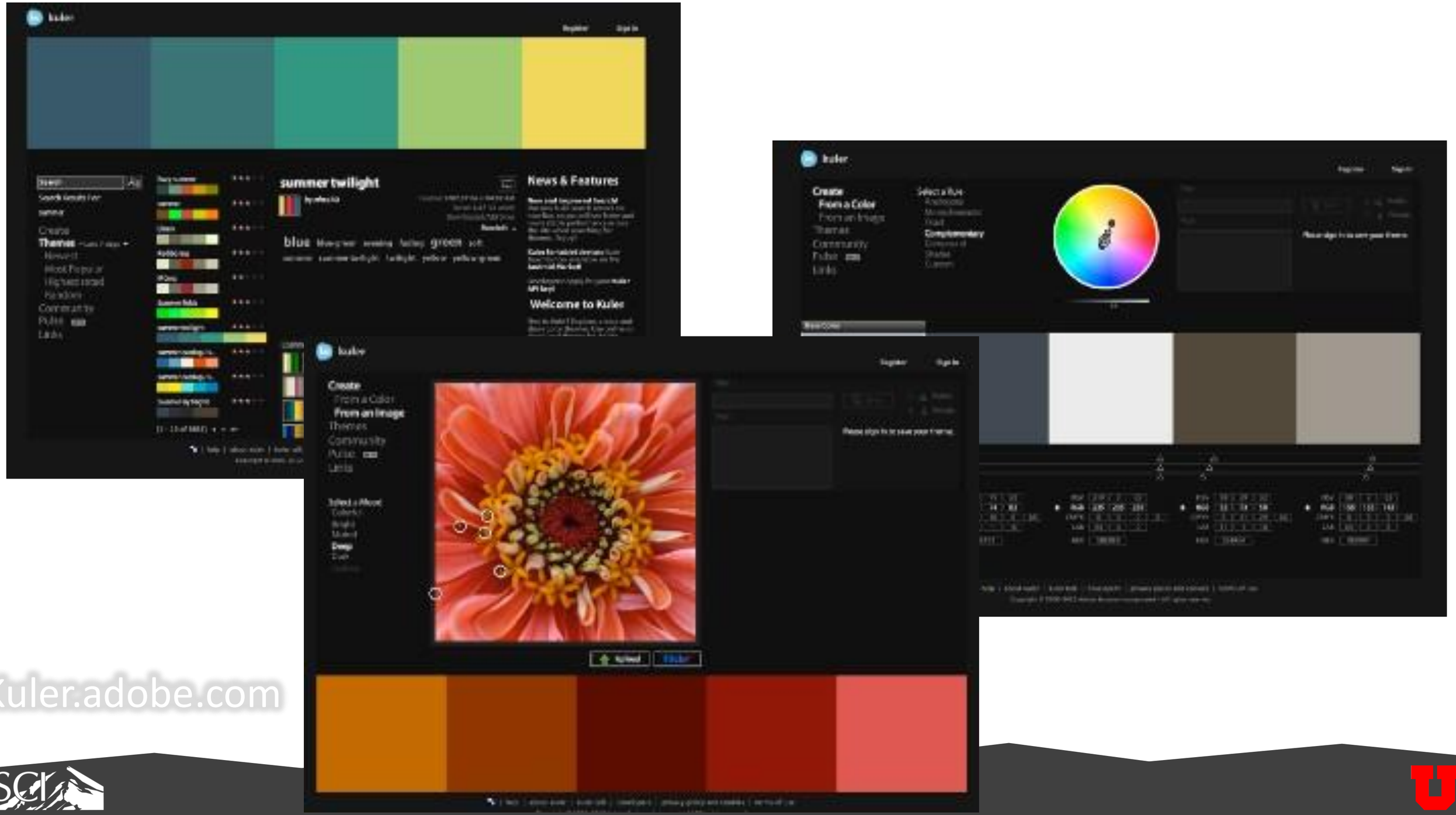

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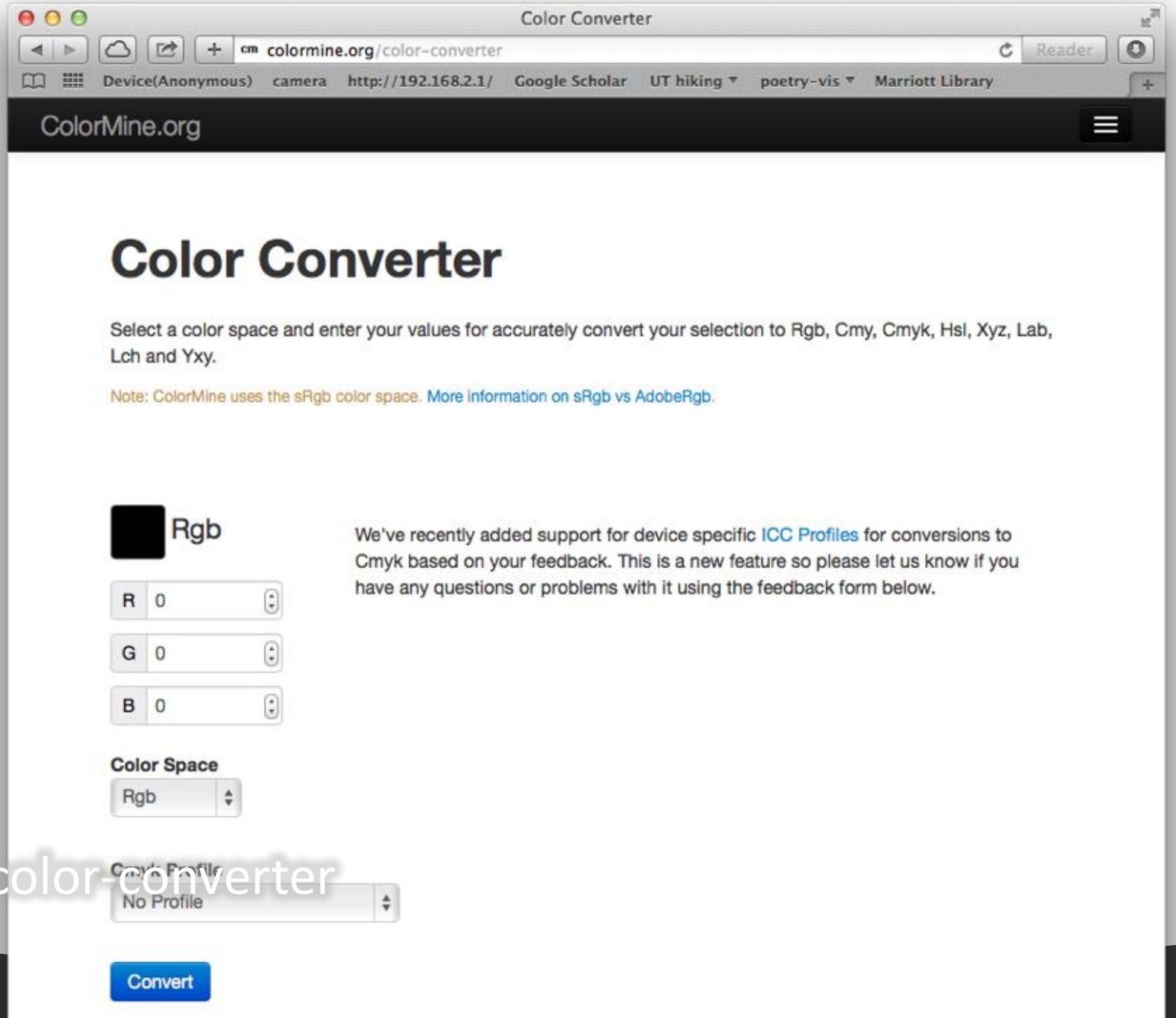

Colormine.org/color-converter

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-Eve D.

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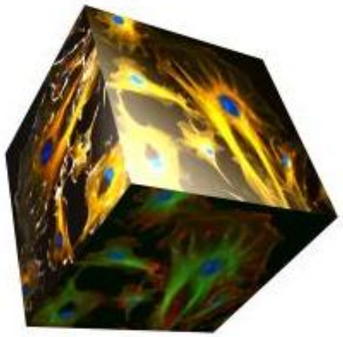

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