## Color Roadmap

Color Vision
Specifying RGB Color

Color Design for VIS
Color Vision Deficiencies

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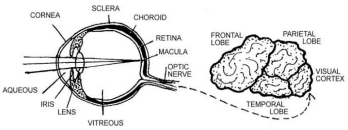
## Physical World / Visual System



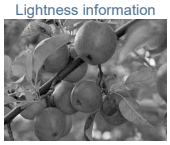

Lights, objects

Eye, optic nerve, visual cortex

Image credits: Dave Connolly, Magden Army Medical Center

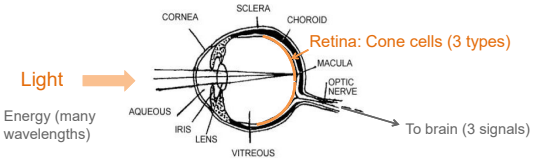
## Fundamental difference: Shape from Color

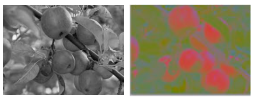
Lightness information



Color information

## Color vision: Encoding light

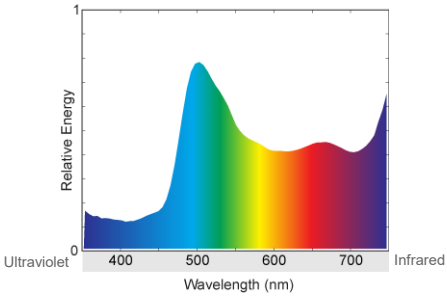


1 for lightness 2 for color

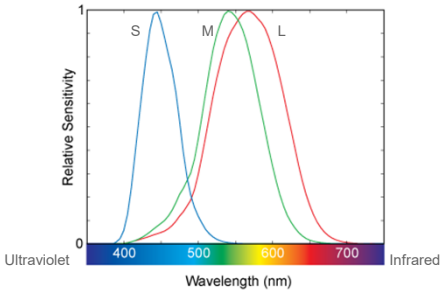
## Light: Energy at different wavelengths

Spectral Distribution, or Spectrum




## Encoding functions: Cone response

Three cones (S, M, L)

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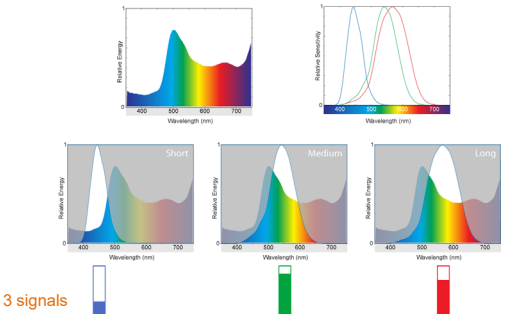
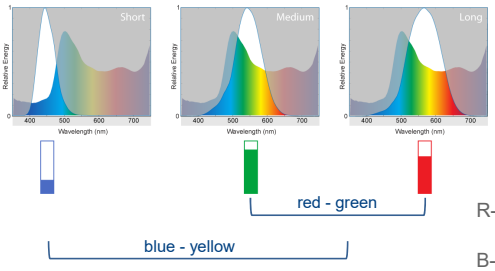
Light → Retina: (Cone cells)




## Encoded light: Lightness + differences



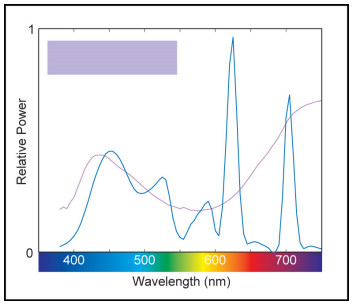

red - green R-G

blue - yellow B-Y

All three combined for lightness L

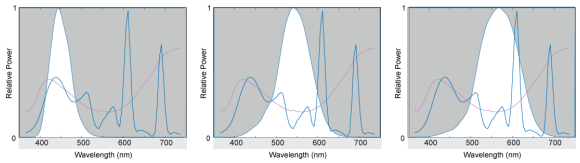
## Encoded light: Two spectra can "look the same"

Metamerism




From M.Stone, *A Field Guide to Digital Color*, AK Peters 2003

## Only cone response matters




Three cones, three signals: Trichromacy

## Consider image reproduction

## Digital imaging: RGB pixels

Natural Spectra

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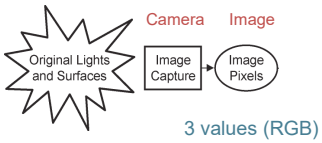
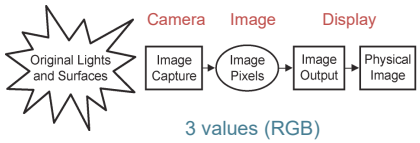
## Digital imaging: RGB pixels




3 values (RGB)

Natural Spectra

## Digital imaging: RGB pixels

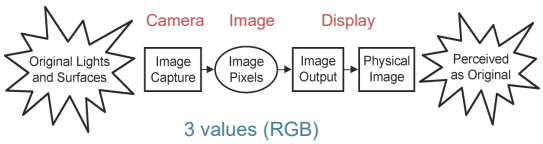



3 values (RGB)

Natural Spectra

Display Spectra

## Digital imaging: RGB pixels

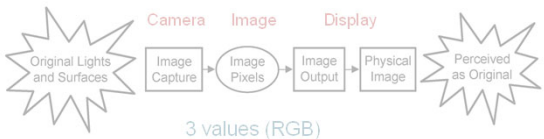



3 values (RGB)

Natural Spectra

Display Spectra

## Digital imaging: RGB pixels




3 values (RGB)

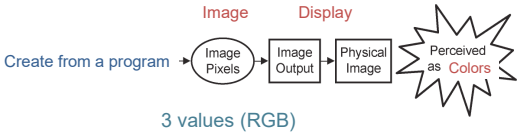
Natural Spectra

Display Spectra

This is an imperfect process

Image editors: Photoshop, Lightroom, etc.

## Designing for Displays




3 values (RGB)

Display Spectra

Perceived color depends on the display properties

## 3

**Perception**

Cone response
Lightness + color

**Creation**

RGB, HSV
CMY(K), BRY

**Measurement**

Tristimulus values (XYZ)
CIELAB (L*,a*,b*)
CIELUV (L*,u*,v*)
…

**Encoding**

sRGB
Adobe RGB
rec 709 (video)
…

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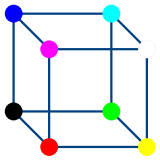
## Specifying RGB Color

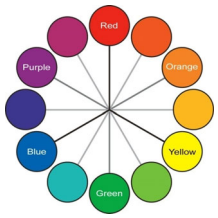
## RGB Color Cube



R,G,B vector space
0..1, or 0..255

## Hue (color wheel)

Consistent order, different spacings



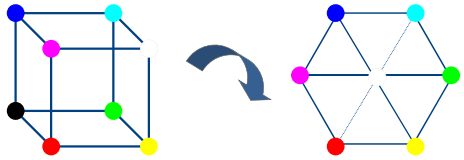

## Value (lightness)

Perceived lightness

## Chroma (saturation)

Intensity, purity, distance from gray

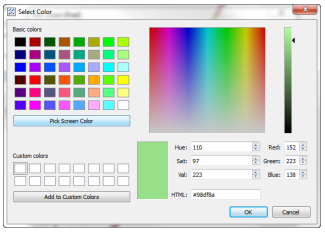
## More “intuitive” RGB



R,G,B vector space
0..1, or 0..255

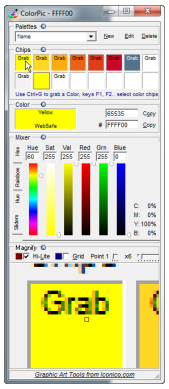
HSV, HLS, HSB…
Simple transform of RGB

## RGB color pickers

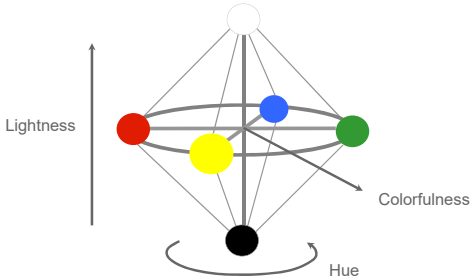


QT picker, used by Tableau

ColorPic




## Perceptual Color Spaces

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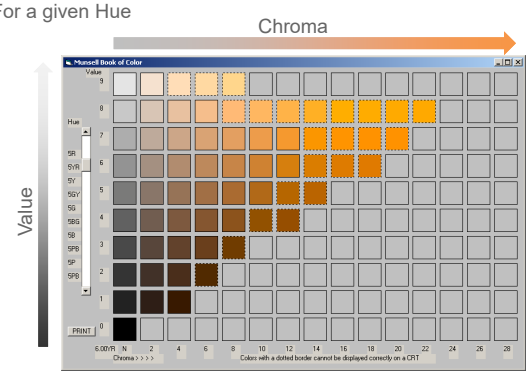
## Albert Munsell

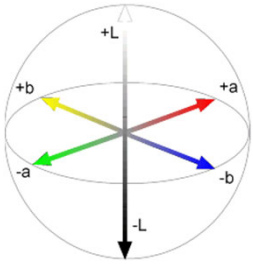
Developed the first perceptual color system based on his experience as an artist (1905).

For a given Hue




Colors with a dotted border cannot be displayed correctly on a CRT

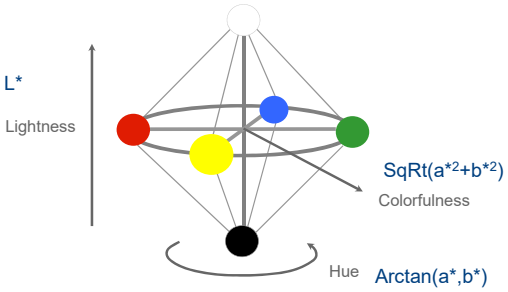
## CIELAB



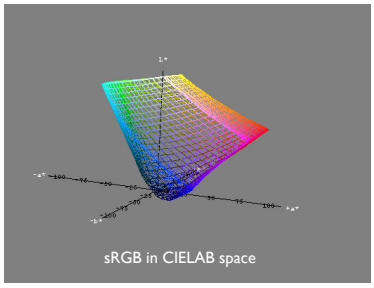

Computed from XYZ
- Calibrated RGB
- Reference white
- L*, a*,b*

"Perceptually uniform"

## CIELAB is a perceptual color space



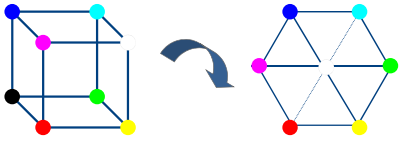

## RGB color gamut in CIELAB




Exact specification requires display calibration

## These are NOT perceptual models

V or L describe generated lightness, not perception



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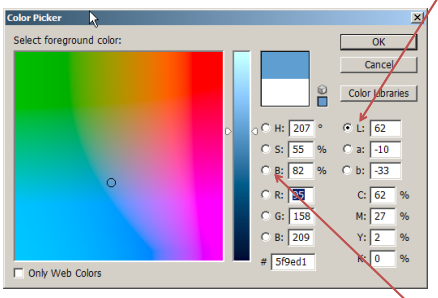
Same generated lightness: B or V, from HSB, HSV
Different perceived lightness: Y from XYZ (luminance)
Different perceived lightness: L*, from CIELAB

B = 100
Y = 90
L* = 98

B = 100
Y = 9
L* = 30

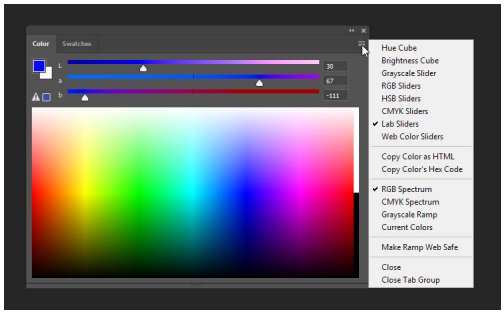
## Designing with CIELAB

L* = perceived lightness



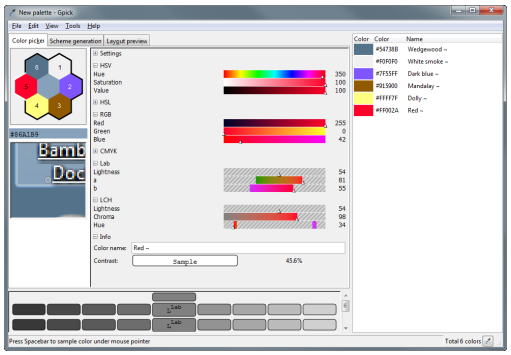

Adobe Photoshop

B = %max (R,G,B)

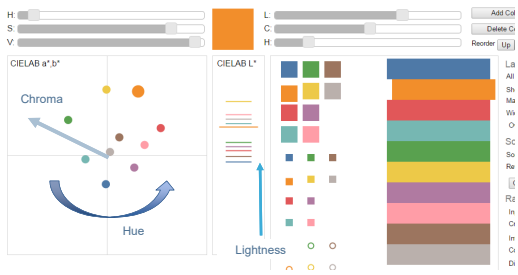


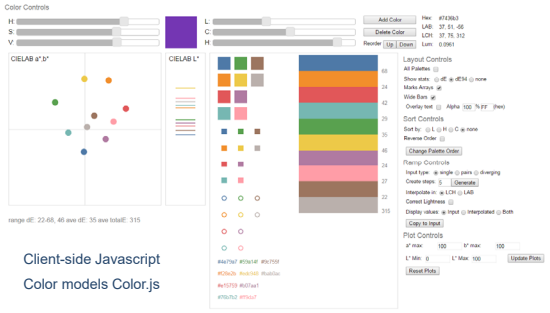

Current Photoshop

http://www.gpick.org/



## Maureen's Palette Designer



Client-side Javascript
Color models Color.js

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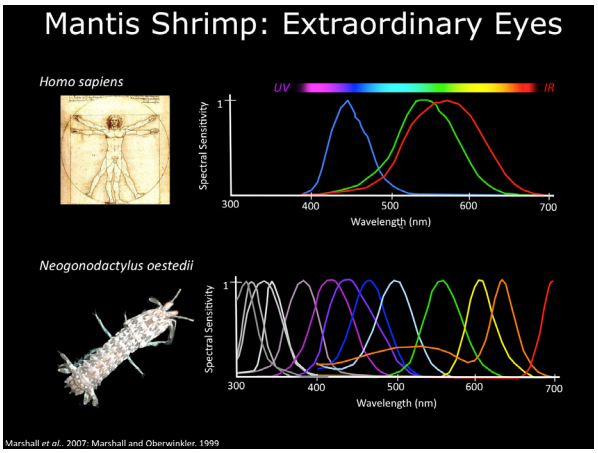
Mantis Shrimp




## Perception

Cone response
Lightness + color

## Creation

ABCDEFGHIJKLMNO,
…

15

## Measurement

Tristimulus values (XYZ)
CIELAB (L*,a*,b*)
CIELUV (L*,u*,v*)
…

## Encoding

sRGB
Adobe RGB
rec 709 (video)
…

Questions on part 1?

"… avoiding catastrophe becomes the first principle in bringing color to information:
*Above all, do no harm."*

*—E. R. Tufte*

If you can't use color wisely,
it is best to avoid it entirely
Above all, do no harm

## Tufte's fundamental uses

To label (identify or group)
To measure (color to quantity, color scales)
To represent or to imitate reality
To enliven or decorate

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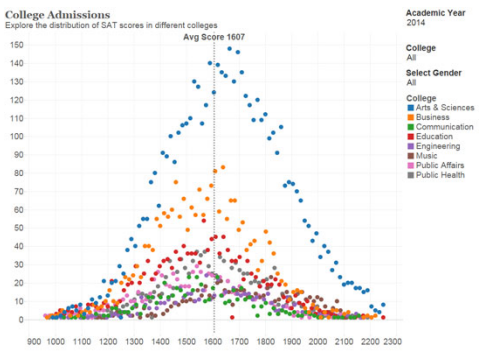
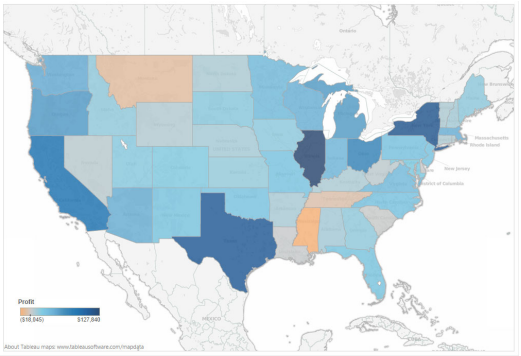
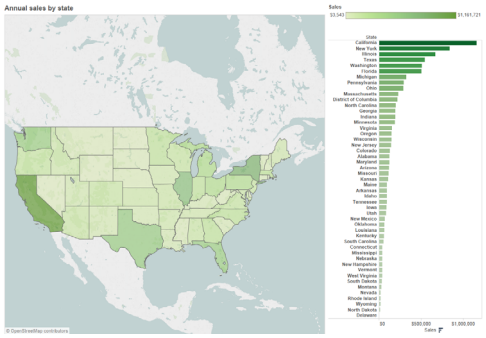
## To Label: Categorical Palettes



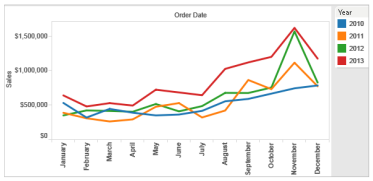

## To Measure: Quantitative Ramps




## Lightness encodes values




## Different colorings tell different stories




## Similar, but still distinctly different

## Ordered colors for ordered relationships

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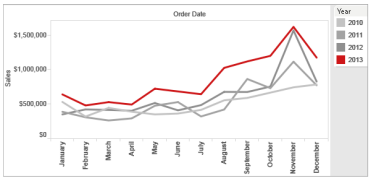
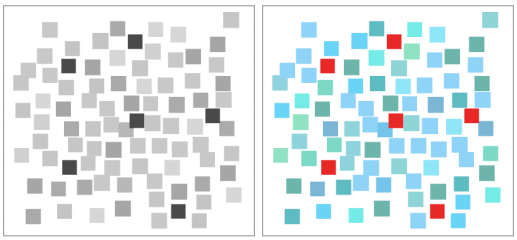
## Contrasting color for emphasis




## Roles for color

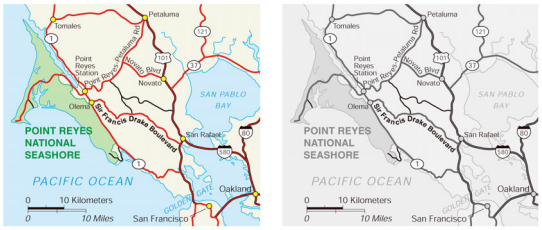
To label (identify or group)
To measure (color to quantity, color scales)
To represent or to imitate reality
To enliven or decorate
To manage attention

## Contrast & Analogy



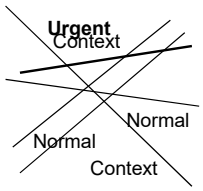
Contrast separates, analogy groups

## "Get it right in black and white"



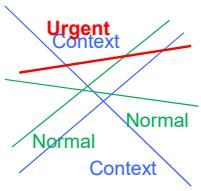

Maps courtesy of the National Park Service (www.nps.gov)

## Fix this




From Larry Arend colorusage.arc.nasa.gov

## Contrast creates visual layers




Color contrast

Luminance contrast

From Larry Arend colorusage.arc.nasa.gov

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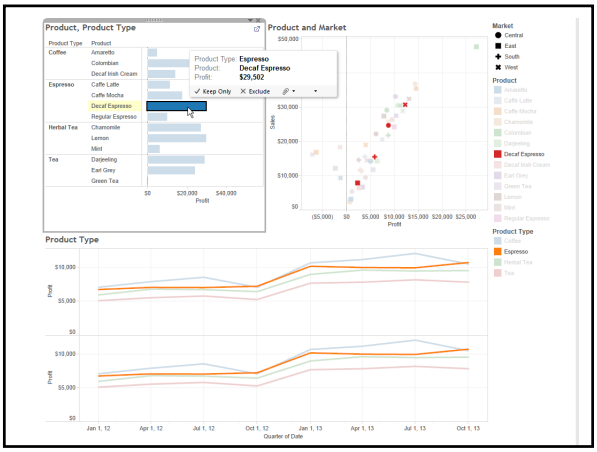
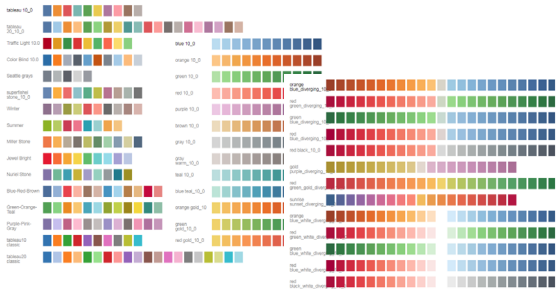



Know what is important to show

## Color palettes for VIS



## Principles for palettes

Visibly distinct (including size, background, etc.)

Easy to remember, to reference

Make them beautiful

## Principles for palettes

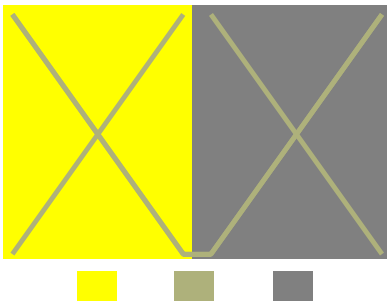
Visibly distinct (including size, background, etc.)

Easy to remember, to reference

Make them beautiful

"Color is the most relative medium in art."

*—Josef Albers, Interaction of Color*



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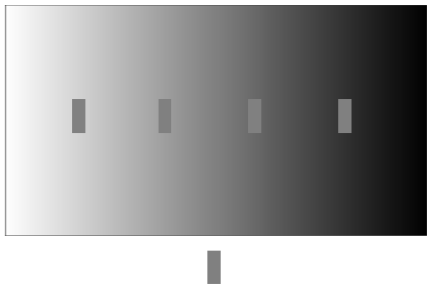
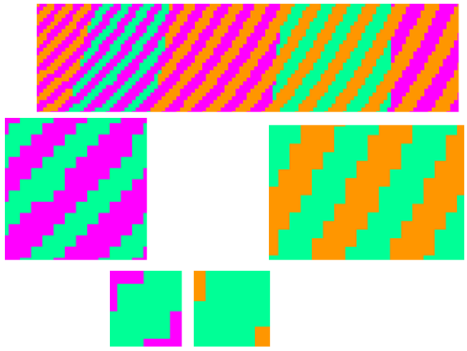
## Gray is relative

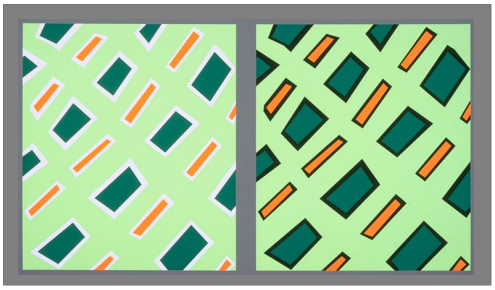


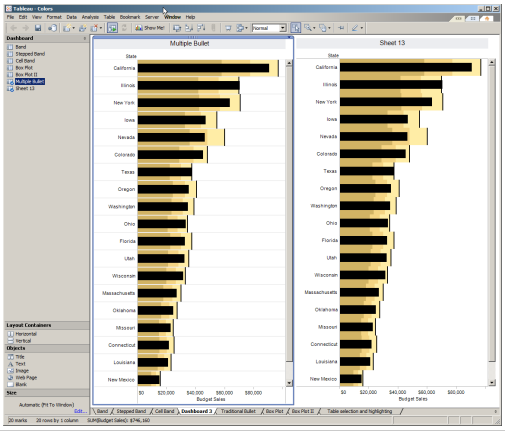
From Stephen Few

## Simultaneous contrast: color is relative

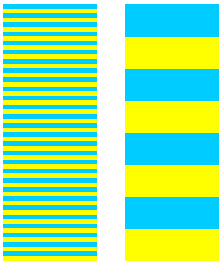


## Bezold Effect: Outlines matter





## Color and contrast depends on size



Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University

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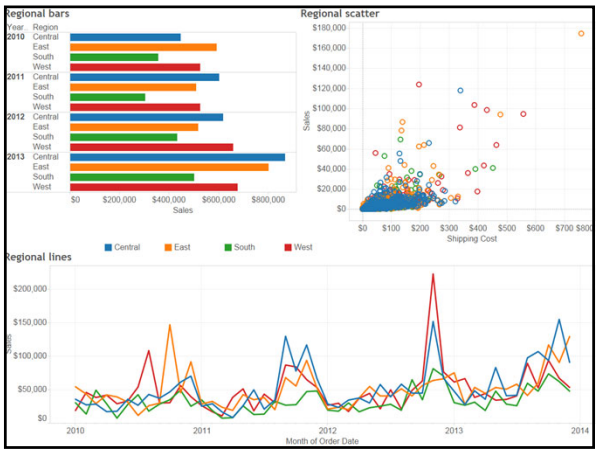
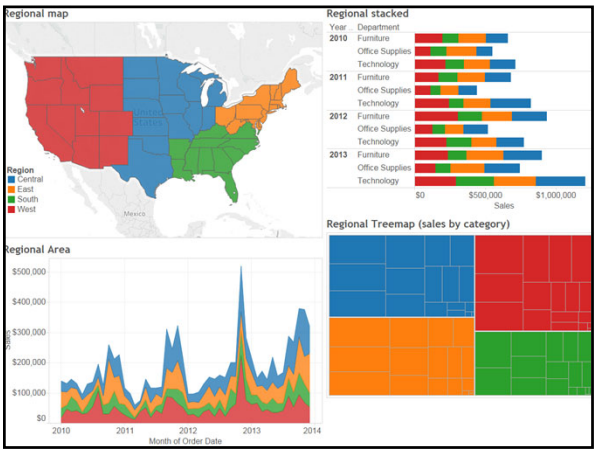
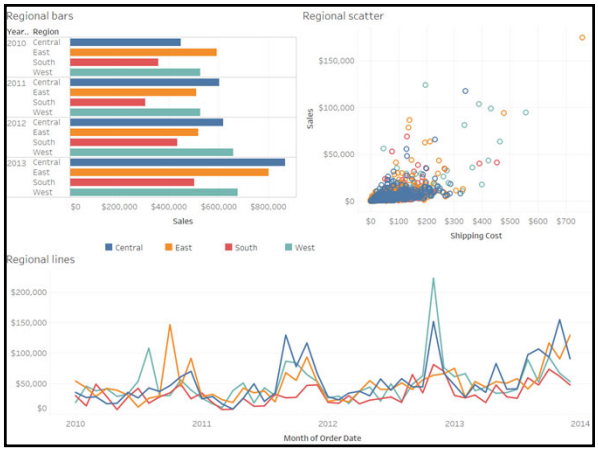
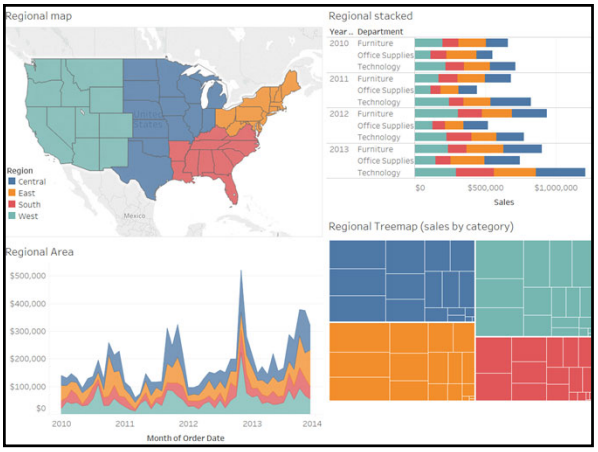


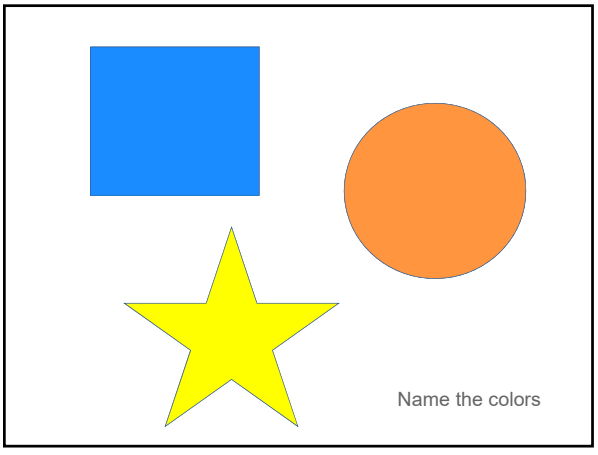




## Principles for palettes

- Visibly distinct (including size, background, etc.)
- Easy to remember, to reference
- Make them beautiful

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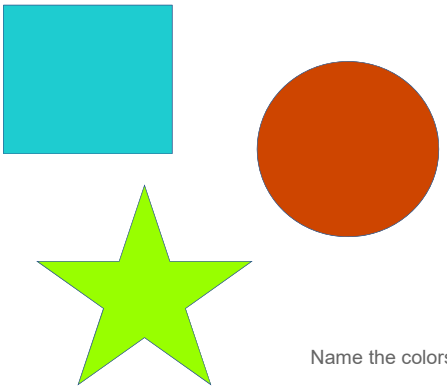


Name the colors

## Color Names

Basic names (Berlin & Kay, 1969)
- Linguistic study of names across 20 languages
- Found 11 “basic names,” similar linguistic evolution

World Color Survey (Kay, Berlin, Maffi, Merrifield, Cook, 2009)

Through the Language Glass: Why the World Looks Different in Other Languages (Guy Deutscher, 2010)

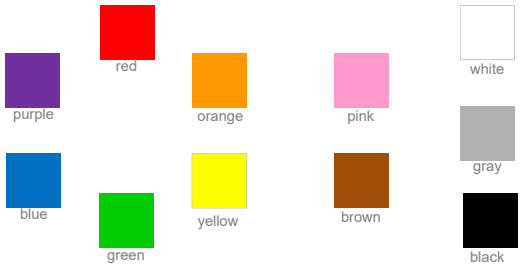
How people think about color

red
yellow
blue
green
orange
brown
violet (purple)
black

From crayola.com

## Basic color names (English)

Red, orange, yellow, green, blue, purple, pink, brown, black, white, gray




## Tableau 10 and 20 (2004)

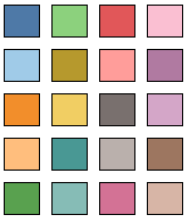
Basic names + teal



Light-dark pairs

## Tableau 10 and 20 (2016)

Basic names + teal



Light-dark pairs
Not all T10 in T20

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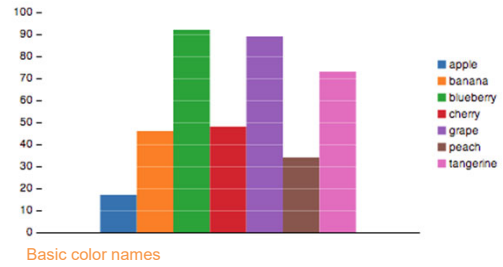
Can we do better?

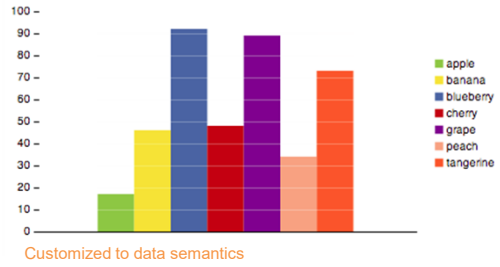
## Color and data semantics




Basic color names

Which bar represents bananas?

## Color and data semantics




Customized to data semantics

Which bar represents bananas?

Lin, Fortuna, Kulkami, Stone, Heer, Selecting Semantically-Resonant Colors for Data Visualization

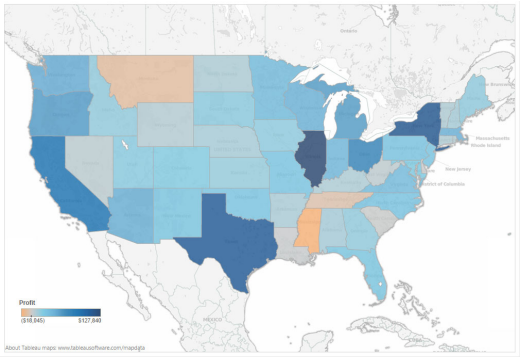
## Principles for palettes

Visibly distinct (including size, background, etc.)

Easy to remember, to reference

Make them beautiful

## To Measure: Color as value




## Principles for palettes

Visibly distinct (including size, background, etc.)

Easy to remember, to reference

Make them beautiful

Make a legible scale

Quantize for accuracy

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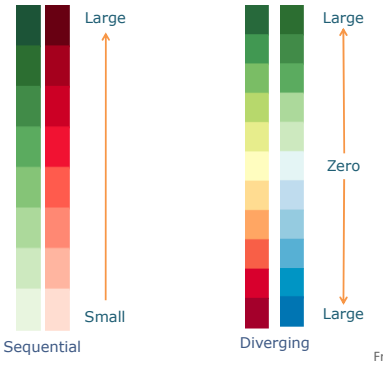
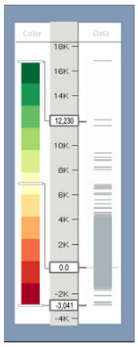
## Types of color scales




From Cynthia Brewer

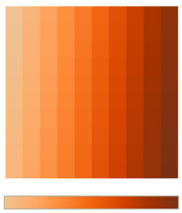
## The real problem: Data to color mapping

Uniform color steps



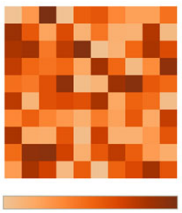

Non-uniform data distribution

## Color to quantity is very limited



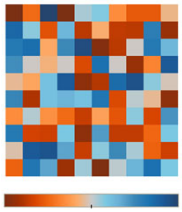
100 linear values

## Same domain, random values

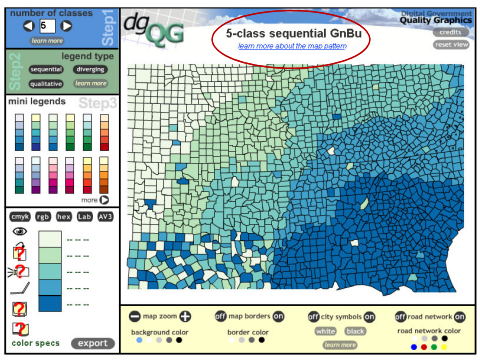


100 random values

## Same values, more colors



100 random values

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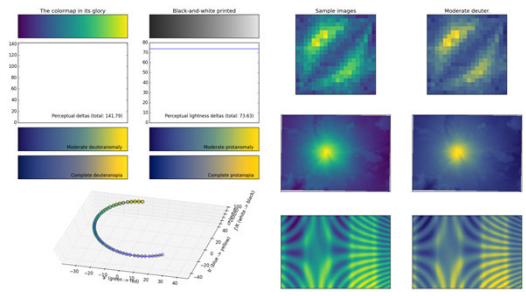
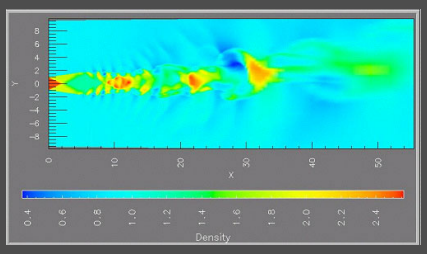
## Multi-Hued Colormaps



Viridis, https://bids.github.io/colormap/

## But beware of the uncontrolled “rainbow”




Creates strong categories…does it match the data?

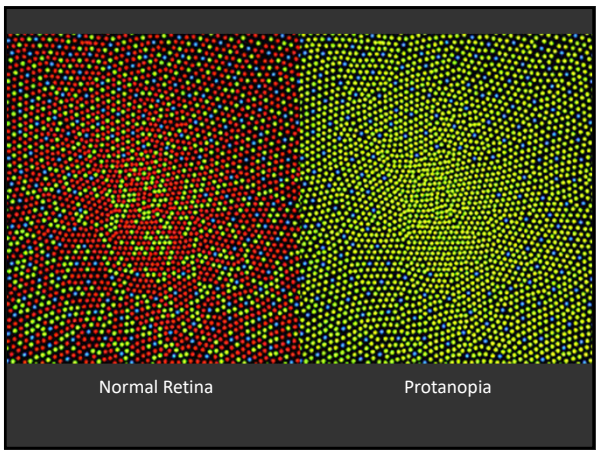
## Almost done

## Color vision deficiency (CVD)

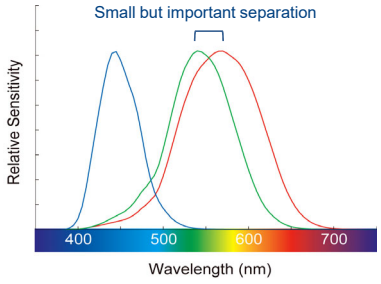
“normal”

“weak red-green”

Simulation from Coblinder




## Most CVD involves problems with red-green

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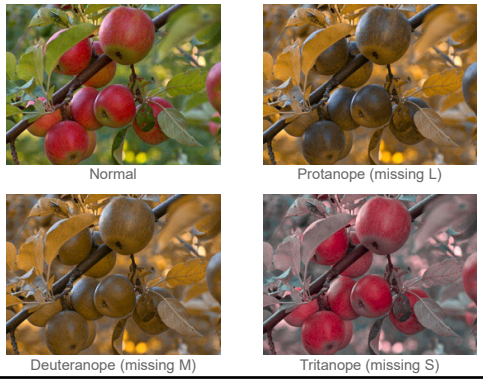
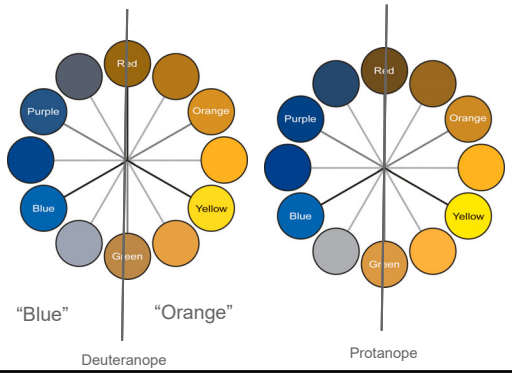
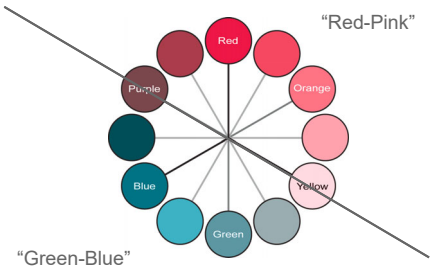
## Extreme CVD (simulation)




## The two forms of “red-green” CVD



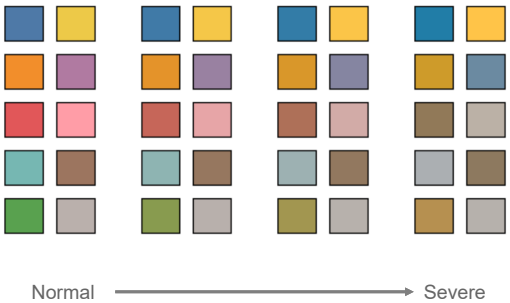

## Tritanopia




## Reduces color name space

Red-green not the only problem

## Tableau 10 and CVD




## Rules for accessibility

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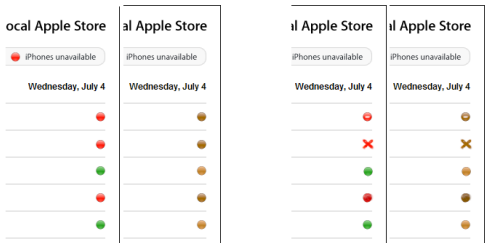
## Avoid encoding by color alone



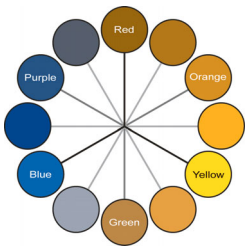

Original problem

Possible solutions

## Encode with lightness

Deuteranope simulation

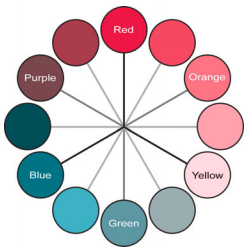
## Use “safe” colors




“Blue”

“Orange”

“Red-Pink”




“Green-Blue”

## CVD Simulation

- Chromatic vision simulator: http://asada.tukusi.ne.jp/webCVS/index.html
- Color Oracle: http://colororacle.org/index.html

- Vischeck: http://www.vischeck.com/
- Built into current Adobe tools: View>Proof setup
- Coblis http://www.color-blindness.com/coblis-color-blindness-simulator/
- NoCoffee Vision Simulator (Chrome extension) https://accessgarage.wordpress.com/2013/02/09/458/

## Questions?

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