

Data Visualization

VISUAL PERCEPTION (2)

Overview

Motivation

Color perception

Color specification

Color use

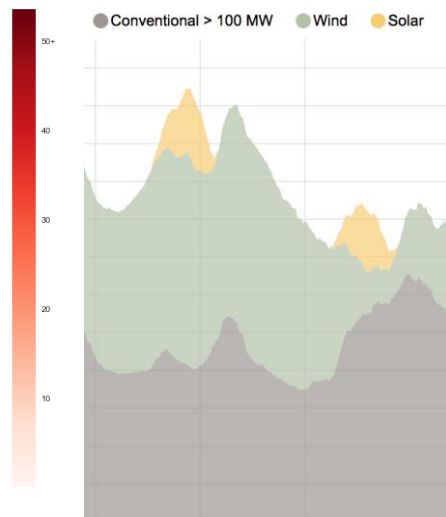
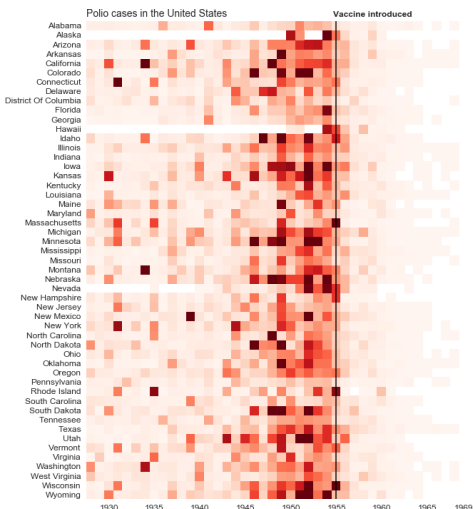
Motivation

Motivation

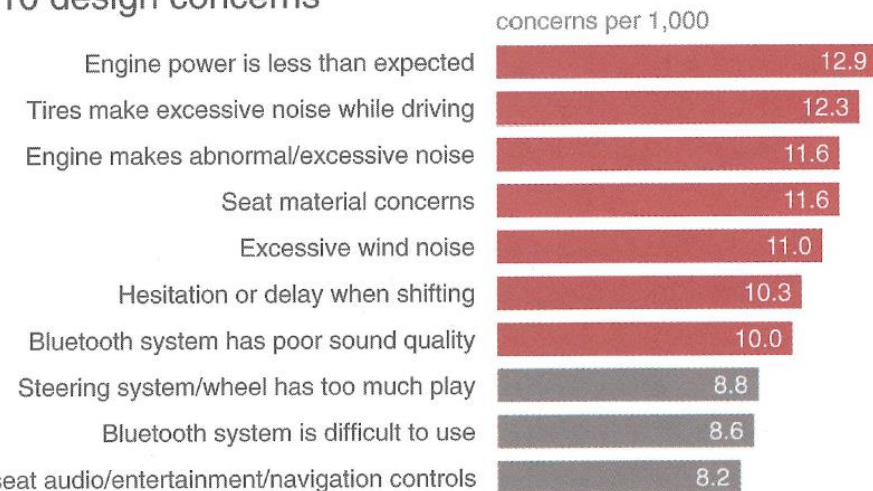
Color is a very powerful visual channel

Often used to

- Detect patterns (for example, in heat maps)
- Label data to distinguish among categories
- Highlight specific objects (to draw attention)



Top 10 design concerns



Color (mis)use

Above all, do no harm

Edward Tufte

Color (mis)use

READING, WRITING, AND EARNING MONEY

The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if there is any correlation.



① HIGH SCHOOL GRADUATES 65% 75% 82% 88%



② COLLEGE GRADUATES 15% 22% 30% 40%

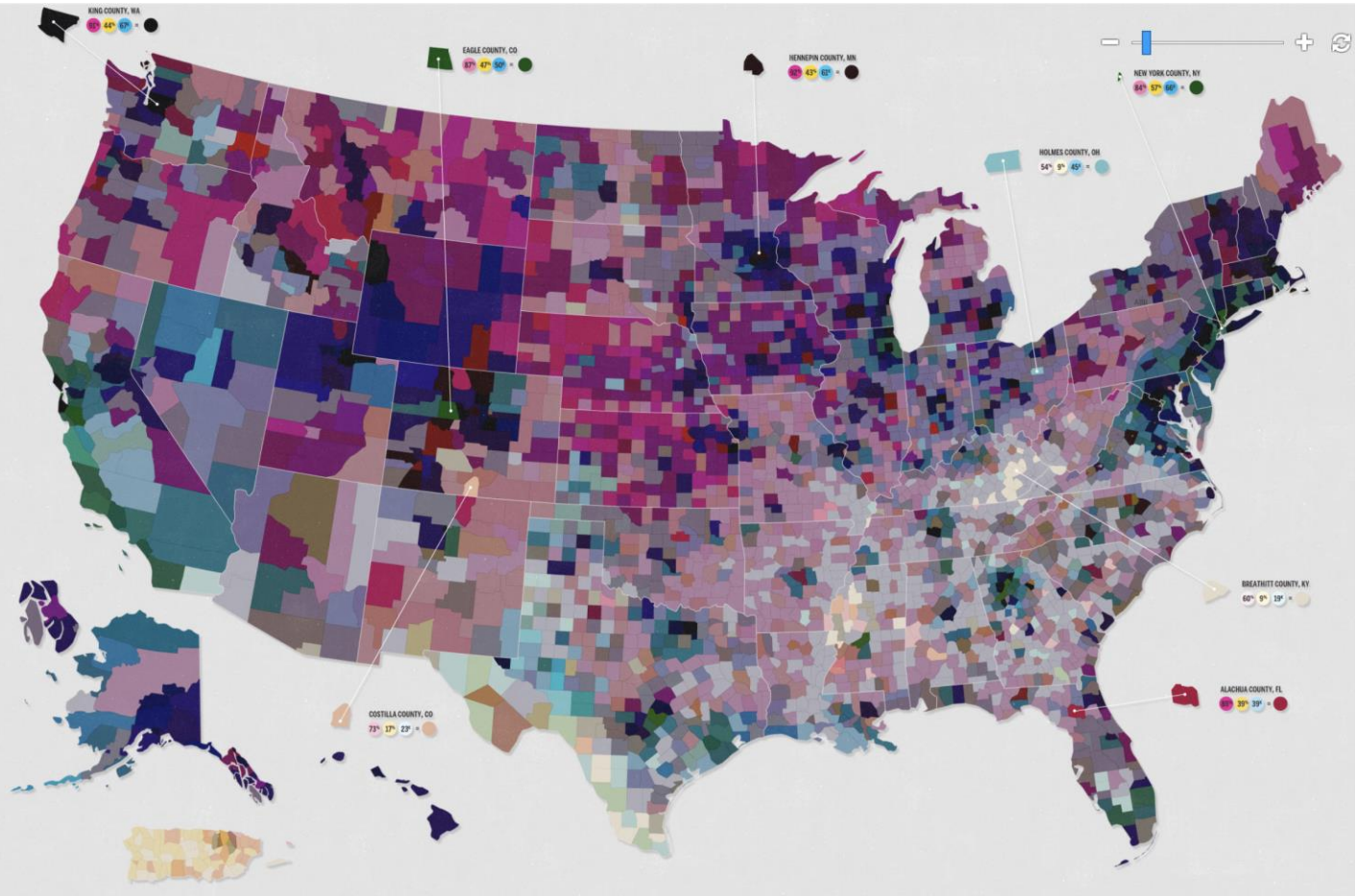


③ MEDIAN HOUSEHOLD INCOME 25% 40% 50% 60%

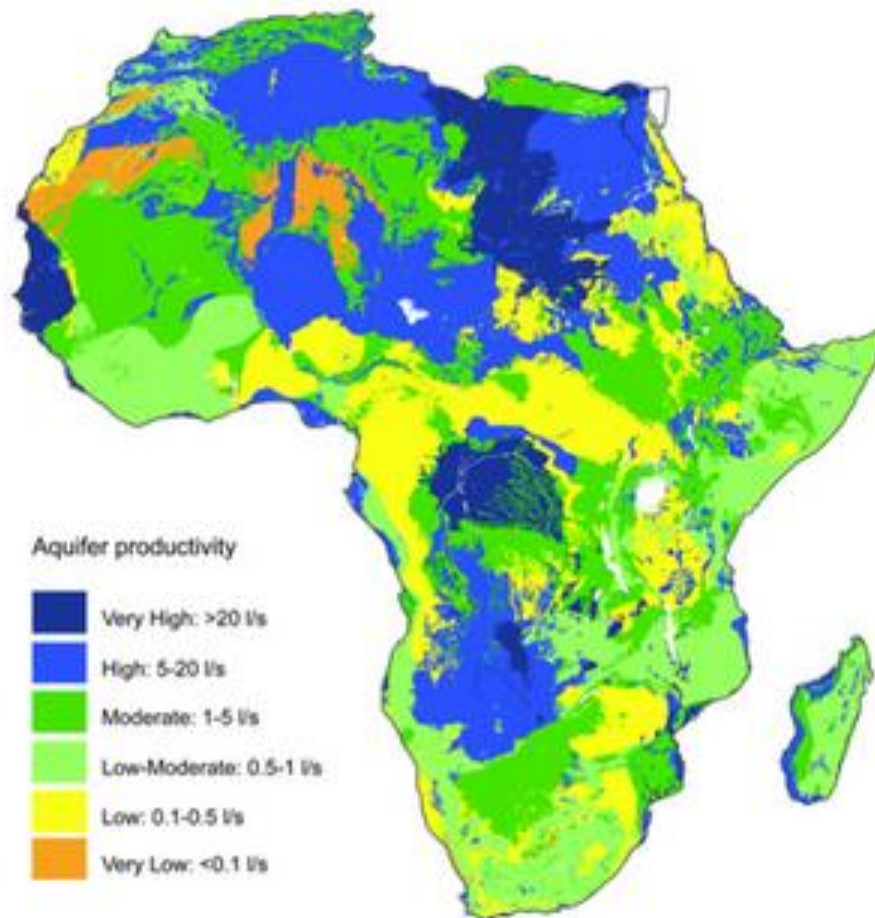
The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



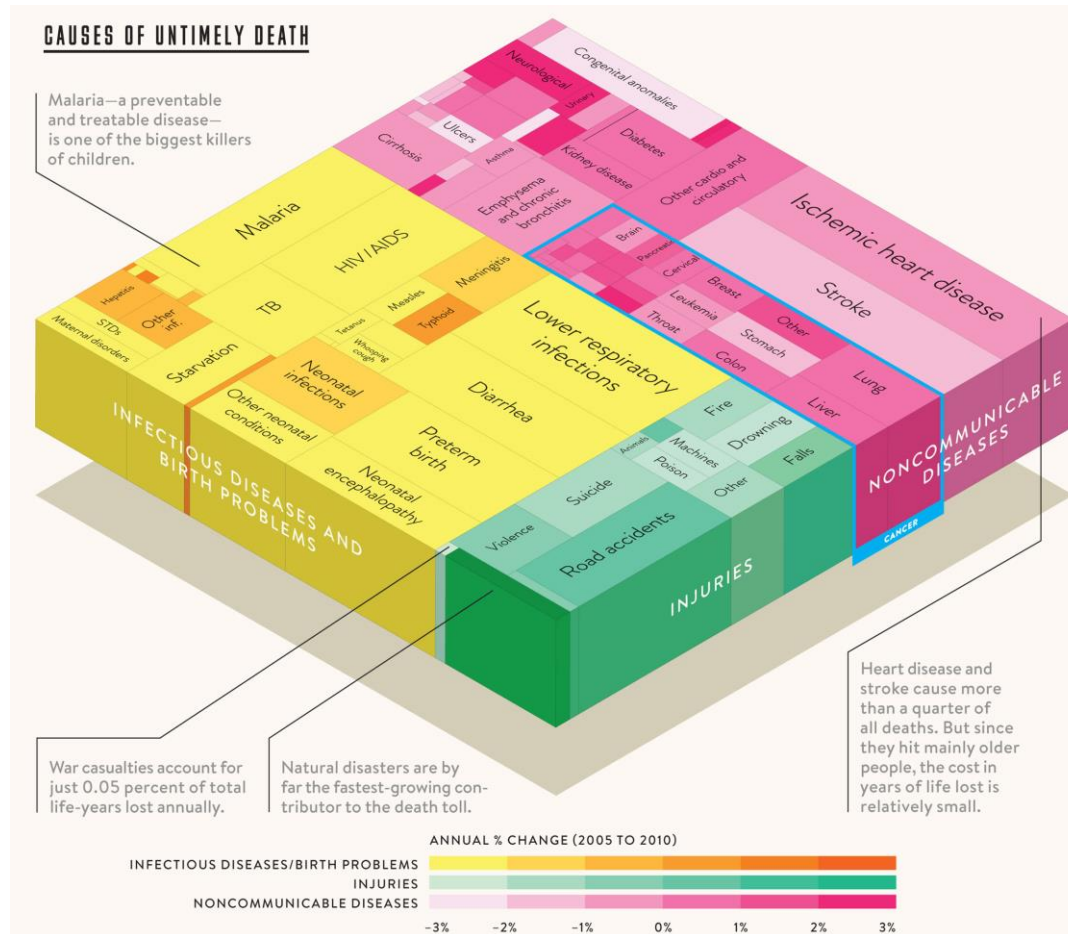
A collaboration between GOOD and Gregory Mihalak
SOURCE: US Census



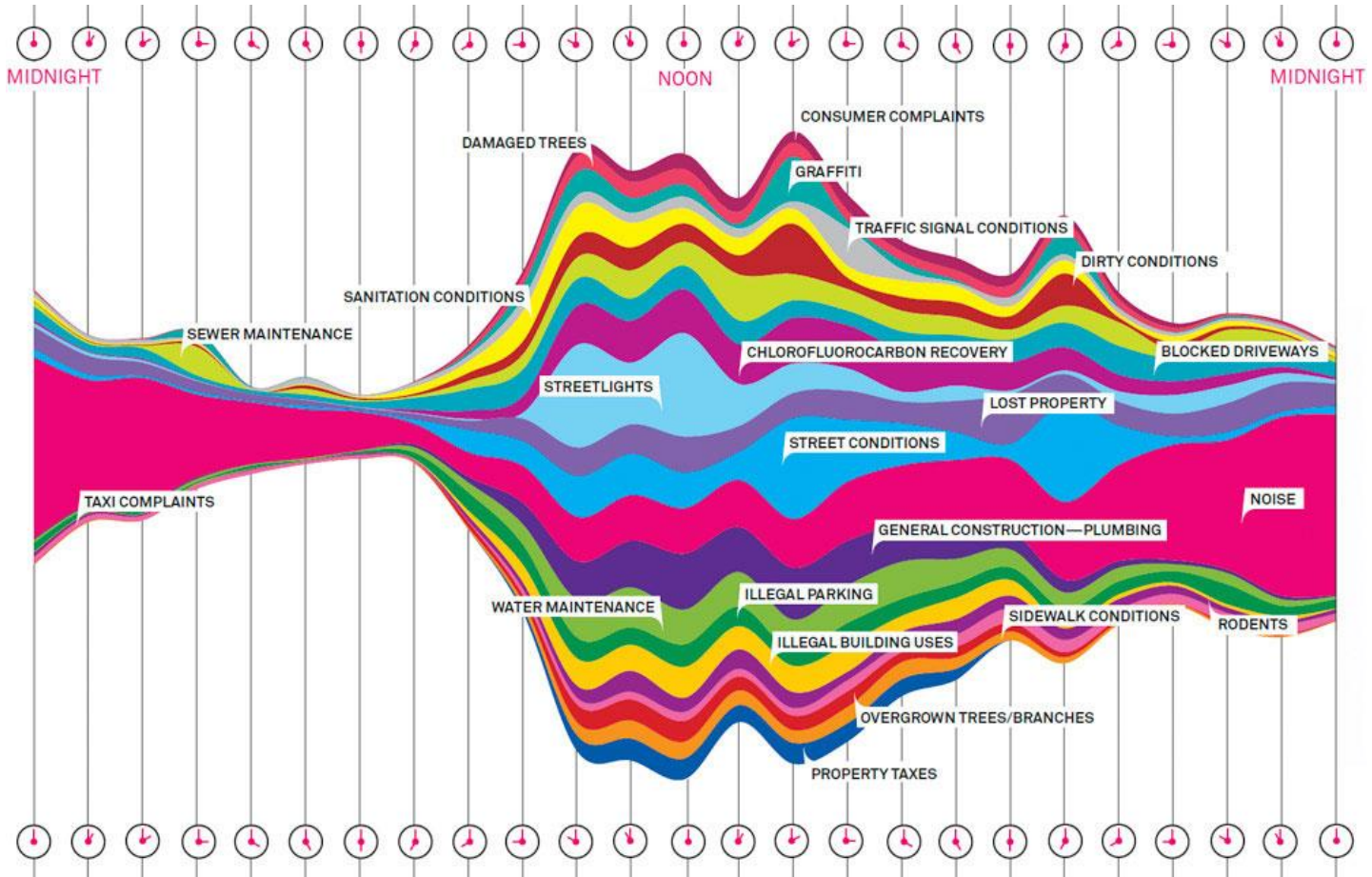
Color (mis)use



Color (mis)use

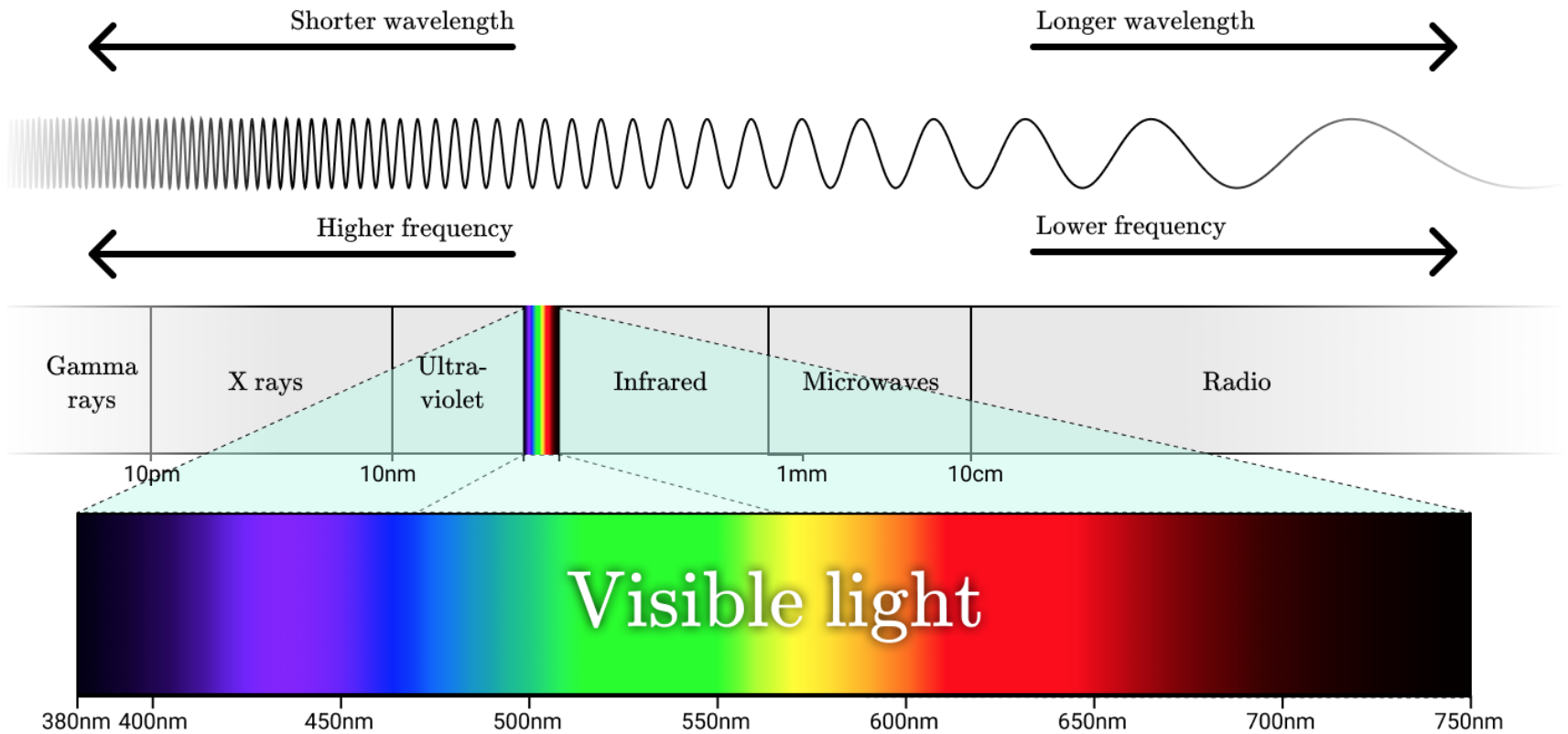


Color (mis)use

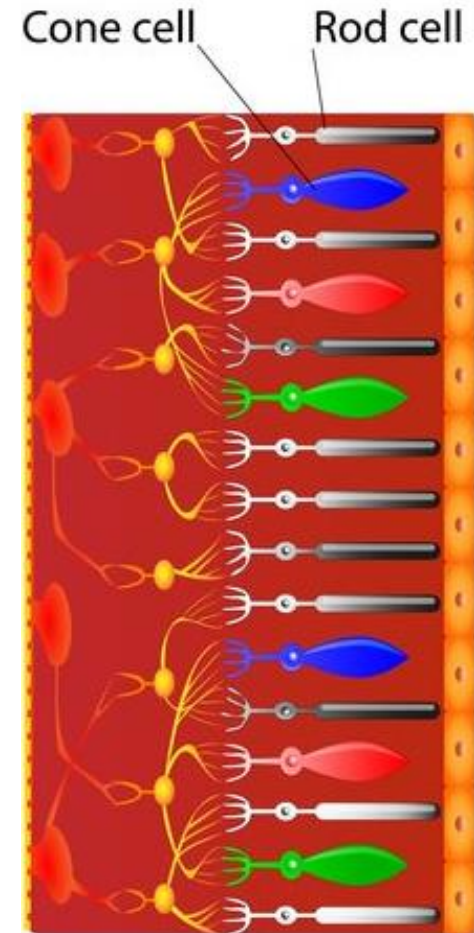
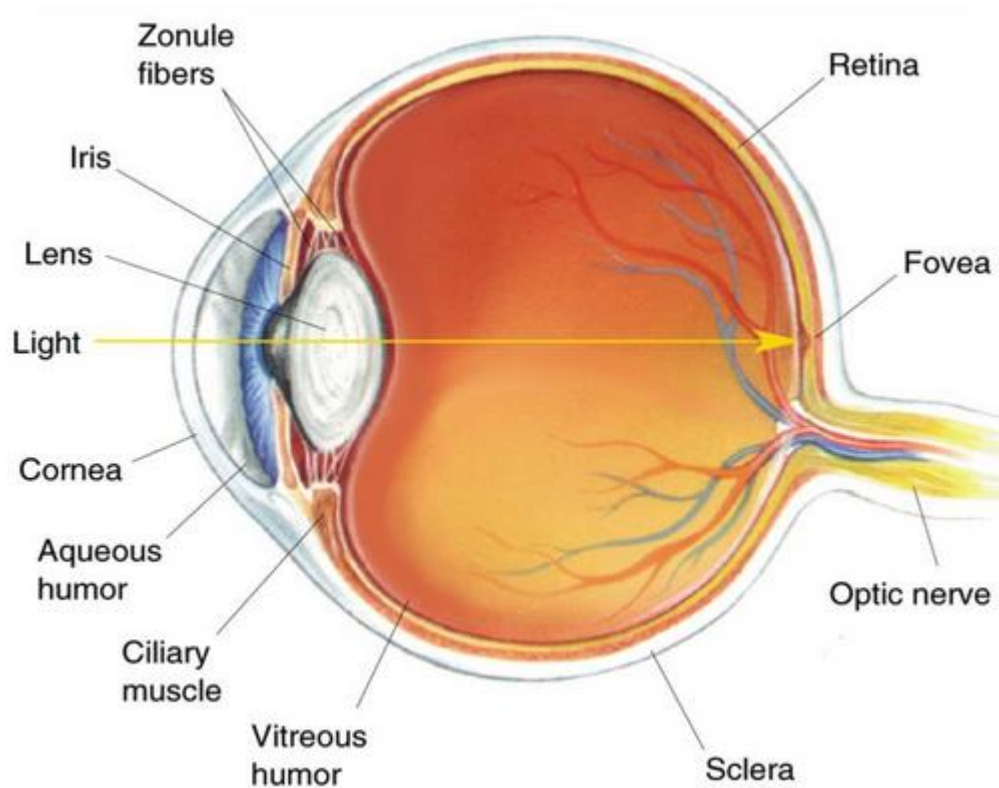


Color perception

Light

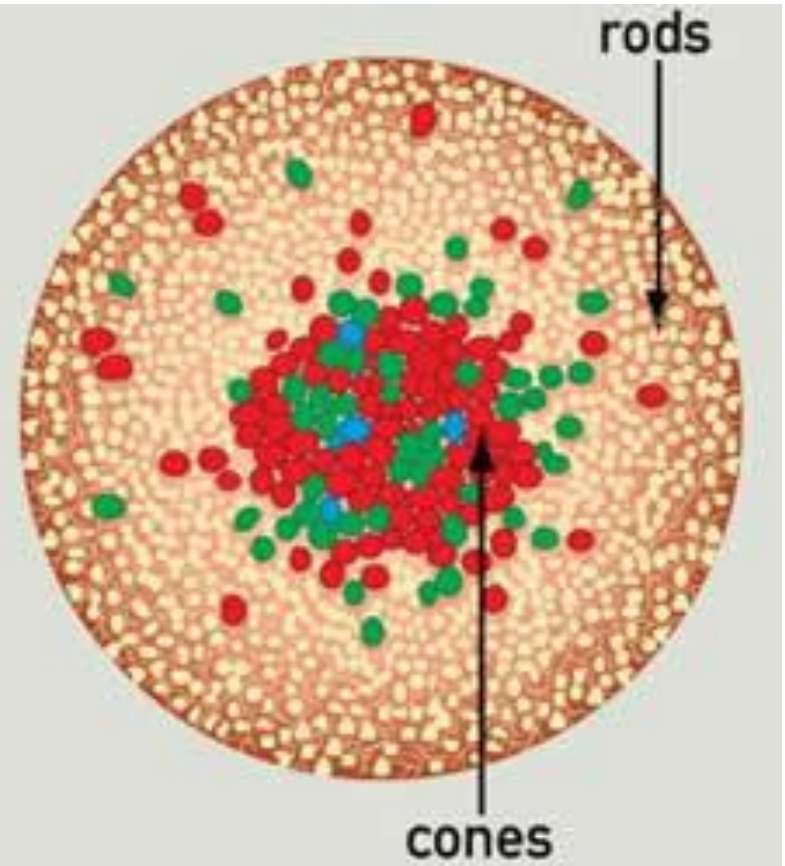
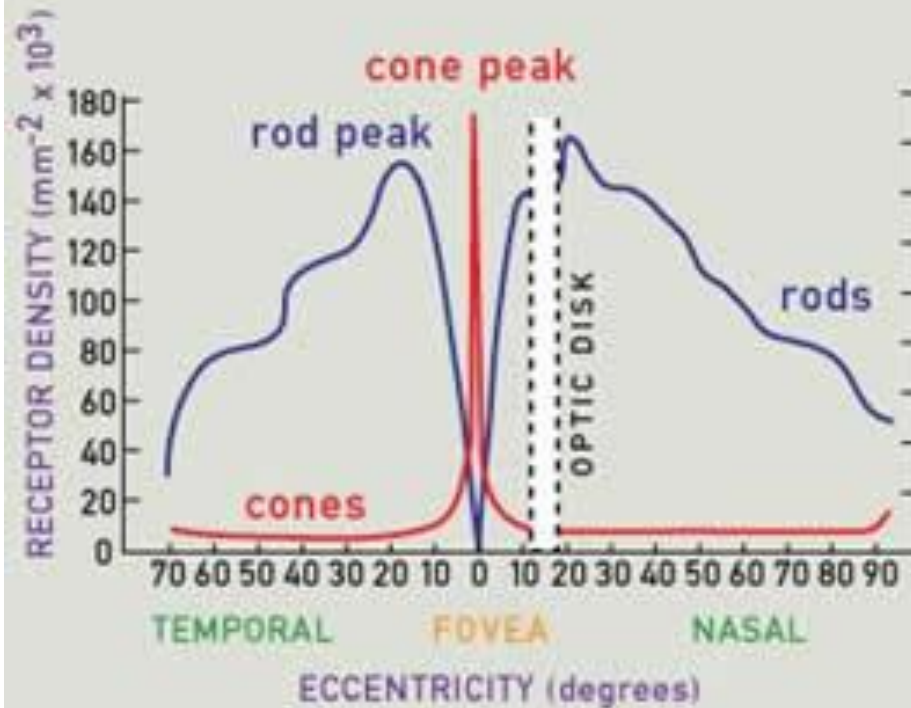


Human eye anatomy

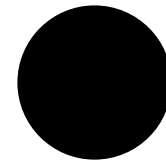
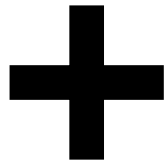


Rods and cones (photoreceptors)

~ 20 times as many rods as cones



Blind spot



Filling in the blanks

*We don't see images with our eyes, we see them
with our brains.*

Stephen Few

The eye is not a camera

Filling in the blanks



Filling in the blanks

Saccadic eye movement

- Fast eye movement to sample the area around the focus of attention
- Eyes in continual motion (series of fixations of connected by saccades – about 3 per second)



What we perceive is the sum of the input that has been received in the last few fixations (things don't disappear when we blink)

Filling in the blanks



"2011-07-12-Railway People" by Chuwa (Francis) is licensed under CC BY-SA 2.0, color illusion remix by <http://pippin.gimp.org/>

Role of attention

Visual perception is driven by our attention

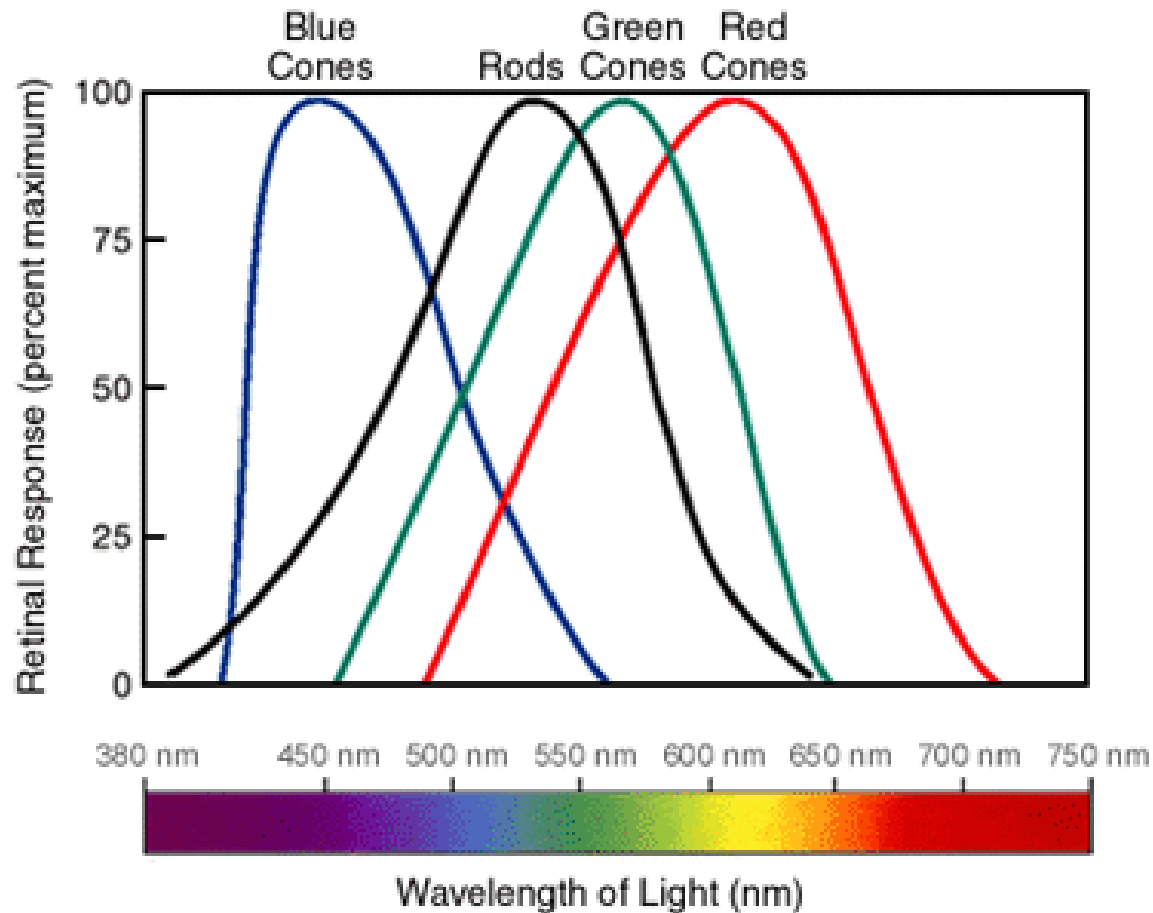
Inattentional blindness

- We are blind to the things we do not pay attention to

Importance for design

- Guide the attention of the viewer in a way that is useful for achieving the goal
- Be aware of how your design choices affect the attention of the user
- You don't want to inadvertently attract attention to unimportant information

Sensitivity of rods and cones



Trichromatic theory of color

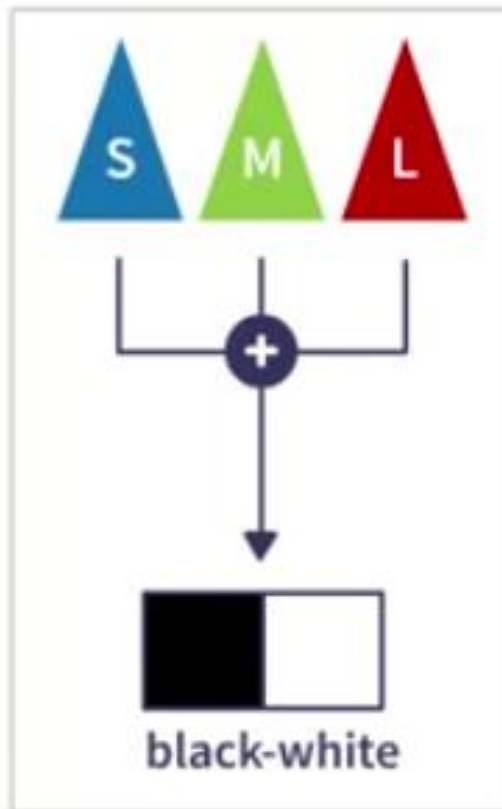
We have three kinds of color receptors

- S = short wavelength (“blue” cones)
- M = medium wavelength (“green” cones)
- L = long wavelength (“red” cones)

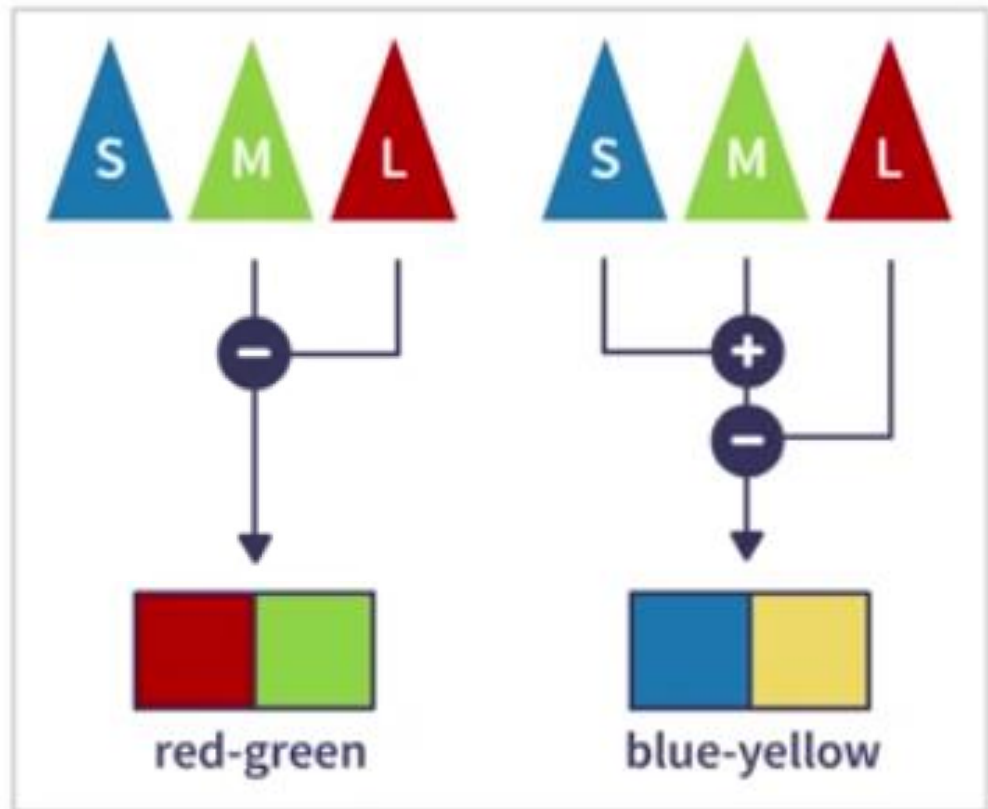
Any visible color can be expressed as a combination of three primary colors

However, we don't perceive color in terms of amount of blue, green and red

Color opponent process theory



Achromatic System

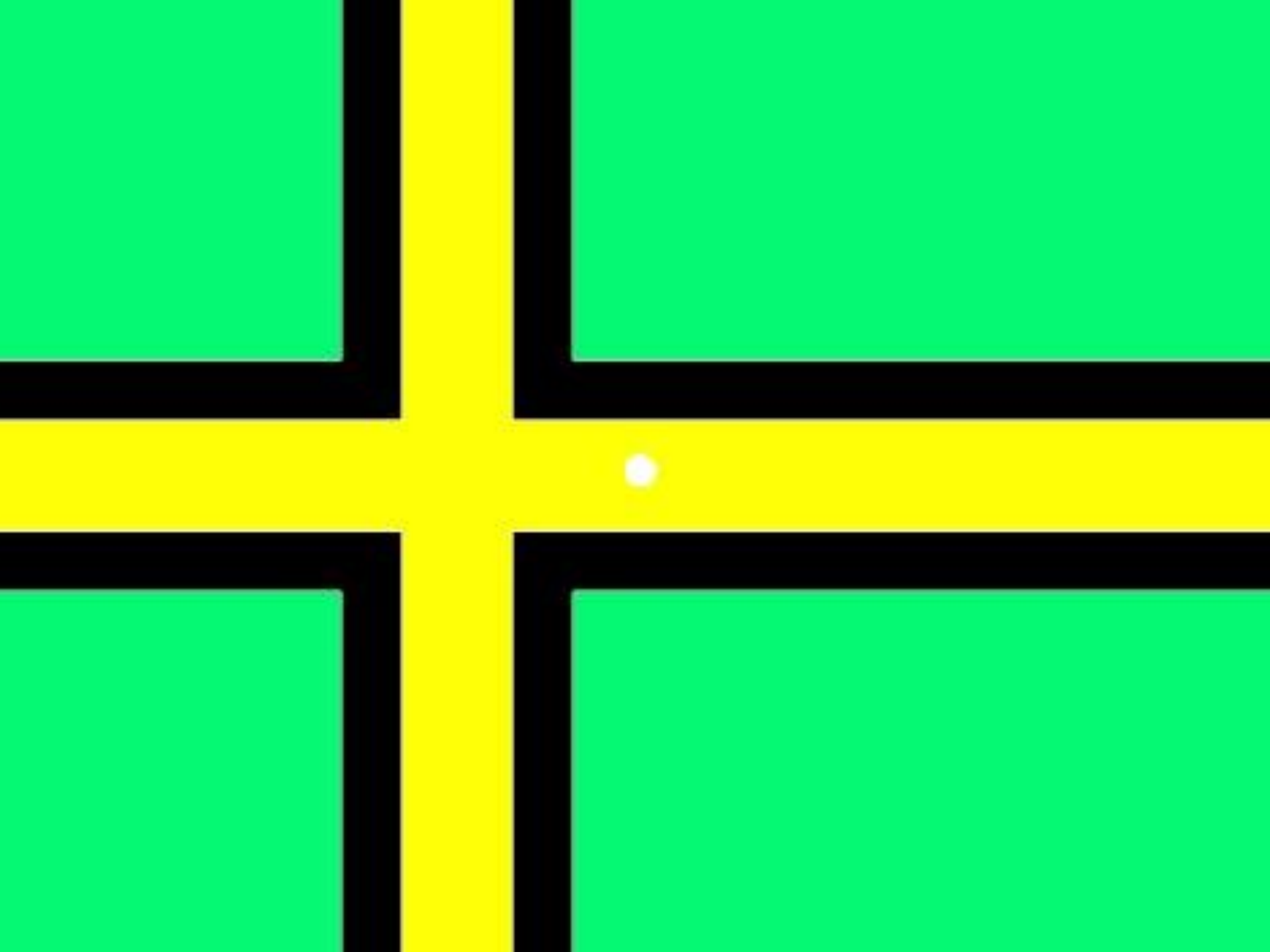


Chromatic System

Color opponent process theory

Facts that seem to corroborate the theory

- We don't perceive neither the "red-green color" nor the "blue-yellow color"
- Colorblind people tend to be blind on exactly these two axes (most often red-green and lest often blue-yellow)
- The following example



Color opponent process theory

Facts that seem to corroborate the theory

- We don't perceive neither the "red-green color" nor the "blue-yellow color"
- Colorblind people tend to be blind on exactly these two axes (most often red-green and least often blue-yellow)
- The previous example

After staring at these colors, the sensors inhibit them and you see their opposites

Color perception summary

Human eye

- Fovea
- Rods (low light conditions, no colors)
- Cones (colors when enough light)
- Saccadic eye movement

Trichromacy

- Three receptors of color

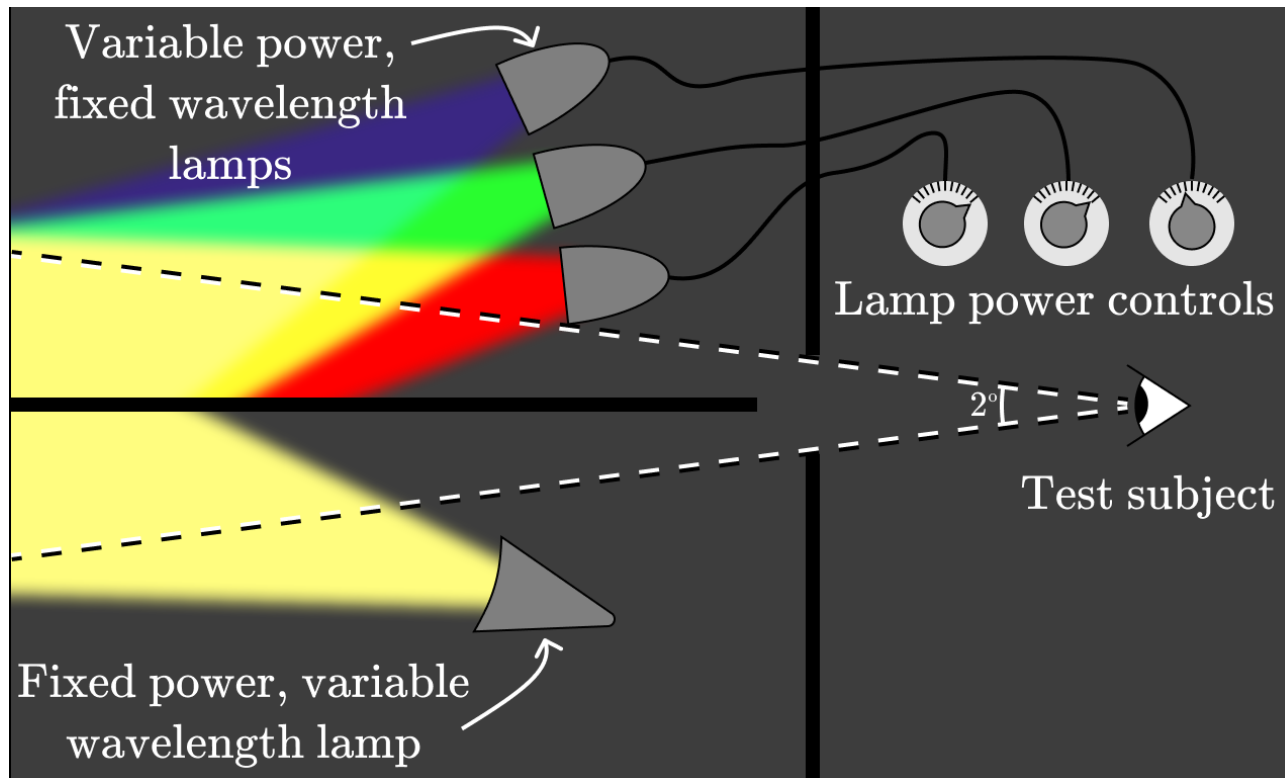
Opponent process theory

- Signals from the eye transformed in the visual cortex to black-white, red-green and blue-yellow axes

Color specification

Color specification

Every color can be expressed as the sum of three colors (in a 3-D space)

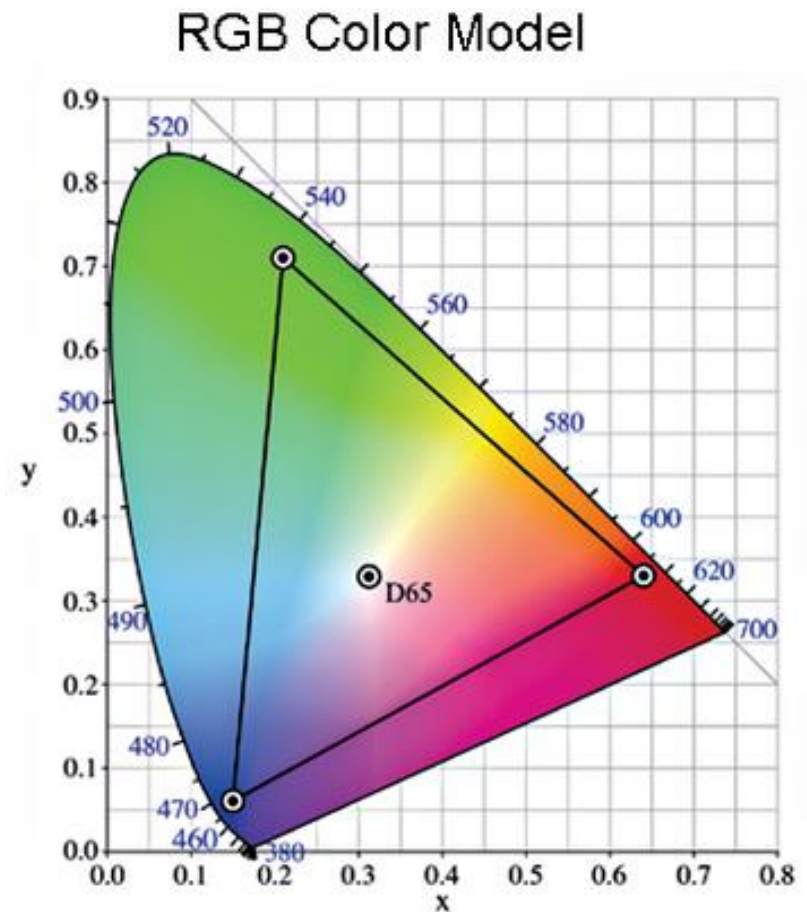


Color spaces

A color space is a (3-D) system that describes colors

The **gamut** of the color space is the whole set of colors that can be reproduced by this color space

Not all color spaces are equivalent



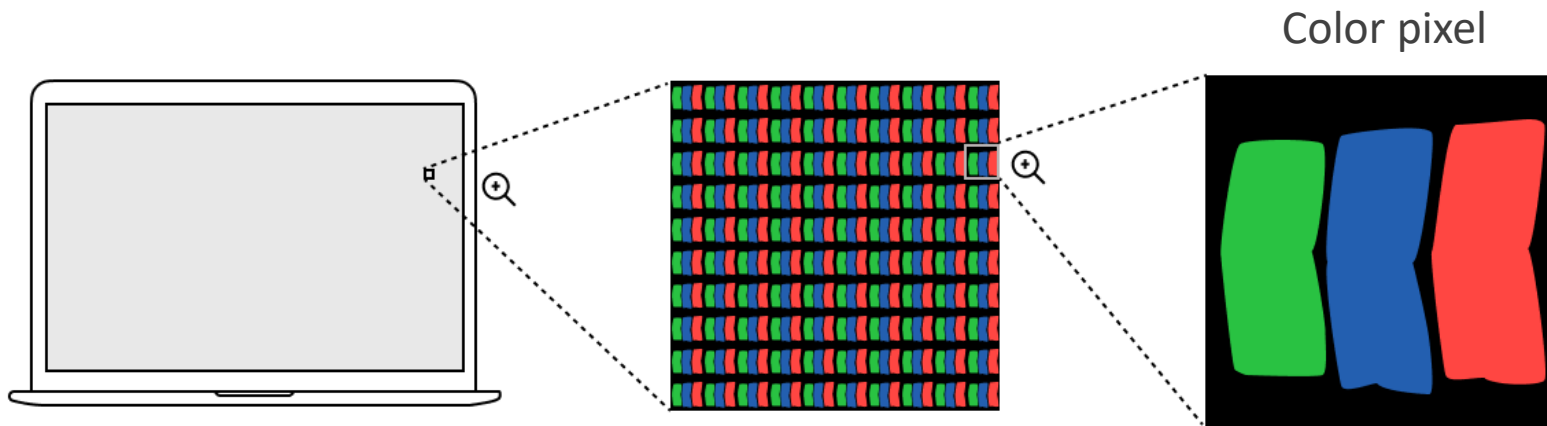
Properties of color spaces

	Intuitive	Perceptually uniform
RGB		
HSL / HSV		
CIE Lab		
CIE LCh / HCL		

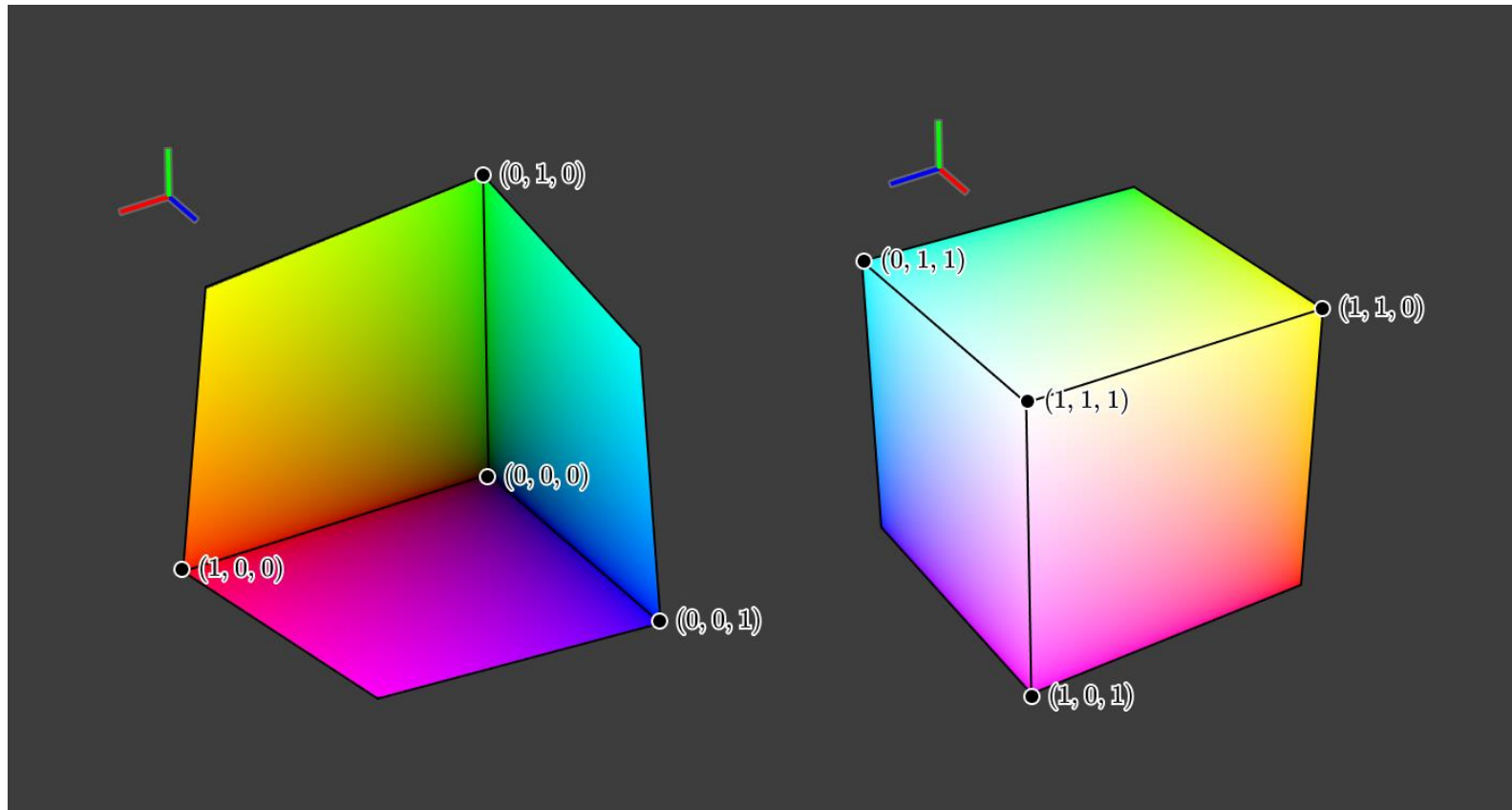
RGB

- R = red
- G = green
- B = blue

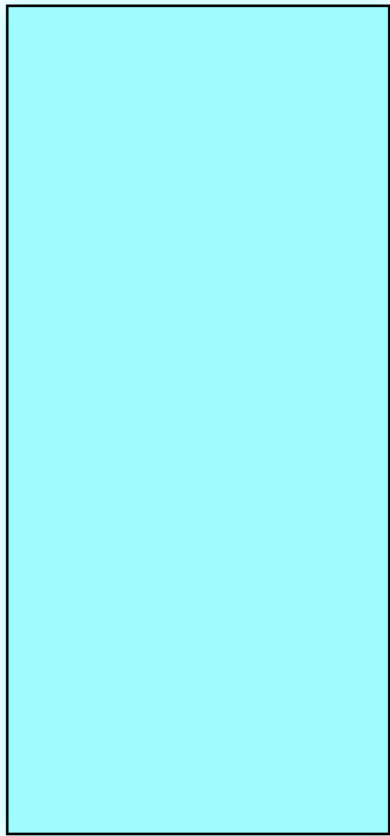
Commonly used in digital devices



RGB



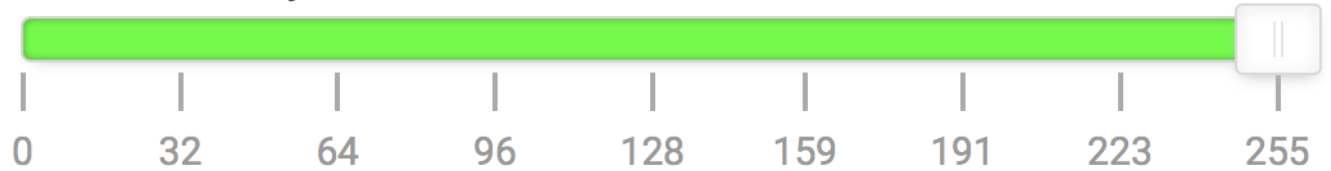
RGB



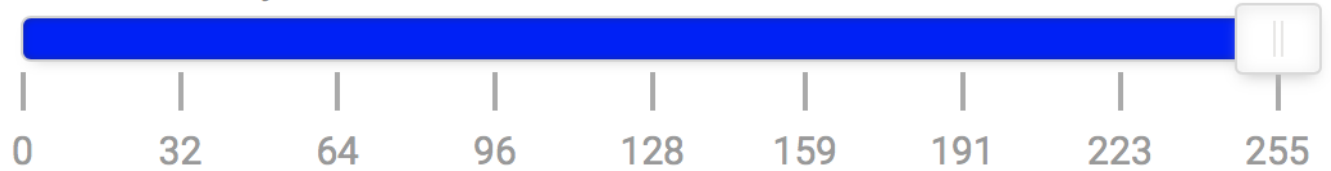
Red - Currently set to 126



Green - Currently set to 255



Blue - Currently set to 255



RGB

G and B fixed (G = 192, B = 0), changes only in R



R = 5



R = 55



R = 105



R = 155



R = 205



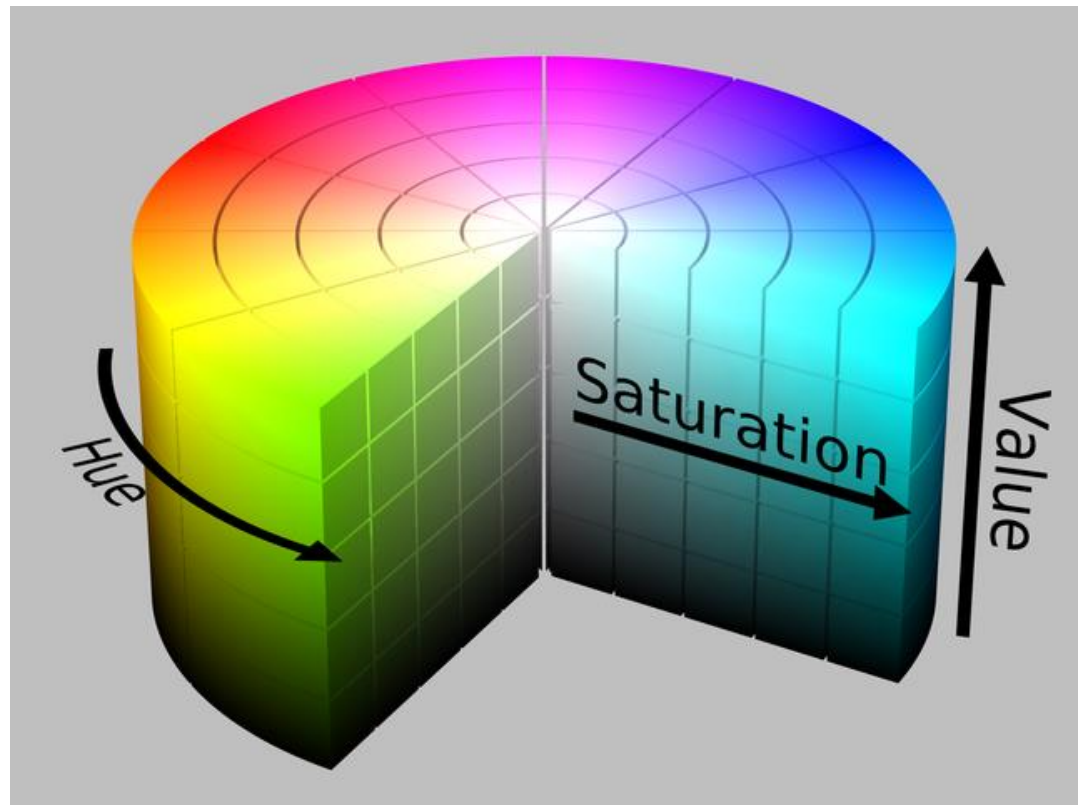
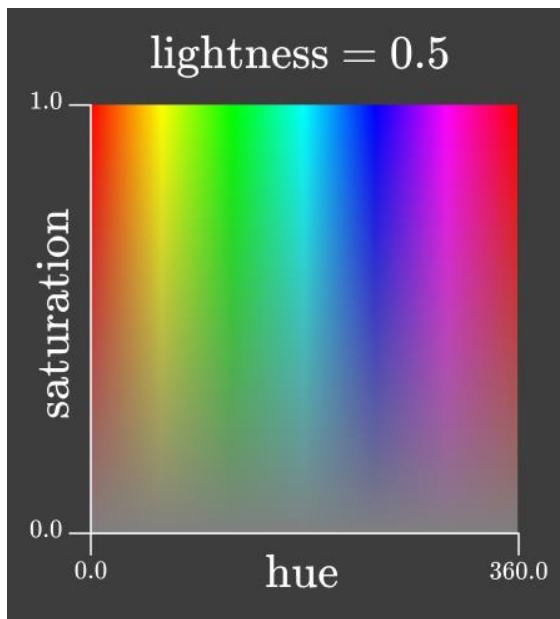
R = 255

Properties of color spaces

	Intuitive	Perceptually uniform
RGB	✗	✗
HSL / HSV		
CIE Lab		
CIE LCh / HCL		

HSL / HSV

- H = hue
- S = saturation
- L/V = lightness/value



HSL / HSV

A MOST EXCELLENT

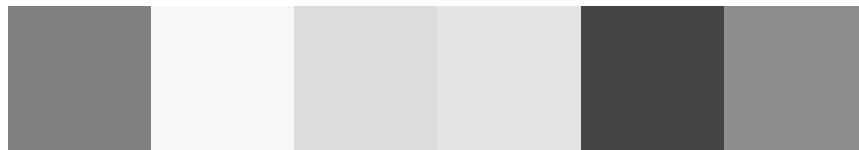
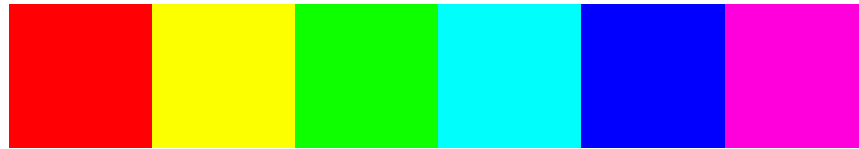
HSL COLOR PICKER

CREATED FOR YOUR ENJOYMENT, BY BRANDON MATHIS





The interface includes a color wheel on the left, a preview area with a blue square, and four sliders on the right. The sliders are labeled with their respective values: 212, 66, 50, and 1. Below the sliders, the color is displayed in three formats: hex code (#2b7ad4), rgba (rgba(43, 122, 212, 1)), and hsla (hsla(212, 66%, 50%, 1)).

#2b7ad4 rgba(43, 122, 212, 1) hsla(212, 66%, 50%, 1)

HSL / HSV



Properties of color spaces

	Intuitive	Perceptually uniform
RGB		
HSL / HSV		
CIE Lab		
CIE LCh / HCL		

CIE Lab

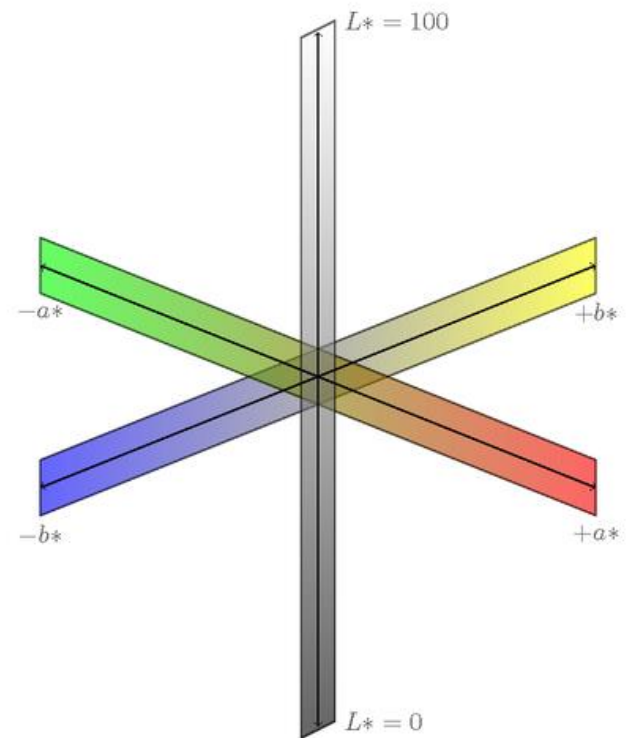
CIE (International Commission on Illumination)

Specified according to the opponent process theory

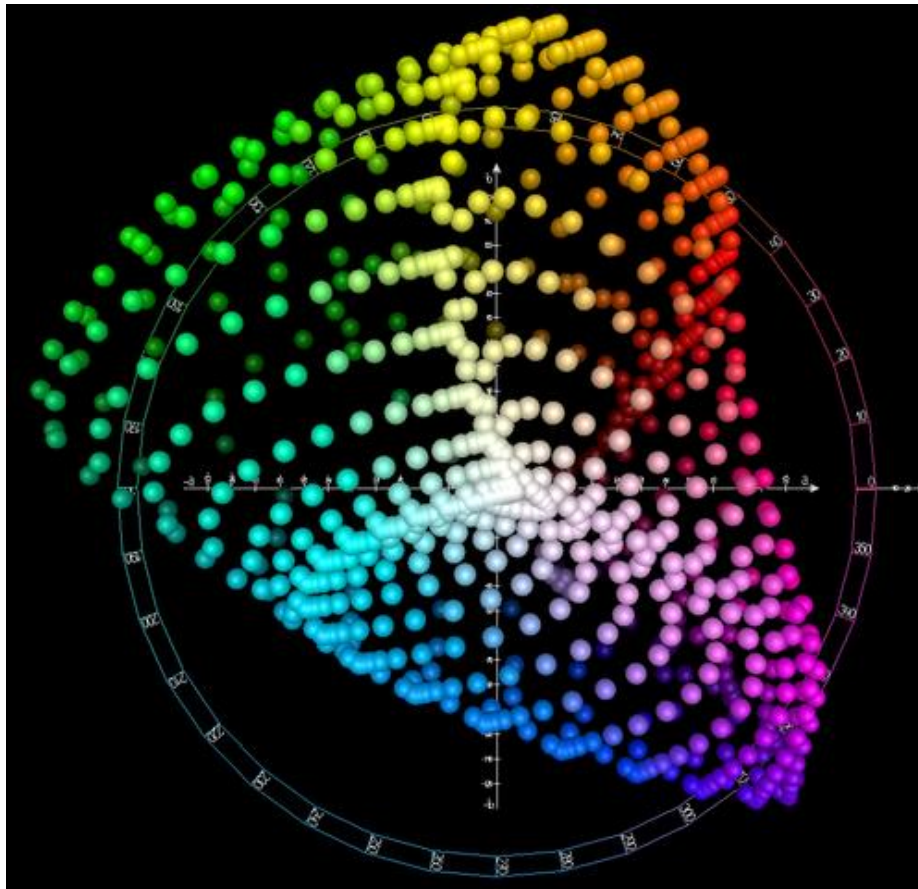
- L^* = lightness
- a^* = green-red axis
- b^* = blue-yellow axis

Designed to be perceptually linear

A nonlinear transformation of color wavelengths

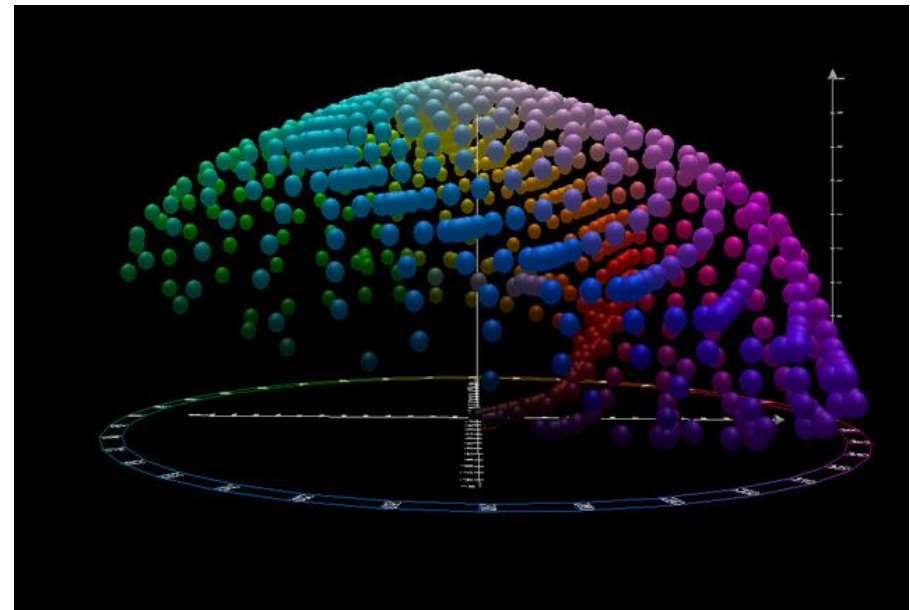


CIE Lab



Top view

Front view



CIE Lab

David Johnstone

Lch and Lab colour and gradient picker

Page background colour:

Colour selection mode:

Number of stops:

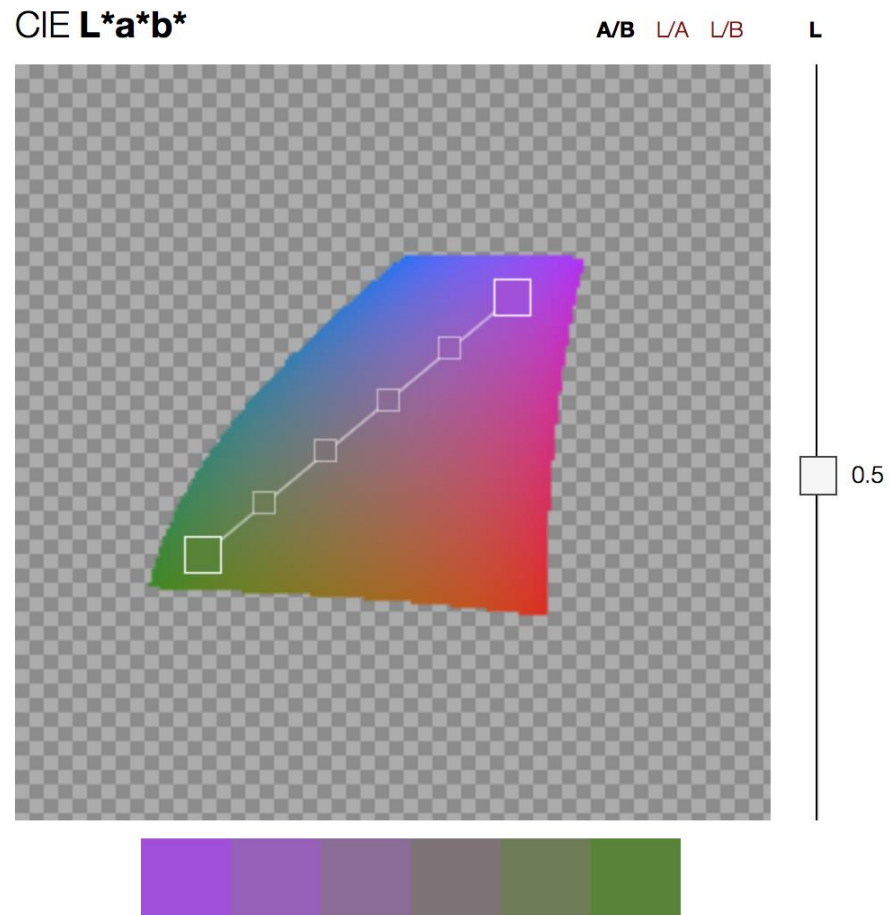
L: 60

a: -100







b: 3



CIE Lab



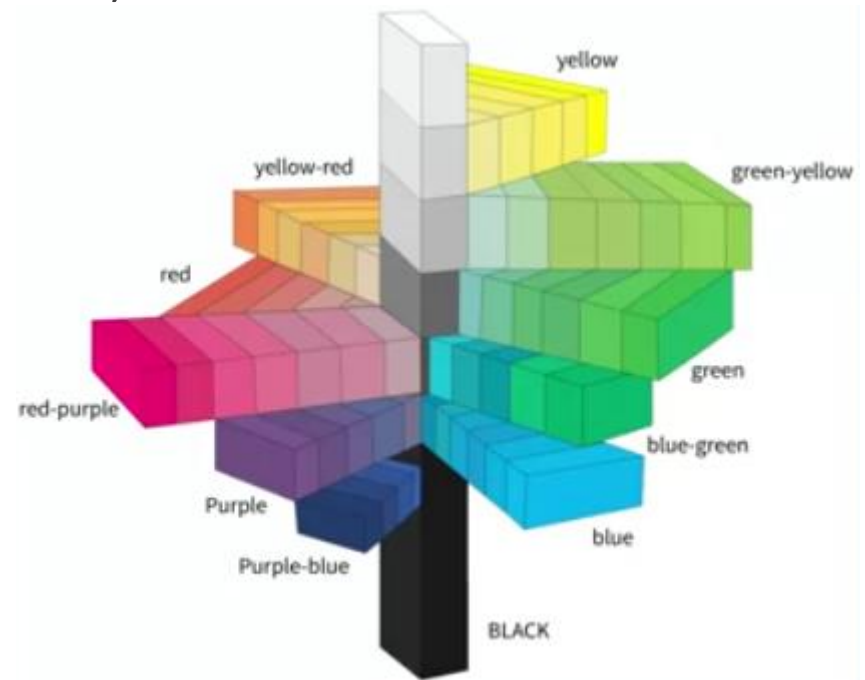
Properties of color spaces

	Intuitive	Perceptually uniform
RGB		
HSL / HSV		
CIE Lab		
CIE LCh / HCL		

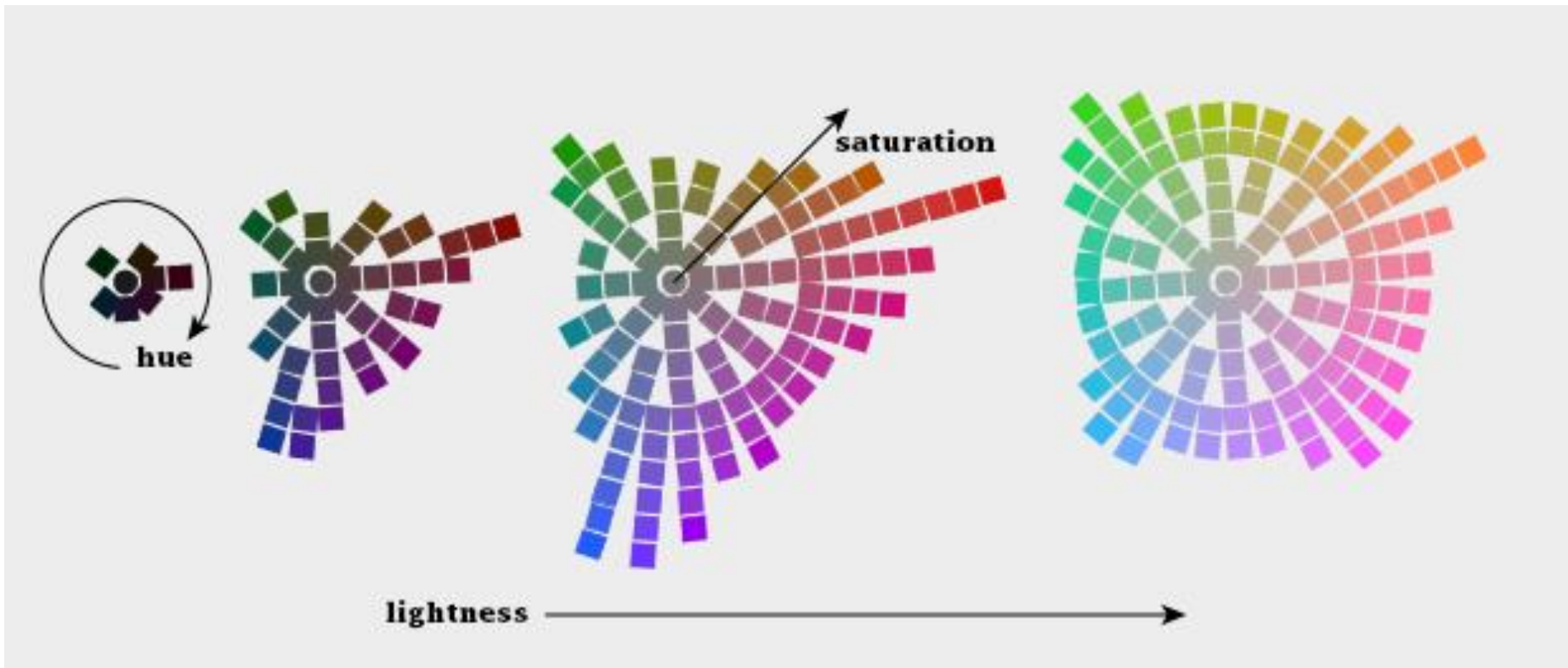
CIE LCh / HCL

Transformation of CIE Lab to cylindrical coordinates

- L^* = lightness (as in CIE Lab)
- C^* = chroma (corresponds to saturation)
- h = hue



CIE LCh / HCL



CIE LCh / HCL

David Johnstone

Lch and Lab colour and gradient picker

Page background colour:

Colour selection mode:

Number of stops:

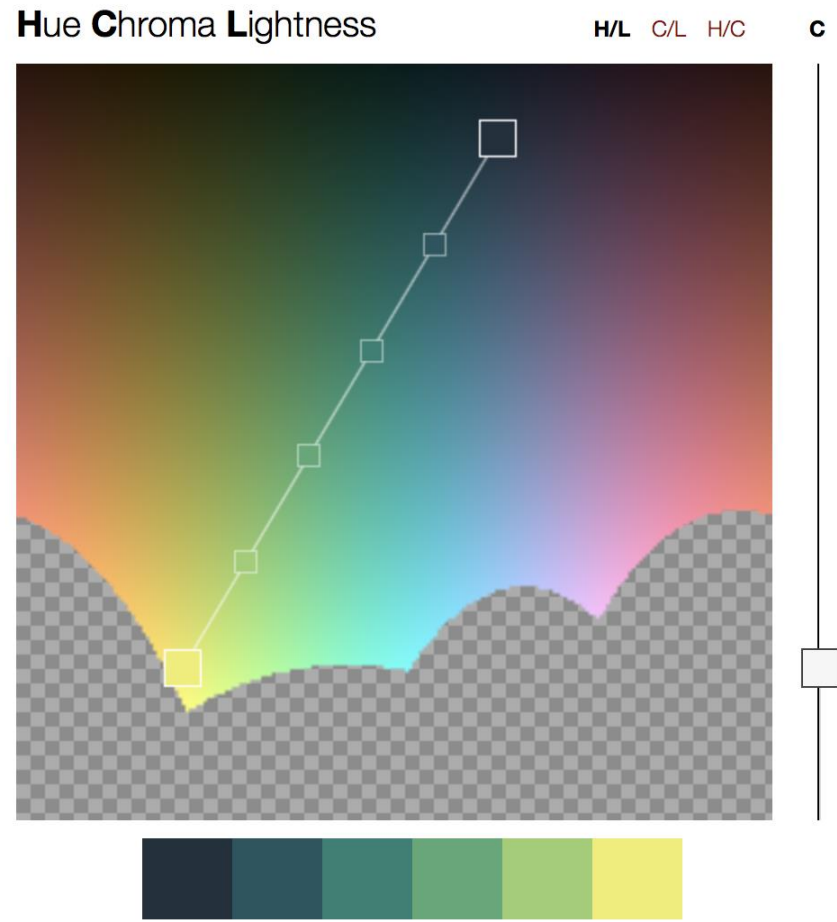
L: 79

c: 63









h: 58



CIE LCh / HCL



Color specification summary

	Intuitive	Perceptually uniform
RGB		
HSL / HSV		
CIE Lab		
CIE LCh / HCL		

Color use

Color use

Color maps

Semantics of color

Color blindness

Importance of size

Relative perception

- Importance of contrast
- Importance of background
- Importance of surrounding color

Choosing colors

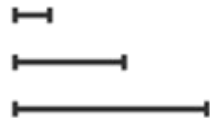
Data attributes

→ Ordered

→ Ordinal



→ Quantitative



→ Categorical



⊙ Ordering Direction

→ Sequential



1, 2, 3, ...

small, medium, large

→ Diverging



..., -2, -1, 0, 1, 2, ...

neg., neutral, pos.

Color maps

Single variable

- Sequential color maps
- Diverging color maps
- Categorical color maps

Two variables

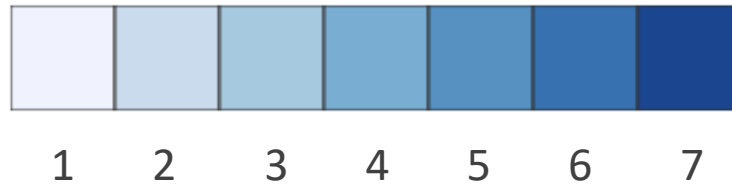
- Bivariate color maps

Sequential color maps

Desired properties

- Perceived differences correspond to value differences
- High discriminability

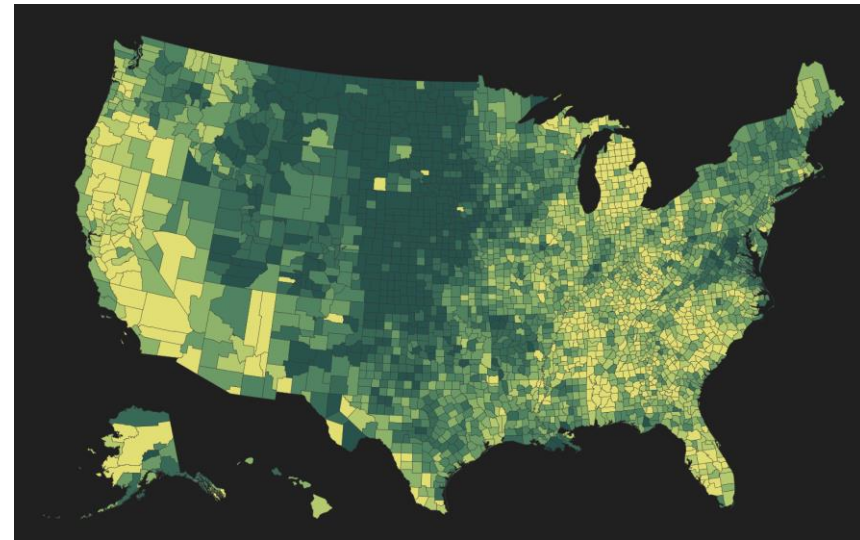
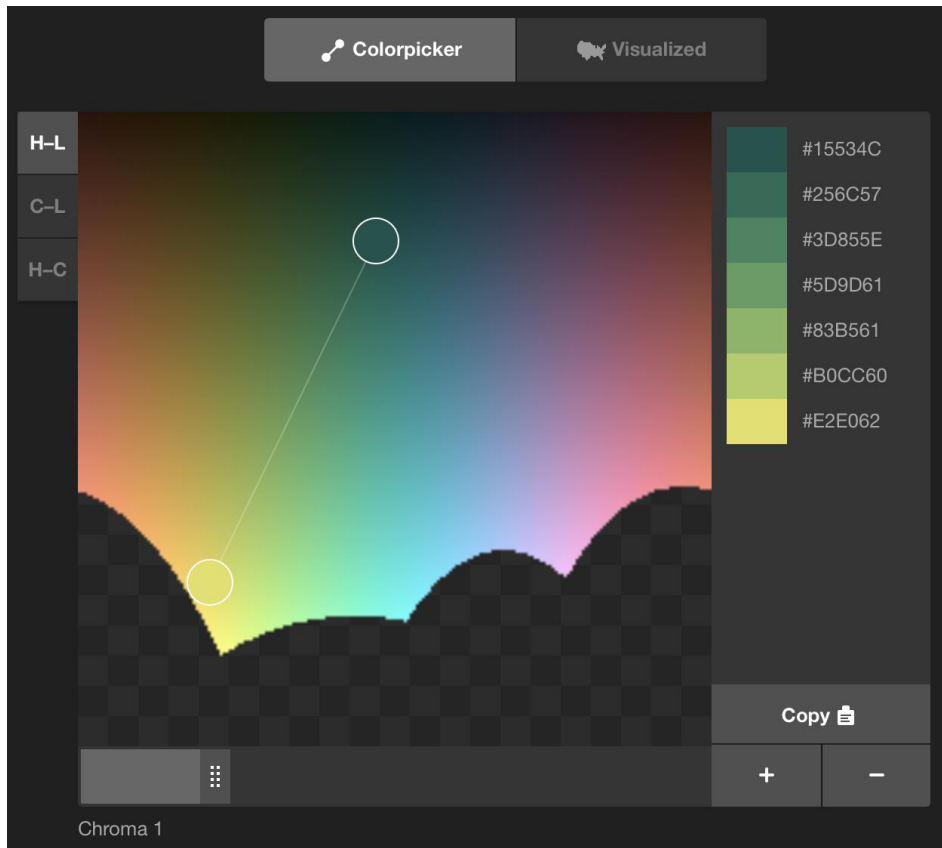
Single hue



Multi-hue



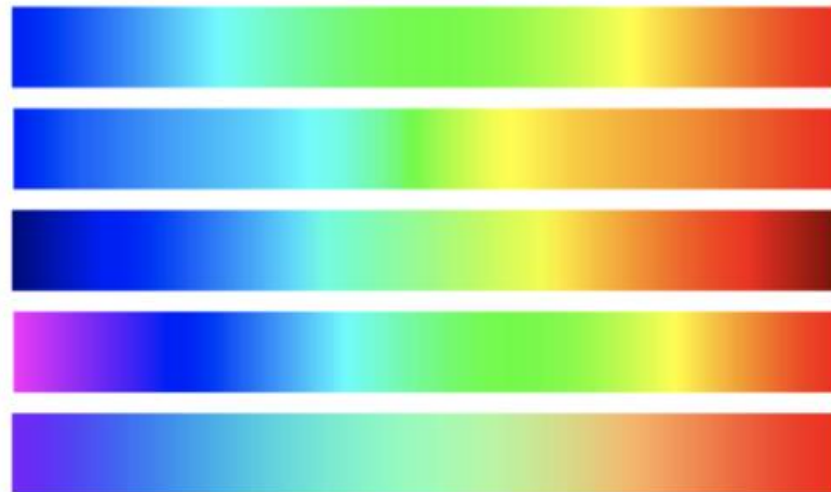
Sequential color maps



Sequential color maps: rainbow

Do not use it!

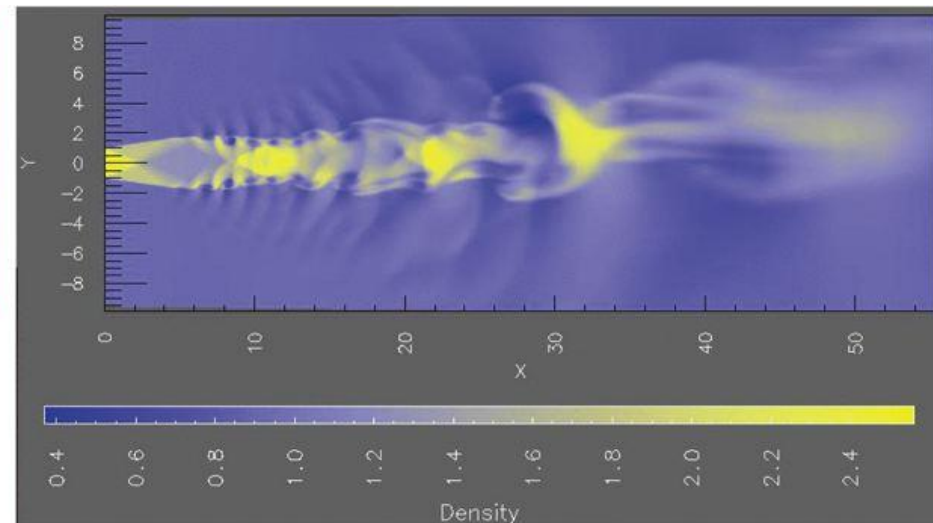
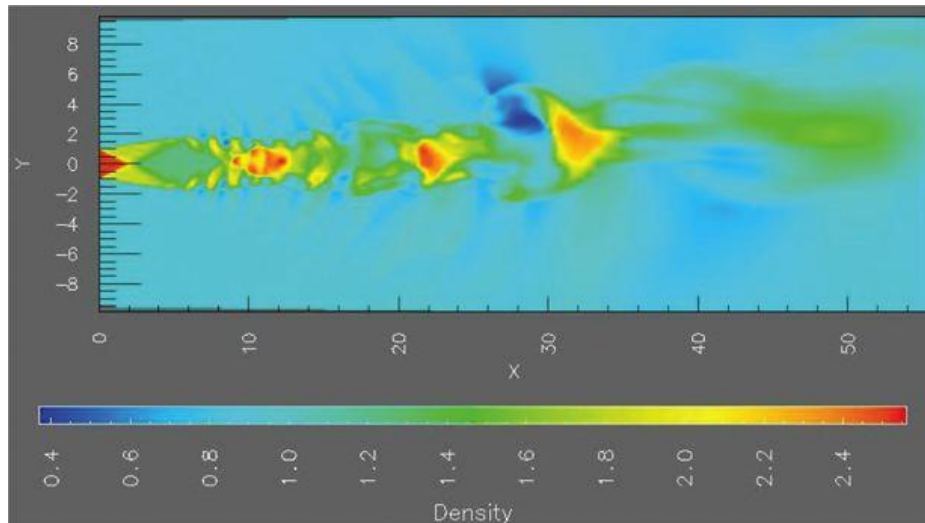
- Hue (that has no perceptual order) is used to indicate order
- Perceptual nonlinearity: divisions between hues create edges in visualization that have nothing to do with the data



Sequential color maps: rainbow

Do not use it!

- The details are harder to see
- Only advantage: Colors can be easily named
- Overused because chosen as the default color map on many software

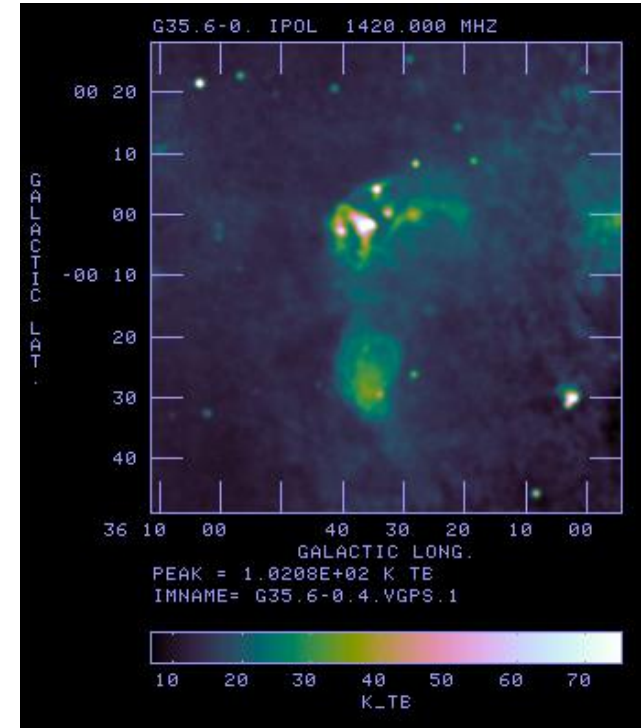
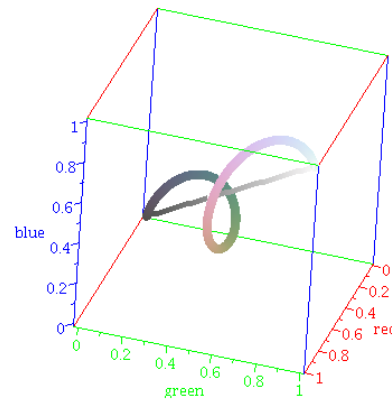


Sequential color maps

Cubehelix

- Continuous increase in lightness
- Named colors
- Suitable for grayscale printing (scientific papers)

A color map generator



Diverging color maps

Encode two properties at the same time

- Above/below threshold (usually zero)
- Magnitude above/below threshold

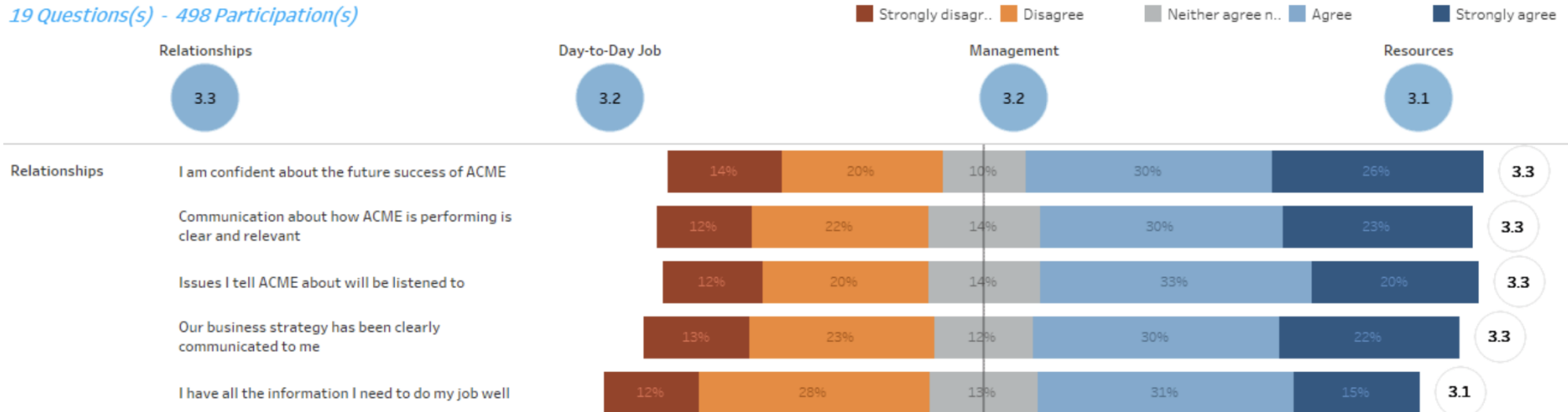
Desired properties

- Perceived differences correspond to value differences
- High discriminability
- Same luminance “ramp” on both sides



Diverging color maps

19 Questions(s) - 498 Participation(s)



Categorical color maps

Desired properties

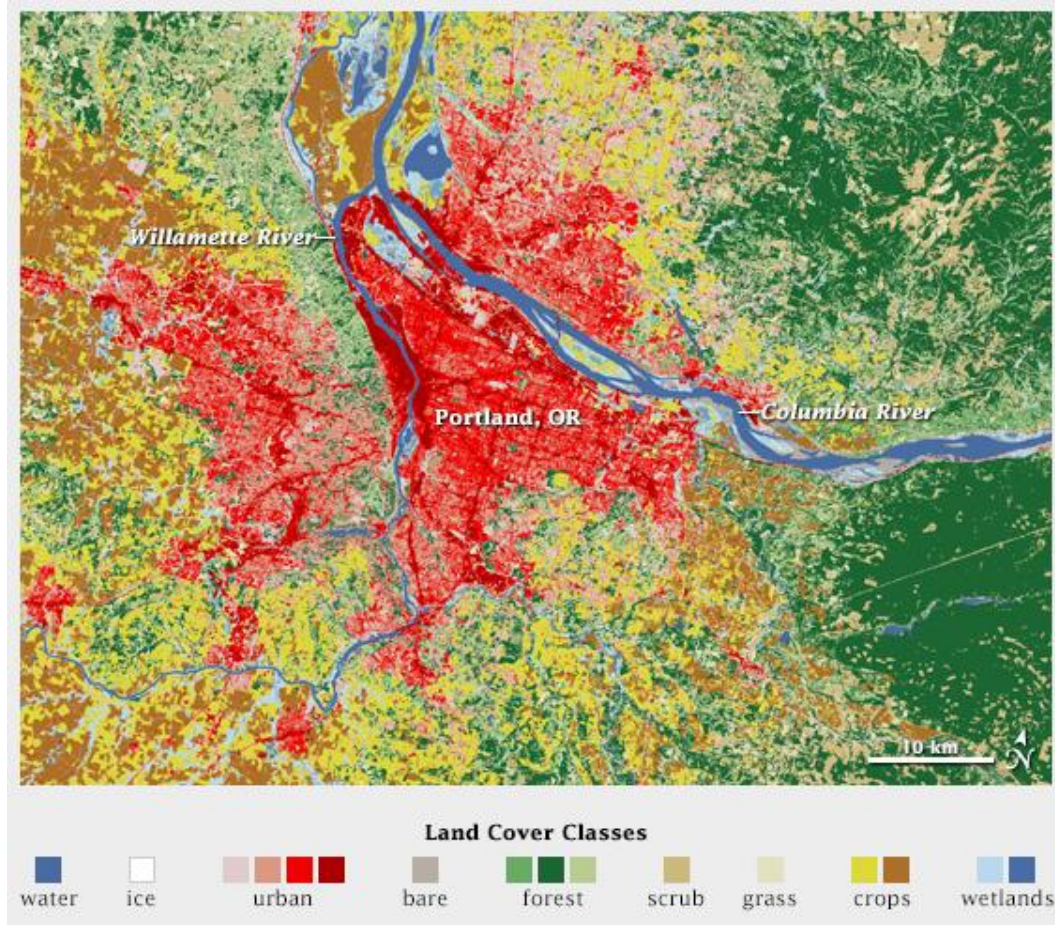
- Uniform saliency (nothing stands out)
- High discriminability



Use colors that can be named

Do not use too many different colors/categories

Categorical color maps



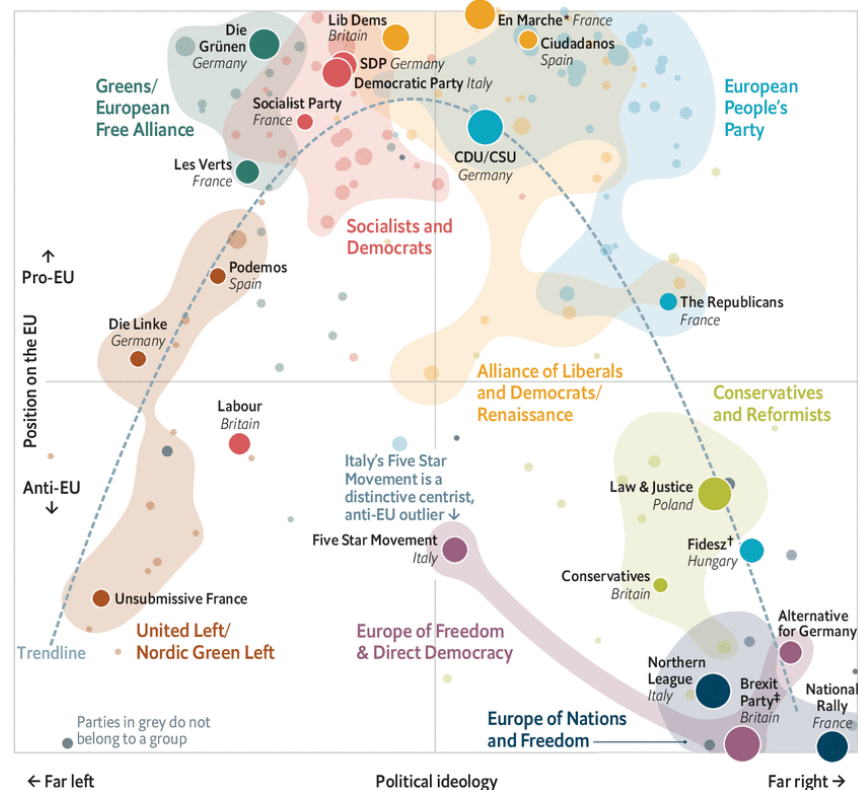
Categorical color maps

Anti-EU parties cluster at ideological extremes, whereas pro-EU ones are centrist

European Parliament political parties and groupings

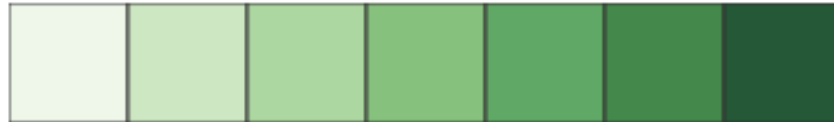
By ideology and position on the EU

Party name — ● — Parliamentary grouping 2019 election, provisional results, seats ○ 10 ○ 20

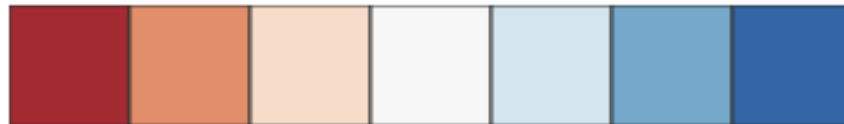


Univariate color maps

Sequential color maps



Diverging color maps

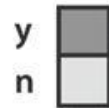


Categorical color maps



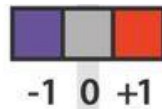
Bivariate color maps

Binary



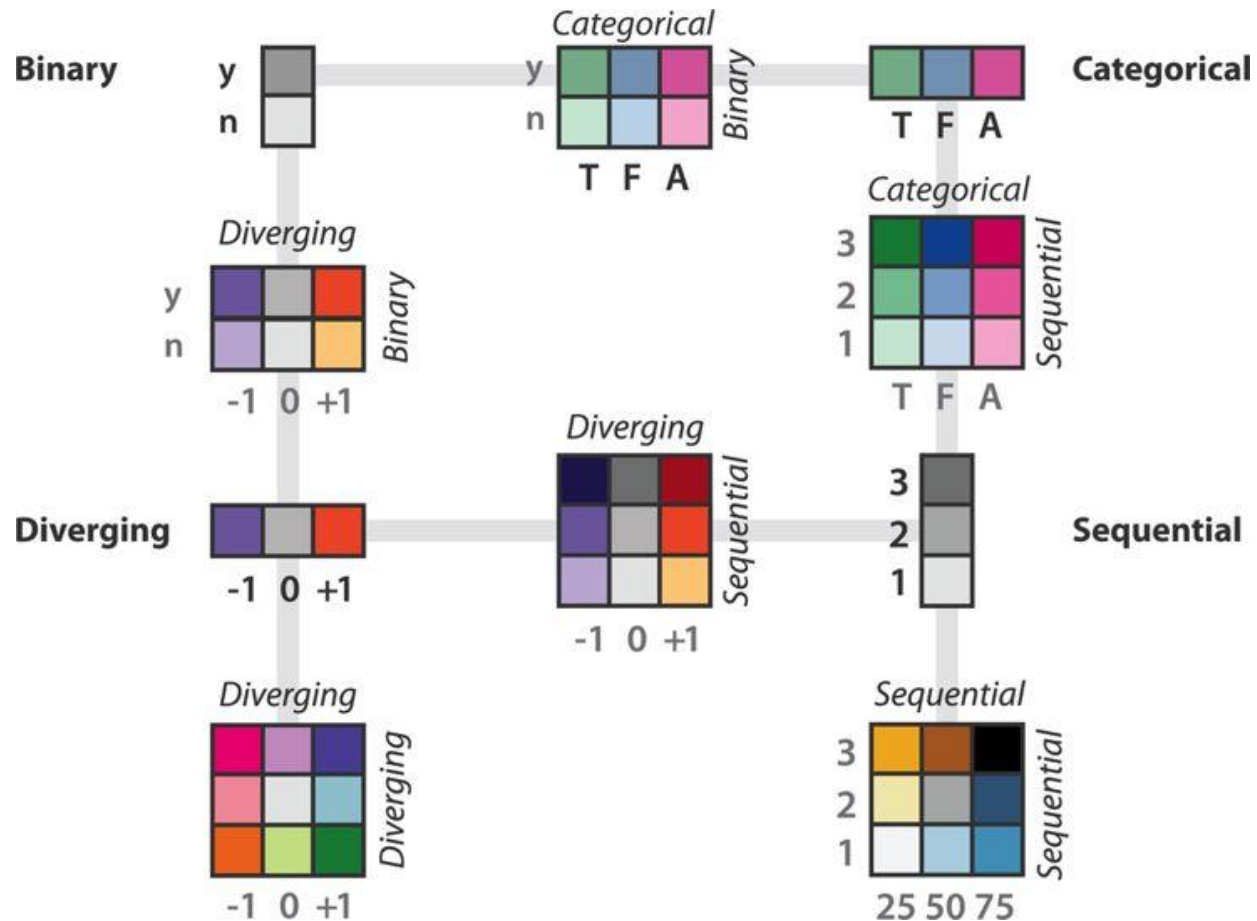
Categorical

Diverging



Sequential

Bivariate color maps

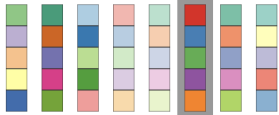


Existing color maps

Number of data classes: **how to use** | **updates** | **downloads** | **credits**

Nature of your data:
 sequential diverging qualitative

Pick a color scheme:



Only show:
 colorblind safe
 print friendly
 photocopy safe

Context:
 roads
 cities
 borders

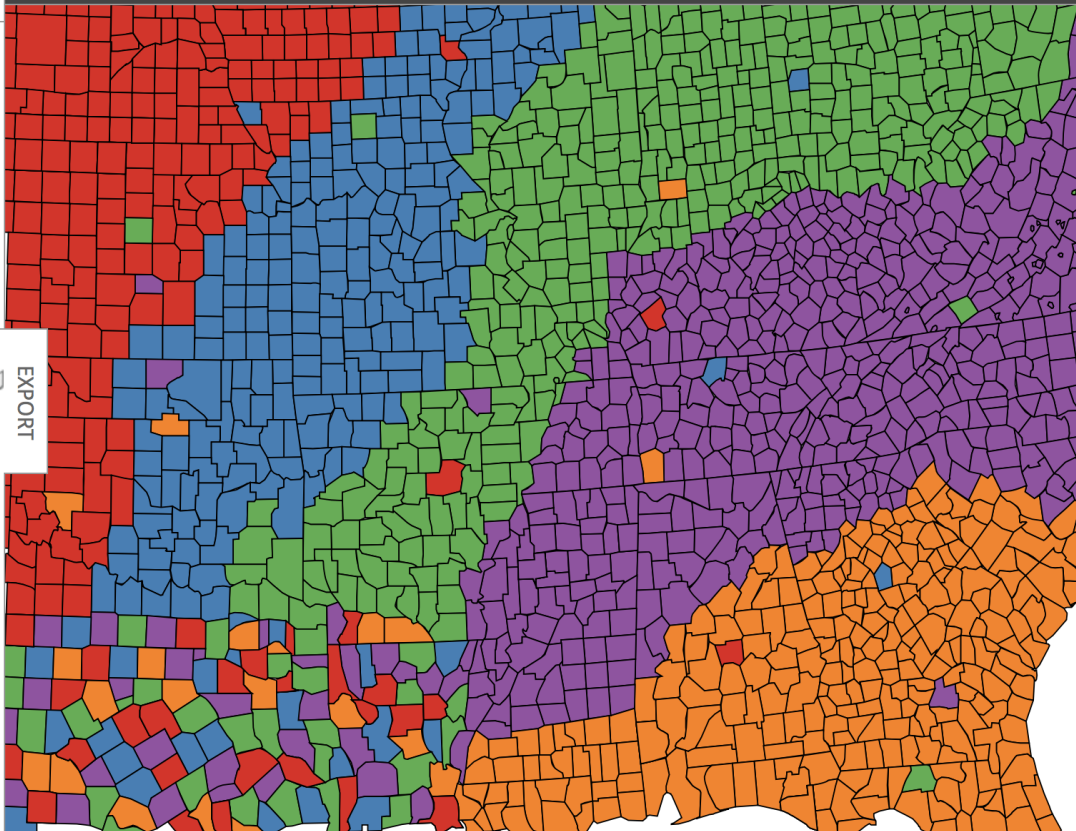
Background:
 solid color
 terrain

color transparency

5-class Set1
HEX
#e41a1c
#377eb8
#4daf4a
#984ea3
#ff7f00

EXPORT

COLORBREWER 2.0
color advice for cartography



Custom color maps

3 Check and configure the resulting palette

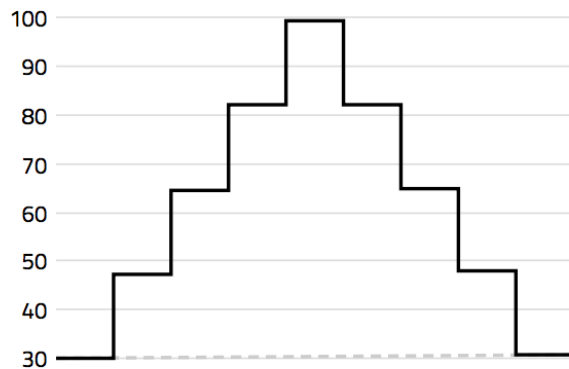
✓ This palette is colorblind-safe.

correct lightness bezier interpolation

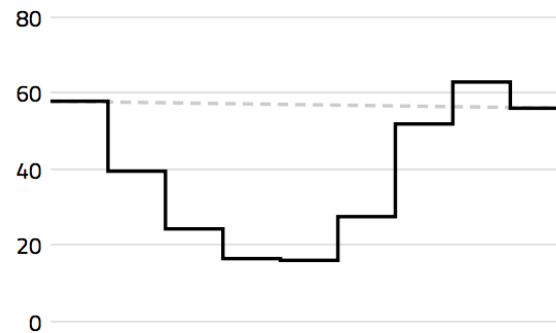
simulate: normal deut. prot. trit.



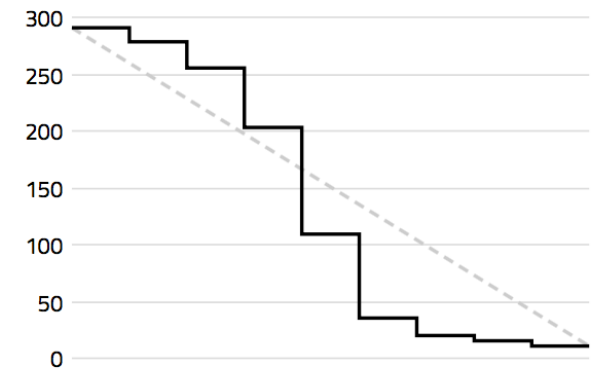
lightness



saturation



hue



Semantics of color

Green = good

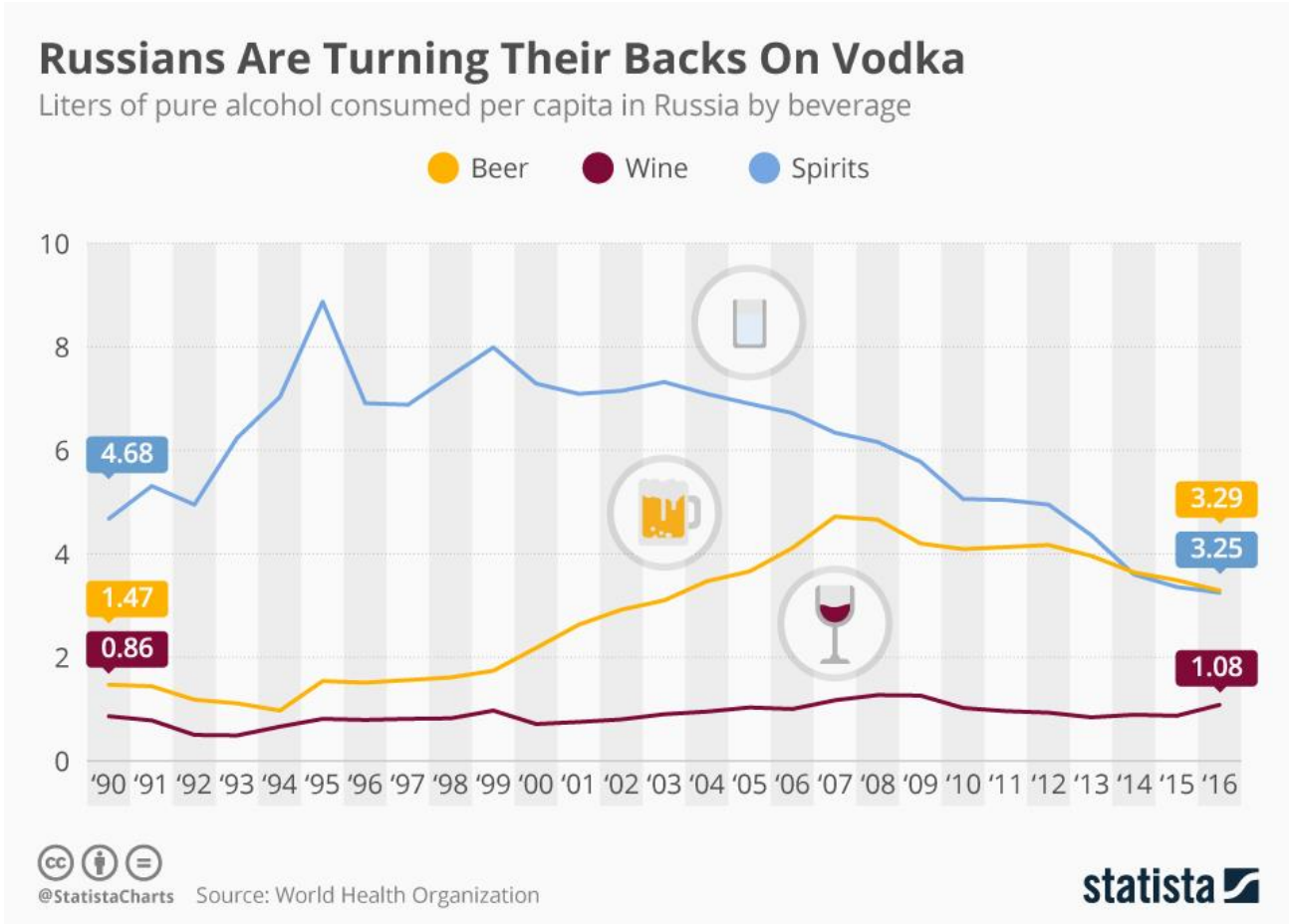
Red = bad

Gray perceived as “no color”

- Missing data
- Uncategorized data
- Non-emphasized data

Very powerful when used appropriately

Semantics of color

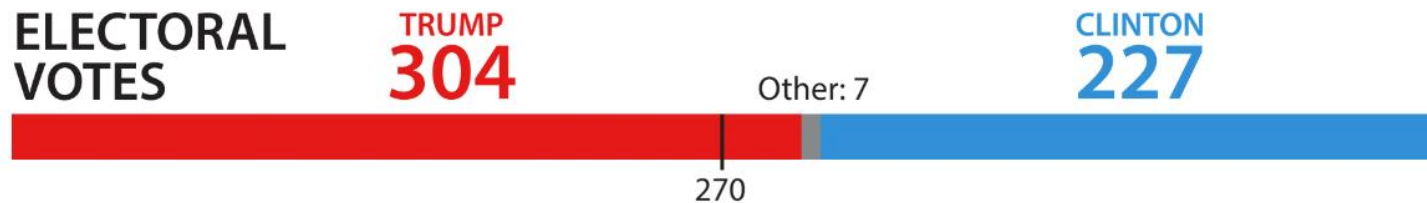


Semantics of color

Use color consistently

Example from US politics

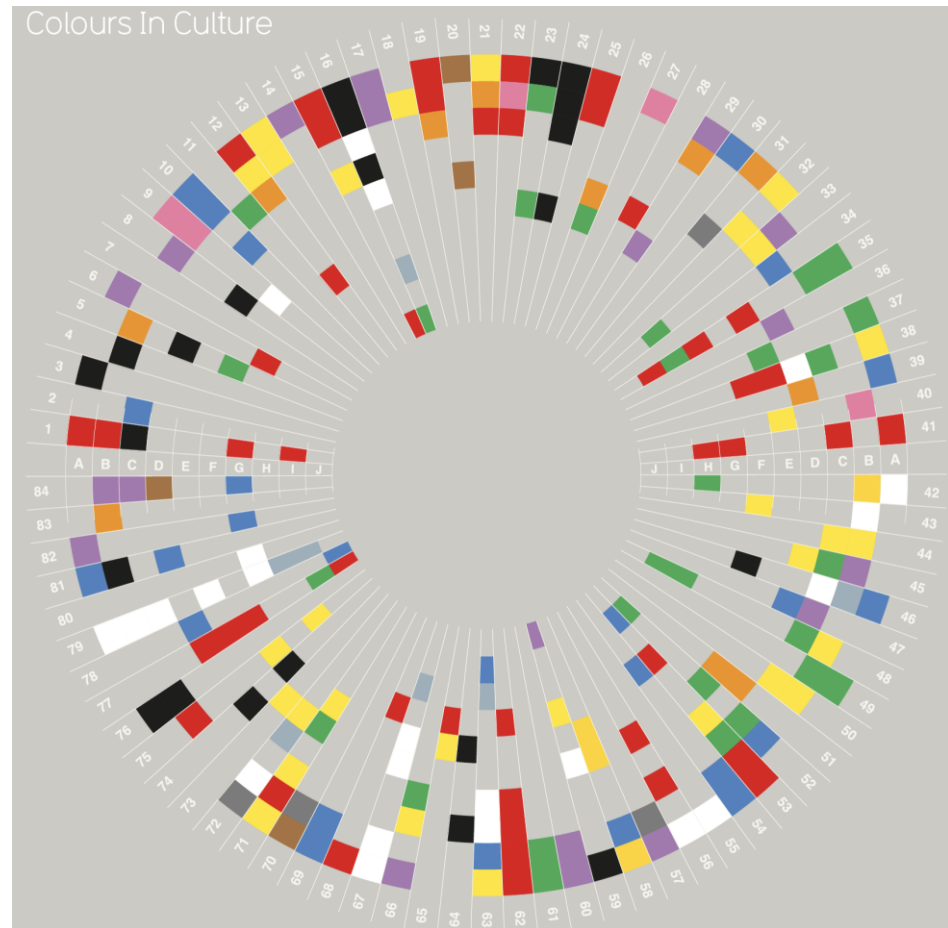
- Republicans = red
- Democrats = blue



Semantics of color

Meaning changes depending on culture

- A Western / American
- B Japanese
- C Hindu
- D Native American
- E Chinese
- F Asian
- G Eastern European
- H Arab
- I African
- J South American



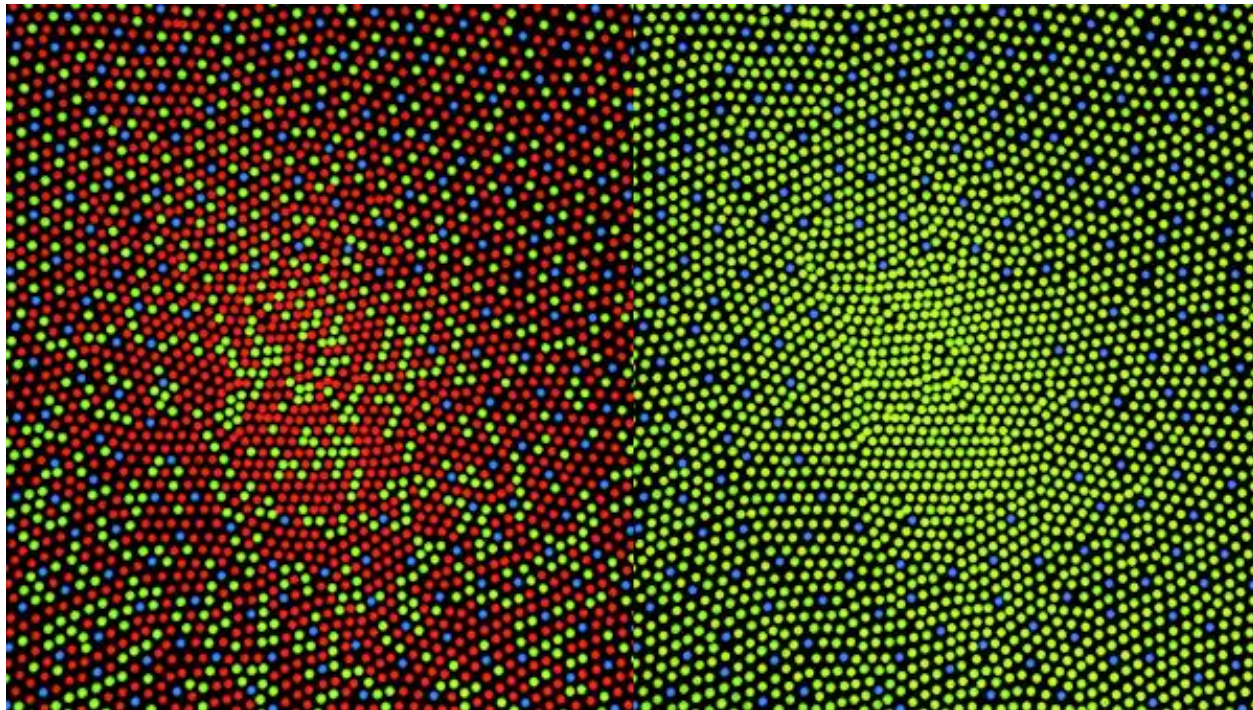
Semantics of color

Floor of a
children's
hospital

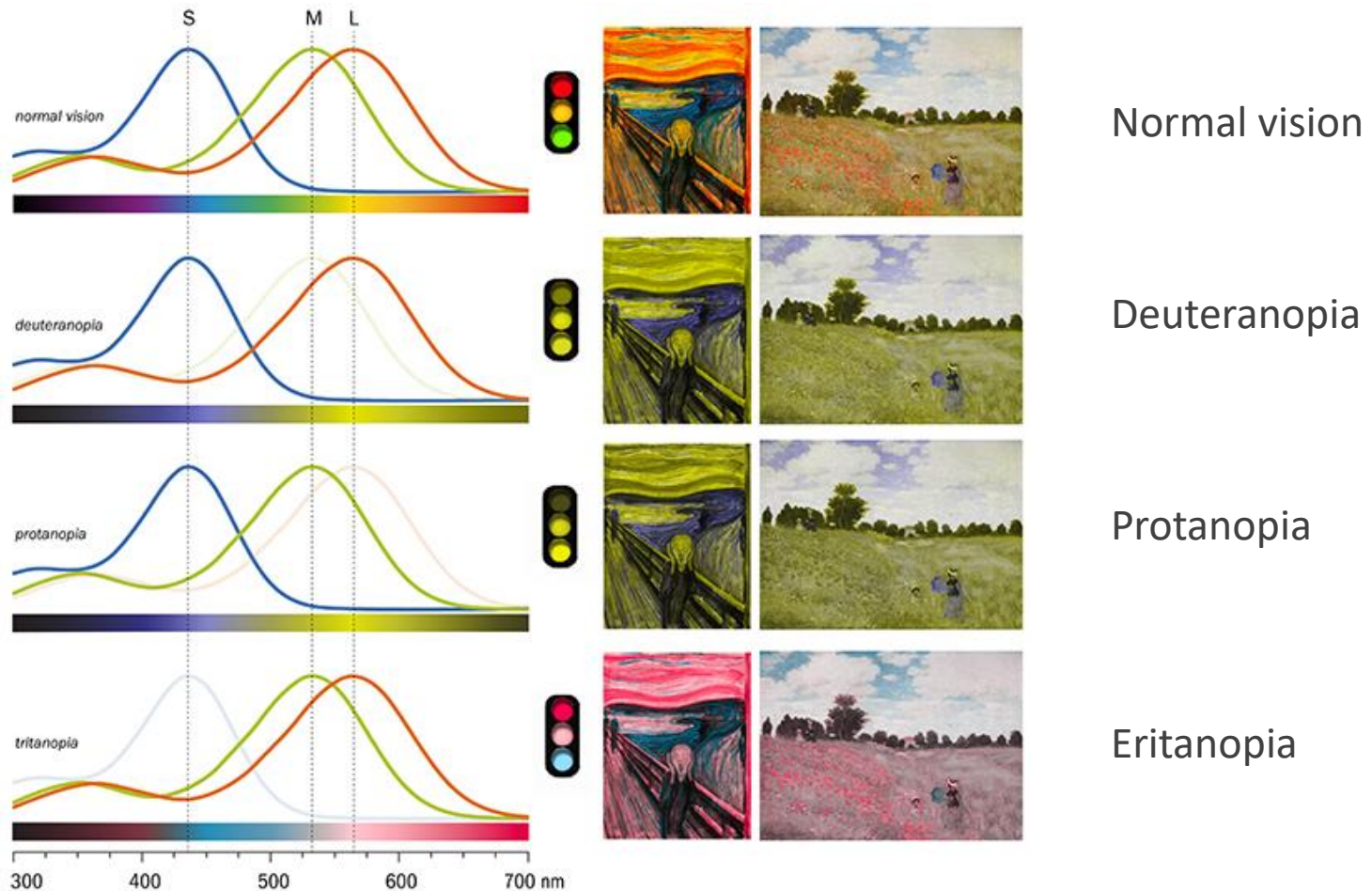


Color blindness

Red-green color blindness affects up to 8% of males and 0.5% of females of Northern European descent



Color blindness



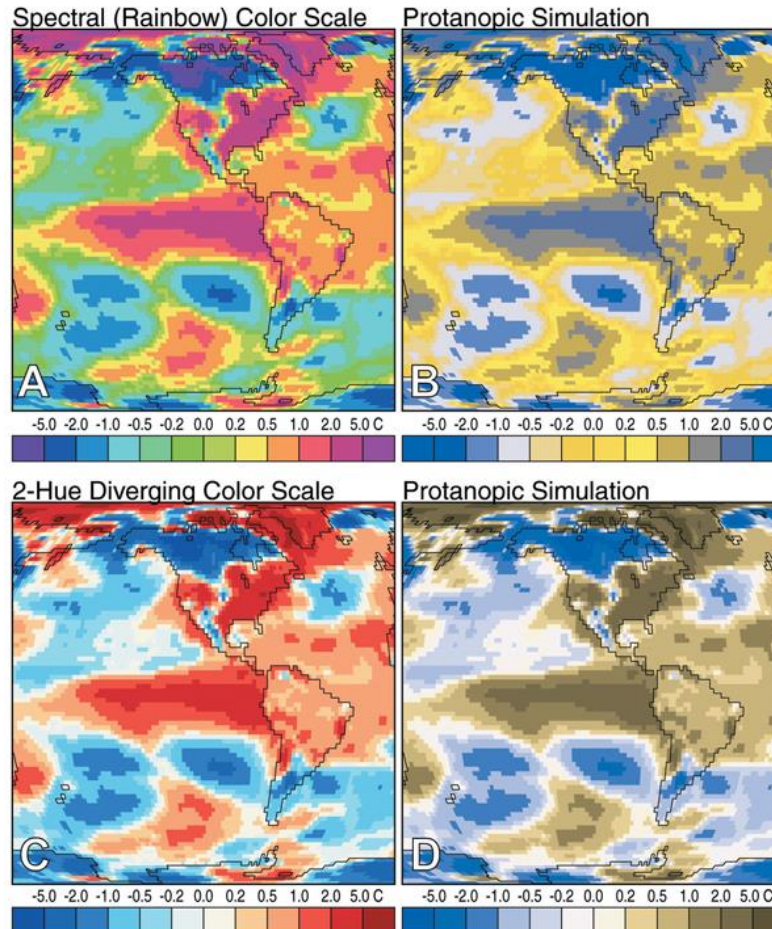
Color blindness

indistinguishable colors in color blindness



























<http://mkweb.bcgsc.ca/colorblind>

Color blindness



Color blindness

Color	Color name	RGB (1–255)	CMYK (%)	P	D
	Black	0, 0, 0	0, 0, 0, 100		
	Orange	230, 159, 0	0, 50, 100, 0		
	Sky blue	86, 180, 233	80, 0, 0, 0		
	Bluish green	0, 158, 115	97, 0, 75, 0		
	Yellow	240, 228, 66	10, 5, 90, 0		
	Blue	0, 114, 178	100, 50, 0, 0		
	Vermillion	213, 94, 0	0, 80, 100, 0		
	Reddish purple	204, 121, 167	10, 70, 0, 0		

Wong, B. (2011) Points of view: Color blindness. *Nature Methods* 8:441.

See also tools from <https://www.color-blindness.com/2008/12/23/15-tools-color-blindness/>

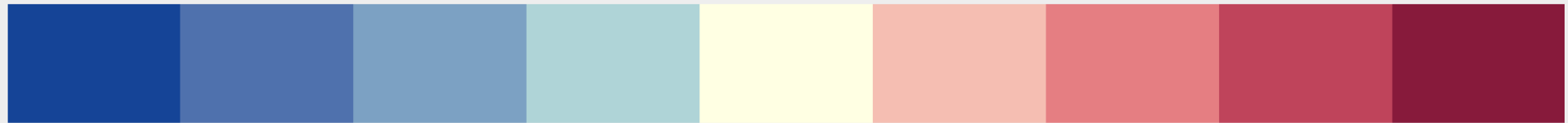
Color blindness

3 Check and configure the resulting palette

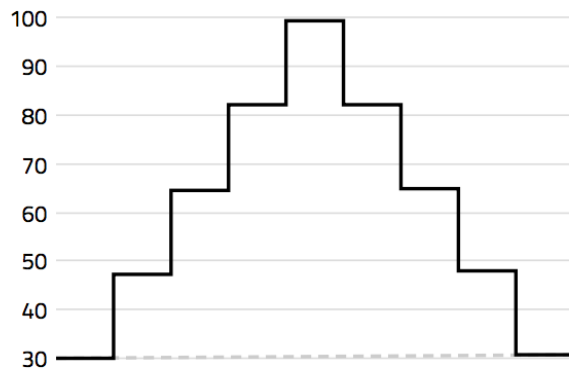
✓ This palette is colorblind-safe.

correct lightness bezier interpolation

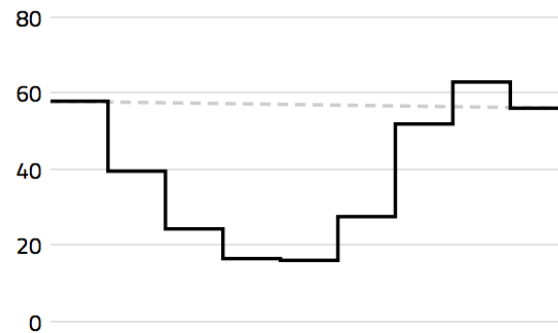
simulate:



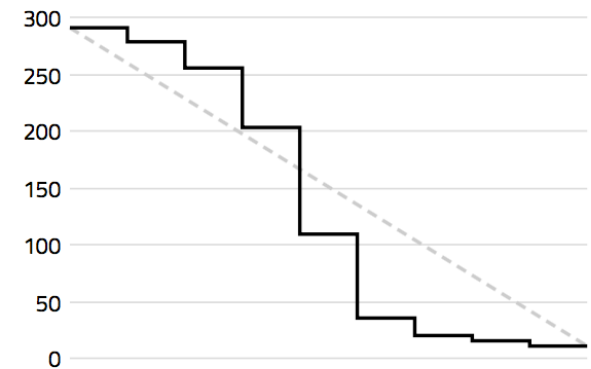
lightness



saturation



hue



Color blindness

VIZ PALETTE By: Elijah Meeks & Susie Lu

PICK

Use Chroma.js

Use Colorgical

Use ColorBrewer

EDIT

7 Colors

Add

#hex rgb

hsl

GET

#hex rgb

hsl

- 1 ● #ffd700 ✕
- 2 ● #ffb14e ✕
- 3 ● #fa8775 ✕
- 4 ● #ea5f94 ✕
- 5 ● #cd34b5 ✕
- 6 ● #9d02d7 ✕
- 7 ● #0000ff ✕

- String quotes
- Object with metadata

```
[{"#ff4700",  
"#ffb14e",  
"#fa8775",  
"#ea5f94",  
"#cd34b5",  
"#9d02d7",  
"#0000ff"}]
```

COLORS IN ACTION

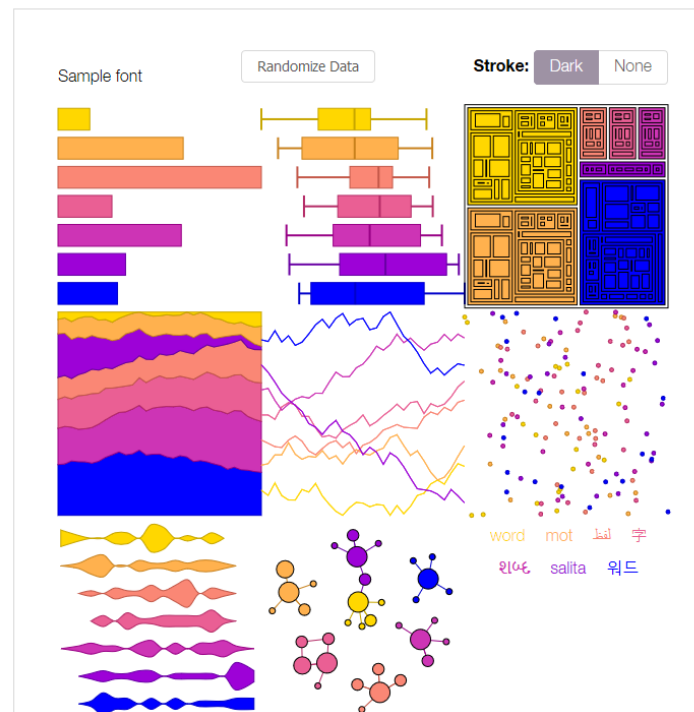
Font color: ● #000000 ✎

Charts made with Semiotic

Color Population:

No Color Deficiency - 96% Deuteranomaly - 2.7% Protanomaly - 0.66%

Protanopia - 0.59% Deuteranopia - 0.56%



Color blindness

Use colorblind safe palettes

Blue/orange and blue/red normally safe

Test design with color blindness simulators

If you really need to use red/green, make sure they vary in lightness



Normal vision



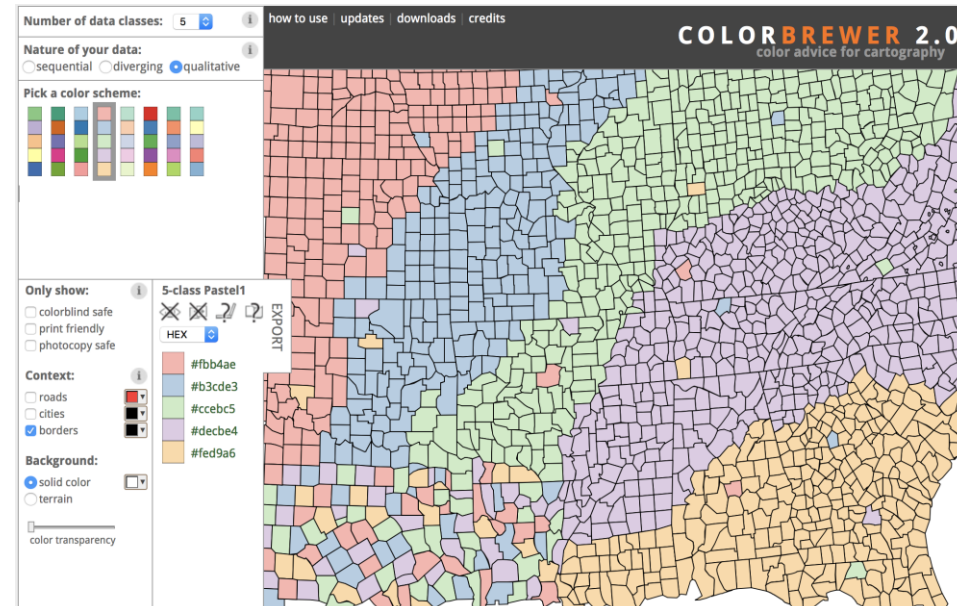
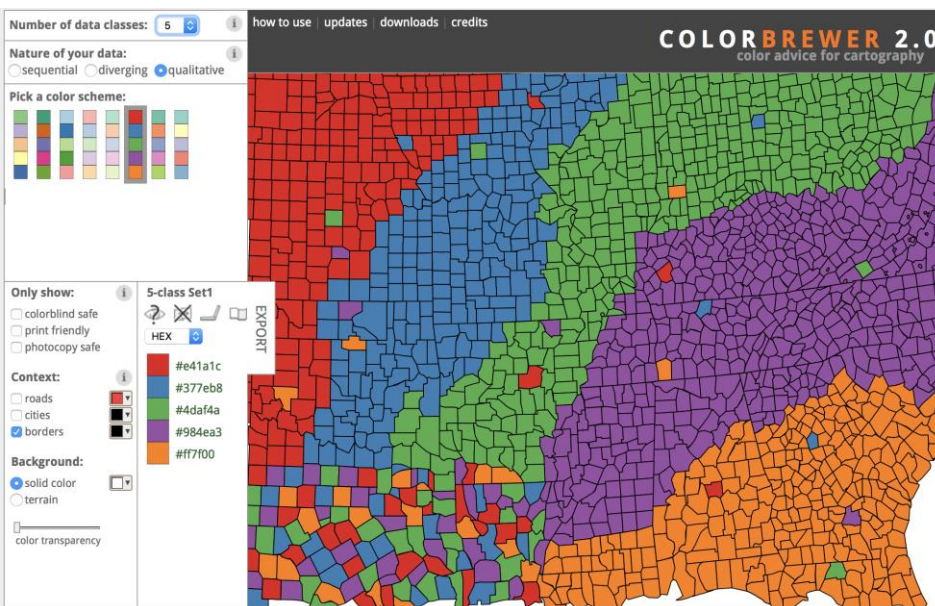
Deuteranopia

Importance of size

Small size hurts discriminability

Small area → high saturation

Large area → low saturation



Relative perception

Our color perception is not absolute, but relative

- Importance of contrast
- Importance of background
- Importance of surrounding color

Importance of contrast

CONTRAST RATIOS

1.0				
1.1	Choose if you dislike readers.	That's bad.	That's bad.	Horrible.
1.5	Ok in 1% of the cases.	Not ideal.	That's bad.	My eyes!
2.5	Can be a good choice.	Ok.	Not ideal.	That's bad.
4.5	Safe choice.	Great.	Ok.	Not ideal.

Contrast is most easily changed using luminance/lightness

Importance of contrast

Colour Contrast Check

Date created: January 11, 2005
Date last modified: January 11, 2015

Foreground Colour:

63BD7B

Red:

Green:

Blue:

Hue (°):

Saturation (%):

Value (%):

Background Colour:

8DE7E7

Red:

Green:

Blue:

Hue (°):

Saturation (%):

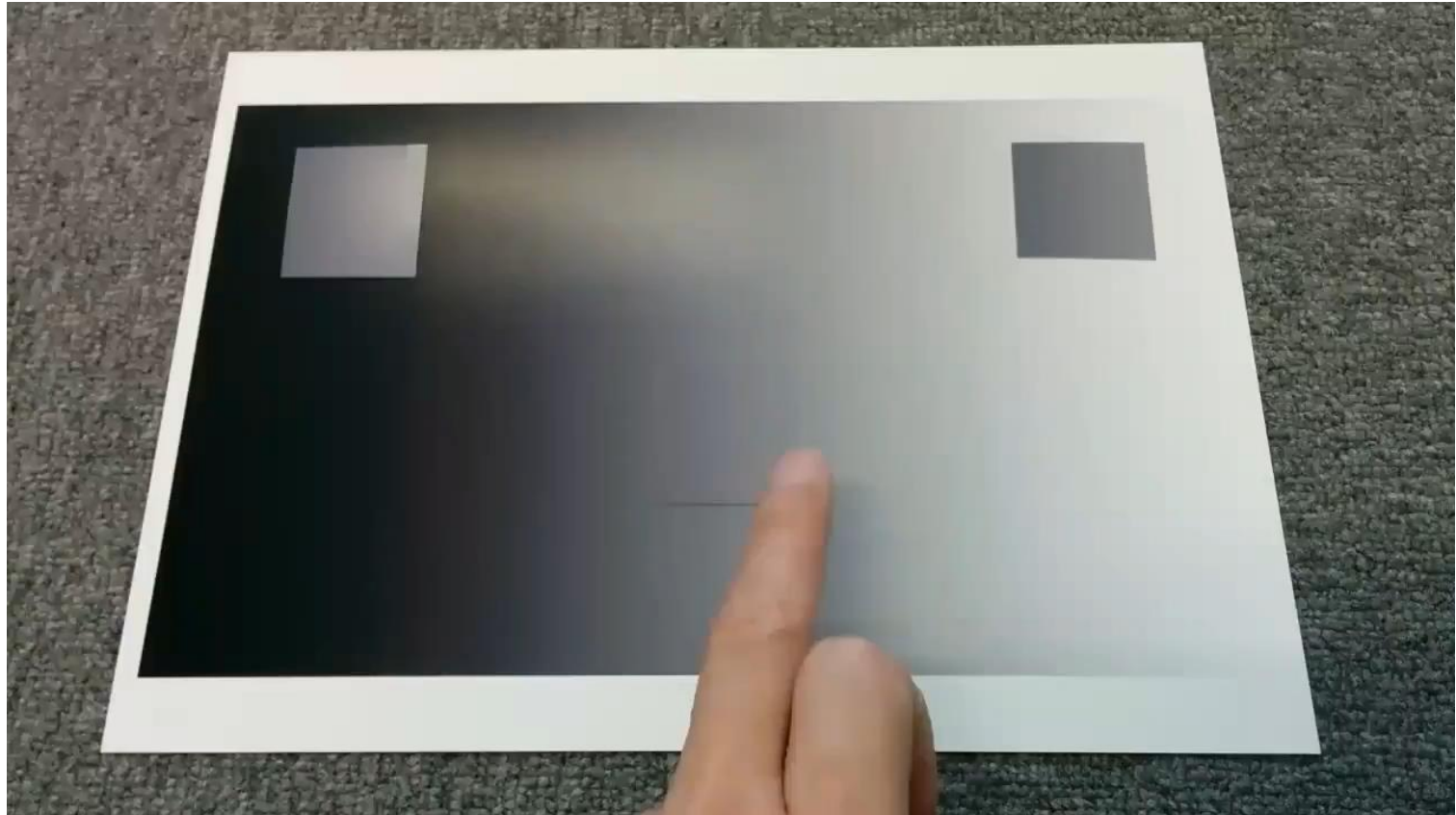
Value (%):

Results

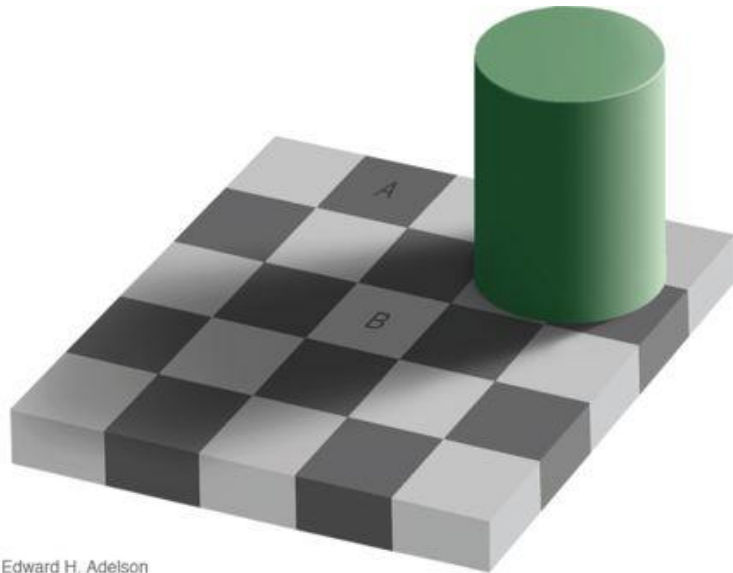
This is example text. **Some of it bolded.**
Some of it italicized.

Brightness Difference: (>= 125)	49.524
Colour Difference: (>= 500)	192
Are colours compliant?	NO
Contrast Ratio	1.618
WCAG 2 AA Compliant	NO
WCAG 2 AA Compliant (18pt+)	NO
WCAG 2 AAA Compliant	NO
WCAG 2 AAA Compliant (18pt+)	NO

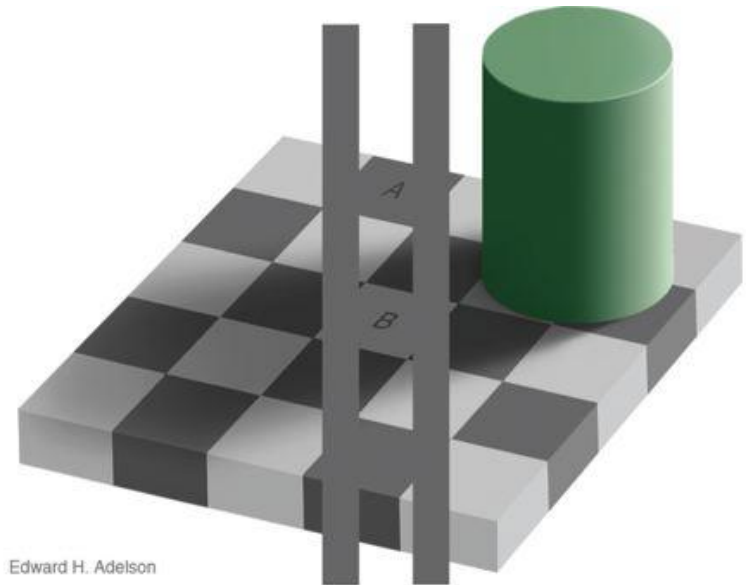
Importance of background



Importance of surrounding color



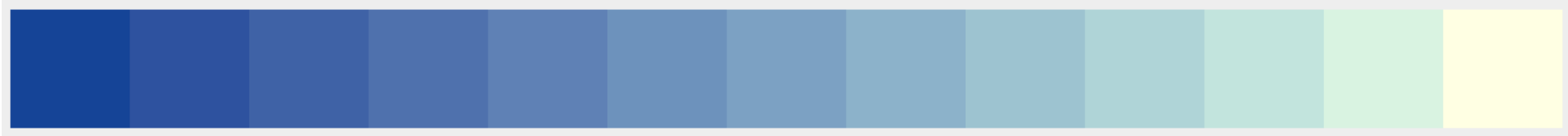
Edward H. Adelson



Edward H. Adelson

Importance of surrounding color

Mach bands



Importance of surrounding color

Our interpretation of colors is based on our expectations

Color constancy

- A feature of human color perception
- Ensures that the perceived color remains relatively constant under varying illumination conditions
- Helps us to identify objects

Strawberries appear to be red although the pixels are not



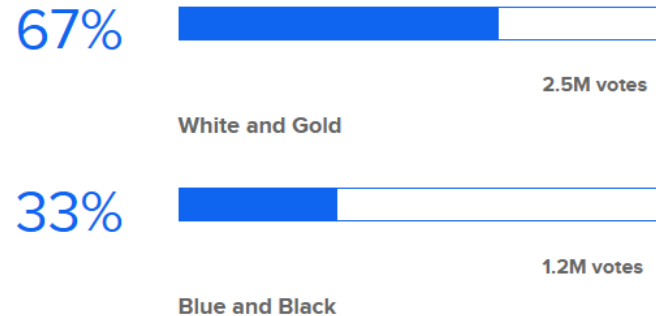
Importance of surrounding color

“The dress”



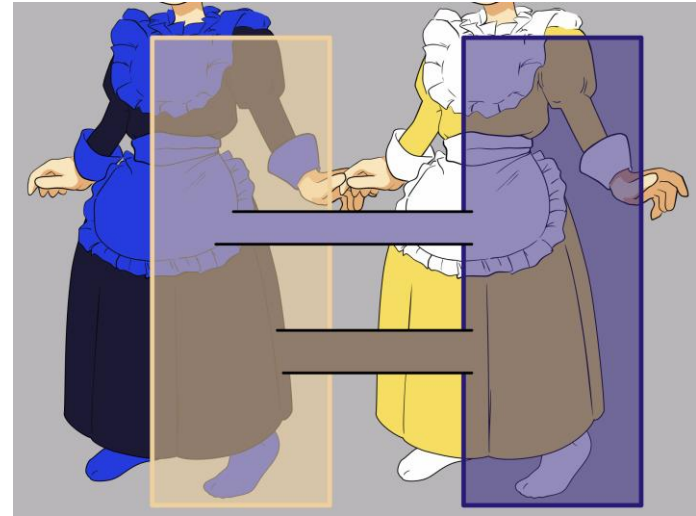
What colors are this dress?

- White and gold
- Blue and black



Importance of surrounding color

“The dress”



Theory: Image overexposed, color interpretation depends on our interpretation of the lighting

- Background lightning → White and gold
- Frontal lightning → Blue and black

Importance of surrounding color

“The dress”



The rabbit-duck illusion



Choosing colors

Use the right amount of contrast to the background



NOT IDEAL



BETTER



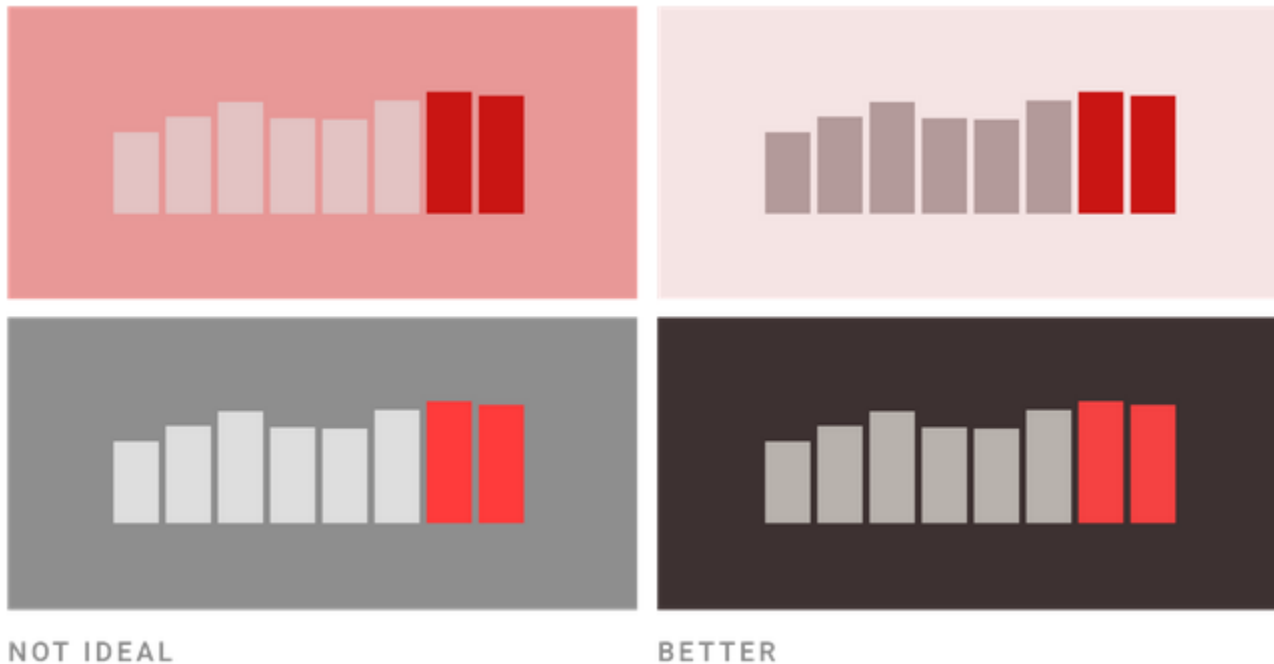
NOT IDEAL



BETTER

Choosing colors

Background should not be too saturated



Choosing colors

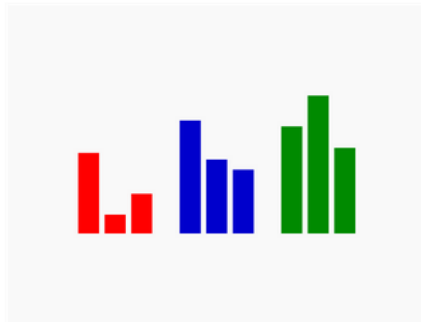
Avoid pure and highly saturated colors



NOT IDEAL



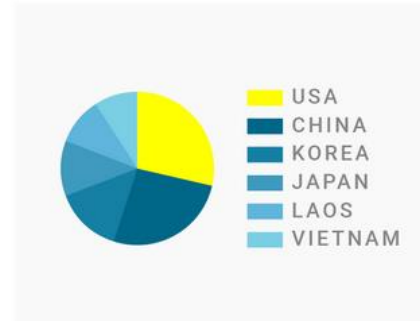
BETTER



NOT IDEAL



BETTER



NOT IDEAL



BETTER

Color use summary

Use color sparingly

Use color consistently

Be thoughtful of the tone that color conveys

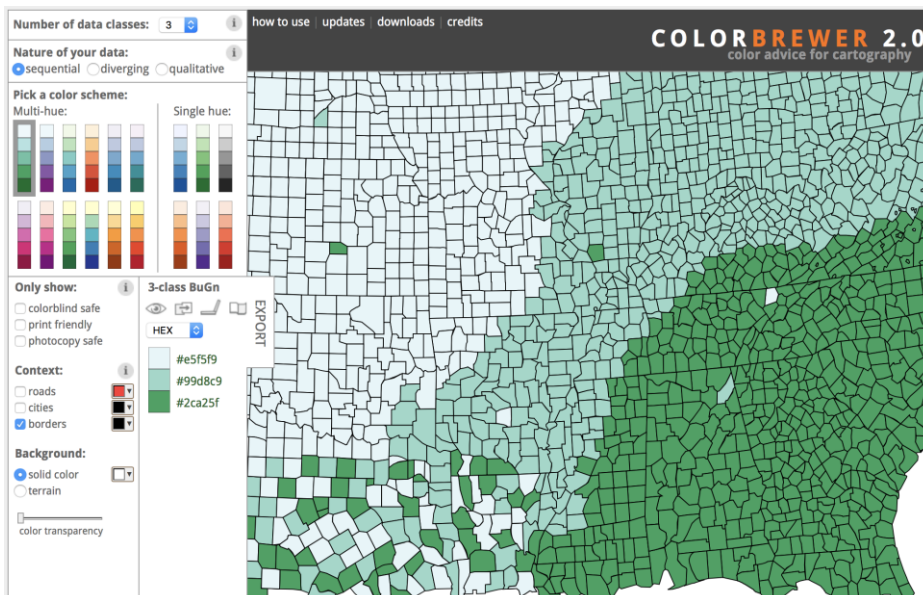
- Enforce emotions
- Consider culture

Design with colorblind in mind

Keep in mind that our perception is relative (the effect of contrast, background color and surrounding color)

Color use summary

Colorbrewer is your friend!



Stay away from the rainbow!

