Data Visualization

VISUAL PERCEPTION (2)

Overview

Motivation

Color perception

Color specification

Color use

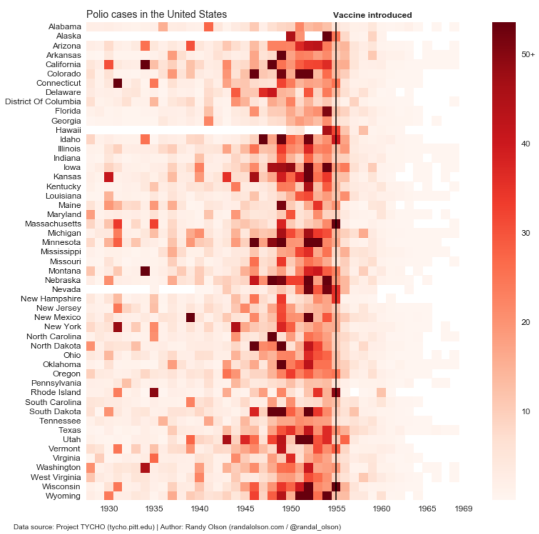
Motivation

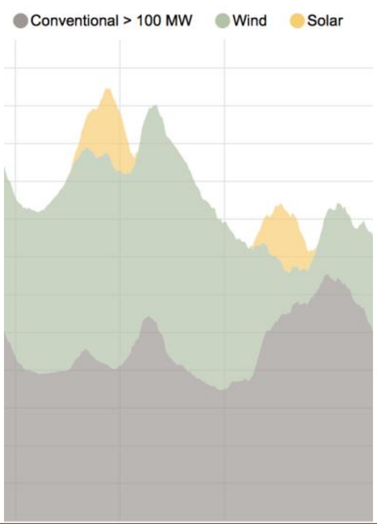
Motivation

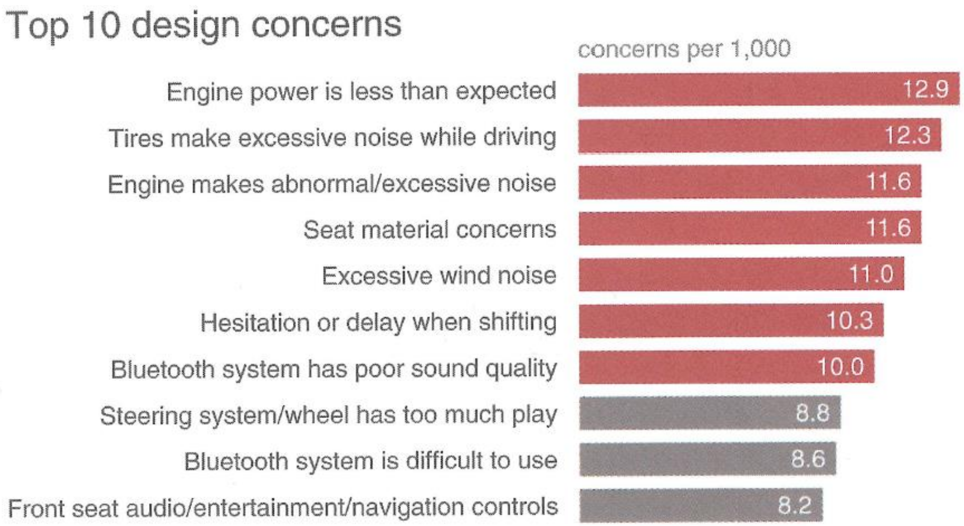
Color is a very powerful visual channel

Often used to

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





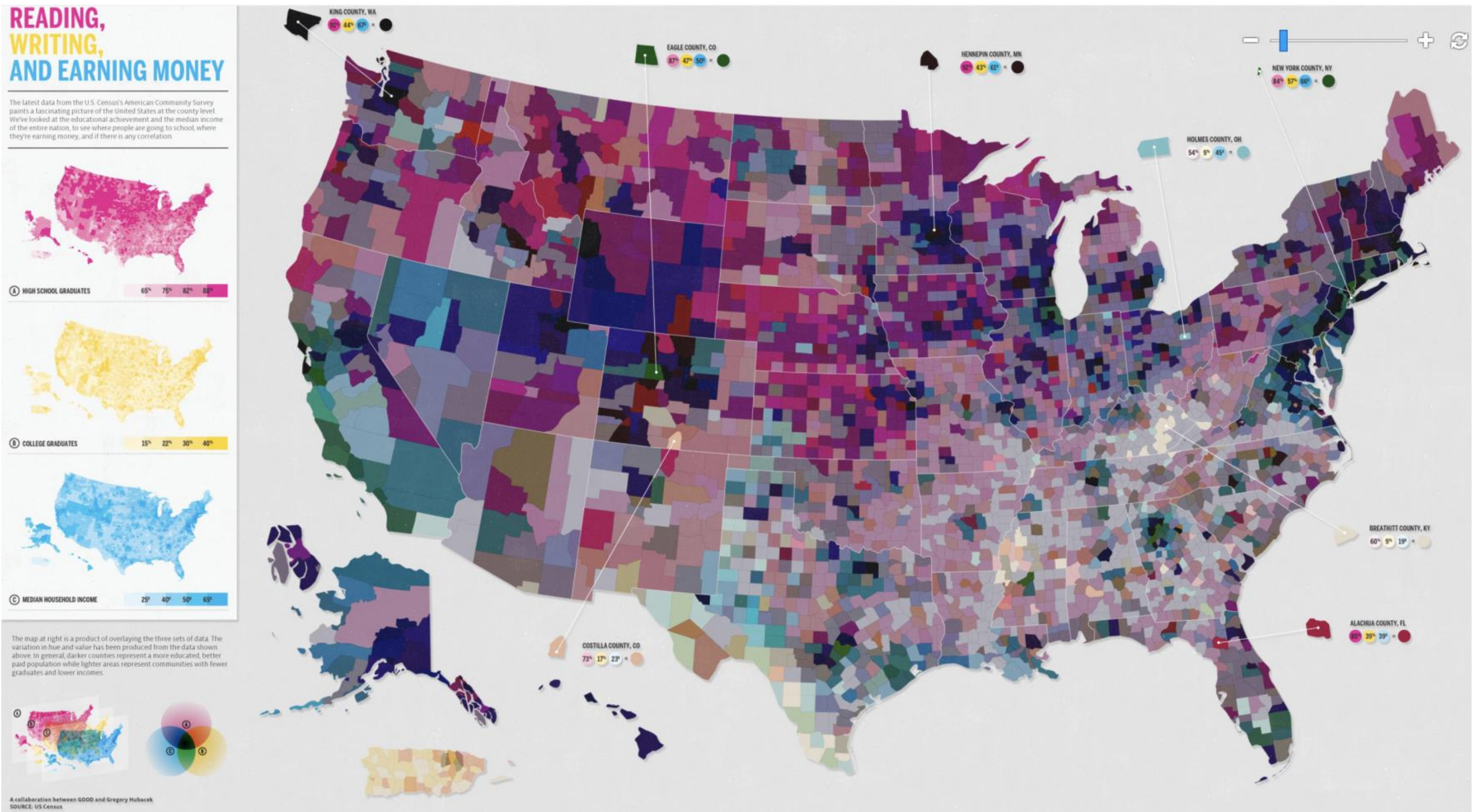


Color (mis)use

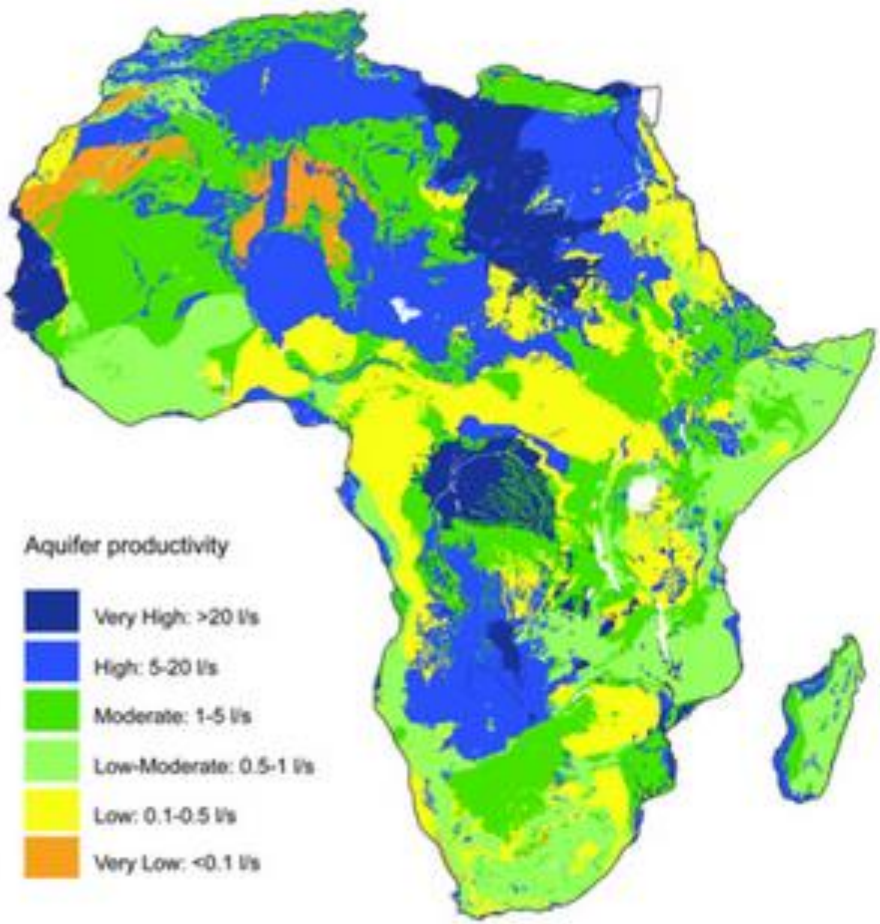
Above all, do no harm

Edward Tufte

Color (mis)use

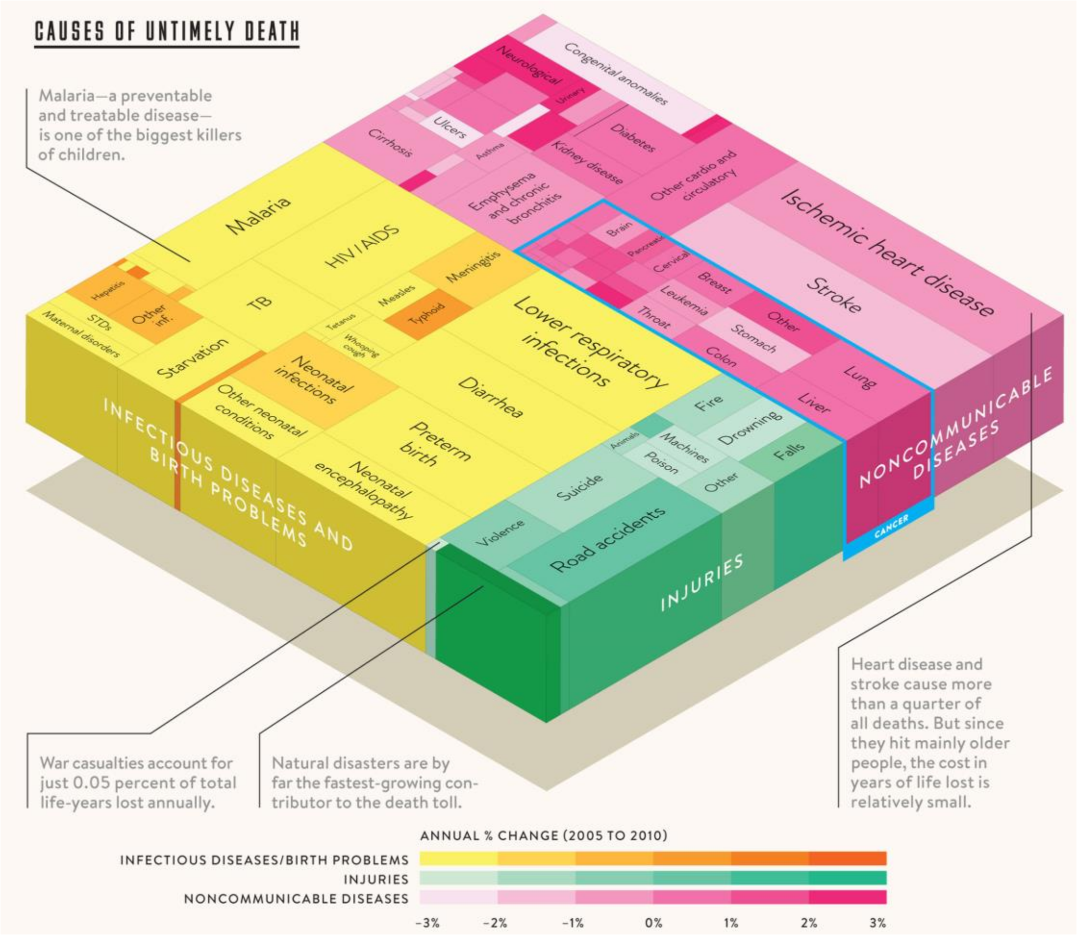


Color (mis)use

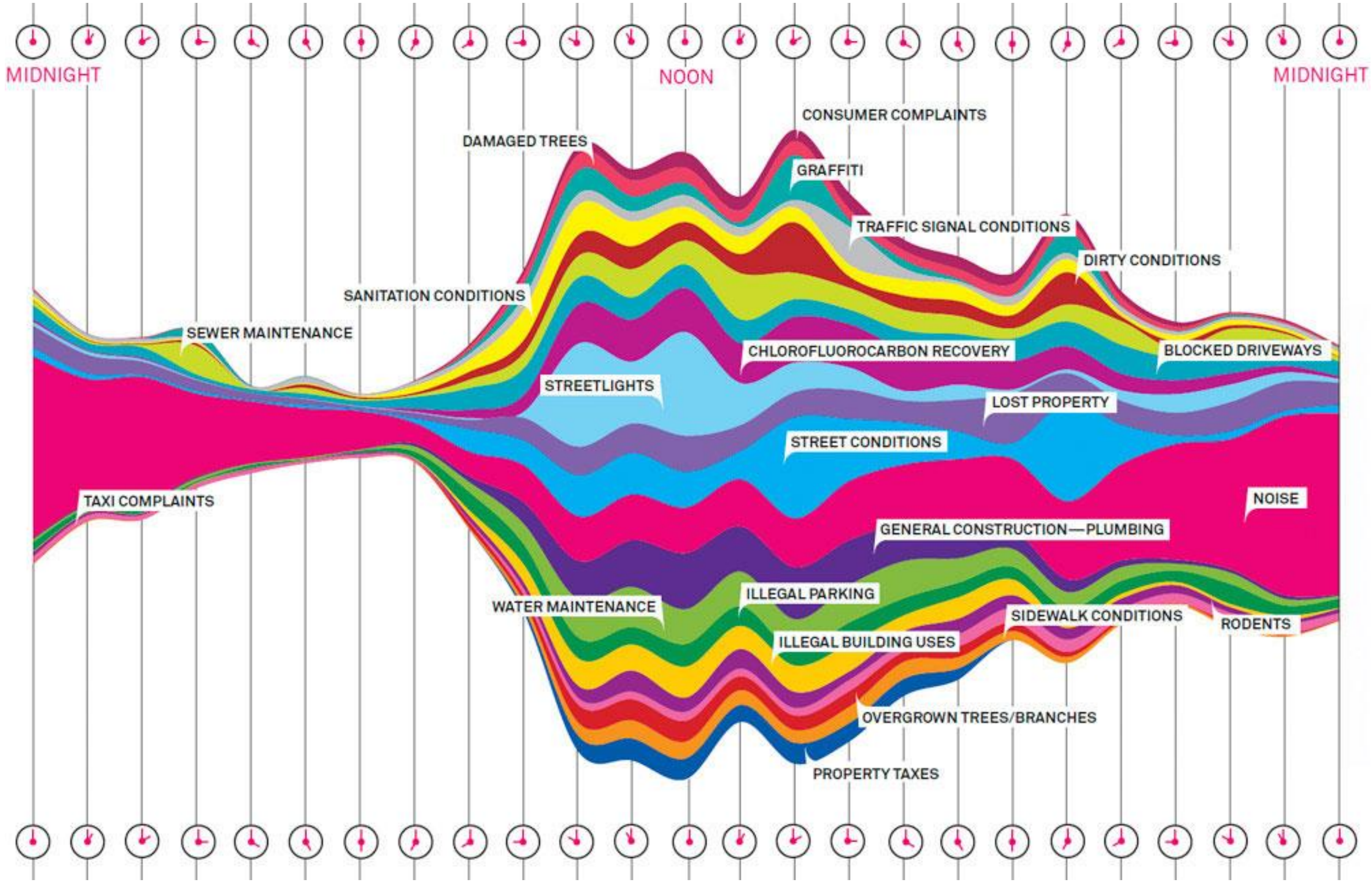


https://www.newsecuritybeat.org/2012/05/full-extent-of-africas-groundwater-resources-visualized-for-the-first-time/

Color (mis)use



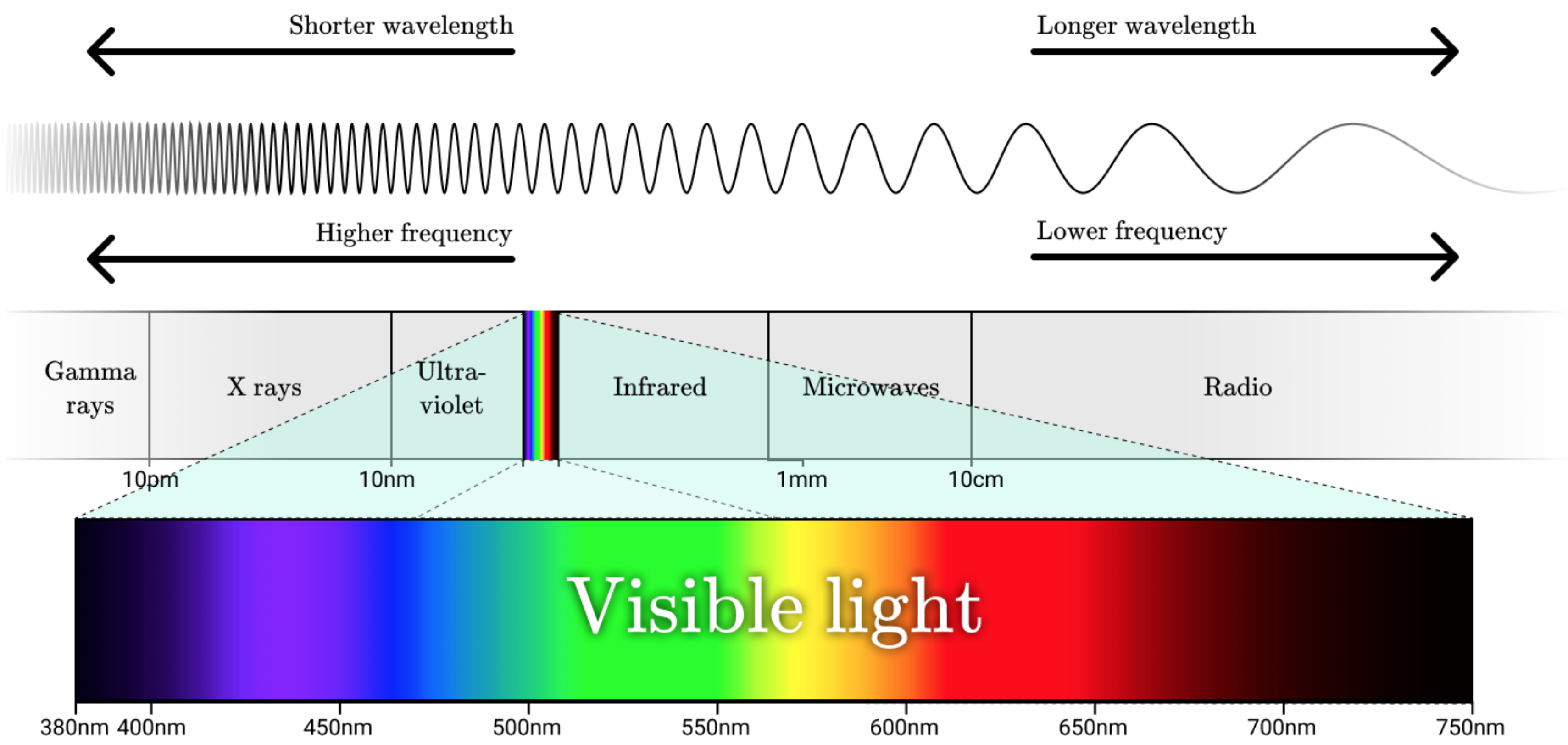
Color (mis)use



https://junkcharts.typepad.com/junk_charts/2010/11/making-charts-beautiful-without-adding-unneeded-bits.html

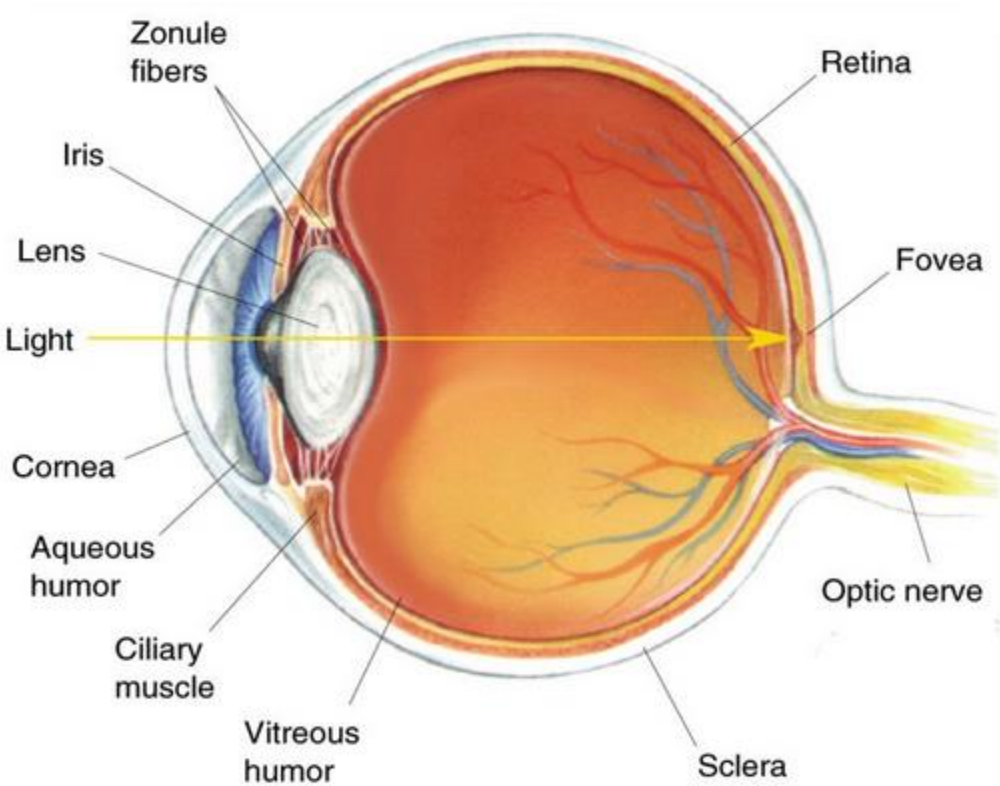
Color perception

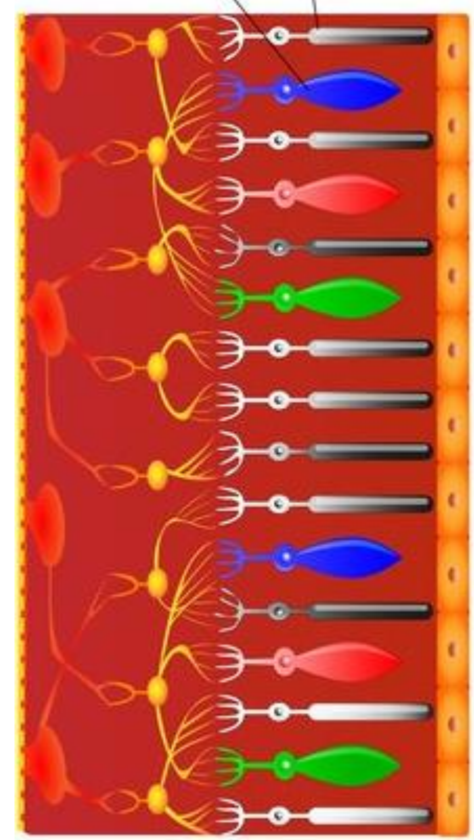
Light



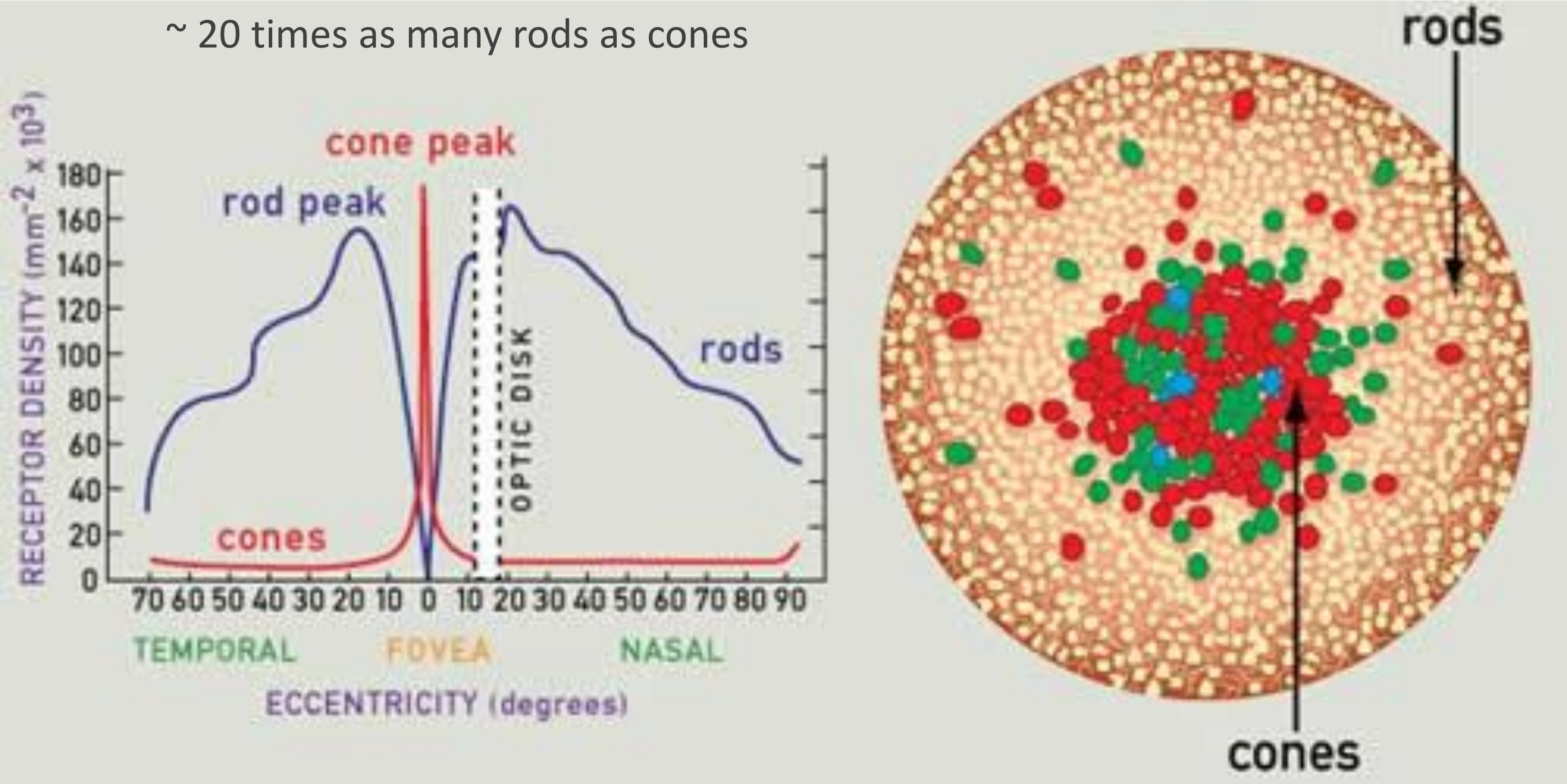
http://jamie-wong.com/post/color/

Human eye anatomy





Rods and cones (photoreceptors)



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

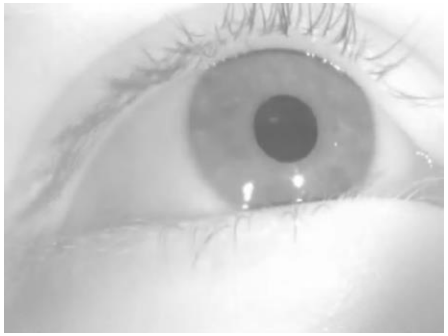
Filling in the blanks

https://en.wikipedia.org/wiki/File:FoveatedLandscape.png

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)

https://en.wikipedia.org/wiki/File:This_shows_a_recording_of_the_eye_movements_of_a_participant_looking_freely_at_a_picture.webm

Filling in the blanks

https://petapixel.com/2019/07/31/this-black-and-white-photo-uses-color-grid-lines-to-trick-your-brain/

Role of attention

Visual perception is driven by our attention

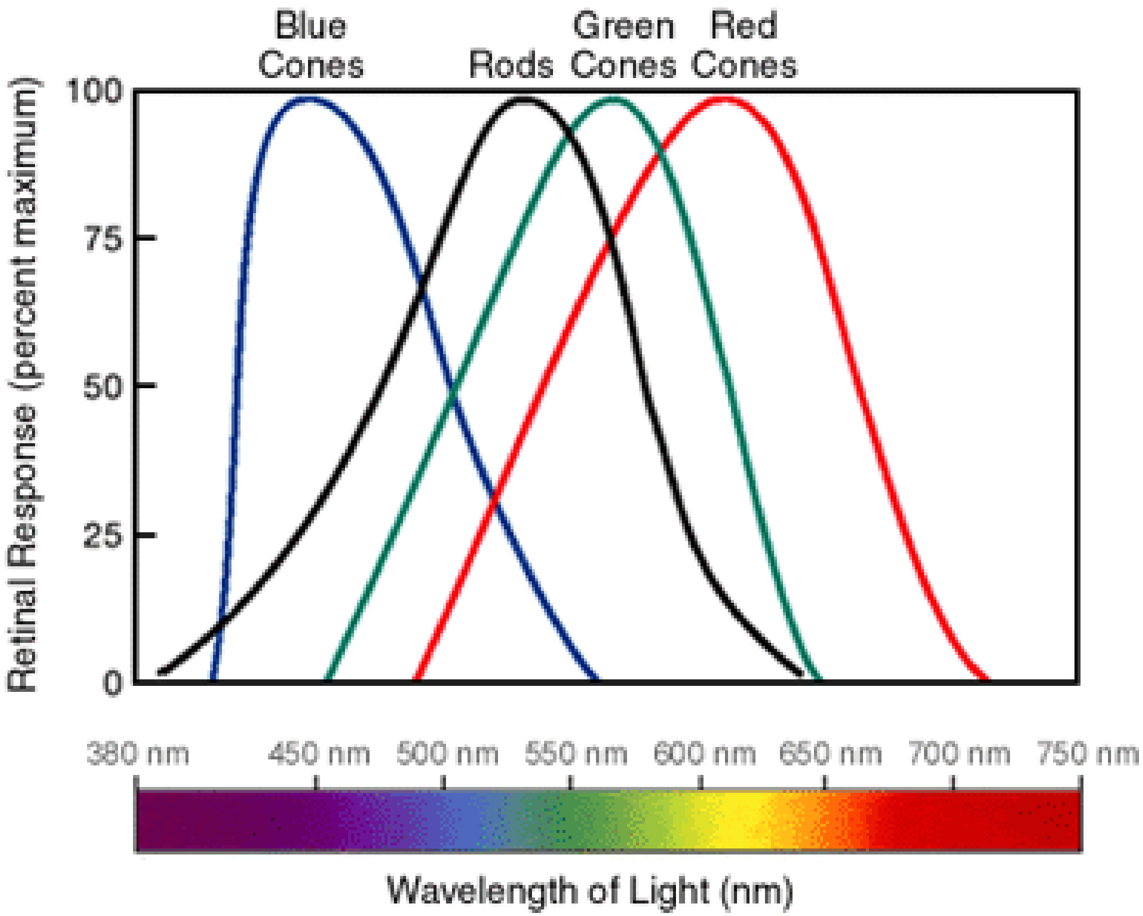
Inattentional blindness

- 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

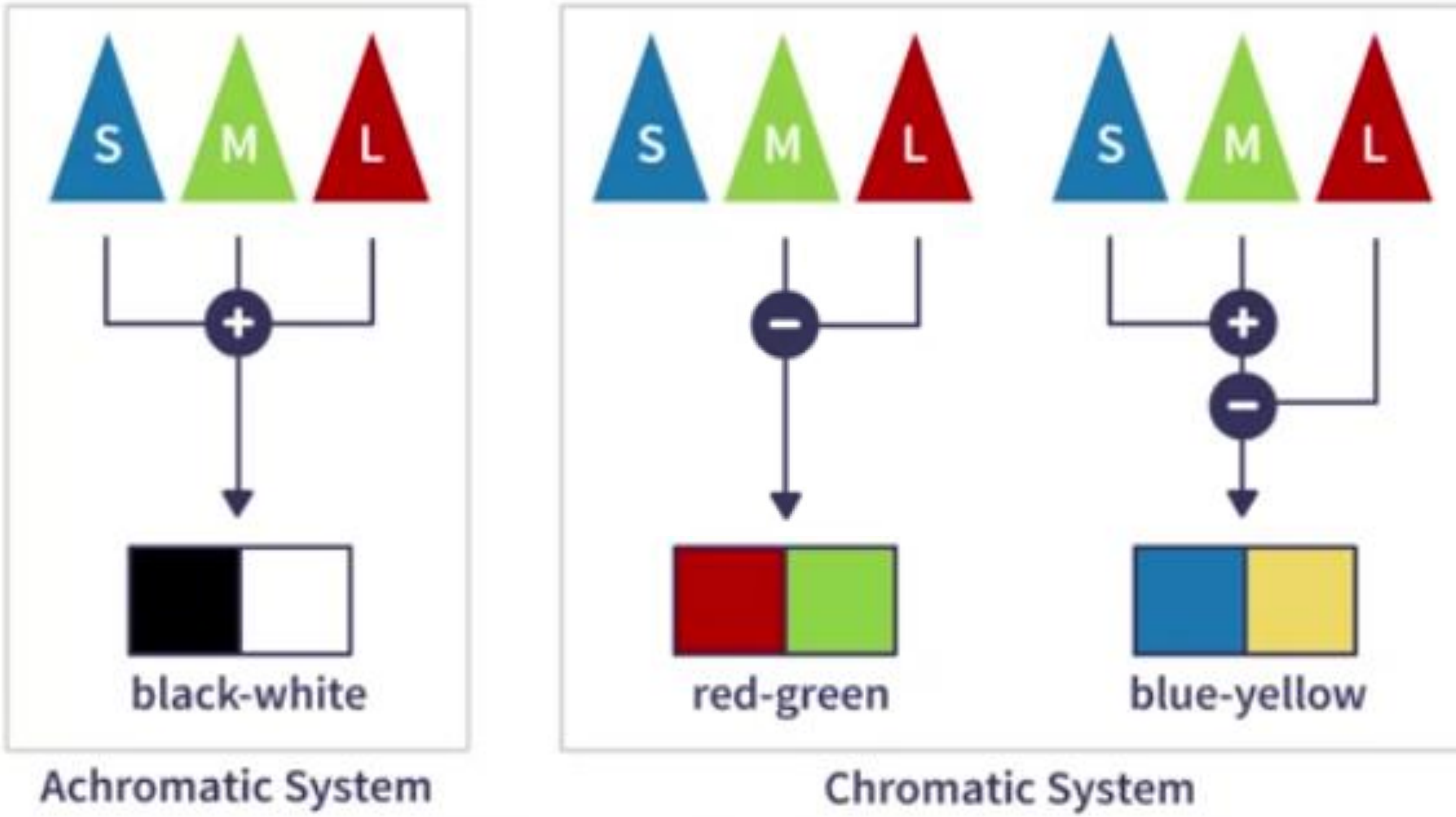
We have three kinds of color receptors

- 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

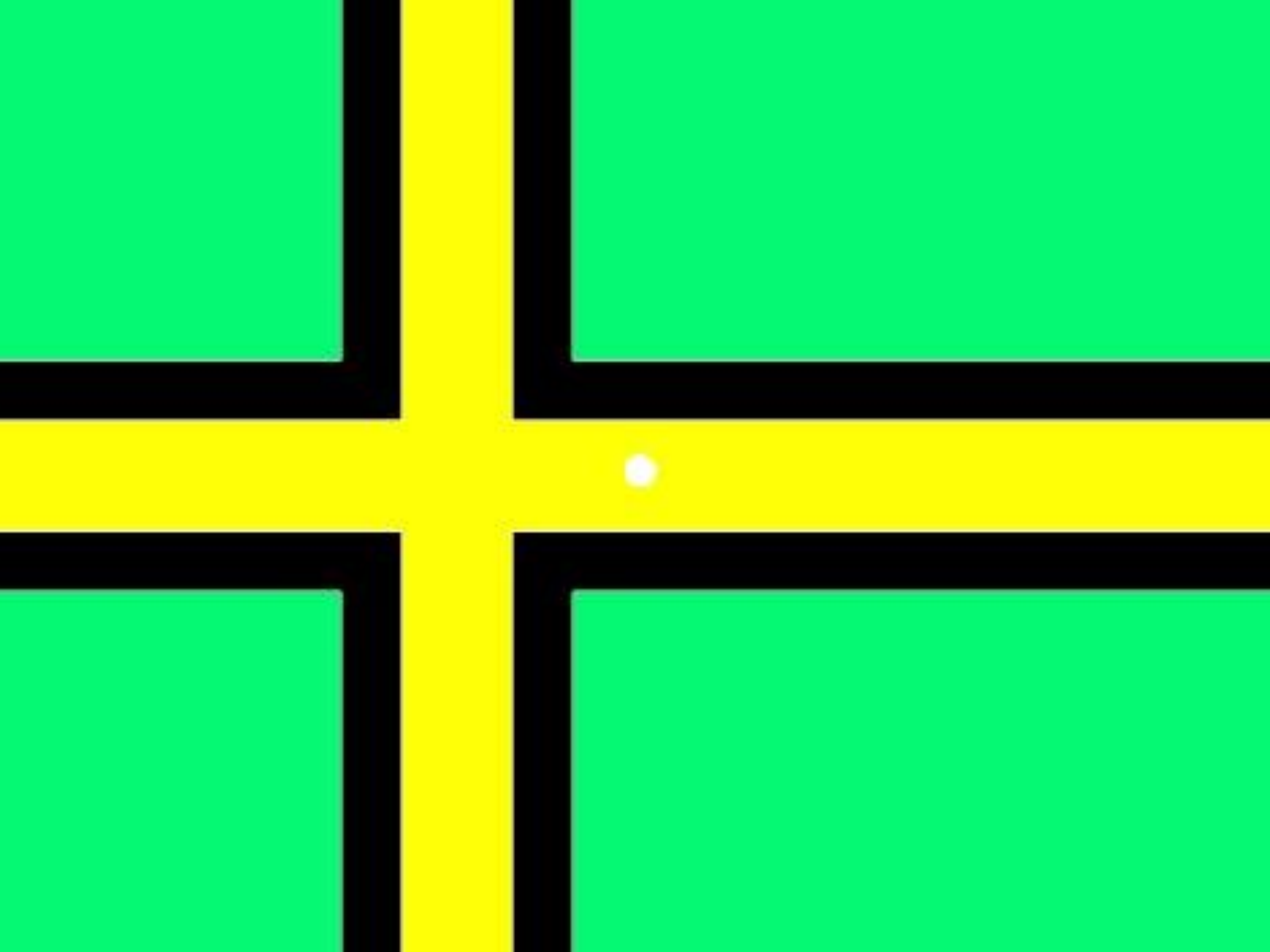
Color opponent process theory



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

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- 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

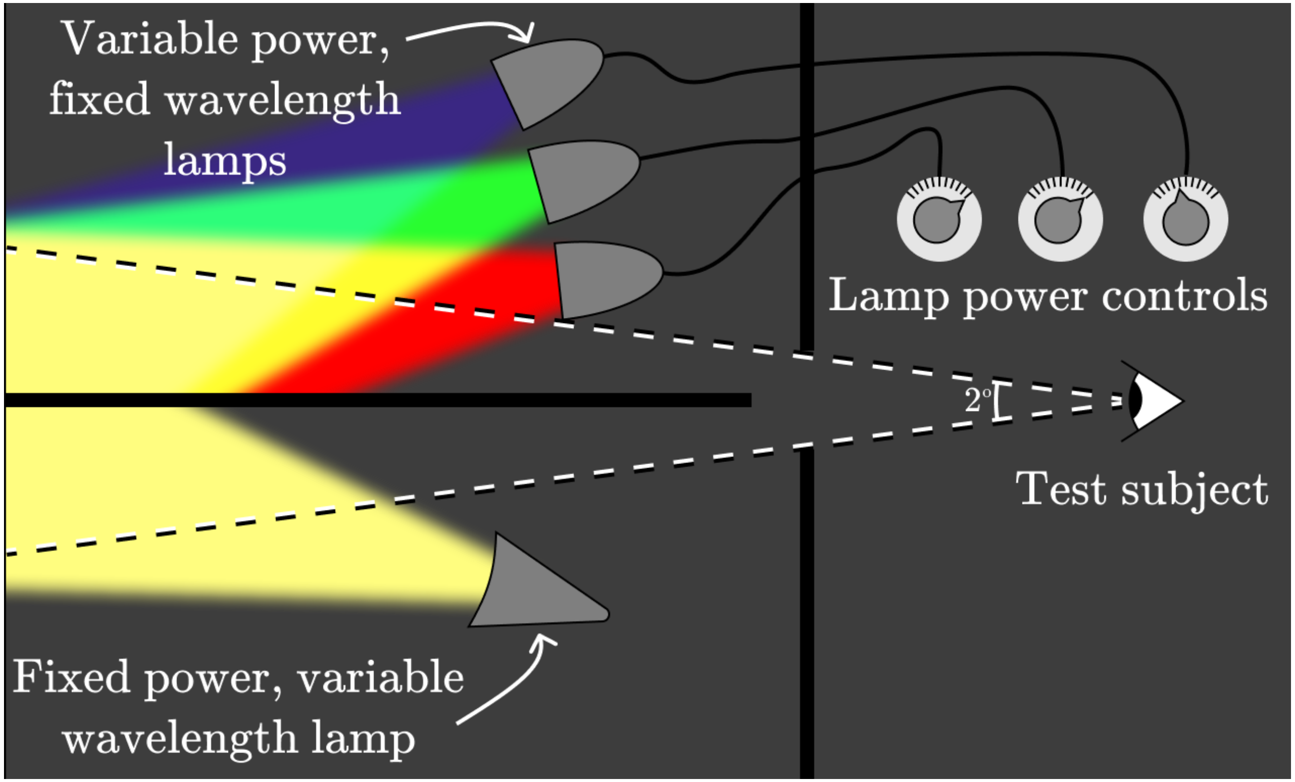
Opponent process theory

- 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)

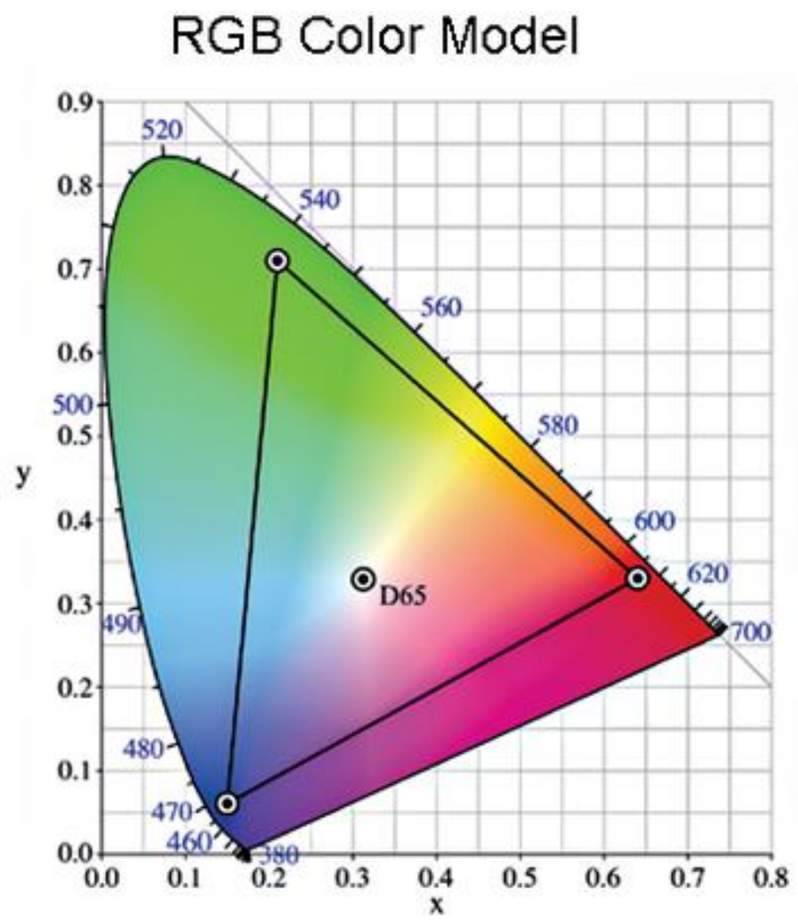


Color spaces

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



https://www.researchgate.net/figure/RGB-Color-Model-and-CIE-Lab-Color-space_fig3_41669565

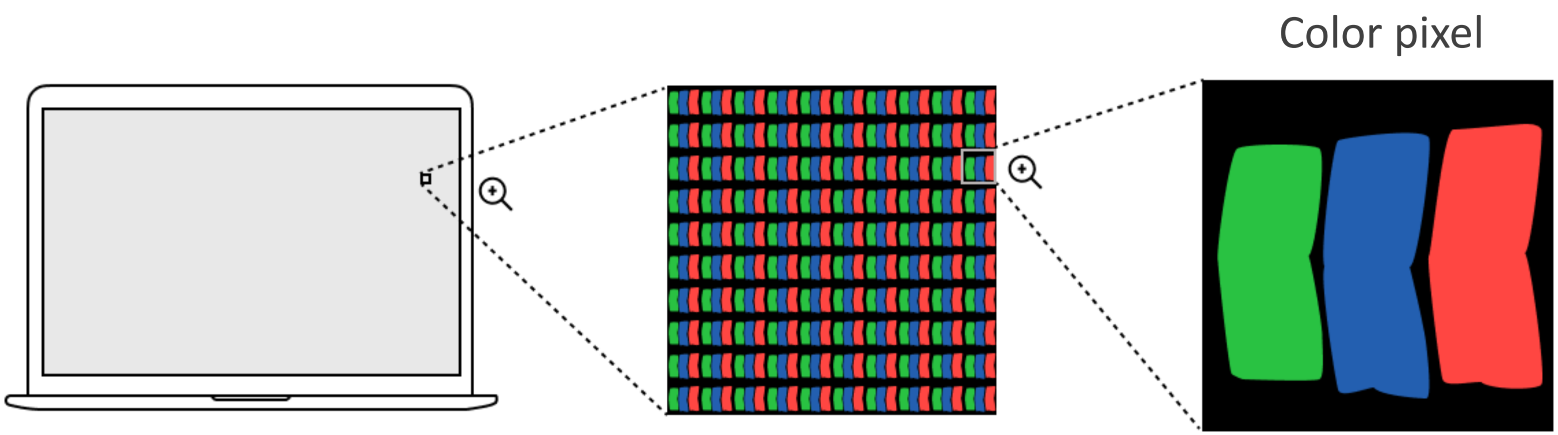
Properties of color spaces

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

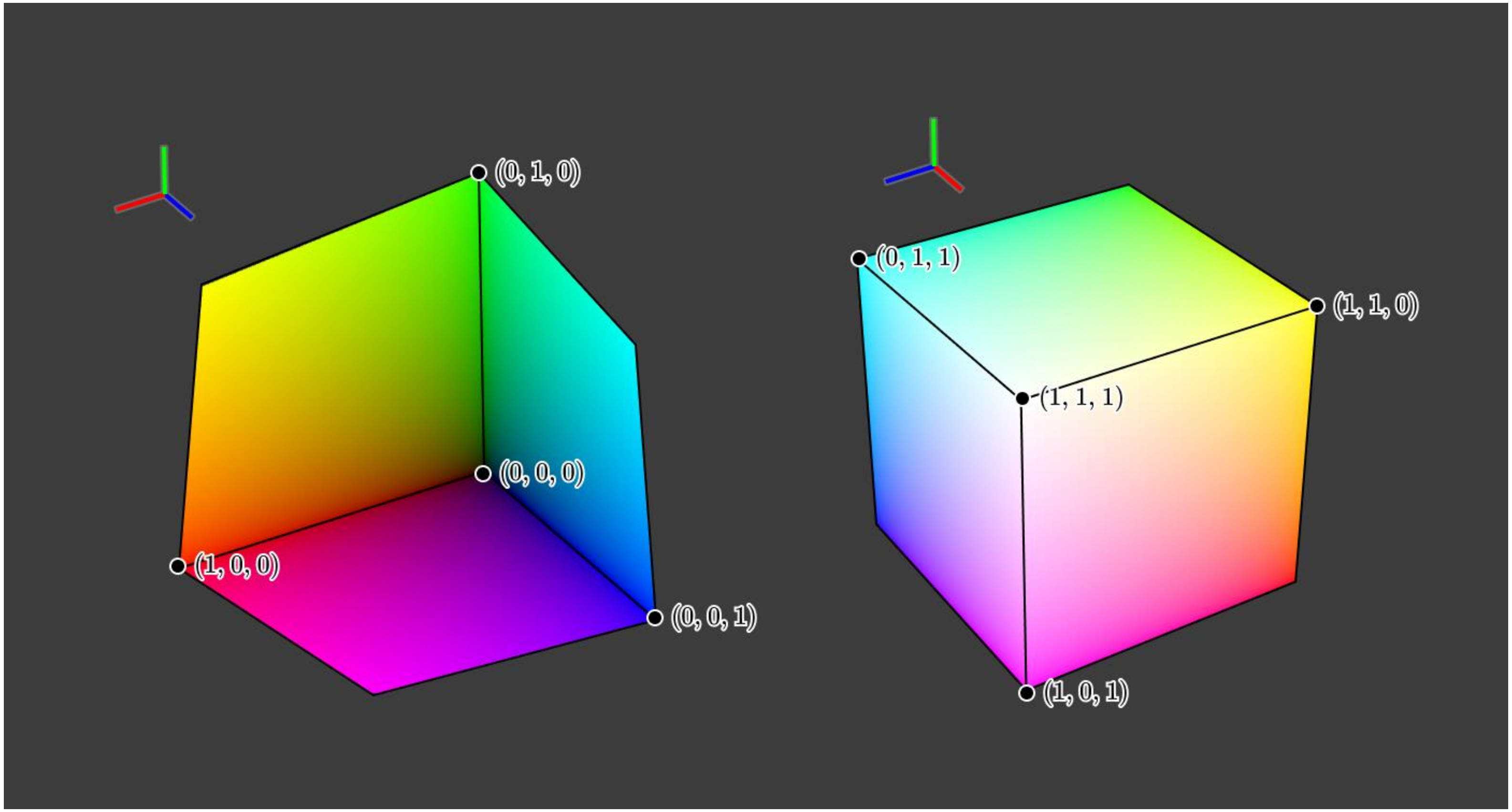
RGB

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

Commonly used in digital devices

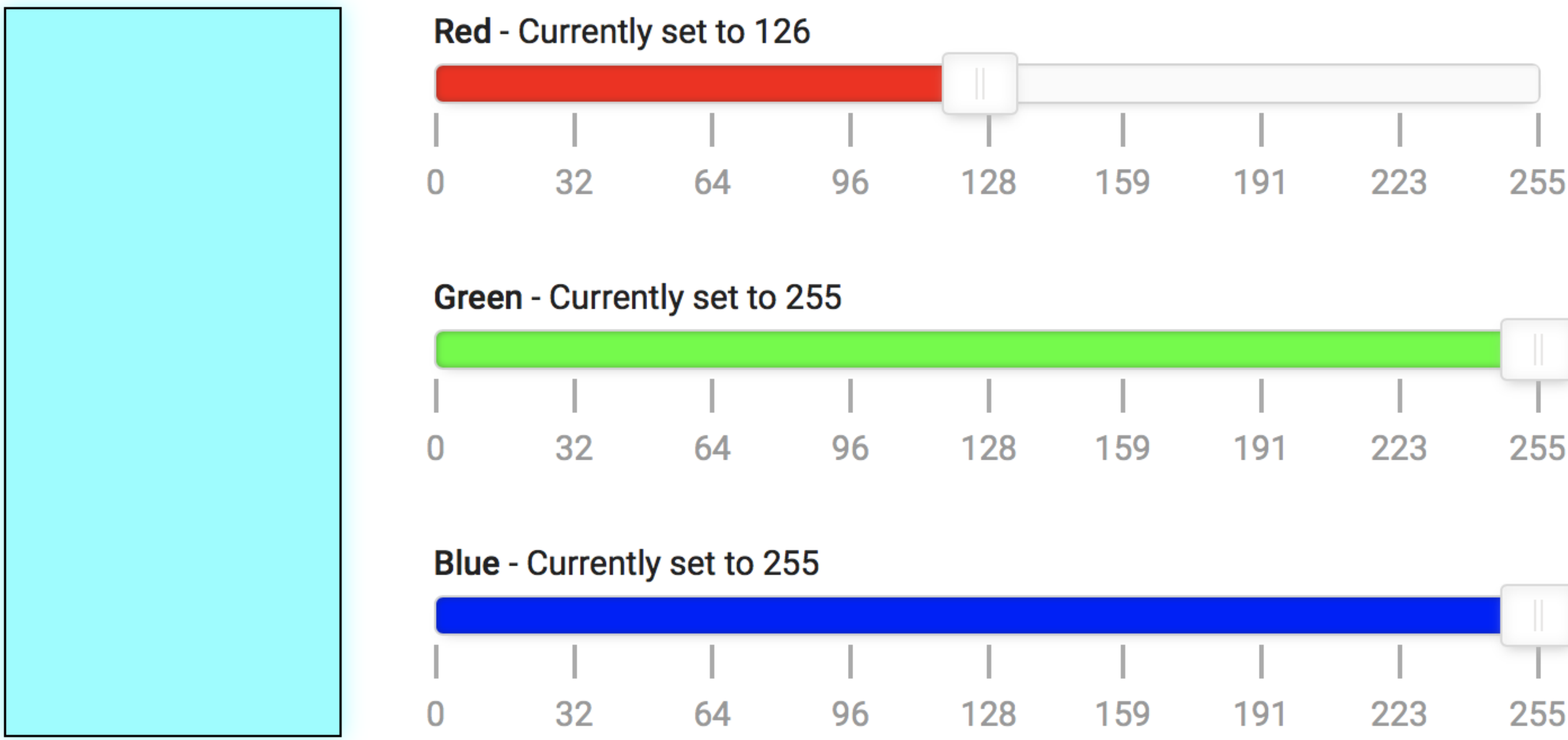


RGB



http://jamie-wong.com/post/color/

RGB


Red - Currently set to 126
0
32
64
96
128
159
191
223
255
Green - Currently set to 255
0
32
64
96
128
159
191
223
255
Blue - Currently set to 255
0
32
64
96
128
159
191
223
255

RGB

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

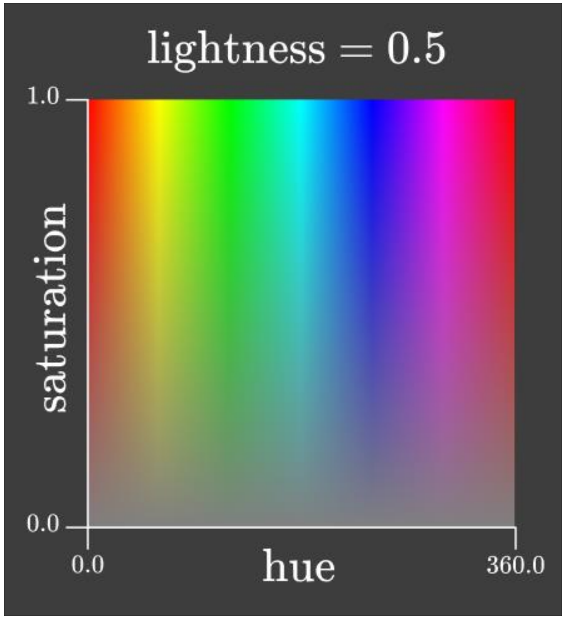
R = 5 R = 55 R = 105 R = 155 R = 205 R = 255

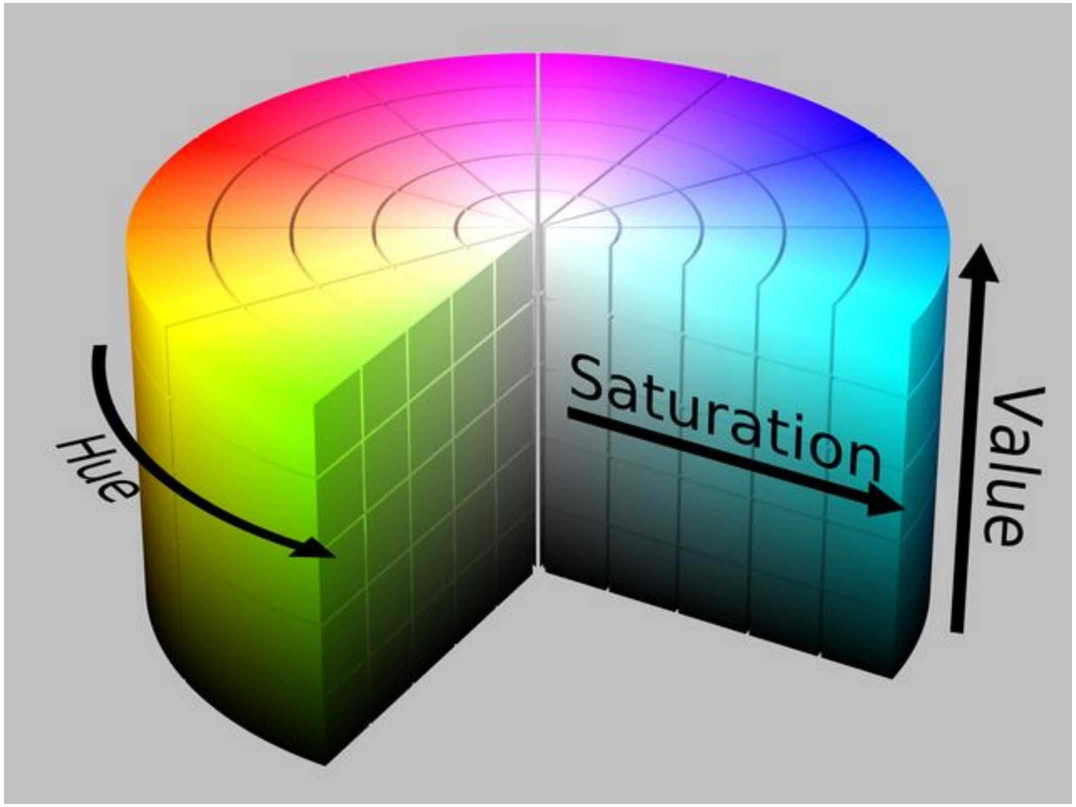
Properties of color spaces

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

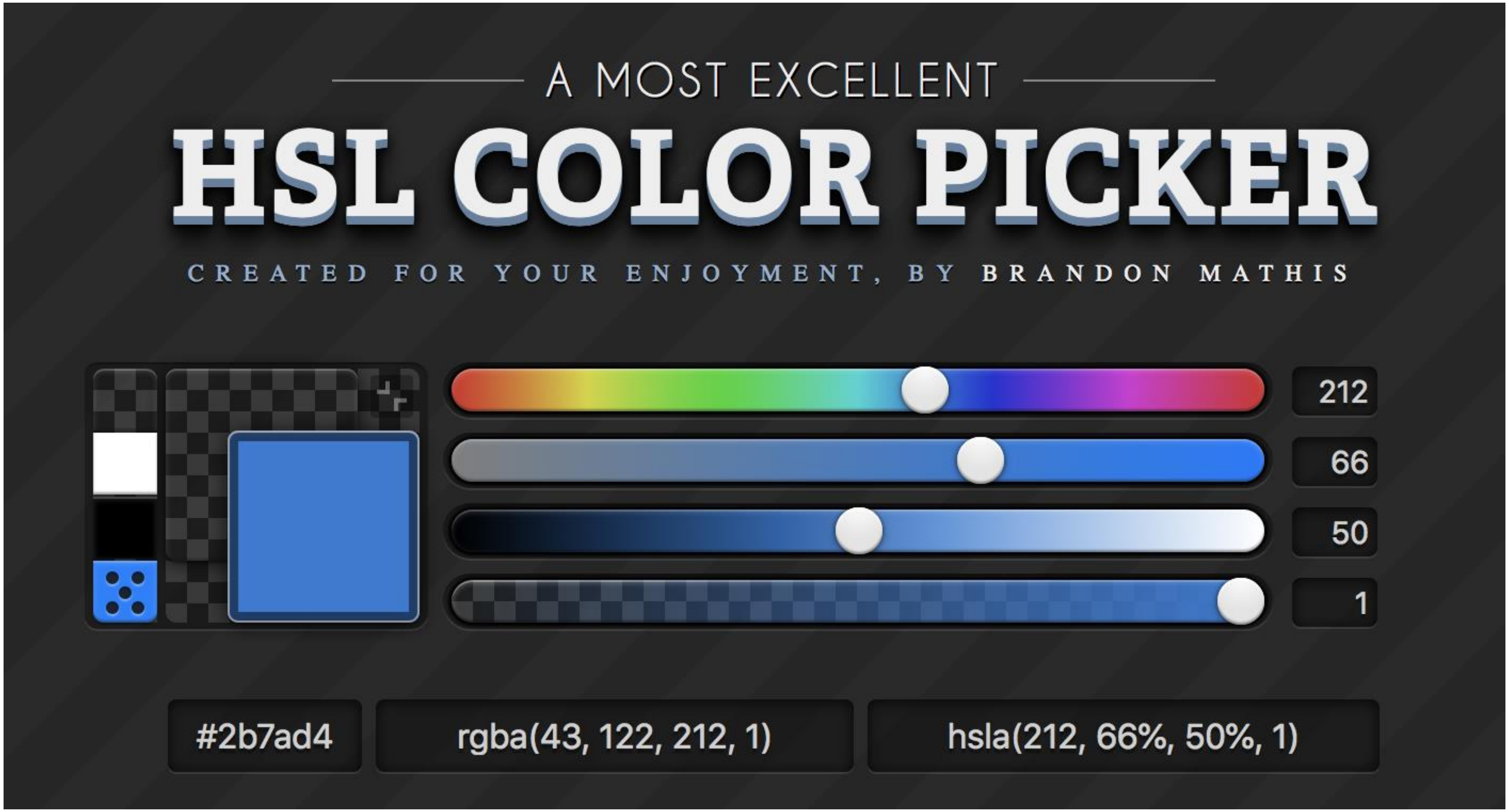
HSL / HSV

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

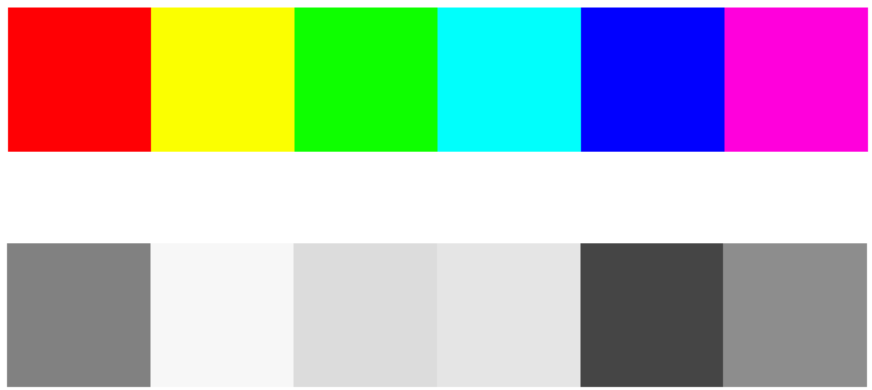




HSL / HSV


A MOST EXCELLENT
HSL COLOR PICKER
CREATED FOR YOUR ENJOYMENT, BY BRANDON MATHIS
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

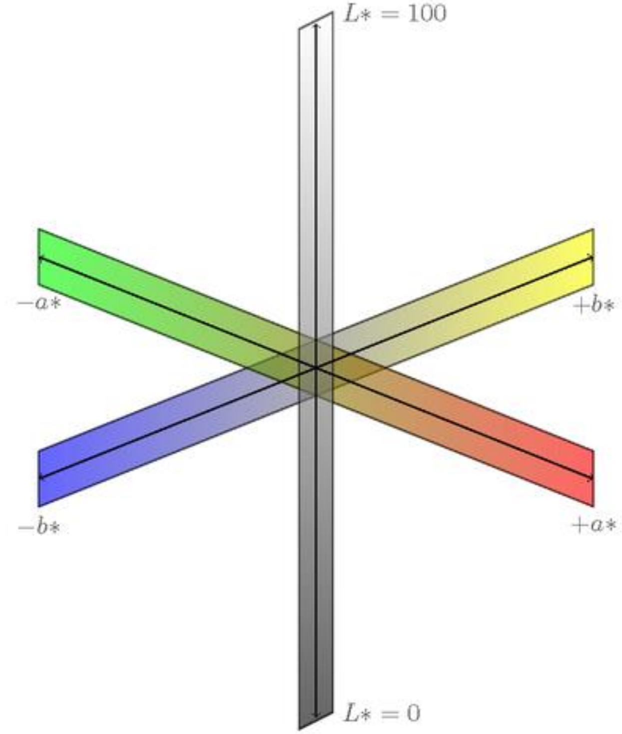
CIE (International Commission on Illumination)

Specified according to the opponent process theory

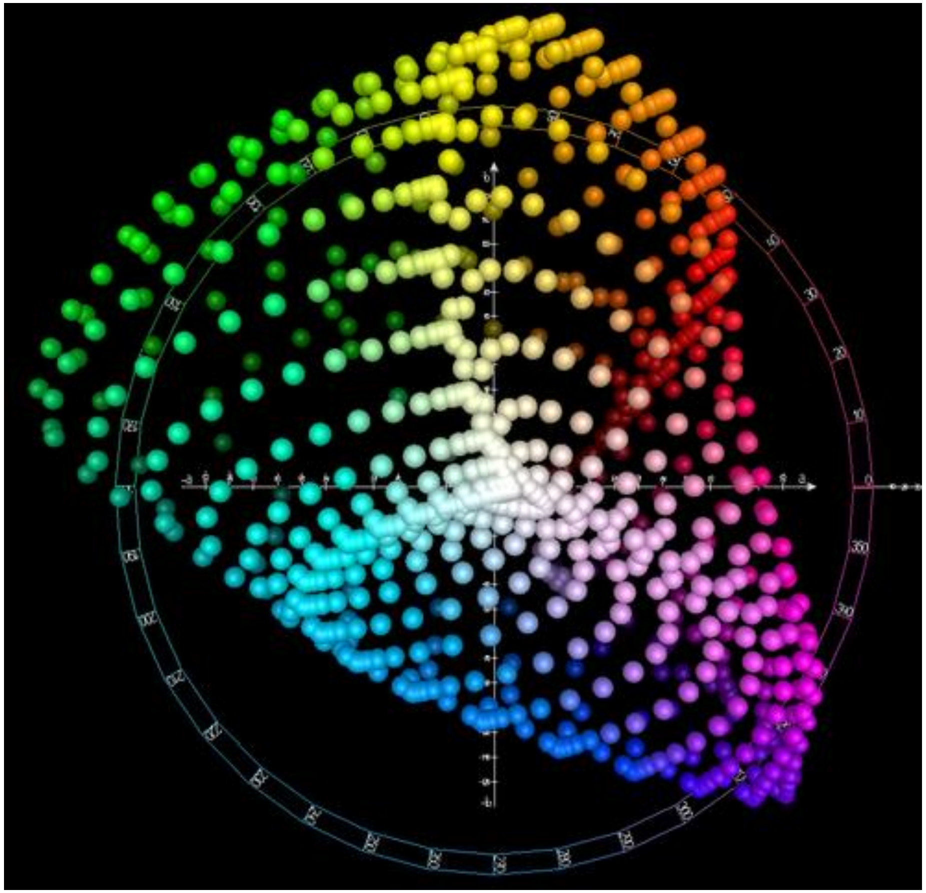
- L* = lightness
- a* = green-red axis
- b* = blue-yellow axis

Designed to be perceptually linear

A nonlinear transformation of color wavelengths

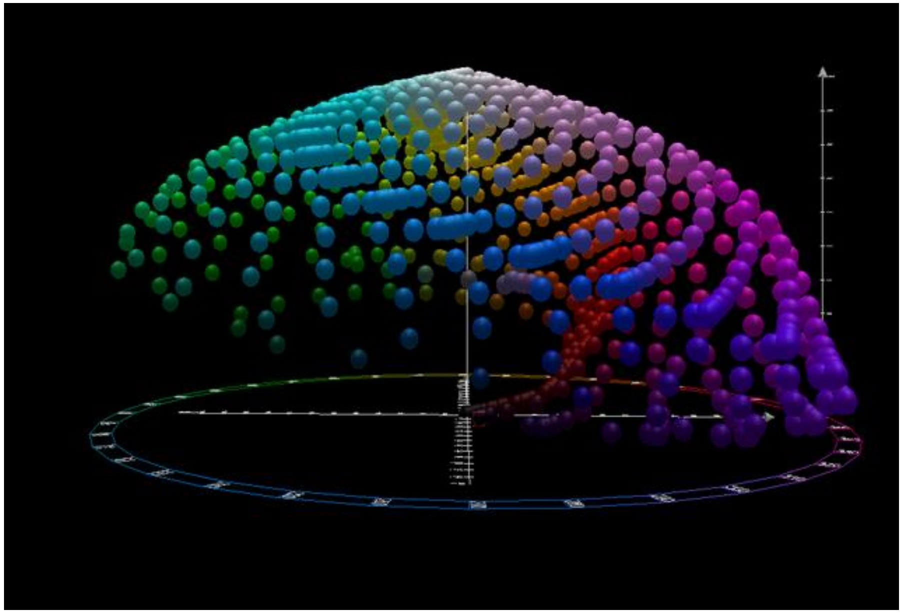


CIE Lab

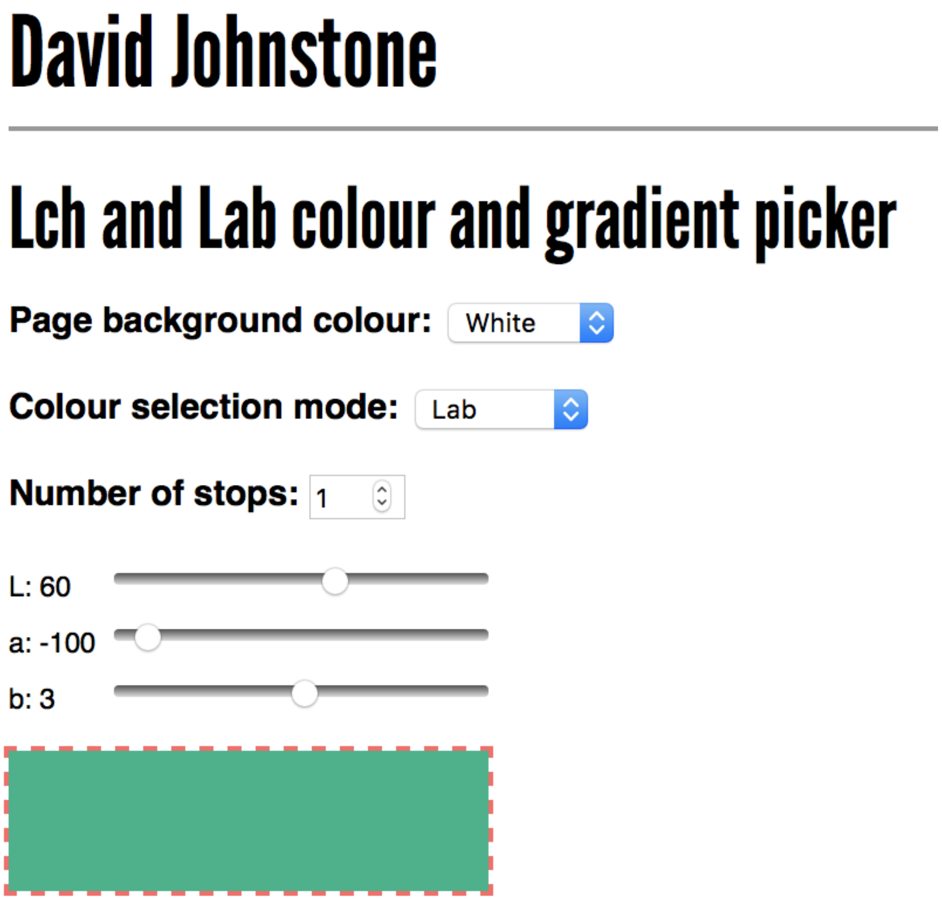


Top view

Front view

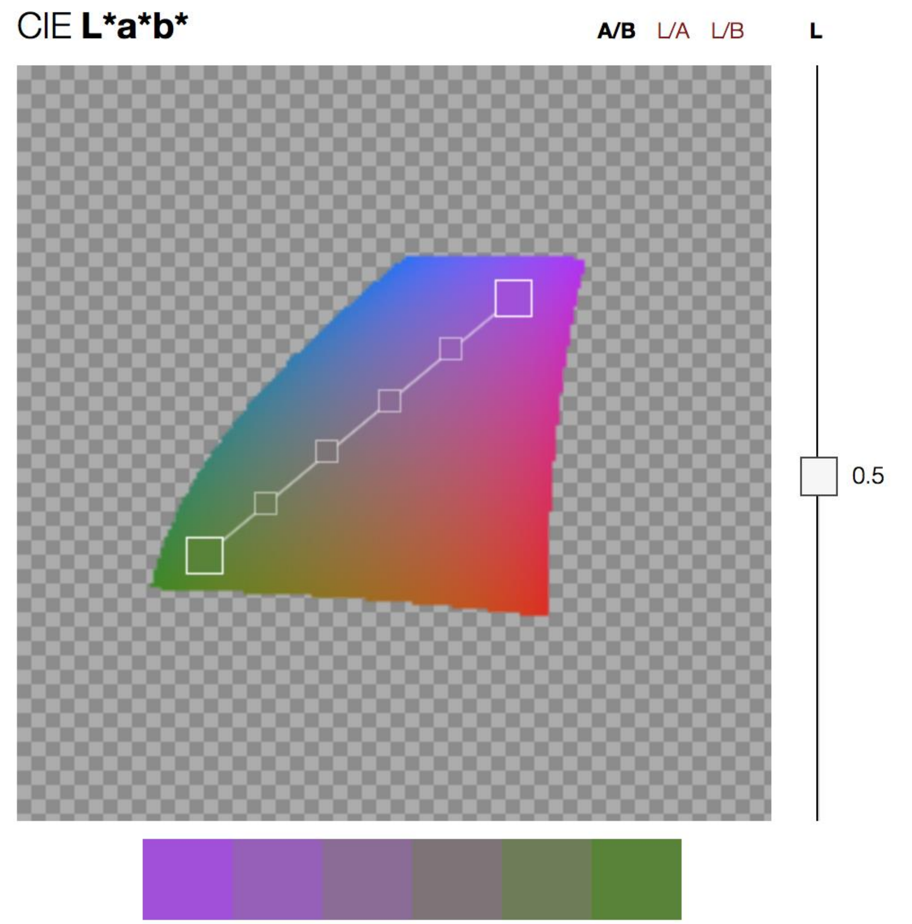


CIE Lab



http://davidjohnstone.net/pages/lch-lab-colour-gradient-picker

CIE Lab



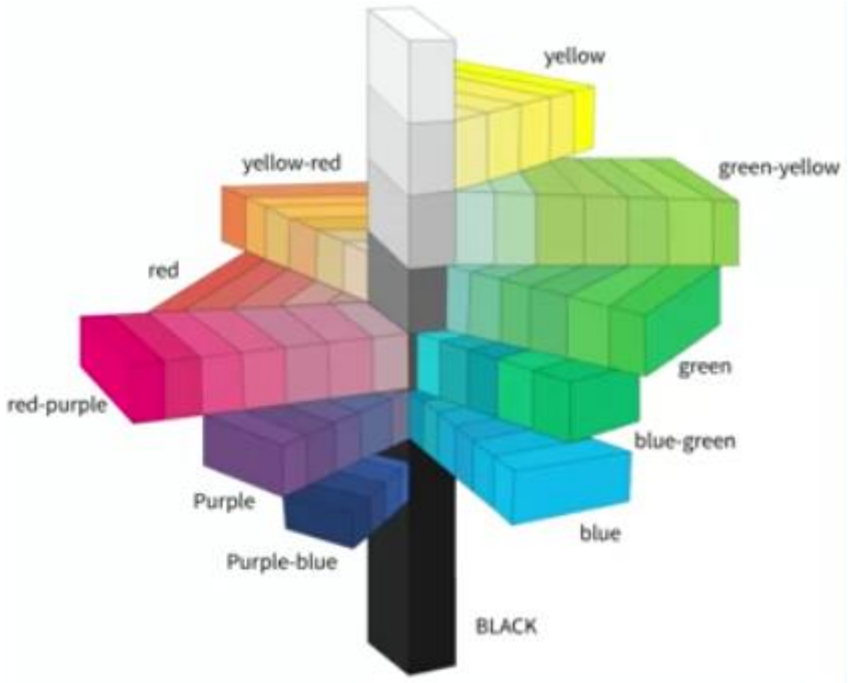
Properties of color spaces

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

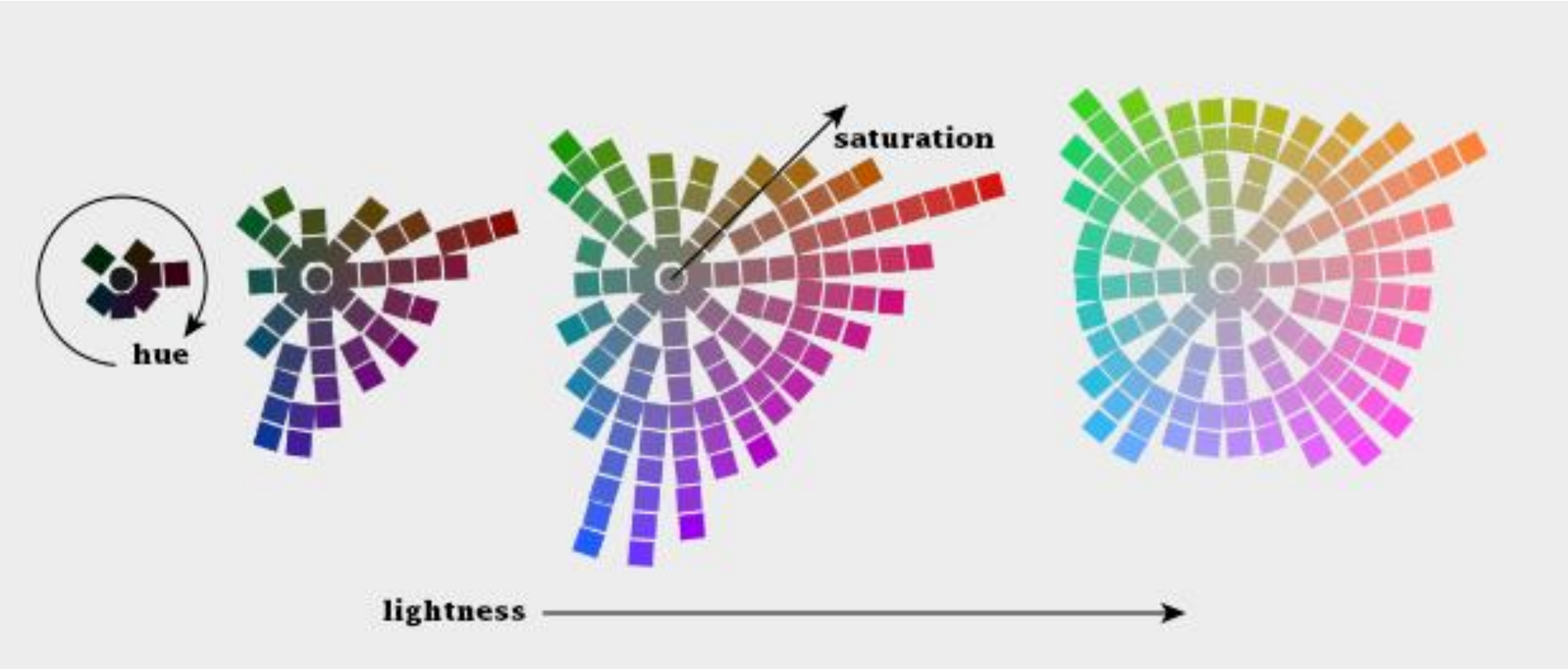
CIE LCh / HCL

Transformation of CIE Lab to cylindrical coordinates

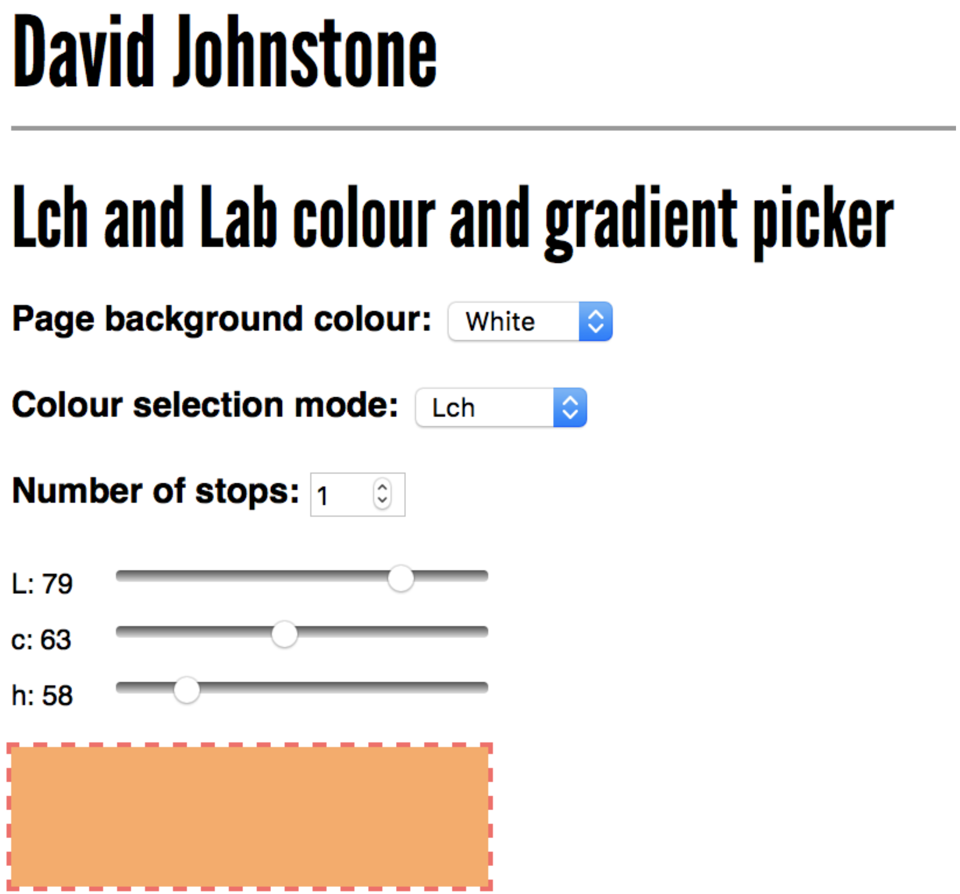
- L* = lightness (as in CIE Lab)
- C* = chroma (corresponds to saturation)
- h = hue



CIE LCh / HCL

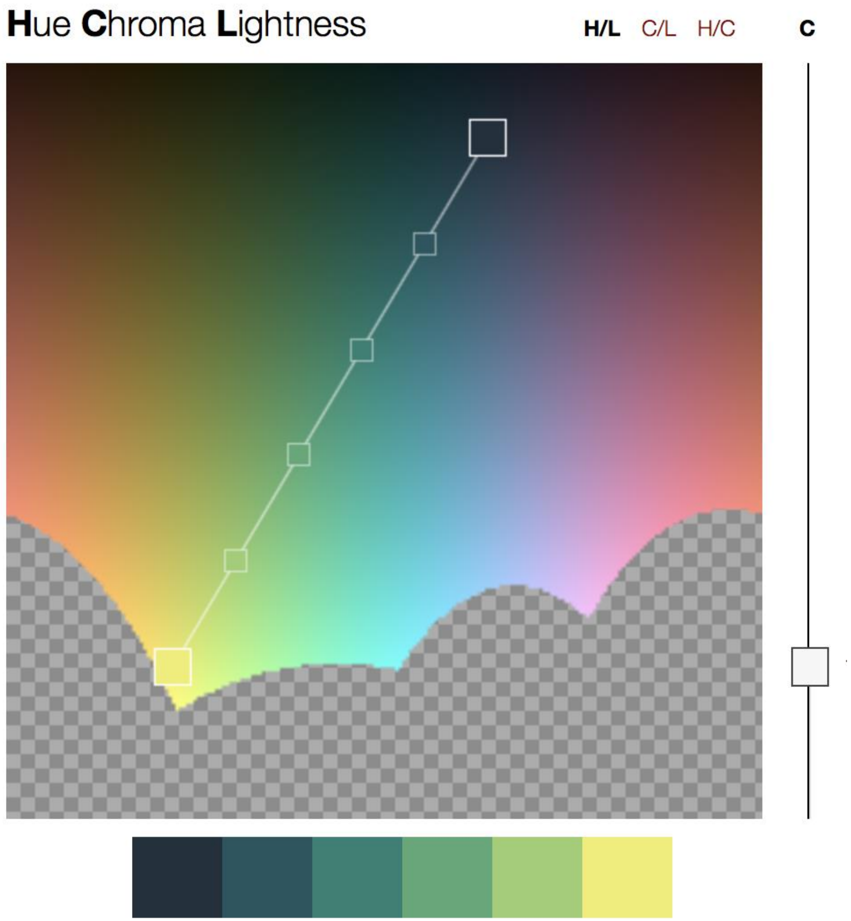


CIE LCh / HCL



David Johnstone
Lch and Lab colour and gradient picker
Page background colour: White
Colour selection mode: Lch
Number of stops: 1
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

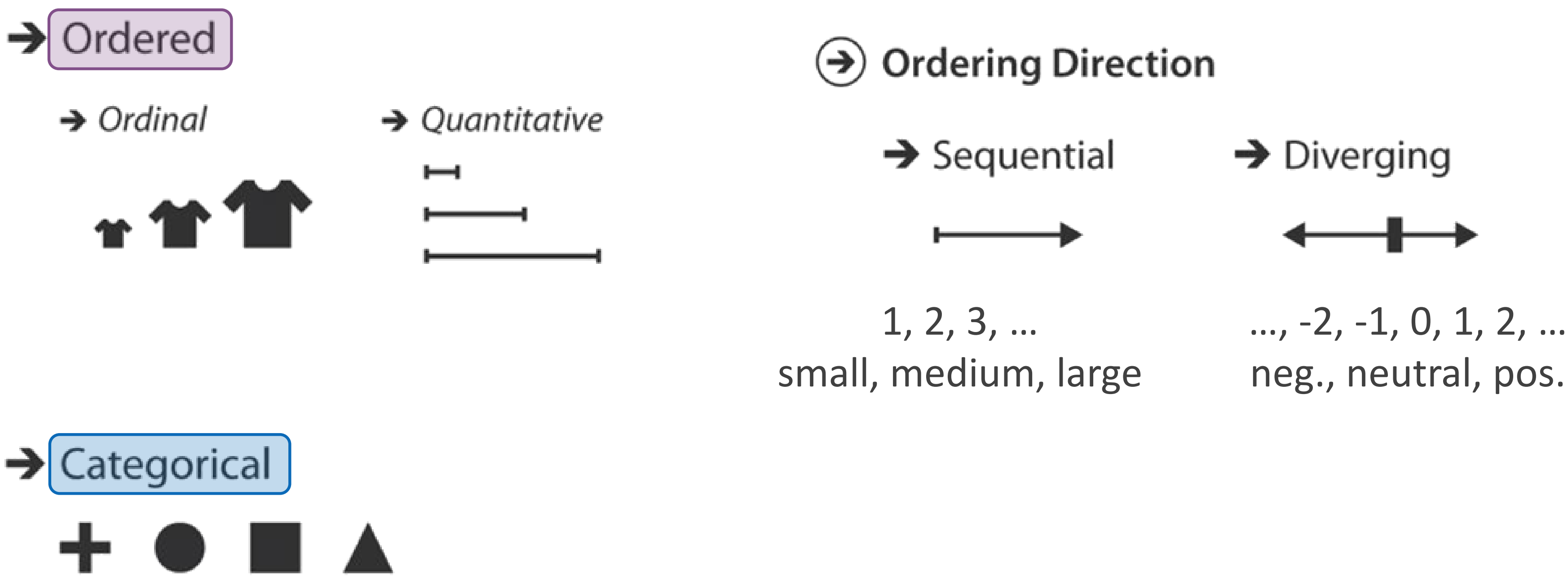
Importance of size

Relative perception

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

Choosing colors

Data attributes



Color maps

Single variable

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

Two variables

- Bivariate color maps

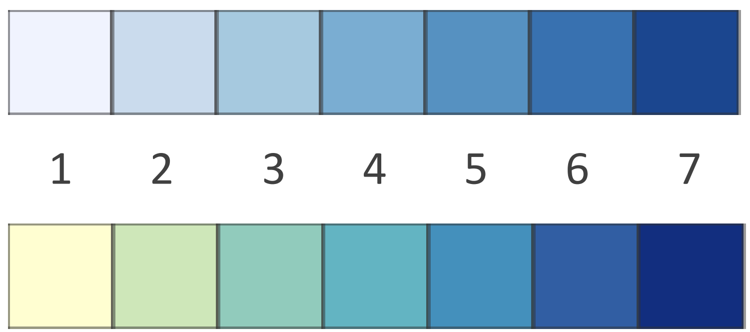
Sequential color maps

Desired properties

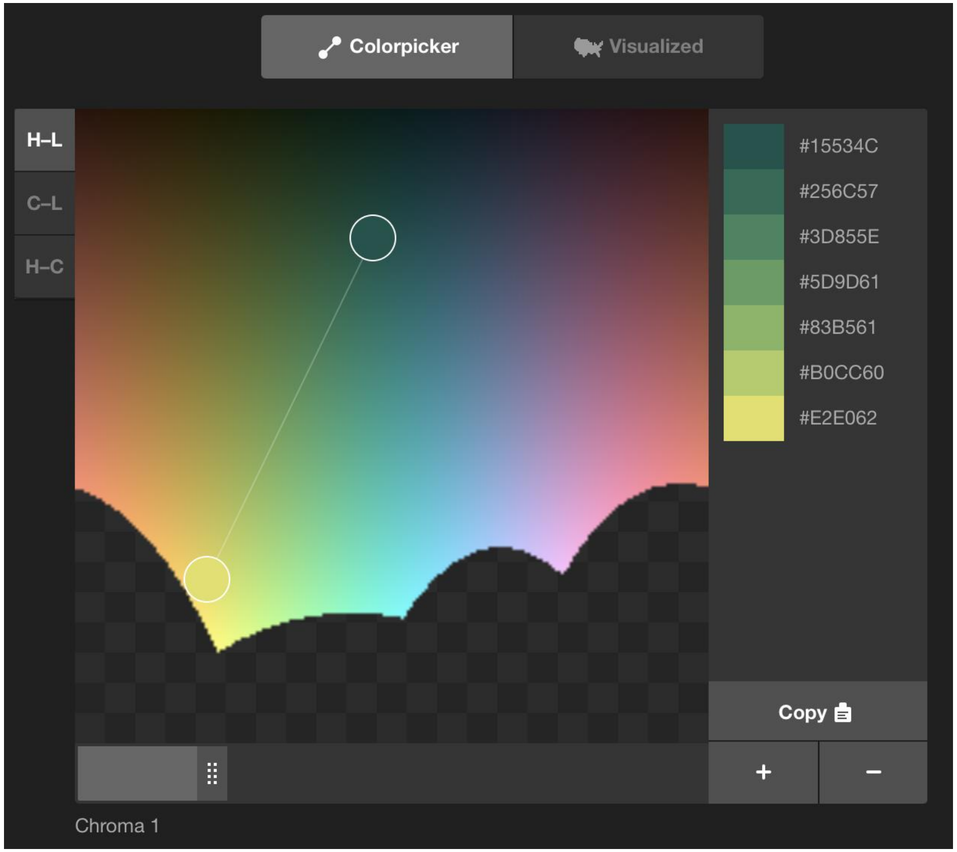
- Perceived differences correspond to value differences
- High discriminability

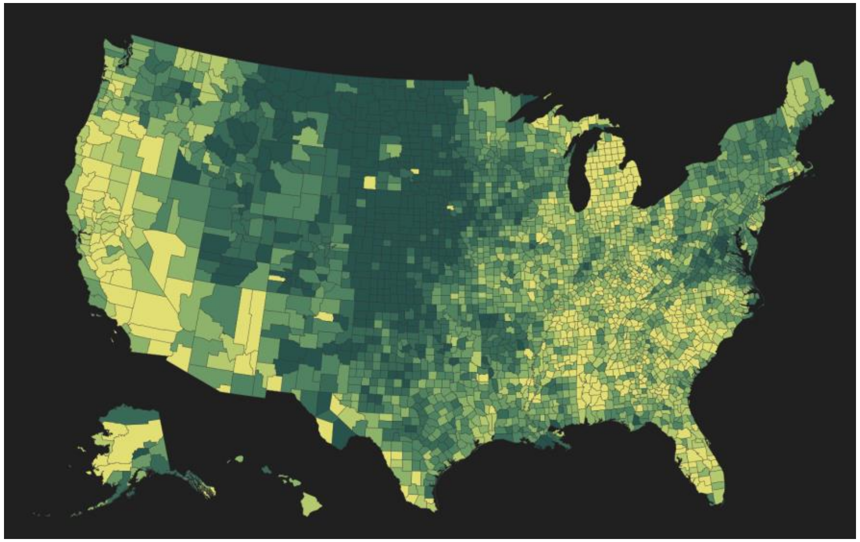
Single hue

Multi-hue



Sequential color maps

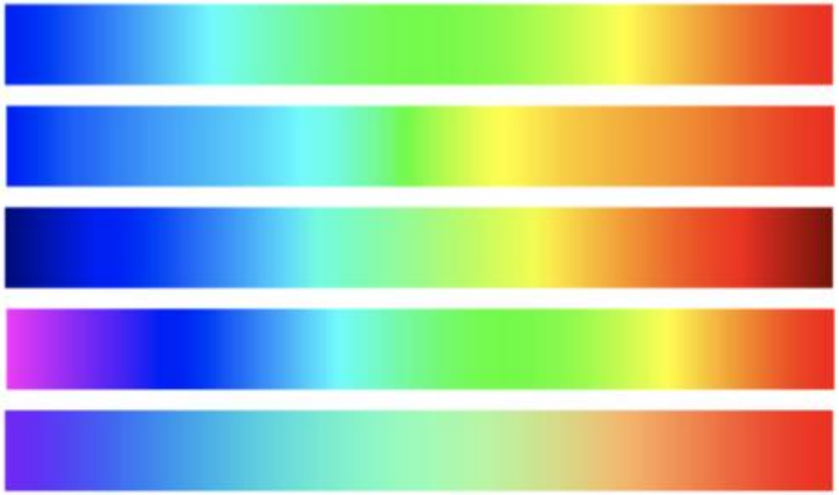




Sequential color maps: rainbow

Do not use it!

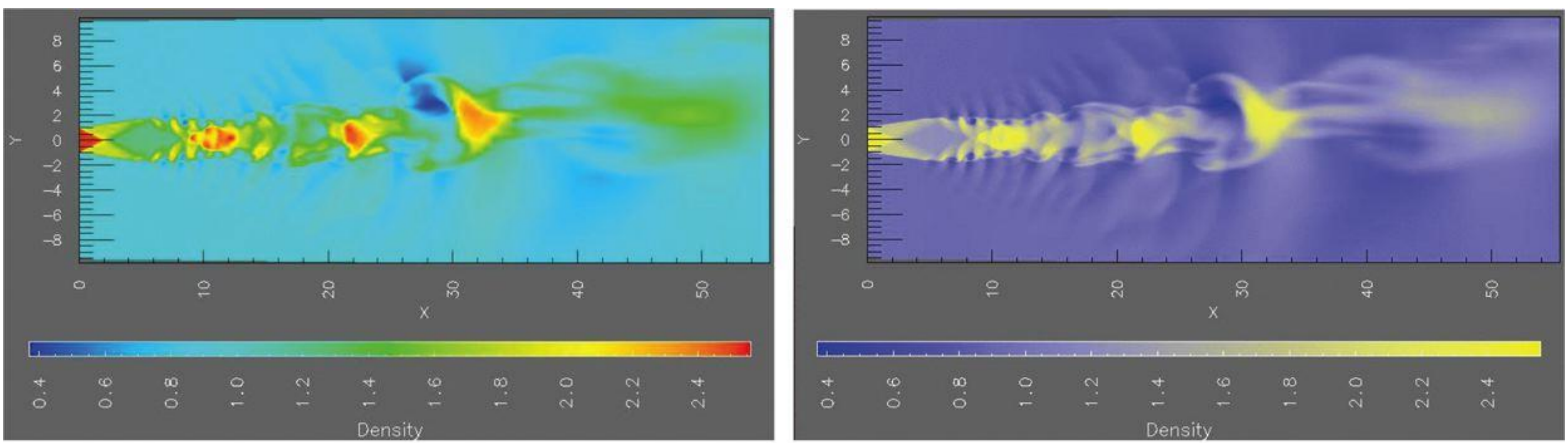
- Hue (that has no perceptual order) is used to indicate order
- Perceptual nonlinearity: divisions between hues create edges in visualization that have nothing to do with the data



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

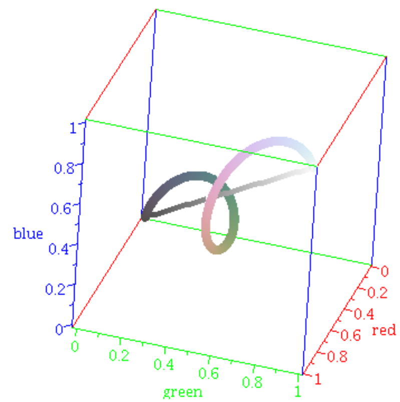


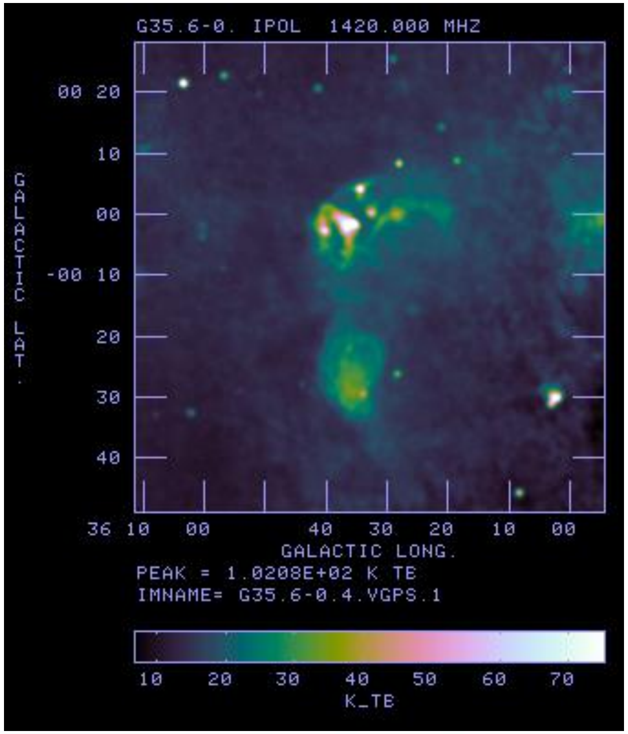
Sequential color maps

Cubehelix

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

A color map generator





Diverging color maps

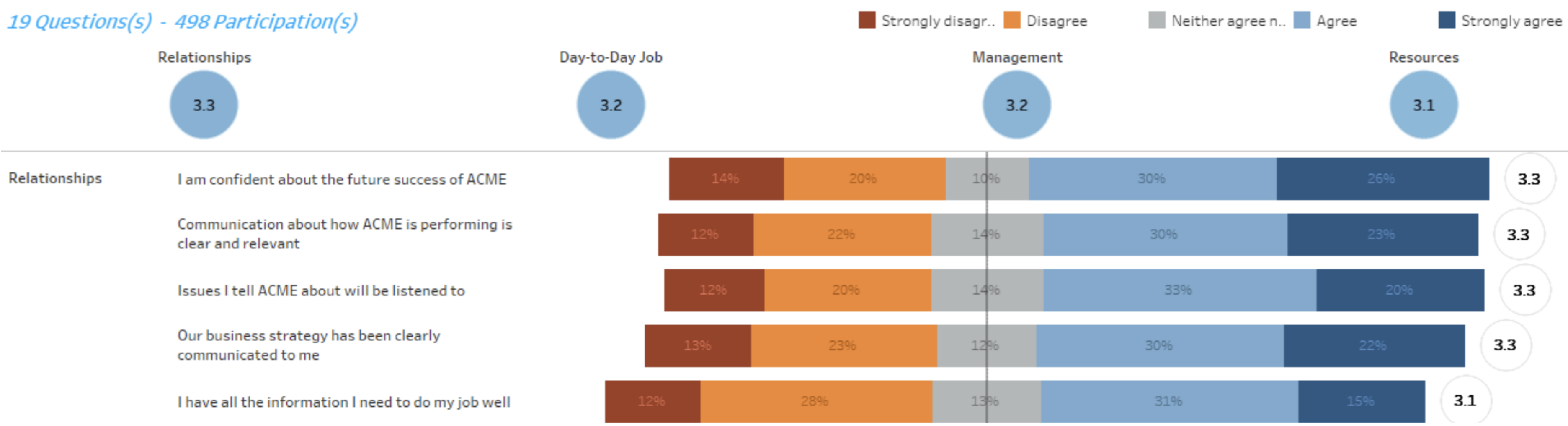
Encode two properties at the same time

- 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

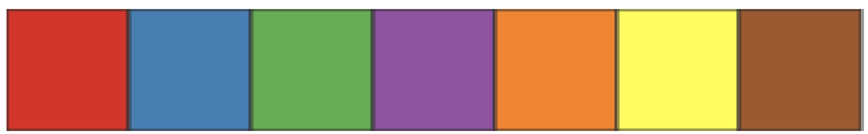
Diverging color maps



Categorical color maps

Desired properties

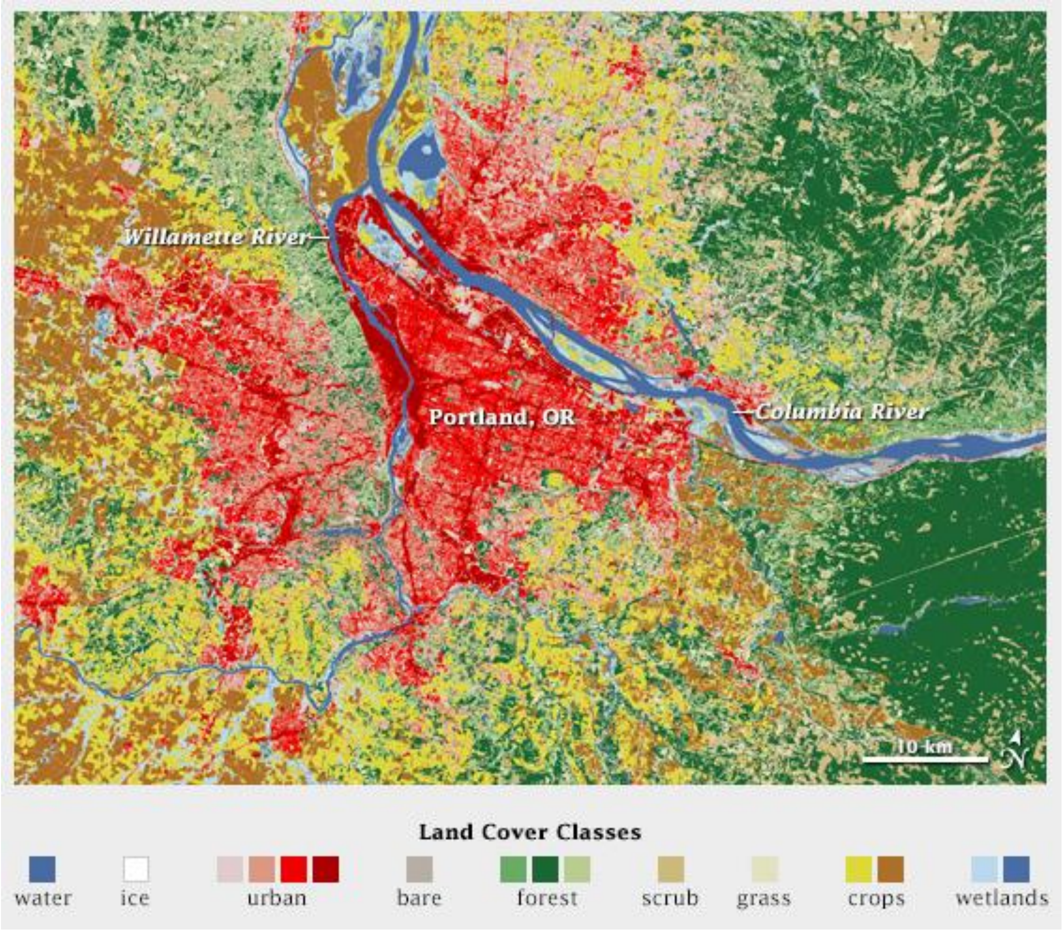
- Uniform saliency (nothing stands out)
- High discriminability



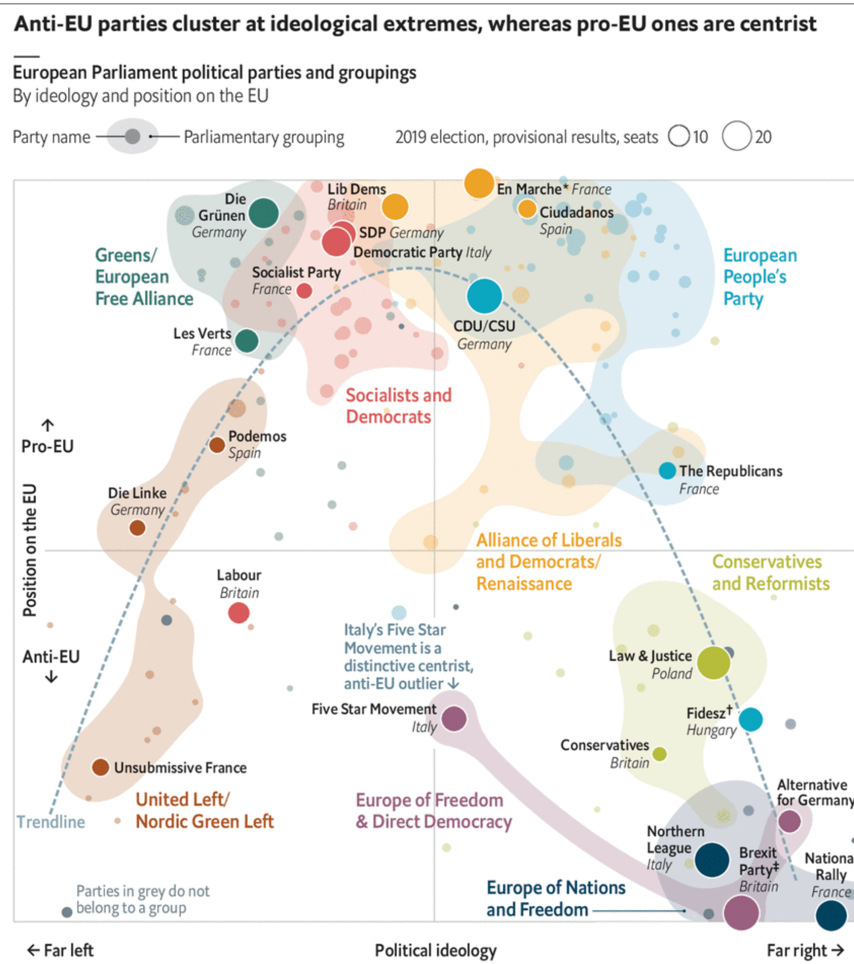
Use colors that can be named

Do not use too many different colors/categories

Categorical color maps

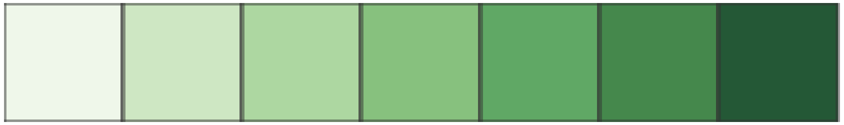


Categorical color maps

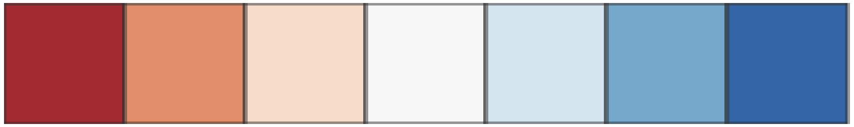


Univariate color maps

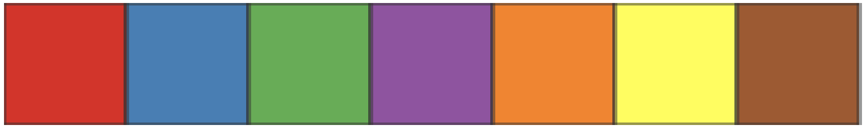
Sequential color maps



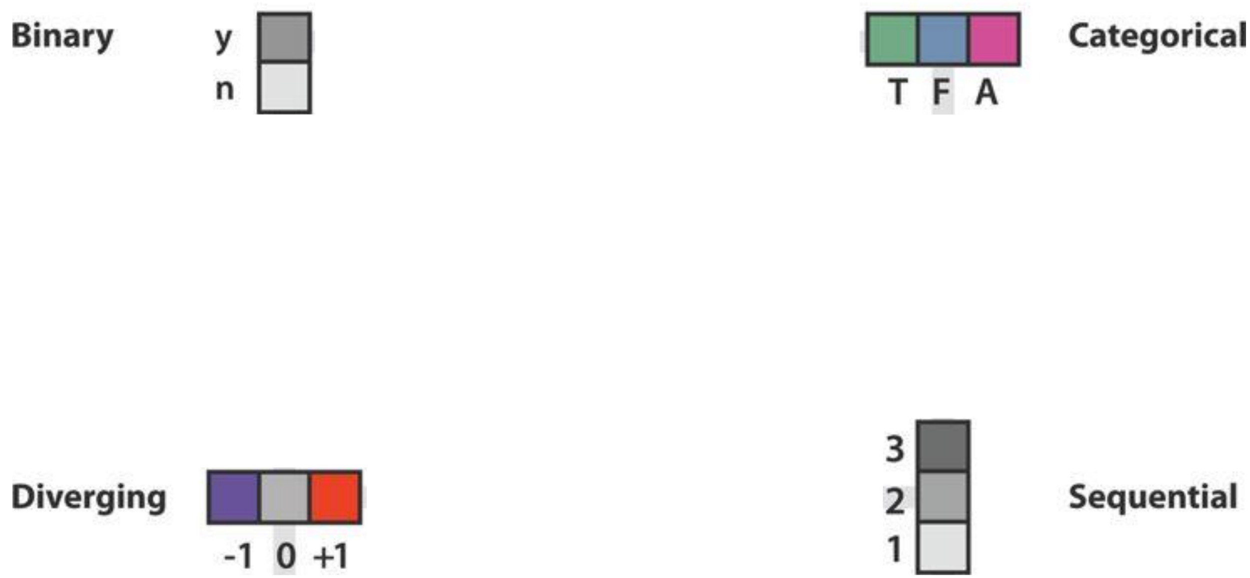
Diverging color maps



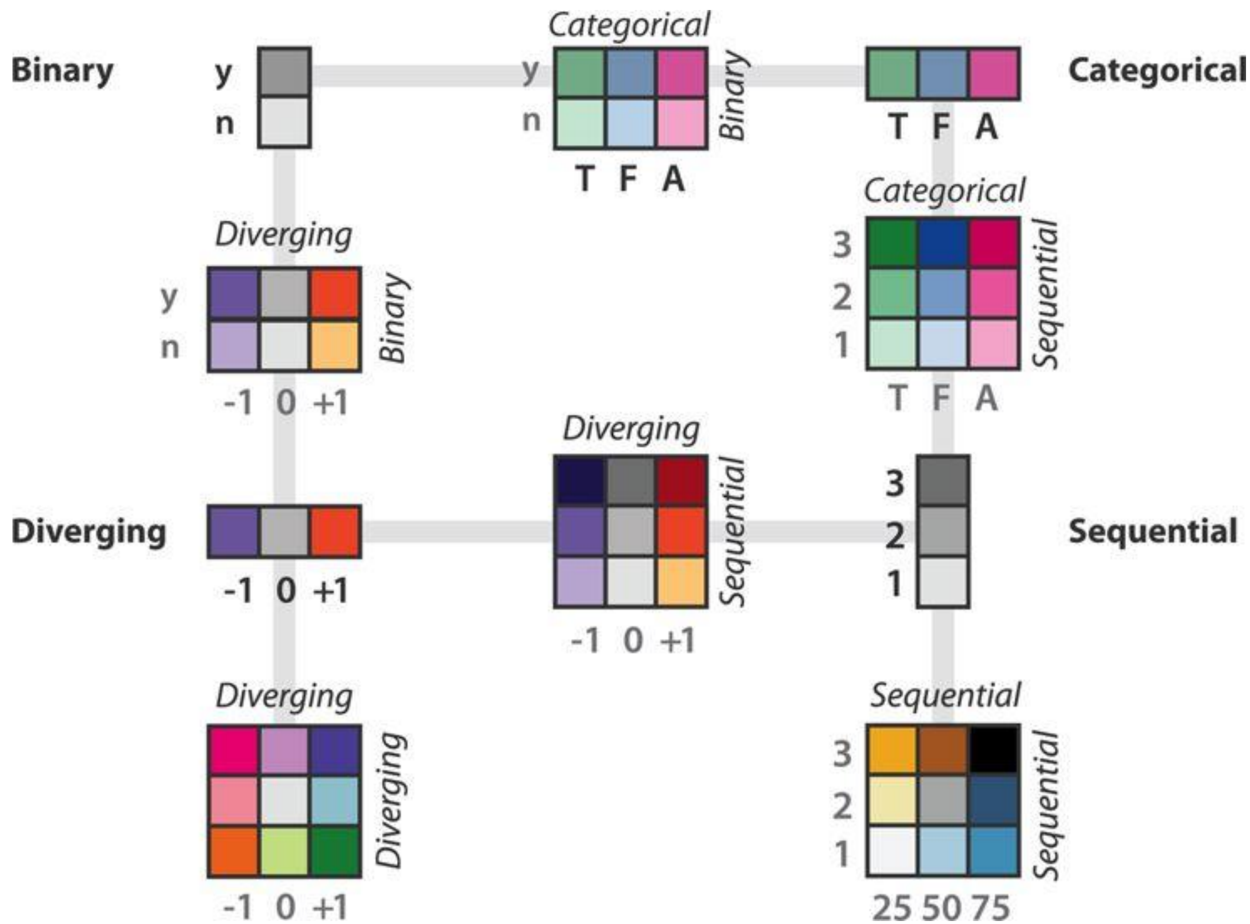
Categorical color maps



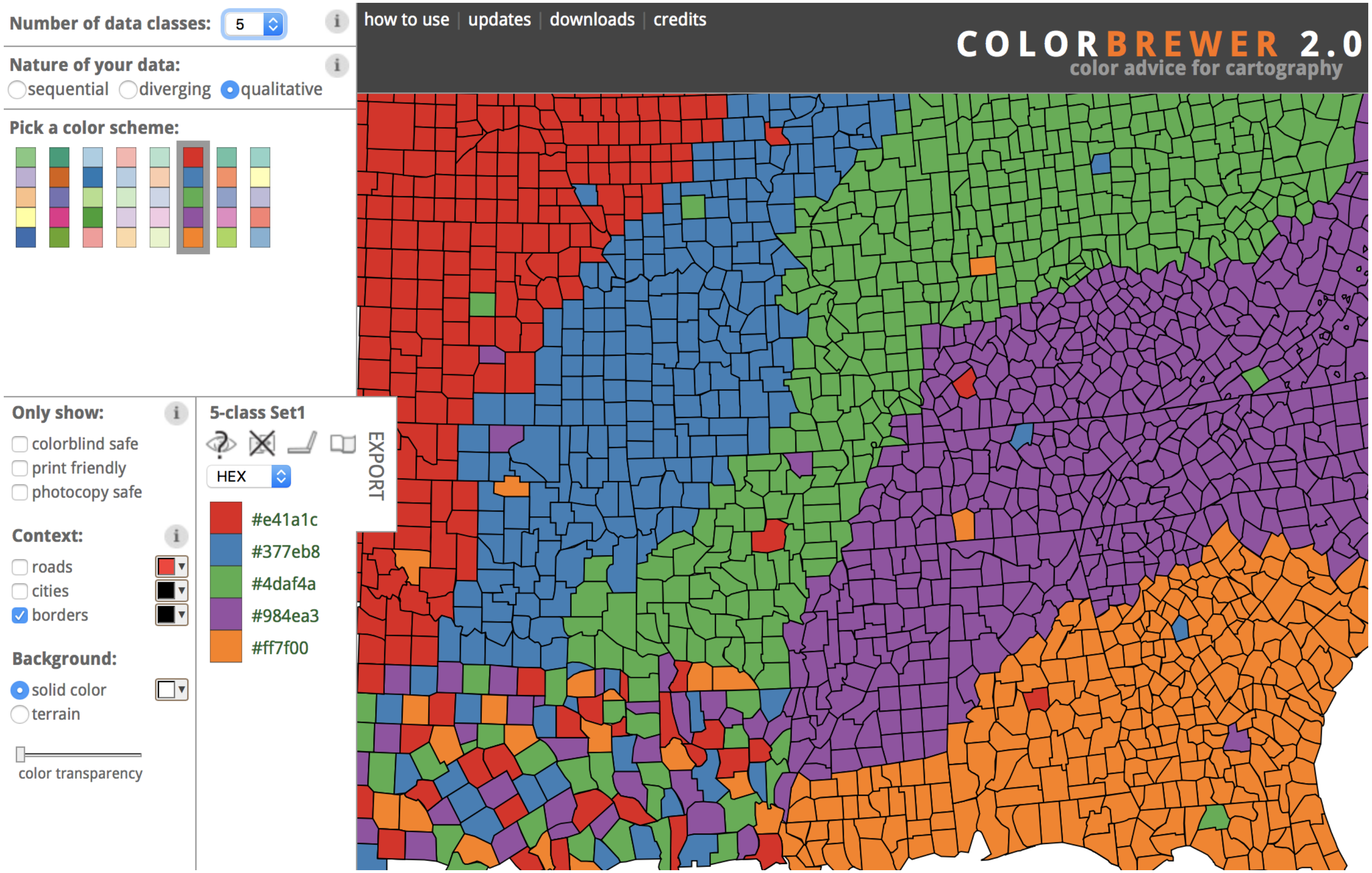
Bivariate color maps



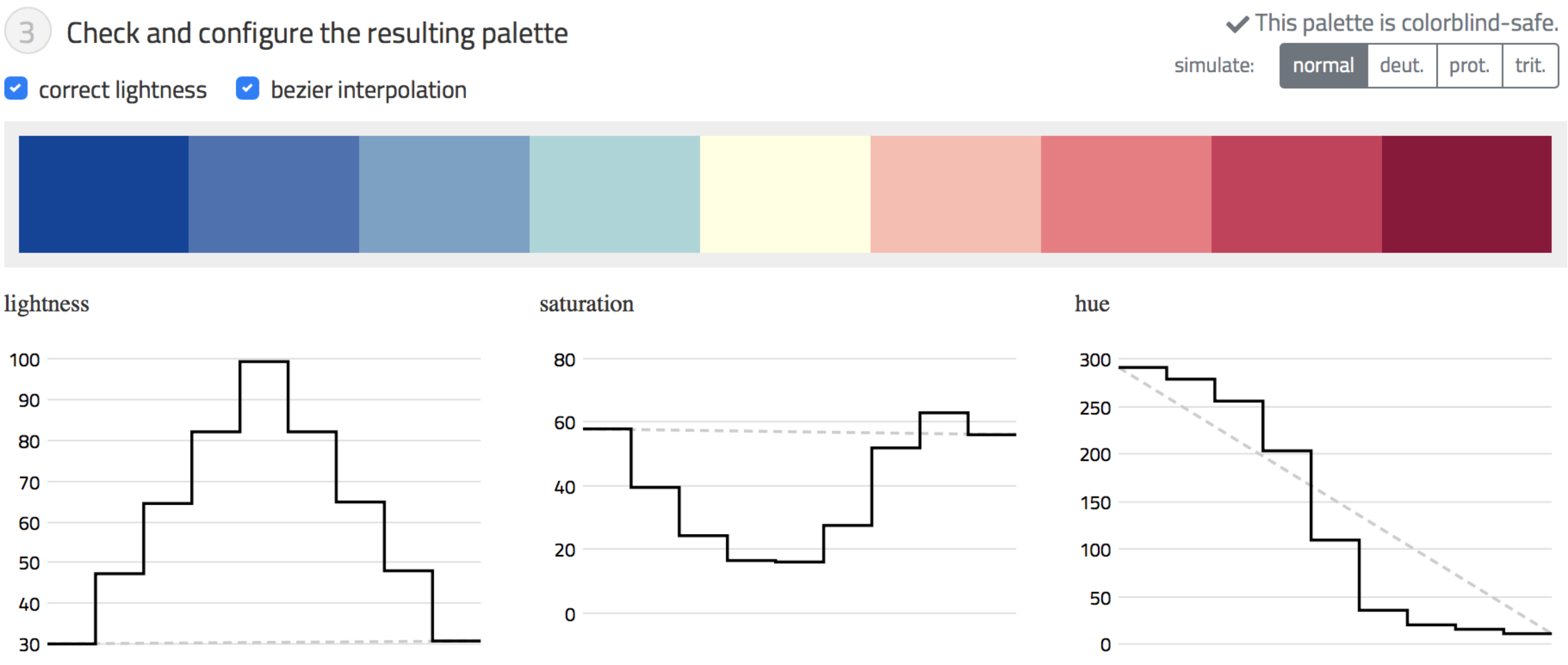
Bivariate color maps



Existing color maps



Custom color maps



https://gka.github.io/palettes/

Semantics of color

Green = good

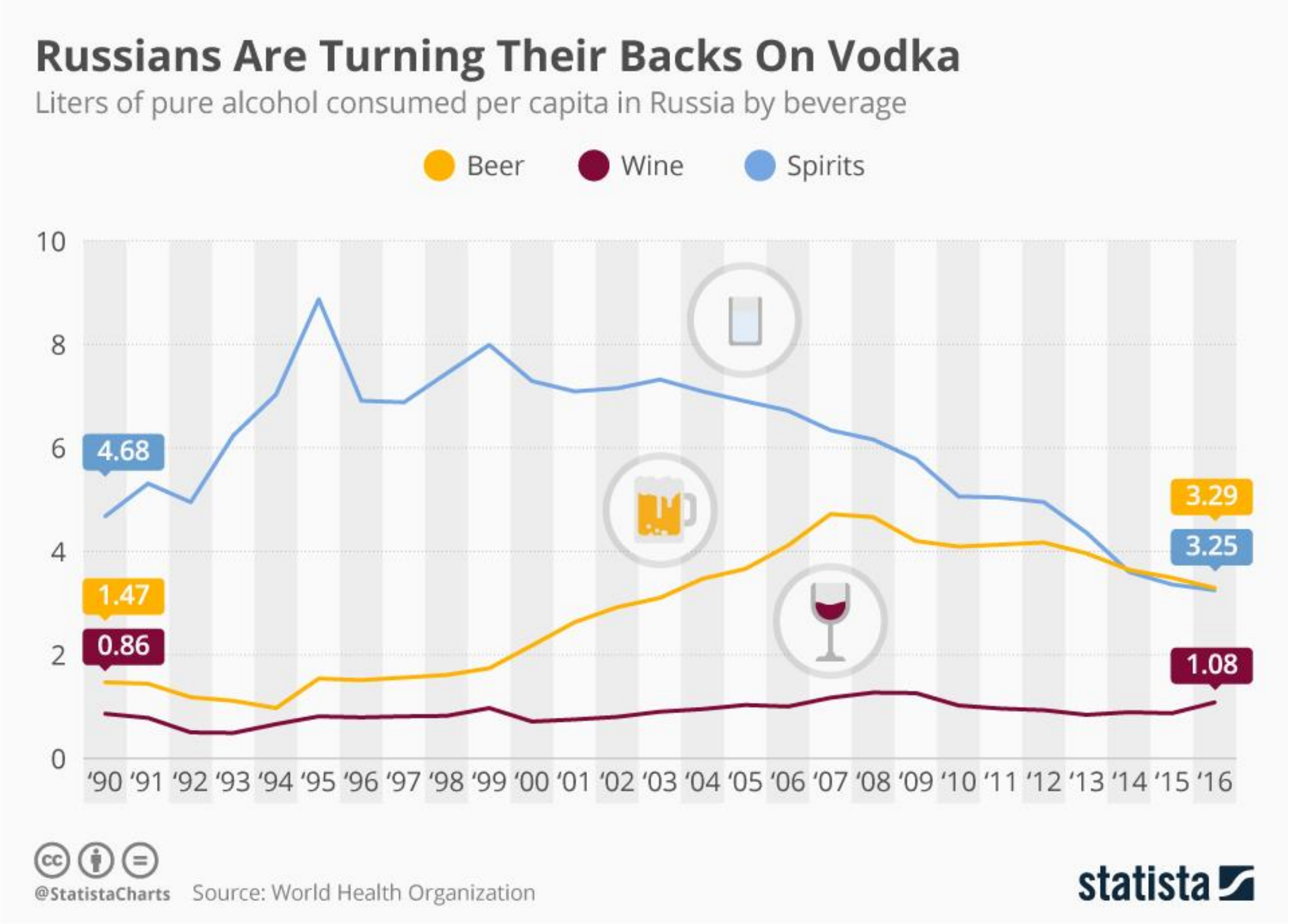
Red = bad

Gray perceived as “no color”

- Missing data
- Uncategorized data
- Non-emphasized data

Very powerful when used appropriately

Semantics of color

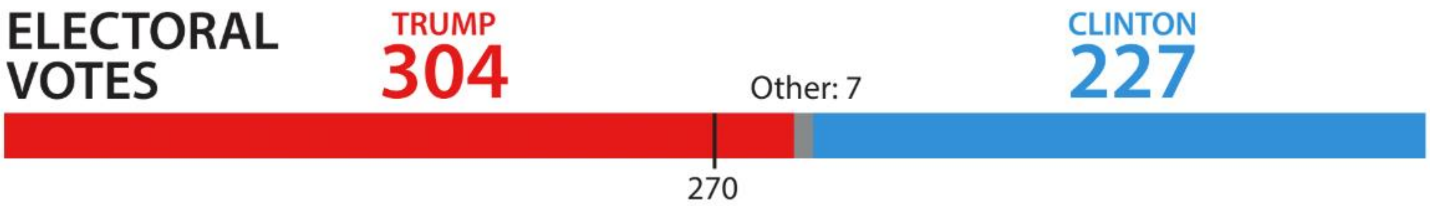


Semantics of color

Use color consistently

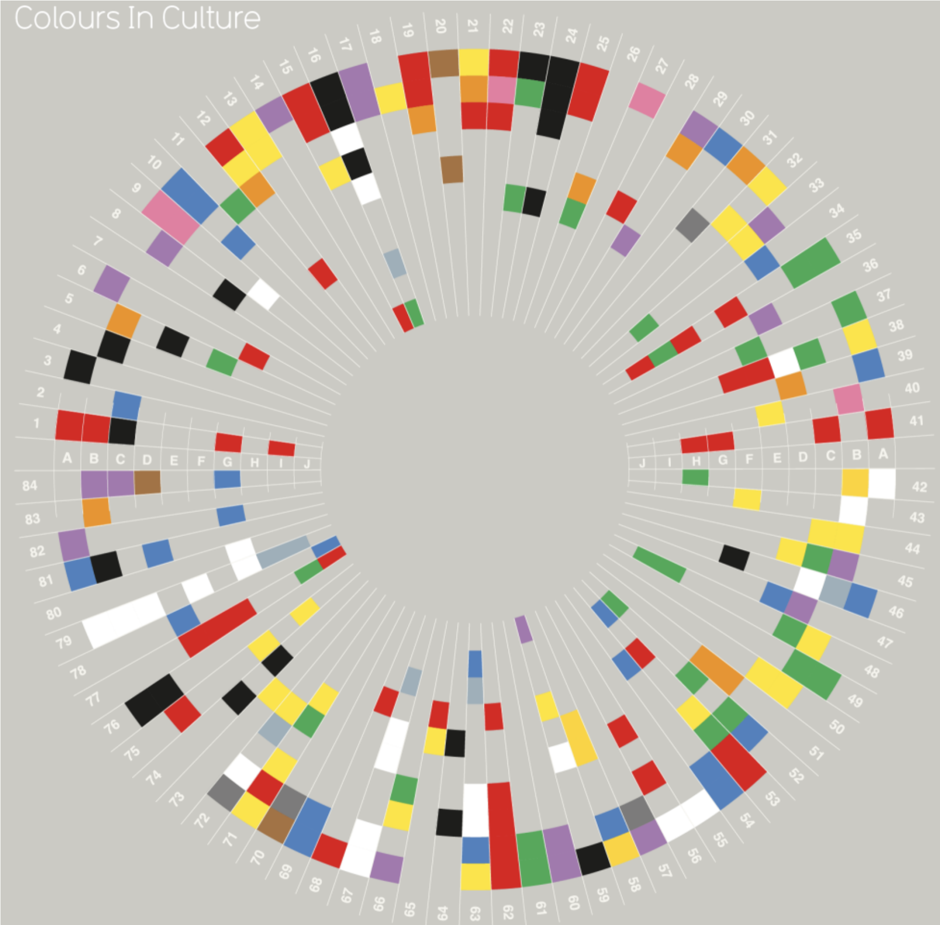
Example from US politics

- Republicans = red
- Democrats = blue



Semantics of color

Meaning changes depending on culture

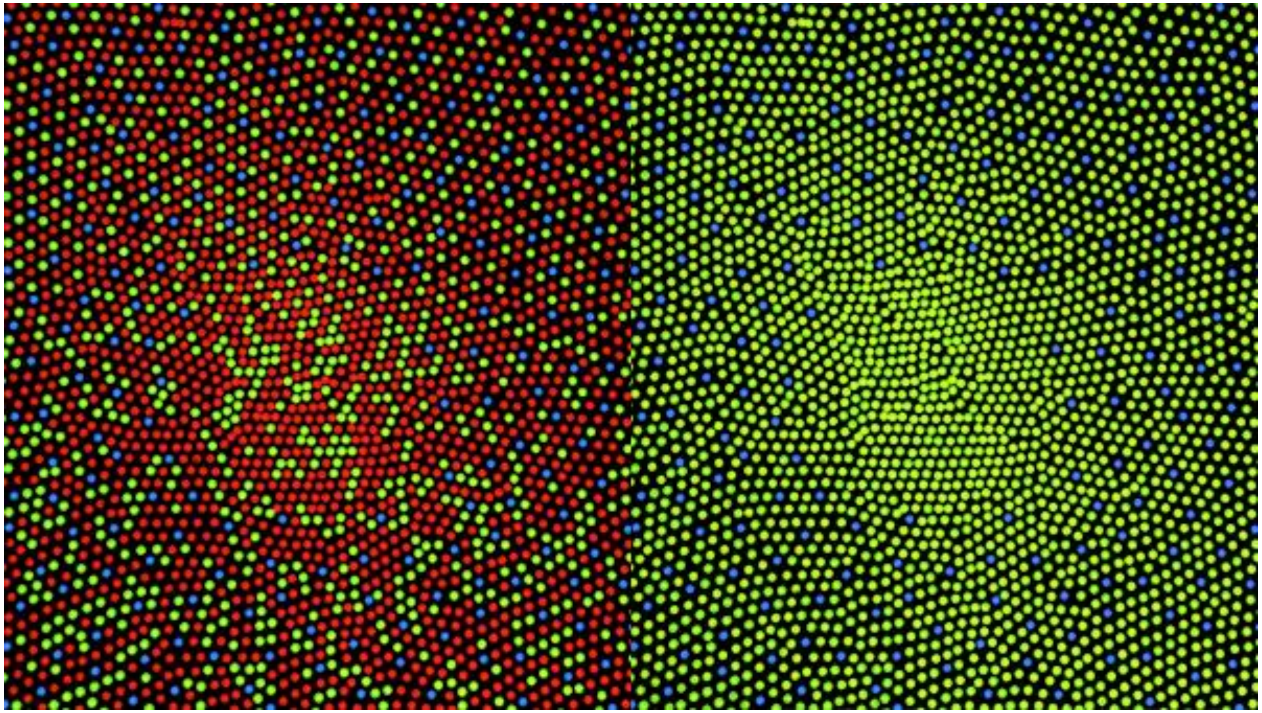


Semantics of color

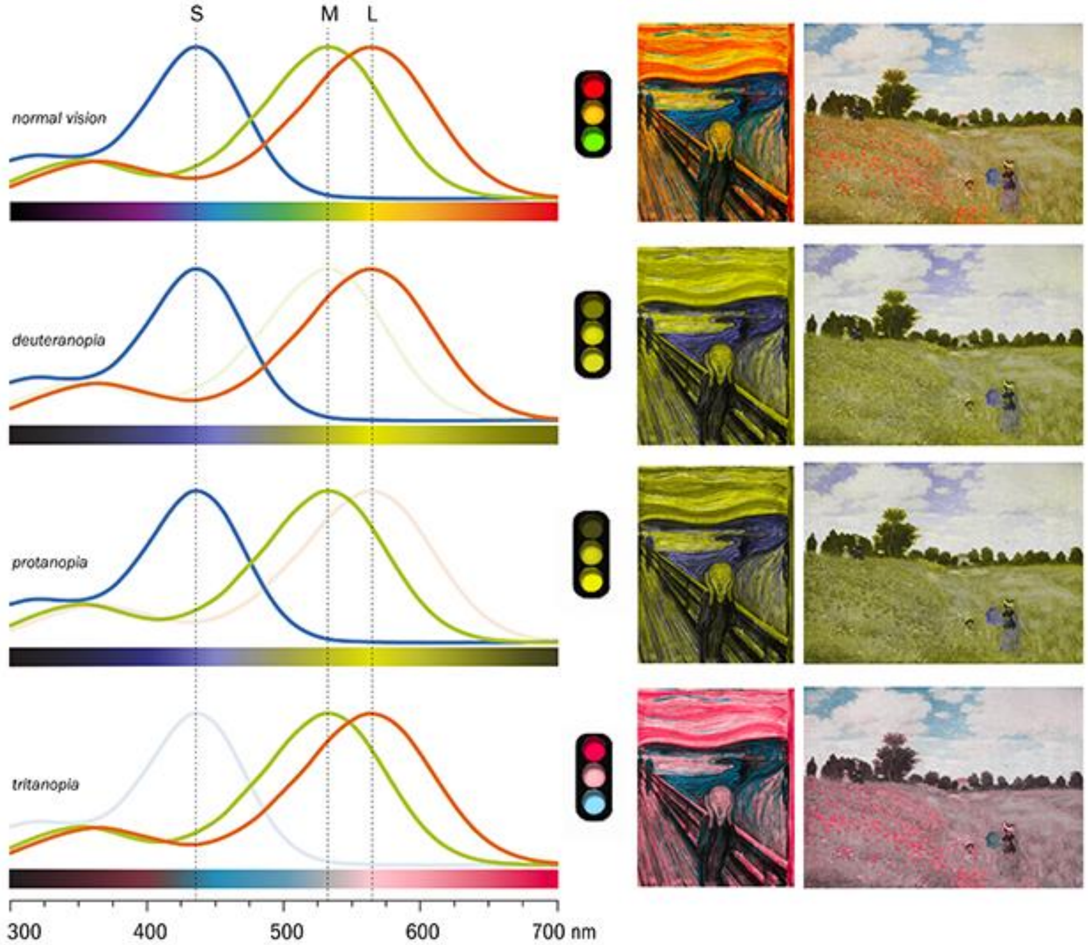
Floor of a children's hospital

Color blindness

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



Color blindness



Normal vision

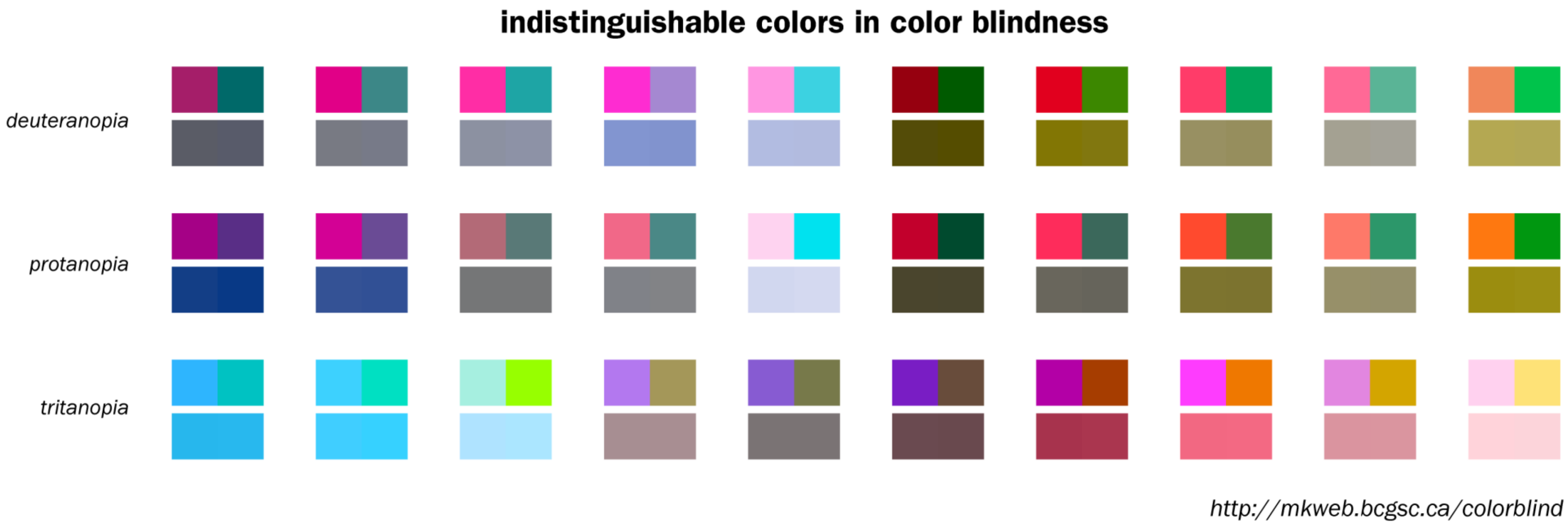
Deuteranopia

Protanopia

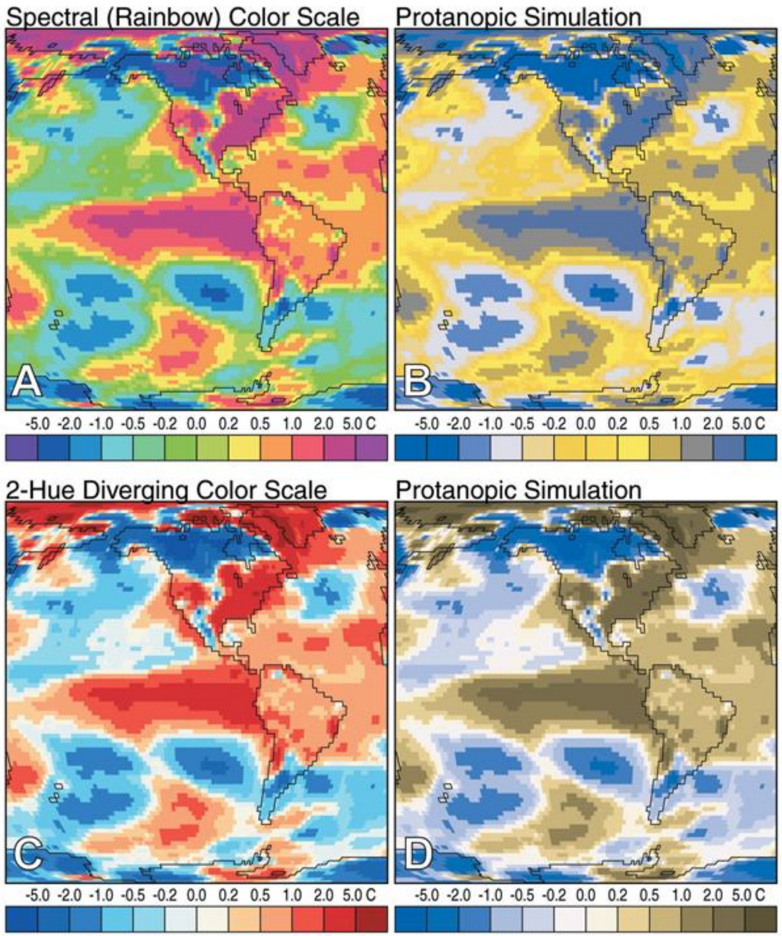
Eritanopia

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

Color blindness



Color blindness



https://visual.ly/blog/rainbow-color-scales/

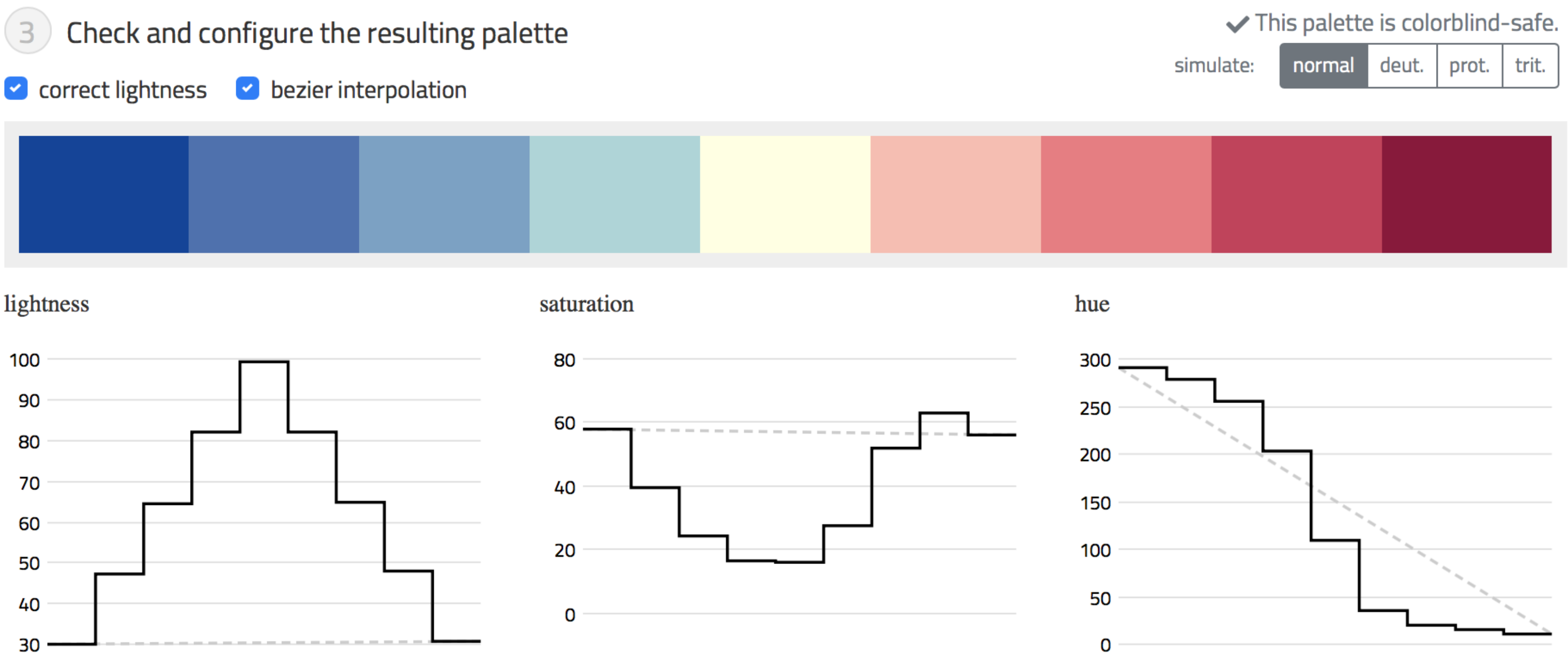
Color blindness

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		

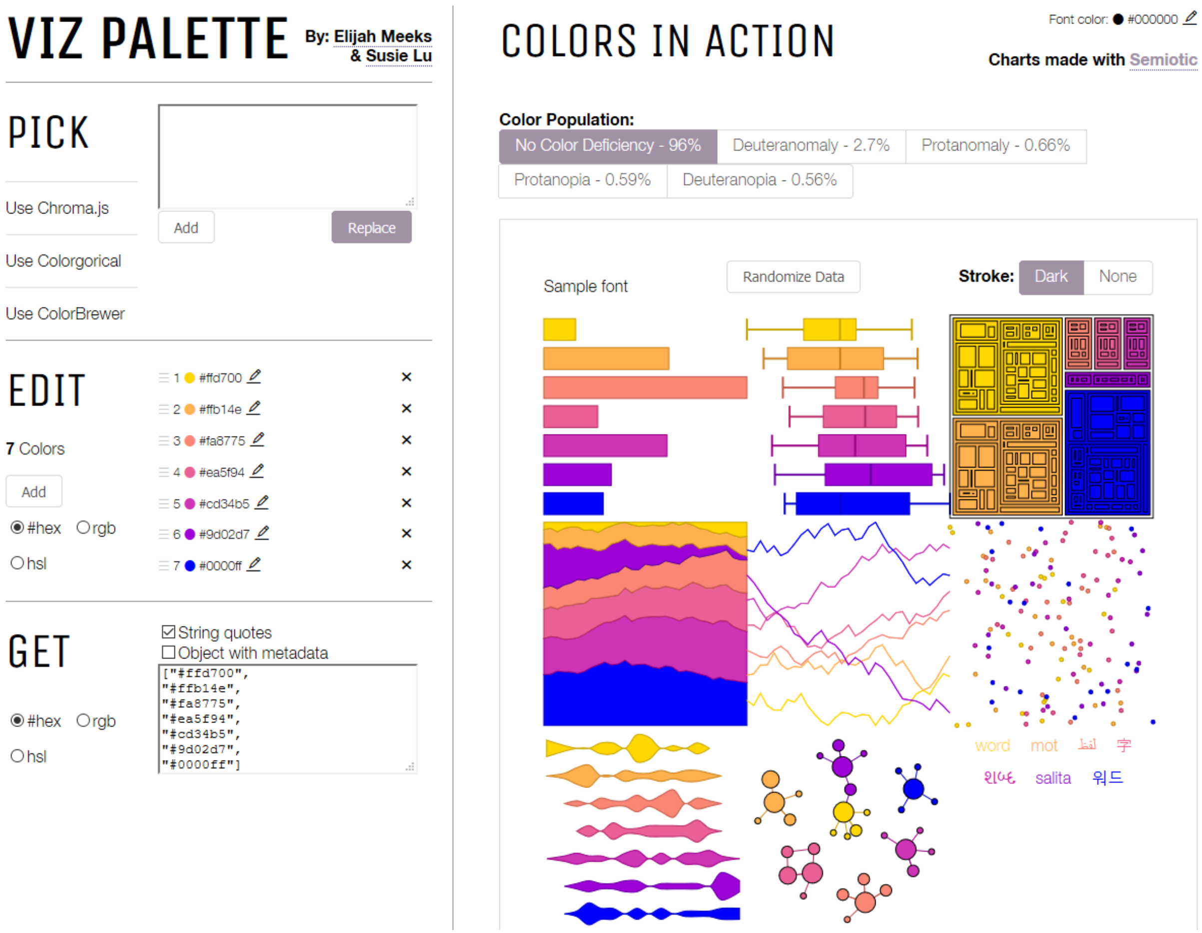
Wong, B. (2011) Points of view: Color blindness. Nature Methods 8:441.

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

Color blindness



Color blindness



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

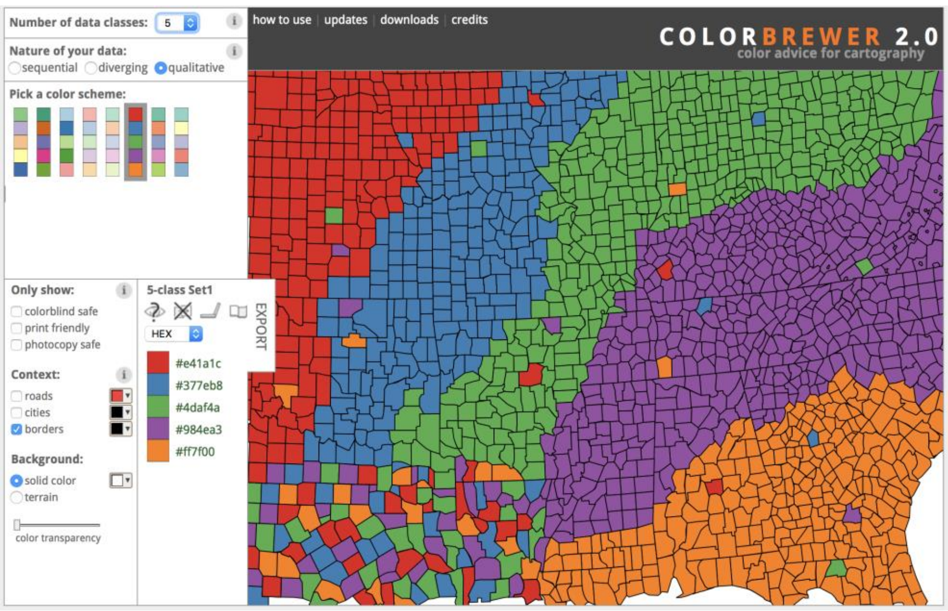
Normal vision Deuteranopia

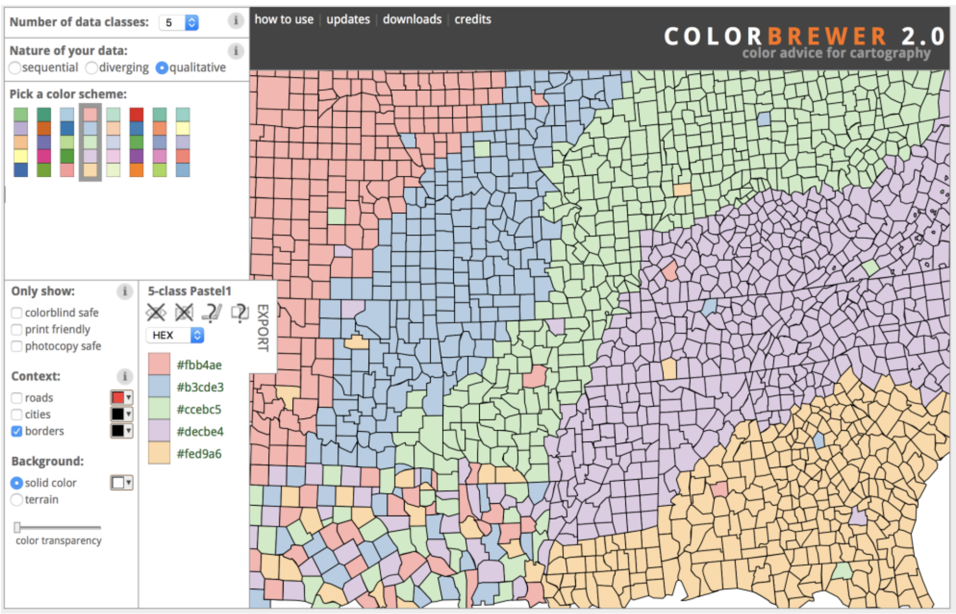
Importance of size

Small size hurts discriminability

Small area ➞ high saturation

Large area ➞ low saturation





Relative perception

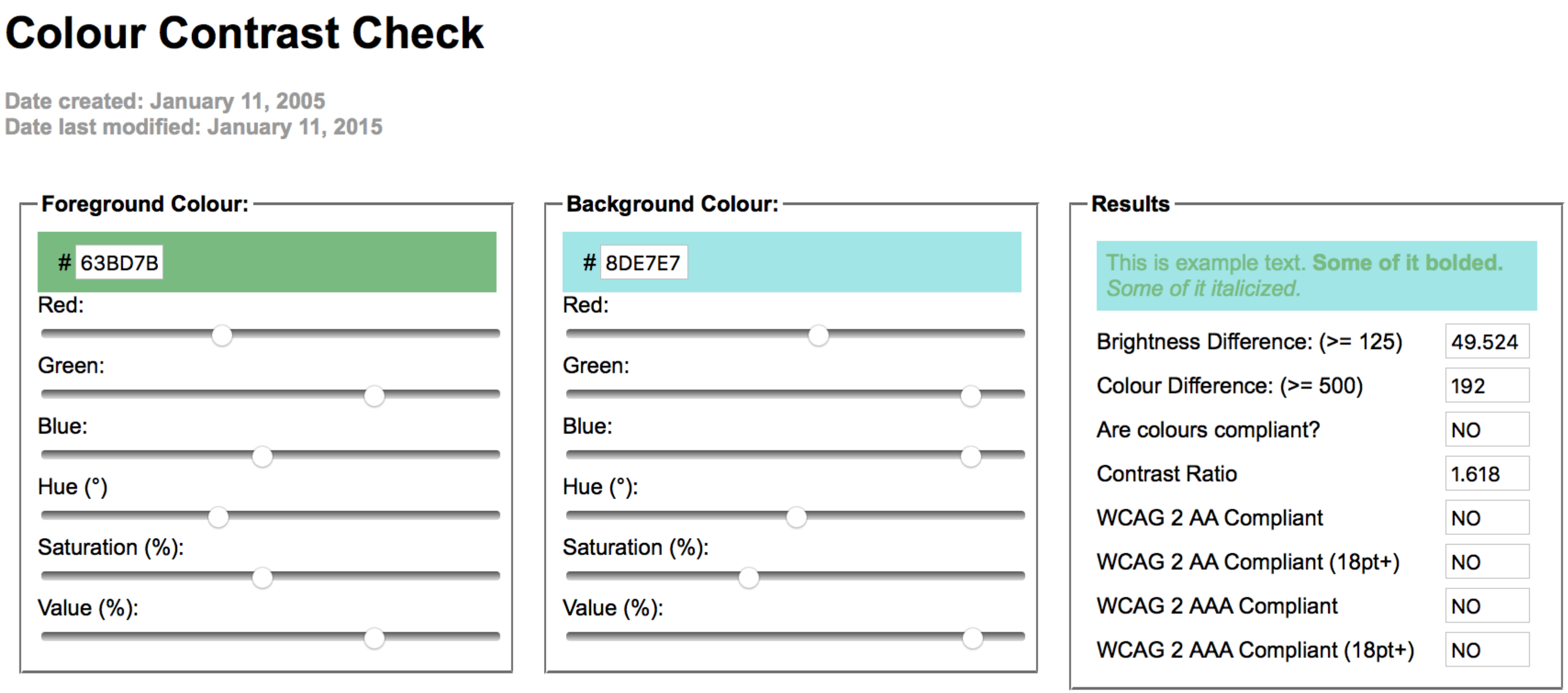
Our color perception is not absolute, but relative

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

Importance of contrast

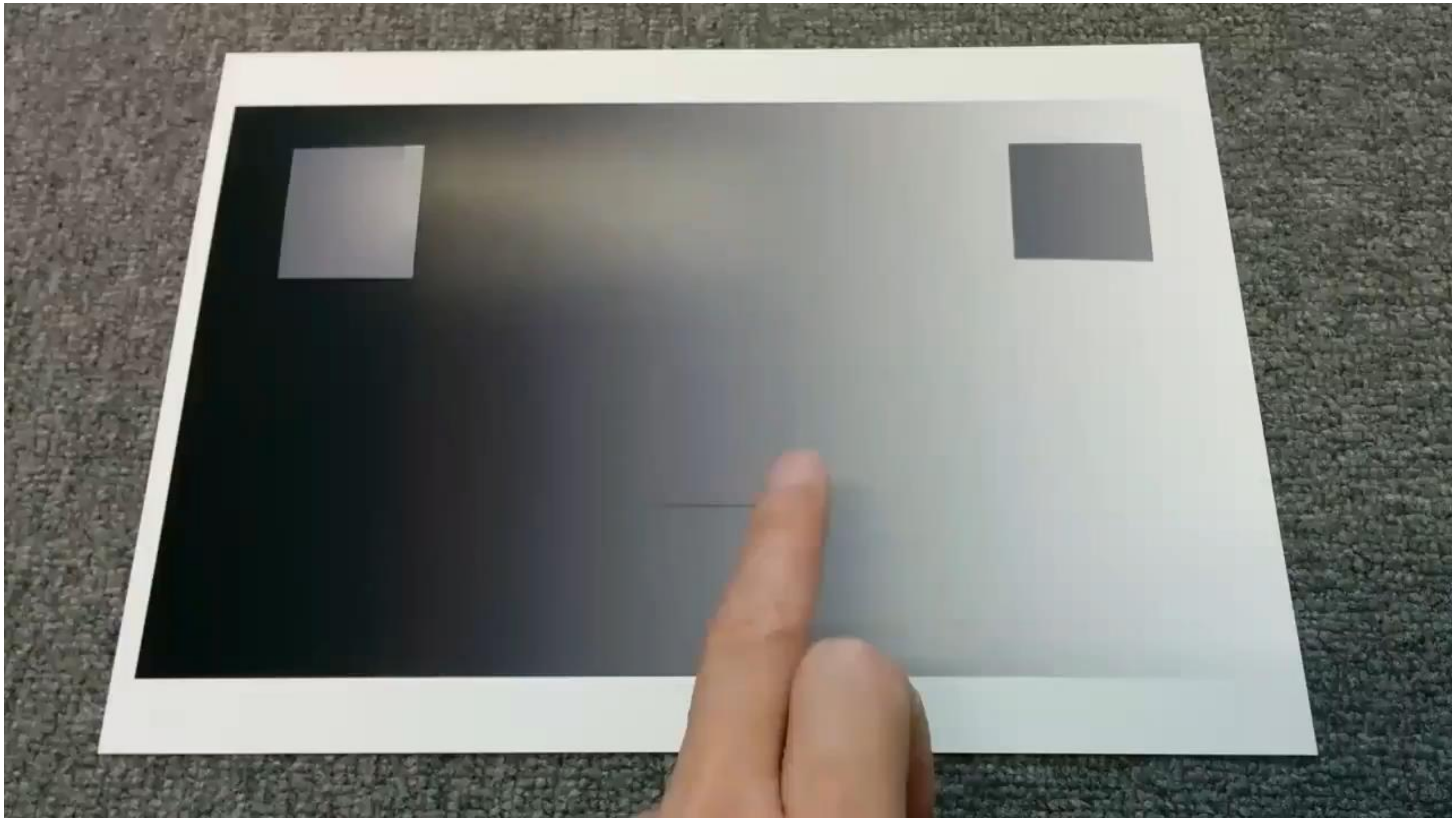
Contrast is most easily changed using luminance/lightness

Importance of contrast

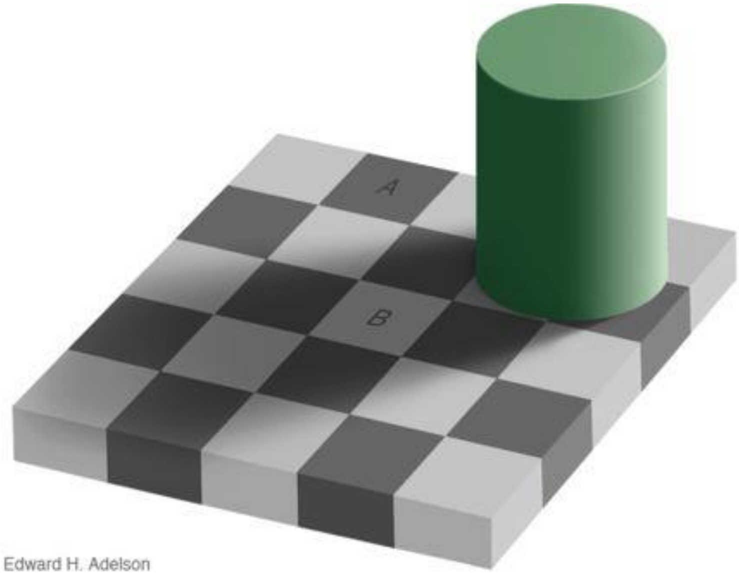


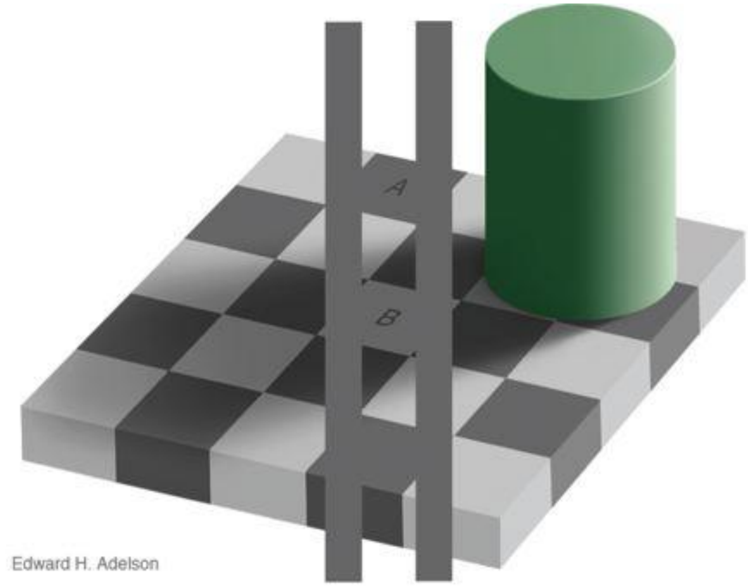
https://snook.ca/technical/colour_contrast/colour.html#fg=63BD7B,bg=8DE7E7

Importance of background



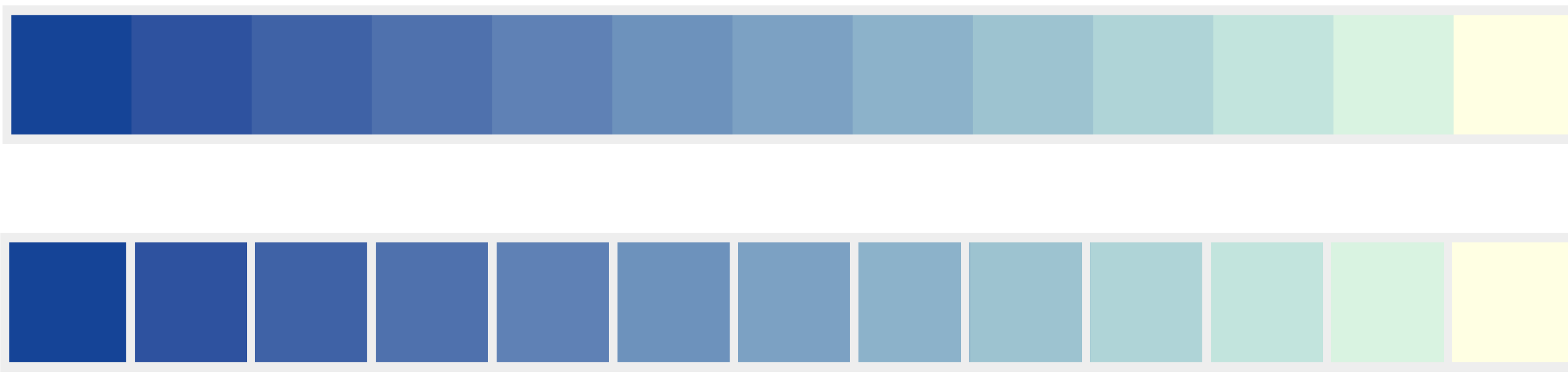
Importance of surrounding color





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

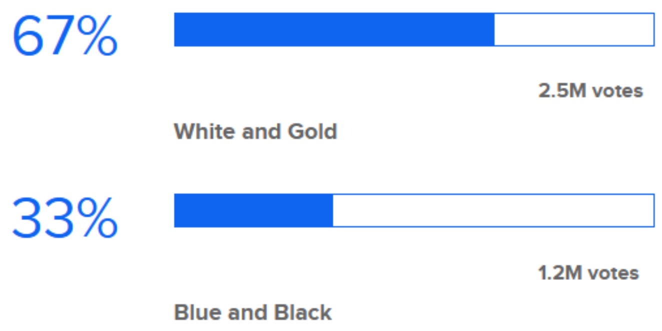
Strawberries appear to be red although the pixels are not

Importance of surrounding color

"The dress"

What colors are this dress?

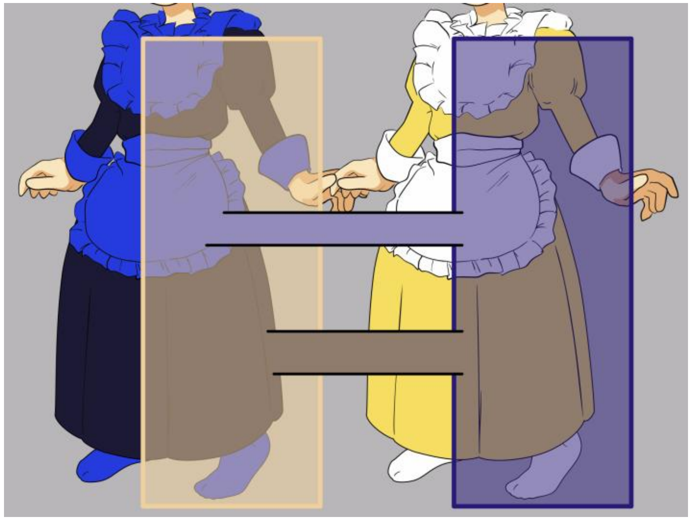
- White and gold
- Blue and black



https://www.buzzfeed.com/catesish/help-am-i-going-insane-its-definitely-blue#subbuzz-quiz-poll-results-5103755

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

https://en.wikipedia.org/wiki/The_dress

Importance of surrounding color

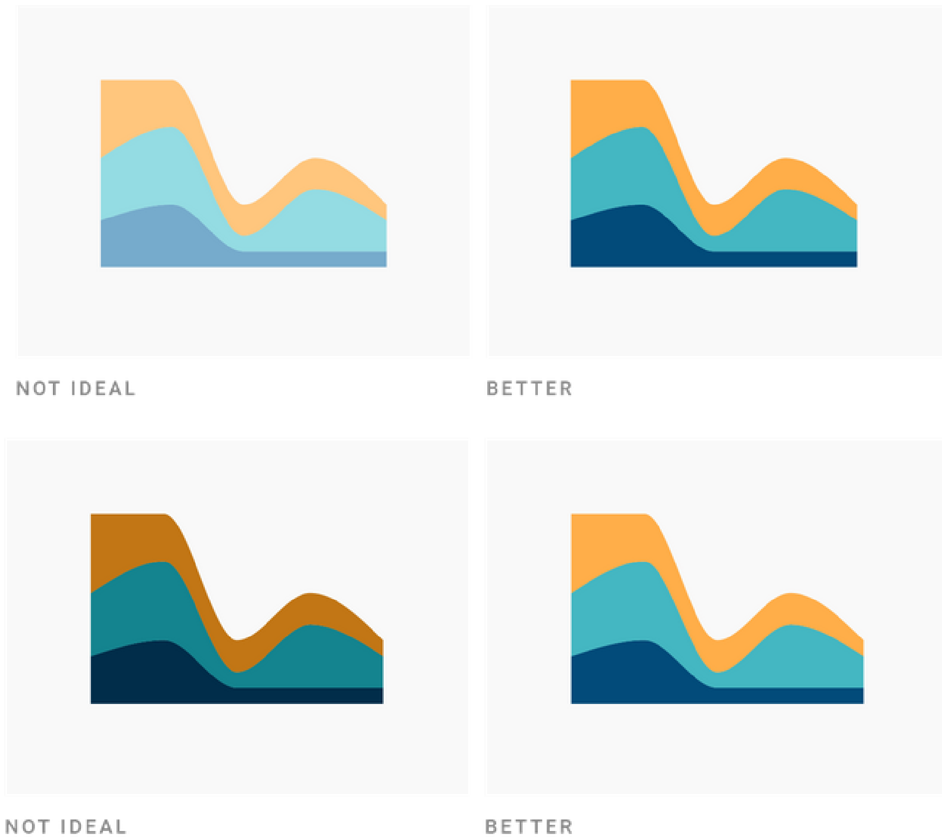
“The dress”

The rabbit-duck illusion

https://en.wikipedia.org/wiki/The_dress
https://en.wikipedia.org/wiki/Rabbit%E2%80%93duck_illusion

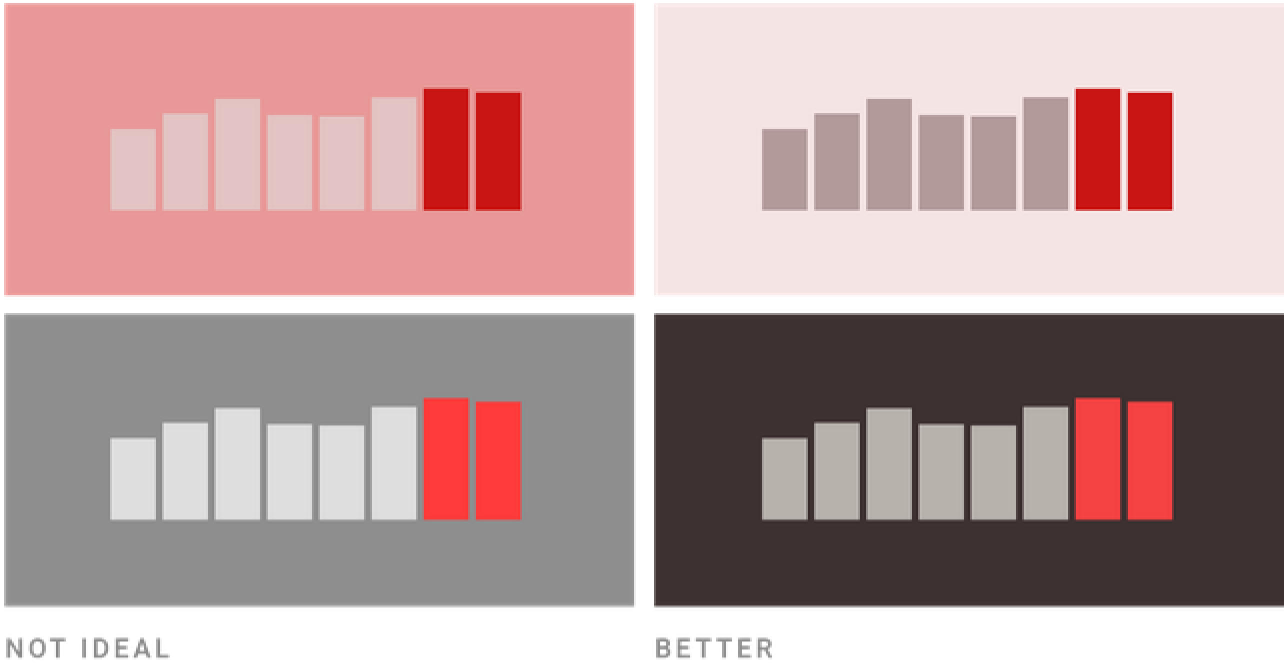
Choosing colors

Use the right amount of contrast to the background



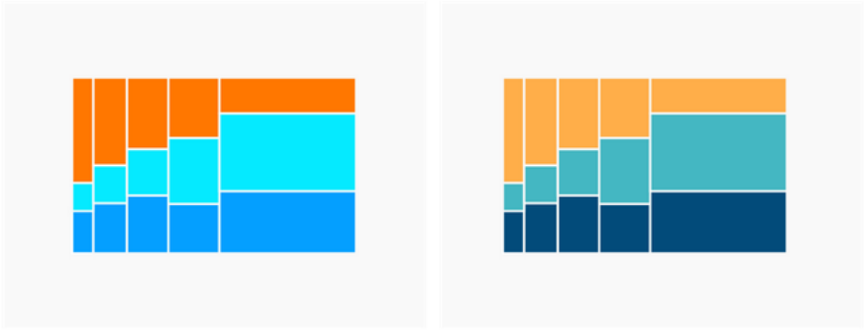
Choosing colors

Background should not be too saturated



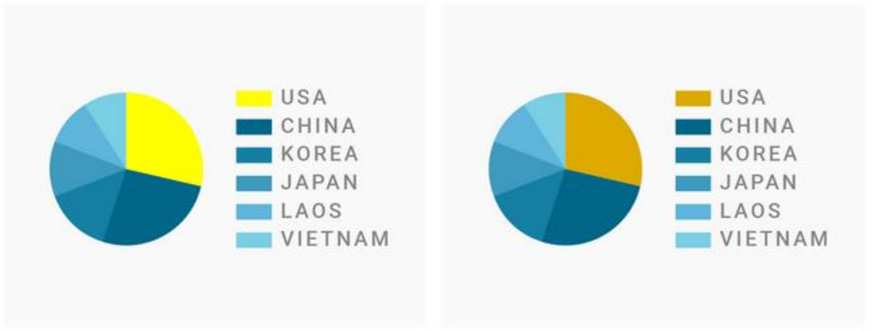
Choosing colors

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

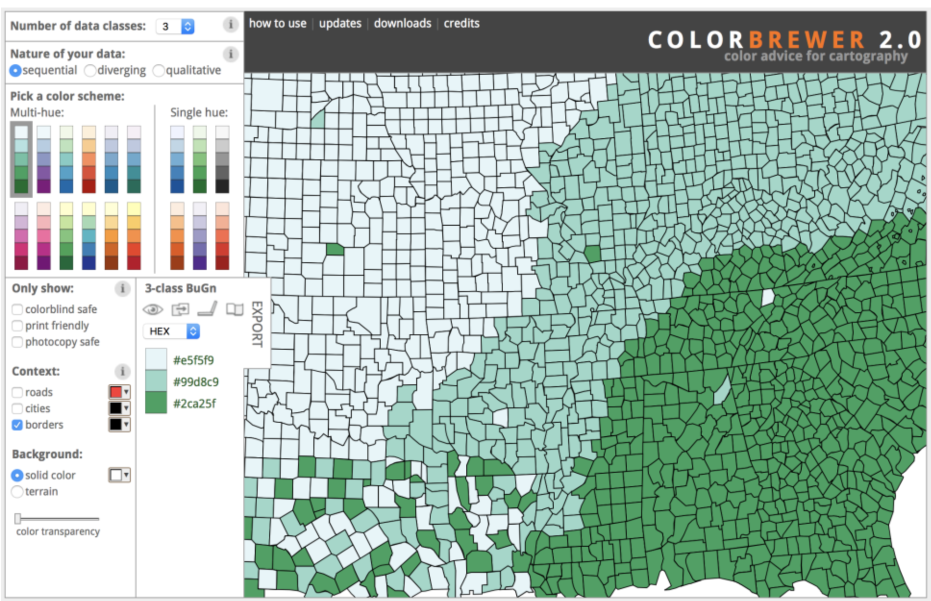
- Enforce emotions
- Consider culture

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!