Data Visualization

COLOR

Overview

Motivation

Color perception

Color specification

Color use

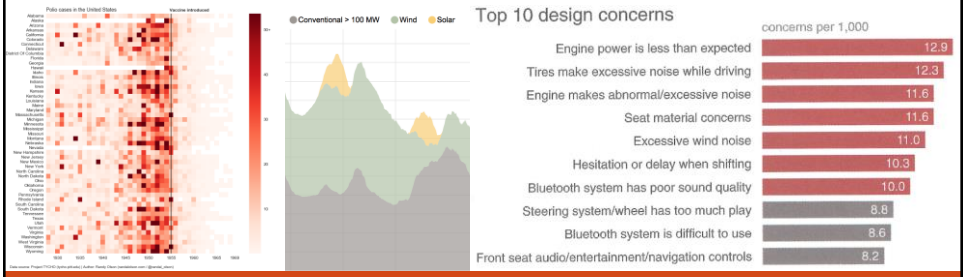
Motivation

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)



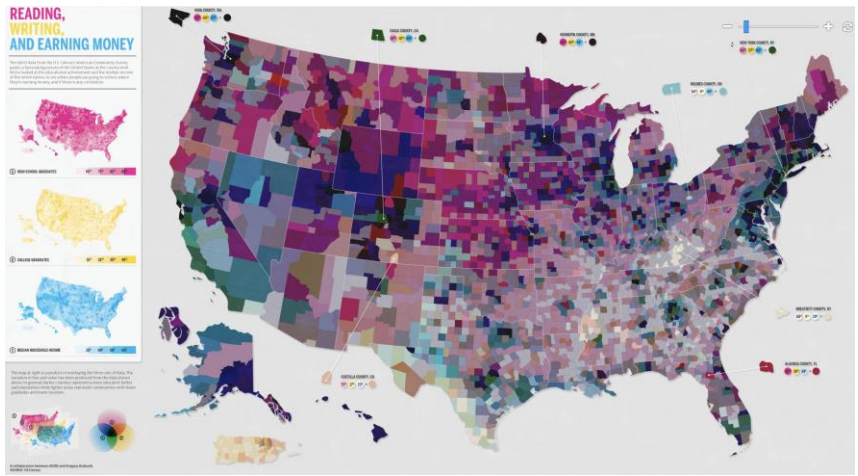
Color (mis)use

Above all, do no harm

Edward Tufte

5

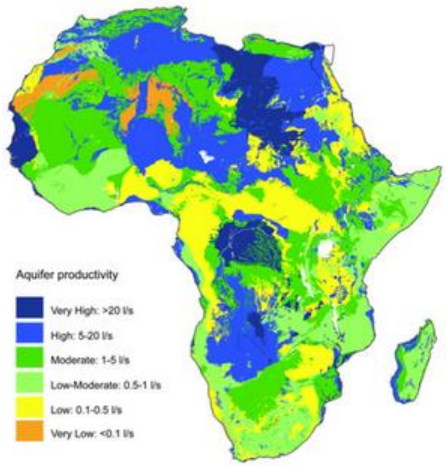
Color (mis)use



https://www.good.is/infographics/america-s-richest-counties-and-best-educated-counties#open

6

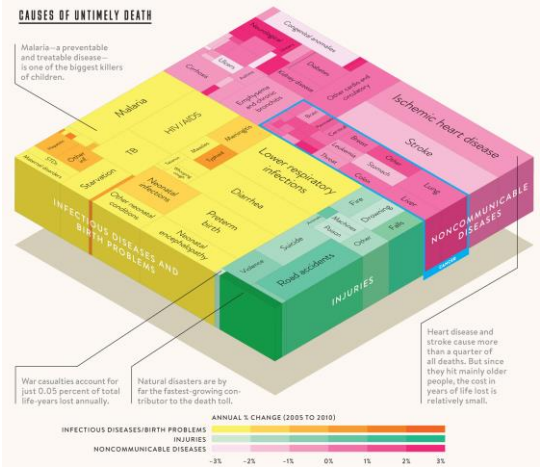
Color (mis)use



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

7

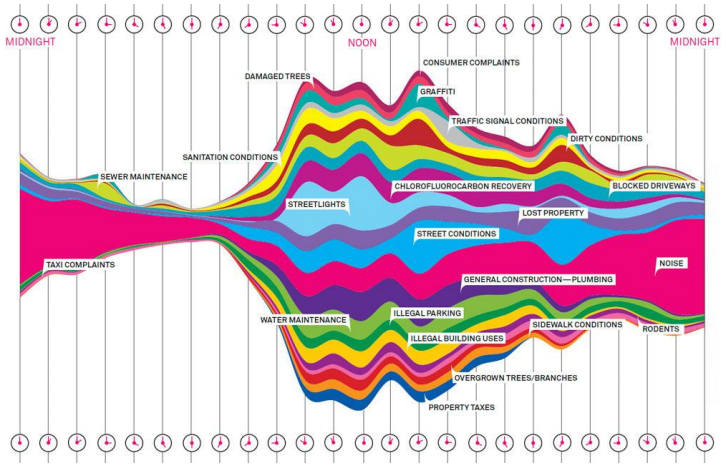
Color (mis)use



https://www.perceptualedge.com/images/example20problem_large.jpg

8

Color (mis)use



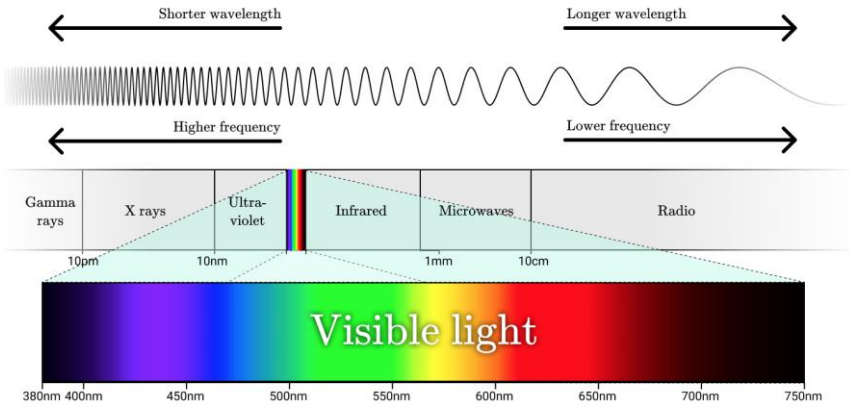
https://junkcharts.typepad.com/junk_charts/2010/11/making-charts-beautiful-without-adding-unneeded-bits.html

9

Color perception

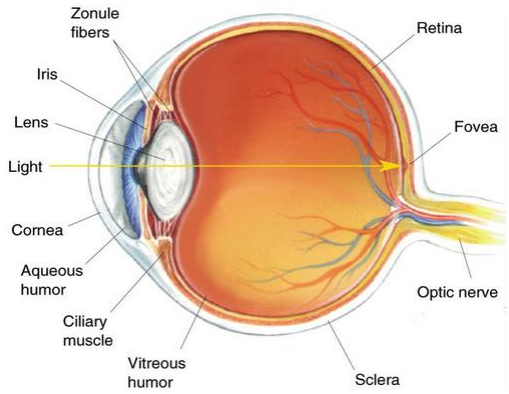
10

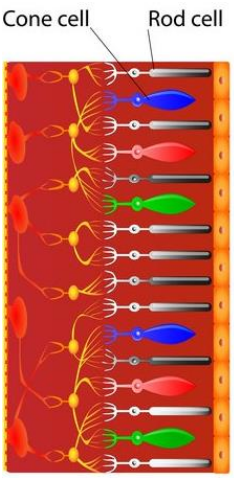
Light



http://jamie-wong.com/post/color/ 11

Human eye anatomy

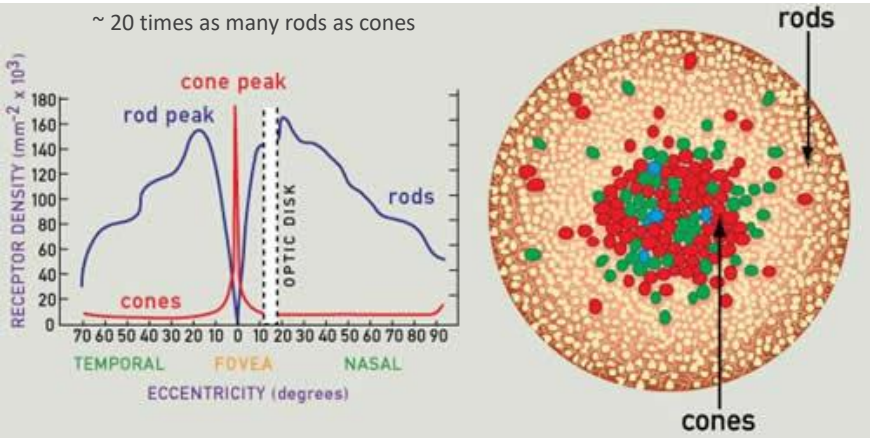




https://www.webrn-maculardegeneration.com/rods-and-cones.html 12

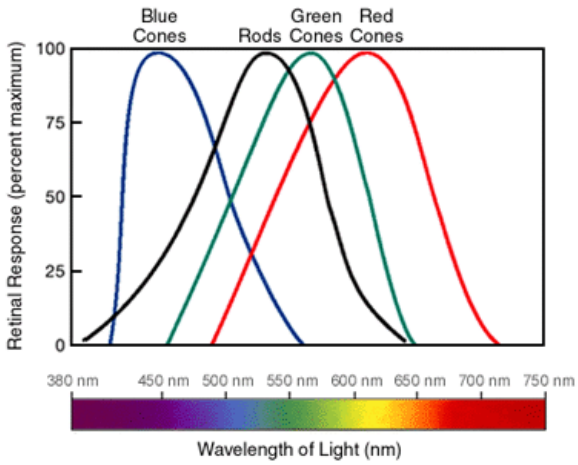
Rods and cones (photoreceptors)

~ 20 times as many rods as cones



http://www.webexhibits.org/causesofcolor/1G.html

Sensitivity of rods and cones



https://askabiologist.asu.edu/rods-and-cones

Trichromatic theory of color

We have three kinds of color receptors

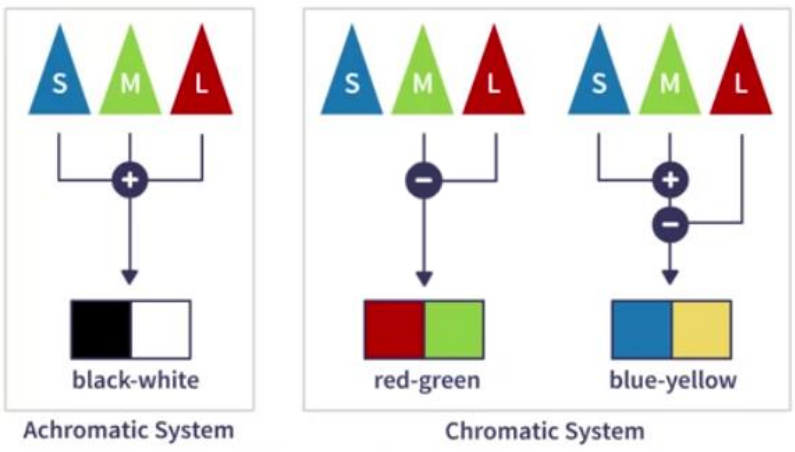
- S = short wavelength ("blue" cones)
- M = medium wavelength ("green" cones)
- L = long wavelength ("red" cones)

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

15

Color opponent process theory



https://www.coursera.org/learn/information-visualization-applied-perception

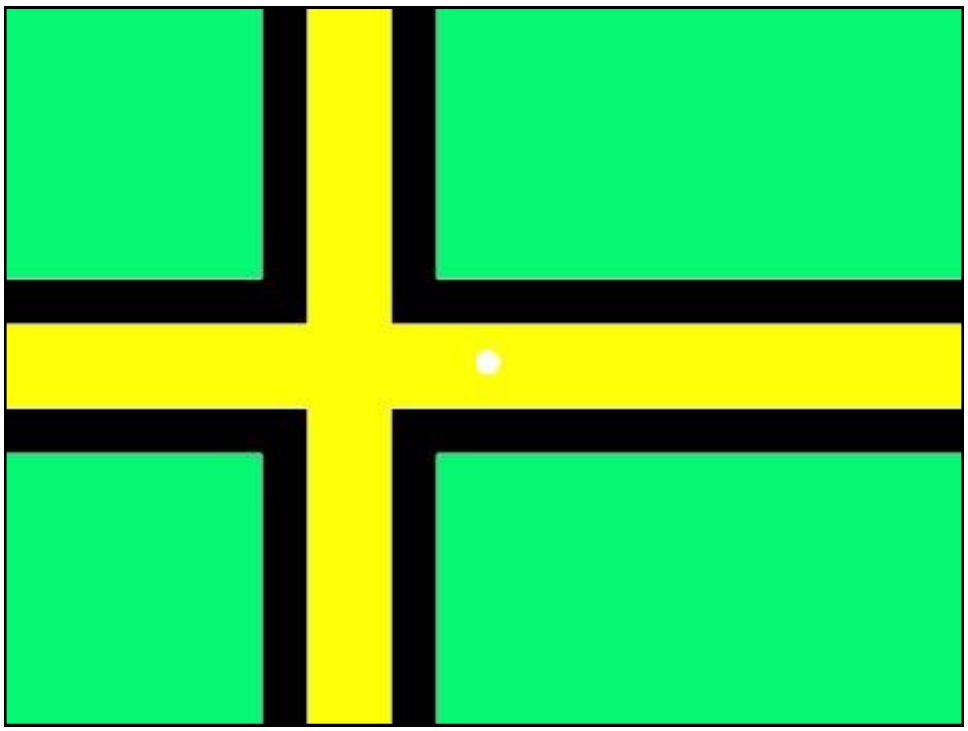
16

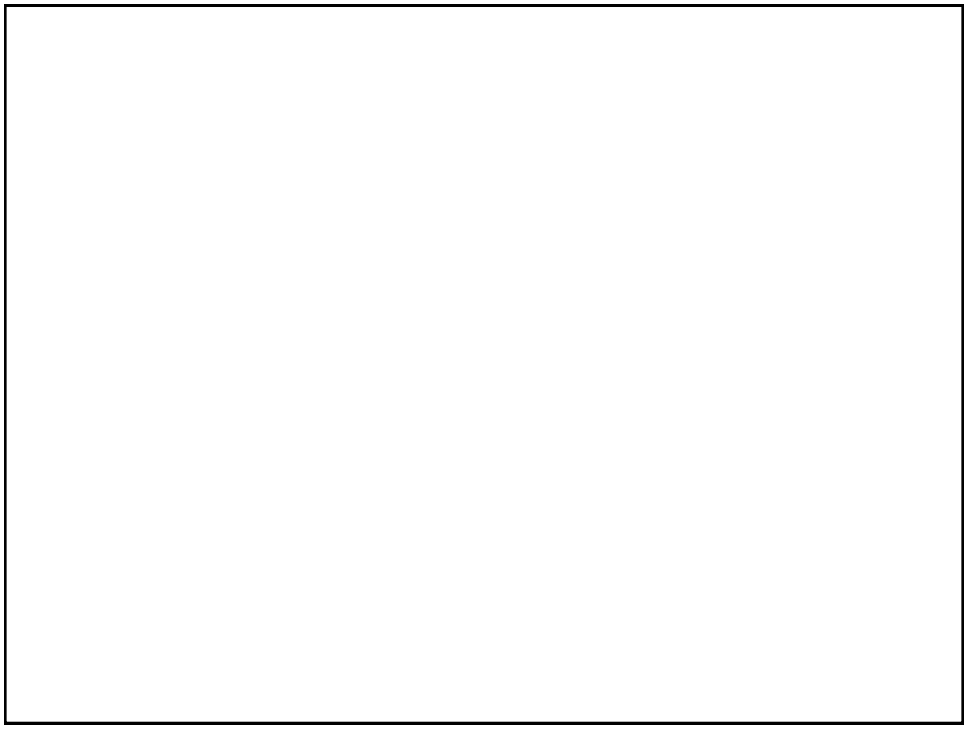
Color opponent process theory

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

17





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 previous example

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

20

Color perception summary

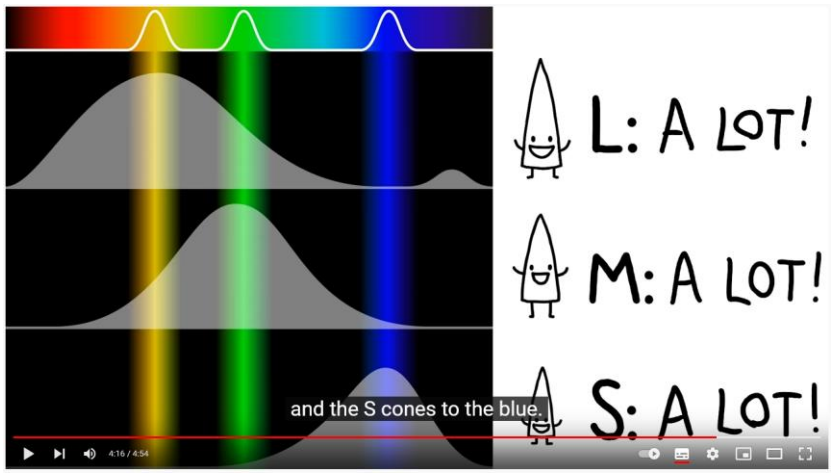
Human eye
- Rods (low light conditions, no colors)
- Cones (colors when enough light)

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

21

Color perception



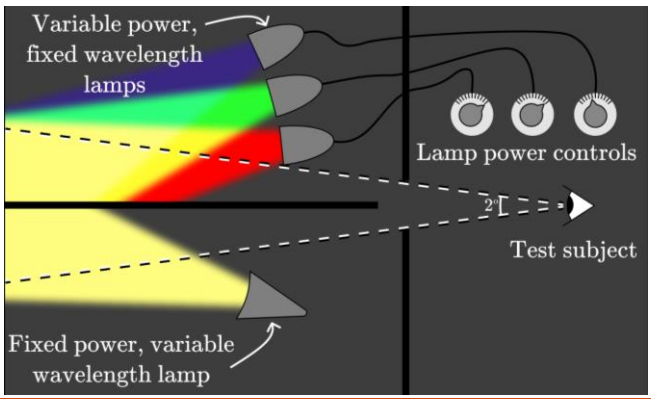
https://www.youtube.com/watch?v=poL7nDmqjmk

22

Color specification

Color specification

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



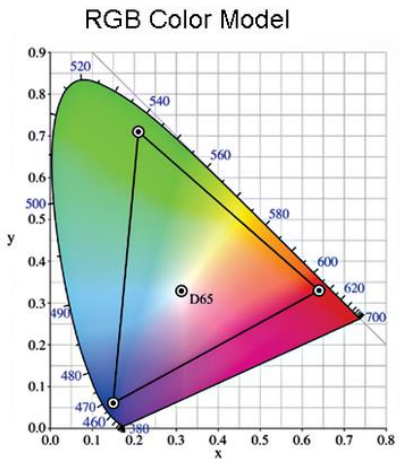
http://jamie-wong.com/post/color/

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

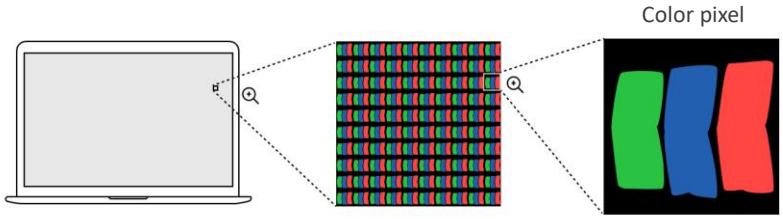
Properties of color spaces

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

RGB

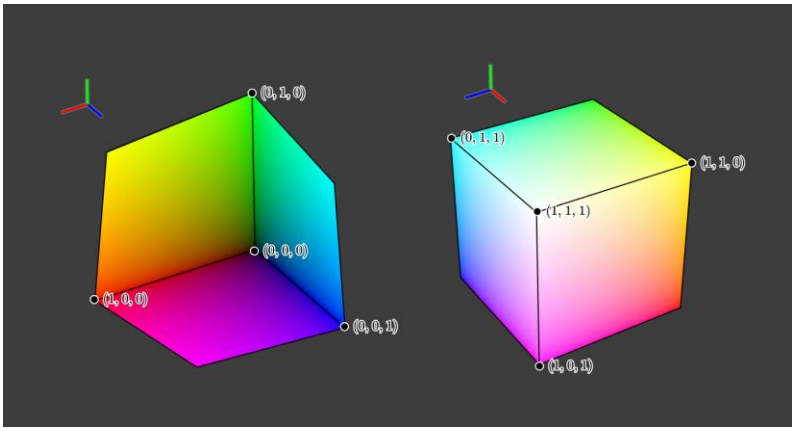
- R = red
- G = green
- B = blue

Commonly used in digital devices



http://jamie-wong.com/post/color/ 27

RGB



http://jamie-wong.com/post/color/ 28

RGB

http://www.csfieldguide.org.nz/en/interactives/rgb-mixer/index.html

29

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

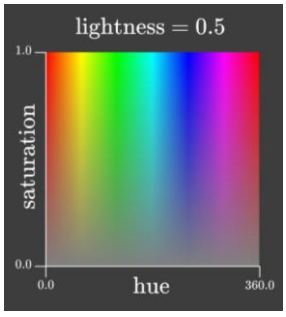
30

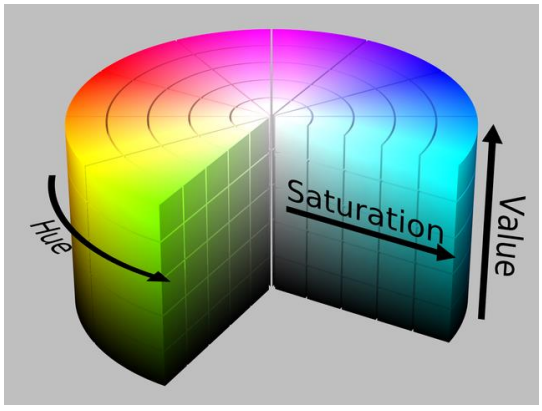
Properties of color spaces

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

HSL / HSV

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





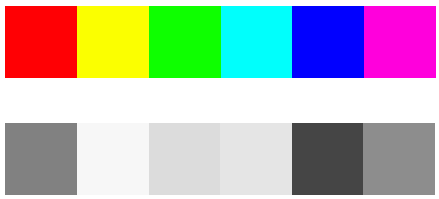
https://en.wikipedia.org/wiki/HSL_and_HSV
http://jamie-wong.com/post/color/

HSL / HSV

http://hslpicker.com

33

HSL / HSV



34

Properties of color spaces

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

CIE Lab

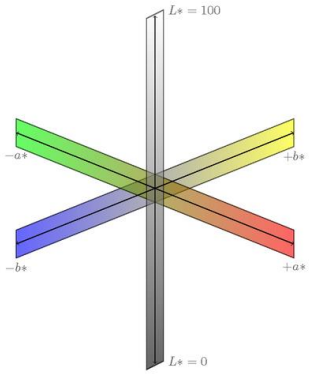
CIE (International Commission on Illumination)

Specified according to the opponent process theory

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

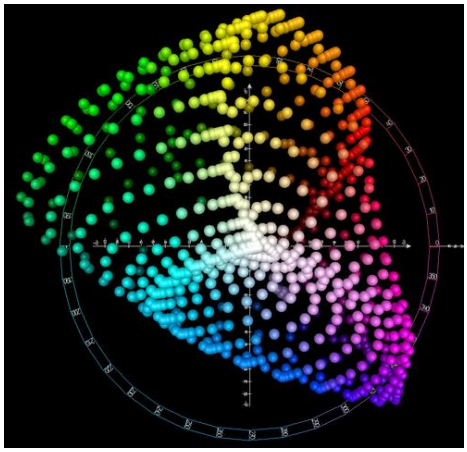
Designed to be perceptually linear

A nonlinear transformation of color wavelengths



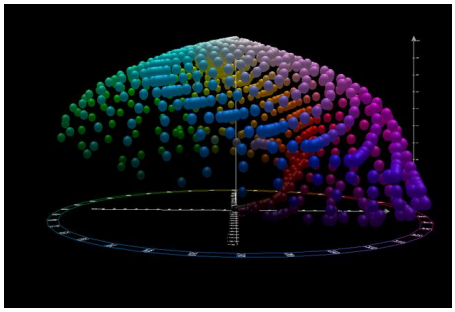
http://www.texample.net/tikz/examples/cielab/

CIE Lab



Top view

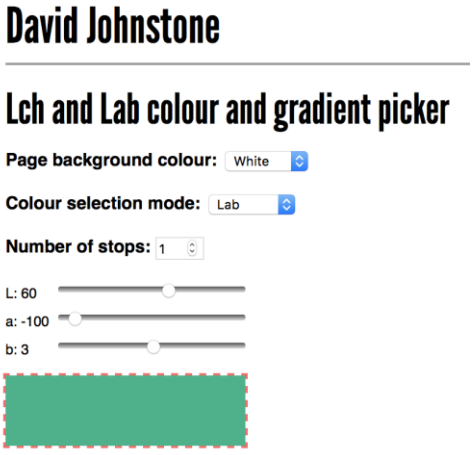
Front view



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

37

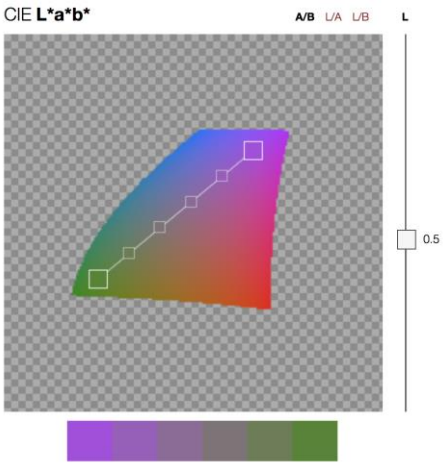
CIE Lab



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

38

CIE Lab



https://www.vis4.net/labs/colorvis/embed.html?m=lab&gradients=6

39

Properties of color spaces

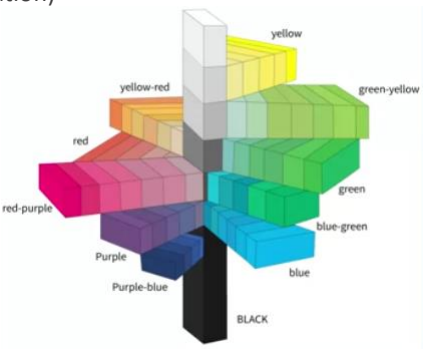
	Intuitive	Perceptually uniform
RGB	✗	✗
HSL / HSV	✓	✗
CIE Lab	✗	✓
CIE LCh / HCL		

40

CIE LCh / HCL

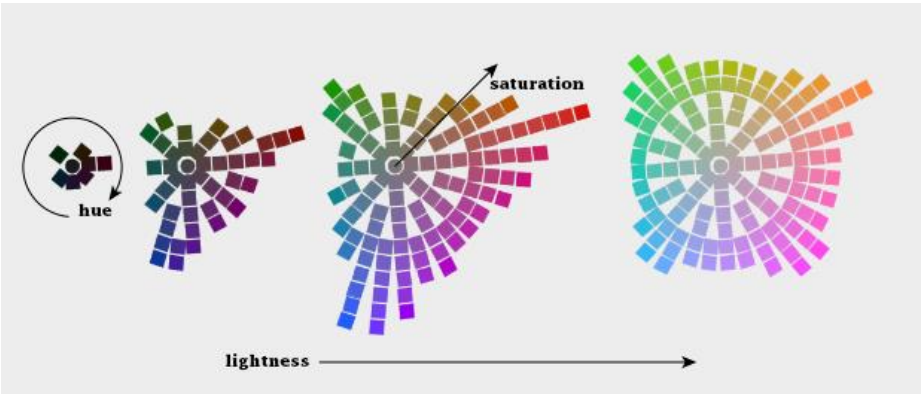
Transformation of CIE Lab to cylindrical coordinates

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



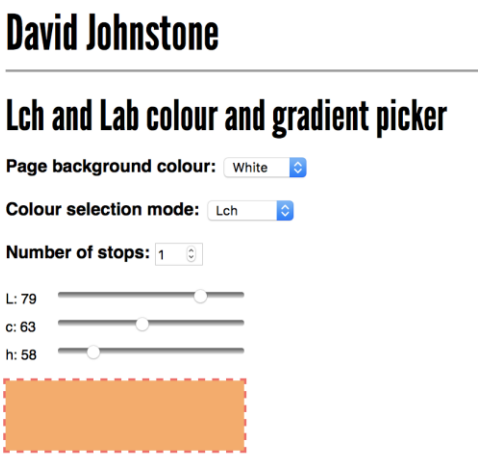
https://www.coursera.org/learn/information-visualization-applied-perception 41

CIE LCh / HCL



https://earthobservatory.nasa.gov/blogs/elegantfigures/2013/08/ 42

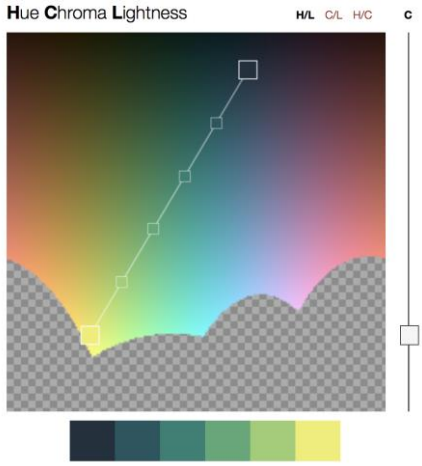
CIE LCh / HCL



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

43

CIE LCh / HCL



https://www.vis4.net/labs/colorvis/embed.html?m=hcl&gradients=6

44

Color specification summary

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

45

Color use

46

Color use

Color maps

Semantics of color

Color blindness

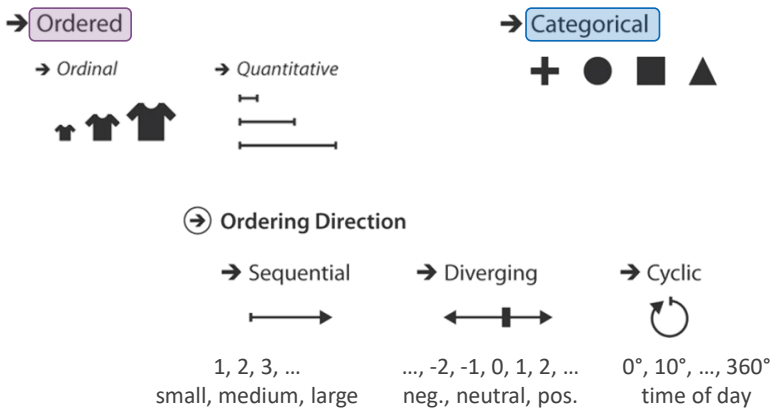
Importance of size

Relative perception
- Importance of contrast
- Importance of background
- Importance of surrounding color

Choosing colors

47

Data attributes



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

48

Color maps

Single variable
- Sequential color maps
- Diverging color maps
- Cyclic/circular color maps
- Categorical color maps

Two variables
- Bivariate color maps

49

Sequential color maps

Desired properties
- Perceived differences correspond to value differences
- High discriminability

Single hue

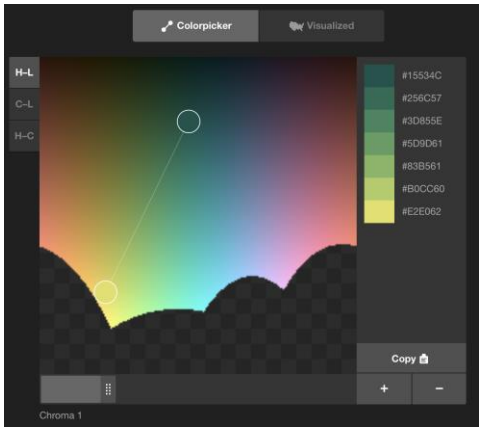
1 2 3 4 5 6 7

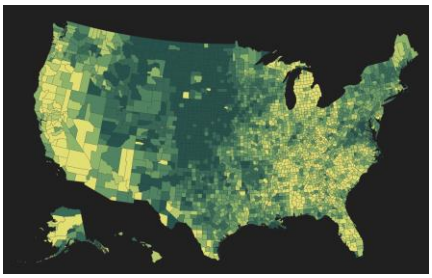
Multi-hue

http://colorbrewer2.org

50

Sequential color maps





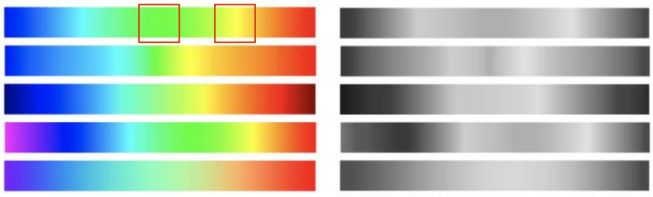
http://tristen.ca/hcl-picker/ 51

Sequential color maps: Rainbow

Overused because chosen as the default color map in many software packages

Issues

- 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

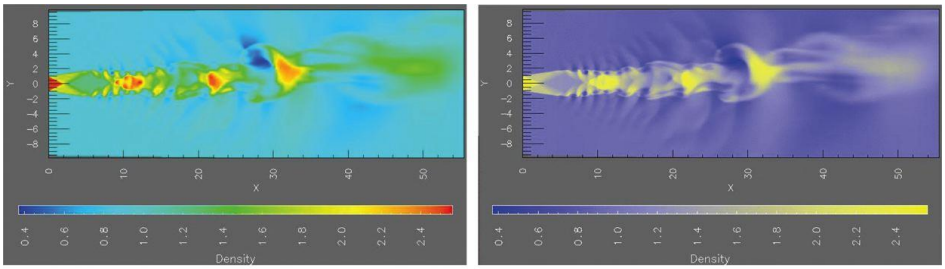


http://sci.utah.edu/~vdl/papers/2019_eurovis_implicit-discretization.pdf 52

Sequential color maps: Rainbow

Properties

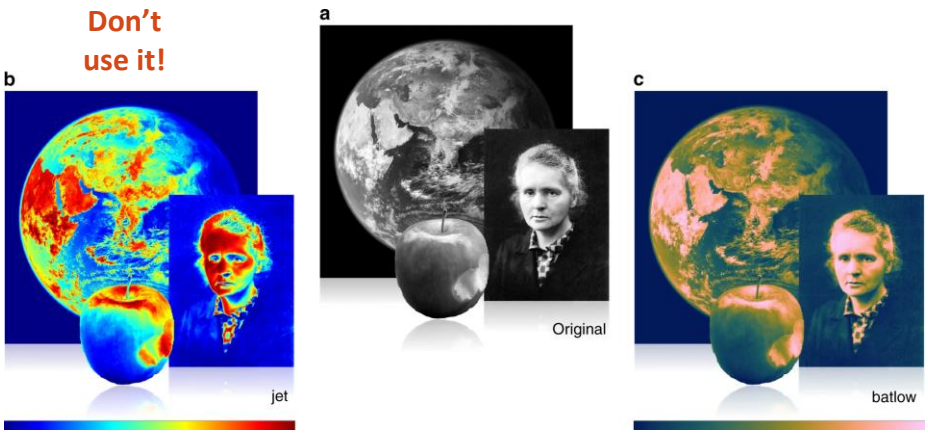
- The details are harder to see
- Only advantage: Colors can be easily named



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 53

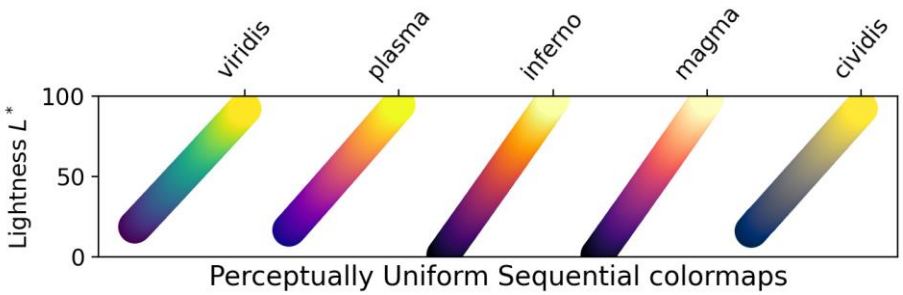
Sequential color maps: Rainbow

Don't use it!



F. Crameri, G. E. Shephard, P. J. Heron. The misuse of colour in science communication. *Nature Communications*, **11**: 5444, 2020 54

Perceptually linear sequential color maps



https://matplotlib.org/stable/tutorials/colors/colormaps.html 55

Diverging color maps

Encode two properties at the same time

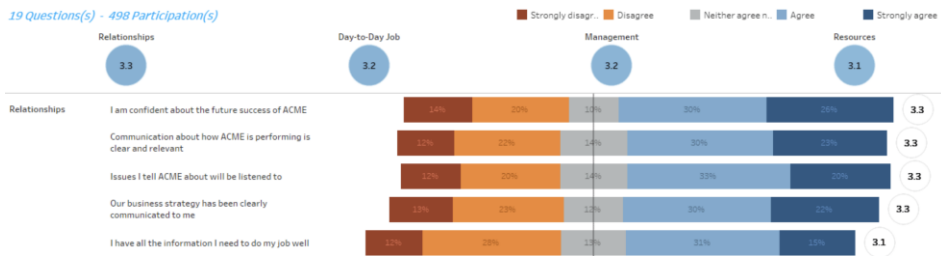
- Above/below threshold (usually zero)
- Magnitude above/below threshold

Desired properties

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

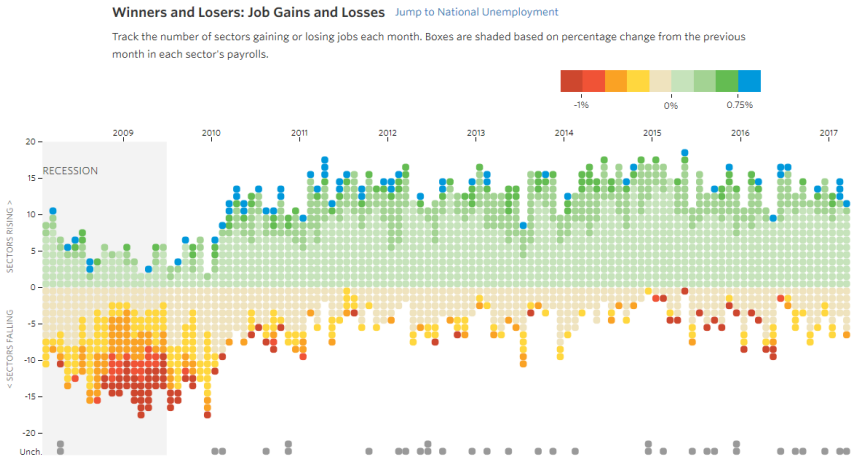
http://colorbrewer2.org 56

Diverging color maps – good example



https://linpack-for-tableau.com/tableau-dashboard/survey-dashboard/ 57

Diverging color maps – bad example

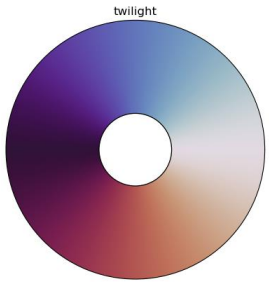


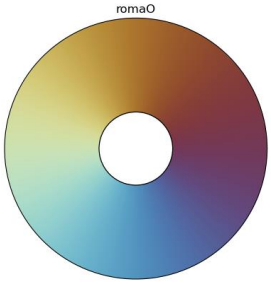
http://graphics.wsj.com/job-market-tracker/ 58

Cyclic/circular color maps

Desired properties

- Perceived differences correspond to value differences
- High discriminability
- Circular continuity (continuous transition between the highest and lowest values)





https://www.fabiocrameri.ch/colourmaps/ 59

Categorical color maps

Desired properties

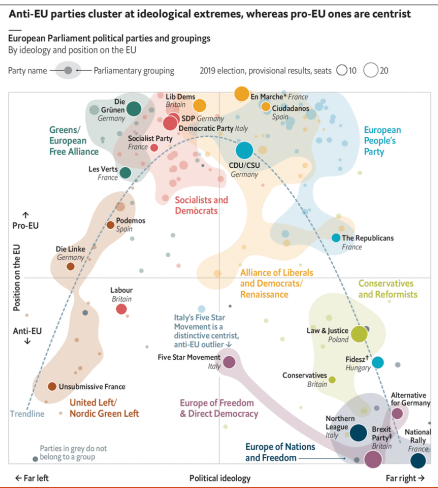
- Uniform saliency (nothing stands out)
- High discriminability

Use colors that can be named

Do not use too many different colors/categories

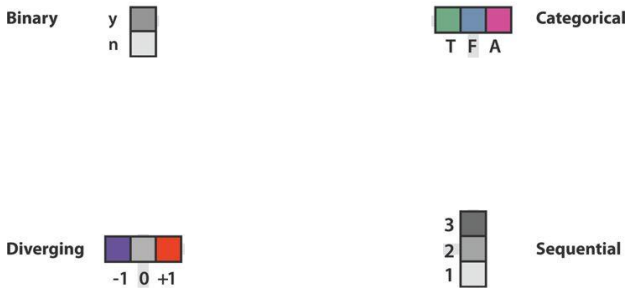
http://colorbrewer2.org 60

Categorical color maps



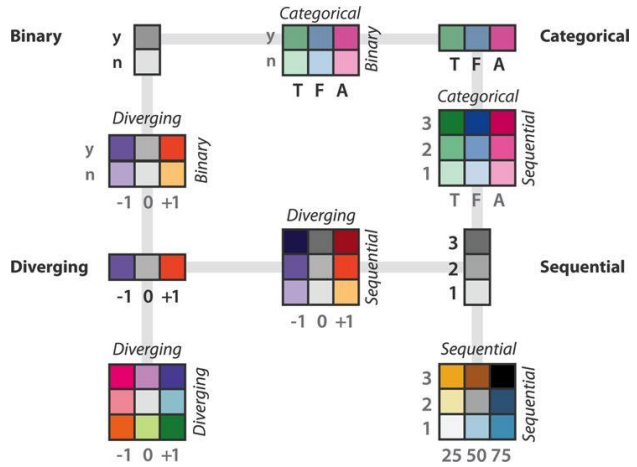
https://www.economist.com/graphic-detail/2019/06/01/centrist-liberals-gained-the-most-power-in-the-eu-parliament

Bivariate color maps



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014

Bivariate color maps

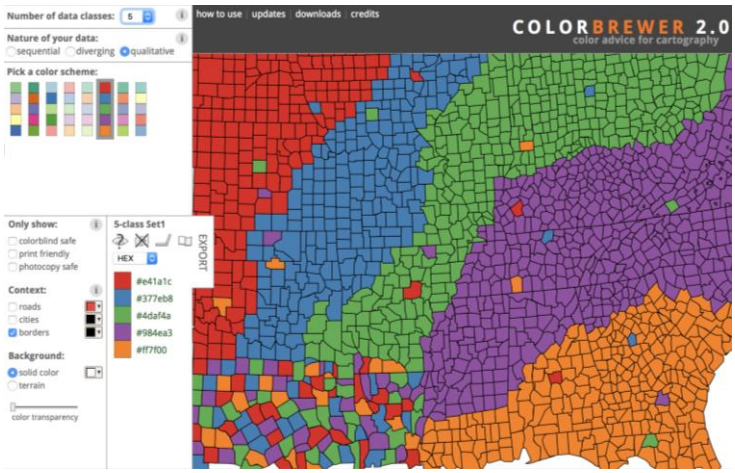


T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 63

Bivariate color map example

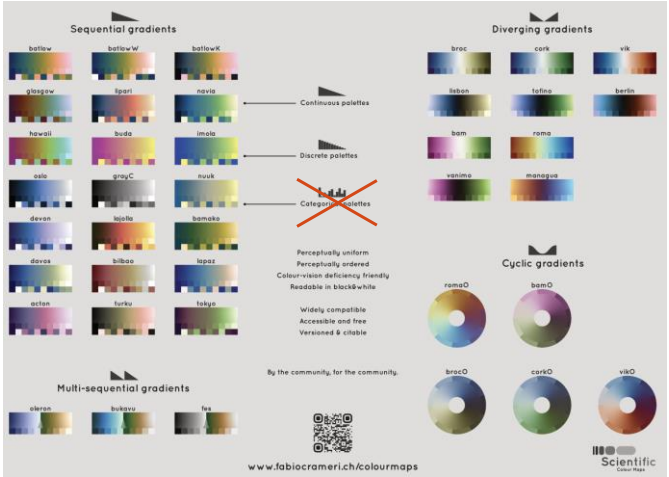
https://github.com/VictimOfMaths/Maps/blob/master/SunvsRain.png 64

Existing color maps



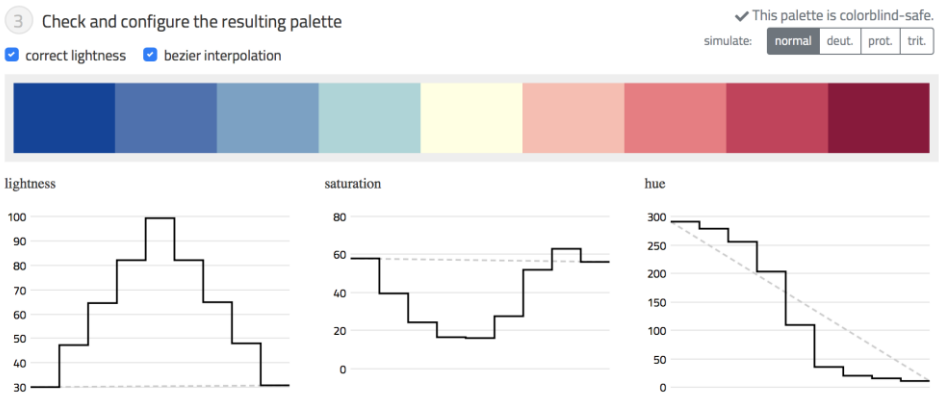
http://colorbrewer2.org

Existing color maps



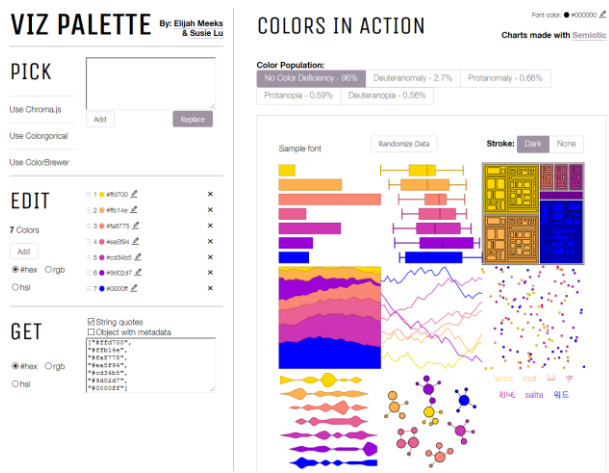
https://www.fabiocrameri.ch/colourmaps/

Custom color maps



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

Custom color maps



https://projects.susielu.com/viz-palette

Semantics of color

Green = good

Red = bad

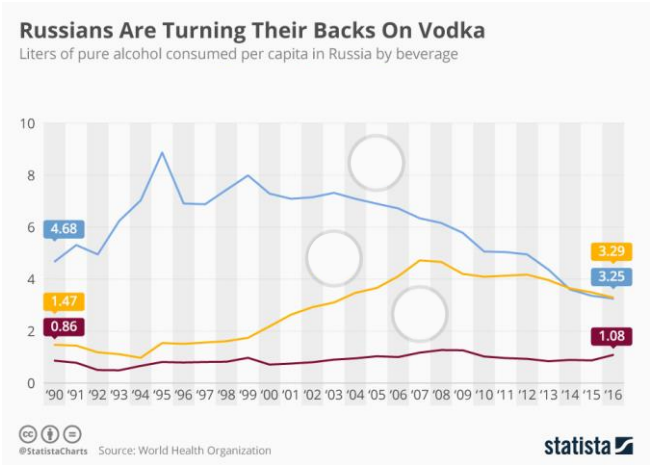
Gray perceived as “no color”

- Missing data
- Uncategorized data
- Non-emphasized data

Very powerful when used appropriately

69

Semantics of color



https://www.statista.com/chart/15918/liters-of-pure-alcohol-consumed-per-capita-in-russia/

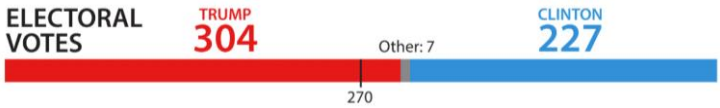
70

Semantics of color

Use color consistently

Example from US politics

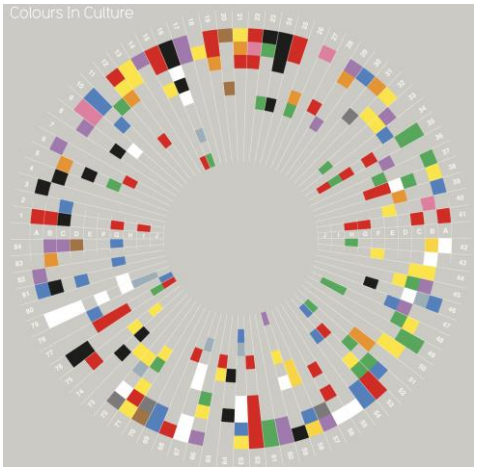
- Republicans = red
- Democrats = blue



71

Semantics of color

Meaning changes depending on culture



https://informationisbeautiful.net/visualizations/colours-in-cultures/

72

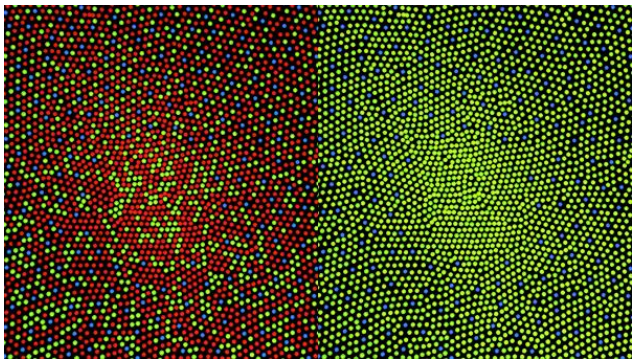
Semantics of color

Floor of a children's hospital

73

Color blindness

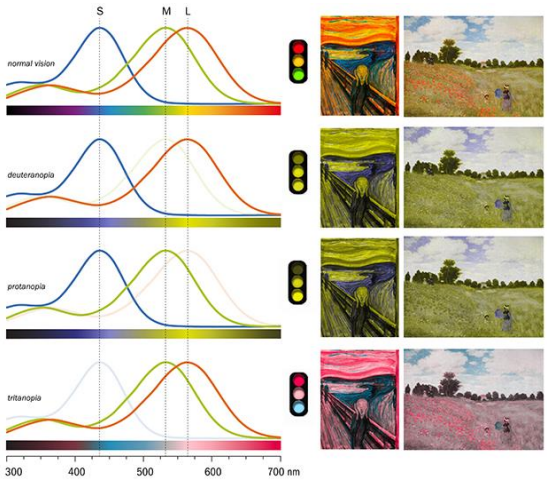
Red-green color blindness affects up to 8% of males and 0.5% of females of Northern European descent



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

74

Color blindness



Normal vision

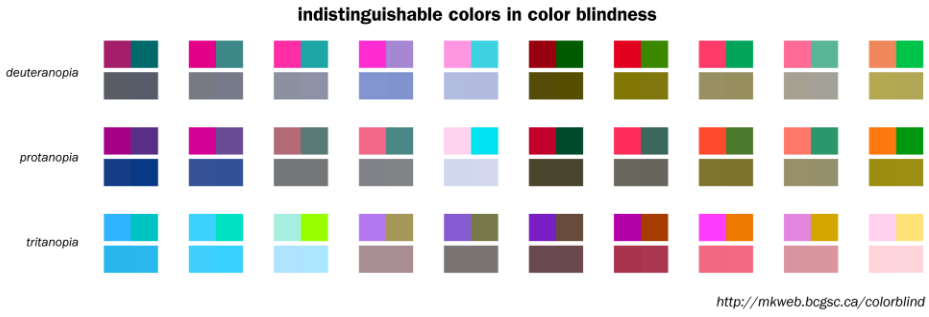
Deuteranopia

Protanopia

Eritanopia

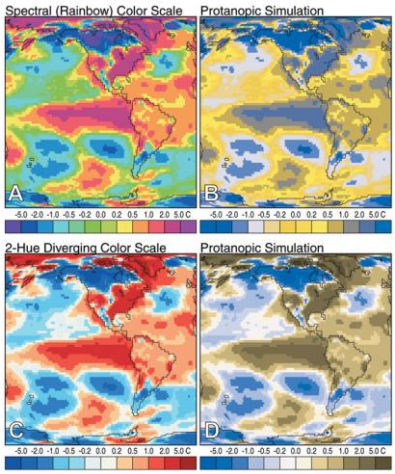
http://mkweb.bcgsc.ca/colorblind/ 75

Color blindness



http://mkweb.bcgsc.ca/colorblind/ 76

Color blindness



https://visual.ly/blog/rainbow-color-scales/ 77

Color blindness

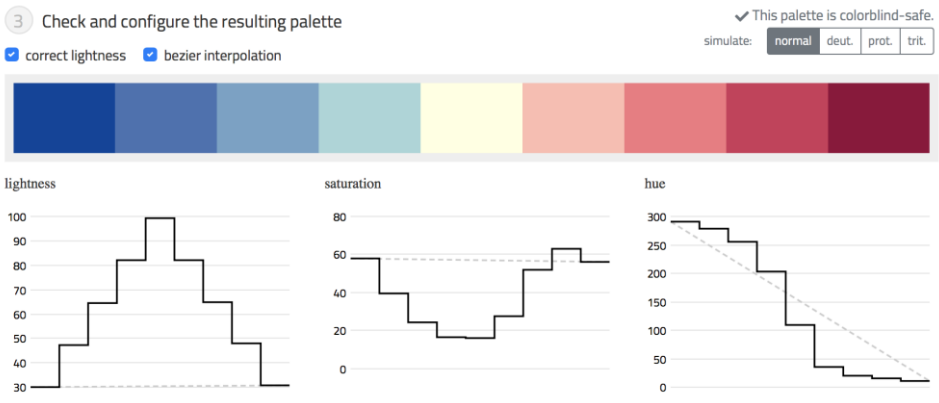
Color	Color name	RGB (1–255)	CMYK (%)	P	D
	Black	0, 0, 0	0, 0, 0, 100		
	Orange	230, 159, 0	0, 50, 100, 0		
	Sky blue	86, 180, 233	80, 0, 0, 0		
	Bluish green	0, 158, 115	97, 0, 75, 0		
	Yellow	240, 228, 66	10, 5, 90, 0		
	Blue	0, 114, 178	100, 50, 0, 0		
	Vermillion	213, 94, 0	0, 80, 100, 0		
	Reddish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

http://mkweb.bcgsc.ca/colorblind/ 78

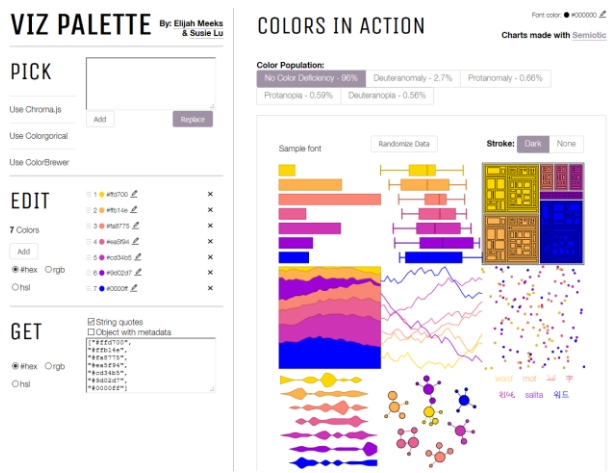
Color blindness – use tools to check



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

79

Color blindness – use tools to check



https://projects.susielu.com/viz-palette

80

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

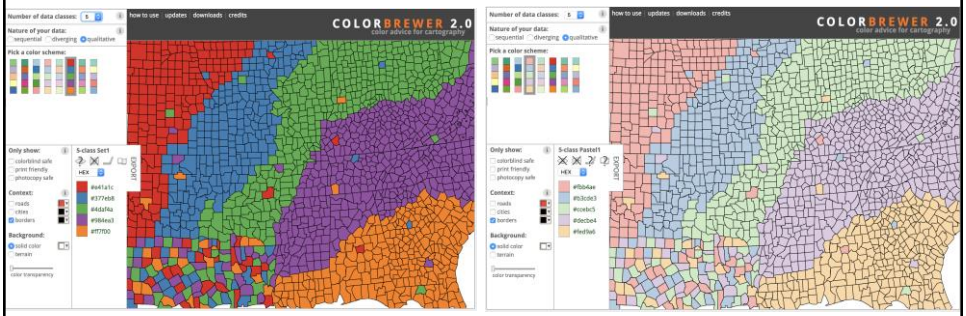
81

Importance of size

Small size hurts discriminability

Small area ➔ high saturation

Large area ➔ low saturation



http://colorbrewer2.org

82

Relative perception

Our color perception is not absolute, but relative

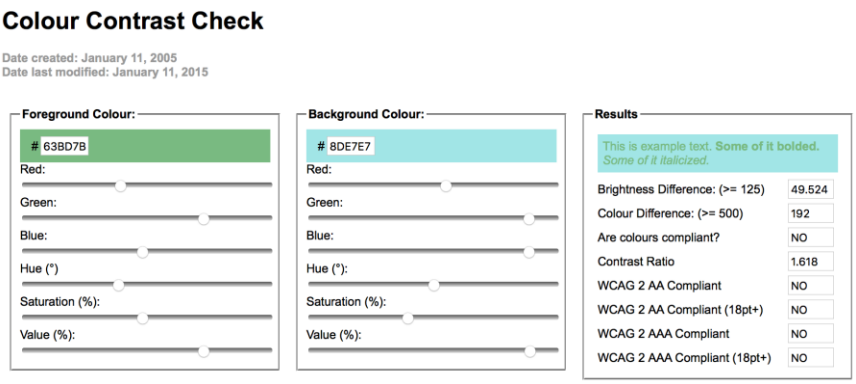
- Importance of contrast
- Importance of background
- Importance of surrounding color

Importance of contrast

Contrast is most easily changed using luminance/lightness

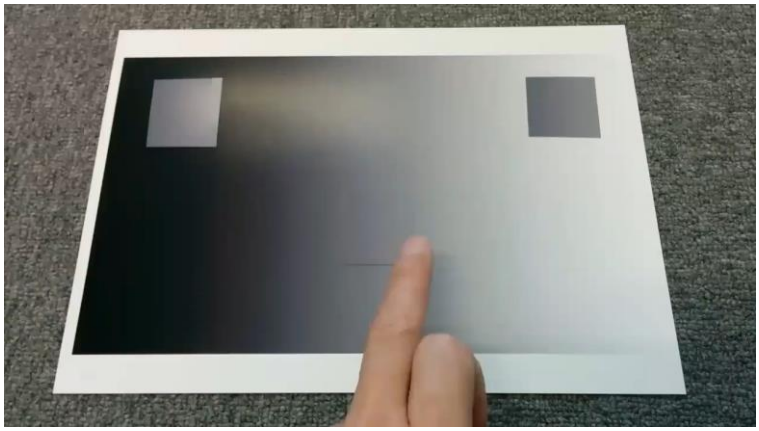
https://blog.datawrapper.de/colors/

Importance of contrast



https://snook.ca/technical/colour_contrast/colour.html#fg=63BD7B,bg=8DE7E7 85

Importance of background

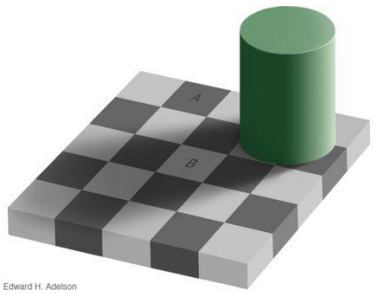


https://twitter.com/AkiyoshiKitaoka/status/1028473566193315841 86

Importance of background

https://www.rtvslo.si/zdravje/novi-koronavirus/svetovalna-skupina-priporoca-tretji-odmerek-za-starejse-od-70-let-in-kronicne-bolnike/592726

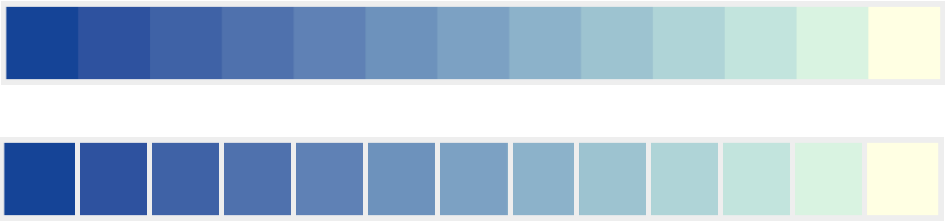
Importance of surrounding color



Edward H. Adelson

Importance of surrounding color

Mach bands



89

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

http://www.psy.ritsumei.ac.jp/~akitaoka/strawberries-color-constancy2017e.pdf

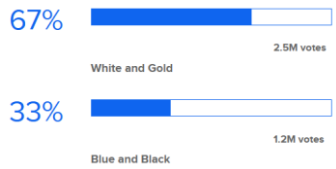
90

Importance of surrounding color

"The dress"

What colors are this dress?

- White and gold
- Blue and black

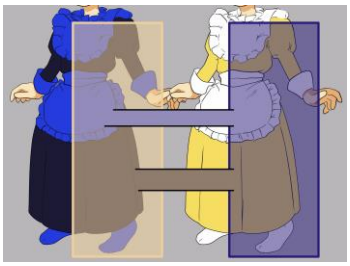


https://www.buzzfeed.com/catesish/help-am-i-going-insane-its-definitely-blue#subbuzz-quiz-poll-results-5103755

91

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

92

Importance of surrounding color

"The dress"

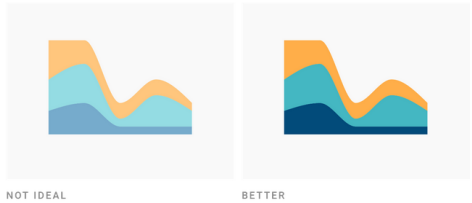
The rabbit-duck illusion

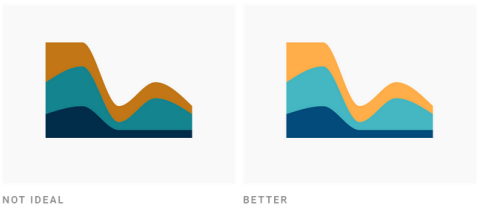
https://en.wikipedia.org/wiki/The_dress
https://en.wikipedia.org/wiki/Rabbit%E2%80%93duck_illusion

93

Choosing colors

Use the right amount of contrast to the background



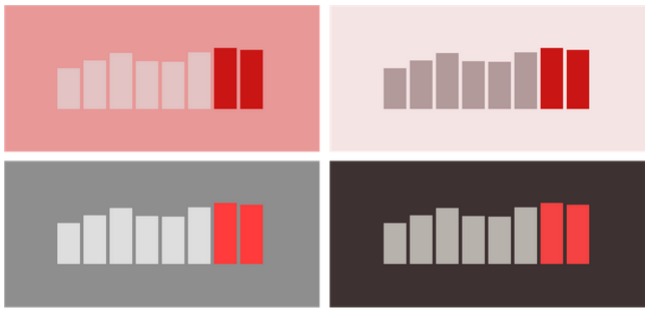


https://blog.datawrapper.de/beautifulcolors/

94

Choosing colors

Background should not be too saturated

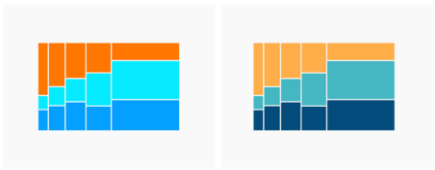


NOT IDEAL BETTER

https://blog.datawrapper.de/beautifulcolors/ 95

Choosing colors

Avoid pure and highly saturated colors



NOT IDEAL BETTER

NOT IDEAL BETTER NOT IDEAL BETTER

https://blog.datawrapper.de/beautifulcolors/ 96

Color use summary

Use color sparingly

Use color consistently

Be thoughtful of the tone that color conveys

- Enforce emotions
- Consider culture

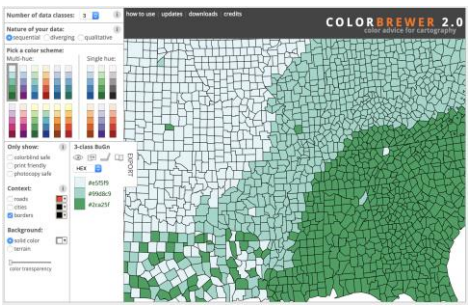
Design with colorblind in mind

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

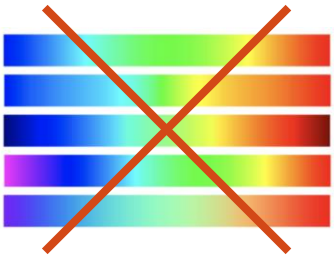
http://colorbrewer2.org 97

Color use summary

Colorbrewer is your friend!



Stay away from the rainbow!



http://colorbrewer2.org 98