Data Visualization

VISUAL PERCEPTION (2)

Tea Tušar, Data Science and Scientific Computing

Color

Color

Motivation

Color perception

Color specification

Color use

3

Motivation

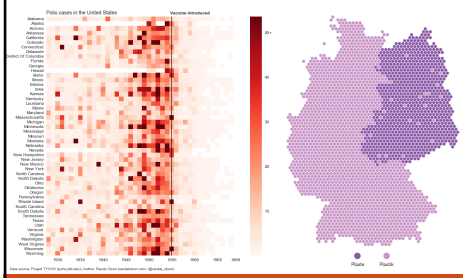
4

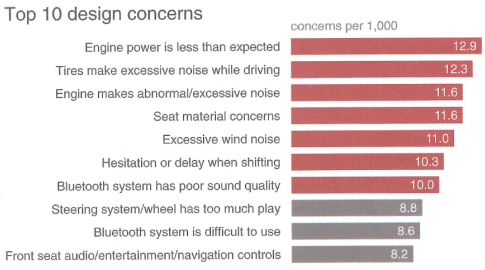
Motivation

Color is a very powerful visual channel

Often used to

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



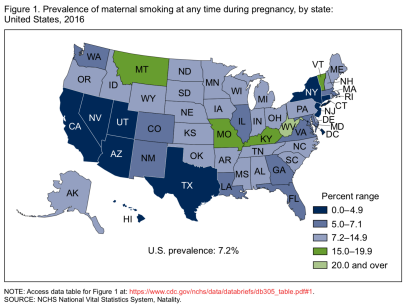


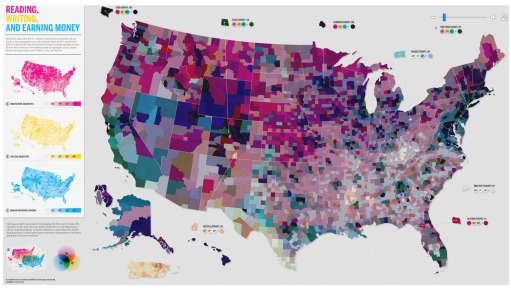
5

Color (mis)use

Above all, do no harm

Edward Tufte





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Color perception

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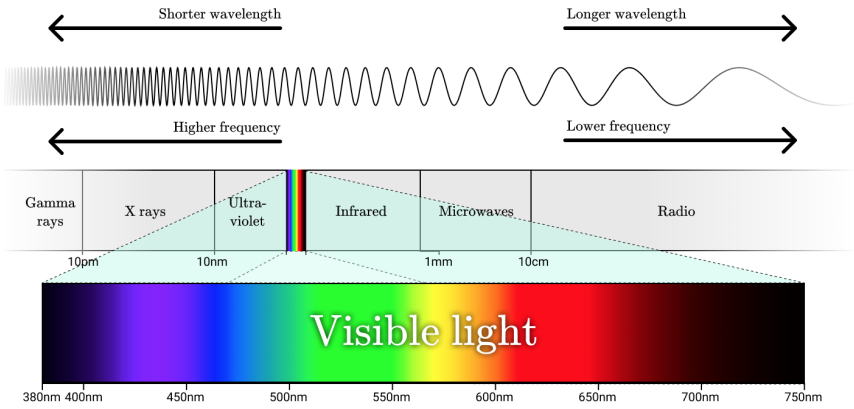
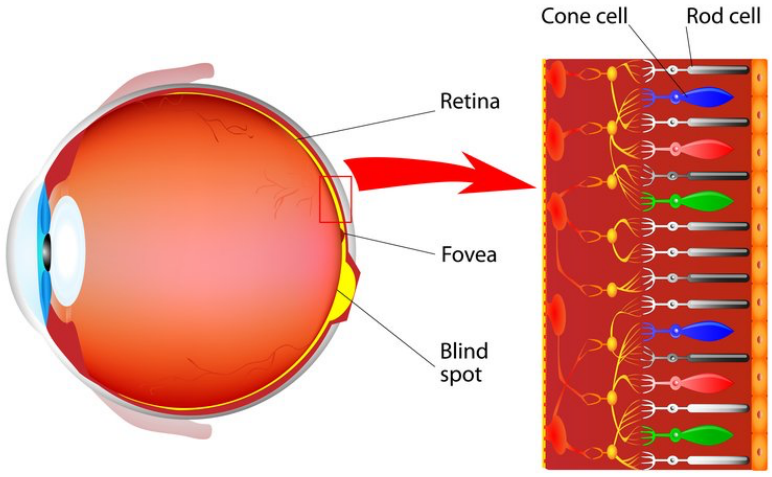
Light



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

8

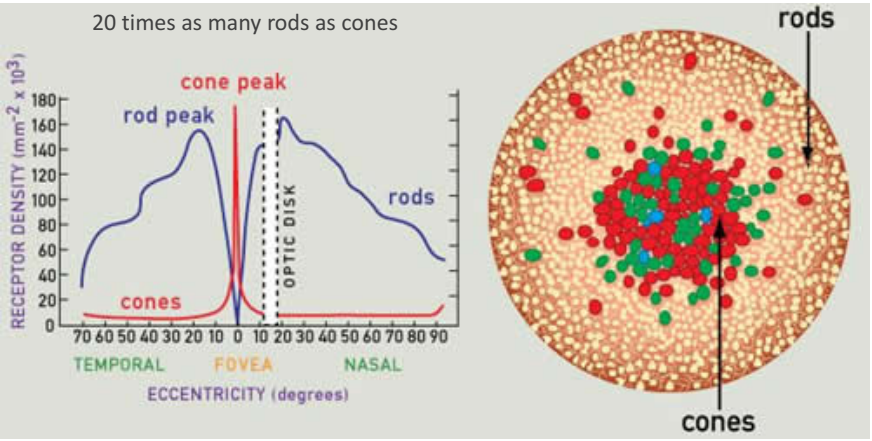
The human eye



https://www.webrn-maculardegeneration.com/rods-and-cones.html 9

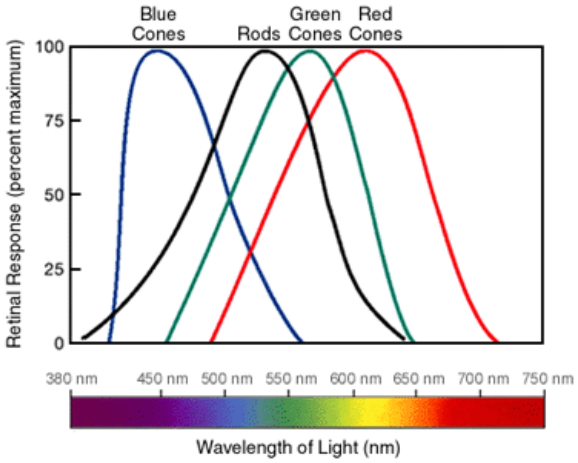
Rods and cones

20 times as many rods as cones



http://www.webexhibits.org/causesofcolor/1G.html 10

Sensitivity of rods and cones



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

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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

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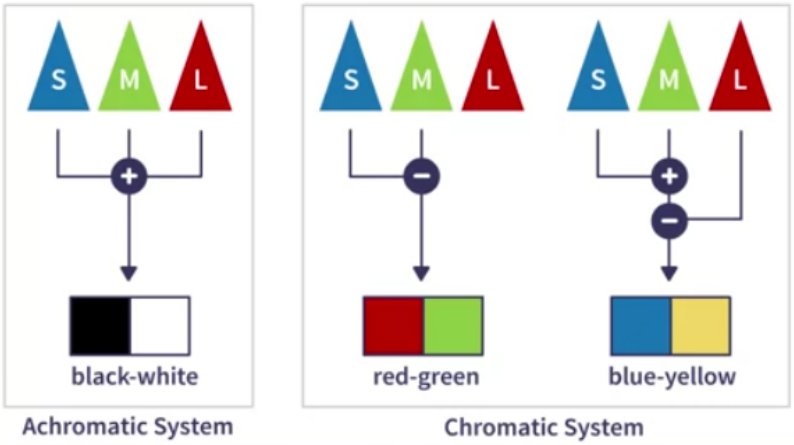
Color opponent process theory



https://www.coursera.org/learn/information-visualization-applied-perception 13

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

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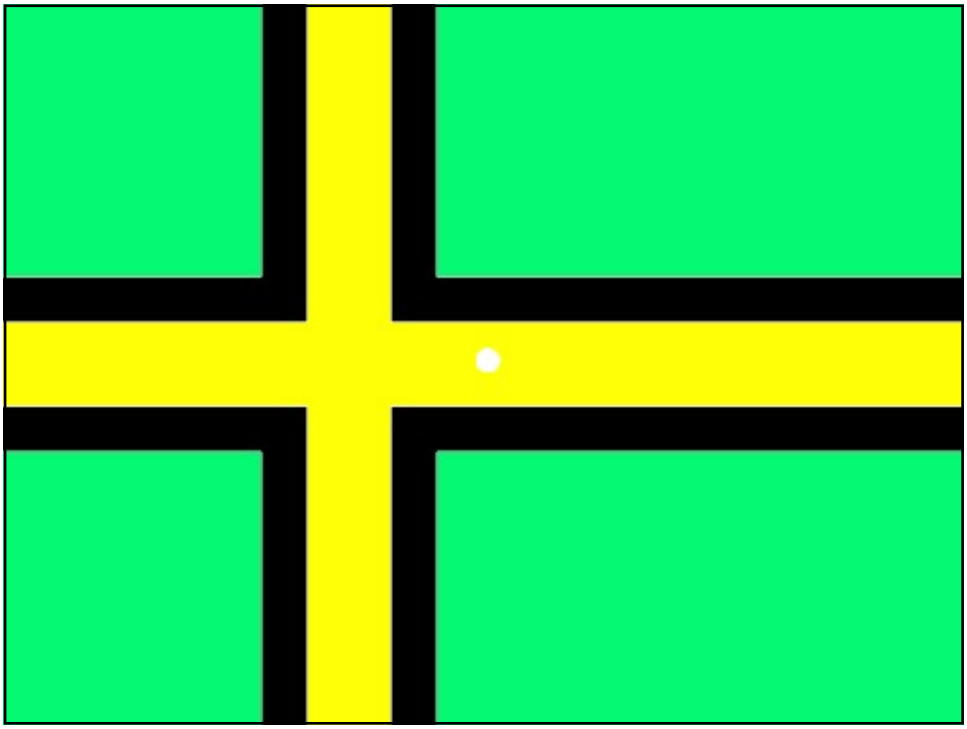

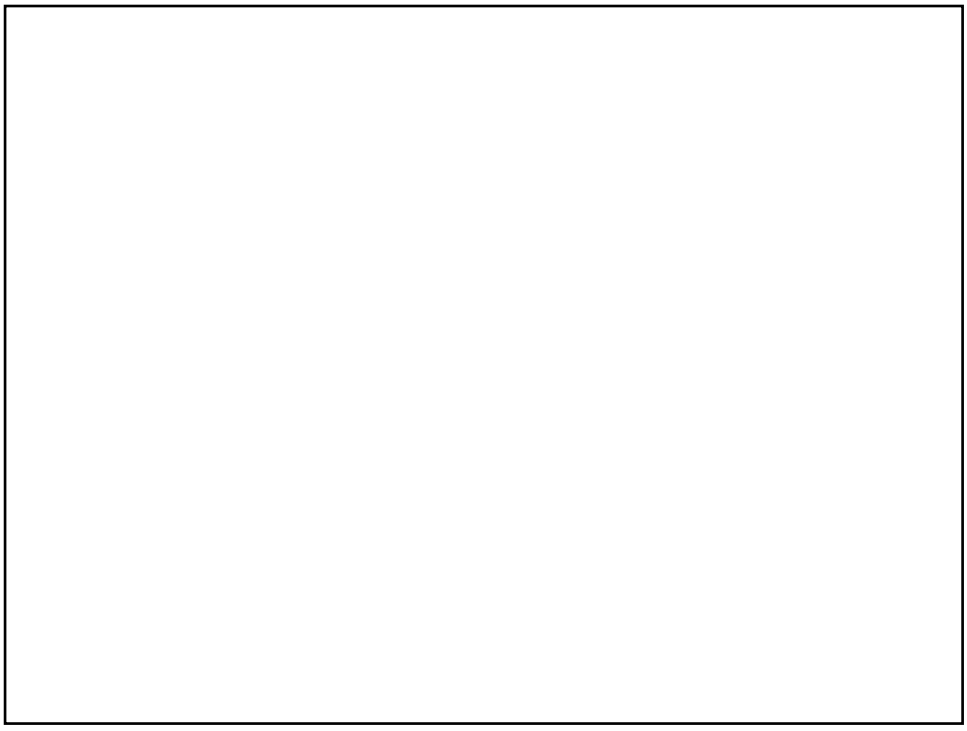

Color opponent process theory

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

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Color perception summary

Human eye

- Fovea
- 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

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Color specification

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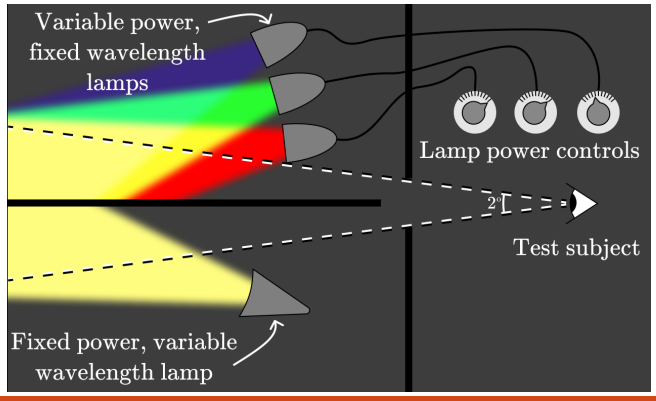
Color specification

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



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

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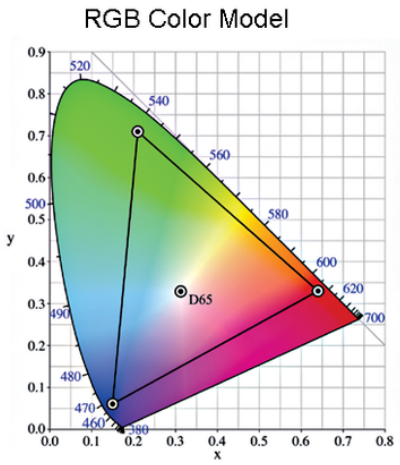
Color spaces

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

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Properties of color spaces

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

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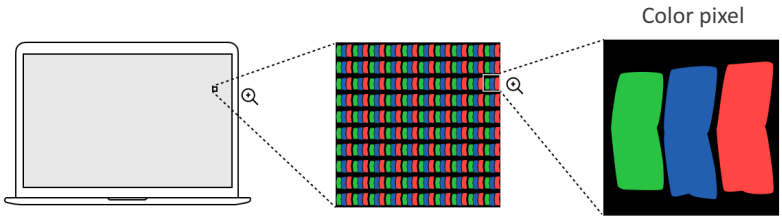
RGB

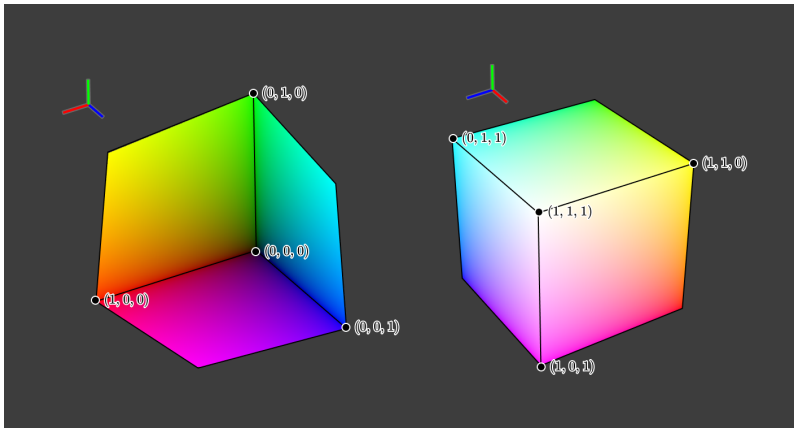
- R = red
- G = green
- B = blue

Commonly used in digital devices



http://jamie-wong.com/post/color/ 23

RGB



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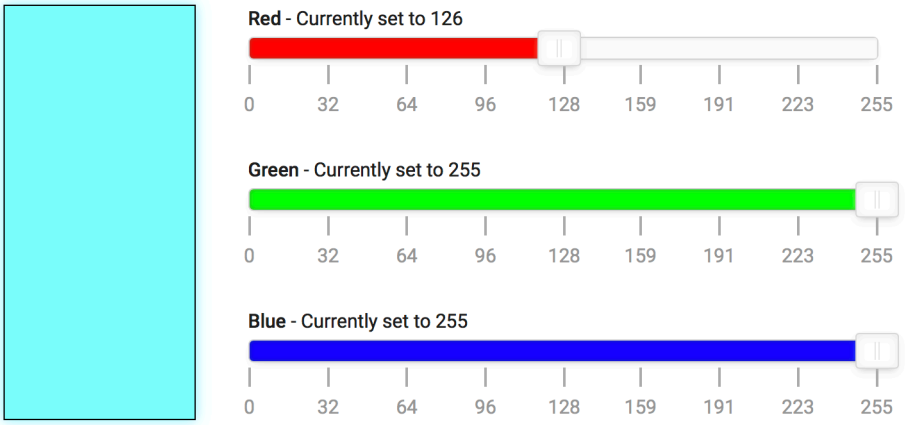
RGB



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

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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

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Properties of color spaces

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

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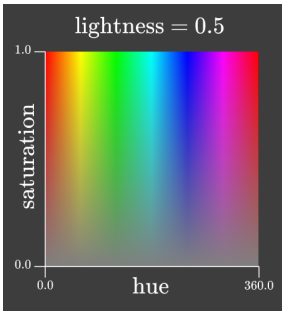
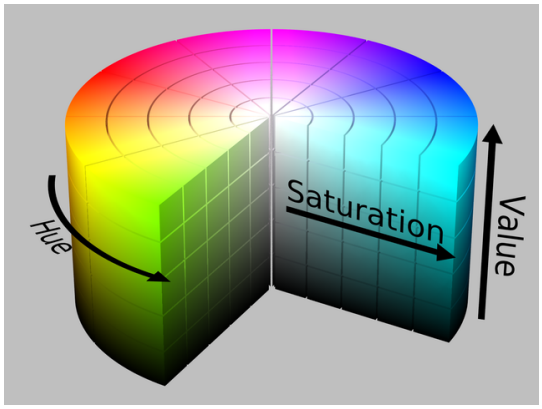
HSL / HSV

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





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

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HSL / HSV

http://hslpicker.com

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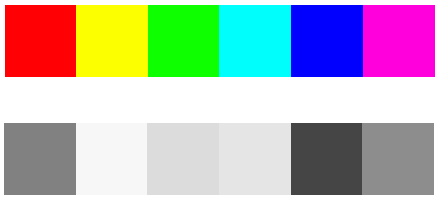
HSL / HSV



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Properties of color spaces

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

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CIE Lab

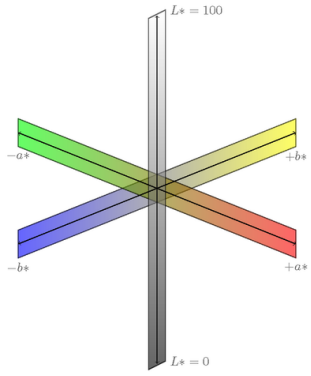
CIE (International Commission on Illumination)

Specified according to the opponent process theory

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

Designed to be perceptually linear

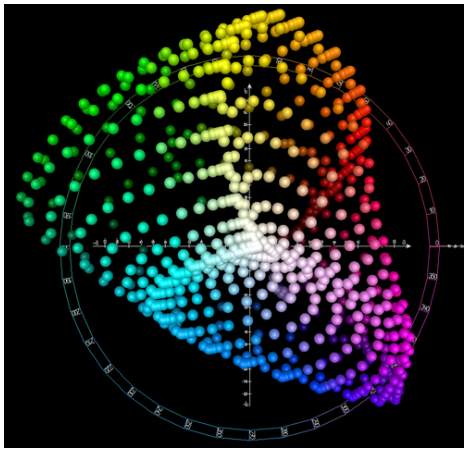
A nonlinear transformation of color wavelengths



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

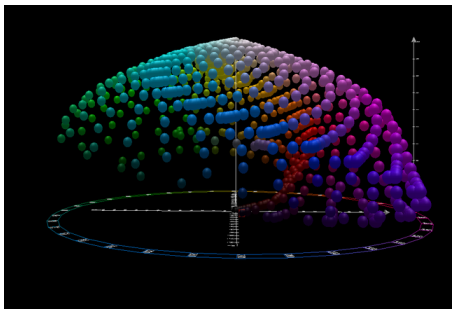
32

CIE Lab



Top view

Front view



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

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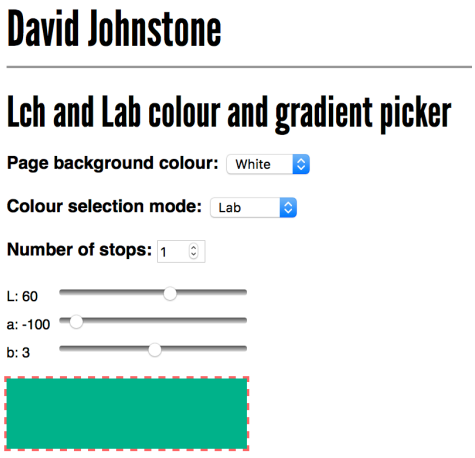
CIE Lab



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

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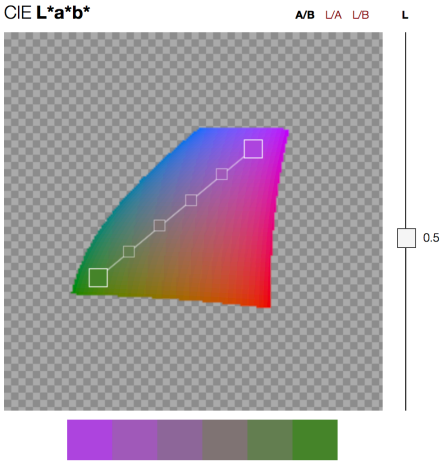
CIE Lab



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

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Properties of color spaces

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

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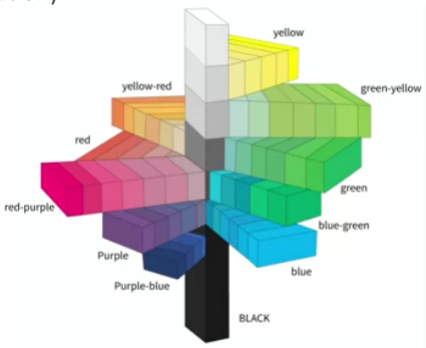
CIE LCh / HCL

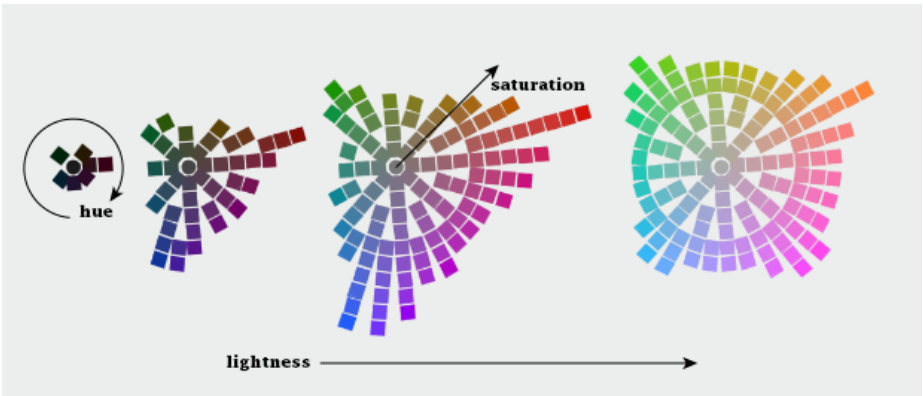
Transformation of CIE Lab to cylindrical coordinates

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



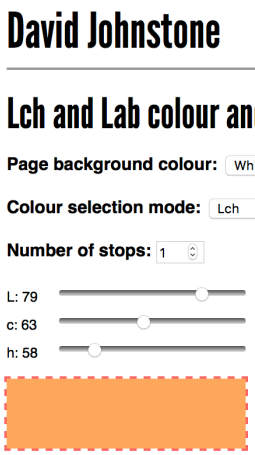
https://www.coursera.org/learn/information-visualization-applied-perception 37

CIE LCh / HCL



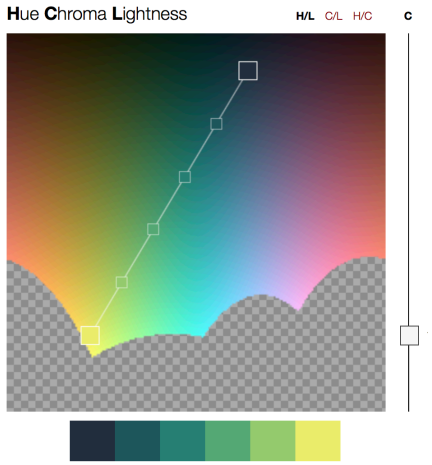
https://earthobservatory.nasa.gov/blogs/elegantfigures/2013/08/ 38

CIE LCh / HCL



http://davidjohnstone.net/pages/lch-lab-colour-gradient-picker 39

CIE LCh / HCL



https://www.vis4.net/labs/colorvis/embed.html?m=hcl&gradients=6 40

Color specification summary

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

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Color use

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Color use

Color maps

Semantics of color

Color blindness

Importance of size

Importance of contrast

Importance of background

Importance of surrounding color

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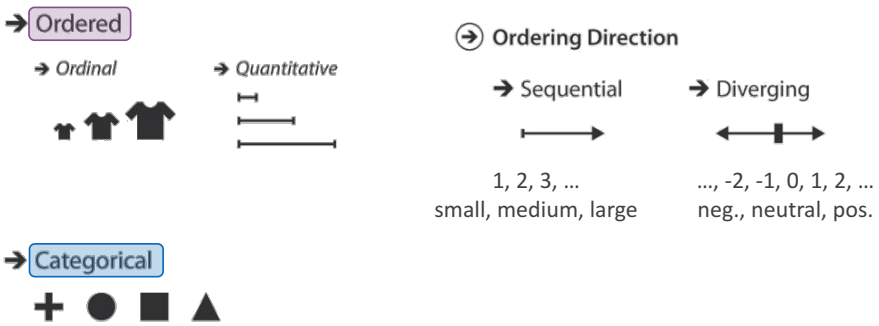
Data attributes



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

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Color maps

Sequential color maps

Diverging color maps

Categorical color maps

Bivariate color maps

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Sequential color maps

Desired properties

- Perceived differences correspond to value differences
- High discriminability

Single hue 

Multi-hue 

http://colorbrewer2.org

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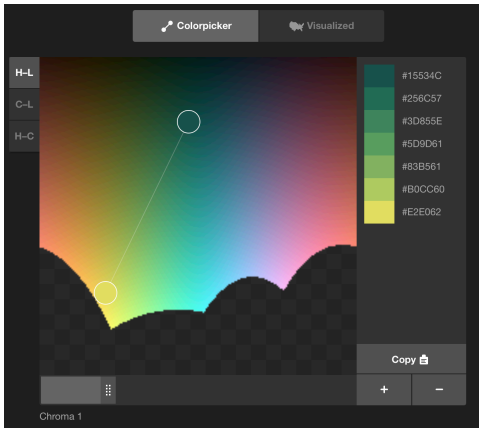
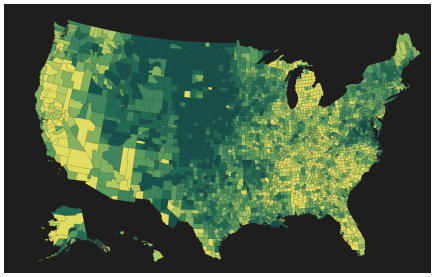
Sequential color maps



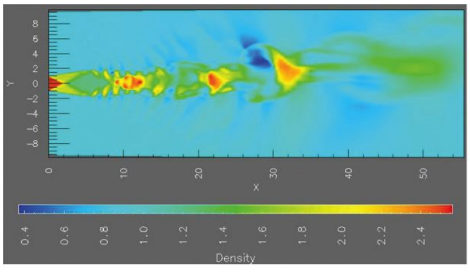


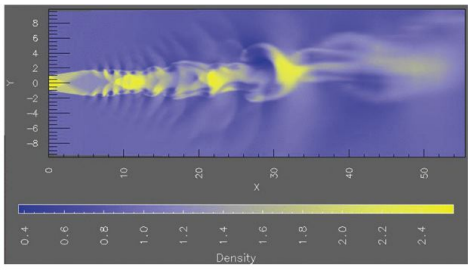
http://tristen.ca/hcl-picker/ 47

Sequential color maps

Do not use the rainbow map!

- Hue (that has no perceptual order) is used to indicate order
- The scale is not perceptually linear
- [Advantage: Colors can be easily named]





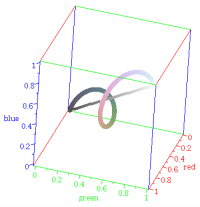
T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 48

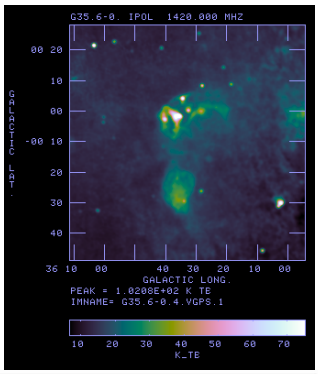
Sequential color maps

Cubehelix

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

A color map generator





https://www.mrao.cam.ac.uk/~dag/CUBEHELIX/ 49

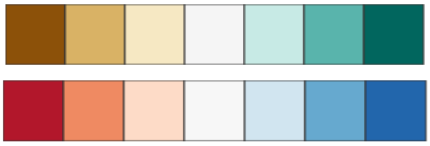
Diverging color maps

Encode two properties at the same time

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

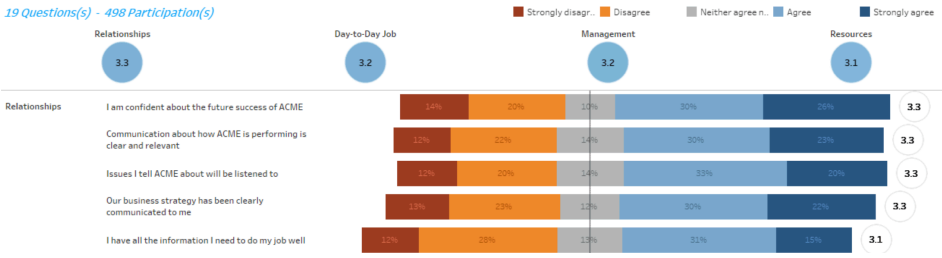
Desired properties

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



http://colorbrewer2.org 50

Diverging color maps



https://linpack-for-tableau.com/tableau-dashboard/survey-dashboard/ 51

Categorical color maps

Desired properties

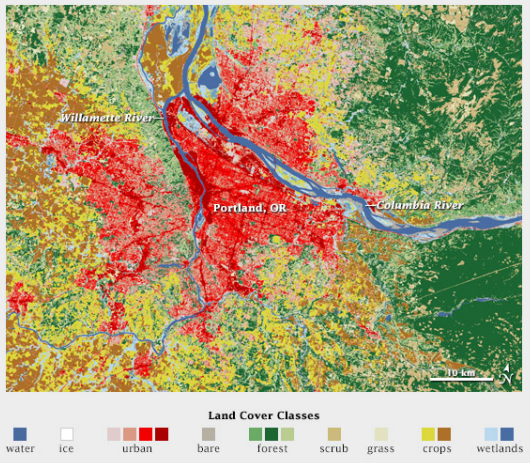
- Uniform saliency (nothing stands out)
- High discriminability

Use colors that can be named

Do not use too many different colors

http://colorbrewer2.org 52

Categorical color maps



https://earthobservatory.nasa.gov/blogs/elegantfigures/2013/08/ 53

Univariate color maps

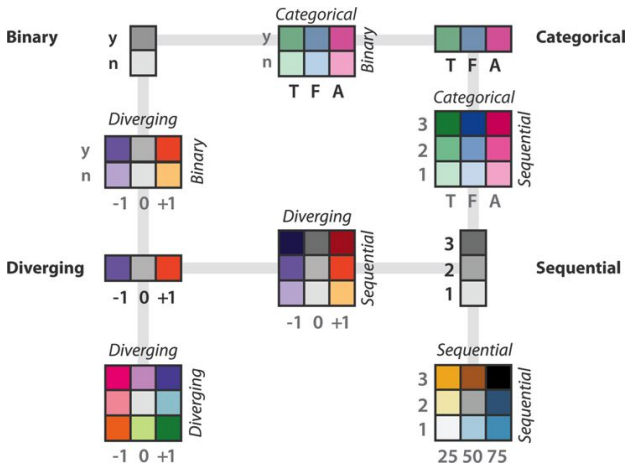
Sequential color maps

Diverging color maps

Categorical color maps

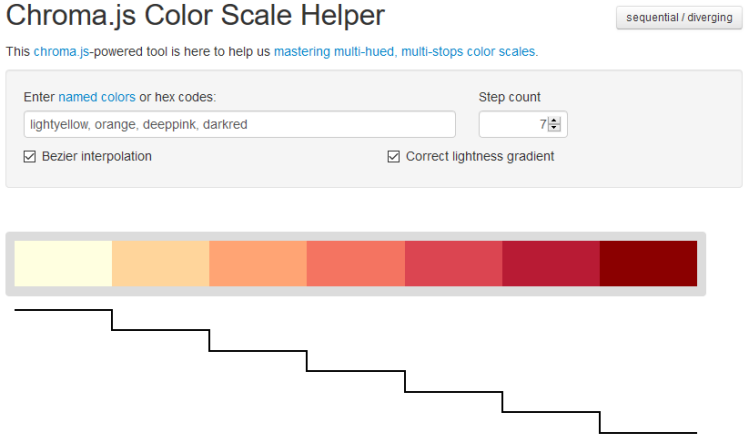
http://colorbrewer2.org 54

Bivariate color maps



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 55

Create your own color map



https://gka.github.io/palettes/ 56

Semantics of color

Green = good

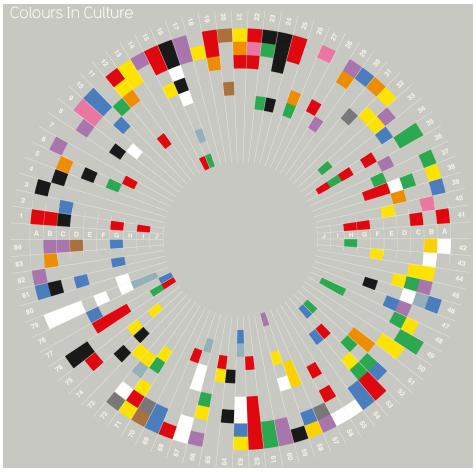
Red = bad

Very powerful when used appropriately

Meaning changes depending on culture

Gray perceived as "no color"

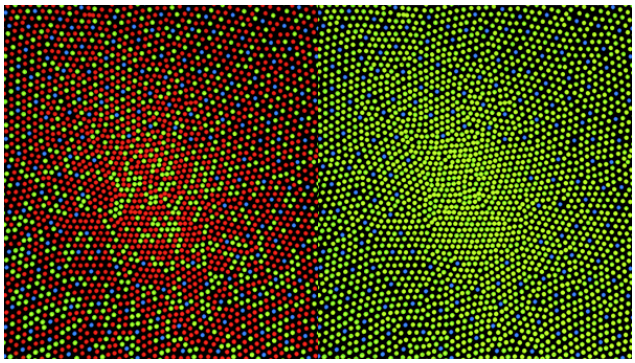
- Missing data
- Uncategorized data
- Non-emphasized data



https://informationisbeautiful.net/visualizations/colours-in-cultures/ 57

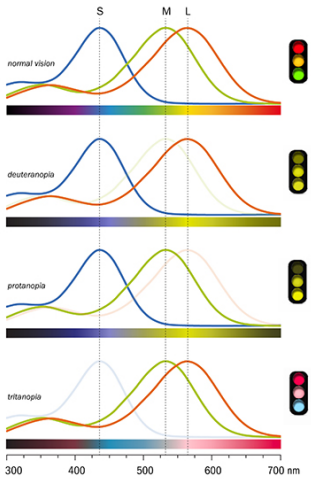
Color blindness

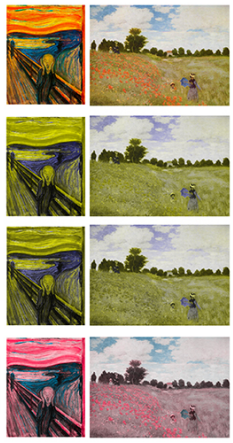
Red-green color blindness affects up to 8% of males and 0.5% of females of Northern European descent



https://en.wikipedia.org/wiki/Color_blindness 58

Color blindness





Normal vision

Deuteranopia

Protanopia

Eritanopia

http://mkweb.bcgsc.ca/colorblind/ 59

Color blindness

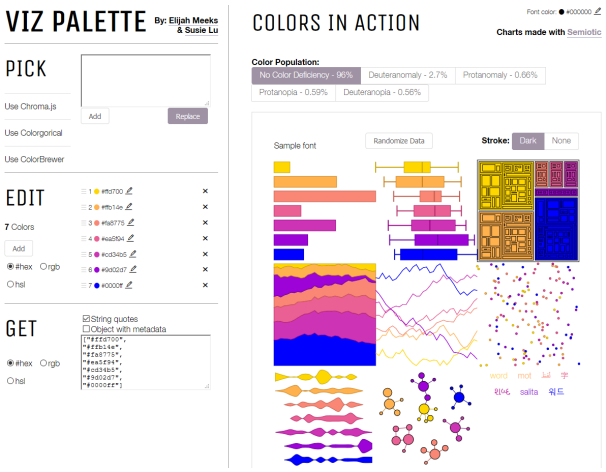
Color	Color name	RGB (1–255)	CMYK (%)	P	D
	Black	0, 0, 0	0, 0, 0, 100		
	Orange	230, 159, 0	0, 50, 100, 0		
	Sky blue	86, 180, 233	80, 0, 0, 0		
	Bluish green	0, 158, 115	97, 0, 75, 0		
	Yellow	240, 228, 66	10, 5, 90, 0		
	Blue	0, 114, 178	100, 50, 0, 0		
	Vermillion	213, 94, 0	0, 80, 100, 0		
	Reddish 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/ 60

Color blindness



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

Color blindness

Use colorblind safe palettes

Blue/orange and blue/red normally safe

Consider variations in color intensity

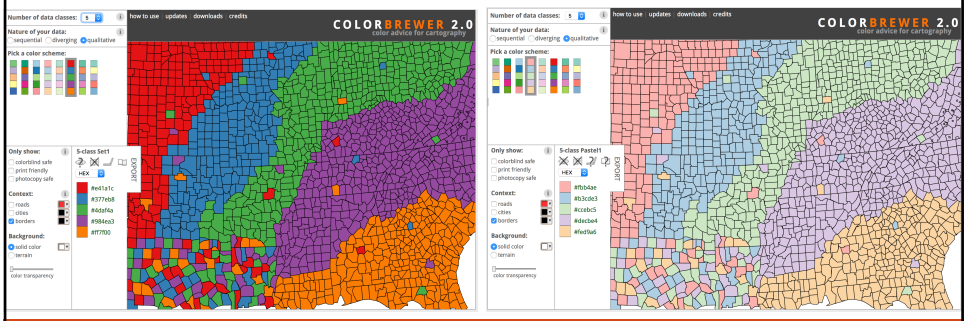
Test design with color blindness simulators

Importance of size

Small size hurts discriminability

Small area ➡ high saturation

Large area ➡ low saturation



http://colorbrewer2.org

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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

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

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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.*

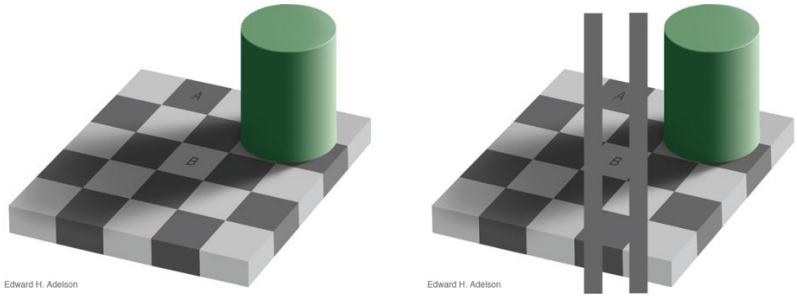
Brightness Difference: (>= 125)	49.524
Colour Difference: (>= 500)	192
Are colours compliant?	NO
Contrast Ratio	1.618
WCAG 2 AA Compliant	NO
WCAG 2 AA Compliant (18pt+)	NO
WCAG 2 AAA Compliant	NO
WCAG 2 AAA Compliant (18pt+)	NO

https://snook.ca/technical/colour_contrast/colour.html#fg=63BD7B,bg=8DE7E7 65

Importance of background

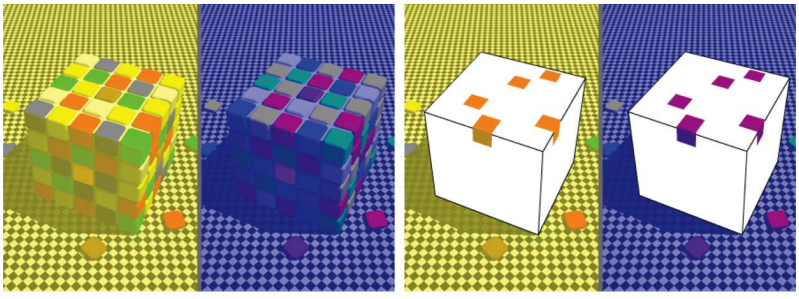
https://www.washingtonpost.com/news/wonk/wp/2015/02/27/12-fascinating-optical-illusions-show-how-color-can-trick-the-eye/?utm_term=.259e58ecc28b 66

Importance of surrounding color



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 67

Importance of surrounding color



T. Munzner. *Visualization Analysis & Design*. CRC Press, Boca Raton, 2014 68

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 the effect of contrast, background color and surrounding color

Color use summary

Colorbrewer is your friend!