Information Visualization
Color

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Lecture 12/13, 13 & 25 Feb 2020

https://www.students.cs.ubc.ca/~cs-436v/20Jan/

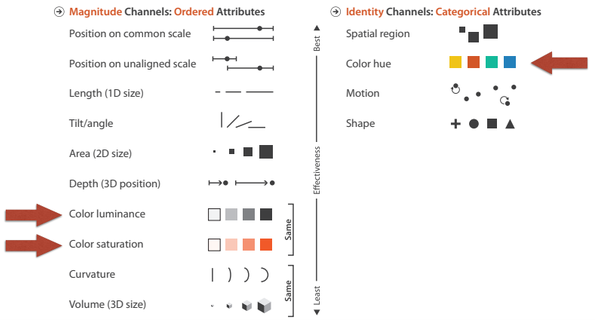
Upcoming

- Foundations 4: out Feb 13, due Feb 26 (right after reading week)
- Programming 3: out Feb 13, due Mar 4 (1 week after reading week)
- D3 videos/readings week 6
  - Color and Size legends with D3.js [30 min]
  - Scatter Plot with Menus [46 min]
  - Circles on a Map [42 min]
  - Line Charts with Multiple Lines [42 min]
- Quiz 6, due by Fri Feb 14, 8am
- Team formation, due by Fri Feb 14 11:59pm

Outline

- Color in vision theory
- Color channels in vis
  - Decomposition
    - HSL
    - Other color spaces
  - Color deficiency
  - Interaction with others
- Practical advice
  - Colormaps
  - Tools and programming libraries

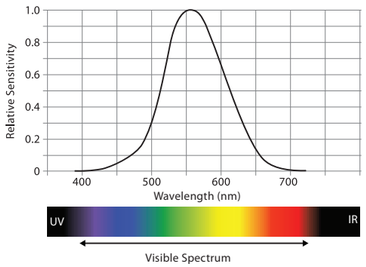
Channels: the big picture



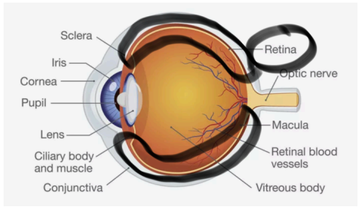
Color in Vision Theory

Light

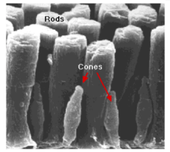
If I tell you the wavelength, can you tell what color you are seeing?

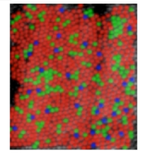


Eye anatomy



Cone and Rod Cells on Retina



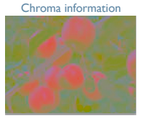


~120 million rods: black vs. white
~5-6 million cones: color

R 63% - G 31% - B 6%

Opponent precess

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

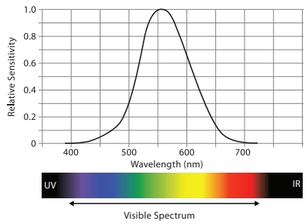


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Light

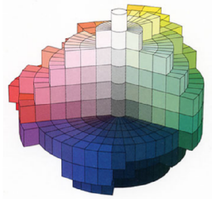
If I tell you the wavelength, can you tell what color you are seeing?

Color != Wavelength



Color Appearance

- Given L, a, b, can we tell what color it is?



CIE LAB color space

Color/Lightness constancy: Illumination conditions

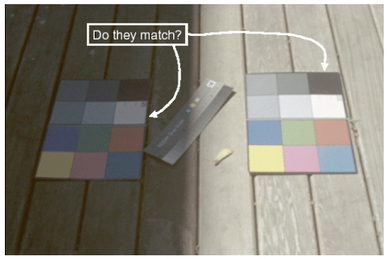


Image courtesy of John McCann

Color/Lightness constancy: Illumination conditions

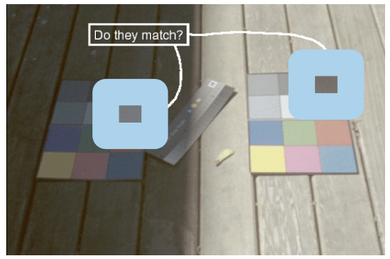
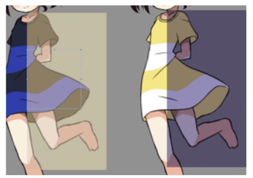


Image courtesy of John McCann

Contrast with background

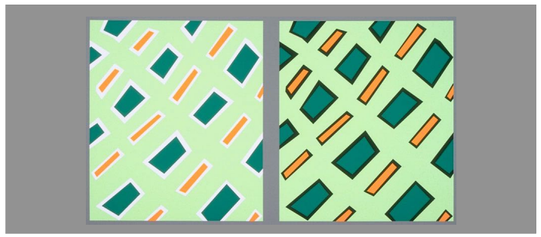
Contrast with background



Black and blue? White and gold?

https://imgur.com/hxJjUQB
https://en.wikipedia.org/wiki/The_dress

Bezold Effect: Outlines matter

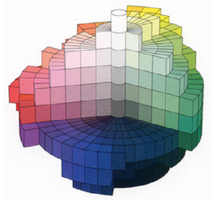


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color Appearance

- Given L, a, b, can we tell what color it is?

- Chromatic adaptation
- Luminance adaptation
- Simultaneous contrast
- Spatial effects
- Viewing angle
- …



Cognition (beyond retina, in brain)

- Given the L, a, b values, the lighting conditions, the surroundings, viewing angle …

- Can you tell me what this color is?
  - Middle part of an apple
  - Bottom part of an apple
  - The branch

Name the colours

https://blog.xkcd.com/2010/05/03/color-survey-results/

Name the colours

http://www.thedoghousediaries.com/1406

Name the colours

https://blog.xkcd.com/2010/05/03/color-survey-results/

Color is just part of vision system

- Does not help perceive
  - Position
  - Shape
  - Motion
  - …

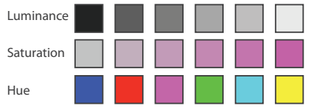
Color Channels in Visualization

Decomposing color

- first rule of color: do not **JUST** talk about color!
  - color is confusing if treated as monolithic

HSL decomposition

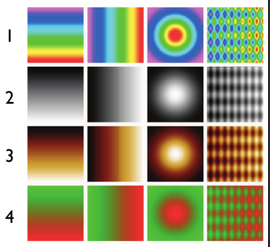
- decompose into three channels
  - ordered can show magnitude
    - **luminance: how bright**
    - **saturation: how colourful**
  - categorical can show identity
    - **hue: what color**



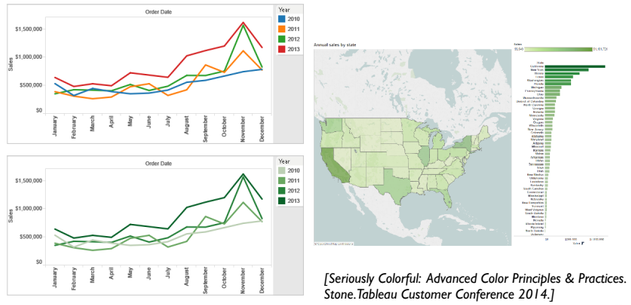
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey: how many discriminable bins can we use?

Quiz: Which color channels?

- Continuous quantitative attribute



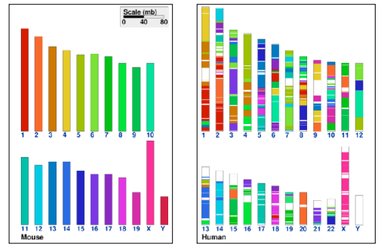
Categorical vs ordered color



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

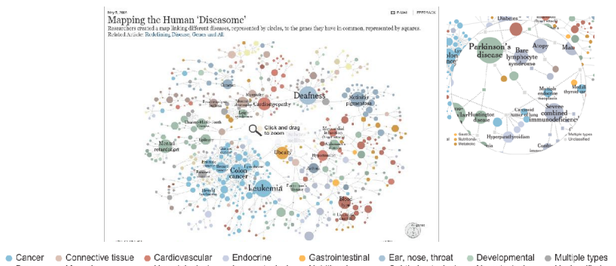
Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights



[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

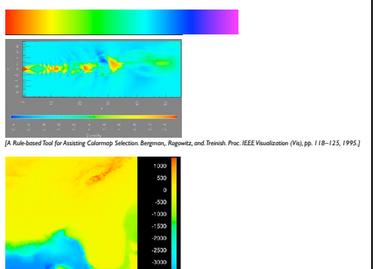
Categorical color: limited number of discriminable bins



https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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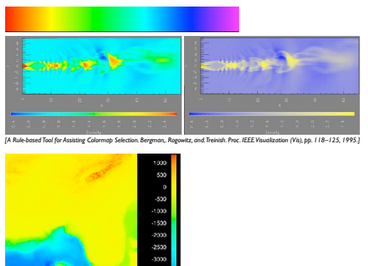
- alternatives
  - large-scale structure: fewer hues



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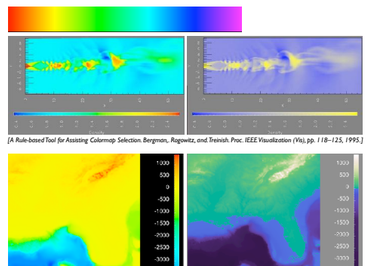
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



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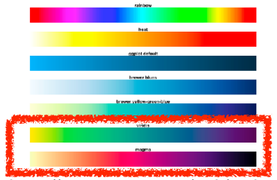
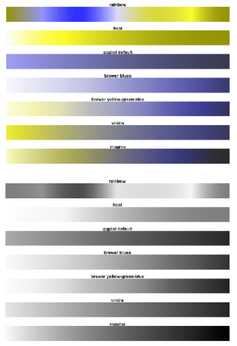
Viridis

- colorful, perceptually uniform, colorblind-safe, monotonically increasing luminance





https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

Ordered color: Rainbow is poor default

- problems
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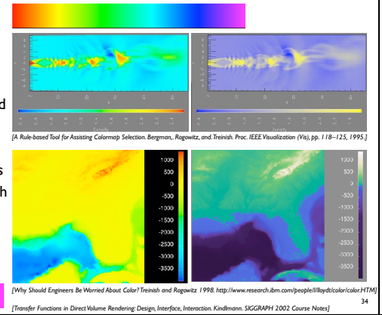
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
  - segmented rainbows for binned or categorical



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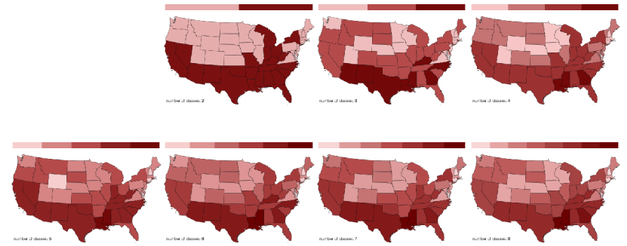
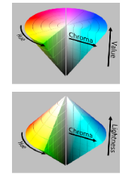
Ordered color: how many bins?



Gregor Aisch

Many color spaces

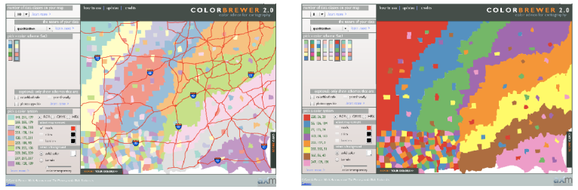
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance or L*
- Luminance, hue, saturation
  - good for encoding
  - but not standard graphics/tools colorspace
- CIE L*a*b*: good for computation
  - L* intuitive: perceptually linear luminance
  - a*b* axes: perceptually linear but nonintuitive
- RGB: good for display hardware
  - poor for encoding



Tools and Libraries in Practice

ColorBrewer

- http://www.colorbrewer2.org
- saturation and area example: size affects salience!
- Limited customization: 2 parameters

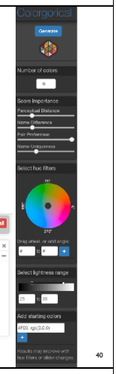


Adobe Color Picker

- https://color.adobe.com/create
- For general design purpose, not particularly for vis

Colorgorical

- http://vrl.cs.brown.edu/color
- Highly customized: #colors, perceptual distance, name uniqueness, hue, lightness range…
- Only targeted at categorical data



Color management in D3

- D3-color
  - https://github.com/d3/d3-color
  - Conversion to/from different color spaces
  - Low-level computations
- D3-scale
  - https://github.com/d3/d3-scale
  - Customize your own color scale using d3.scaleSequential() and d3.scaleOrdinal()
  - Use case: generate color schemes using the web tools mentioned before, then use d3-scale to implement it

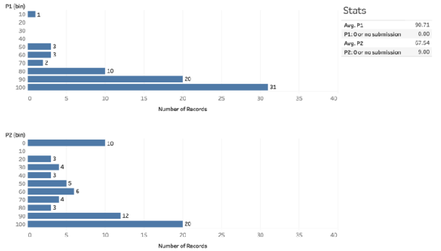
- D3-scale-chromatic:
  - https://github.com/d3/d3-scale-chromatic
  - Implementation of the colormap
  - Lots of good color schemes and scales
  - High-level, ready-to-be-used for most vis
    - Use this for your project

Color 2

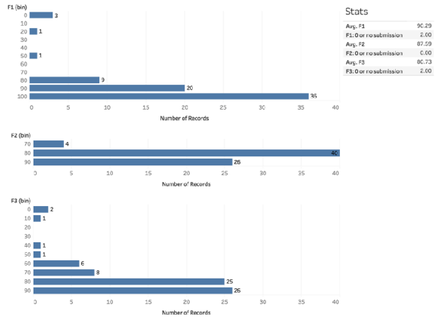
Upcoming

- Foundations 4: due Feb 26
- Programming 3: due Mar 4
- D3 videos/readings week 7
  - Melting and Munging Data [29 min]
  - Map with Selectable Countries [12 min]
  - Hover Selecting a Year on a Line Chart [29 min]
  - *read:* D3 Layouts
- Quiz 7, due by Fri Feb 28, 8am
- Project Milestone 1 (Proposal), due by Fri Mar 6 11:59pm

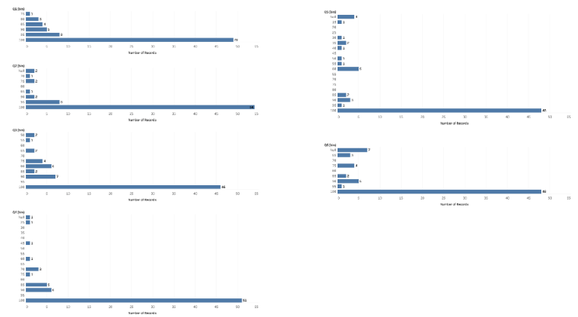
Grades distribution so far: Programming



Grades distribution so far: Foundations



Grade distributions so far: Quizzes



Polls/ announcements

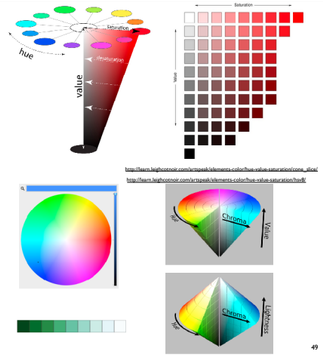
- piazza @188: would you use extra TA office hours?
- grace day granularities
  - grace days are integer not fractional. use full grace day once you're over at all.
- gradescope
  - we'll use it for exam marking
  - email went out for gradescope.ca (**not** gradescope.com)

Reminder: Textbook as additional resource beyond slides

- Visualization Analysis & Design (VAD) textbook as further reading!
  - relevant chapter(s) given at end of each lecture slide deck
  - free to read through UBC library: http://resolve.library.ubc.ca/cgi-bin/catsearch?bid=7678980
- so far
  - Intro: Ch 1
  - Data: Ch 2, Ch 4
  - Tasks: Ch 3
  - Marks and Channels: Ch 5
  - Tables: Ch 7
  - Interactive Views: Ch 10, Ch 11 (except Sec 11.6), Ch 12
  - Maps: Ch 8 (only Sec 8.1-8.3)
  - Color: Ch 10
  - Networks & Trees: Ch 9

Many color spaces

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance or L*
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation

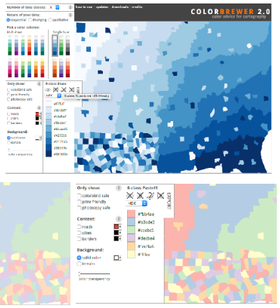


http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/cone_slice/

http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsl/

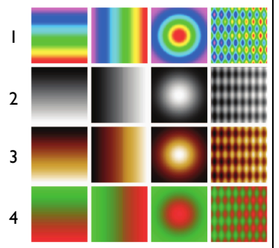
Interaction with other channels: integral/separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large need low saturation
- saturation & luminance:
  - not separable from each other
  - also not separable from transparency
  - 3-4 bins max (if small, separated regions)
  - many bins (with contiguous regions)

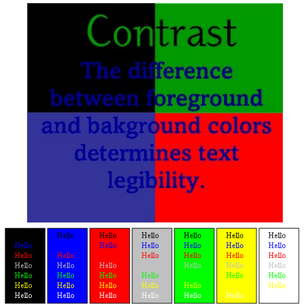


http://colorbrewer2.org/

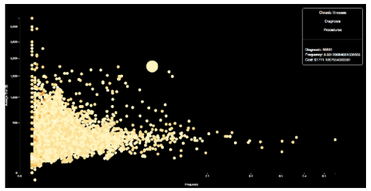
Quiz: Which color channels?



Interaction with the background

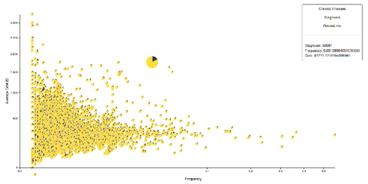


Interaction with the background: tweaking yellow for visibility



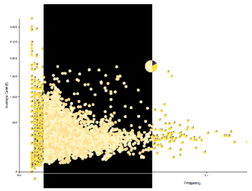
Marks with high luminance on a background with low luminance

Interaction with the background: tweaking yellow for visibility



Marks with medium luminance on a background with high luminance

Interaction with the background: tweaking yellow for visibility

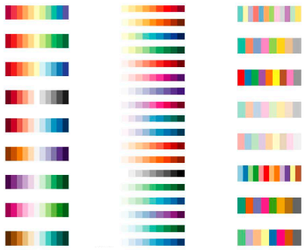


Change luminance of marks depending on background

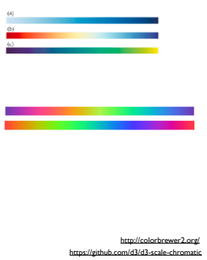
How to use color in visualization

What kinds of color palettes are there?

segmented



continuous



http://colorbrewer2.org/

https://github.com/d3/d3-scale-chromatic

A Study of Colormaps in Network Visualization. Karim et al. Appl. Sci. **2019**, 9, 4228; doi:10.3390/app9204228

Color palettes: univariate

→ Categorical

- categorical
  - aim for maximum distinguishability
  - aka *qualitative*, *nominal*

after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

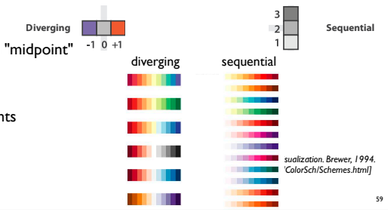
Color palettes: univariate

→ Categorical

→ Ordered

→ *Sequential* → *Diverging*

- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints
- sequential
  - ramp luminance or saturation



sualization. Brewer, 1994. 'ColorSch/Schemes.html]

Color palettes: univariate

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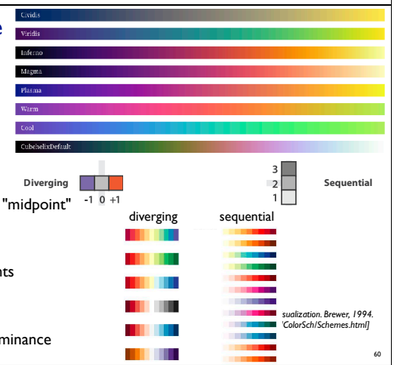
- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints
- sequential
  - ramp luminance or saturation
  - if multi-hue, good to order by luminance



sualization. Brewer, 1994. 'ColorSch/Schemes.html]

Color palettes: univariate

→ Categorical

→ Ordered

→ *Sequential* → *Diverging*

→ Cyclic

cyclic multihue

https://github.com/d3/d3-scale-chromatic

after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

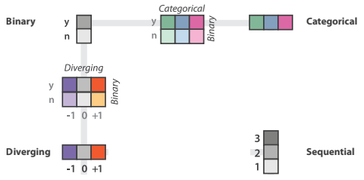
Colormaps: bivariate

→ Categorical

→ Ordered

→ *Sequential* → *Diverging*

→ Bivariate



- bivariate best case
  - binary in one of the directions

d3.schemePaired <>

binary saturation

categorical hue

after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

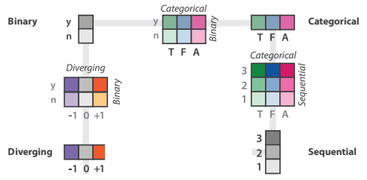
Colormaps: bivariate

→ Categorical

→ Ordered

→ *Sequential* → *Diverging*

→ Bivariate



after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps

→ Categorical

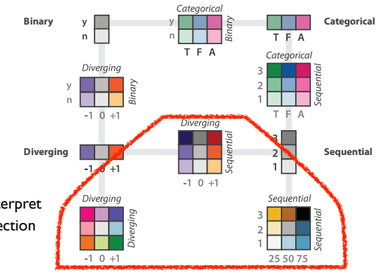
→ Ordered

→ *Sequential* → *Diverging*

→ Bivariate

use with care!

- bivariate can be very difficult to interpret
  - when multiple levels in each direction



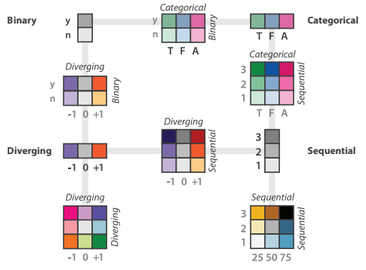
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps

→ Categorical

→ Ordered
- → *Sequential*
- → *Diverging*

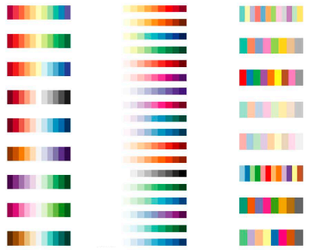
→ Bivariate



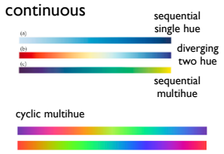
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

What kinds of color palettes are there?

segmented



continuous



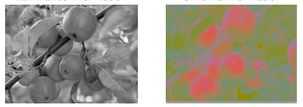
- segmented or continuous?
- diverging or sequential or cyclic?
- single-hue or two-hue or multi-hue?
- perceptually linear?
- ordered by luminance?
- colorblind safe?

https://github.com/d3/d3-scale-chromatic

A Study of Colormaps in Network Visualization. Karim et al. Appl Sci. **2019**, 9, 4228; doi:10.3390/app9204228

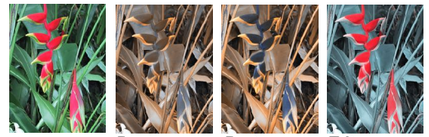
Opponent color and color deficiency

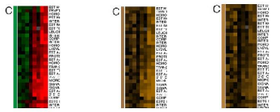
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- "color blind": one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Check with simulator

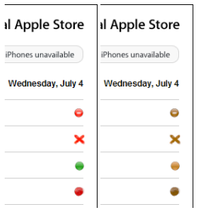


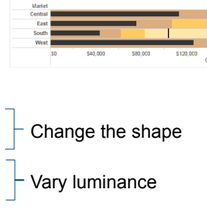


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape





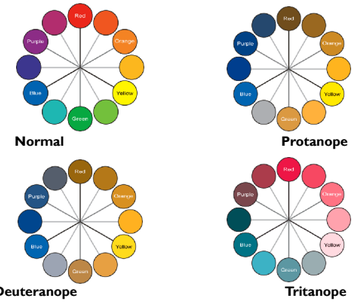
Deuteranope simulation

Change the shape

Vary luminance

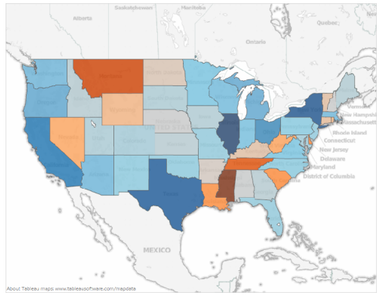
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Blue-Orange is safe



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Credits

- Visualization Analysis and Design (Ch 10)
- Enrico Bertini, NYU Tandon
- Alex Lex & Miriah Meyer, http://dataviscourse.net/
- Jeffrey Heer https://courses.cs.washington.edu/courses/cse512/19sp/