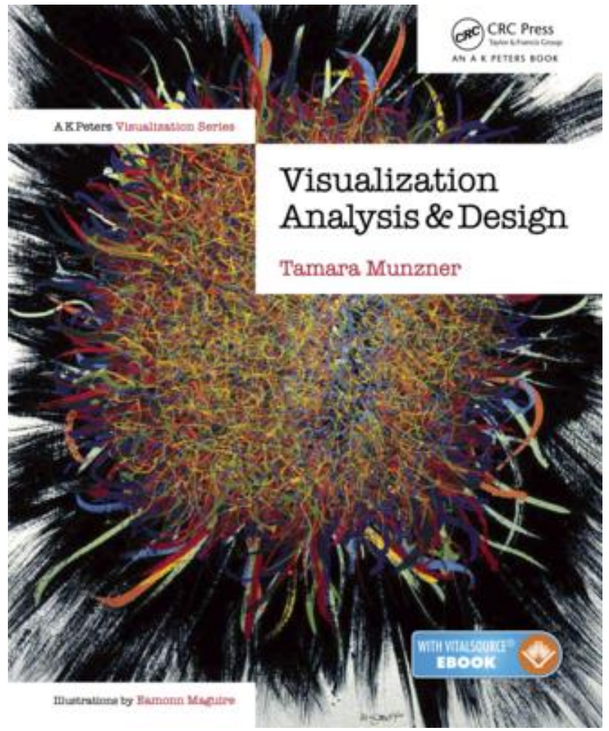
Information Visualization

Color & Interaction

5a color



- Slides refer to https://www.cs.ubc.ca/~tmm/

Color & Interaction

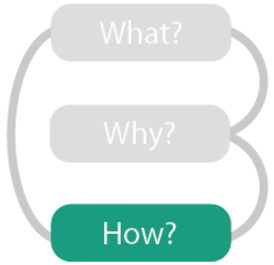
- Map Color (Ch. 10)

- Manipulate: Change, Select, Navigate (Ch. 11)

- Facet: Juxtapose, Partition, Superimpose (Ch. 12)

Map Color

Idiom design choices: Encode



Encode

Arrange

- Express

- Separate

- Order

- Align

- Use

Map

from categorical and ordered attributes

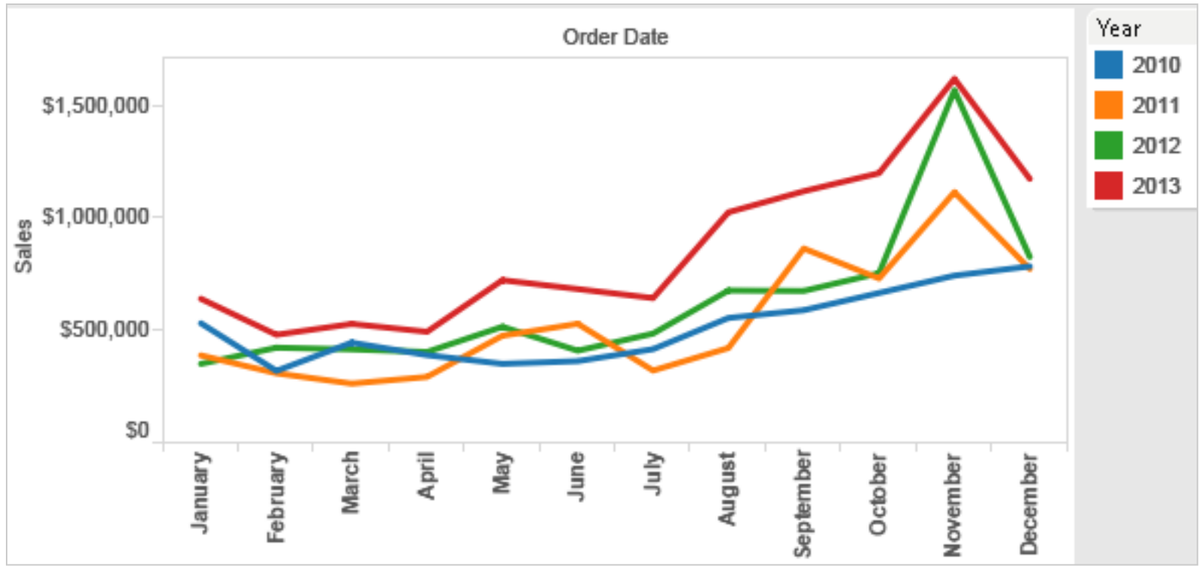
- Color
  - *Hue*
  - *Saturation*
  - *Luminance*

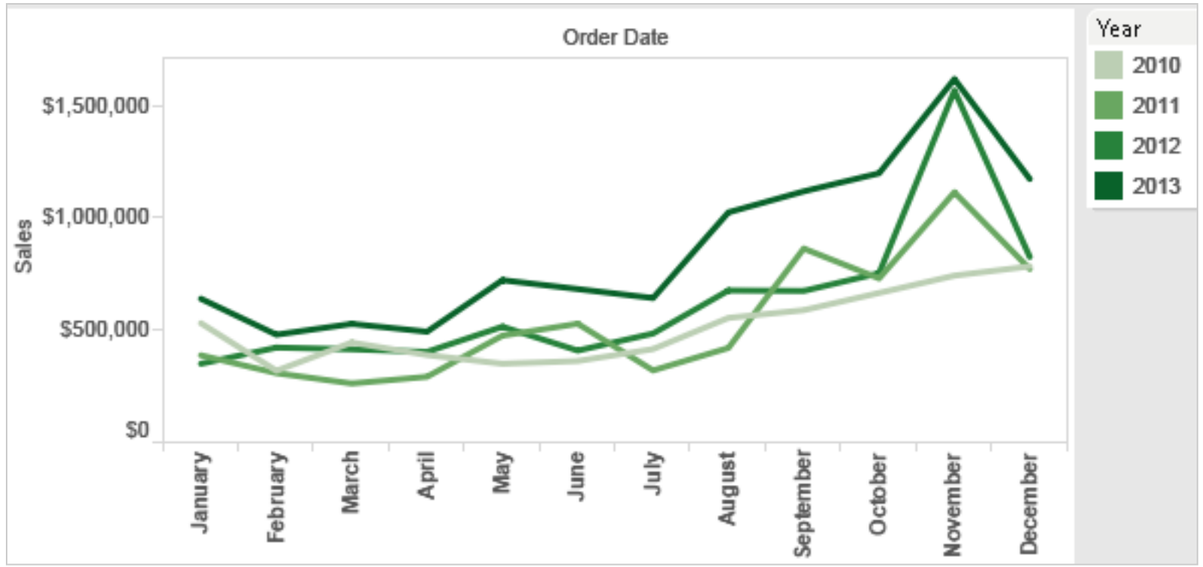
- Size, Angle, Curvature, ...

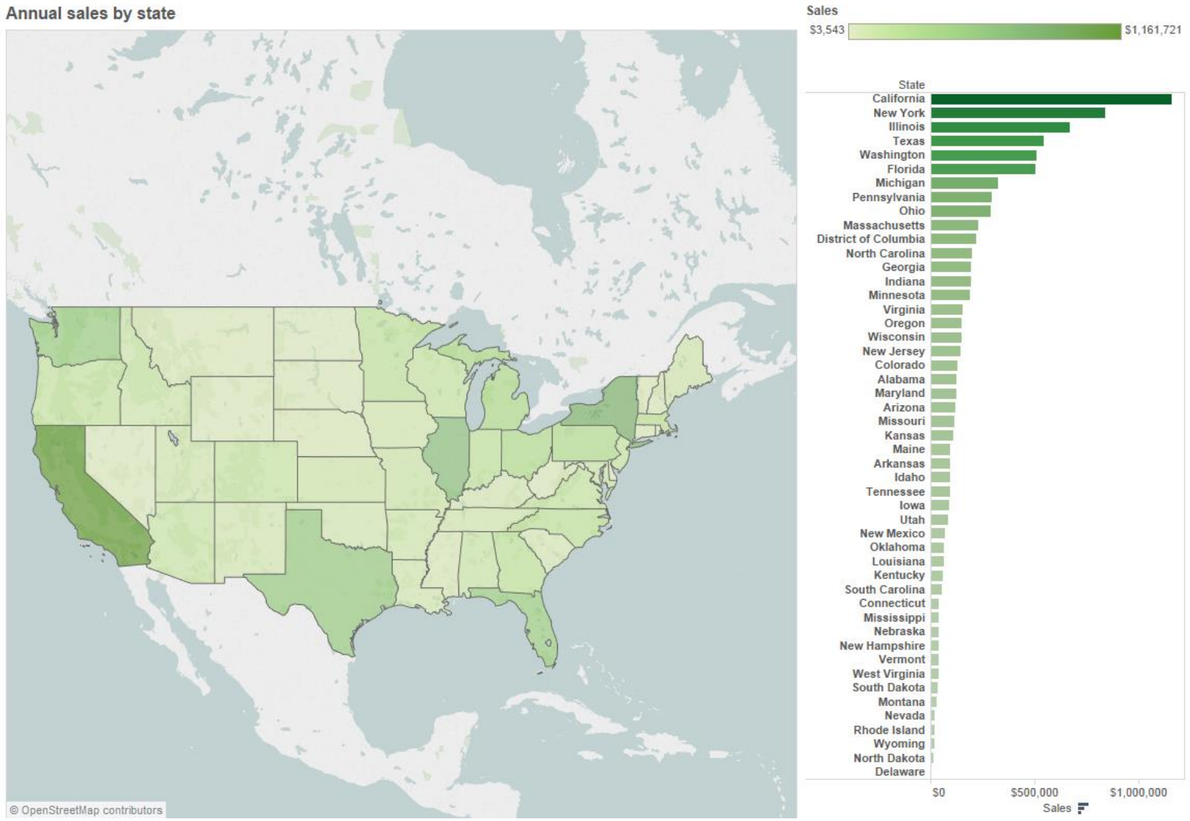
- Shape

- Motion
  Direction, Rate, Frequency, ...

Categorical vs ordered color





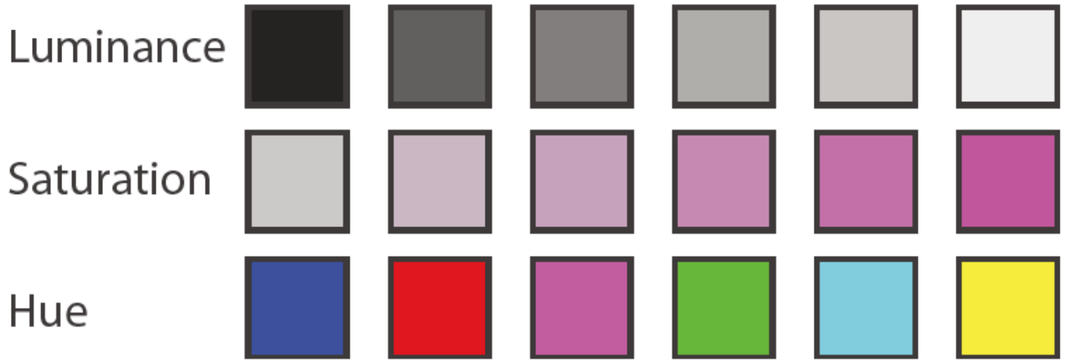


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color: Luminance, saturation, hue

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

- 3 channels
  - identity for categorical
    - hue
  - magnitude for ordered
    - luminance
    - saturation



Channels: Expressiveness types and effectiveness rankings

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Same

Curvature

Volume (3D size)

Same

Identity Channels: Categorical Attributes

Spatial region

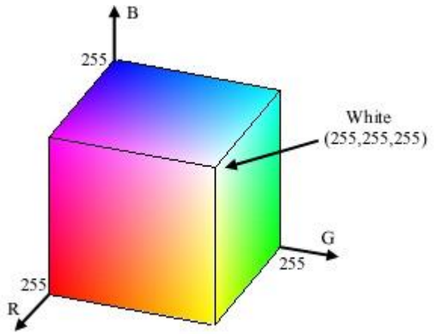
Color hue

Motion

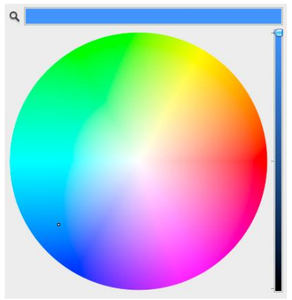
Shape

Color spaces

- RGB: poor for encoding



- HSL: better, but beware
  - lightness ≠ luminance



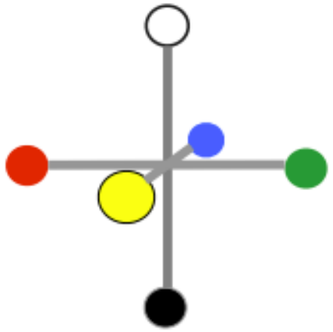
Corners of the RGB color cube

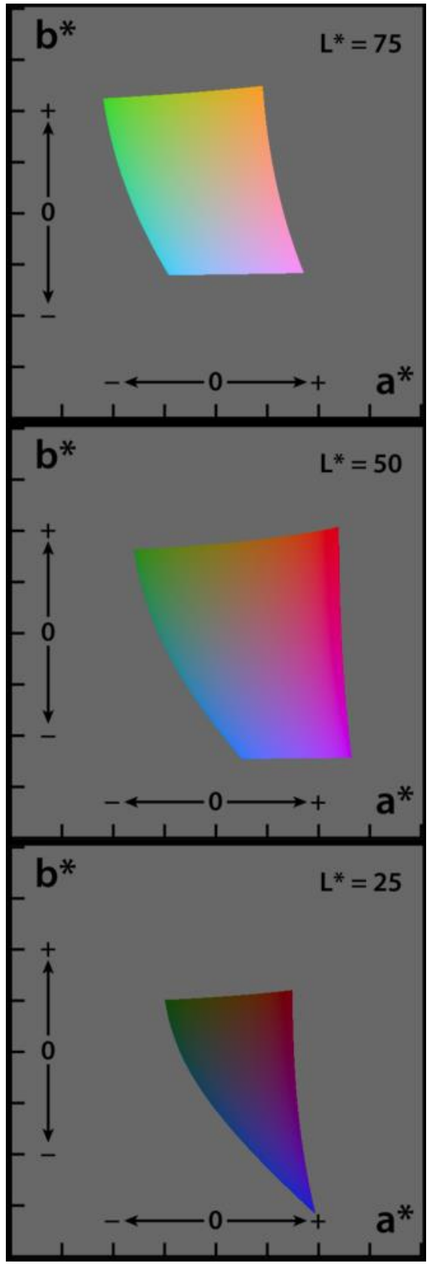
L from HLS
All the same

Luminance values

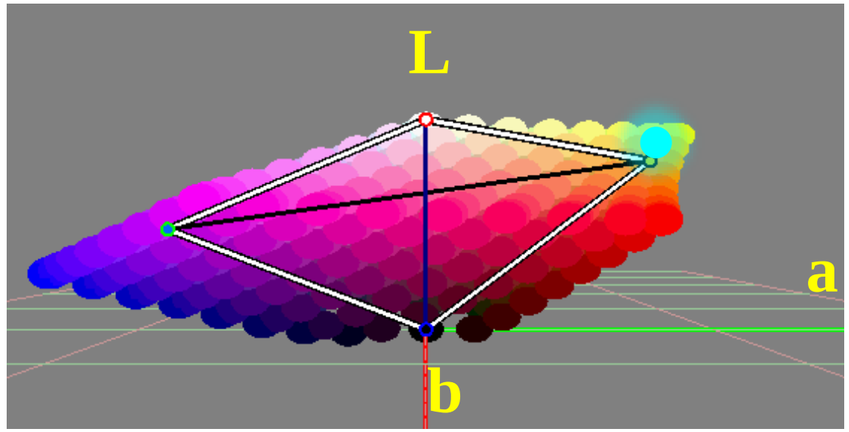
Perceptual colorspace: L*a*b*

- 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*)



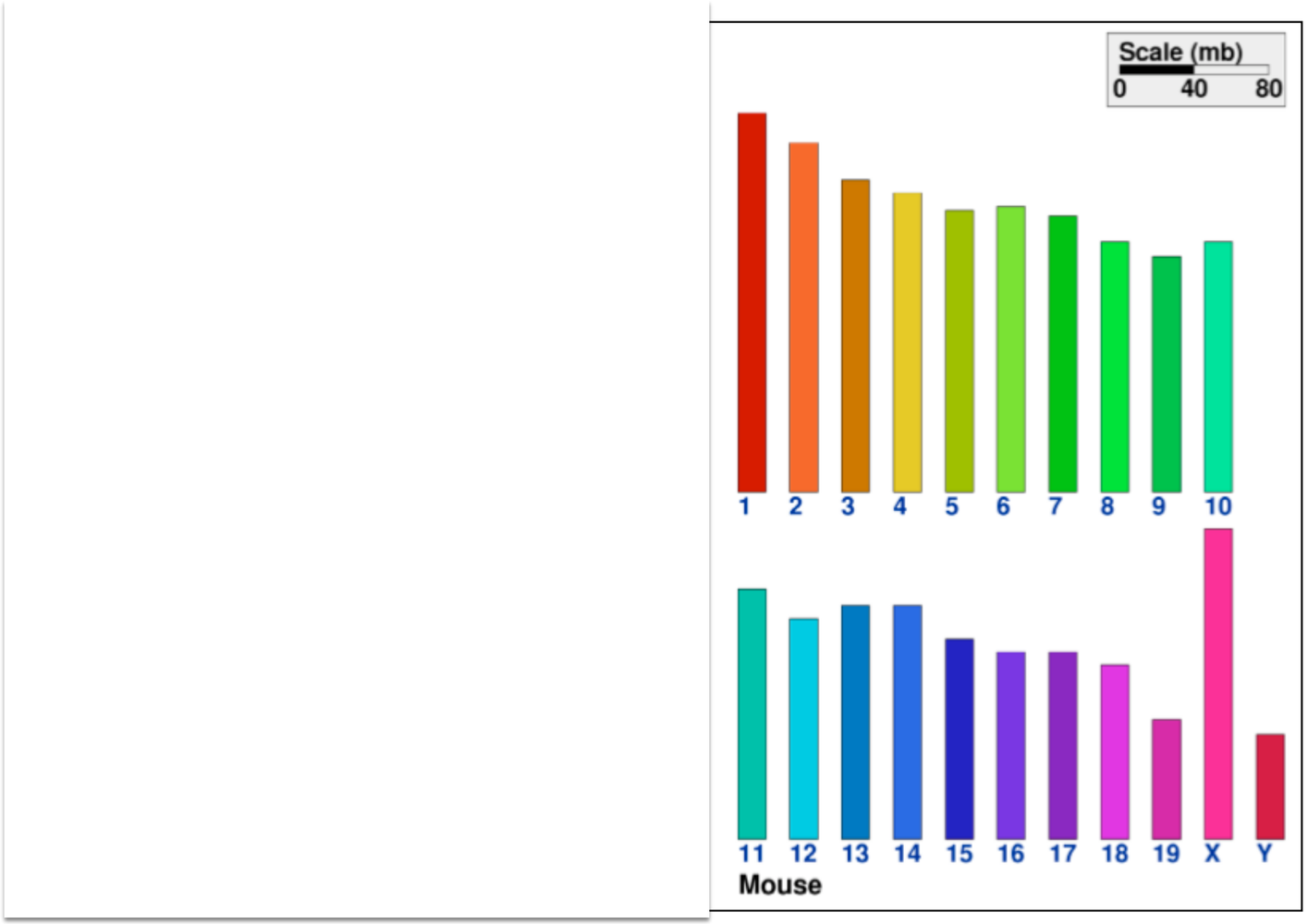


- CIE L*A*B* color space
  - Perception uniform color space
    - great for interpolating
  - complex shape
    - poor for encoding



Categorical color: Discriminability constraints

- noncontiguous small regions of color: only 6-12 bins



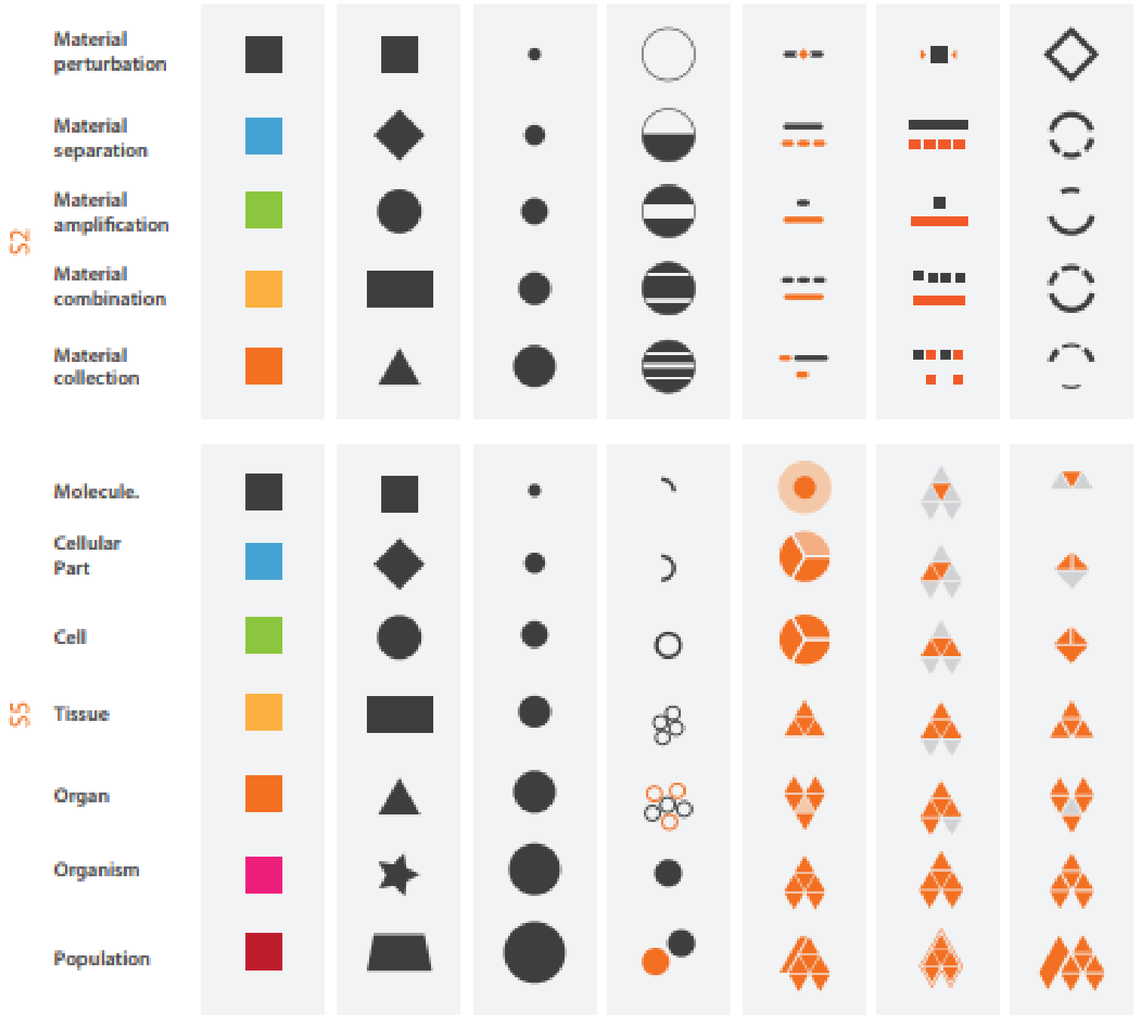
[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Categorical color: limited number of discriminable bins

- **human perception built on relative comparisons**
  - great if color contiguous
  - surprisingly bad for absolute comparisons

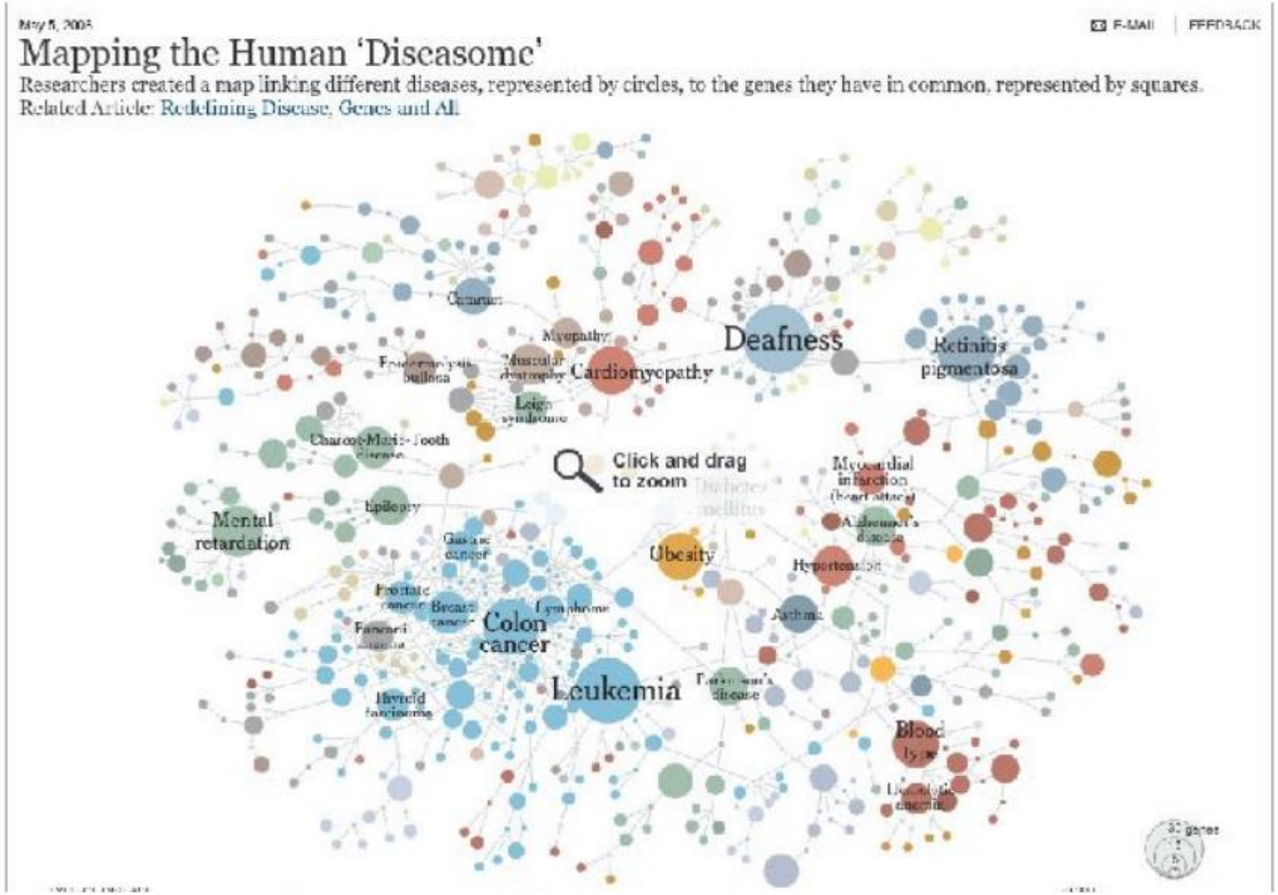
- **noncontiguous small regions of color**
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights

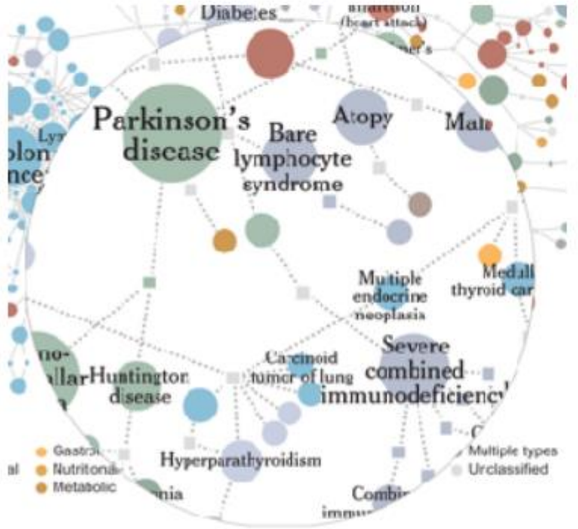
Different visual encoding



Categorical color: limited number of discriminable bins

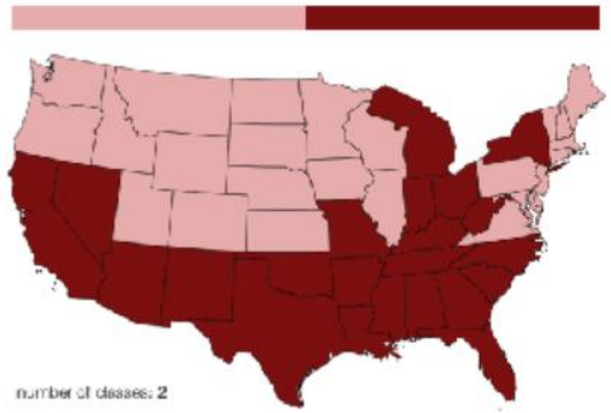
Cancer
Bone
Skeletal
Connective tissue
Muscular
Dermatological
Cardiovascular
Hematological
Renal
Endocrine
Immunological
Gastrointestinal
Nutritional
Metabolic
Ear, nose, throat
Ophthalmological
Respiratory
Developmental
Neurological
Psychiatric
Multiple types
Unclassified

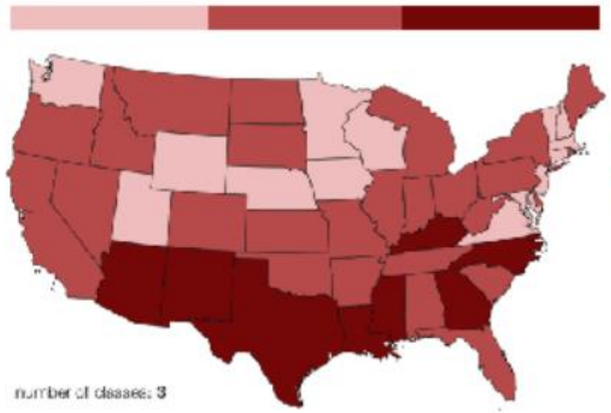


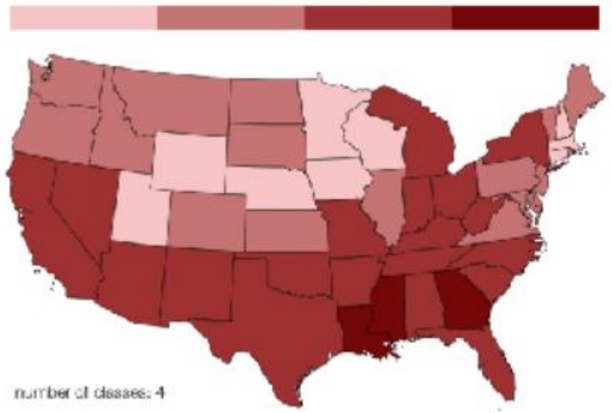


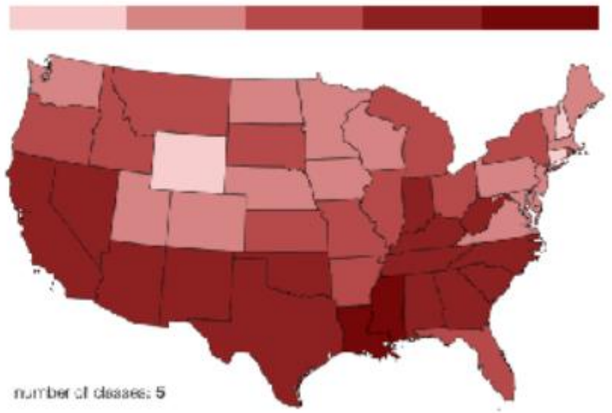
https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

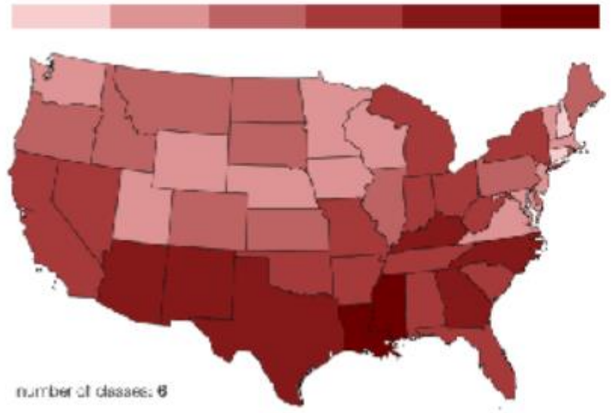
Ordered color: limited number of discriminable bins

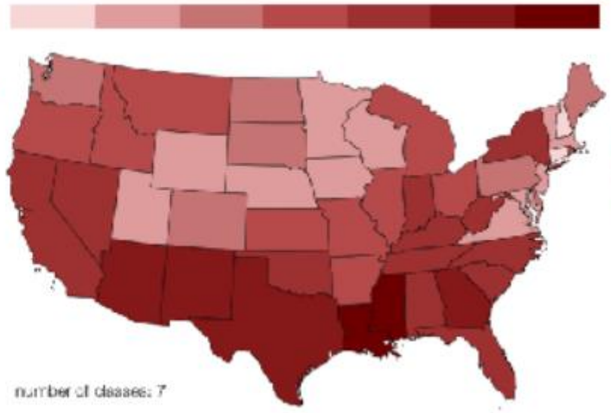


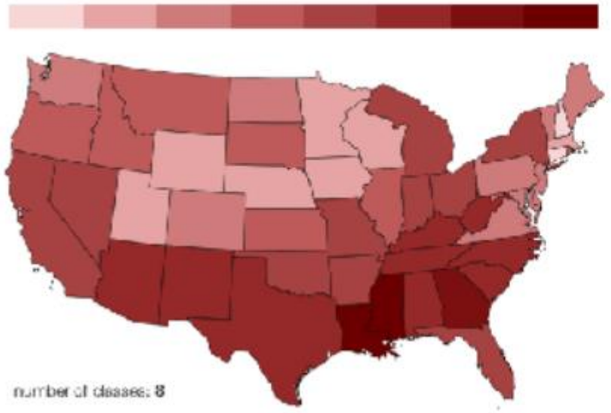












Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default

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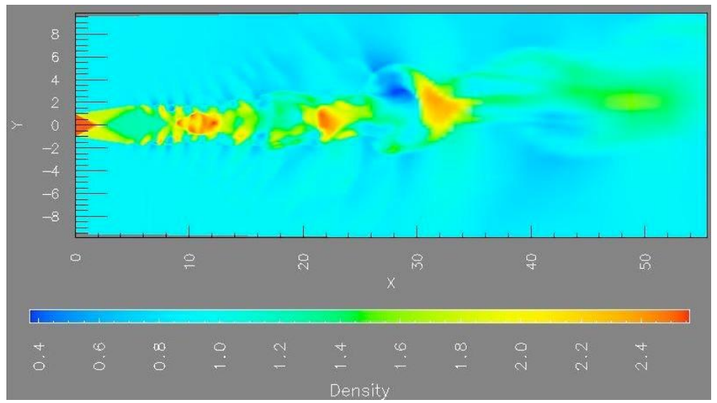
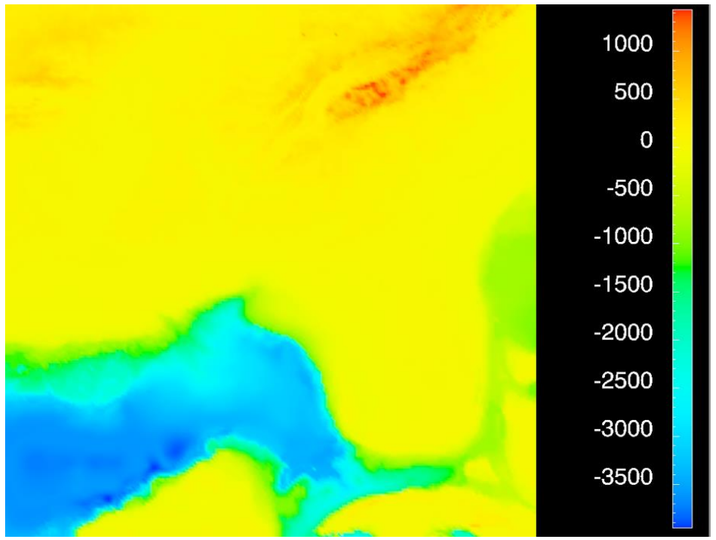
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



[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]

Ordered color: Rainbow is poor default

- problems
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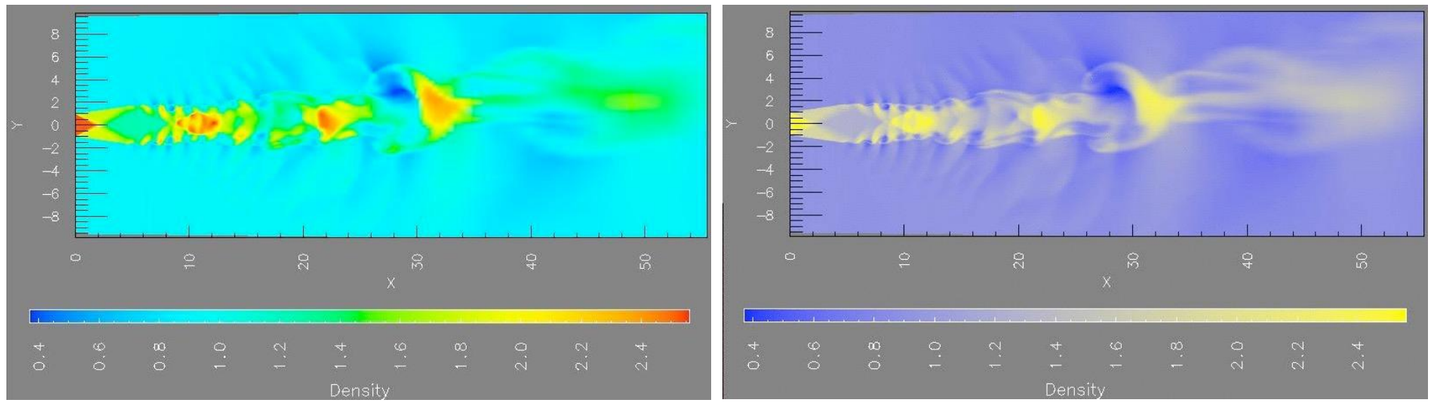
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues



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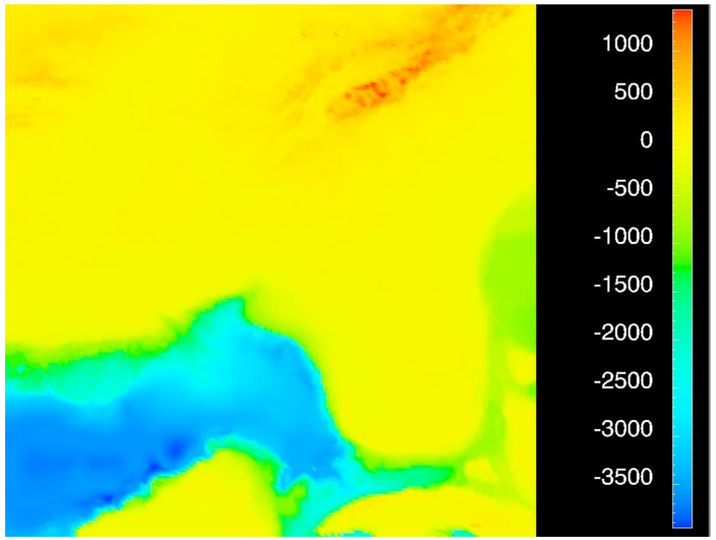

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- problems
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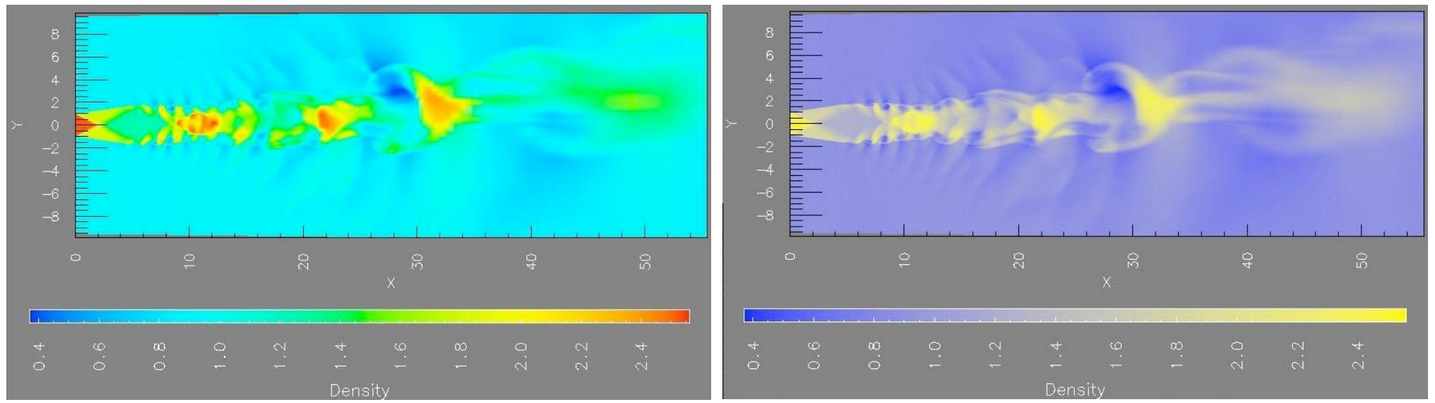
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



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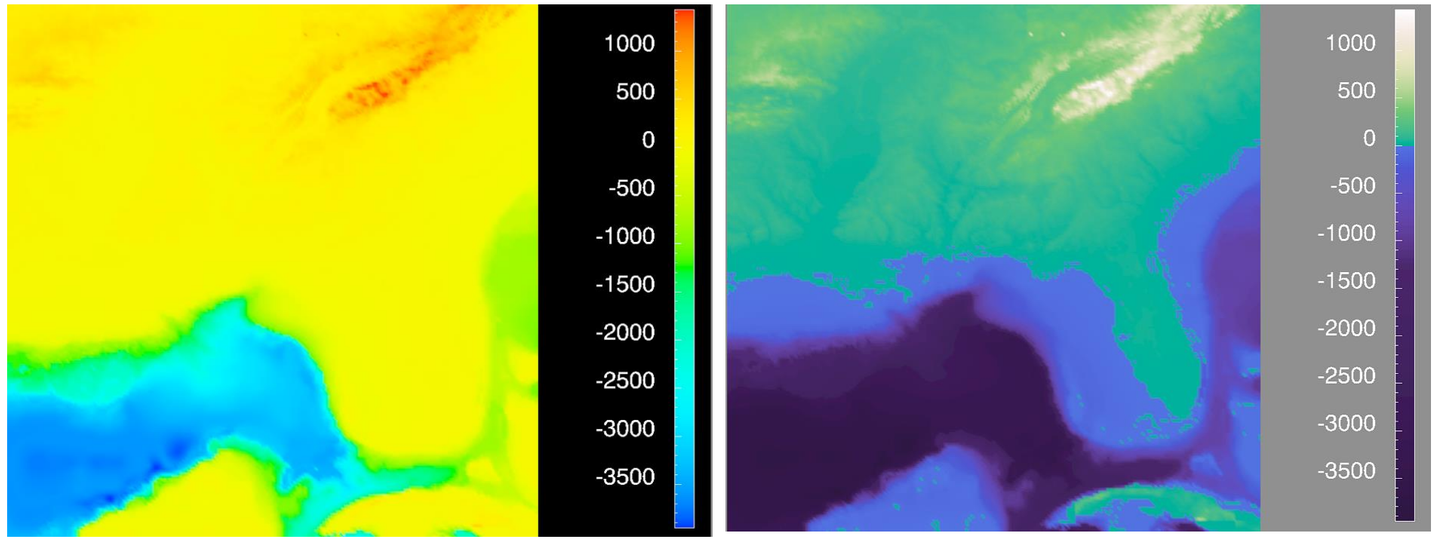

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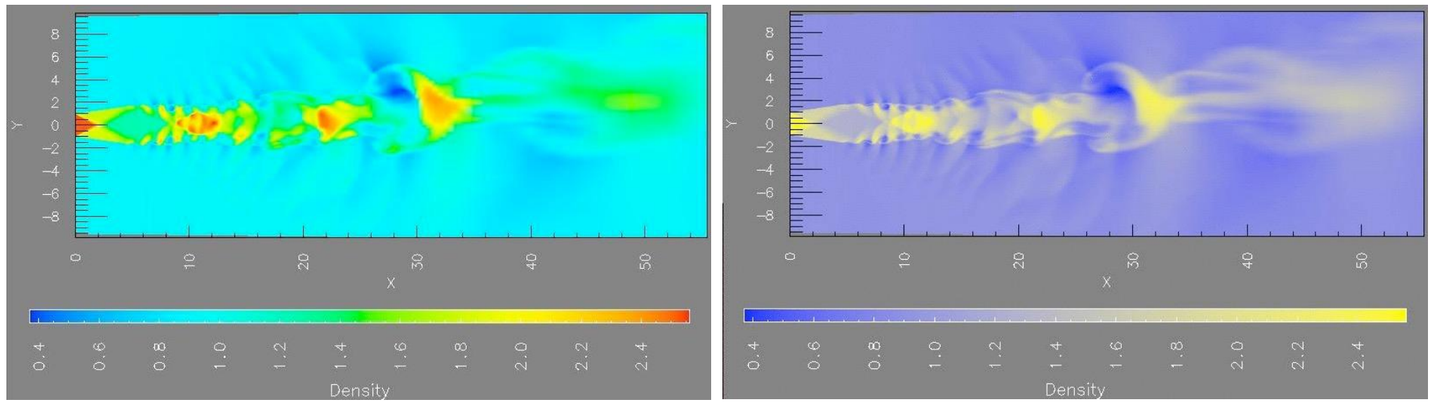
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - 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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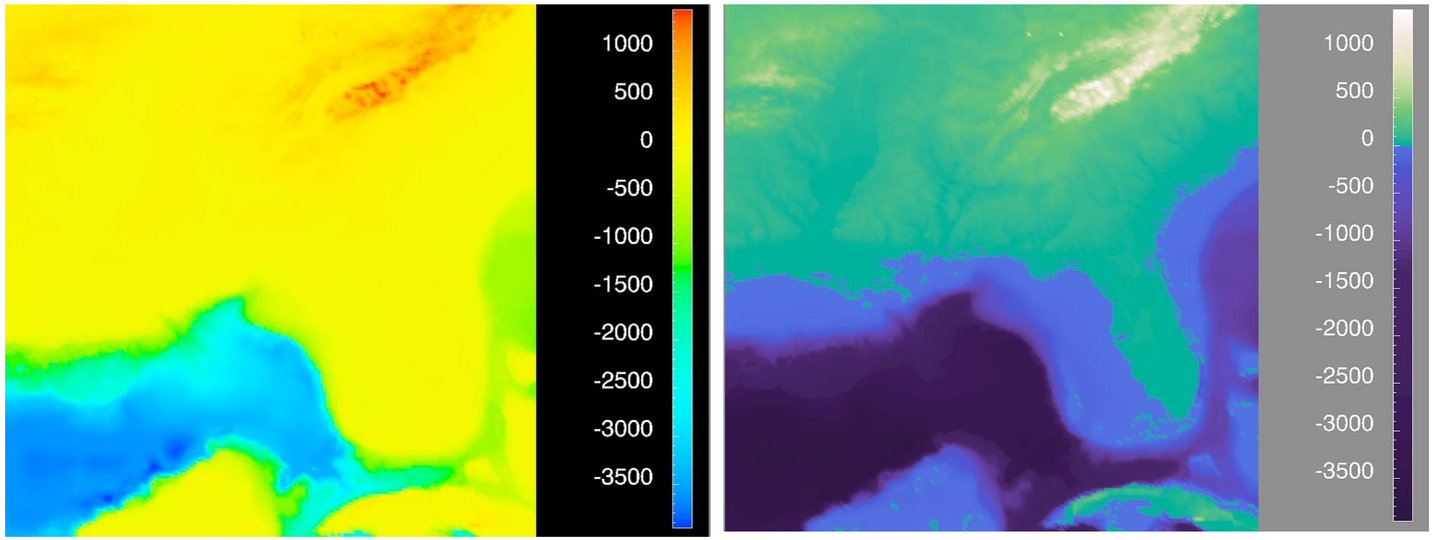

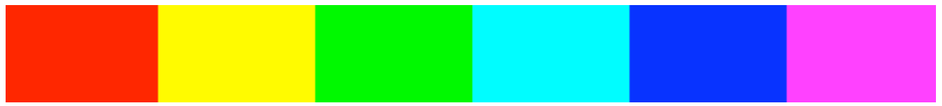

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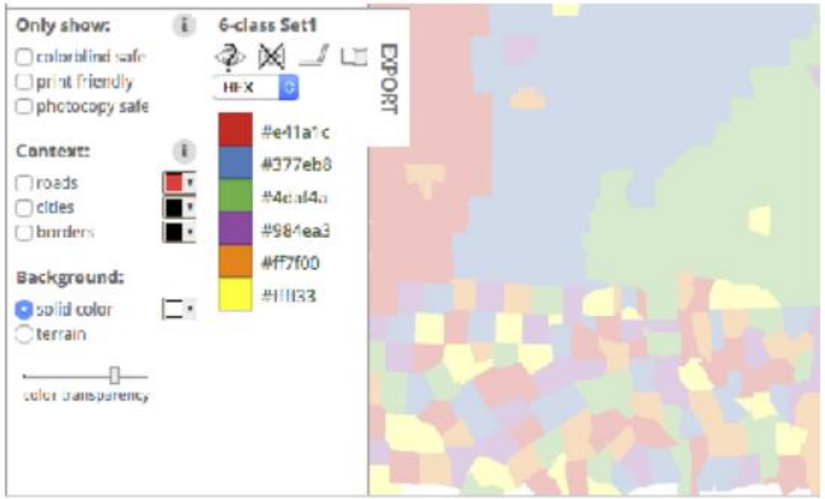
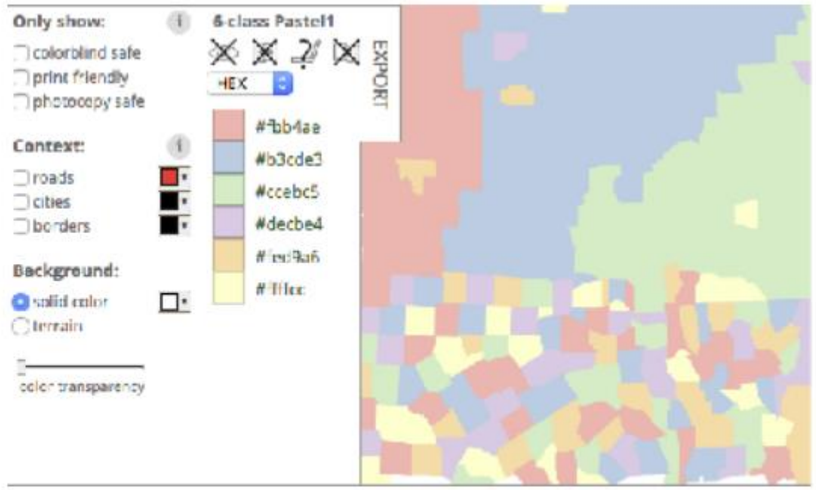
Interaction with other channels: integral/separable

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

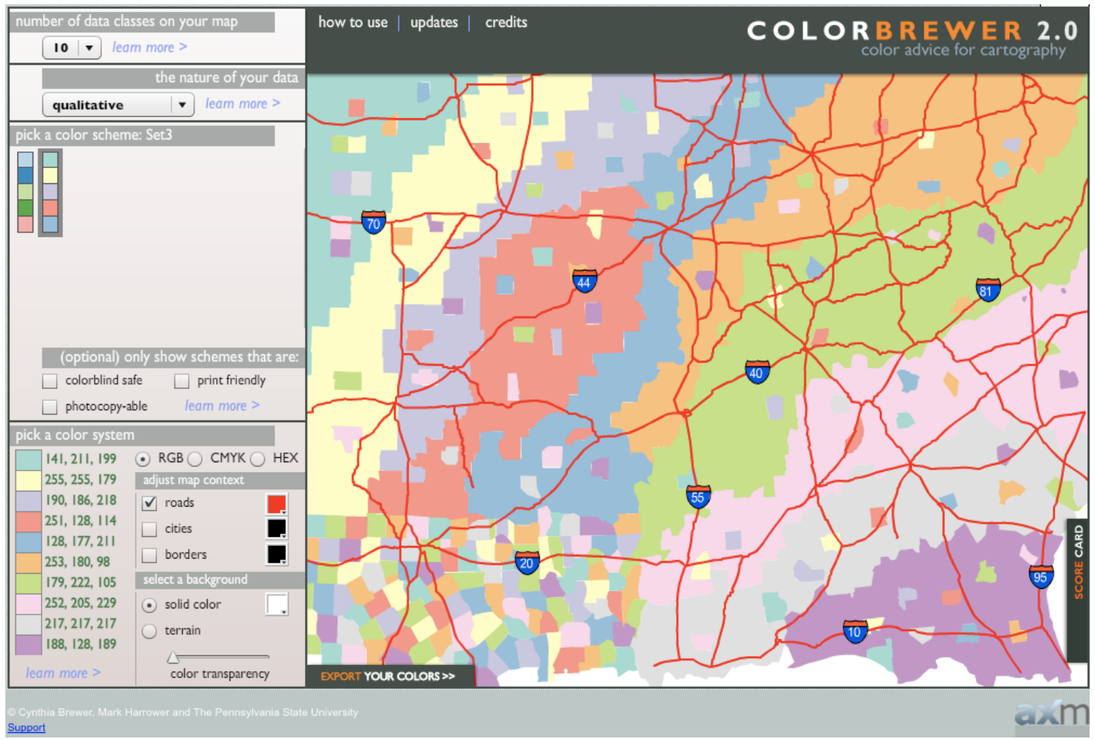


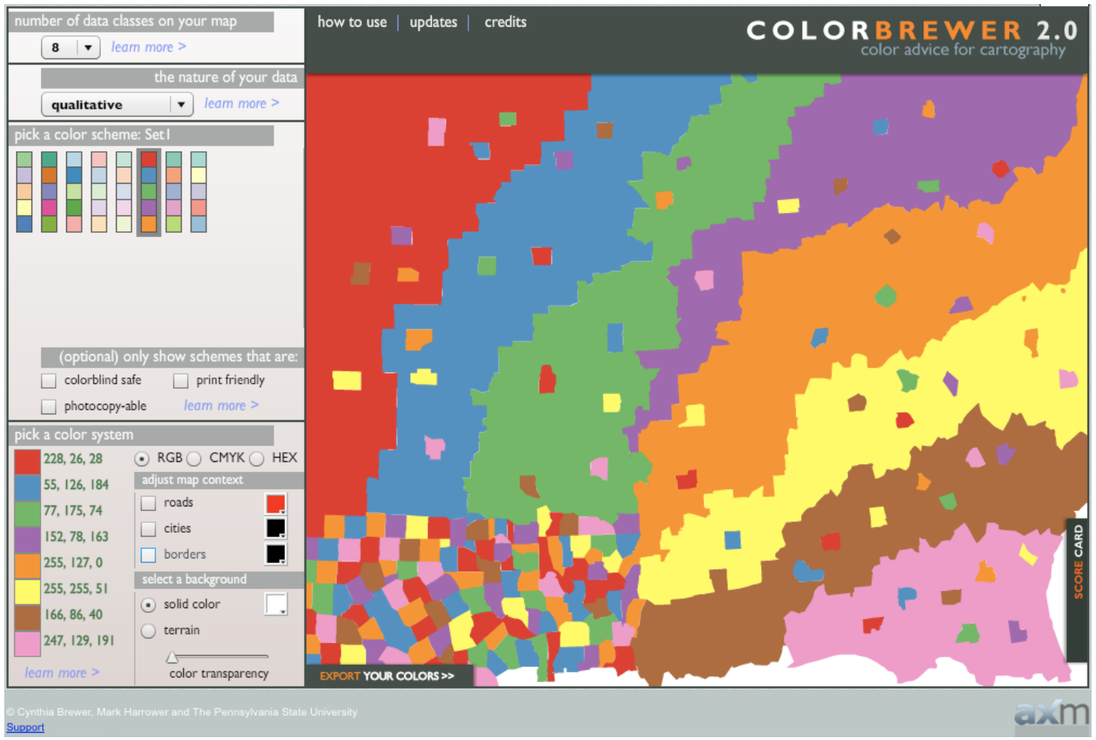


http://colorbrewer2.org/

ColorBrewer

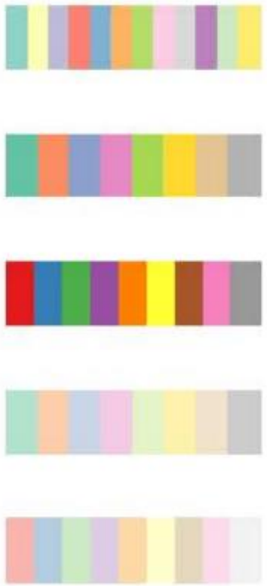
- http://www.colorbrewer2.org
- saturation and area example: size affects salience!
  - small regions need high saturation
  - large regions need low saturation





Colormaps: univariate

➔ Categorical



categorical

- aim for maximum distinguishability
- aka qualitative, nominal

Colormaps: univariate

➔ Categorical

➔ Ordered

➔ *Sequential*

➔ *Diverging*

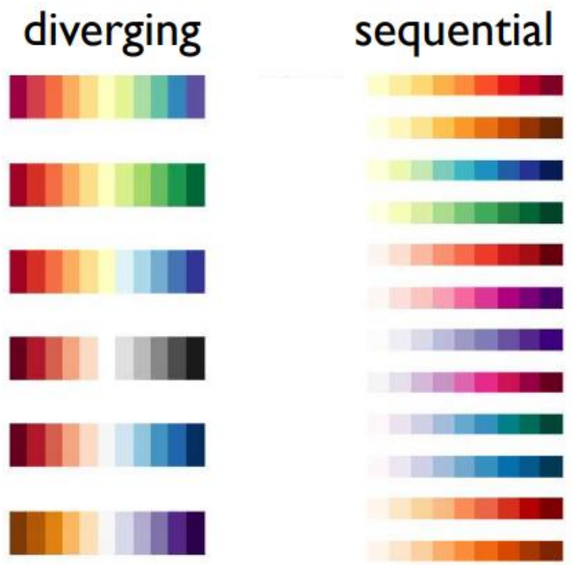
Categorical

Diverging

Sequential

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

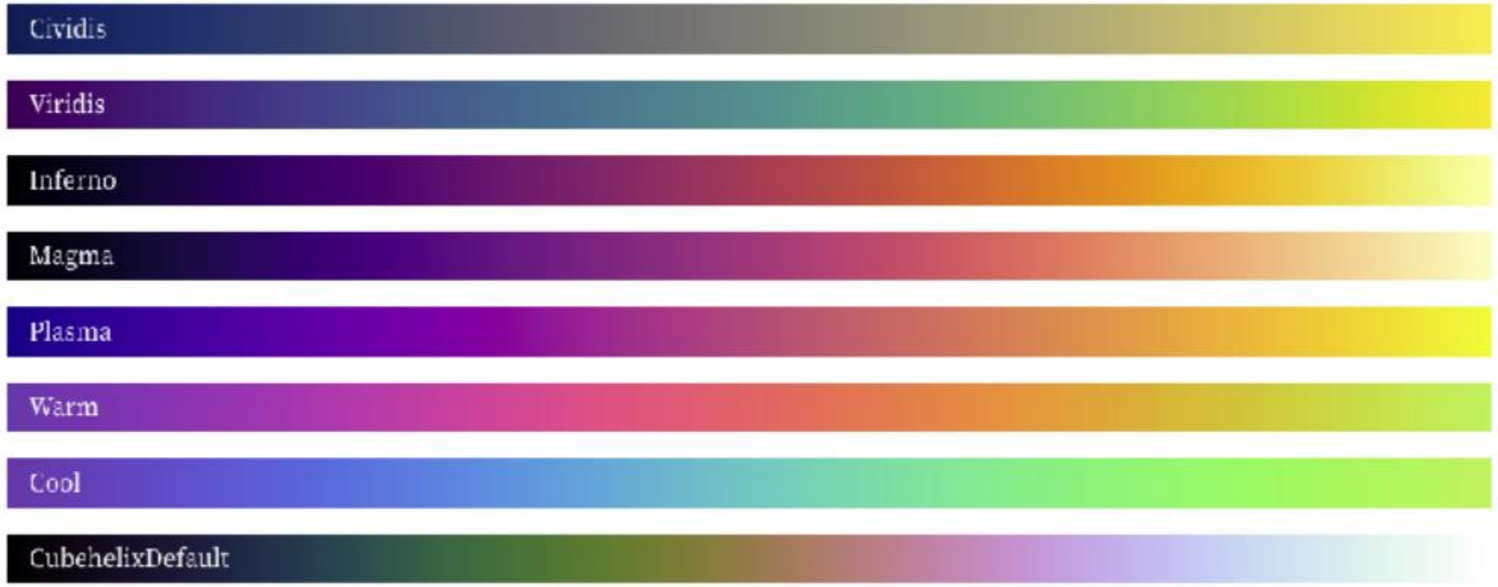


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps: univariate

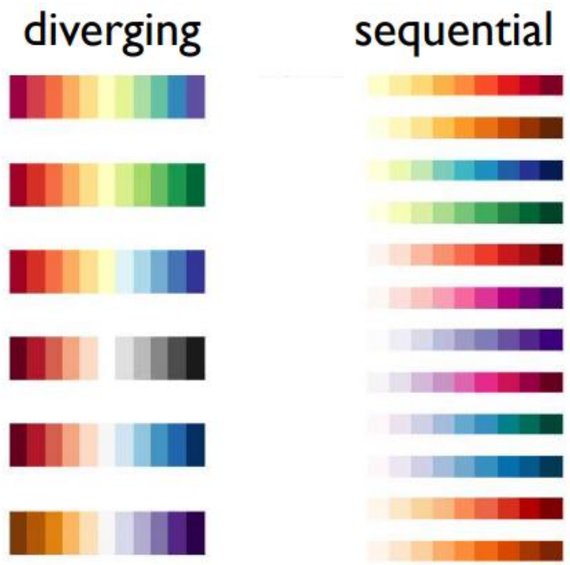
- Categorical

- 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
- if multi-hue, good to order by luminance



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Colormaps: univariate

- Categorical

- Ordered
  - *Sequential*
  - *Diverging*

  - Cyclic

cyclic multihue

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

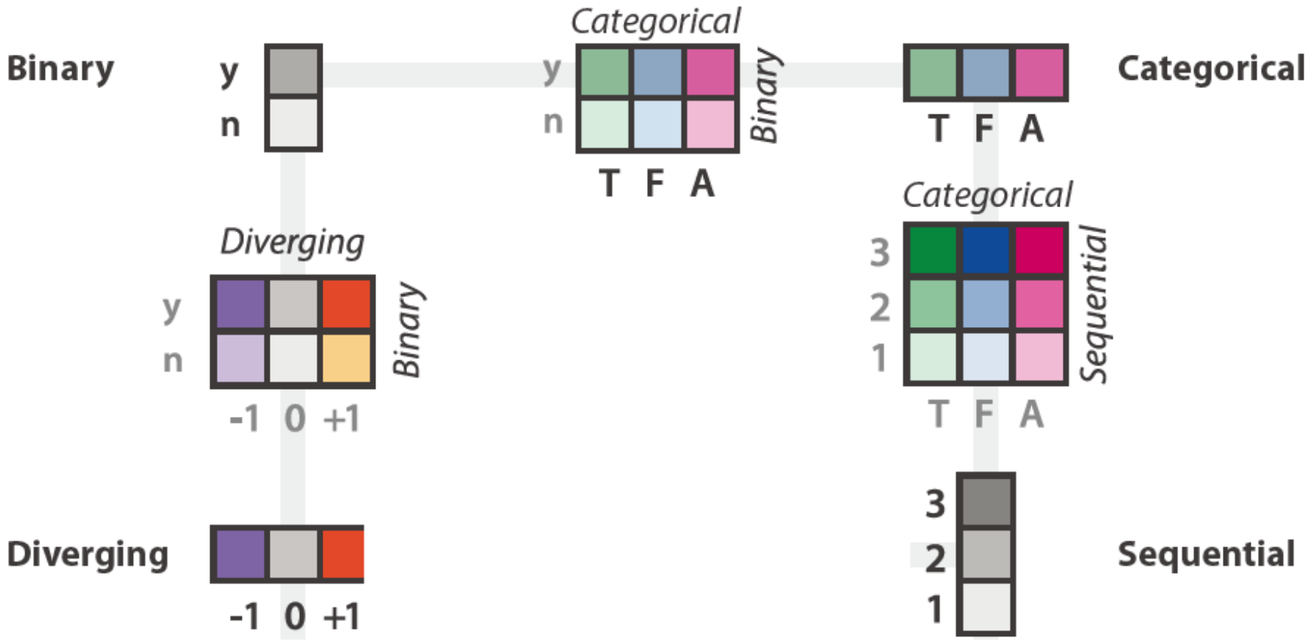
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps: bivariate

- Categorical

- Ordered
  - *Sequential*
  - *Diverging*

- Bivariate

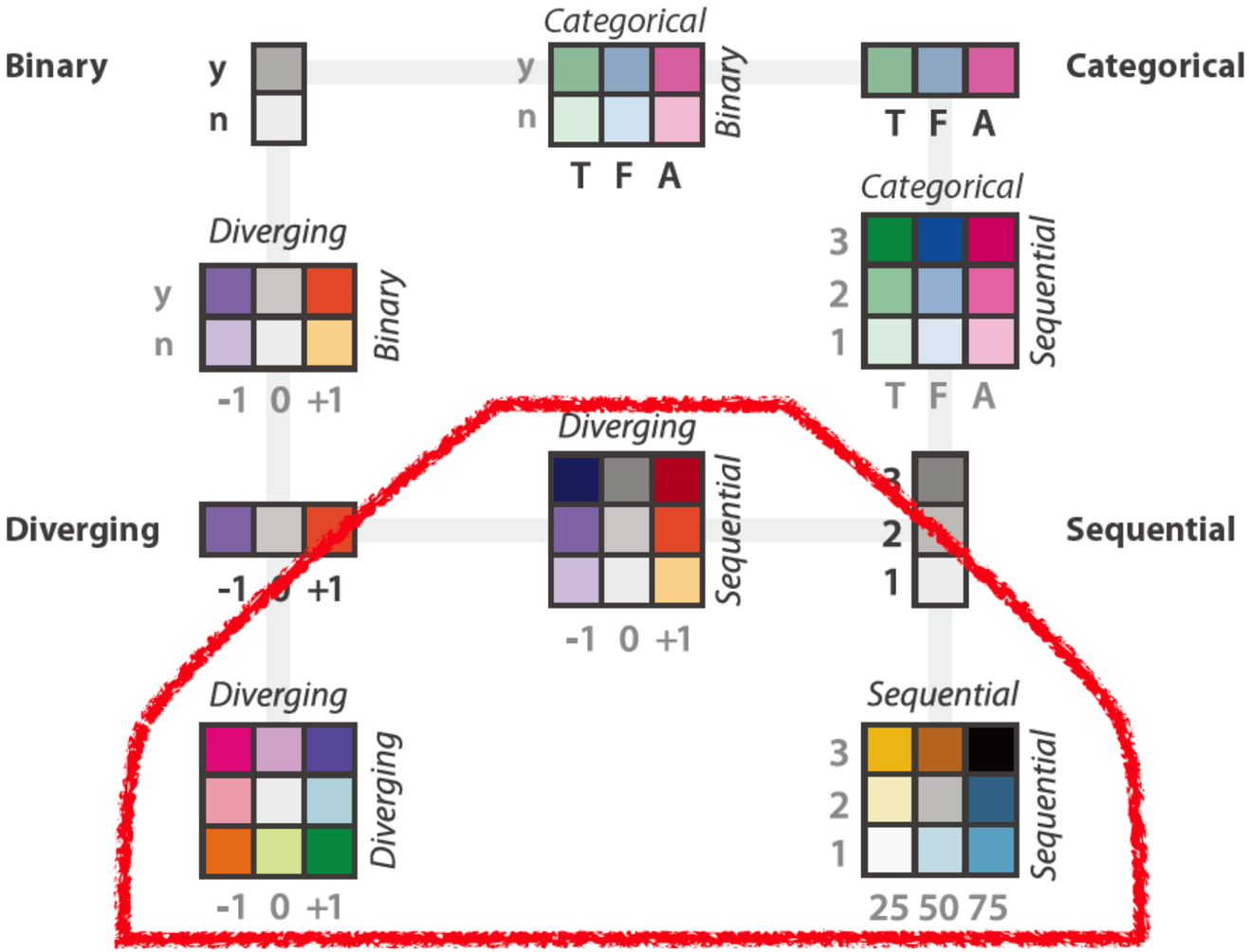


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps: bivariate

- Categorical
- Ordered
  - *Sequential*
  - *Diverging*
- Bivariate

use with care!



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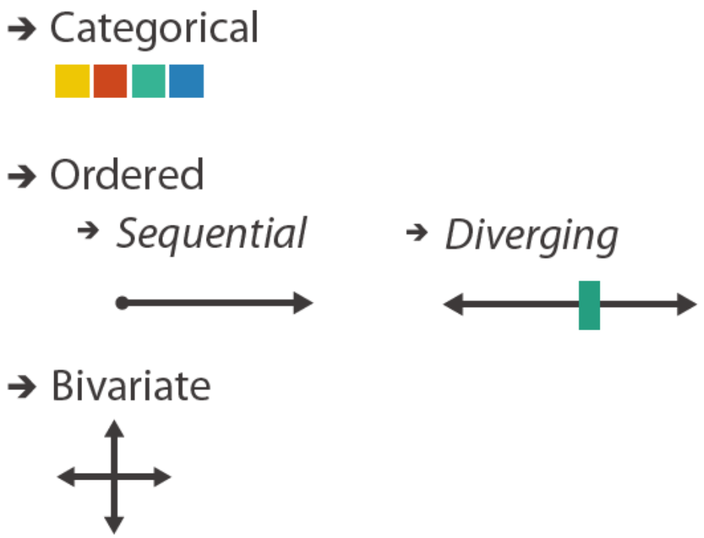
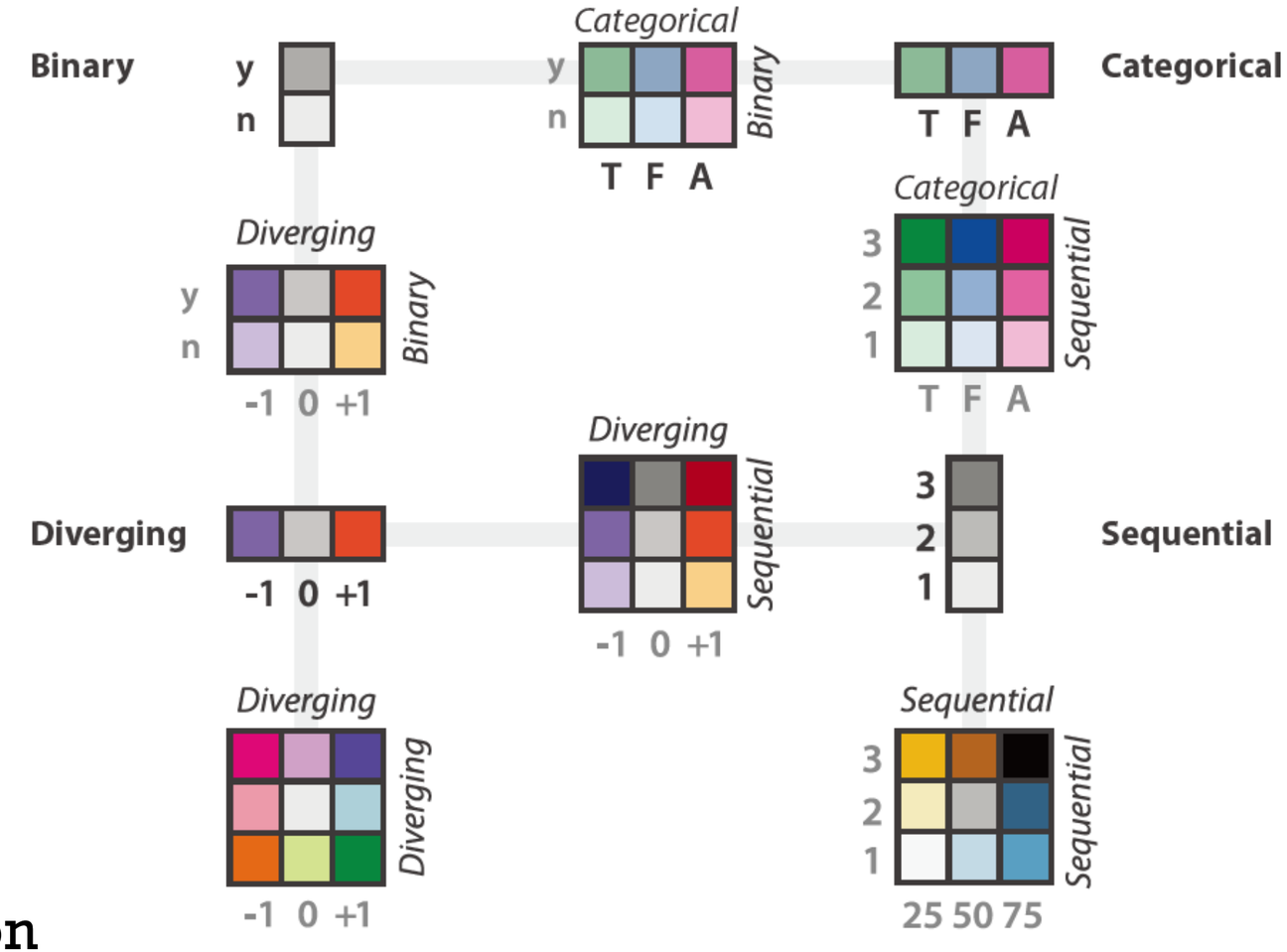
Colormaps: bivariate





- color channel interactions
  - size heavily affects salience
    - small regions need high saturation
    - large need low saturation
  - saturation & luminance: 3-4 bins max
    - also not separable from transparency

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

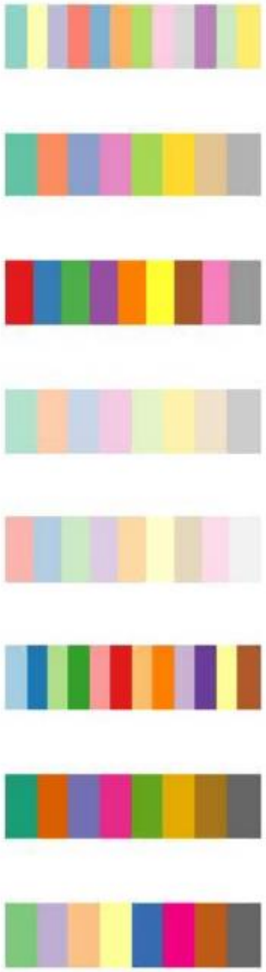
What kinds of color palettes are there?

segmented

diverging

sequential

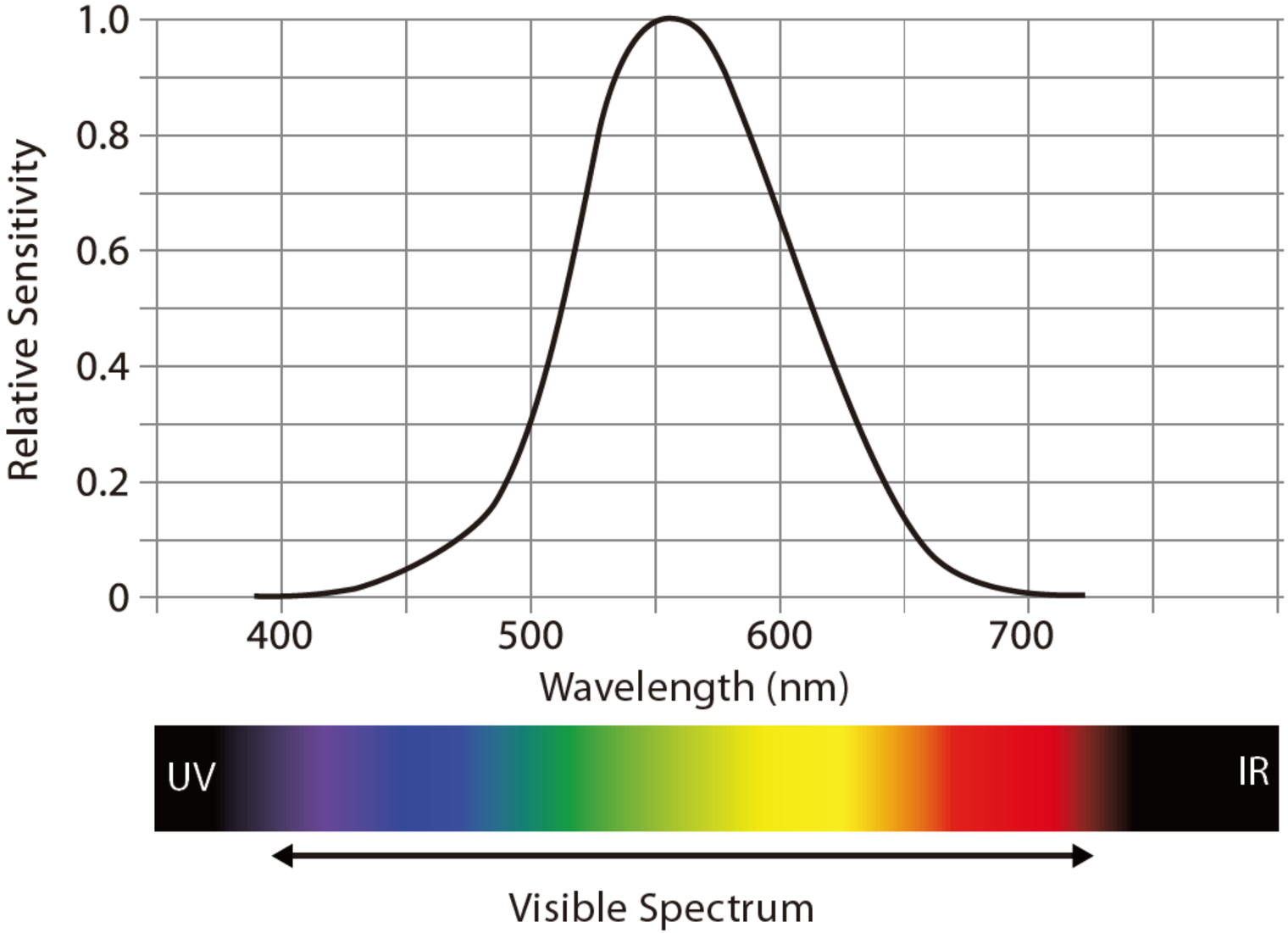
categorical



continuous

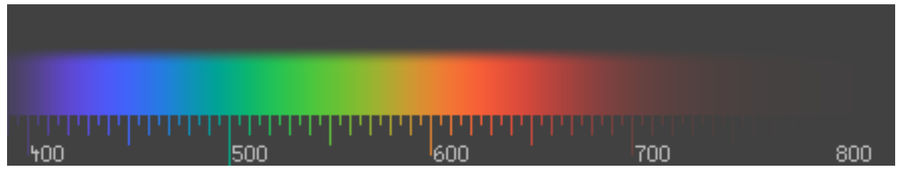
cyclic multihue

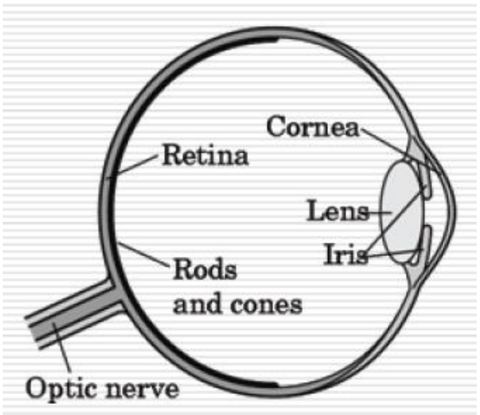
Spectral sensitivity

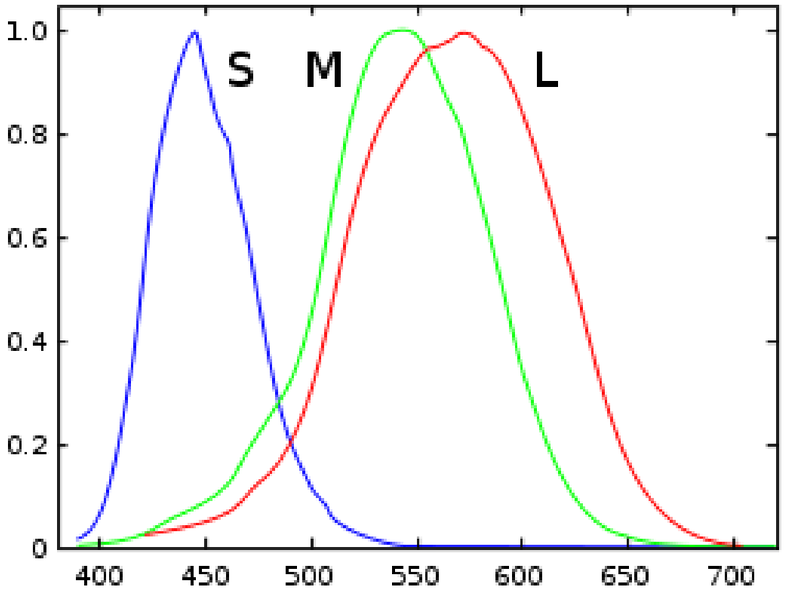


Three-Color Theory

- Human visual system has two types of sensors
  - Rods:
    - monochromatic, night vision
  - Cones
    - Color sensitive
    - Three types of cone
    - Only three values (the *tristimulusvalues) are sent to the brain*





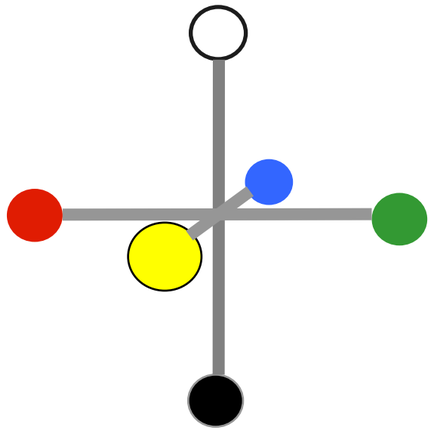


Opponent color and color deficiency

- perceptual processing before optic nerve
  - one achromatic luminance channel L
    - edge detection through luminance contrast
  - two chroma channels, R-G and Y-B axis
- "color blind" if one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare

Lightness information

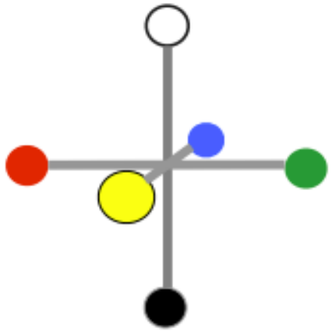
Color information

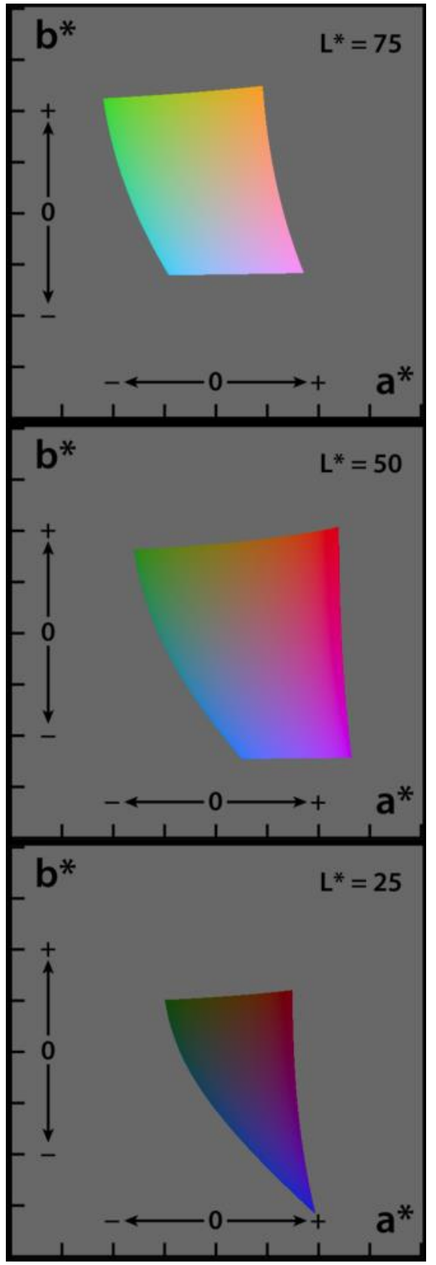


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

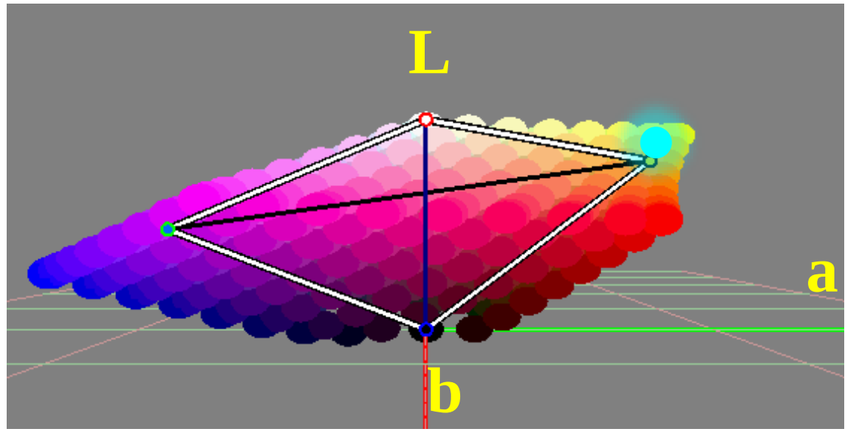
Perceptual colorspace: L*a*b*

- 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*)

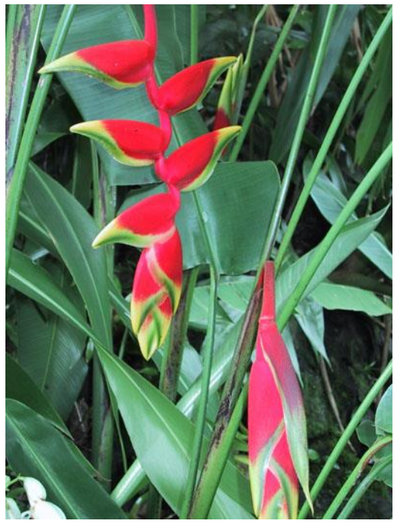




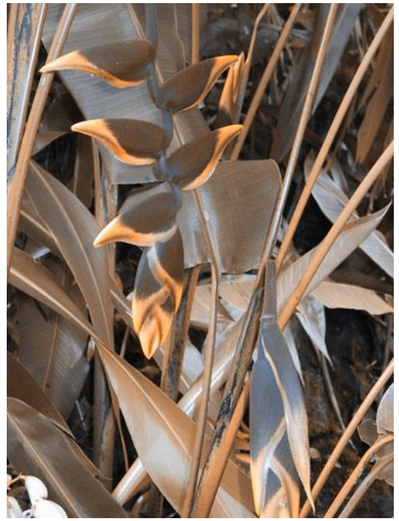
- CIE L*A*B* color space
  - Perception uniform color space
    - great for interpolating
  - complex shape
    - poor for encoding



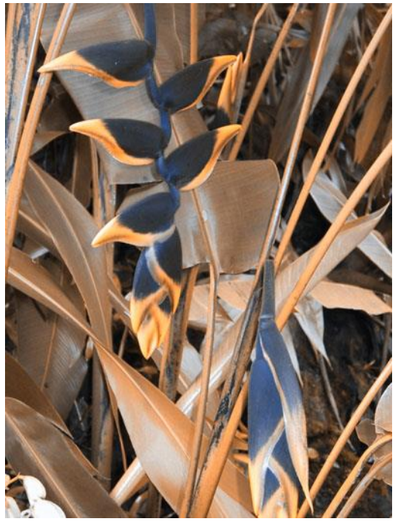
Designing for color deficiency: Check with simulator



Normal vision

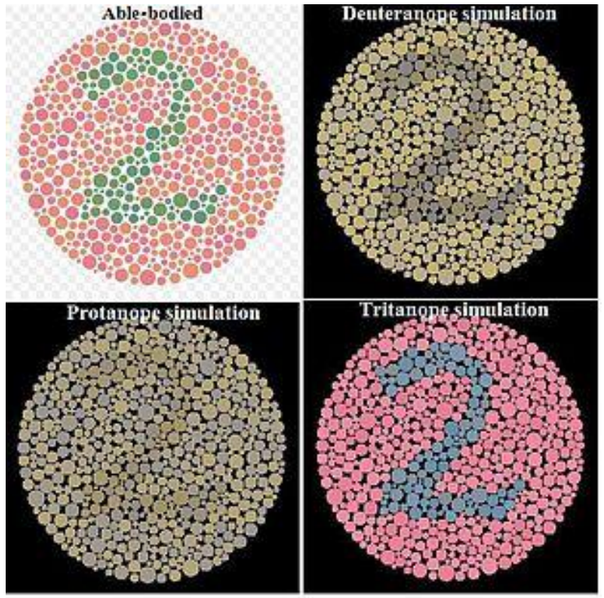


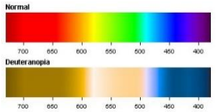
Deuteranope

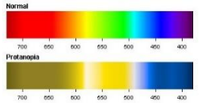


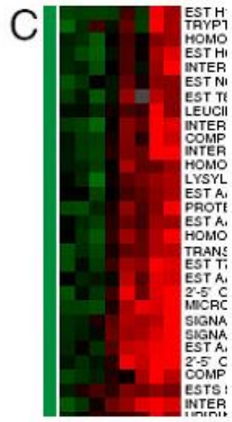
Protanope

Tritanope







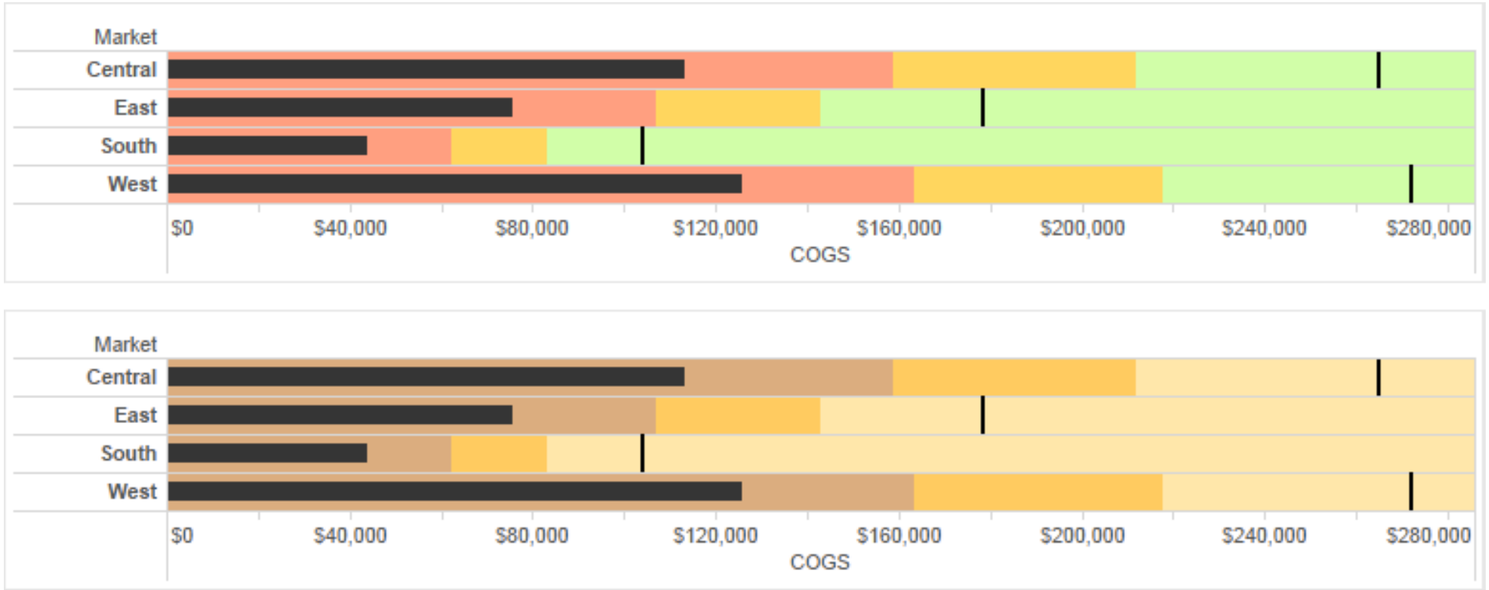


color blind simulation

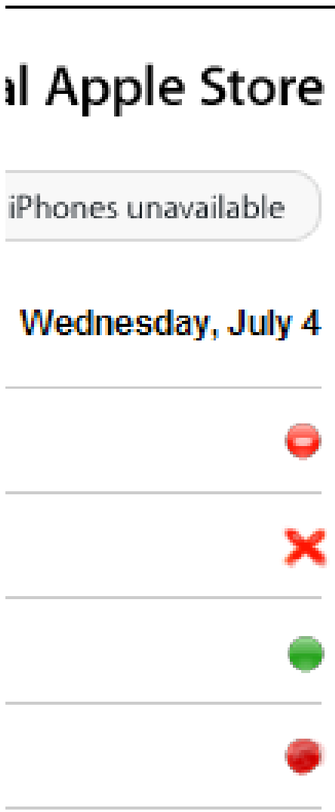
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape

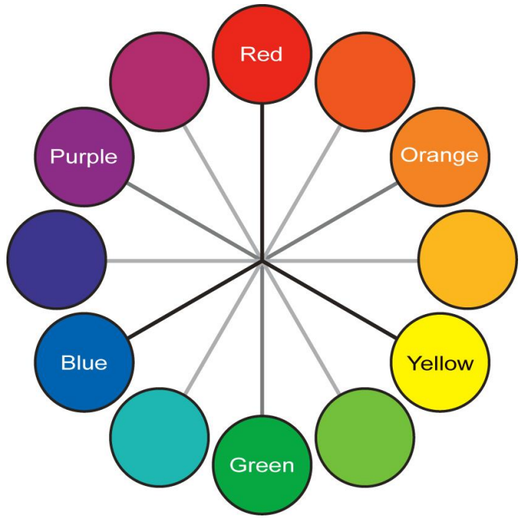


Deuteranope simulation

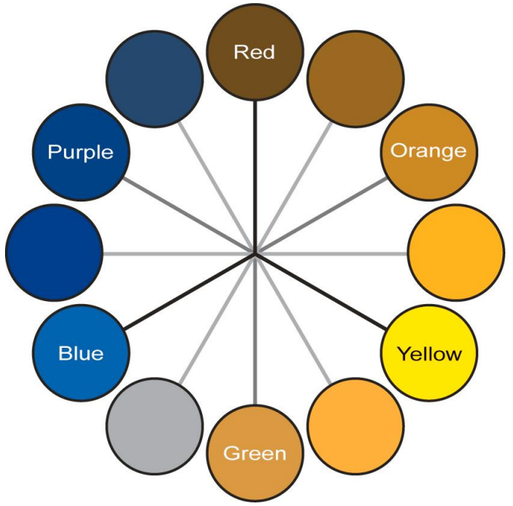


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

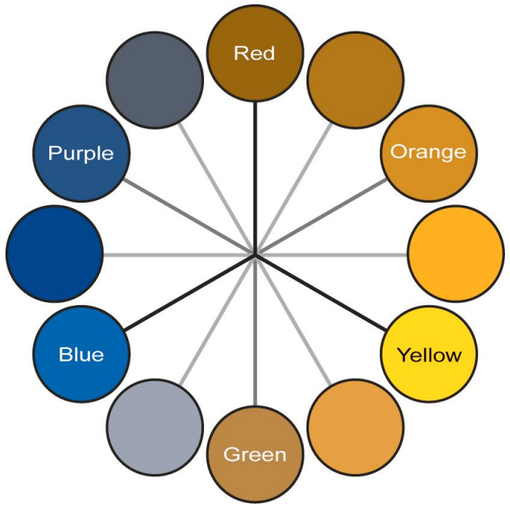
Color deficiency: Reduces color to 2 dimensions



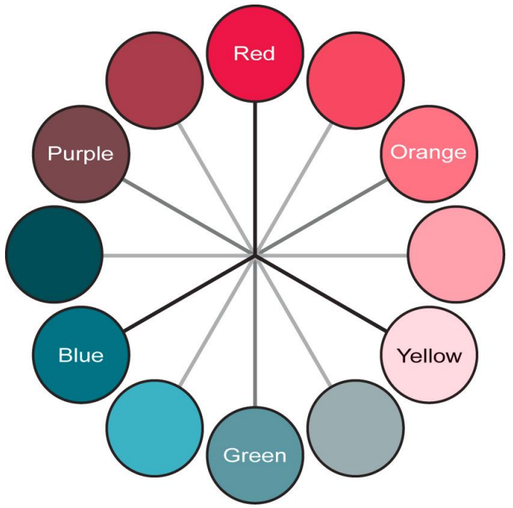
Normal



Protanope



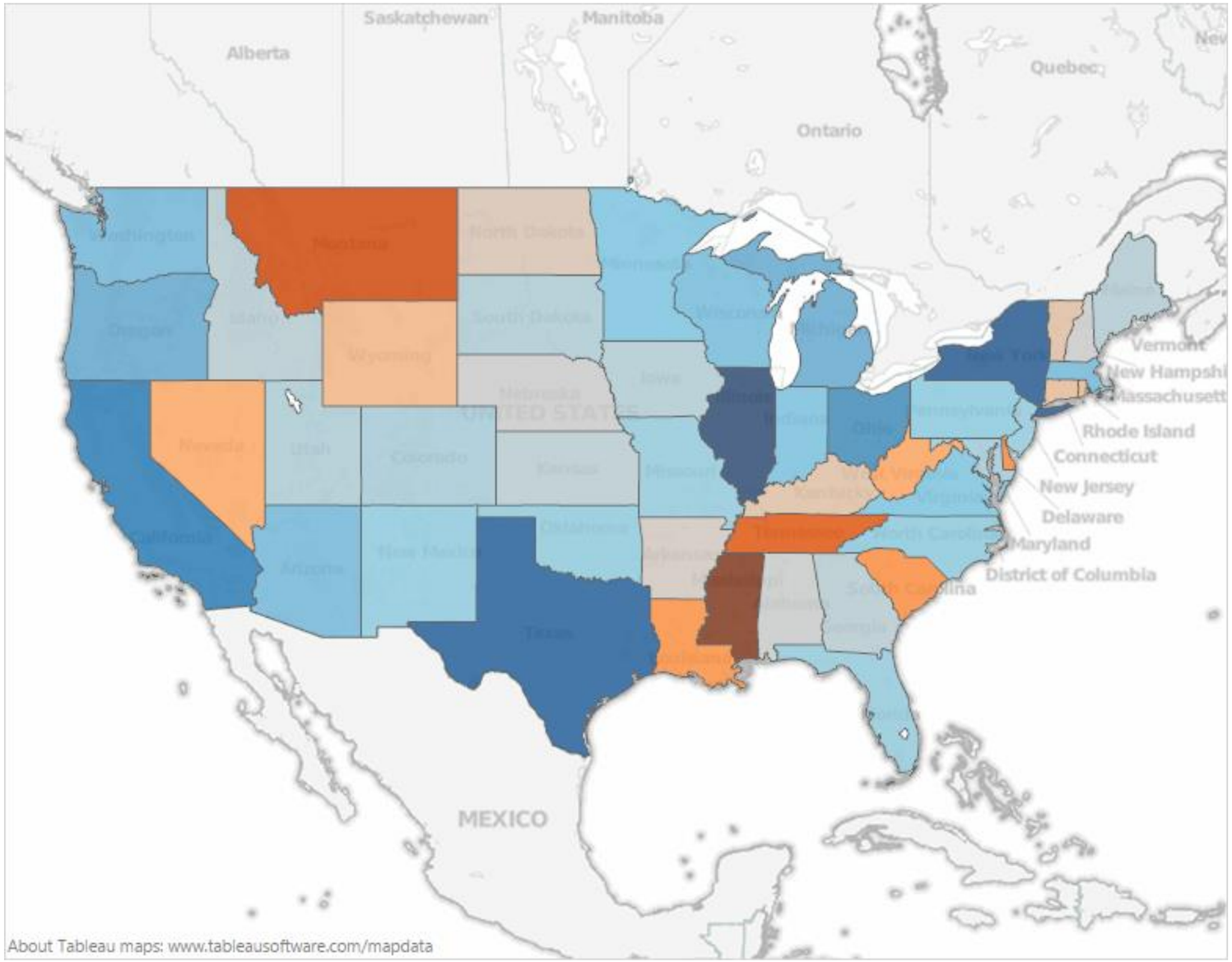
Deuteranope



Tritanope

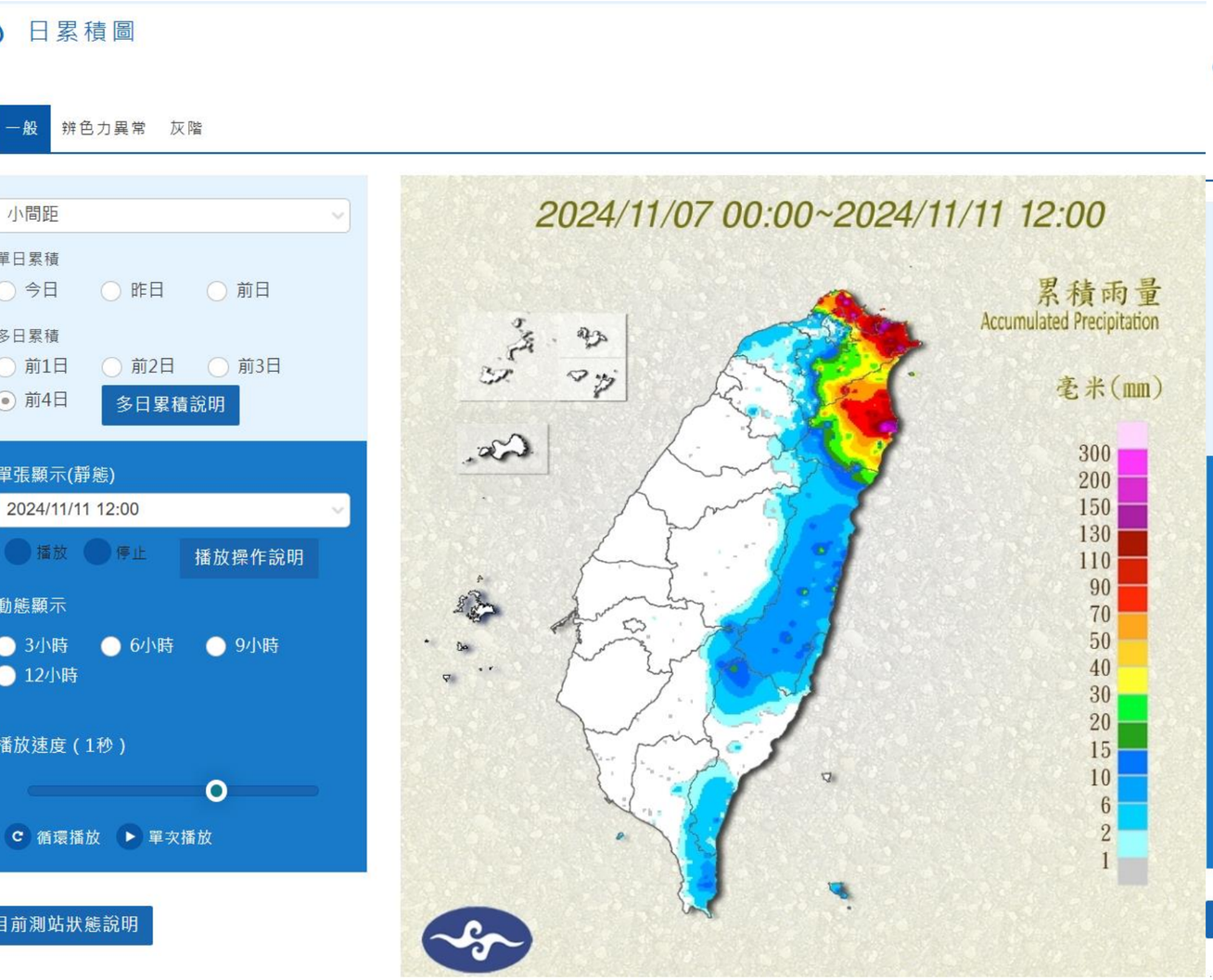
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

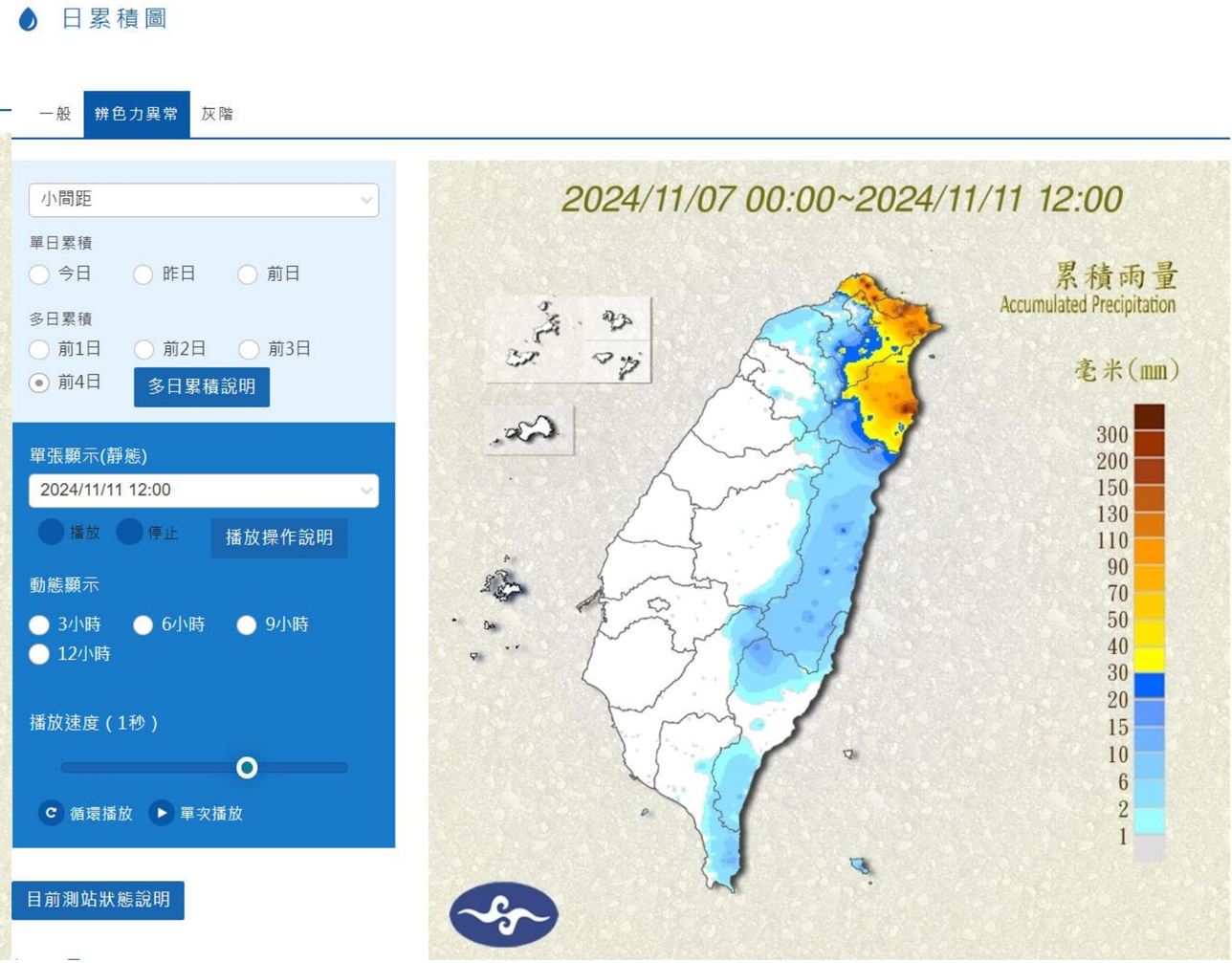
Designing for color deficiency: Blue-Orange is safe



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

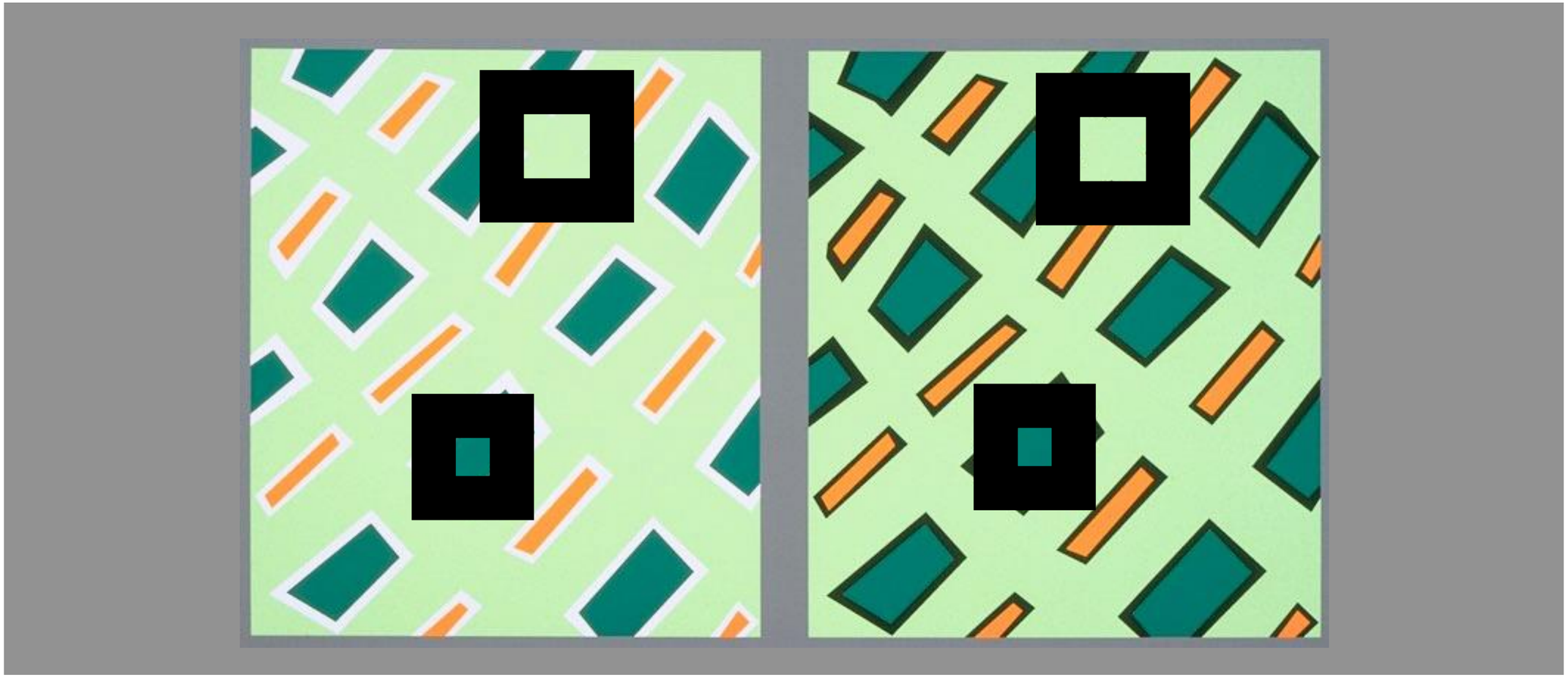
Designing for color deficiency: Blue-Orange is safe





Bezold Effect: Outlines matter

- color constancy: simultaneous contrast effect



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

Color/Lightness constancy: Illumination conditions

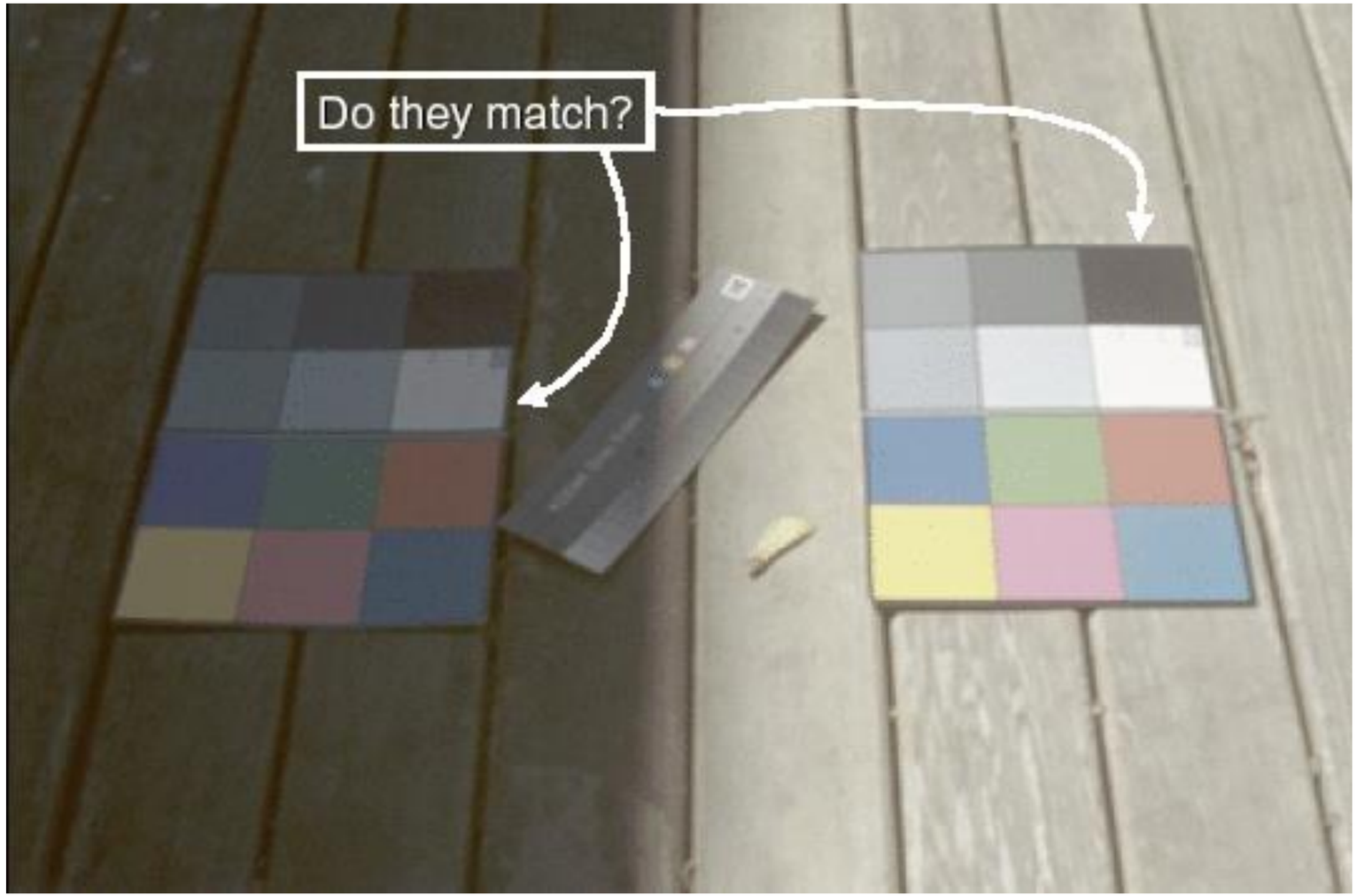


Image courtesy of John McCann

Color/Lightness constancy: Illumination conditions

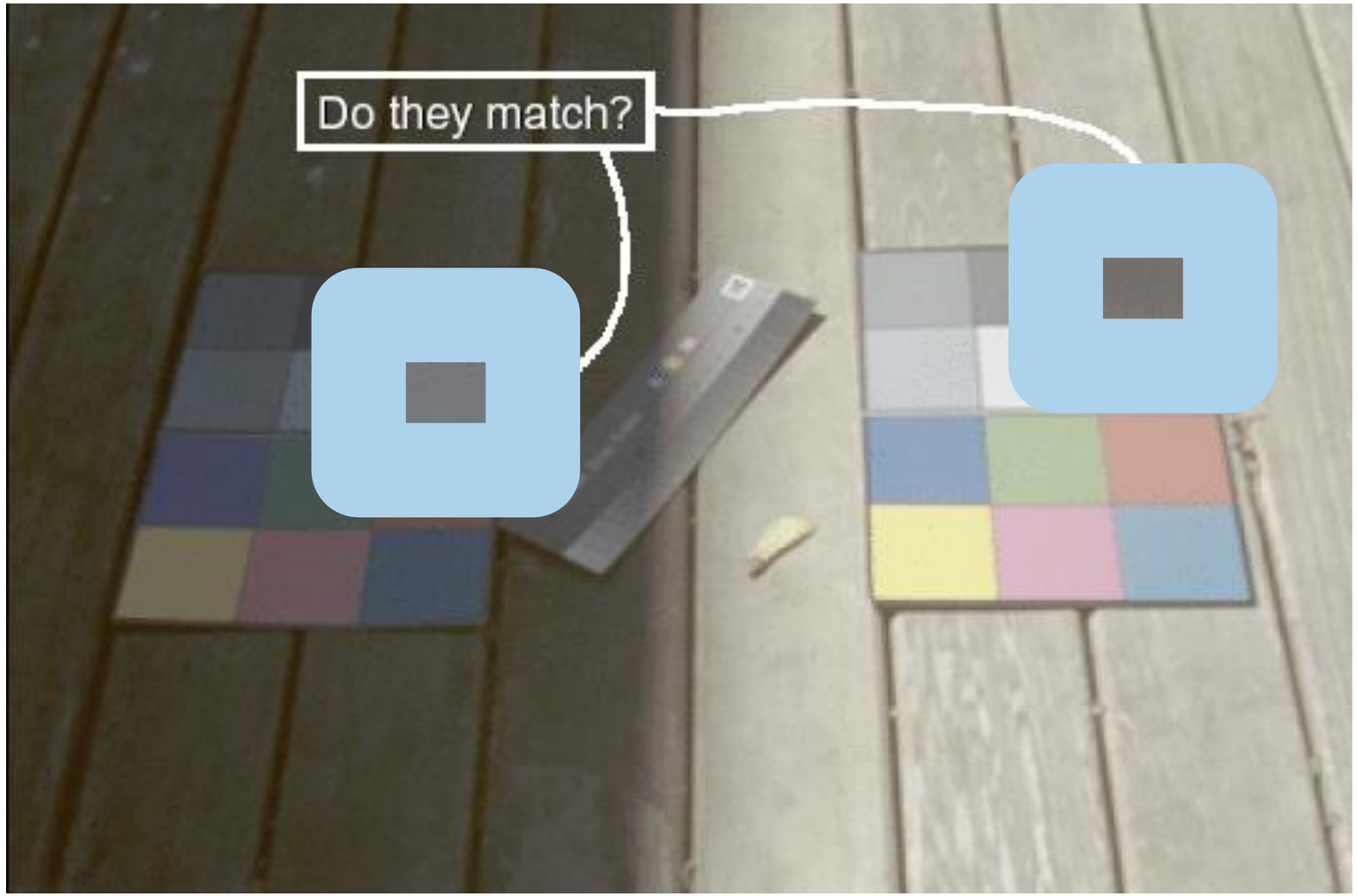
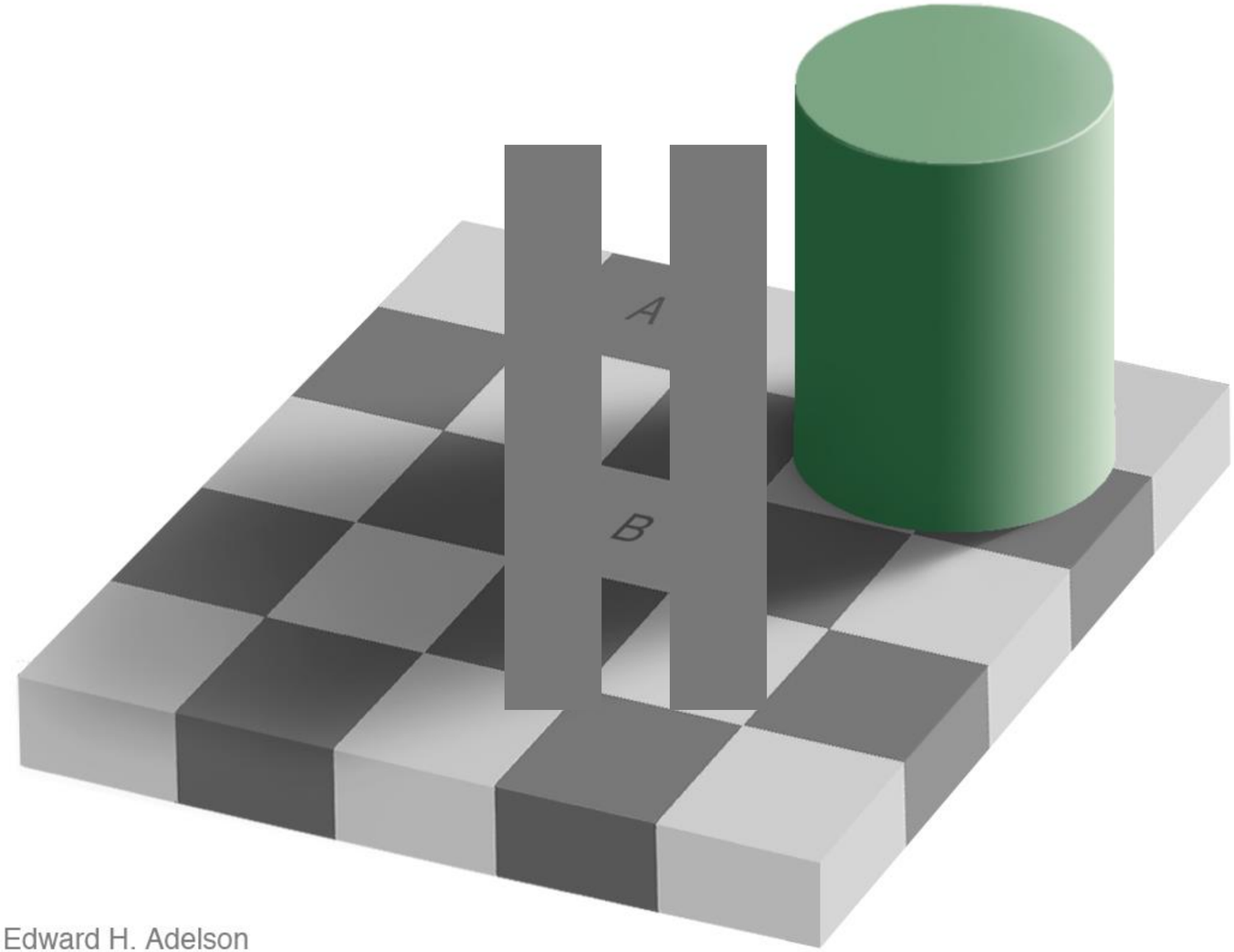


Image courtesy of John McCann

Checker shadow Illusion



Edward H. Adelson

Color naming

Color naming

[DOGHOUSE | Color Wheel (thedoghousediaries.com)]

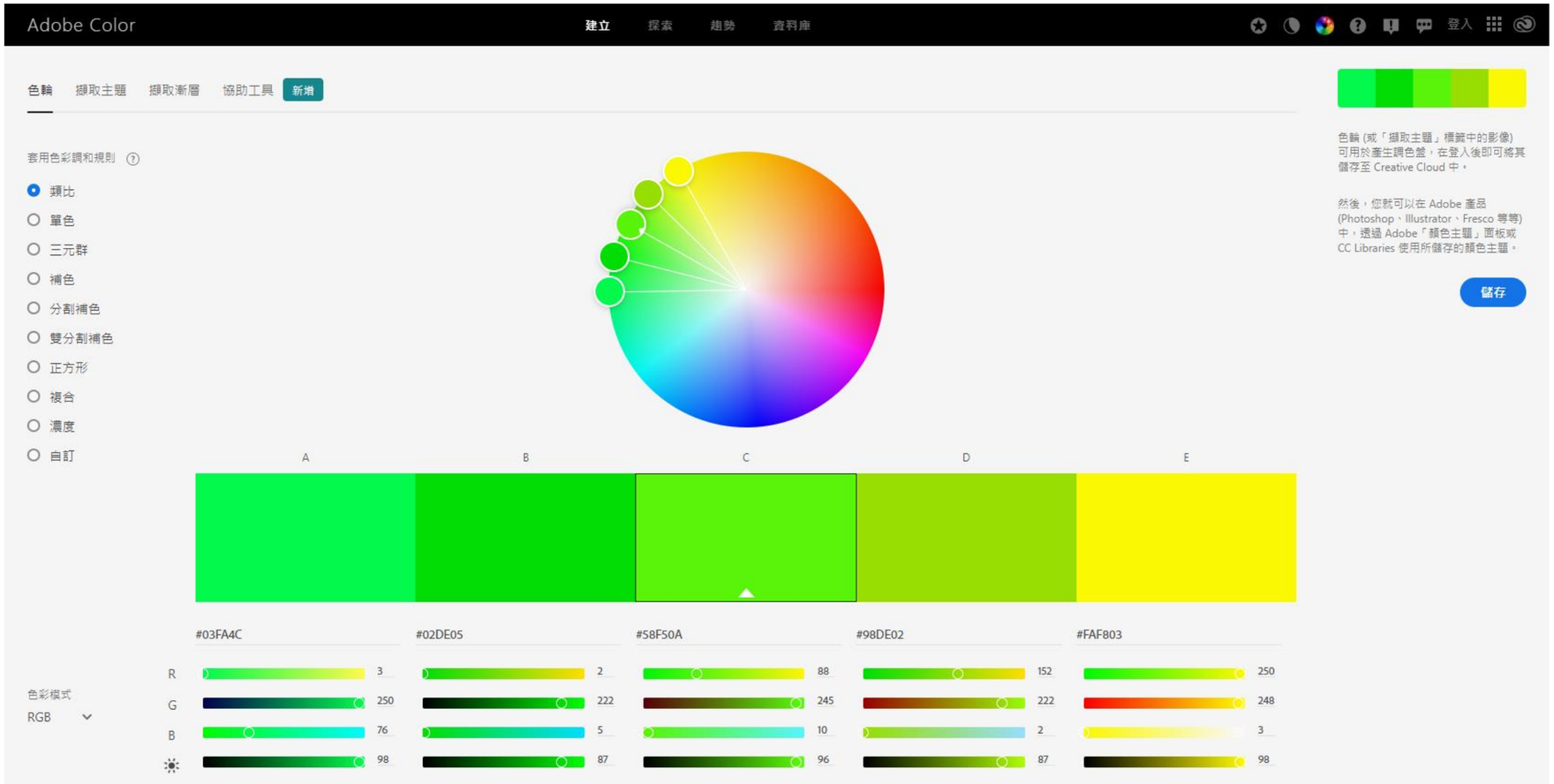
Color naming

- nameability affects
  - communication
  - memorability
- can integrate into color models
  - in addition to perceptual considerations

[Color Survey Results – xkcd]

Adobe Color Picker

- for general design purpose, not particularly for vis



https://color.adobe.com/create

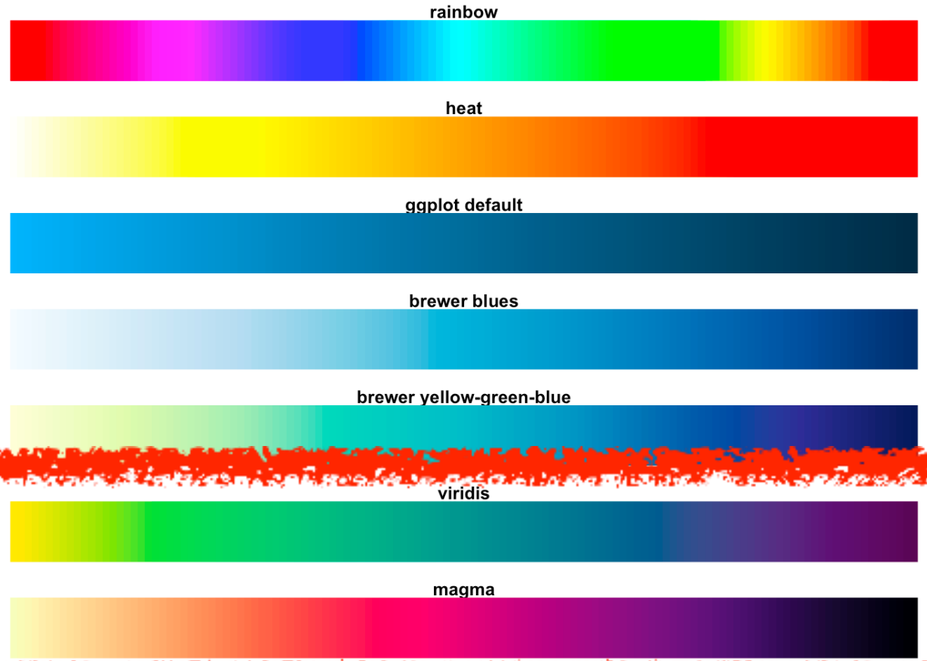
Color management in D3

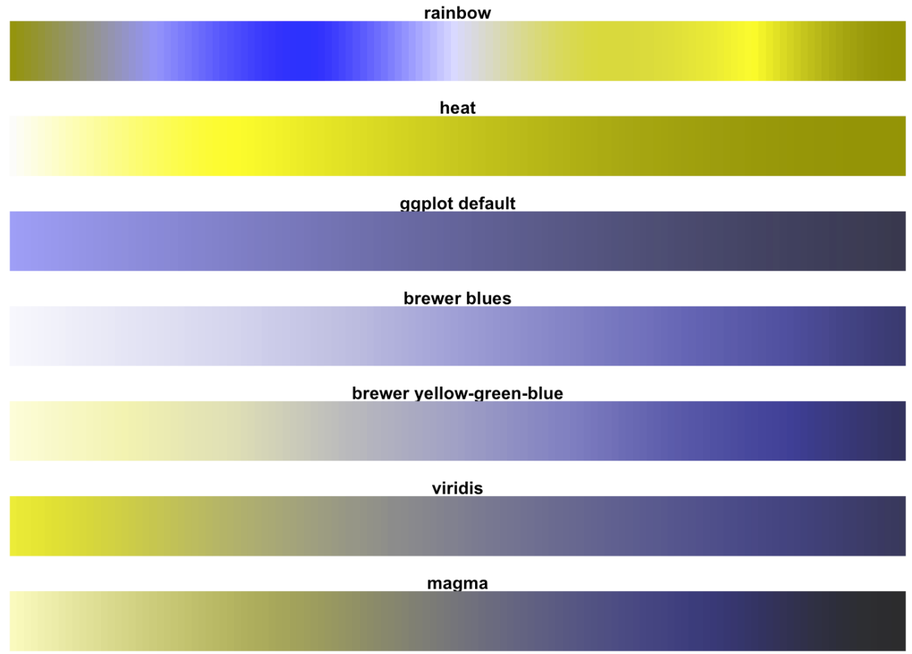
- D3-color
  - https://github.com/d3/d3-color
  - Conversion to/from different color spaces
  - Low-level computations
- D3-scale
  - https://github.com/d3/d3-scale
  - Customize your own color scale
  - using d3.scaleSequential() and d3.scaleOrdinal()
  - Use case: generate color schemes using the web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

Viridis

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





Green-Blind (Deuteranopia)

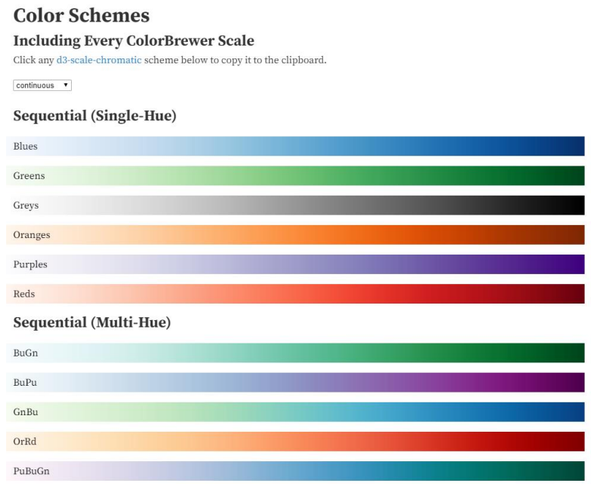
Desaturated

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

D3.js scale-chromatic

```
var accent =
d3.scaleOrdinal(d3.schemeAccent);
```

```
var piyg = d3.scaleSequential(d3.interpolatePiYG);
```



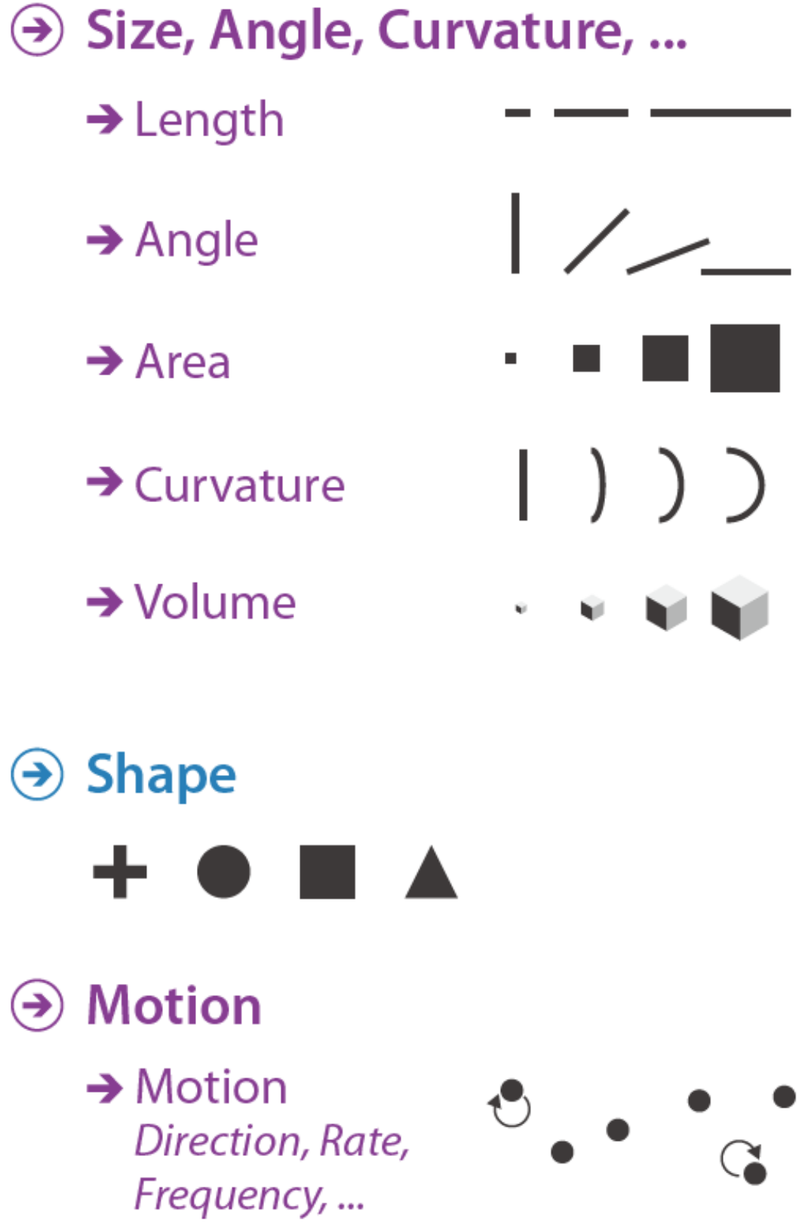
demo

```
var    yellow = d3.interpolateYlGn(0), // "rgb(255, 255, 229)"
yellowGreen = d3.interpolateYlGn(0.5), // "rgb(120, 197, 120)"
      green = d3.interpolateYlGn(1); // "rgb(0, 69, 41)"
```

Given a number *t* in the range [0,1], returns the corresponding color from the “RdYlGn” diverging color scheme represented as an RGB string.

Map other channels

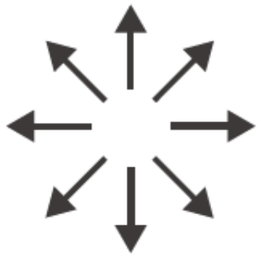
- size
  - length accurate, 2D area ok, 3D volume poor
- angle
  - nonlinear accuracy
    - horizontal, vertical, exact diagonal
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - binary: great for highlighting
  - use with care to avoid irritation



Angle

Sequential ordered
line mark or arrow glyph

Diverging ordered
arrow glyph



Cyclic ordered
arrow glyph

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014
  - *Chap 10: Map Color and Other Channels*
- ColorBrewer, Brewer.
  - http://www.colorbrewer2.org
- *Color In Information Display*. Stone. IEEE Vis Course Notes, 2006.
  - http://www.stonesc.com/Vis06
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- *Rainbow Color Map (Still) Considered Harmful.* Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14–17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.
- https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html