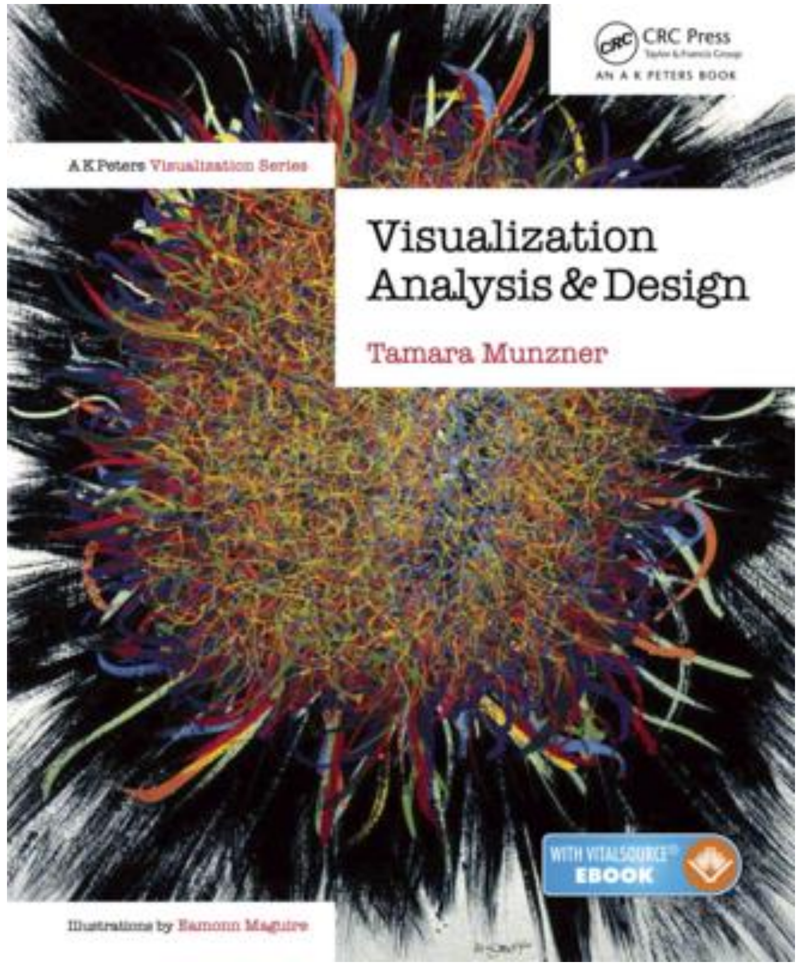
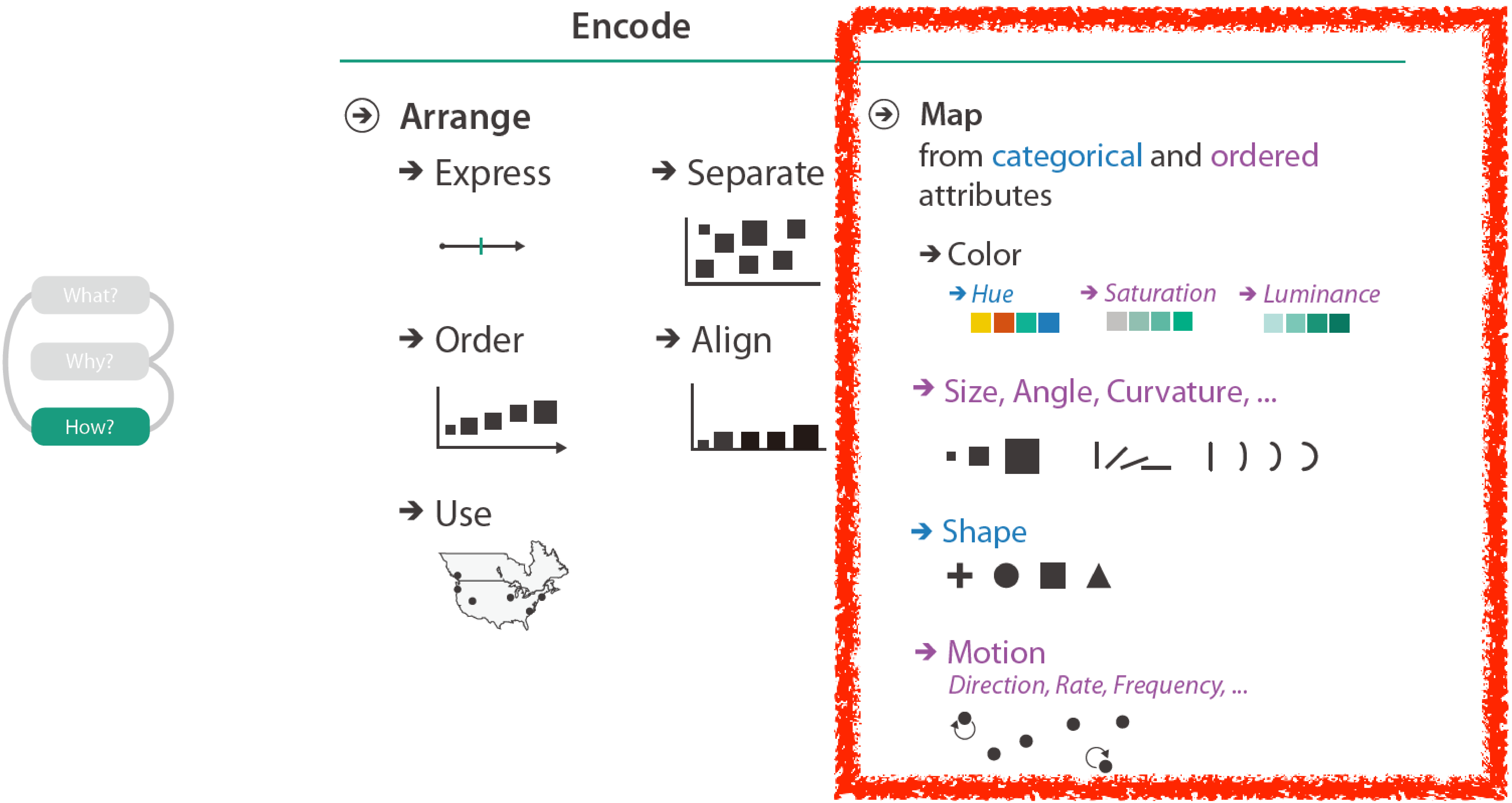
Color

Yu-Shuen Wang, CS, NCTU

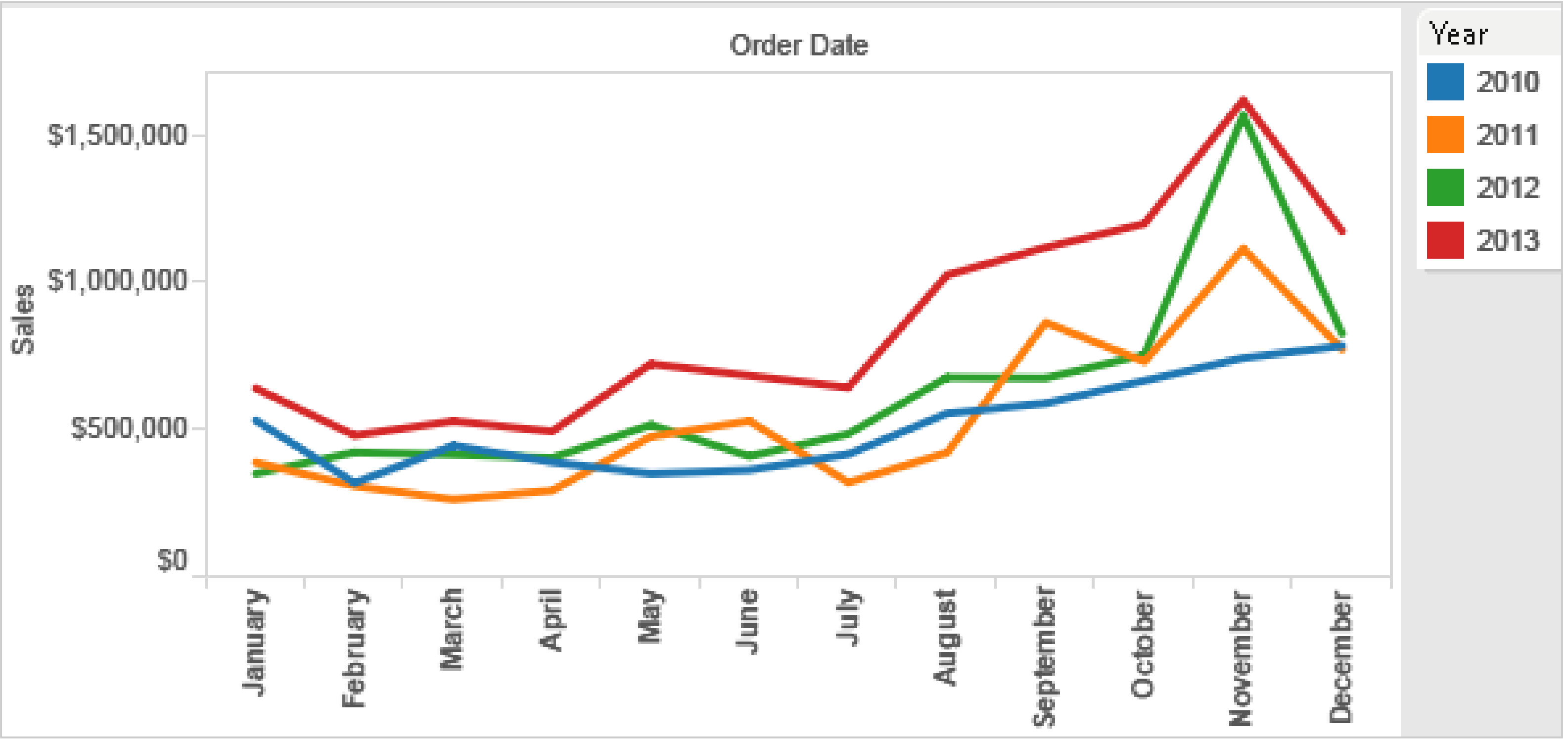


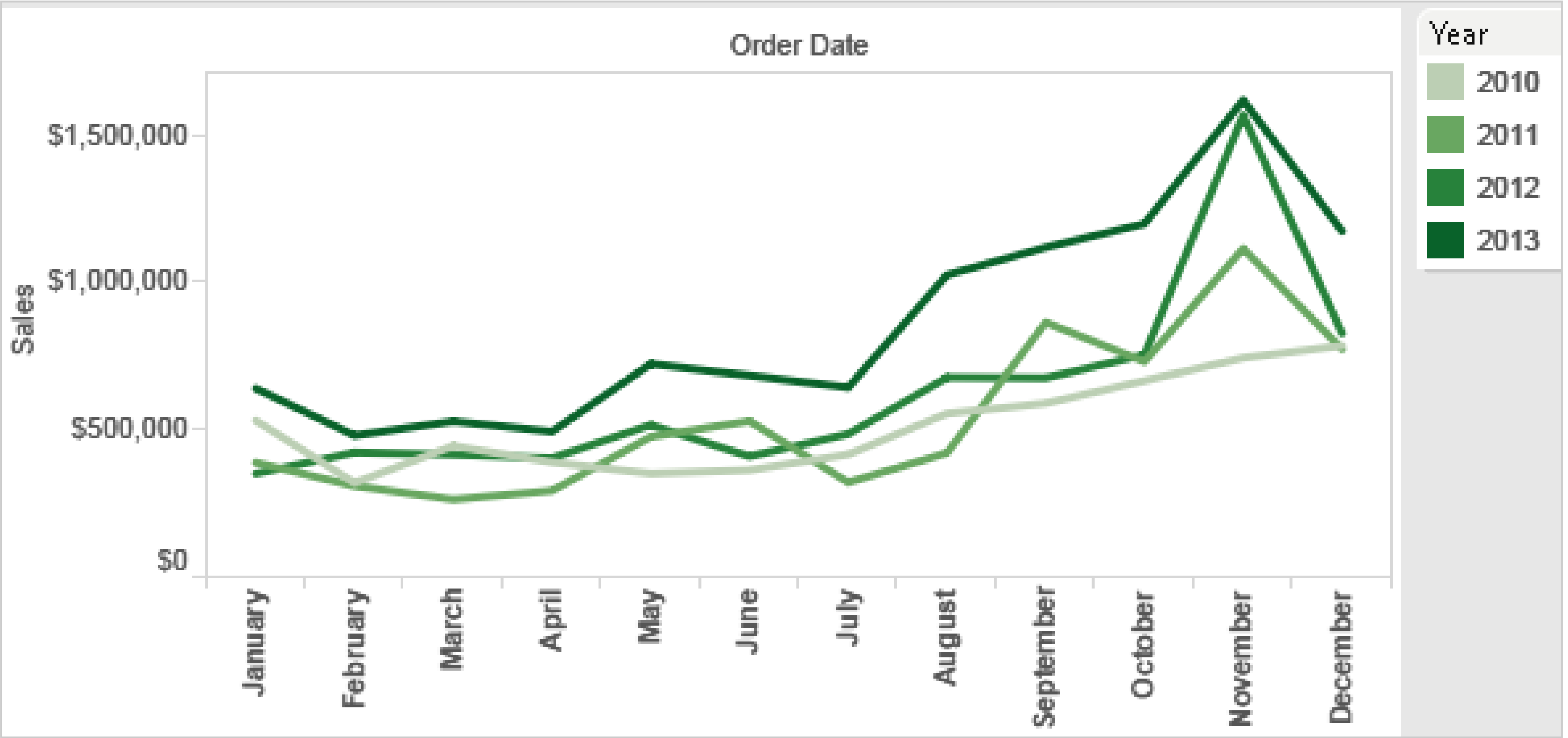
- Slides refer to https://www.cs.ubc.ca/~tmm/

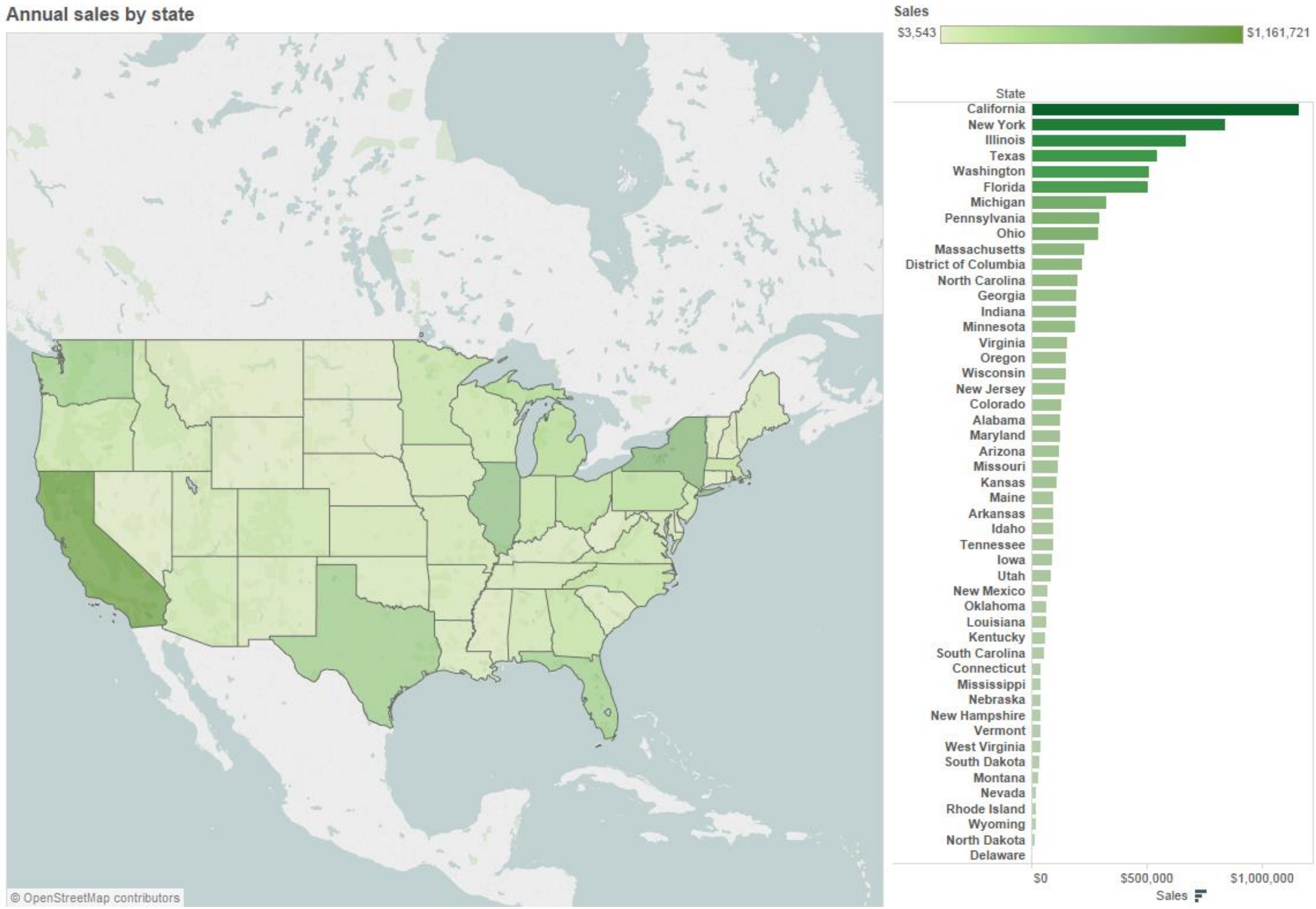
Idiom design choices: Encode



Categorical vs ordered color





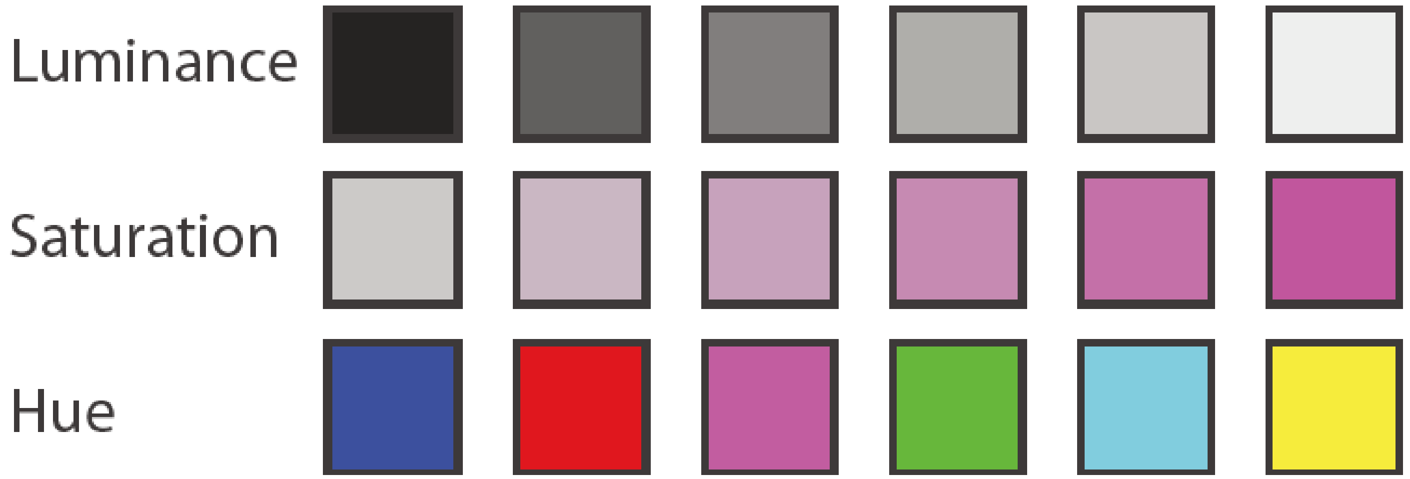


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color: Luminance, saturation, hue

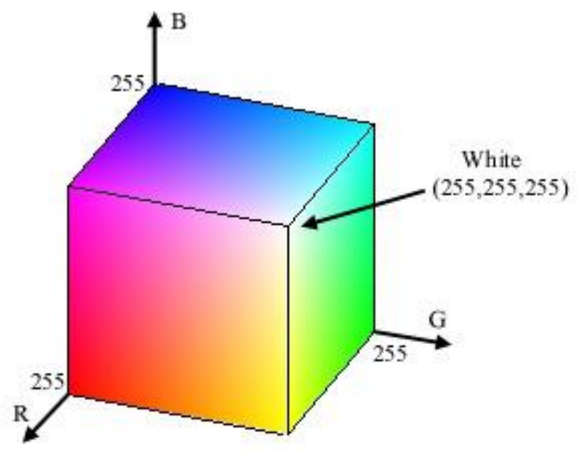
- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic

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

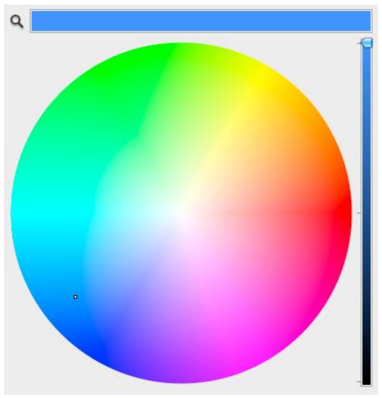


Color spaces

- RGB: poor for encoding



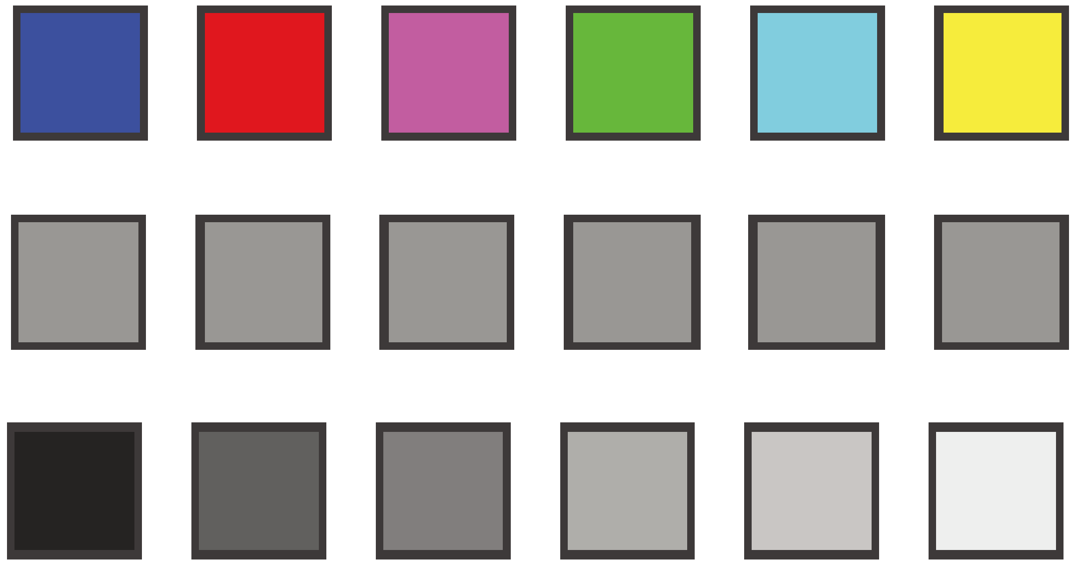
- HSL: better, but beware
  - –lightness ≠ luminance



Corners of the RGB color cube

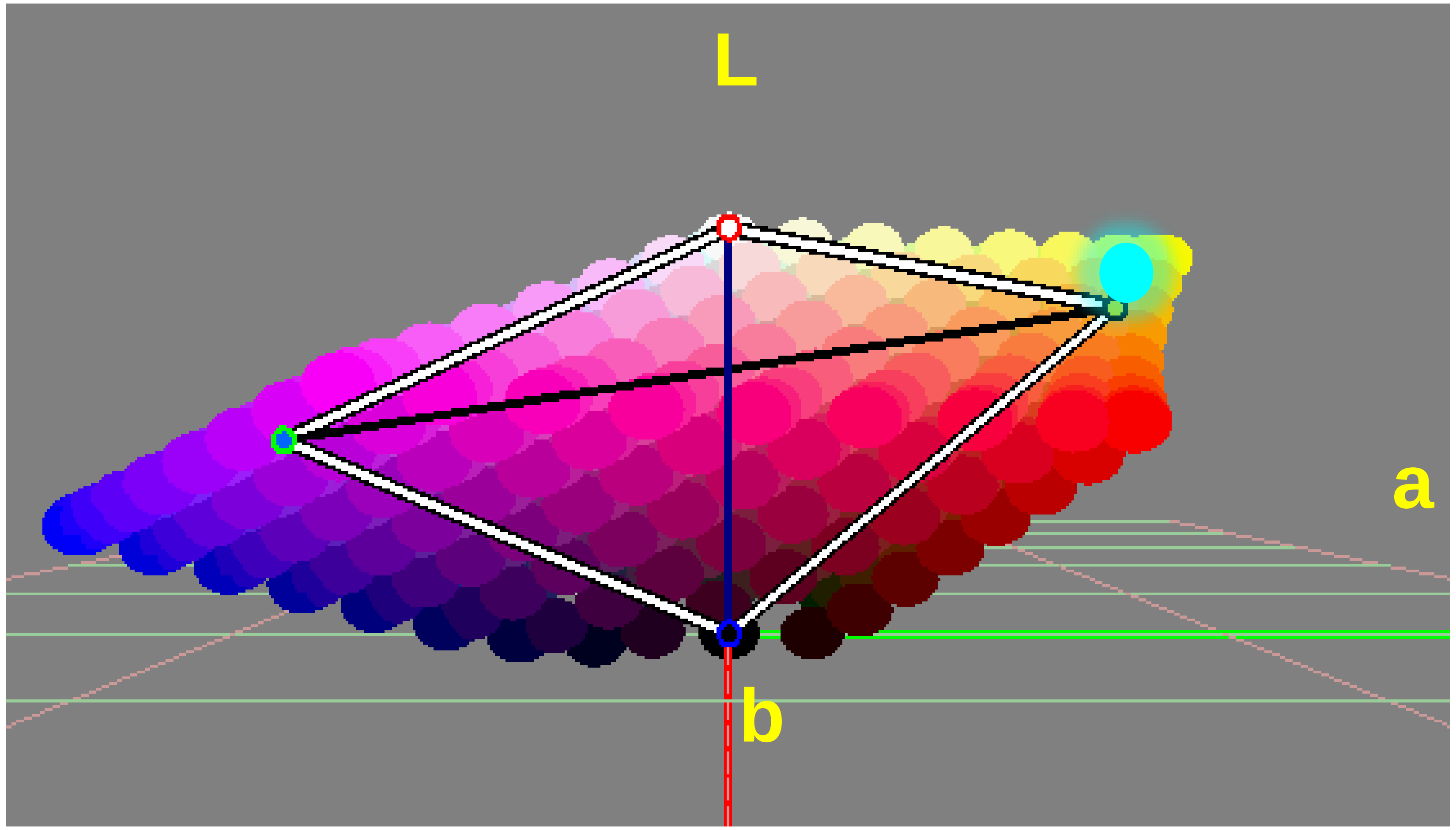
L from HLS
All the same

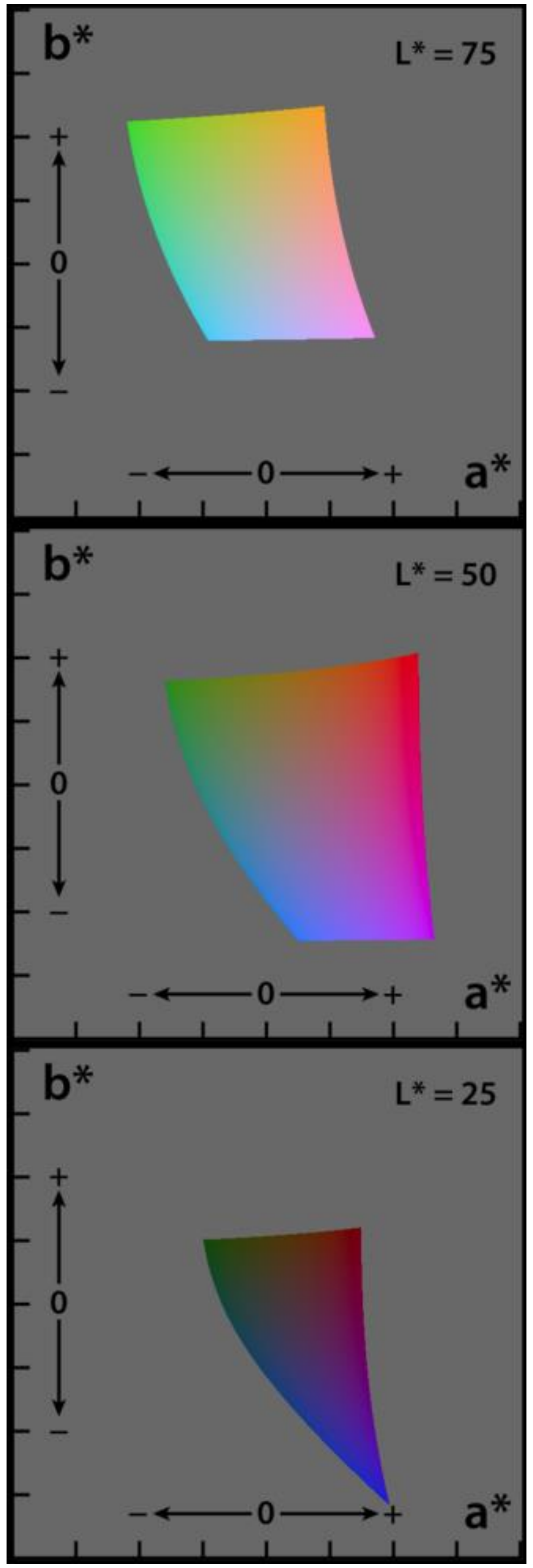
Luminance values



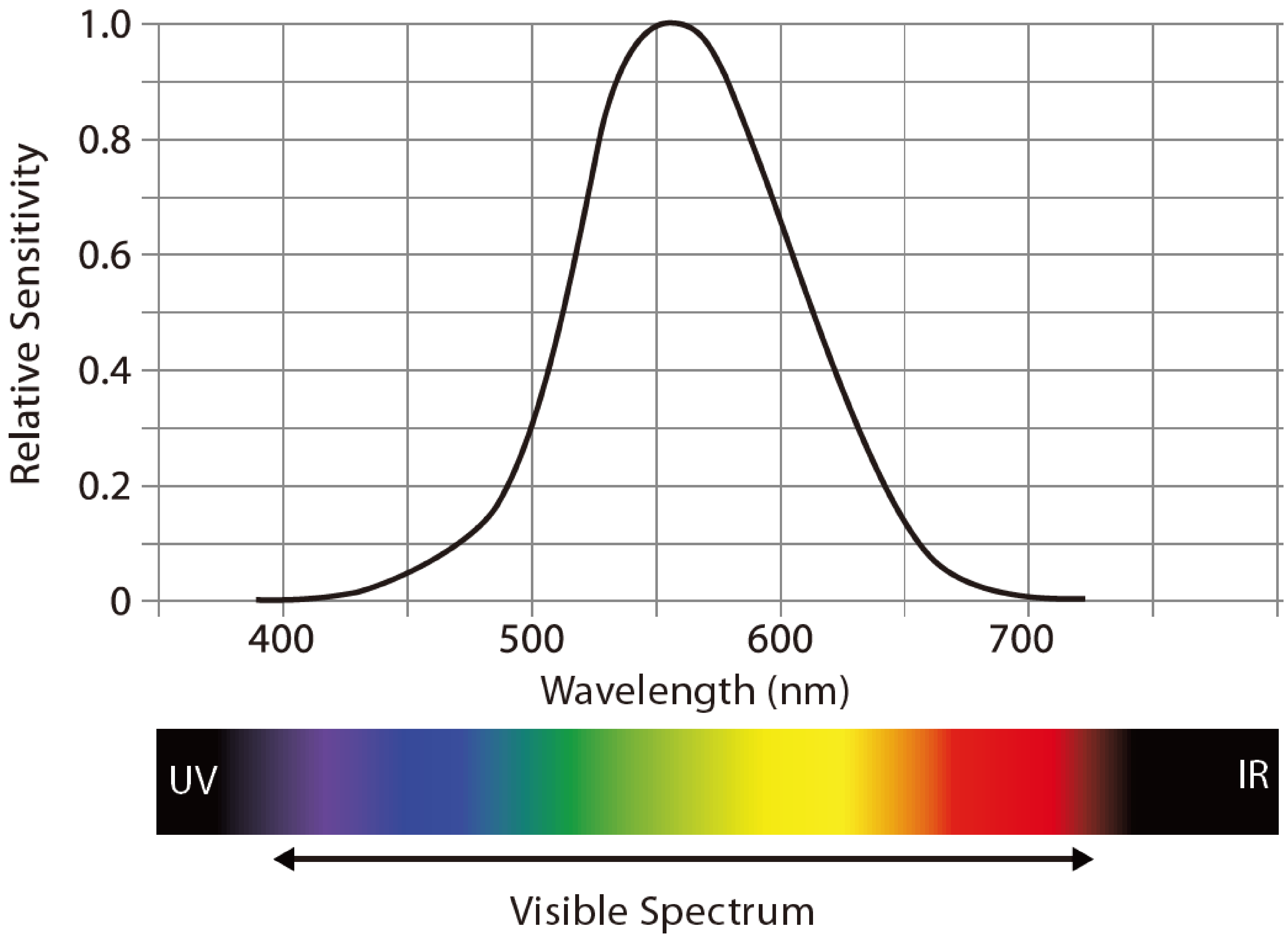
Color spaces

- CIE L*A*B* color space
  - Perception uniform color space



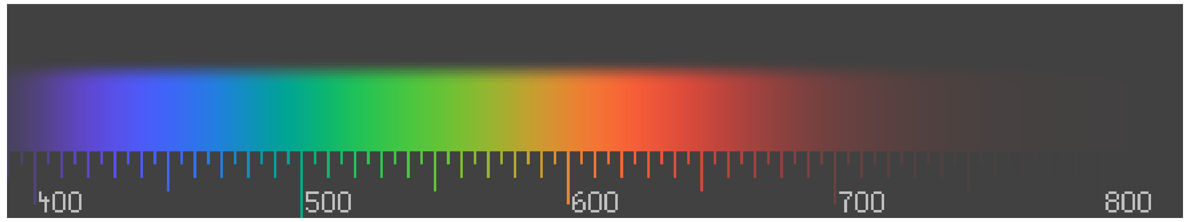


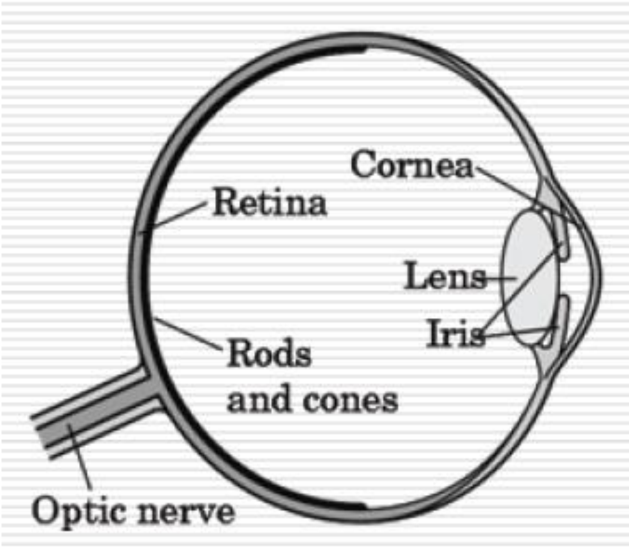
Spectral sensitivity

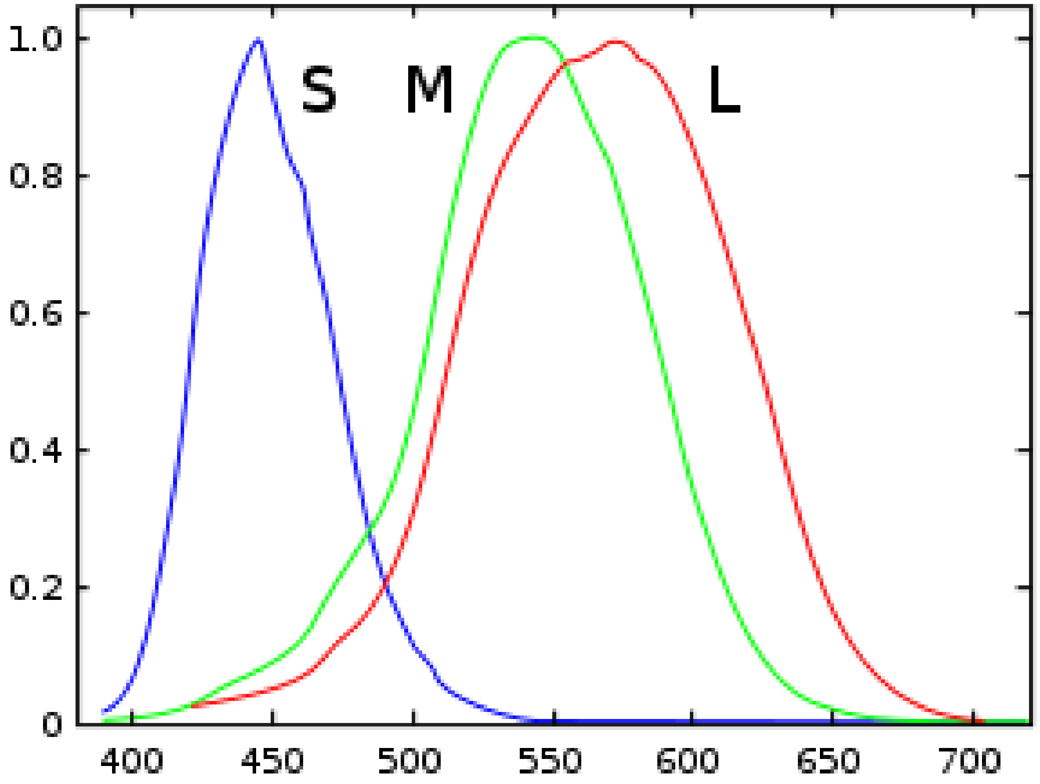


Three-Color Theory

- 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*

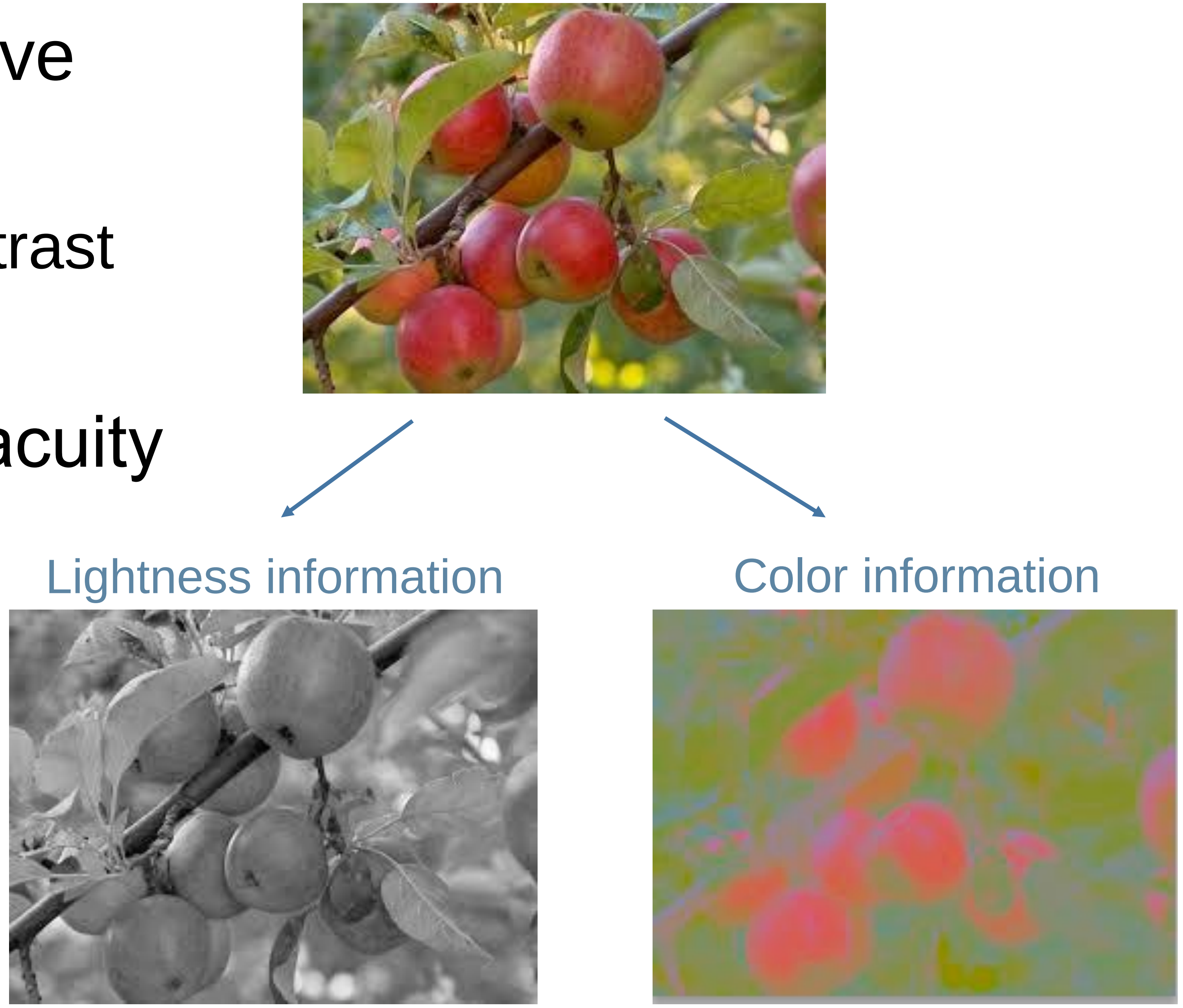




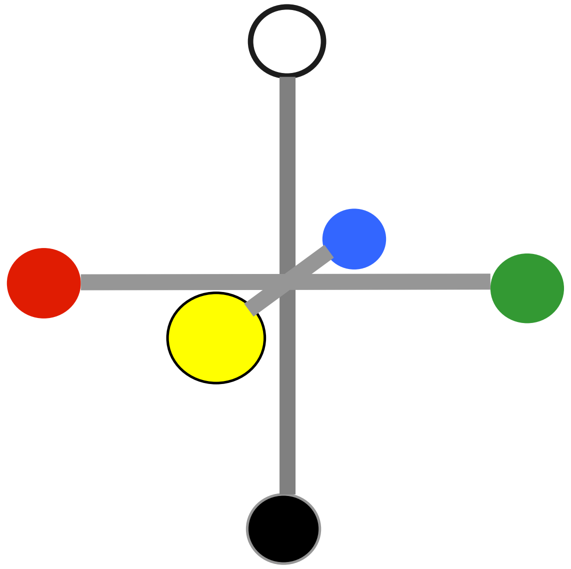


Opponent color and color deficiency

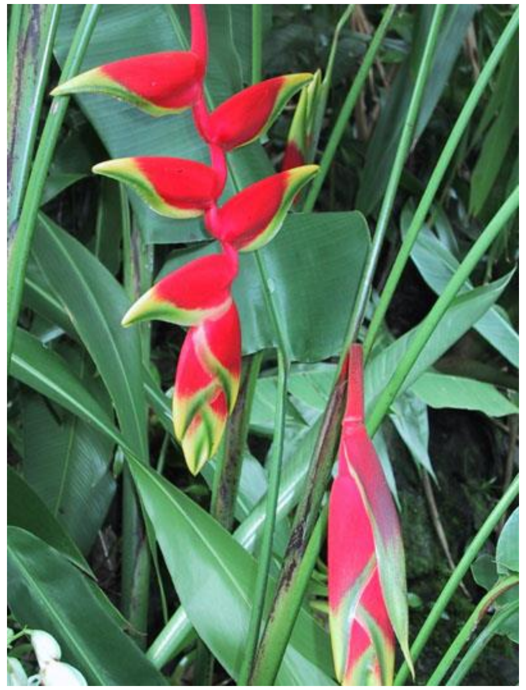
- perceptual processing before optic nerve
  - one achromatic luminance channel L
    - edge detection through luminance contrast
  - two chroma channels, R-G and Y-B axis
- “color blind” if one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare



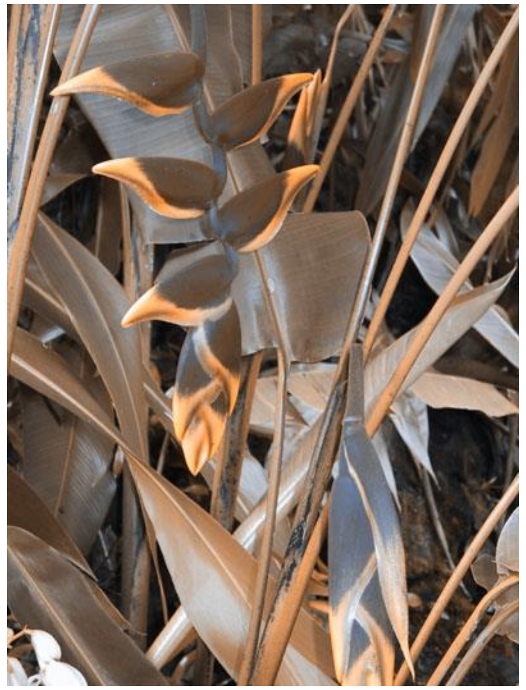
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]



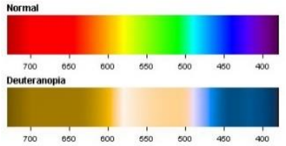
Designing for color deficiency: Check with simulator

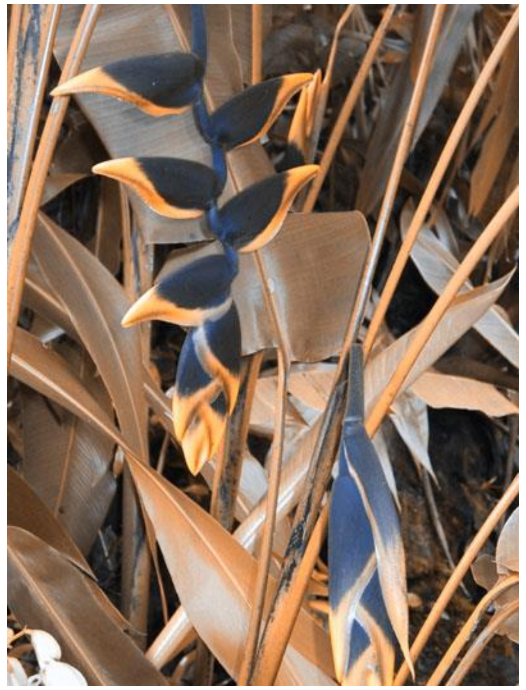


Normal vision

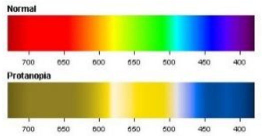


Deuteranope

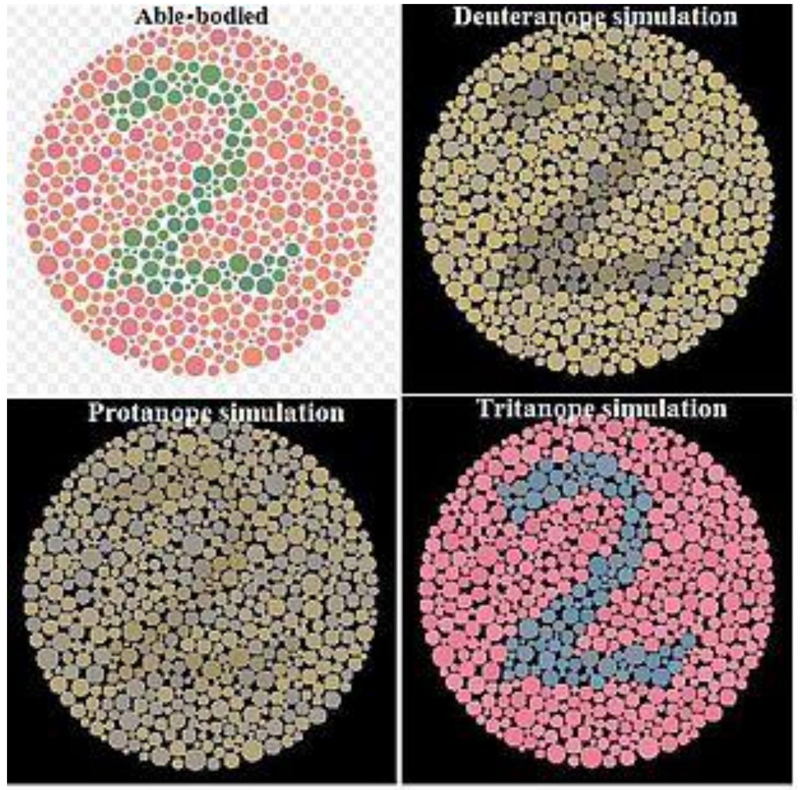


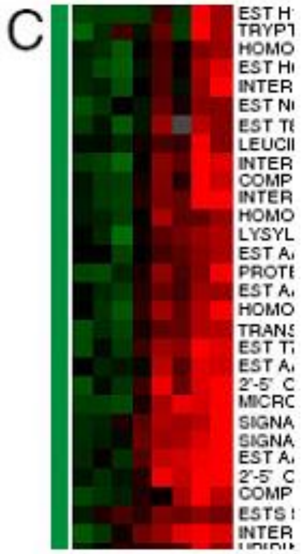


Protanope



Tritanope





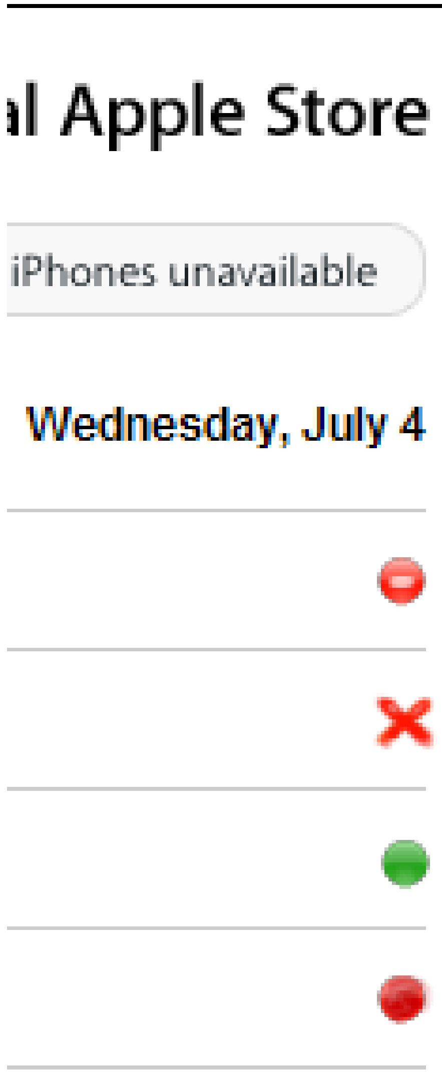
~~http://rehue.net~~

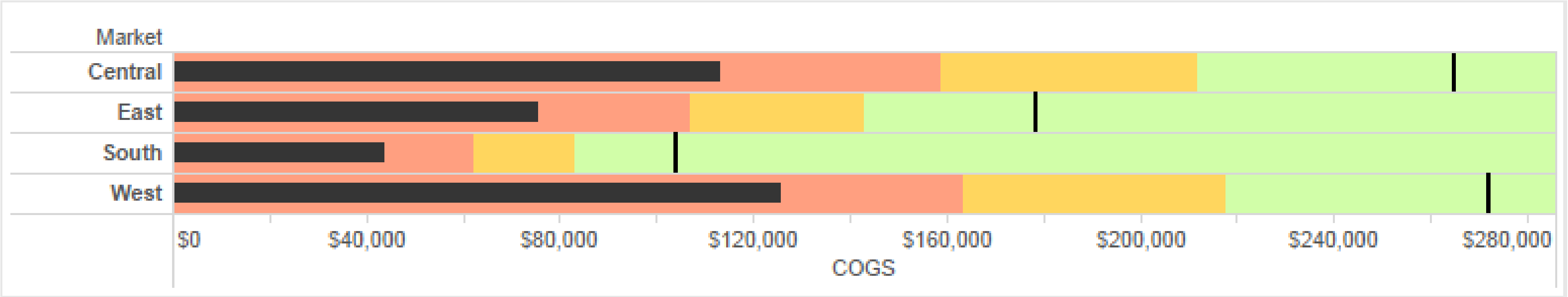
color blind simulation

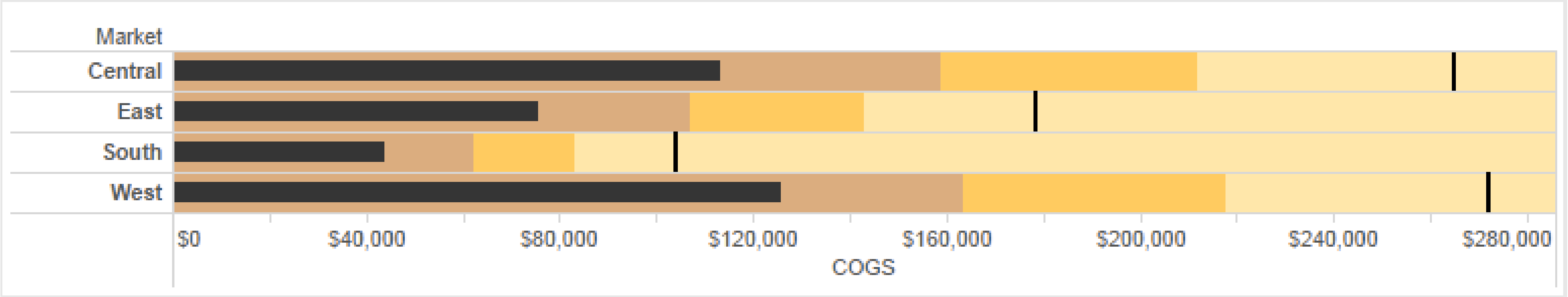
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape



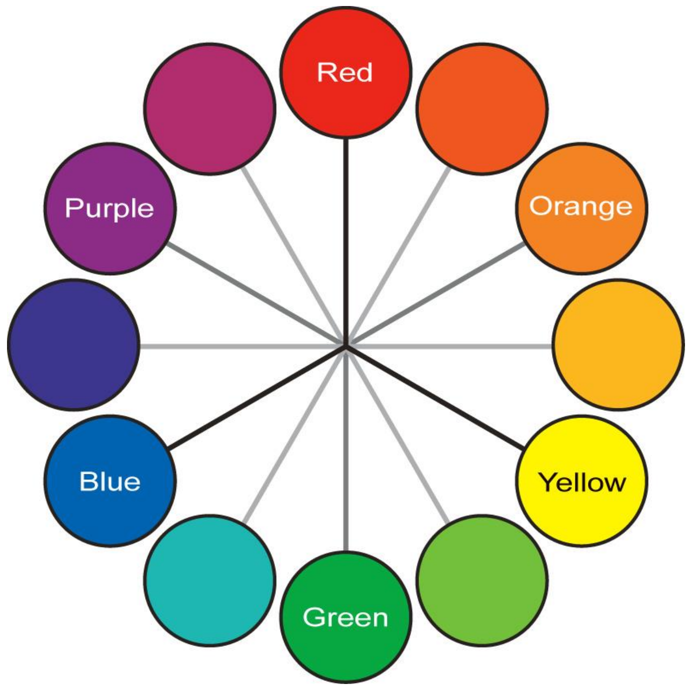




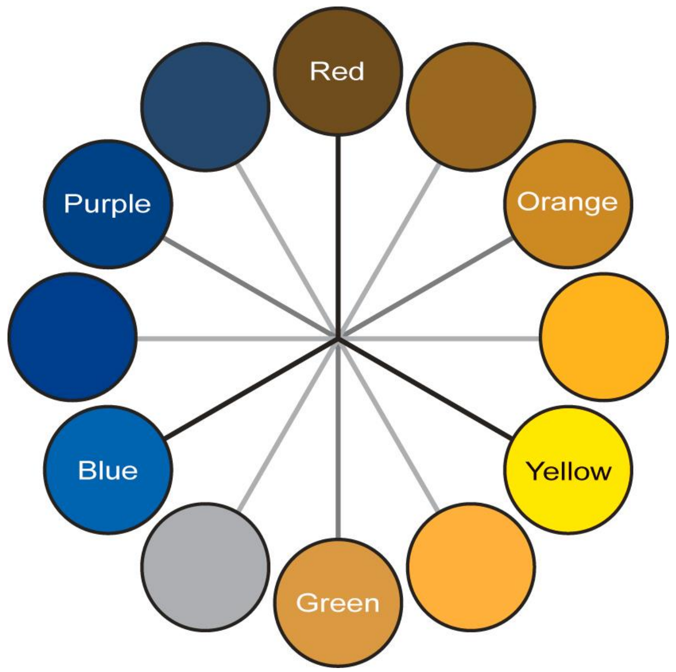
Deuteranope simulation

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

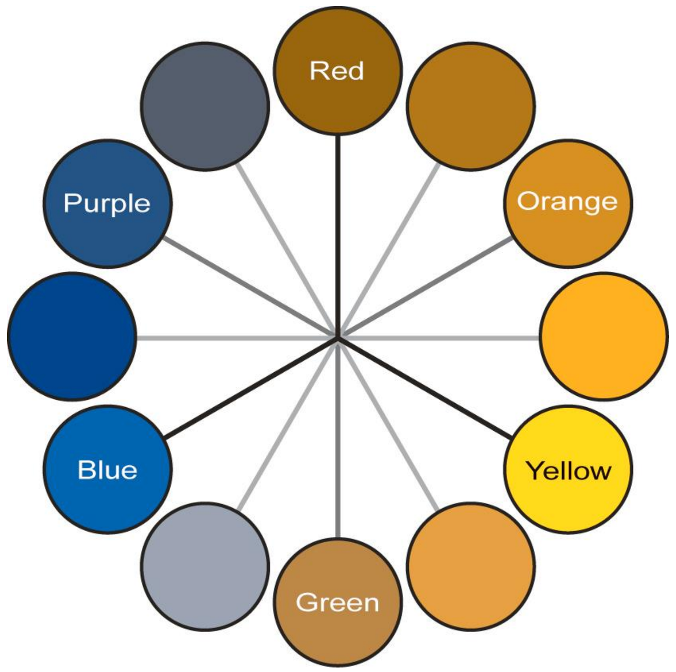
Color deficiency: Reduces color to 2 dimensions



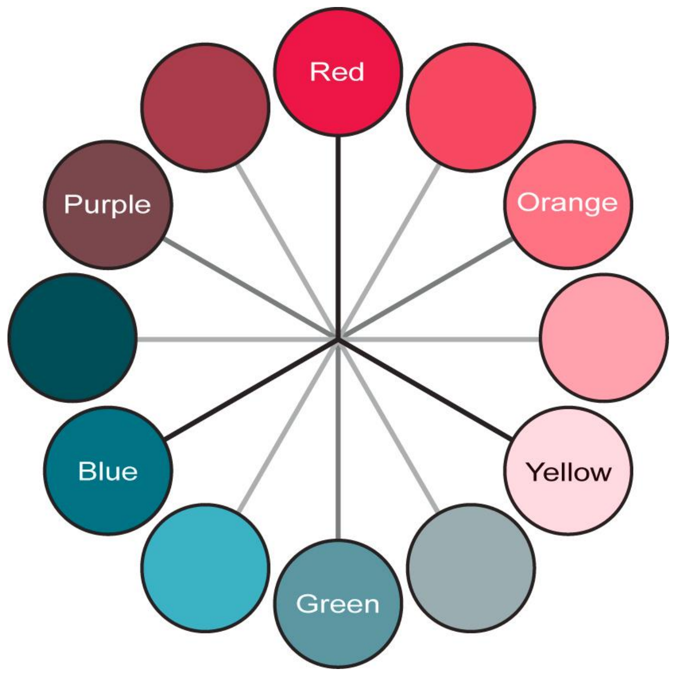
Normal



Protanope



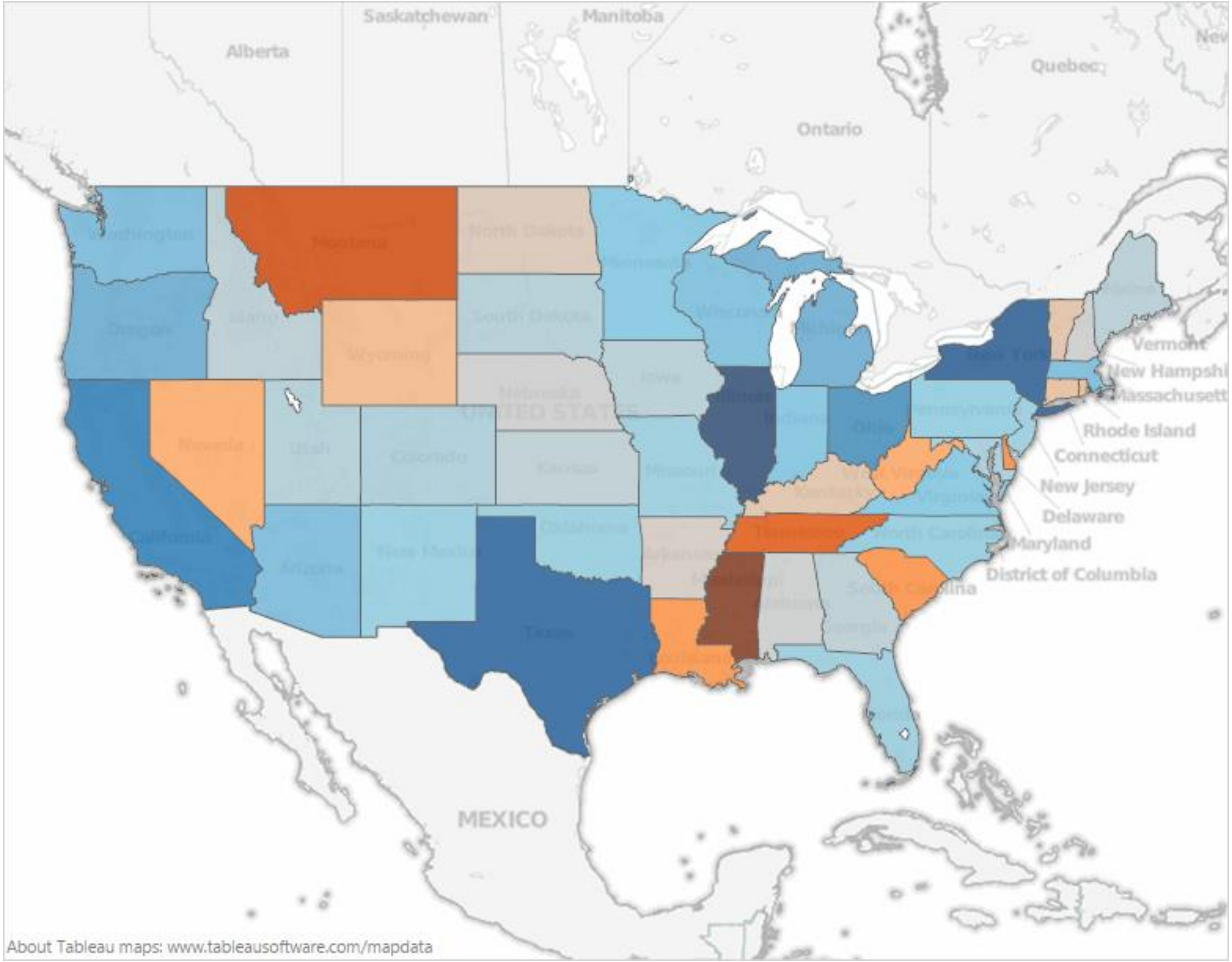
Deuteranope



Tritanope

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

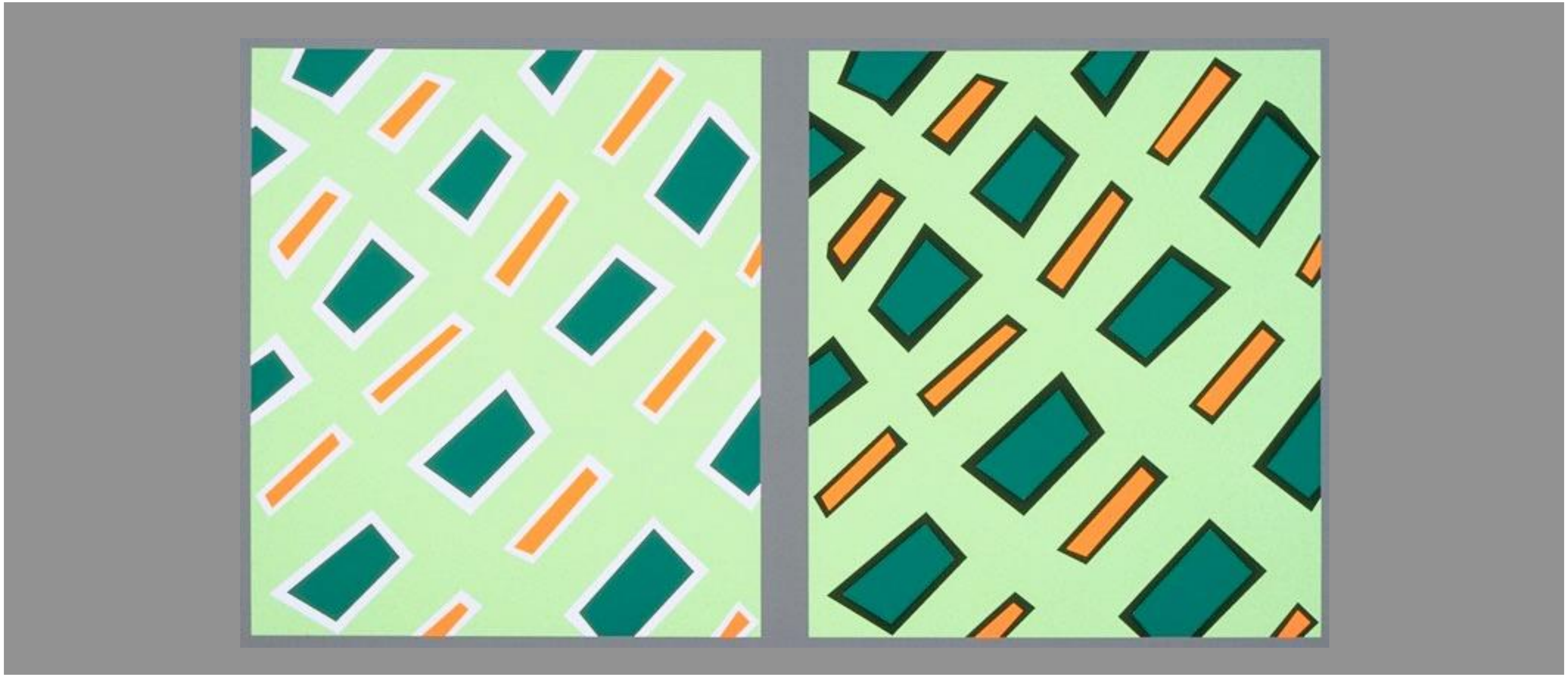
Designing for color deficiency: Blue-Orange is safe



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

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

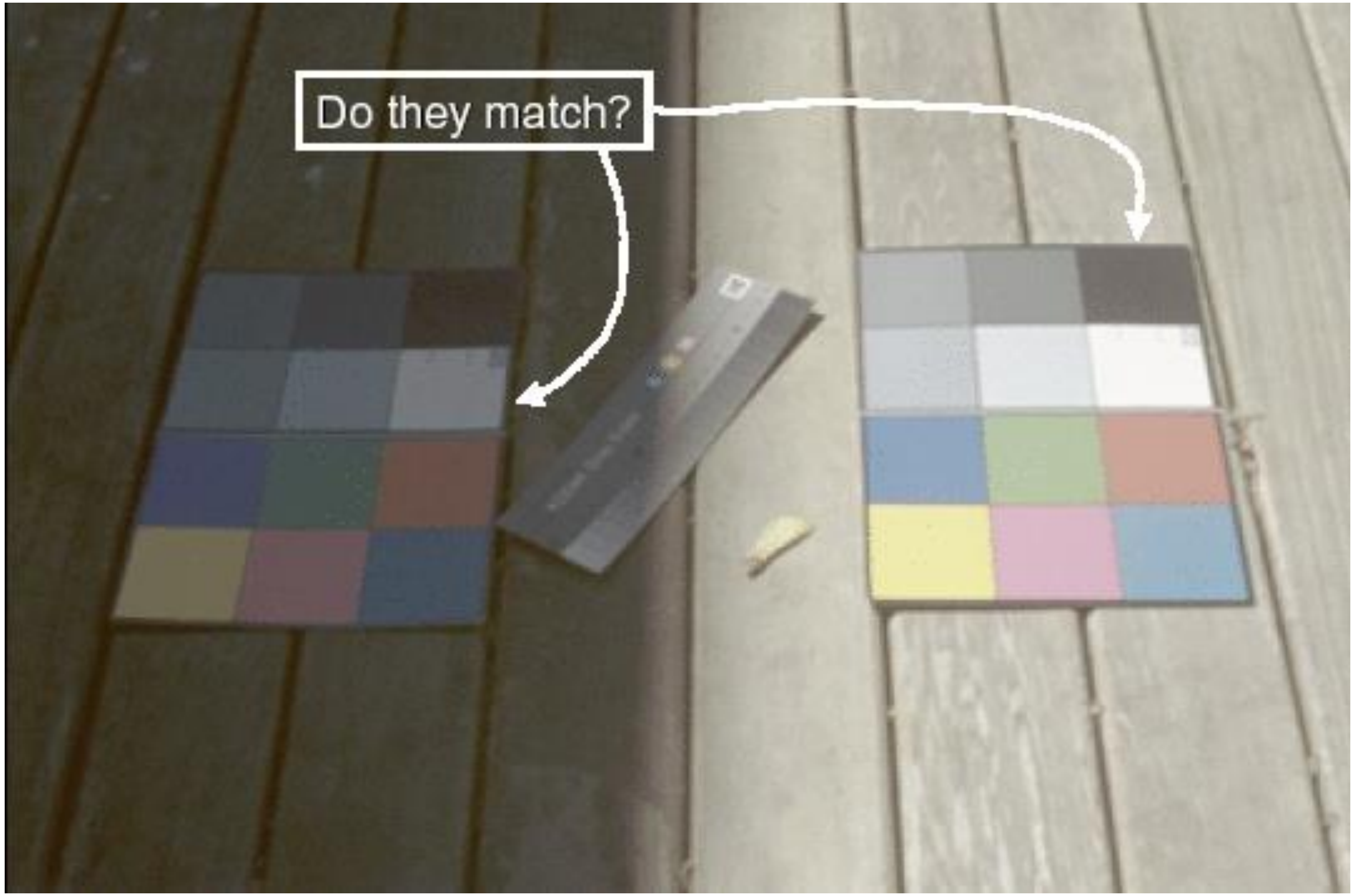


Image courtesy of John McCann

Color/Lightness constancy: Illumination conditions

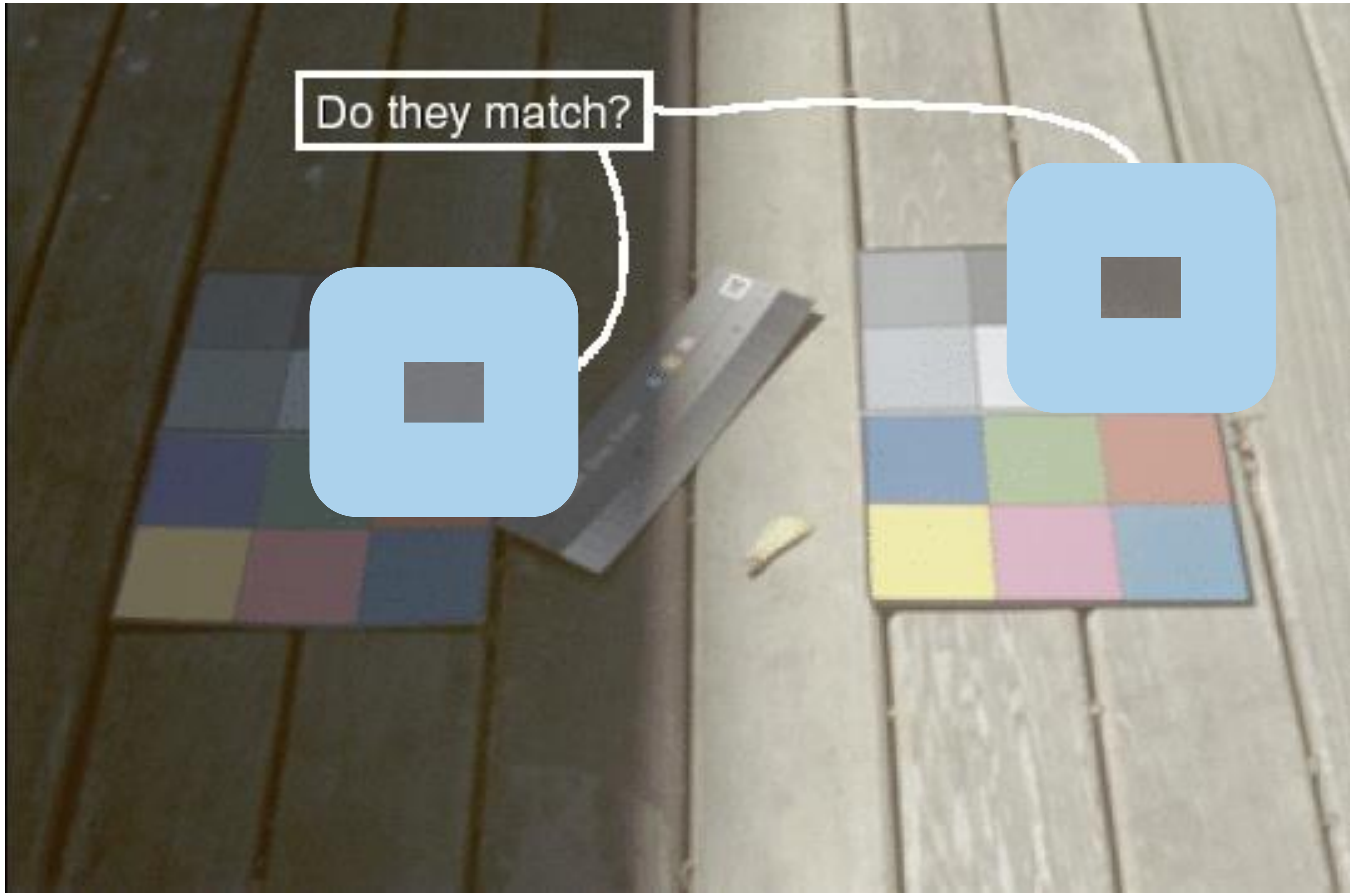
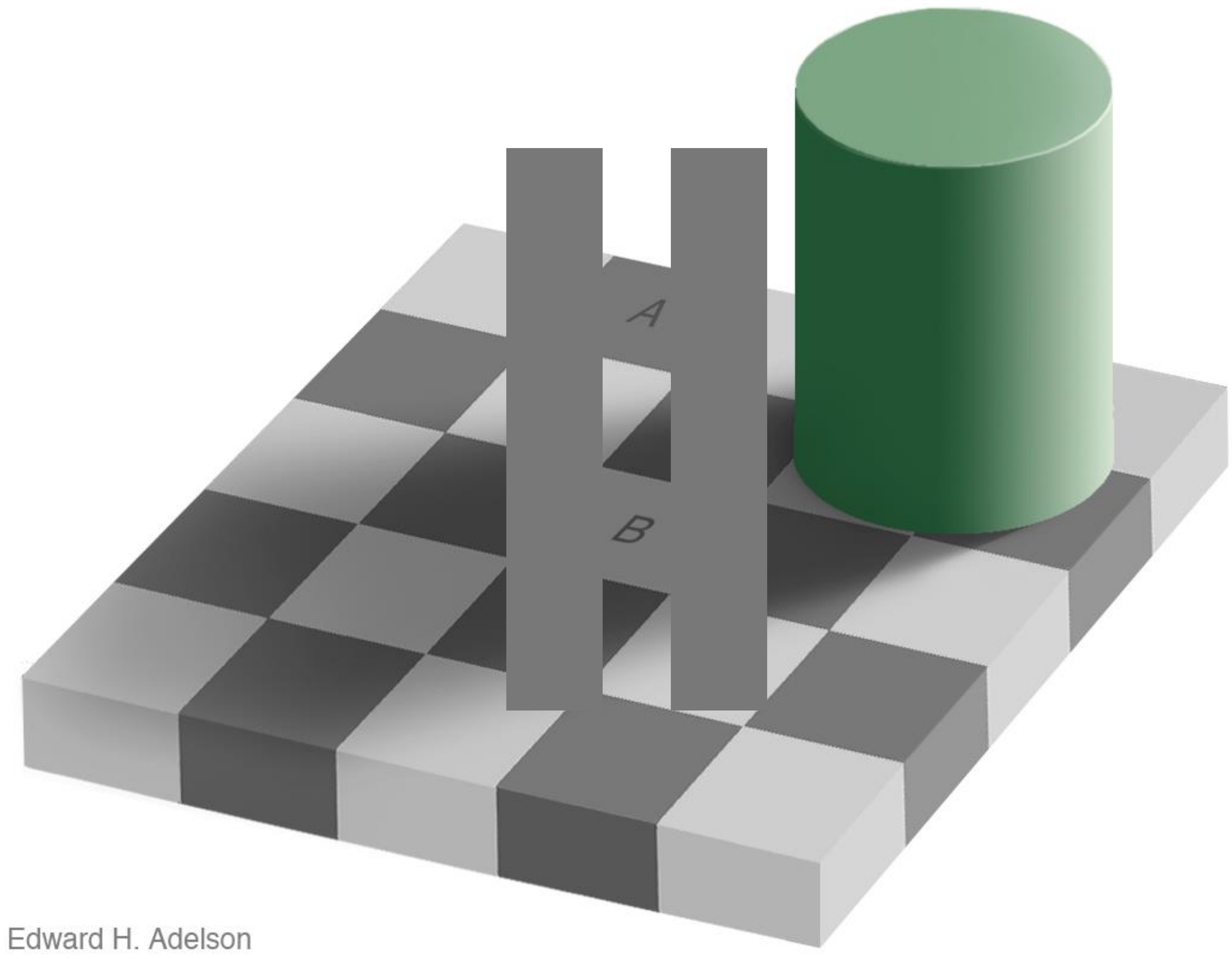


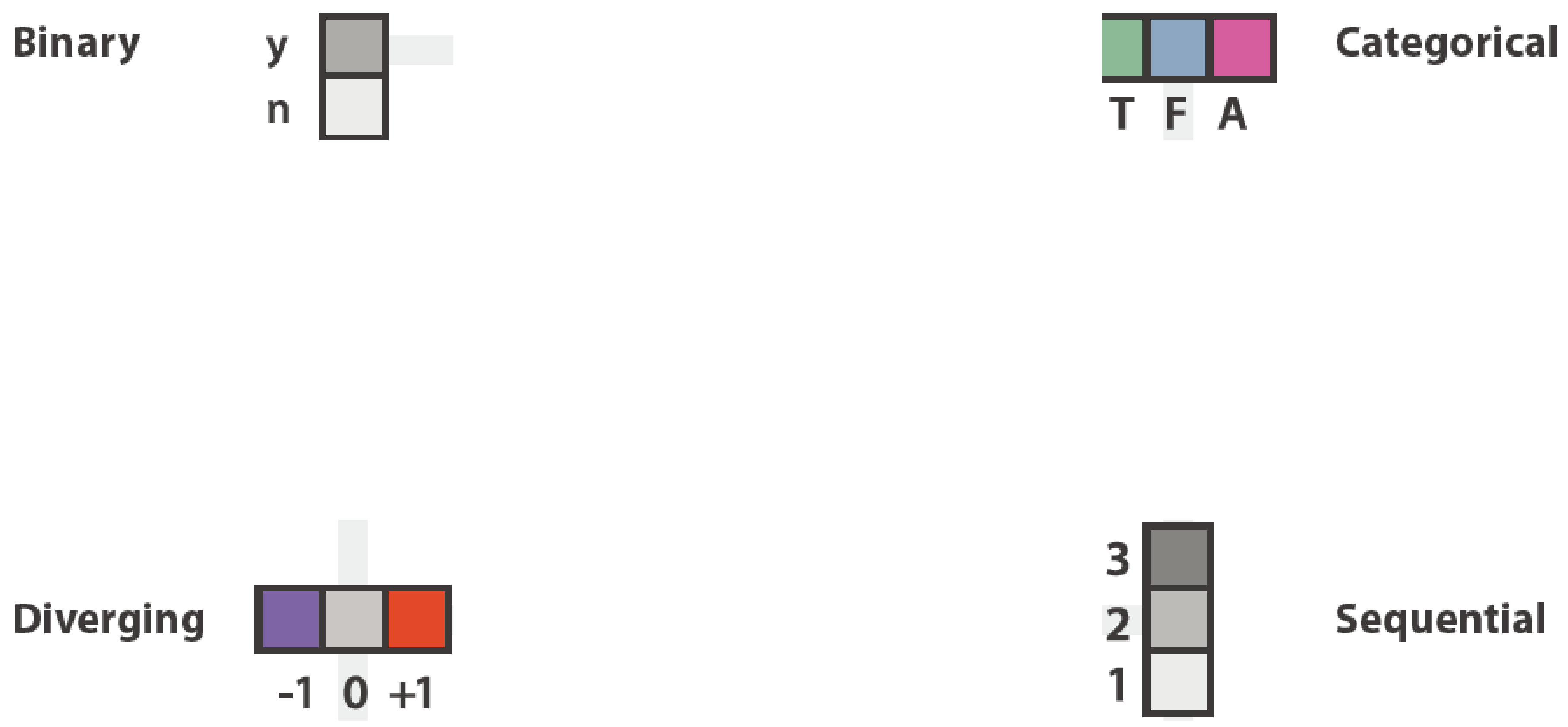
Image courtesy of John McCann

Checker shadow Illusion



Colormaps

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



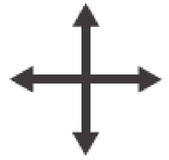
[after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)

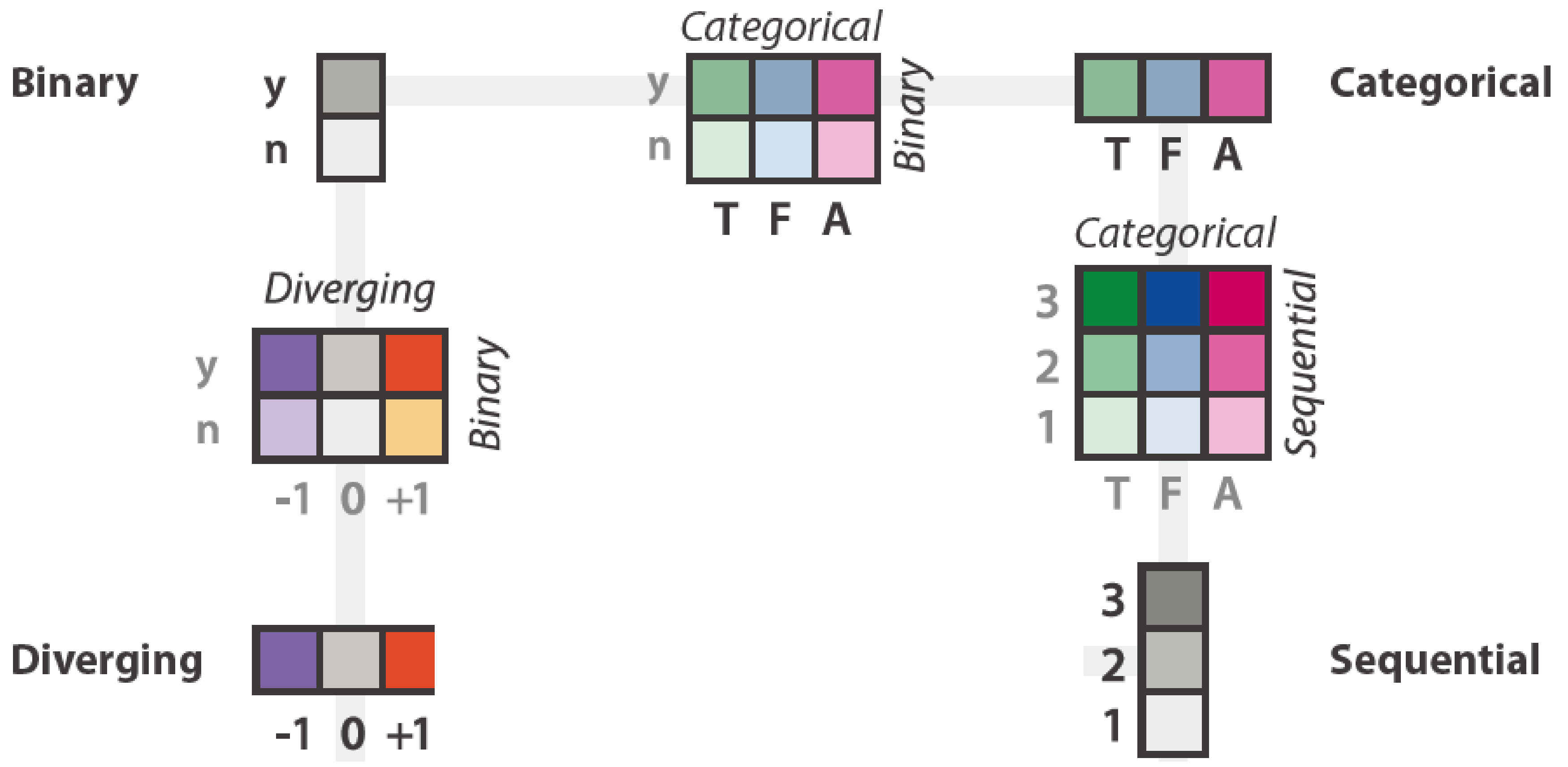
Colormaps

- 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]

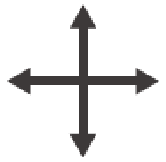
Colormaps

- Categorical

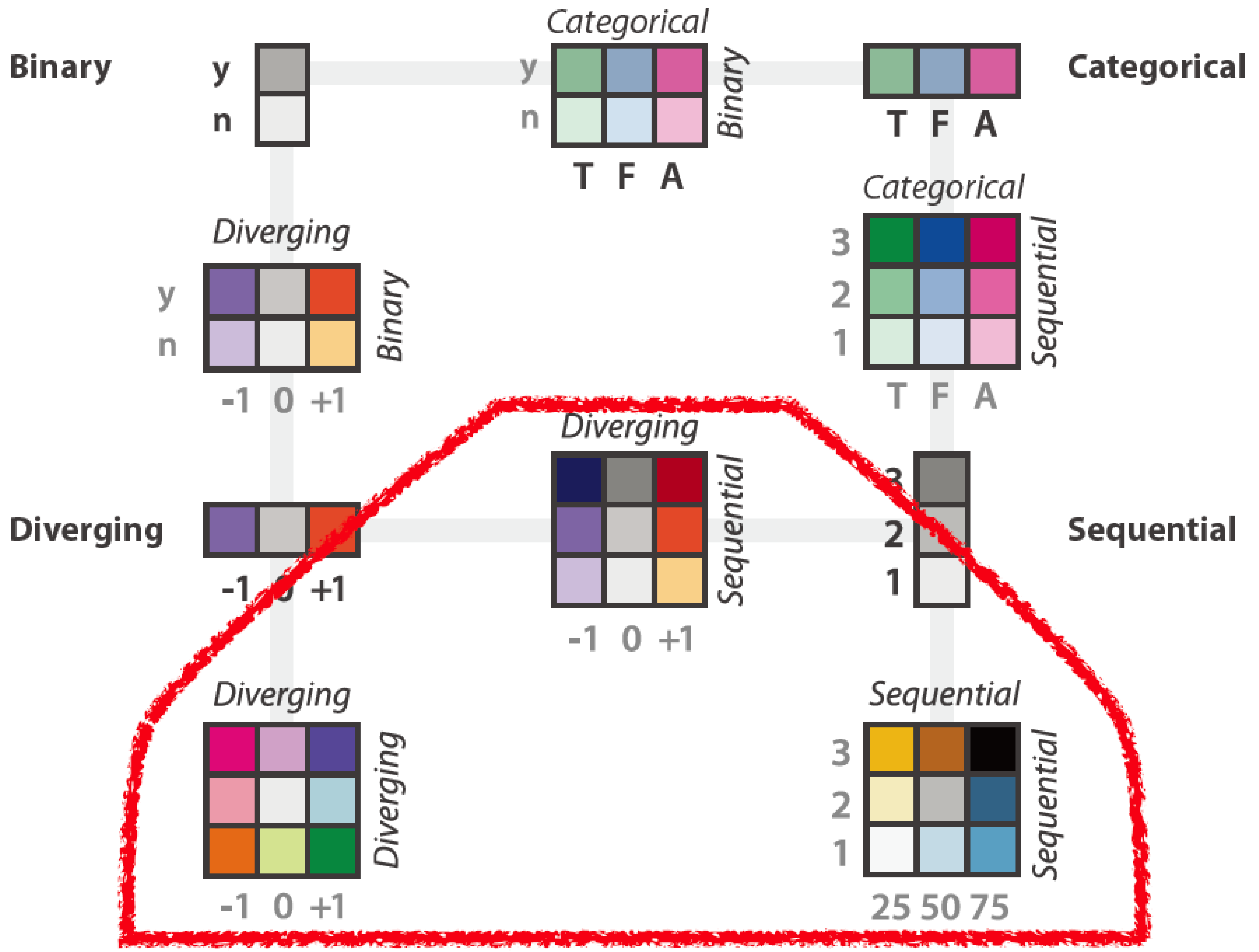
- Ordered
  - *Sequential*

  - *Diverging*

- Bivariate

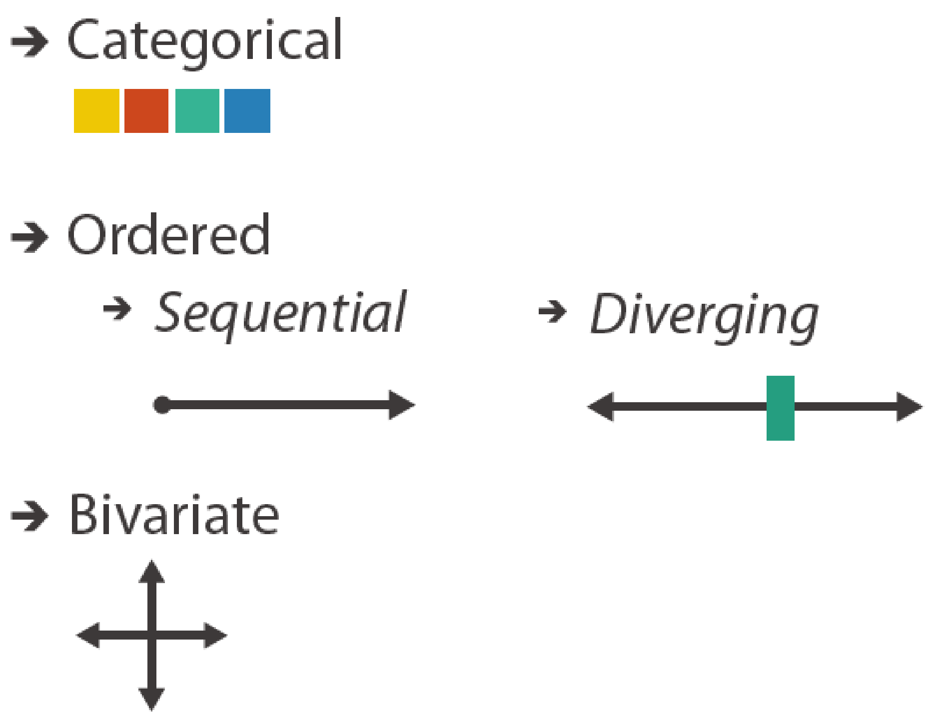


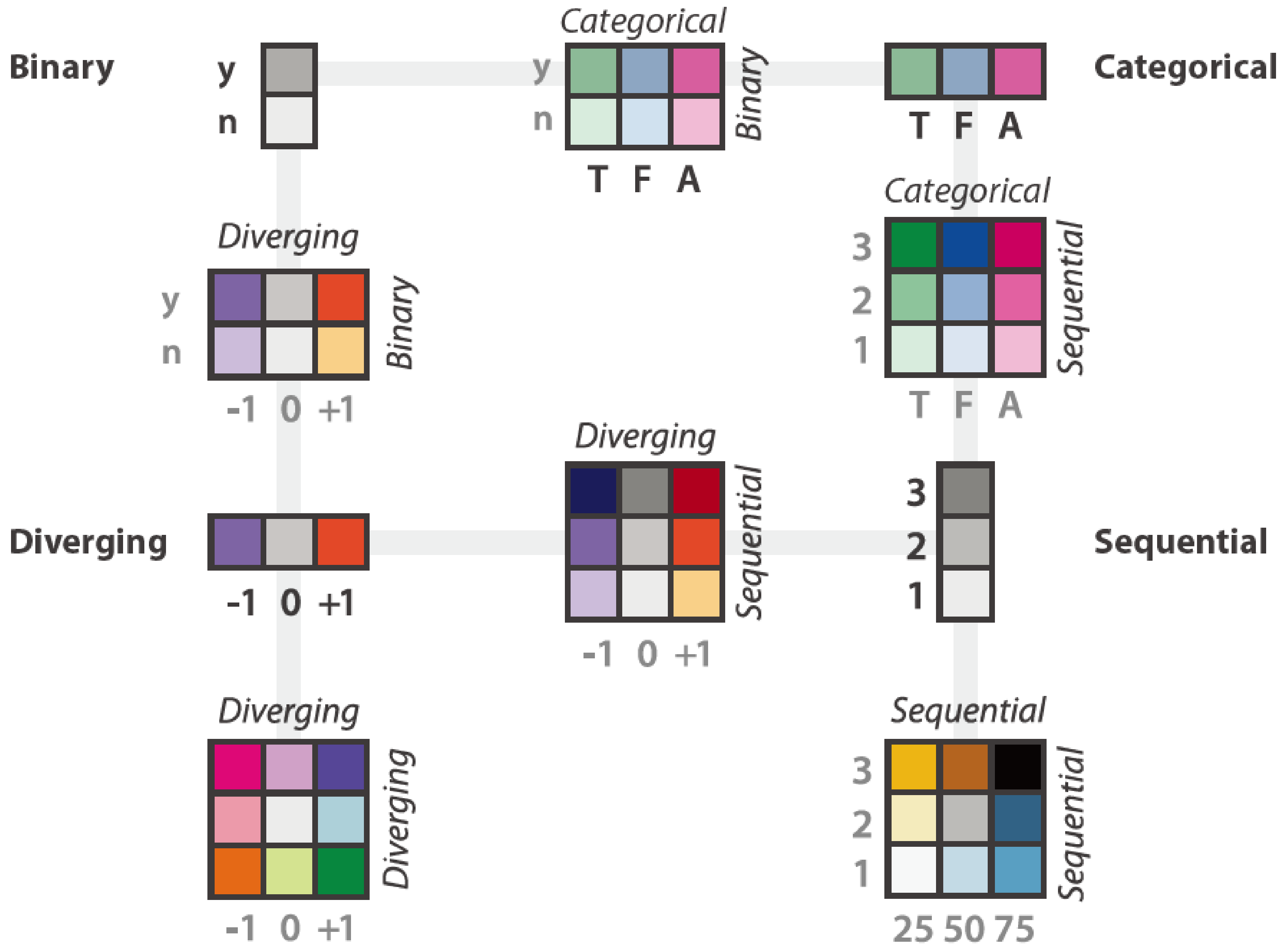
use with care!



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

Colormaps



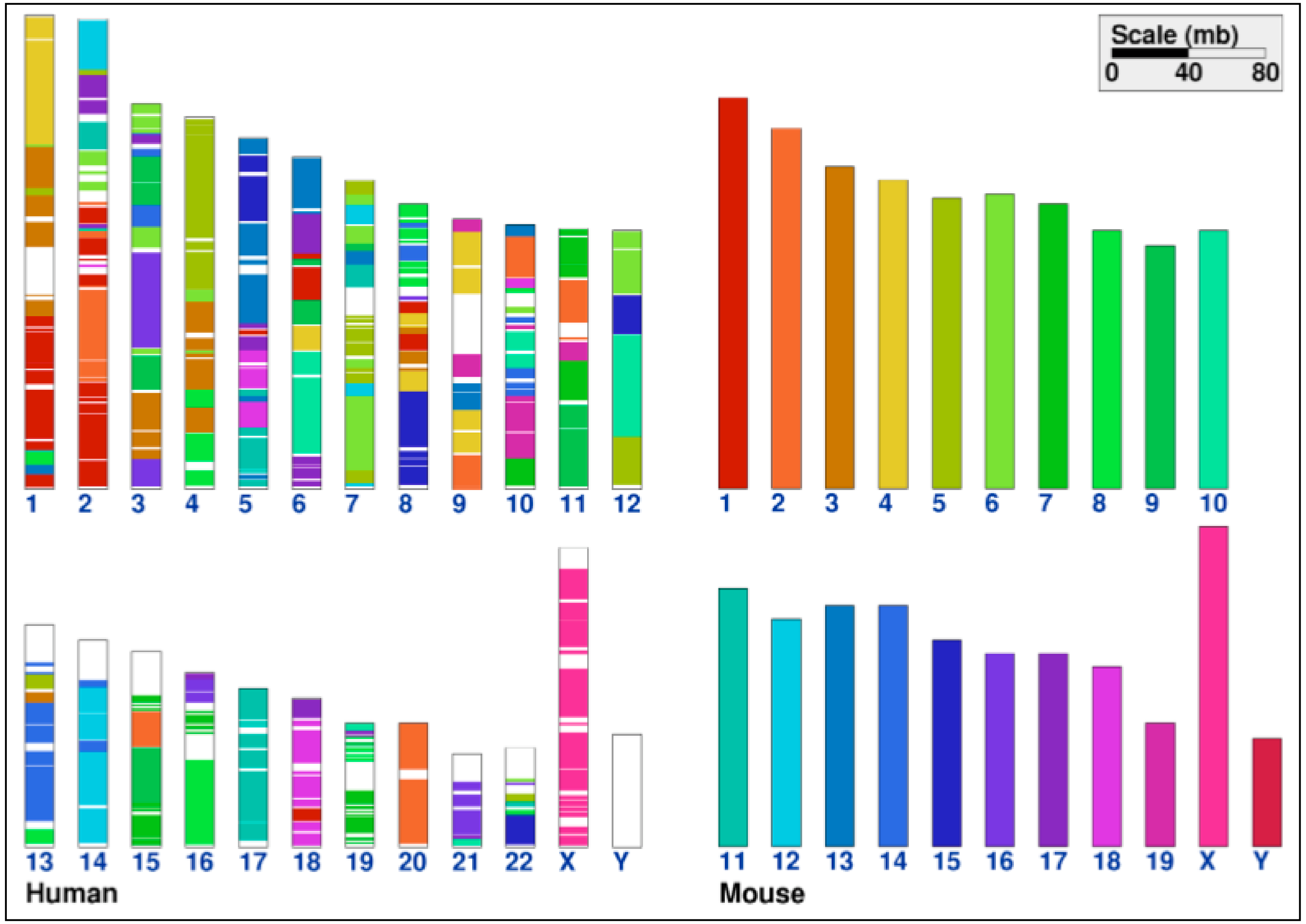


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

- 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

Categorical color: Discriminability constraints

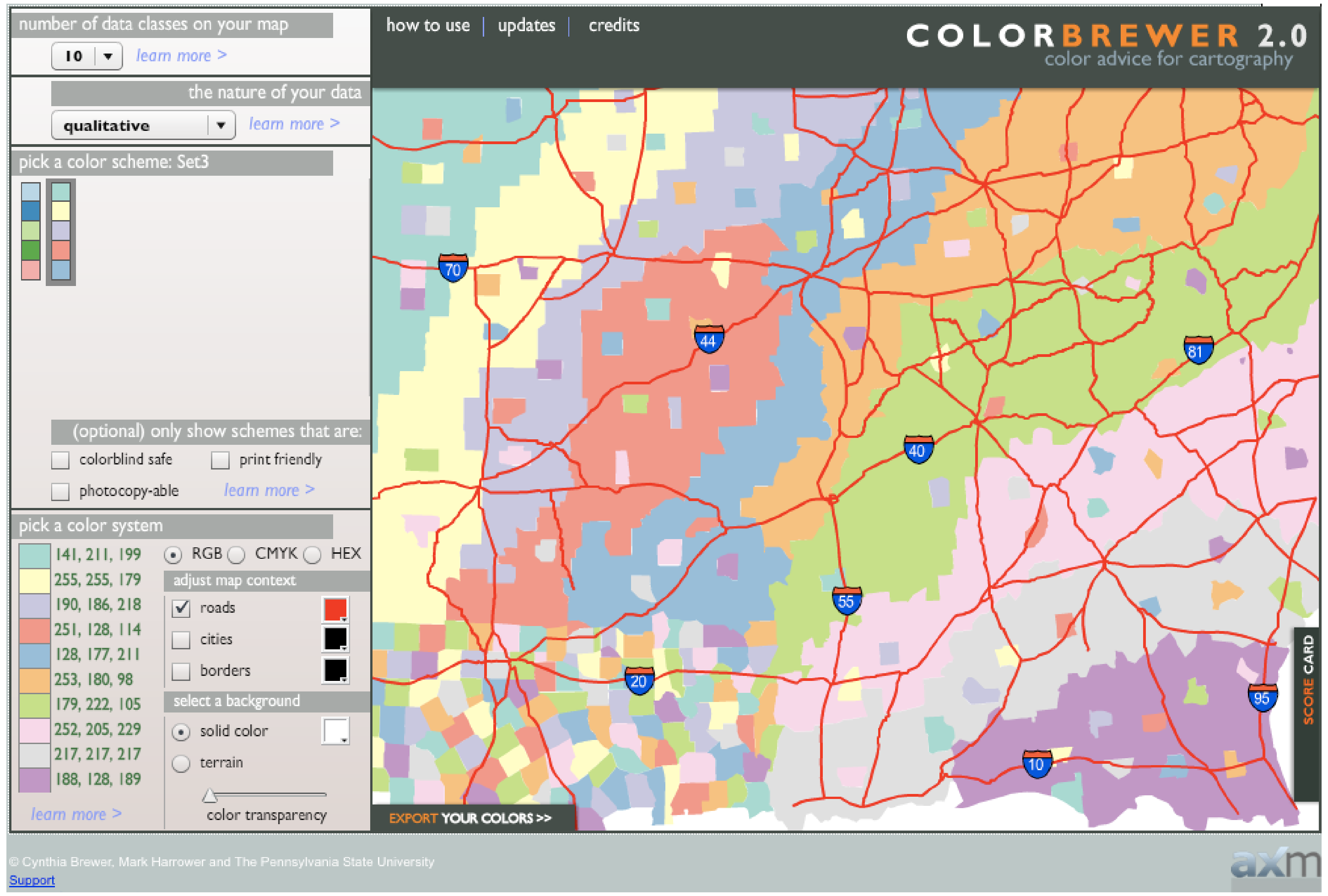
- noncontiguous small regions of color: only 6-12 bins

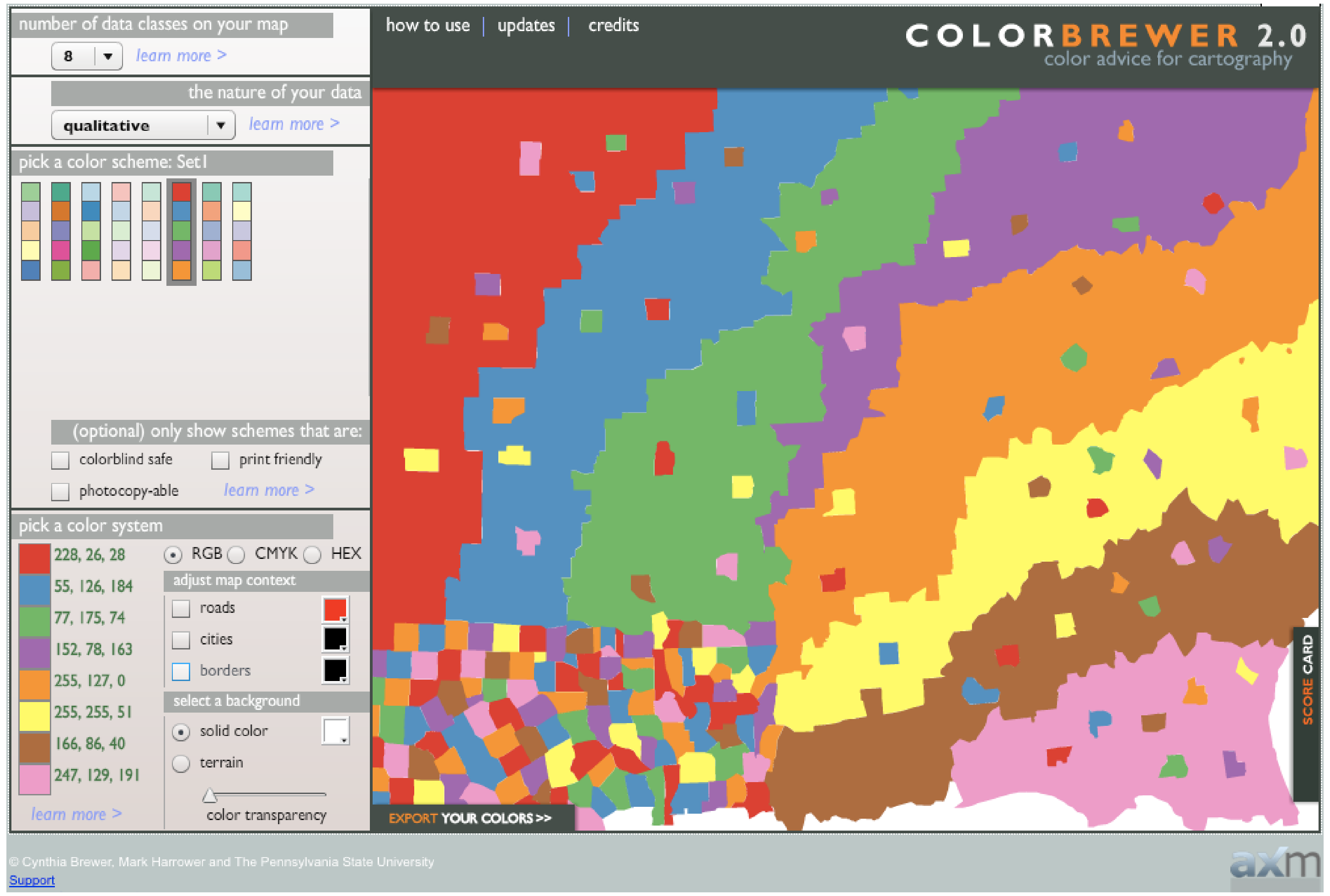


[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

ColorBrewer

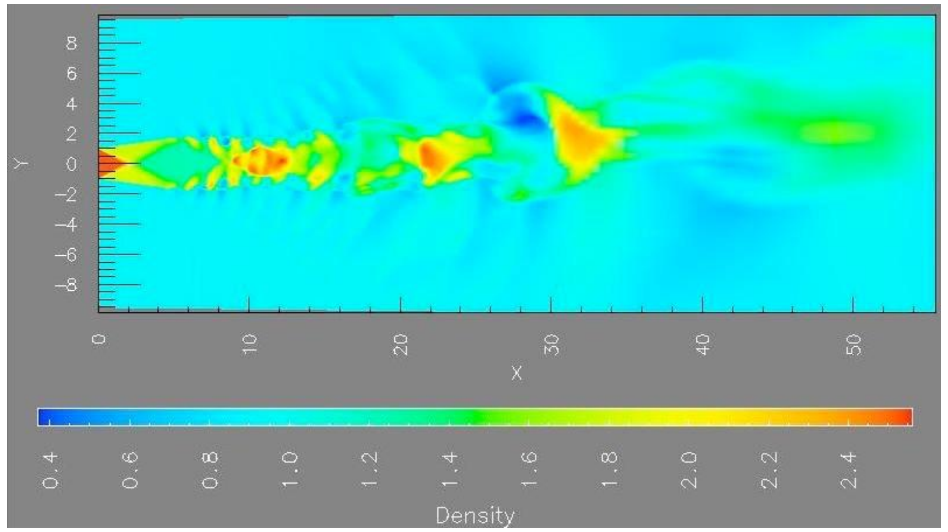
- http://www.colorbrewer2.org
- saturation and area example: size affects salience!



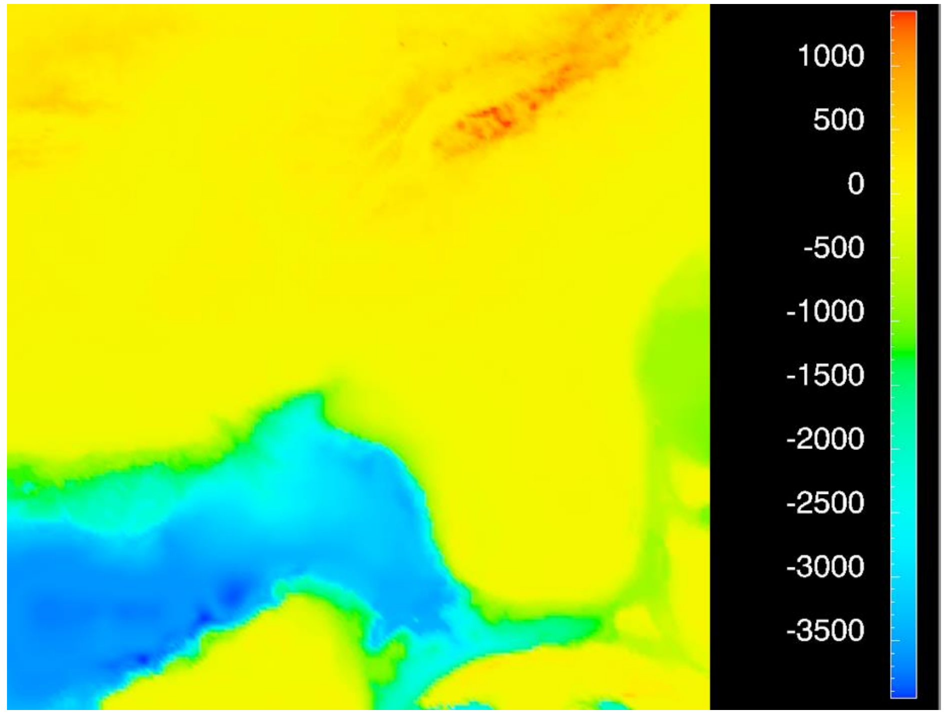


Ordered color: Rainbow is poor default

- 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.]

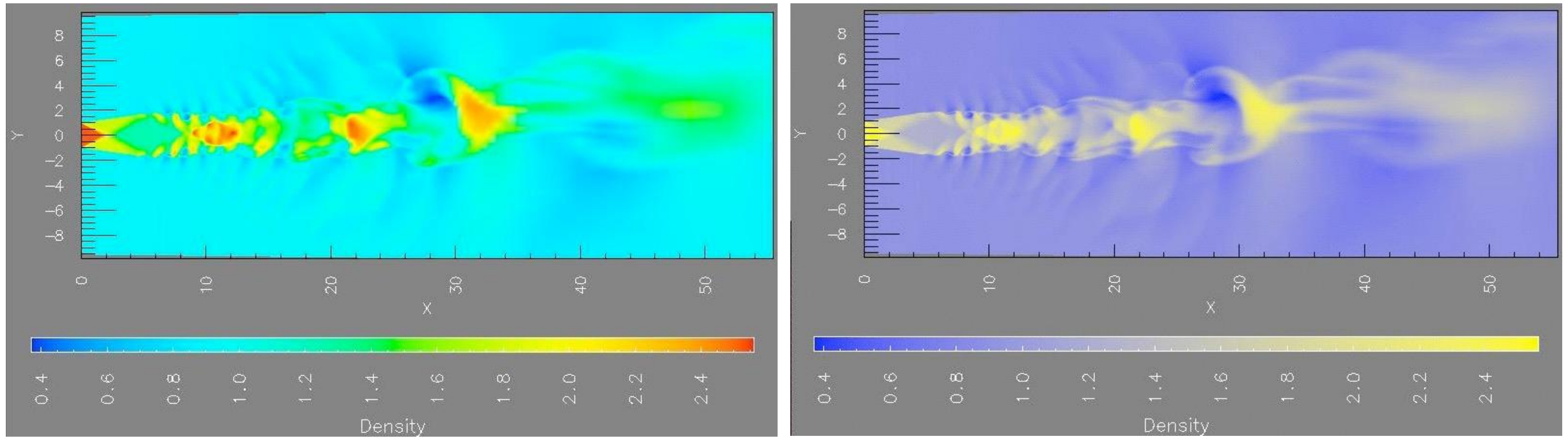


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

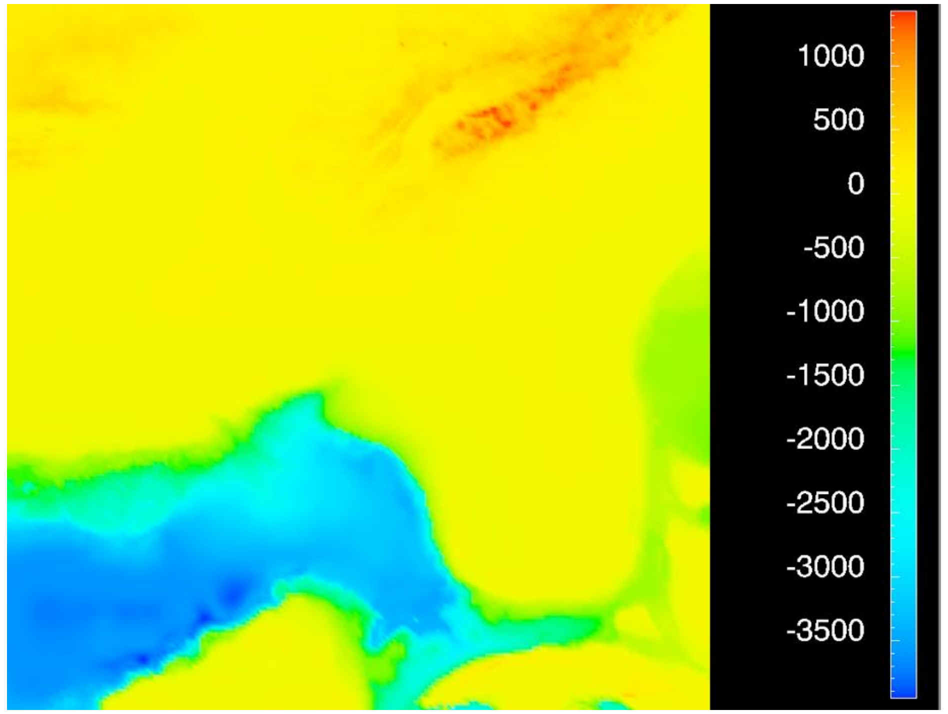
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

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



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

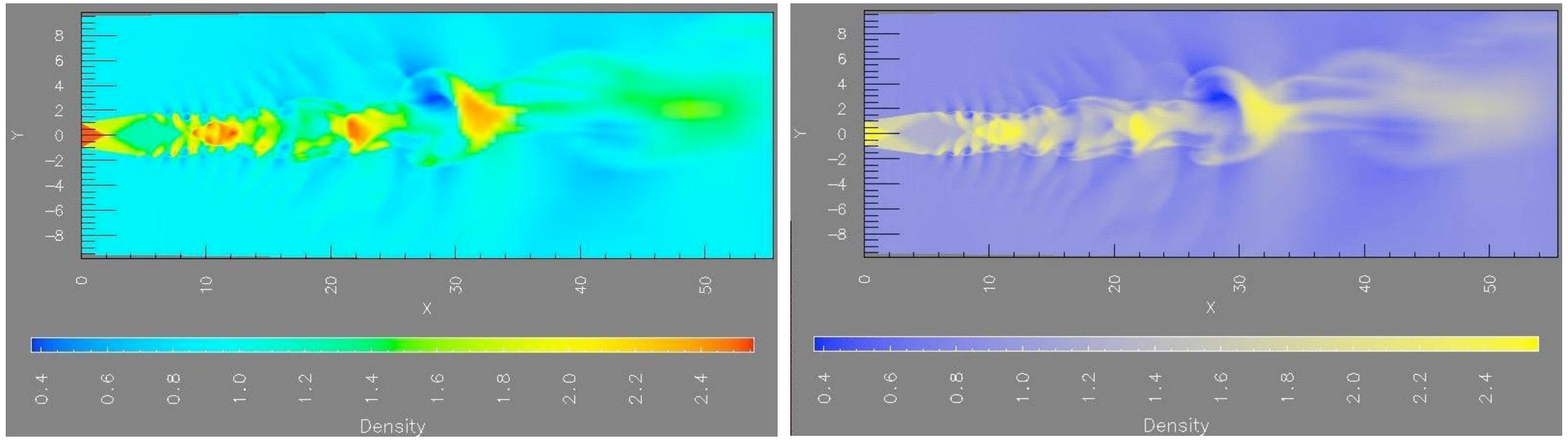


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

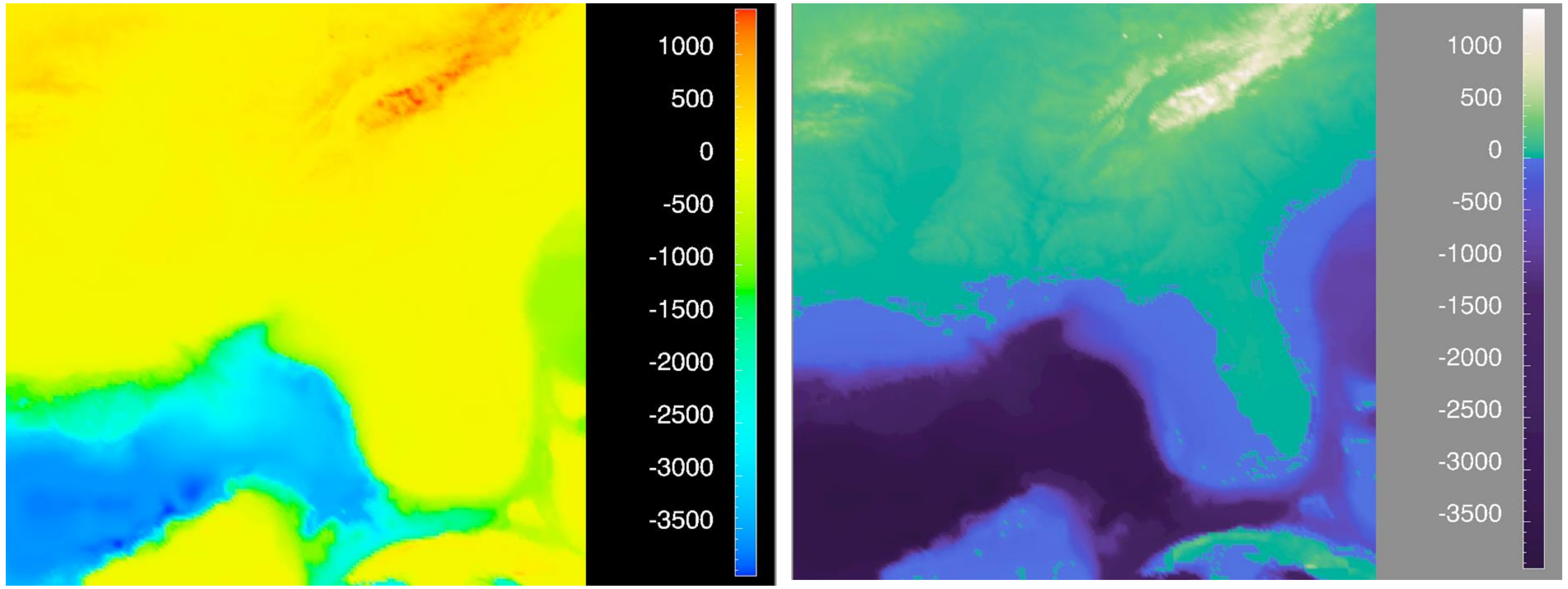
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

- problems
  - –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]



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

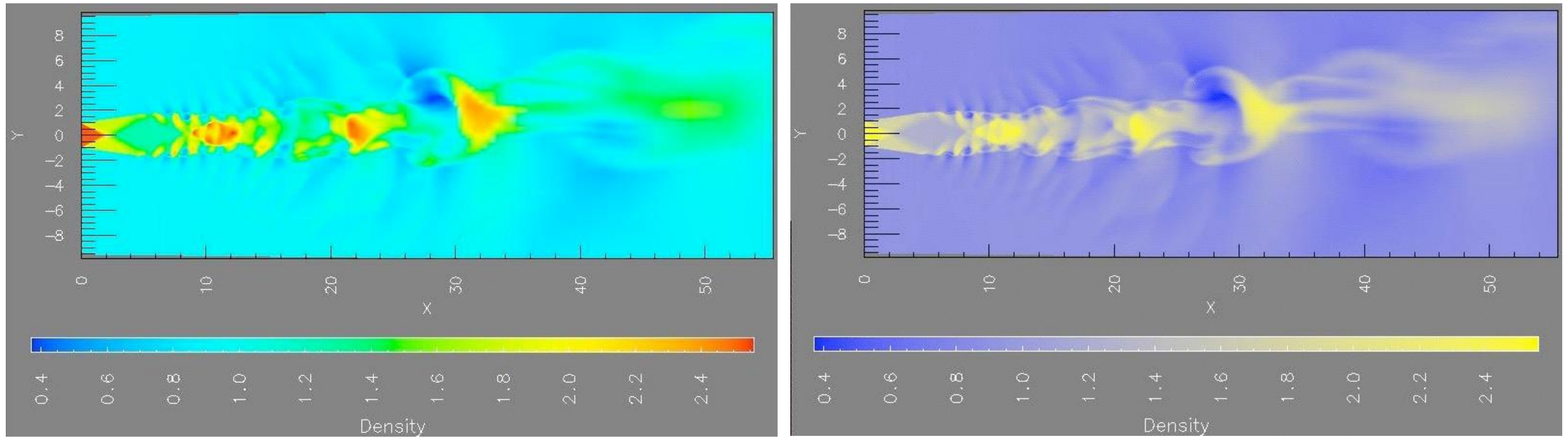


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

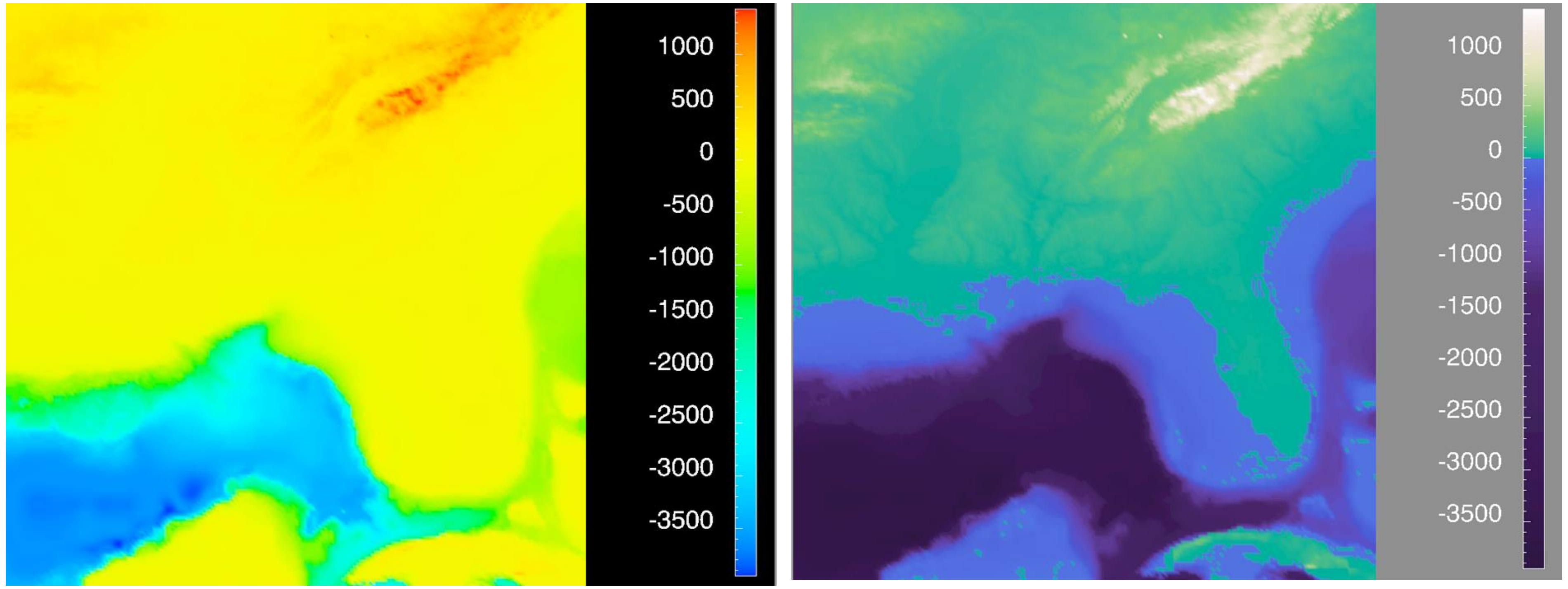
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

- problems
  - 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

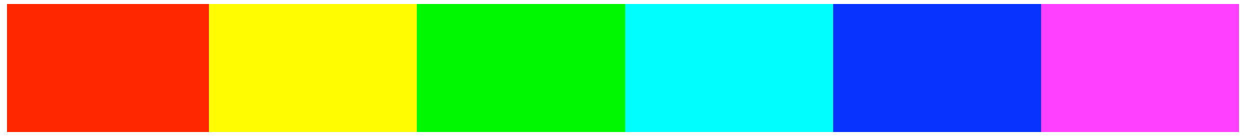


[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



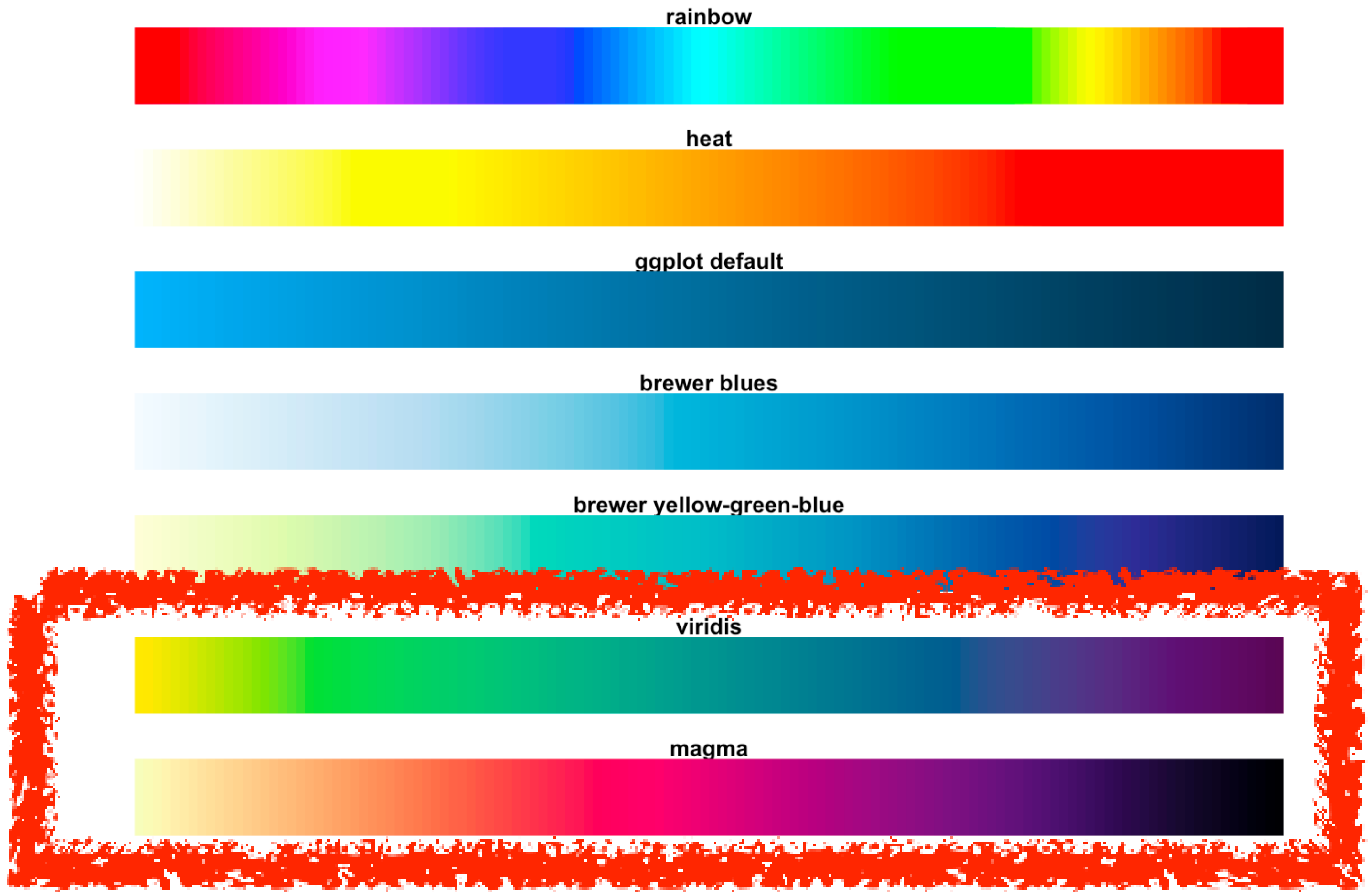
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

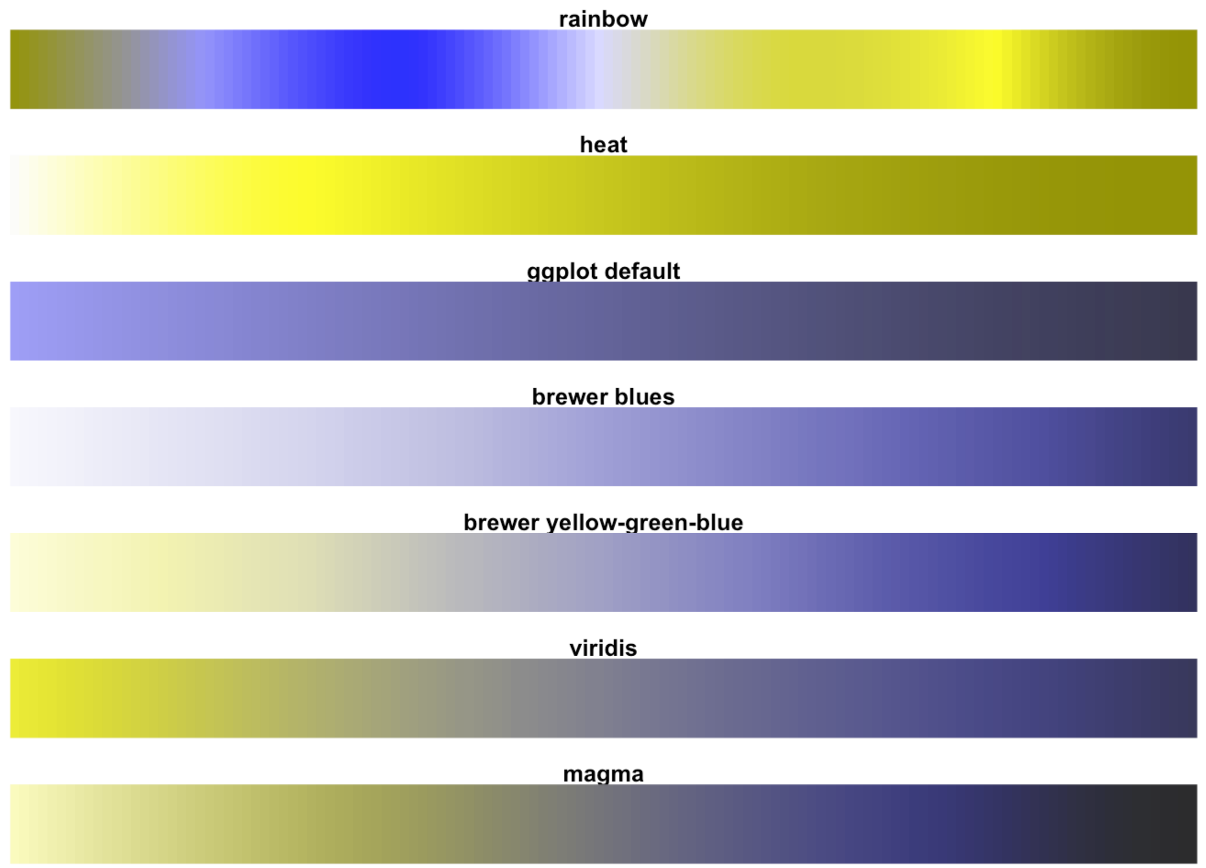


Viridis

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



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

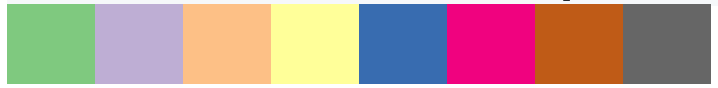


Green-Blind (Deuteranopia)

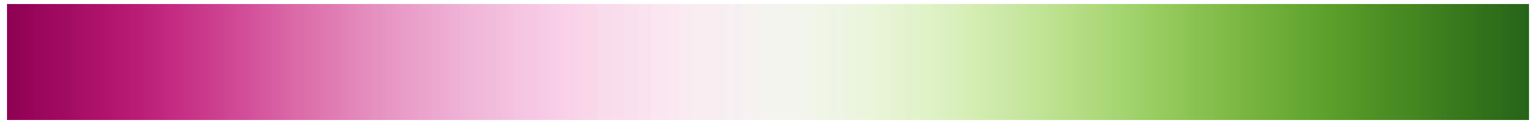
Desaturated

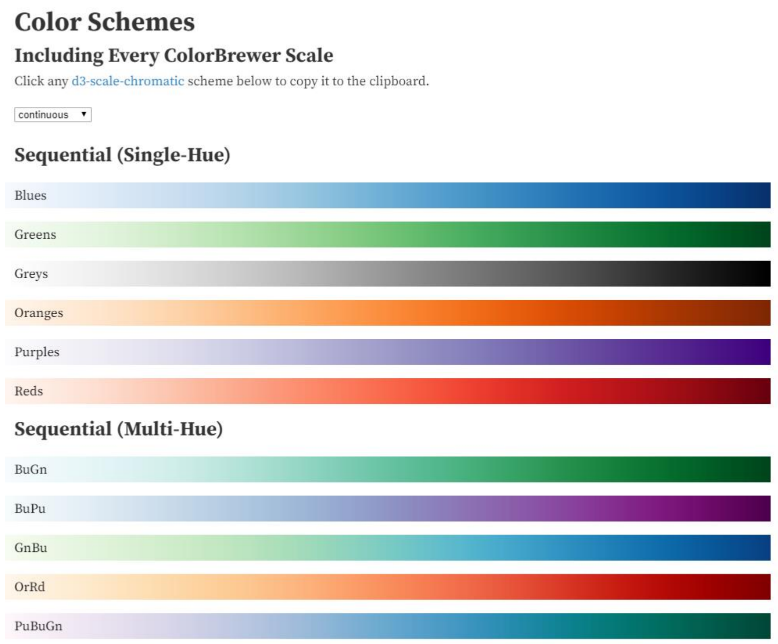
D3.js scale-chromatic

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



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





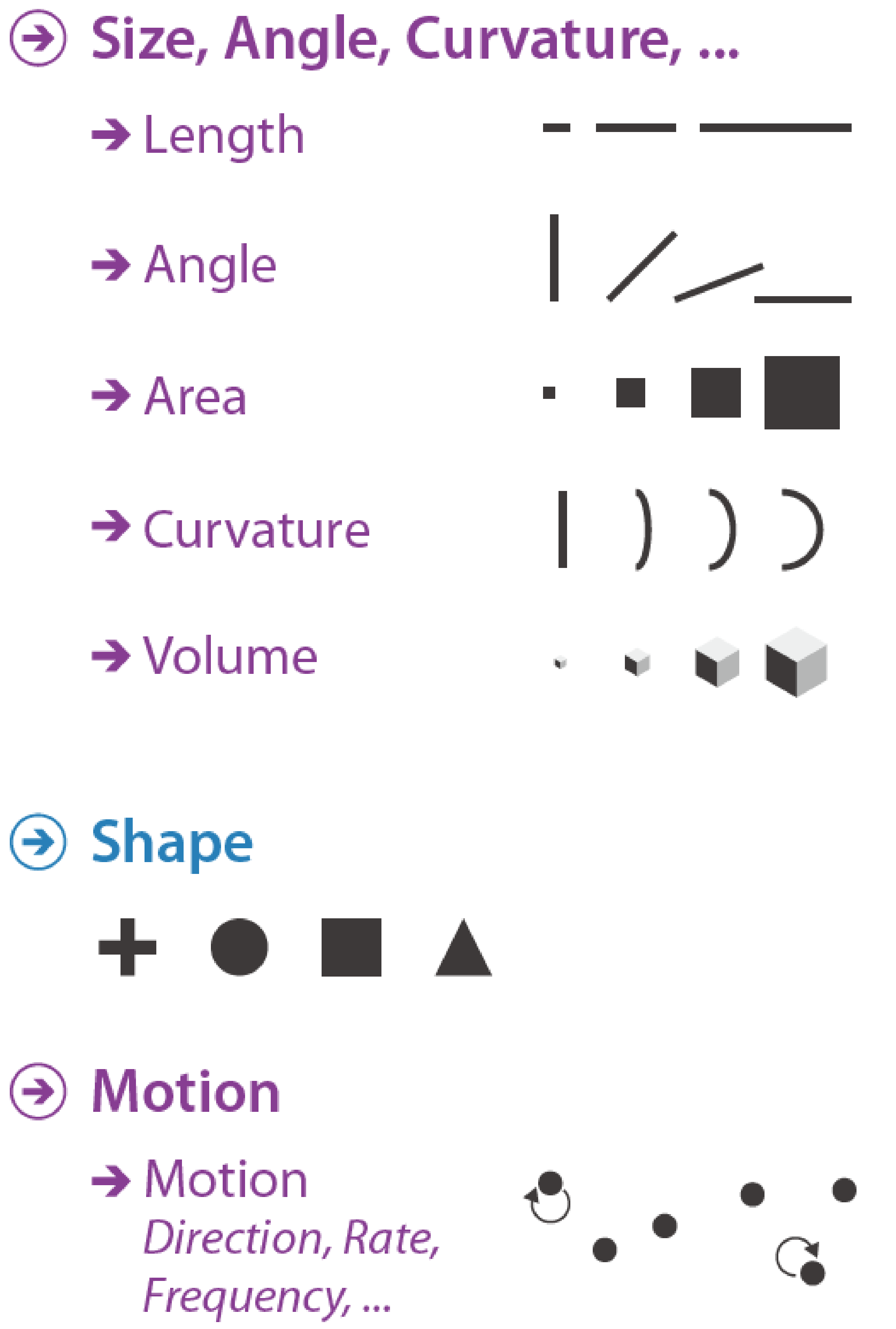
demo

```
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)"
```

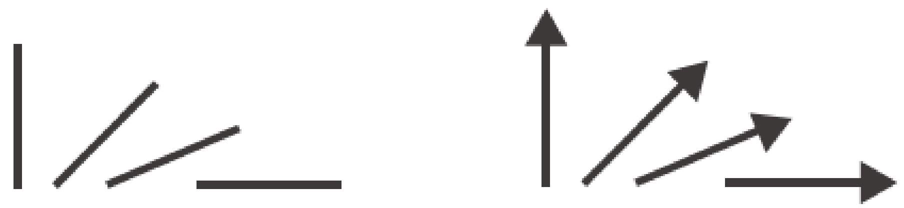
Given a number *t* in the range [0,1], returns the corresponding color from the “RdYlGn” diverging color scheme represented as an RGB string.

Map other channels

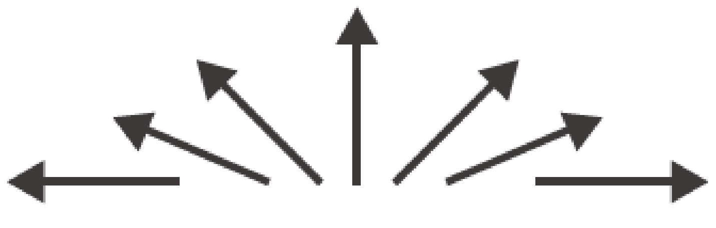
- size
  - length accurate, 2D area ok, 3D volume poor
- angle
  - nonlinear accuracy
    - horizontal, vertical, exact diagonal
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - binary: great for highlighting
  - use with care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



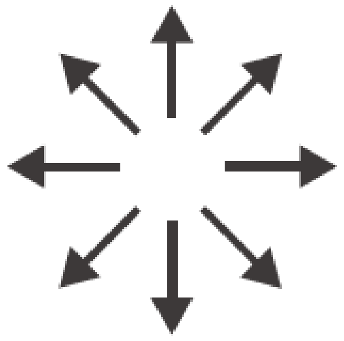
Angle



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