

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

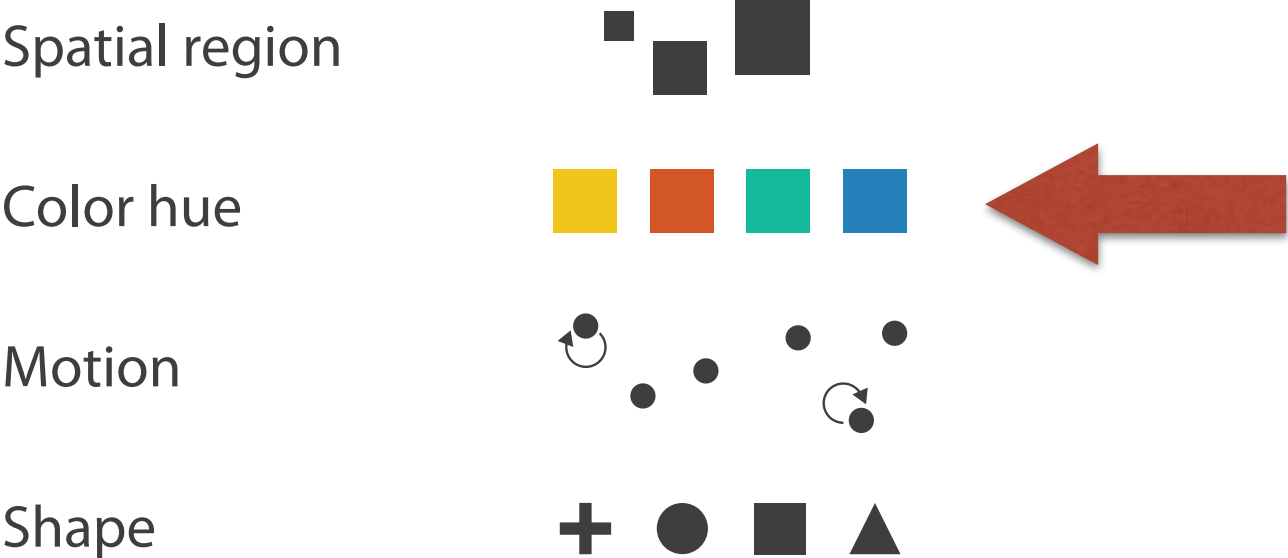
- Color in vision theory
- Color channels in vis
 - Decomposition
 - HSL
 - Other color spaces
 - Color deficiency
 - Interaction with others
- Practical advice
 - Colormaps
 - Tools and programming libraries

Channels: the big picture

➔ **Magnitude** Channels: **Ordered** Attributes



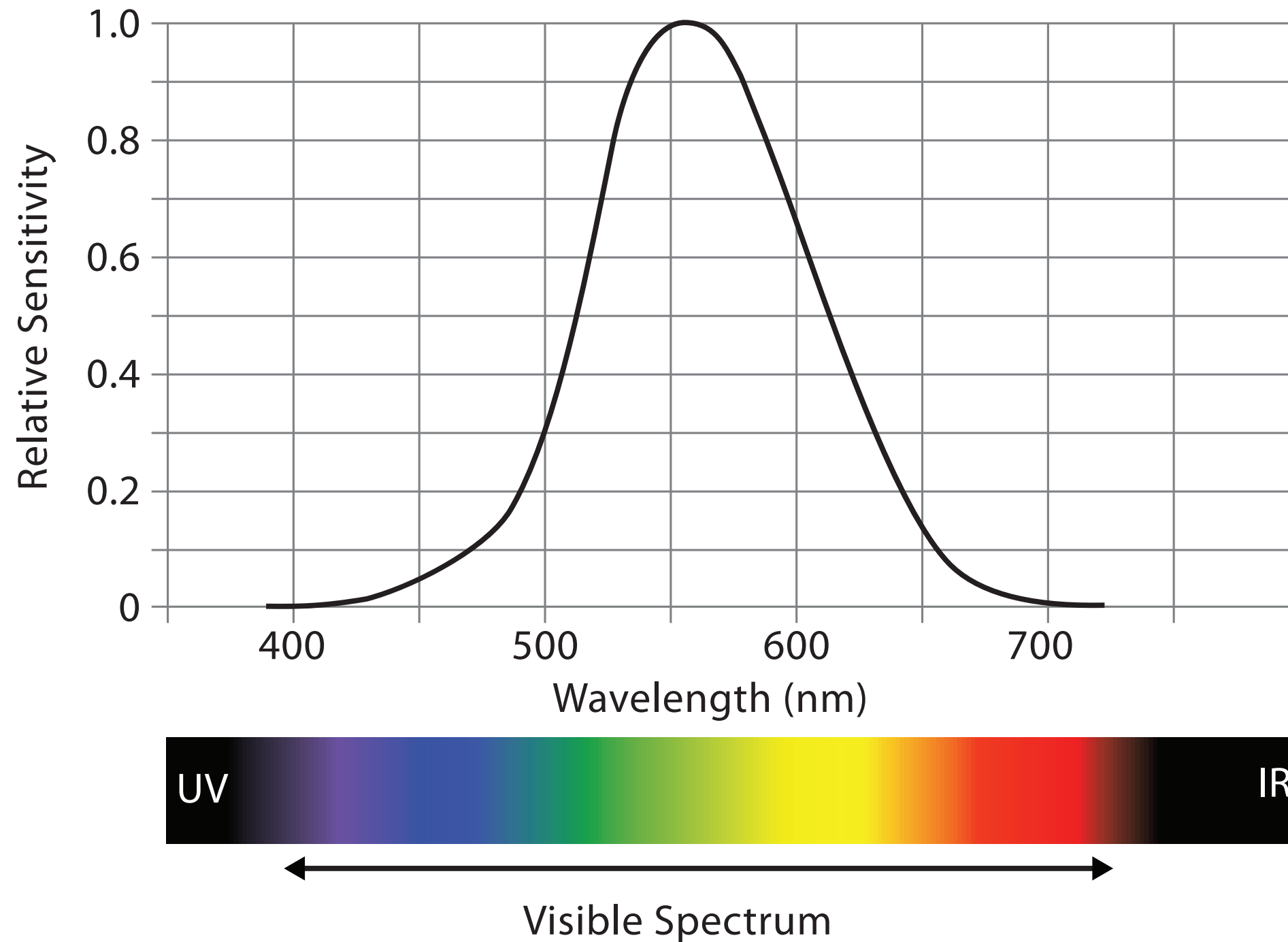
➔ **Identity** Channels: **Categorical** Attributes



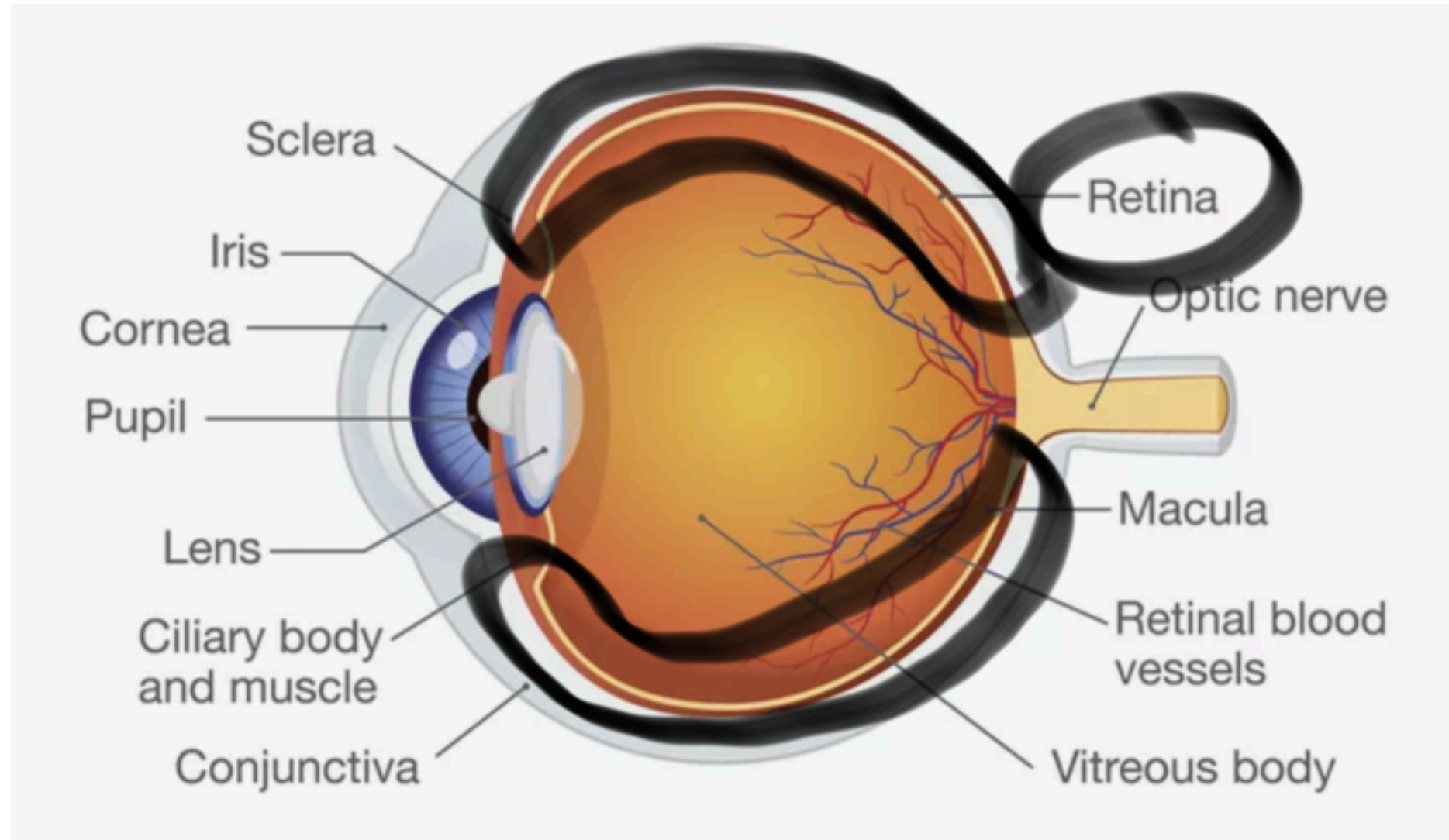
Color in Vision Theory

Light

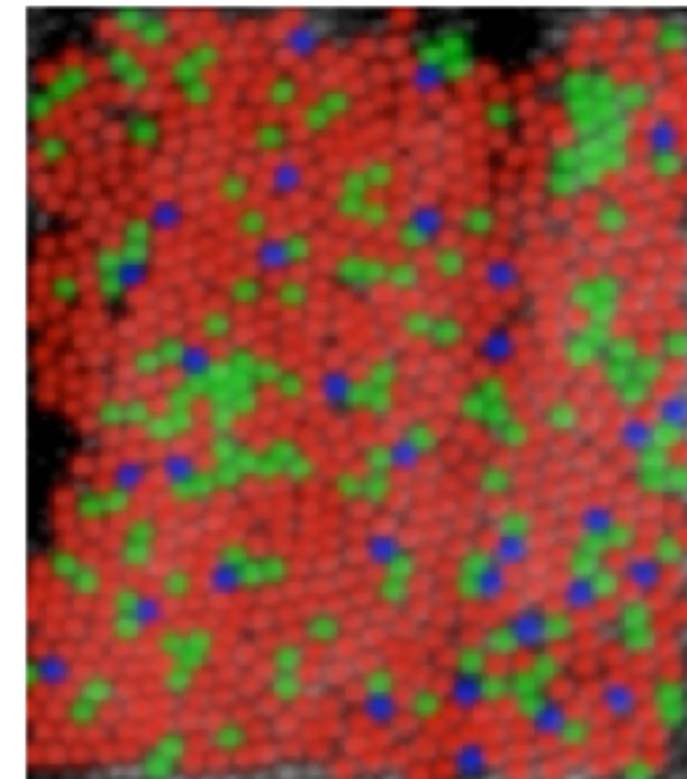
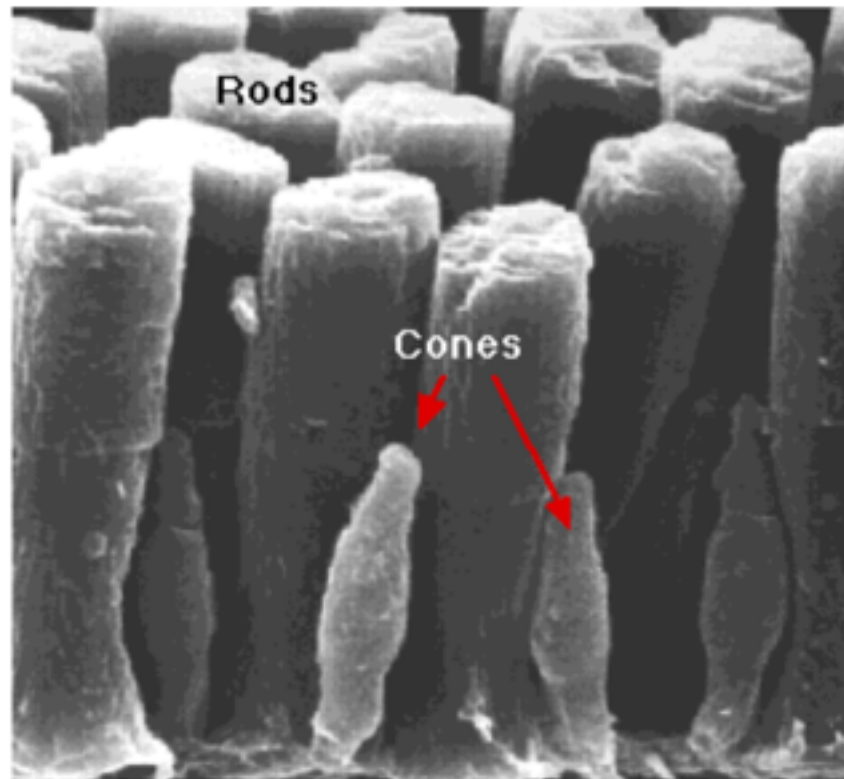
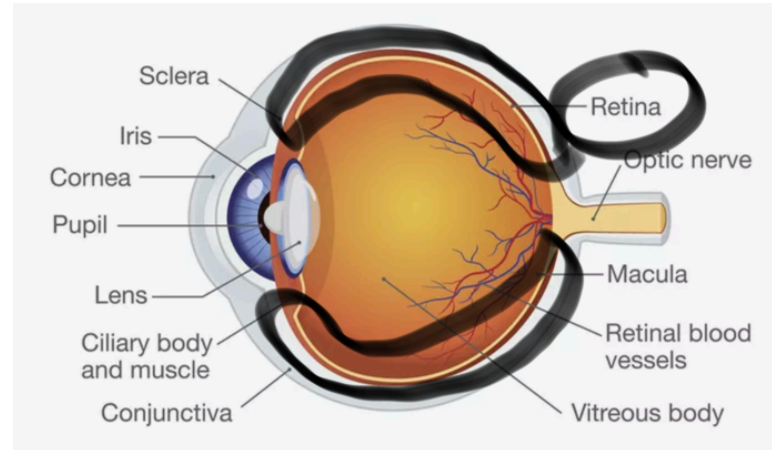
If I tell you the wavelength, can you tell what color you are seeing?



Eye anatomy



Cone and Rod Cells on Retina

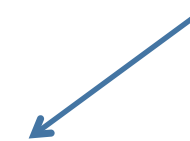
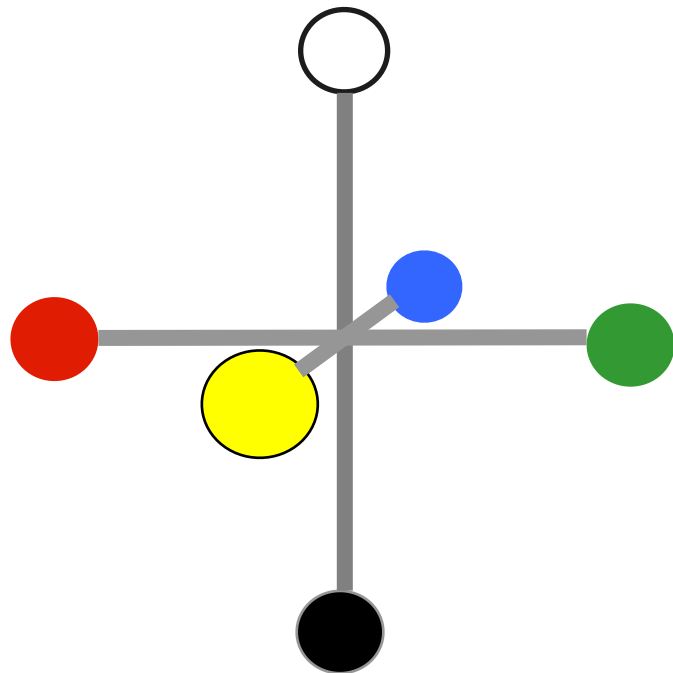


~120 million rods: black vs. white
~5-6 million cones: color

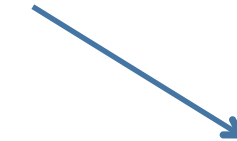
R 63% - G 31% - B 6%

Opponent process

- 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^*)



Luminance information



Chroma information

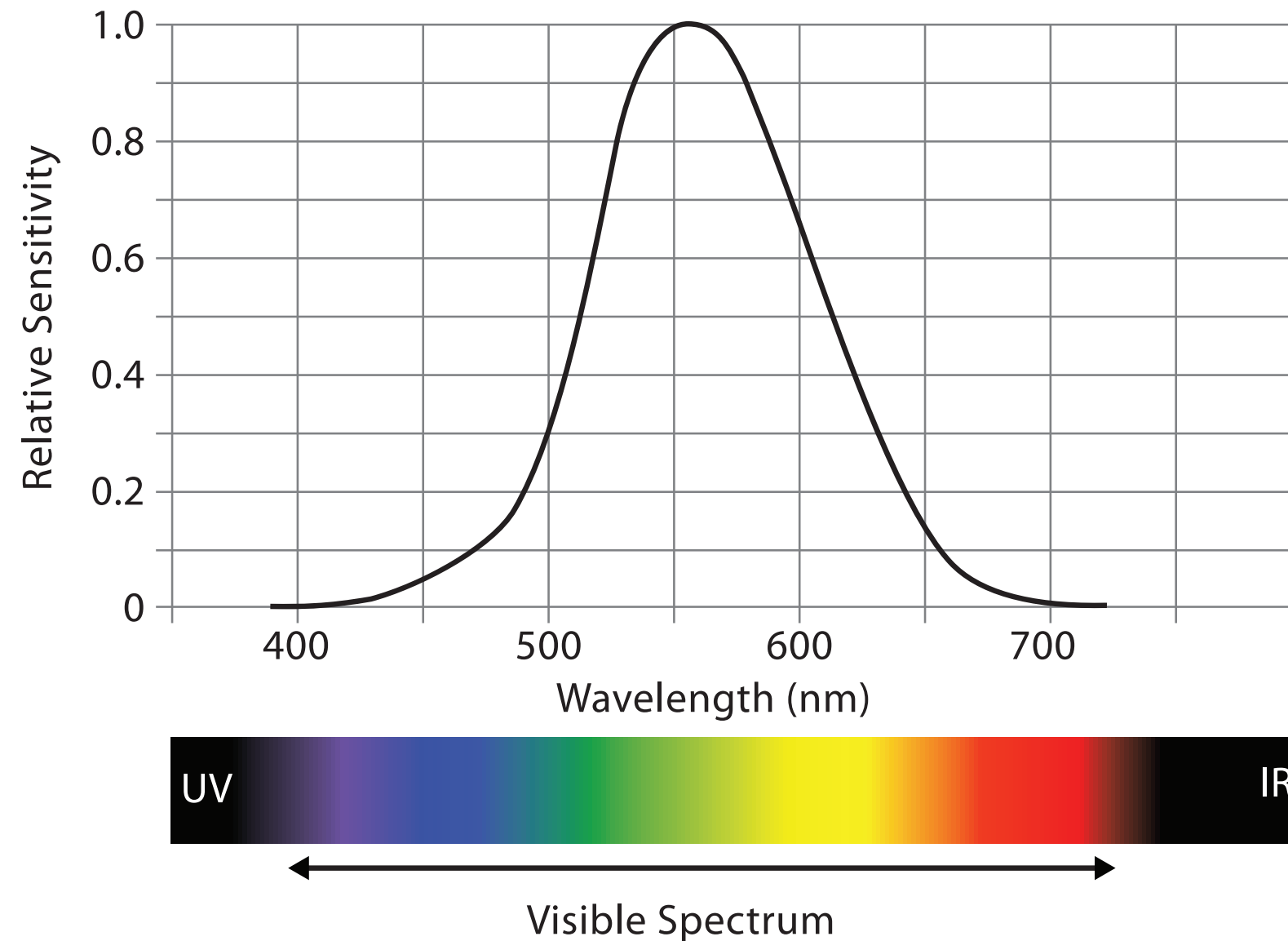


*[Seriously Colorful: Advanced Color Principles & Practices.
Stone.Tableau Customer Conference 2014.]*

Light

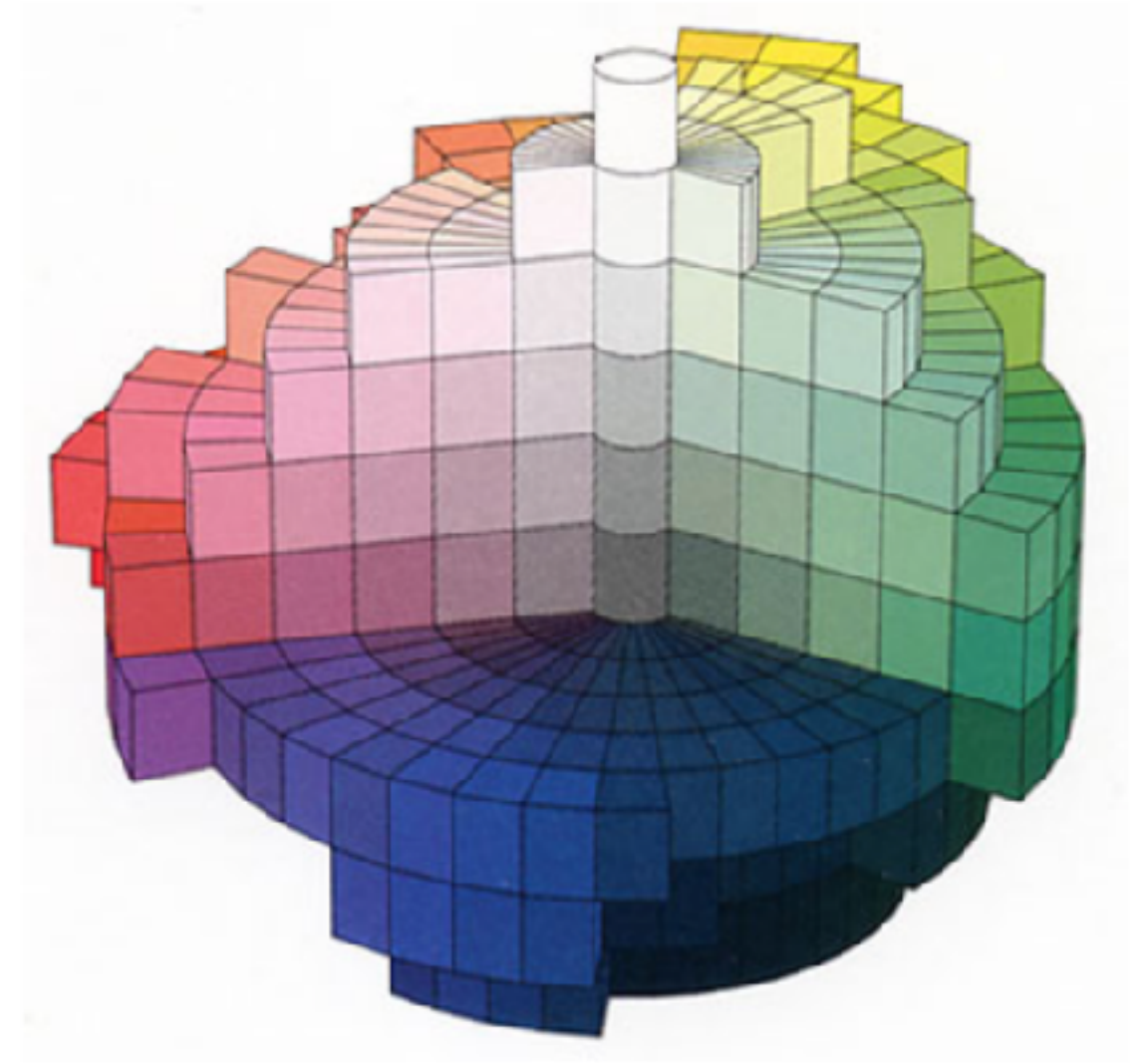
If I tell you the wavelength, can you tell what color you are seeing?

Color != Wavelength



Color Appearance

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



CIE LAB color space

Color/Lightness constancy: Illumination conditions

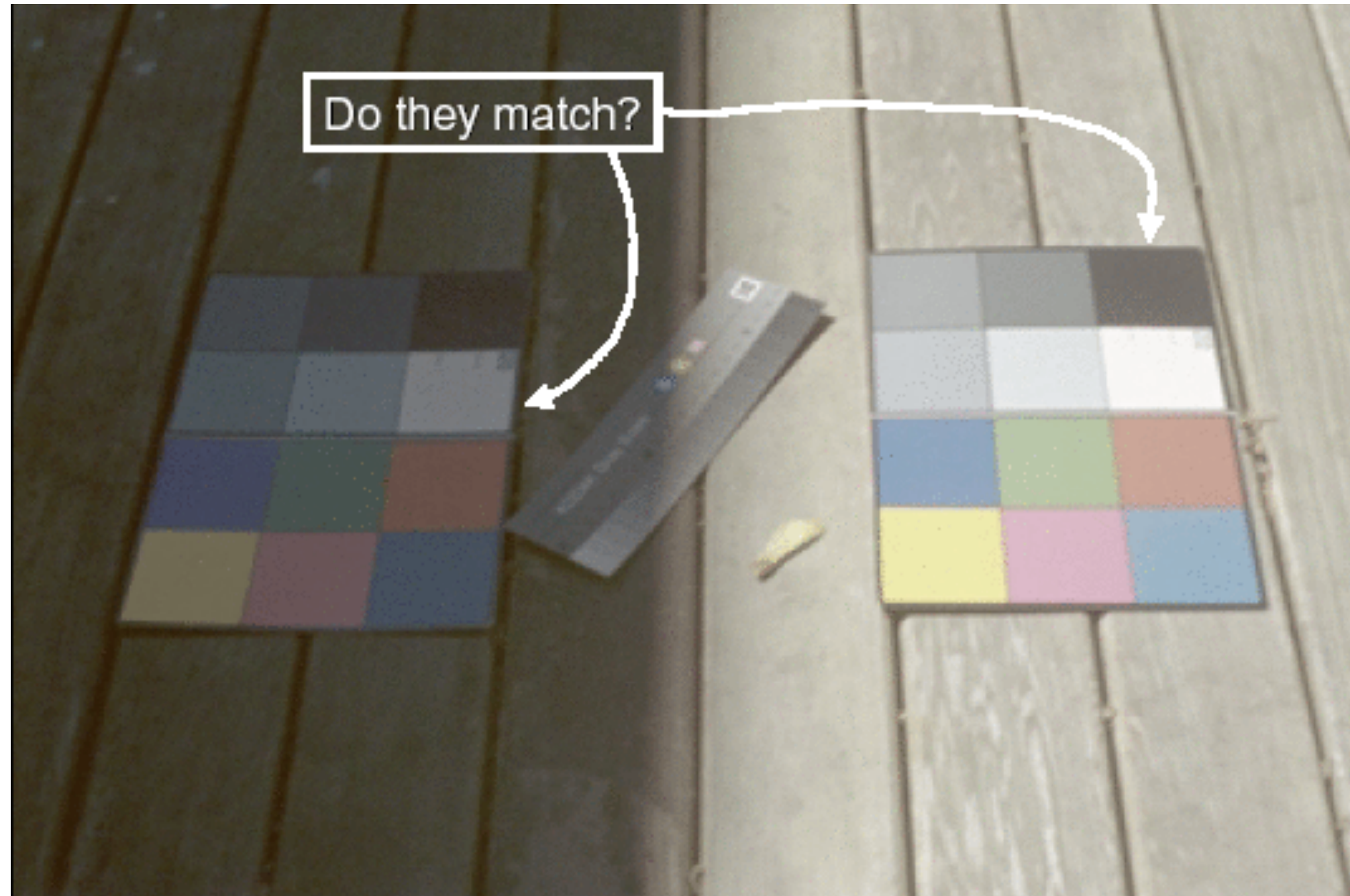


Image courtesy of John McCann

Color/Lightness constancy: Illumination conditions

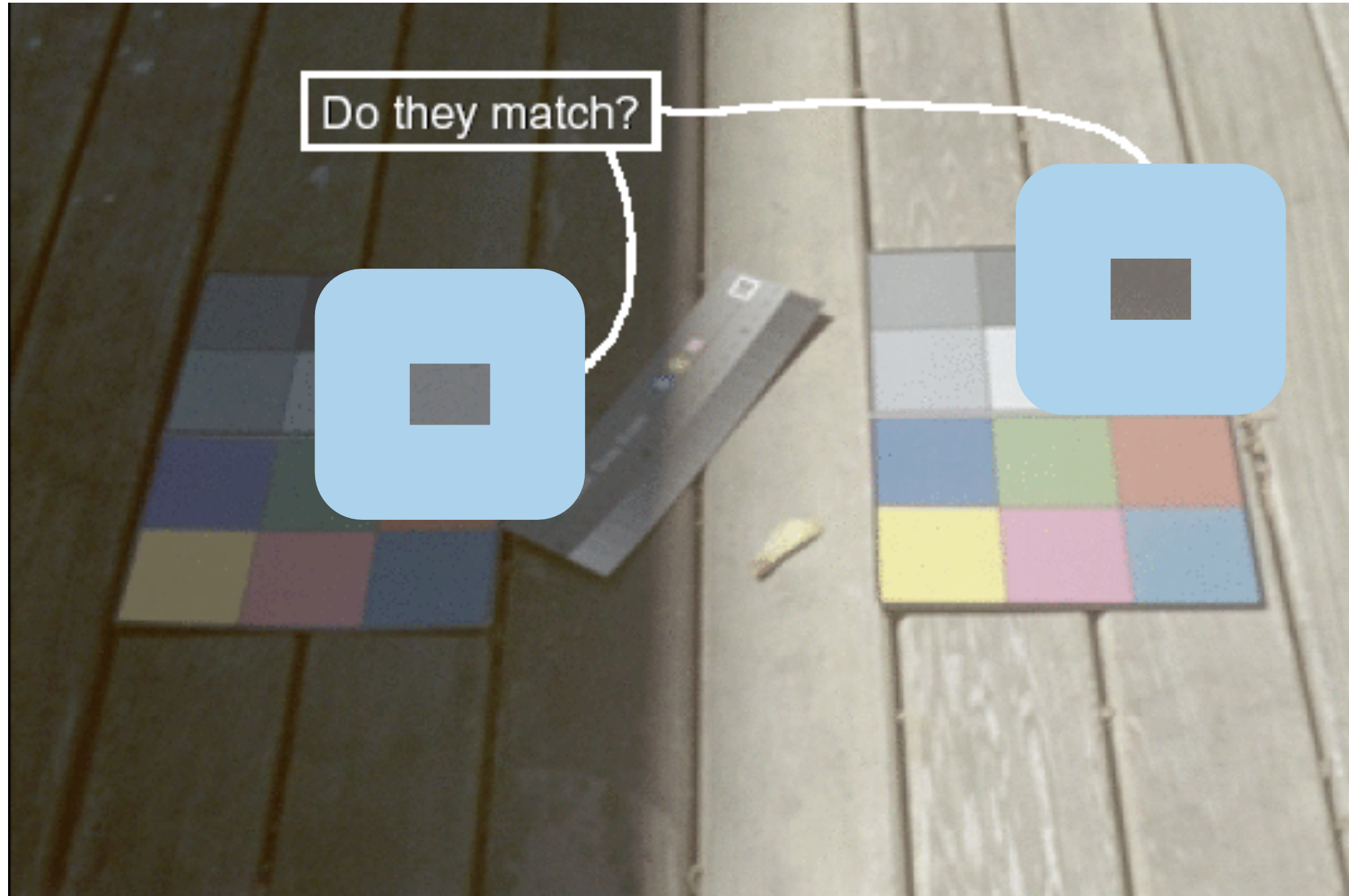
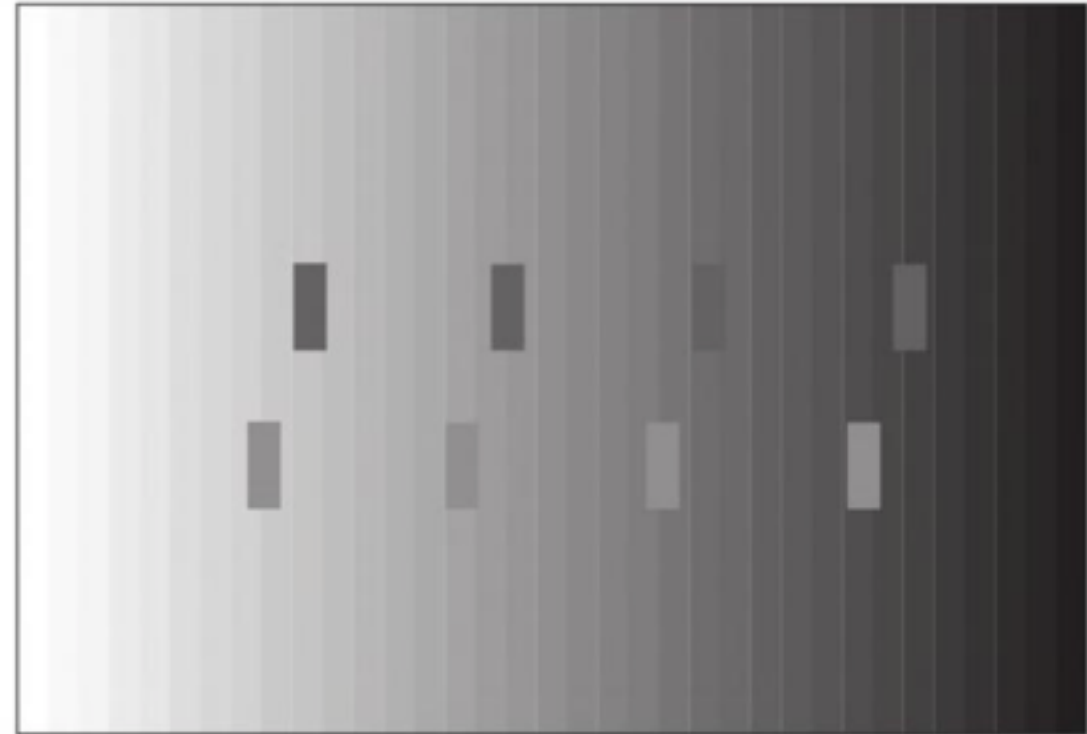
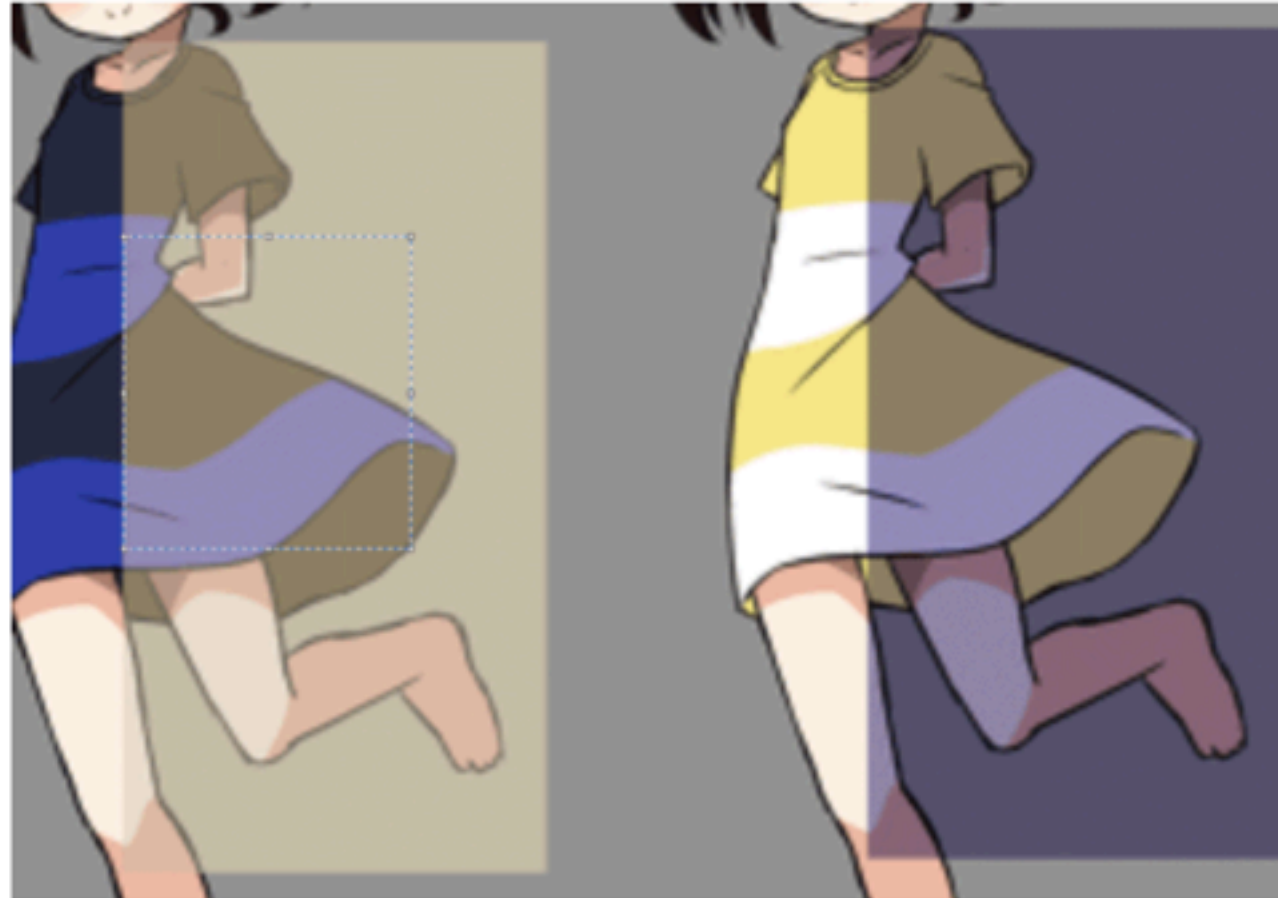


Image courtesy of John McCann

Contrast with background



Contrast with background

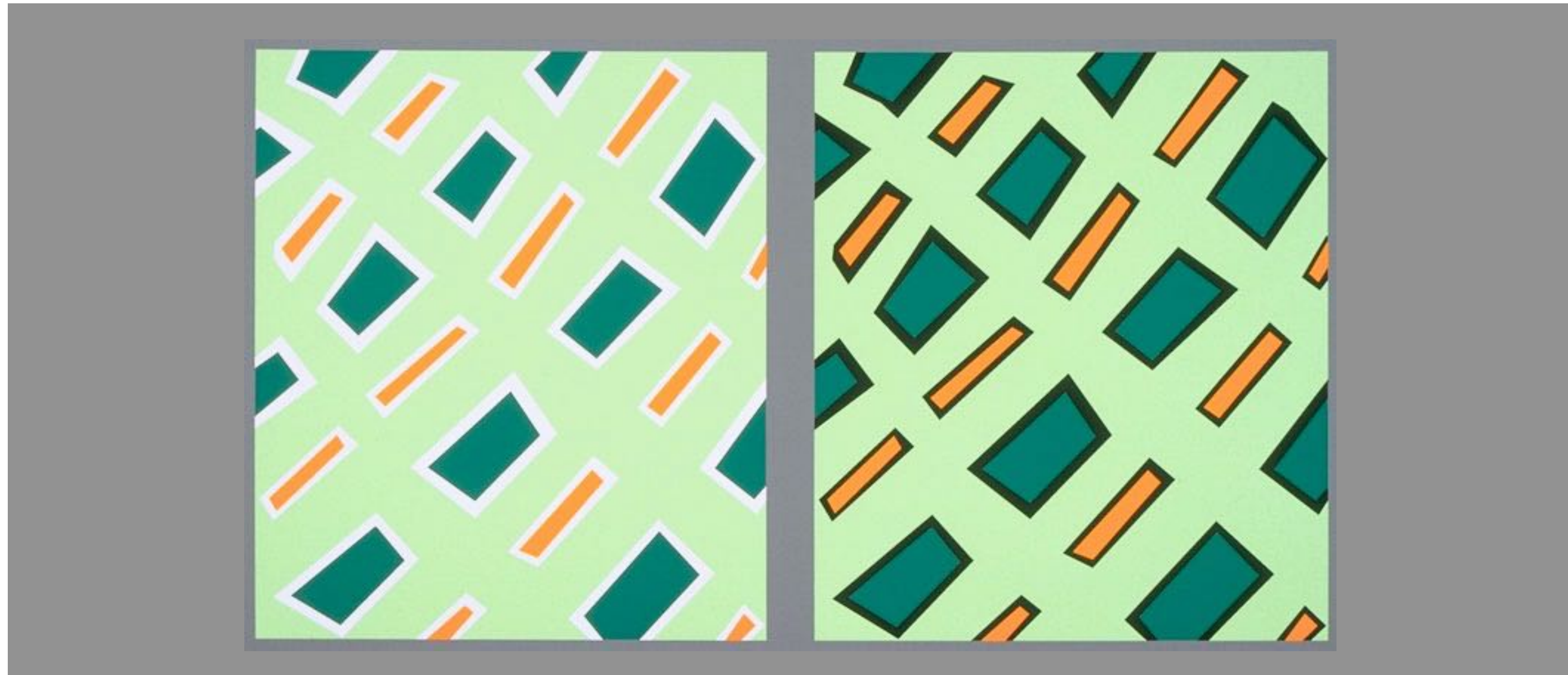


Black and blue? White and gold?

<https://imgur.com/hxJjUQB>

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

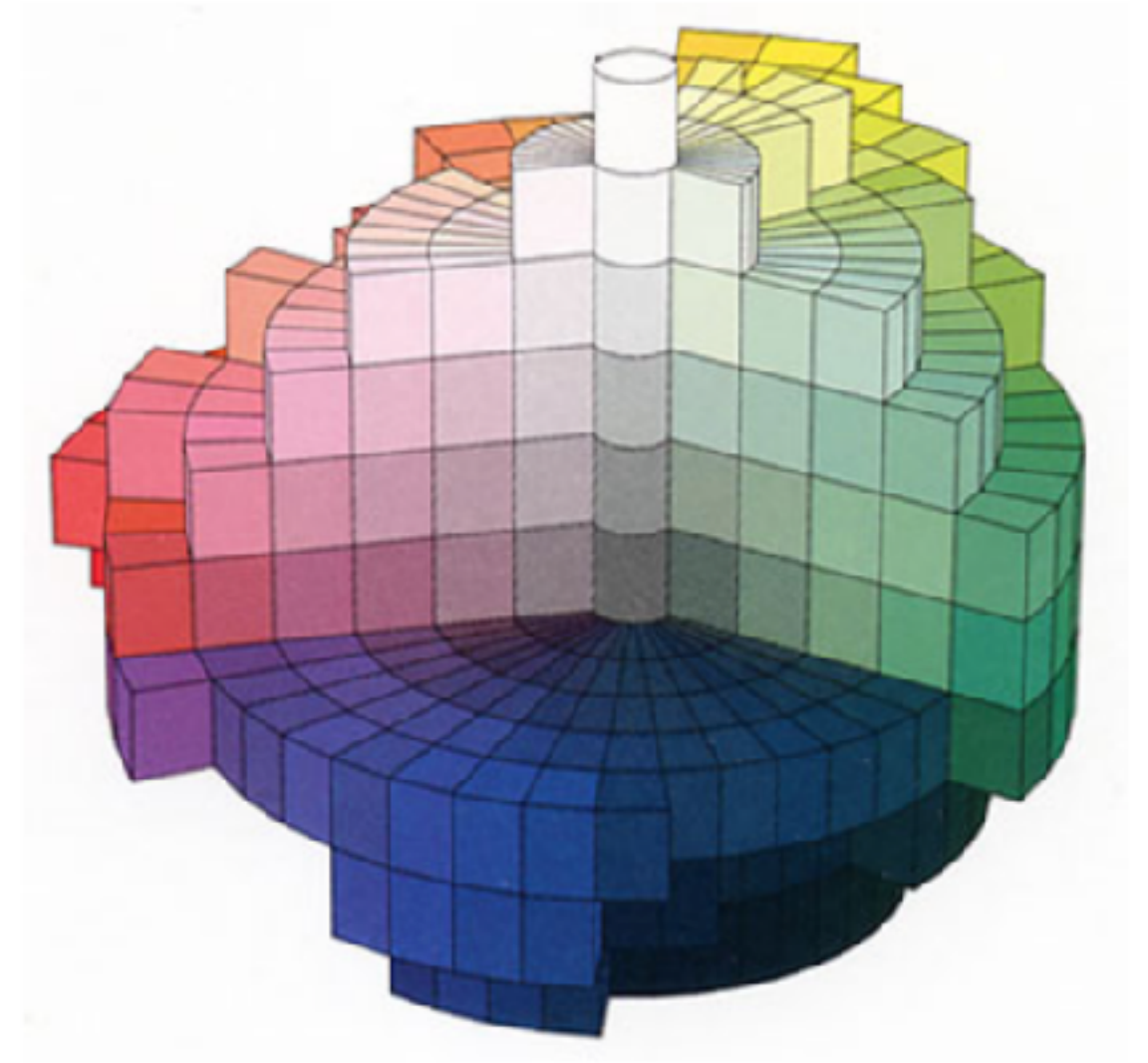
Bezold Effect: Outlines matter



[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
- ...

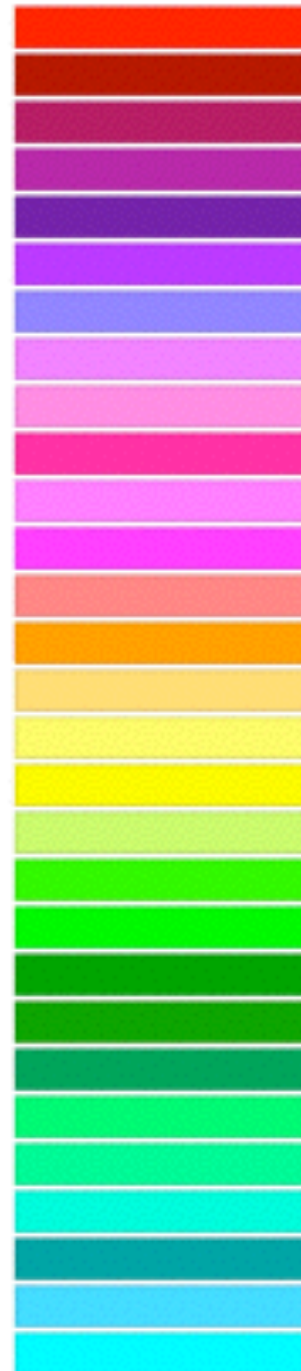


Cognition (beyond retina, in brain)

- 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



Name the colours

Color names if you're a girl...		Color names if you're a guy...
Maraschino		Red
Cayenne		
Maroon		Purple
Plum		
Eggplant		
Grape		
Orchid		
Lavender		
Carnation		Pink
Strawberry		
Bubblegum		
Magenta		
Salmon		
Tangerine		Orange
Cantaloupe		
Banana		Yellow
Lemon		
Honeydew		Green
Lime		
Spring		
Clover		
Fern		
Moss		
Flora		
Sea Foam		
Spindrift		Blue
Teal		
Sky		
Turquoise		

Doghouse Diaries
"We take no as an answer."

Name the colours

Actual color names
if you're a girl ...

Actual color names
if you're a guy ...



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

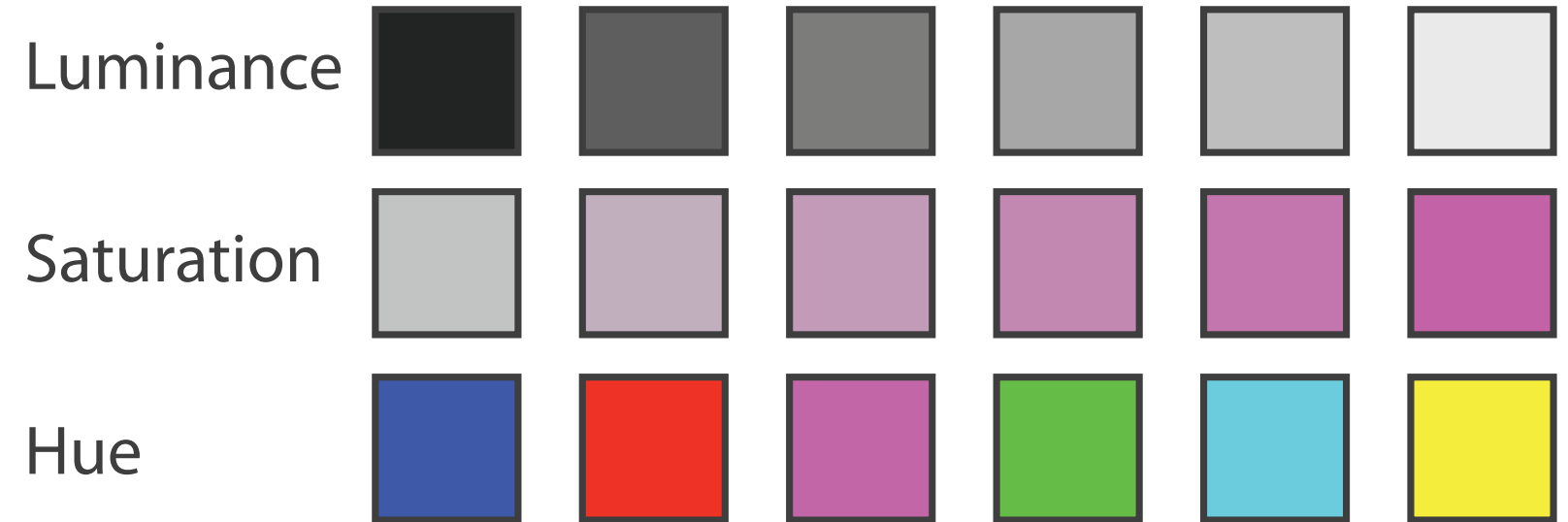
- ordered can show magnitude

- **luminance: how bright**

- **saturation: how colourful**

- categorical can show identity

- **hue: what color**



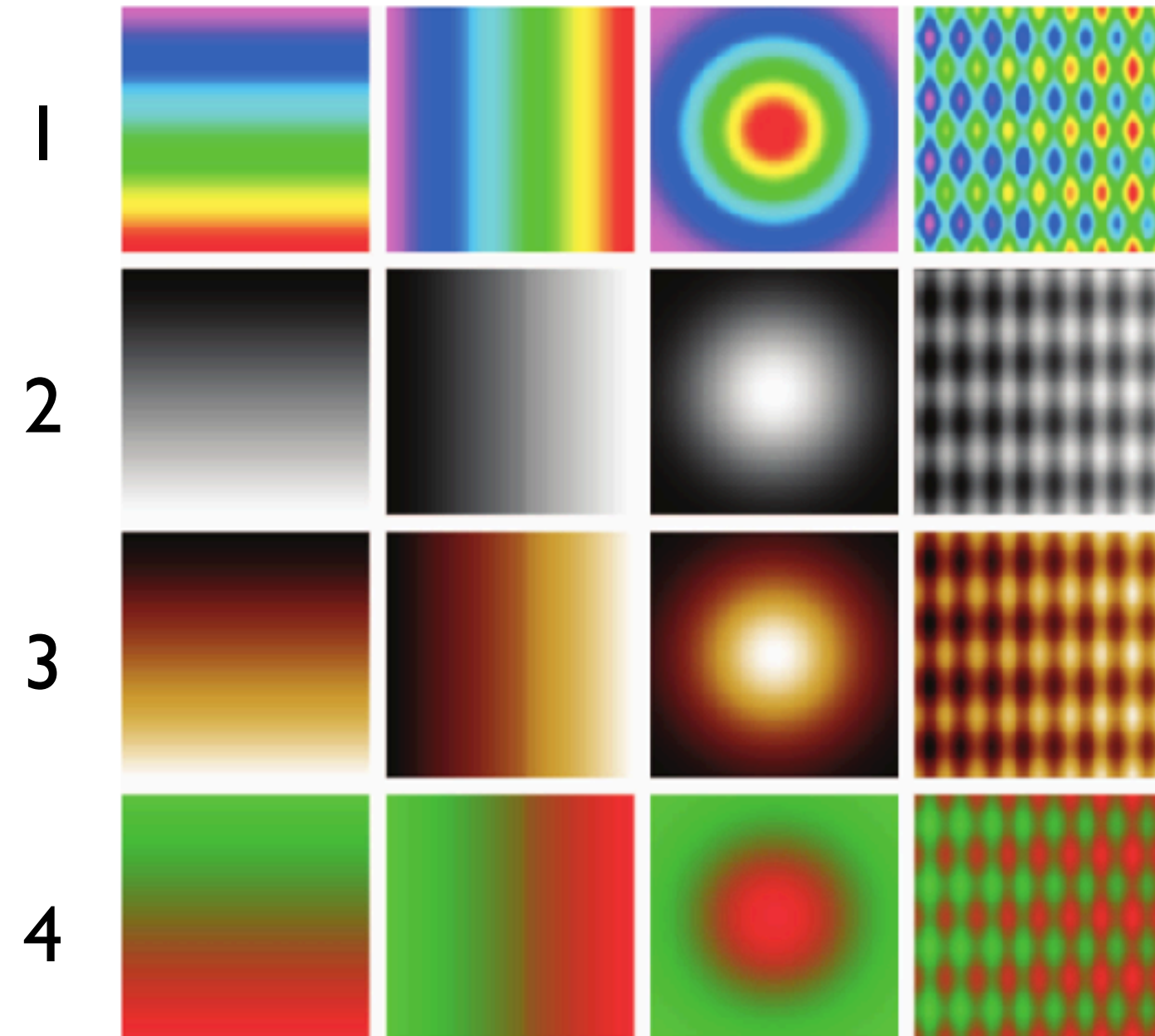
- channels have different properties

- what they convey directly to perceptual system

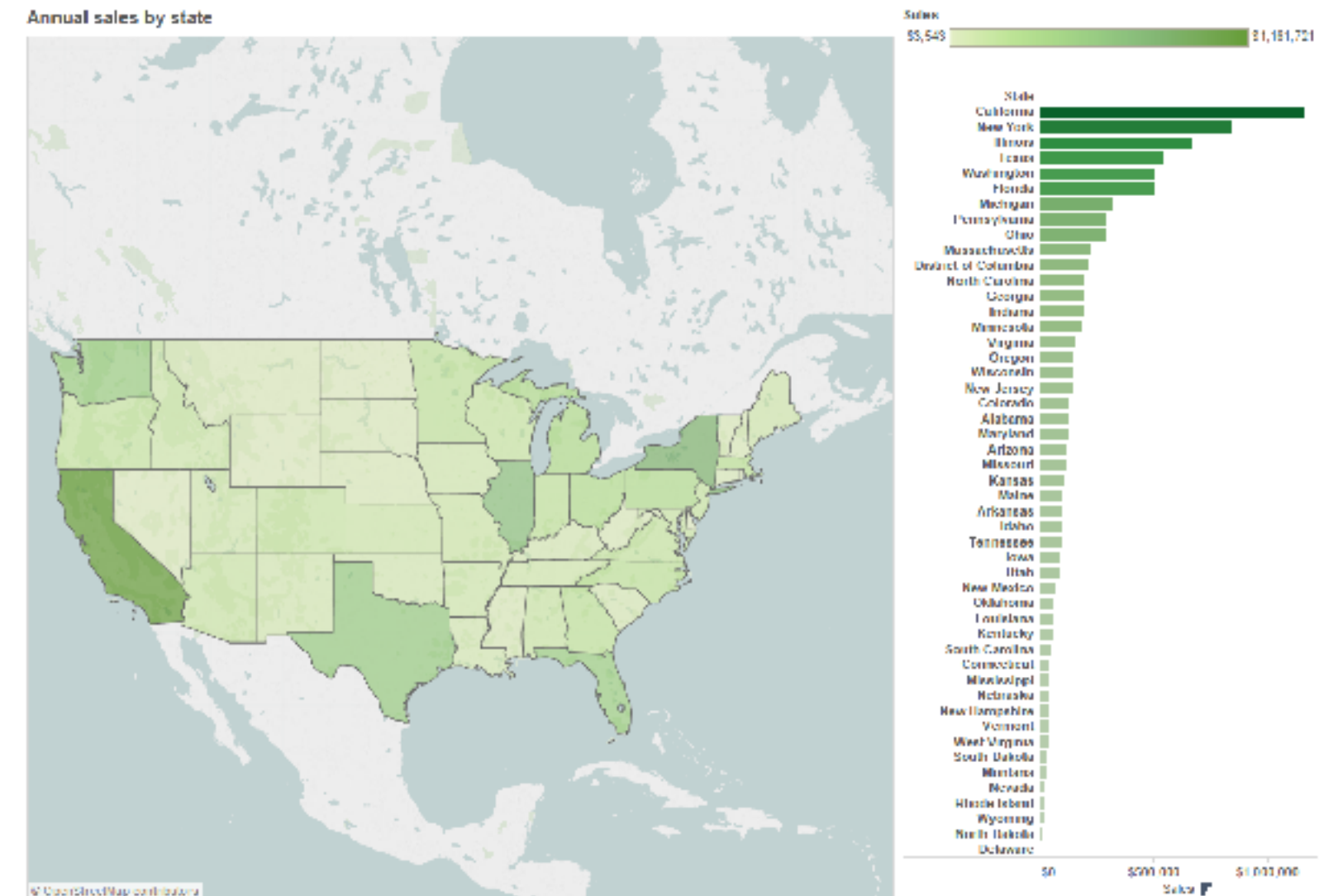
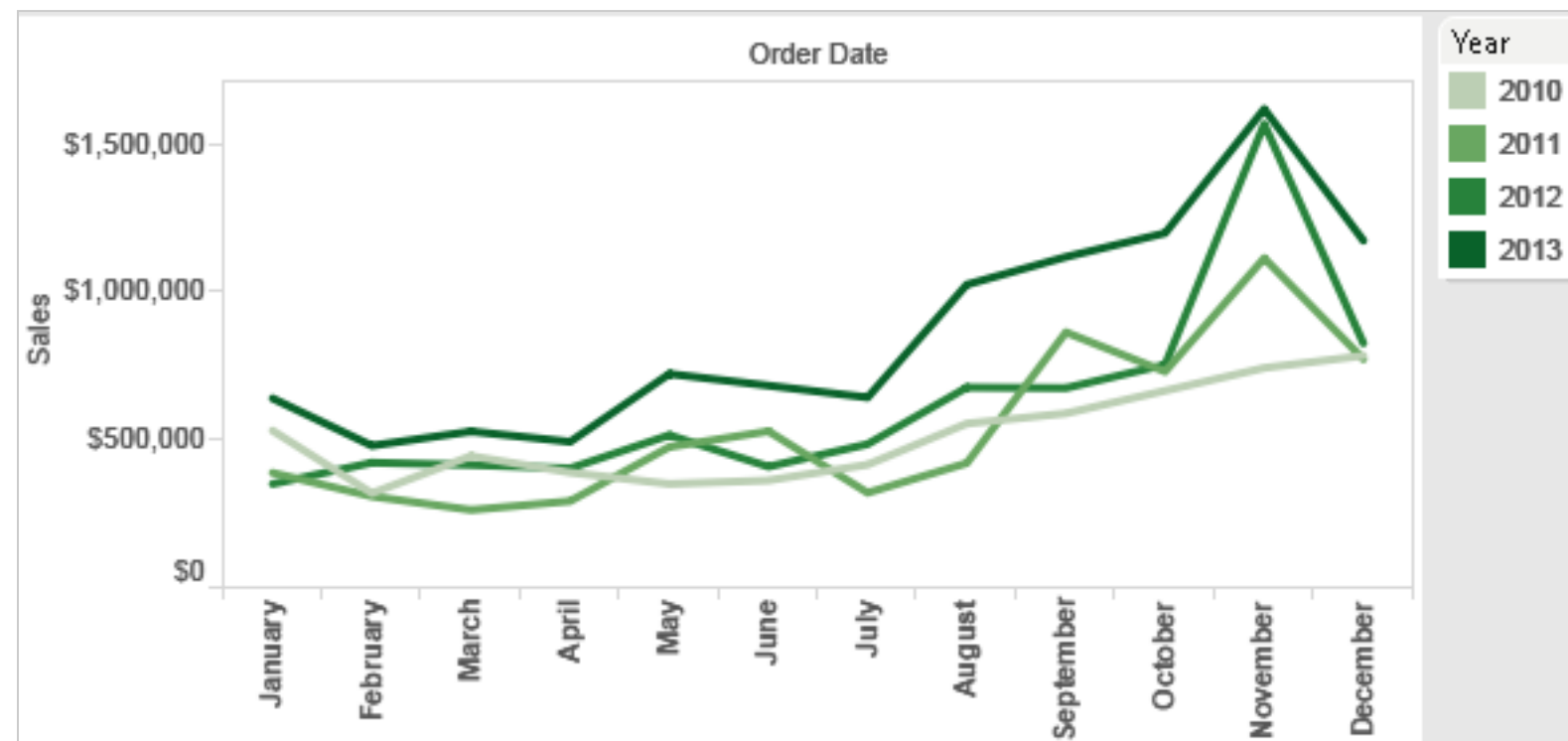
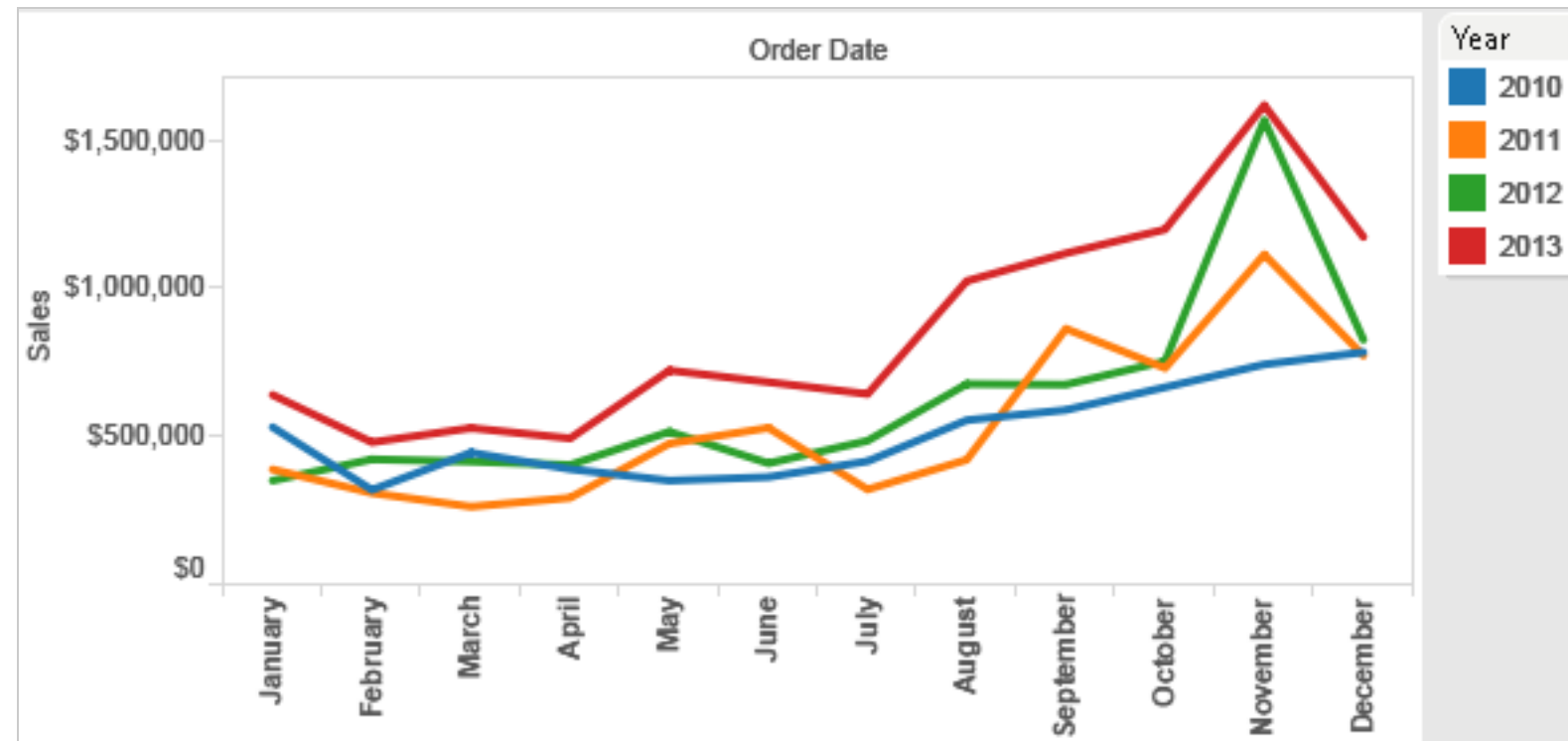
- how much they can convey: how many discriminable bins can we use?

Quiz: Which color channels?

- Continuous quantitative attribute



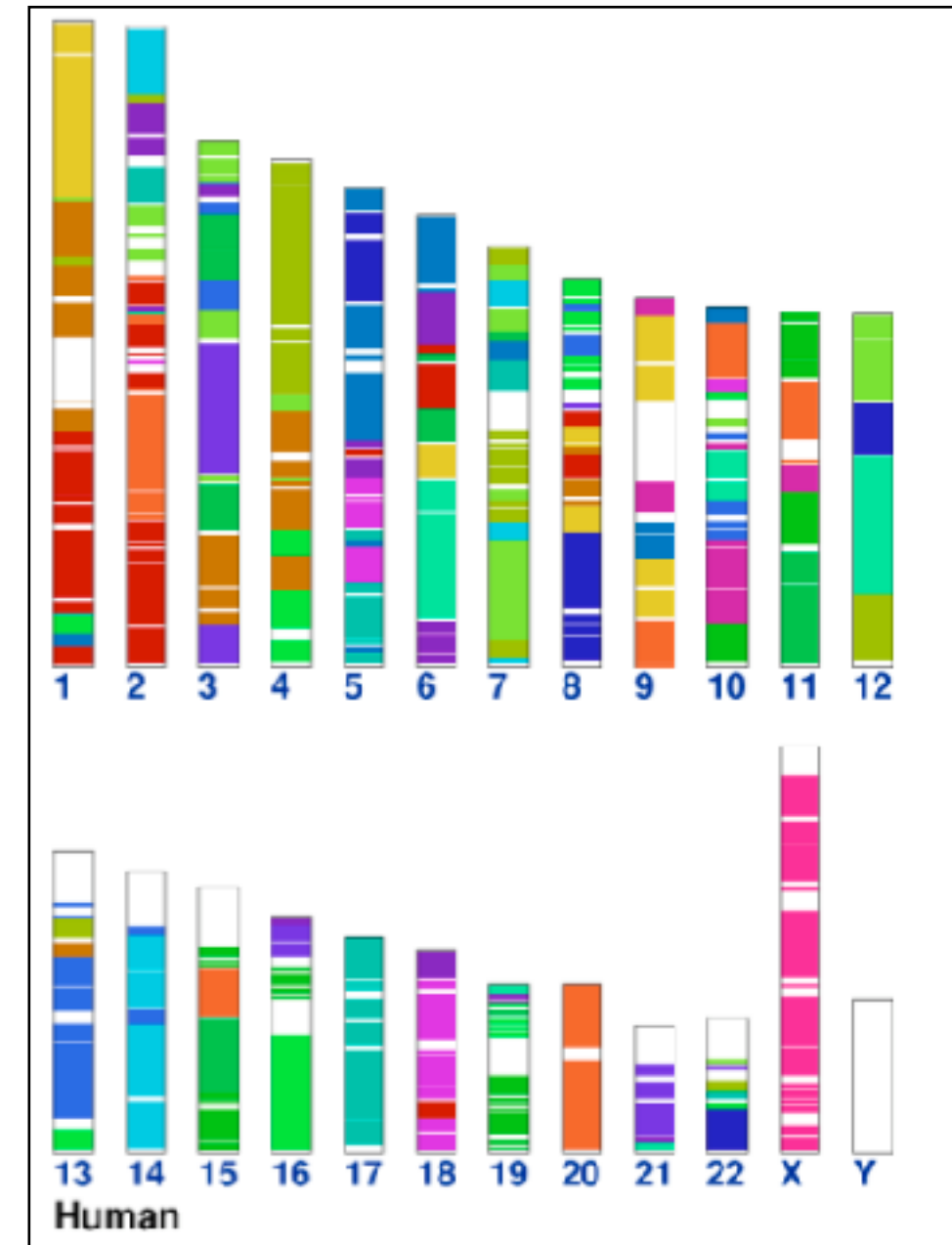
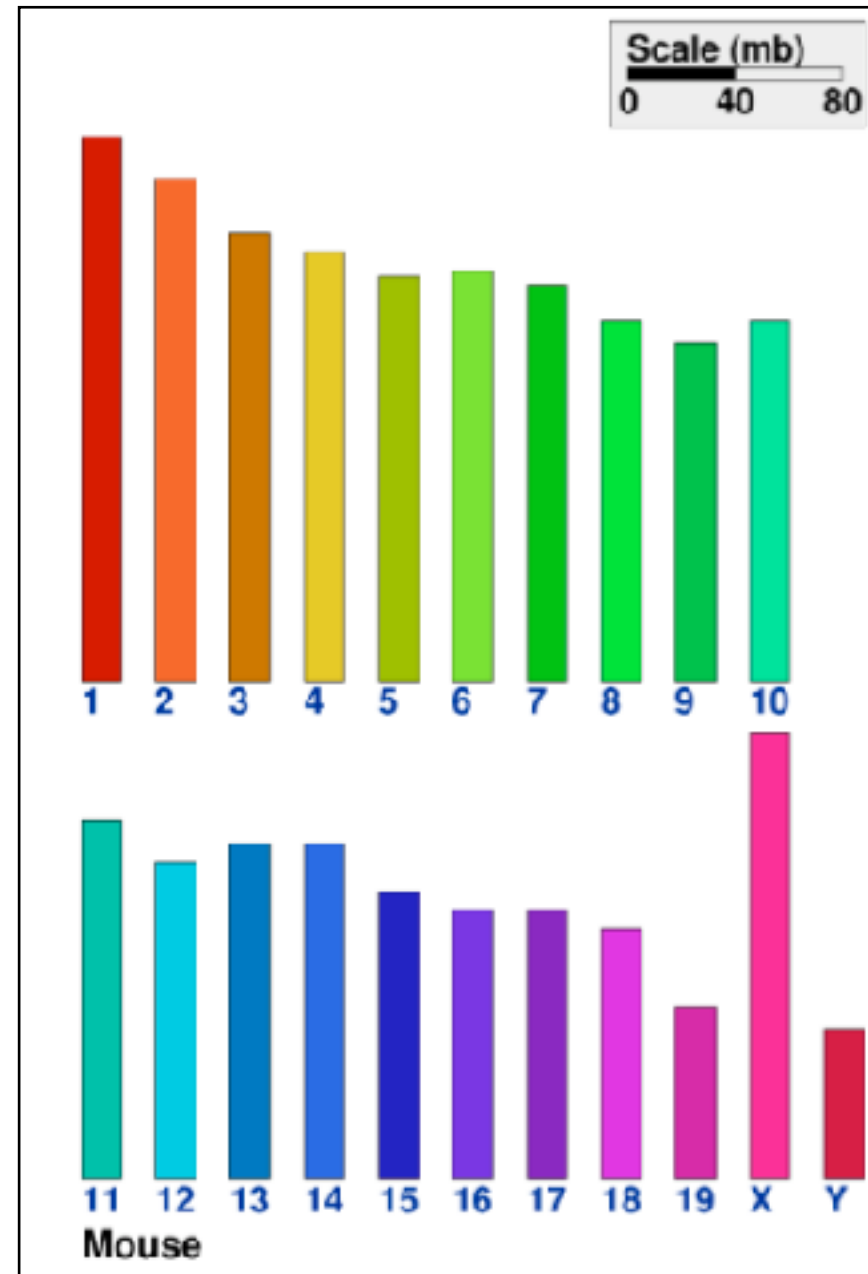
Categorical vs ordered color



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

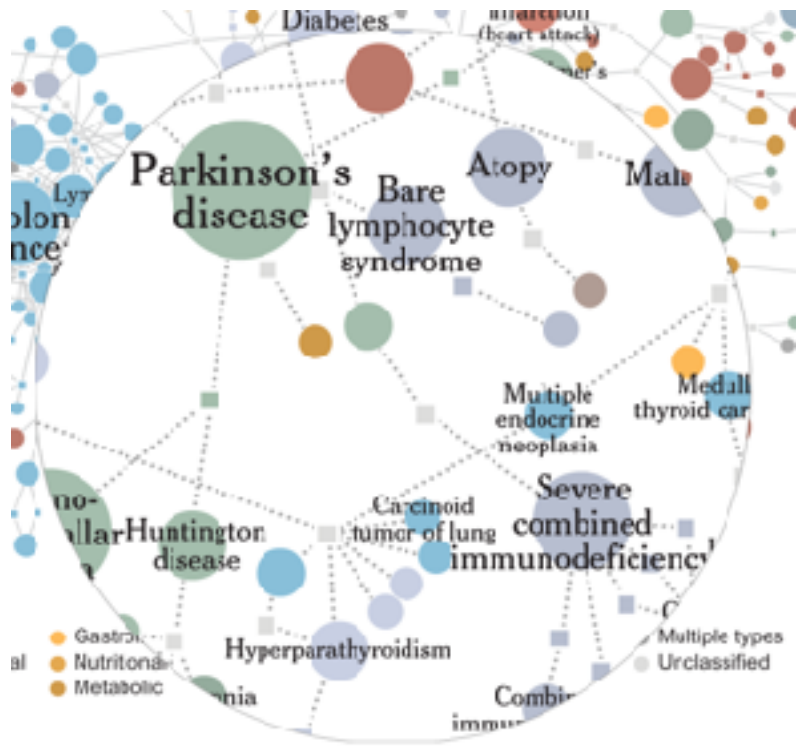
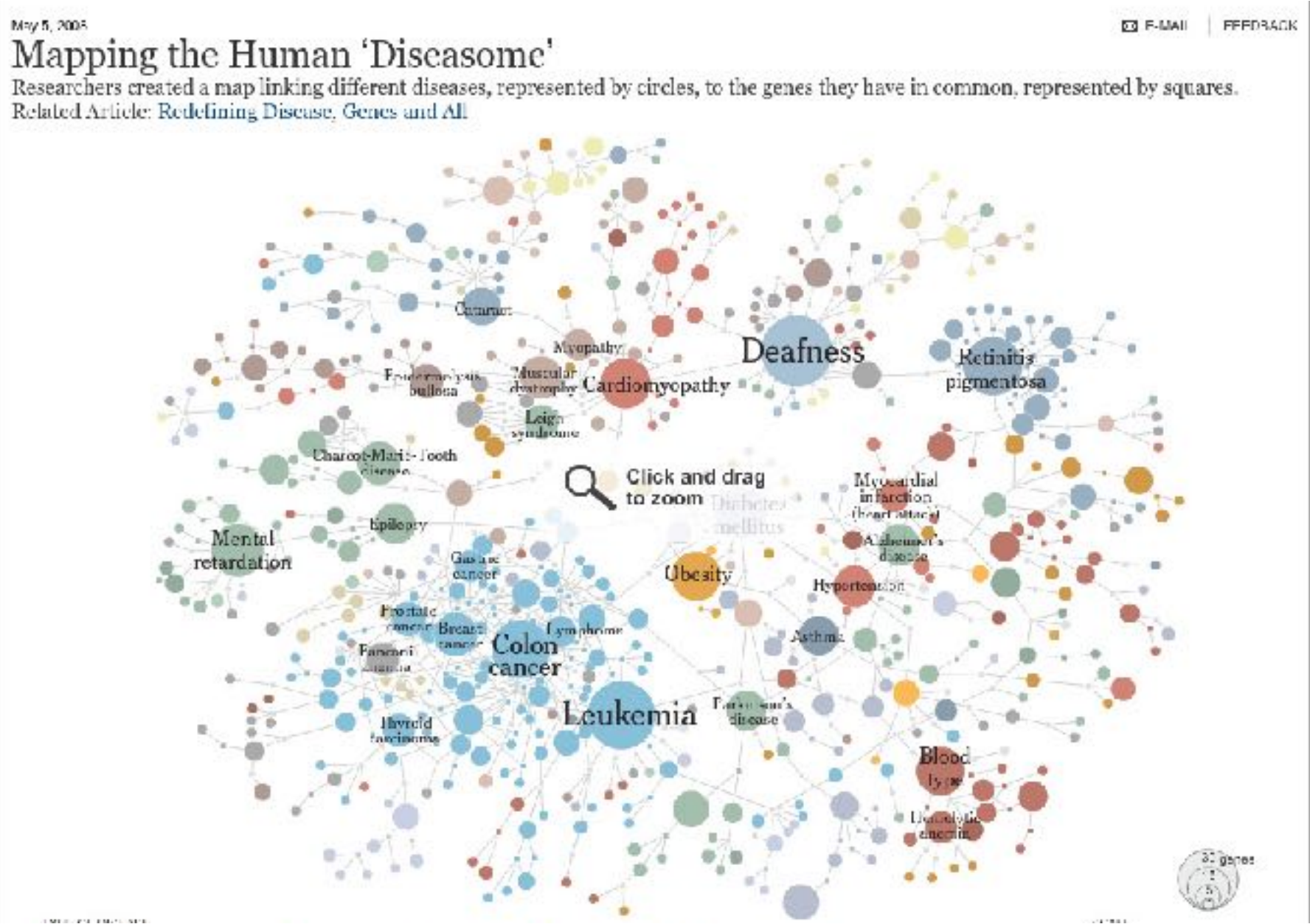
Categorical color: limited number of discriminable bins

- 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.]

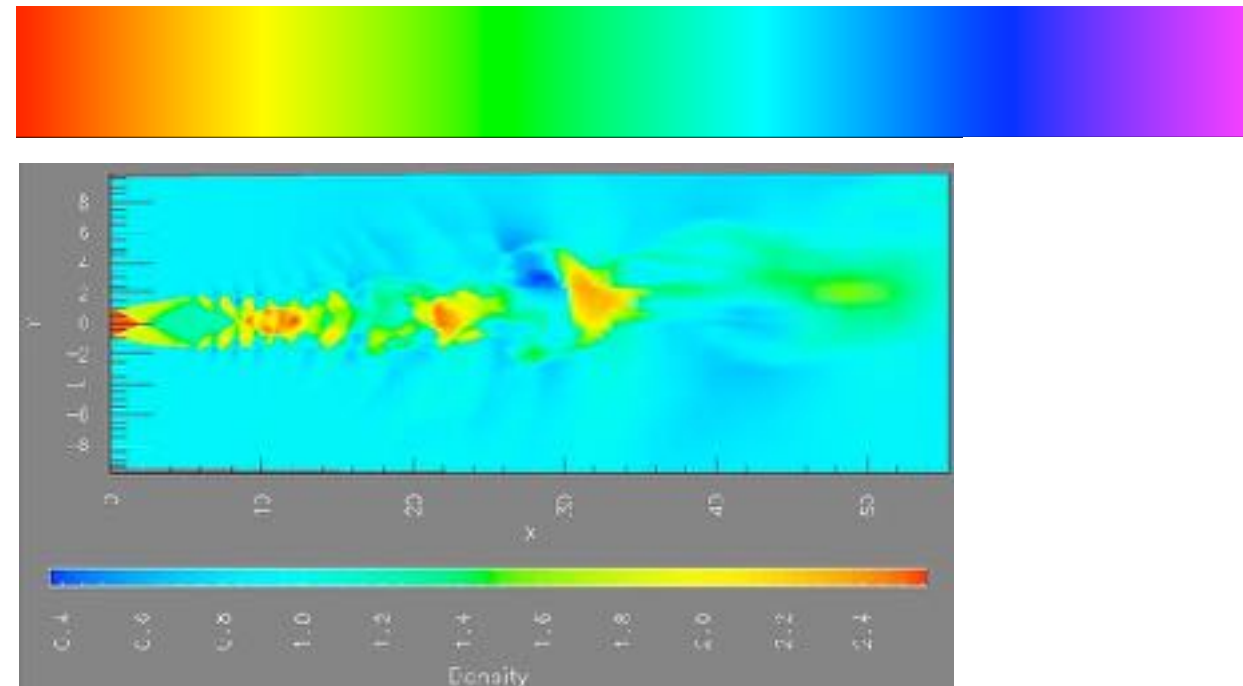
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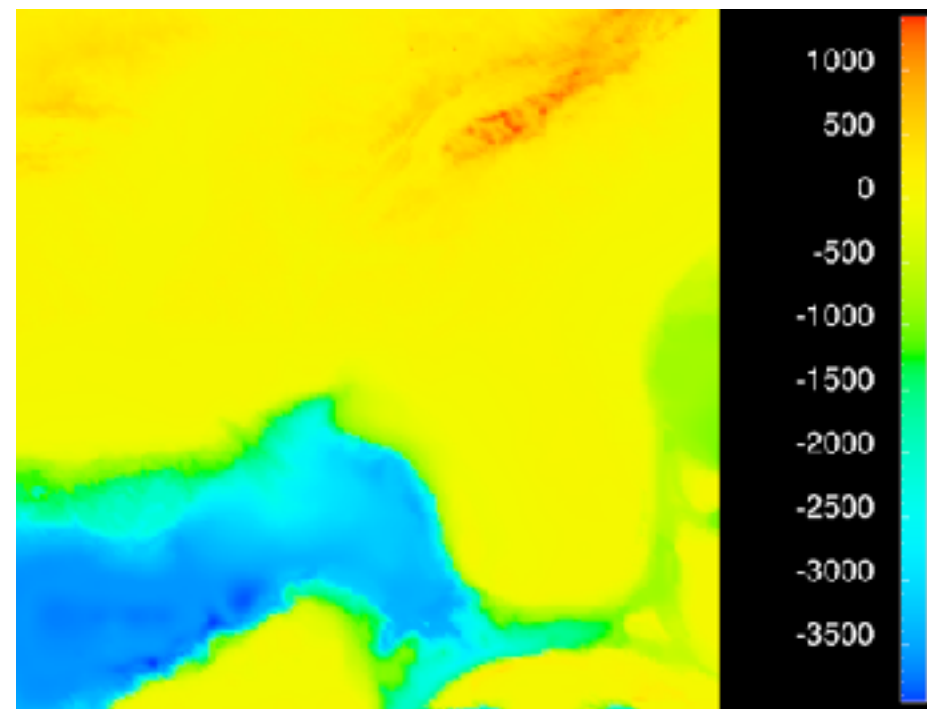
- | | | | | | | | |
|------------|---------------------|------------------|-----------------|--------------------|---------------------|-----------------|------------------|
| ● Cancer | ● Connective tissue | ● Cardiovascular | ● Endocrine | ● Gastrointestinal | ● Ear, nose, throat | ● Developmental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

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.]

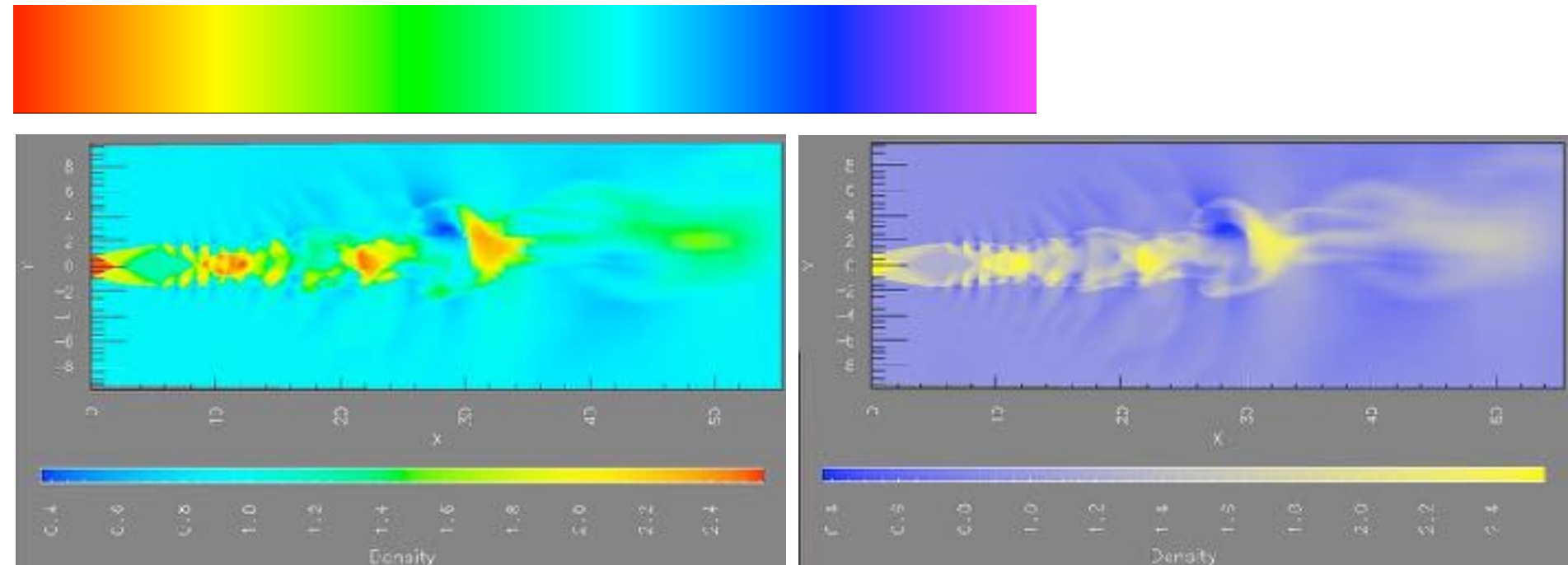


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <http://www.research.ibm.com/people/lloyd/color/color.HTM>]

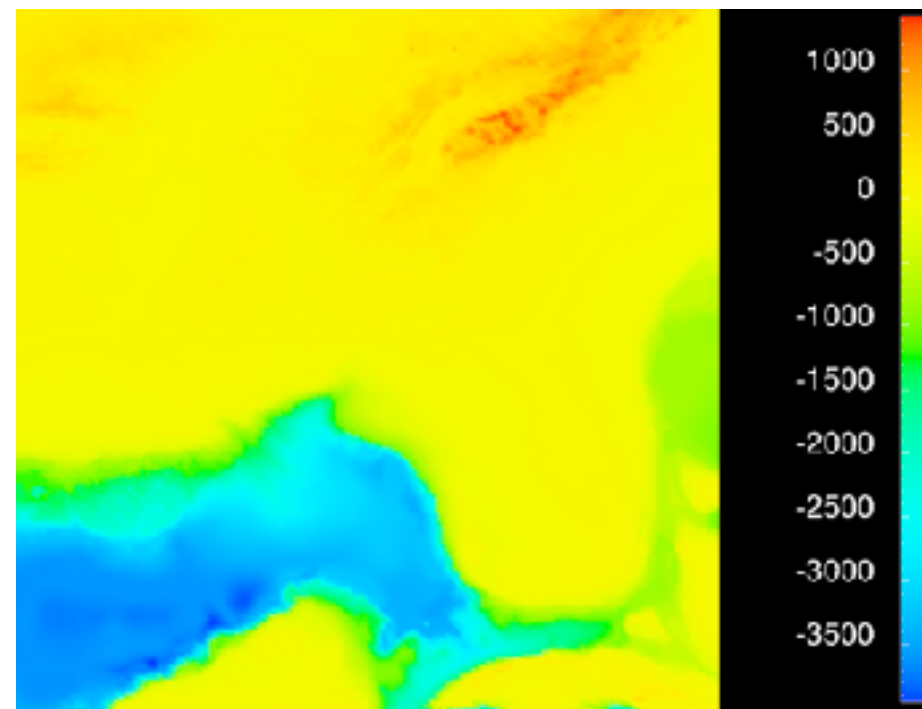
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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 - fine-grained structure visible and nameable
- alternatives
 - large-scale structure: fewer hues



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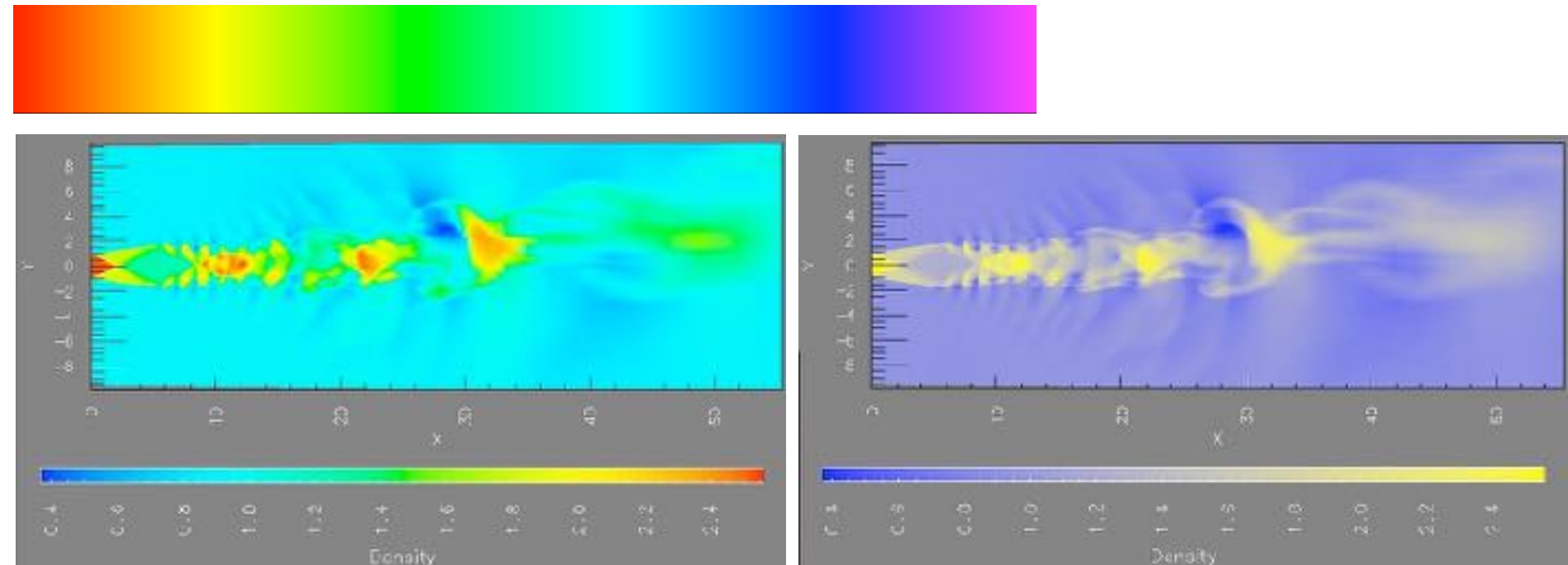


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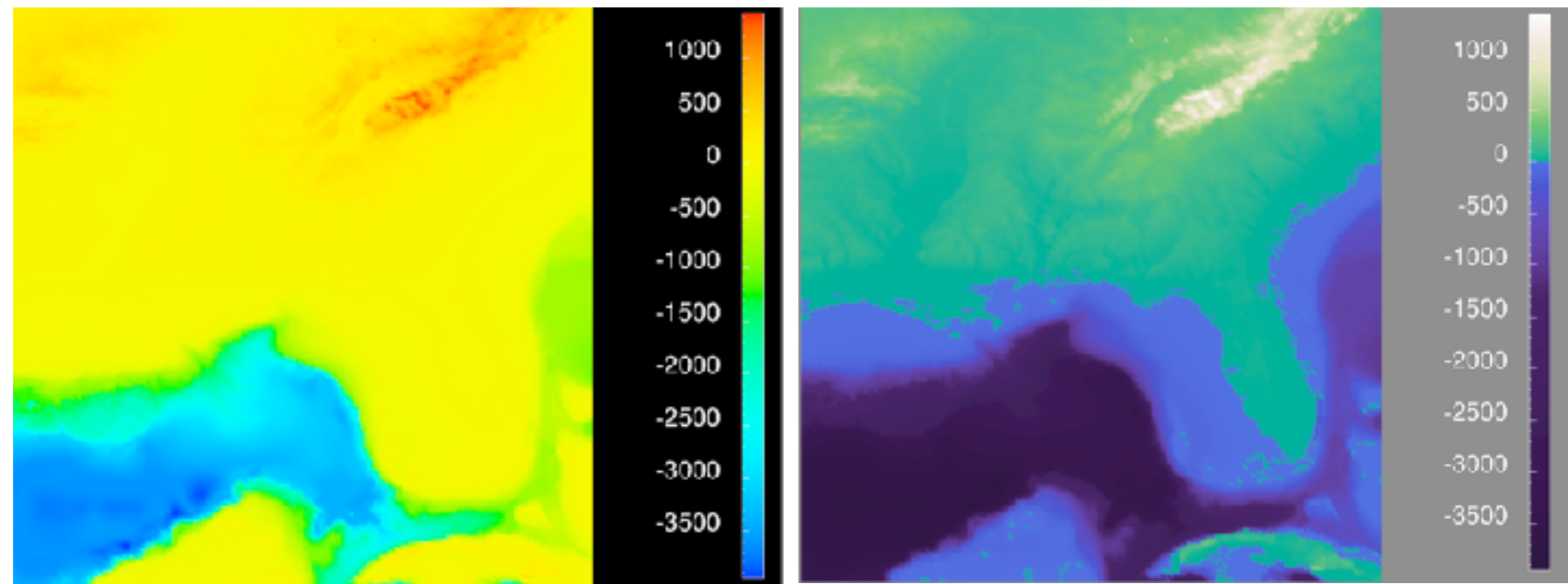
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 - large-scale structure: fewer hues
 - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



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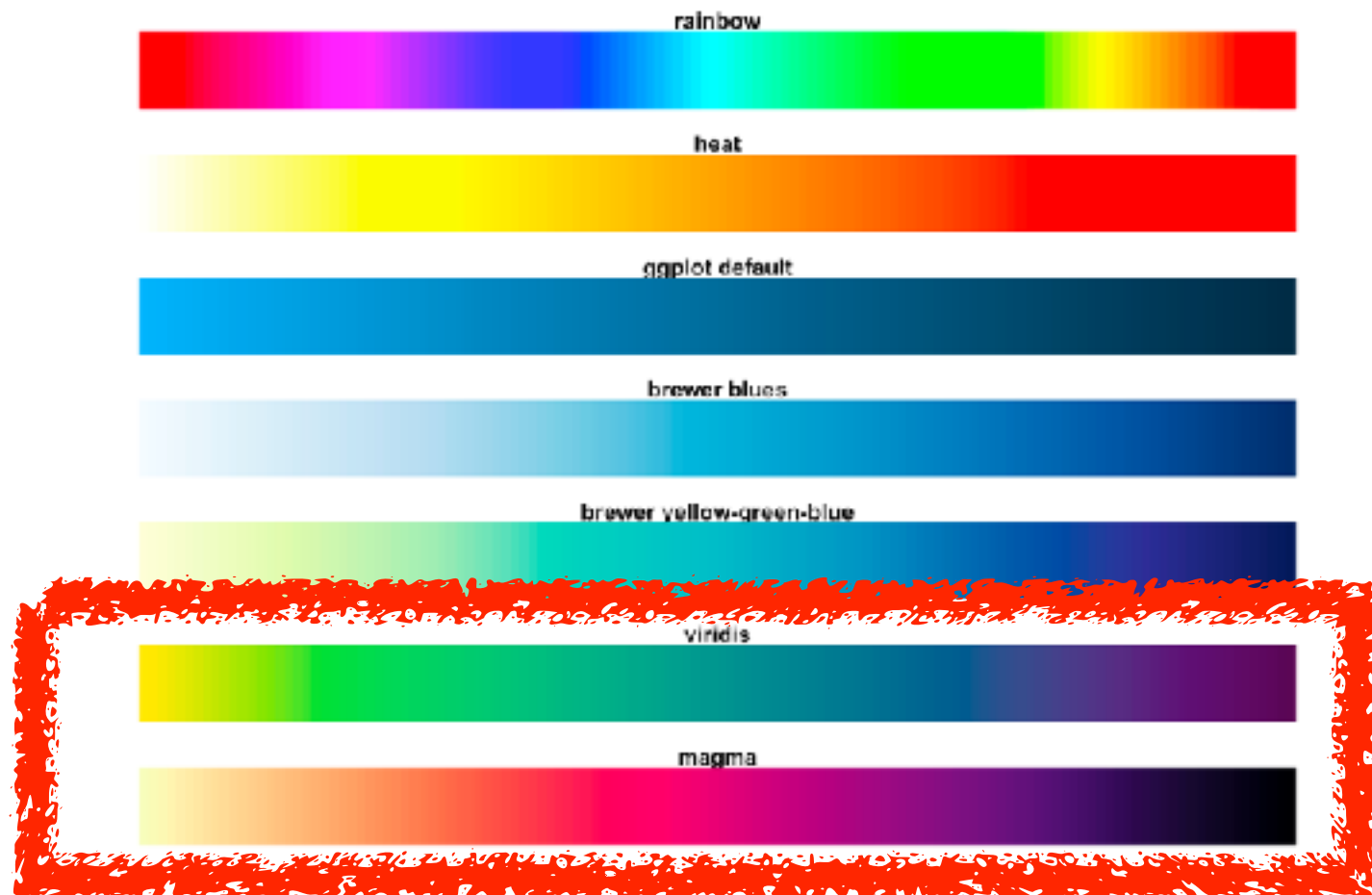


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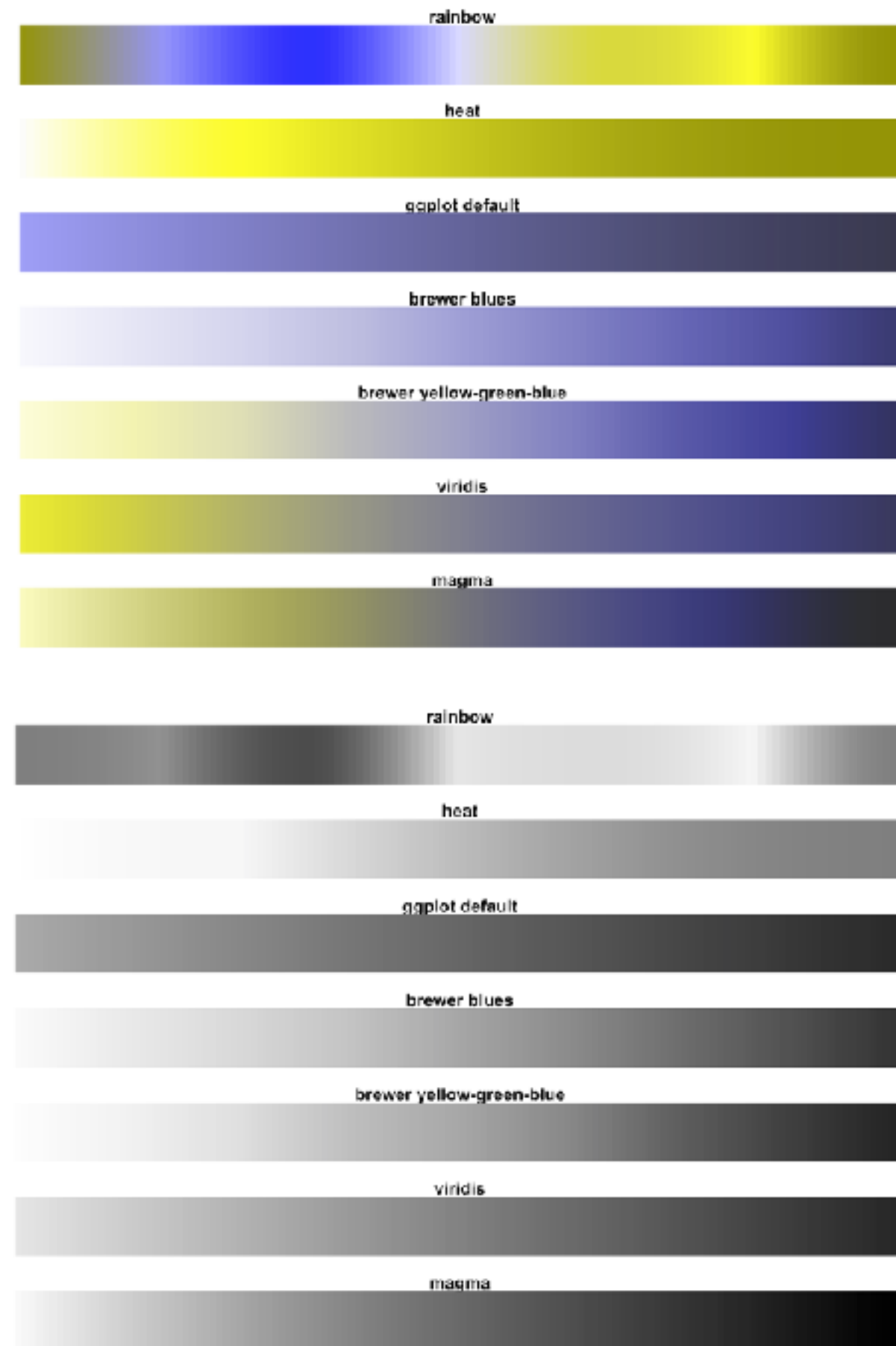
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Viridis

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

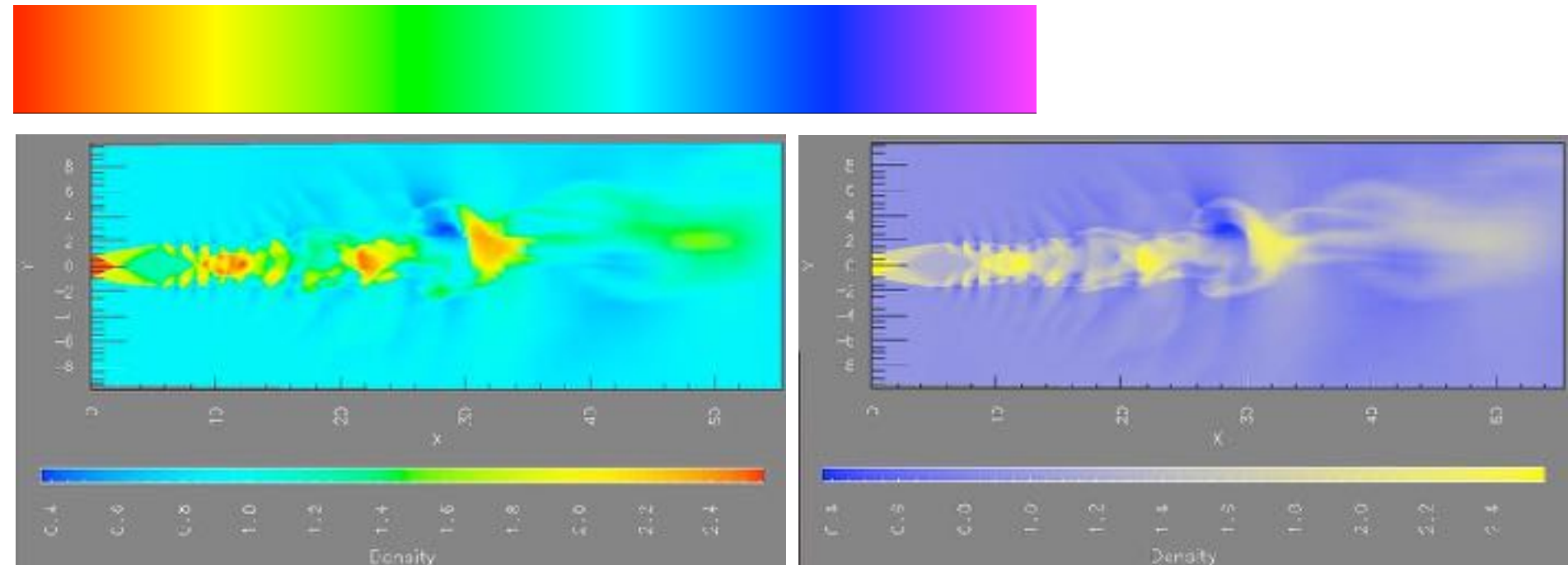


<https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html>

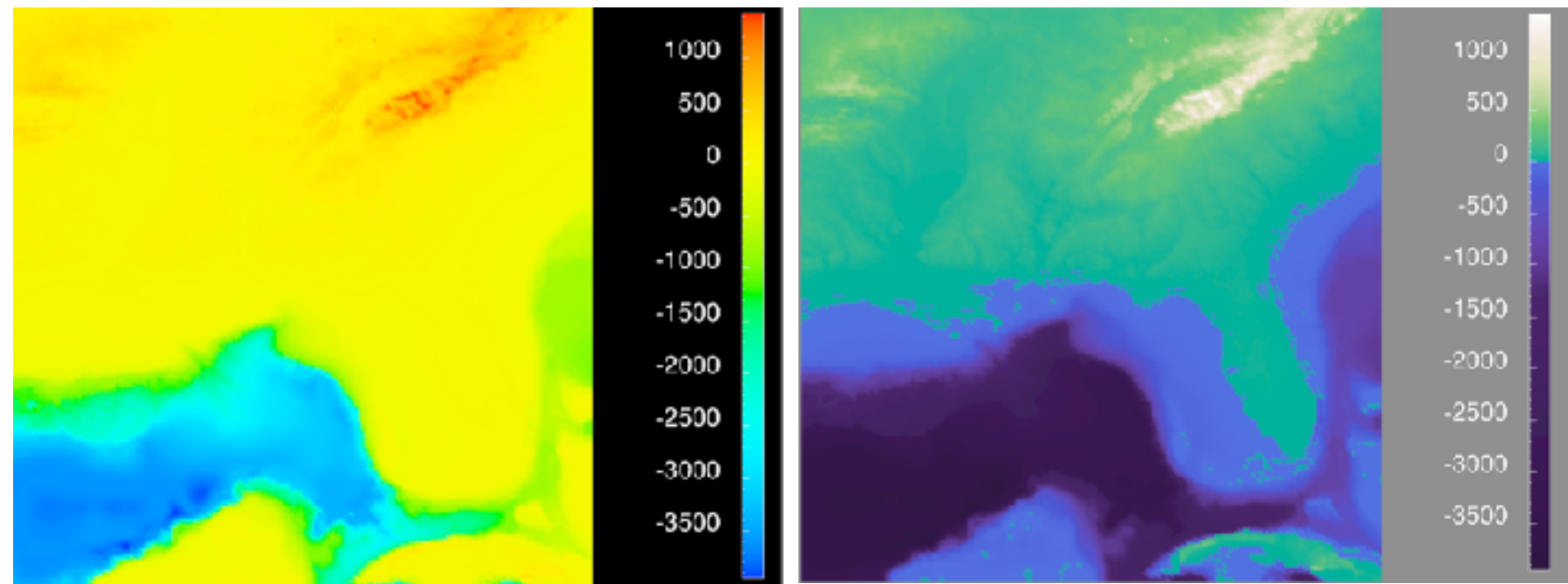


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 - large-scale structure: fewer hues
 - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
 - segmented rainbows for binned or categorical



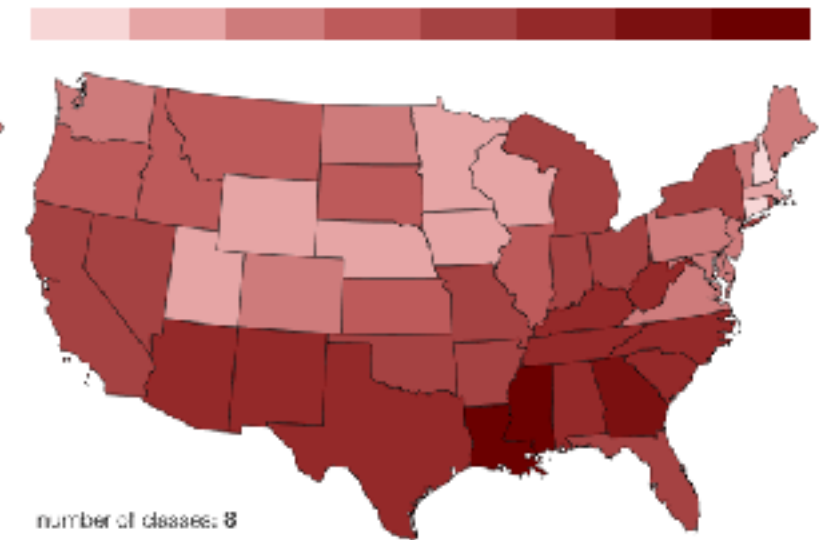
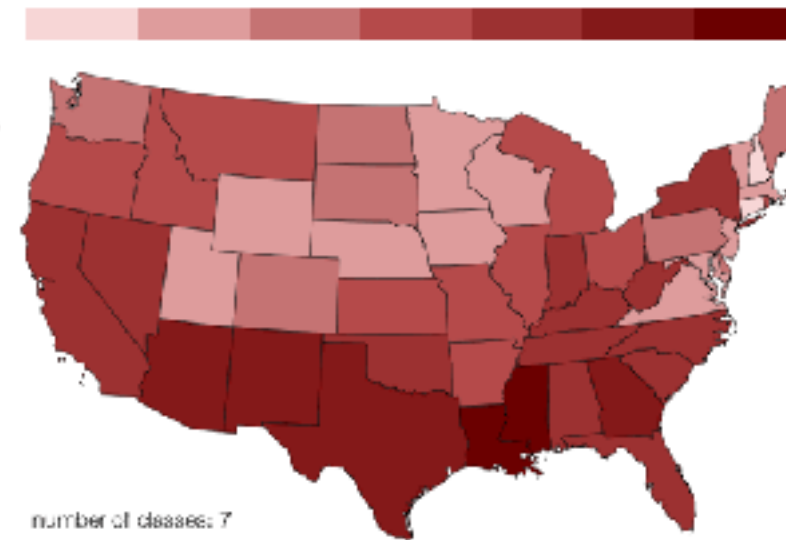
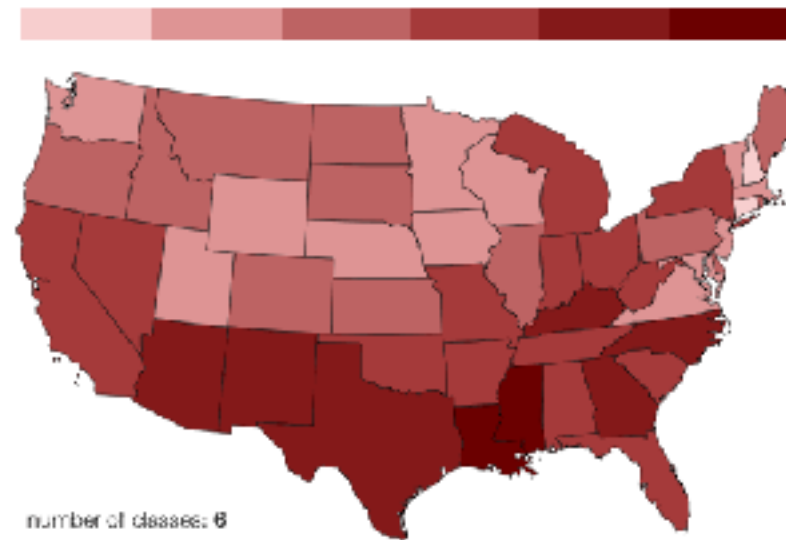
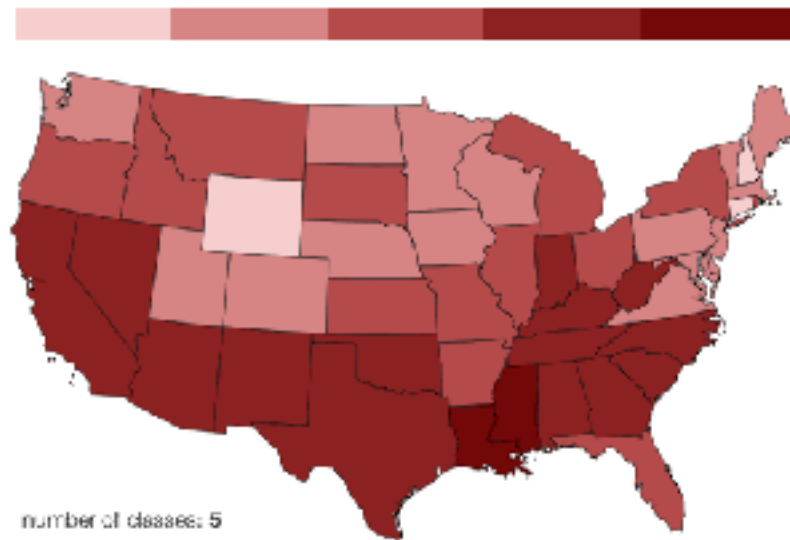
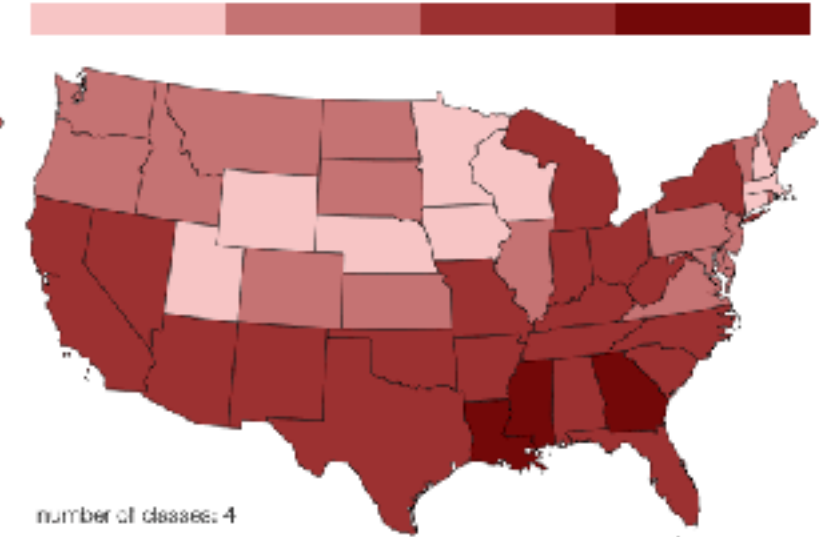
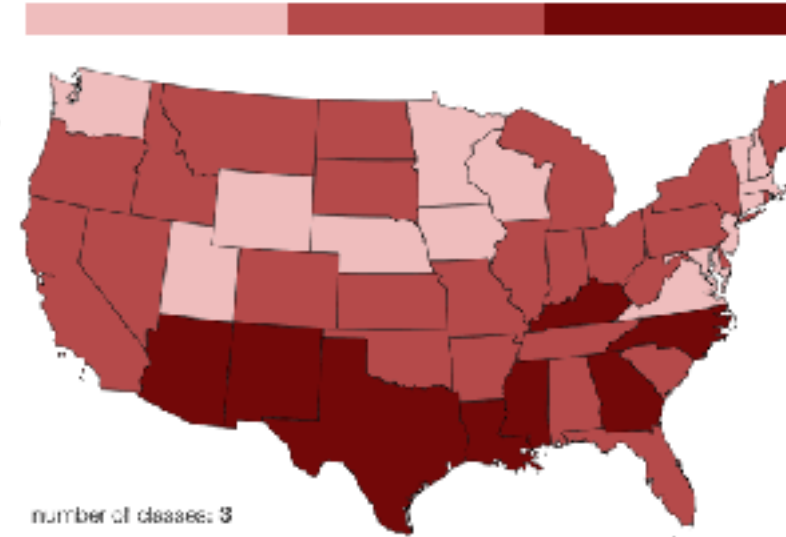
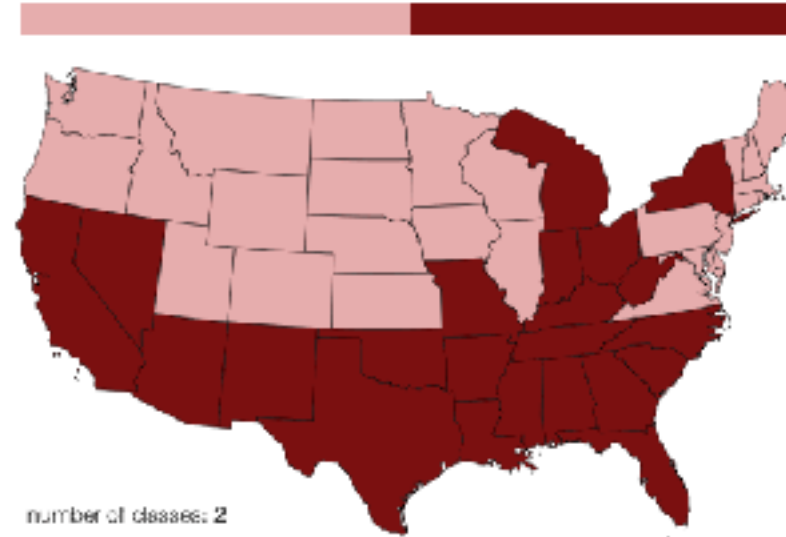
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Ordered color: how many bins?



Many color spaces

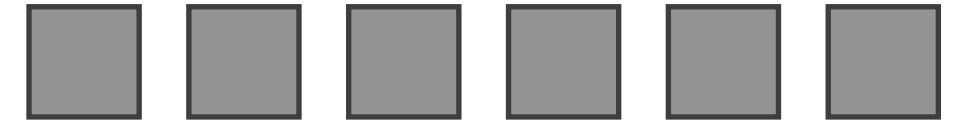
- HSL/HSV: somewhat better for encoding
 - hue/saturation wheel intuitive
 - beware: only pseudo-perceptual!
 - lightness (L) or value (V) \neq luminance or L^*
- Luminance, hue, saturation
 - good for encoding
 - but not standard graphics/tools colorspace
- CIE $L^*a^*b^*$: good for computation
 - L^*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

Corners of the RGB color cube

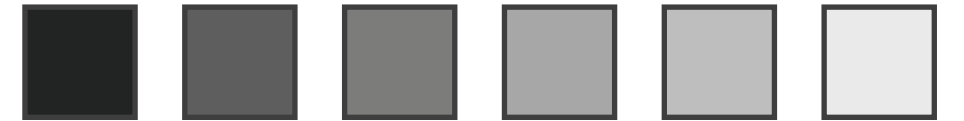


L from HLS

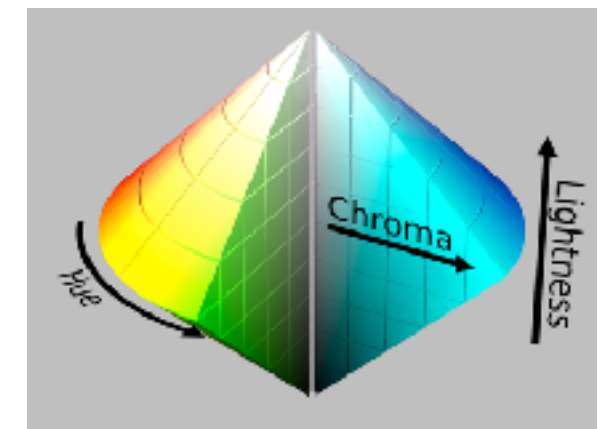
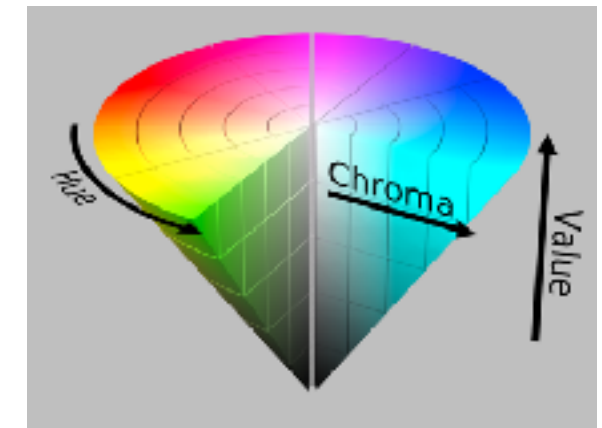
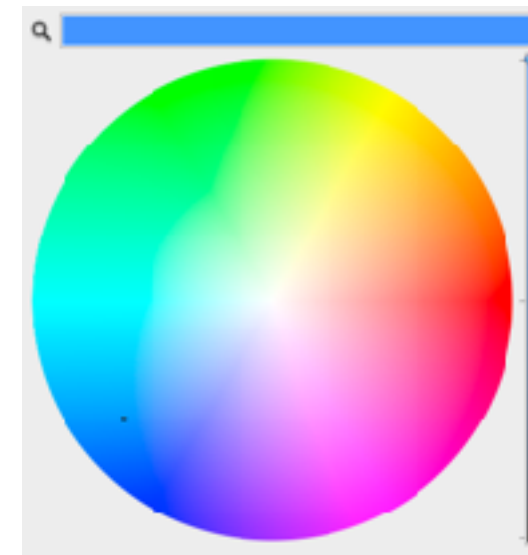
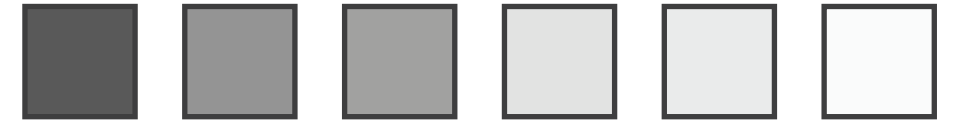
All the same



Luminance values



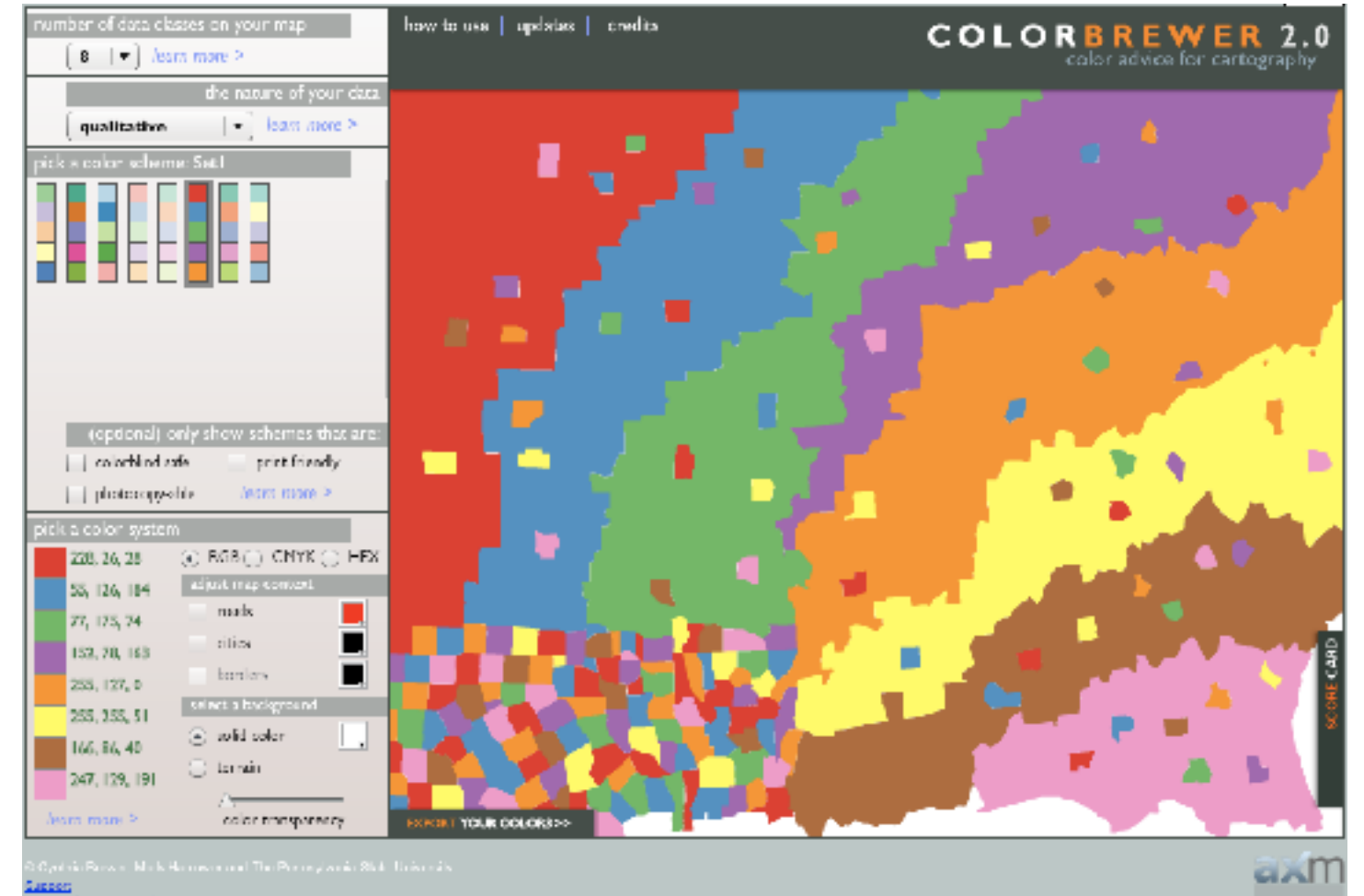
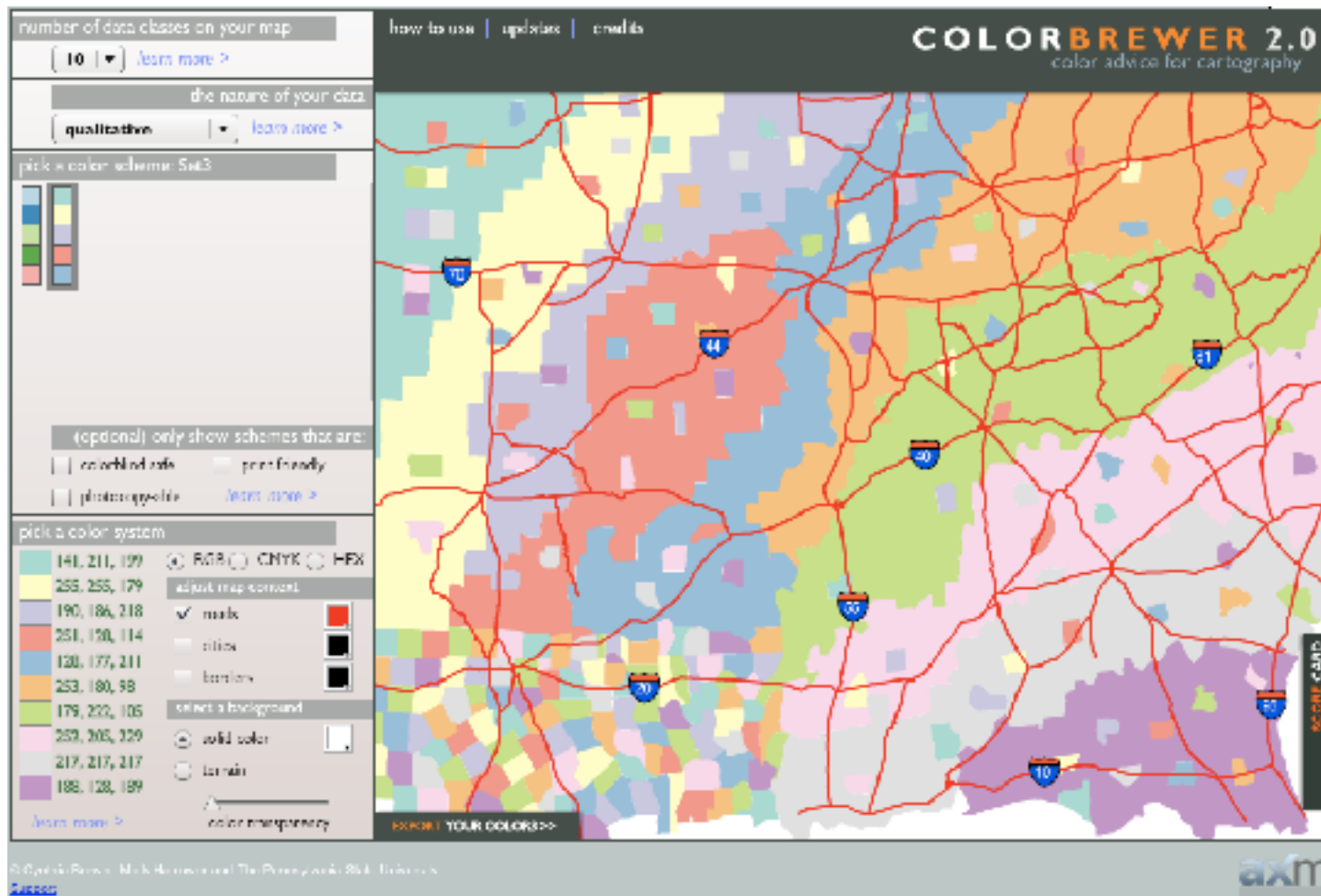
L^* values



Tools and Libraries in Practice

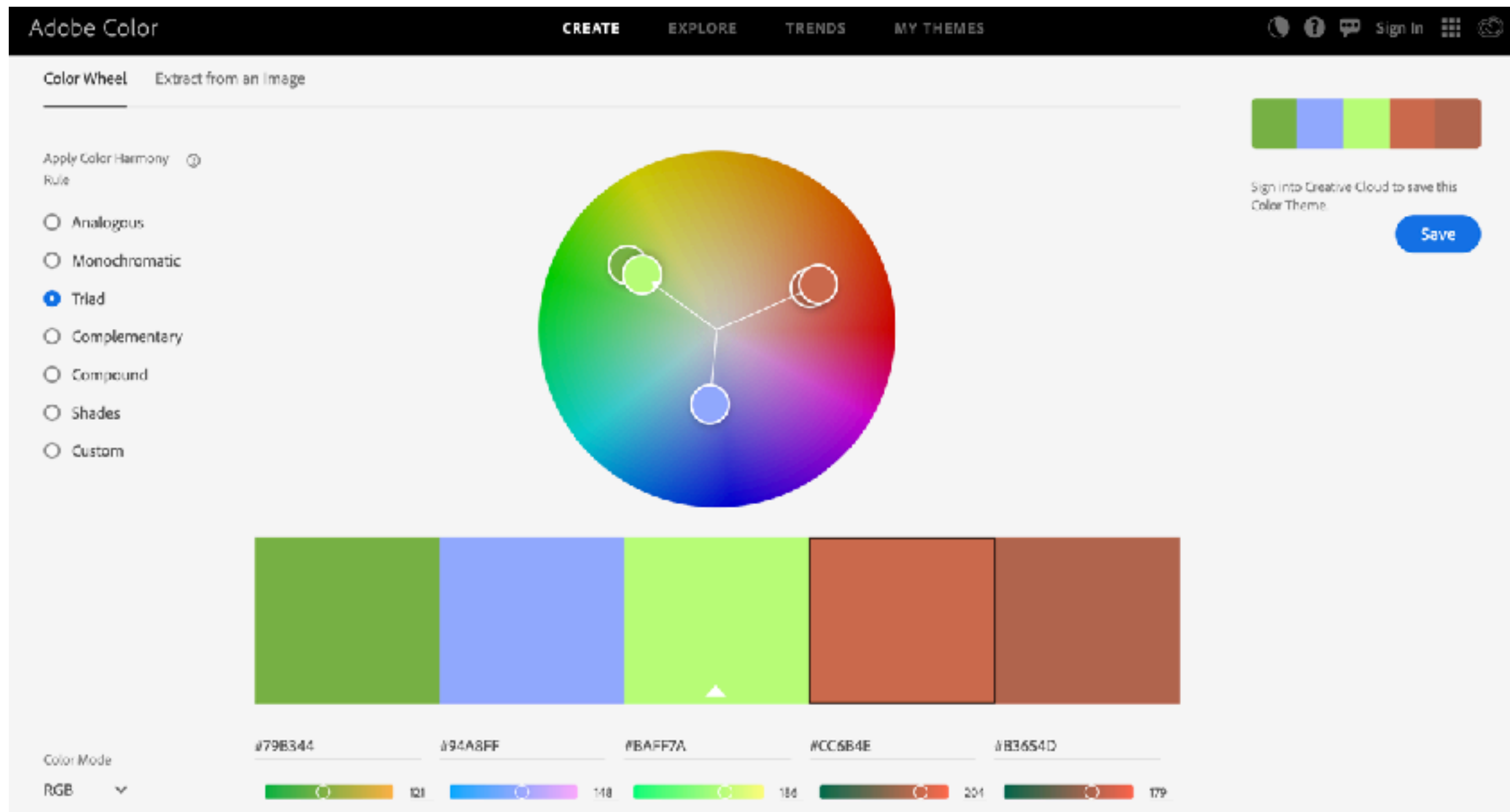
ColorBrewer

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



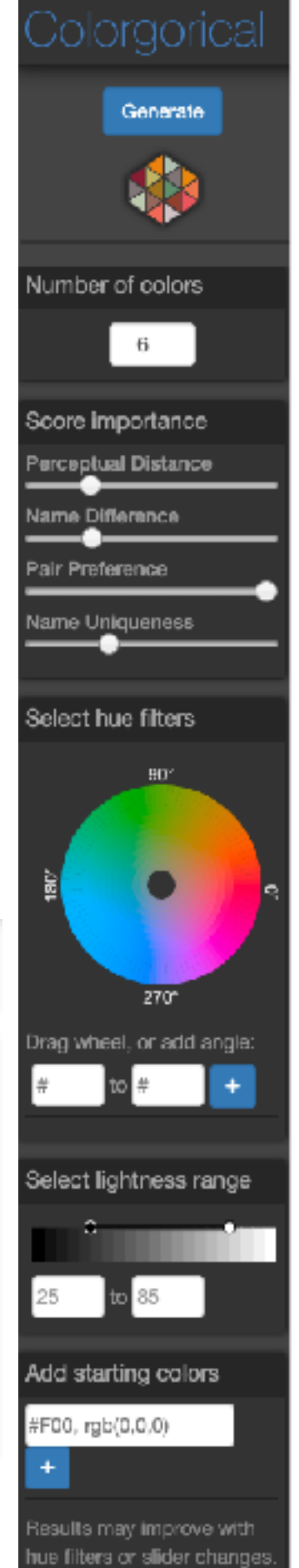
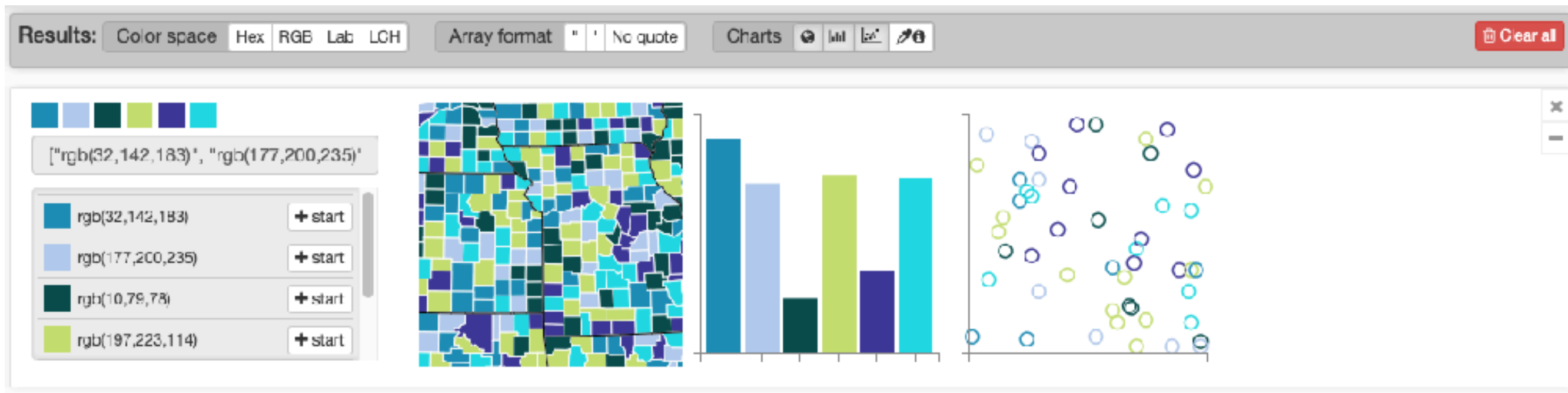
Adobe Color Picker

- <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

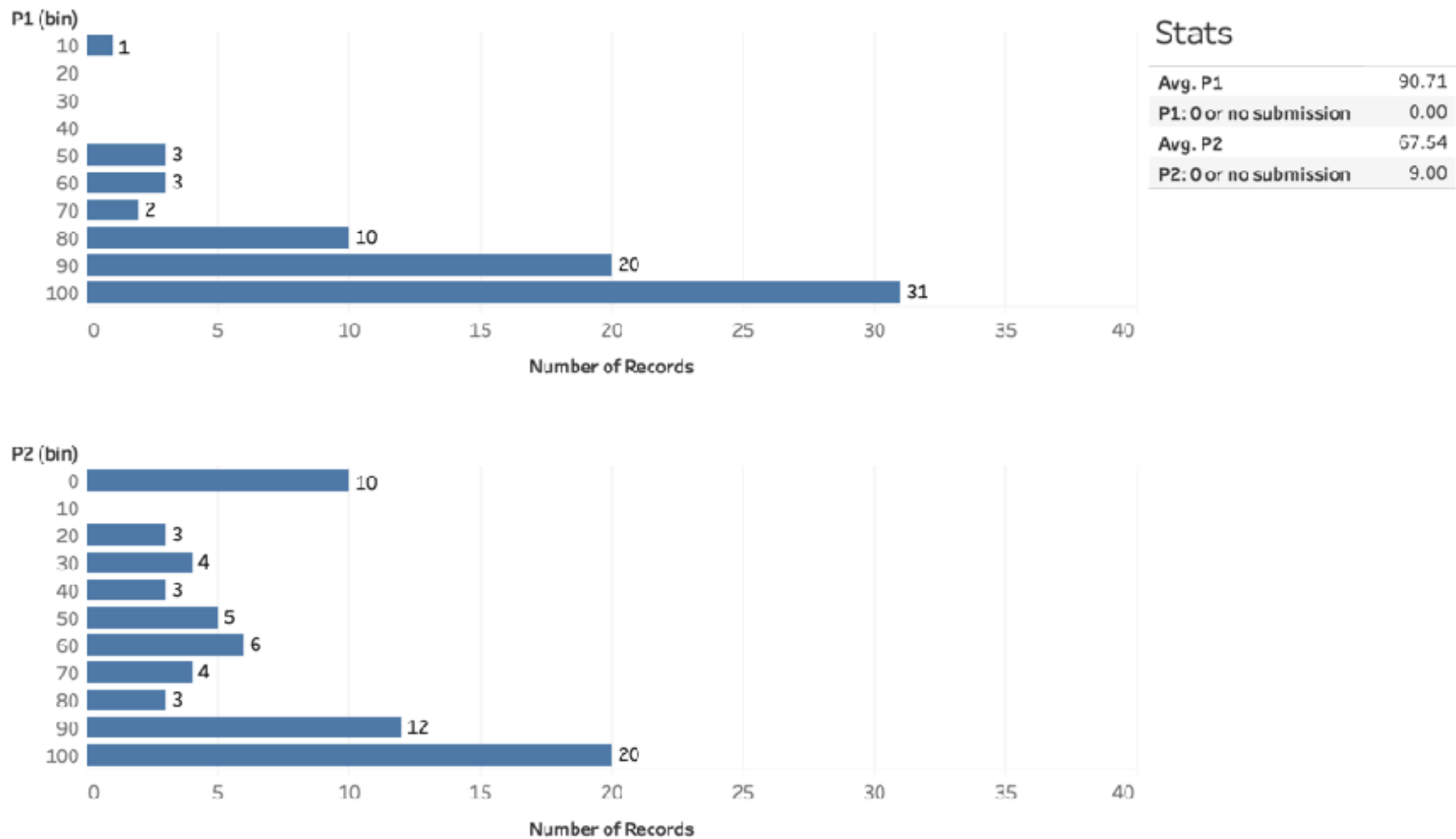
- D3-scale-chromatic:
 - <https://github.com/d3/d3-scale-chromatic>
 - Implementation of the colormap
 - Lots of good color schemes and scales
 - High-level, ready-to-be-used for most vis
 - Use this for your project

Color 2

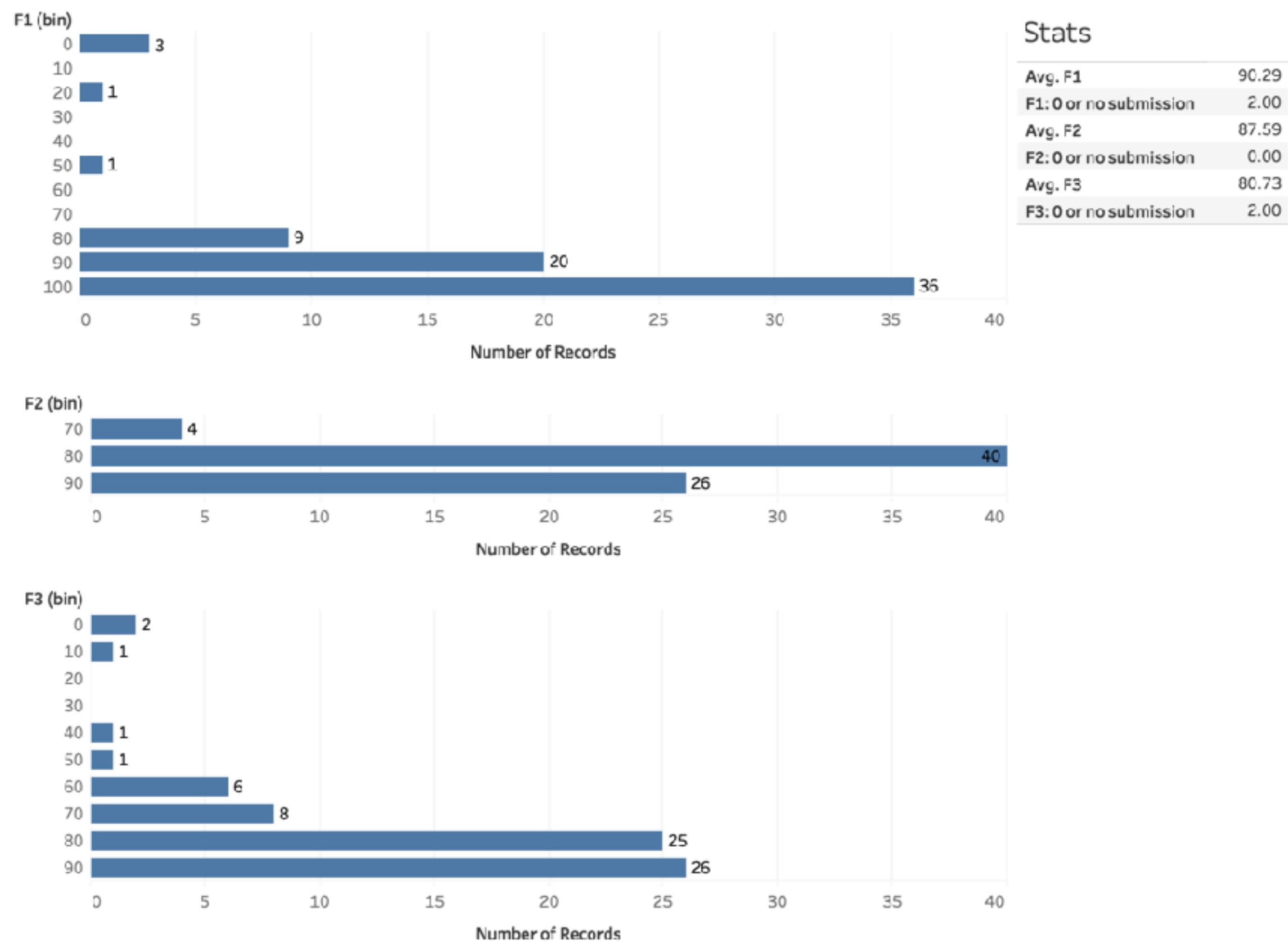
Upcoming

- 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

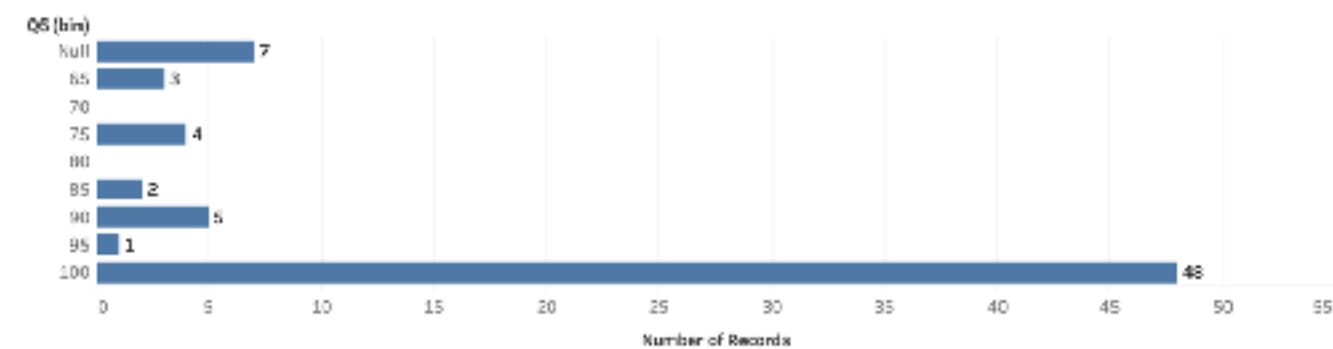
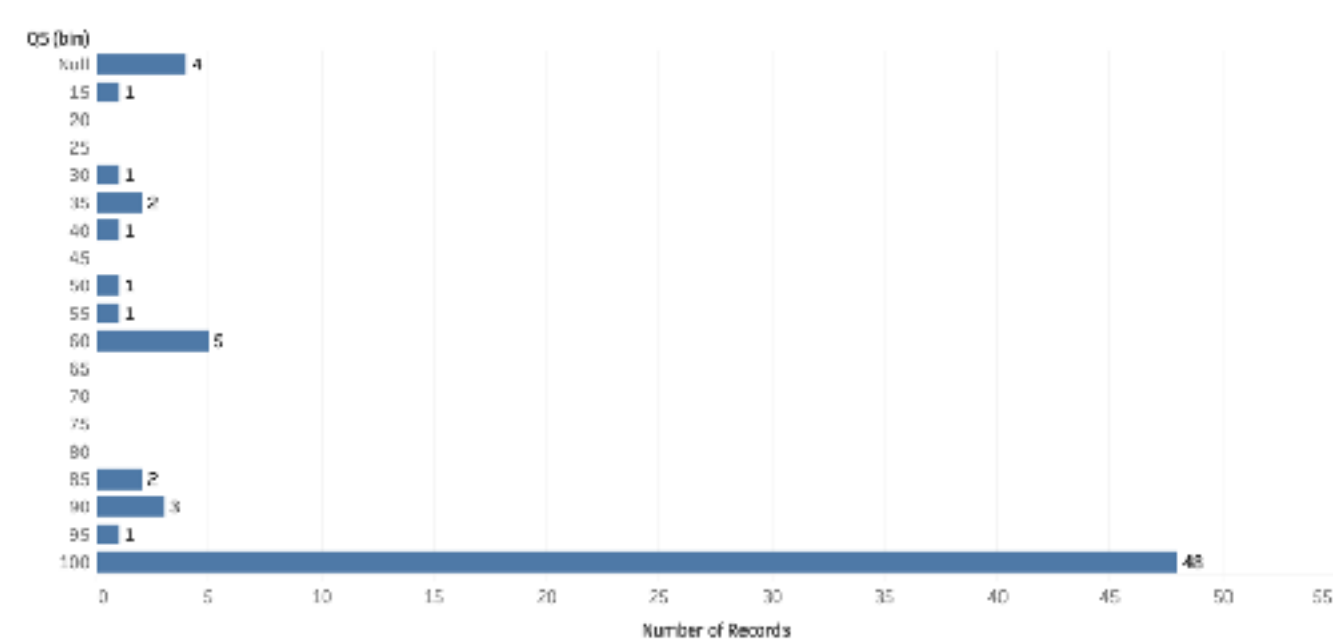
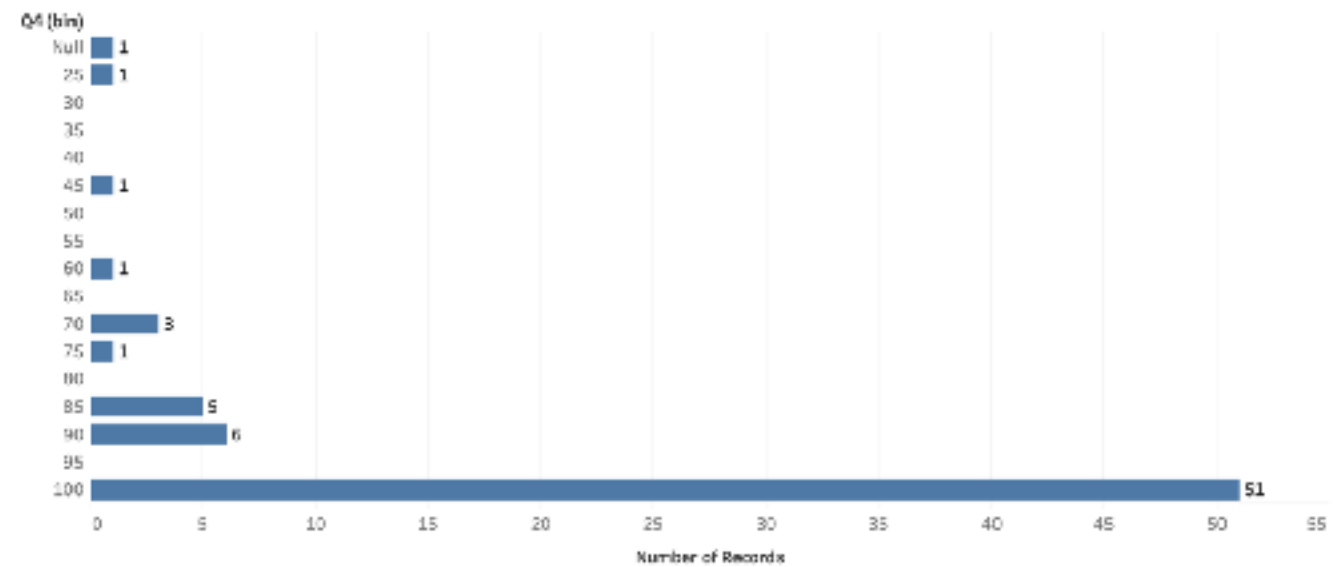
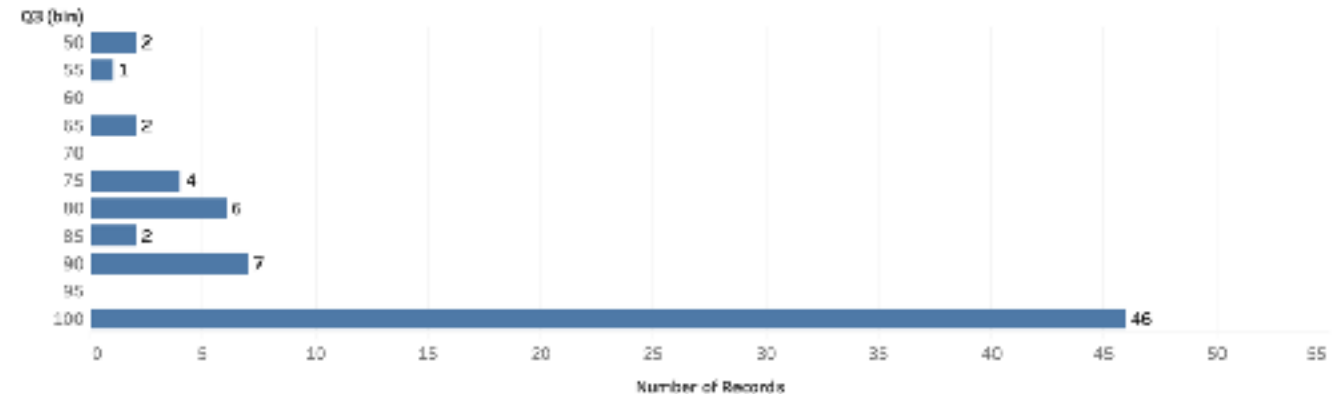
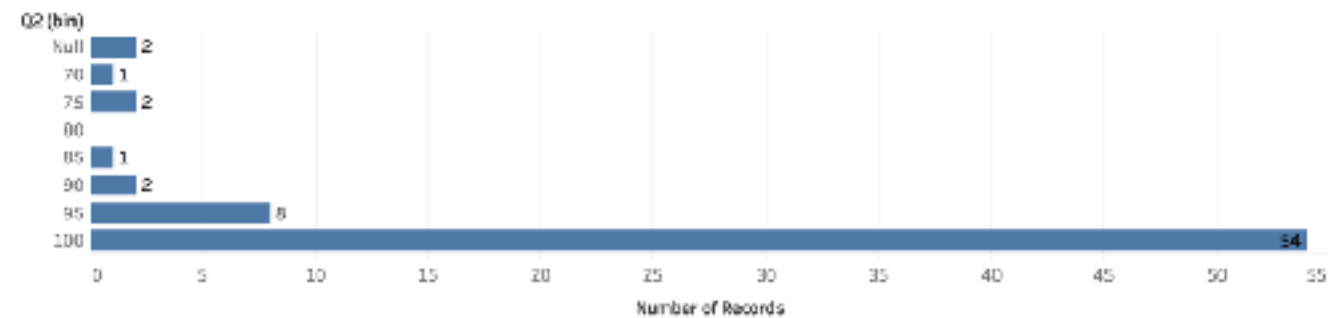
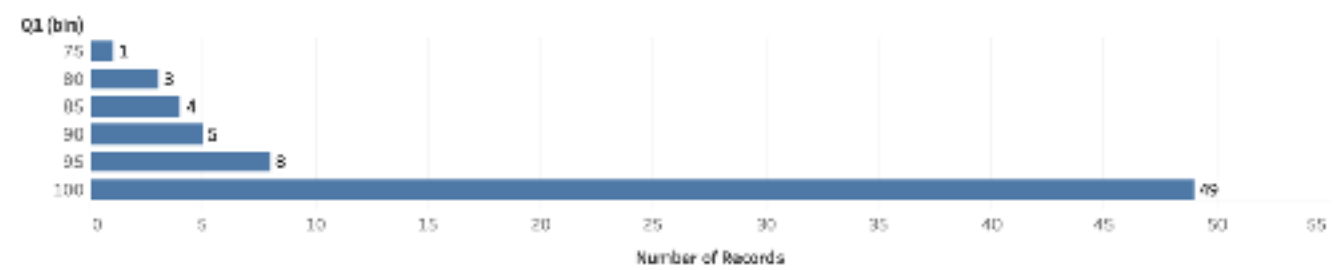
Grades distribution so far: Programming



Grades distribution so far: Foundations



Grade distributions so far: Quizzes



Polls/ announcements

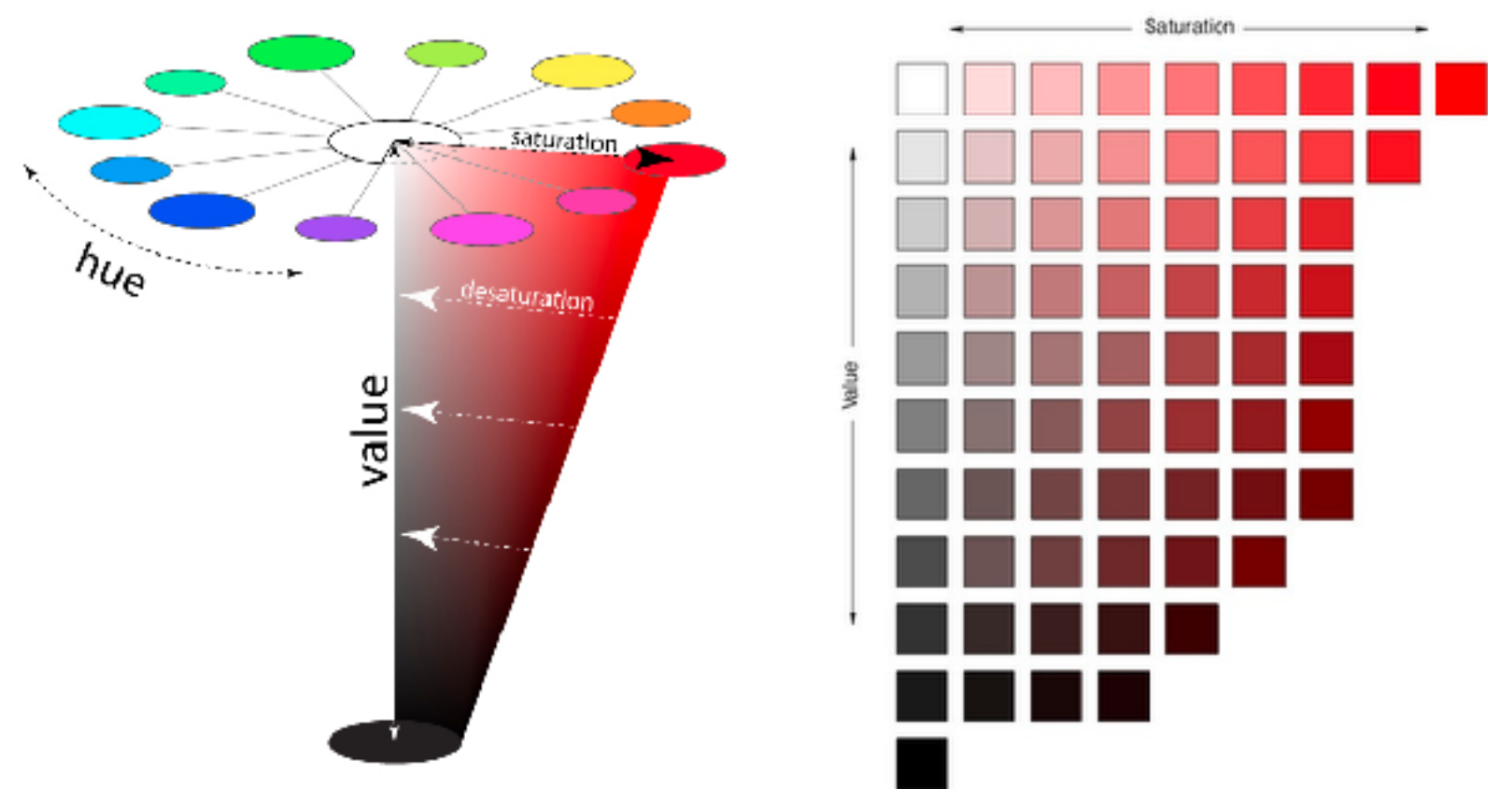
- piazza @188: would you use extra TA office hours?
- grace day granularities
 - grace days are integer not fractional. use full grace day once you're over at all.
- gradescope
 - we'll use it for exam marking
 - email went out for gradescope.ca (**not** gradescope.com)

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

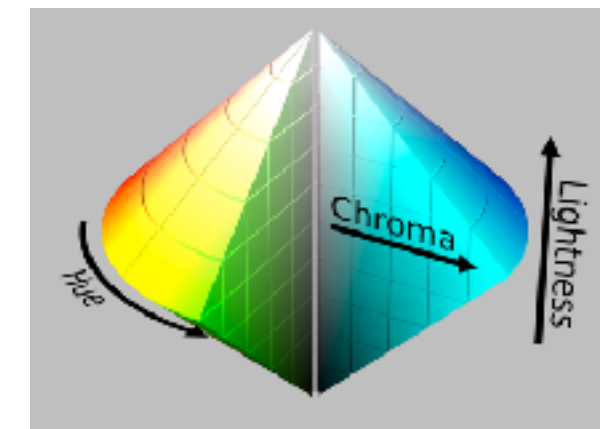
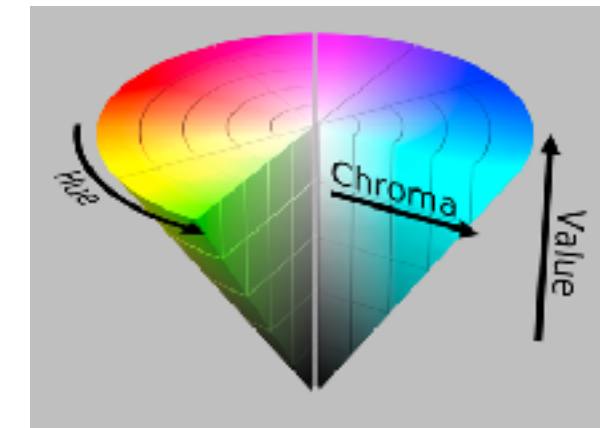
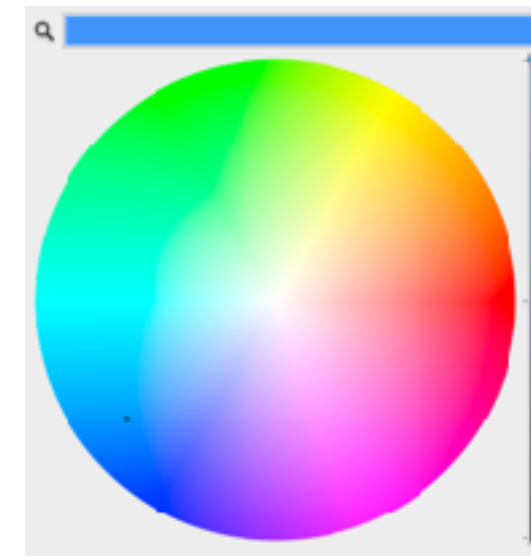
Many color spaces

- HSL/HSV: somewhat better for encoding
 - hue/saturation wheel intuitive
 - beware: only pseudo-perceptual!
 - lightness (L) or value (V) \neq 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



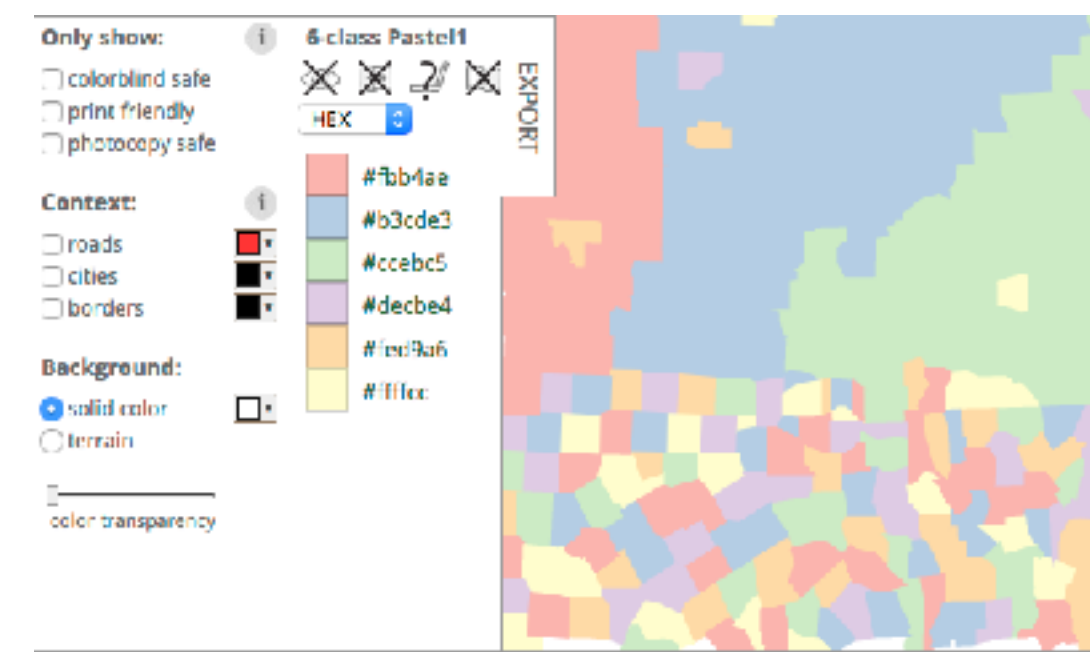
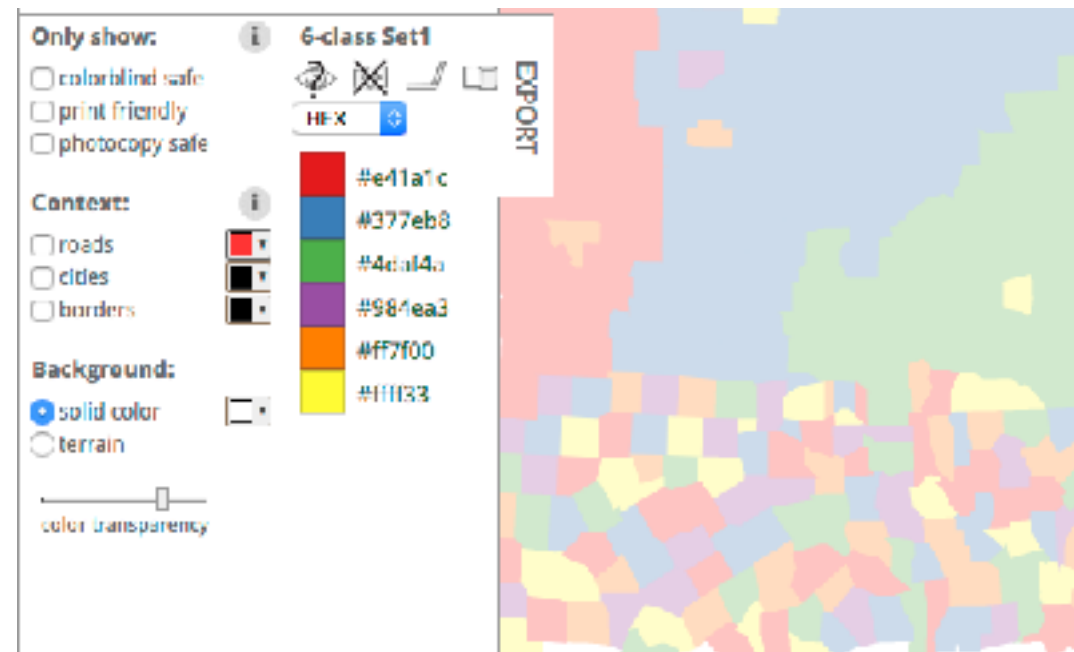
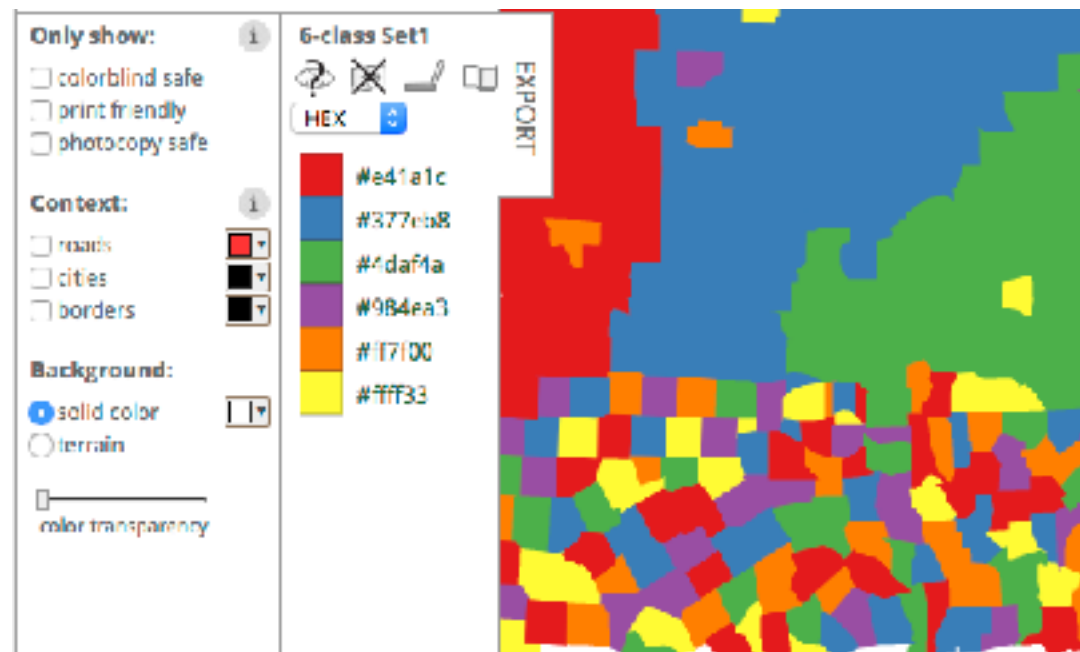
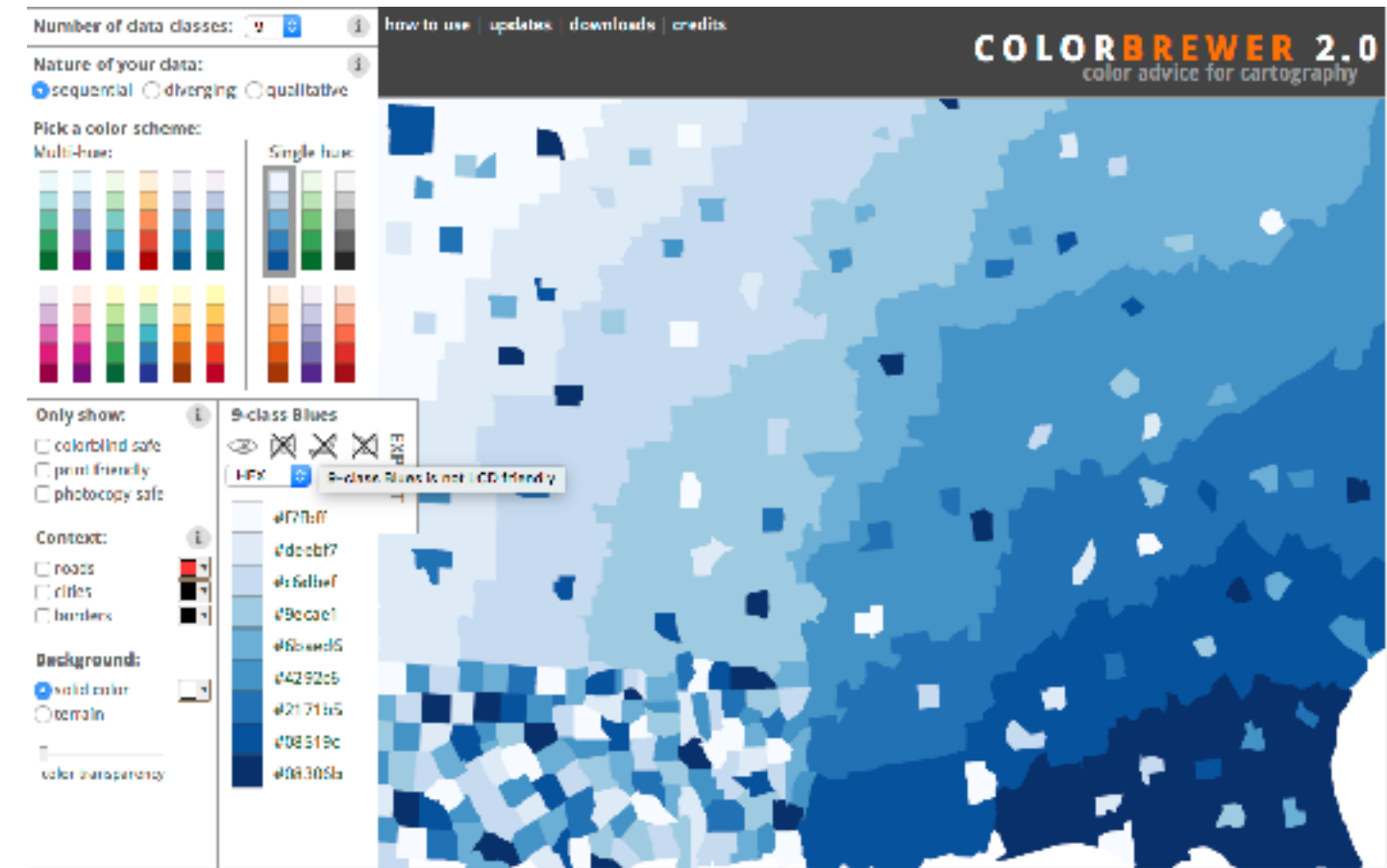
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/cone_slice/

<http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/>

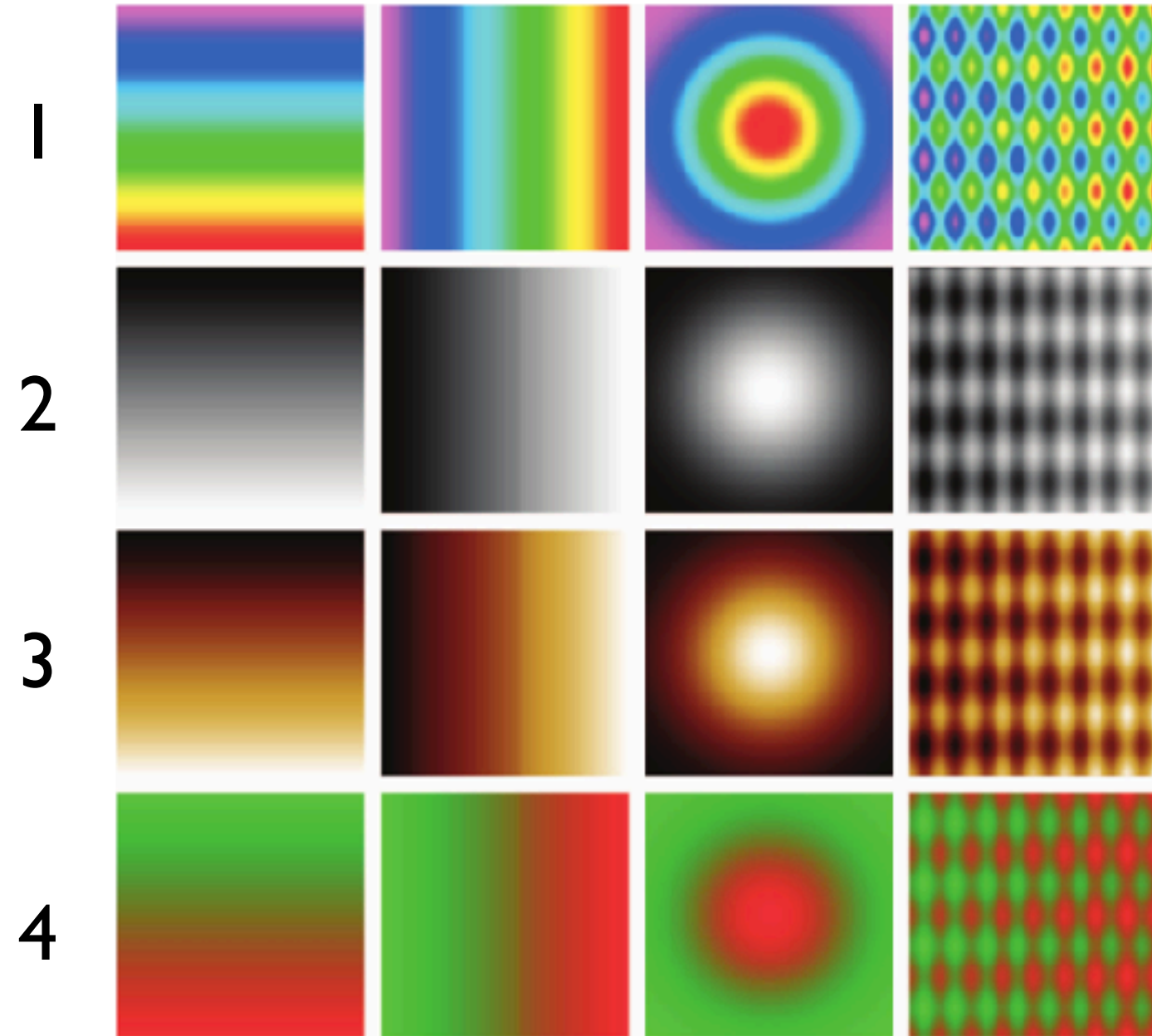


Interaction with other channels: integral/separable

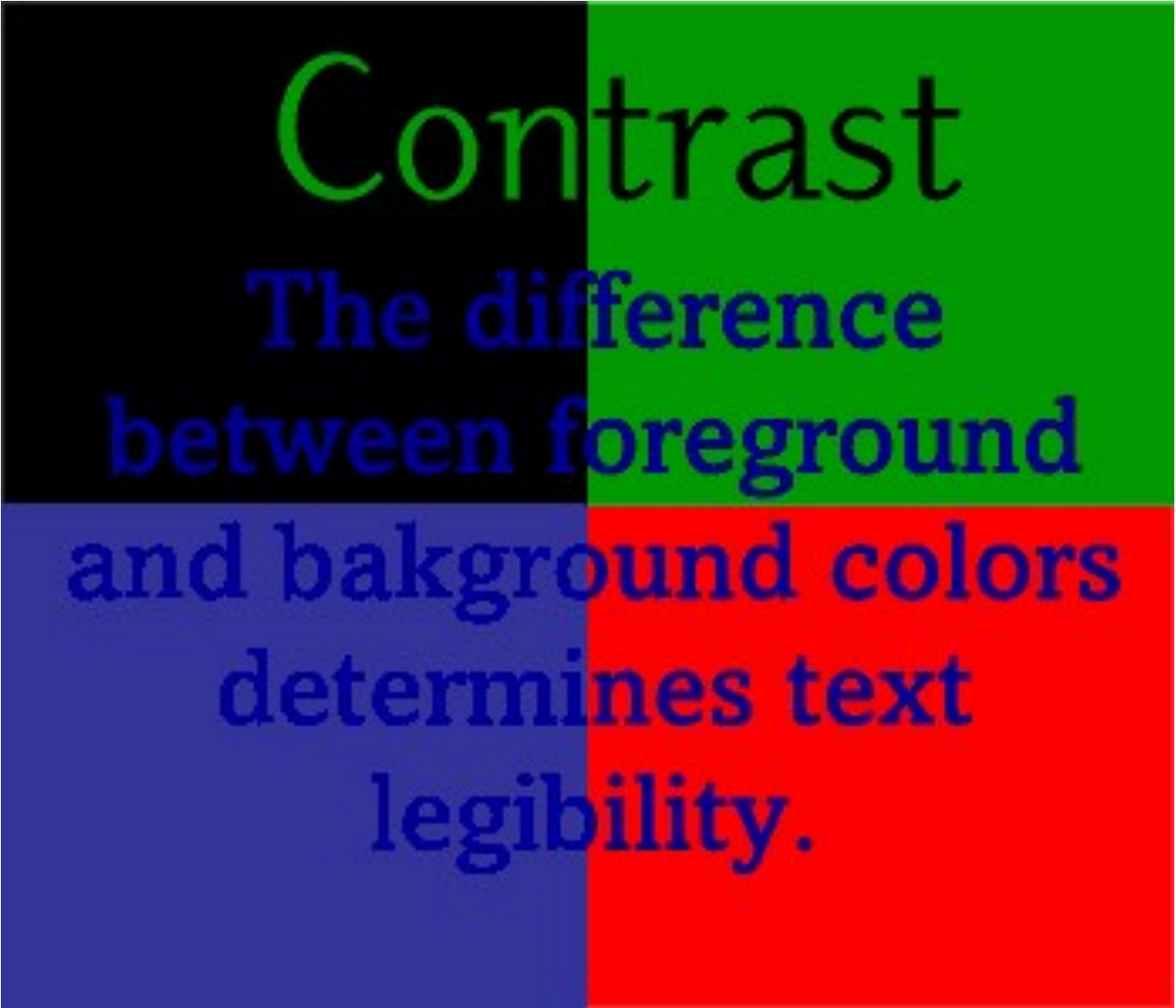
- color channel interactions
 - size heavily affects salience
 - small regions need high saturation
 - large need low saturation
- saturation & luminance:
 - not separable from each other
 - also not separable from transparency
 - 3-4 bins max (if small, separated regions)
 - many bins (with contiguous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



Quiz: Which color channels?

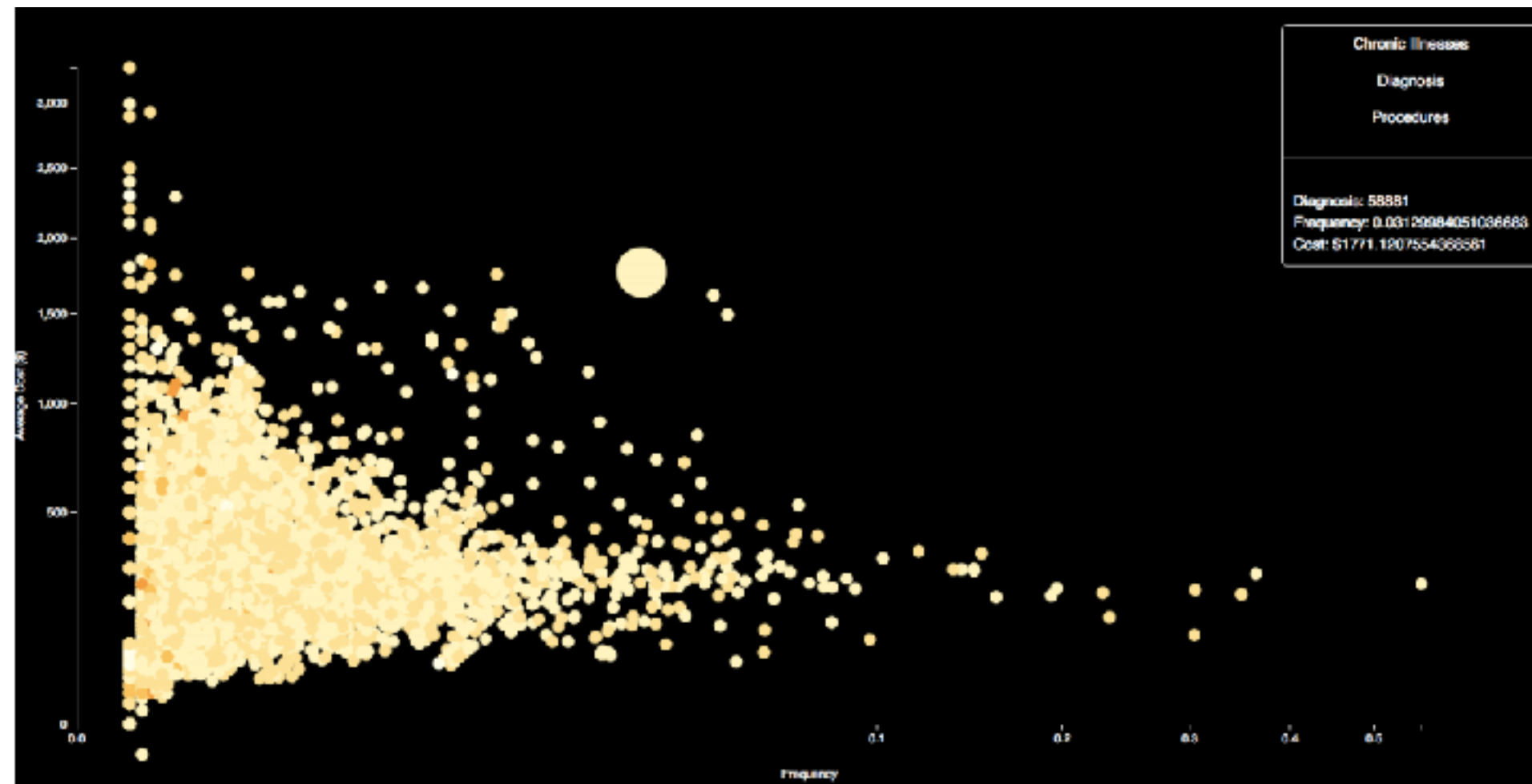


Interaction with the background



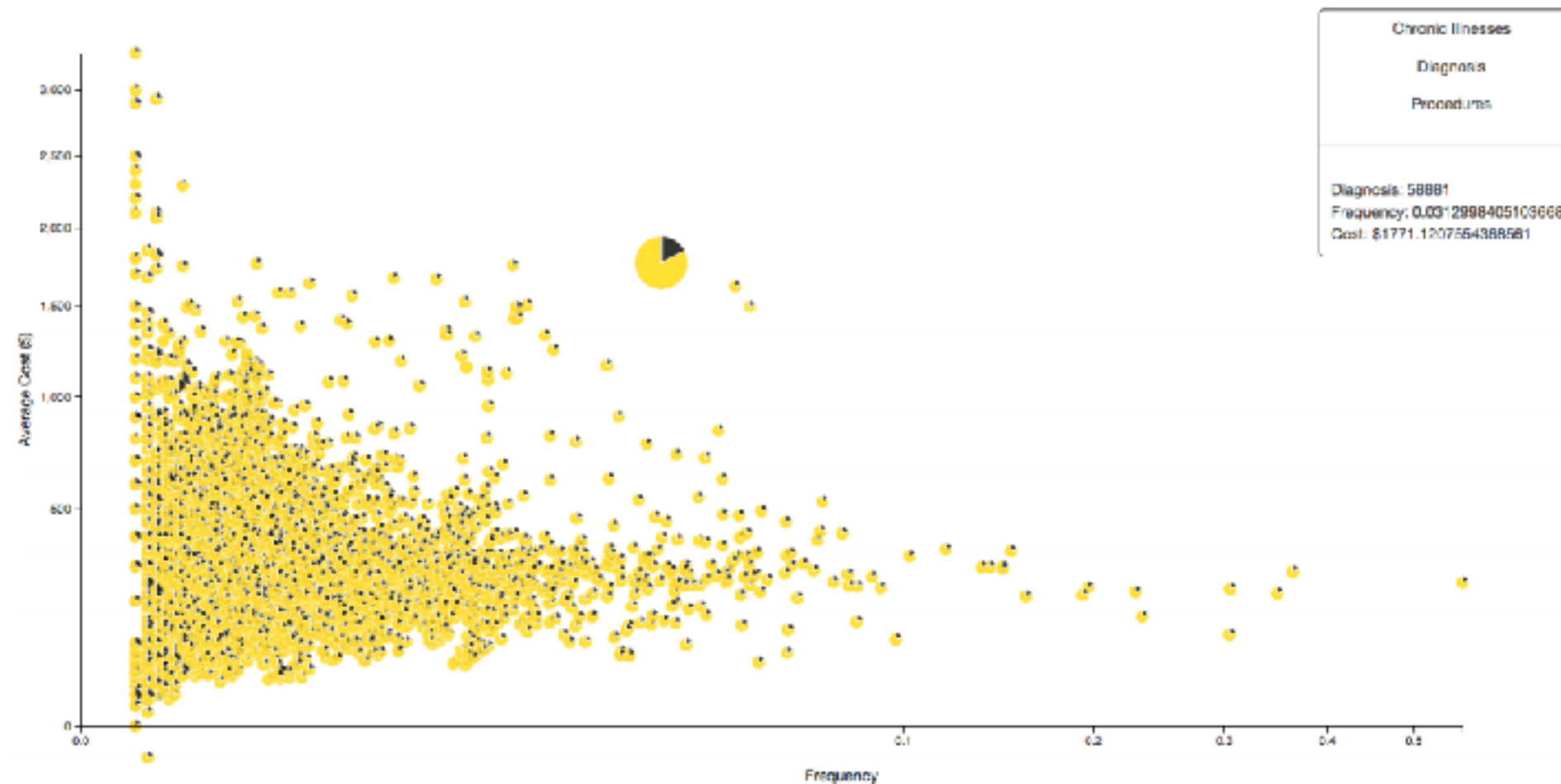
Hello	Hello	Hello	Hello	Hello	Hello	Hello
Hello	Hello	Hello	Hello	Hello	Hello	Hello
Hello	Hello	Hello	Hello	Hello	Hello	Hello
Hello	Hello	Hello	Hello	Hello	Hello	Hello
Hello	Hello	Hello	Hello	Hello	Hello	Hello

Interaction with the background: tweaking yellow for visibility



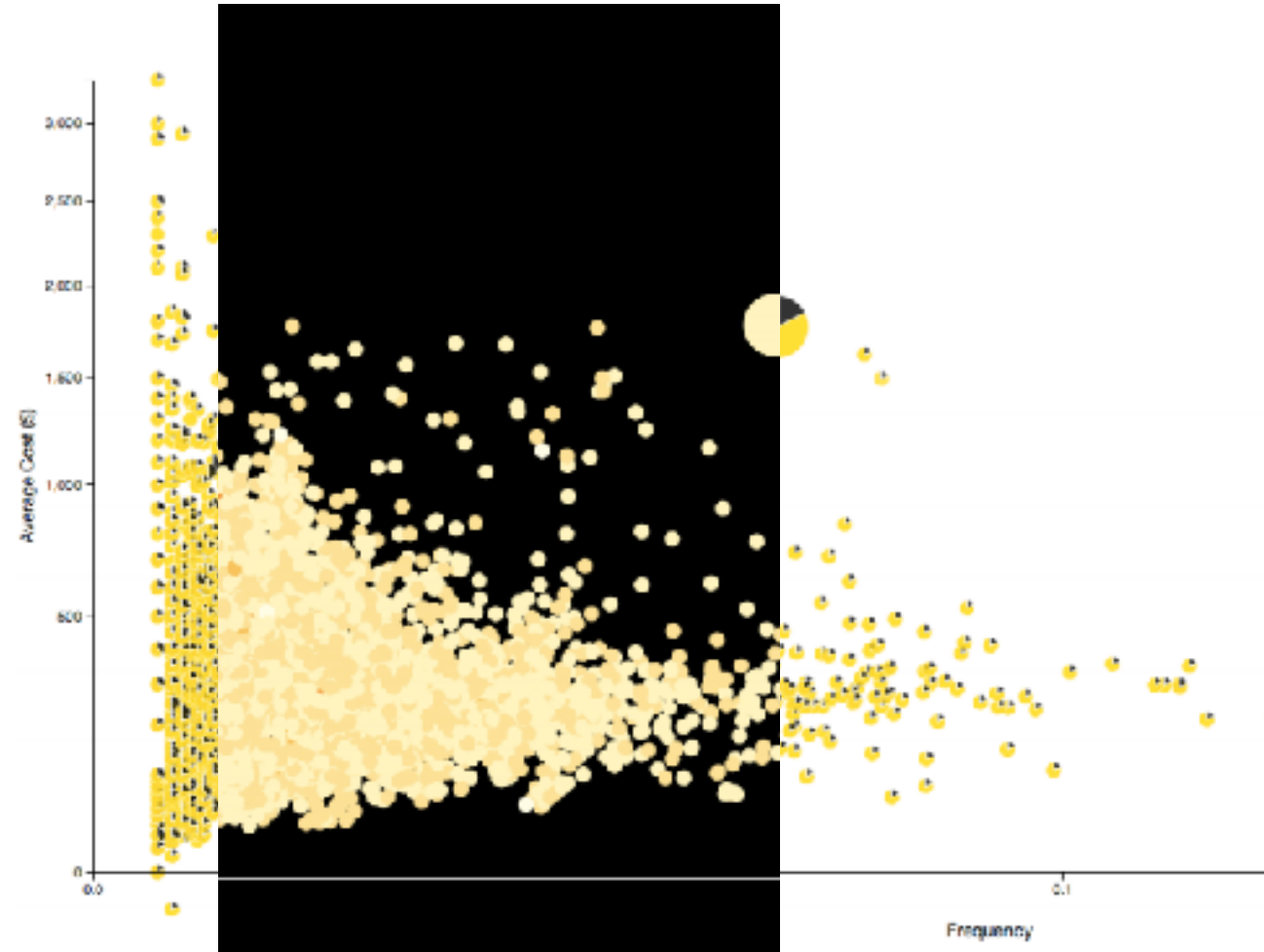
Marks with high luminance on a background with low luminance

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

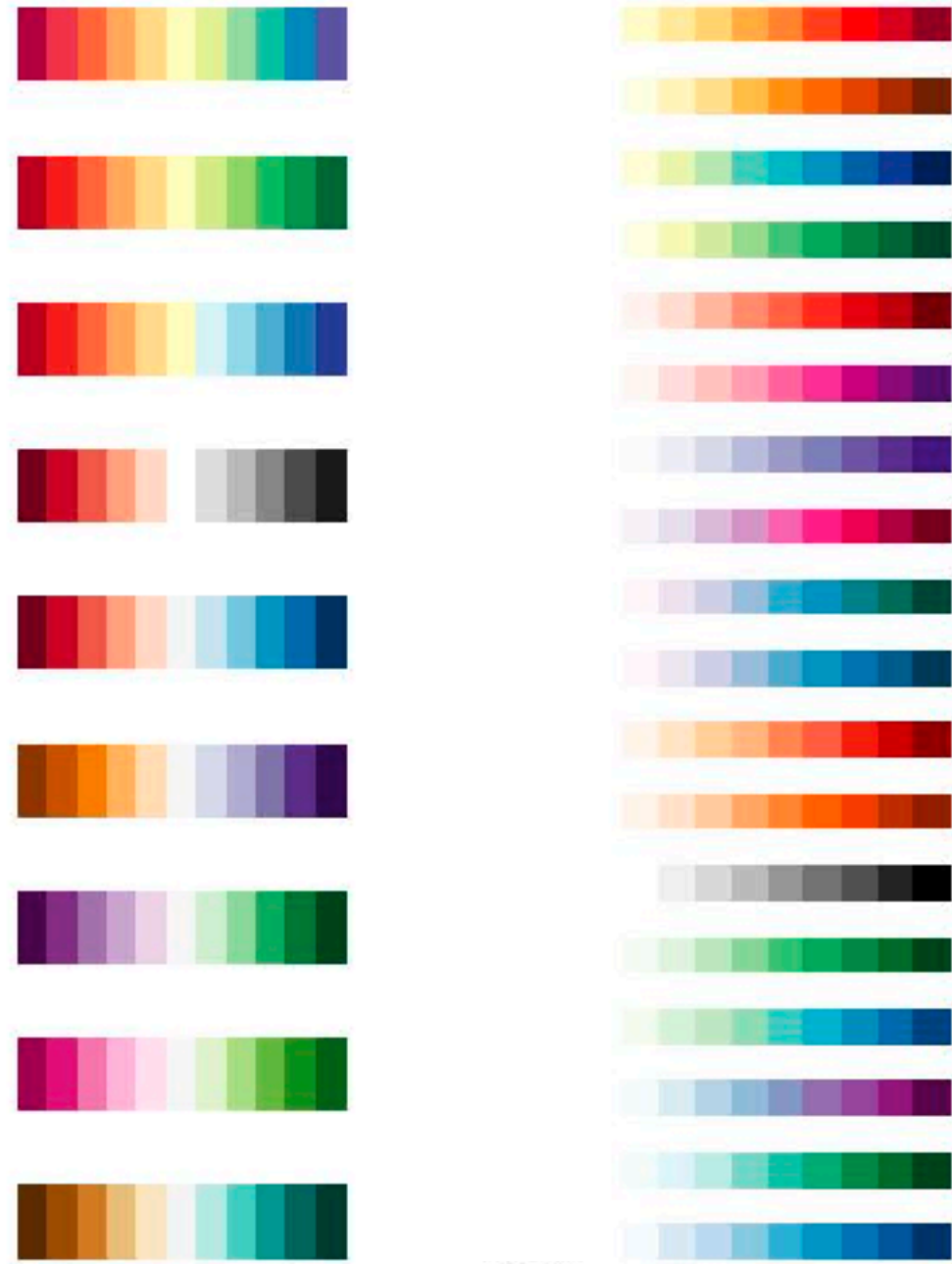


Change luminance of marks depending on background

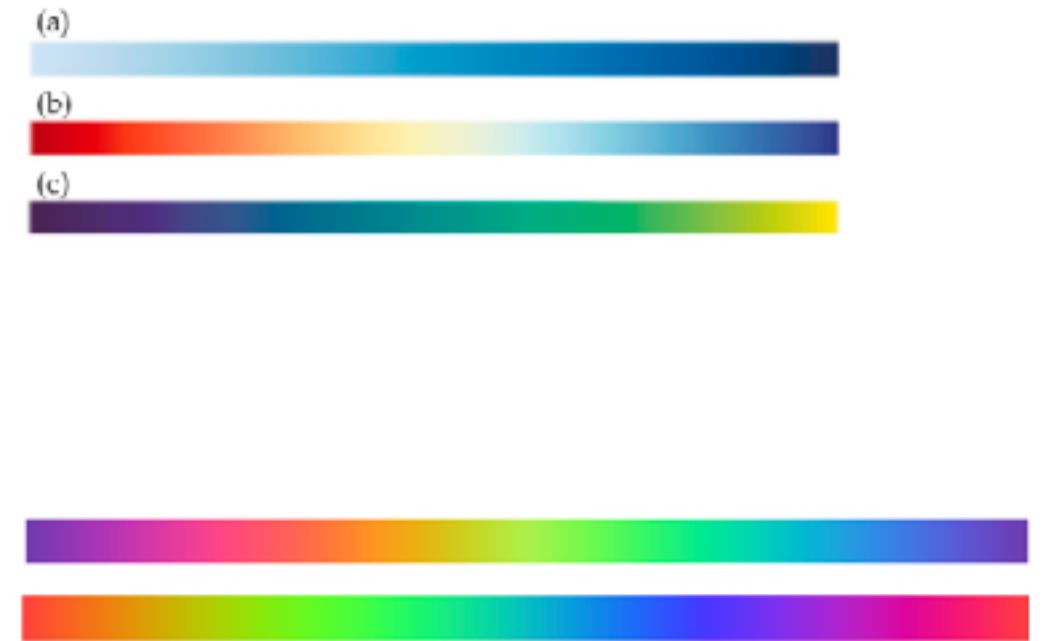
How to use color in visualization

What kinds of color palettes are there?

segmented



continuous



<http://colorbrewer2.org/>

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

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*



Categorical

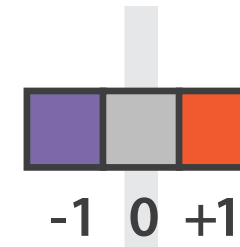
- diverging

- useful when data has meaningful "midpoint"
- use neutral color for midpoint
 - white, yellow, grey
- use saturated colors for endpoints

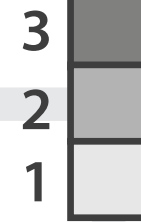
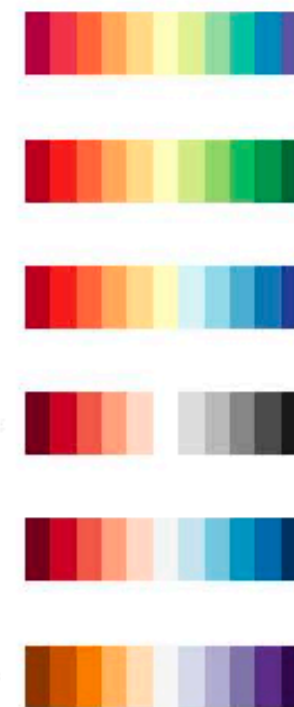
- sequential

- ramp luminance or saturation

Diverging

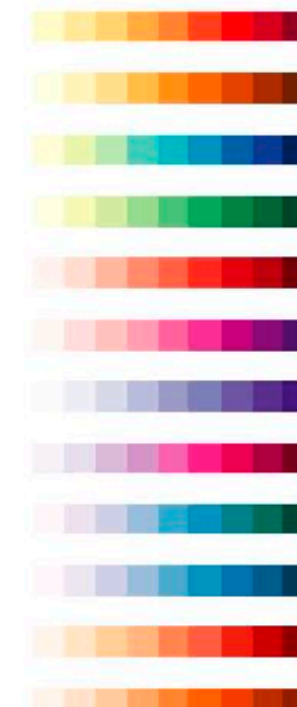


diverging



Sequential

sequential



Visualization. Brewer, 1994.
[ColorSch/Schemes.html]

Color palettes: univariate

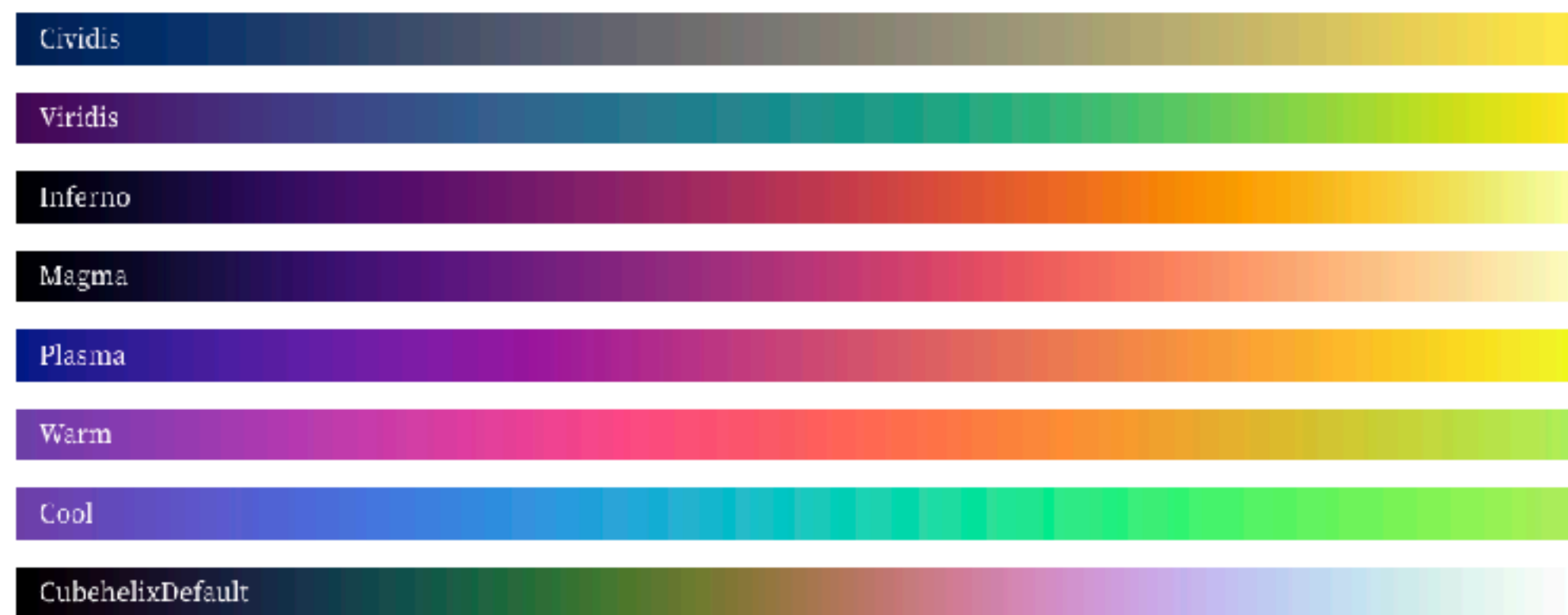
→ Categorical



→ Ordered

→ *Sequential*

→ *Diverging*



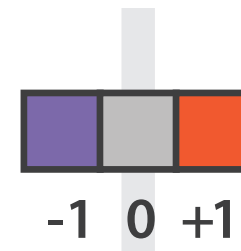
- diverging

- useful when data has meaningful "midpoint"
- use neutral color for midpoint
 - white, yellow, grey
- use saturated colors for endpoints

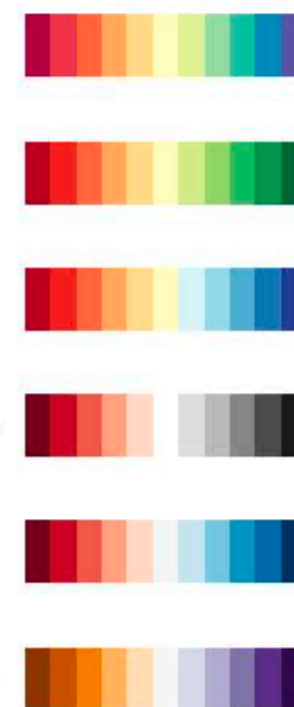
- sequential

- ramp luminance or saturation
- if multi-hue, good to order by luminance

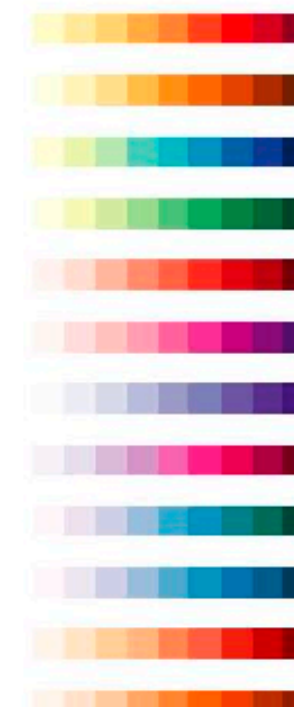
Diverging



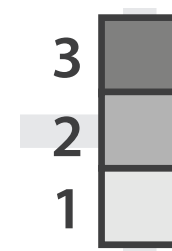
diverging



sequential



Sequential



Visualization. Brewer, 1994.
[ColorSch/Schemes.html]

Color palettes: univariate

→ Categorical



→ Ordered

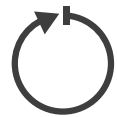
→ *Sequential*



→ *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

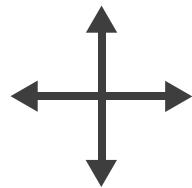
→ *Sequential*



→ *Diverging*



→ Bivariate

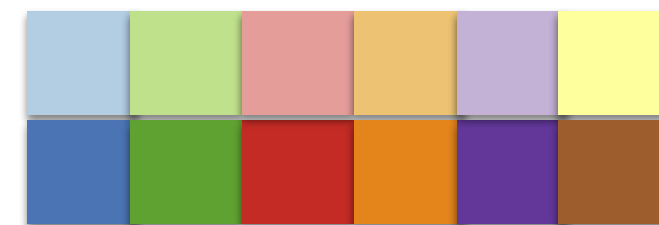
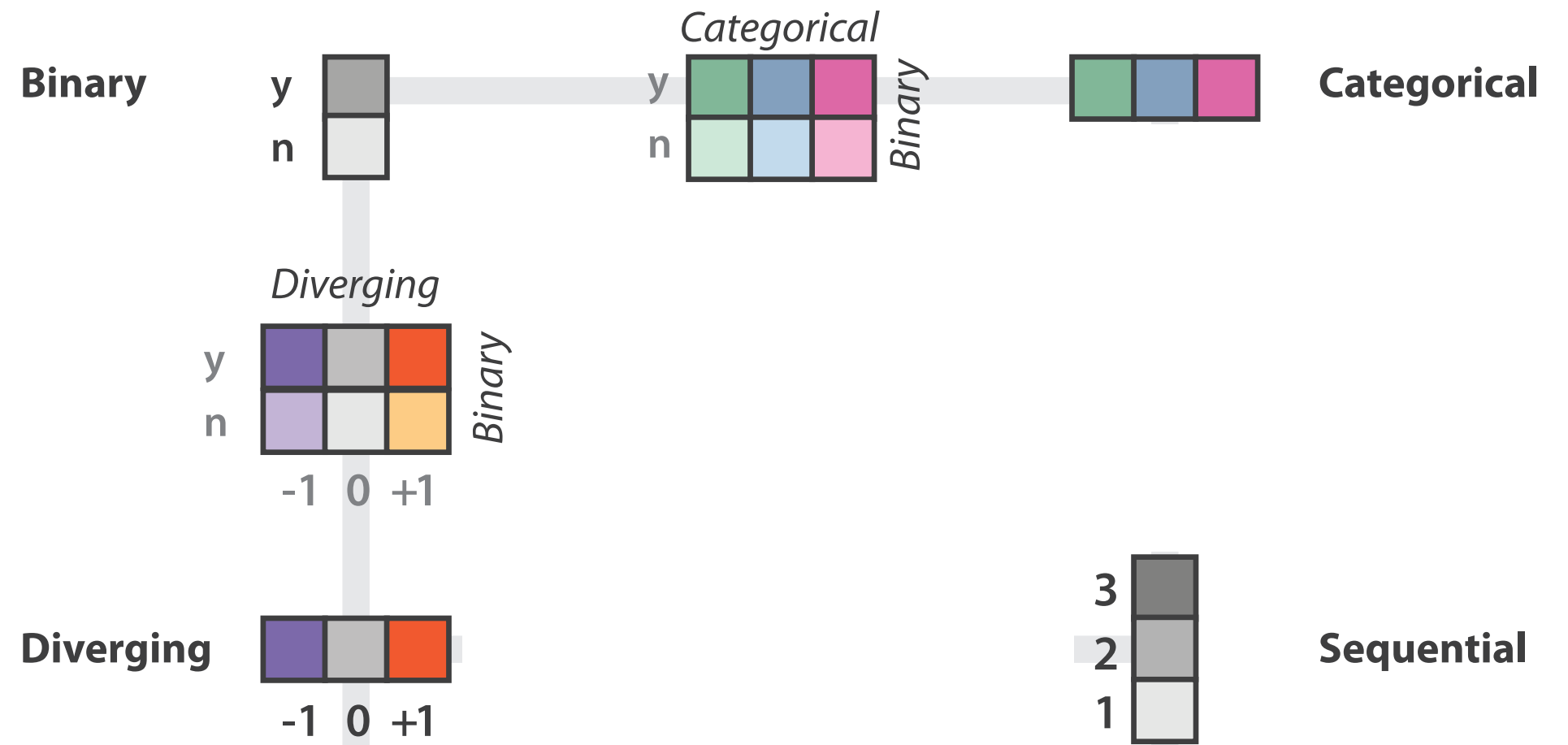


- bivariate best case

- binary in one of the directions



d3.schemePaired <>



binary saturation

categorical hue

Colormaps: bivariate

→ Categorical



→ Ordered

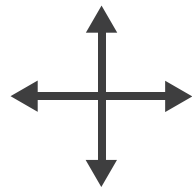
→ *Sequential*



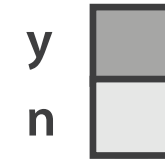
→ *Diverging*



→ Bivariate



Binary



Categorical

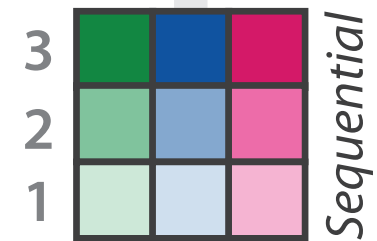


Binary

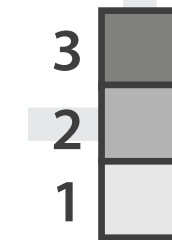
Categorical



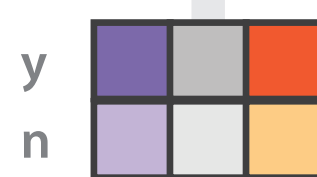
Categorical



Sequential

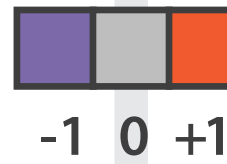


Diverging



Binary

Diverging



Colormaps

→ Categorical



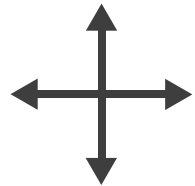
→ Ordered

→ Sequential

→ Diverging

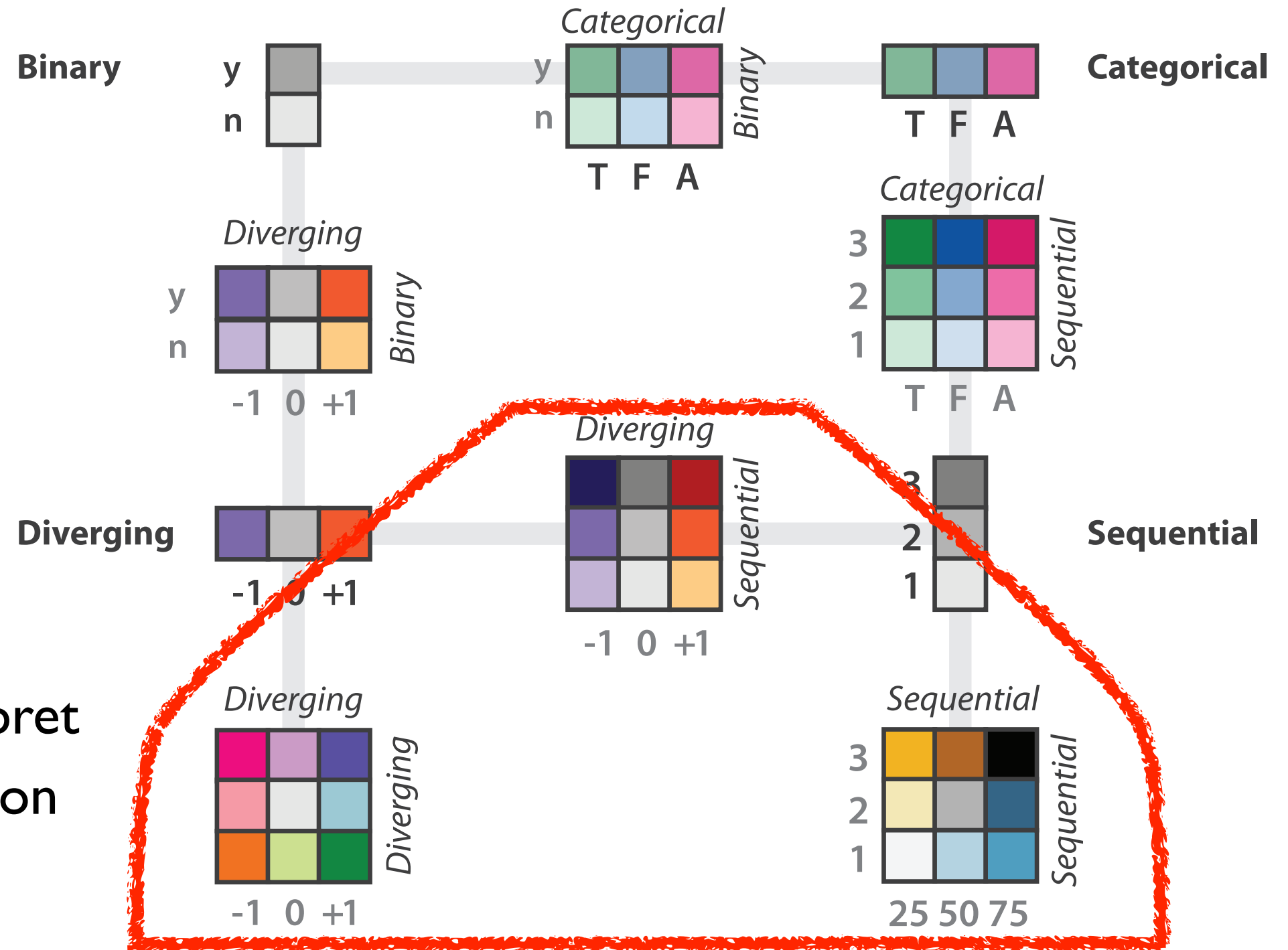


→ Bivariate



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

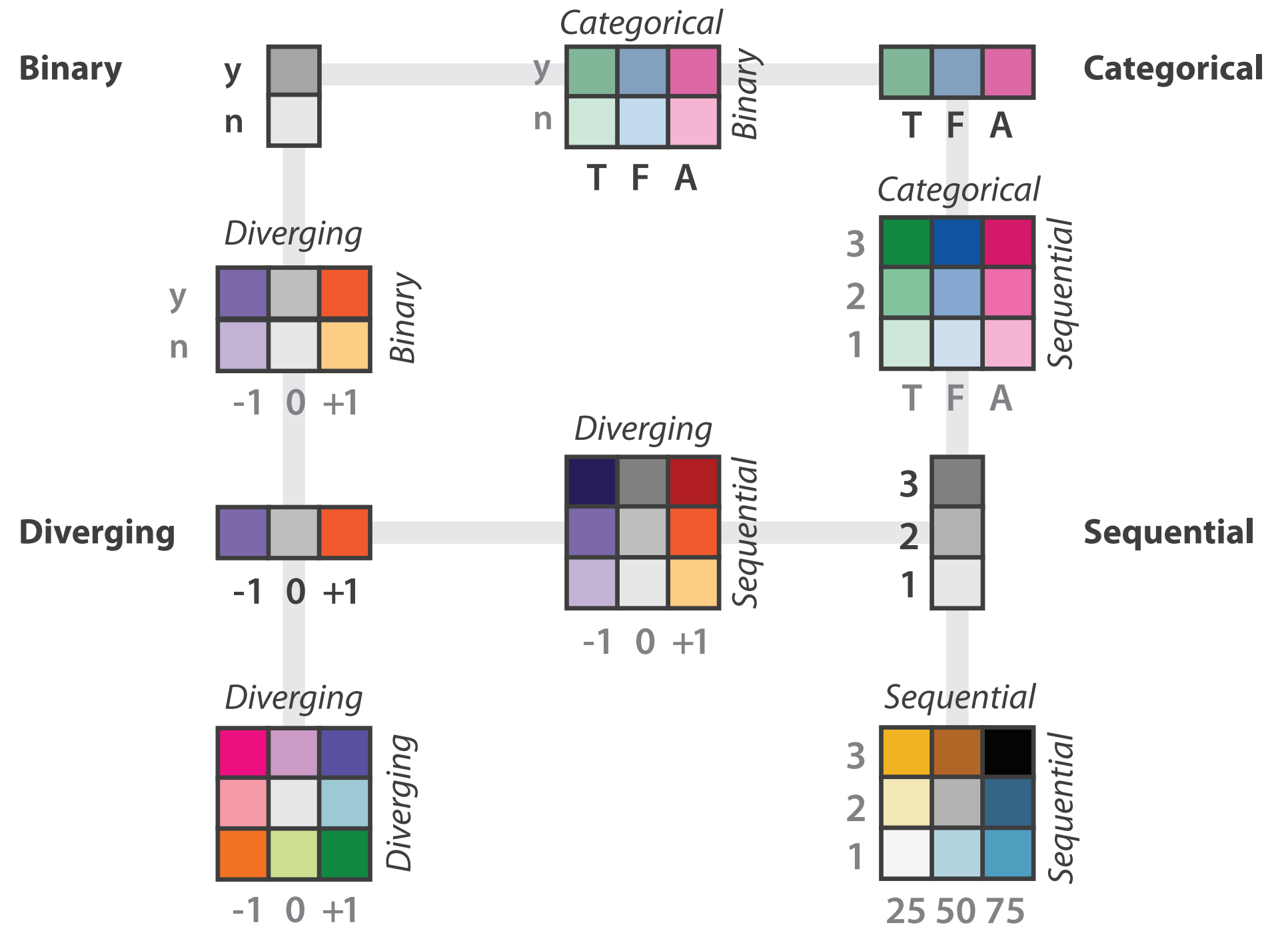
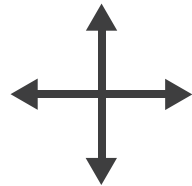
→ *Sequential*



→ *Diverging*



→ Bivariate

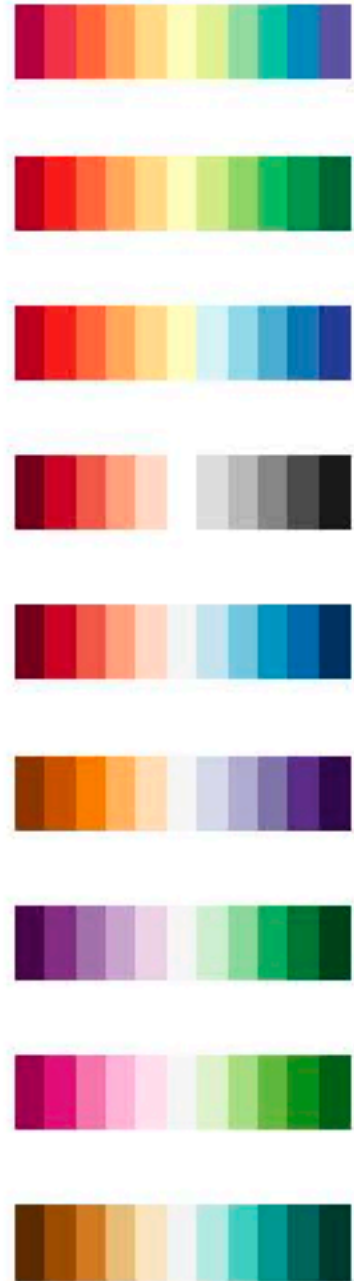


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994.
<http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html>]

What kinds of color palettes are there?

segmented

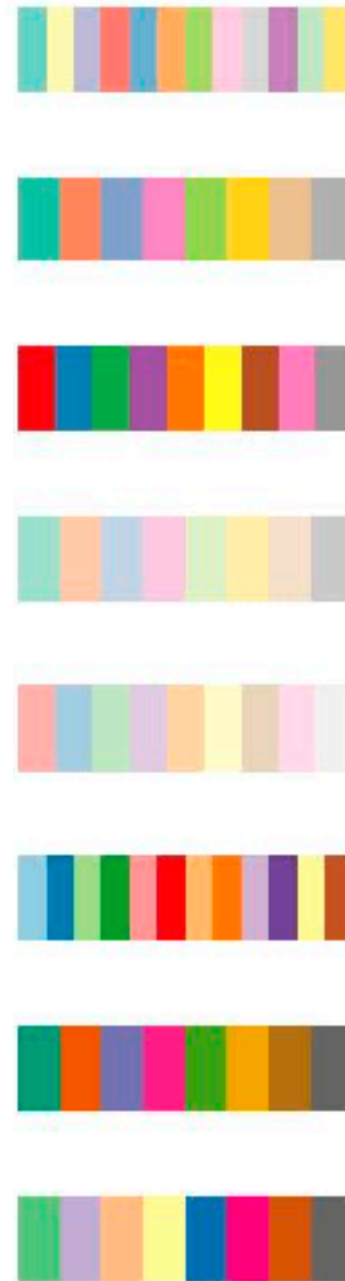
diverging



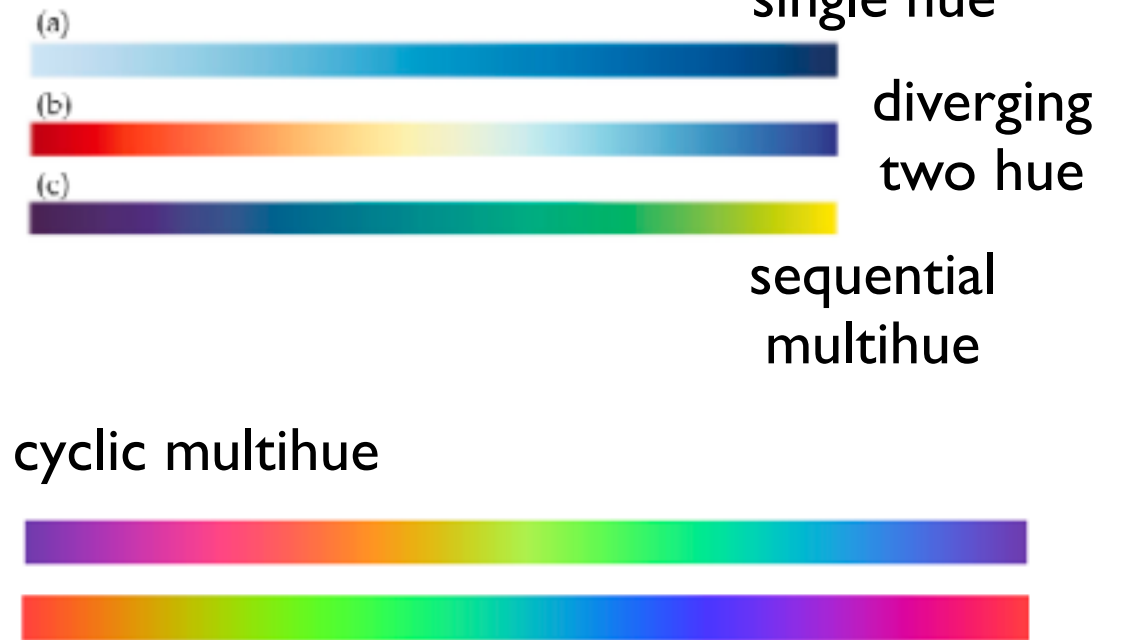
sequential



categorical



continuous

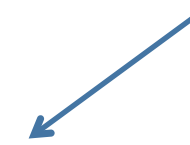
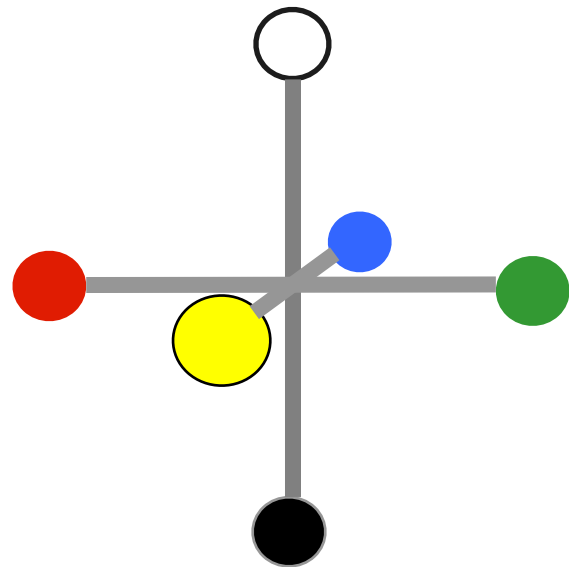


- segmented or continuous?
- diverging or sequential or cyclic?
- single-hue or two-hue or multi-hue?
- perceptually linear?
- ordered by luminance?
- colorblind safe?

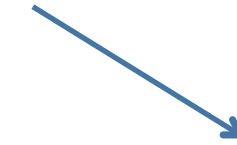
<https://github.com/d3/d3-scale-chromatic>

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



Luminance information



Chroma information



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

Designing for color deficiency: Check with simulator



Normal vision



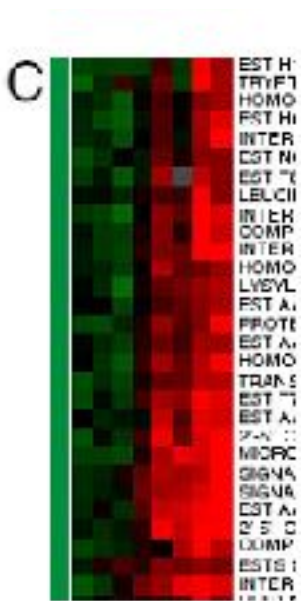
Deuteranope



Protanope



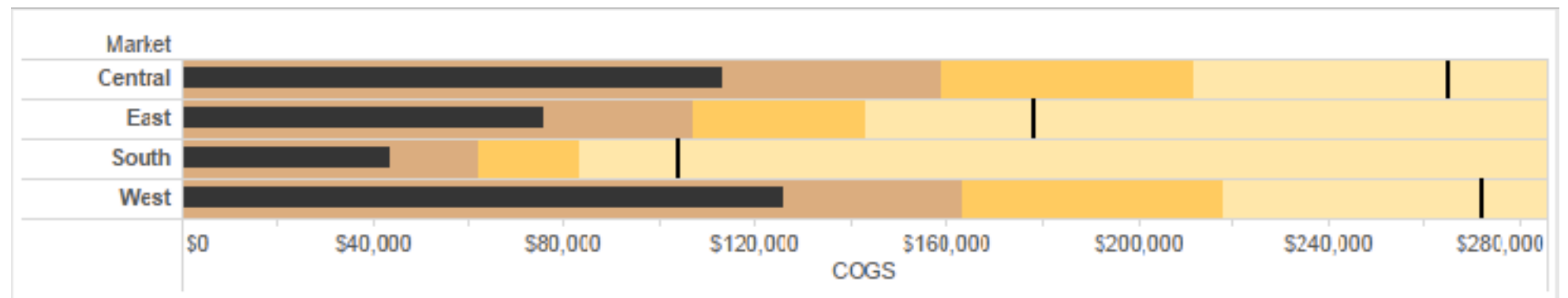
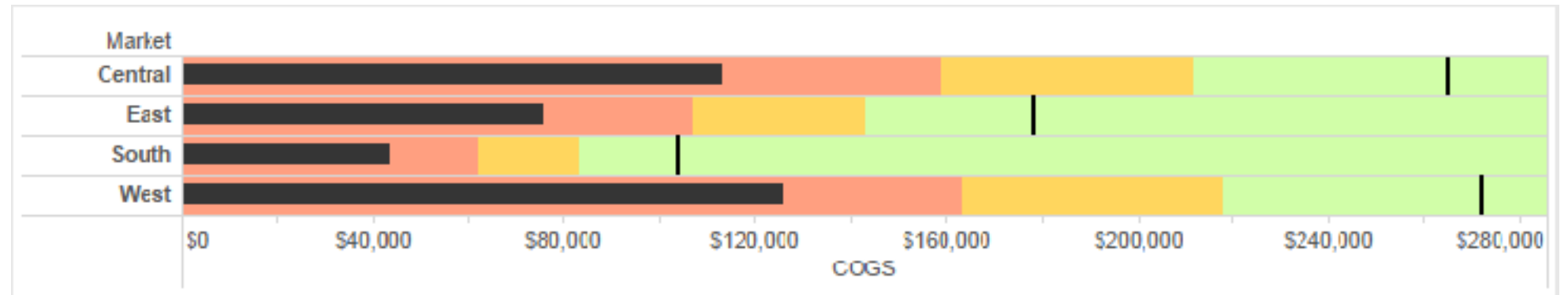
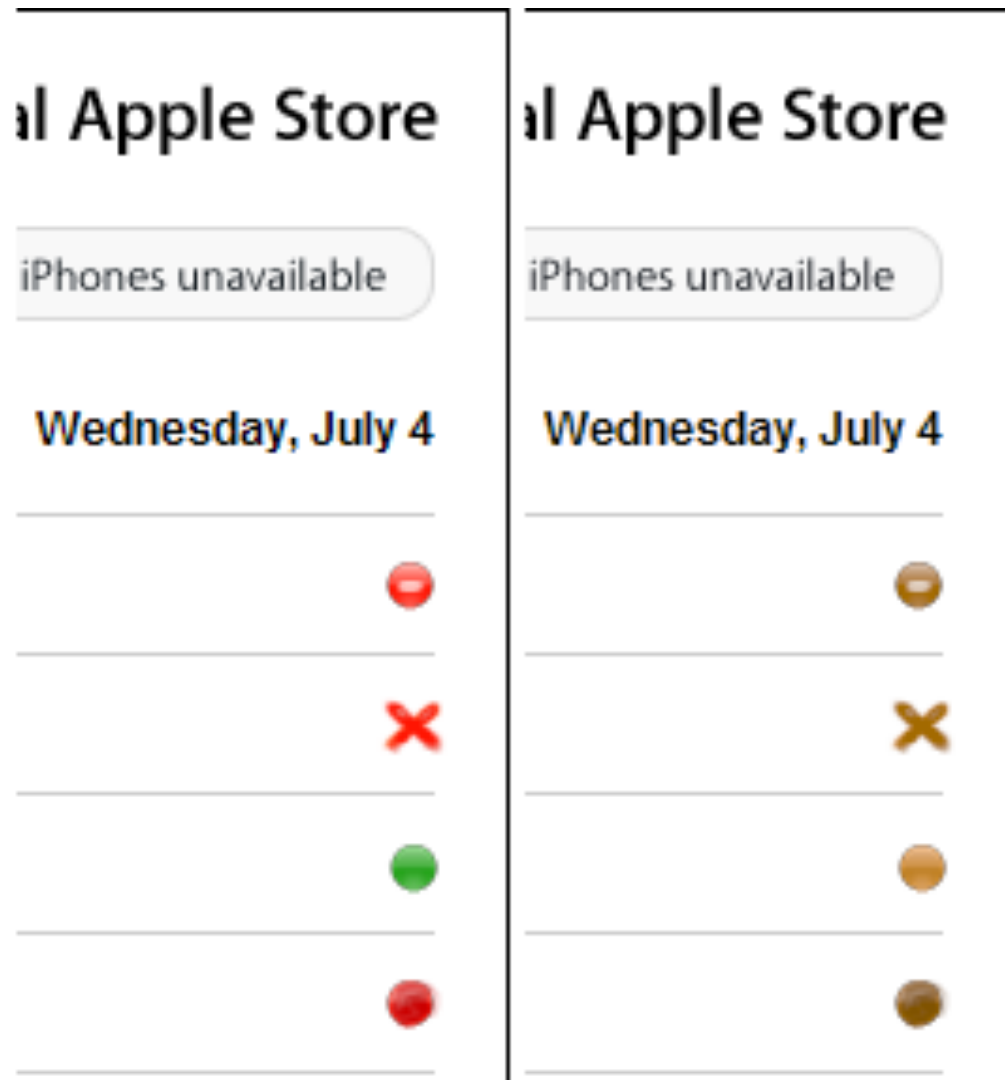
Tritanope



[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

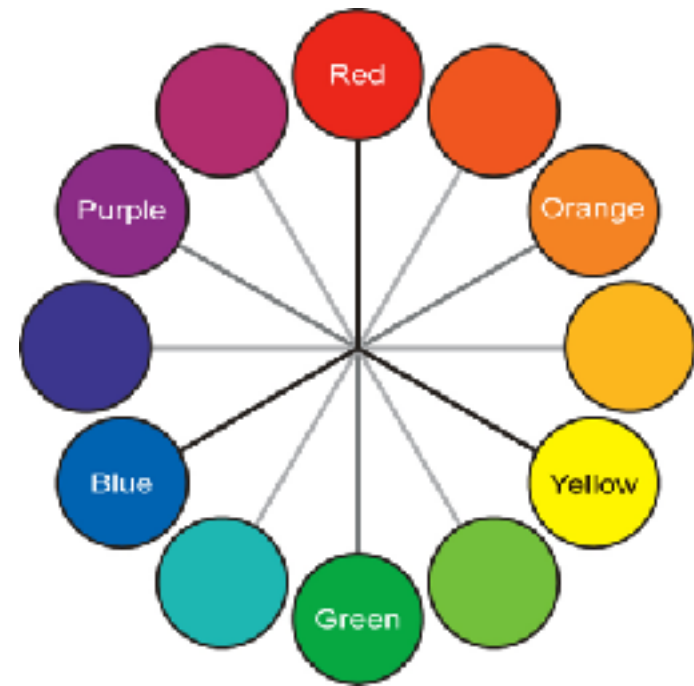


Deuteranope simulation

Change the shape

Vary luminance

Color deficiency: Reduces color to 2 dimensions



Normal



Protanope



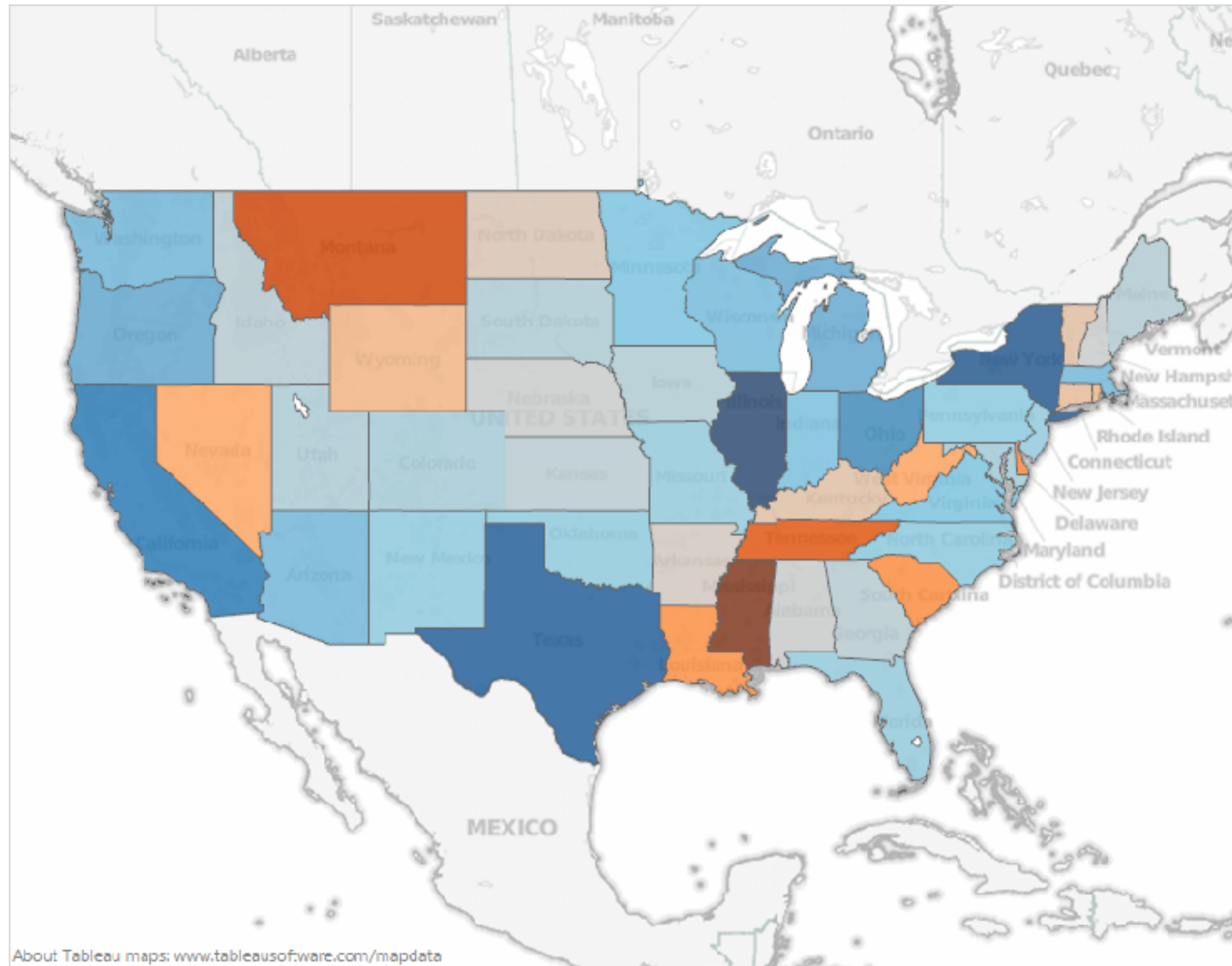
Deuteranope



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.]

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/>