Information Visualization
Color, ArteryViz, Rainbows Rev
Ex: Two Numbers, Colors

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Department of Computer Science
University of British Columbia

Week 5, 6 Oct 2021

https://www.cs.ubc.ca/~tmm/courses/547-21

Plan for today

- last week reading Q&A
  - Tables, LineUp, Bertifier
- small group exercises
  - Two Numbers
  - (break)
  - Color
- this week reading Q&A
  - Color, ArteryViz, Rainbows Revisited

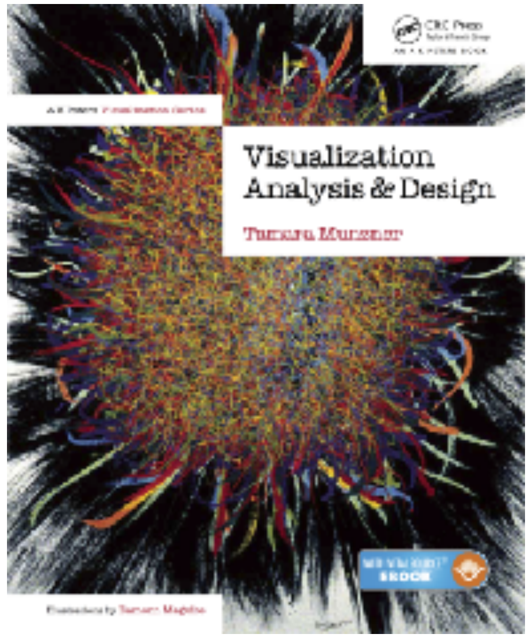
Next week

- to read & discuss (async, before next class)
  - VAD book, Ch 9: Networks and Trees
  - paper: ABySS-Explorer [design study]
  - paper: Geneaological Graphs [technique]
- pre-proposal meetings
  - I'll use full class slot plus some extra slots
  - exact timing TBD after I see final number of groups (10-15 min)
  - stay tuned on Piazza for signup link

Q&A / Backup Slides

Visualization Analysis & Design

Color (Ch 10)



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@tamaramunzner

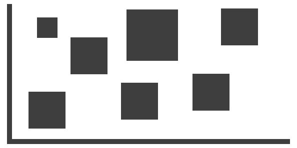
Idiom design choices: Visual encoding

Encode

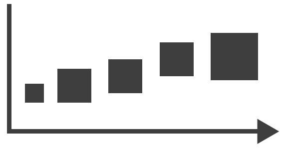
Arrange

➔ Express

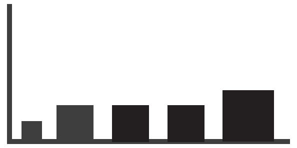
➔ Separate



➔ Order



➔ Align



➔ Use

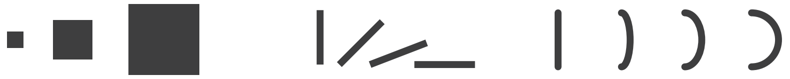
Map

from categorical and ordered attributes

➔ Color

➔ *Hue* ➔ *Saturation* ➔ *Luminance*

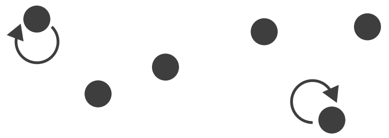
➔ Size, Angle, Curvature, ...

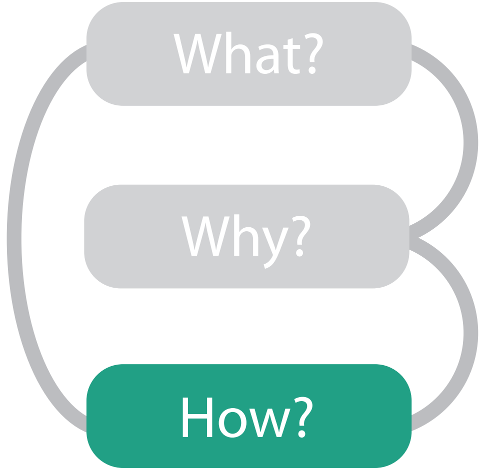


➔ Shape

➔ Motion

Direction, Rate, Frequency, ...





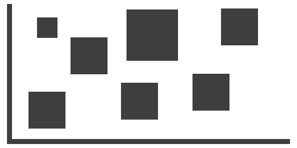
Idiom design choices: Beyond spatial arrangement

Encode

Arrange

→ Express

→ Separate



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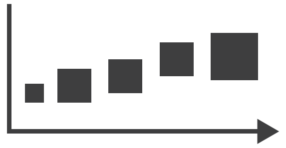

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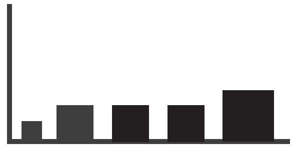

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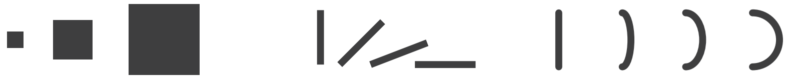

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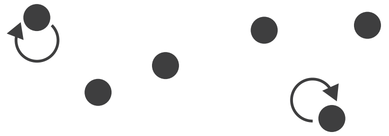
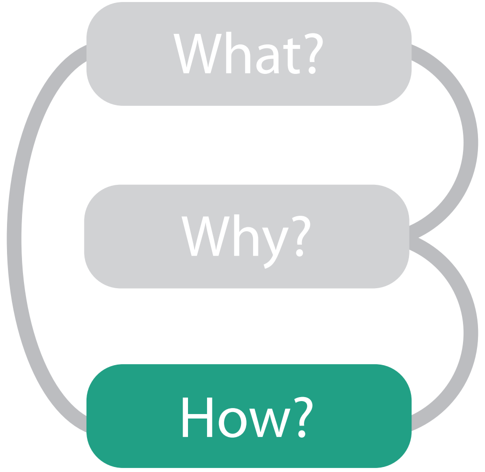
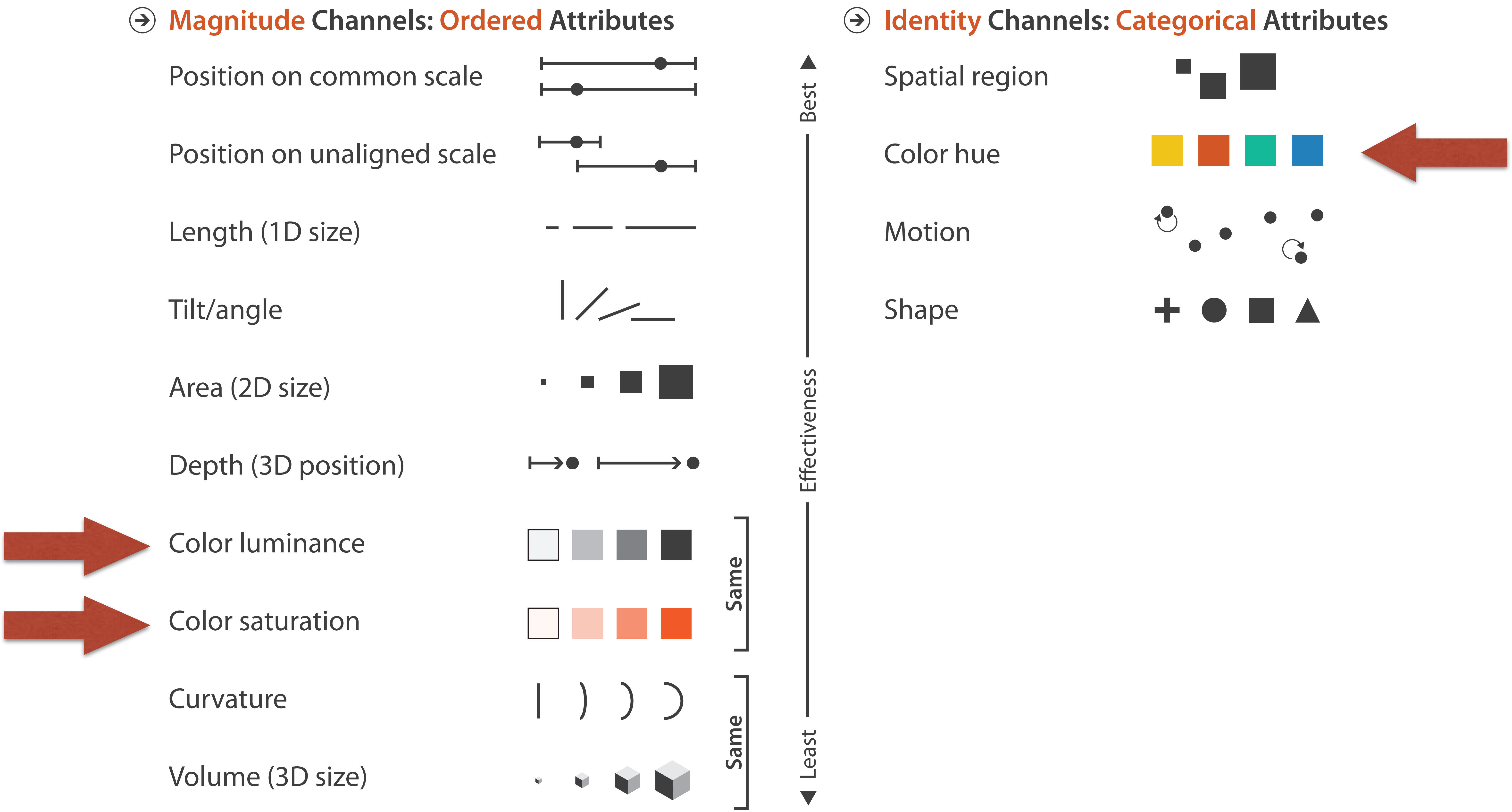




Channels: What's up with color?



Decomposing color

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- first rule of color: do not (just) talk about color!
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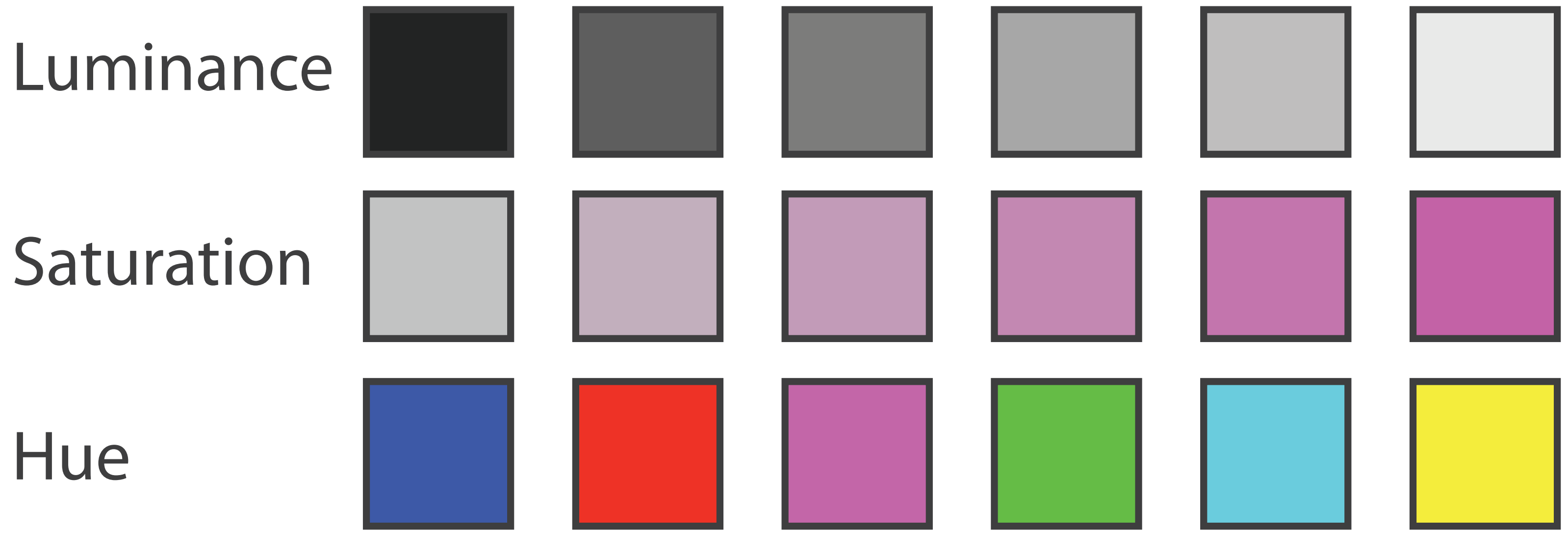

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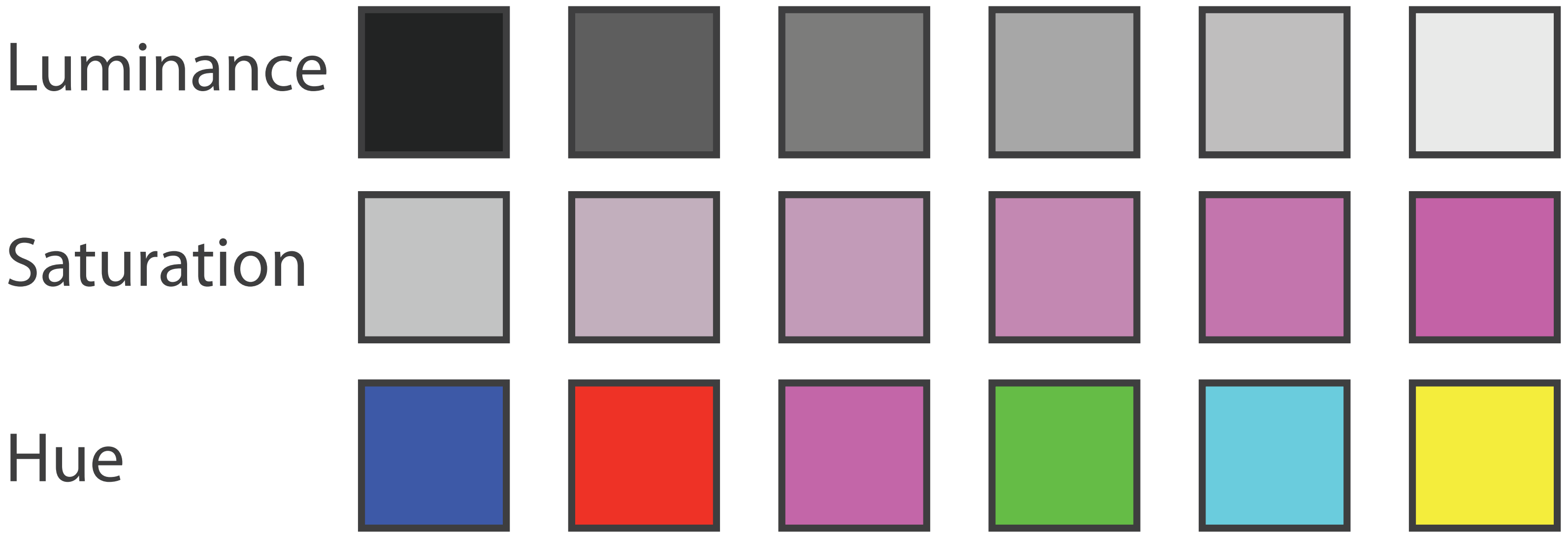
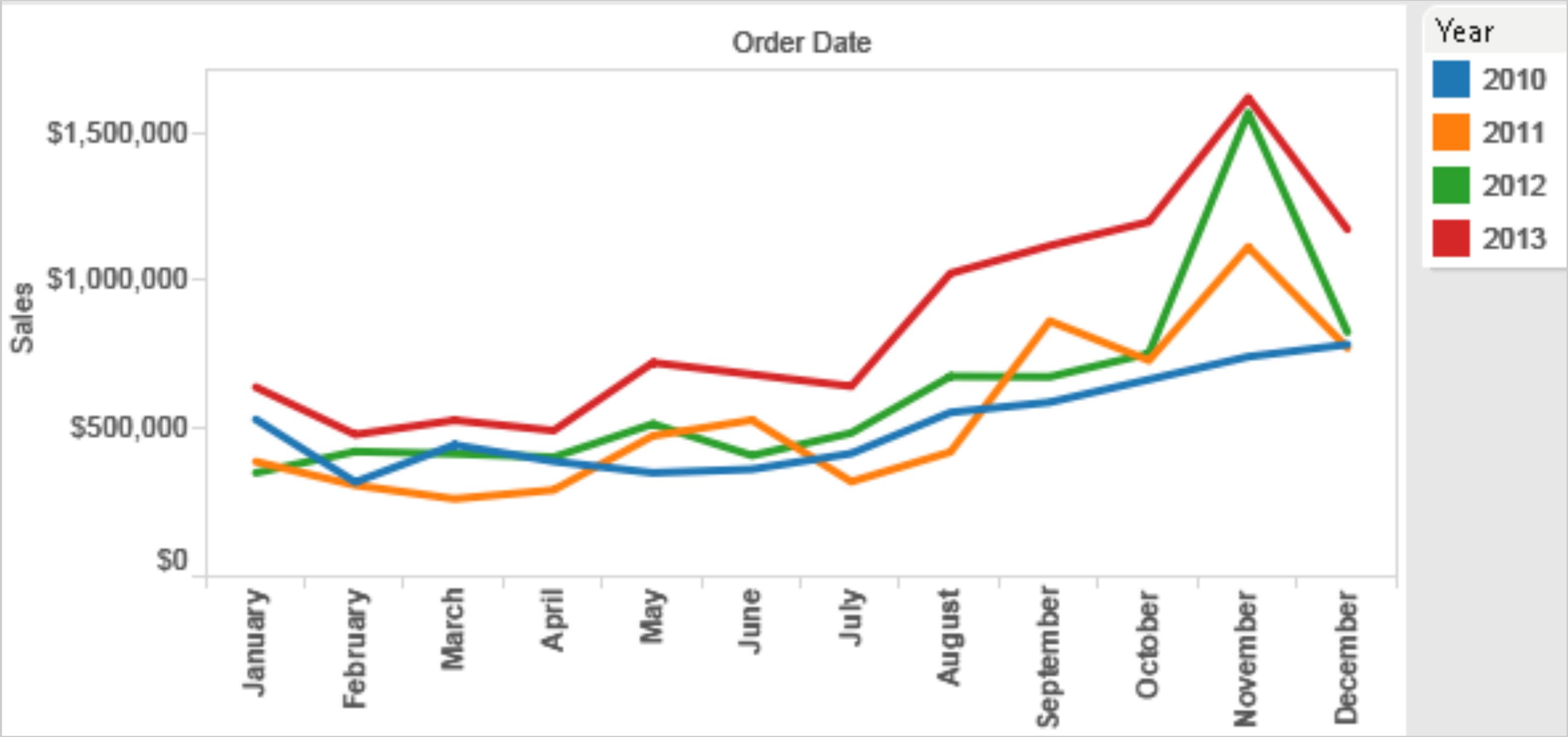
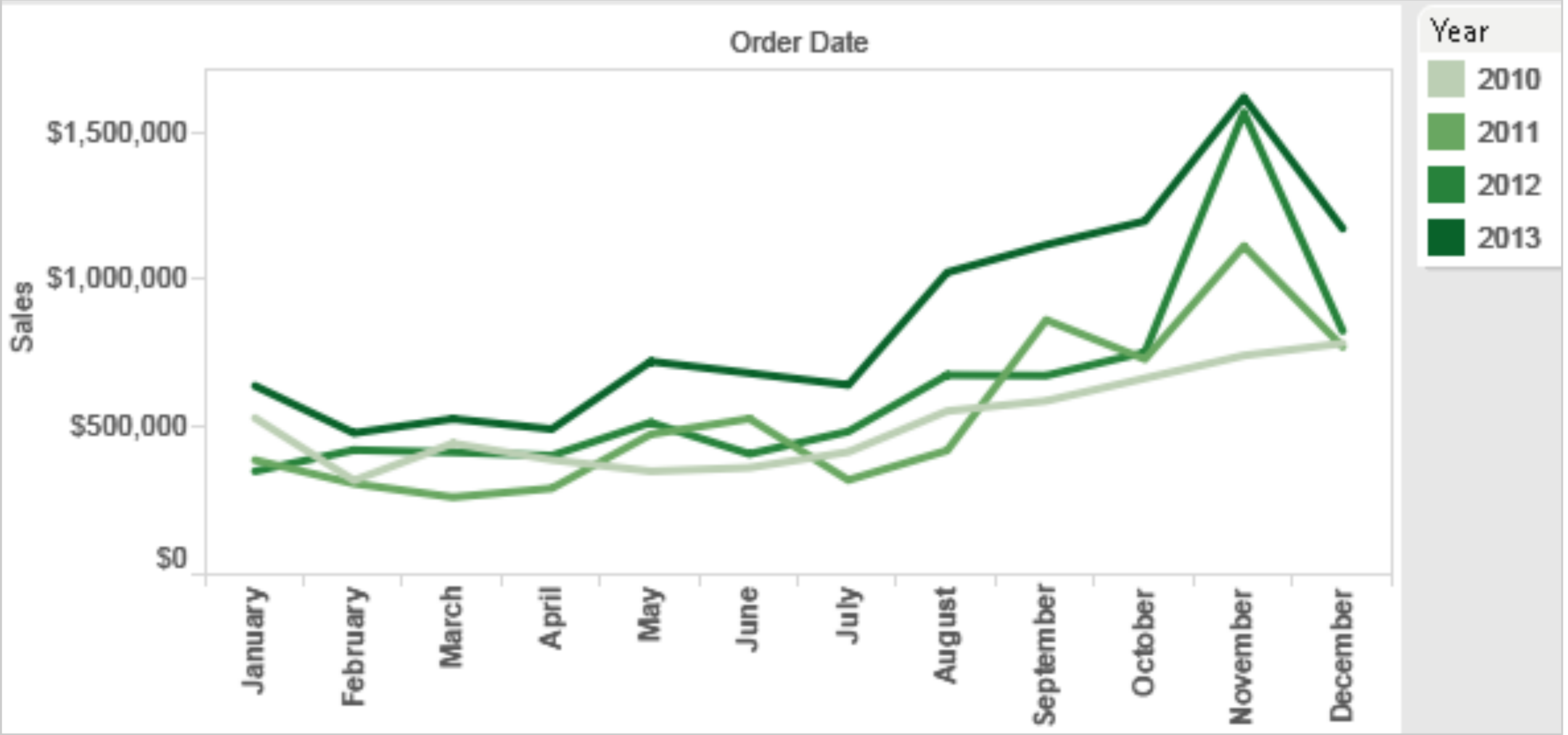


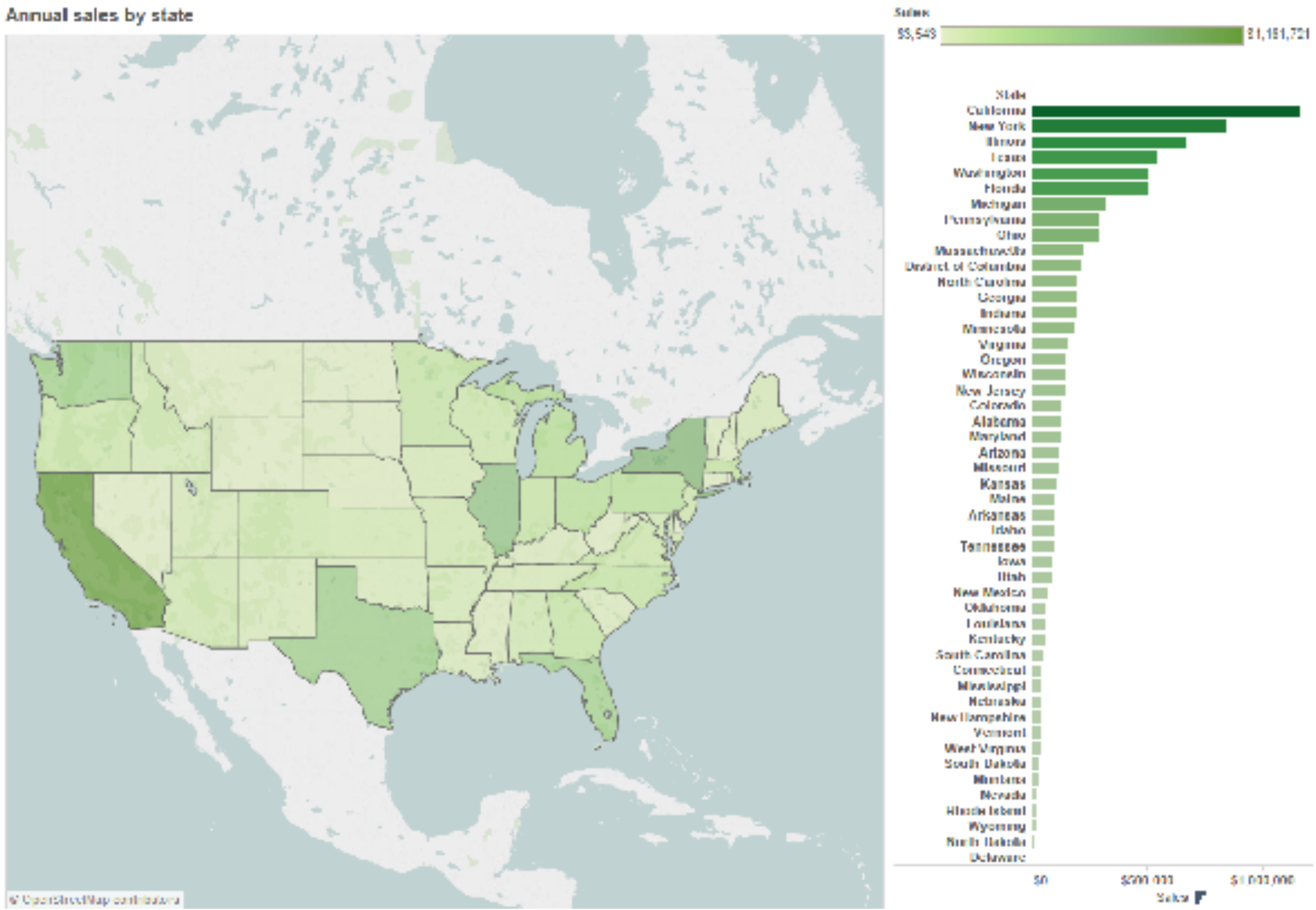
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable bins can we use?

Color Channels in Visualization

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

[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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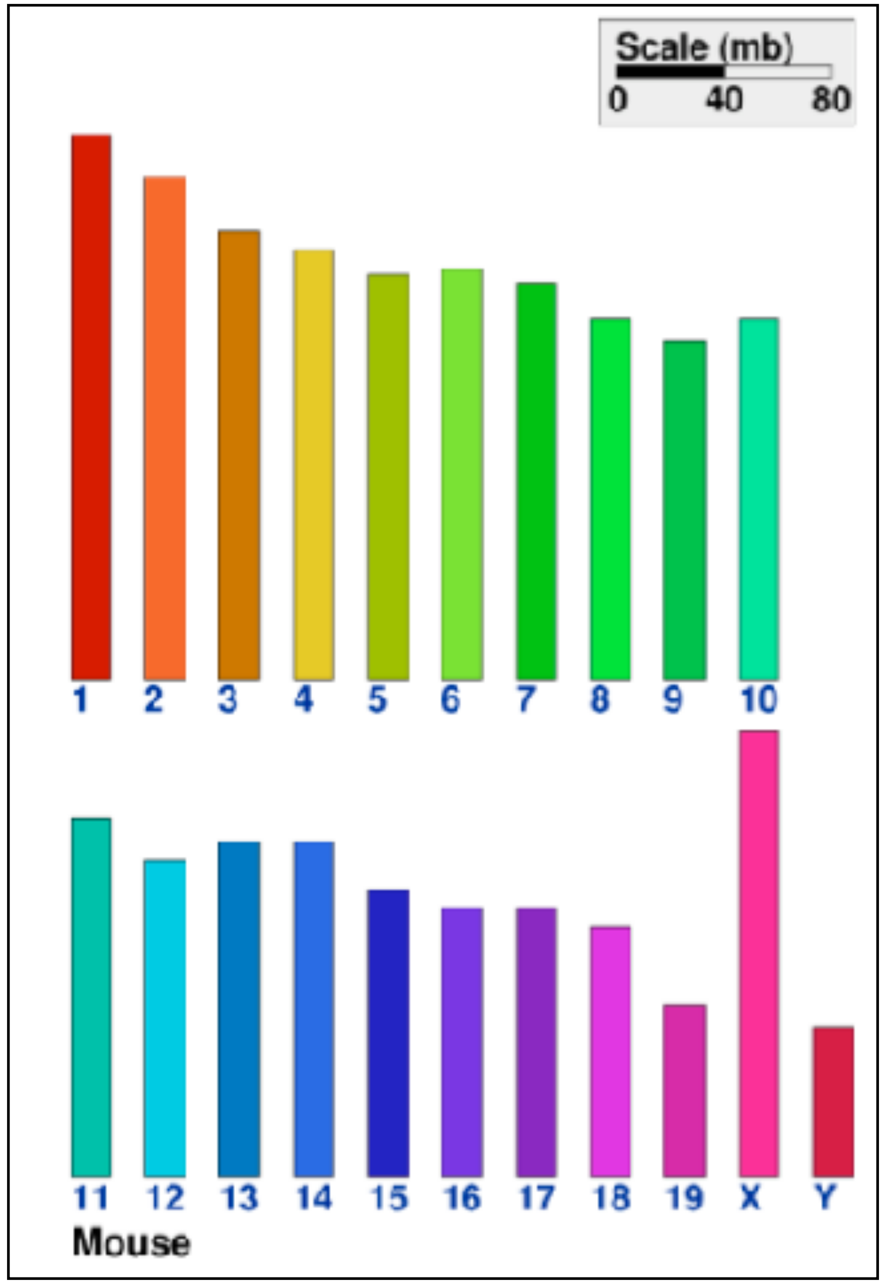

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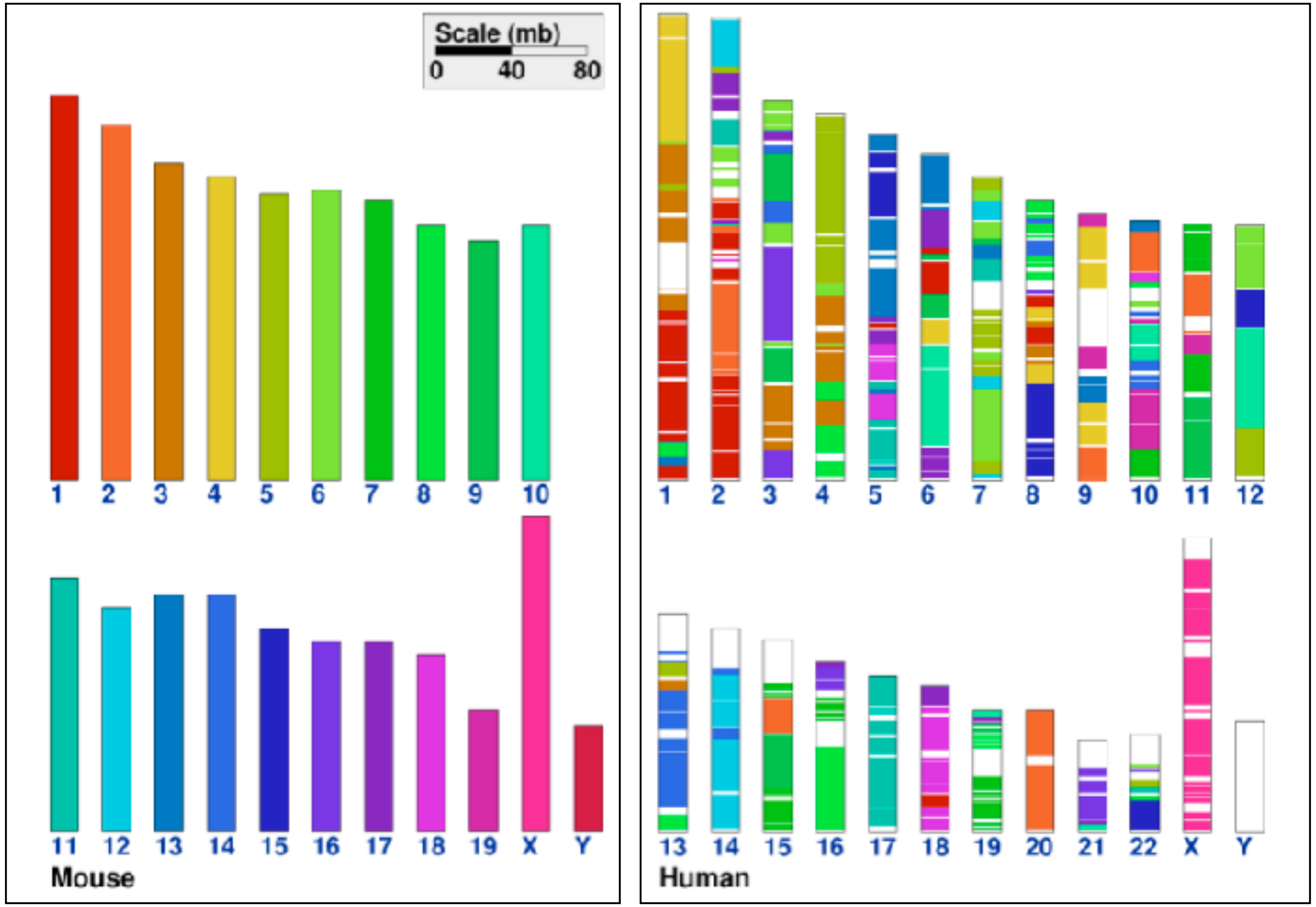

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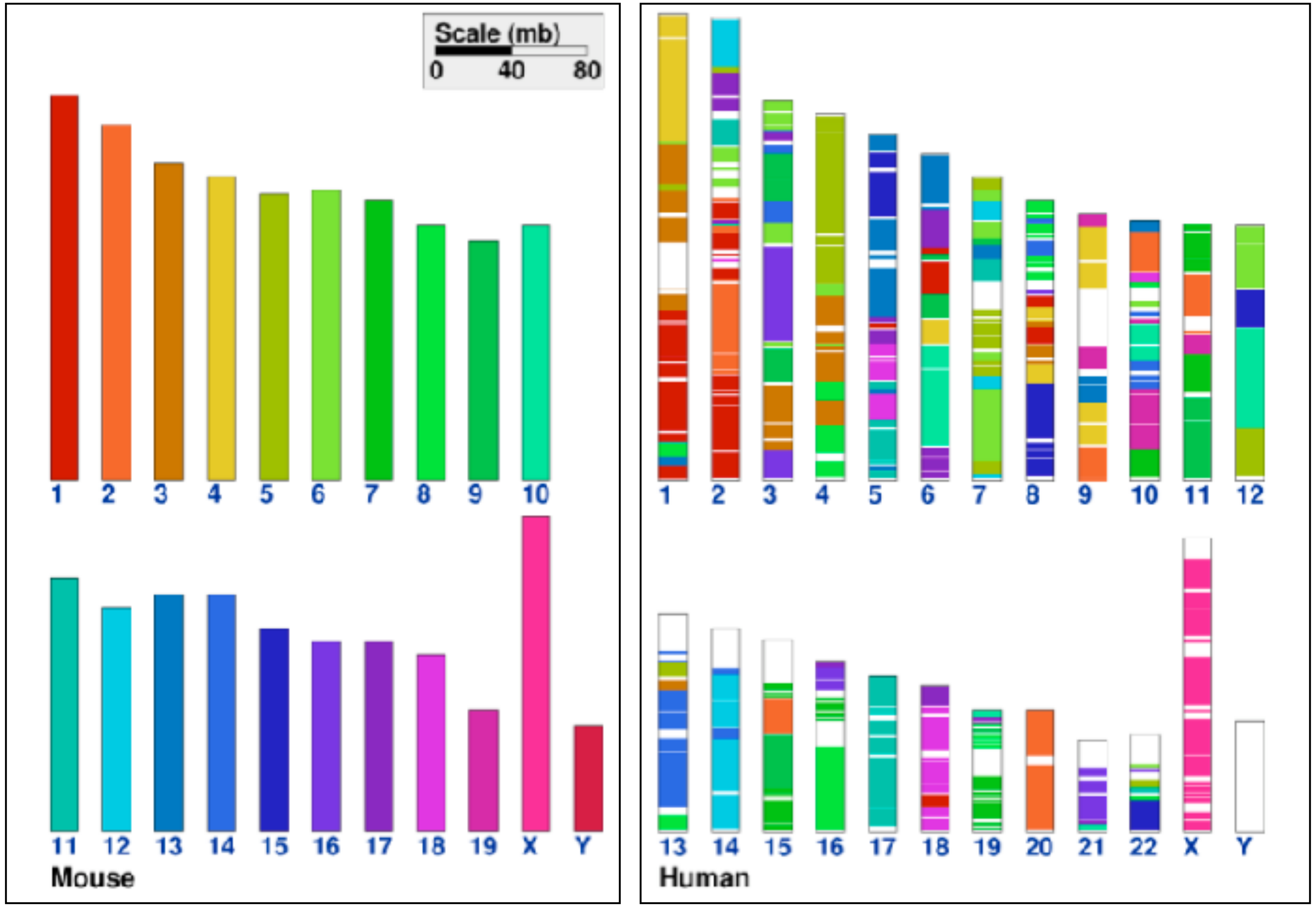
Categorical color: limited number of discriminable bins

- 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



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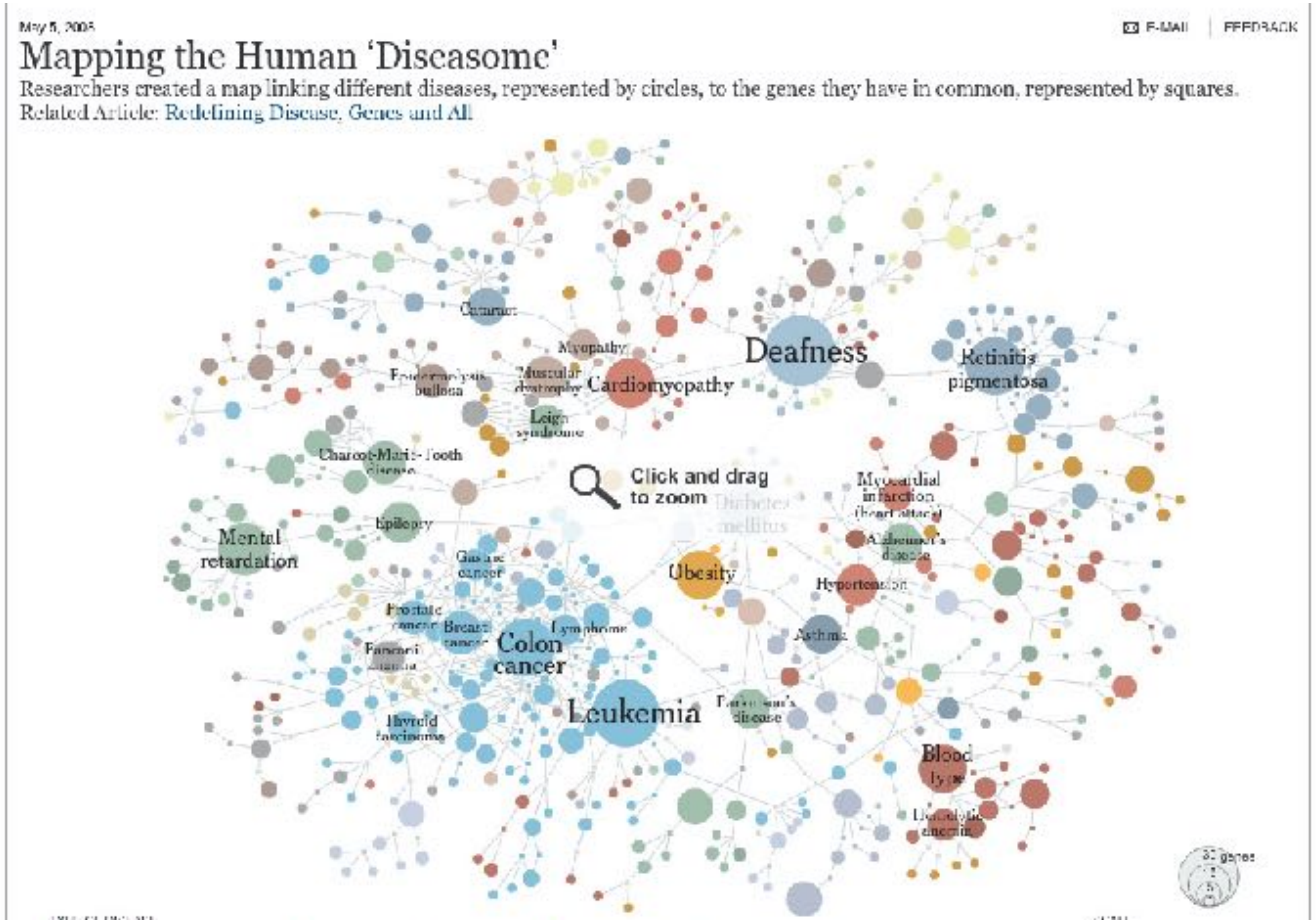
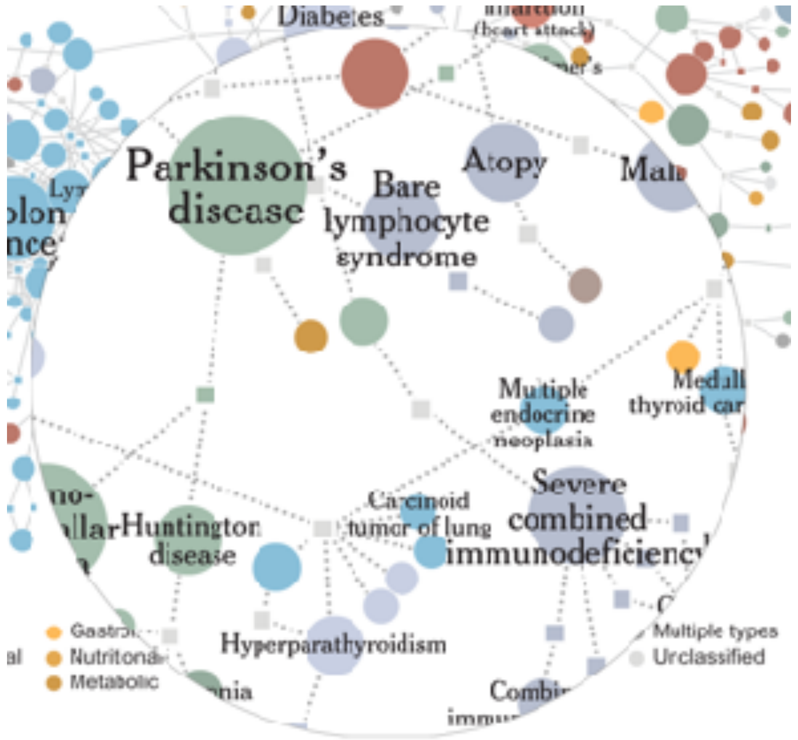
Categorical color: limited number of discriminable bins

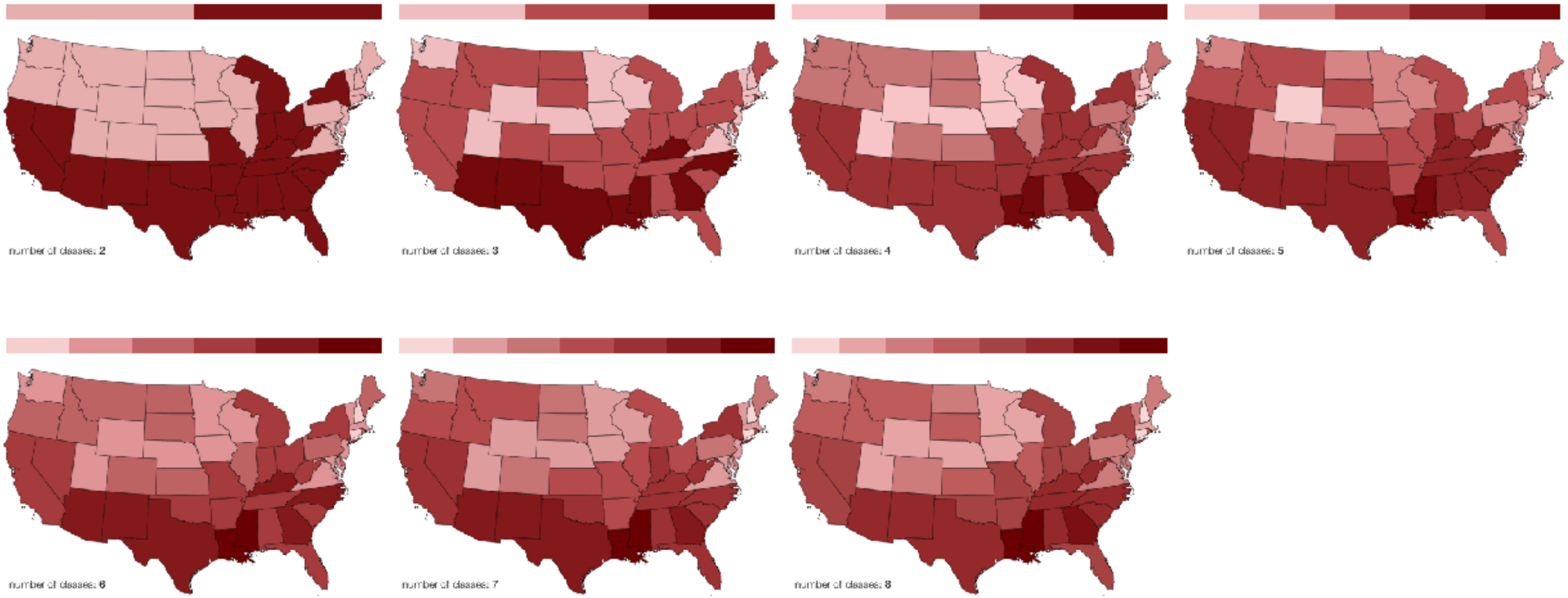
Cancer	Connective tissue	Cardiovascular	Endocrine	Gastrointestinal	Ear, nose, throat	Developmental	Multiple types
Bone	Muscular	Hematological	Immunological	Nutritional	Ophthalmological	Neurological	Unclassified
Skeletal	Dermatological	Renal		Metabolic	Respiratory	Psychiatric	





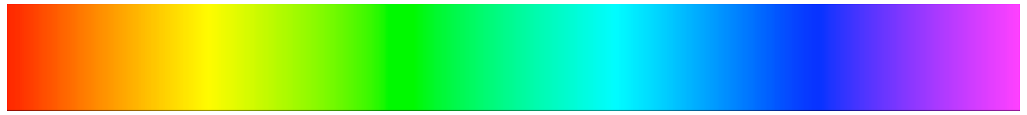
https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

Ordered color: limited number of discriminable bins



Gregor Aisch, vis4.net/blog/posts/choropleth-maps/

Ordered color: Rainbow is poor default



- problems
  - perceptually unordered
  - perceptually nonlinear

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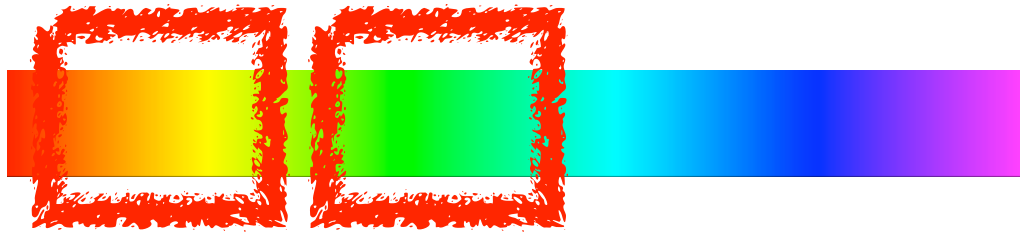

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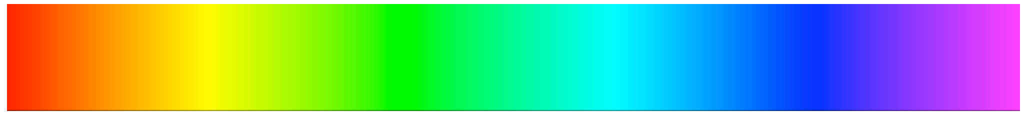

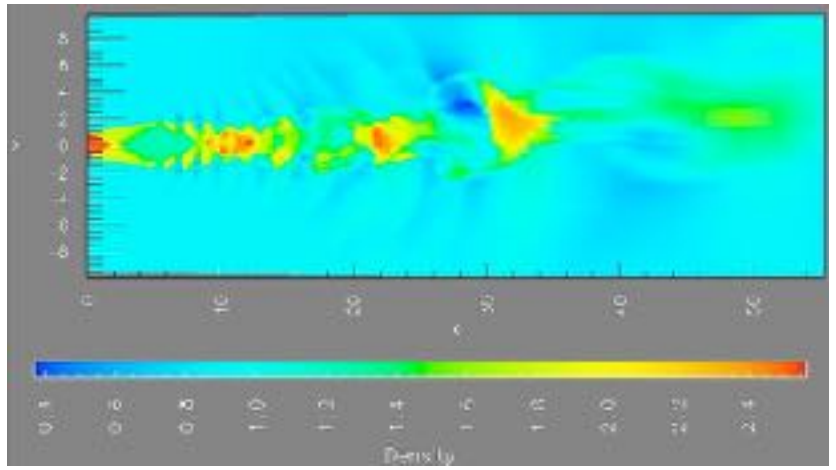

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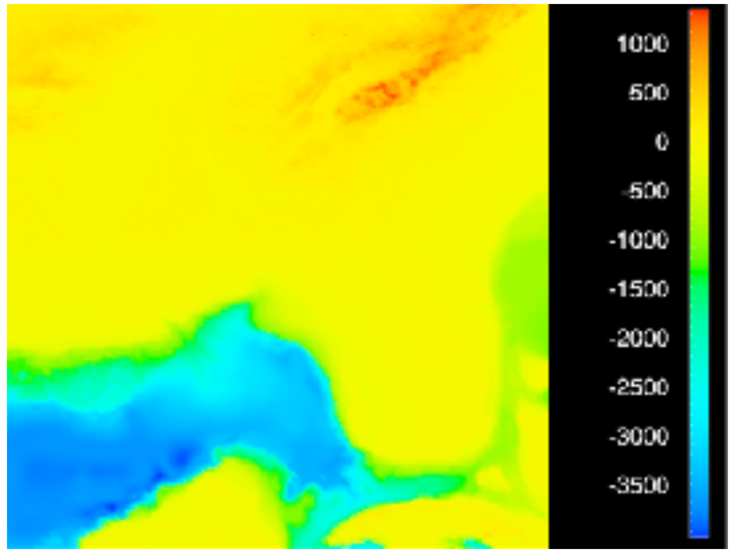

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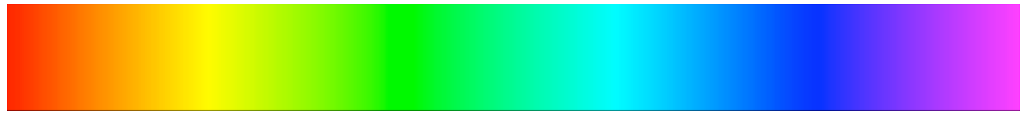
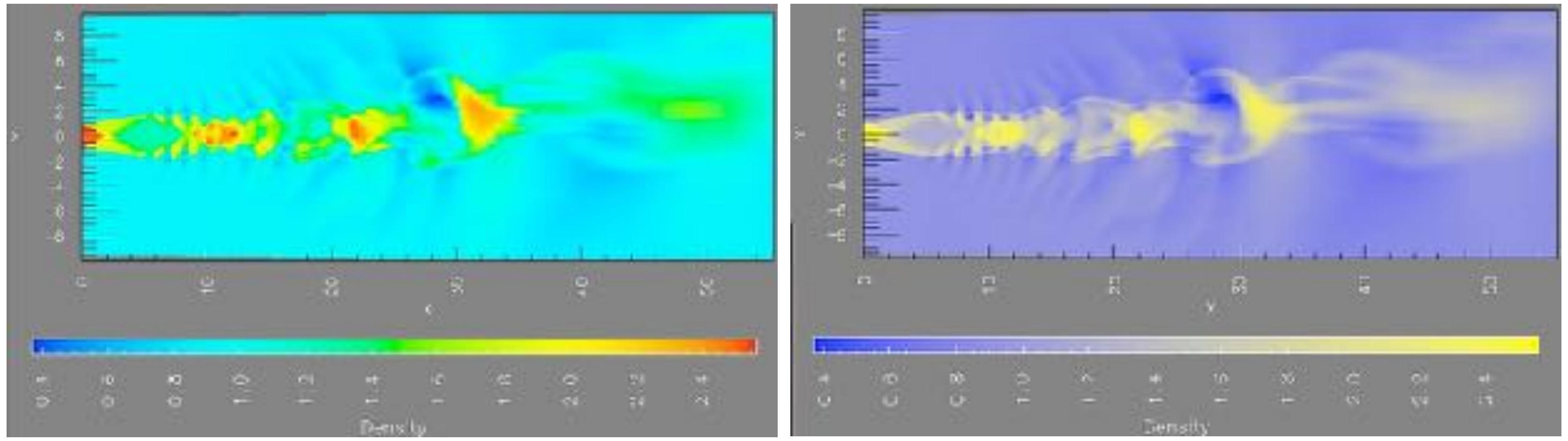
  - large-scale structure: fewer hues





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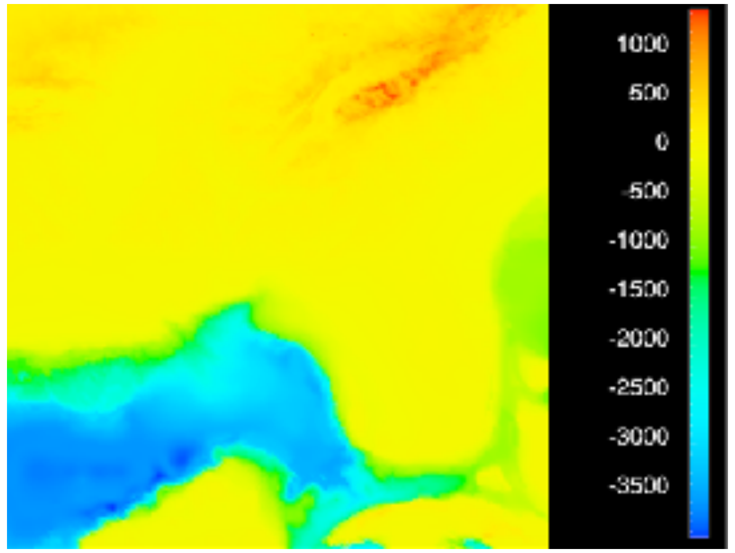

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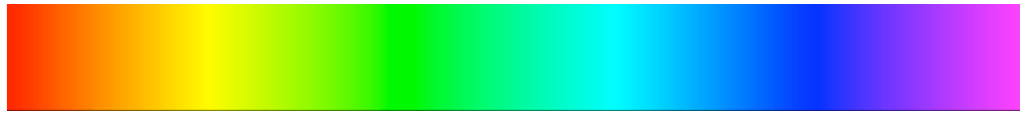
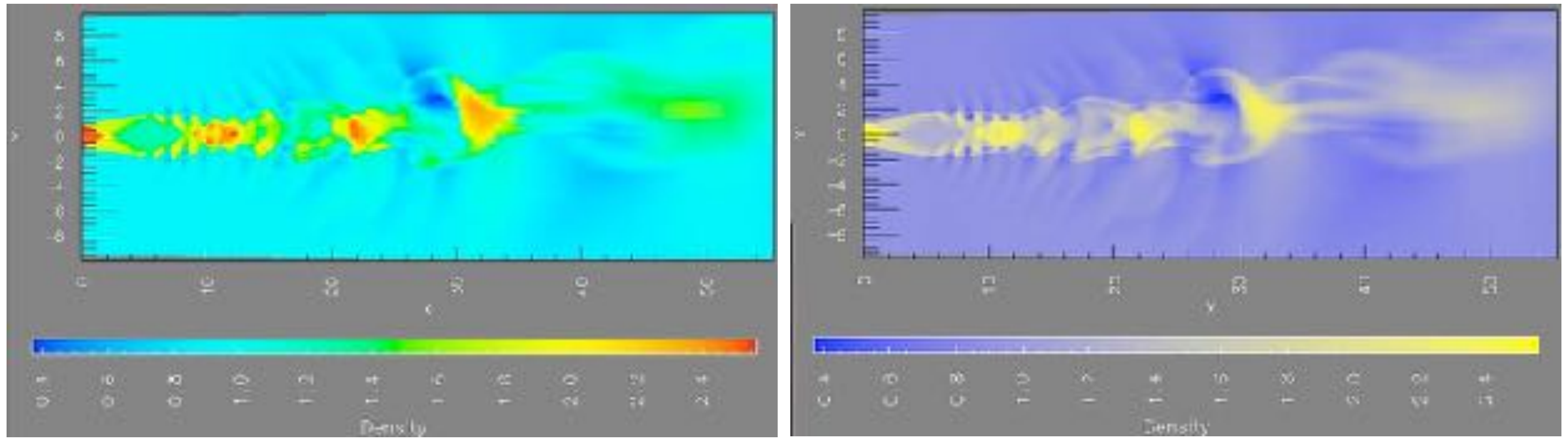
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]





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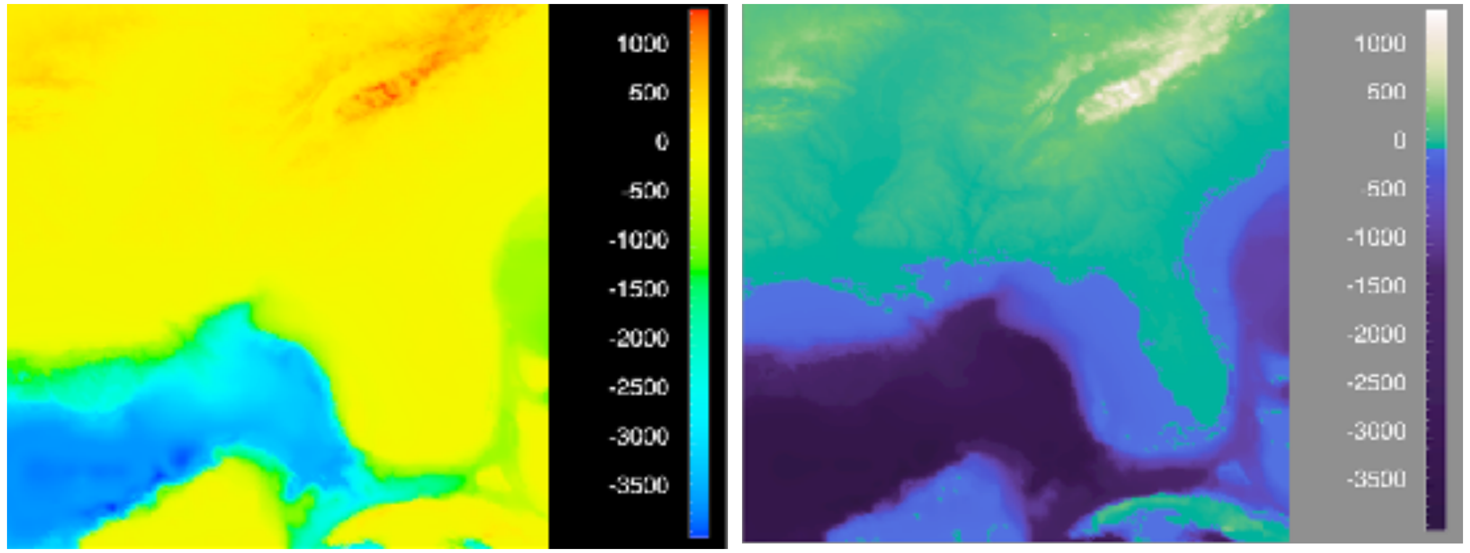

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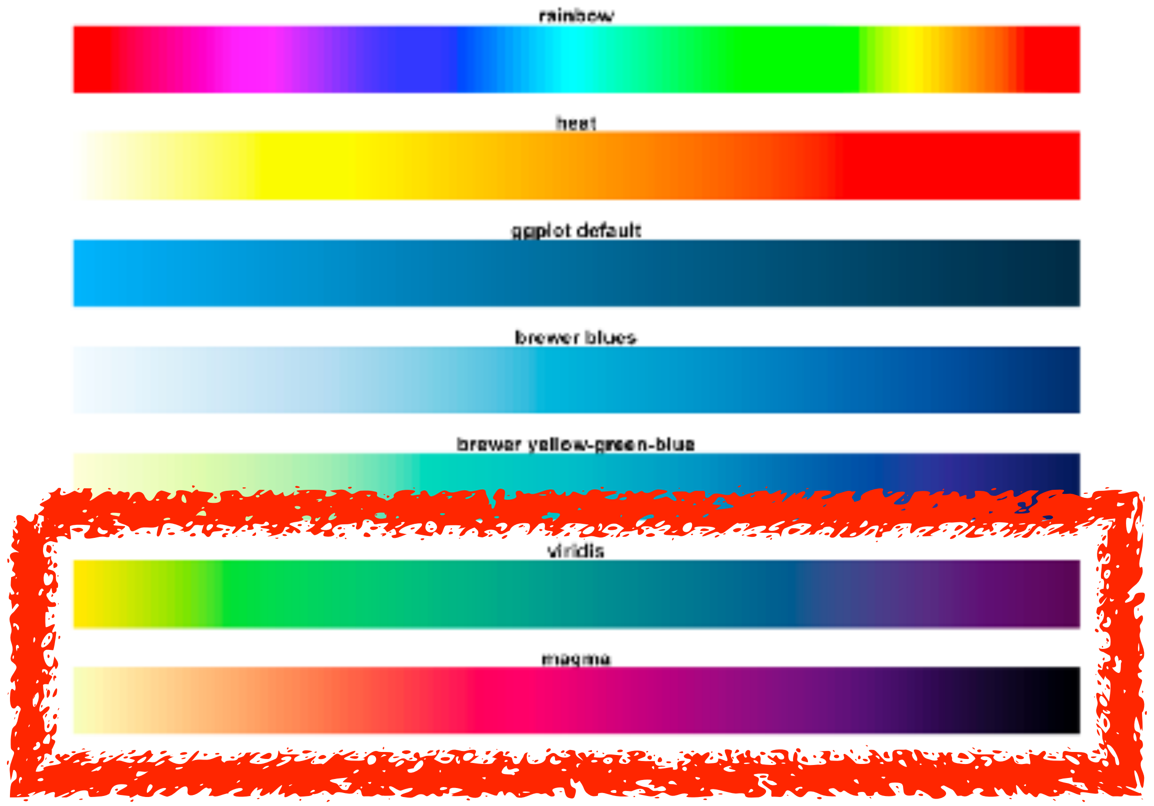
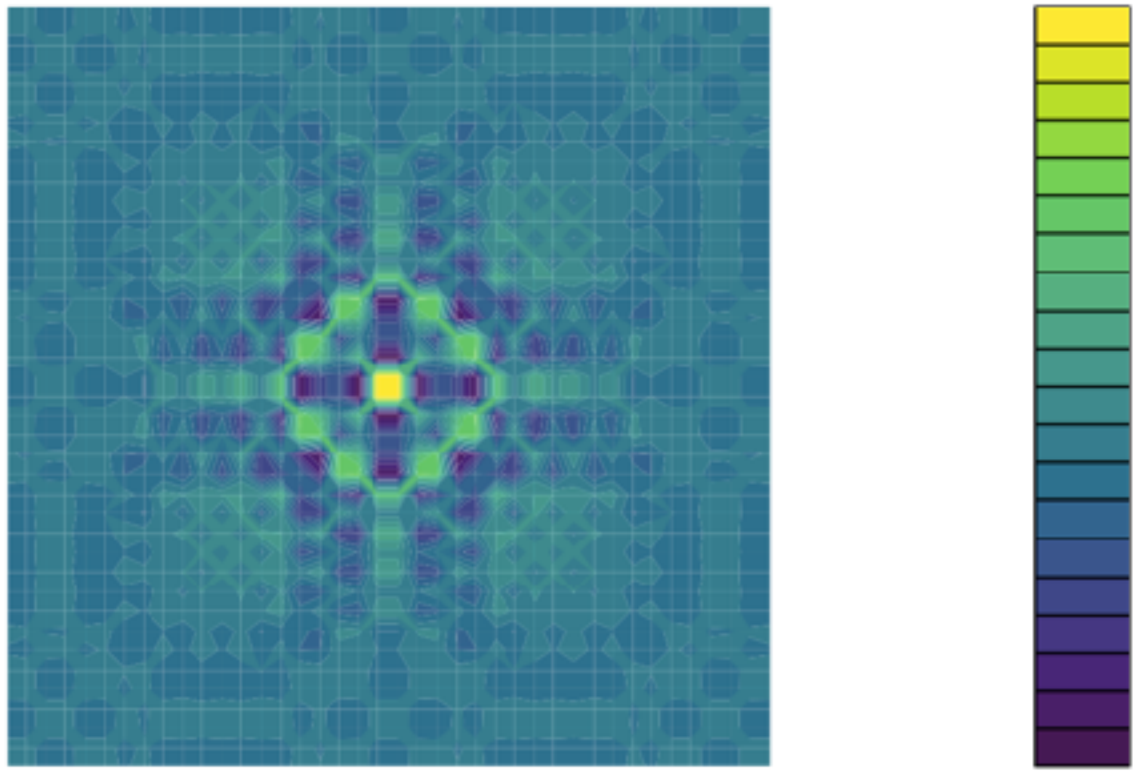
Viridis / Magma: sequential colormaps

- monotonically increasing luminance, perceptually uniform
- colorful, colorblind-safe
  - R, python, D3





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

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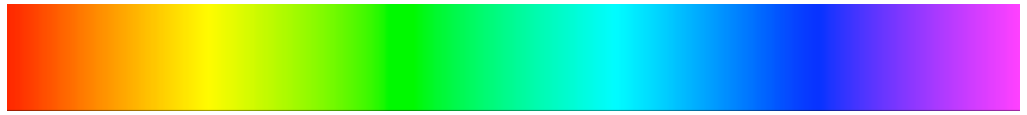
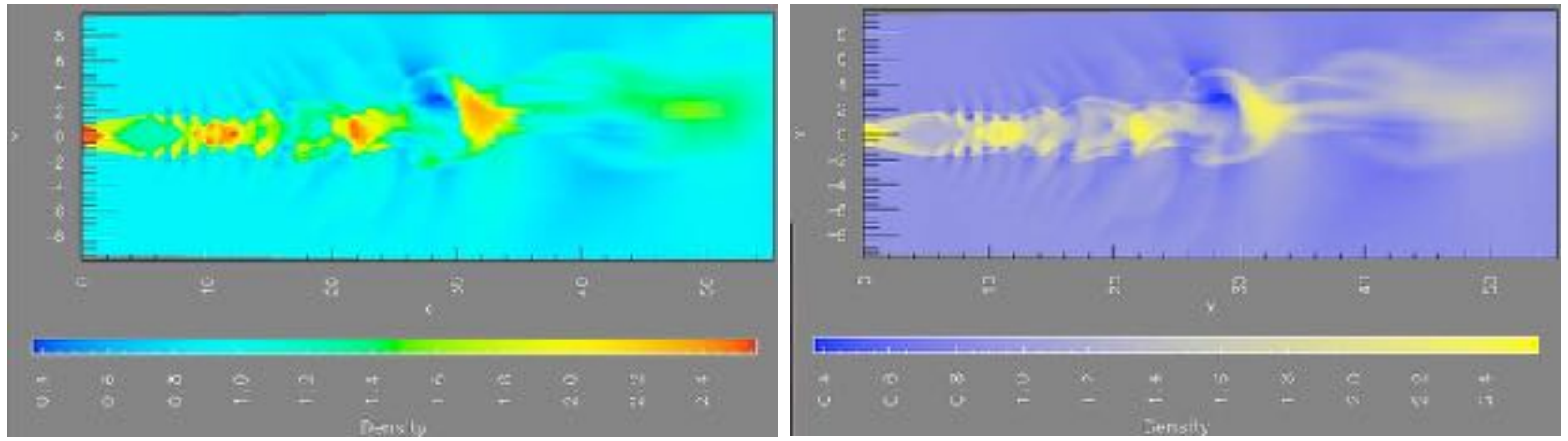
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented saturated rainbow is good!





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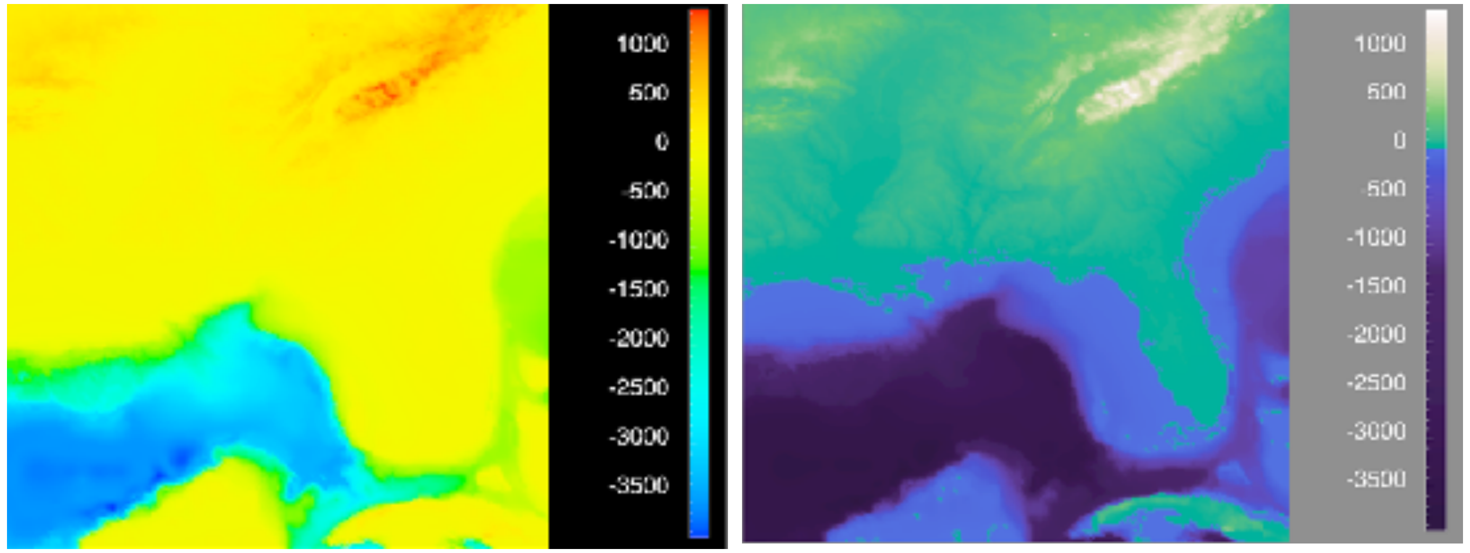

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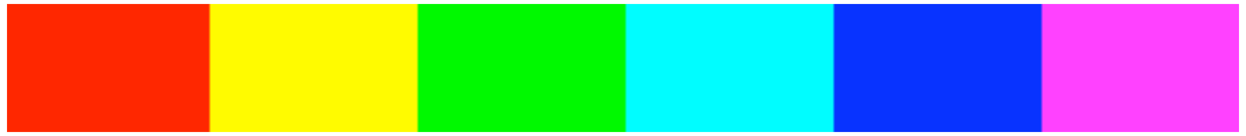
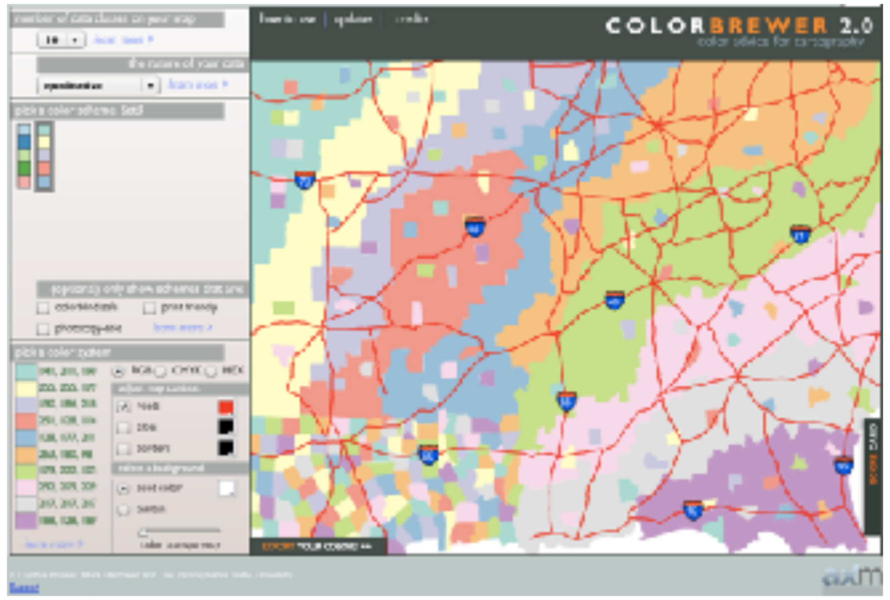
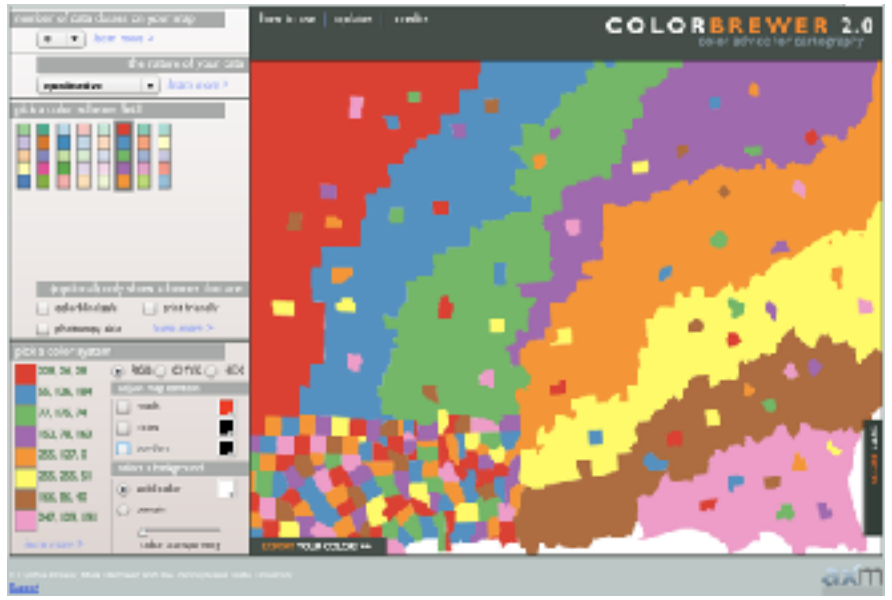


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation





http://colorbrewer2.org/

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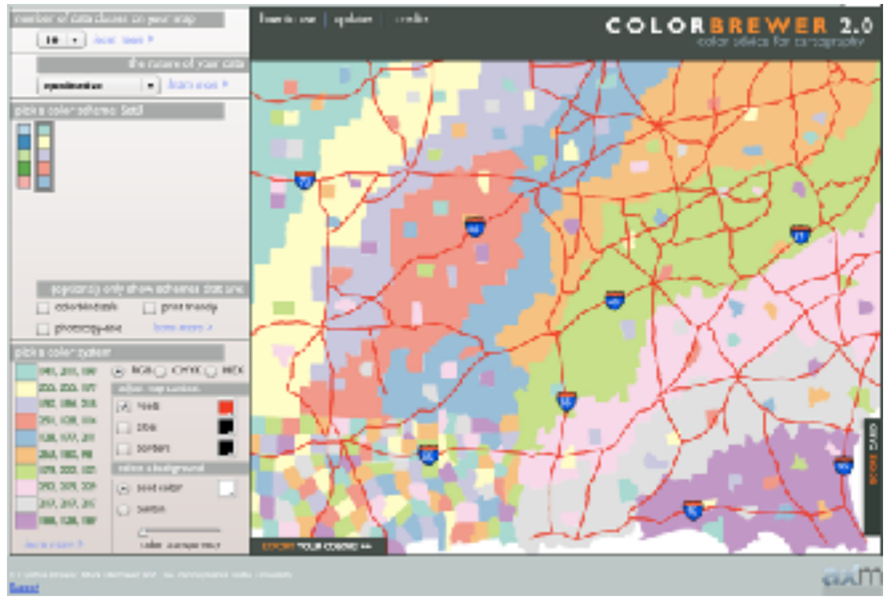
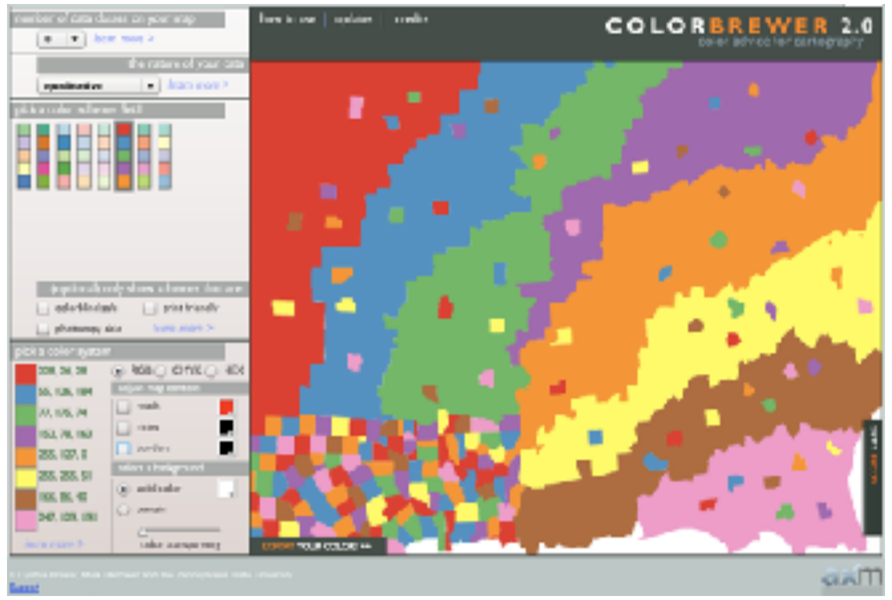
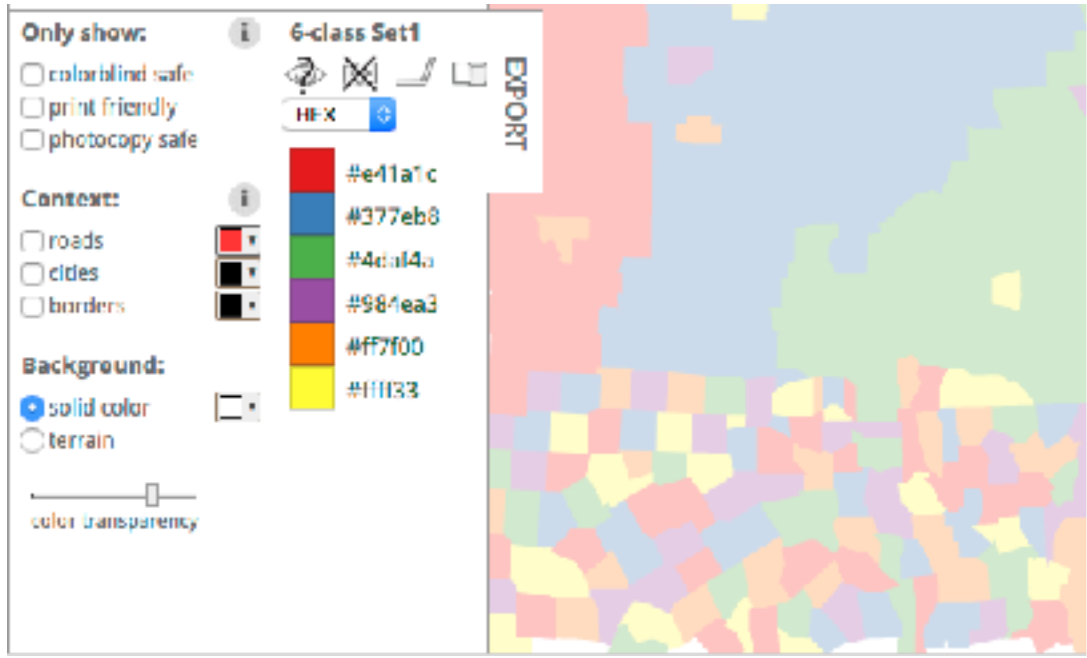
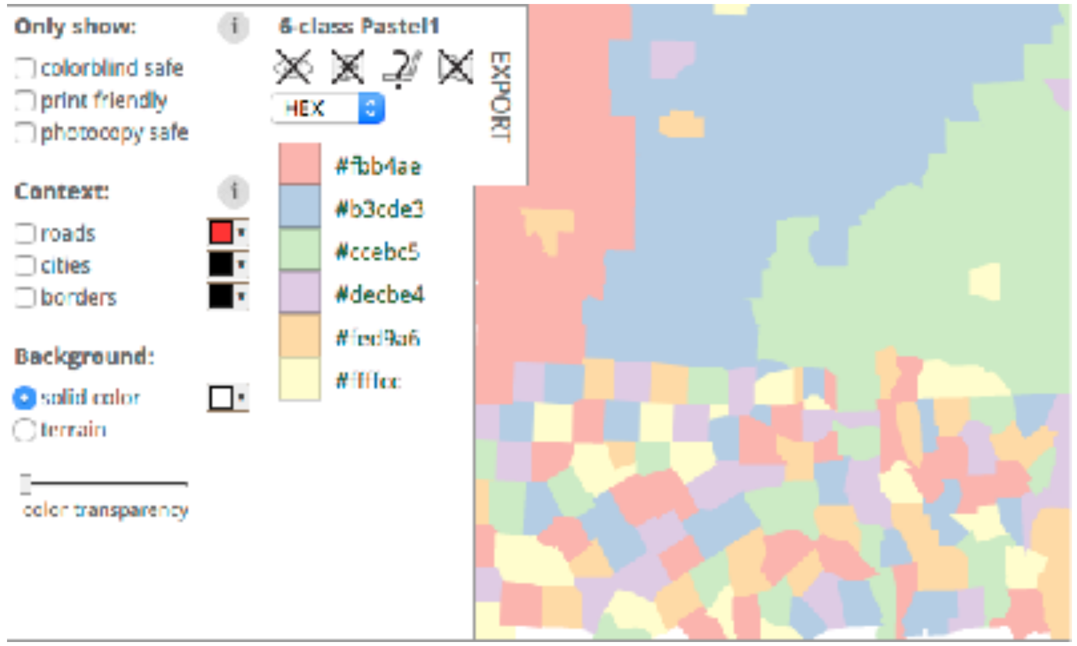
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency









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  - size heavily affects salience
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- saturation & luminance:
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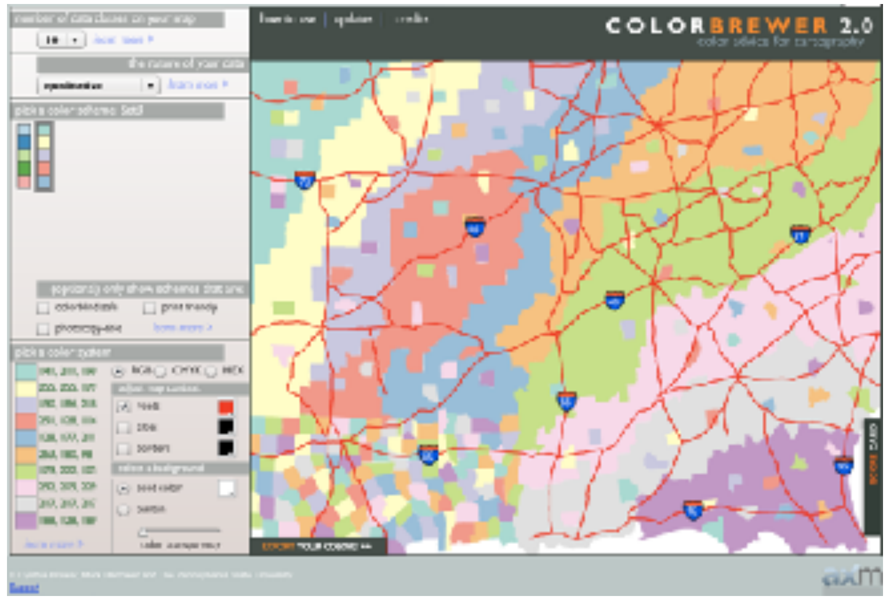
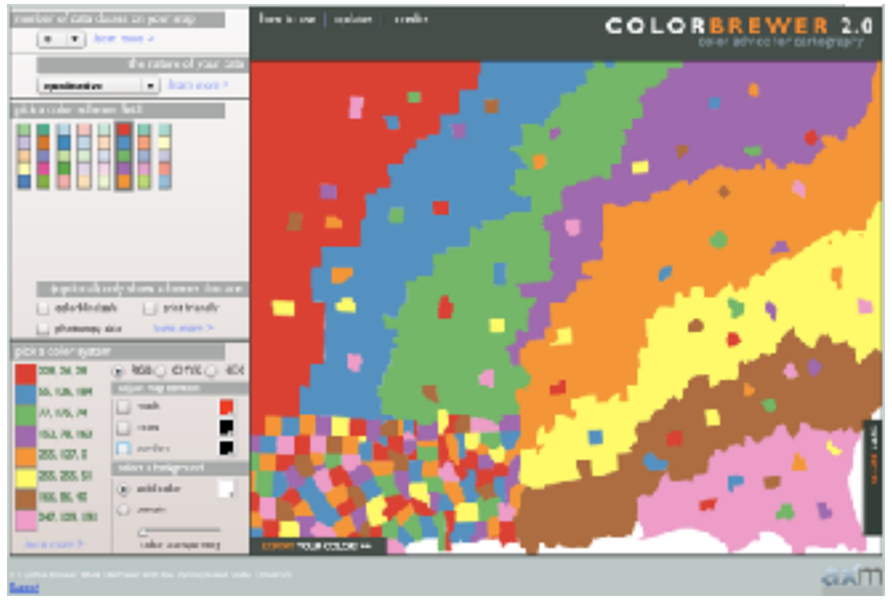
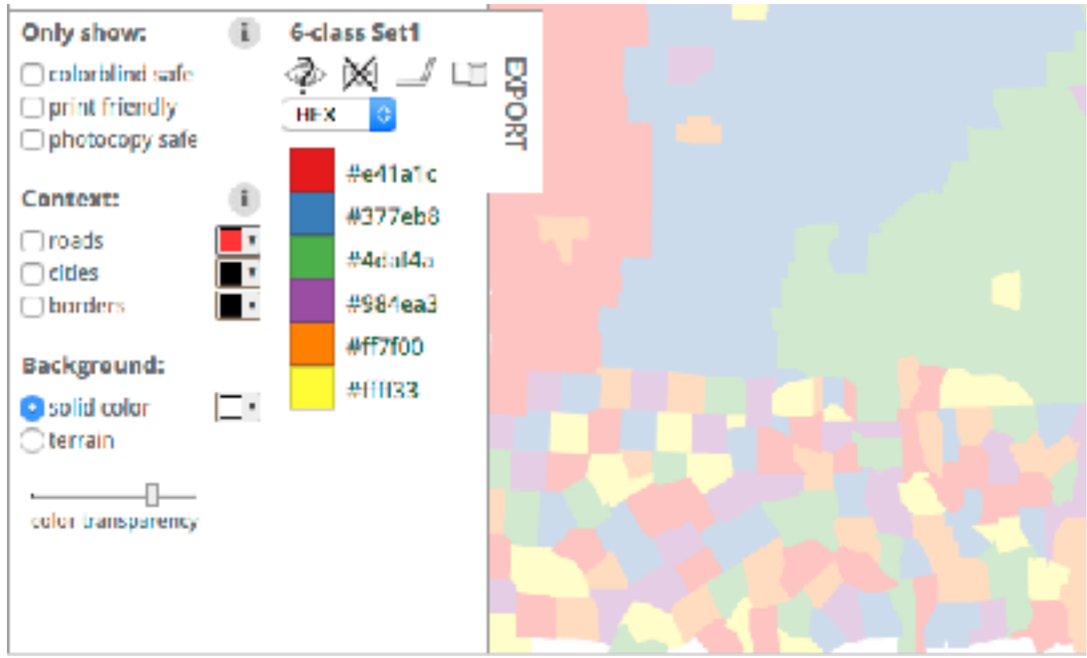
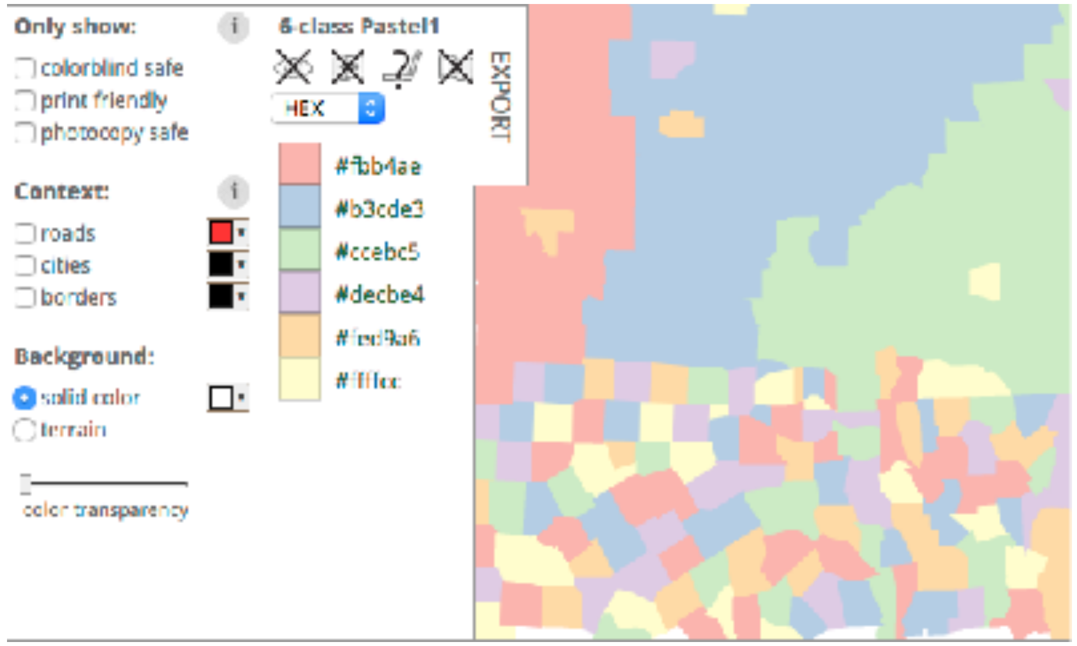
  - also not separable from transparency
  - small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max
  - contiguous regions: many bins (use only one of these channels)









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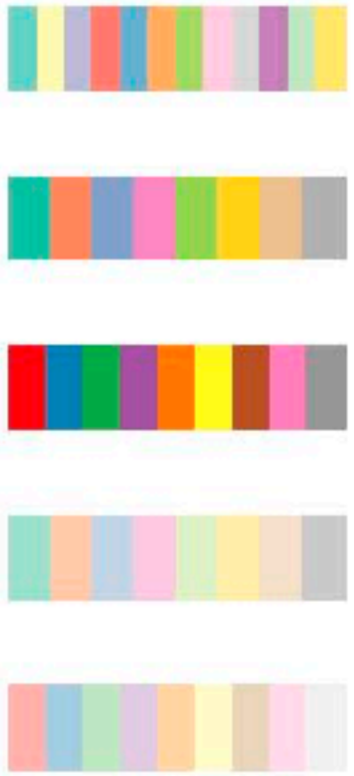
Color Palettes

Color palettes: univariate

➔ Categorical

Categorical



categorical

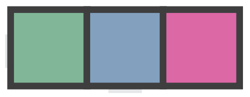
- categorical
  - aim for maximum distinguishability
  - aka *qualitative*, *nominal*

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

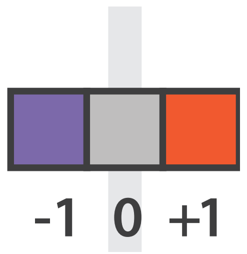
- ➔ Categorical

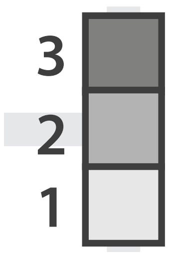
- ➔ Ordered
  - ➔ *Sequential*
  - ➔ *Diverging*



Categorical

Diverging

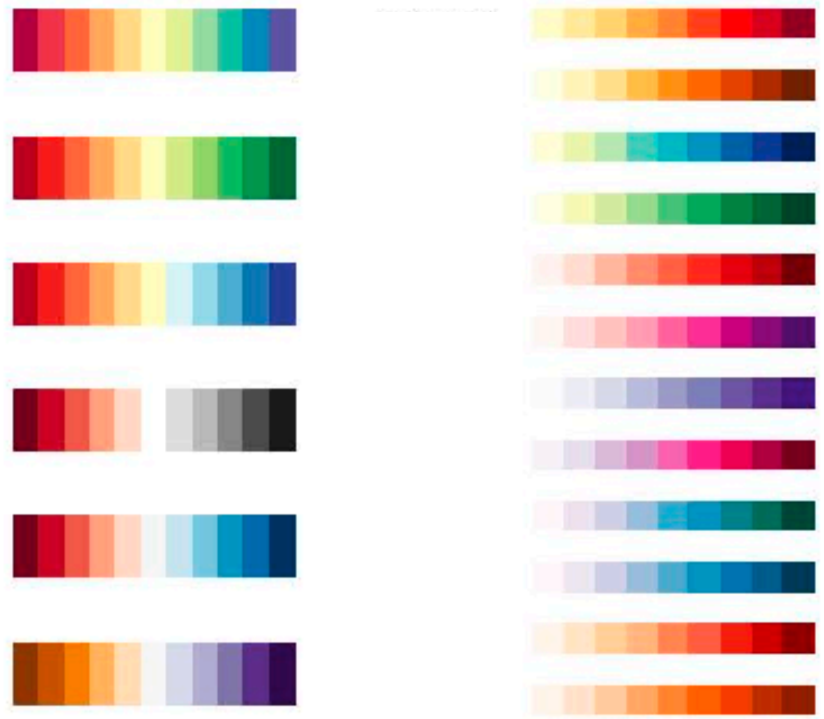




Sequential

- 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

diverging sequential



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

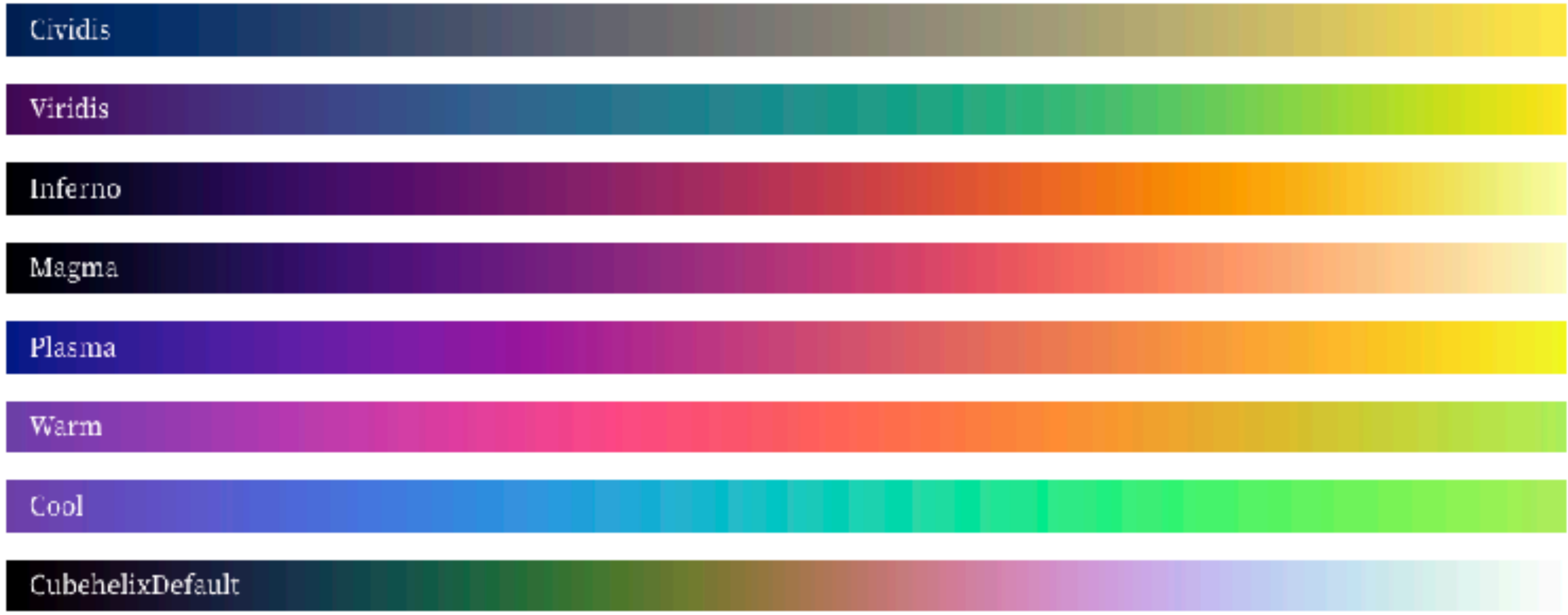
Color palettes: univariate

➔ Categorical

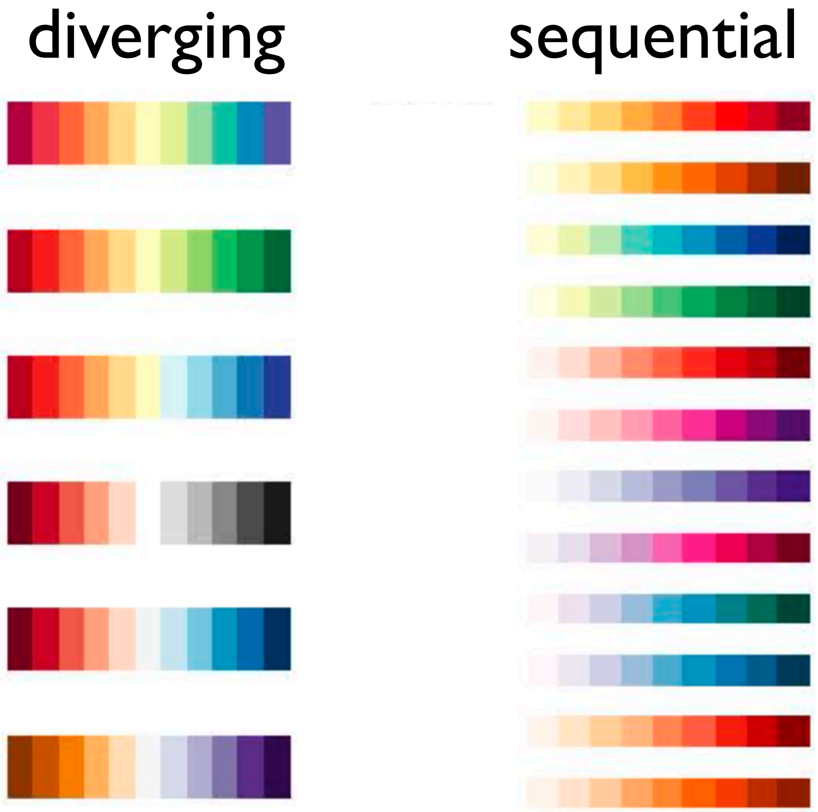
➔ Ordered

- ➔ *Sequential*

- ➔ *Diverging*



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



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

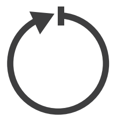
Color palettes: univariate

- Categorical

- Ordered
  - *Sequential*

  - *Diverging*

  - Cyclic



cyclic multihue

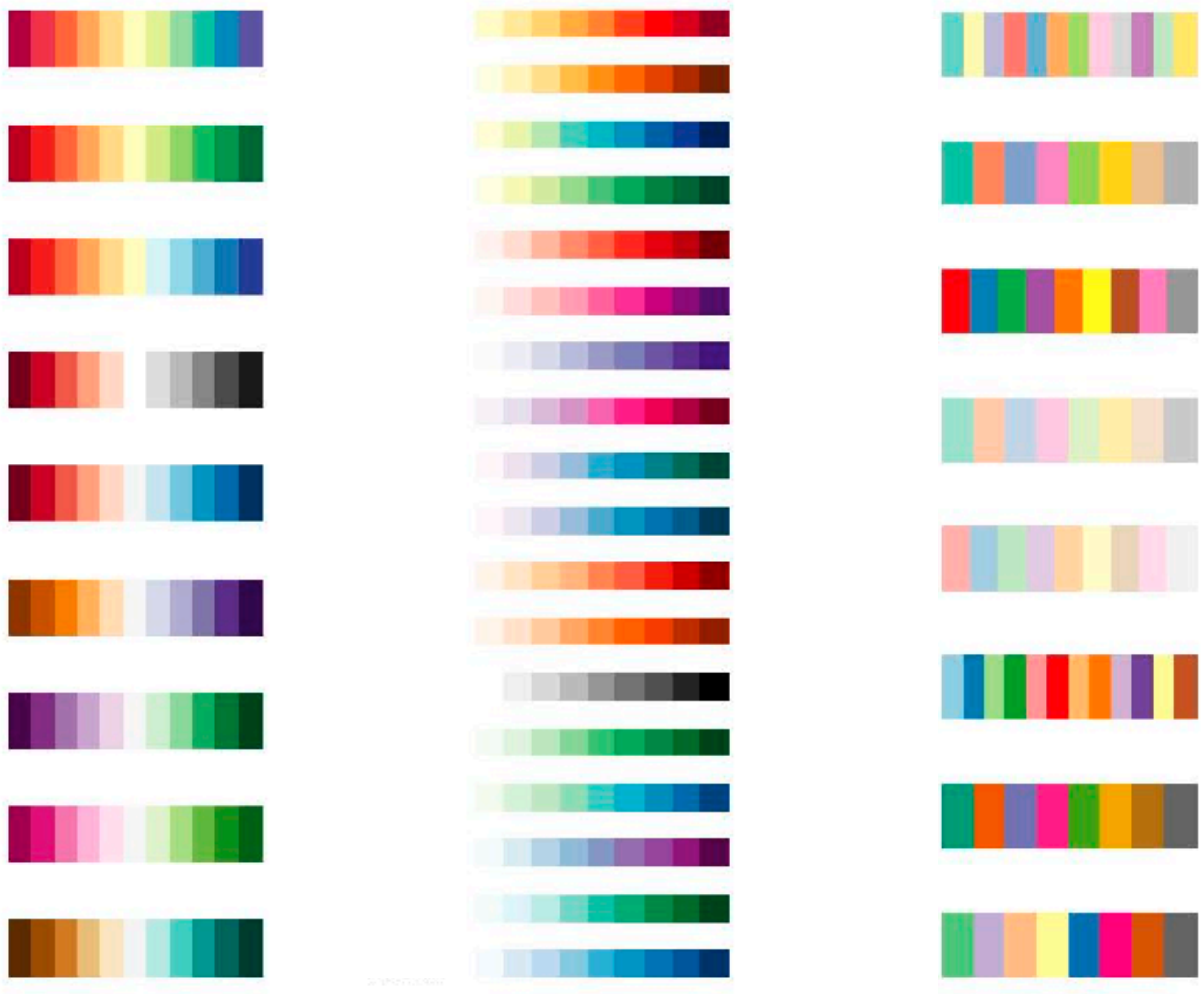
https://github.com/d3/d3-scale-chromatic

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

Color palette design considerations: univariate

segmented

diverging sequential categorical



continuous

sequential single hue

diverging two hue

sequential multihue

cyclic multihue

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

[A Study of Colormaps in Network Visualization. Karim et al. *Appl. Sci.* **2019**, *9*, 4228; doi:10.3390/app9204228] https://github.com/d3/d3-scale-chromatic

Colormaps: bivariate

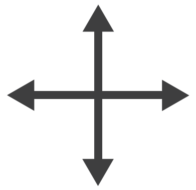
➔ Categorical

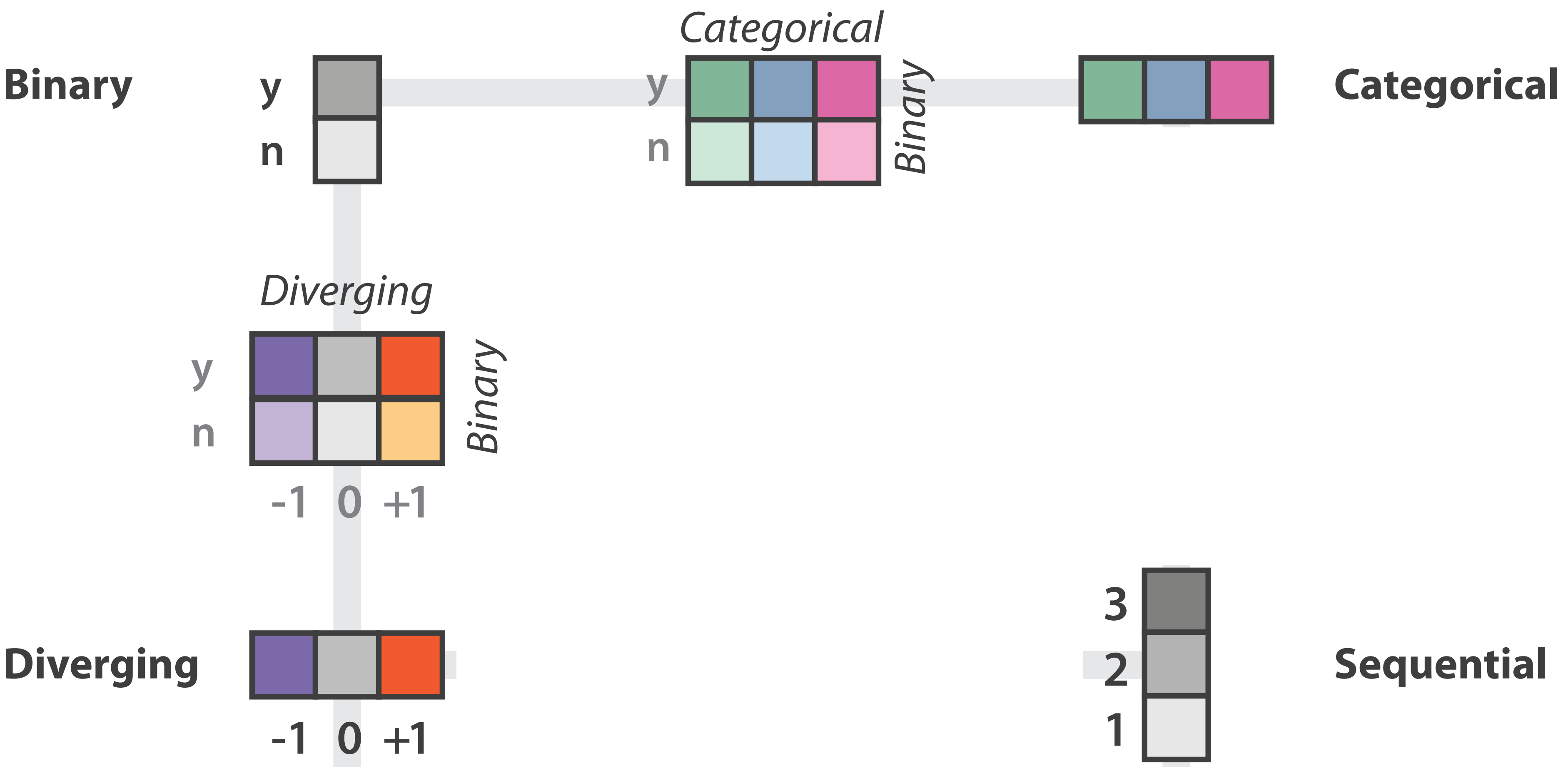
➔ Ordered

➔ *Sequential*

➔ *Diverging*

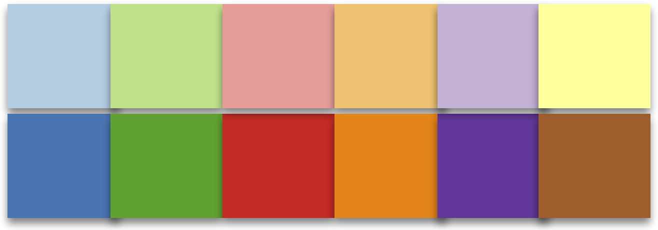
➔ Bivariate





- bivariate best case
  - binary in one of the directions

d3.schemePaired <>



binary saturation

categorical hue

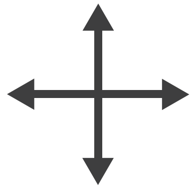
Colormaps: bivariate

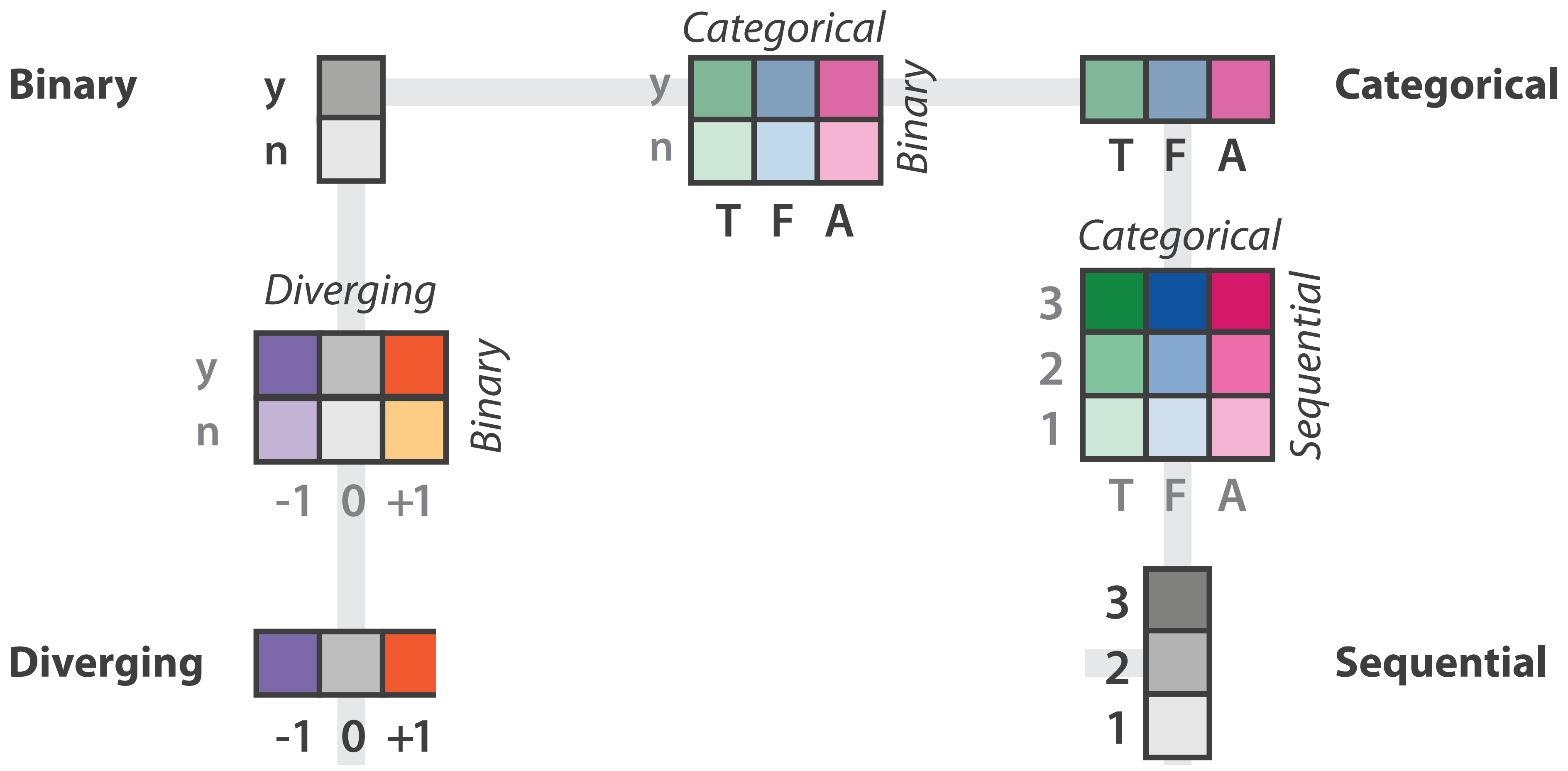
- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

  - ➔ *Diverging*

- ➔ Bivariate





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

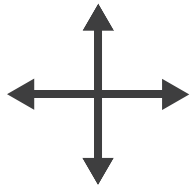
Colormaps

- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

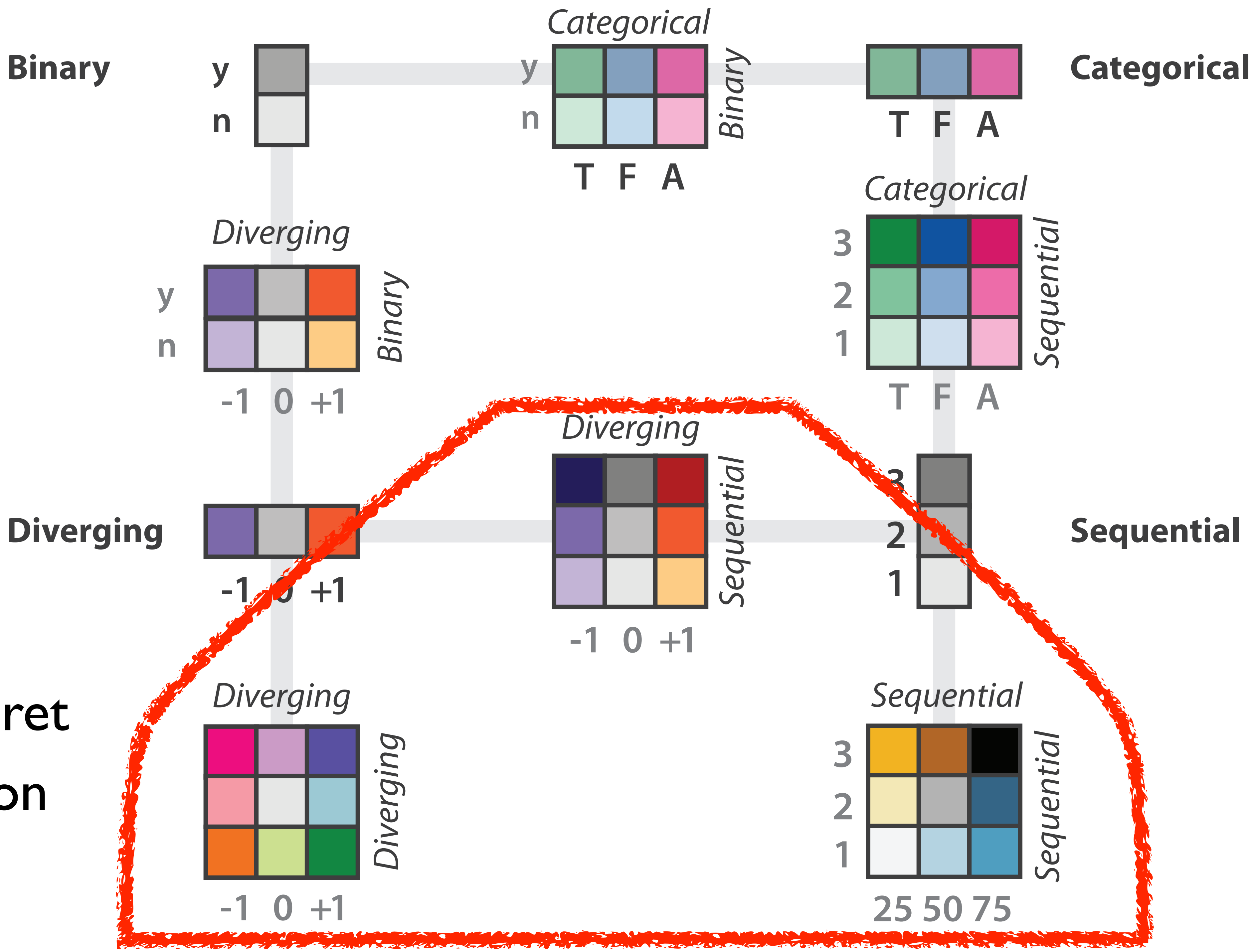
  - ➔ *Diverging*

- ➔ Bivariate



use with care!

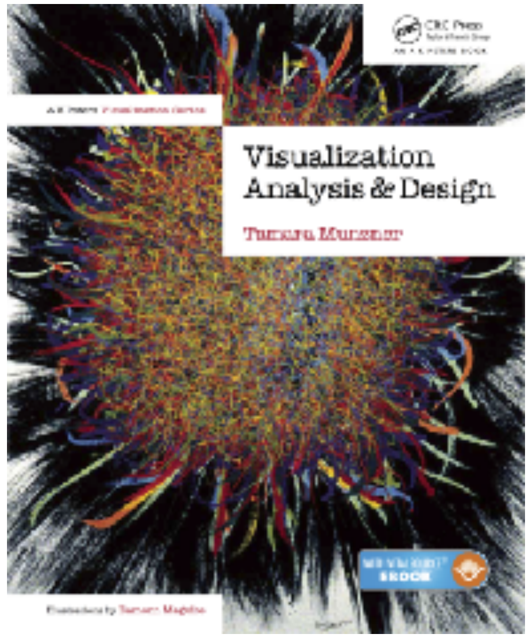
- bivariate can be very difficult to interpret
  - when multiple levels in each direction



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

Visualization Analysis & Design

Color (Ch 10) II



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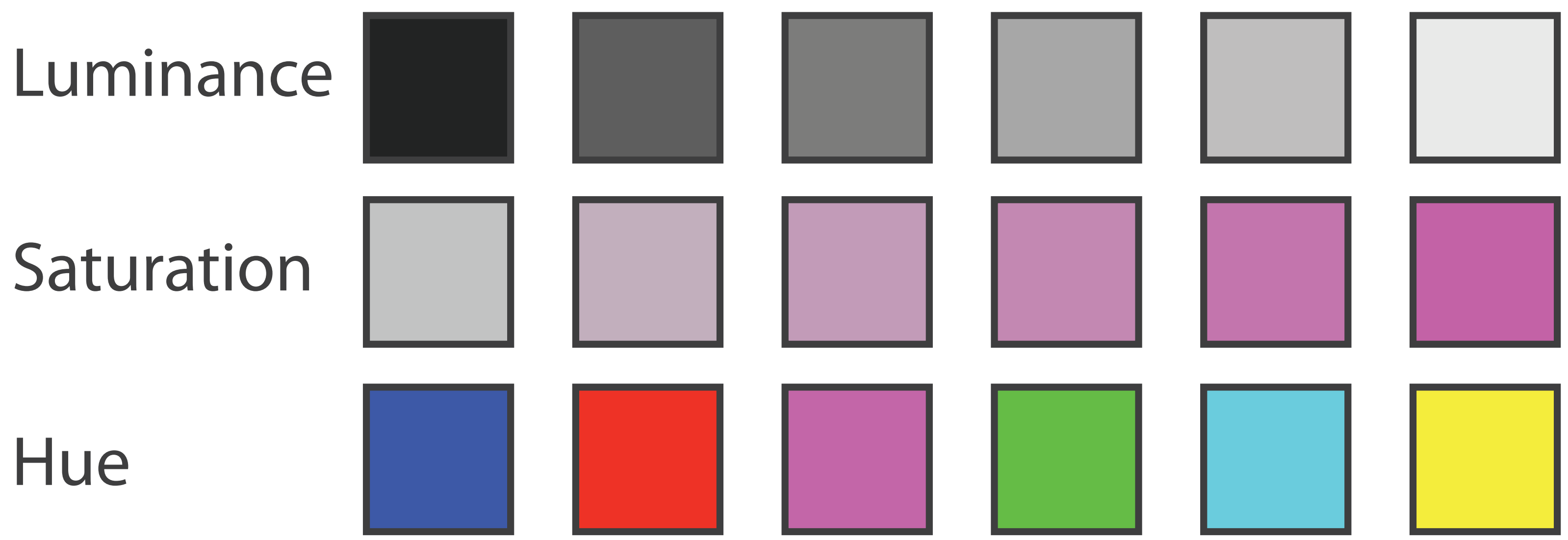
Decomposing color

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



Color Deficiency

Luminance

- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!

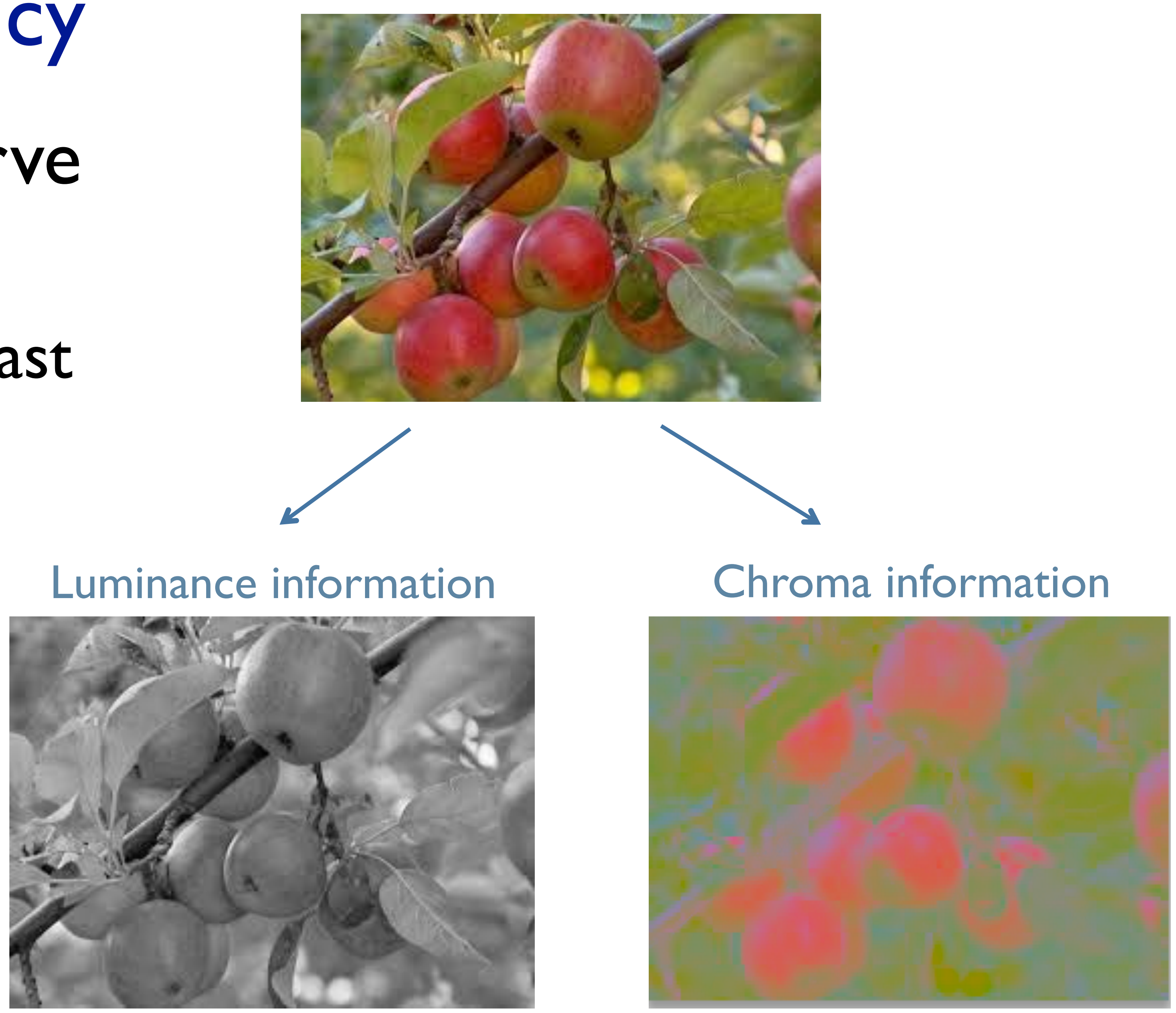
Luminance information

Saturation/hue information

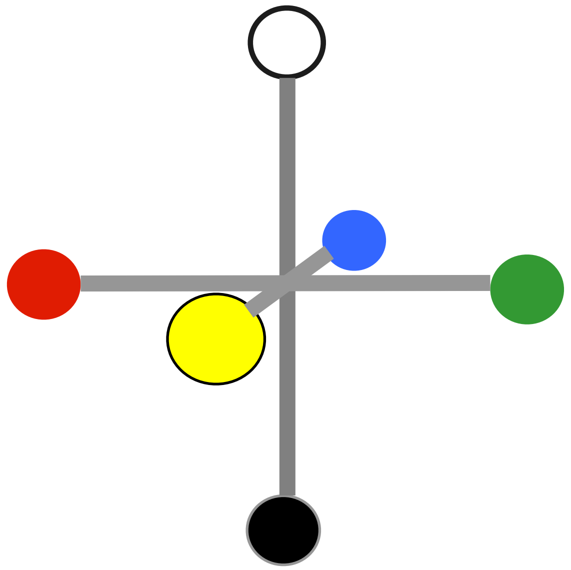
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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*)

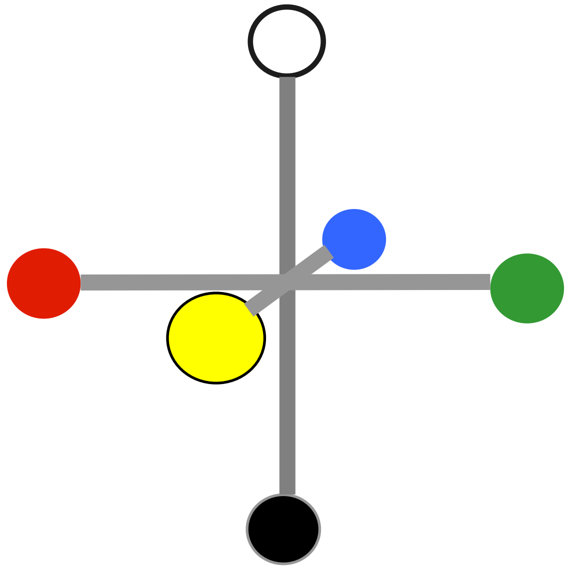


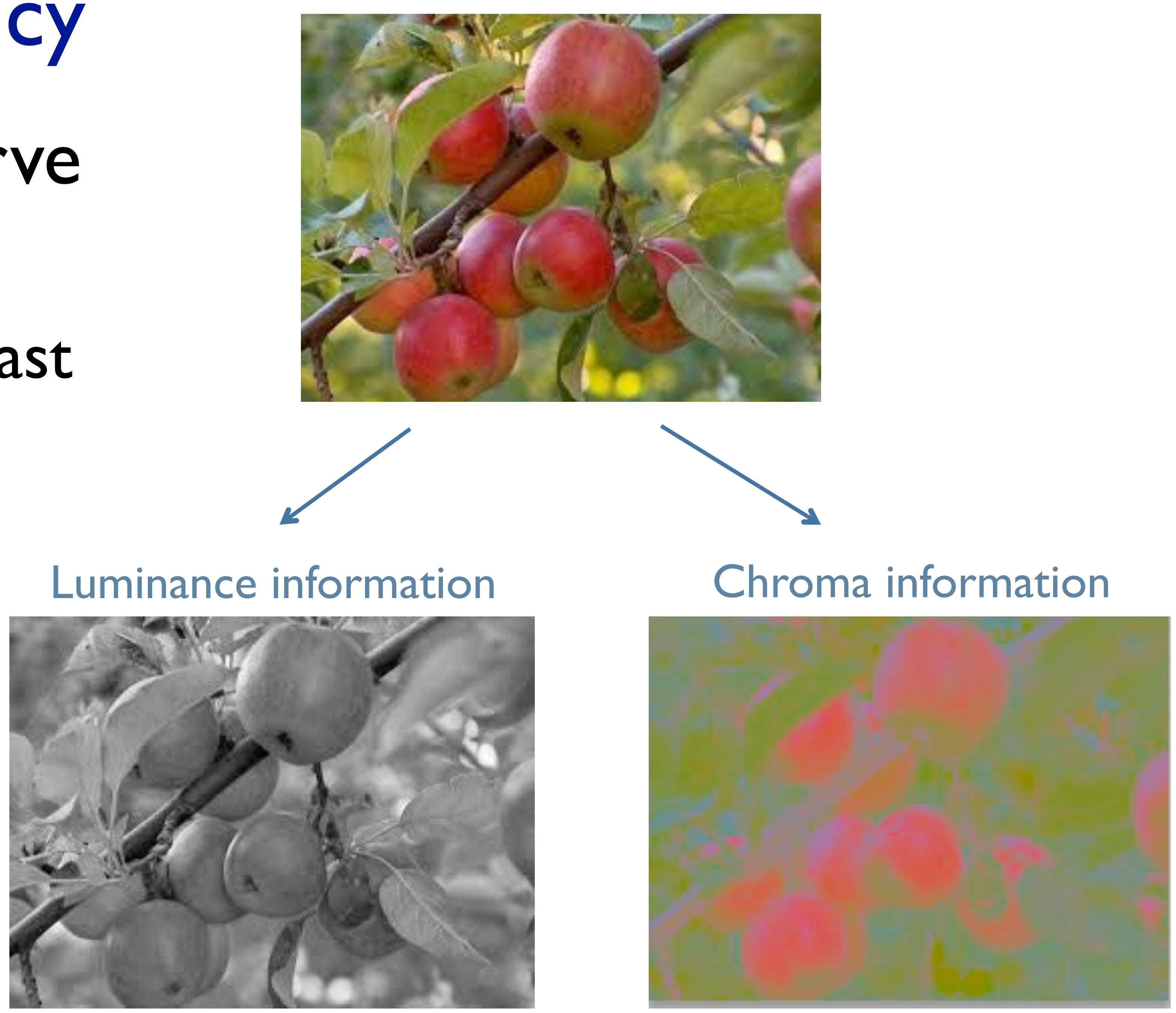
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]



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*)
- "colorblind": degraded acuity, one axis
  - 8% of men are red/green color deficient
  - blue/yellow is rare



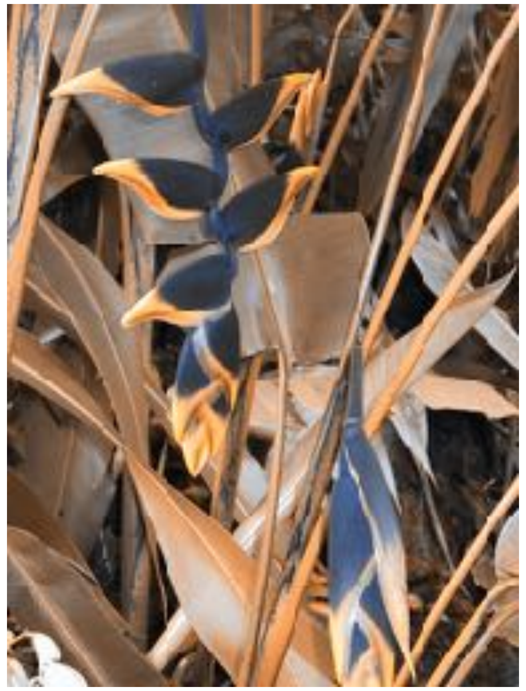


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Check with simulator

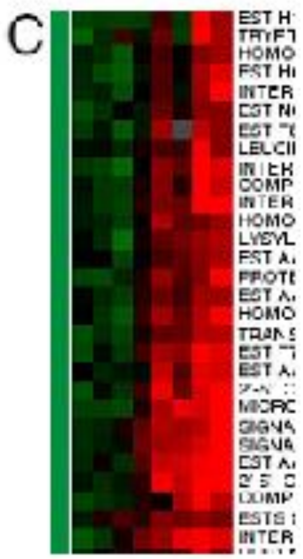
Normal vision

Deuteranope
green-weak



Protanope
red-weak

Tritanope
blue-weak

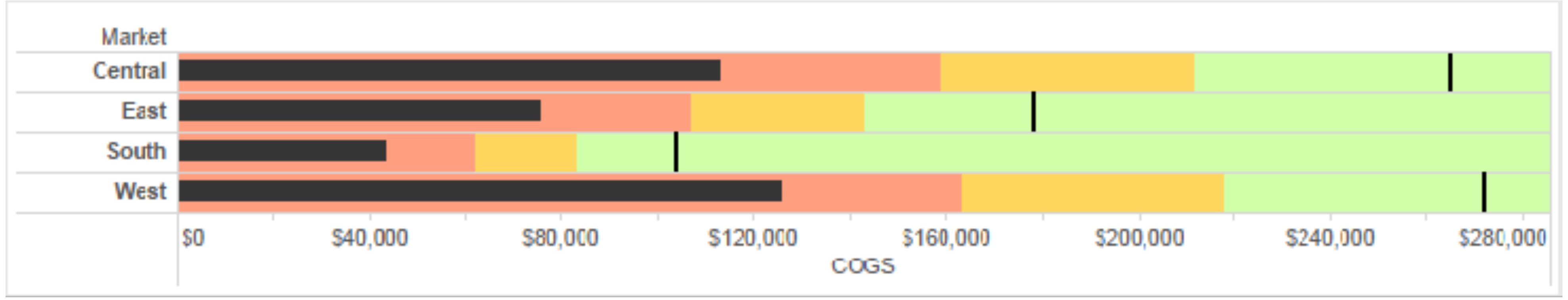


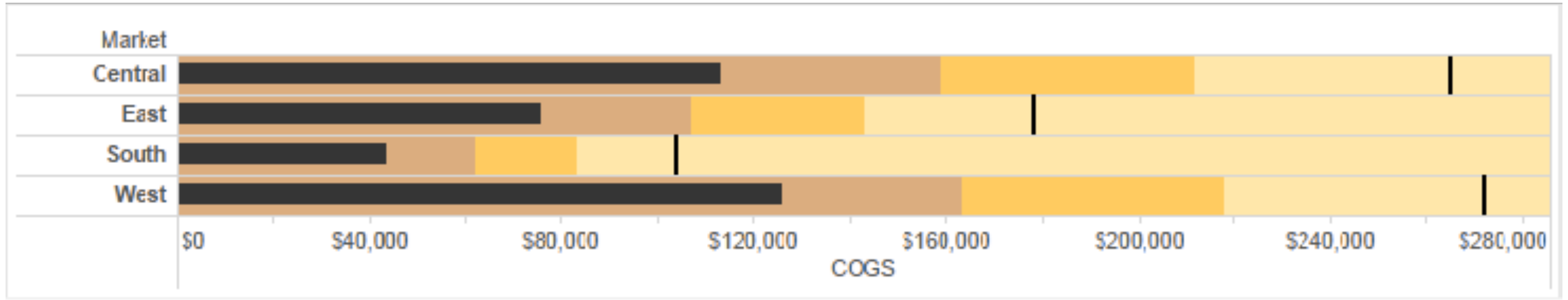
https://www.color-blindness.com/coblis-color-blindness-simulator/

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

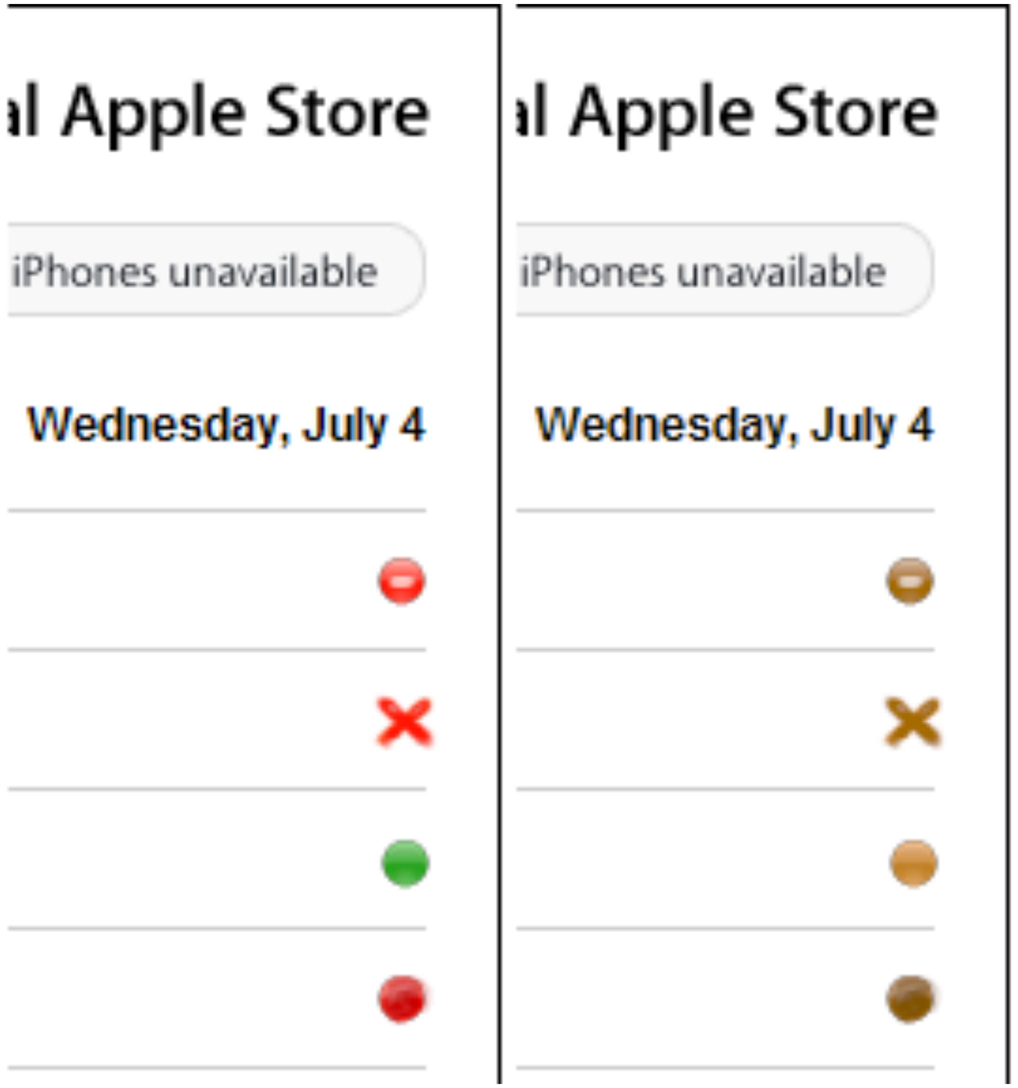
Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape





Deuteranope simulation

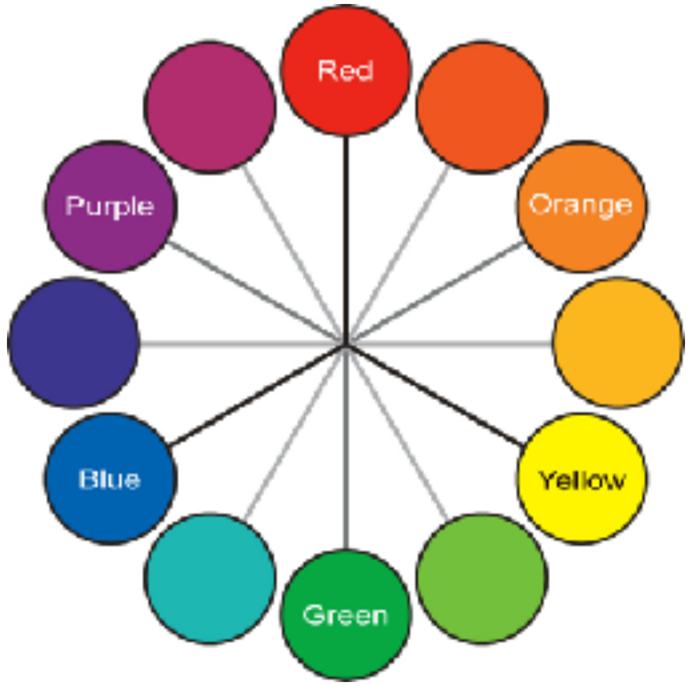


Change the shape

Vary luminance

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

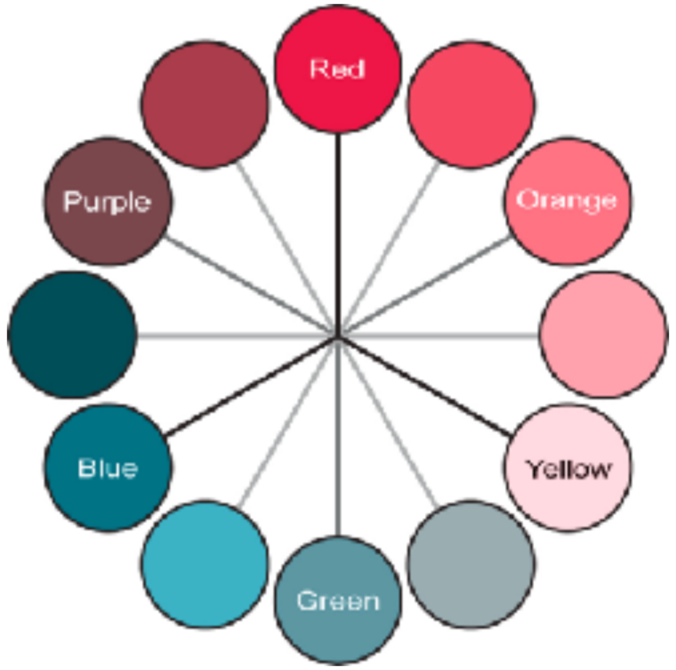
Color deficiency: Reduces color to 2 dimensions



Normal

Protanope

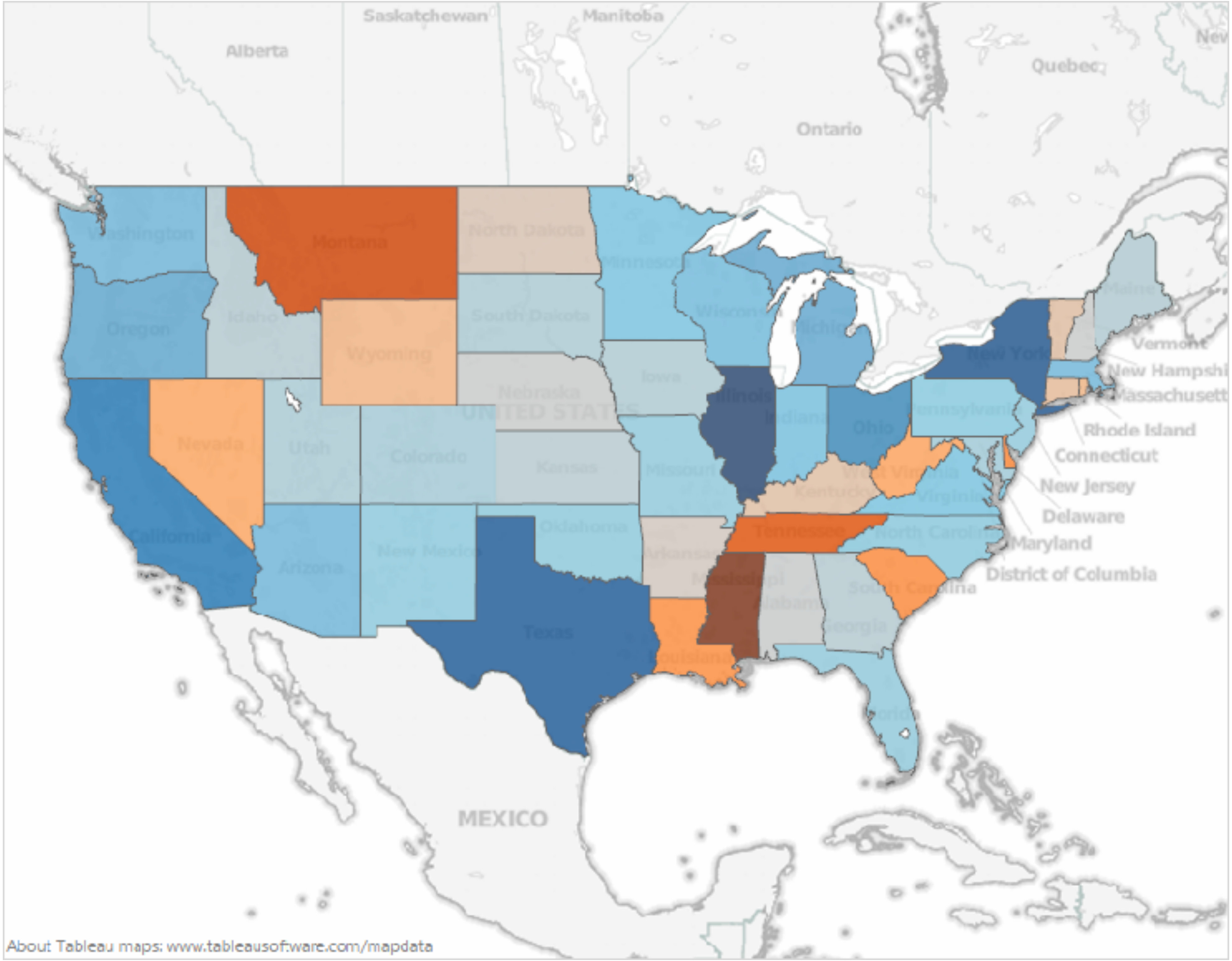
Deuteranope



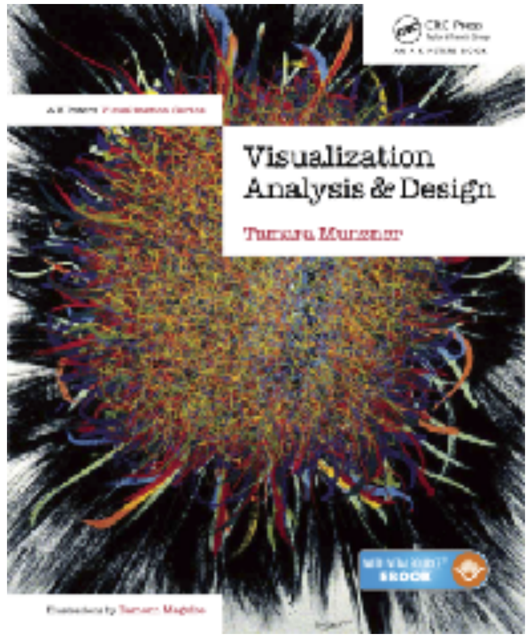
Tritanope

[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.]



Visualization Analysis & Design

Color (Ch 10) III

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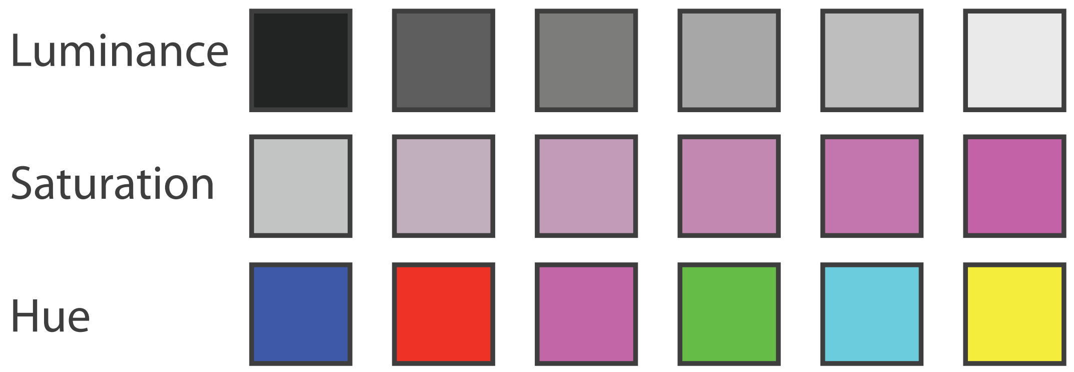
Color Spaces

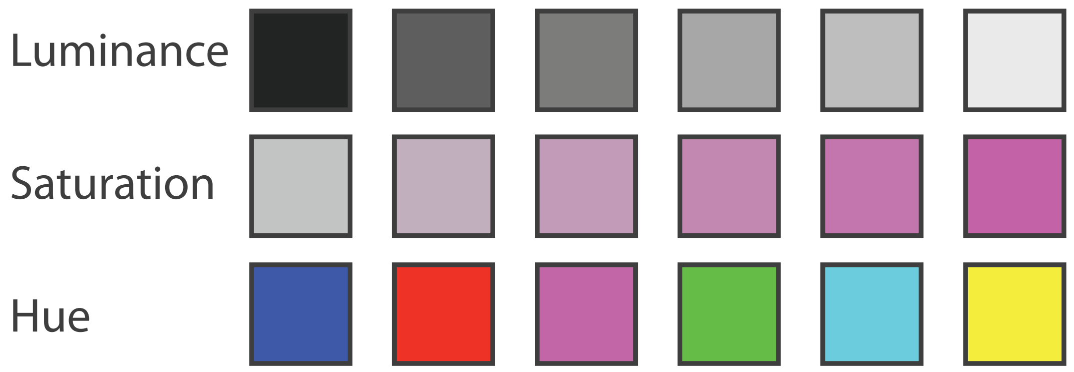
Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding



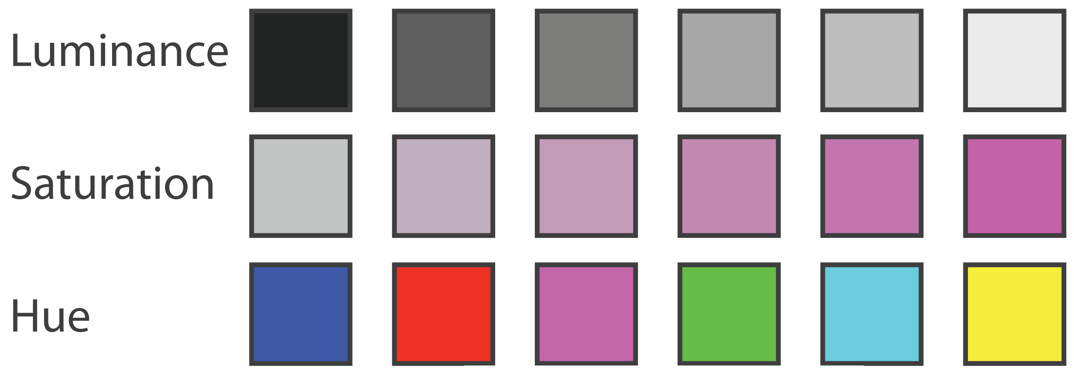
Many color spaces

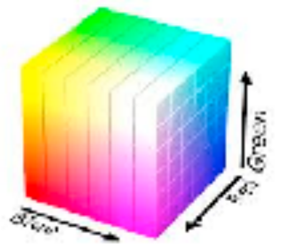
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace



Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware



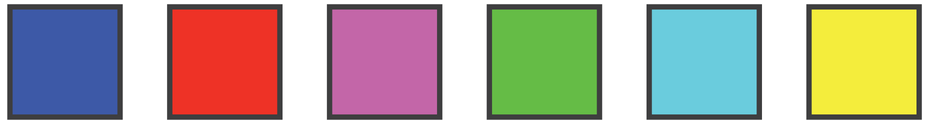


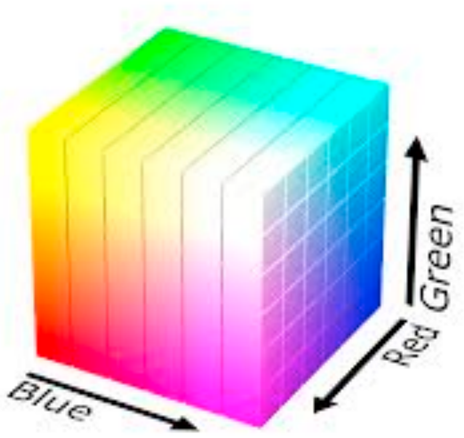
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

RGB

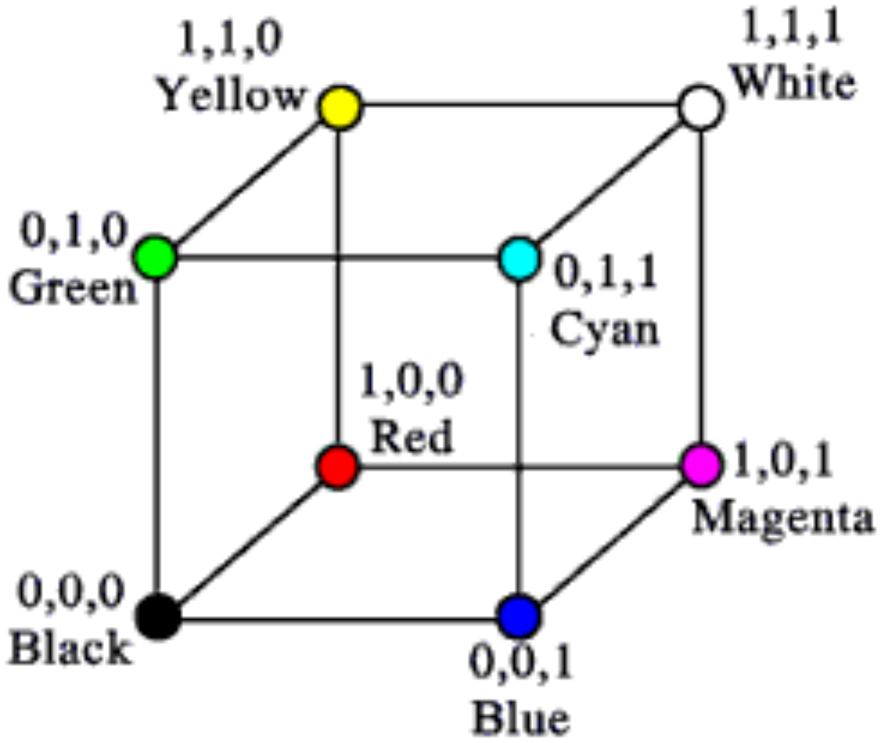
- RGB: good for display hardware

Corners of the RGB color cube





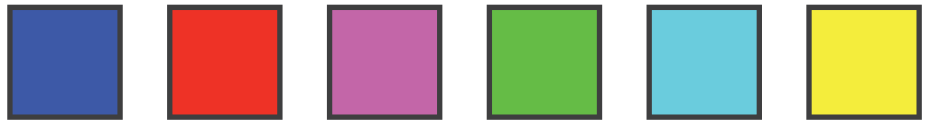
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

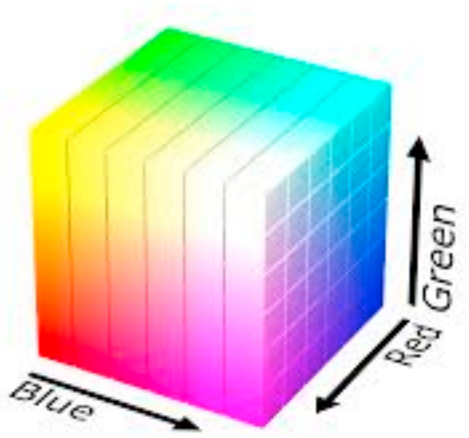


RGB

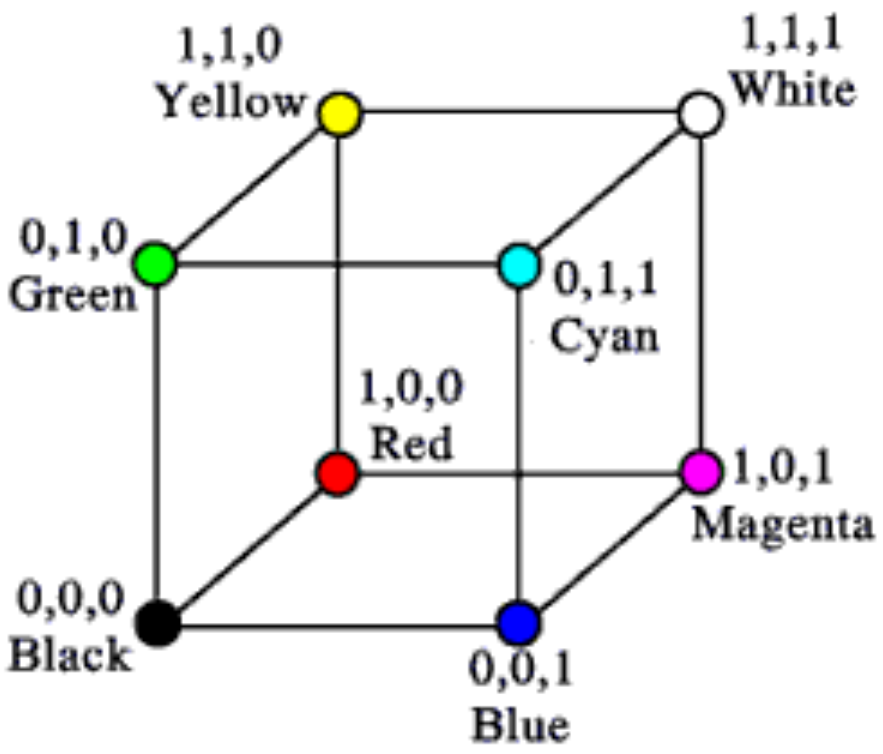
- RGB: good for display hardware
  - poor for encoding & interpolation

Corners of the RGB color cube

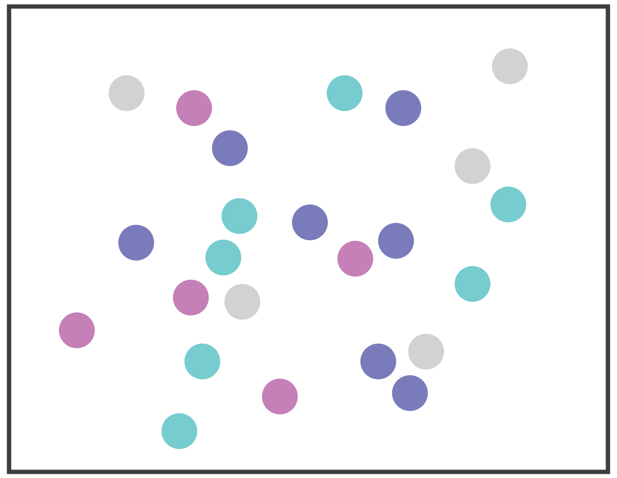




https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png



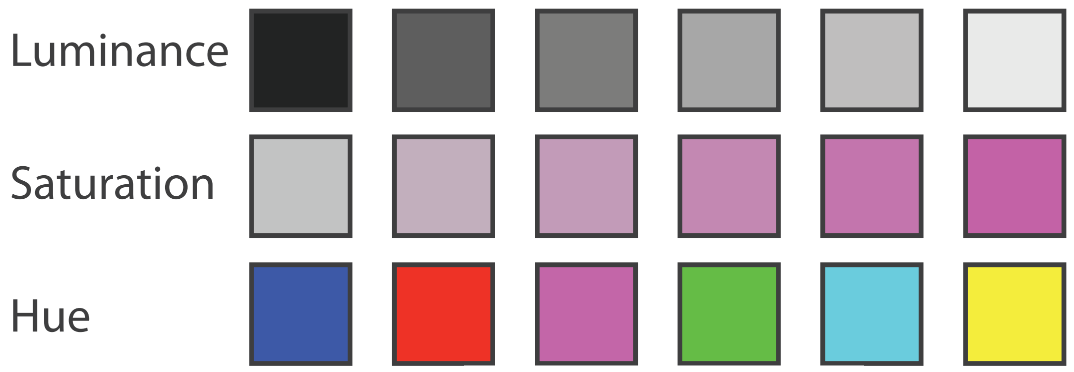
Red
+ Green

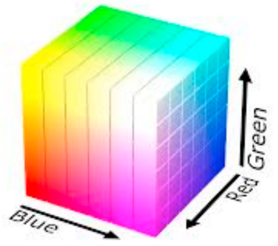


Major interference

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  – good for encoding
  – but not standard graphics/tools colorspace
- RGB: good for display hardware
  – poor for encoding & interpolation

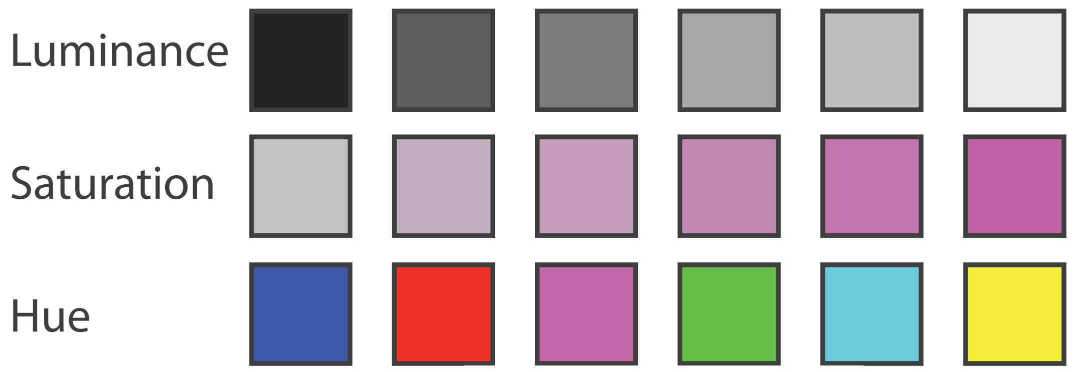


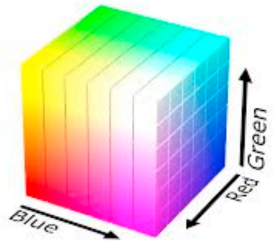


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  – good for encoding
  – but not standard graphics/tools colorspace
- RGB: good for display hardware
  – poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation

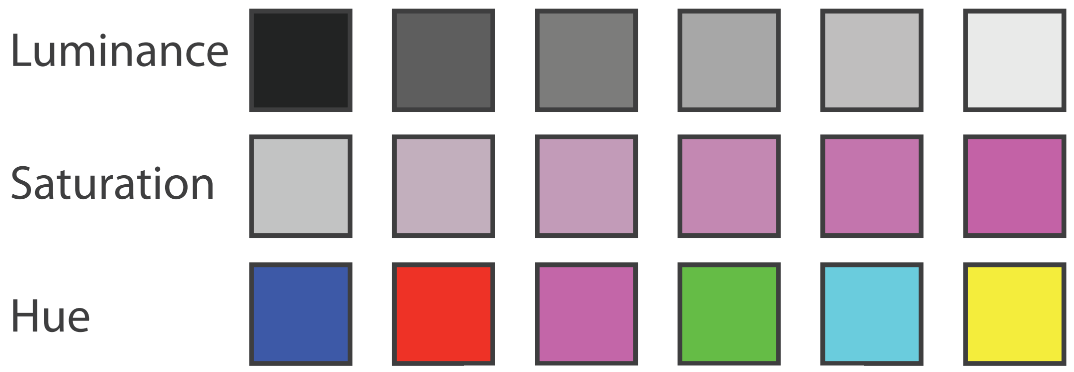


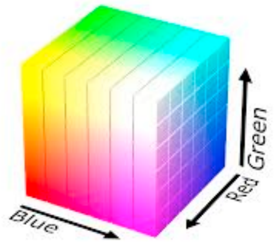


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding

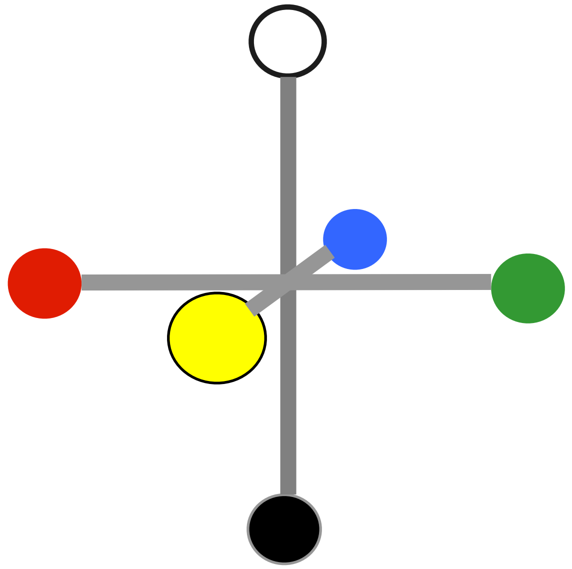


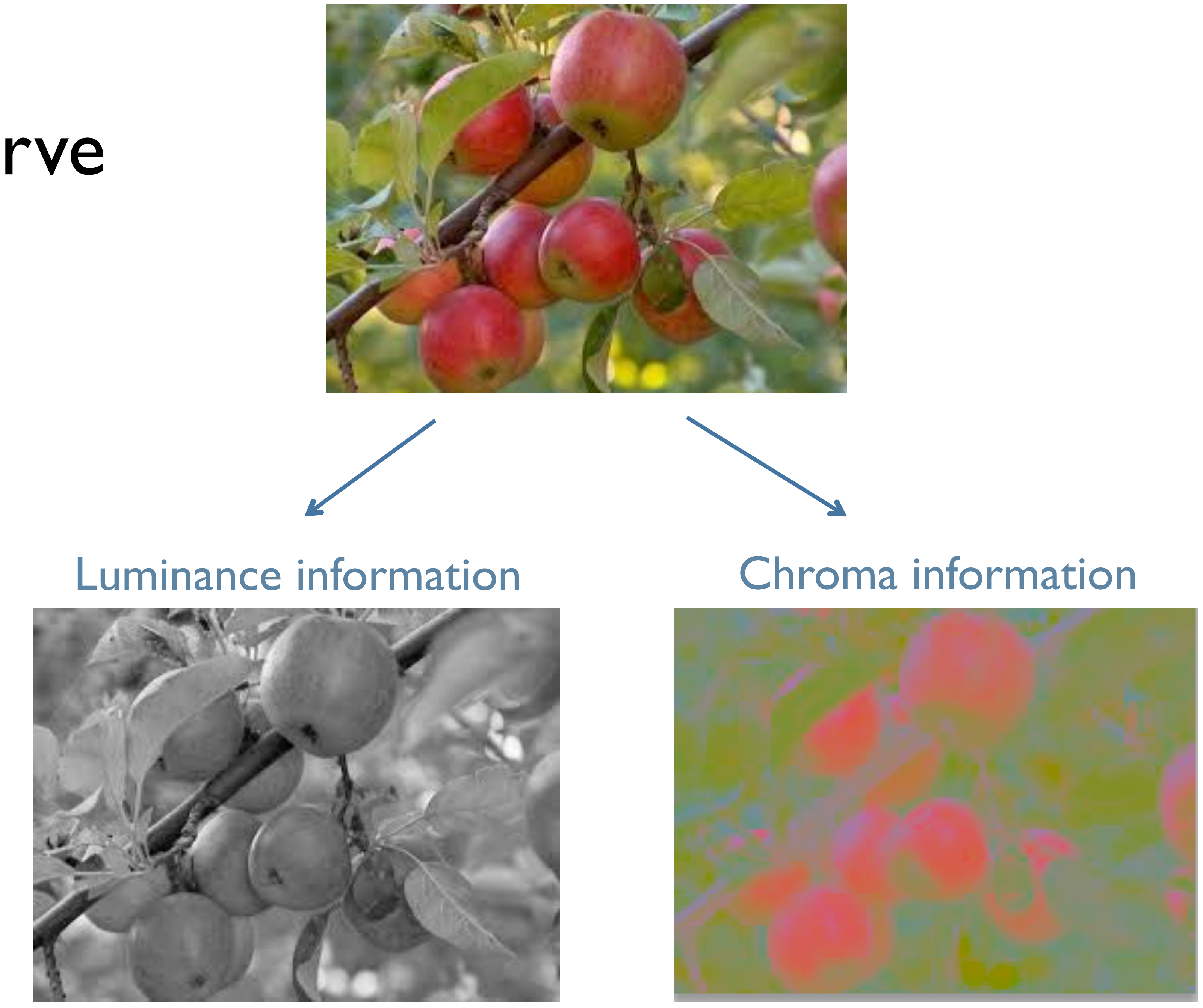


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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*)

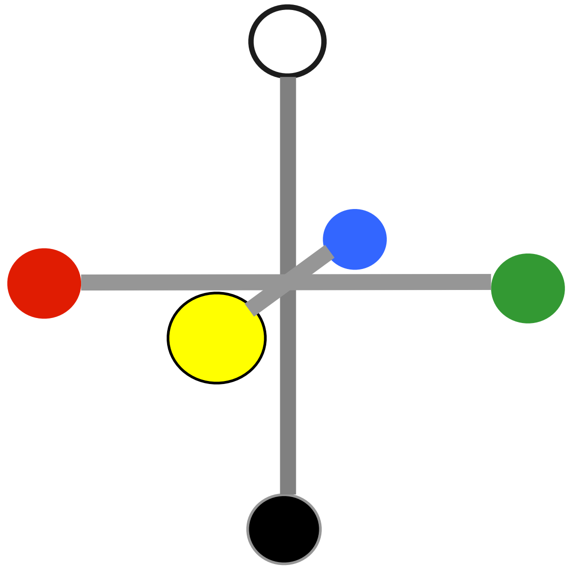


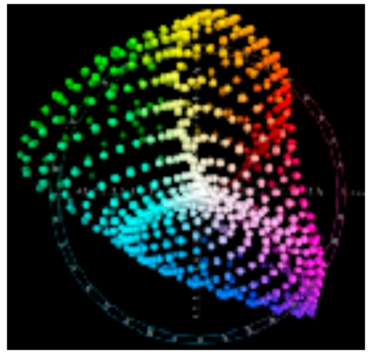


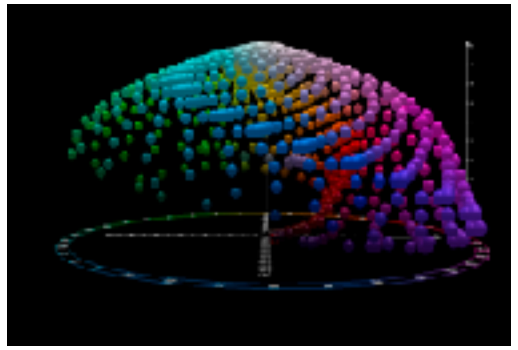
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Perceptual colorspace: L*a*b*

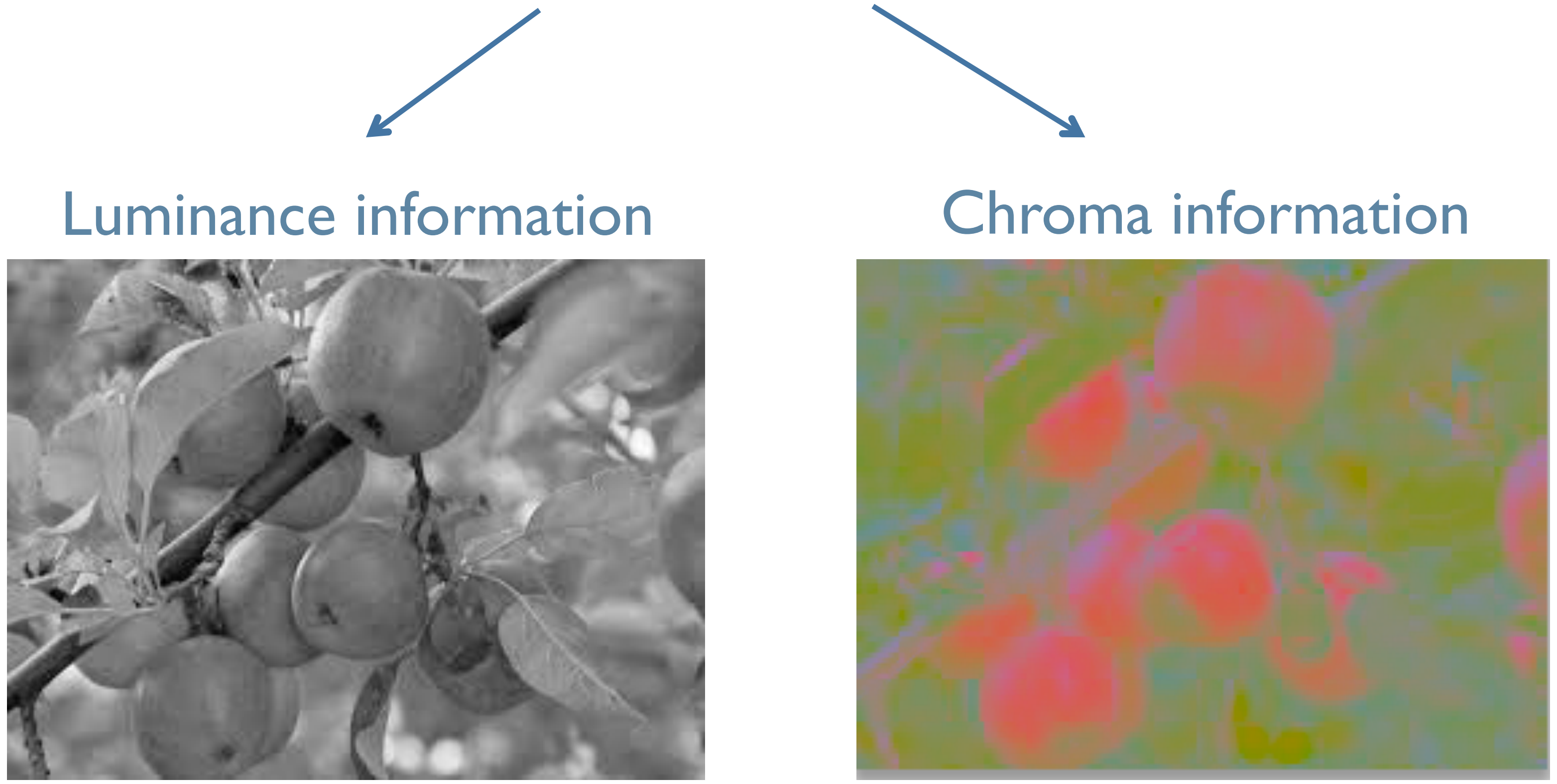
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- CIE LAB
  - perceptually uniform
    - great for interpolating
  - complex shape
    - poor for encoding







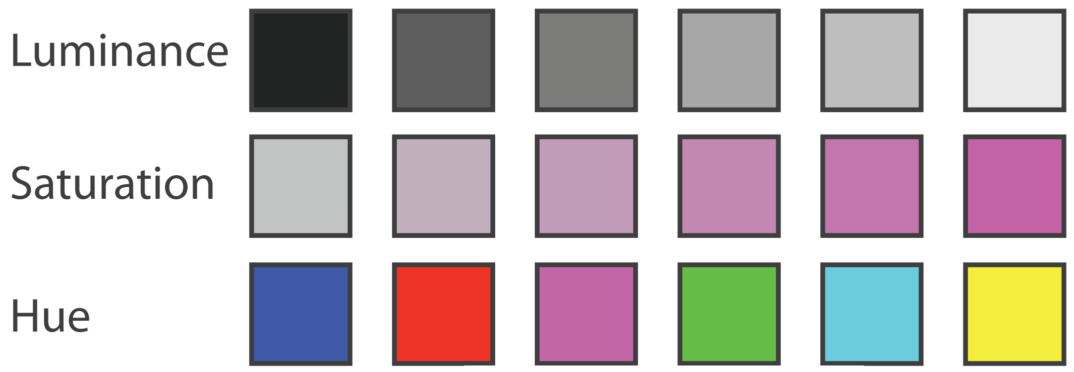
https://en.wikipedia.org/wiki/CIELAB_color_space

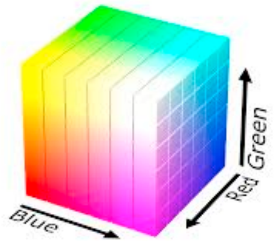


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding

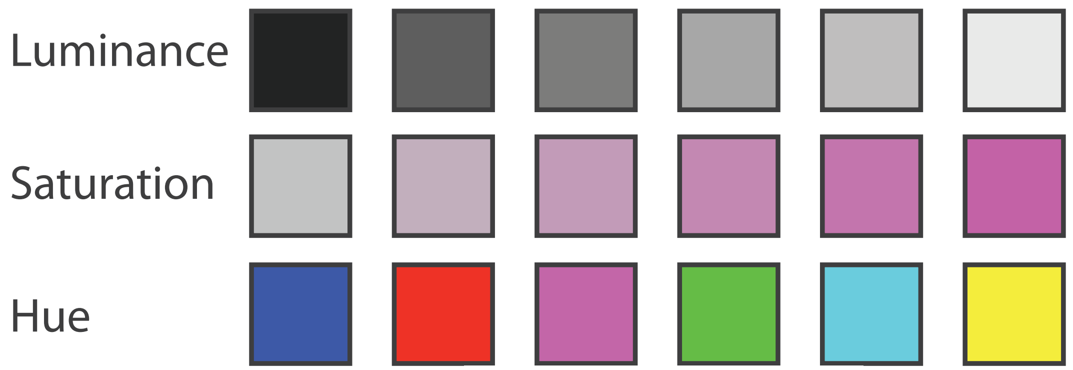


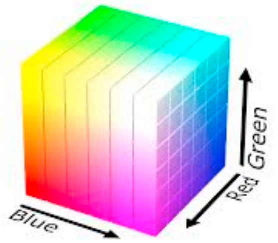


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding





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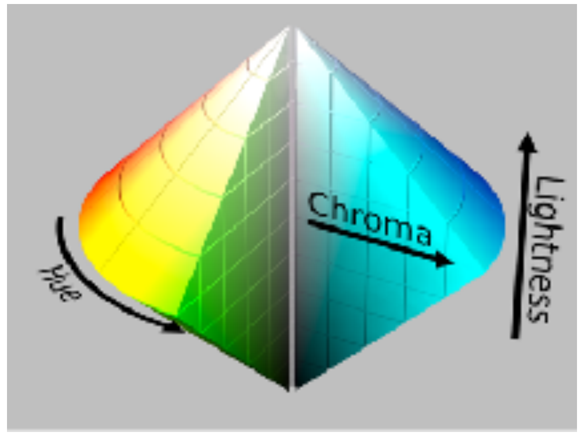
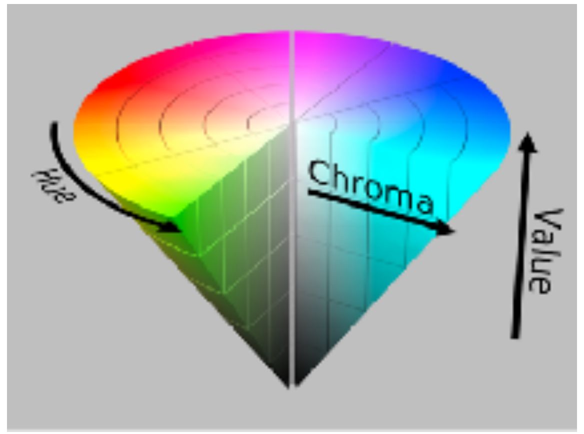
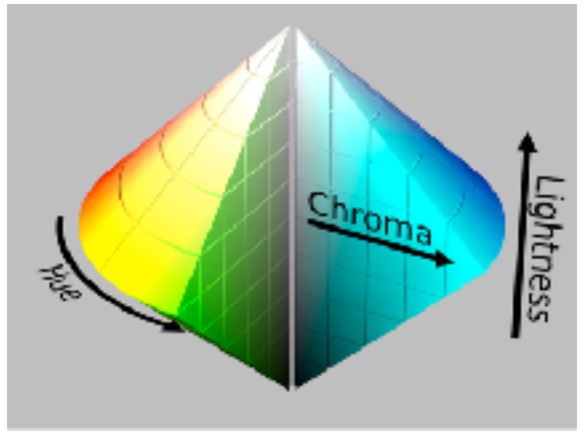
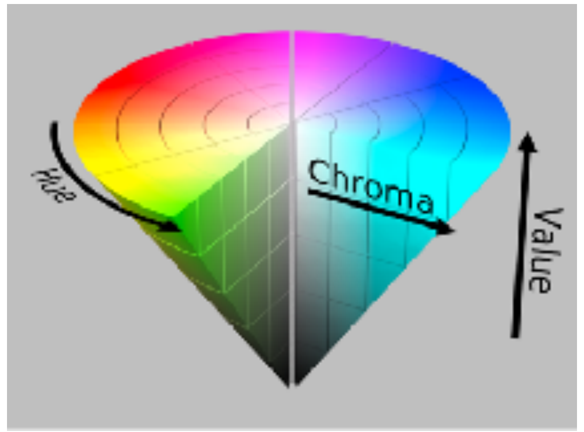


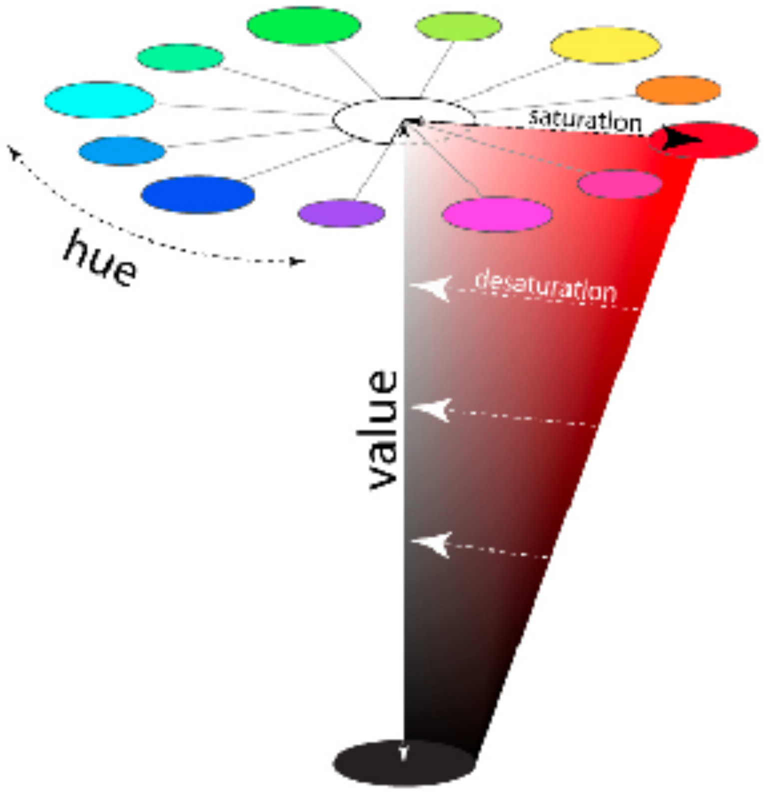


HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
-



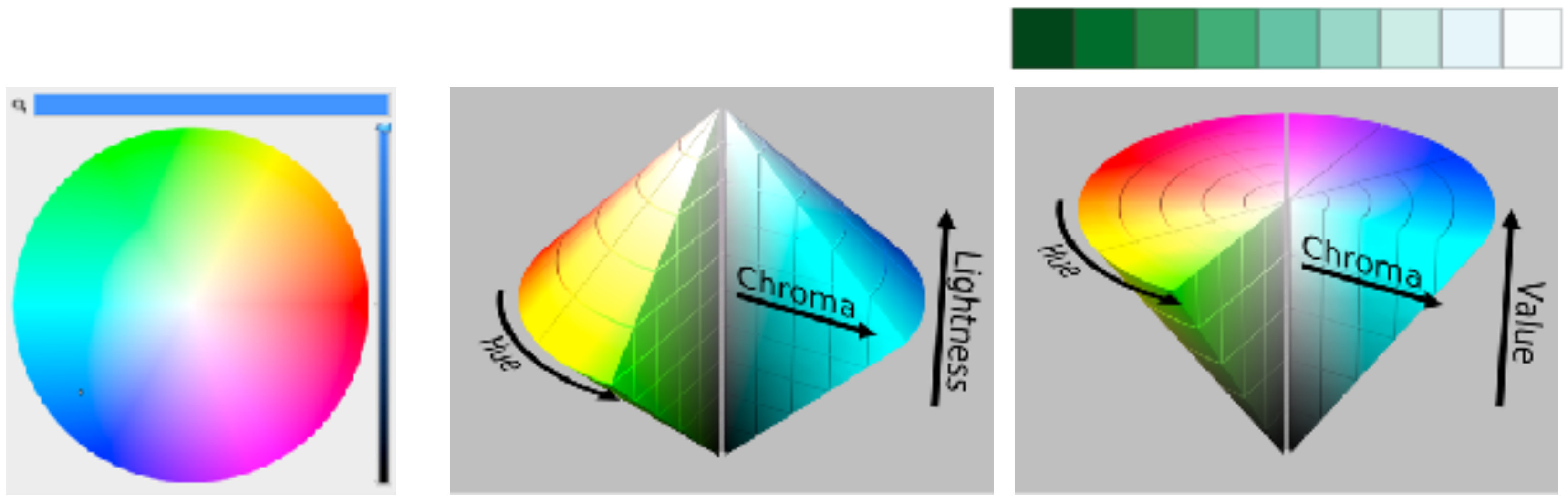


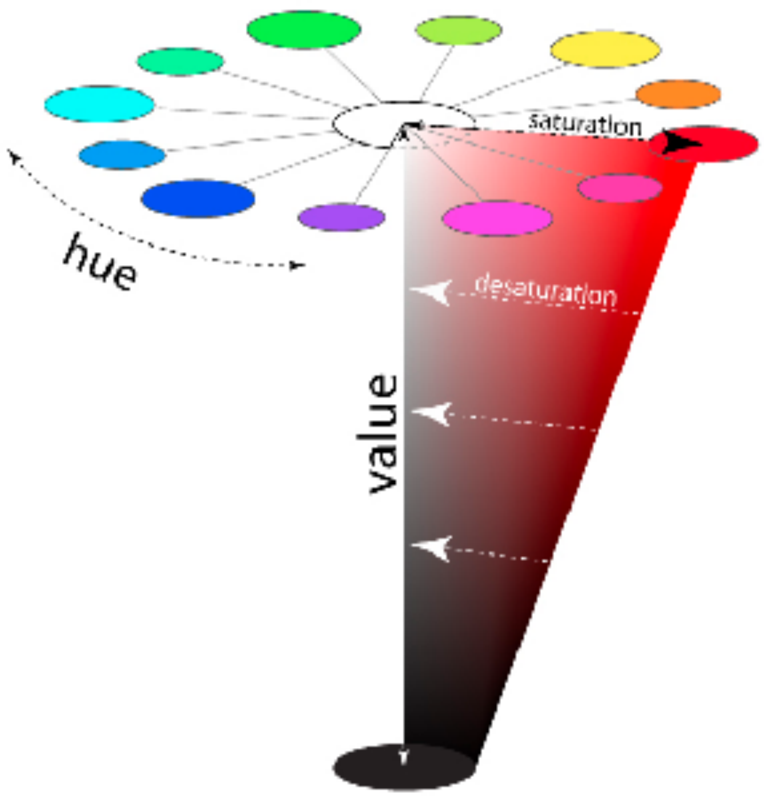


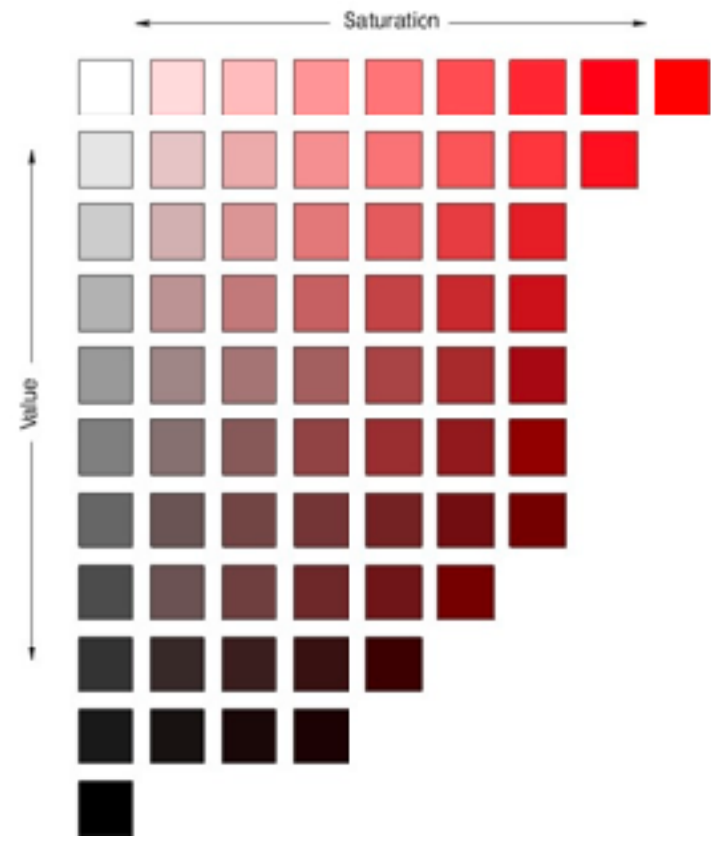
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- 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/hsv8/

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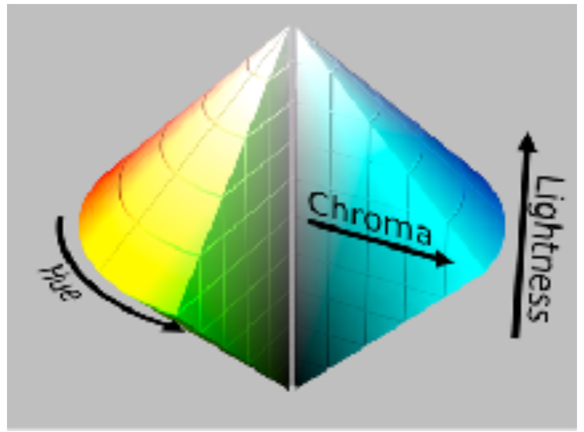
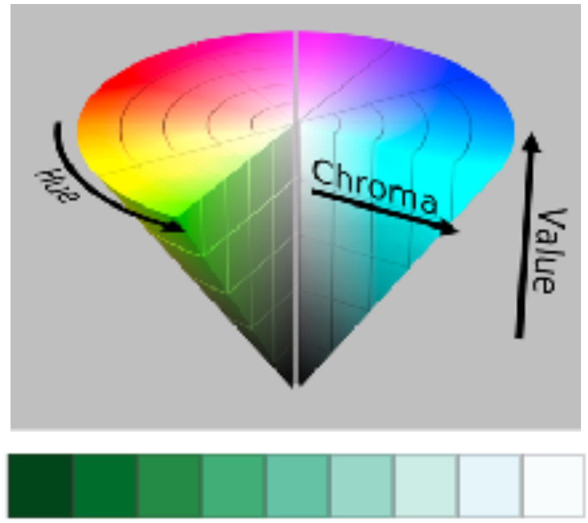
HSL/HSV: Pseudo-perceptual colorspace

- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance

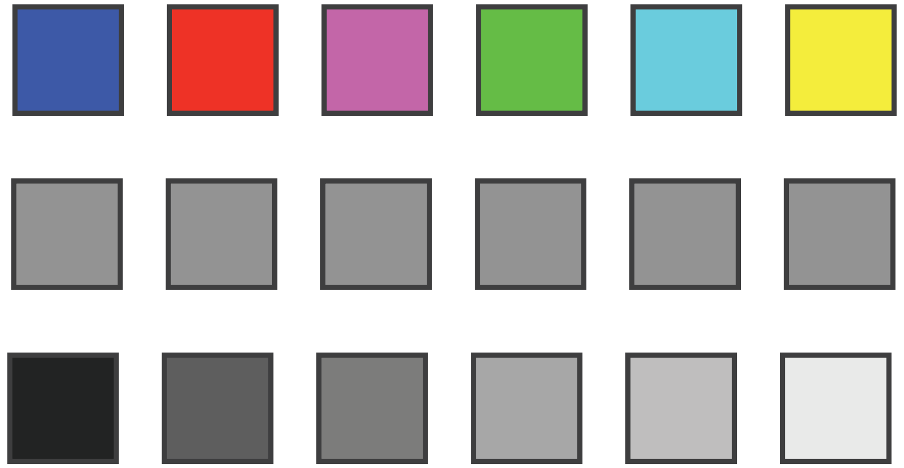




Corners of the RGB color cube

L from HLS
All the same

Luminance values



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

Many color spaces

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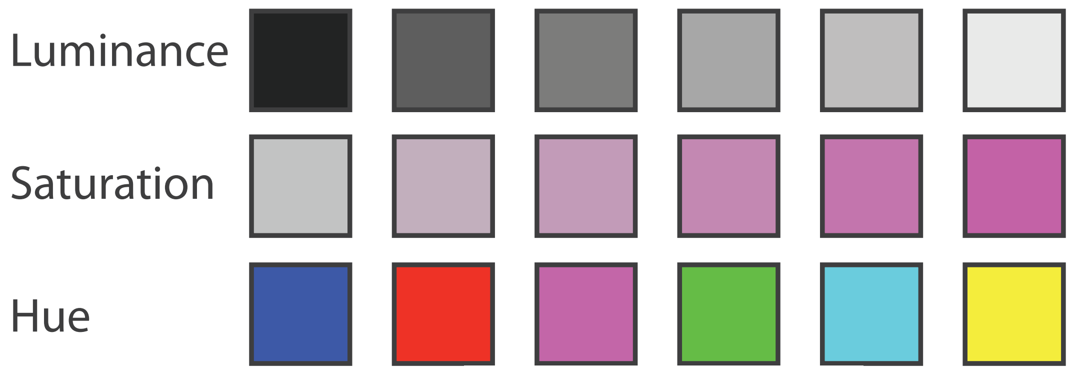
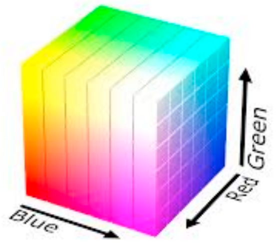
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)





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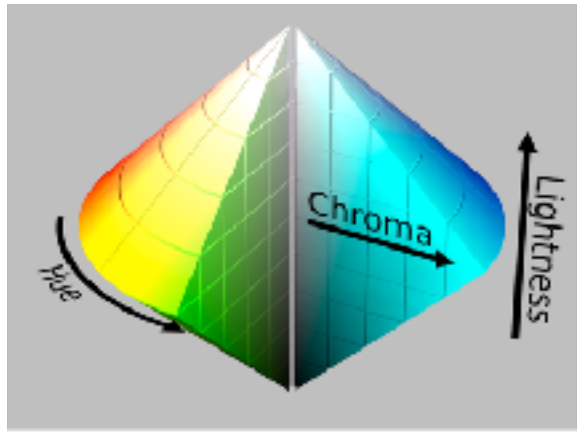
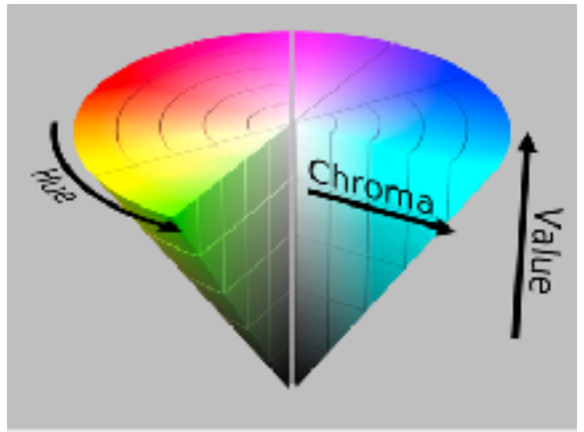
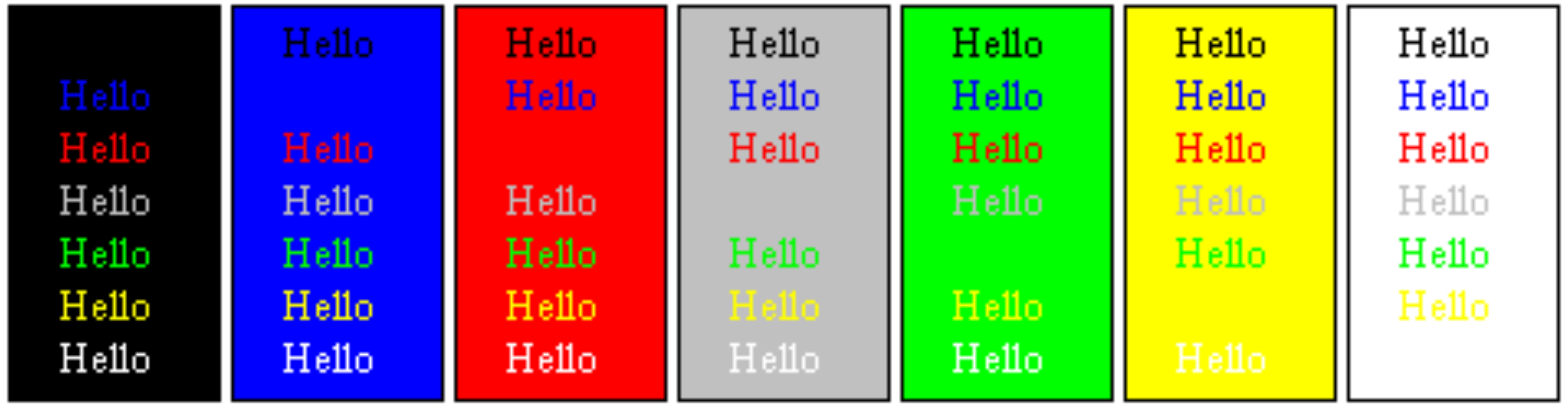




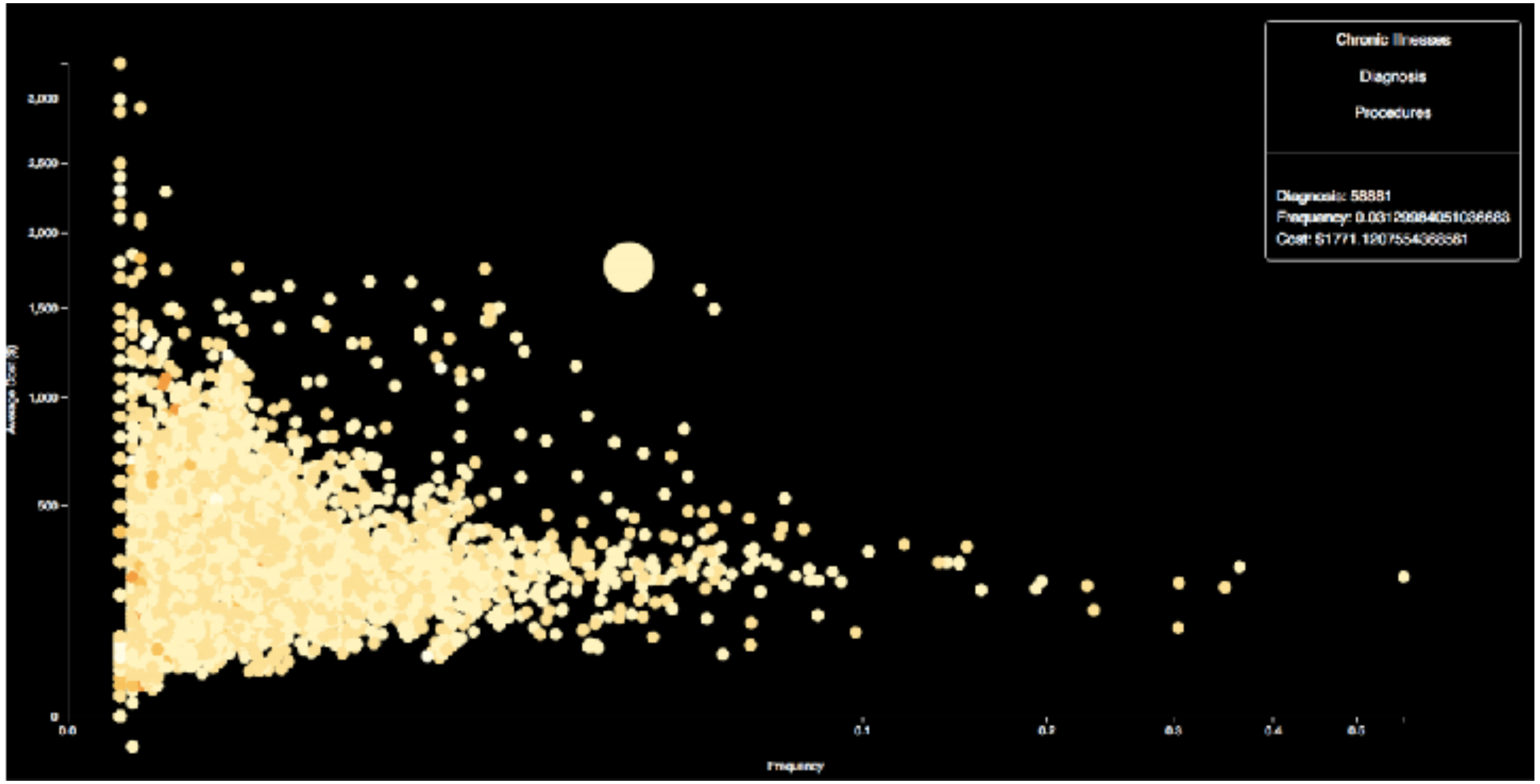
Color Constrast & Naming

Interaction with the background



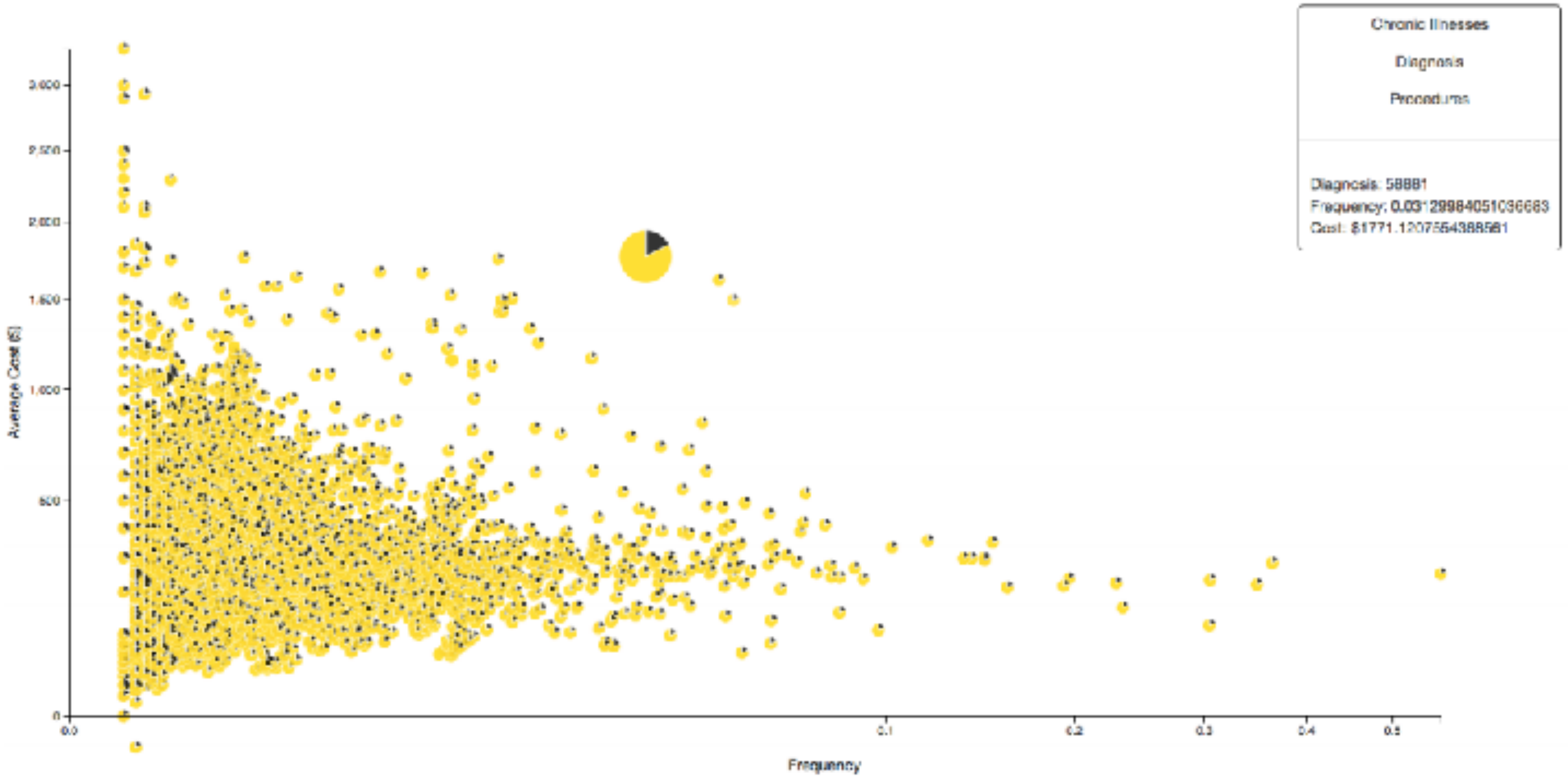
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



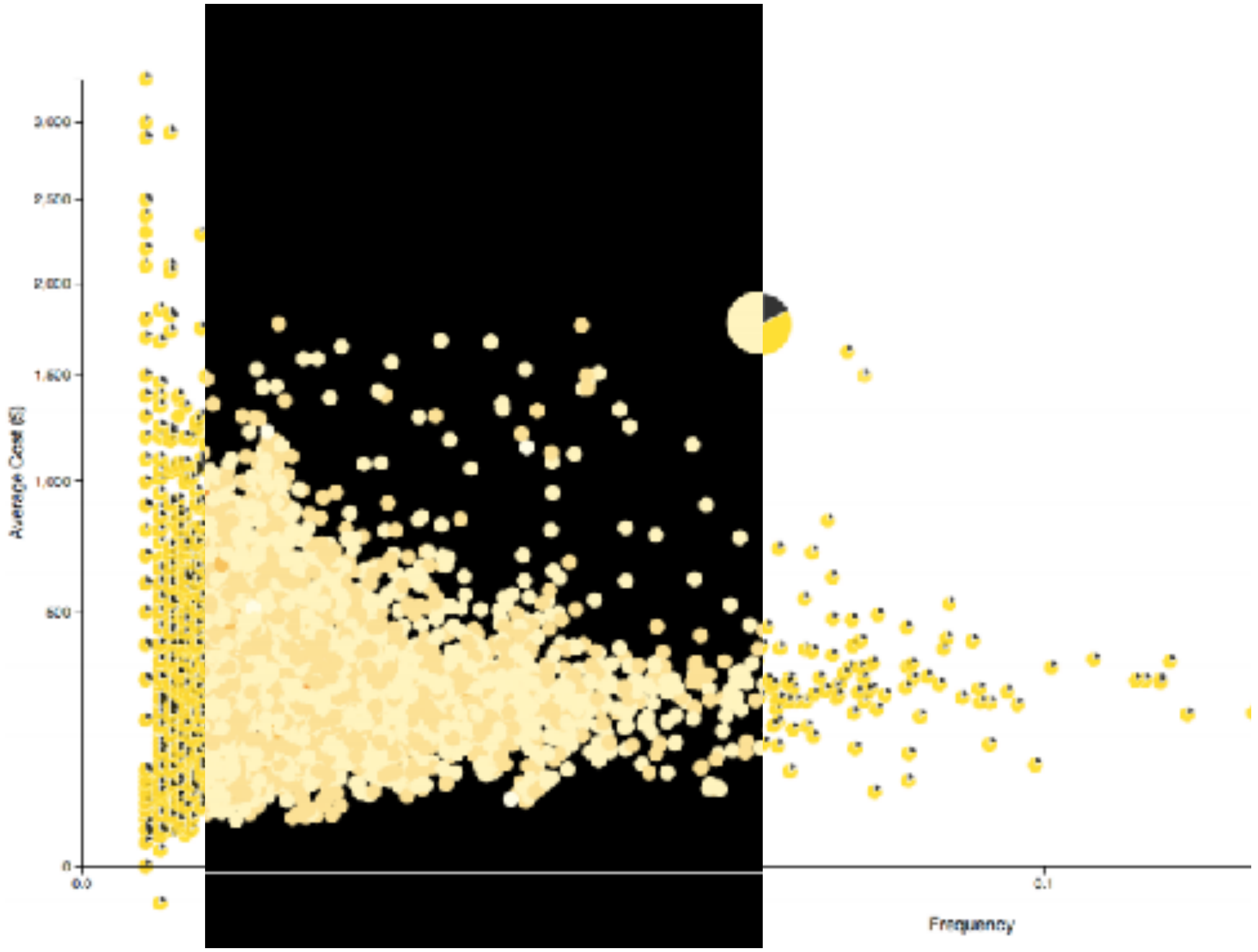
Interaction with the background: tweaking yellow for visibility

- marks with medium luminance on a background with high luminance



Interaction with the background: tweaking yellow for visibility

- change luminance of marks depending on background



Color/Lightness constancy: Illumination conditions

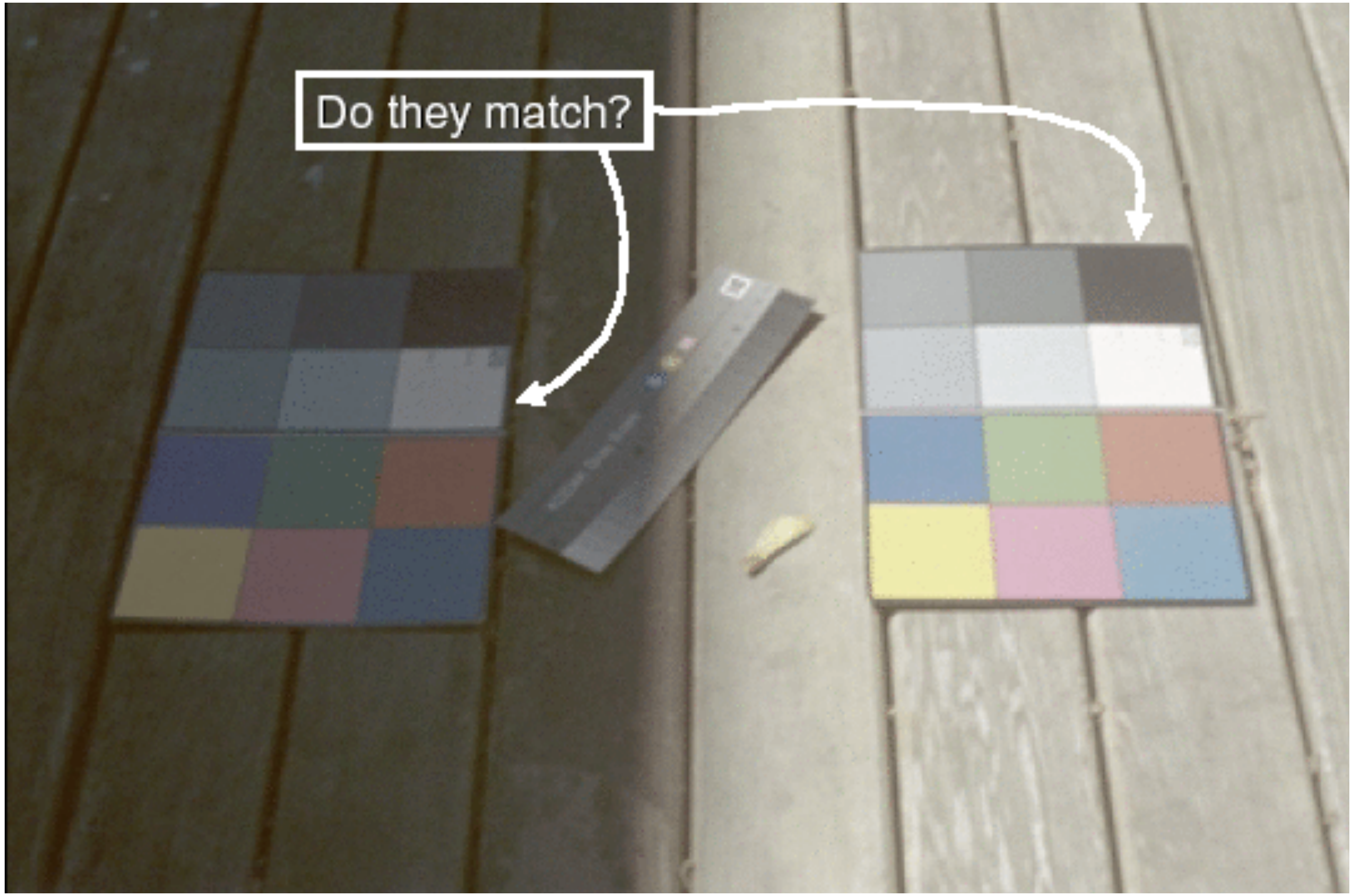


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

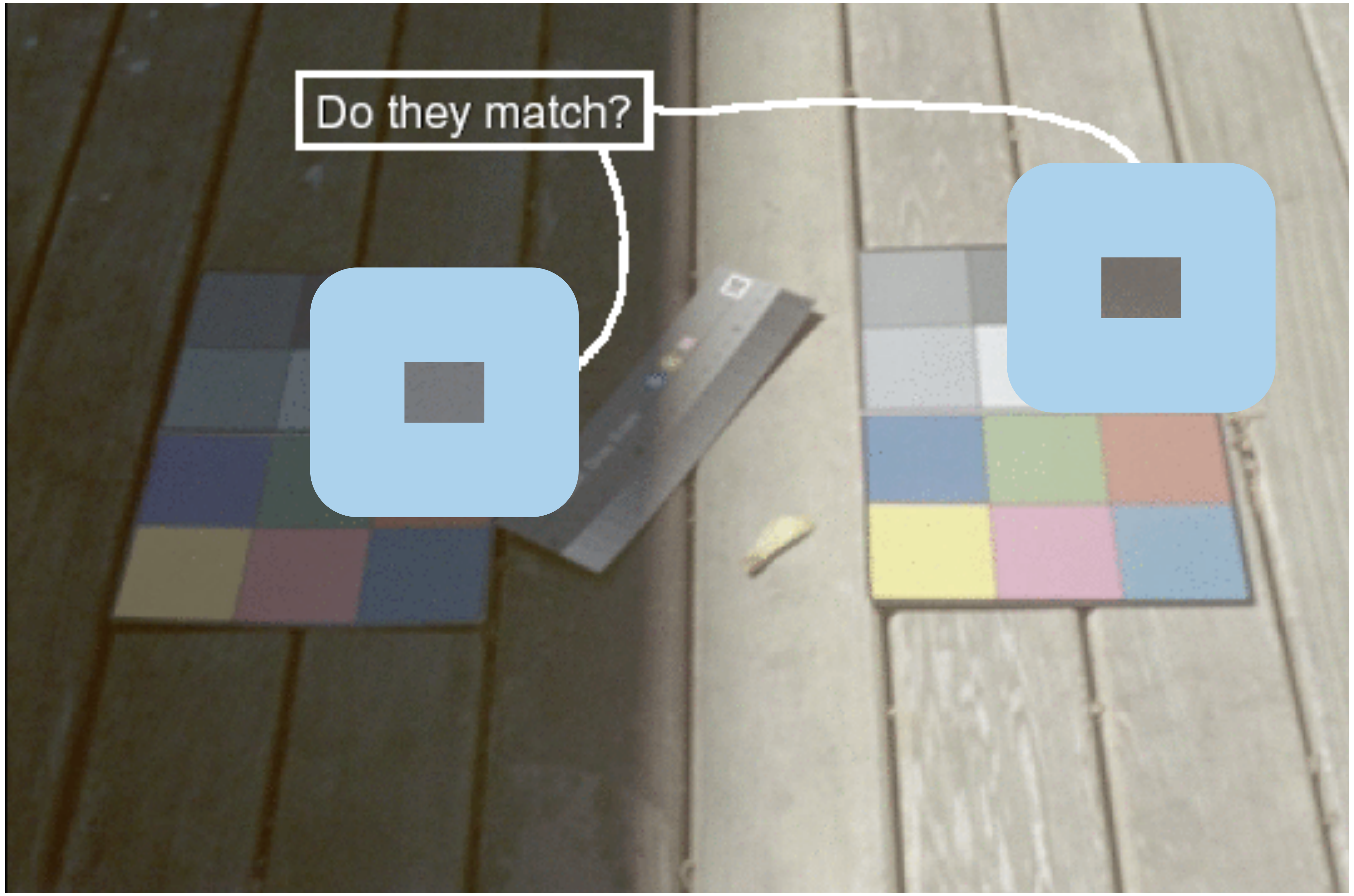
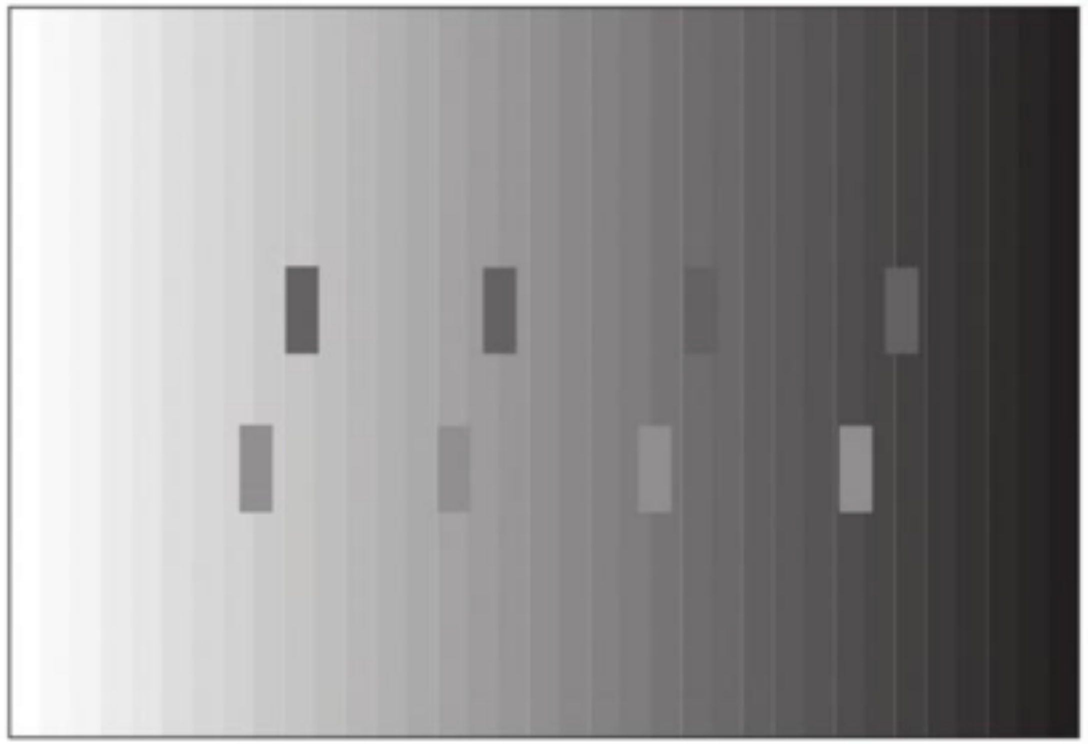
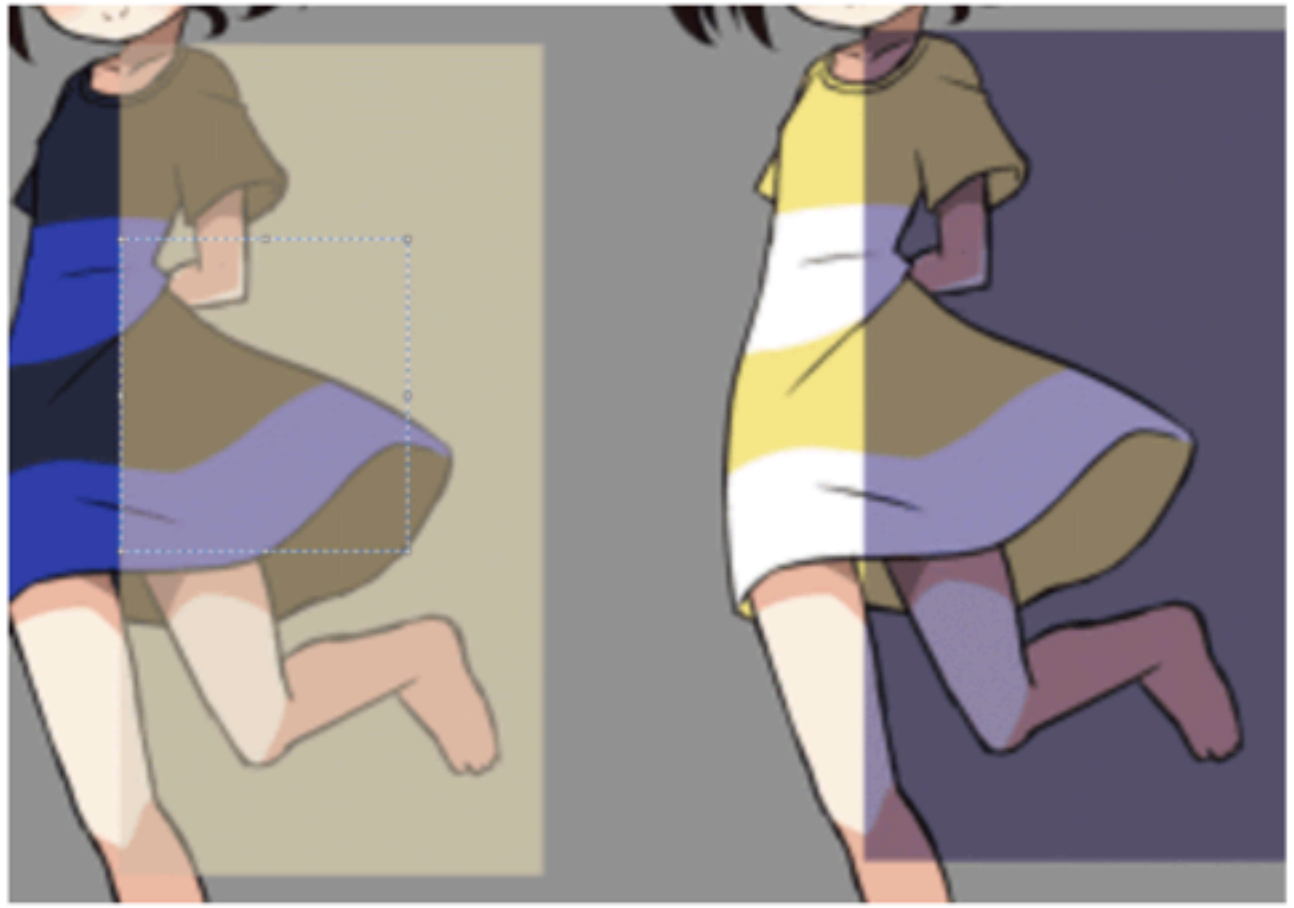


Image courtesy of John McCann via Maureen Stone

Contrast with background



Contrast with background

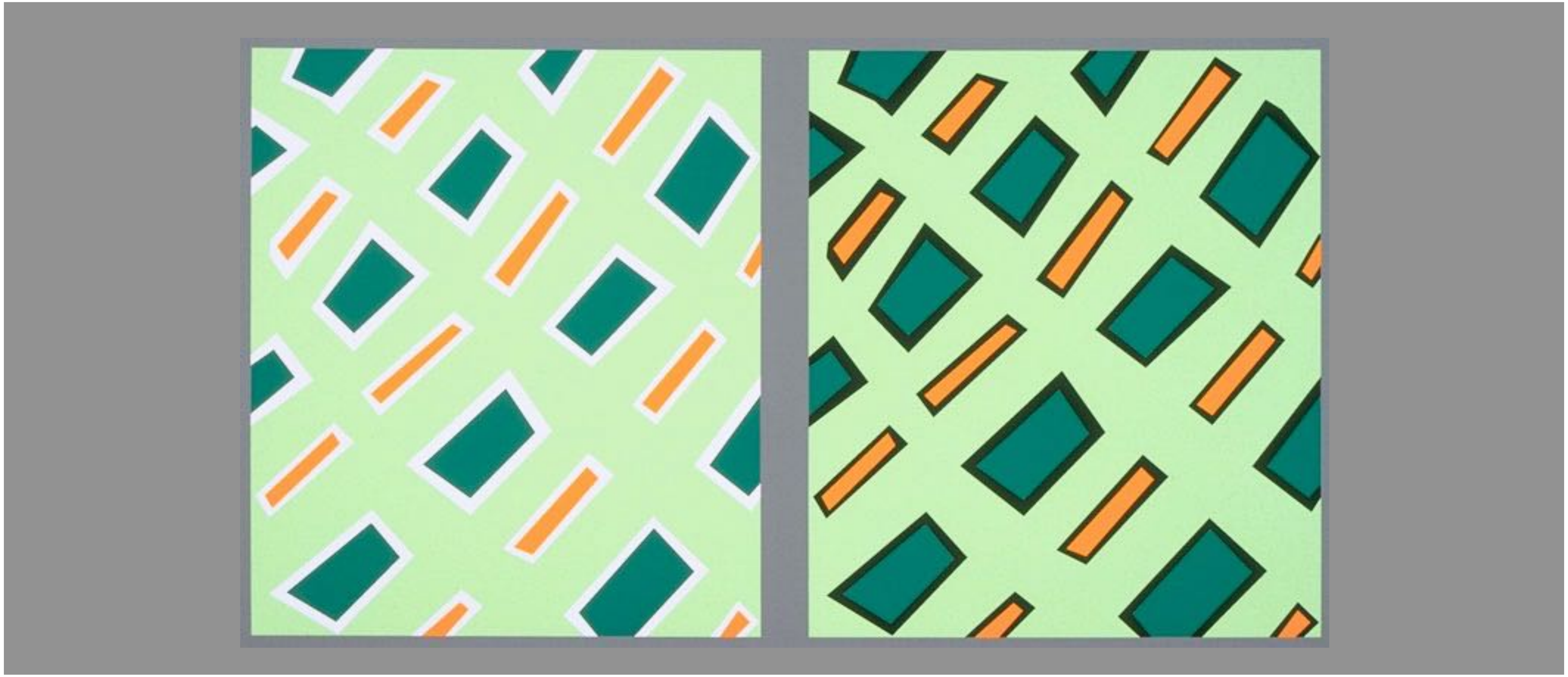


Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

Bezold Effect: Outlines matter

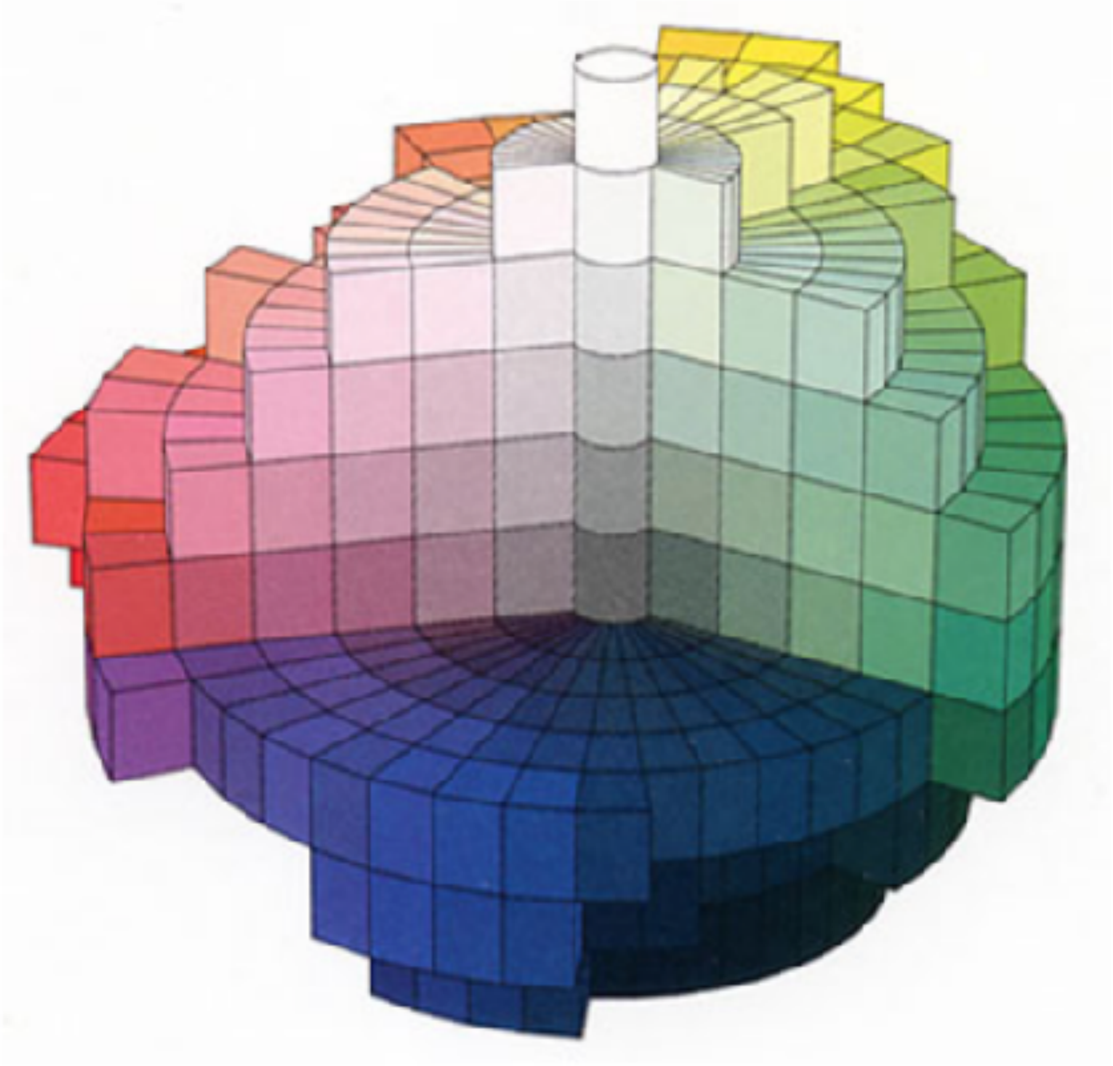


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Color Appearance

- given L, a*, b*, can we tell what color it is?
  - no, it depends

- chromatic adaptation
- luminance adaptation
- simultaneous contrast
- spatial effects
- viewing angle
- …



Color naming

Color naming

http://www.thedoghousediaries.com/1406

Color naming

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

Color naming

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

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

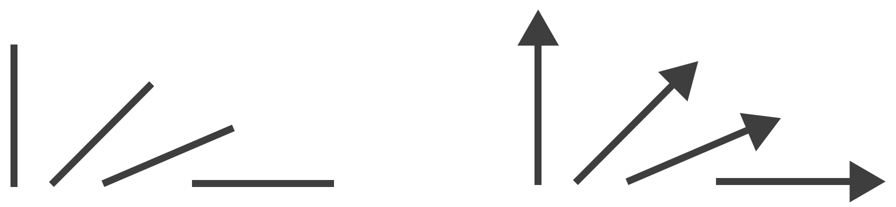
Color is just part of vision system

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

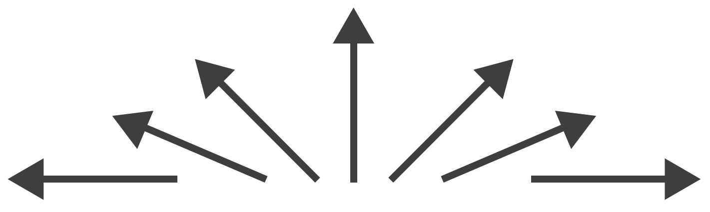
Map Other Channels

Angle / tilt / orientation channel

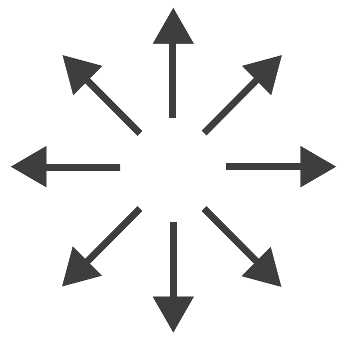
- different mappings depending on range used



Sequential ordered
line mark or arrow glyph



Diverging ordered
arrow glyph

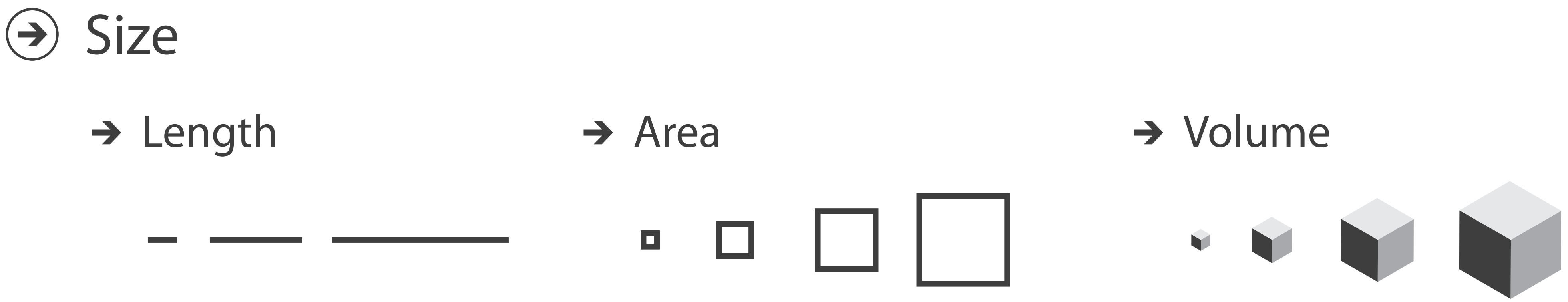


Cyclic ordered
arrow glyph

- nonlinear accuracy
  - high: exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (eg 37 vs 38 degrees)

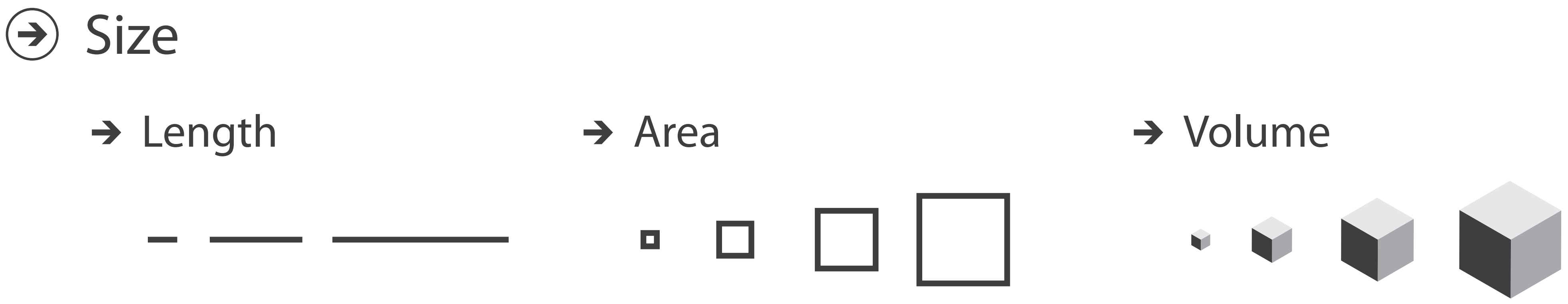
Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor



Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins



Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - great for highlighting (binary)
  - use with care to avoid irritation