Information Visualization
Color, ArteryViz, ColorDiff
Ex: Colors

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University of British Columbia

Week 7, 16 Oct 2025

https://www.cs.ubc.ca/~tmm/courses/547-25

Plan for today

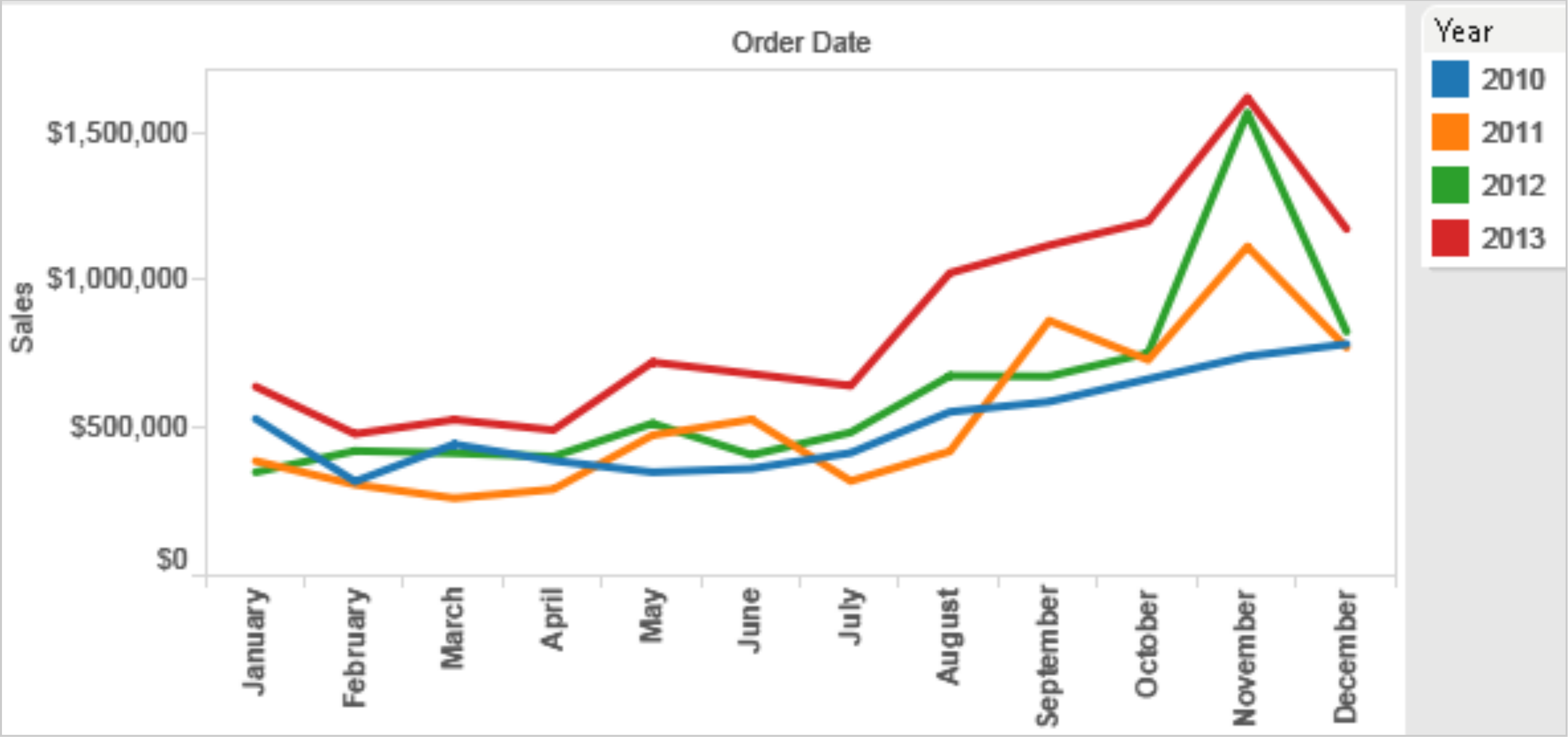
- mini-lecture / Q&A
  - Color
- small group exercises
  - Color
- mini-lecture
  - HemoViz
  - ColorDiff
- last week papers Q&A (if time)
- due Sun Oct 19 noon: written proposals
  - submit on Canvas (People - Project Groups)
  - format: subset of final report
    - final report must be in conference template; up to you whether to start with that now

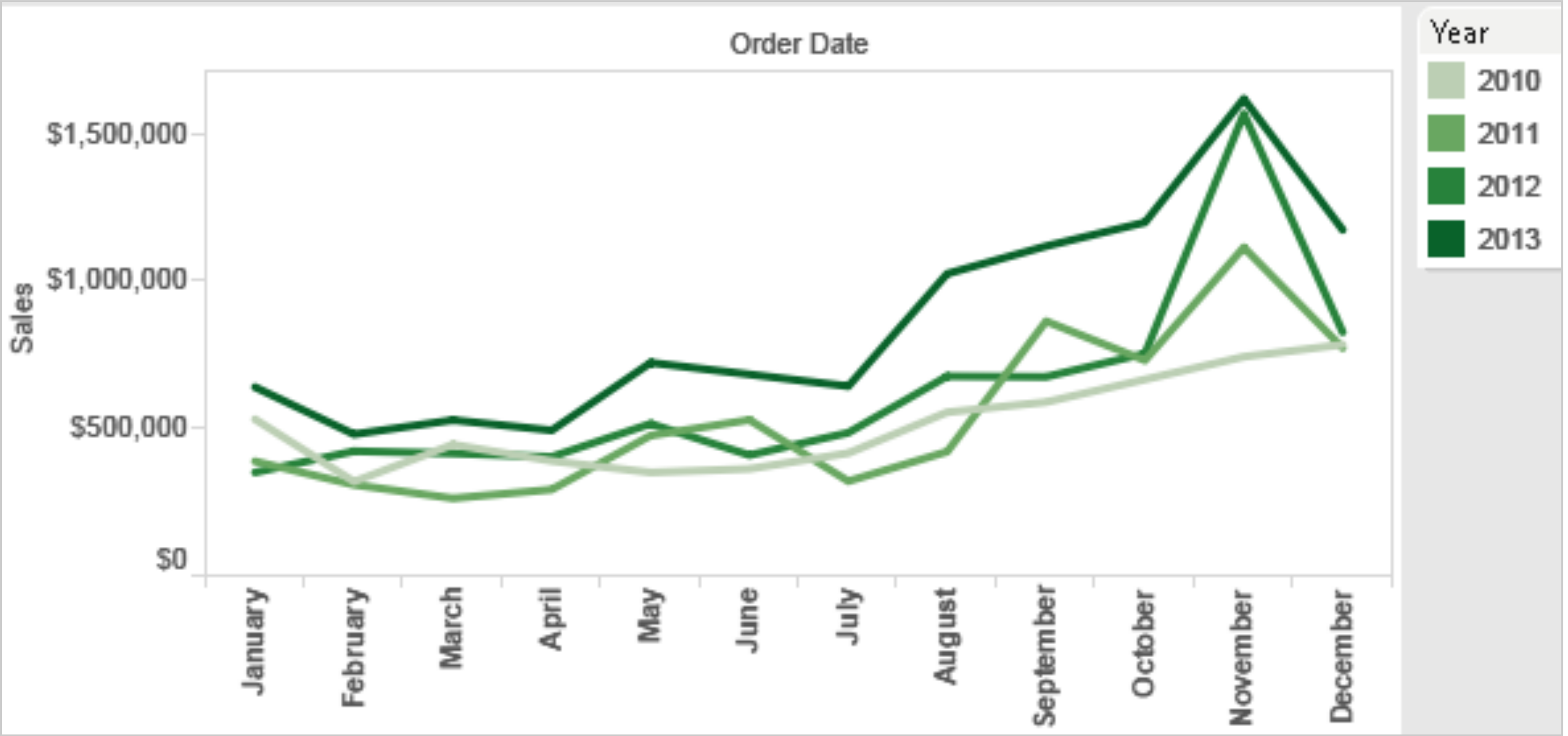
Next week

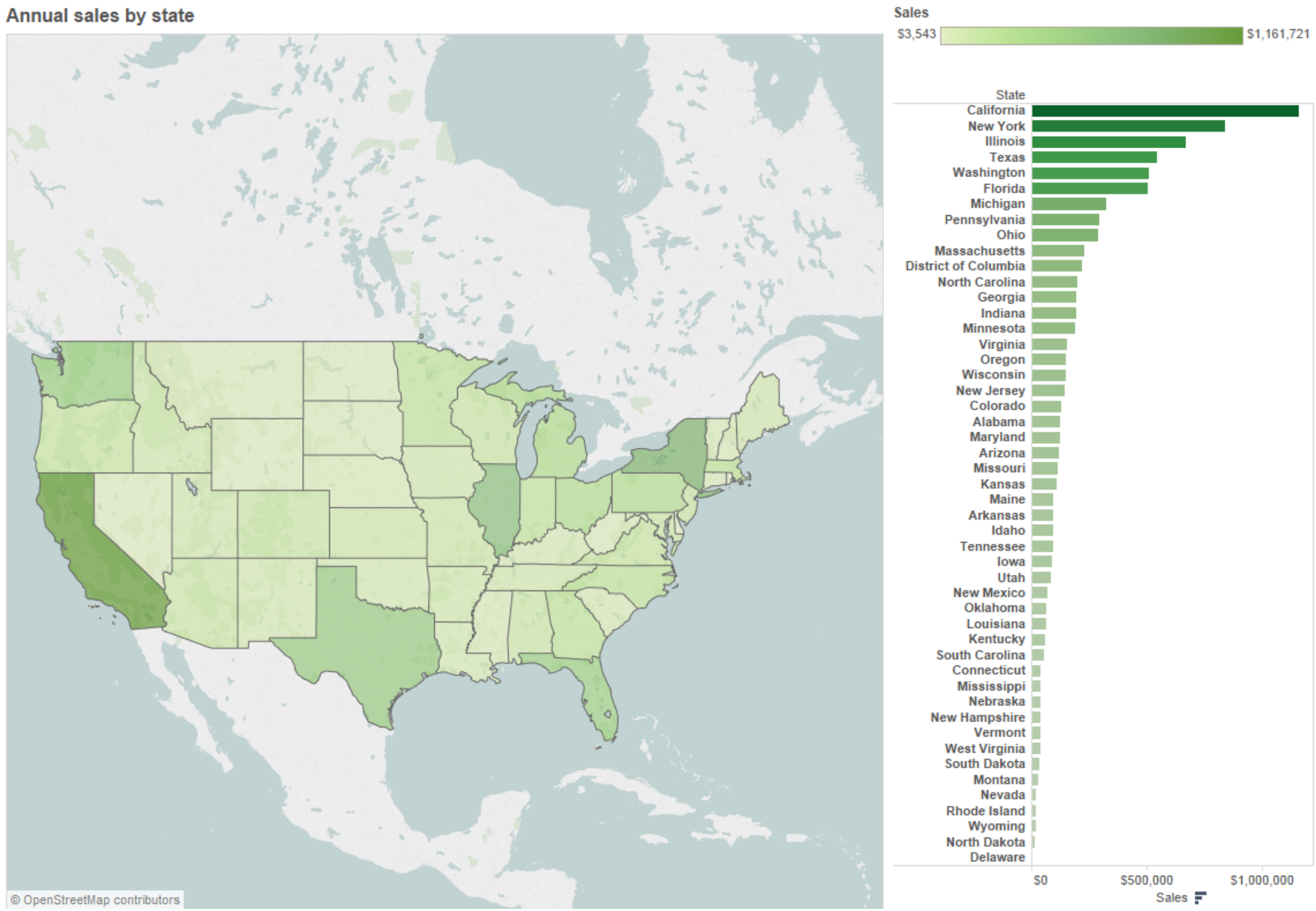
- to read & discuss (async, before next class)
  - VAD book, Ch 8: Arrange Spatial Data
  - paper: Necklace Maps [technique / algorithm]
  - paper: Myriahedral Projections [technique / algorithm]

Mini-Lecture: Color

Categorical vs ordered color



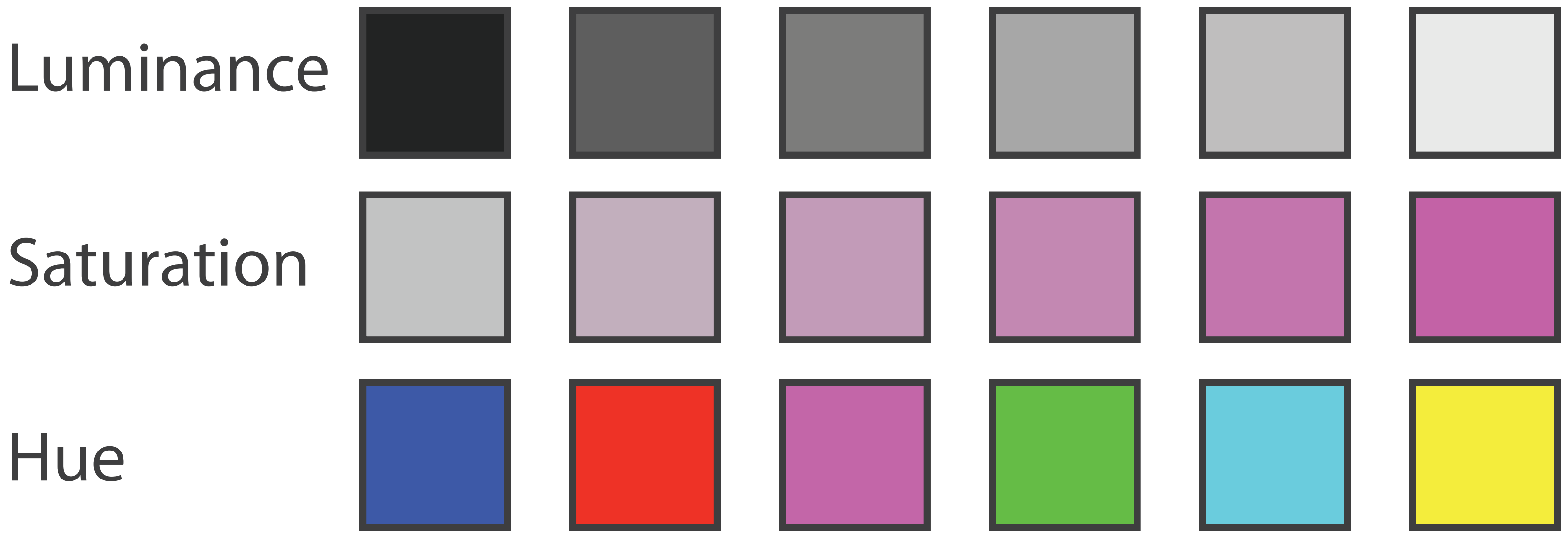




[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Decomposing color

- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance: how bright
    - saturation: how colorful
  - categorical can show identity
    - hue: what color

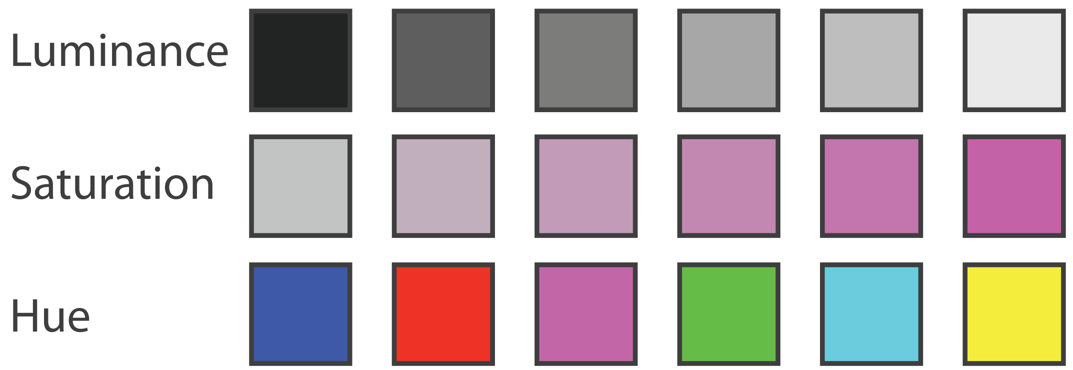


- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey: how many discriminable bins can we use?

Color Spaces

Many color spaces

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



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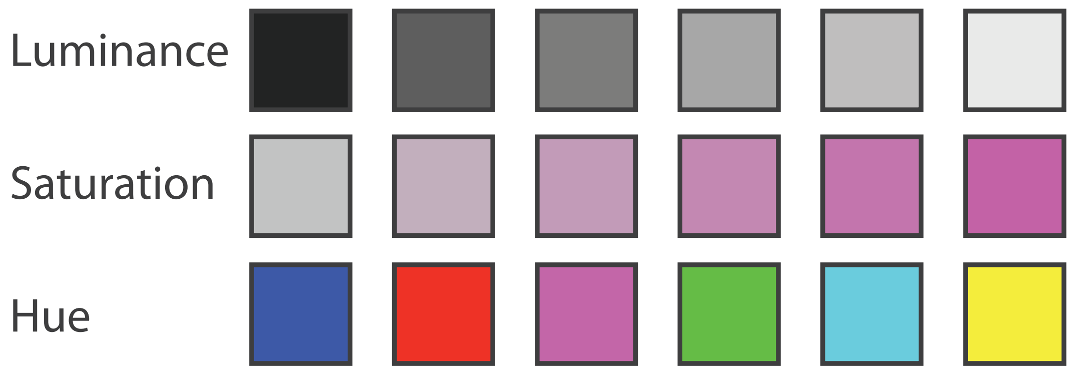
  - but not standard graphics/tools colorspace



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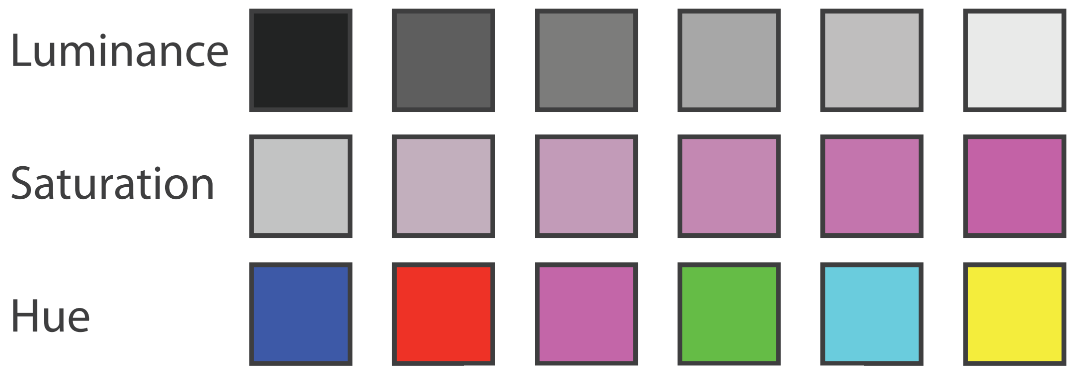
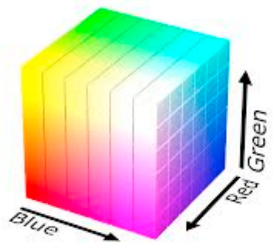


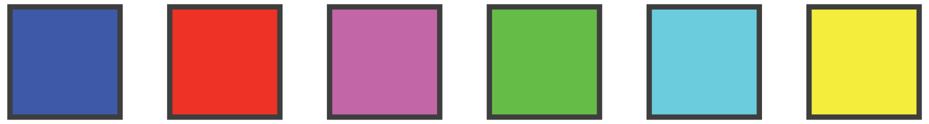


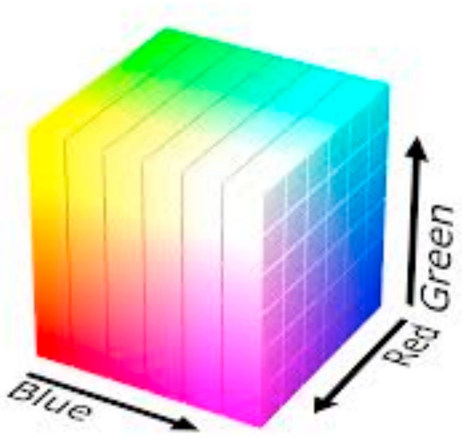
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

RGB

- RGB: good for display hardware

Corners of the RGB color cube





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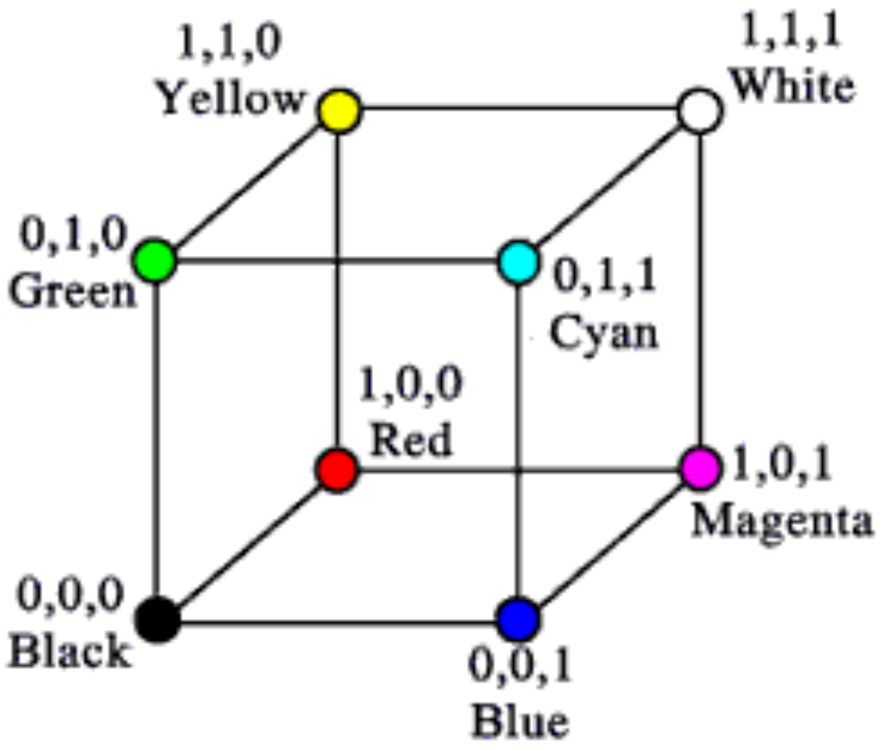
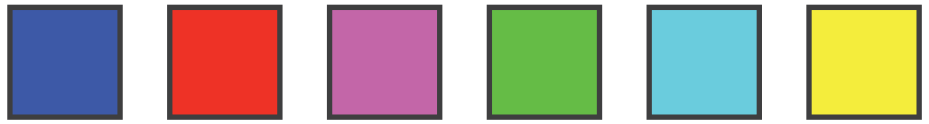
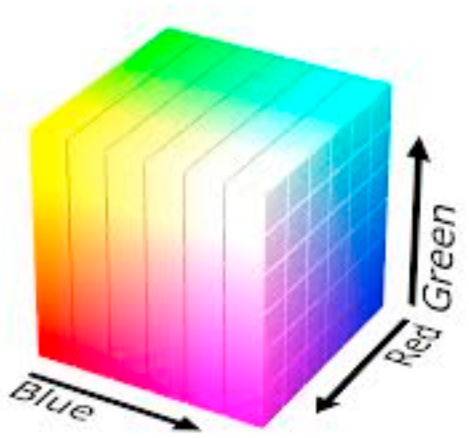


RGB

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

Corners of the RGB color cube





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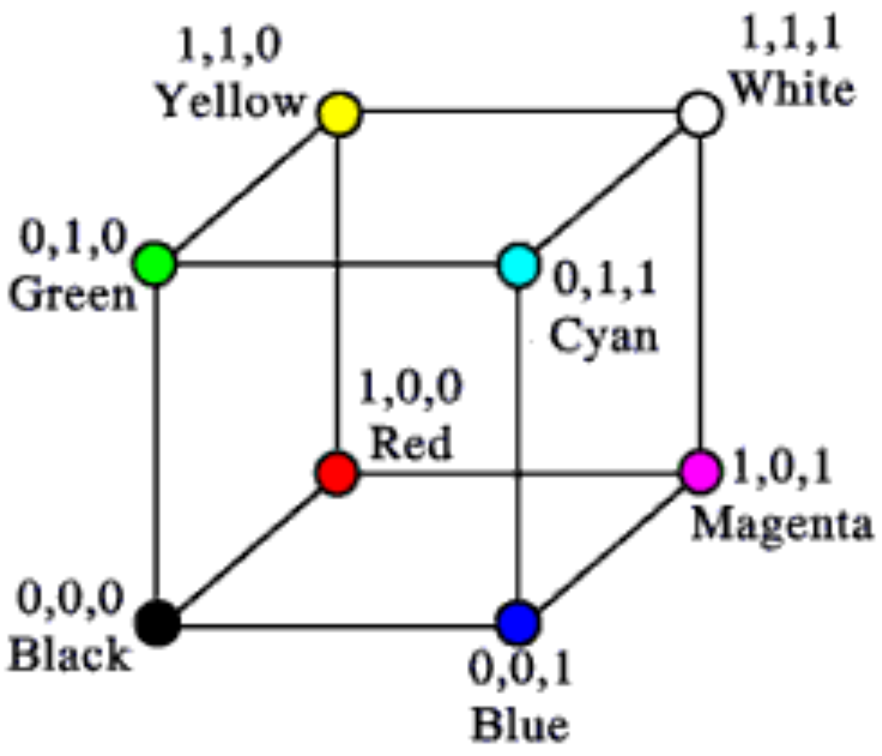
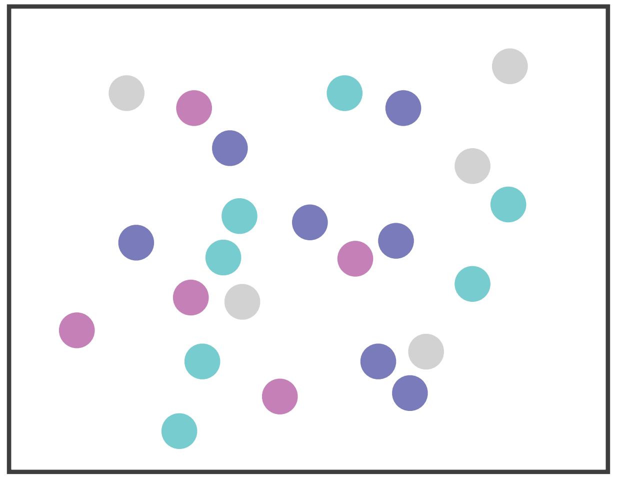


Red
+ Green



Major interference

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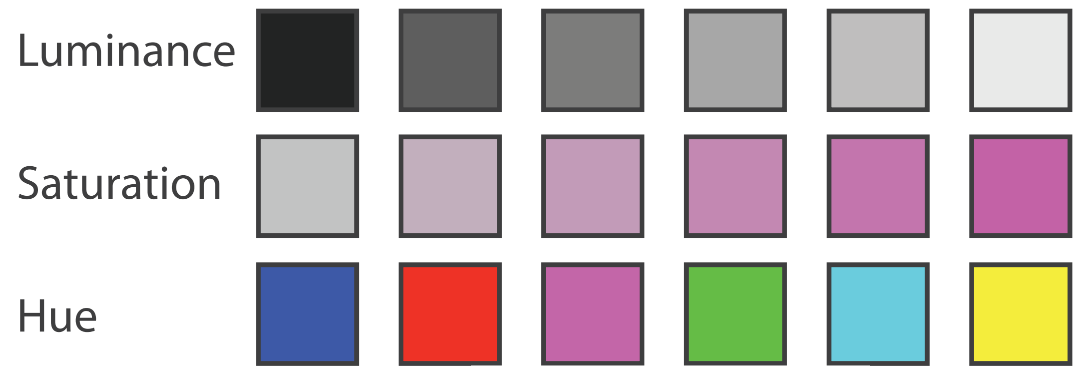

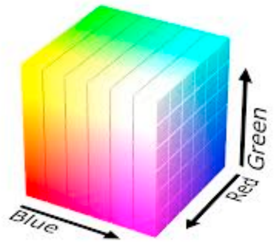

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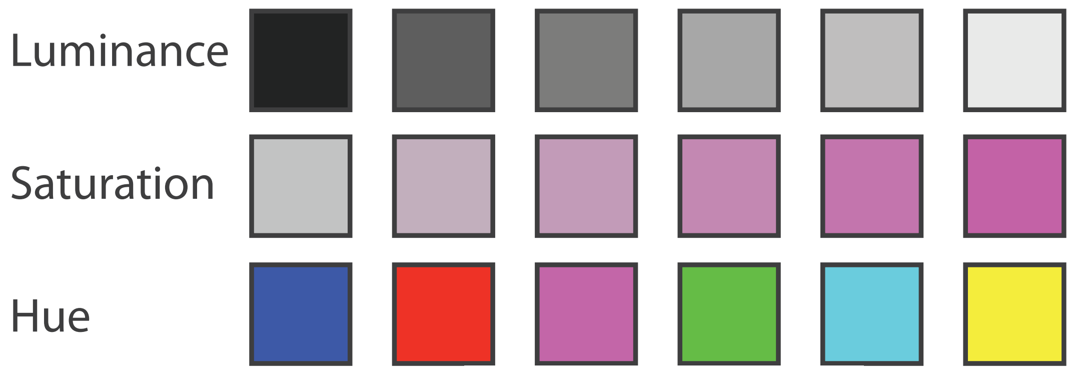

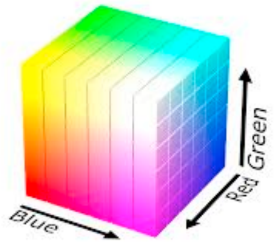

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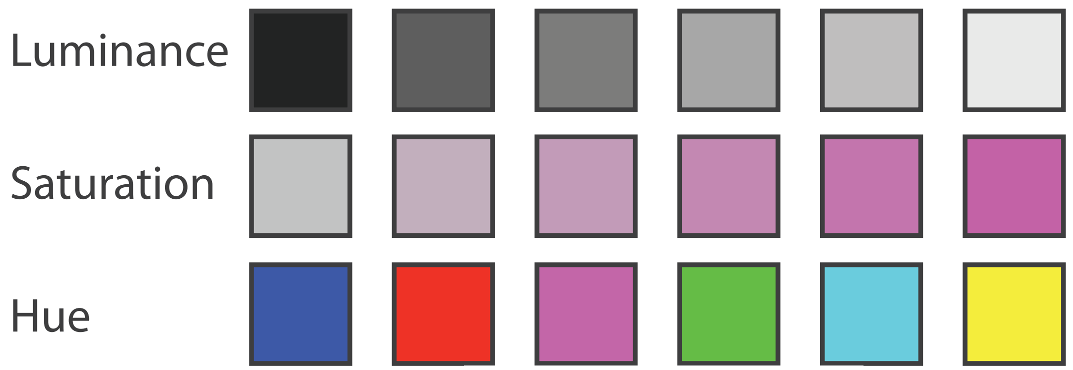

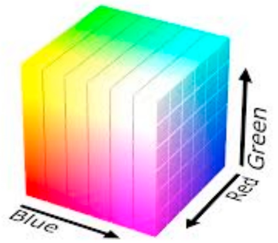

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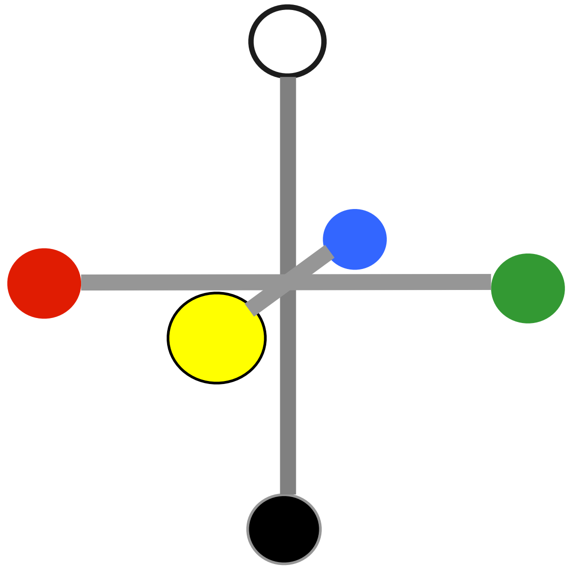
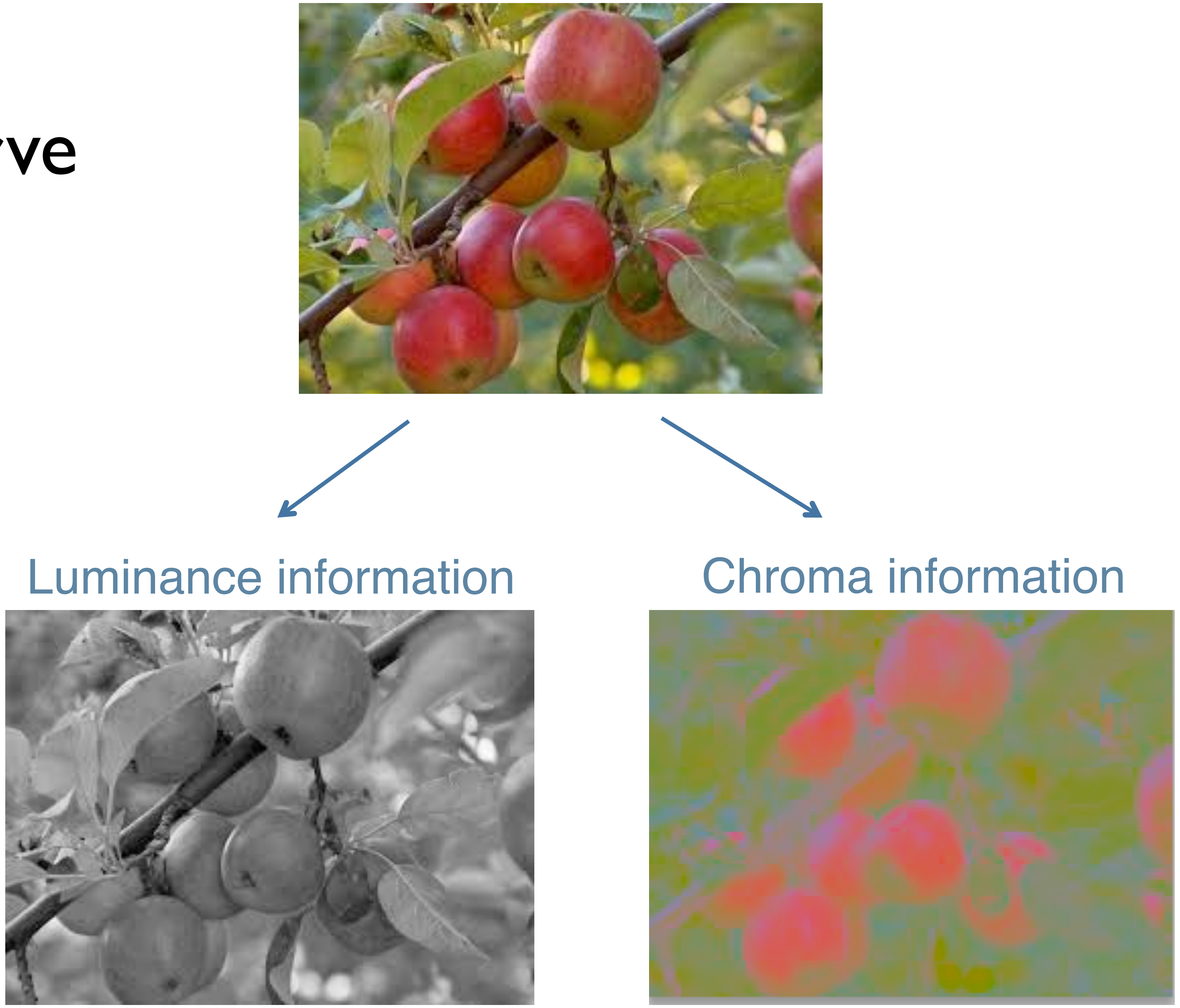
Perceptual colorspace: L*a*b*

- 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.]

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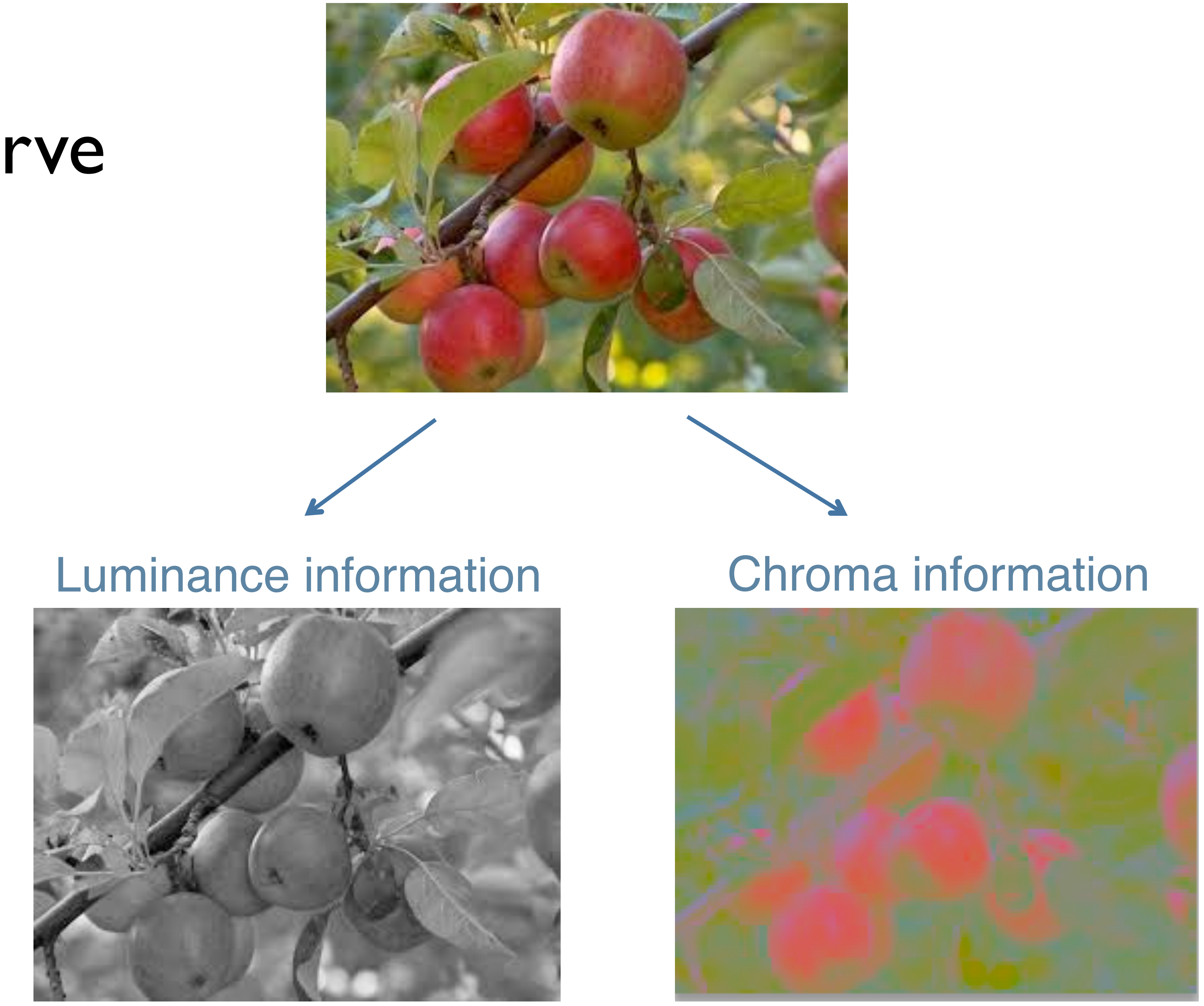
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- CIE LAB
  - perceptually uniform
    - great for interpolating
  - complex shape
    - poor for encoding



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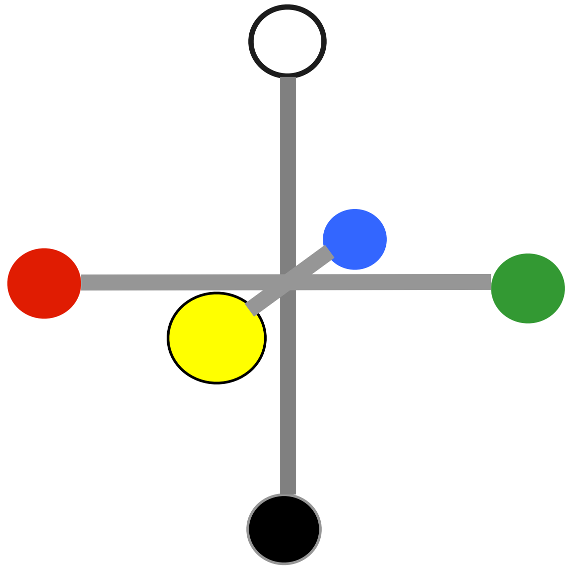

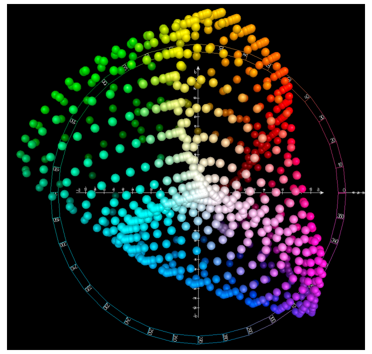

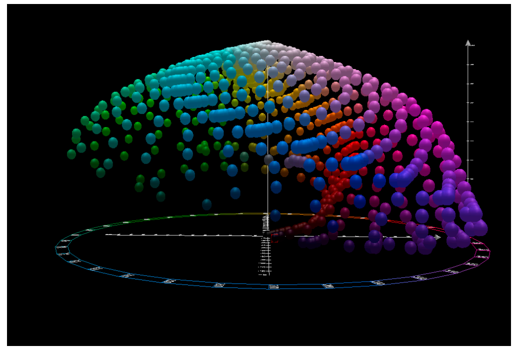

https://en.wikipedia.org/wiki/CIELAB_color_space

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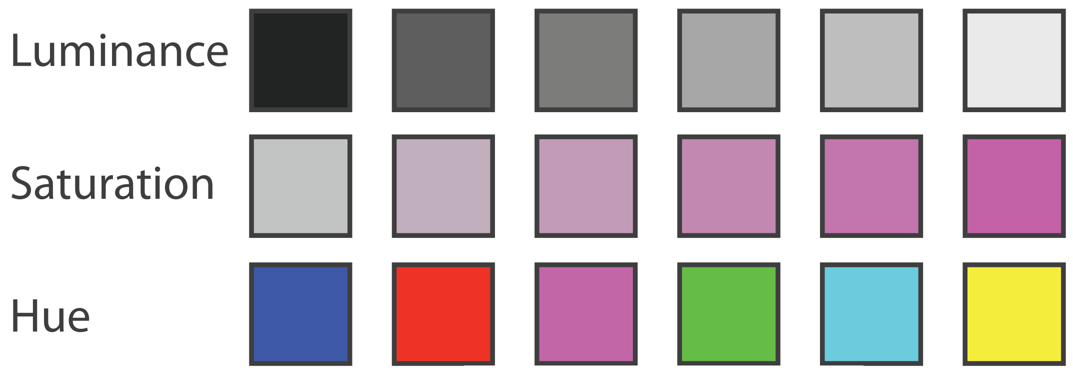

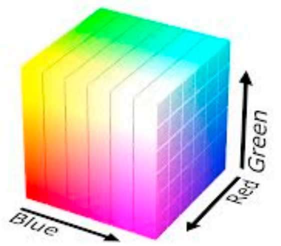

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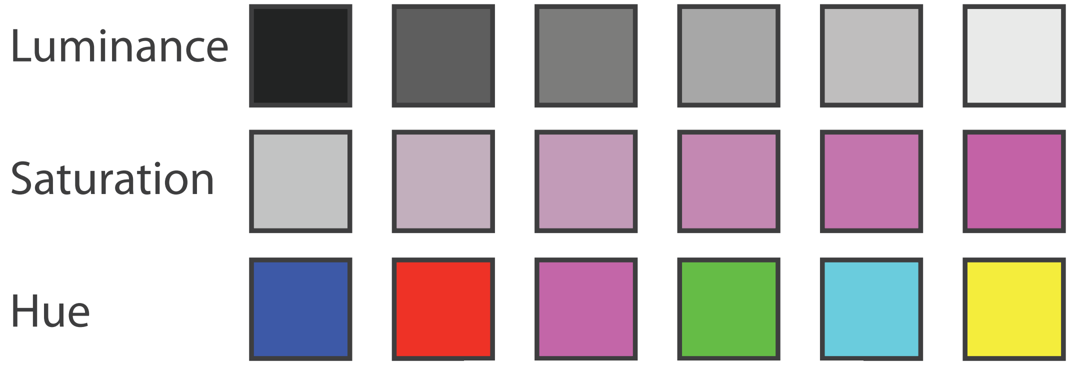
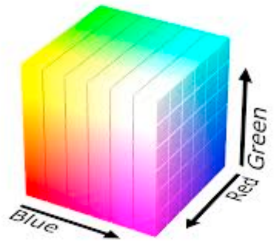
- HSL/HSV: somewhat better for encoding





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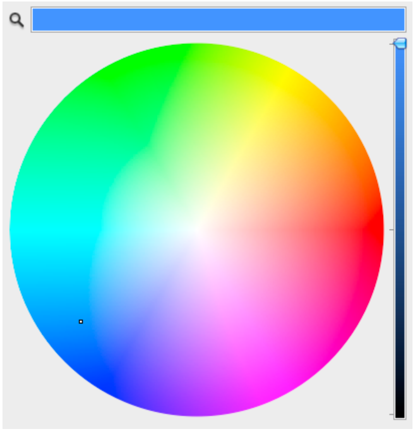
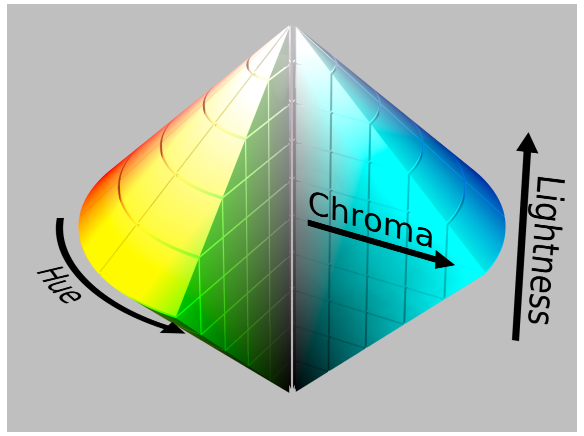
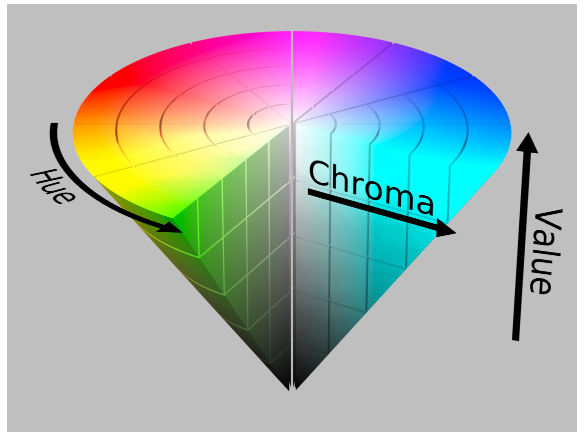
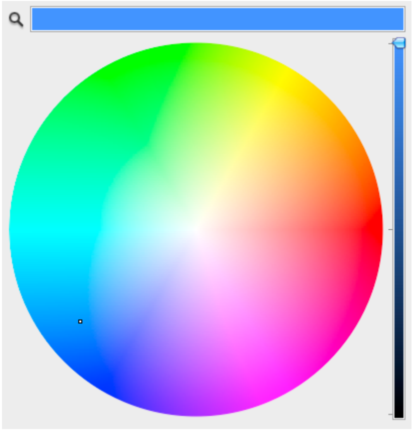


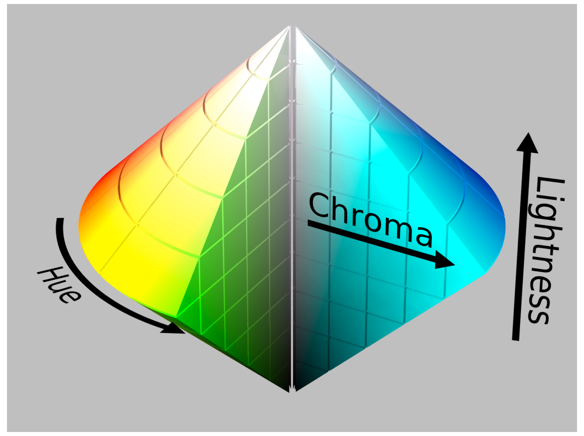


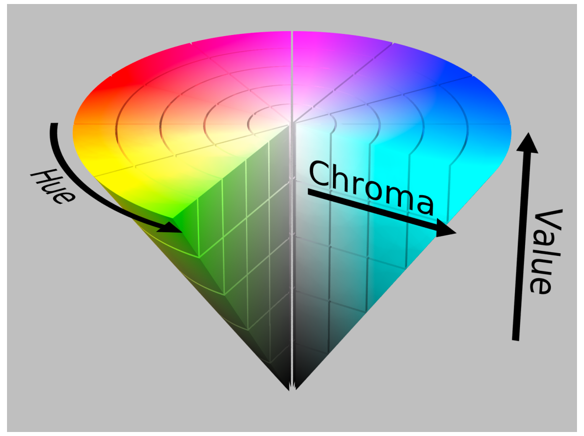


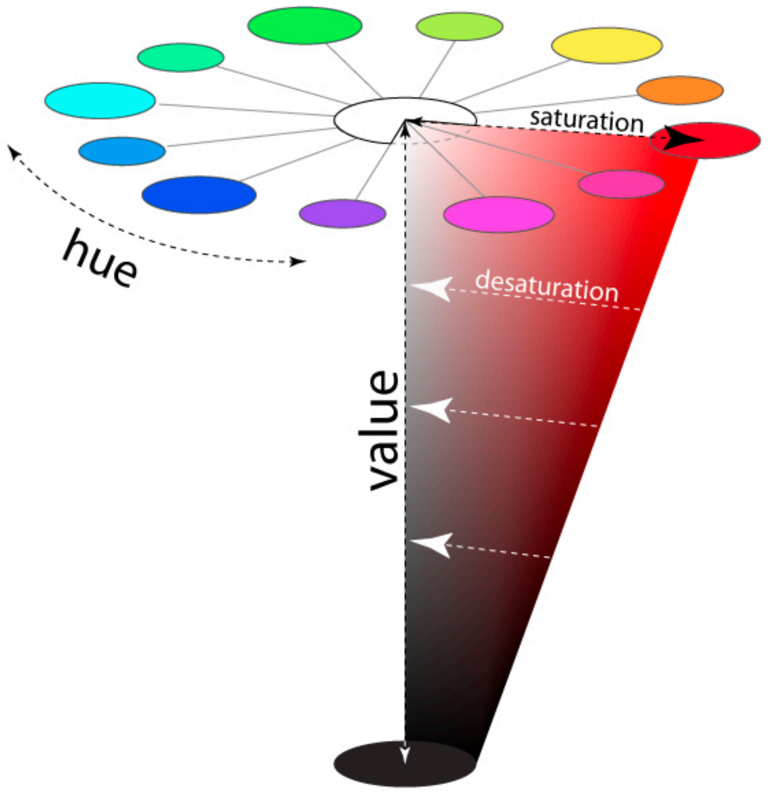
HSL/HSV

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



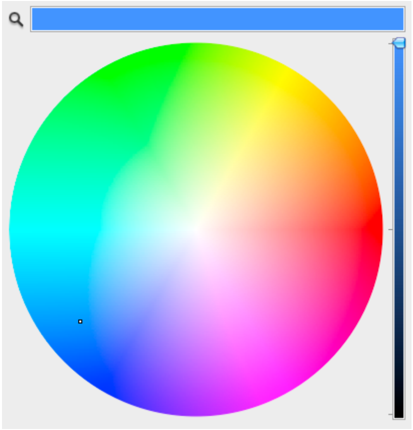


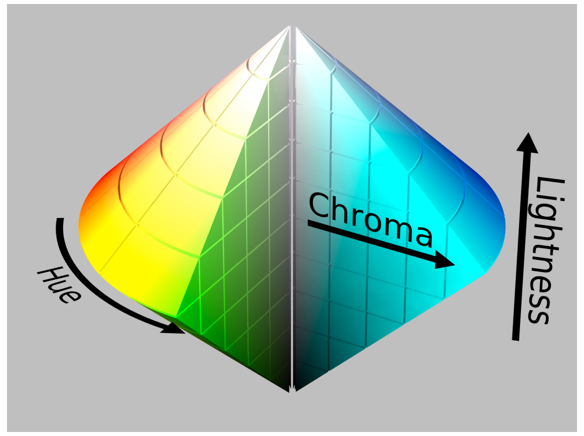


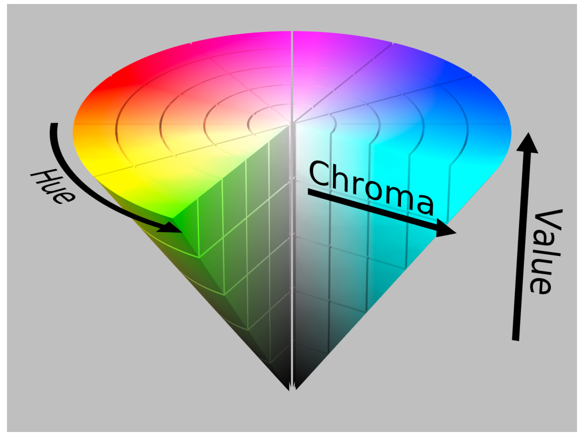


http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV







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  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
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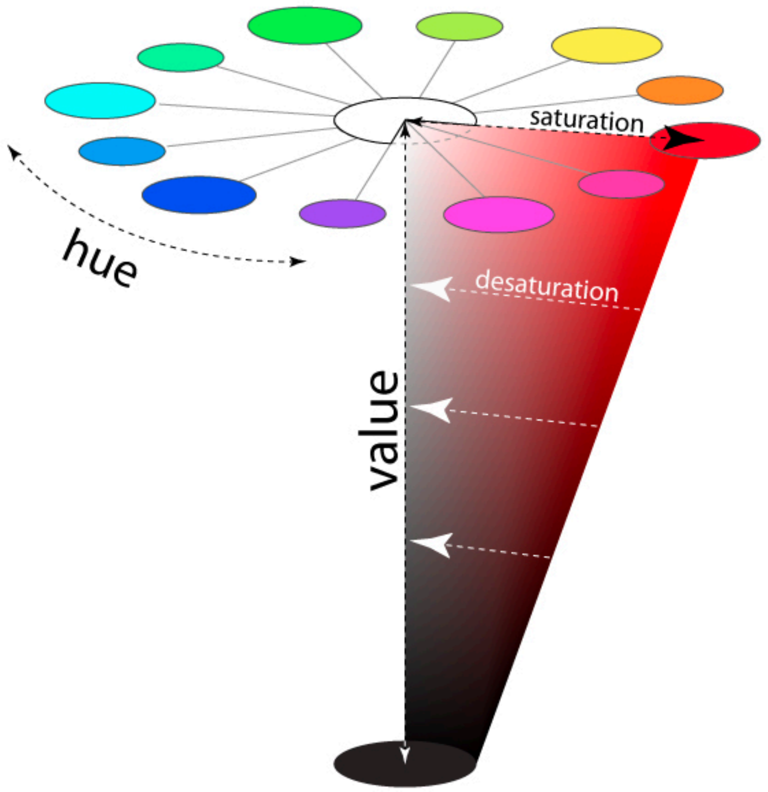
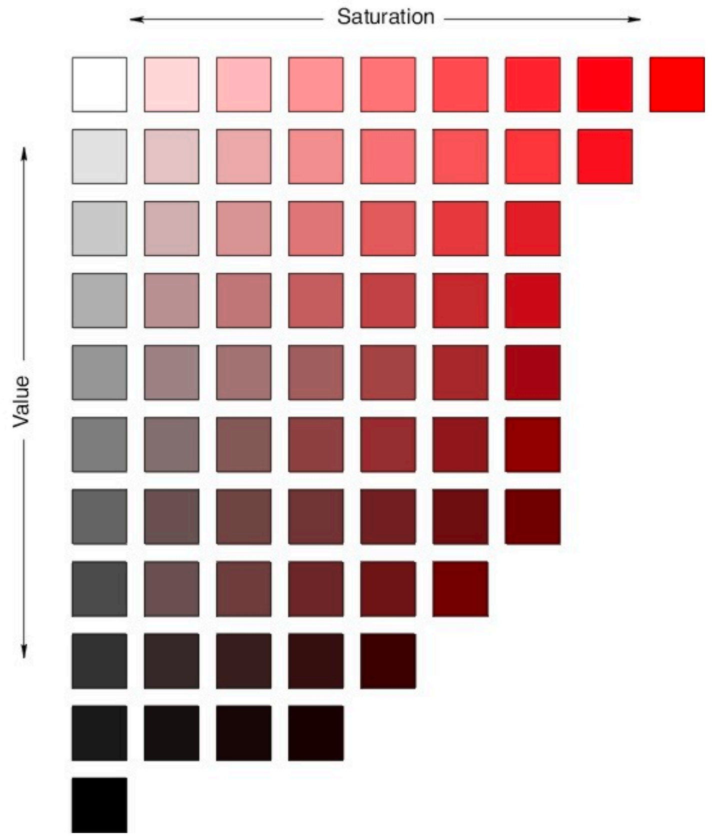
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation





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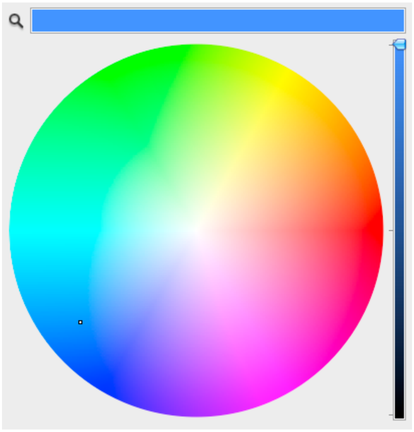
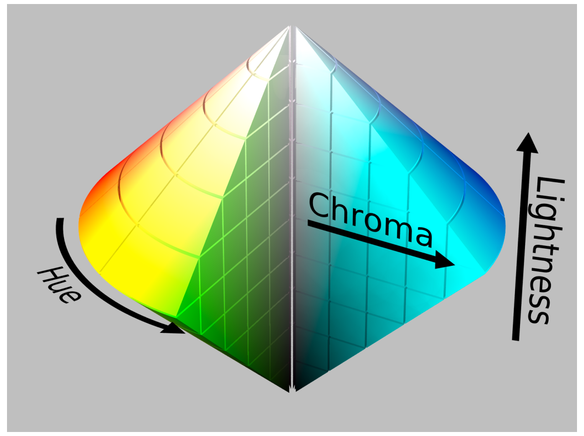
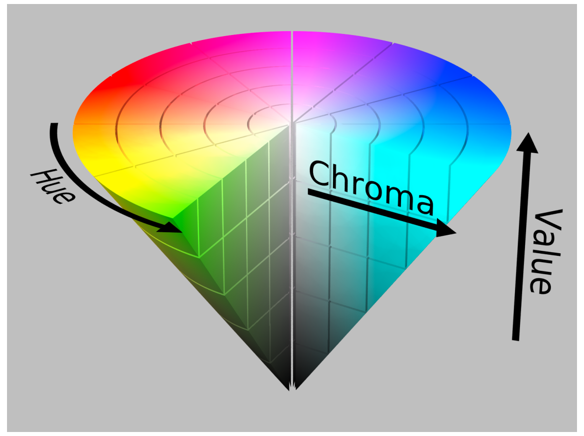
HSL/HSV: Pseudo-perceptual colorspace





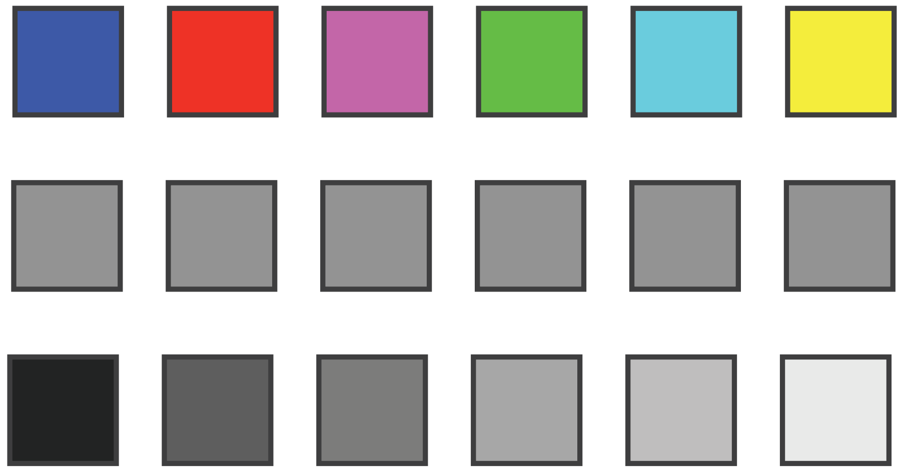


- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance

Corners of the RGB color cube

L from HLS
All the same

Luminance values



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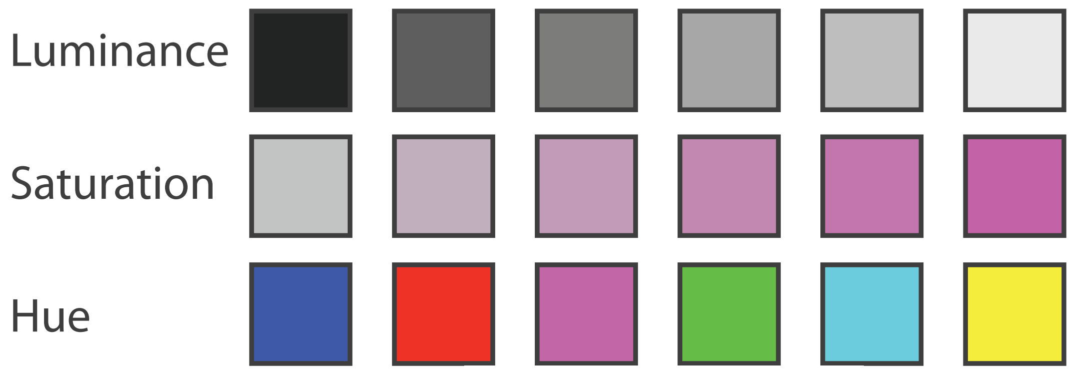
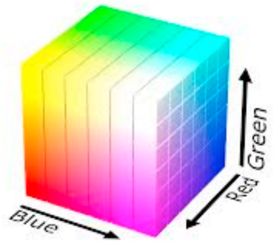
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)





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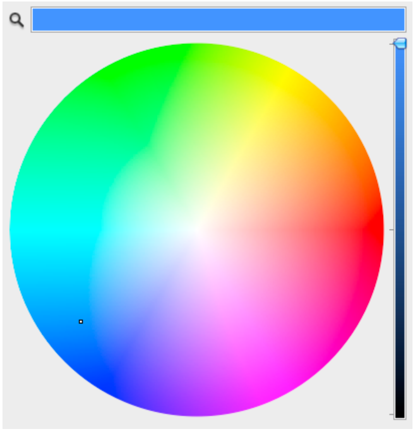
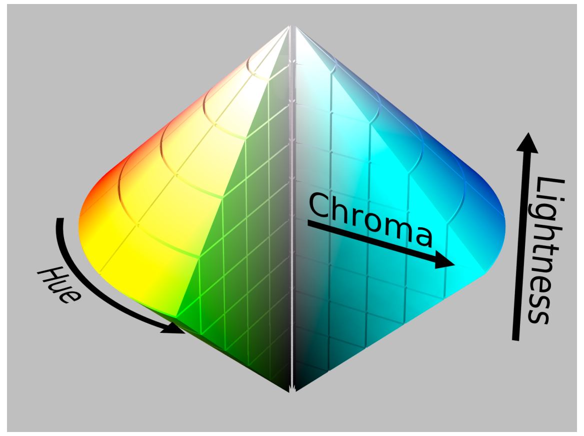
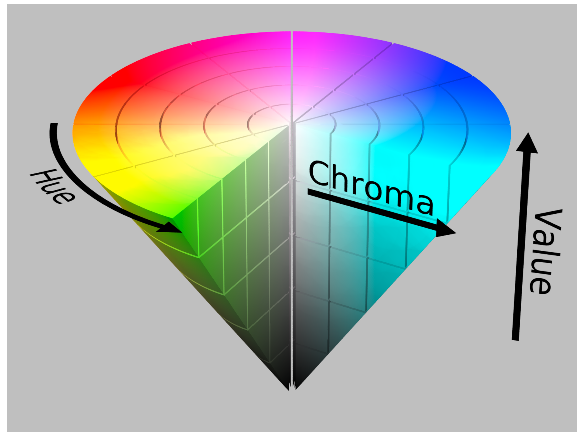
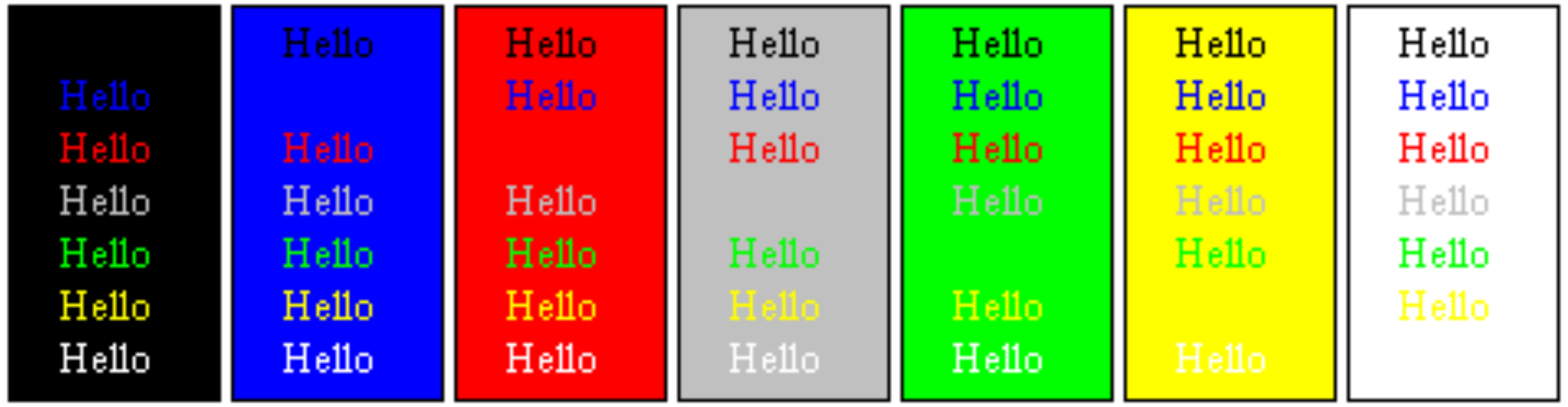






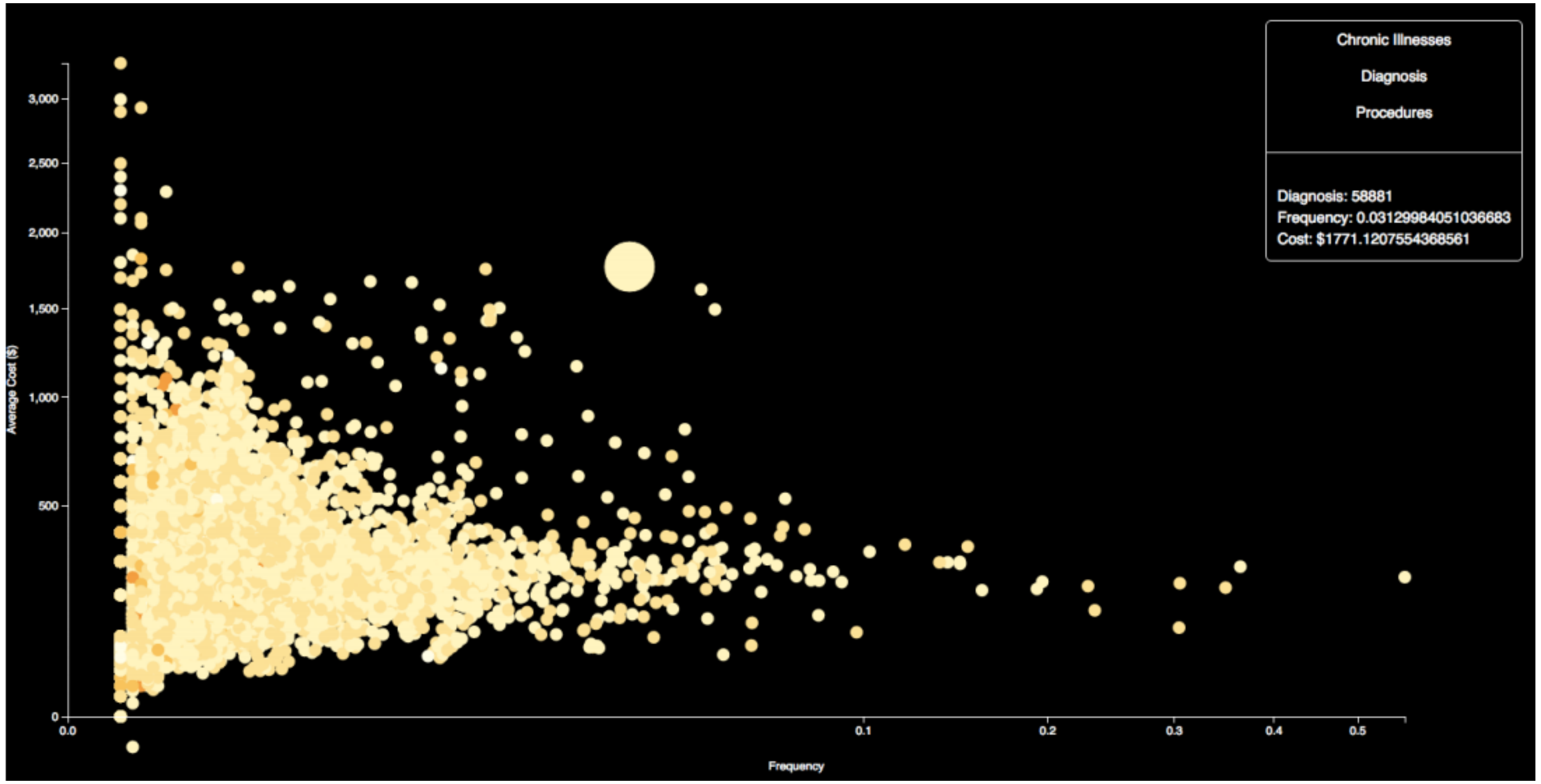
Color Constrast & Naming

Interaction with the background



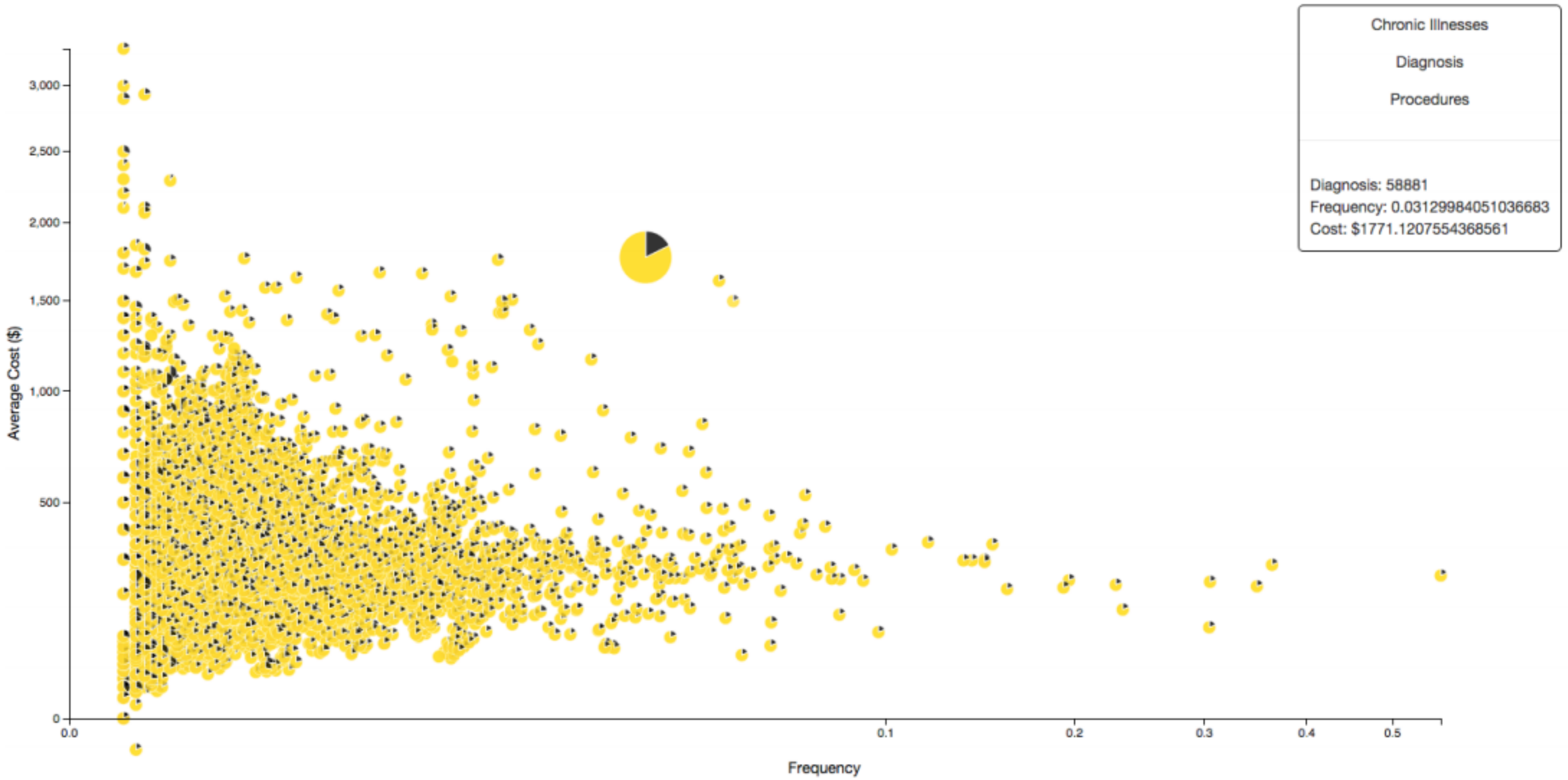
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



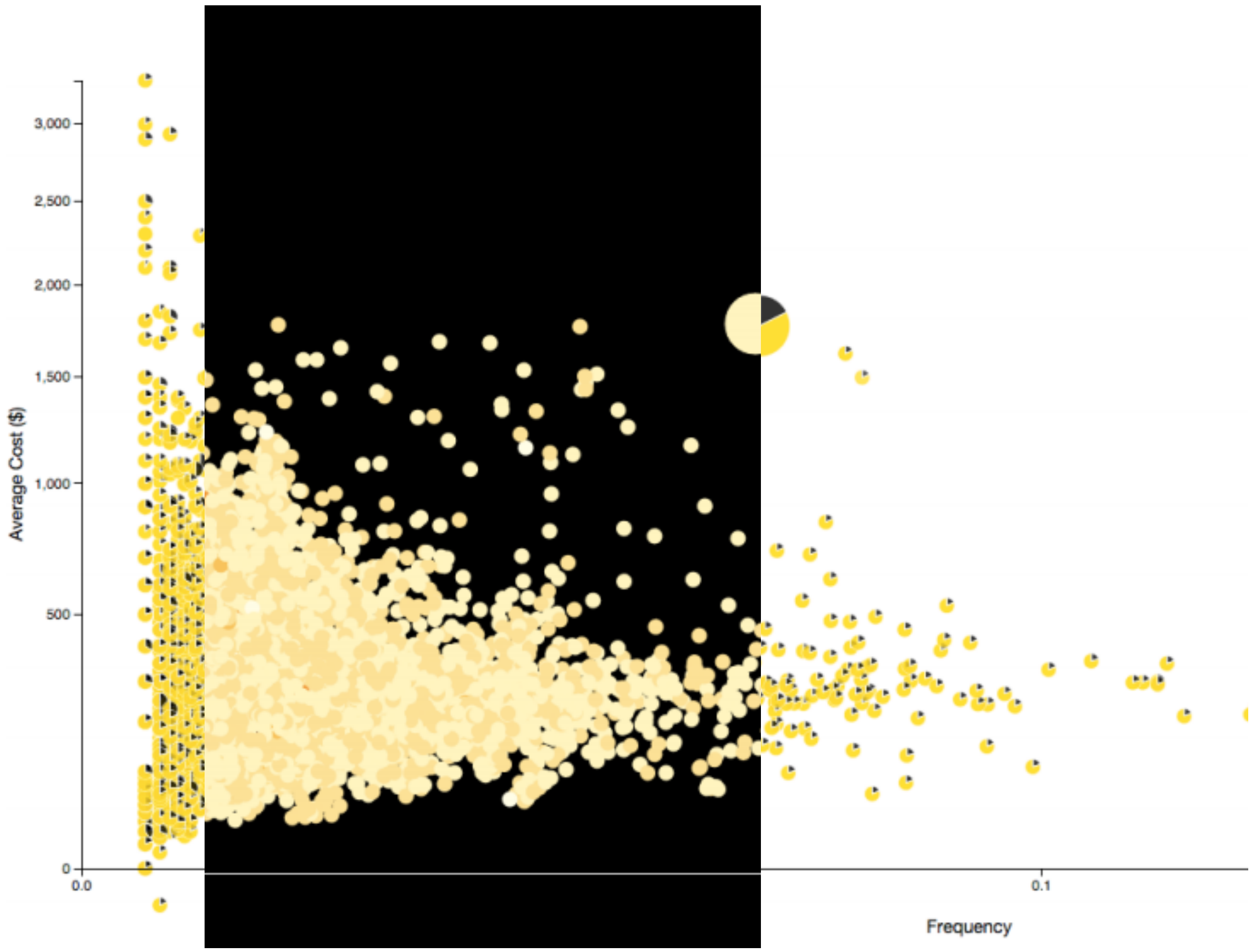
Interaction with the background: tweaking yellow for visibility

- 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

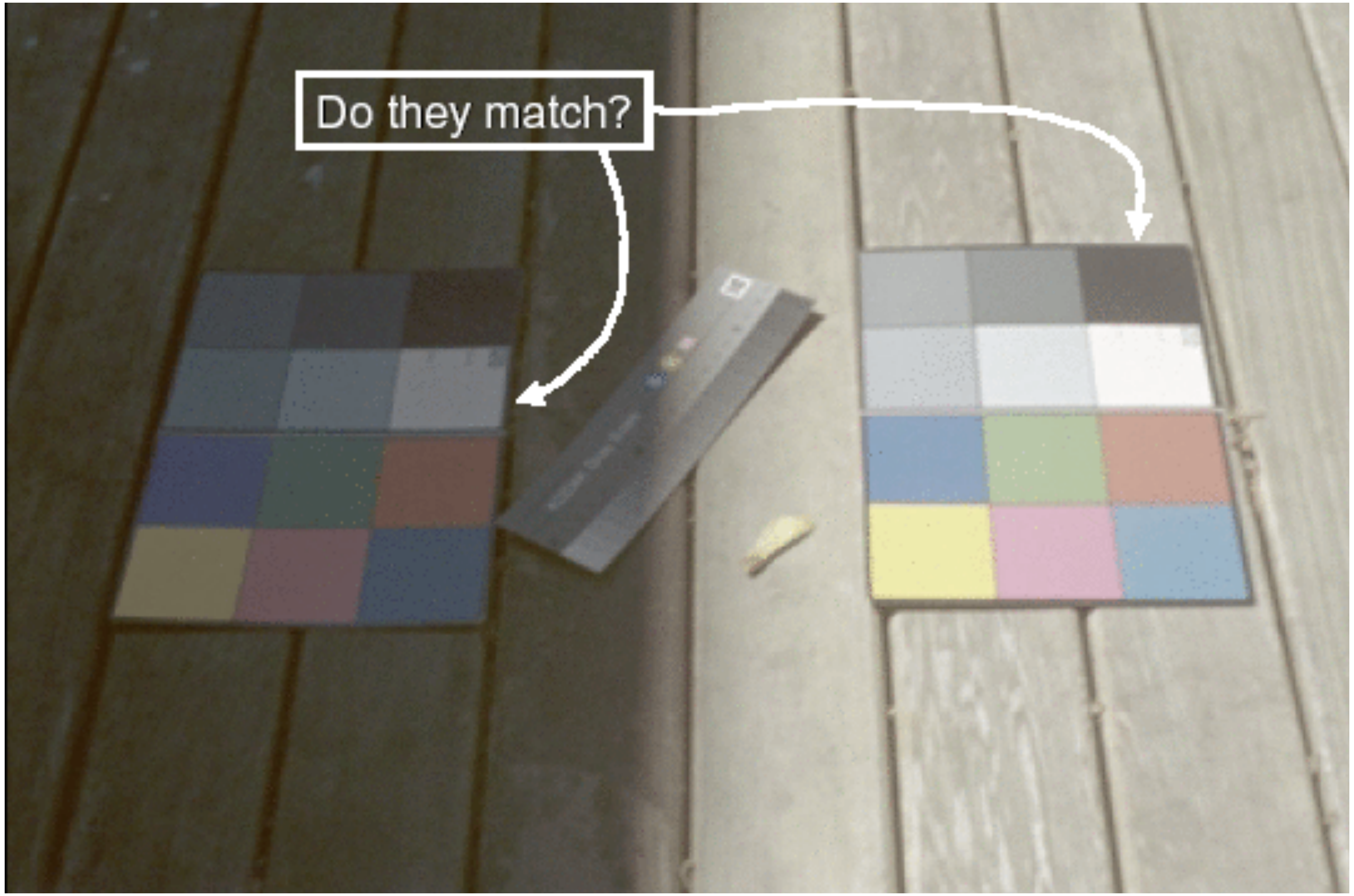


Image courtesy of John McCann via Maureen Stone

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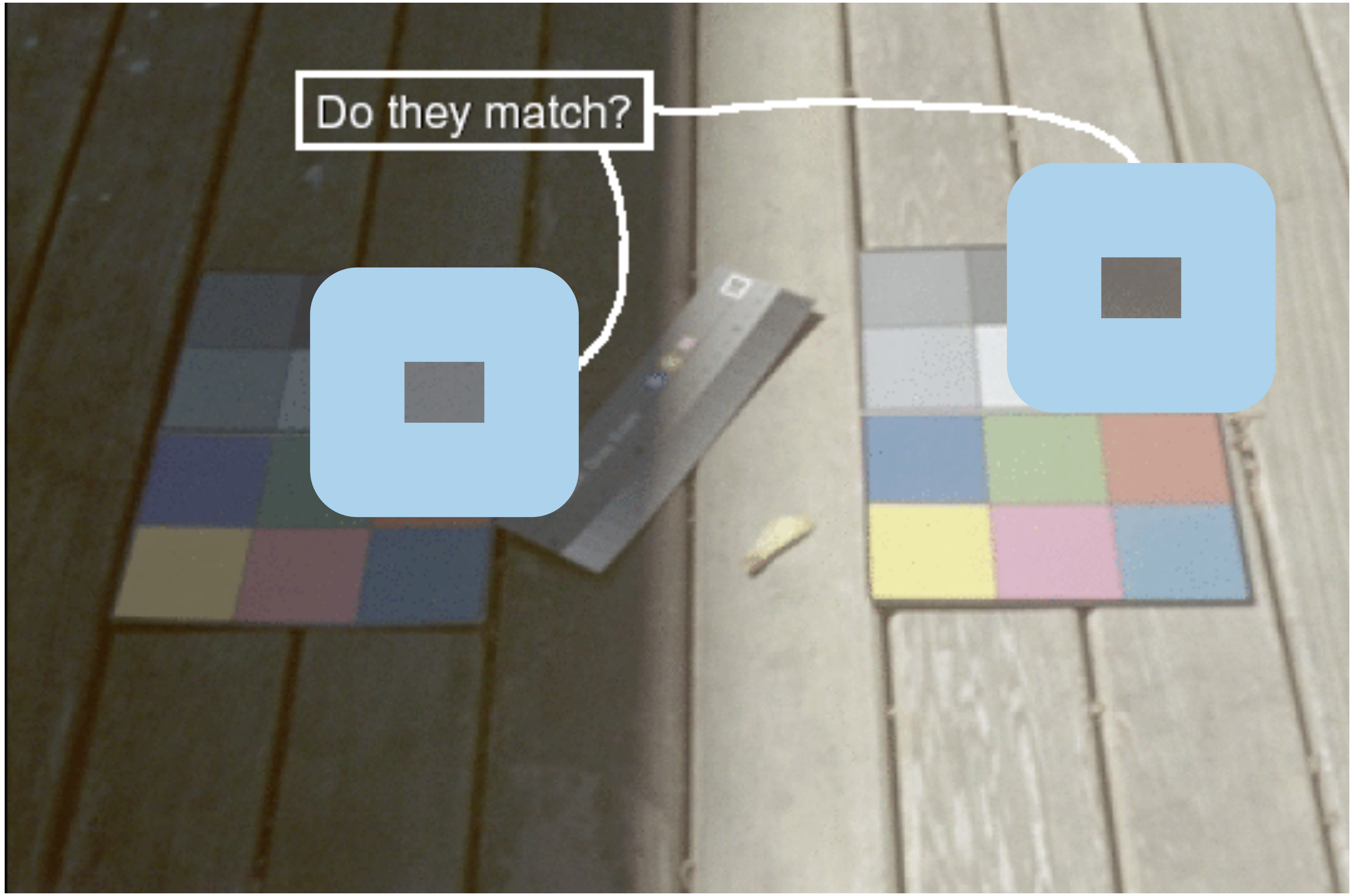
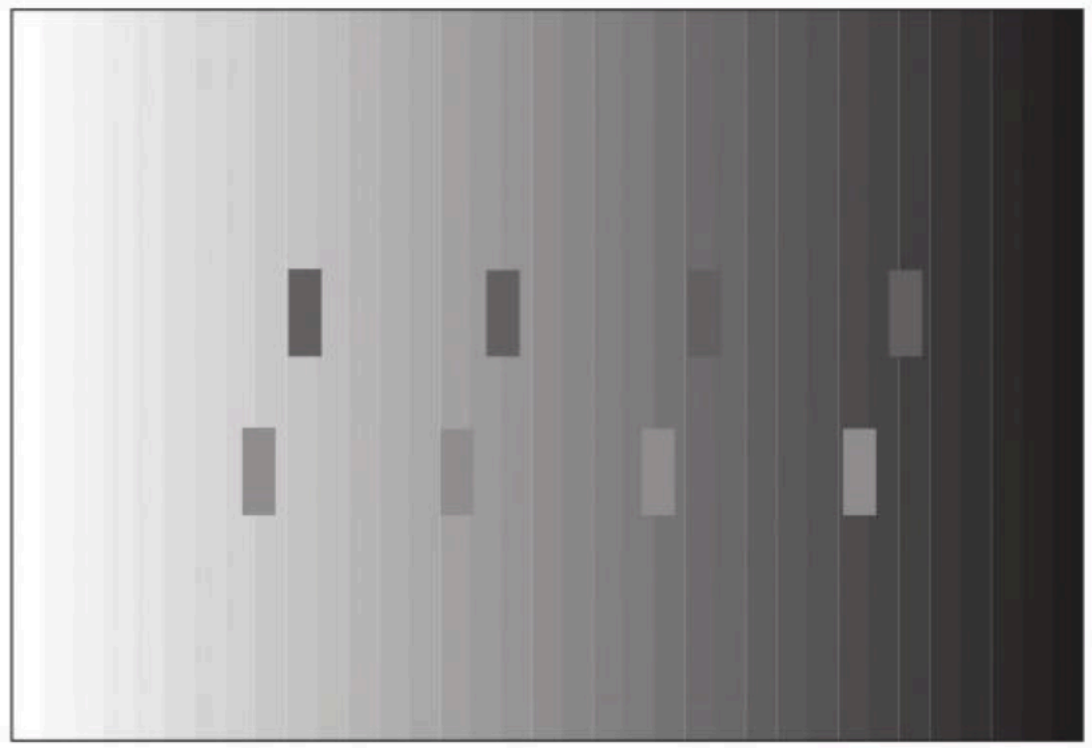
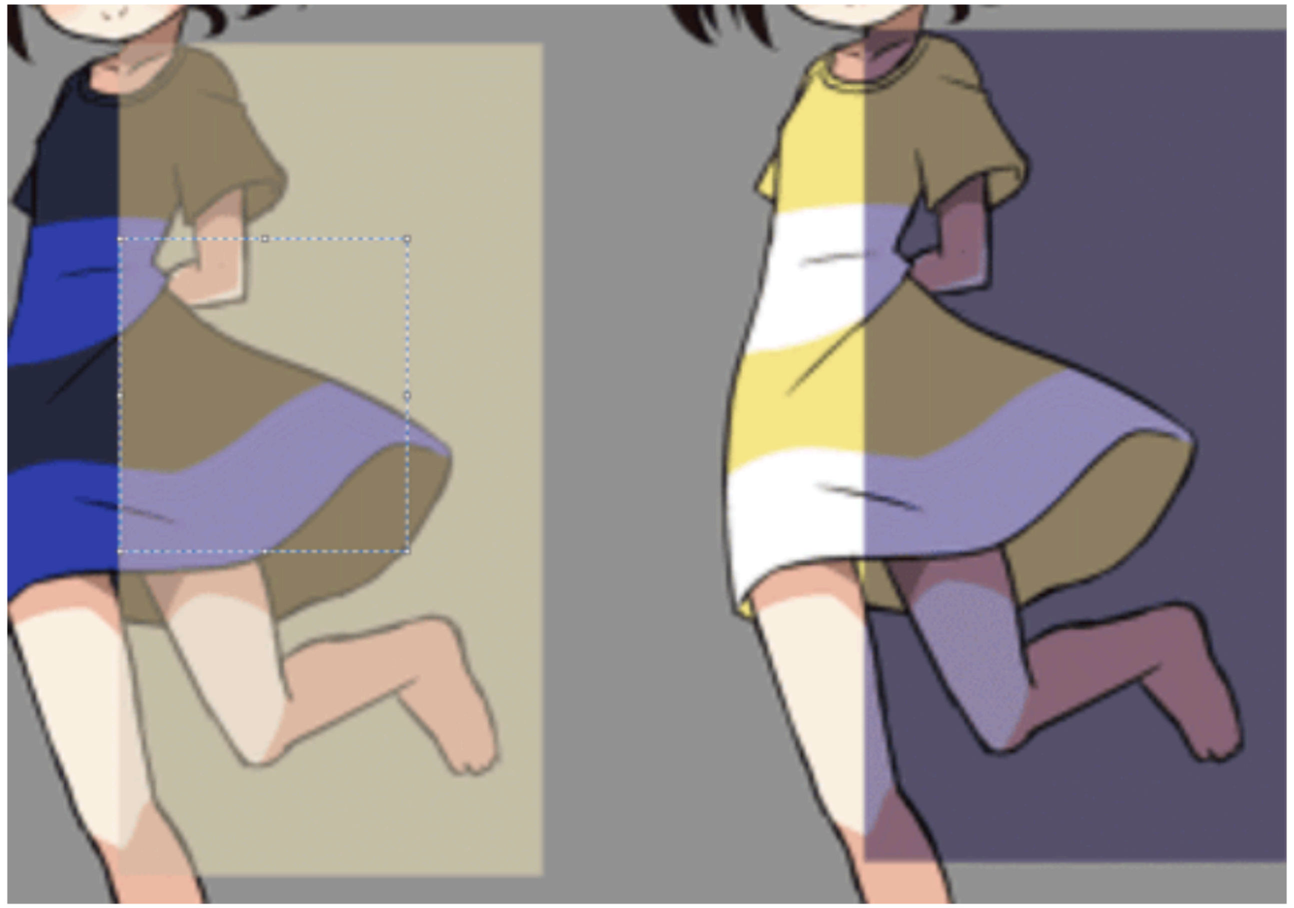


Image courtesy of John McCann via Maureen Stone

Contrast with background



Contrast with background

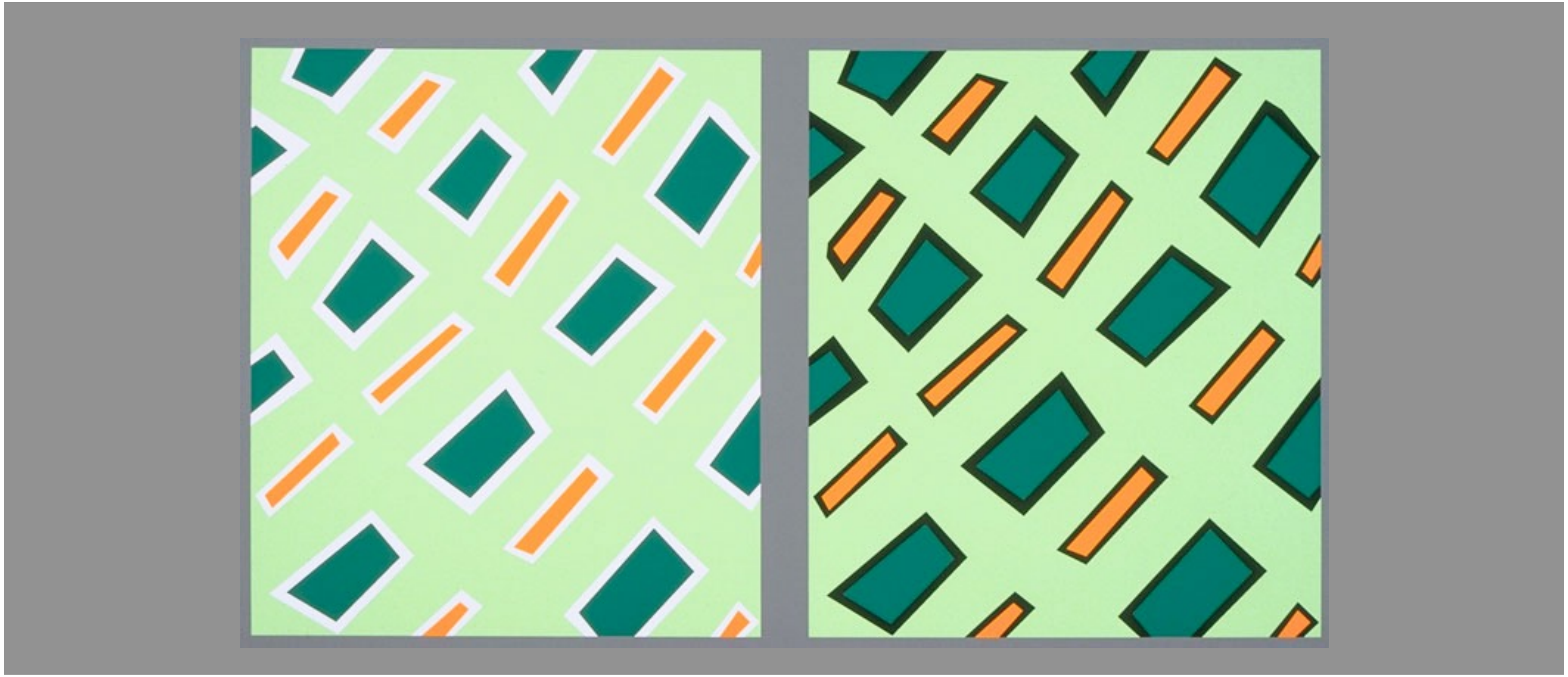


Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

Bezold Effect: Outlines matter

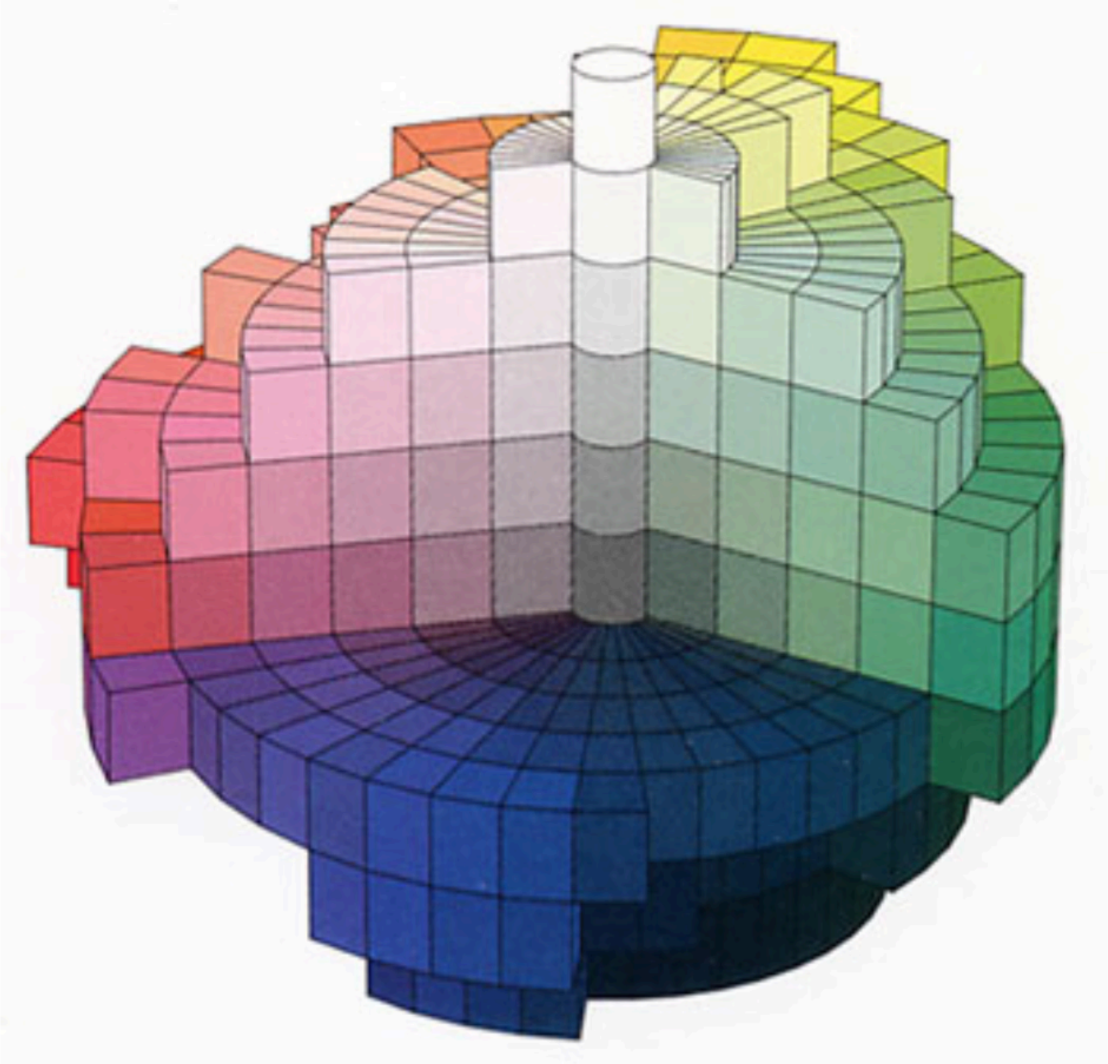


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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

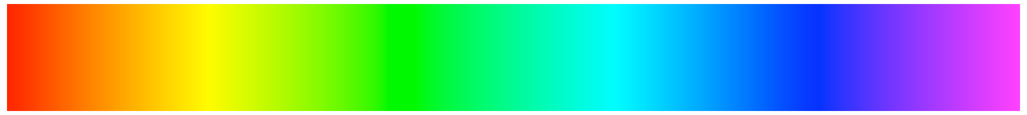
- nameability affects
  - communication
  - memorability
- can integrate into color models
  - in addition to perceptual considerations

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

Color is just part of vision system

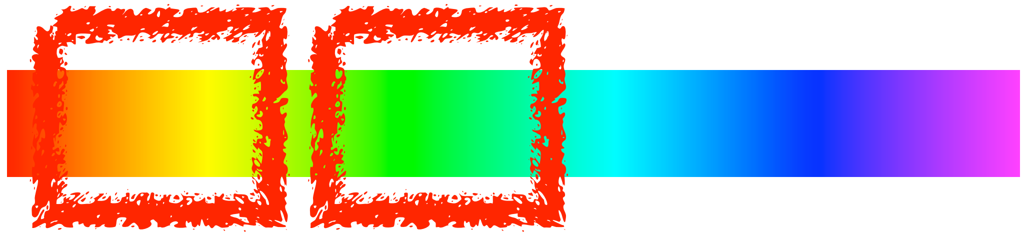
- Does not help perceive
  - Position
  - Shape
  - Motion
  - …

Ordered color: Rainbow is poor default



- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default



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Ordered color: Rainbow is poor default

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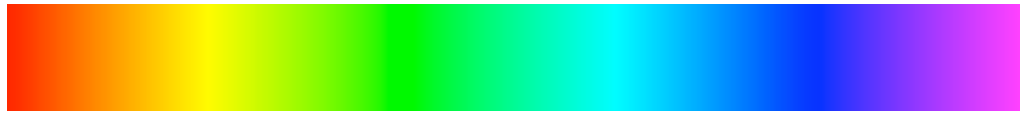
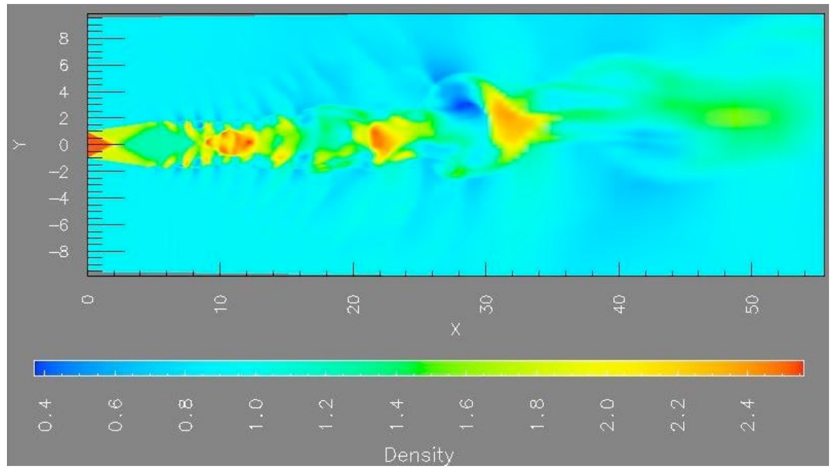
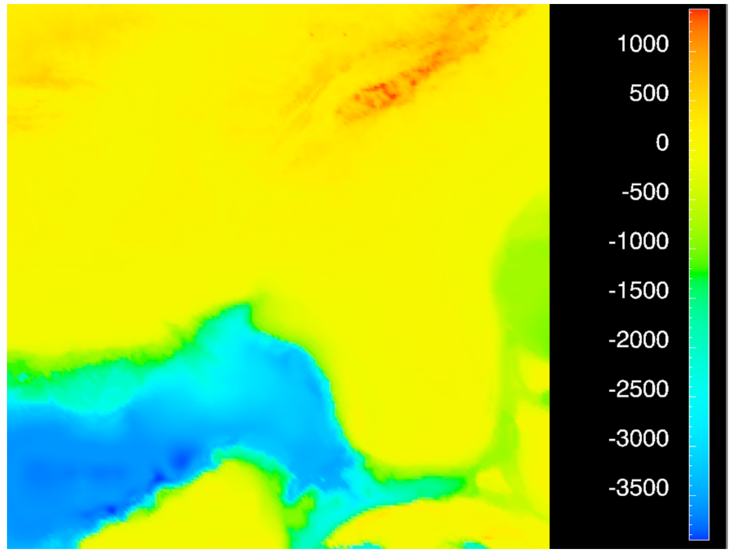
- benefits
  - fine-grained structure visible and nameable





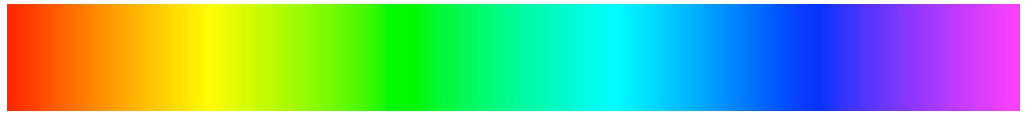
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

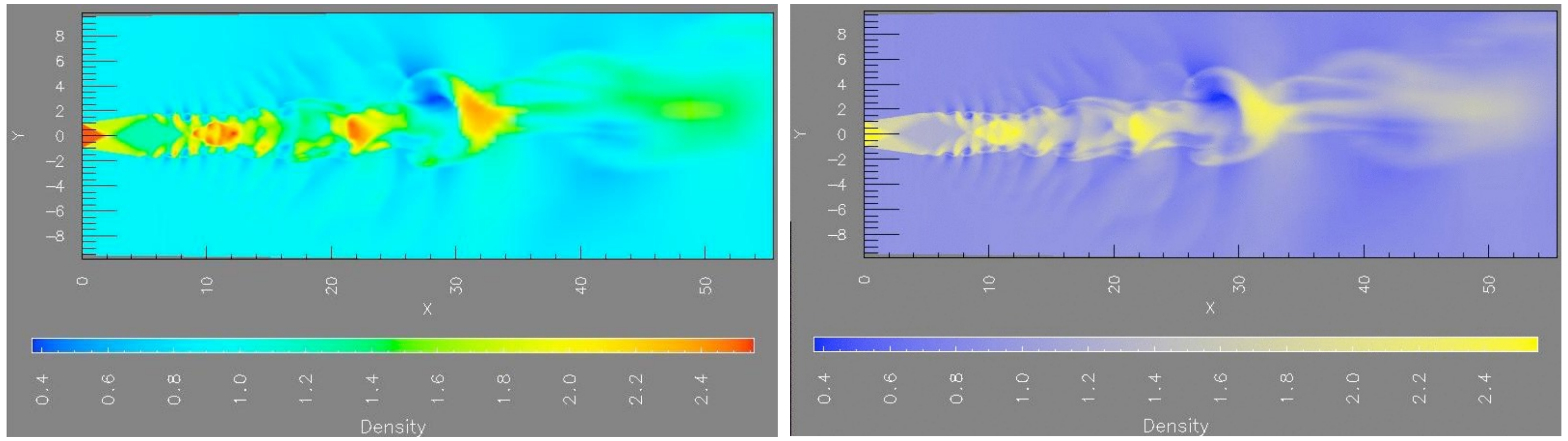


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Ordered color: Rainbow is poor default

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





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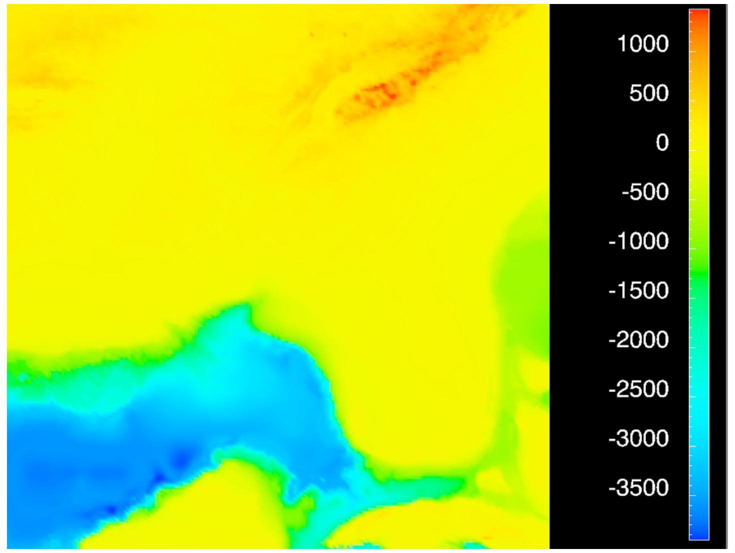

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Ordered color: Rainbow is poor default

- problems
  – perceptually unordered
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- benefits
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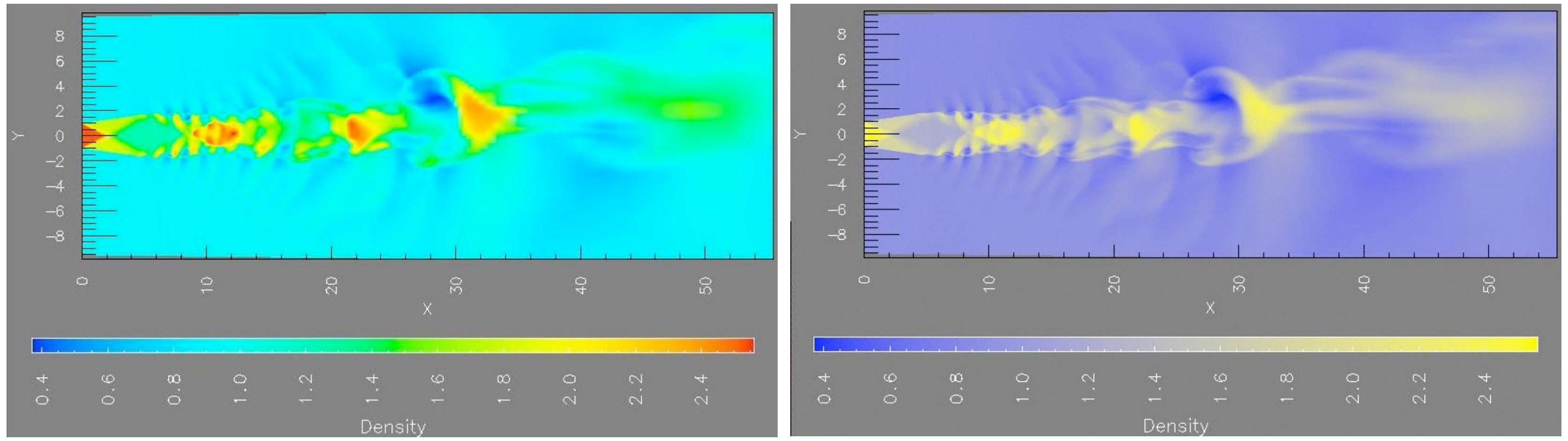
- alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis]



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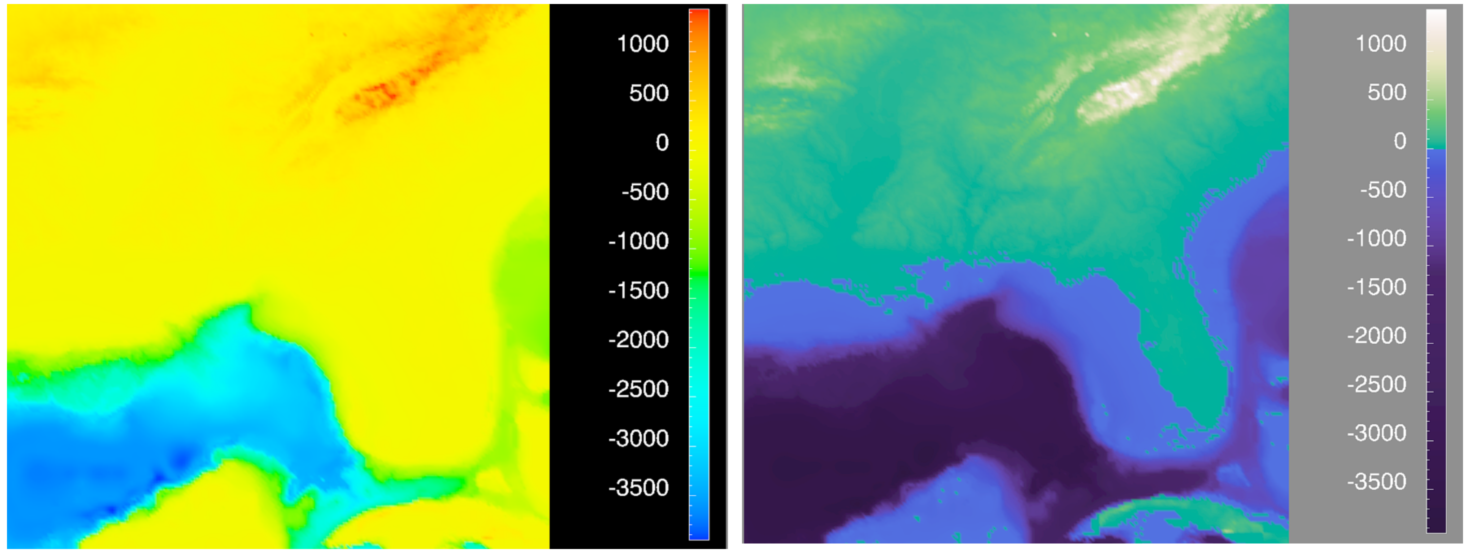
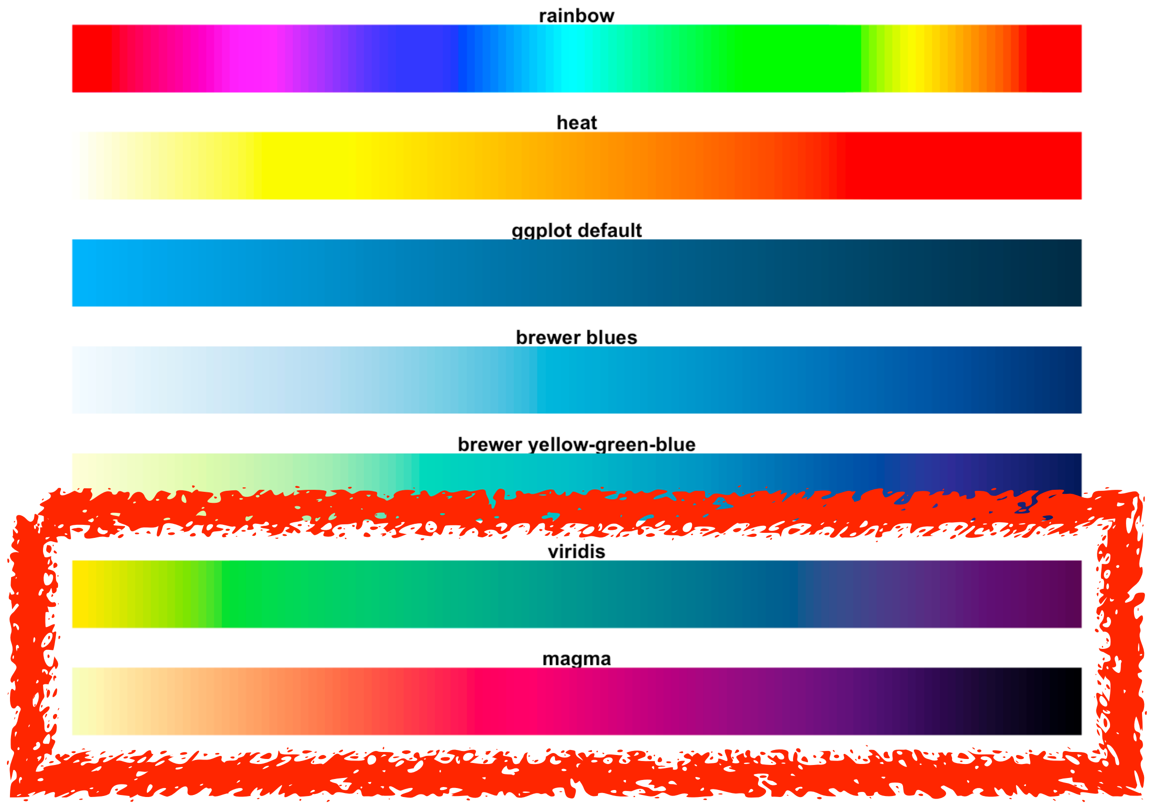
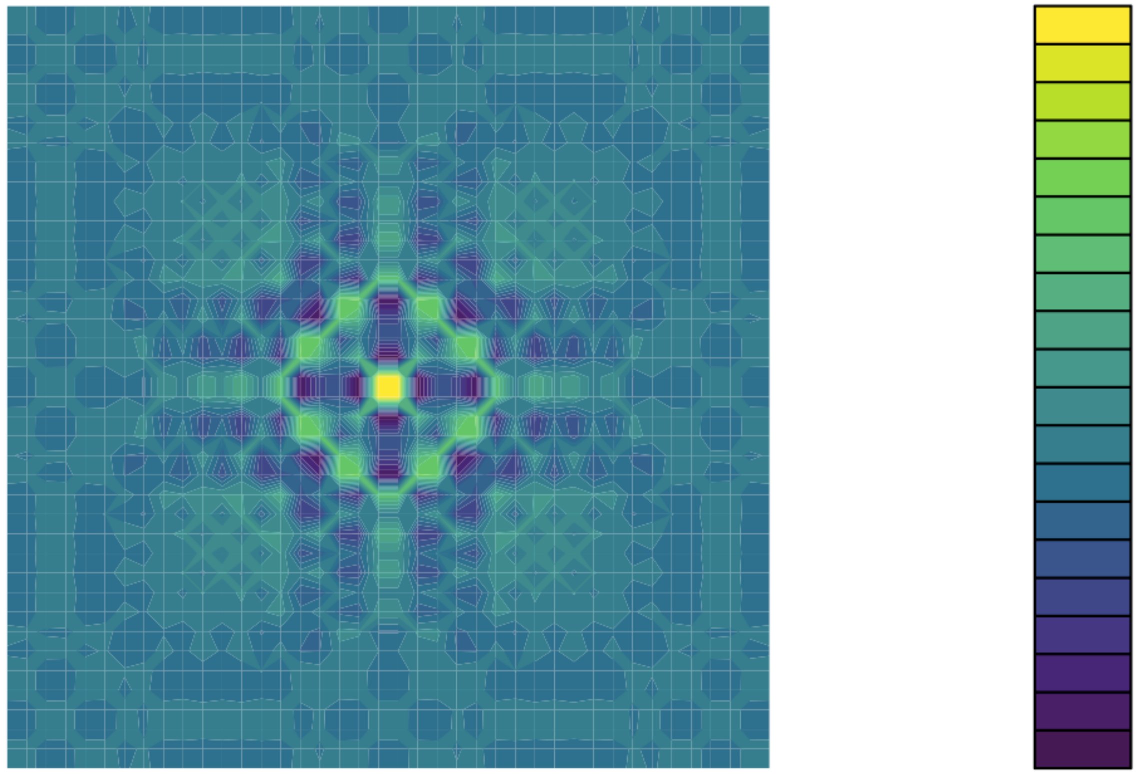


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

Ordered color: Rainbow is poor default

- problems
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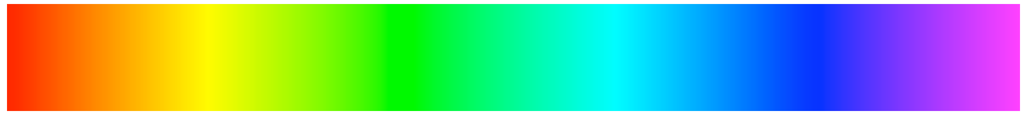
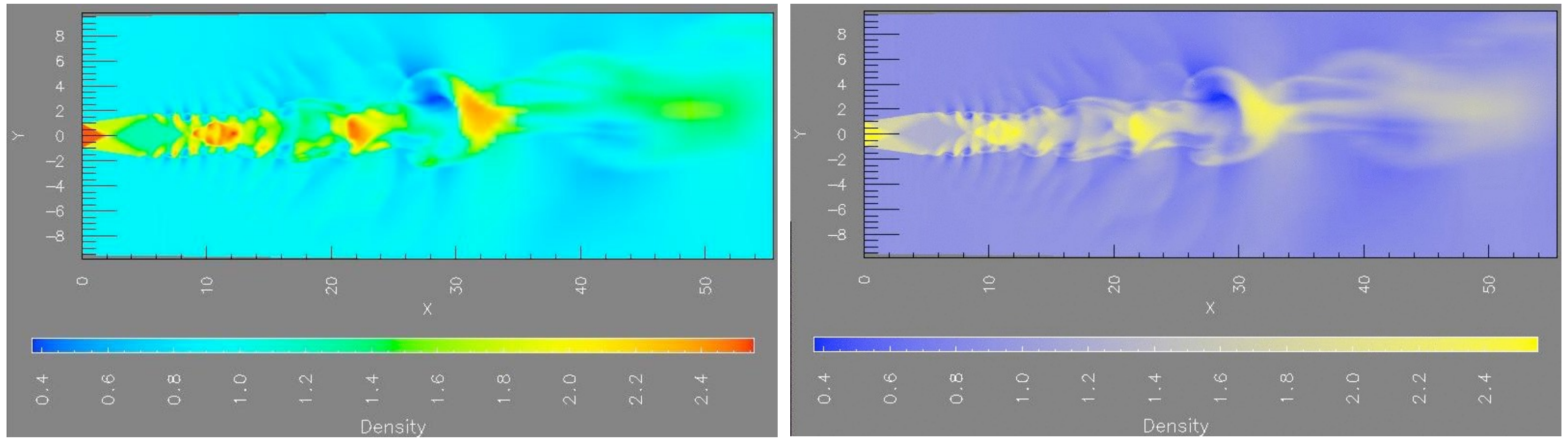
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented saturated rainbow is good!





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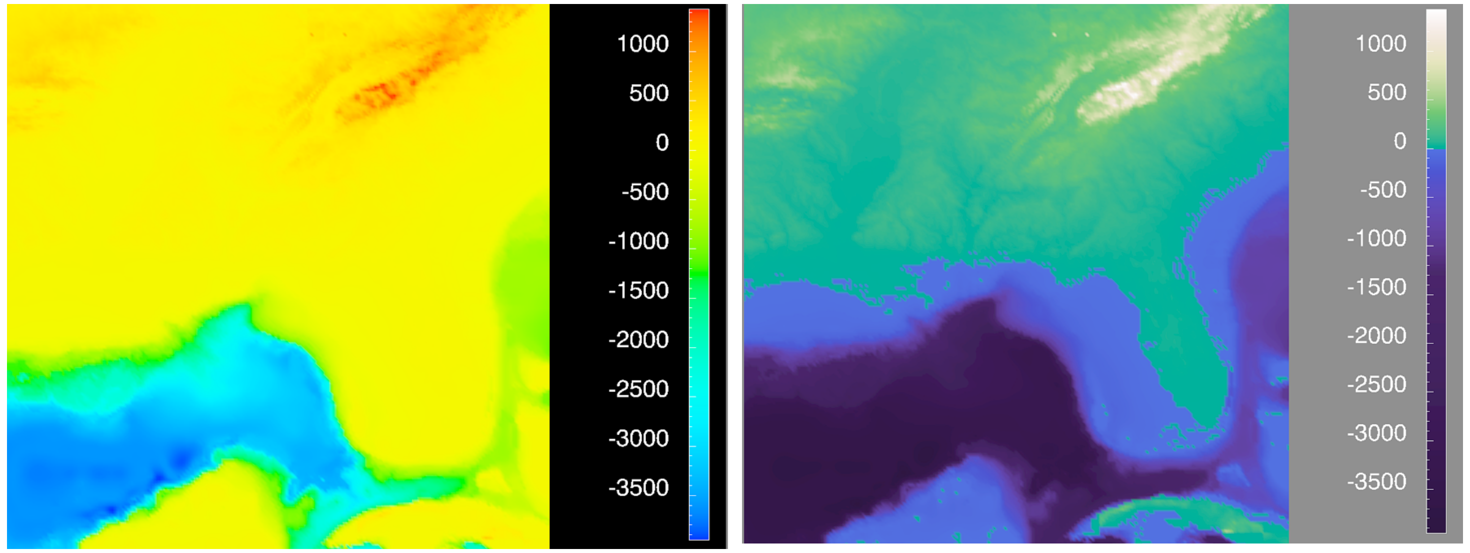
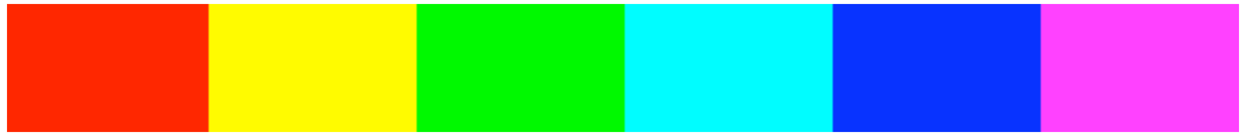


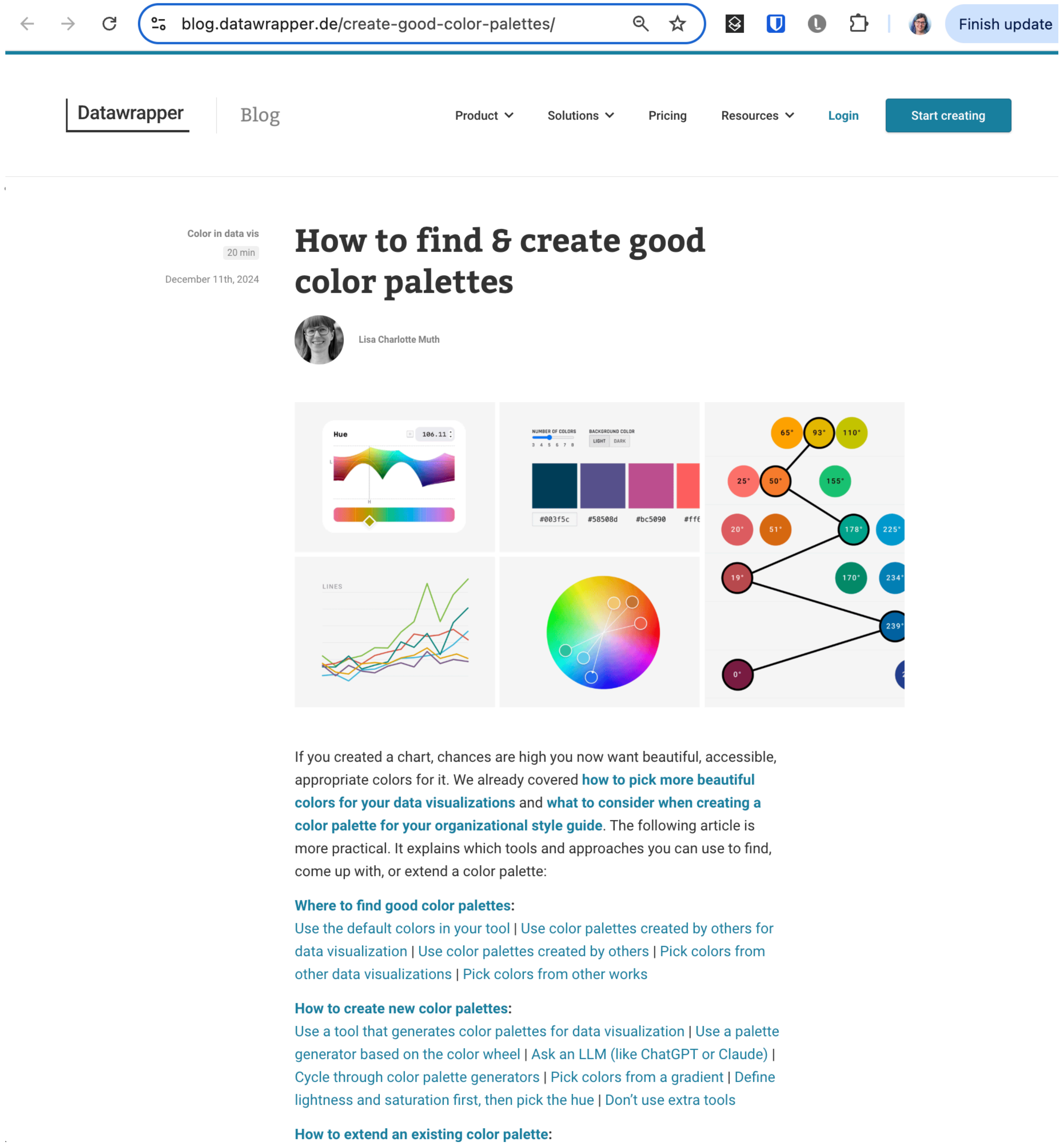
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]



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

More color resources: Muth

- DataWrapper guidance on color palette creation by Lisa Charlotte Muth https://blog.datawrapper.de/create-good-color-palettes/
  - lots of practical advice, easy to understand



blog.datawrapper.de/create-good-color-palettes/

Finish update

Datawrapper Blog

Product Solutions Pricing Resources Login Start creating

Color in data vis

20 min

December 11th, 2024

How to find & create good color palettes

Lisa Charlotte Muth

If you created a chart, chances are high you now want beautiful, accessible, appropriate colors for it. We already covered **how to pick more beautiful colors for your data visualizations** and **what to consider when creating a color palette for your organizational style guide**. The following article is more practical. It explains which tools and approaches you can use to find, come up with, or extend a color palette:

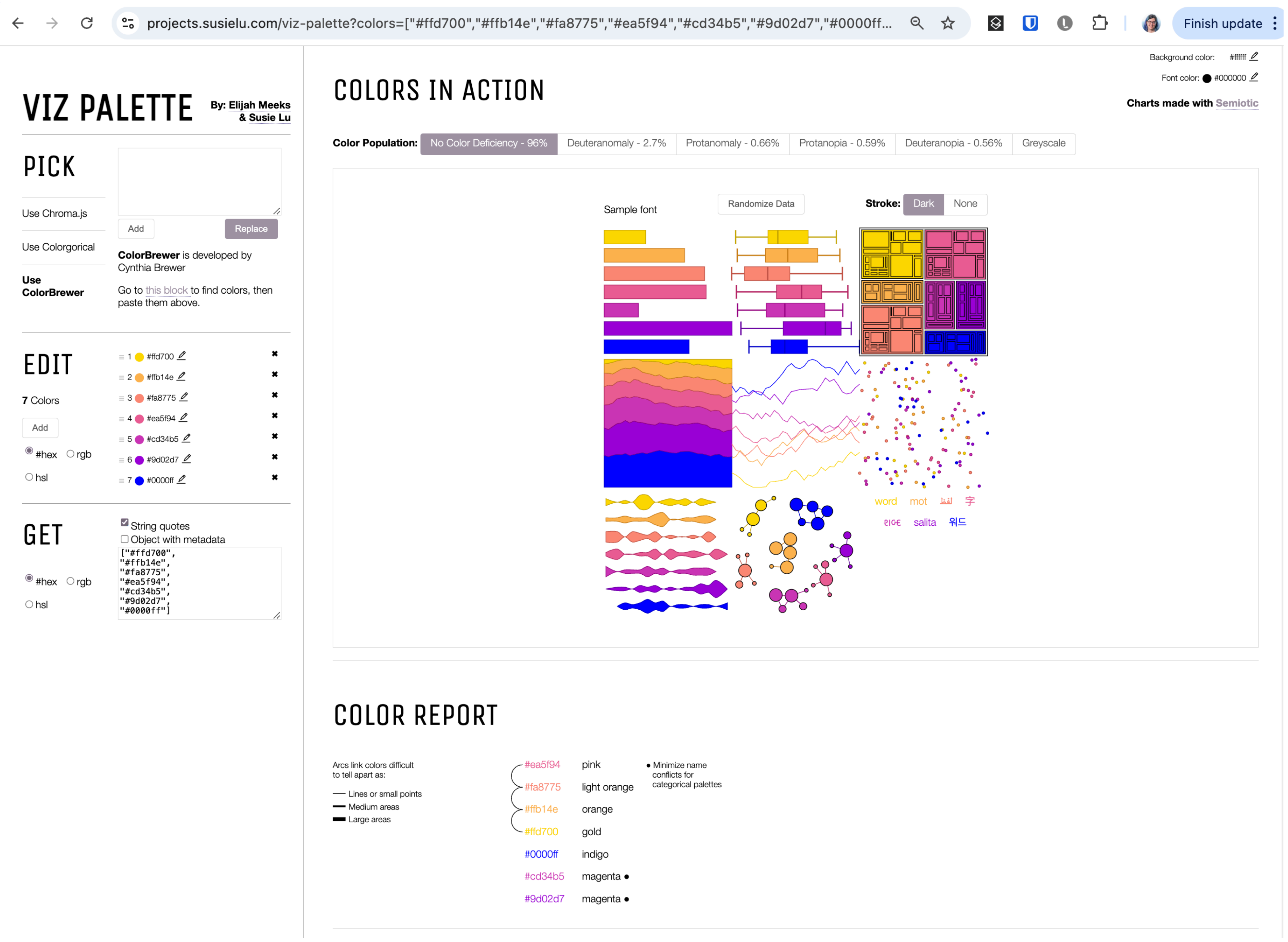
Where to find good color palettes:
Use the default colors in your tool | Use color palettes created by others for data visualization | Use color palettes created by others | Pick colors from other data visualizations | Pick colors from other works

How to create new color palettes:
Use a tool that generates color palettes for data visualization | Use a palette generator based on the color wheel | Ask an LLM (like ChatGPT or Claude) | Cycle through color palette generators | Pick colors from a gradient | Define lightness and saturation first, then pick the hue | Don't use extra tools

How to extend an existing color palette:

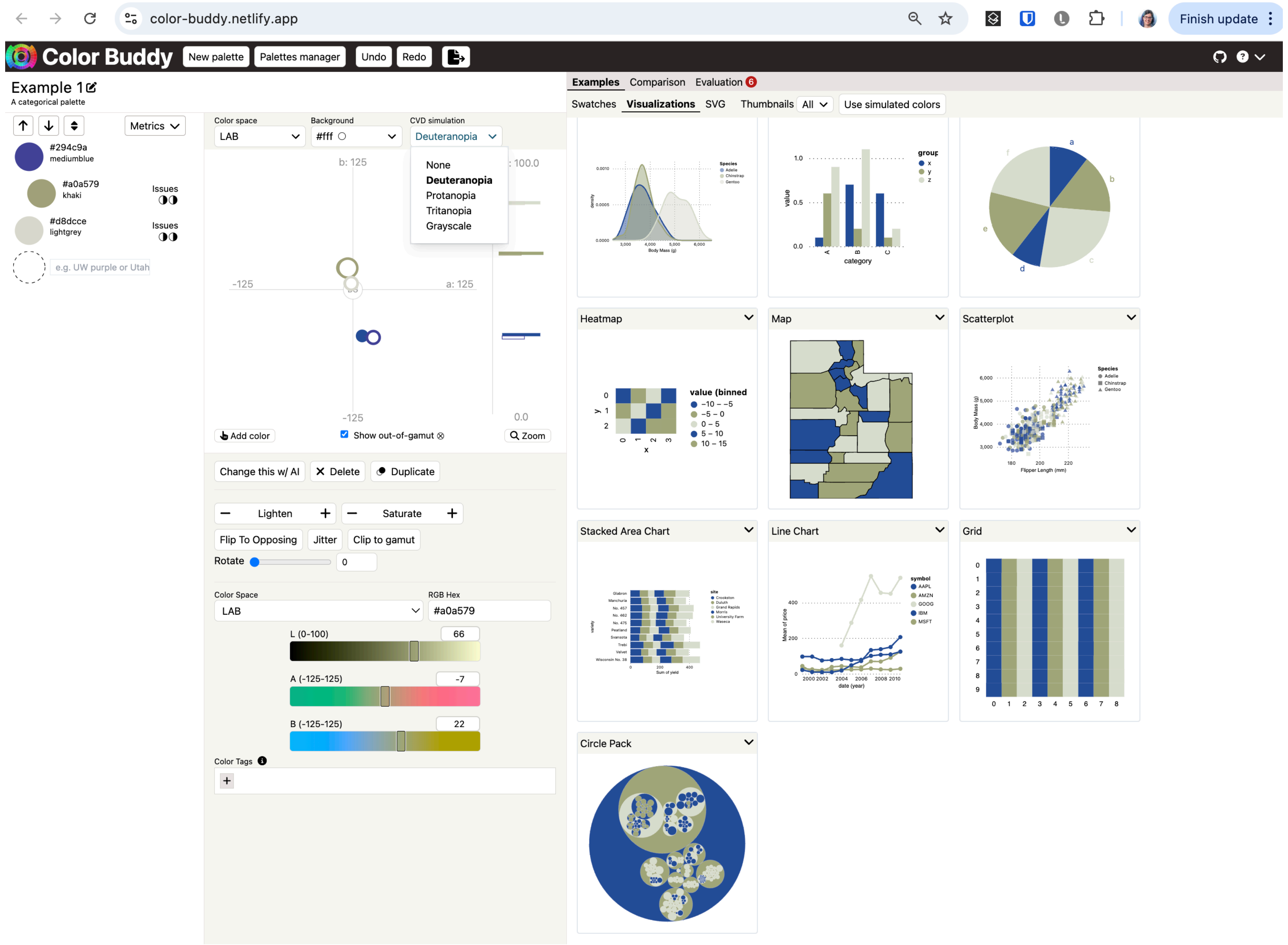
More color resources: Viz Palette

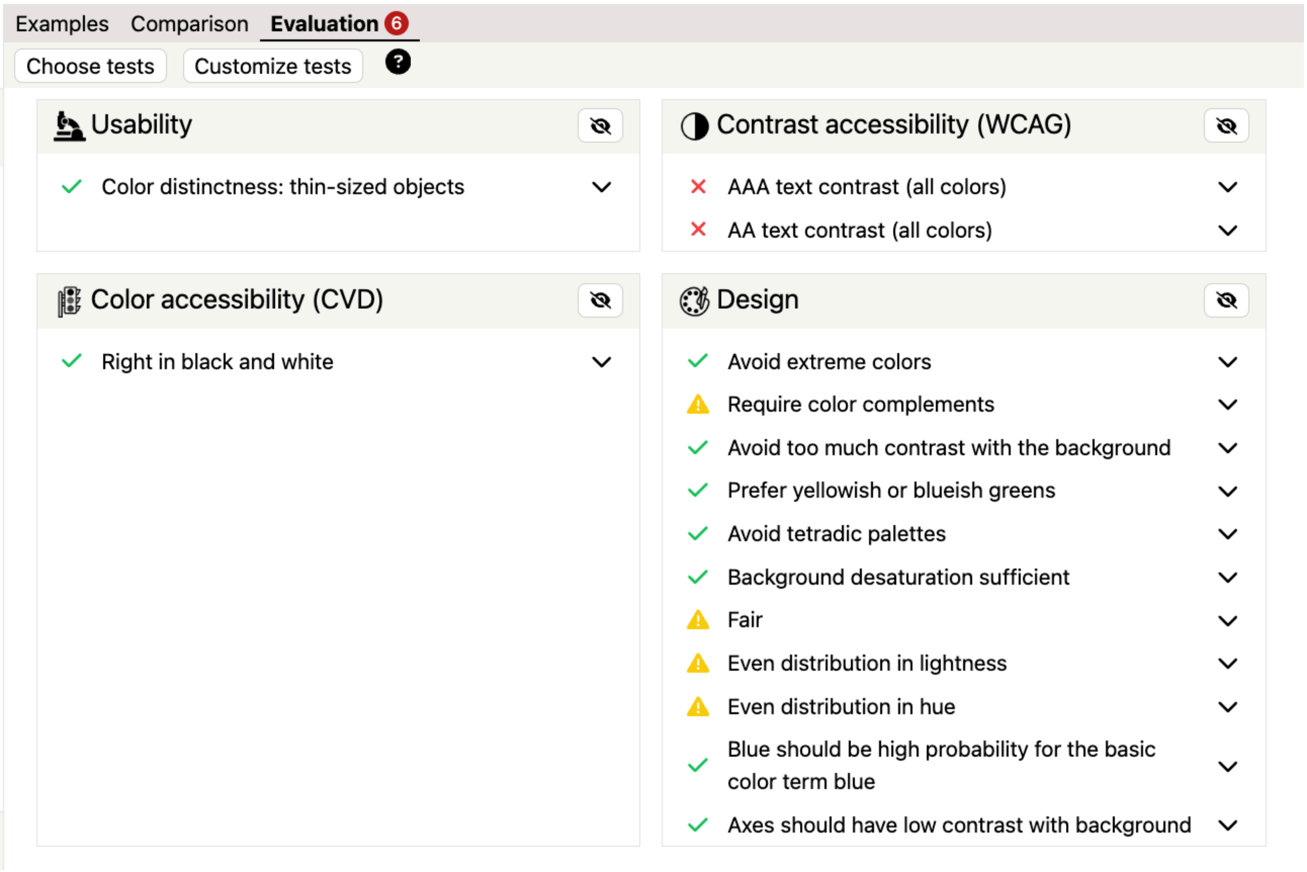
- Viz Palette, by Elijah Meeks and Susie Lu
  https://projects.susielu.com/viz-palette
  – colorblindness checks
  – examples for different mark sizes/types
  – report on distinguishability including names



More color resources: Color Buddy

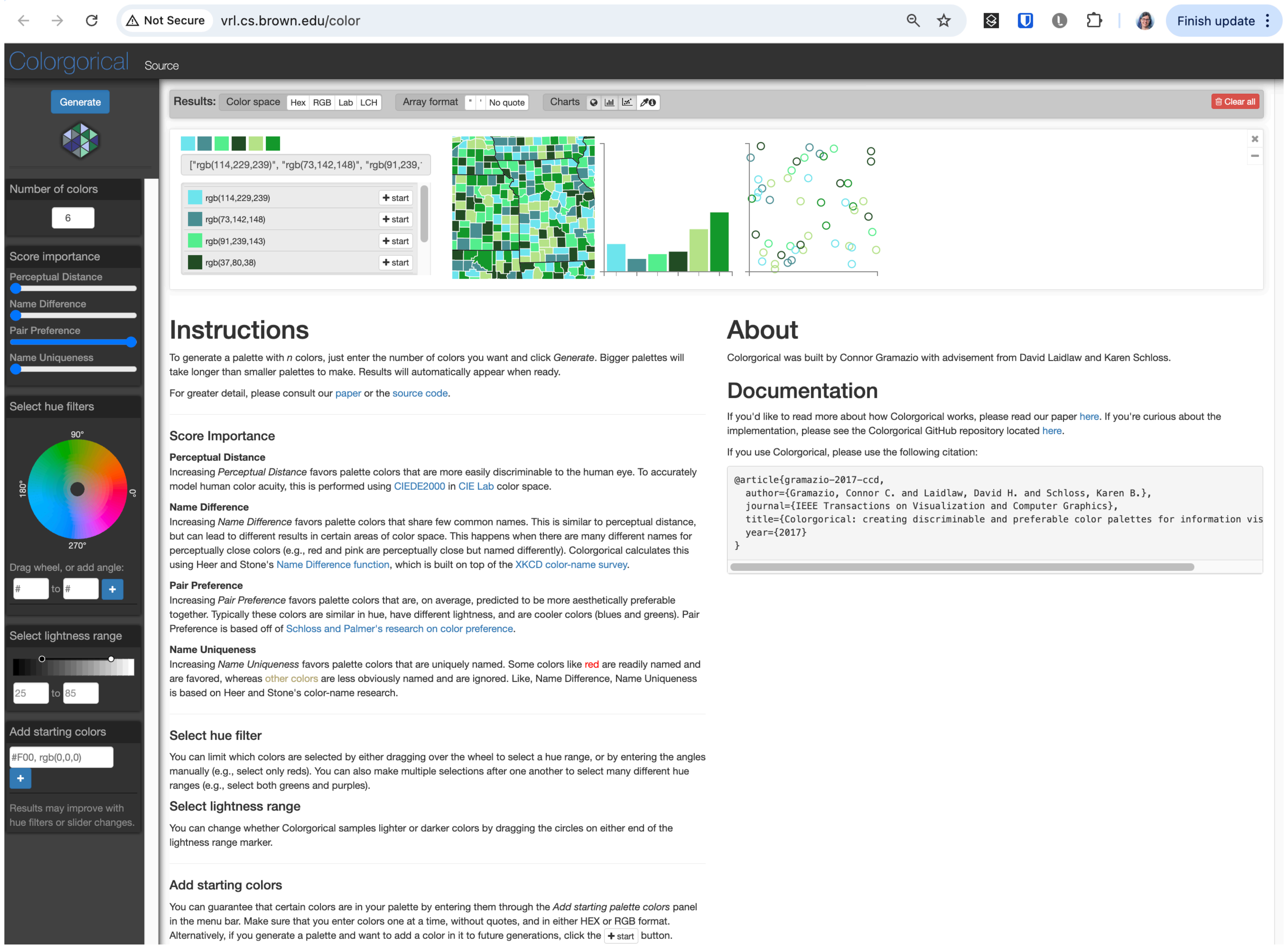
- Color Buddy, by Andrew McNutt and Maureen Stone
  https://color-buddy.netlify.app/
  - check against colorblindness
  - check different mark types/sizes
  - evaluate against design guidelines





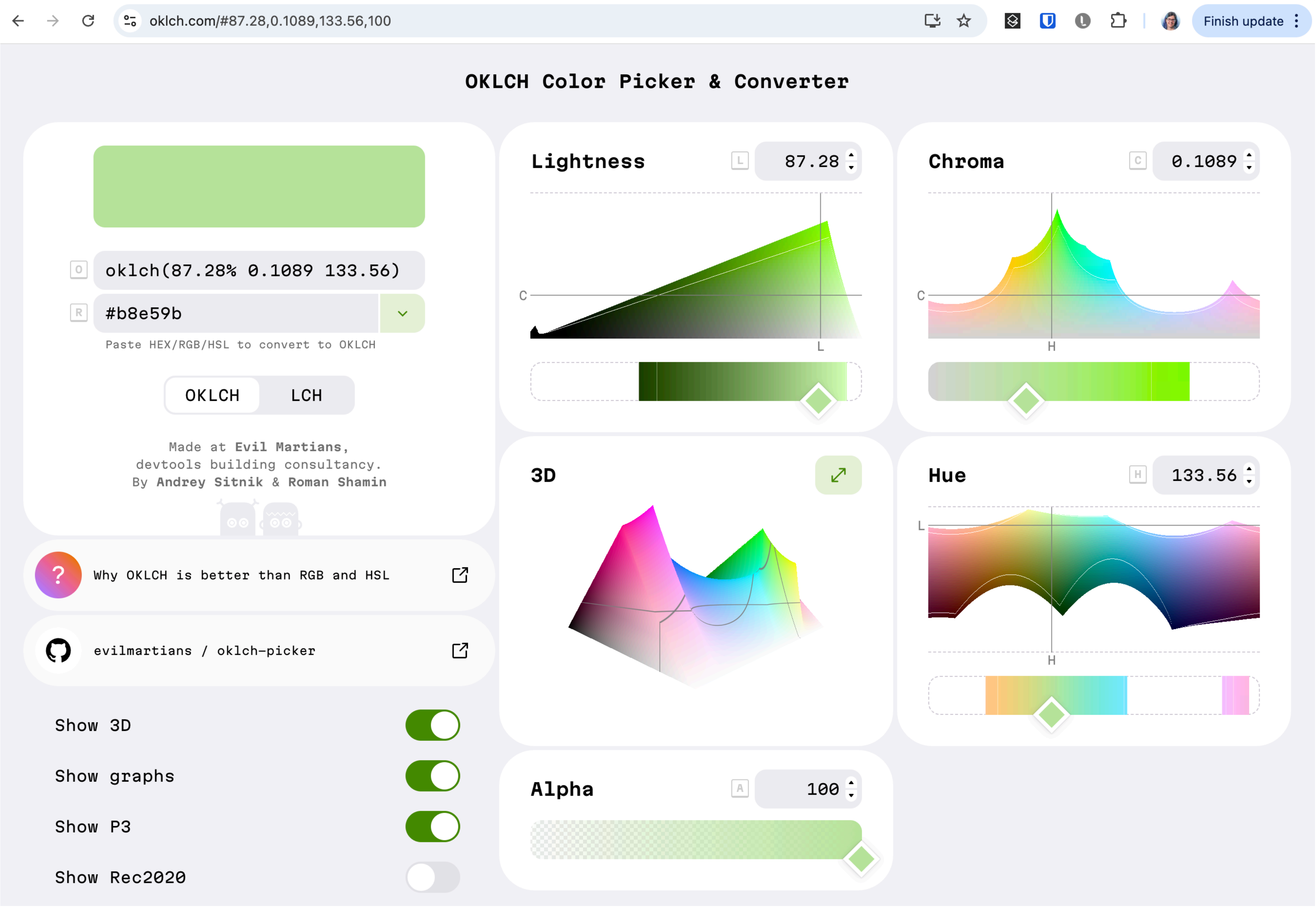
More color resources: Colorgorical

- Colorgorical, by Connor Gramazio
  http://vrl.cs.brown.edu/color
  - categorical color, including name



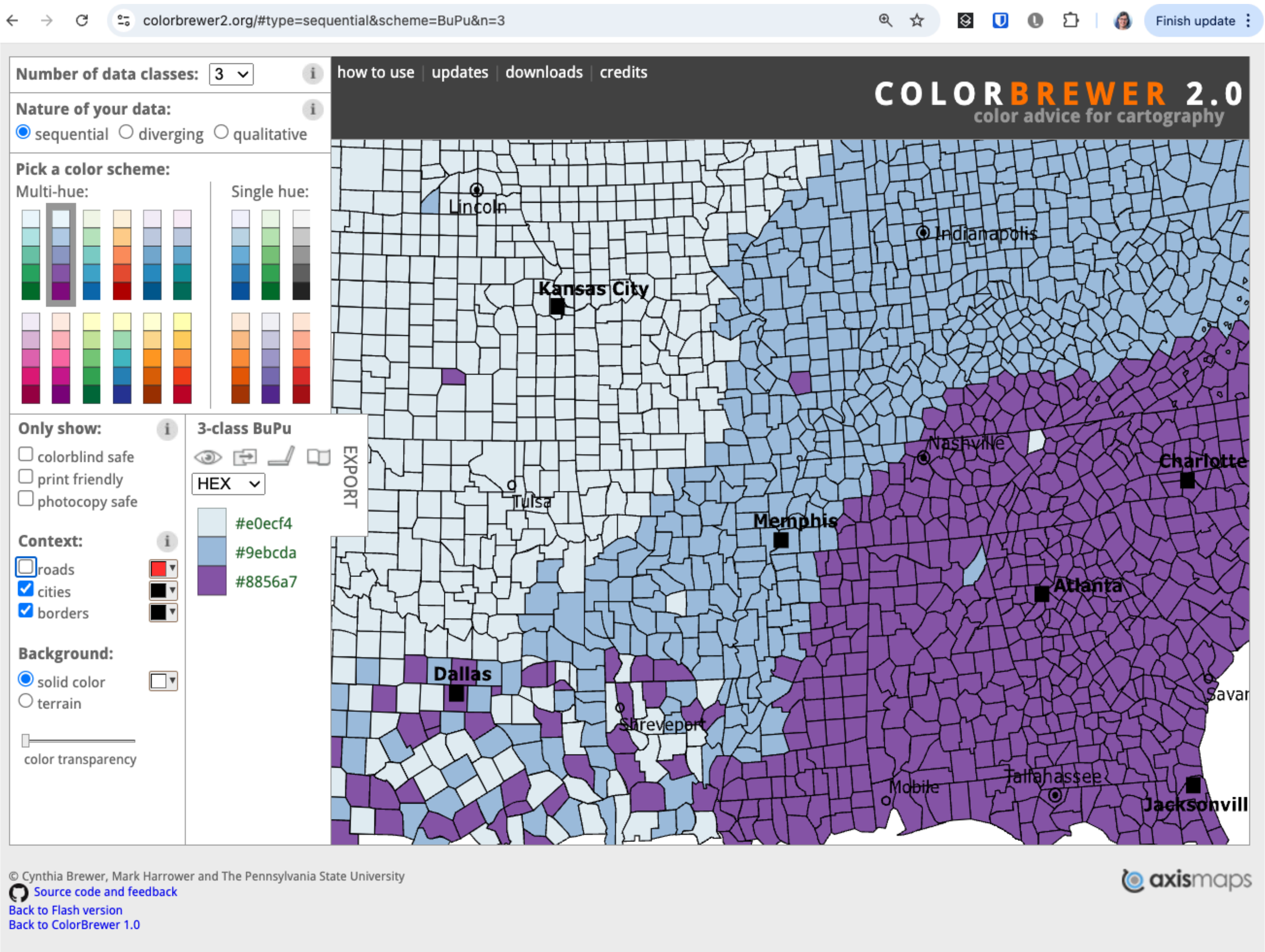
More color resources: oklch.com

- oklch perceptual space color picker/converter, by Andrey Sitnik & Roman Shamin (Evil Martians) https://oklch.com/
  - inspect color space itself



More color resources: ColorBrewer

- ColorBrewer, by Cynthia Brewer
  colorbrewer2.com



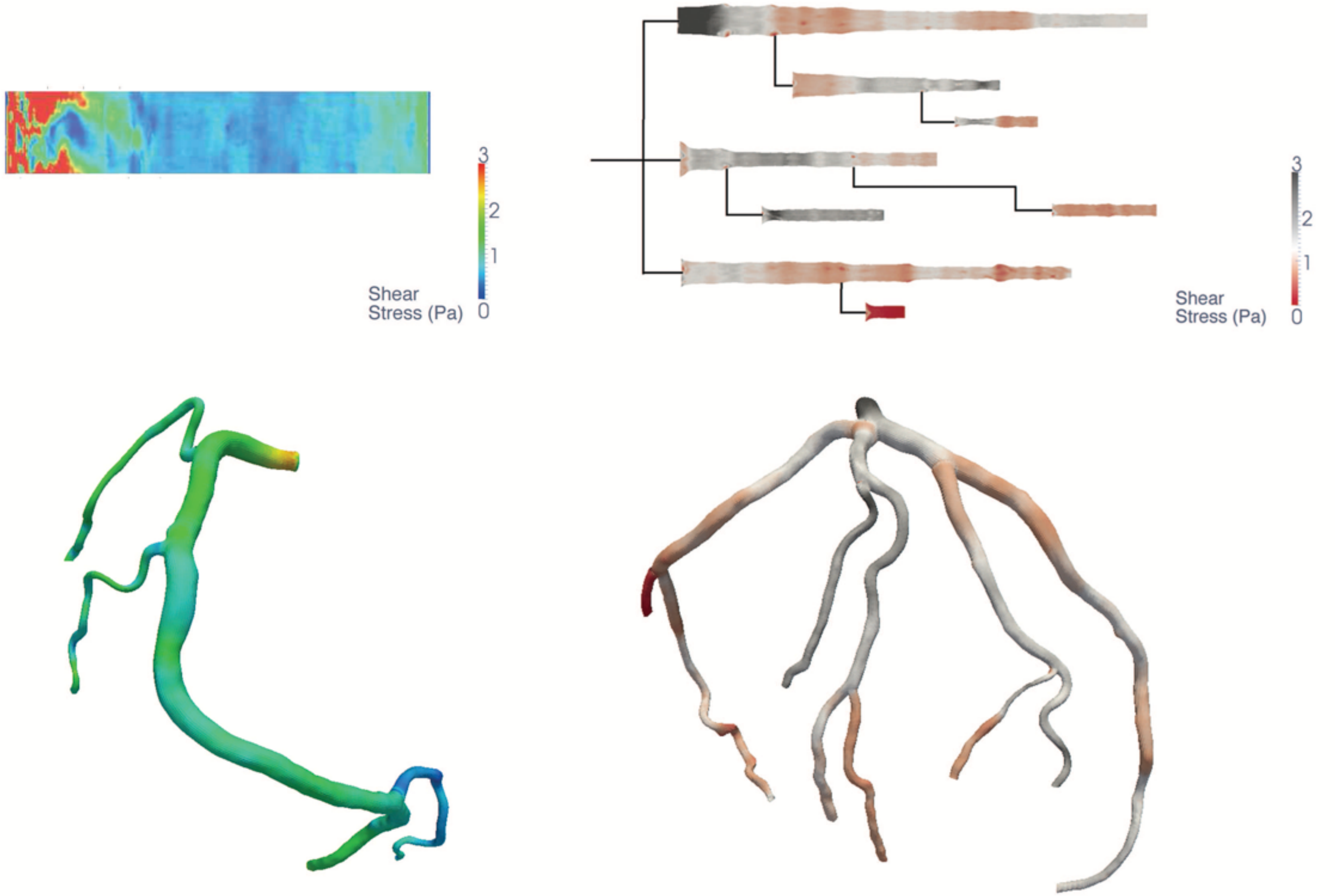
Breakouts

Break: 3:25-3:35

Artery Visualizations for Heart Disease Diagnosis

HemoViz: Design study + empirical evaluation

- C1 qual formative study with experts
  - task taxonomy
- C2 HemoViz design
- deploy attempt fails
  - experts balk: demand 3D and rainbows
- C3 quantitative user study
  - med students, real data
  - 91% with 2D/diverging vs 39% with 3D/rainbows
  - experts willing to use

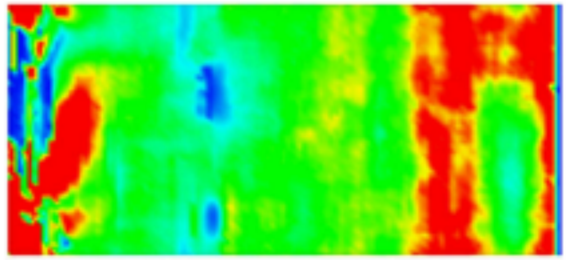


[Fig 1. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]

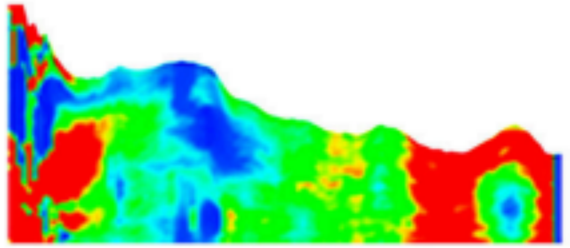
HemoVis tasks

- formative qual user study
- three projection alternatives
- result / contribution:
  (well justified) task taxonomy

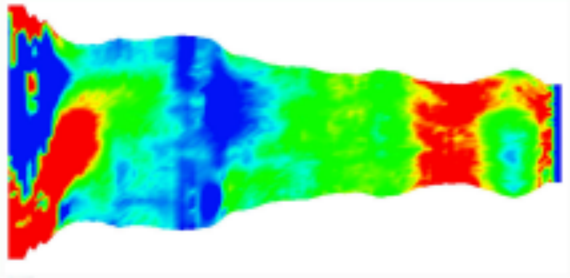
cylindrical



circumference
mapped to height



circumference
mapped symmetrically

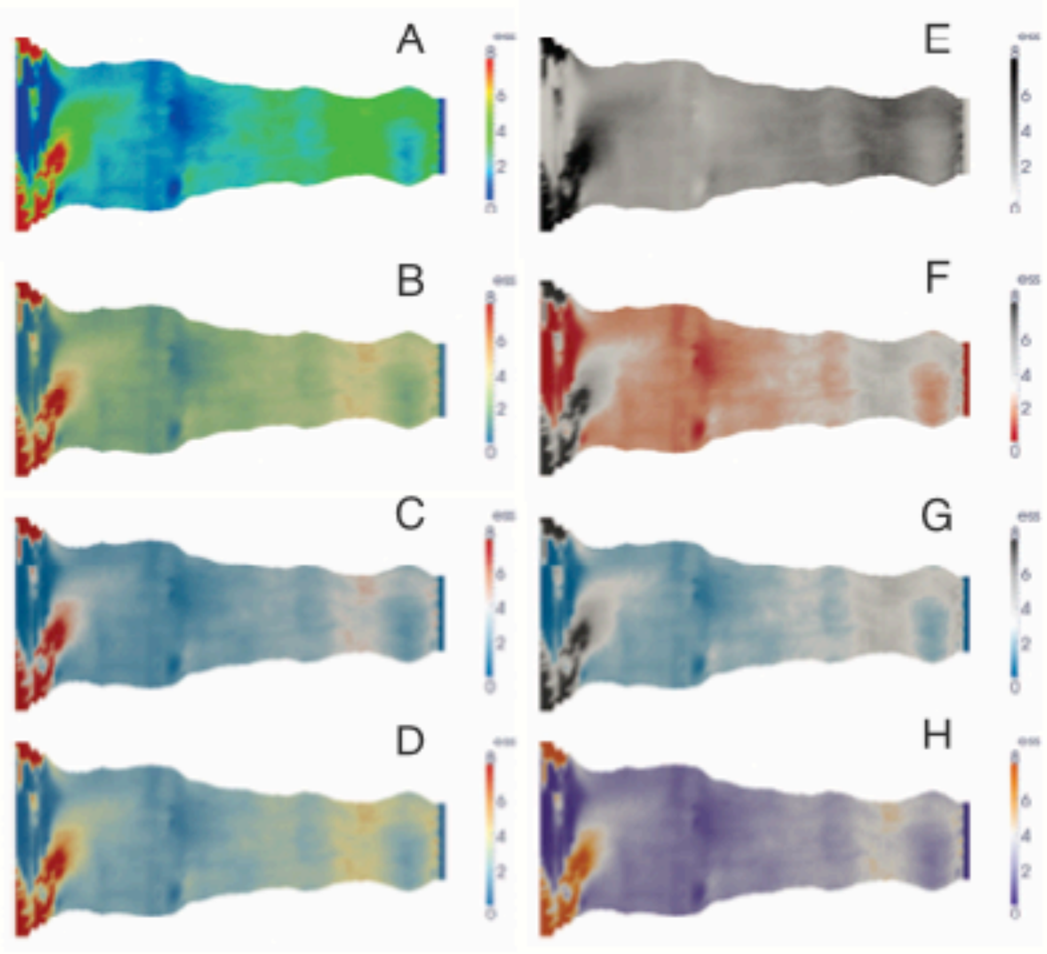


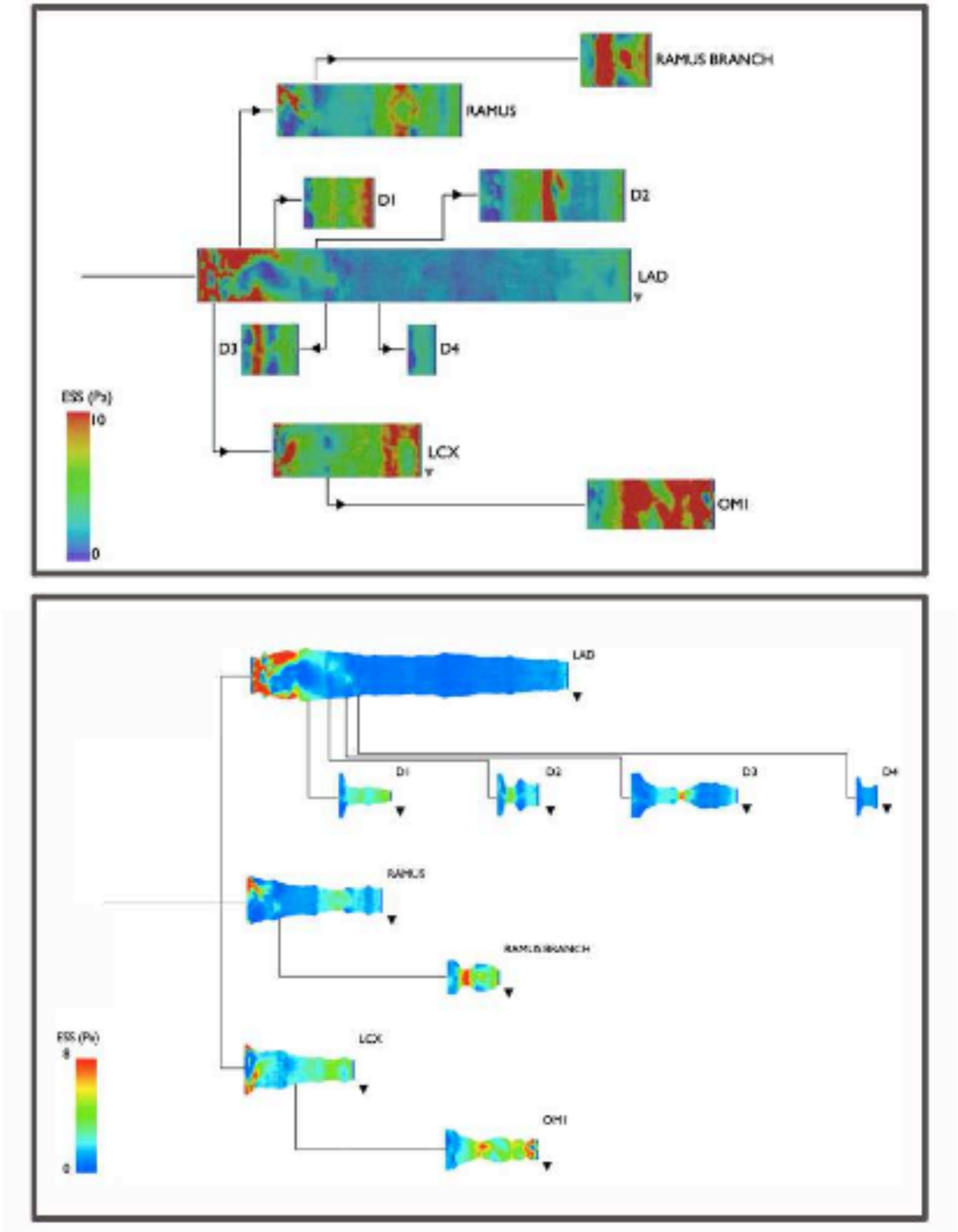
ID	Task	Clinical	Research
1	Identify stenosis or blockage	X	X
2	Identify regions of low ESS	X	X
3	View all ESS data for heterogeneous patterns	X	X
4	Study blood flow (velocity) patterns		X
5	Identify regions of blood recirculation		X
6	Investigate other physical variables of blood flow		X
7	Follow patient's disease progression	X	X

[Fig 2 & Table 1. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]

HemoVis design

- design evolution of tree layout
- color alternatives
  - A rainbow preferred
  - F red/black diverging
  - E greyscale misleading



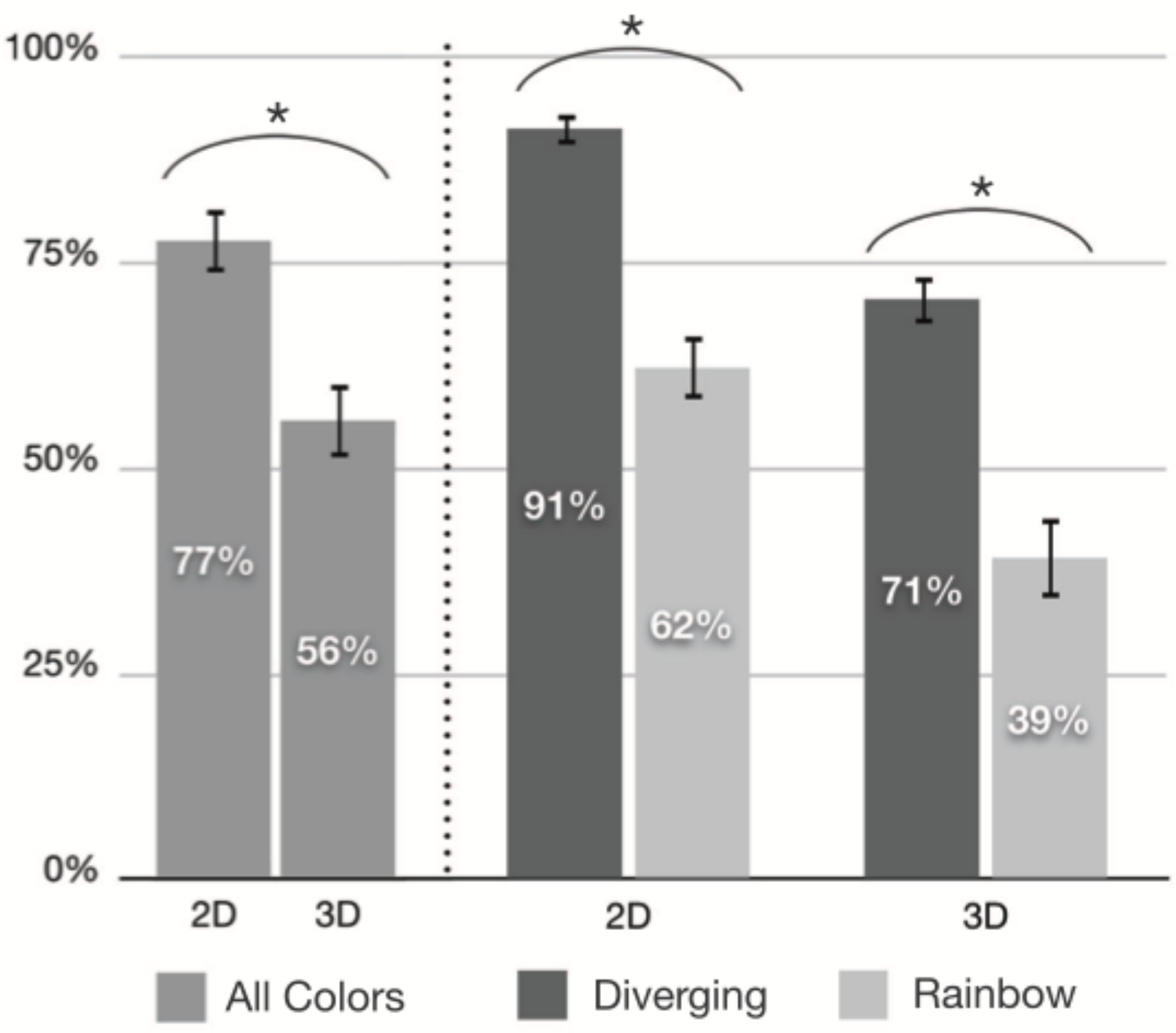


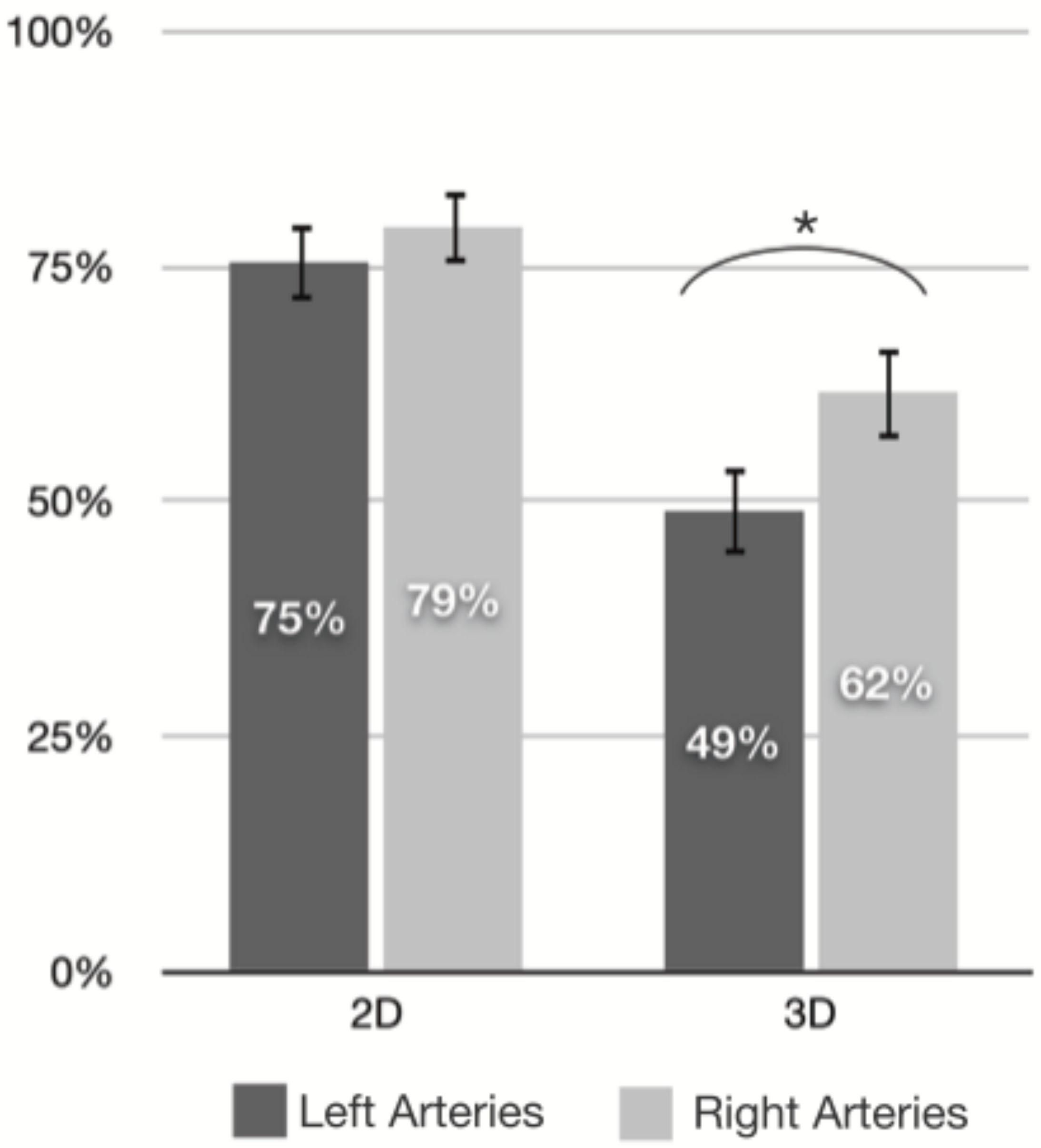
[Fig 3 & 4. Borkin et al. *Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.*]

Deployment

- typical design study: deploy, then validate effectiveness with case studies
- this project: target audience refused to use it, what to do?
  - quant study as ammunition to change minds

Study results: Accuracy

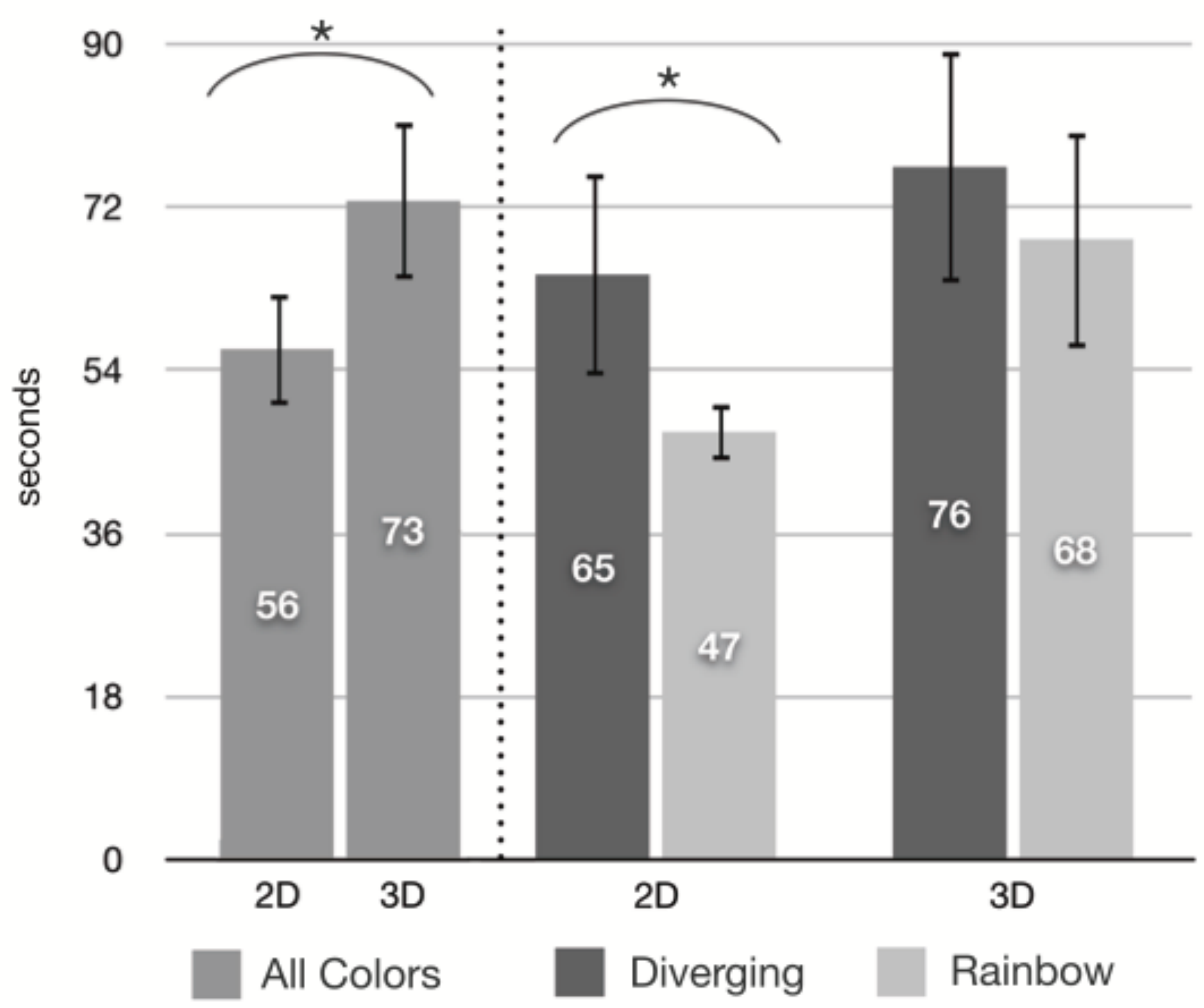




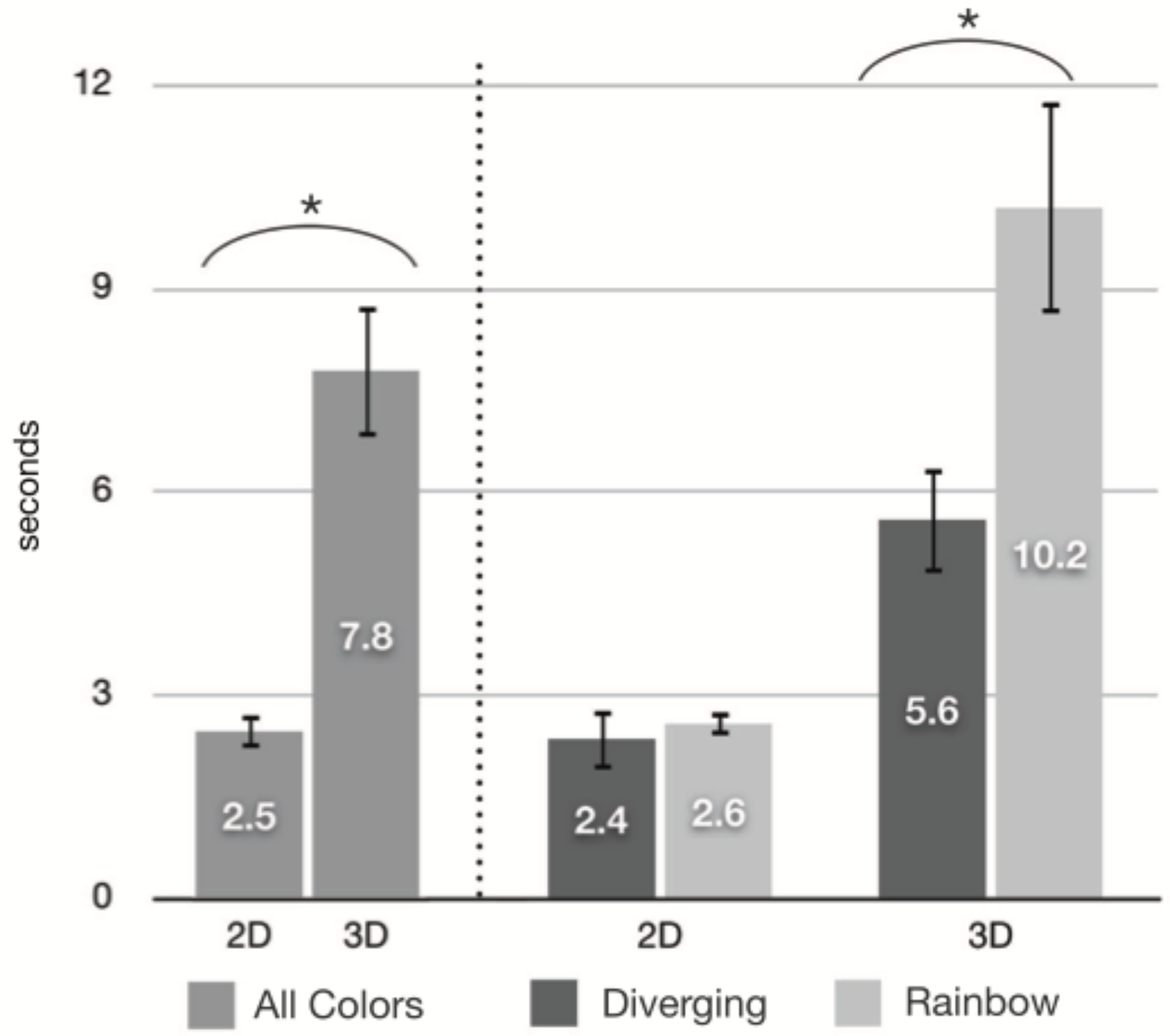
simple complex

Study results: Time

avg total time



time to identify low ESS region



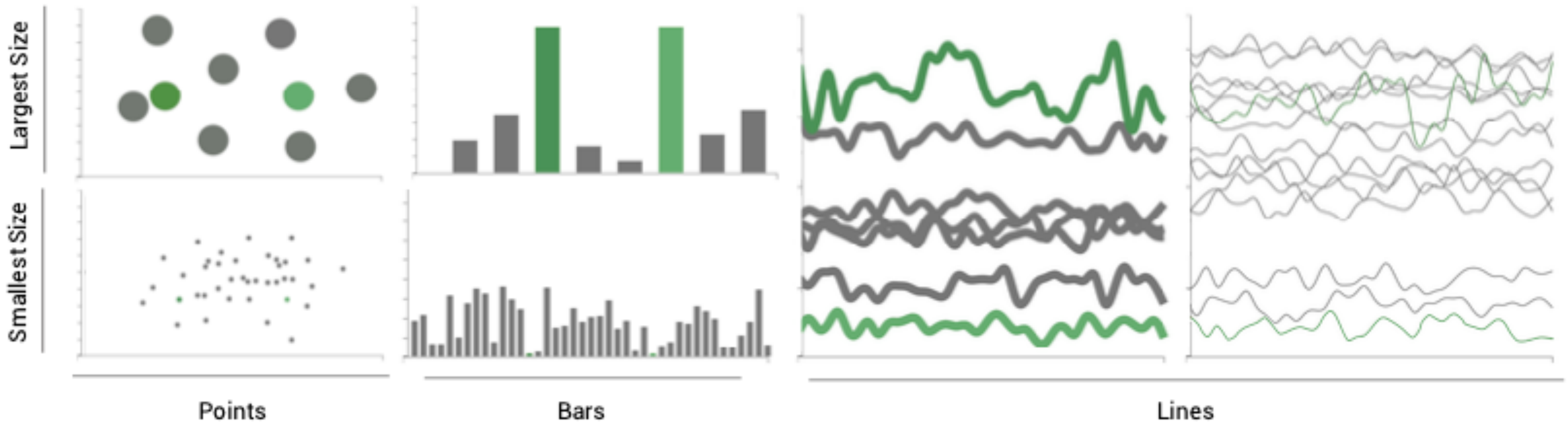
Critique

- many strengths
  - careful and well justified design, convincing human-subjects experiment
    - bringing visualization best practices to medical domain
- limitation
  - paper does not clearly communicate why colormap is diverging not sequential
    - answer by email
    - doctors care about extremely high and extremely low ESS (scalar) values
      - high values (top of scale, dark grey): extreme blood flow patterns may relate to heart malfunctions - but not imminently life threatening and don't indicate plaque locations
      - low values (bottom of scale, dark red): very diseased regions with lots of plaque, docs care a lot!
      - much debate from doctors on where is boundary between "normal" and "low" ESS values
        - » most think below 3 Pa are indicative of disease but many argue other values in the 2-4 range
        - » all docs agree that values below 2 Pa are increasingly dangerous disease levels
        - » thus map has transition at 3 Pa for the diverging point and truly red below 2 Pa
    - why continuous not segmented?
      - doctors gain tremendous insight by seeing the subtle patterning of the ESS values
      - particularly varying values in red region - patterns help them understand disease progression and severity
        - » especially useful for deciding what types of interventions to prescribe for the patient

Color Diff

Modeling Color Difference for Visualization Design

- evaluation paper: very careful quant study
  - factors (independent variables): mark size, color difference, colourspace axis (L*a*b*)
  - dependent measure: discriminability rate (proportion where diff correctly recognized)
  - vision science methodology: JNDs, binary forced-choice
  - model includes mark type and size



Challenges for vision science vs visualization

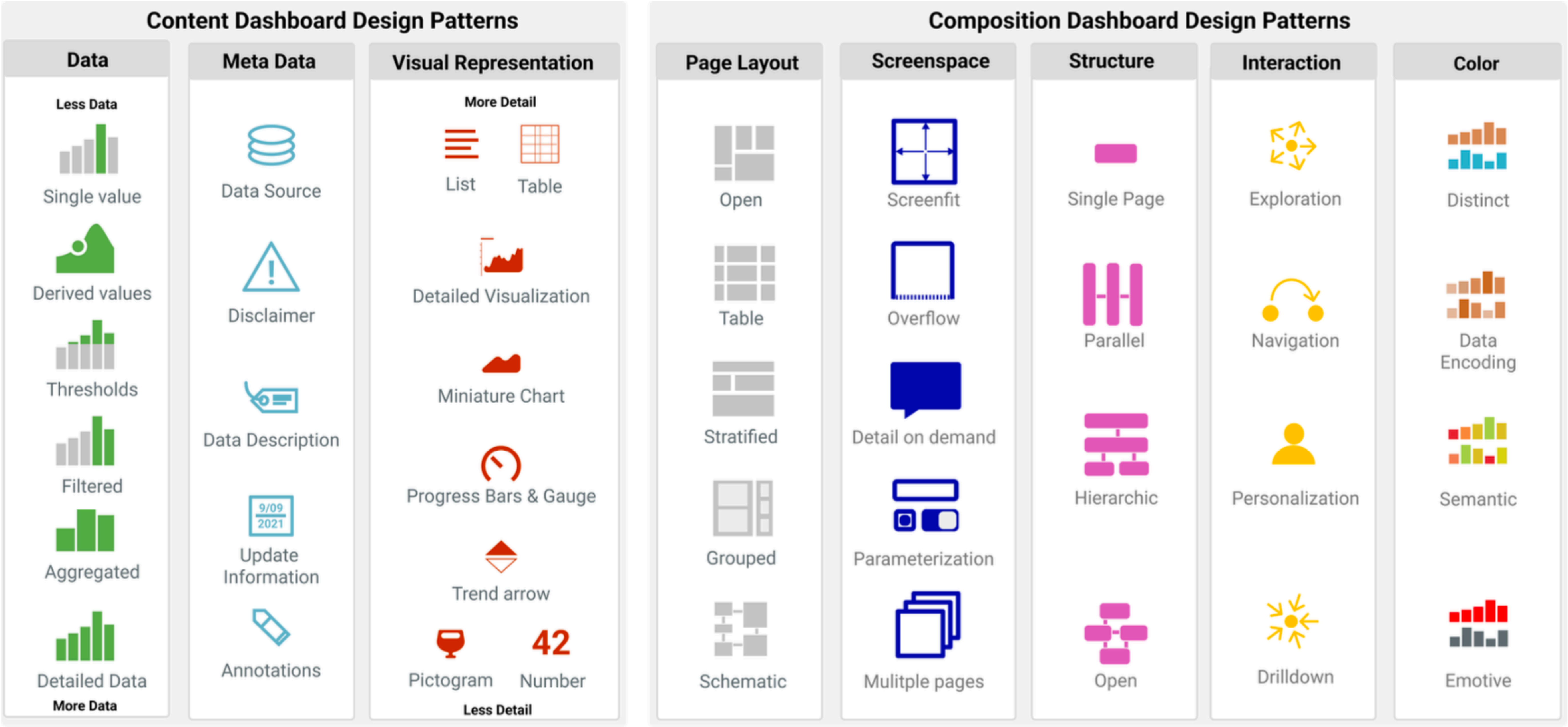
- Simple World Assumption
  - most pw: perfect viewing conditions
  - here: real-world / anywhere, via crowdsourcing
- Isolation Assumption
  - pw: one or two isolated color patches
  - here: visually complex, including distractor marks
- Geometric Assumption
  - pw: all patches same size/shape
  - here: disparate sizes & shapes, varying systematically

- result: models that take size & mark type into account

Dashboard Design Patterns

Dashboard design patterns

- Dashboard Design Patterns. Bach, Freeman, Abdul-Rahman, Turkay, Khan, Fan, and Chen. IEEE TVCG (Proc. VIS 2022) 29(1):342-352, 2023

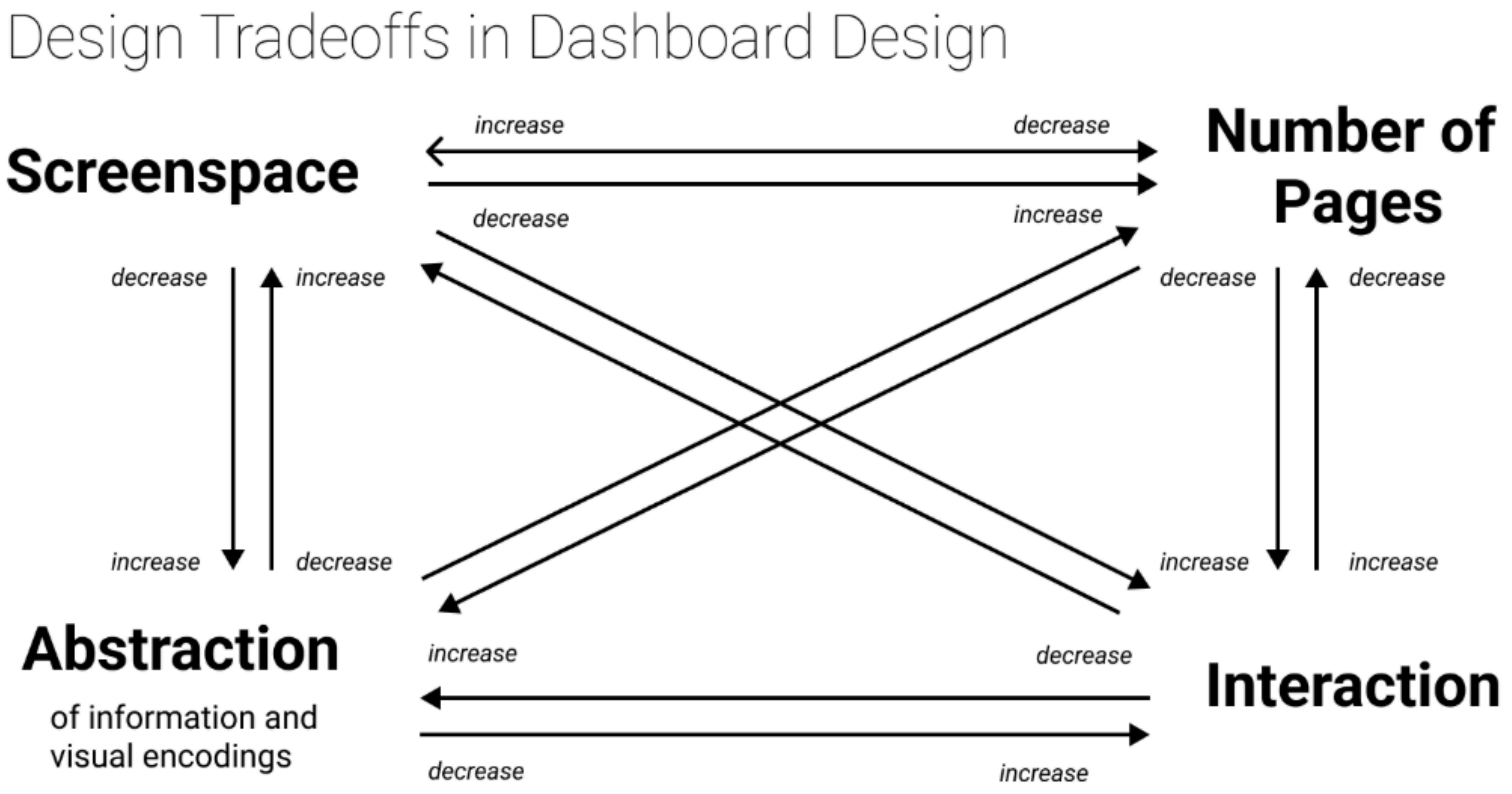


[Fig 1. Bach et al, Dashboard Design Patterns, IEEE VIS 2022, (TVCG 2023)]

Methods

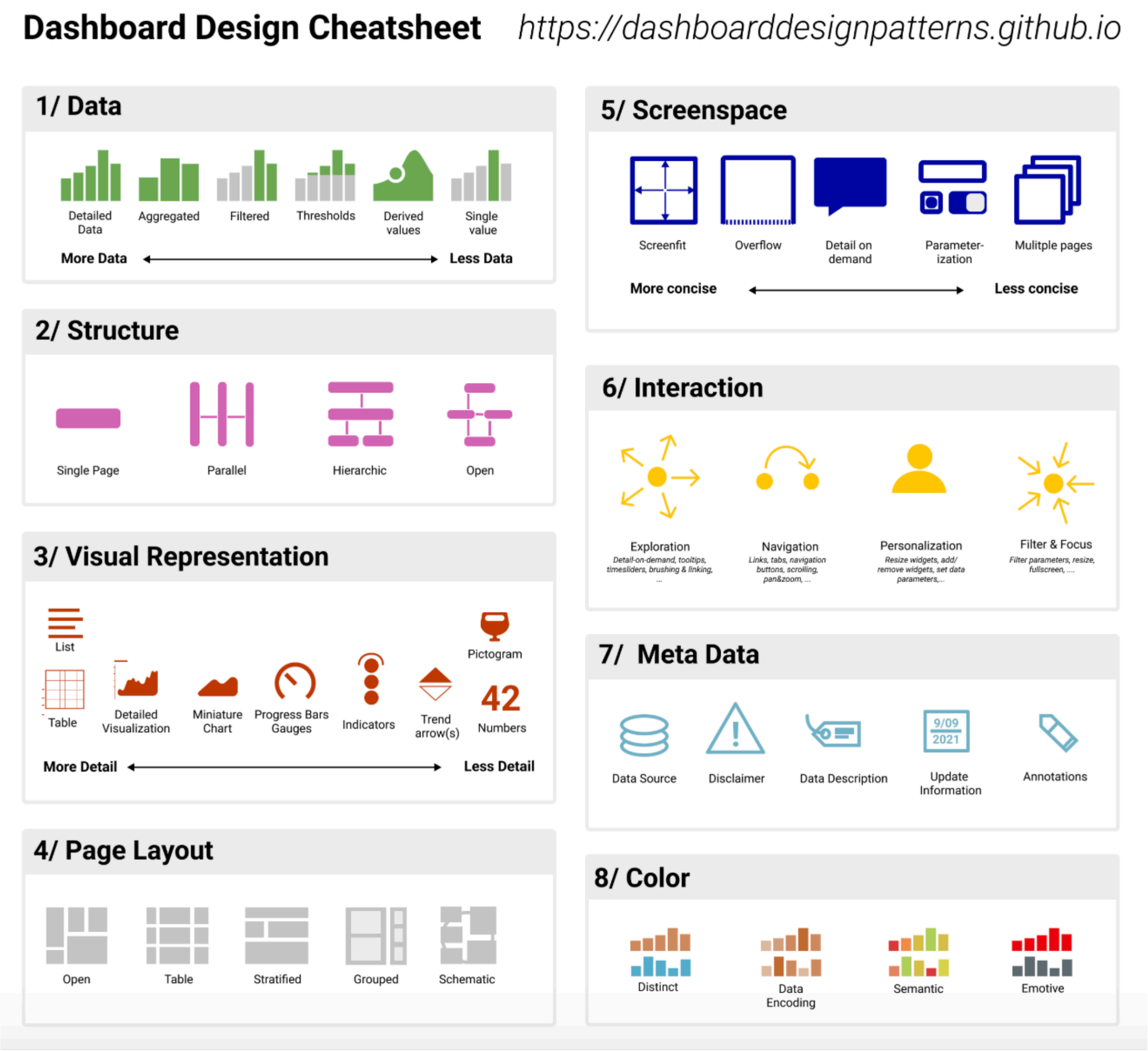
- design space through qualitative analysis
  - systematic review of corpus (144 dashboards)
    - open coding from 3 authors independently
    - refined through iteration with other 3 authors
    - (fewer methods details than some other design space papers)
  - 42 patterns grouped into 8 categories
  - 6 genres
  - design tradeoffs between 4 parameters
  - guidelines (20 & 8)
- evaluation
  - design workshops with 23 participants
  - author experience creating 7000 dashboards

Design tradeoffs



Supplemental materials

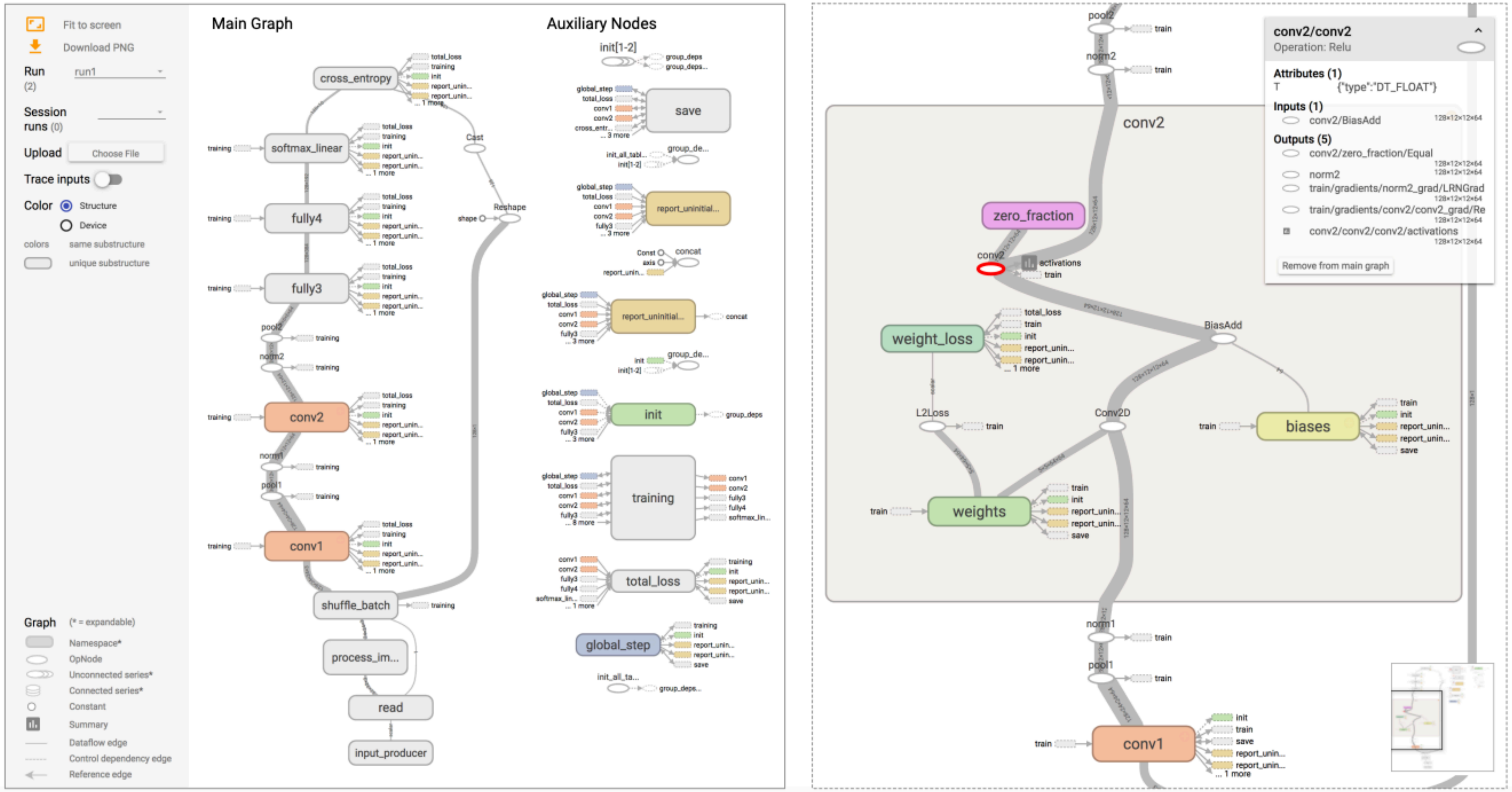
- power of rich supplemental materials
  https://dashboarddesignpatterns.github.io/
- many design space papers now have browsable interfaces
  - Timelines Revisited
  - Multiscale Vis



TensorFlow

TensorFlow

- design study: ML explainability
- embed

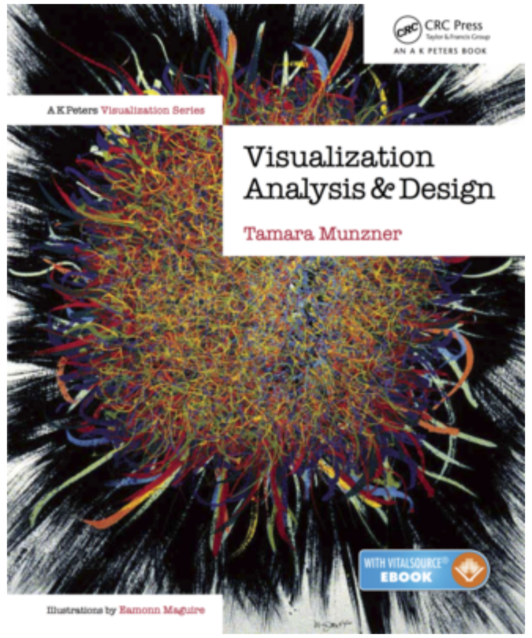


(a) (b)

[Visualizing Dataflow Graphs of Deep Learning Models in TensorFlow. Wongsuphasawat, Smilkov, Wexler, Wilson, Mané, Fritz, Krishnan, Viégas, and Wattenberg. IEEE TVCG (Proc. VAST 2017) 24(1):1-12, 2018.]

Q&A / Backup Slides

Visualization Analysis & Design



Color (Ch 10)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

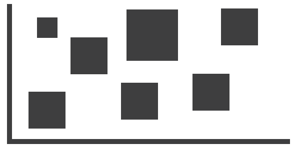
Idiom design choices: Visual encoding

Encode

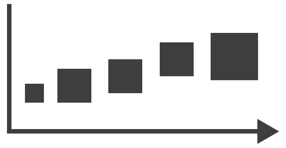
Arrange

→ Express

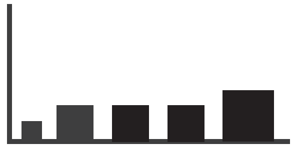
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

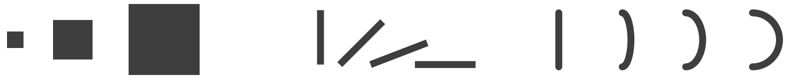
→ Color

→ *Hue*

→ *Saturation*

→ *Luminance*

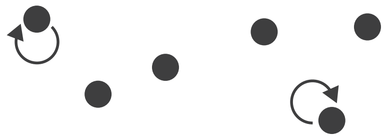
→ Size, Angle, Curvature, ...

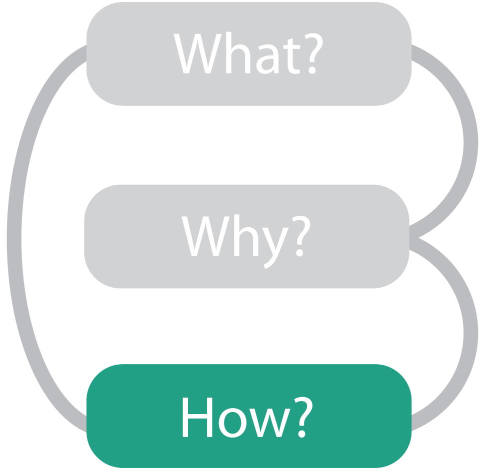


→ Shape

→ Motion

Direction, Rate, Frequency, ...





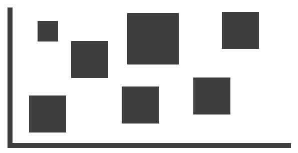
Idiom design choices: Beyond spatial arrangement

Encode

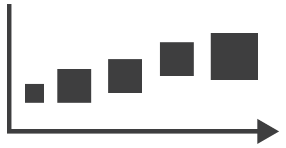
Arrange

→ Express

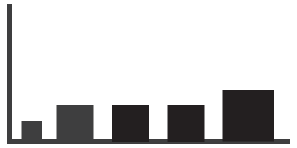
→ Separate



→ Order



→ Align



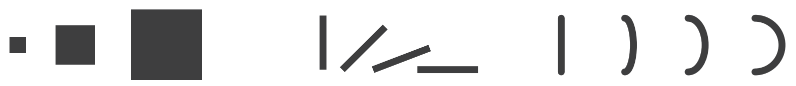
→ Use

Map
from categorical and ordered attributes

→ Color

→ *Hue* → *Saturation* → *Luminance*

→ Size, Angle, Curvature, ...



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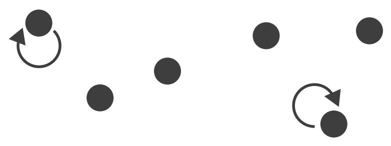
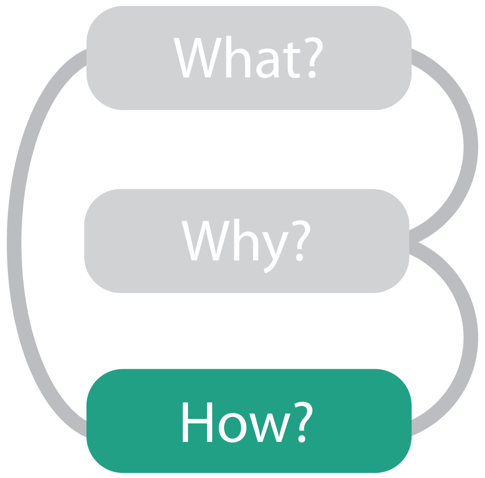
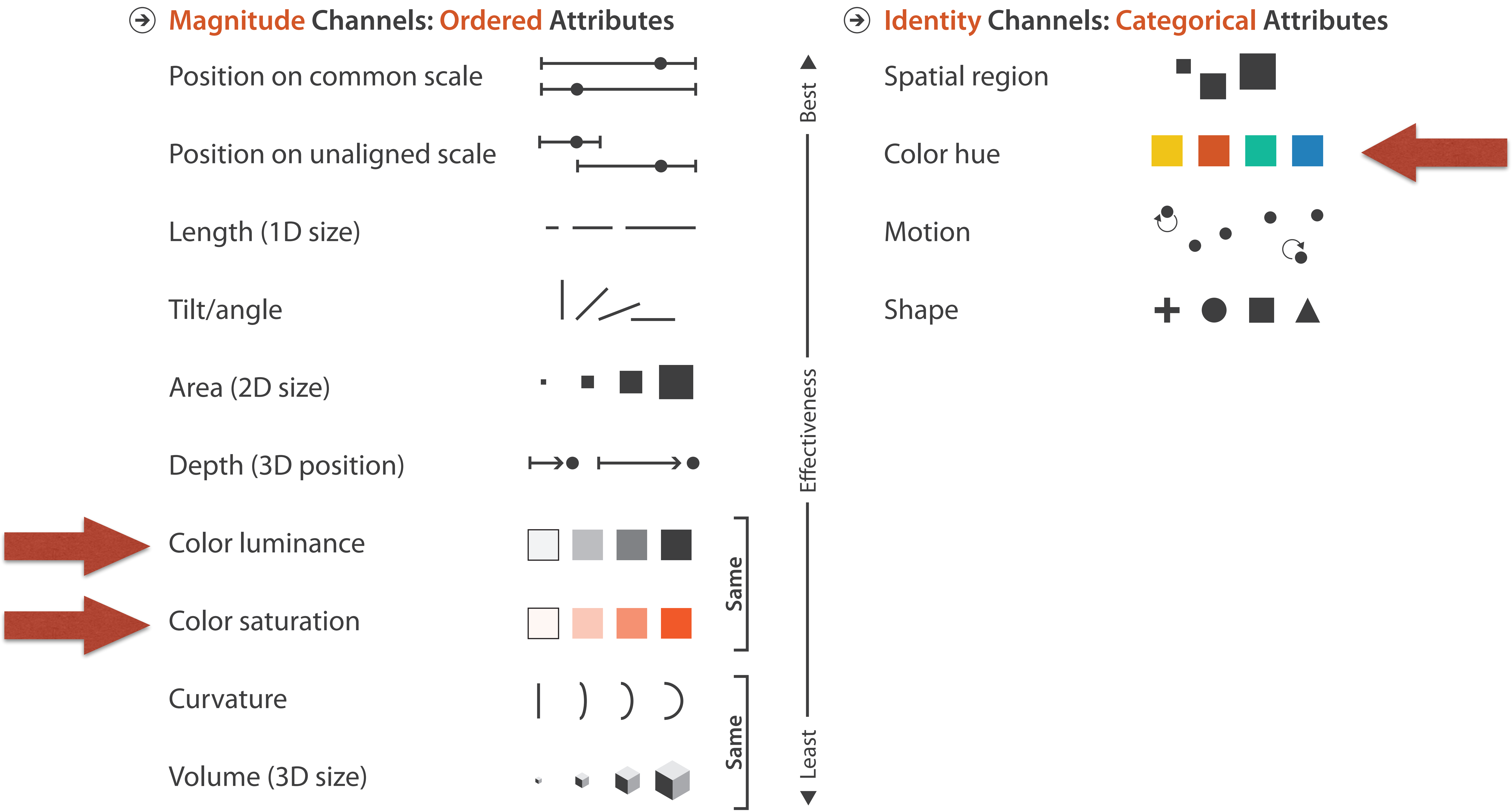
Direction, Rate, Frequency, ...





Channels: What's up with color?



Decomposing color

Decomposing color

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

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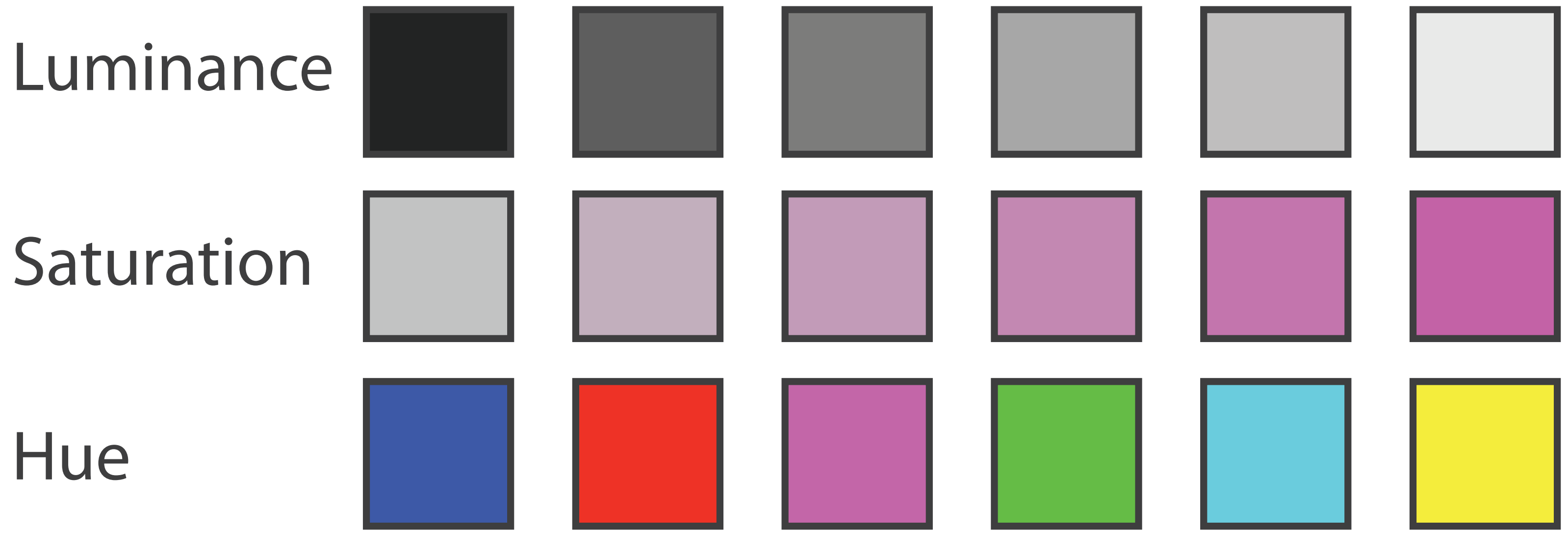
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



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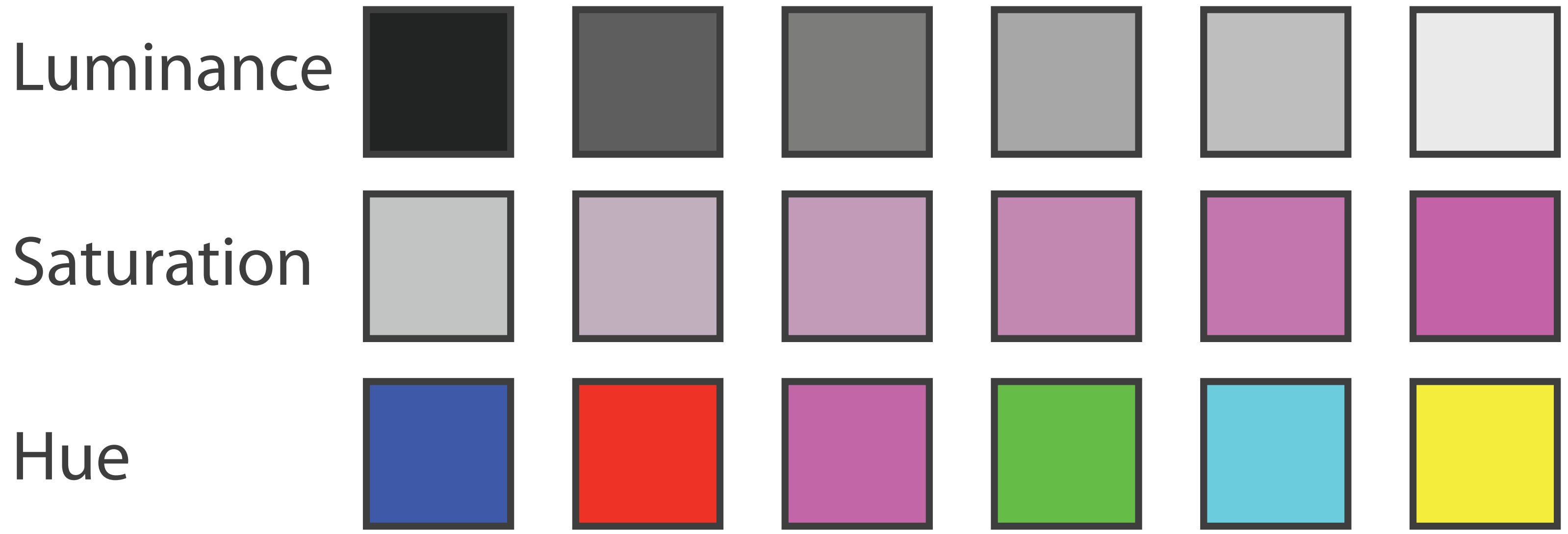
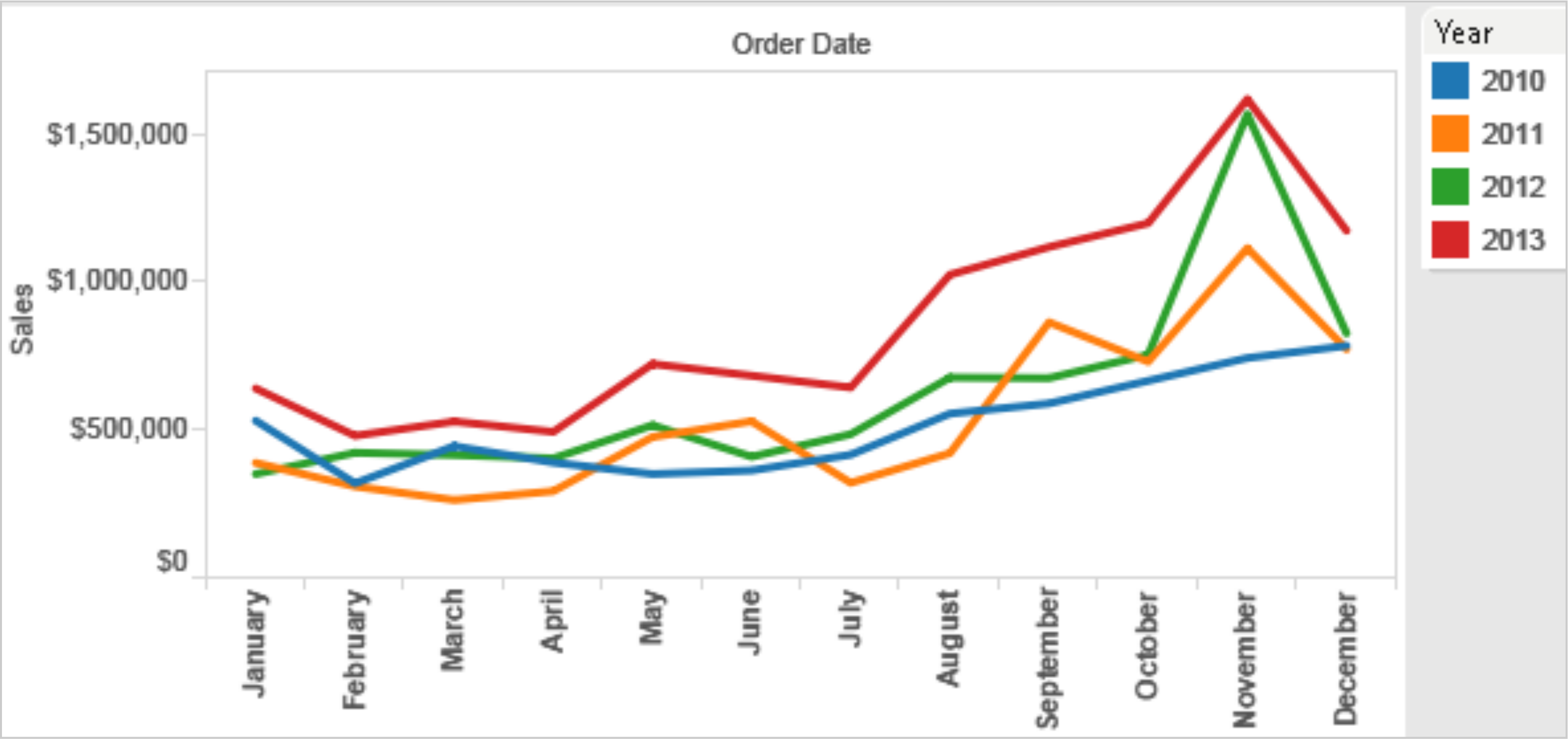
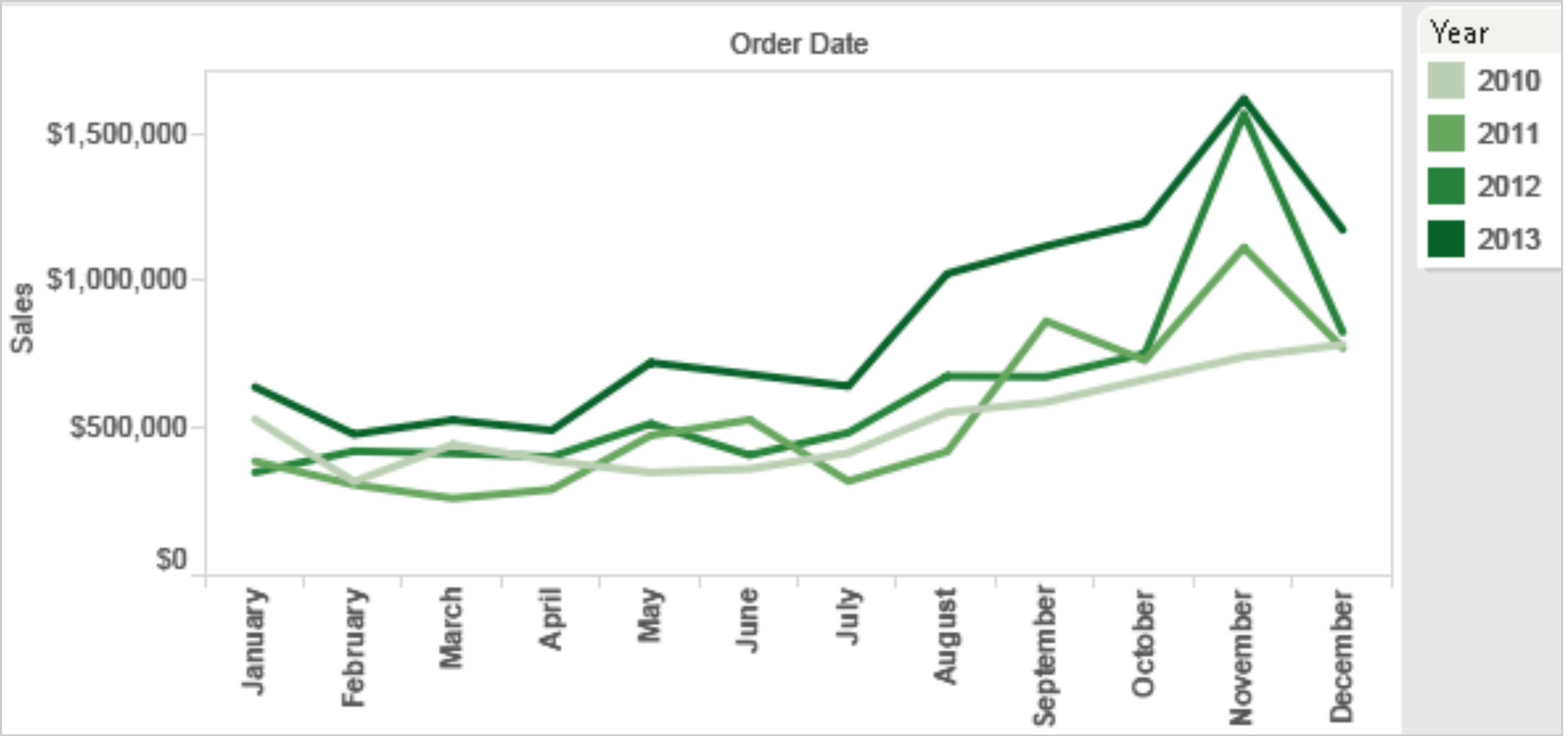


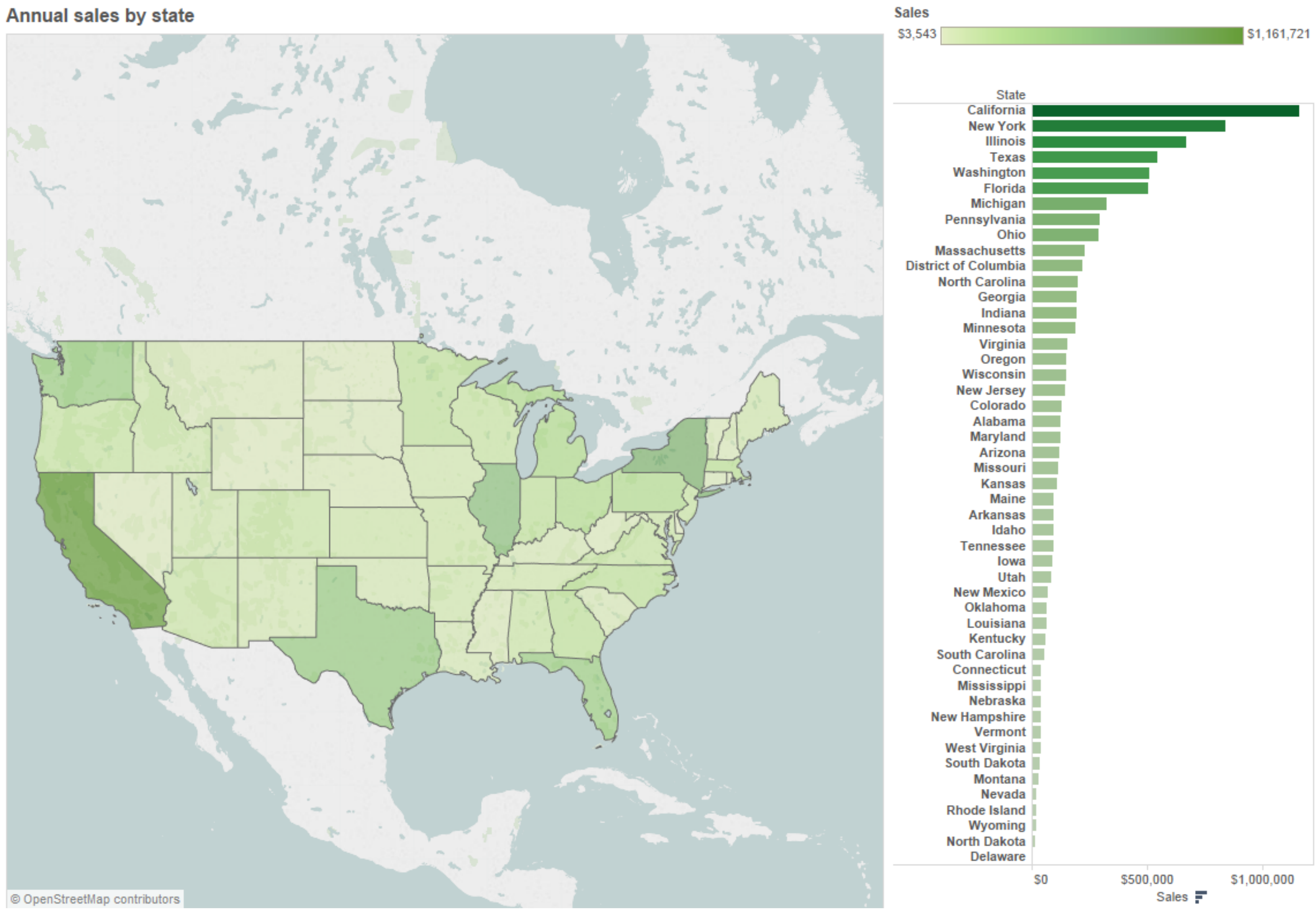
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable bins can we use?

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.]

Categorical color: limited number of discriminable bins

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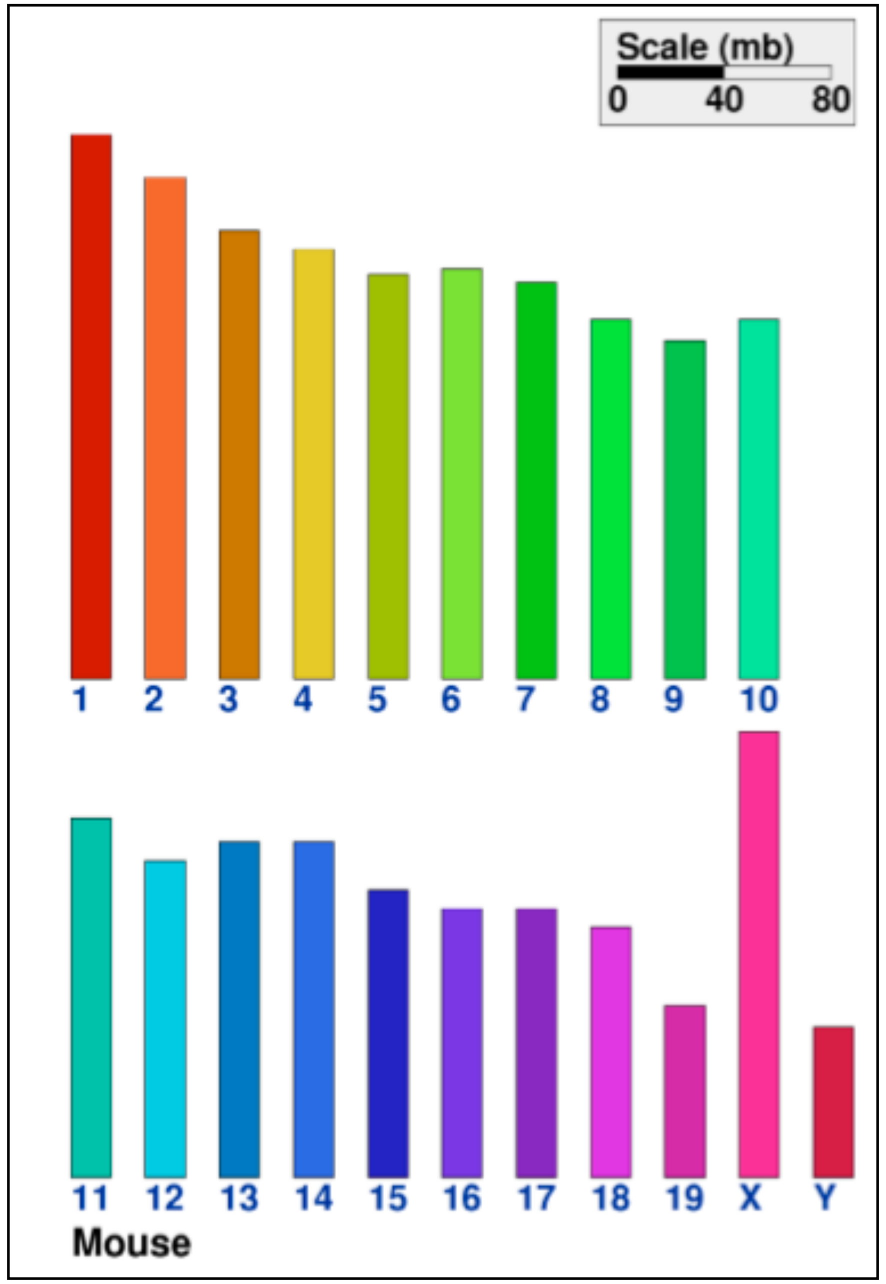

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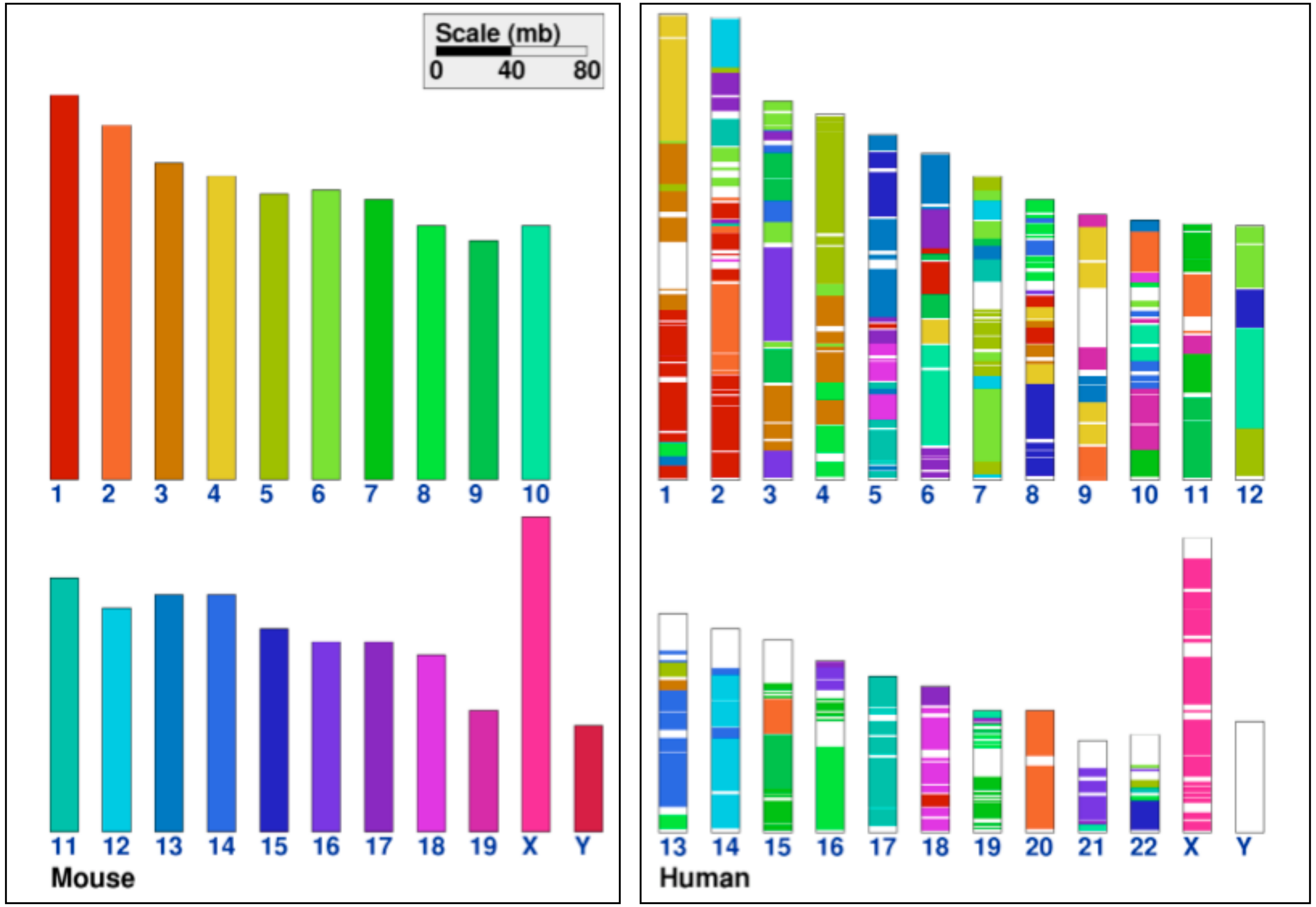

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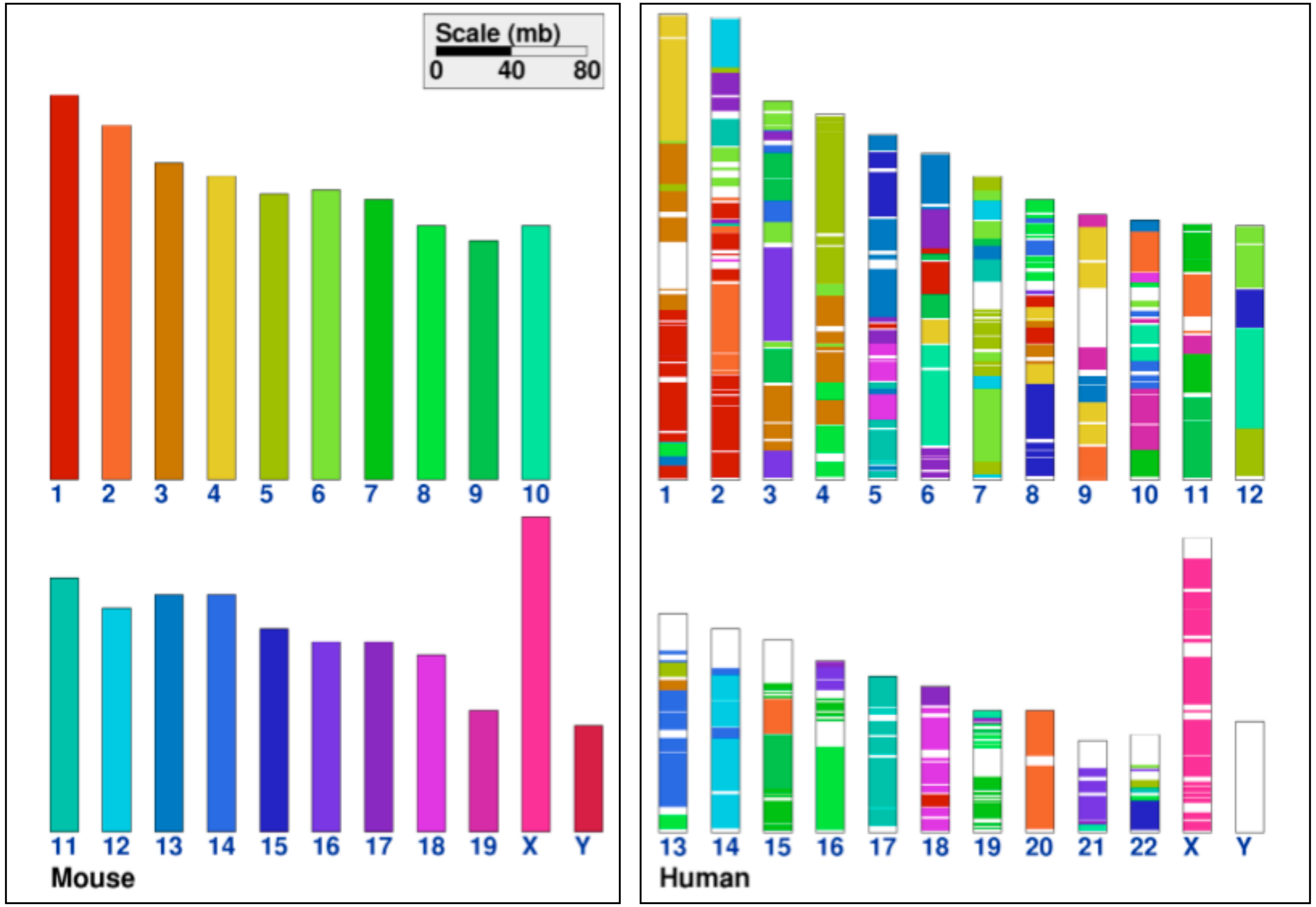
Categorical color: limited number of discriminable bins

- 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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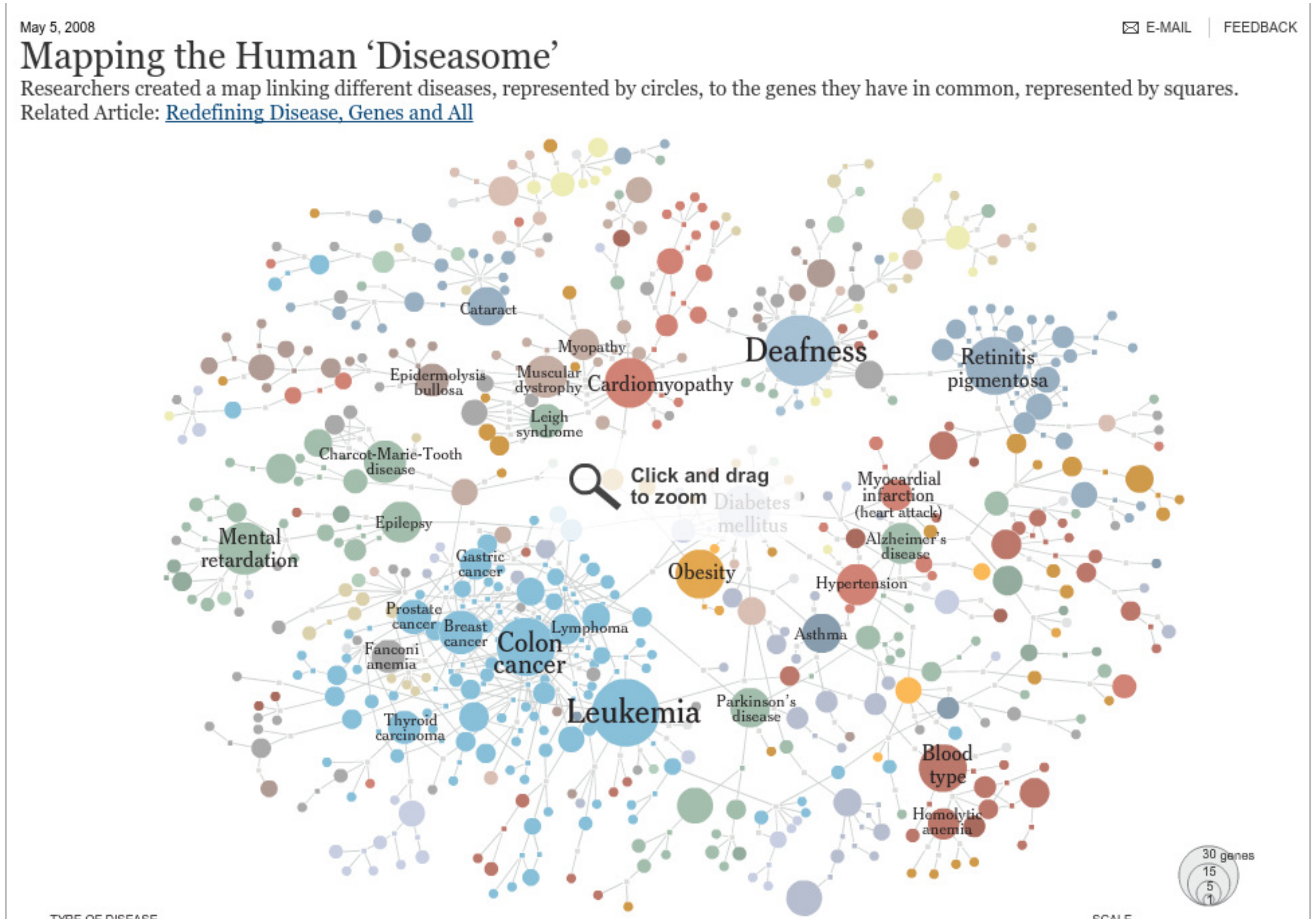
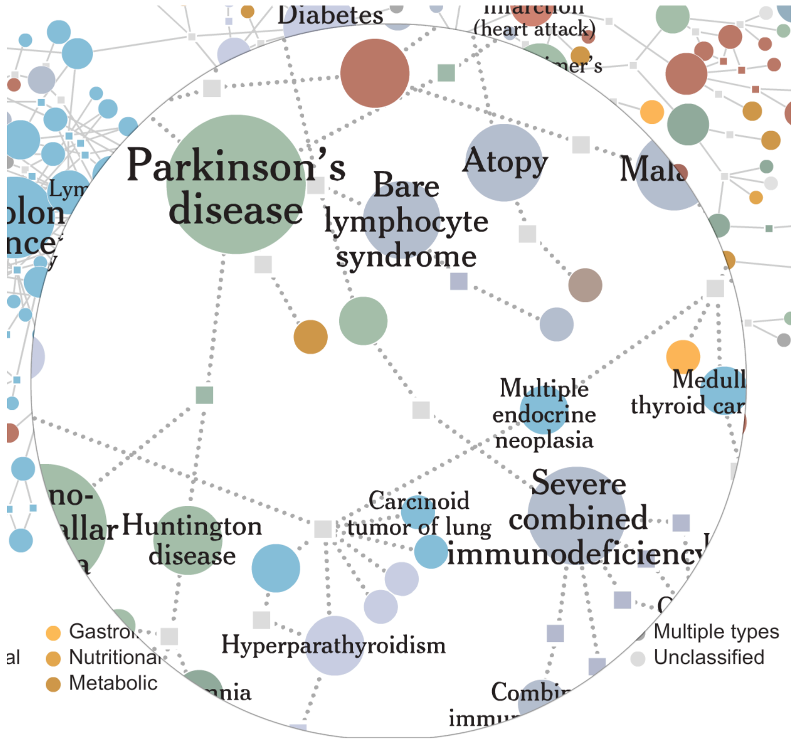
Categorical color: limited number of discriminable bins

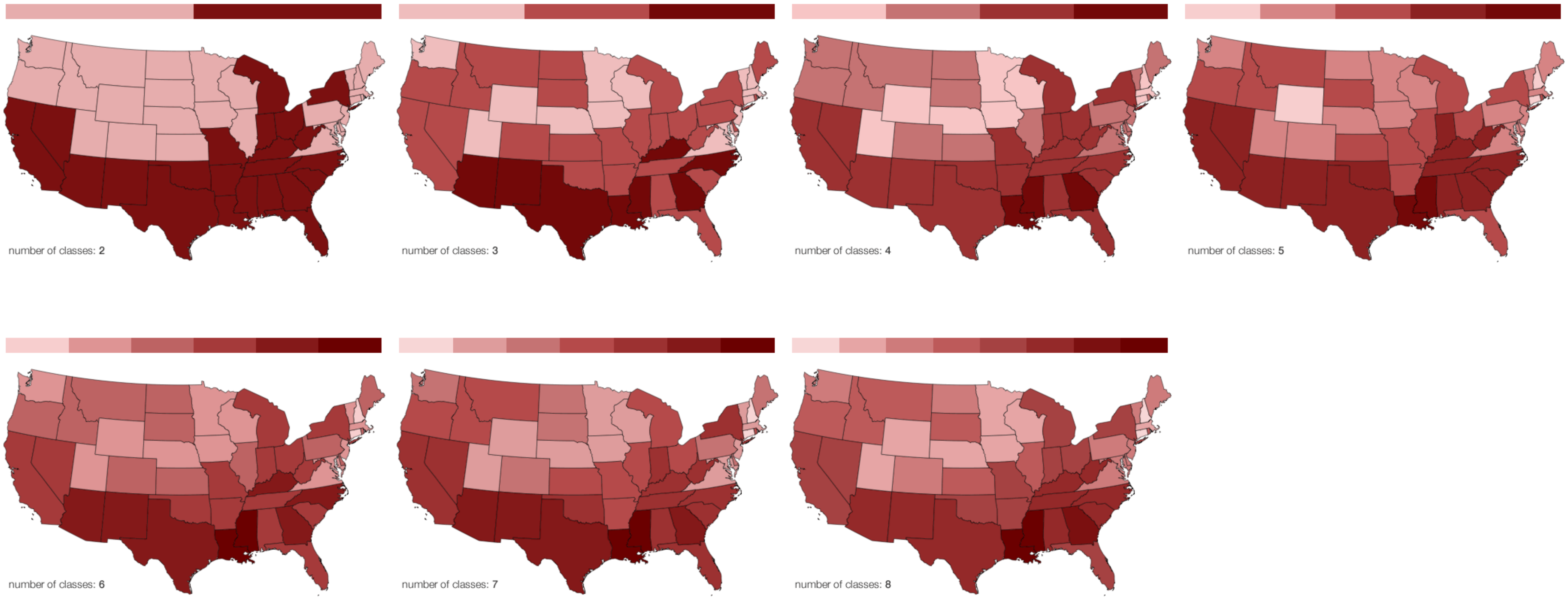
Cancer	Connective tissue	Cardiovascular	Endocrine	Gastrointestinal	Ear, nose, throat	Developmental	Multiple types
Bone	Muscular	Hematological	Immunological	Nutritional	Ophthalmological	Neurological	Unclassified
Skeletal	Dermatological	Renal		Metabolic	Respiratory	Psychiatric	





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

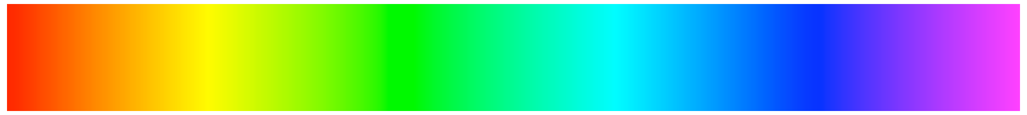
Ordered color: limited number of discriminable bins



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

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear



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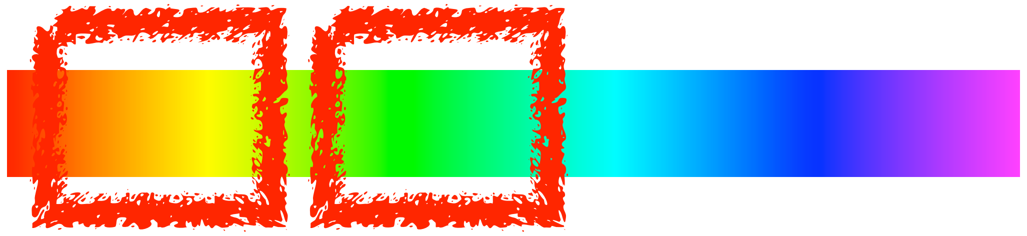

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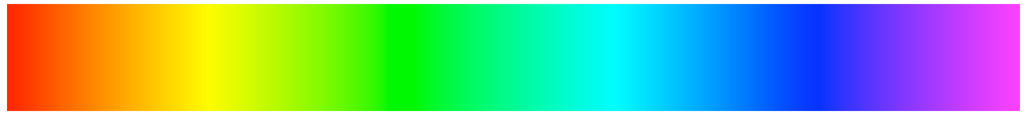
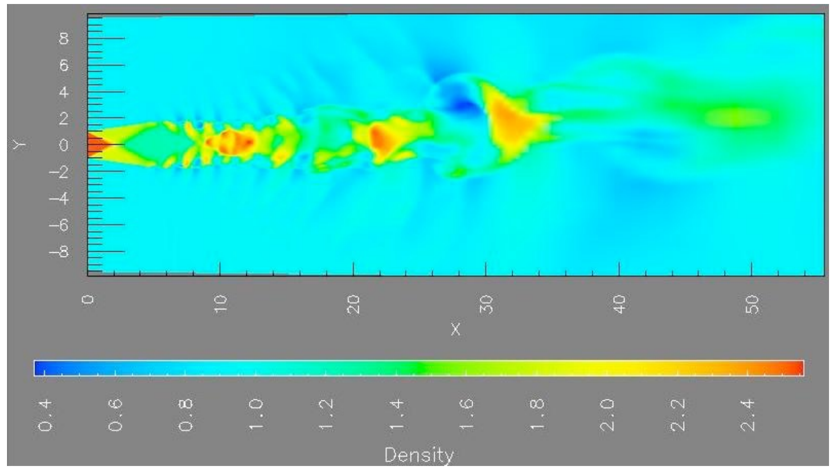
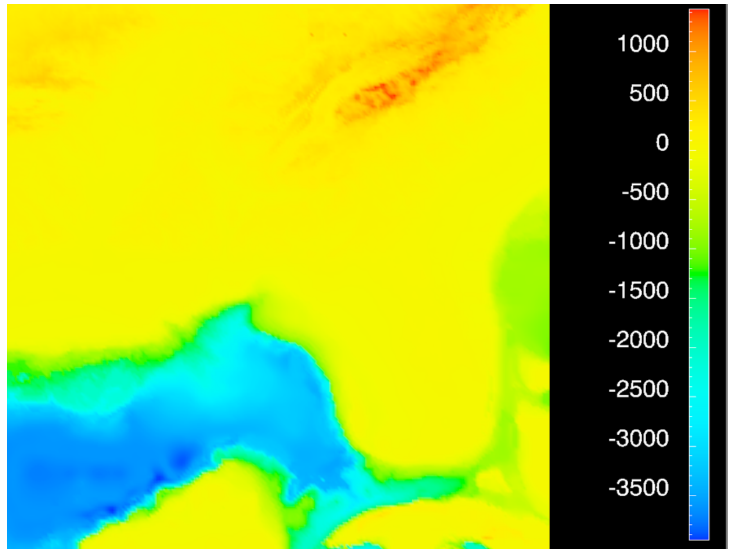
- benefits
  - fine-grained structure visible and nameable





[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]

Ordered color: Rainbow is poor default

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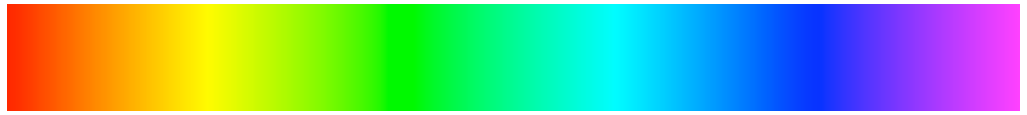
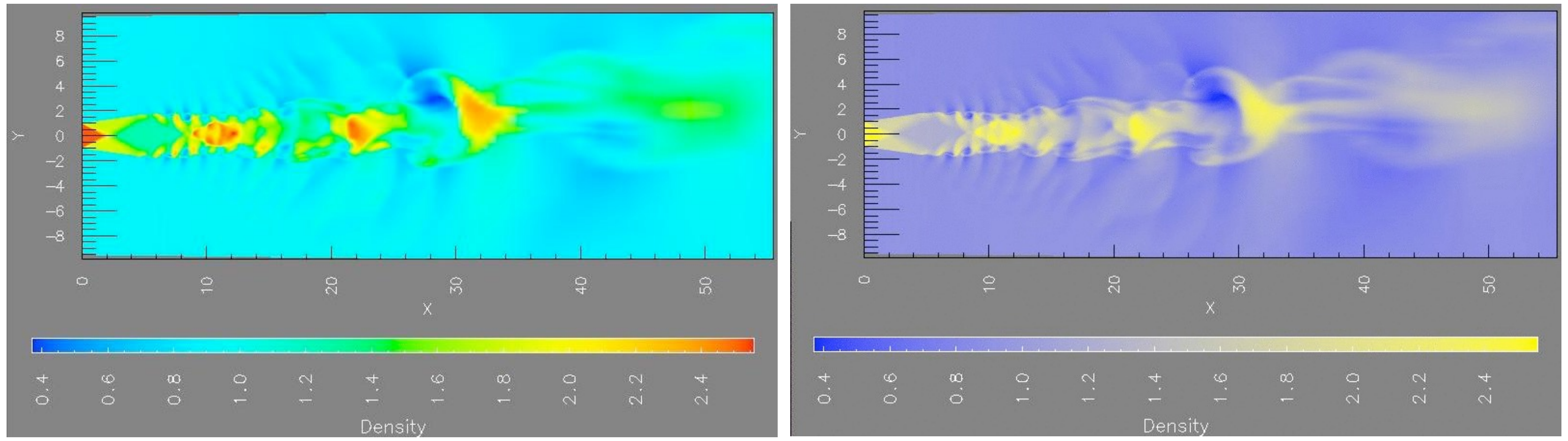
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues





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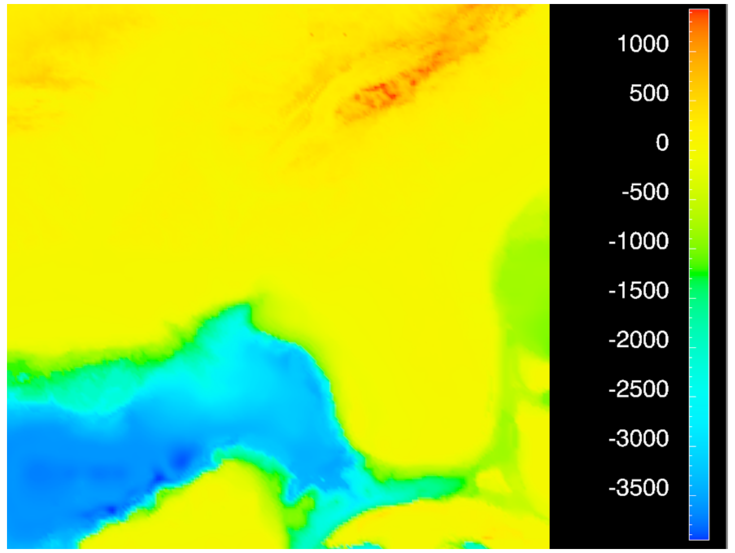

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  - perceptually unordered
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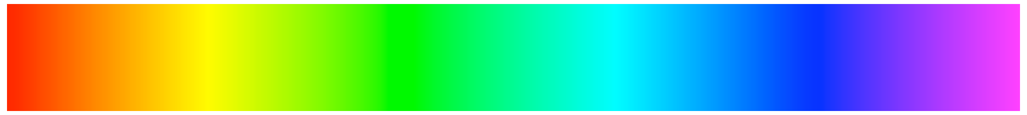
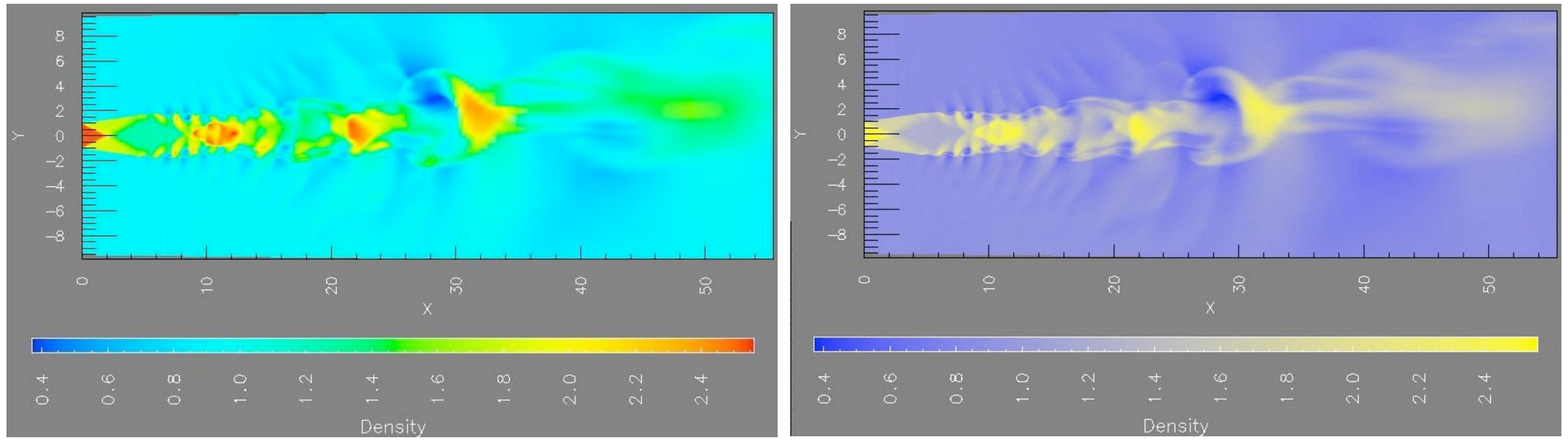
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]





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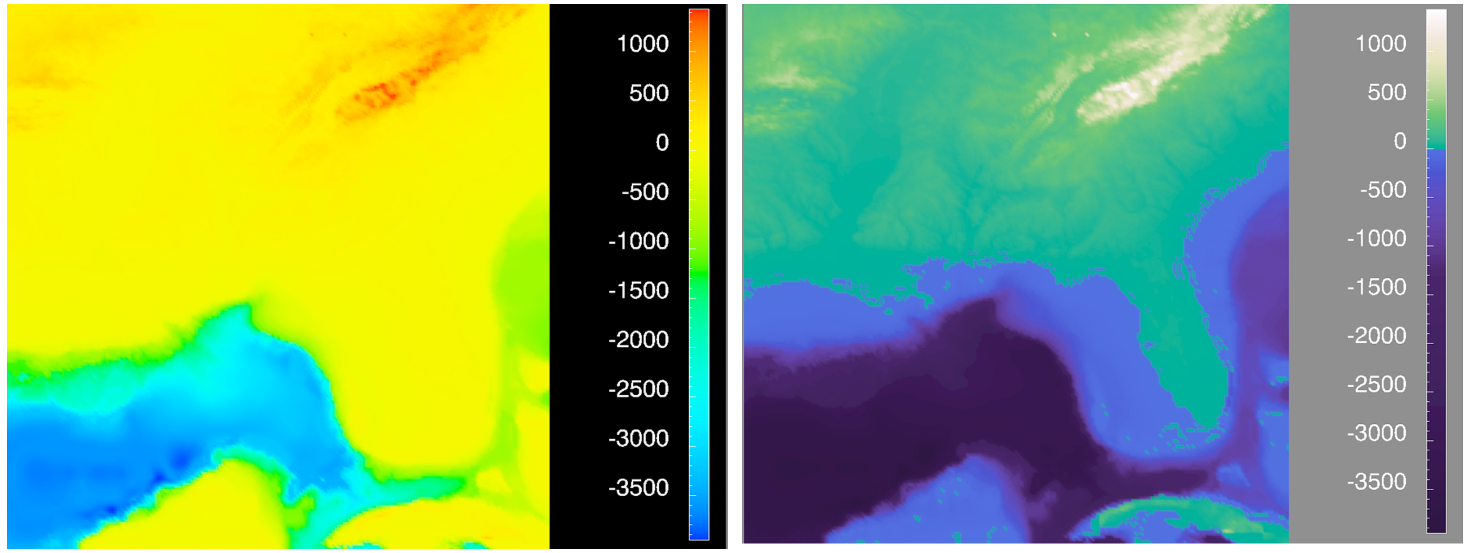

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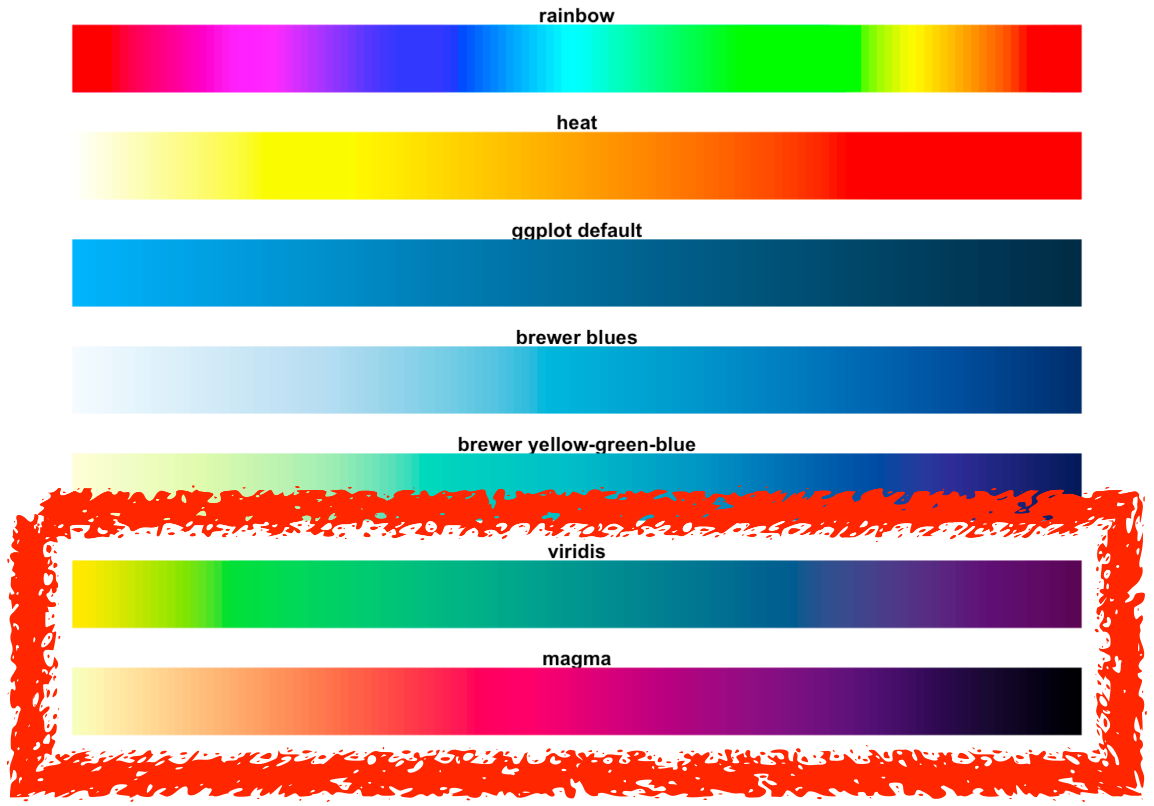
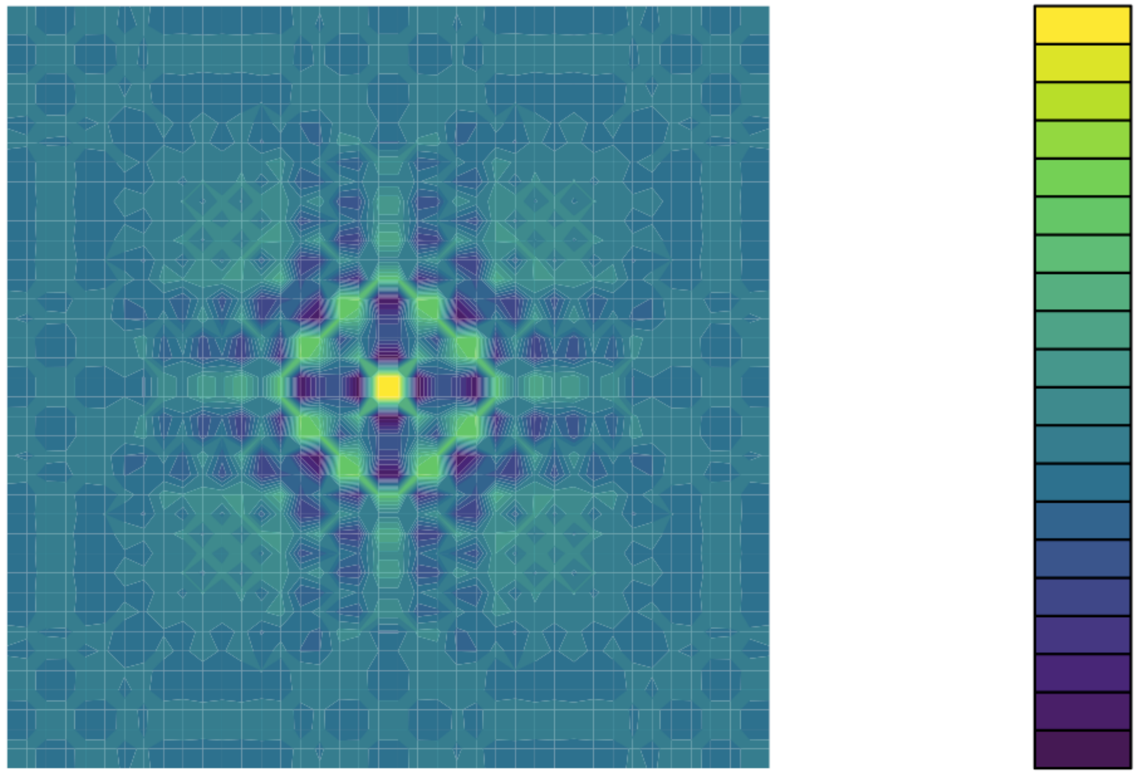
Viridis / Magma: sequential colormaps

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





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

Ordered color: Rainbow is poor default

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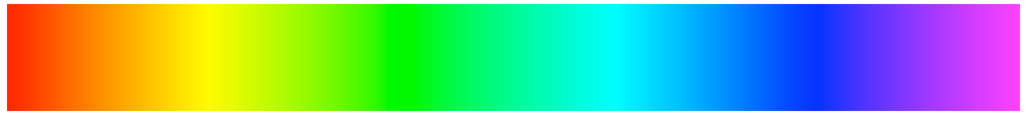
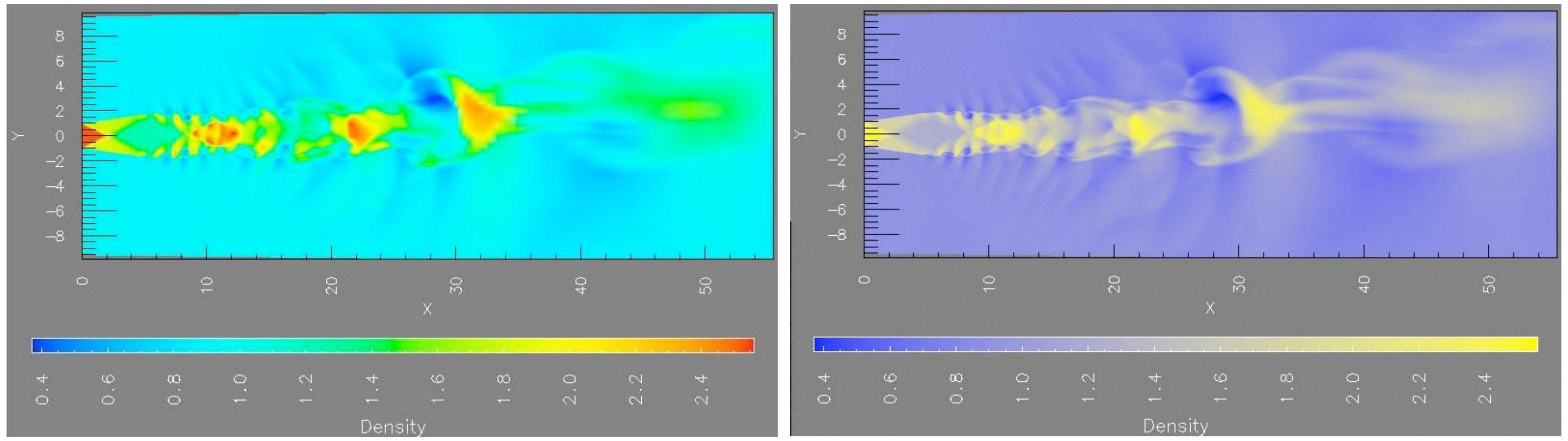
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented saturated rainbow is good!





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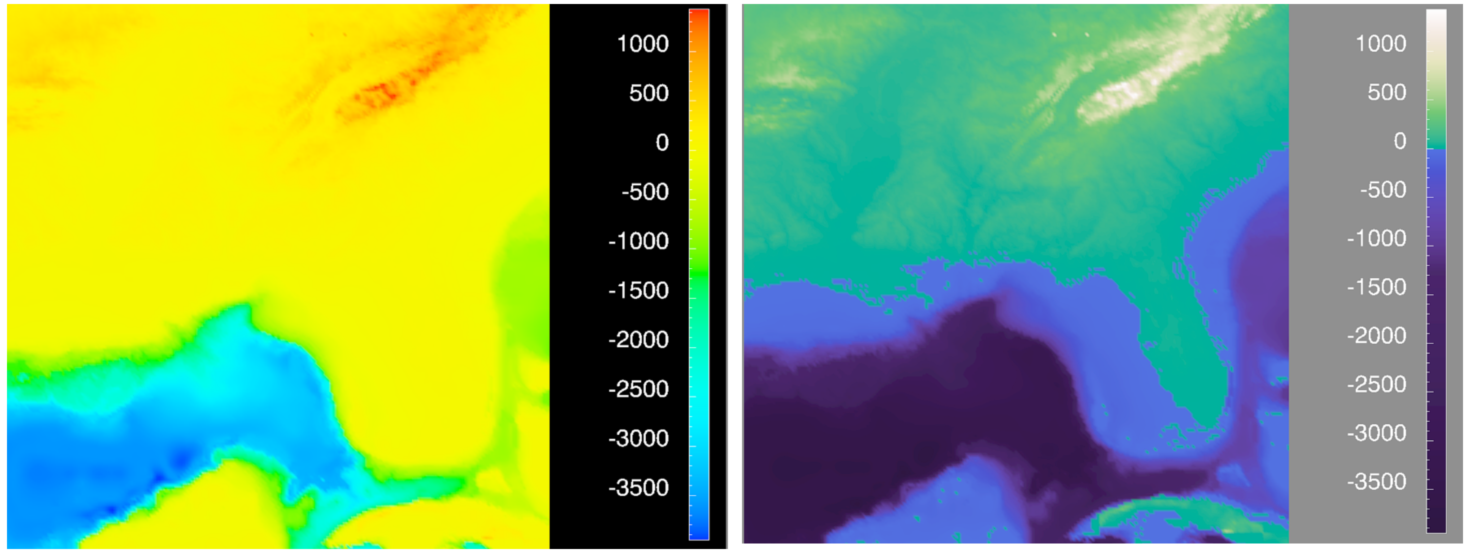

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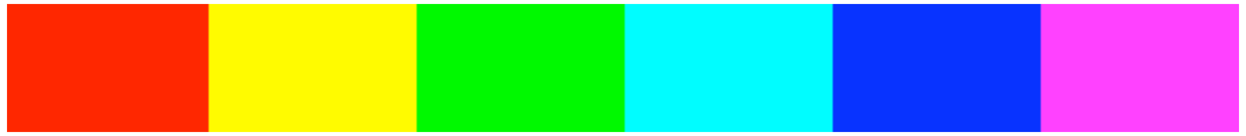
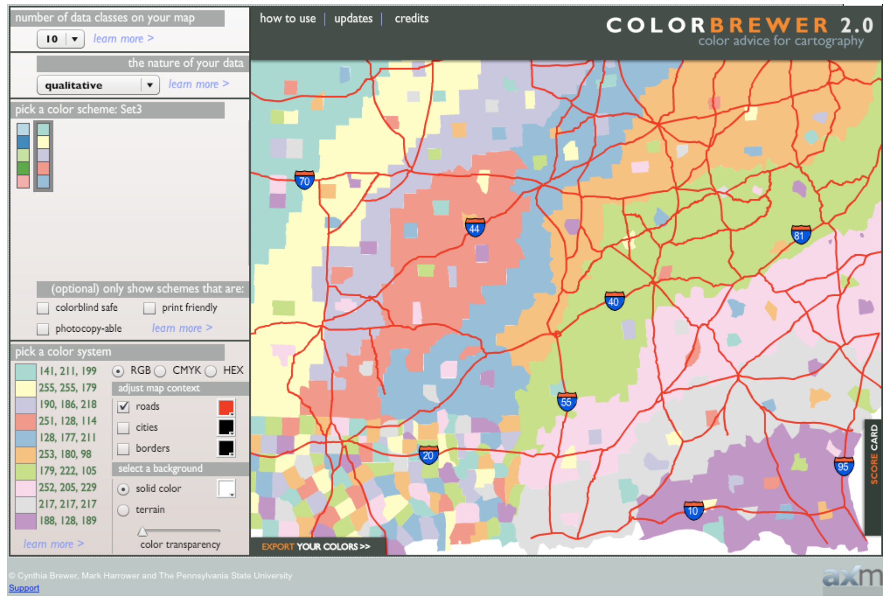
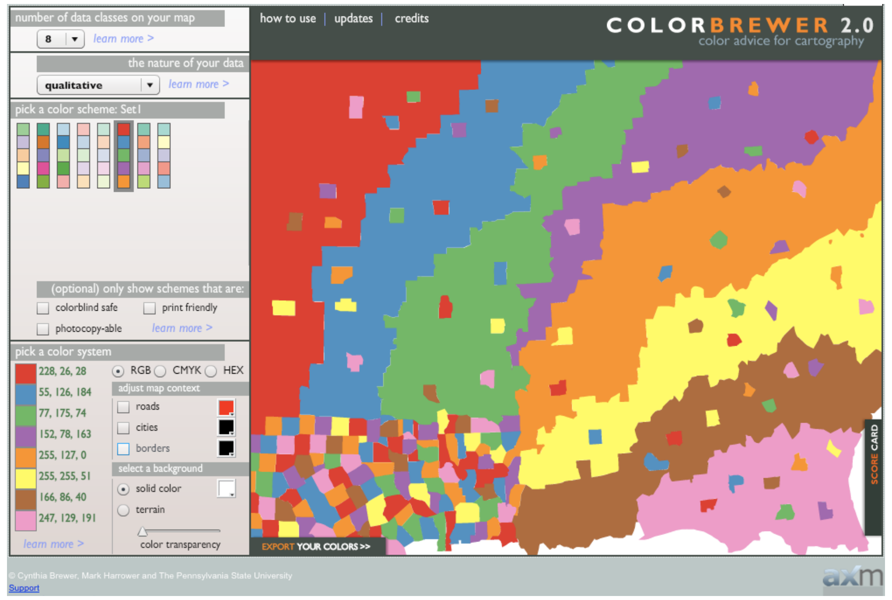


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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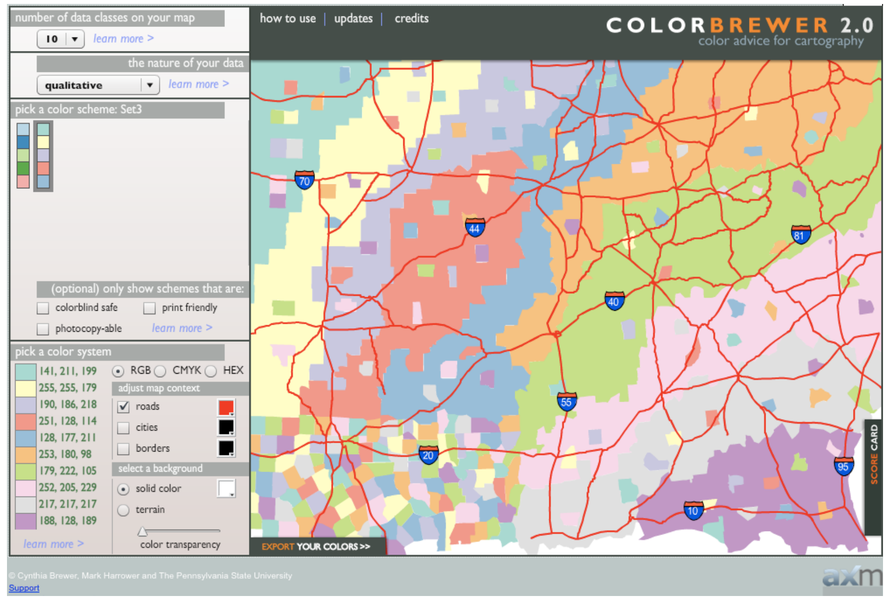
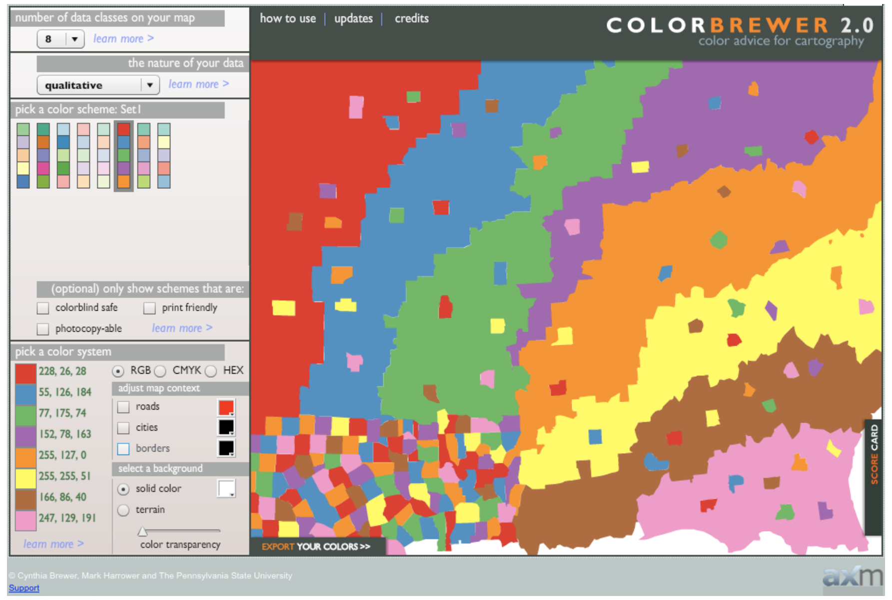
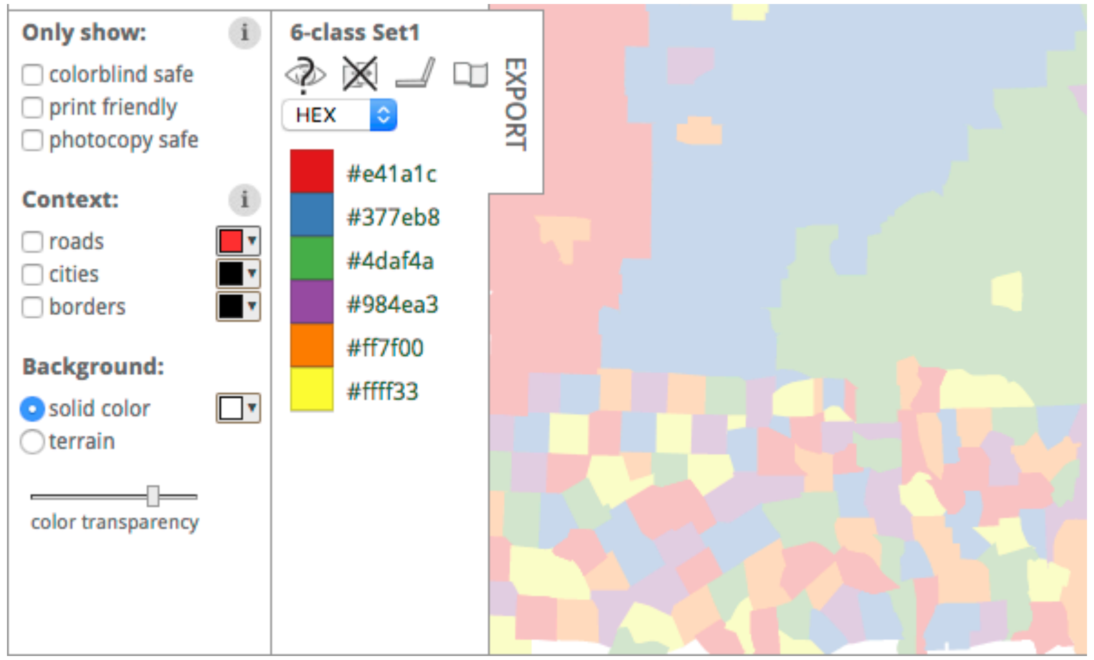
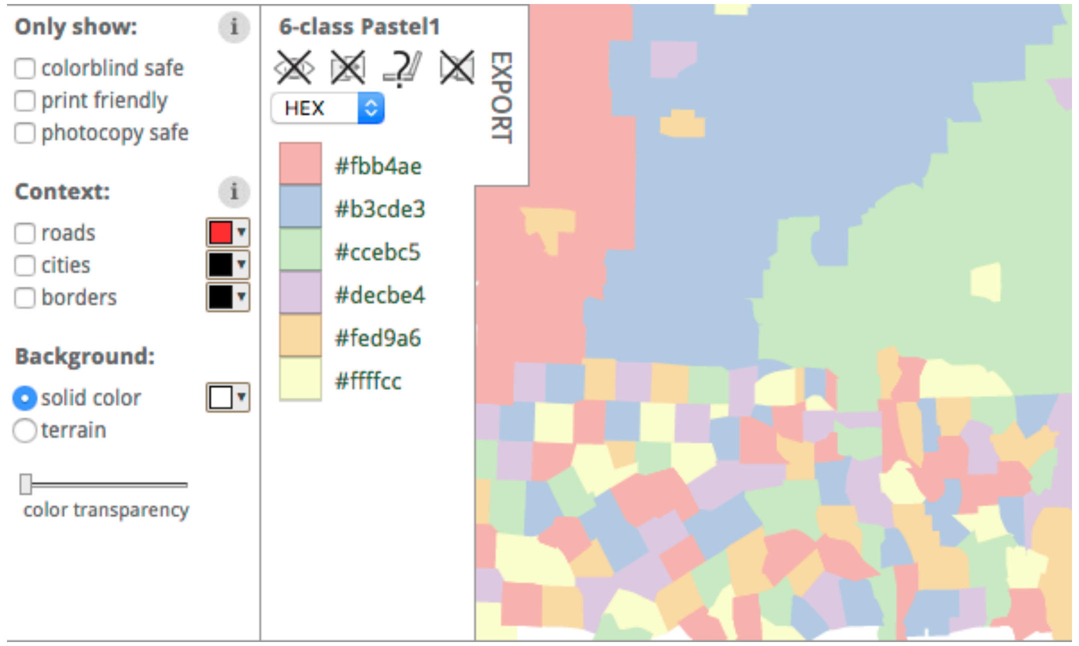
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency









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Interaction between channels: Not fully separable

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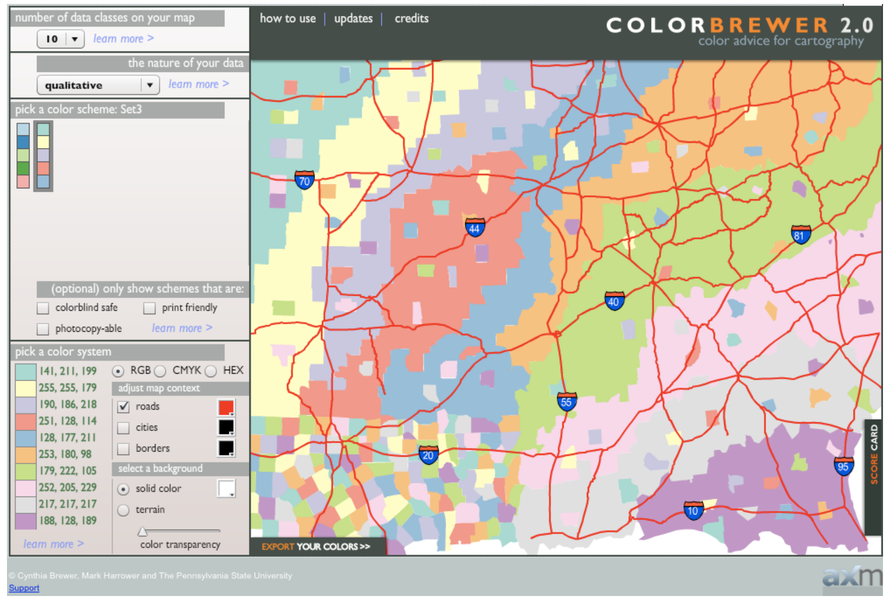
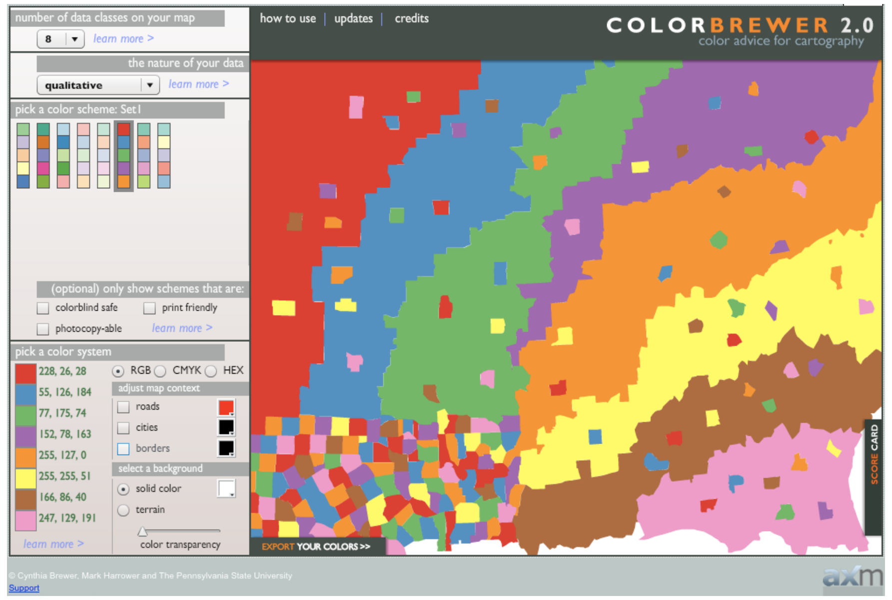
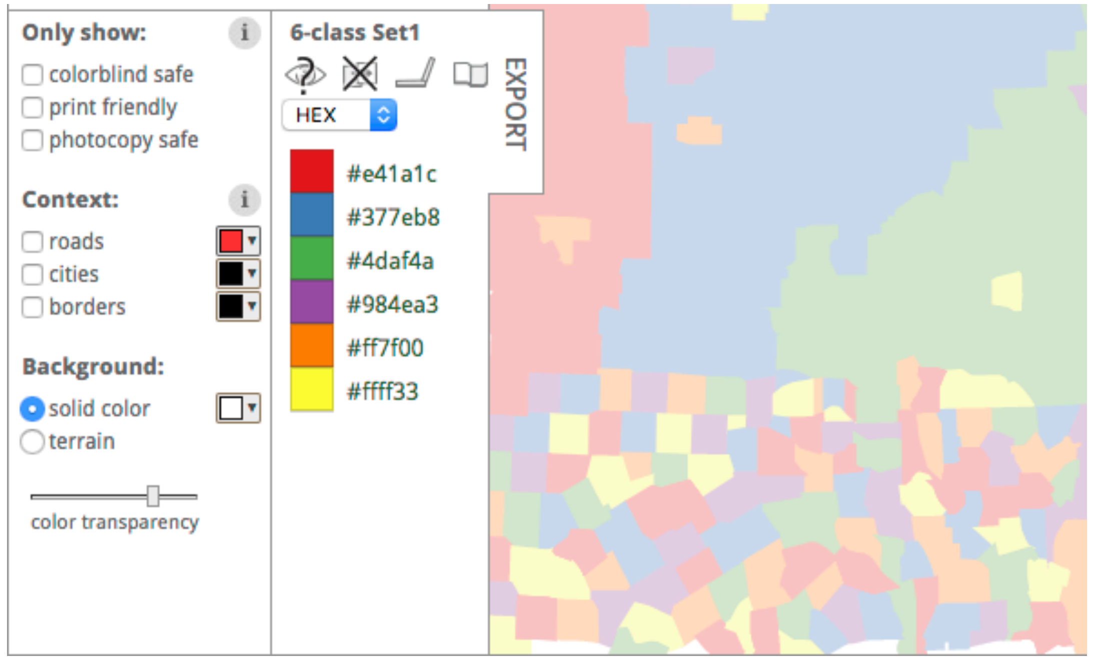
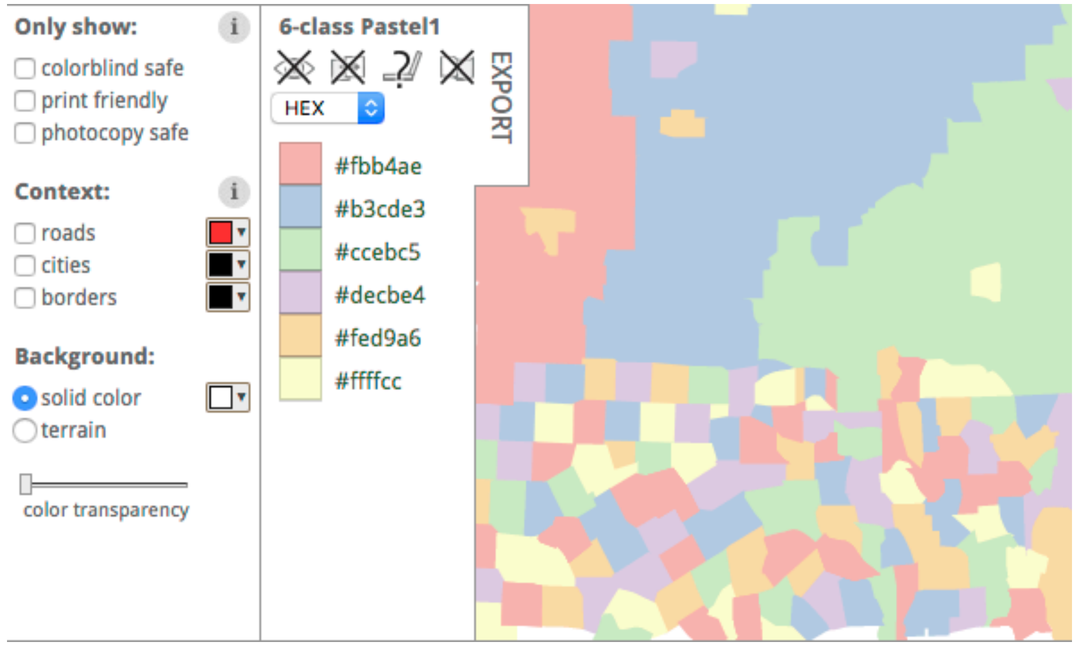
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency
  - small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max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









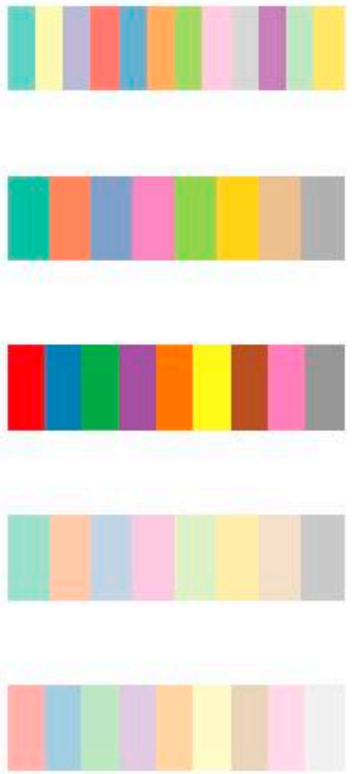
http://colorbrewer2.org/

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]

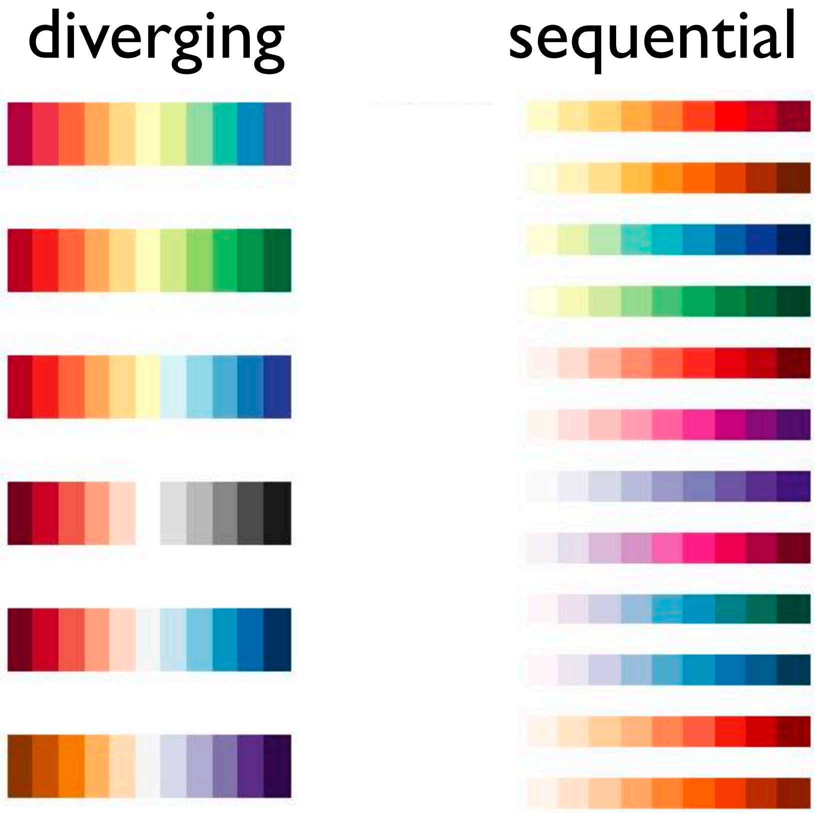
Color palettes: univariate

→ Categorical

→ Ordered

→ *Sequential* → *Diverging*

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



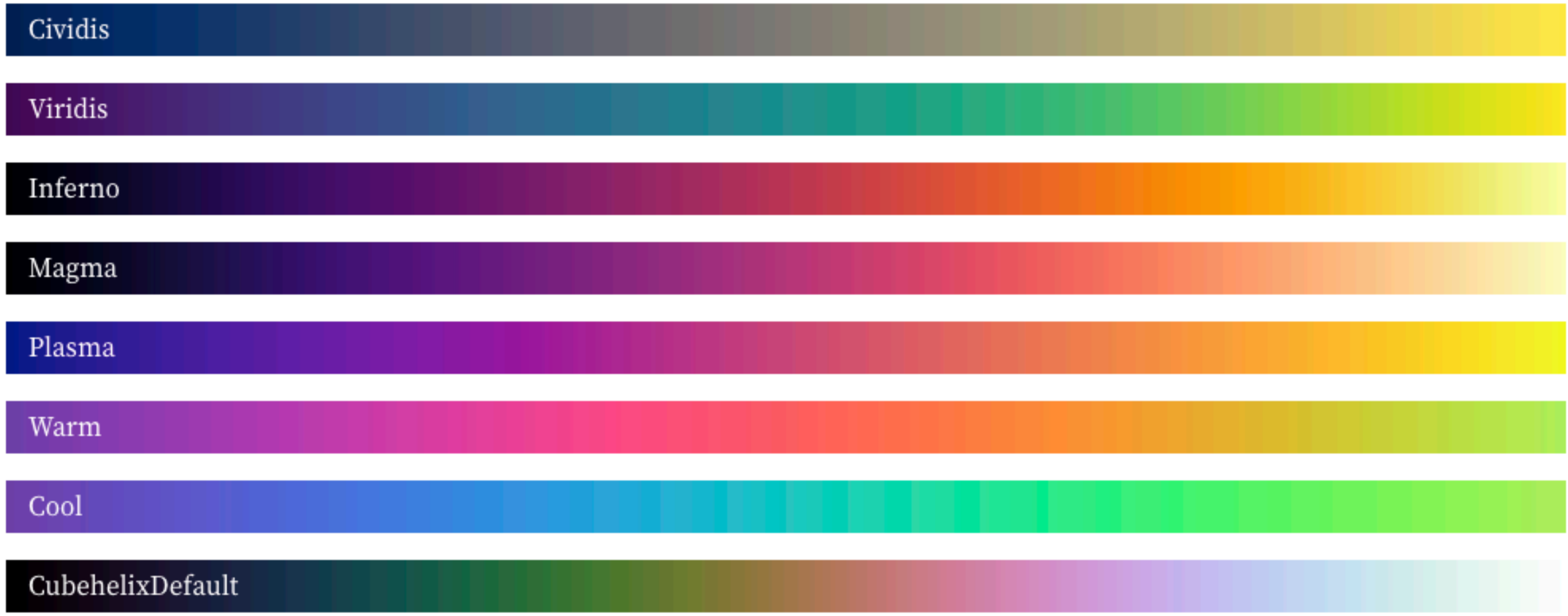
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Color palettes: univariate

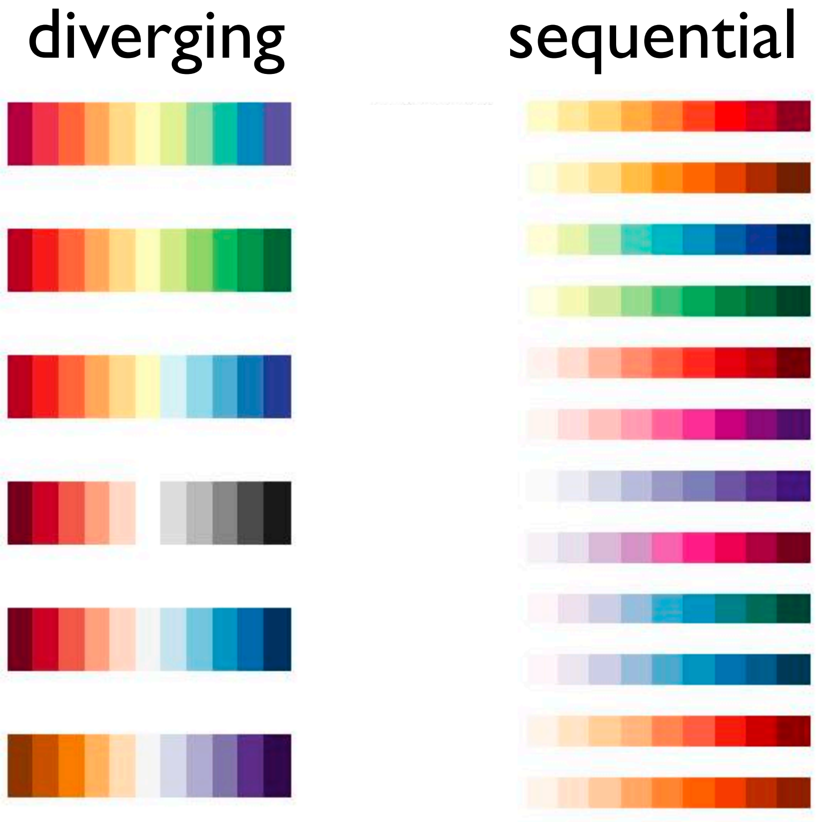
➔ Categorical

➔ 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



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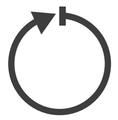
Color palettes: univariate

- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

  - ➔ *Diverging*

  - ➔ Cyclic



cyclic multihue

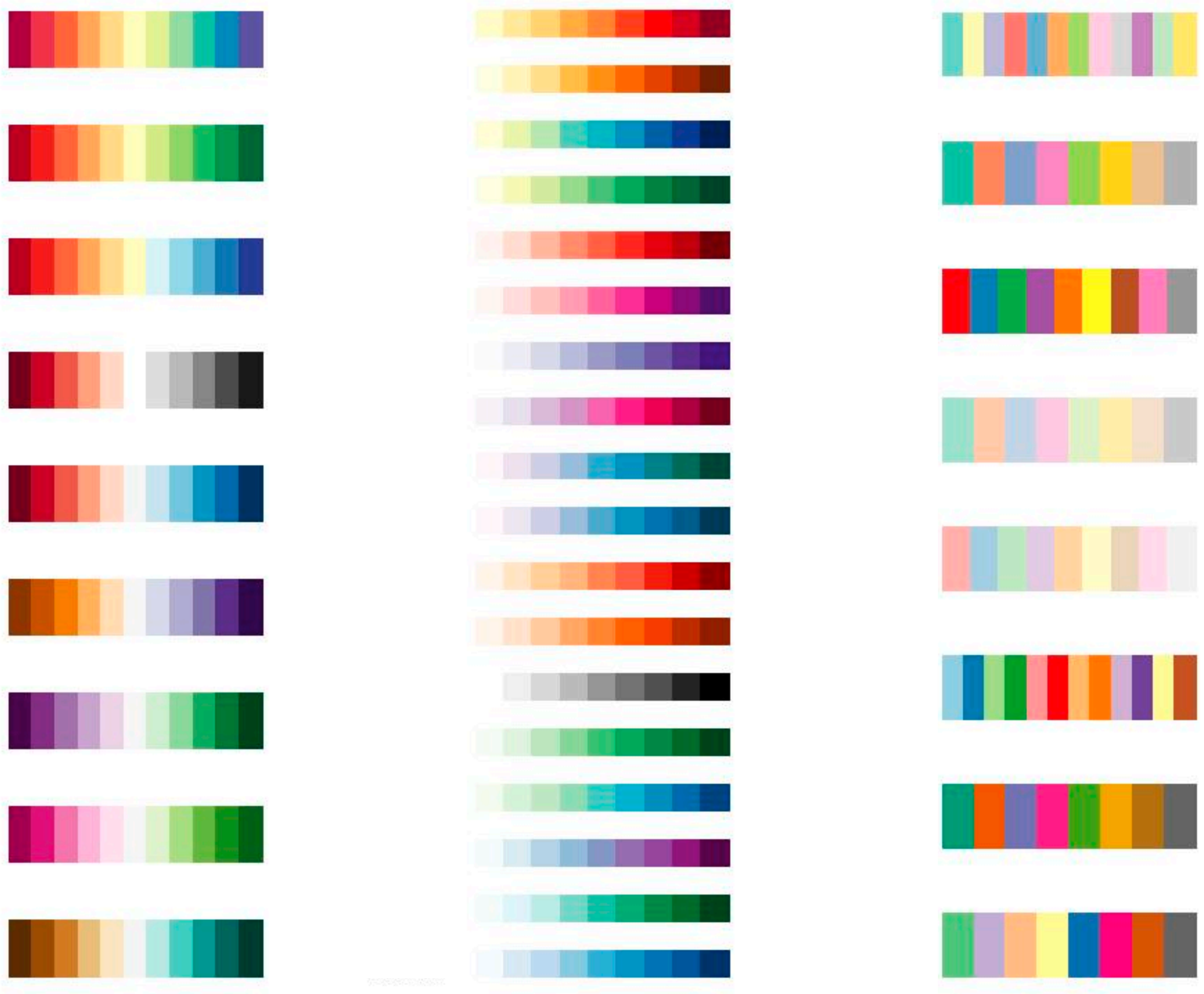
https://github.com/d3/d3-scale-chromatic

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

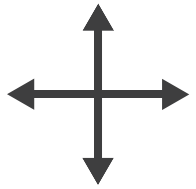
Colormaps: bivariate

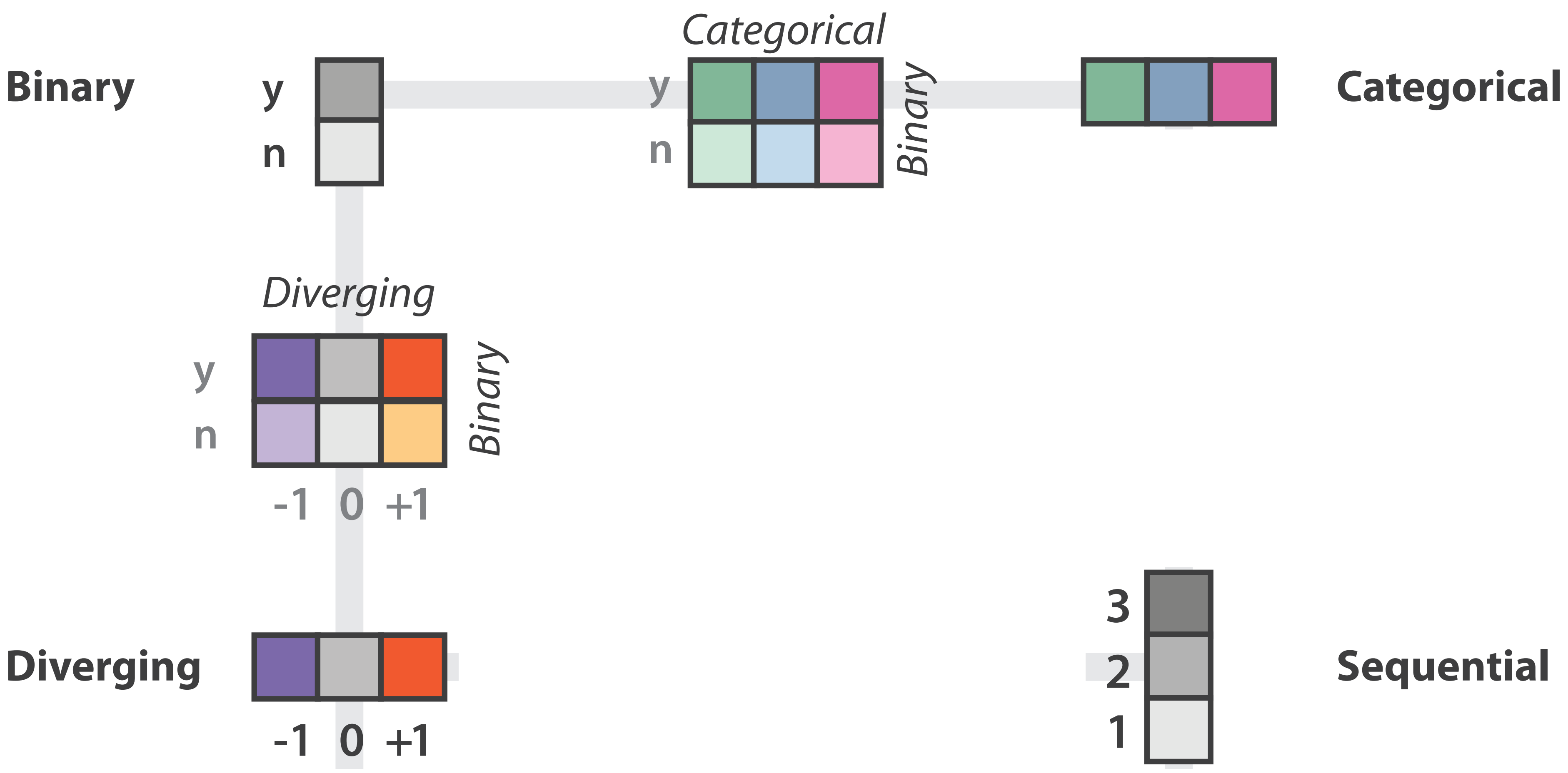
- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

  - ➔ *Diverging*

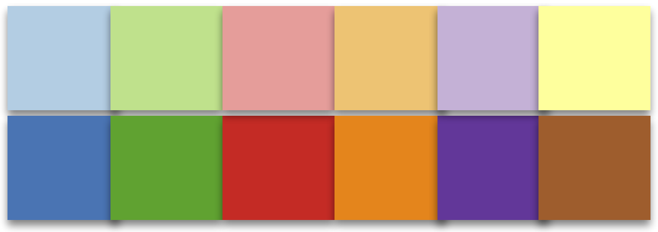
- ➔ Bivariate





- bivariate best case
  - binary in one of the directions

d3.schemePaired <>



binary saturation

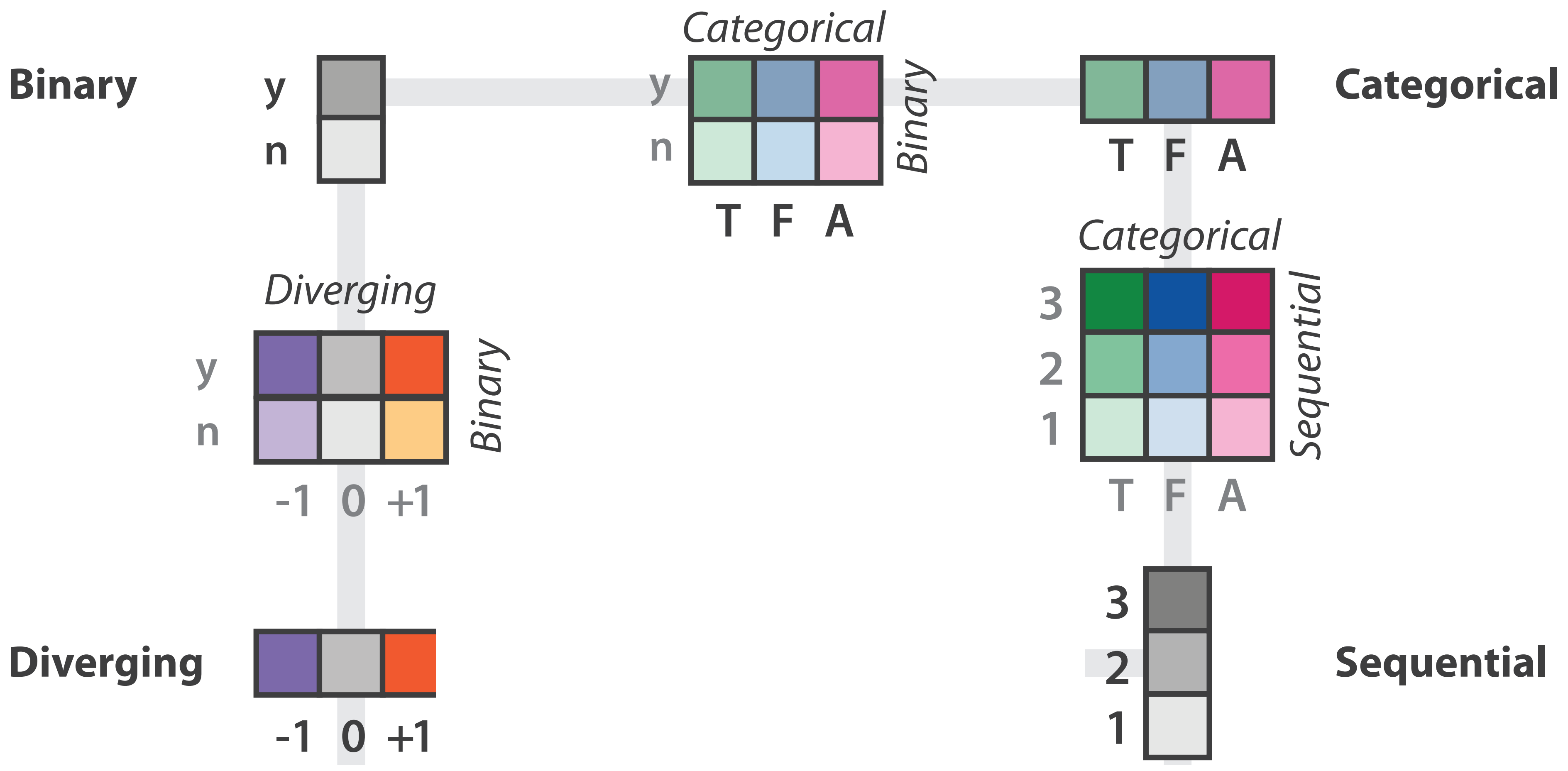
categorical hue

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

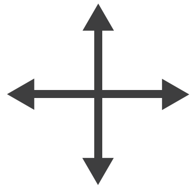
➔ Categorical

➔ Ordered

➔ *Sequential*

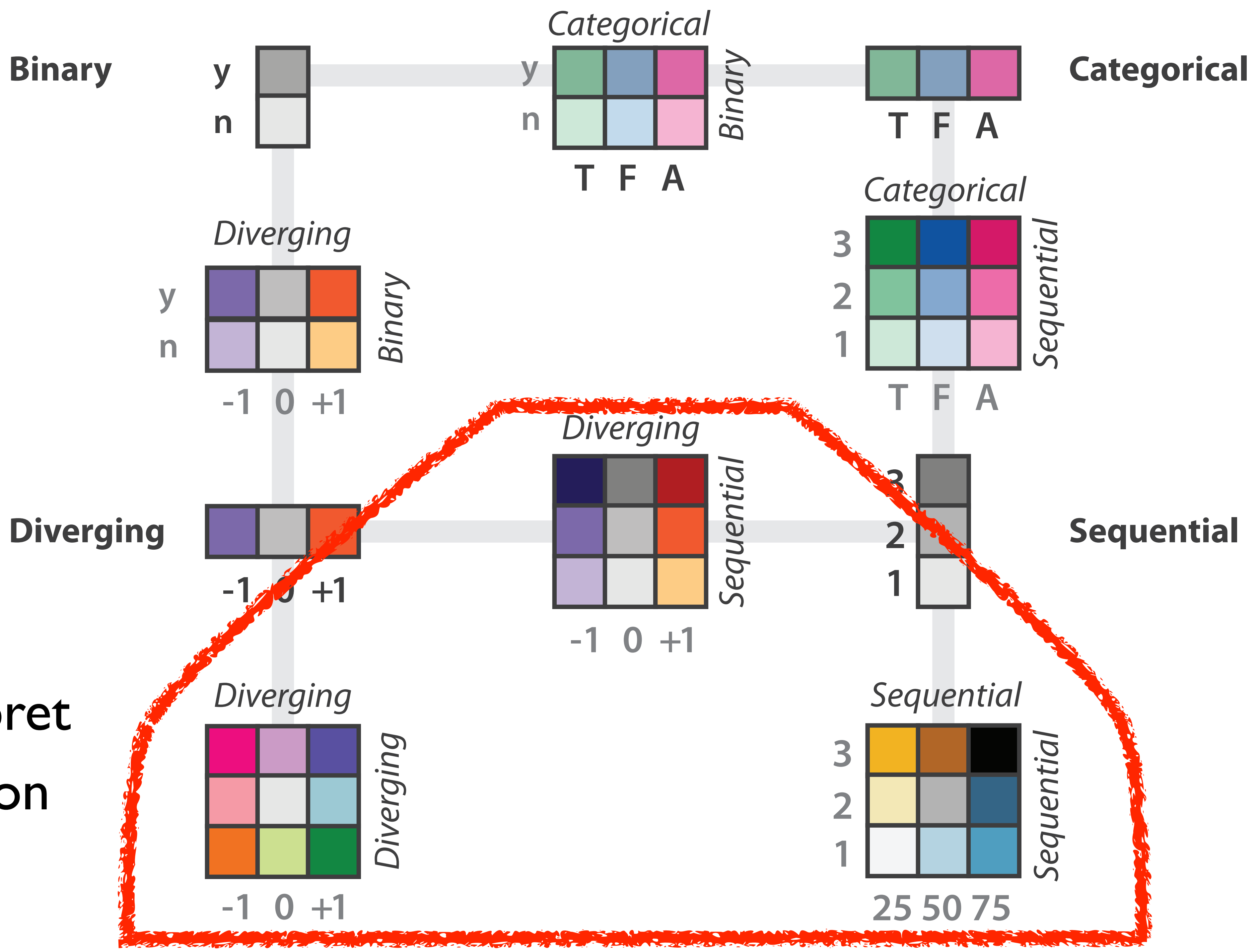
➔ *Diverging*

➔ Bivariate

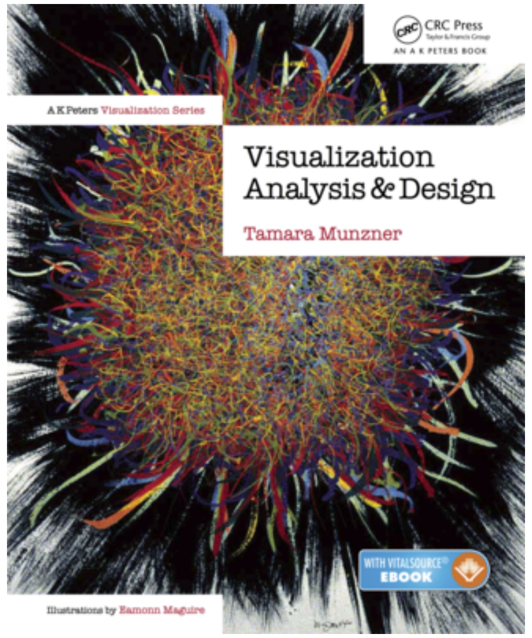


use with care!

- 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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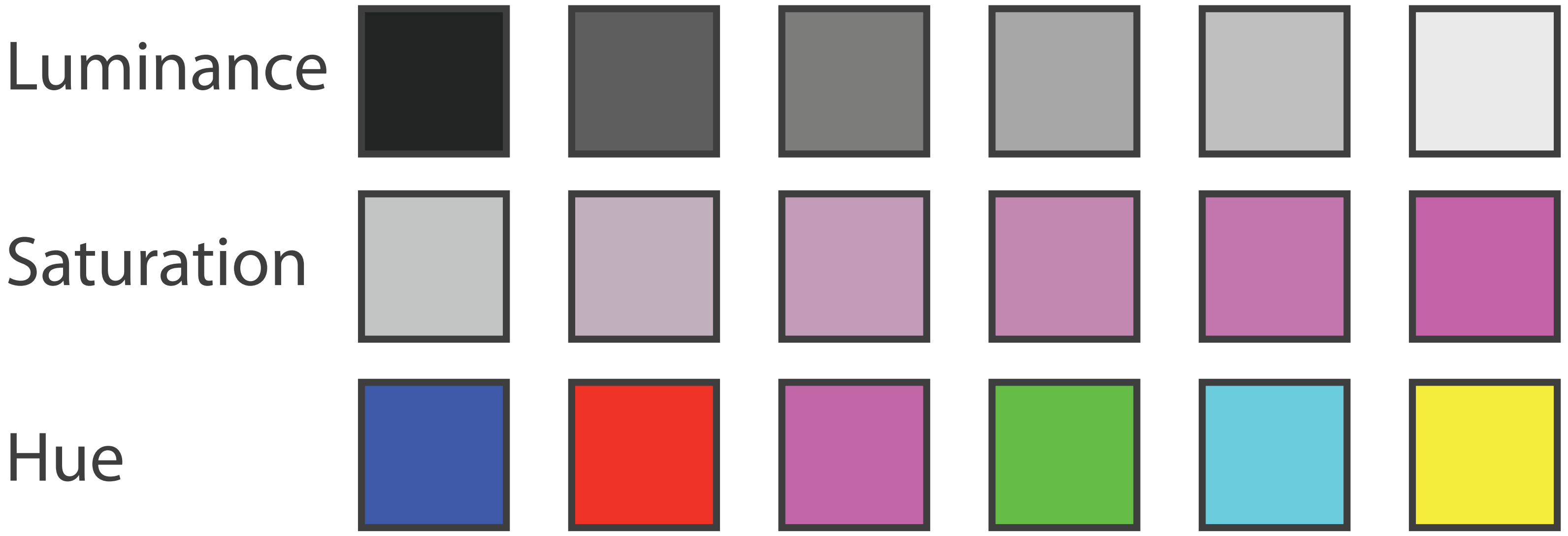
Decomposing color

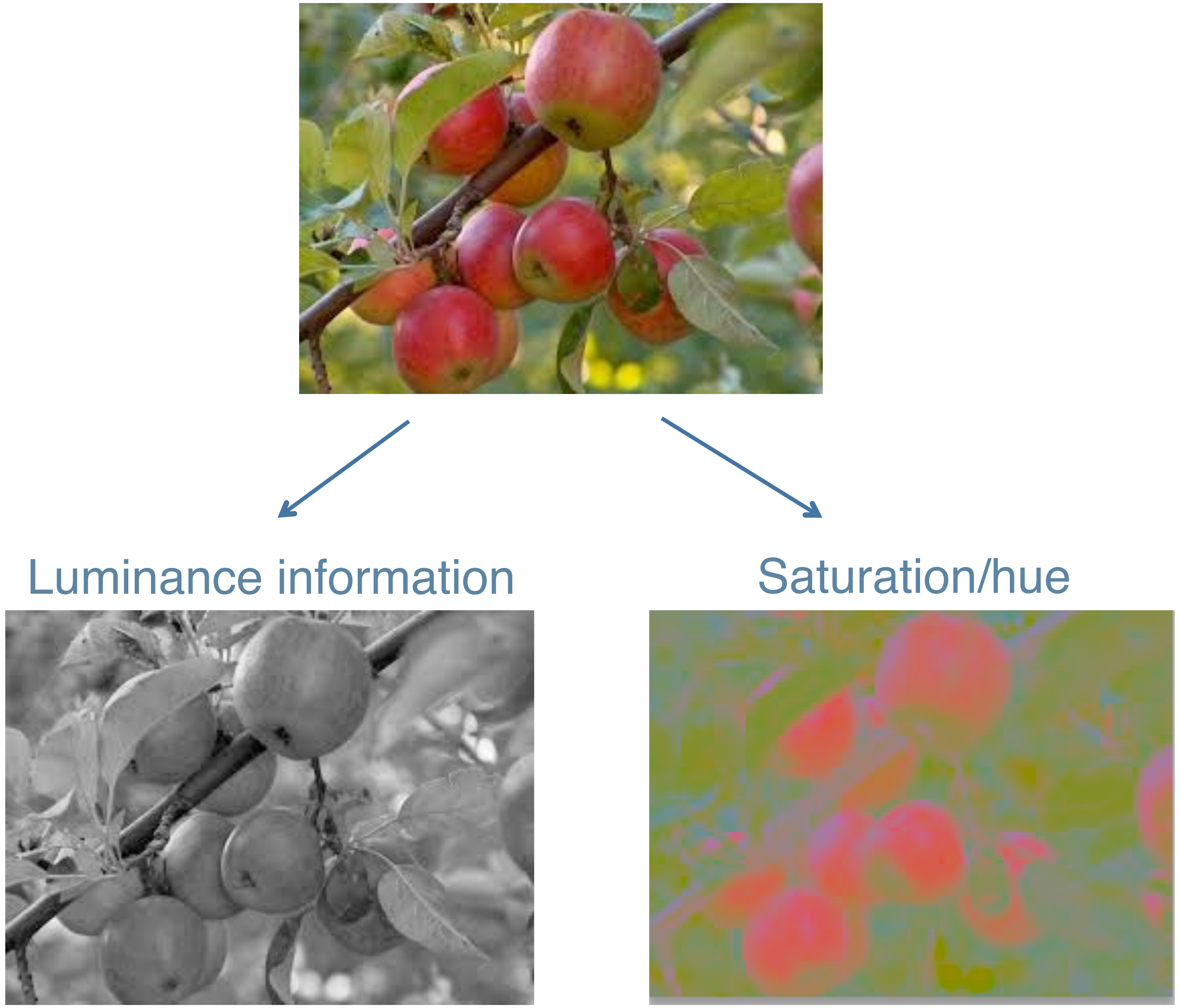
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



Color Deficiency

Luminance

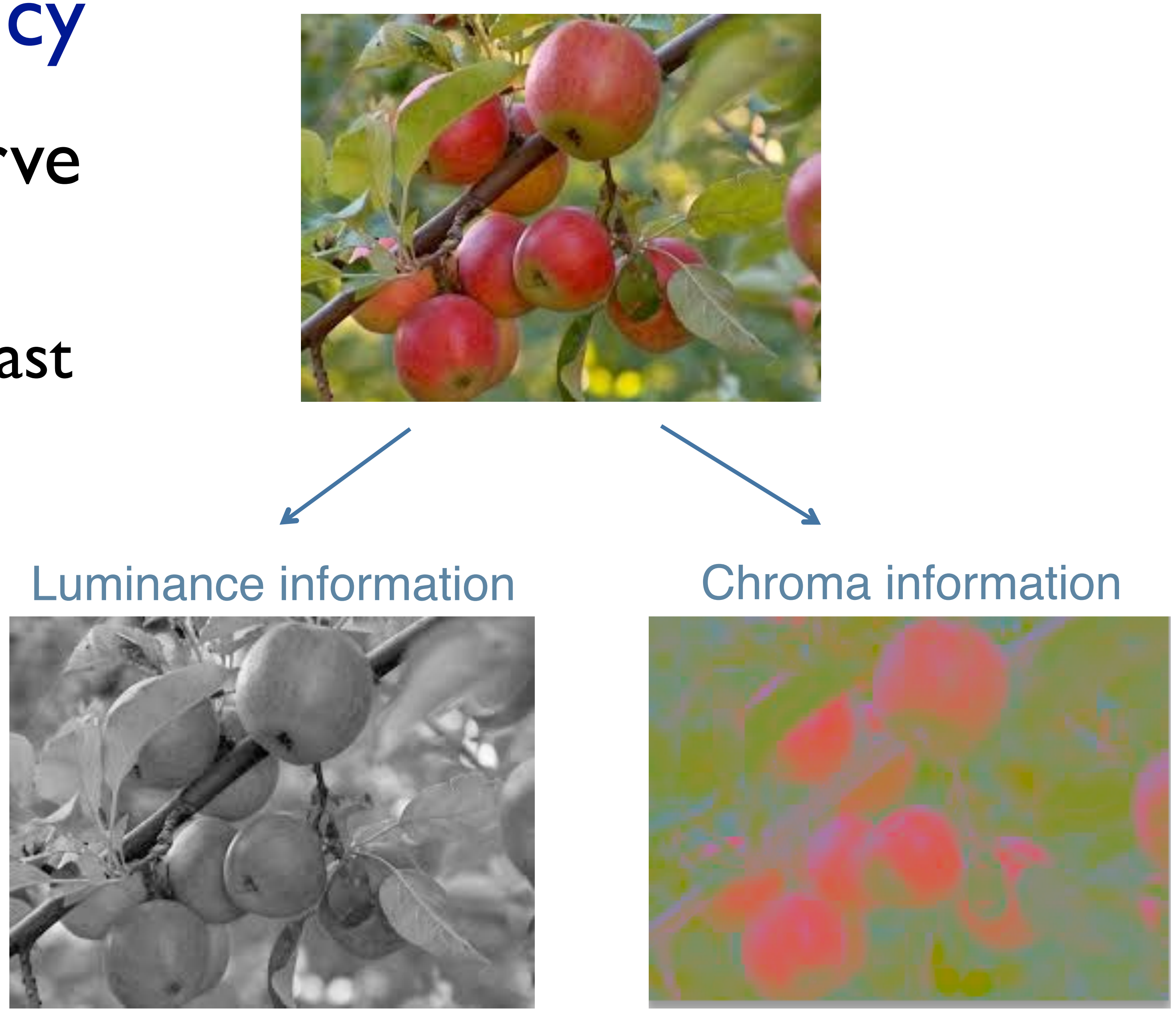
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!



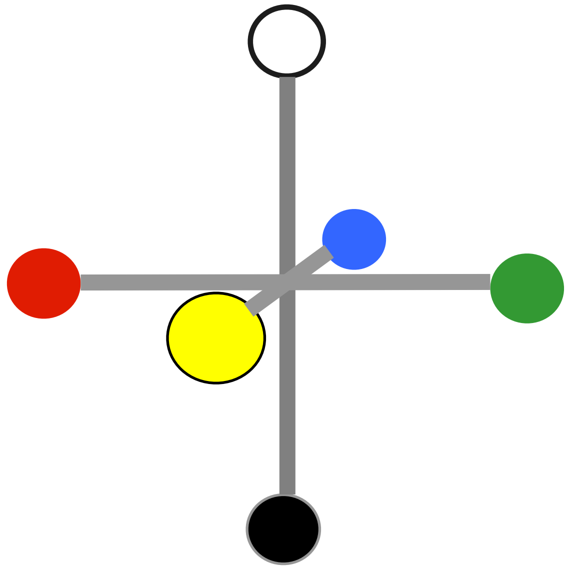
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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*)

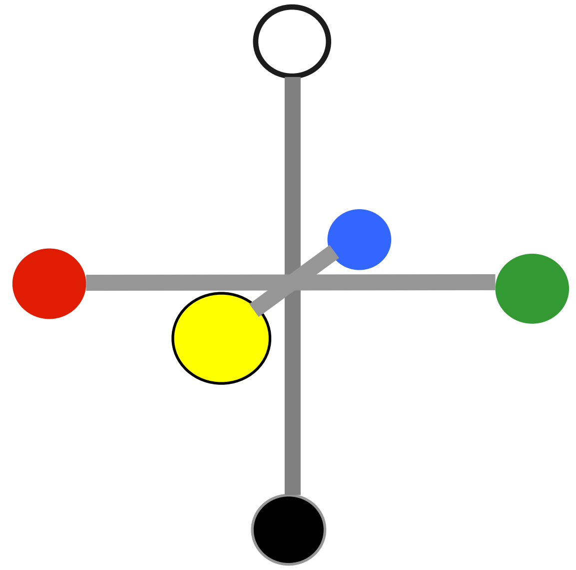


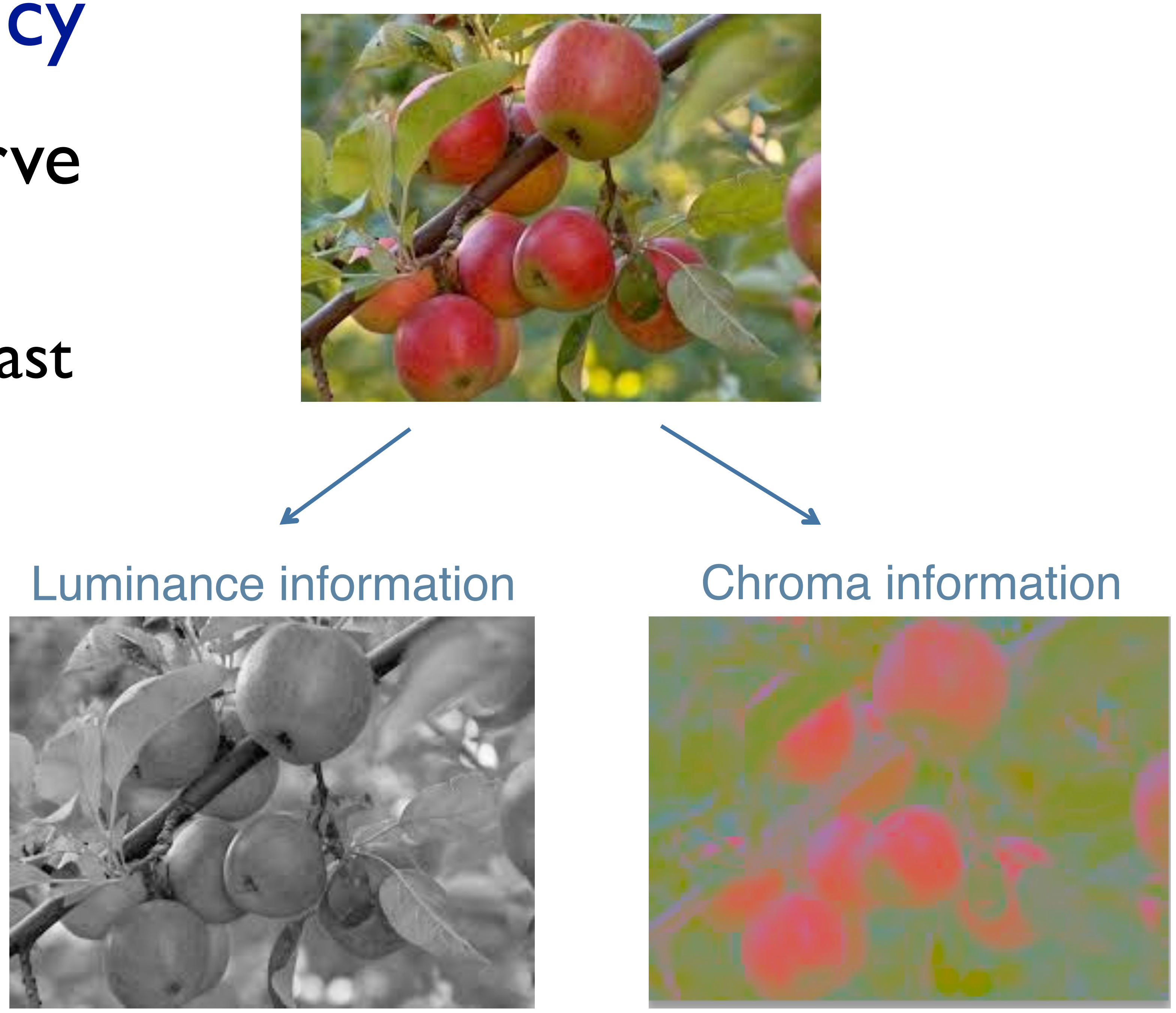
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]



Opponent color and color deficiency

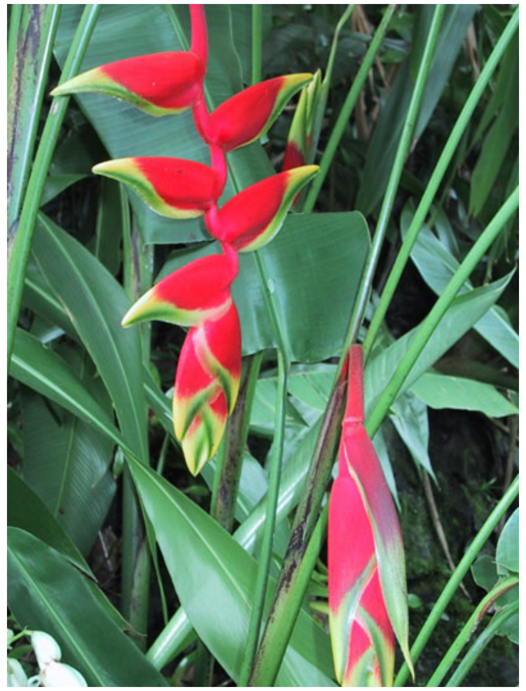
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- "colorblind": degraded acuity, one axis
  - 8% of men are red/green color deficient
  - blue/yellow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



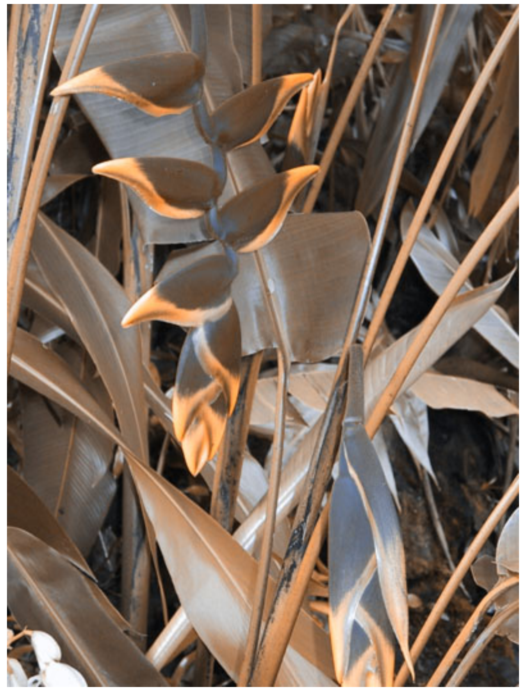


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

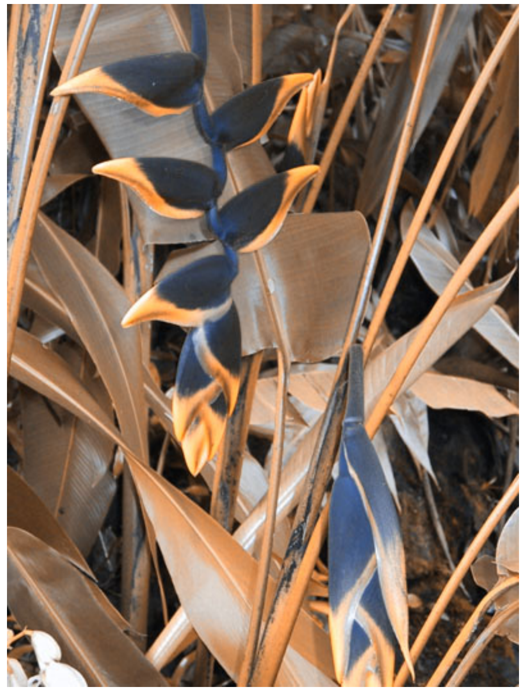
Designing for color deficiency: Check with simulator



Normal vision

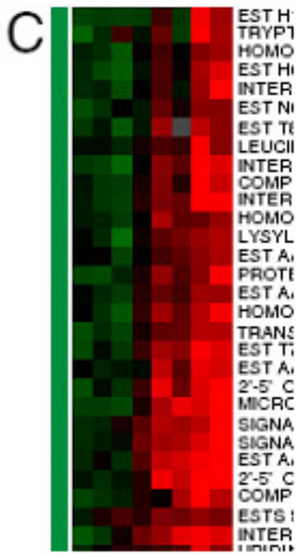


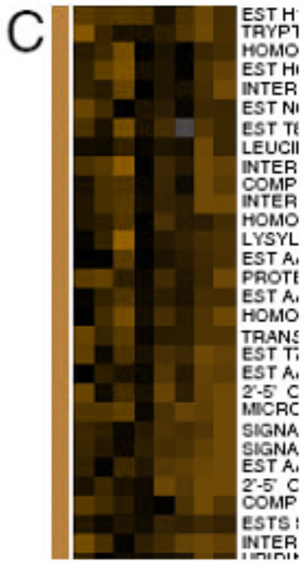
Deuteranope
green-weak



Protanope
red-weak

Tritanope
blue-weak



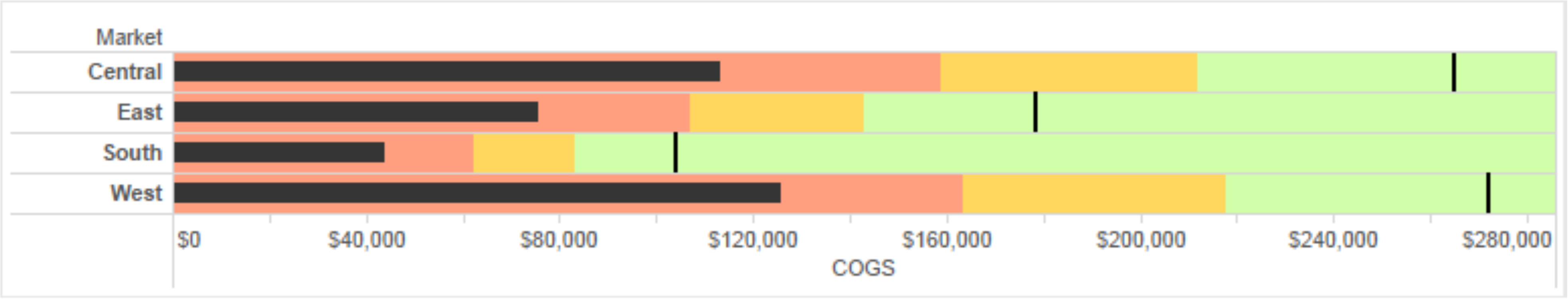


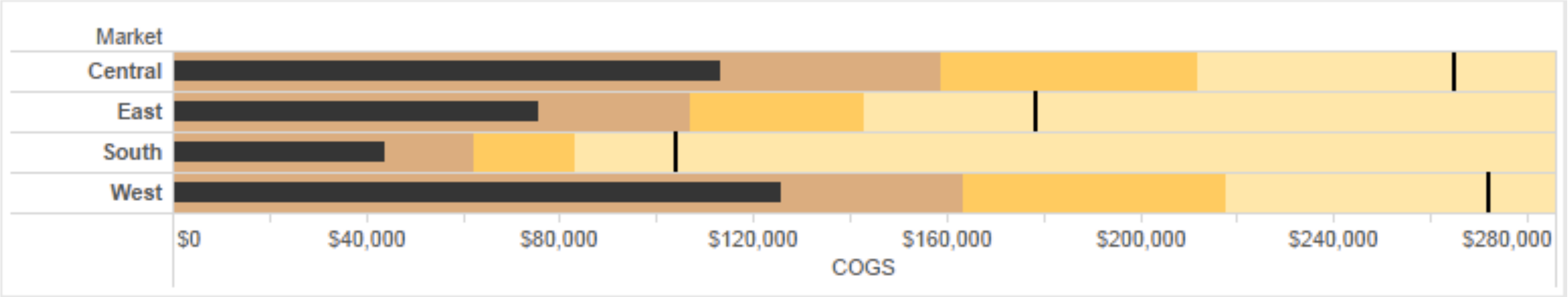
https://www.color-blindness.com/coblis-color-blindness-simulator/

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

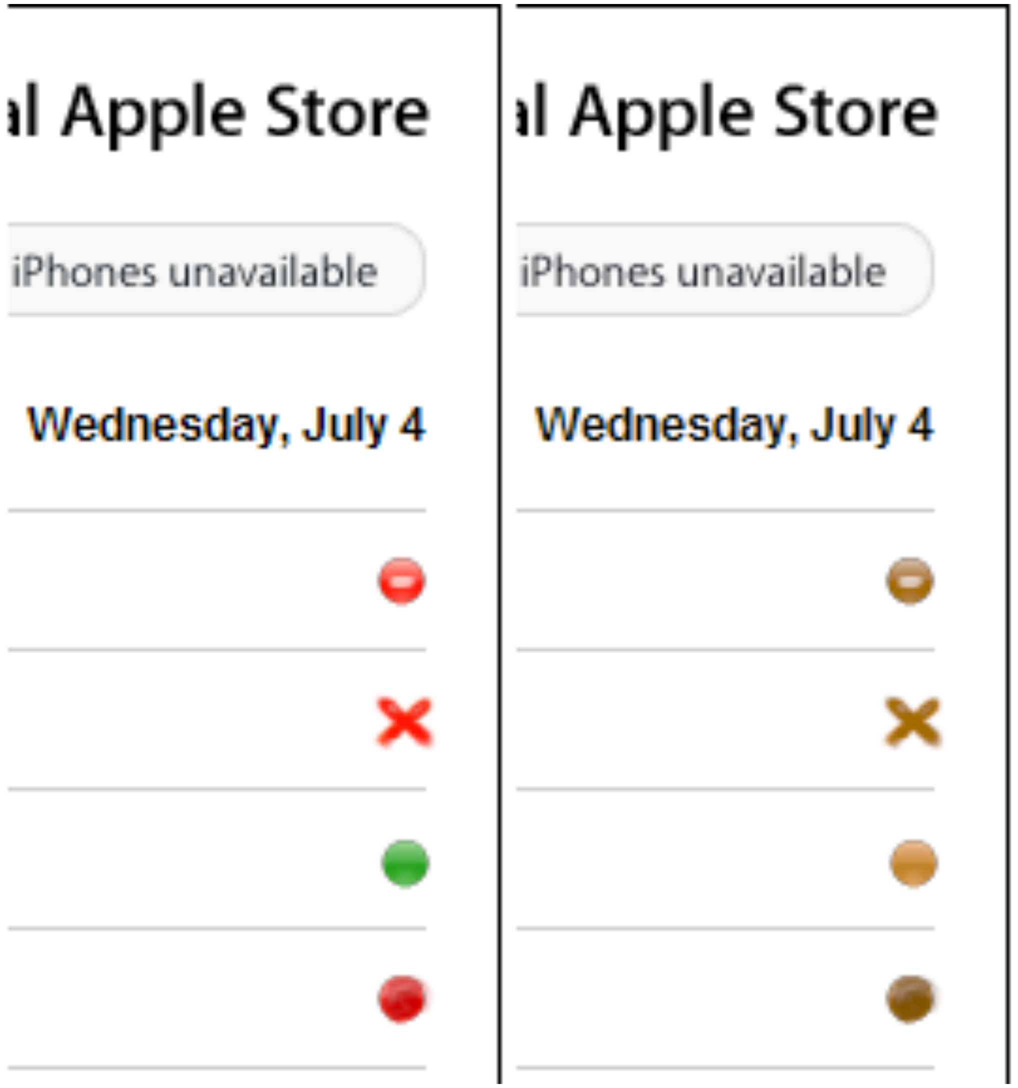
Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape





Deuteranope simulation

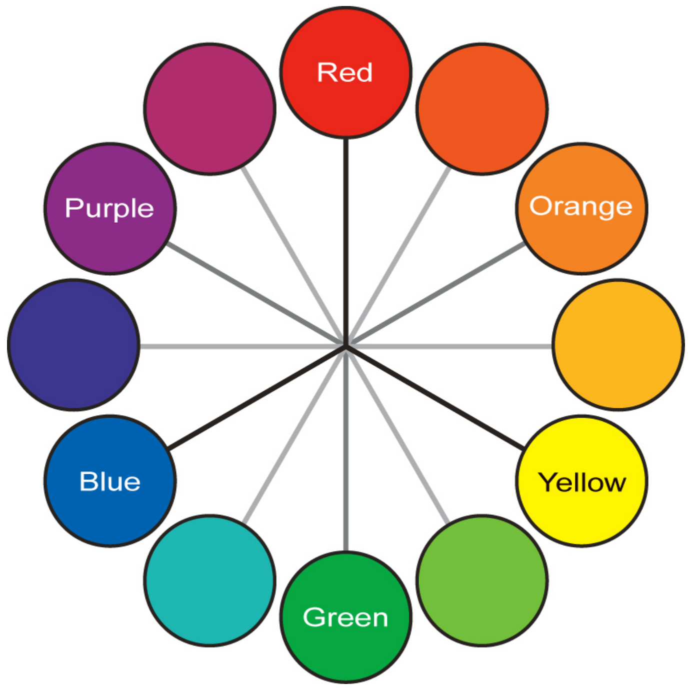


Change the shape

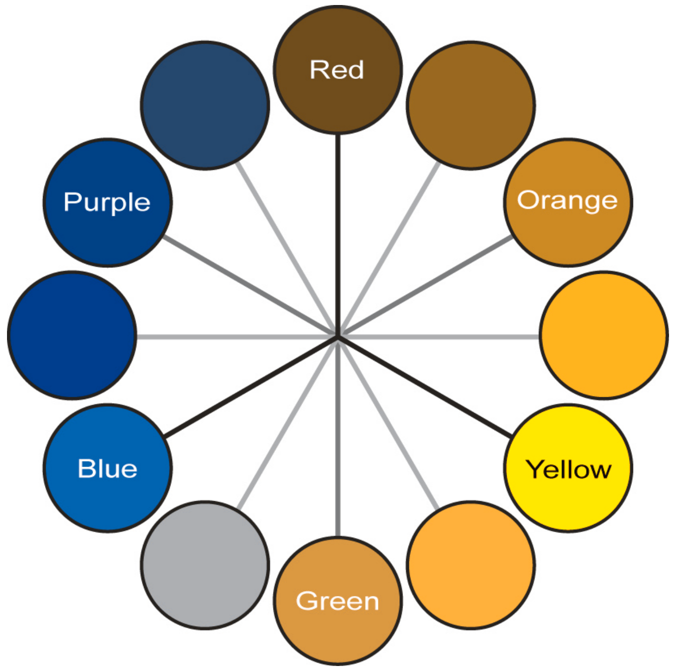
Vary luminance

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

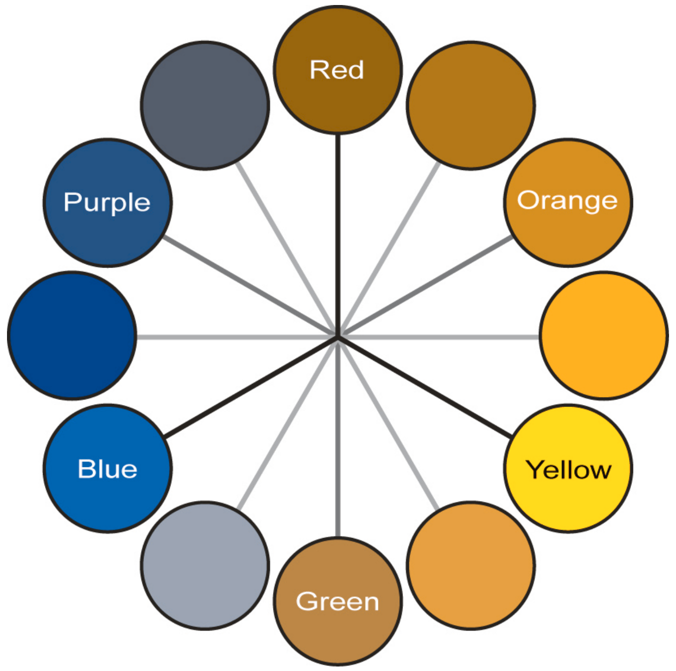
Color deficiency: Reduces color to 2 dimensions



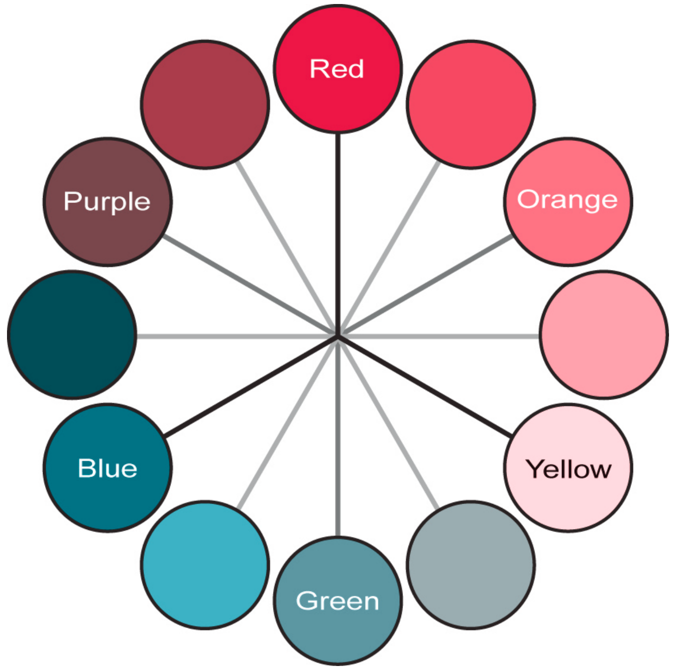
Normal



Protanope



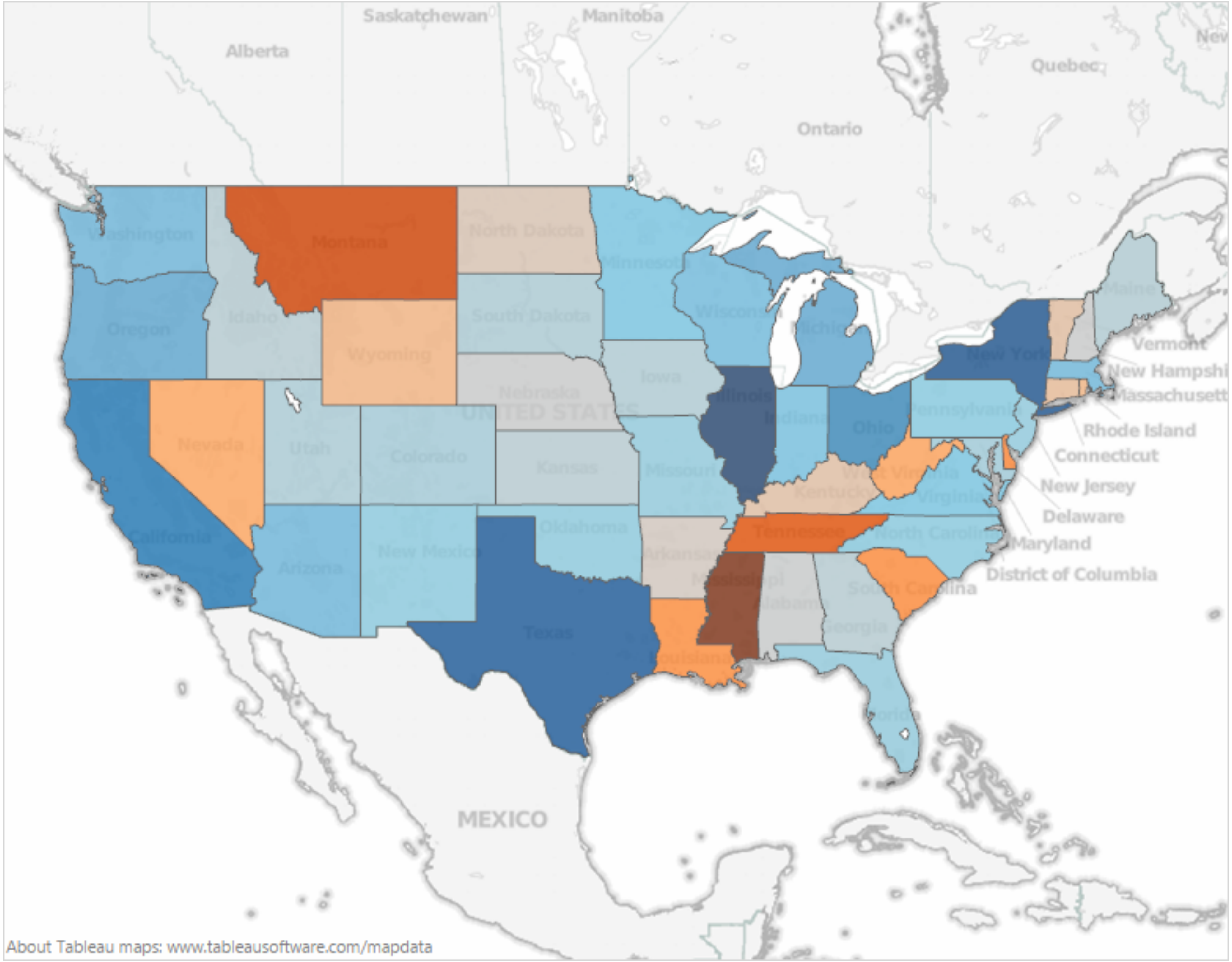
Deuteranope



Tritanope

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

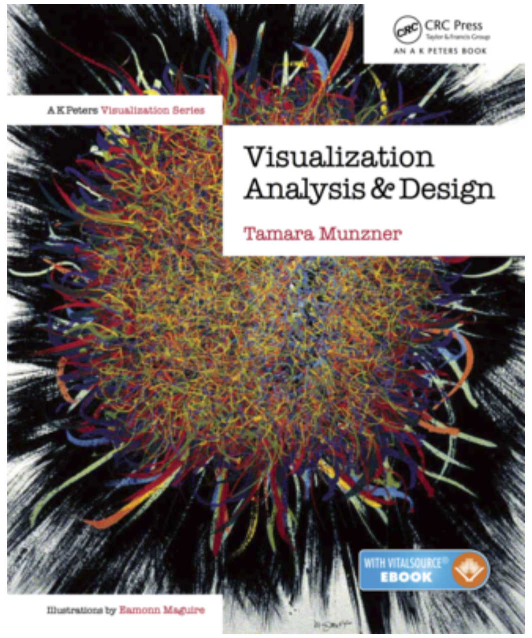
Designing for color deficiency: Blue-Orange is safe



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

Visualization Analysis & Design

Color (Ch 10) III



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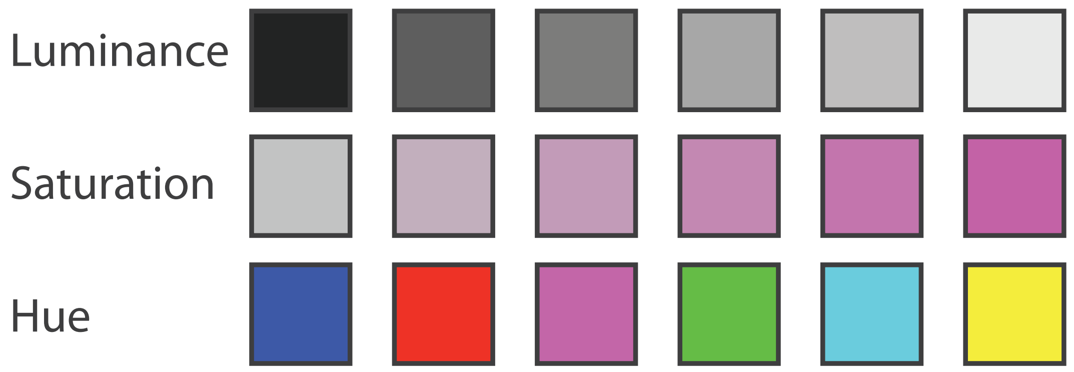
Color Spaces

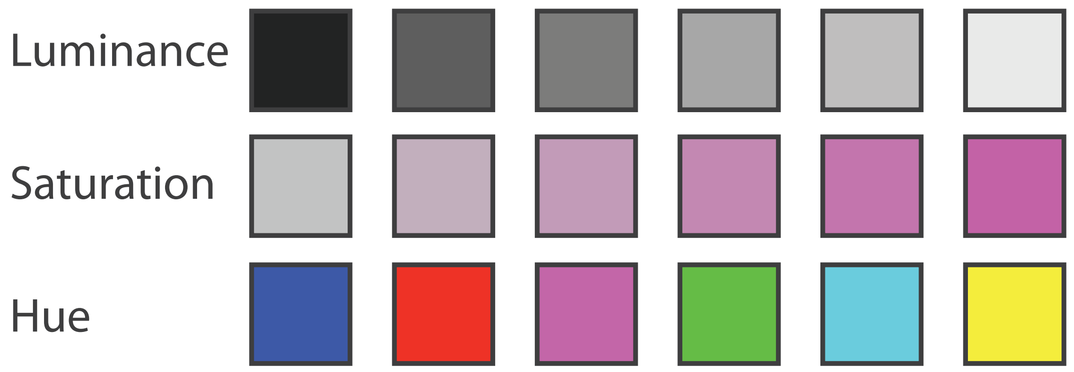
Many color spaces

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



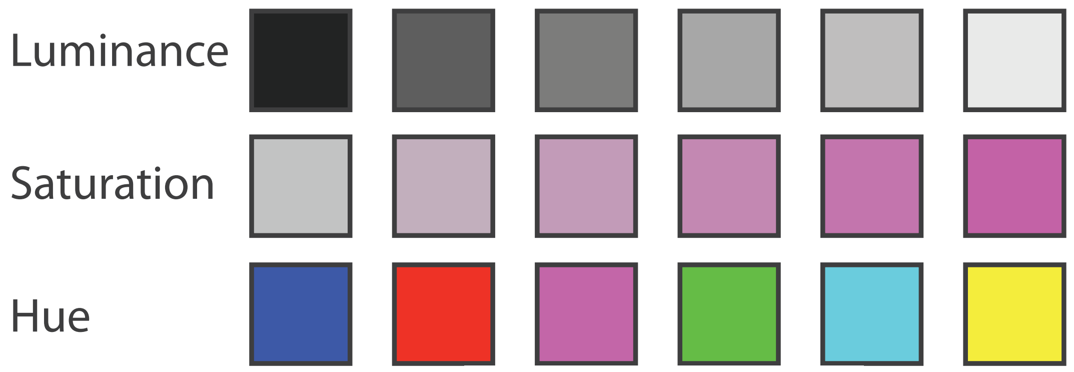
Many color spaces

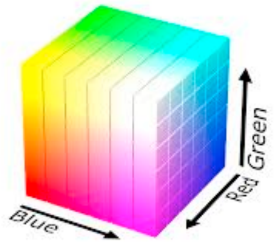
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace



Many color spaces

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



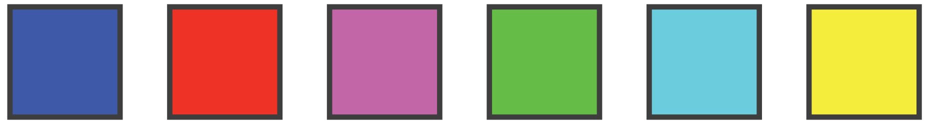


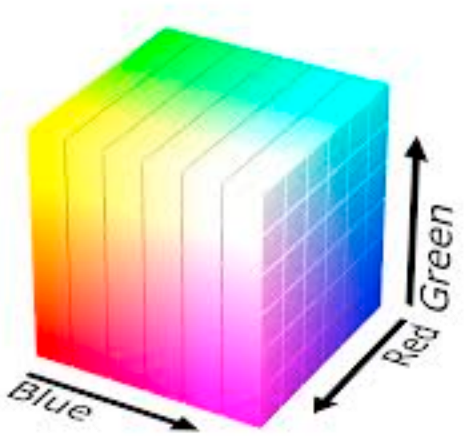
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

RGB

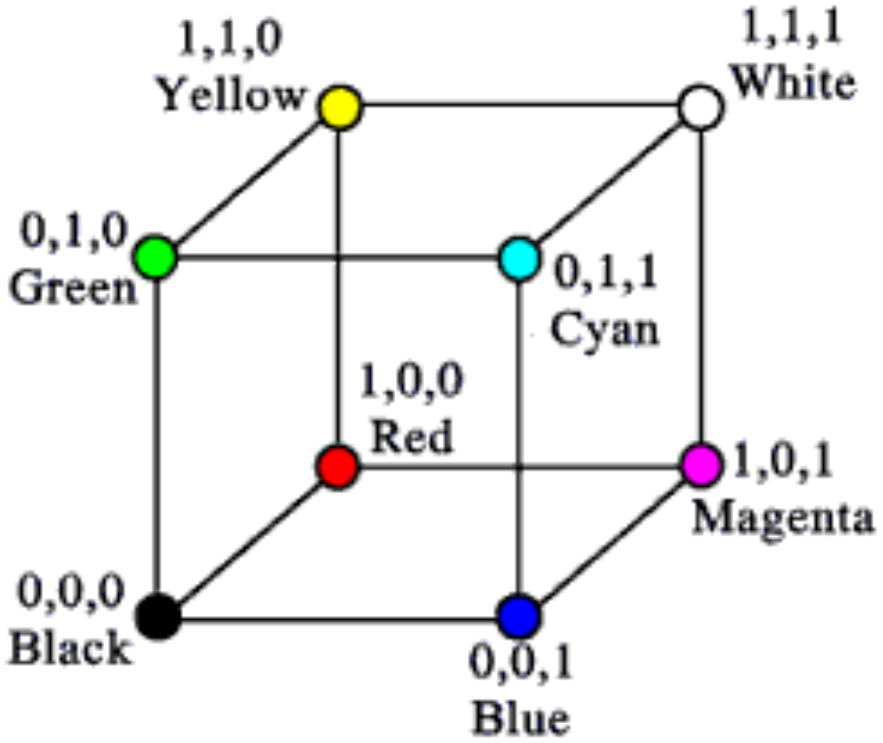
- RGB: good for display hardware

Corners of the RGB color cube





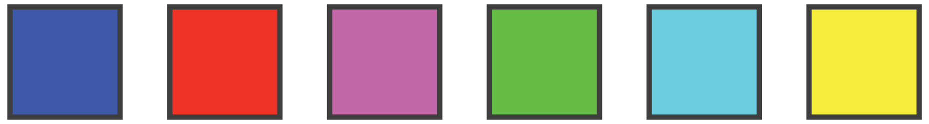
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

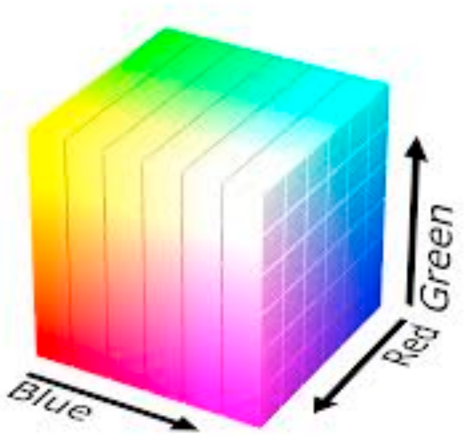


RGB

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

Corners of the RGB color cube





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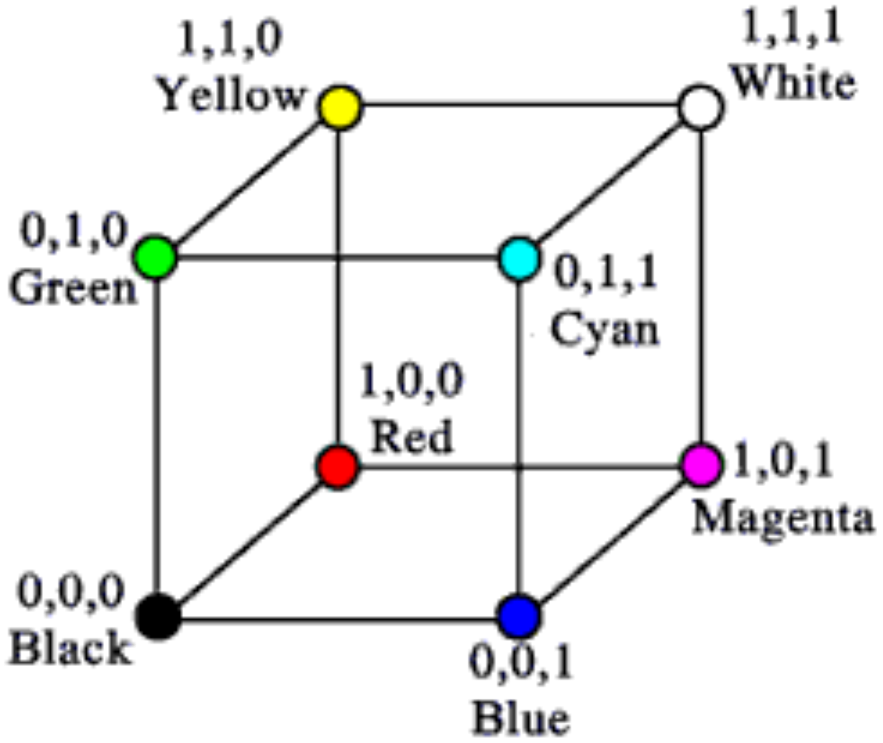
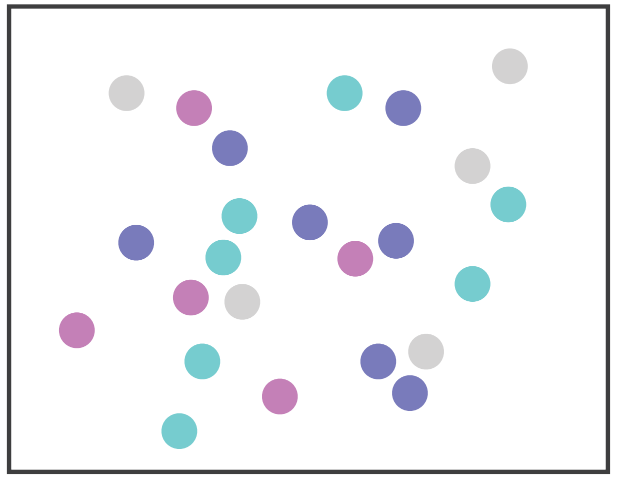


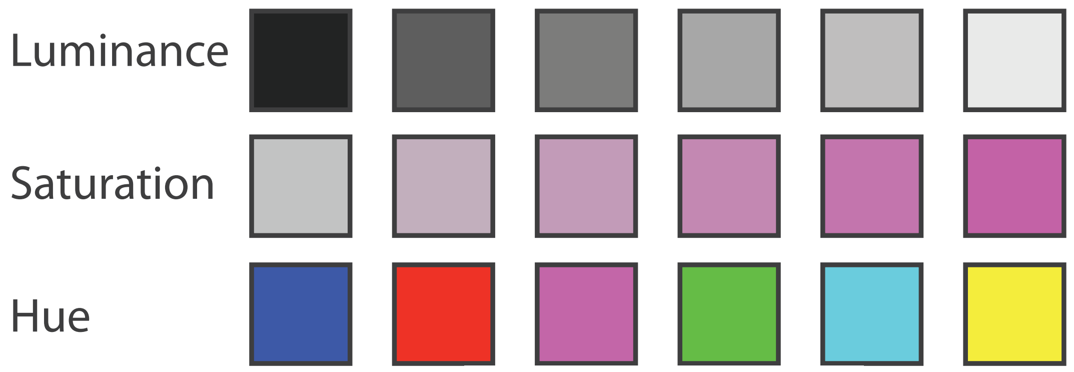
Red
+ Green

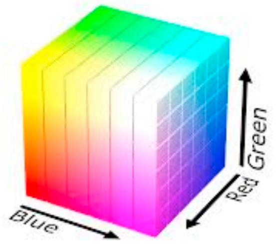


Major interference

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

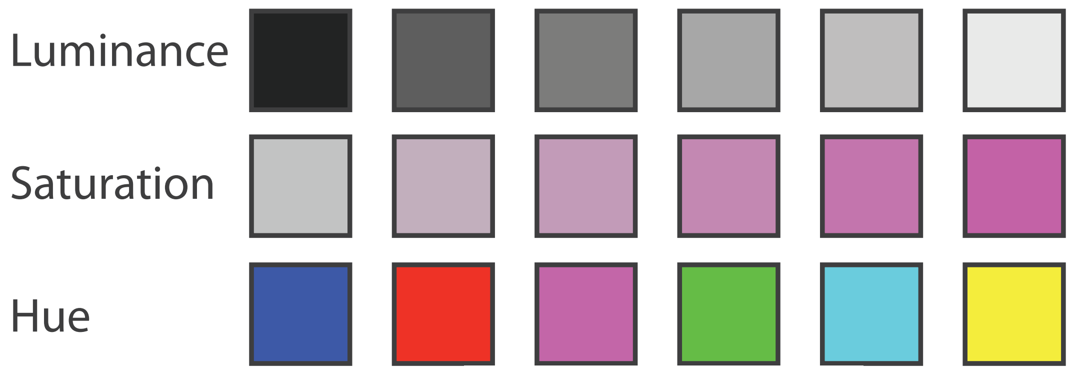


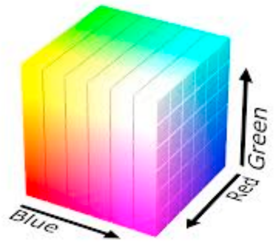


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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





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Many color spaces

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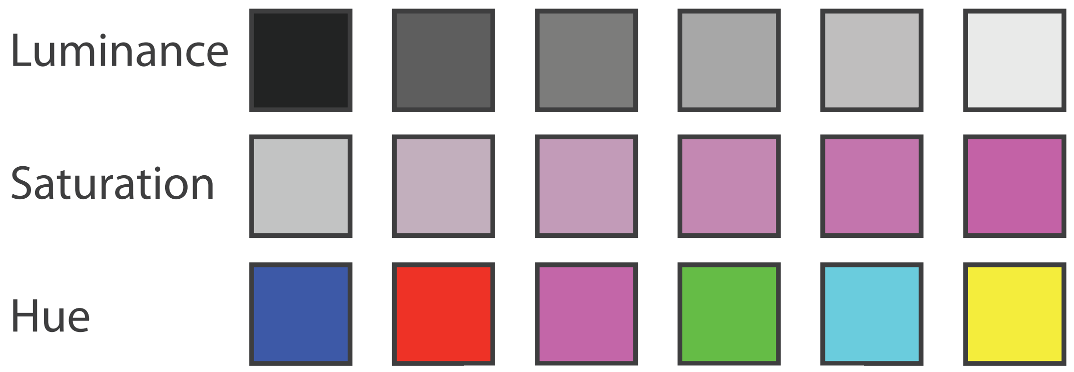
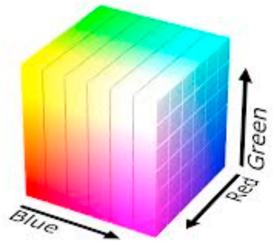
  - hard to interpret, poor for encoding





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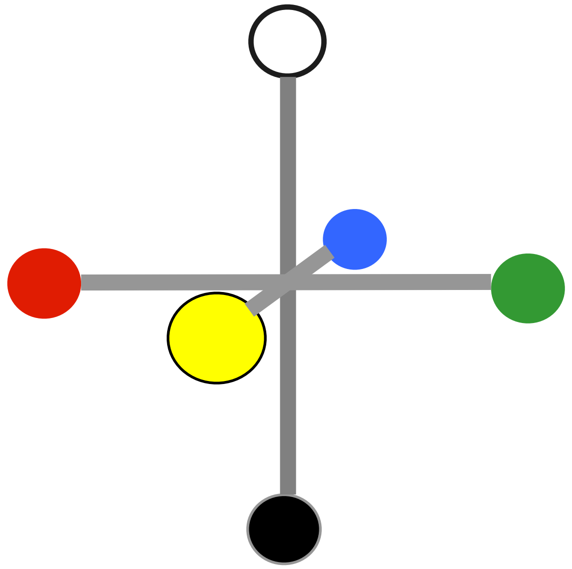
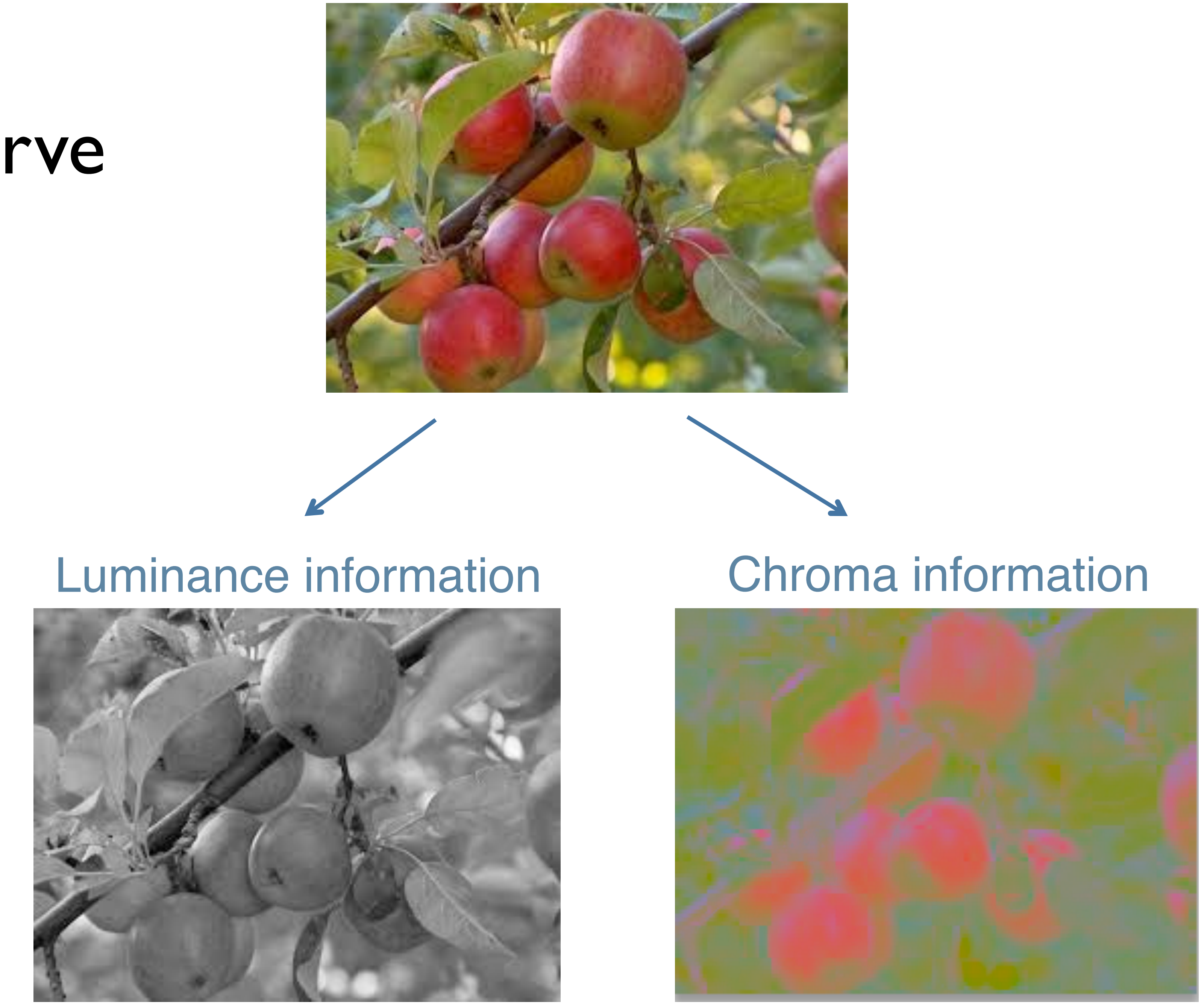
Perceptual colorspace: L*a*b*

- 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*)

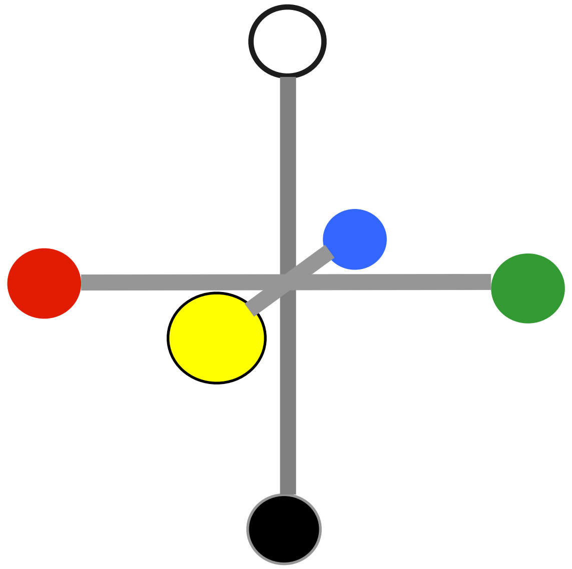


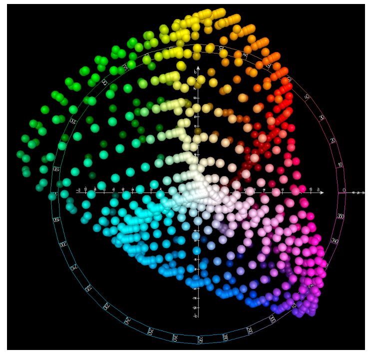


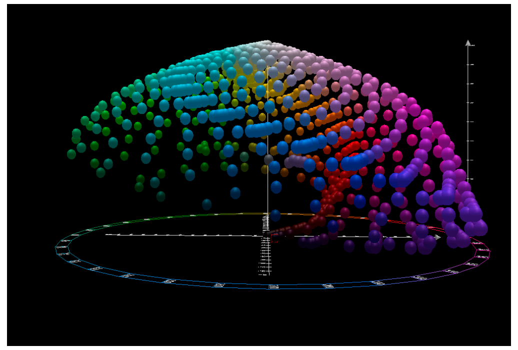
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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

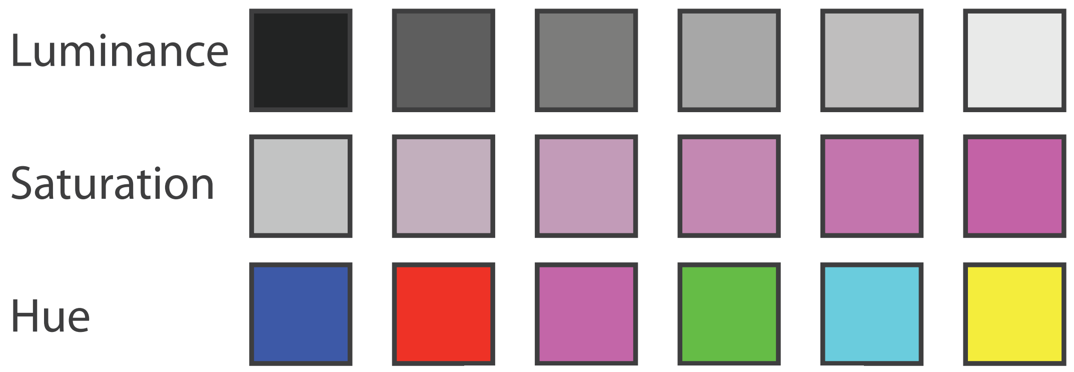
Luminance information

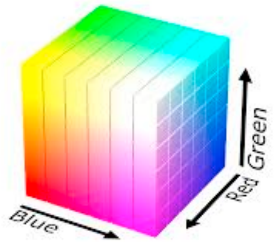
Chroma information

[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

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  - good for encoding
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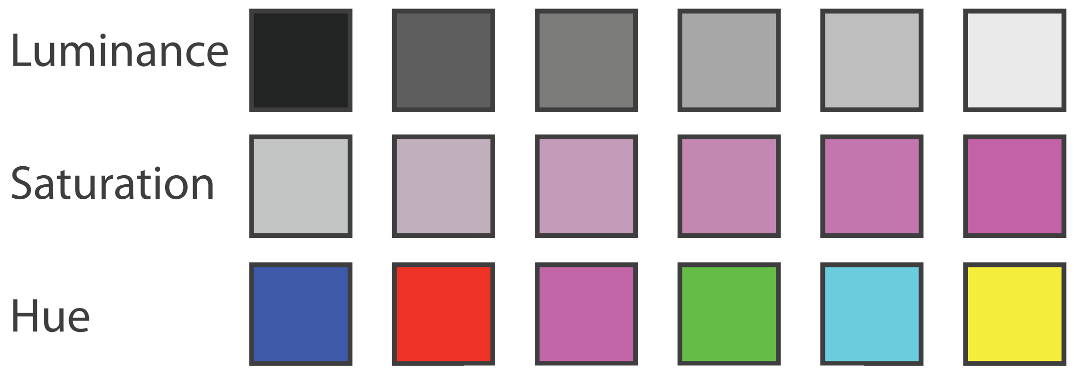
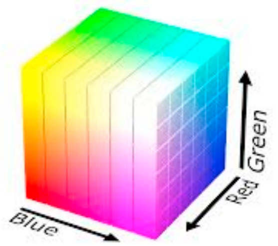
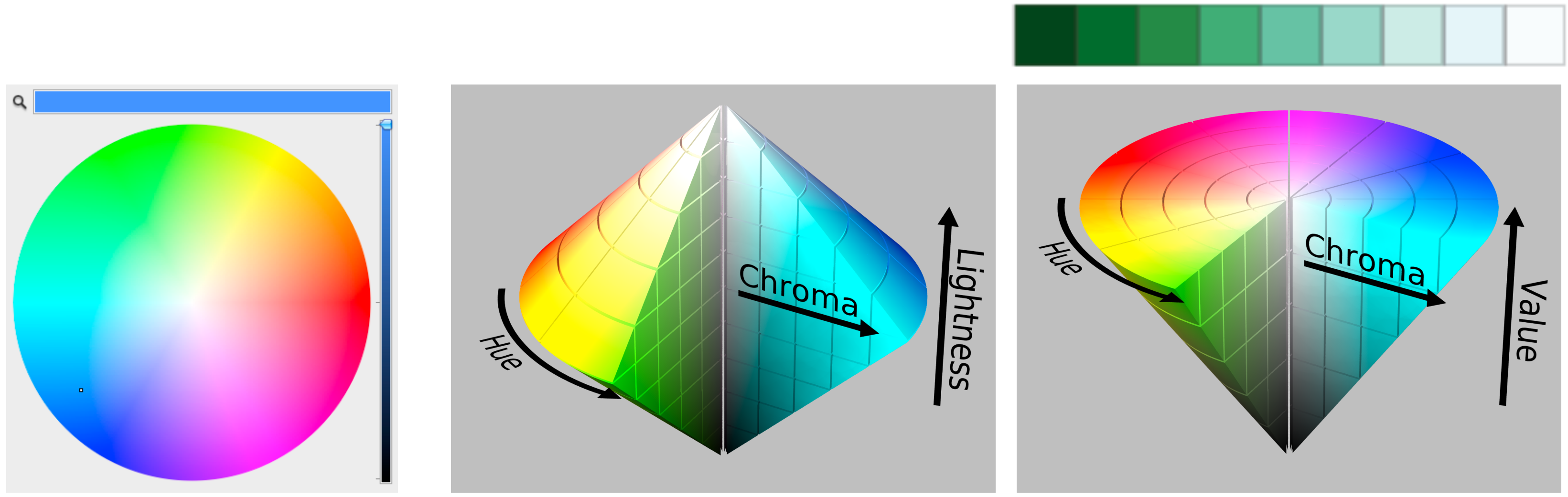
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding



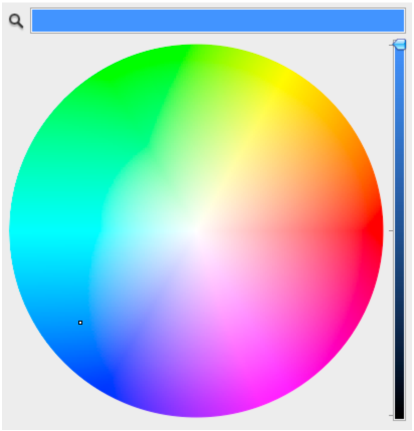


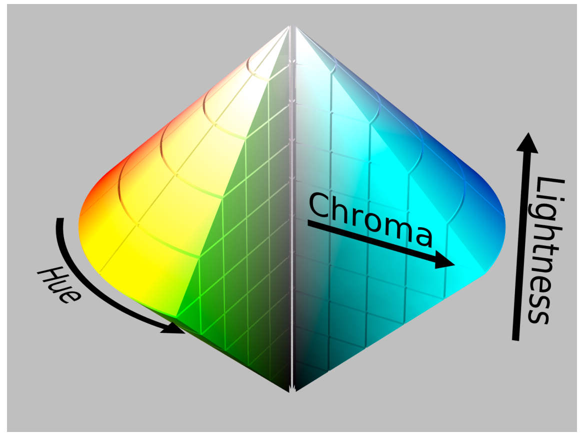
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

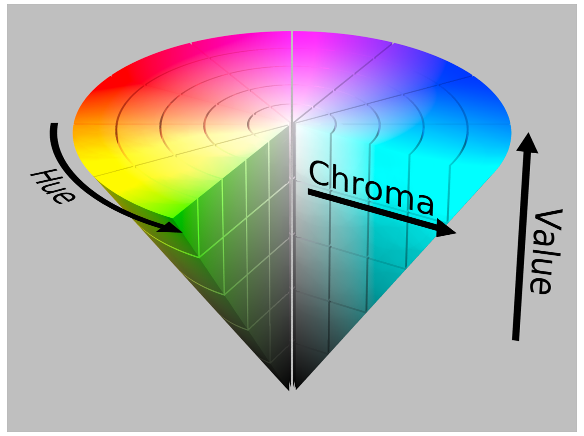


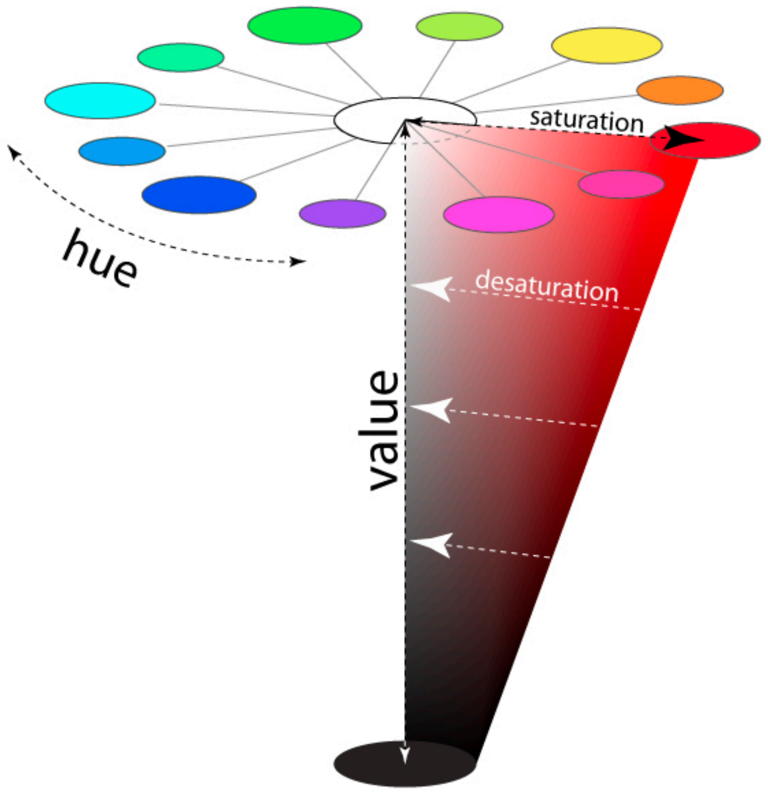
HSL/HSV

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





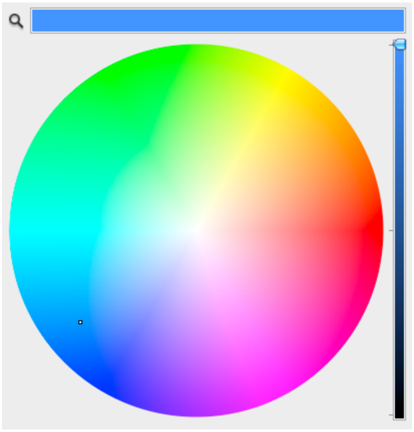


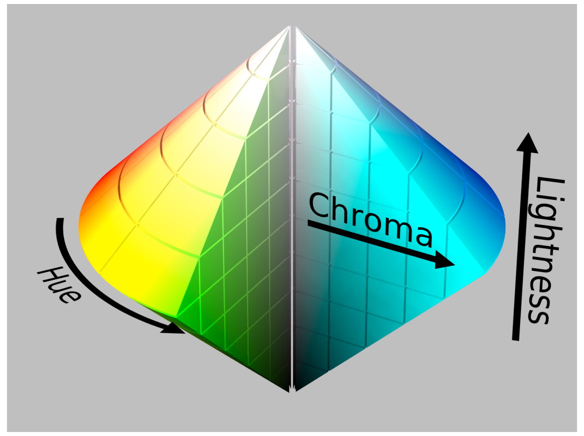


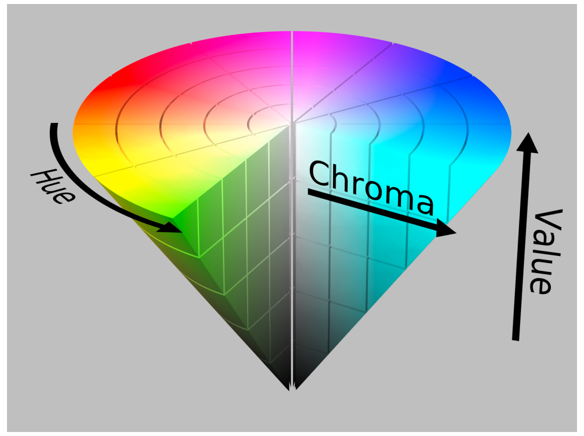
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

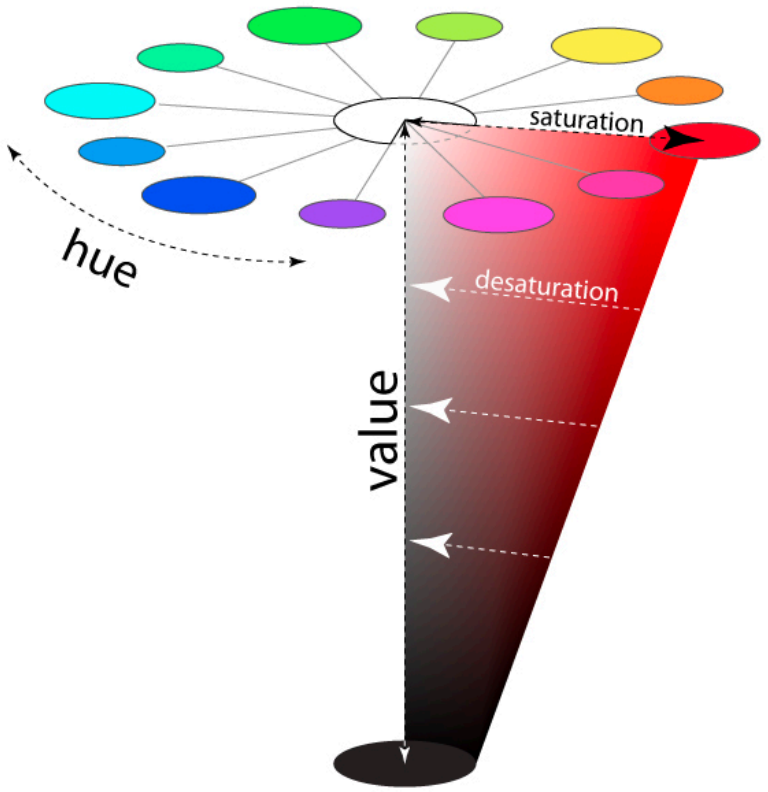
HSL/HSV

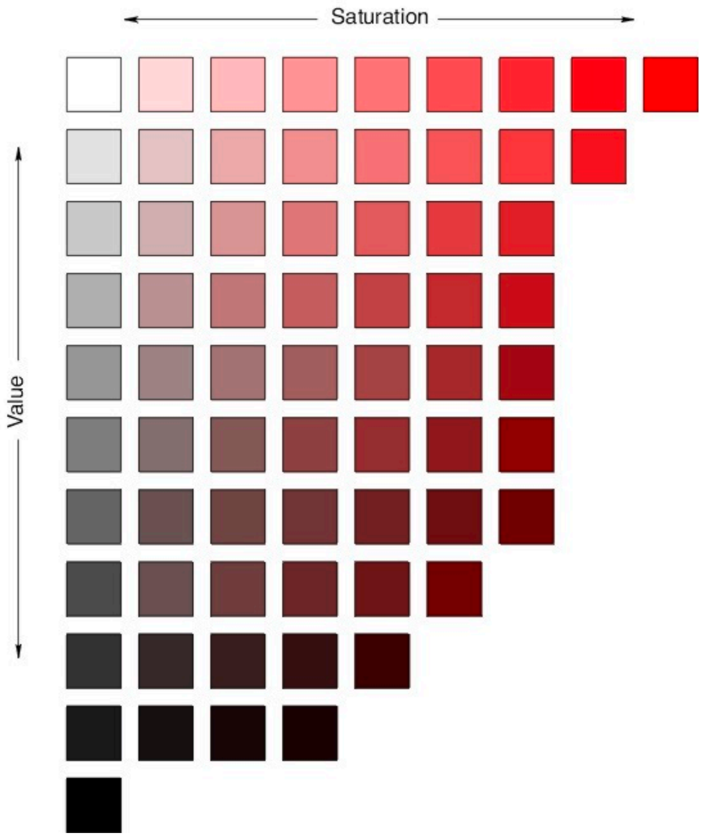
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation









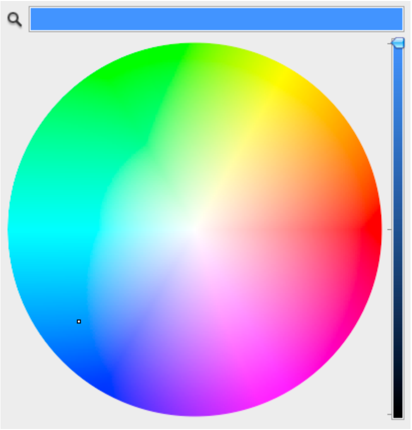


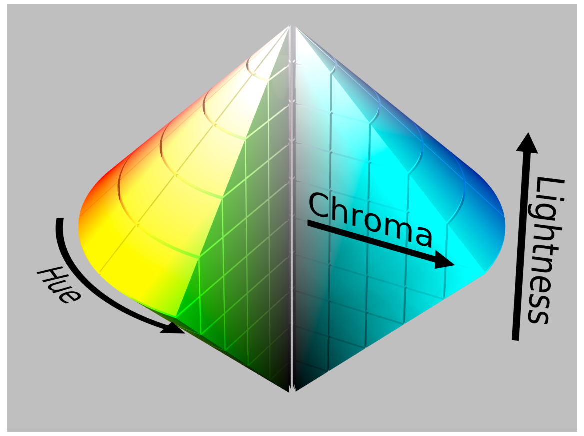
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

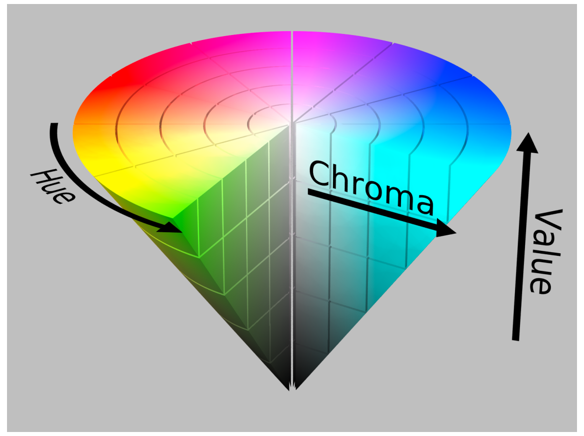
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV: Pseudo-perceptual colorspace

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



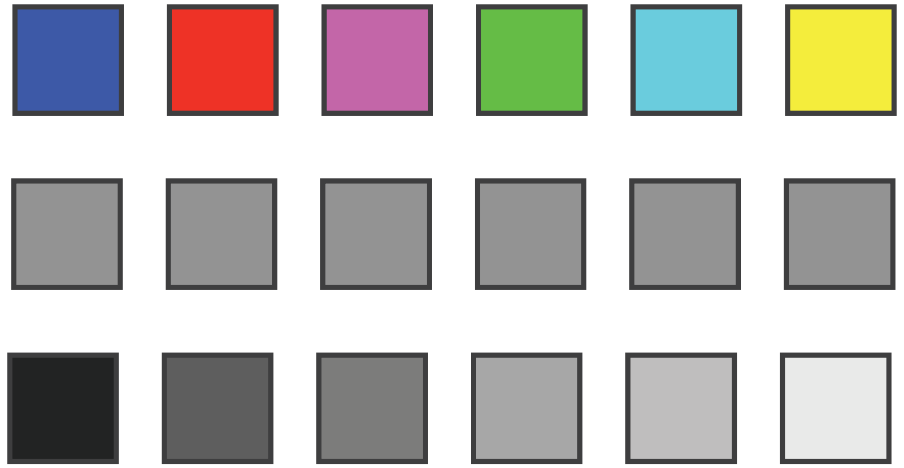




Corners of the RGB color cube

L from HLS
All the same

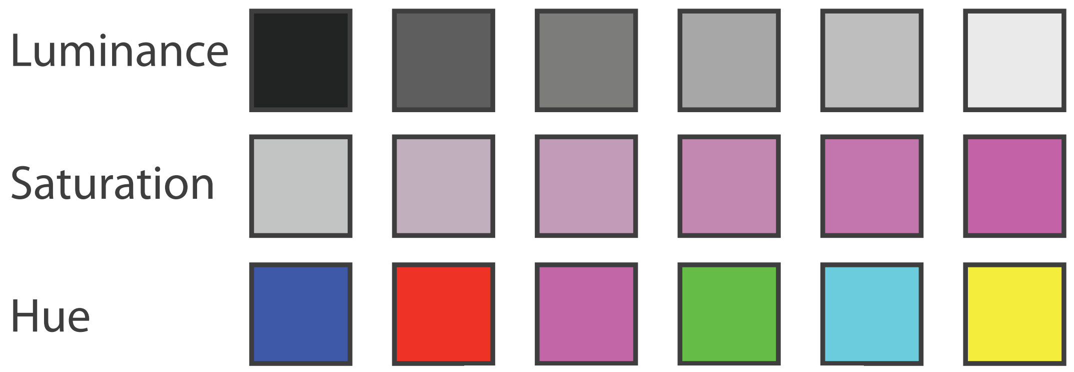
Luminance values

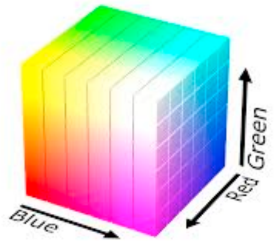


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

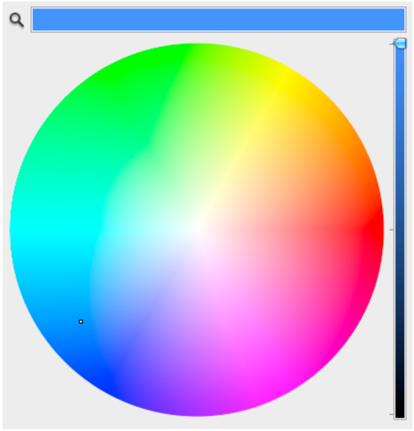
Many color spaces

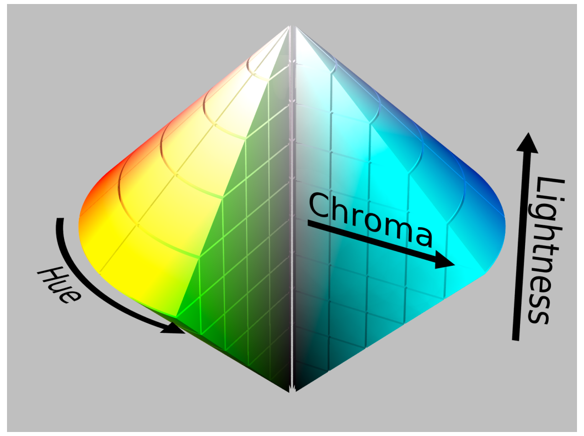
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)

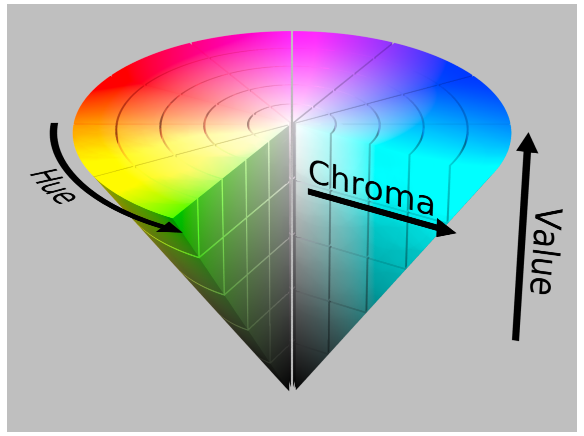




https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

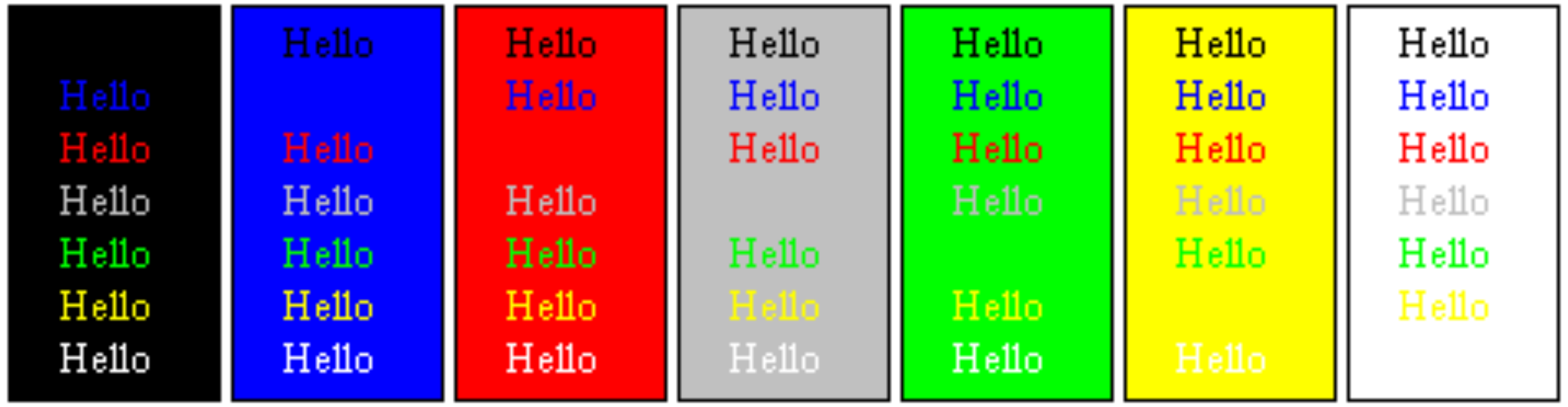






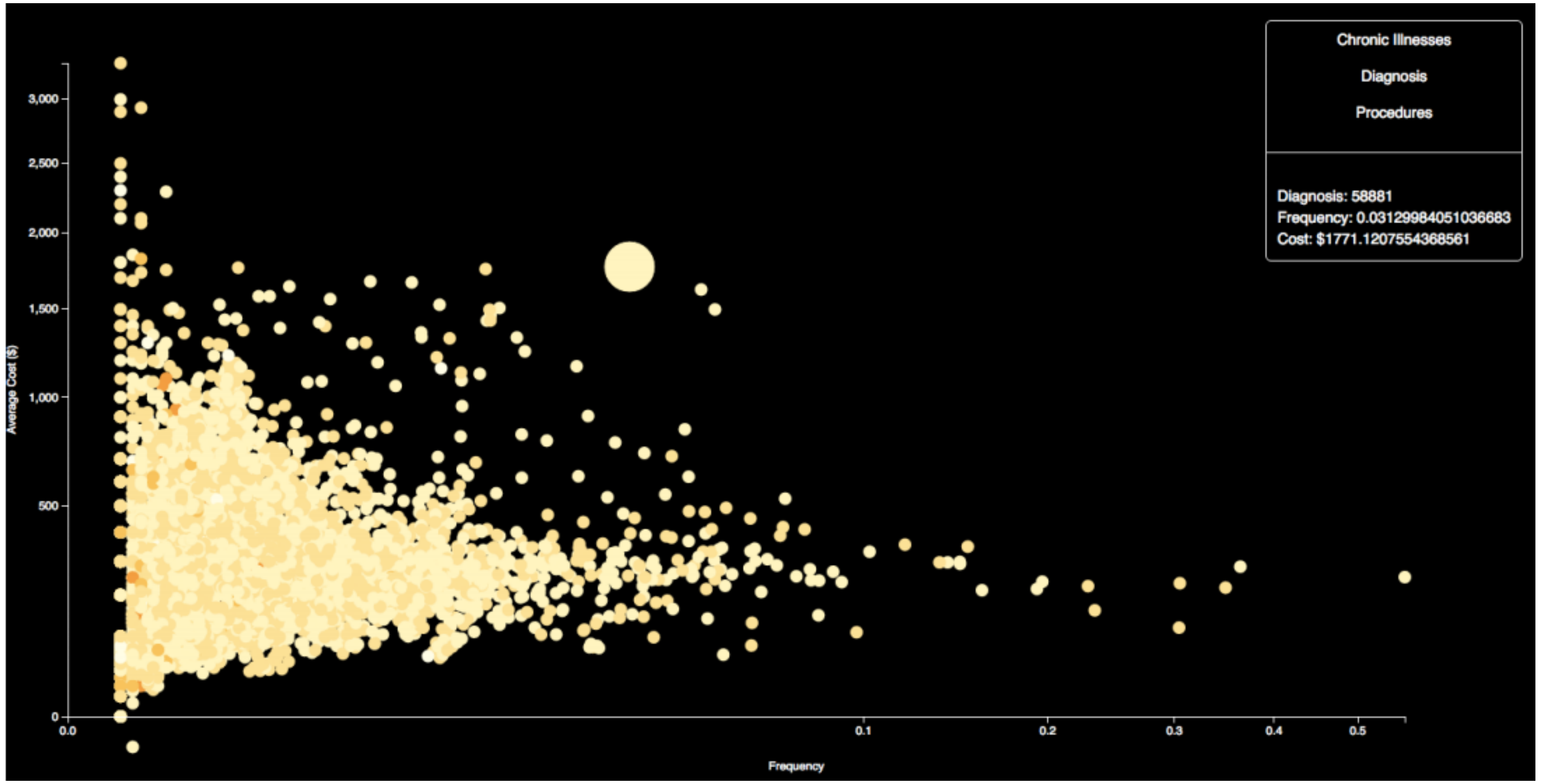
Color Constrast & Naming

Interaction with the background



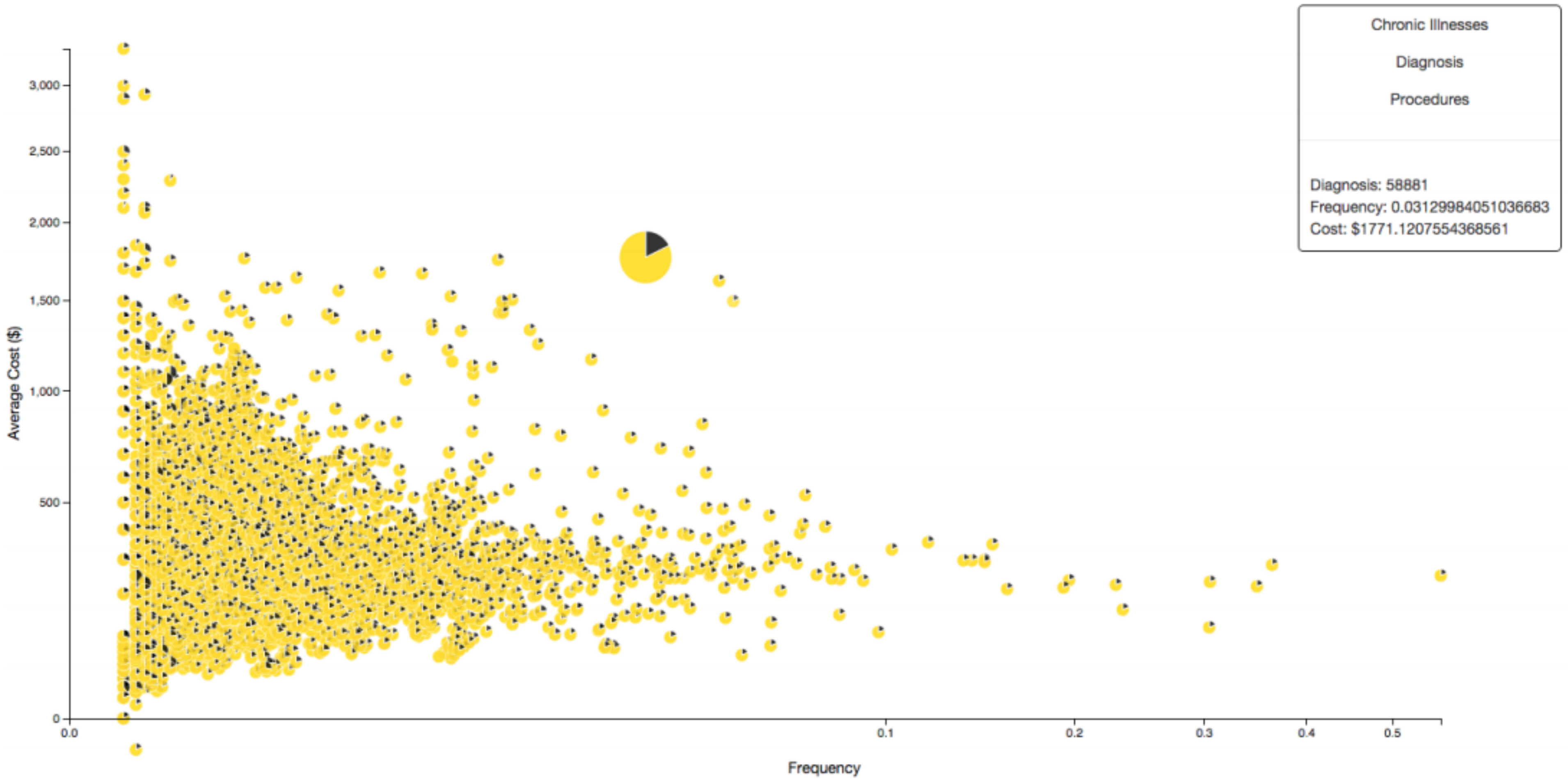
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



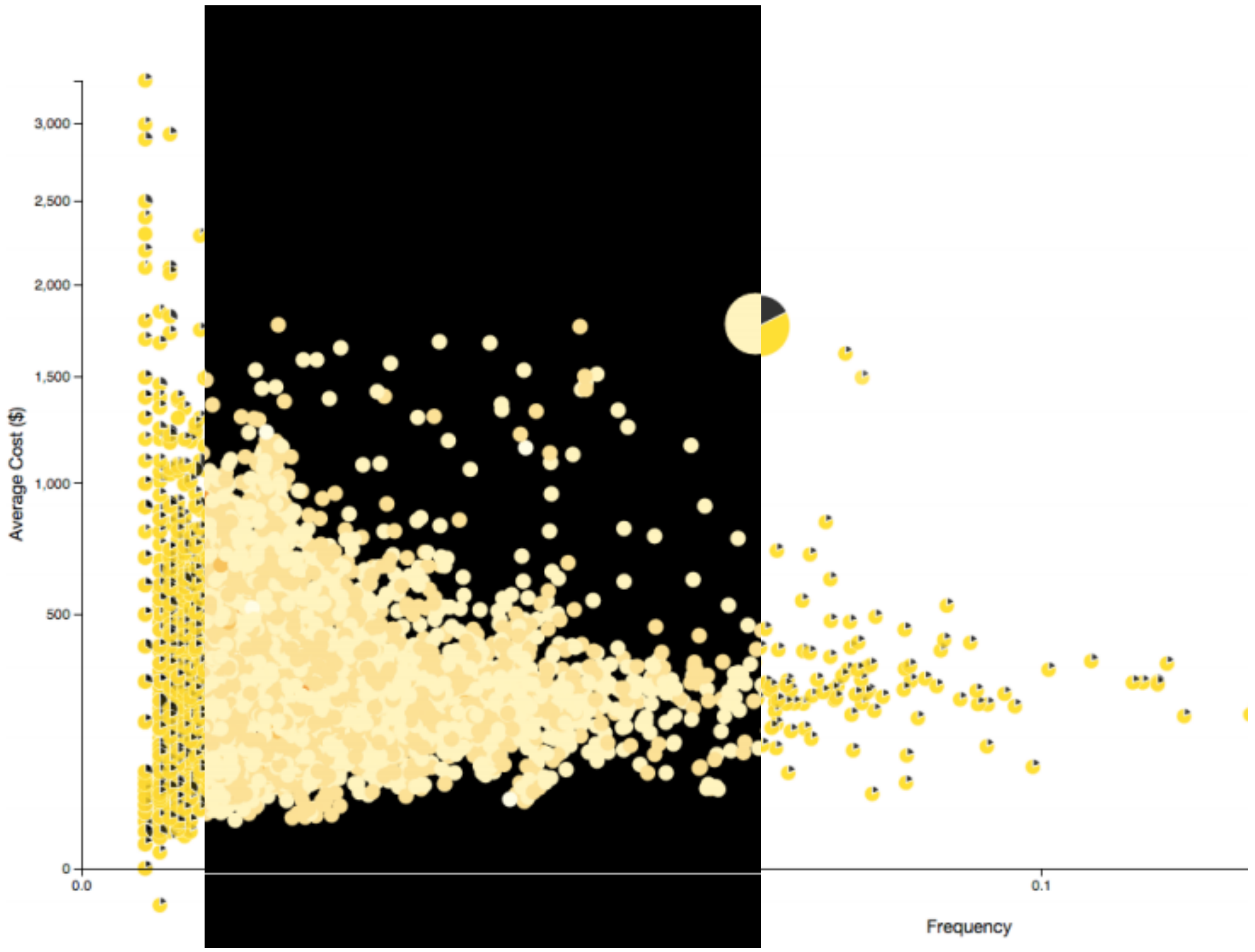
Interaction with the background: tweaking yellow for visibility

- 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

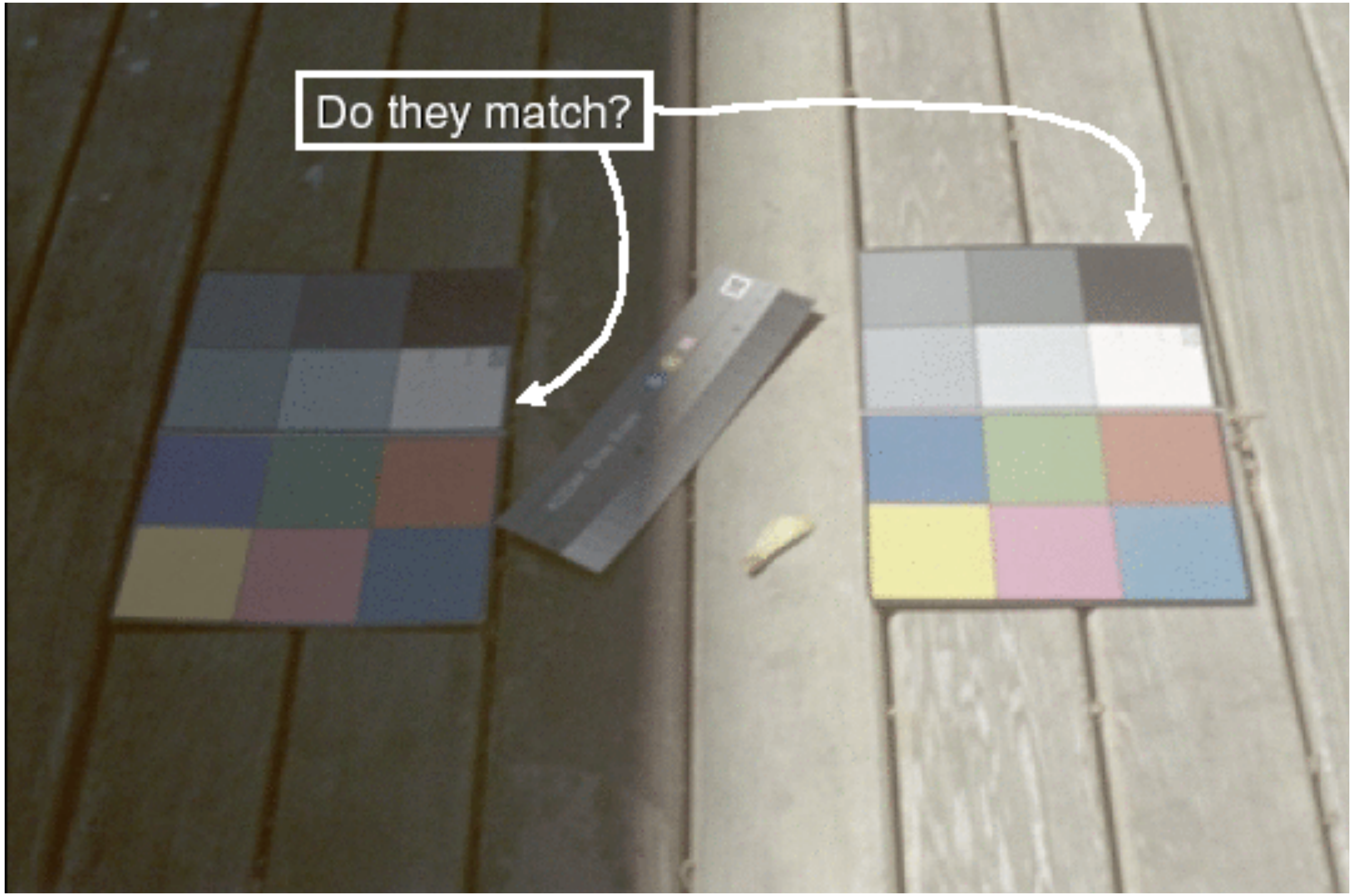


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

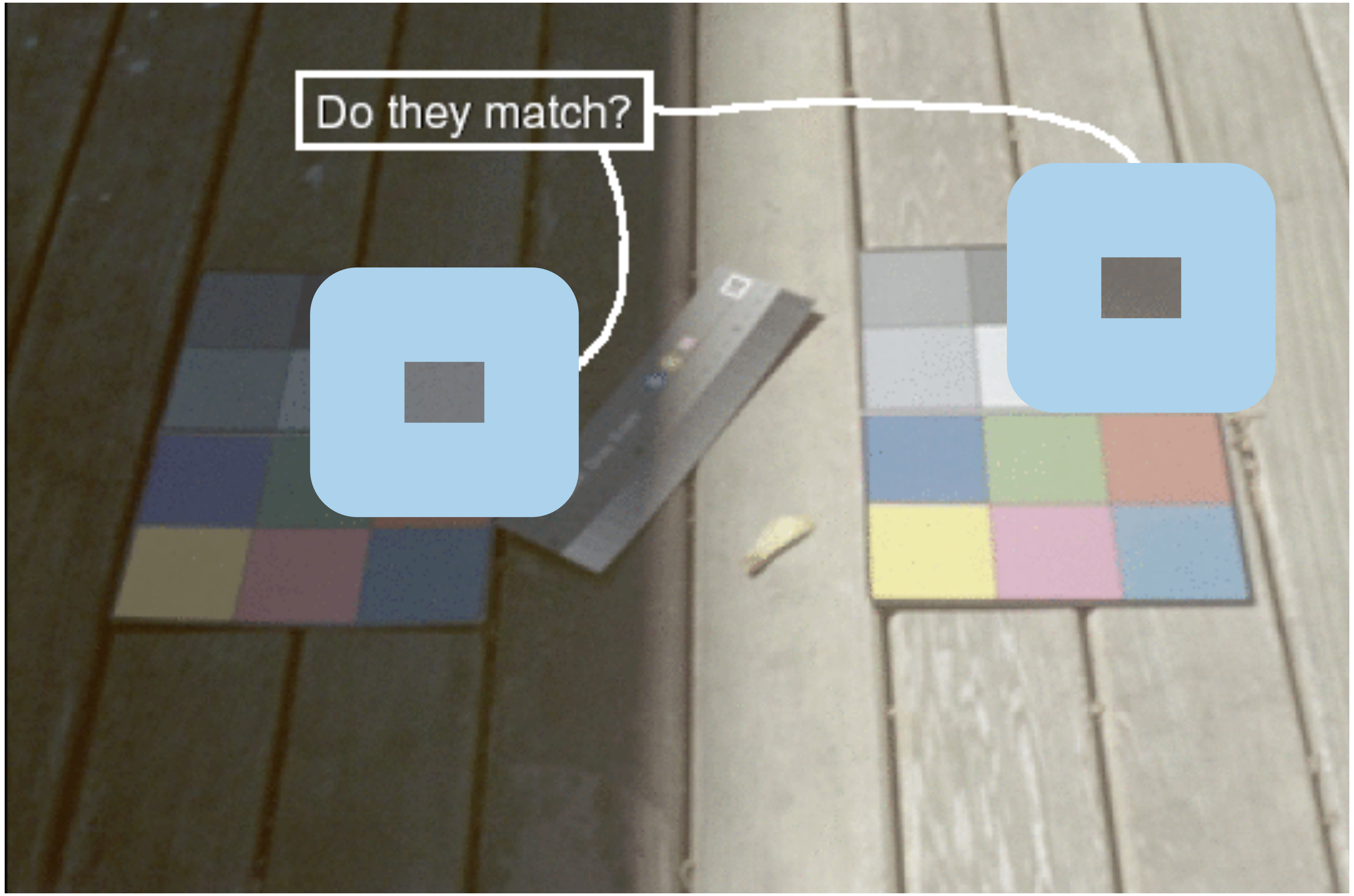
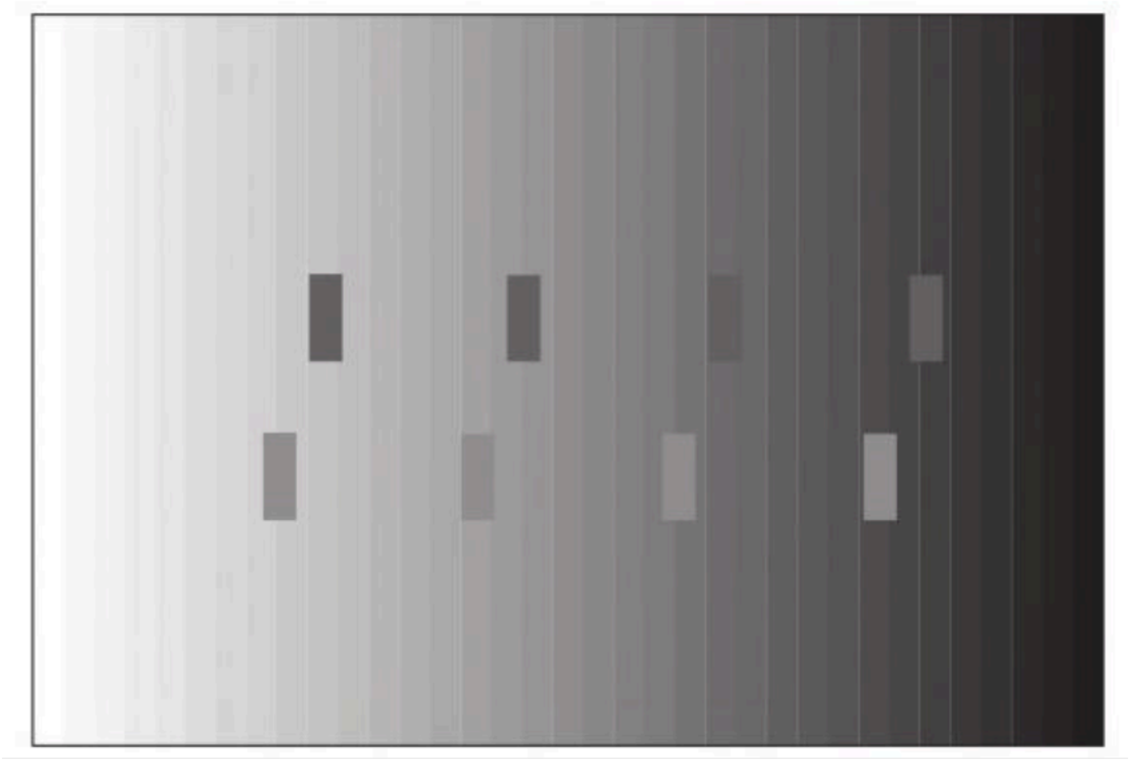
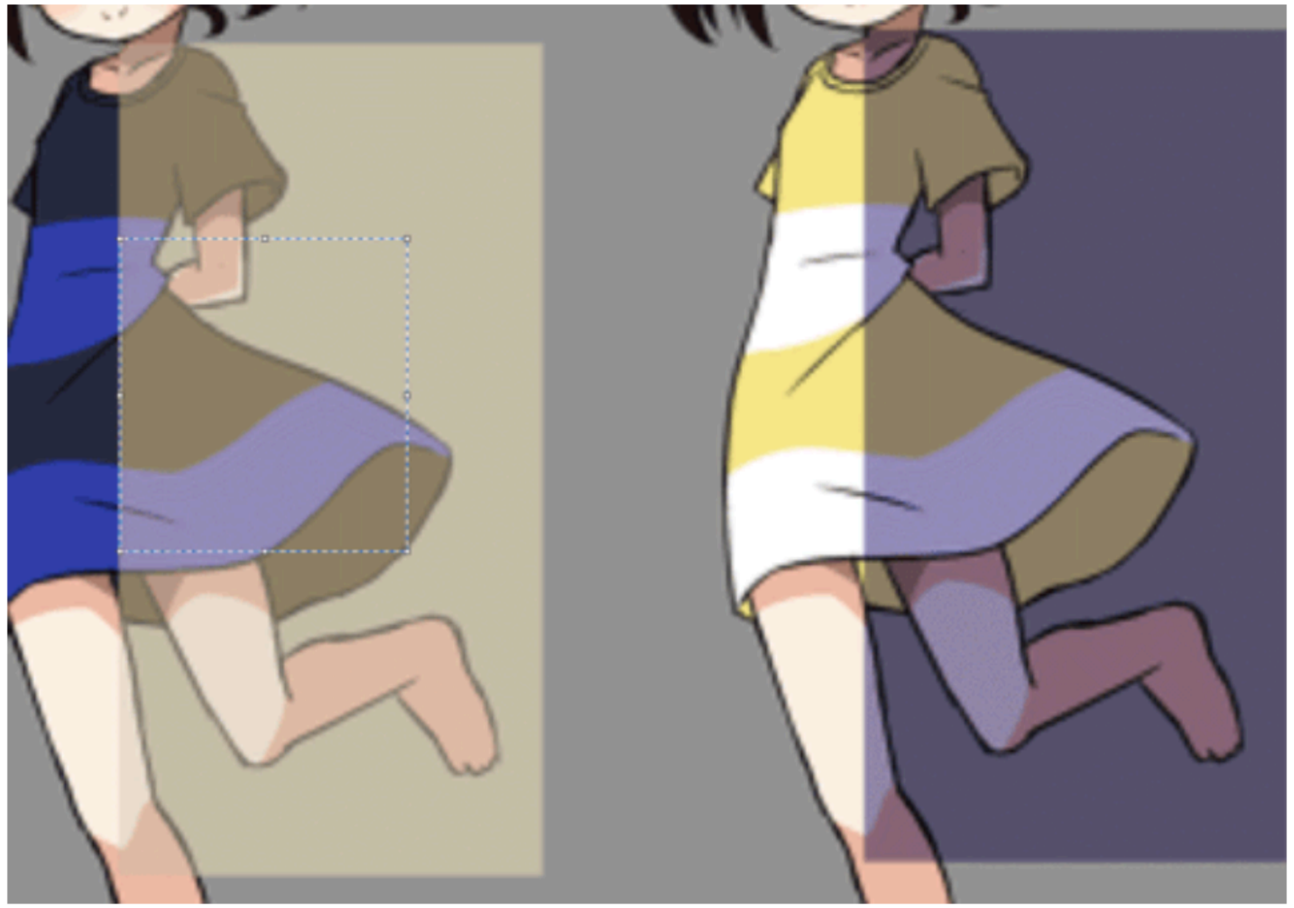


Image courtesy of John McCann via Maureen Stone

Contrast with background



Contrast with background

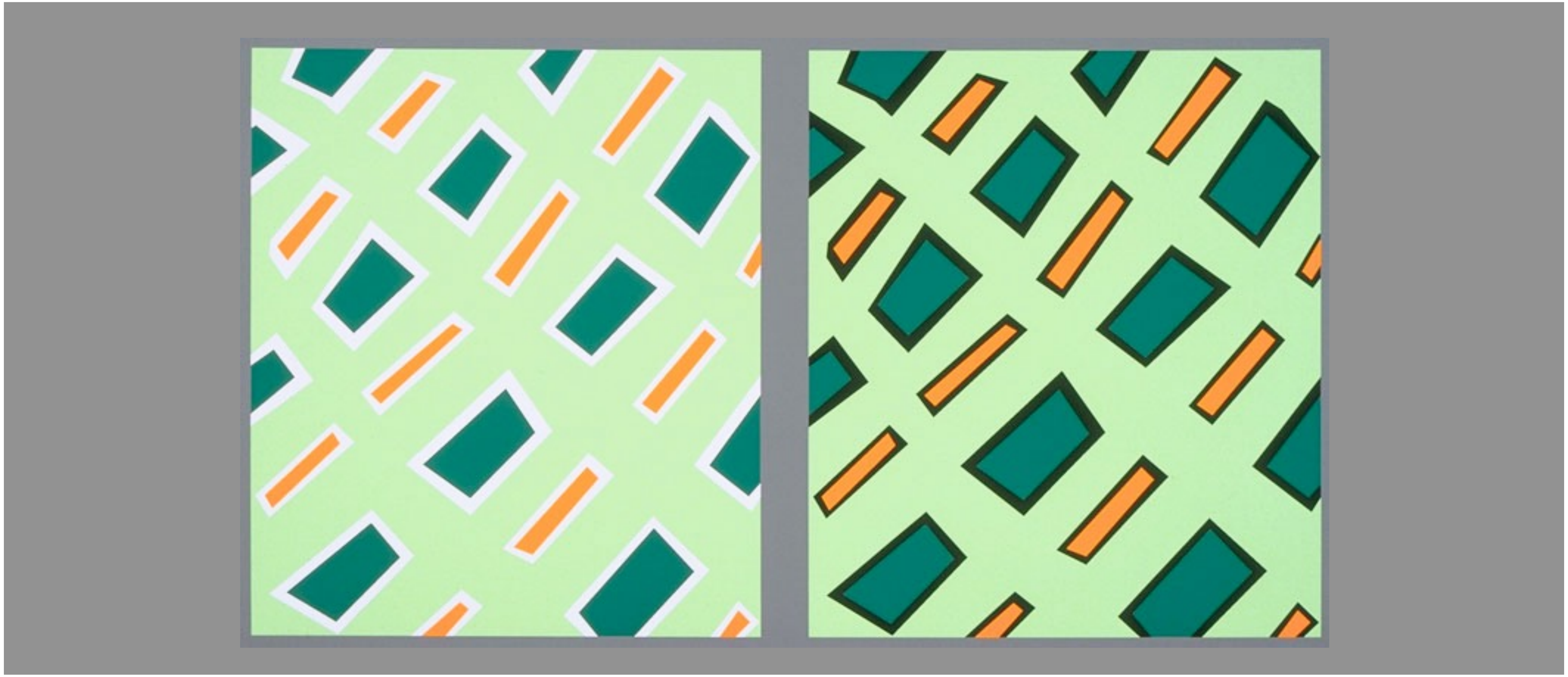


Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

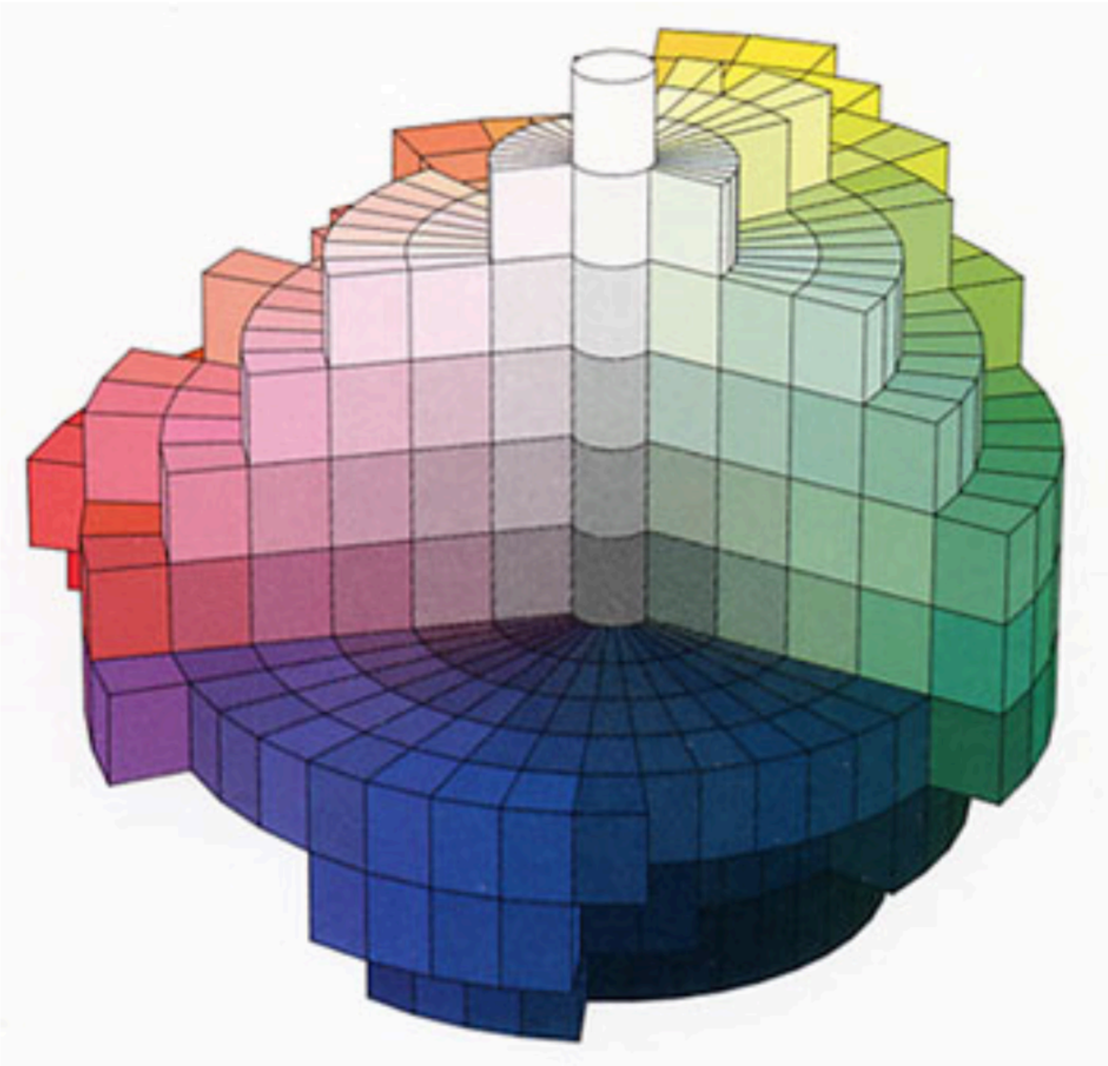
Bezold Effect: Outlines matter



[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/

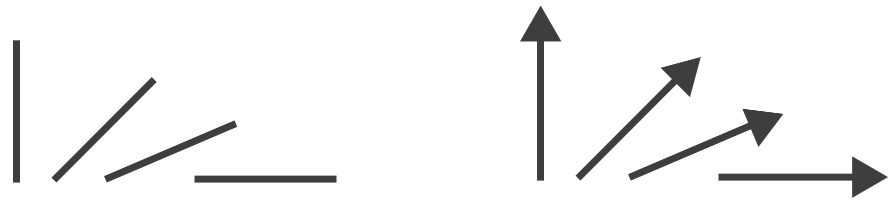
Color is just part of vision system

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

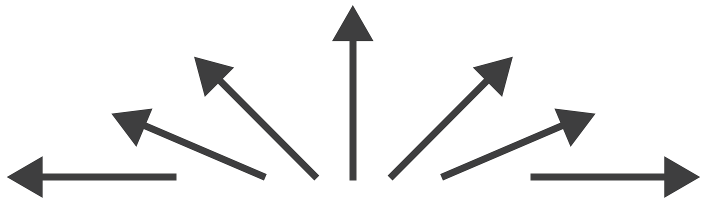
Map Other Channels

Angle / tilt / orientation channel

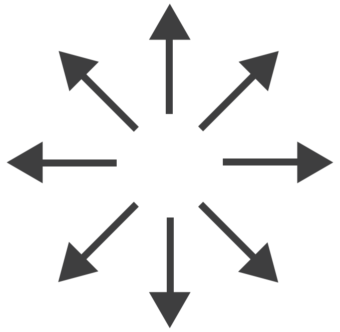
- different mappings depending on range used



Sequential ordered
line mark or arrow glyph



Diverging ordered
arrow glyph

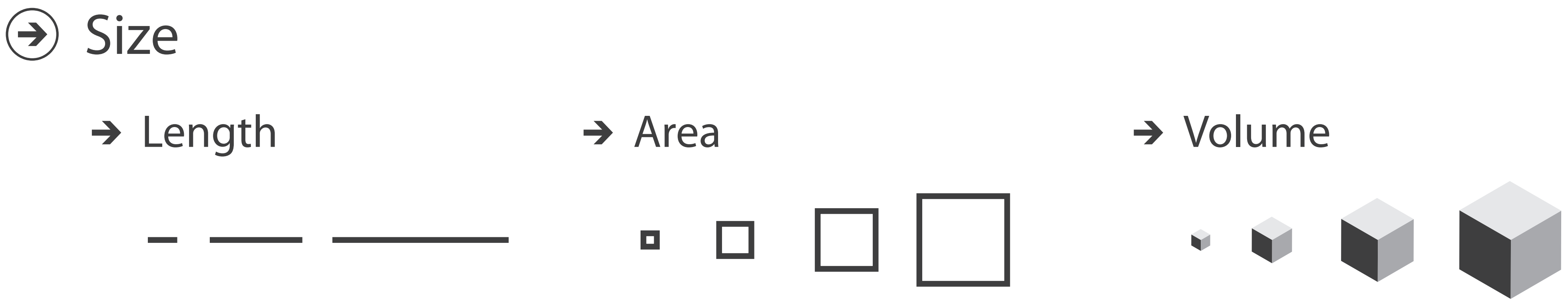


Cyclic ordered
arrow glyph

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

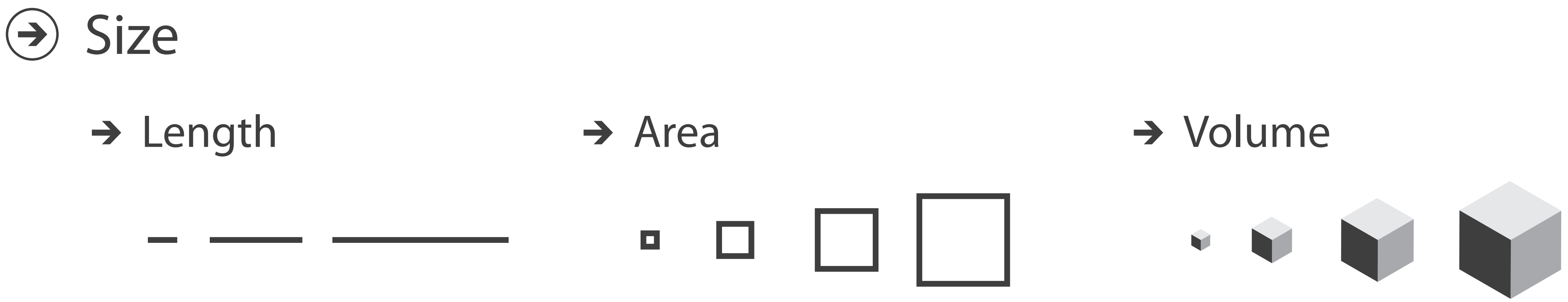
Map other channels

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



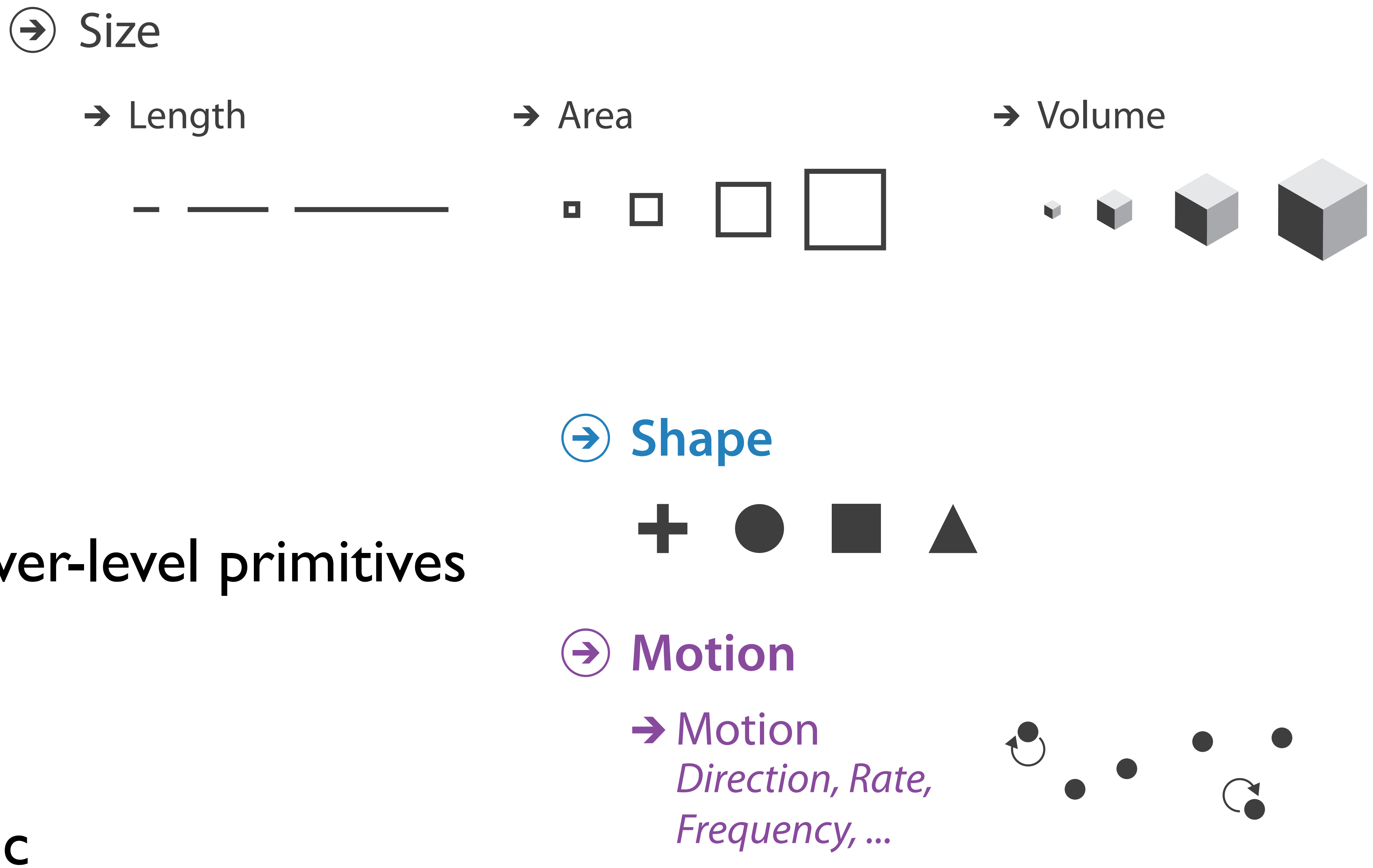
Map other channels

- 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



Spectral sensitivity to luminance