UNIVERSITÀ DI TORINO

Analisi e Visualizzazione di Reti Complesse

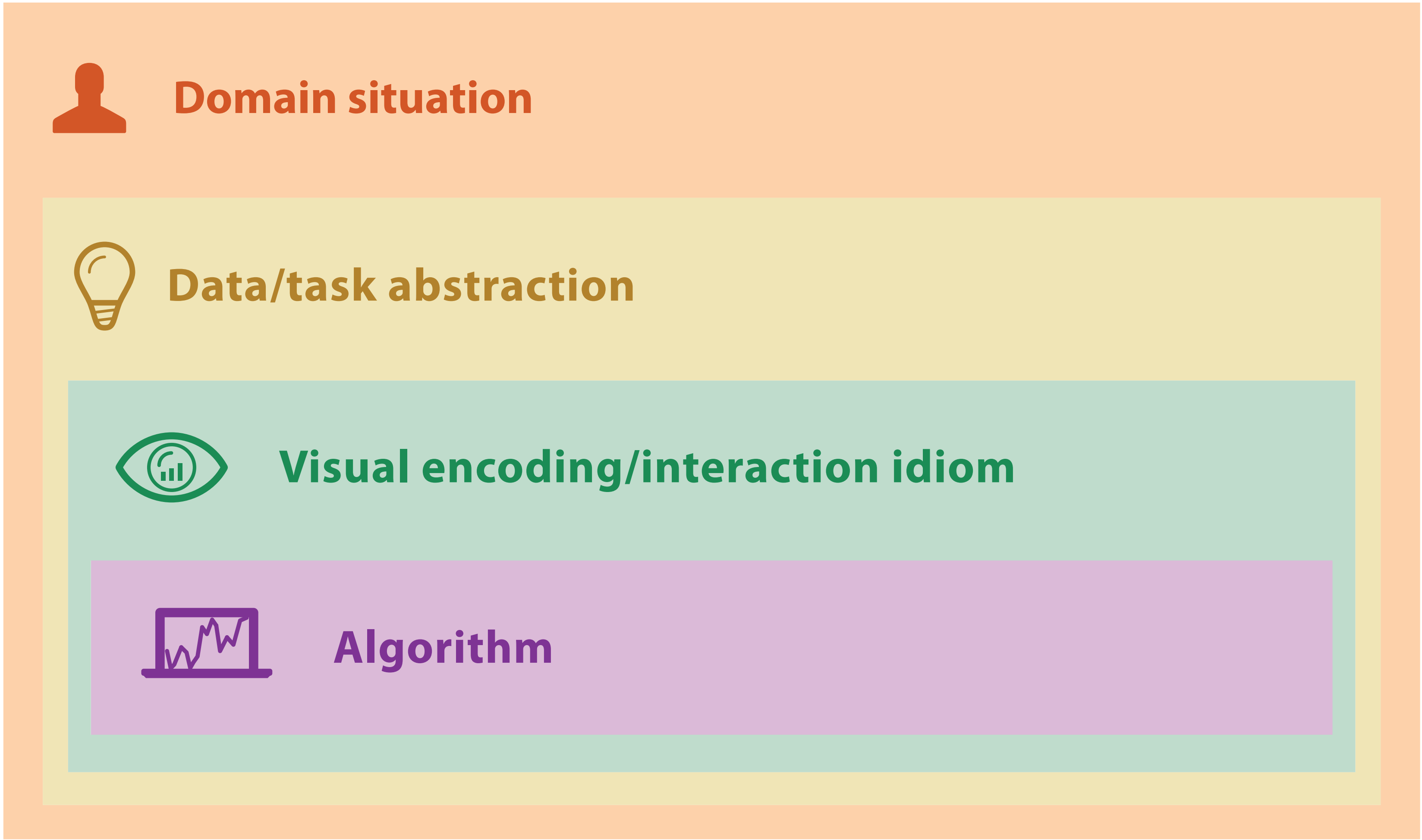
DV03 Marks and Channels Color

Prof. Rossano Schifanella

Marks and Channels

Visual encoding

- How to systematically analyze the idiom structure?



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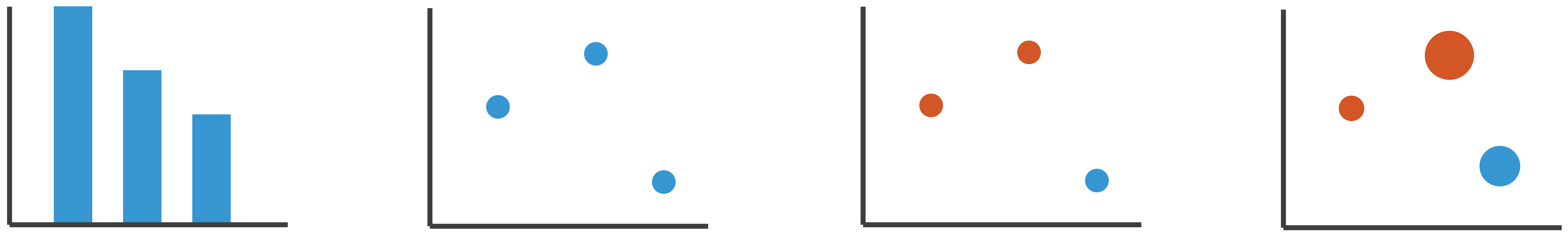

Visual encoding

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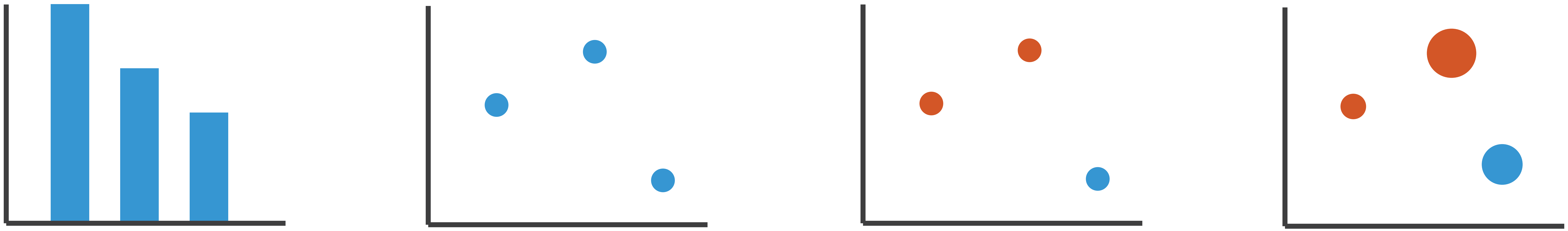
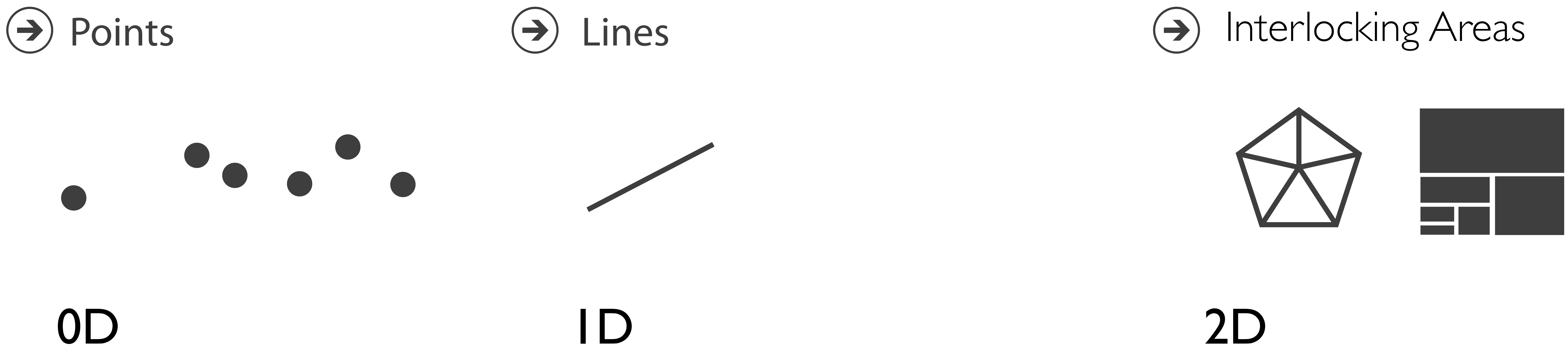


- **marks & channels**
  - **marks**: represent items or links
  - **channels**: change the appearance of marks based on attributes

Marks for items

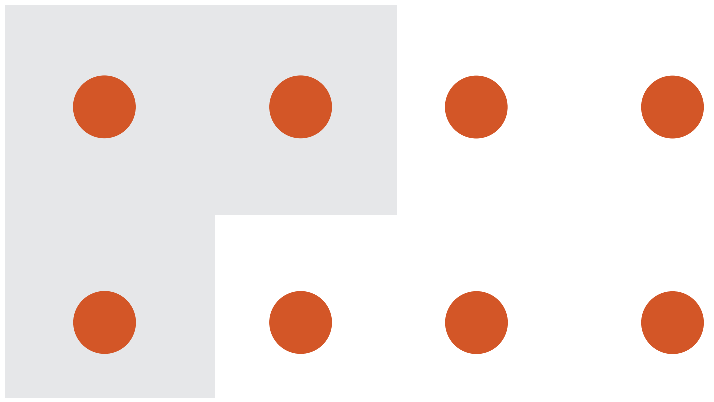
- basic geometric elements

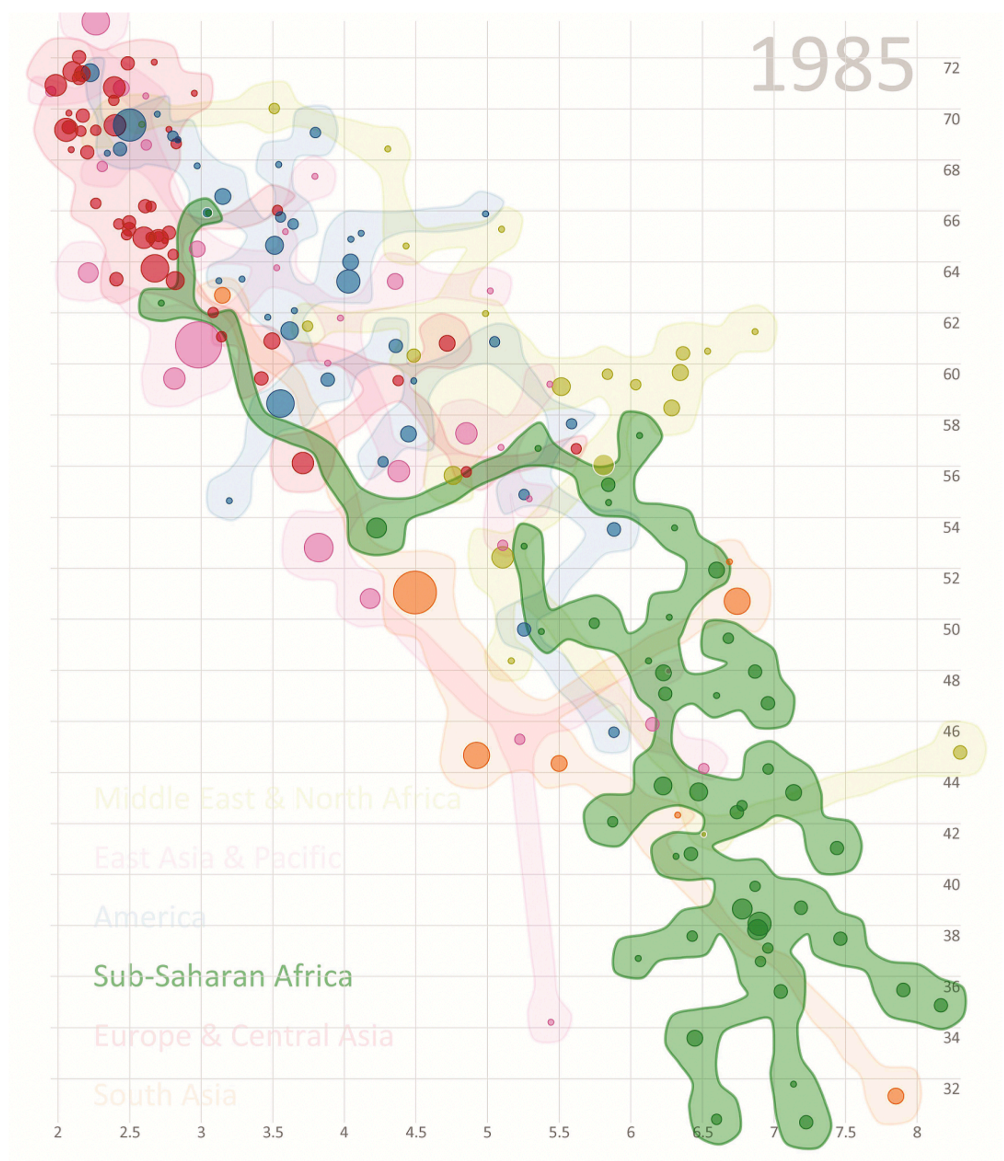


- 3D mark: volume, rarely used

Marks for links

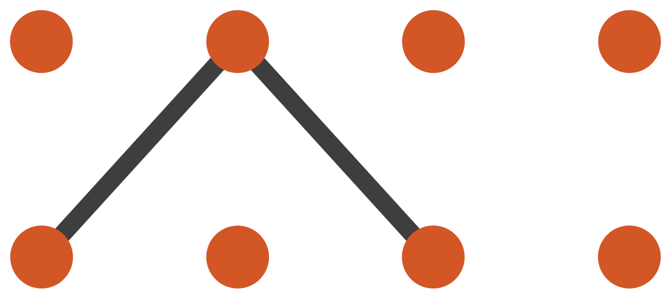
Containment

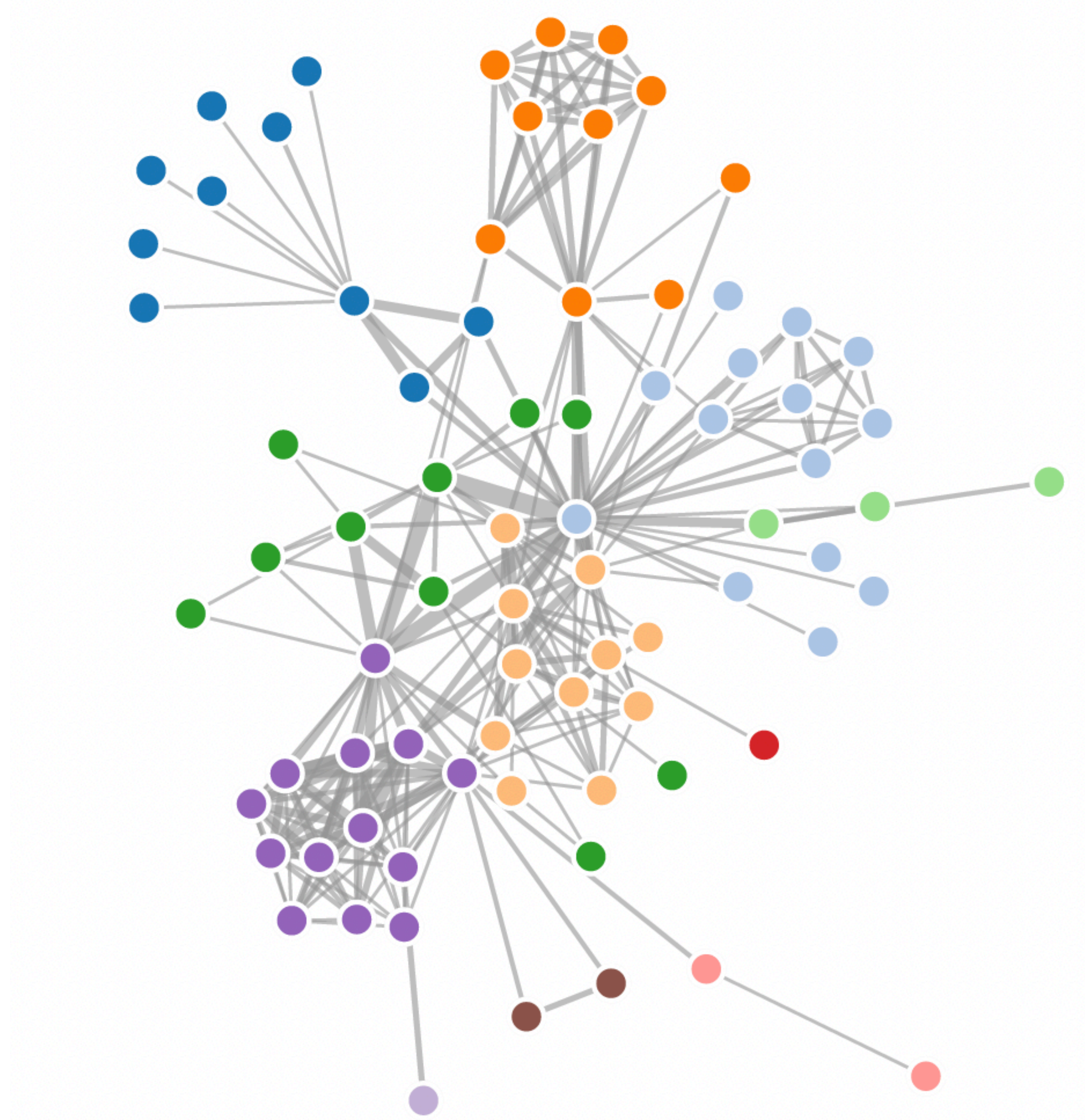




vialab.science.uoit.ca/portfolio/bubblesets

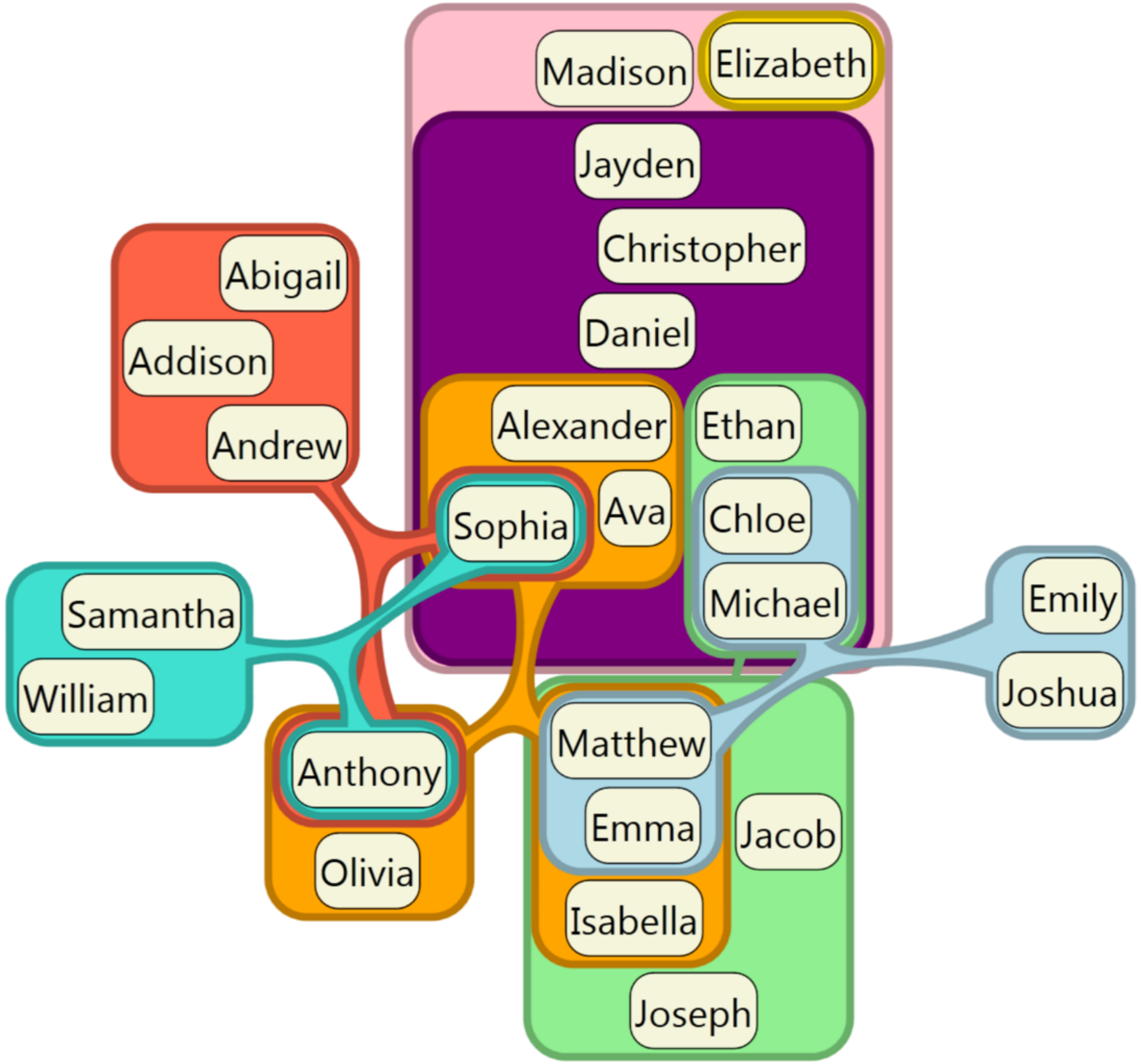
Connection





https://observablehq.com/@d3/force-directed-graph

Containment can be nested

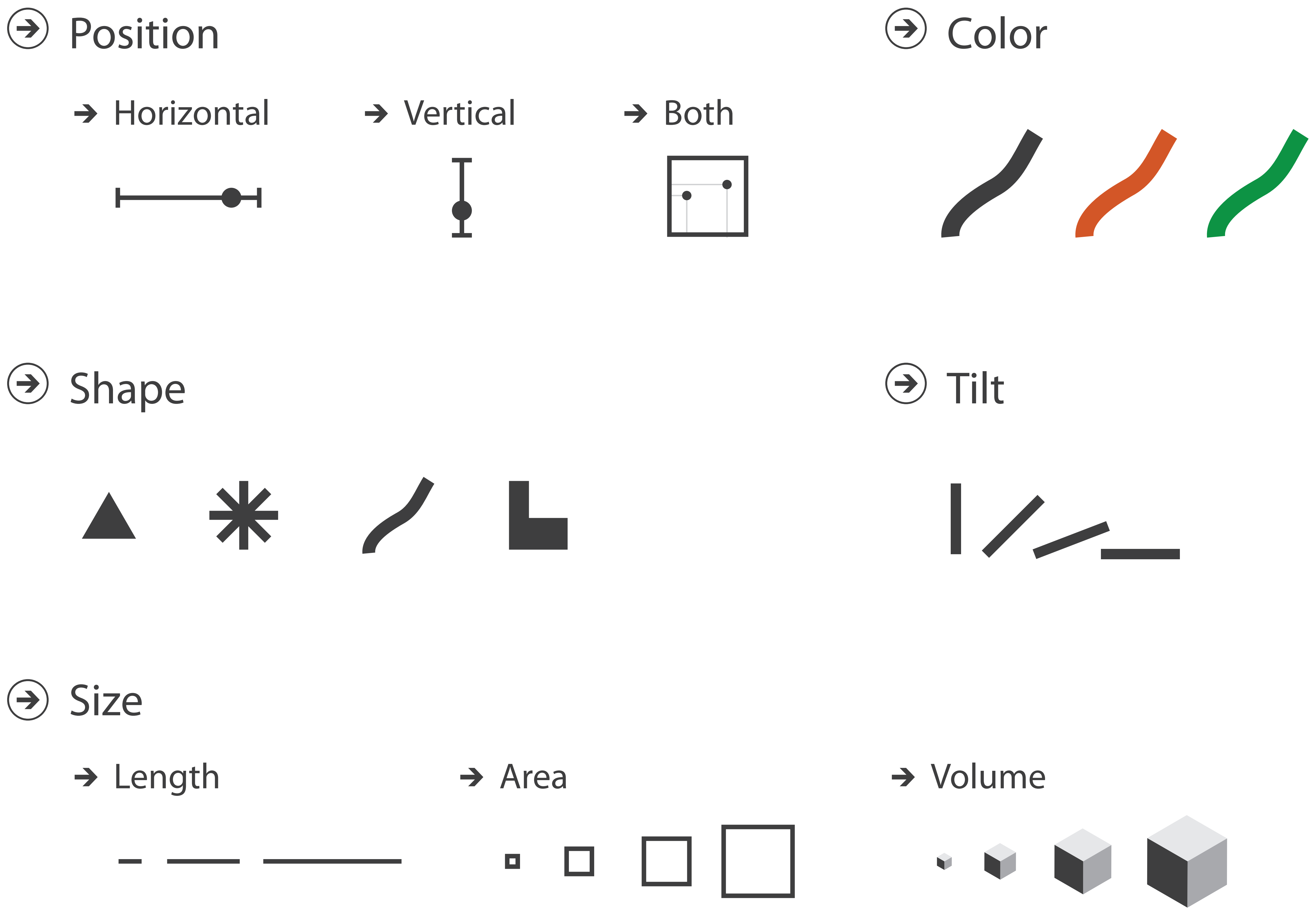


[Untangling Euler Diagrams, Riche and Dwyer, 2010]

Channels

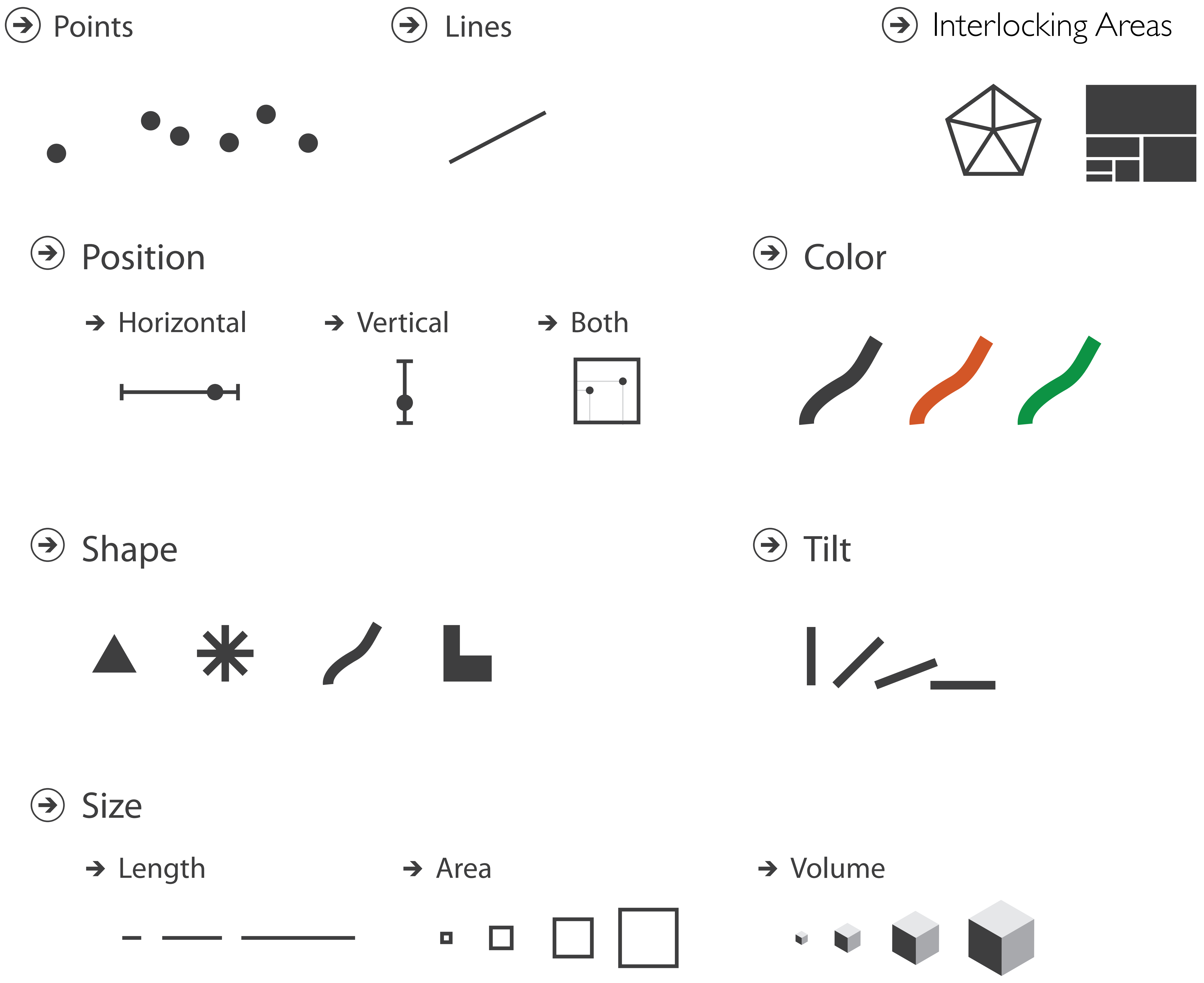
- **control the appearance of the marks**
  - proportional to or based on attributes

- many names
  - visual channels
  - visual variables
  - retinal channels
  - visual dimensions



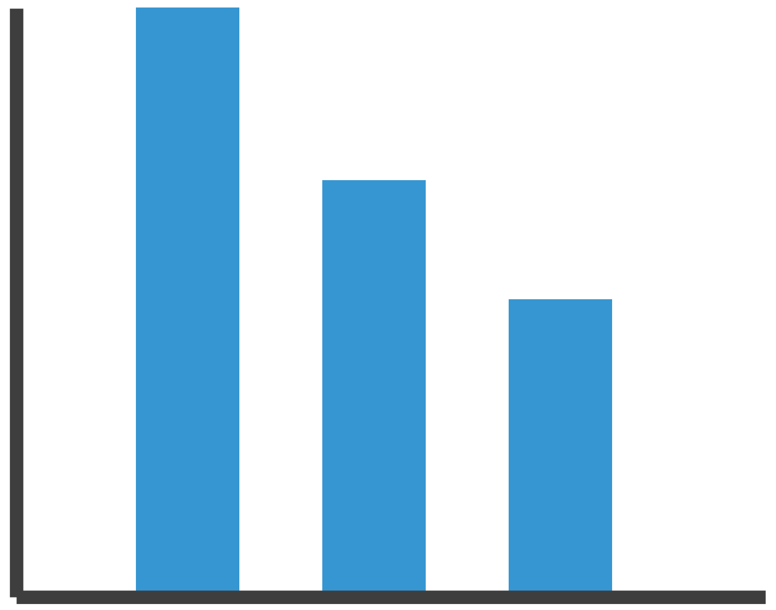
Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
  - type & amount of information that can be conveyed to human perceptual system



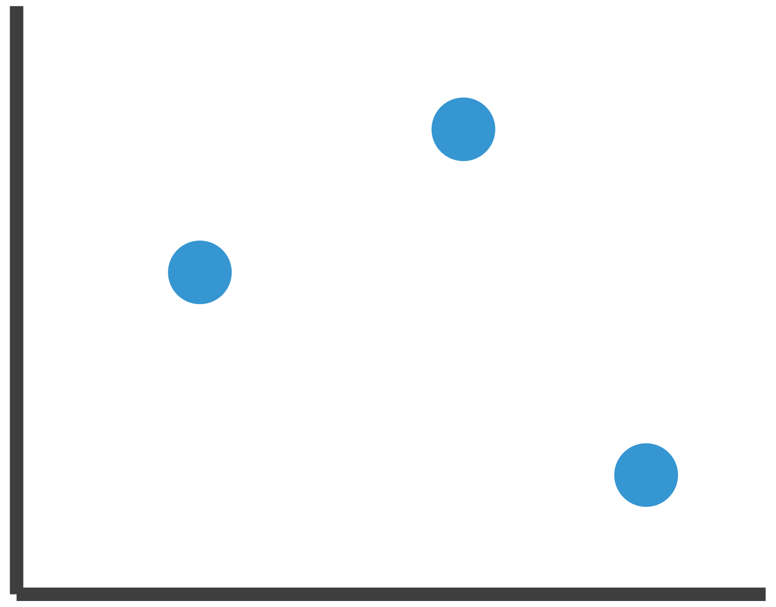
Visual encoding

- analyze idiom structure as combination of marks and channels



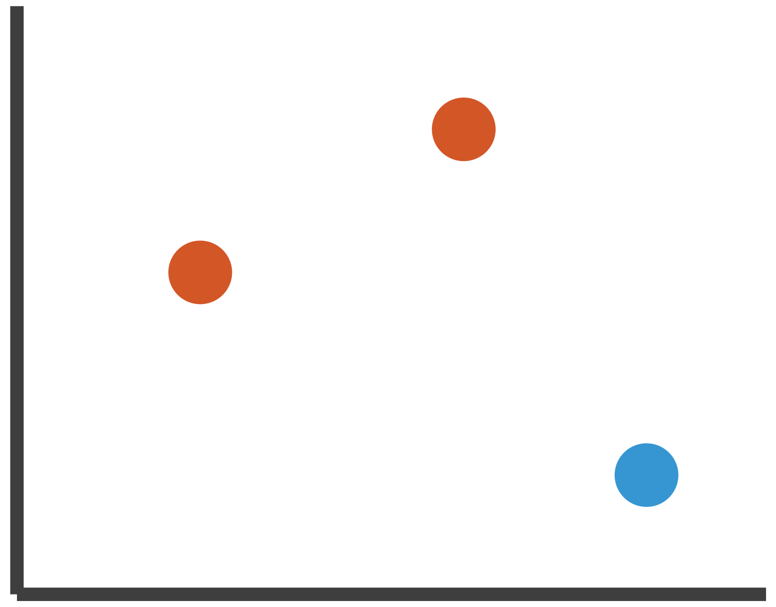
1:
vertical position

mark: line



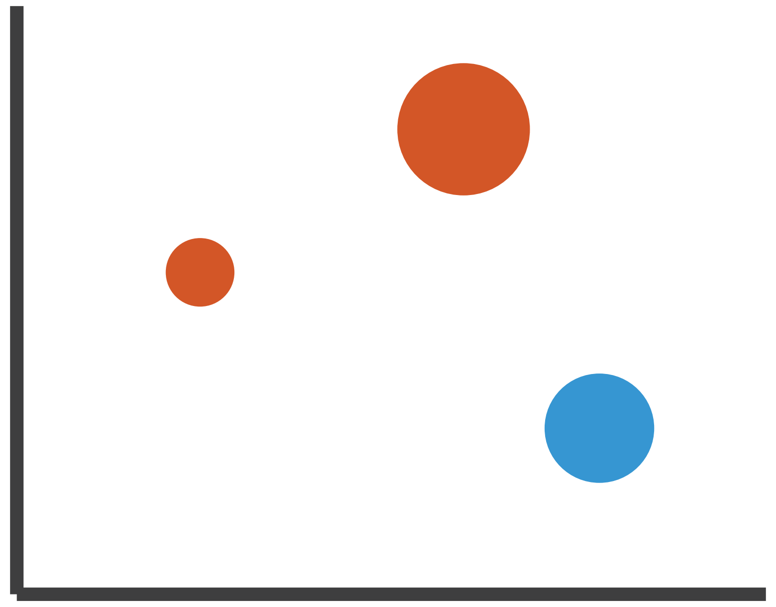
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

mark: point

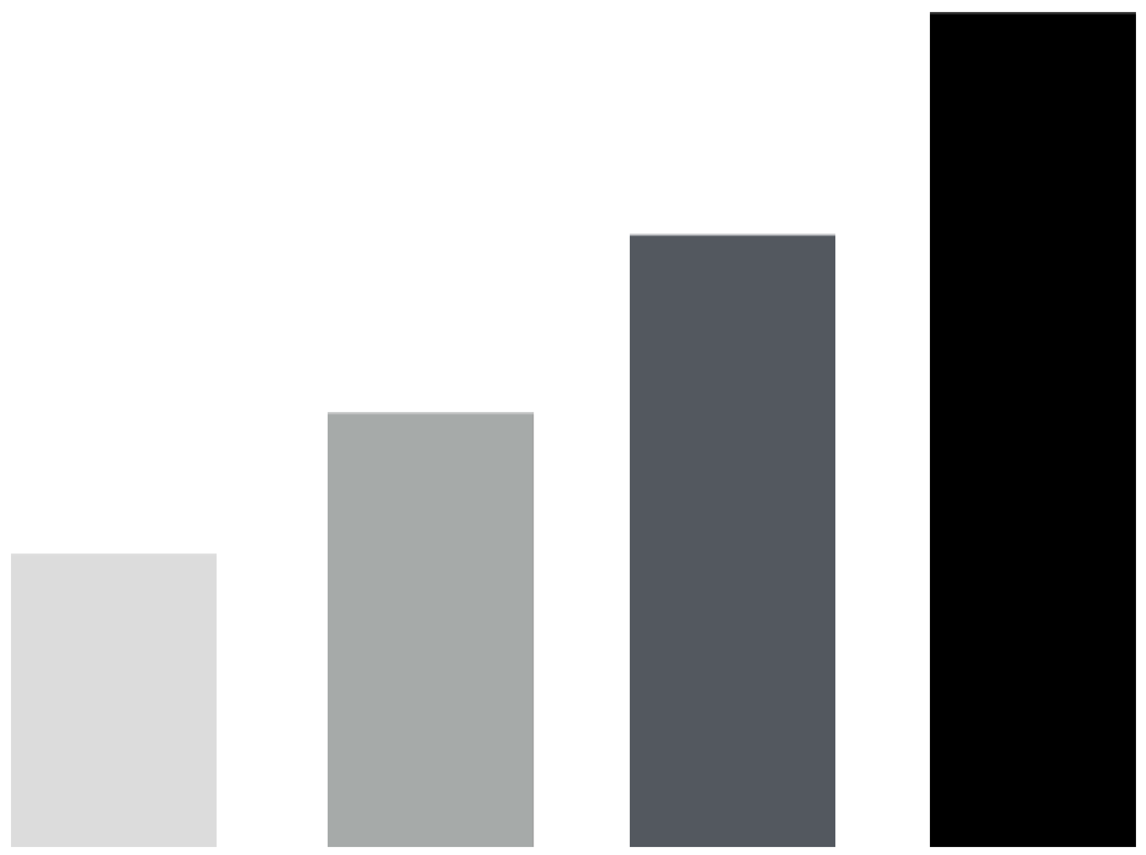


4:
vertical position
horizontal position
color hue
size (area)

mark: point

Redundant encoding

- **multiple channels**
  - sends stronger message
  - but uses up channels



Length, Position, and Luminance

Scope of analysis

- simplifying assumptions: one mark per item, single view

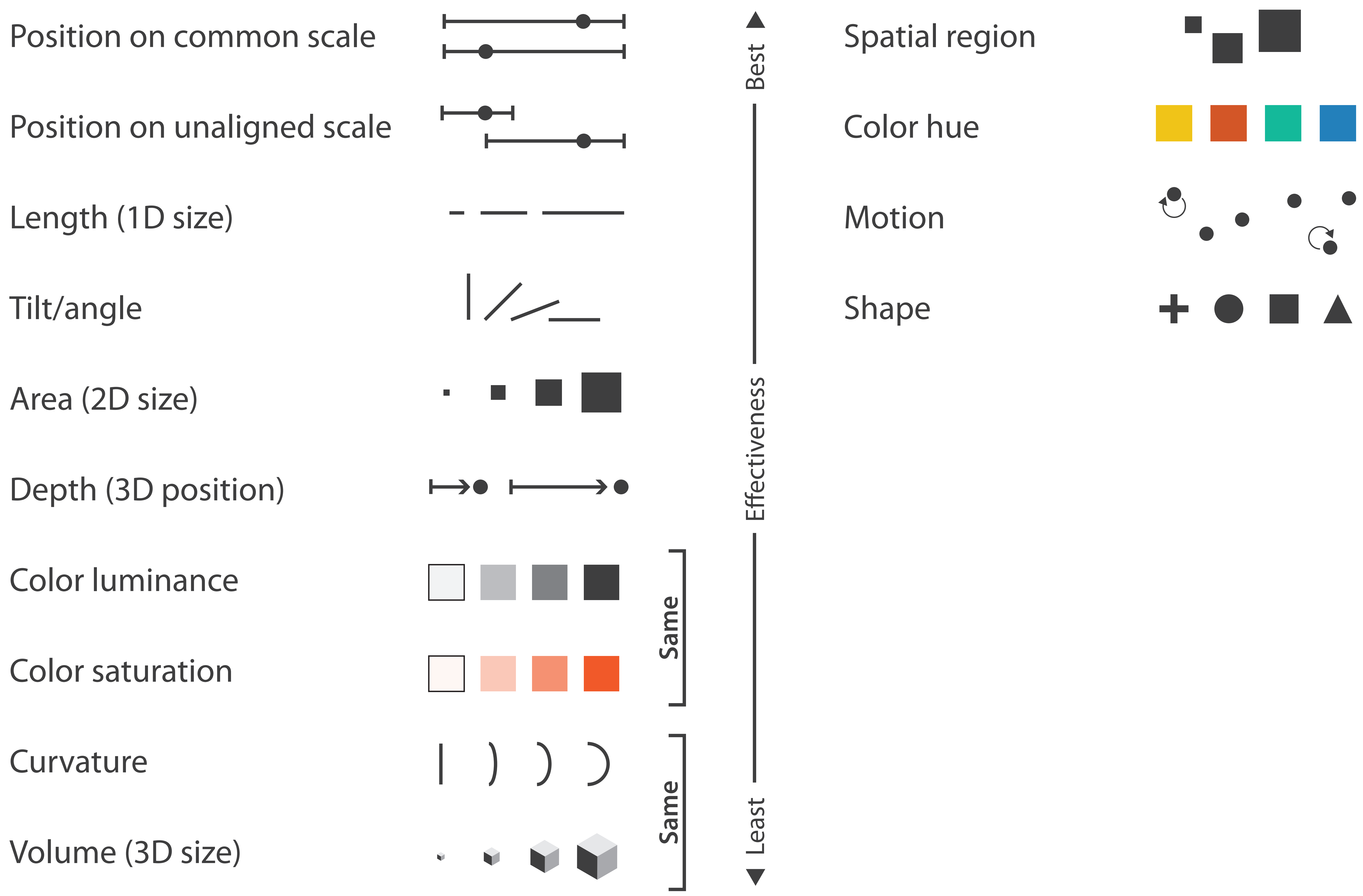
- later on
  - multiple views
  - multiple marks in a region (glyph)
  - some items not represented by marks (aggregation and filtering)

When to use which channel?

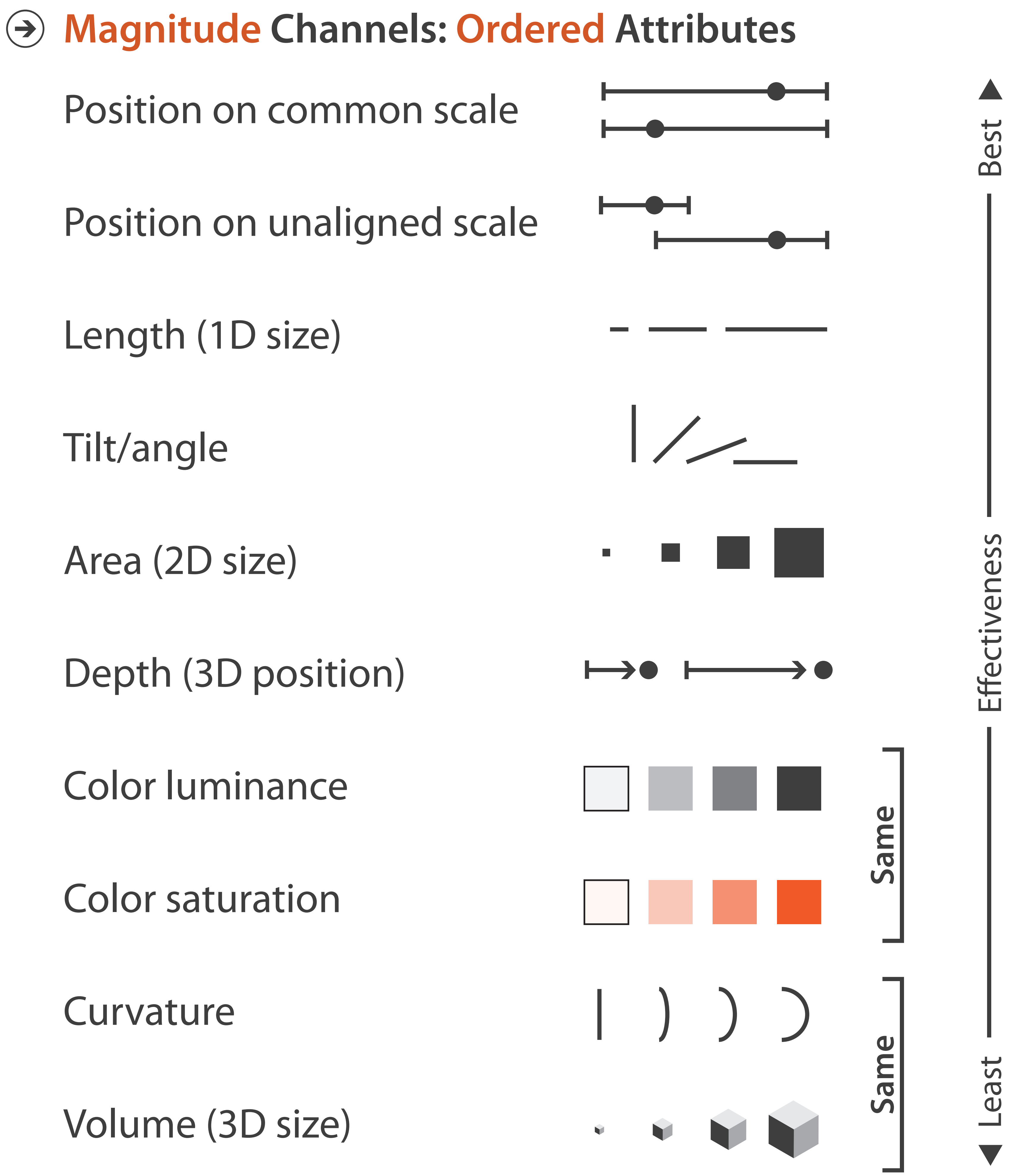
When should you use which channel?

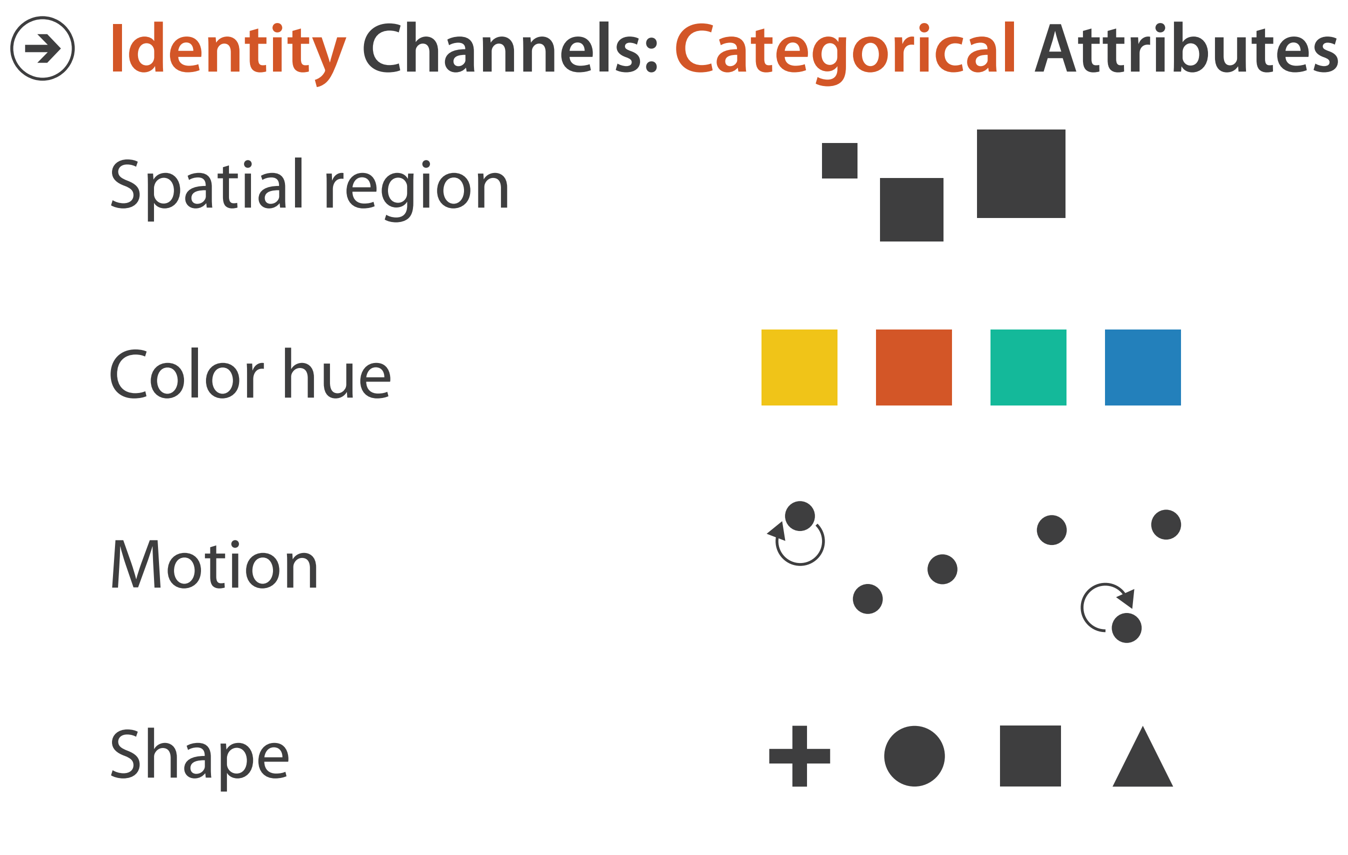
- **expressiveness**
  - match channel type to data type
- **effectiveness**
  - some channels are better than others

Channels: Rankings



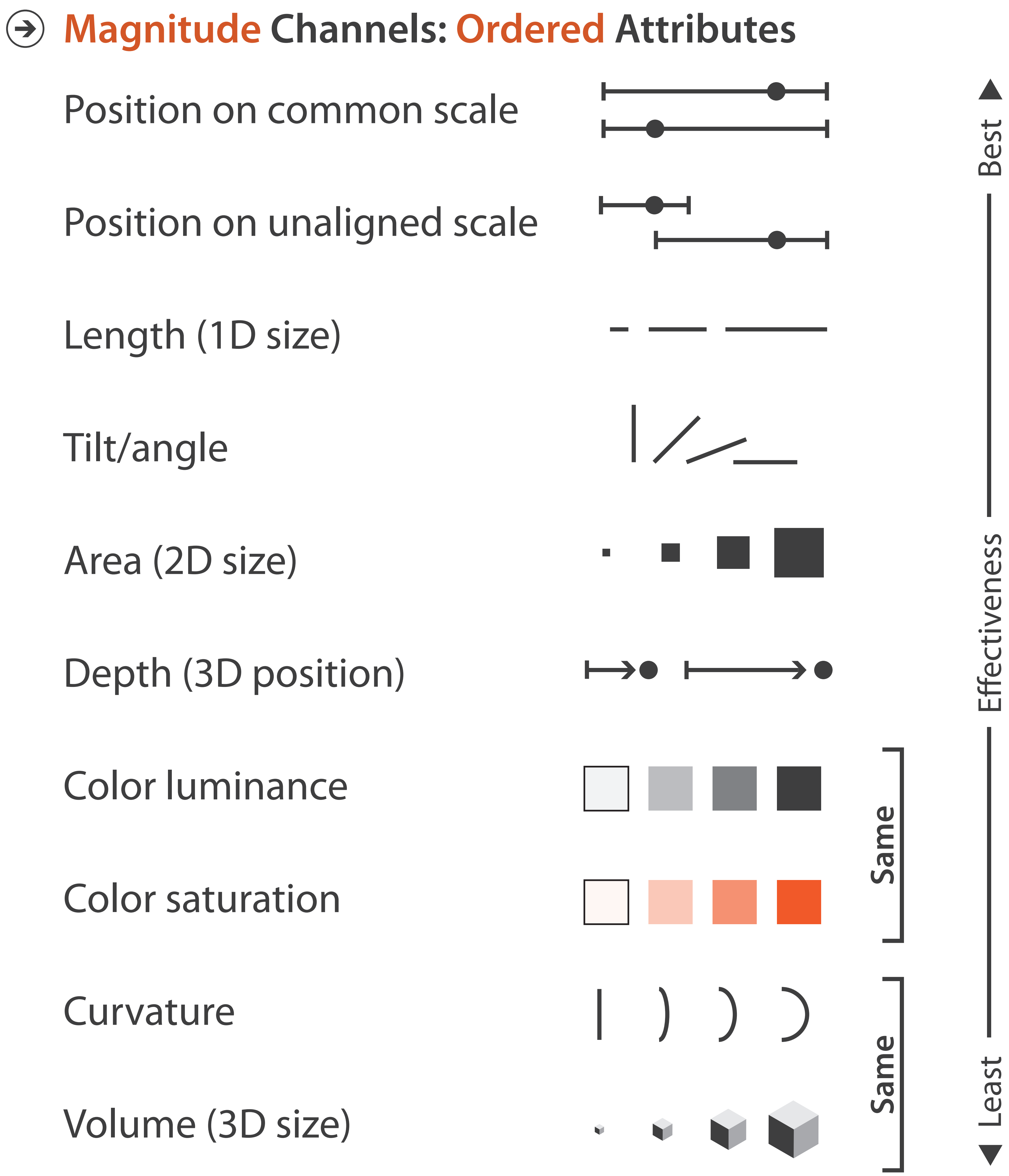
Channels: Rankings

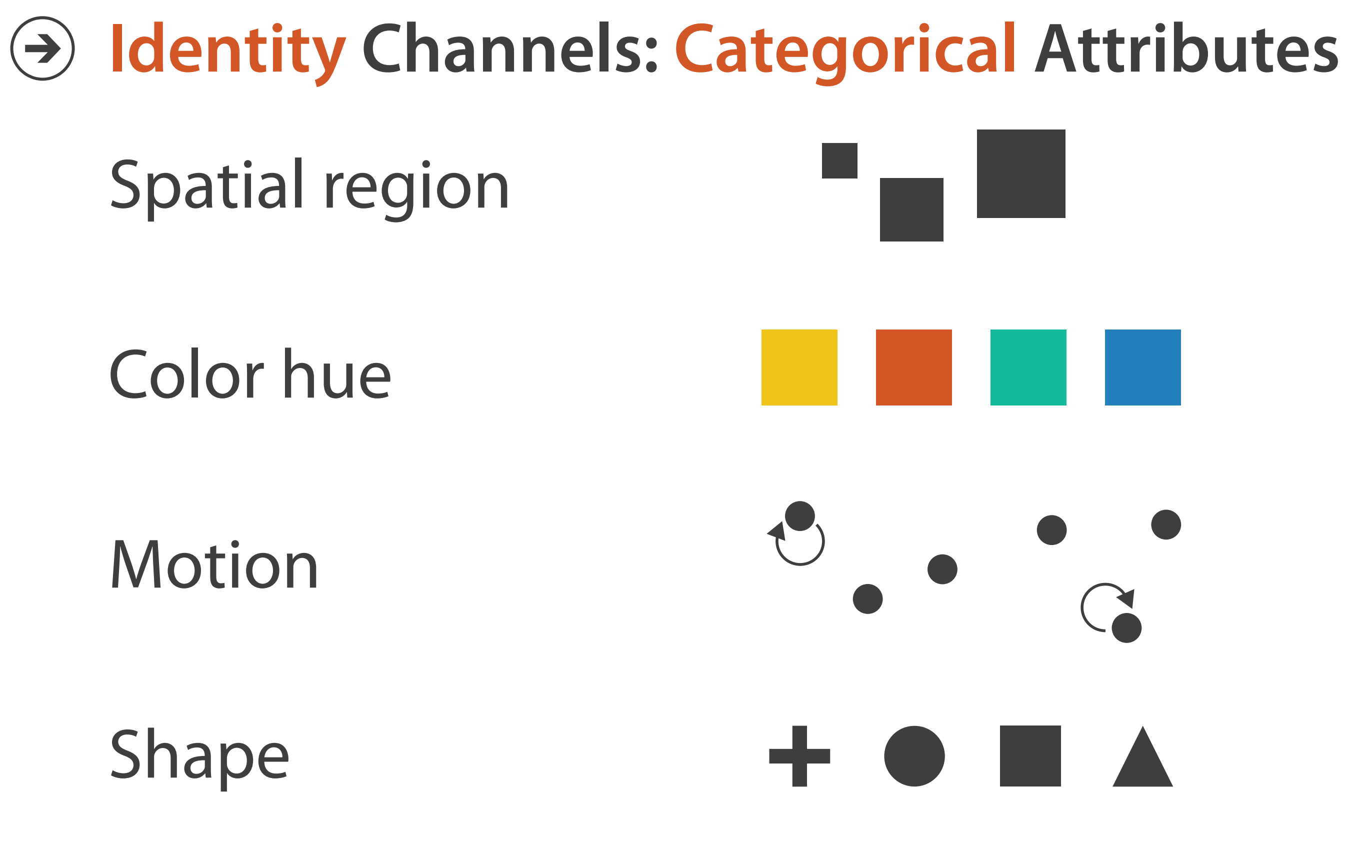




- **expressiveness**
  - **match channel and data characteristics**
  - **magnitude for ordered**
    - how much? which rank?
  - **identity for categorical**
    - what?

Channels: Rankings





- **expressiveness**
  - **match channel and data characteristics**
- **effectiveness**
  - channels differ in the accuracy of perception
  - spatial position ranks high for both

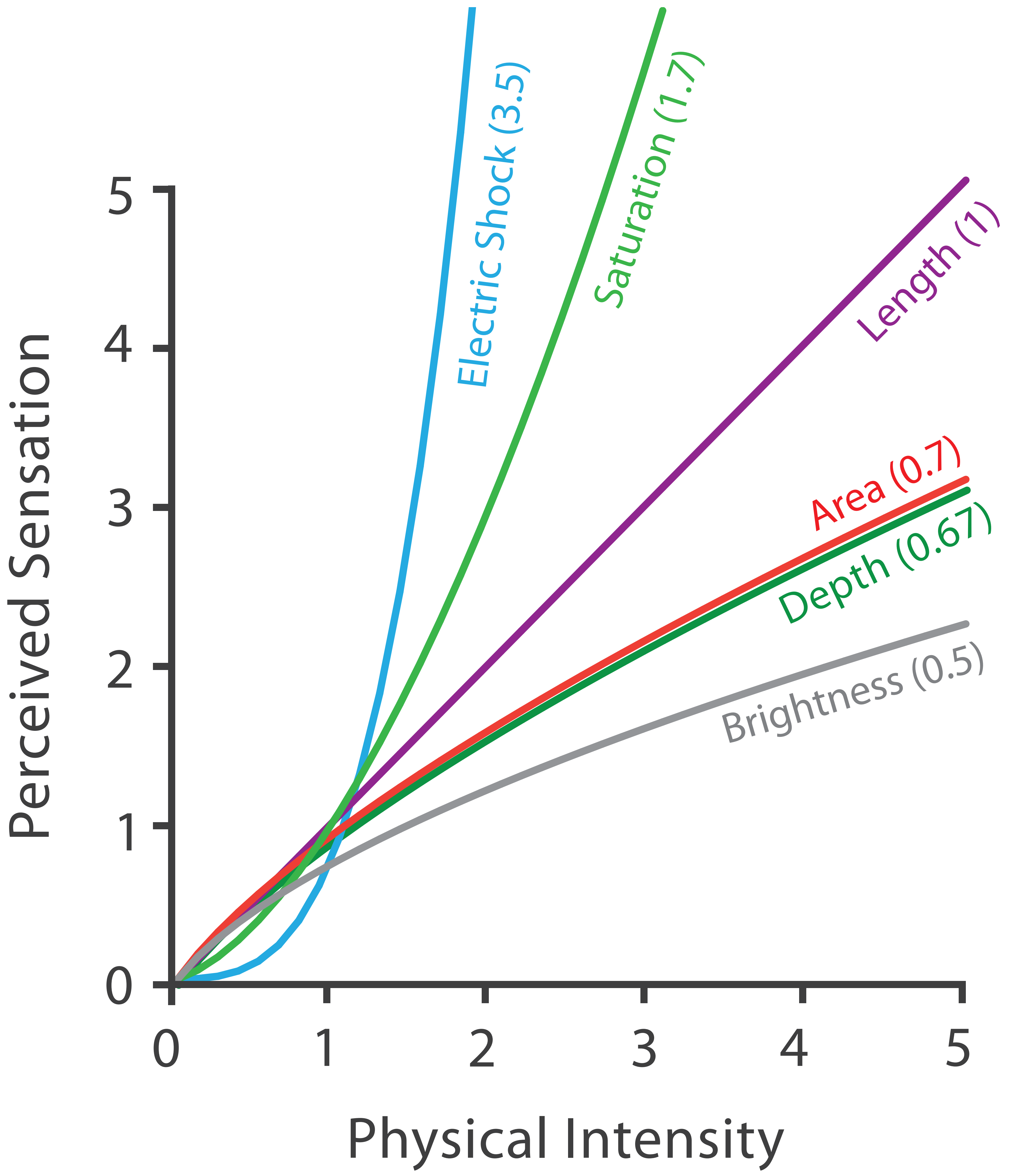
Channel effectiveness

- accuracy: how precisely can we tell the difference between encoded items?
- discriminability: how many unique steps can we perceive?
- separability: is our ability to use this channel affected by another one?
- popout: can things jump out using this channel?

Accuracy: Fundamental theory

- length is accurate: linear
- others magnified or compressed
  - exponent characterizes

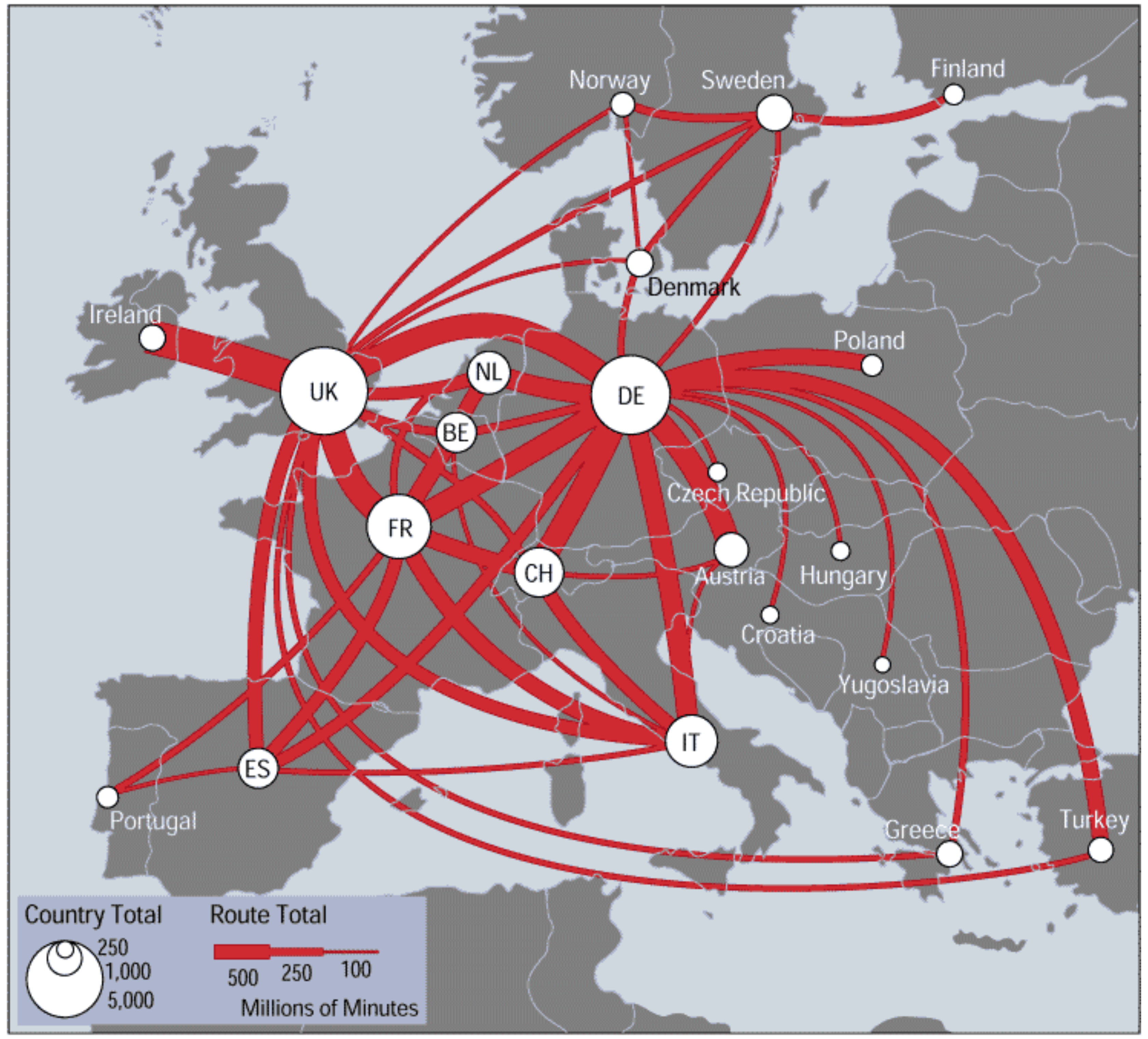
Steven's Psychophysical Power Law: $S= I^N$



S: Sensation
I: Intensity

Discriminability: How many usable steps?

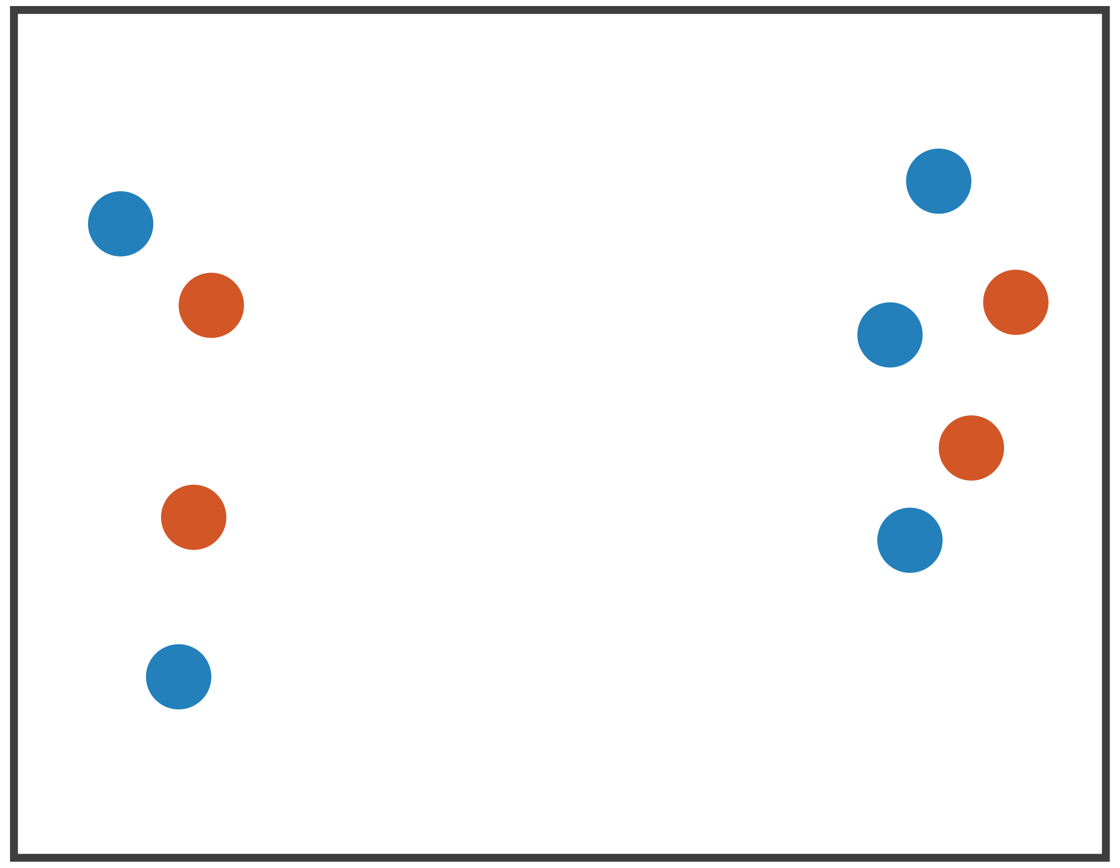
- must be sufficient for number of attribute levels to show
  - linewidth: few bins



[mappa.mundi.net/maps/maps 014/telegeography.html]

Separability vs. Integrality

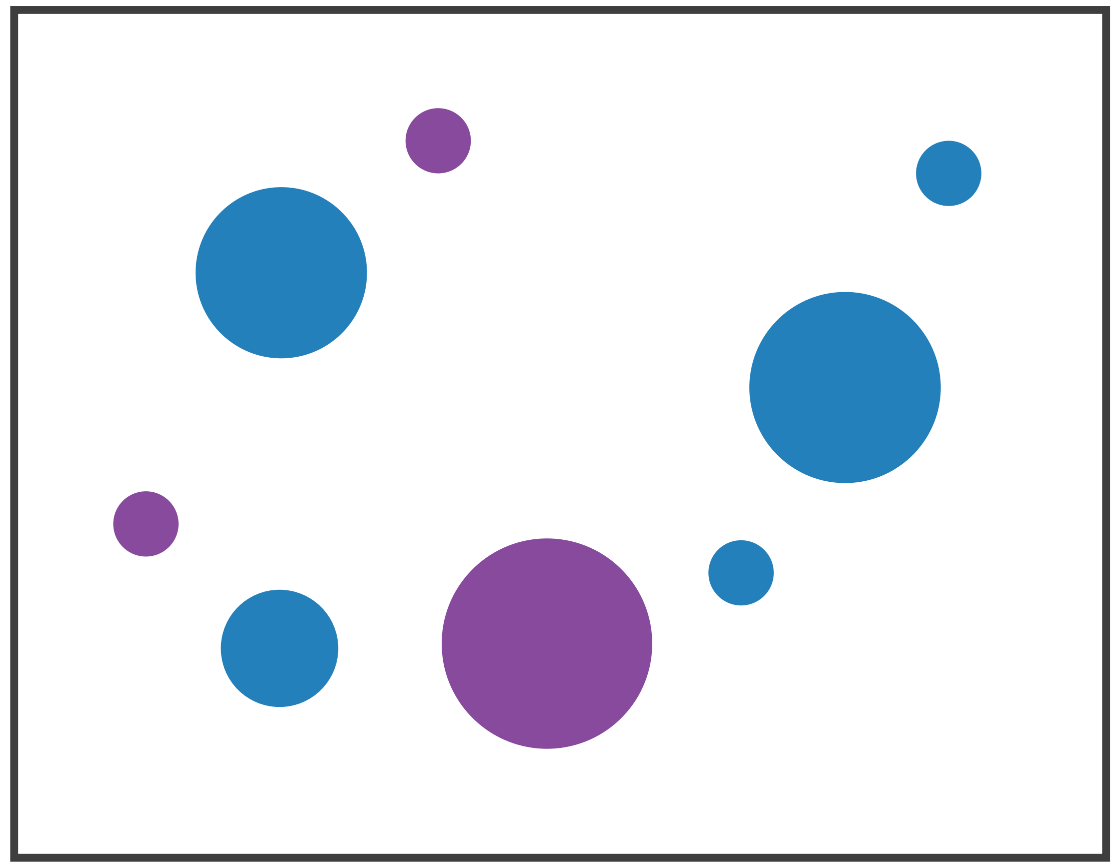
Position
+ Hue (Color)



Fully separable

2 groups each

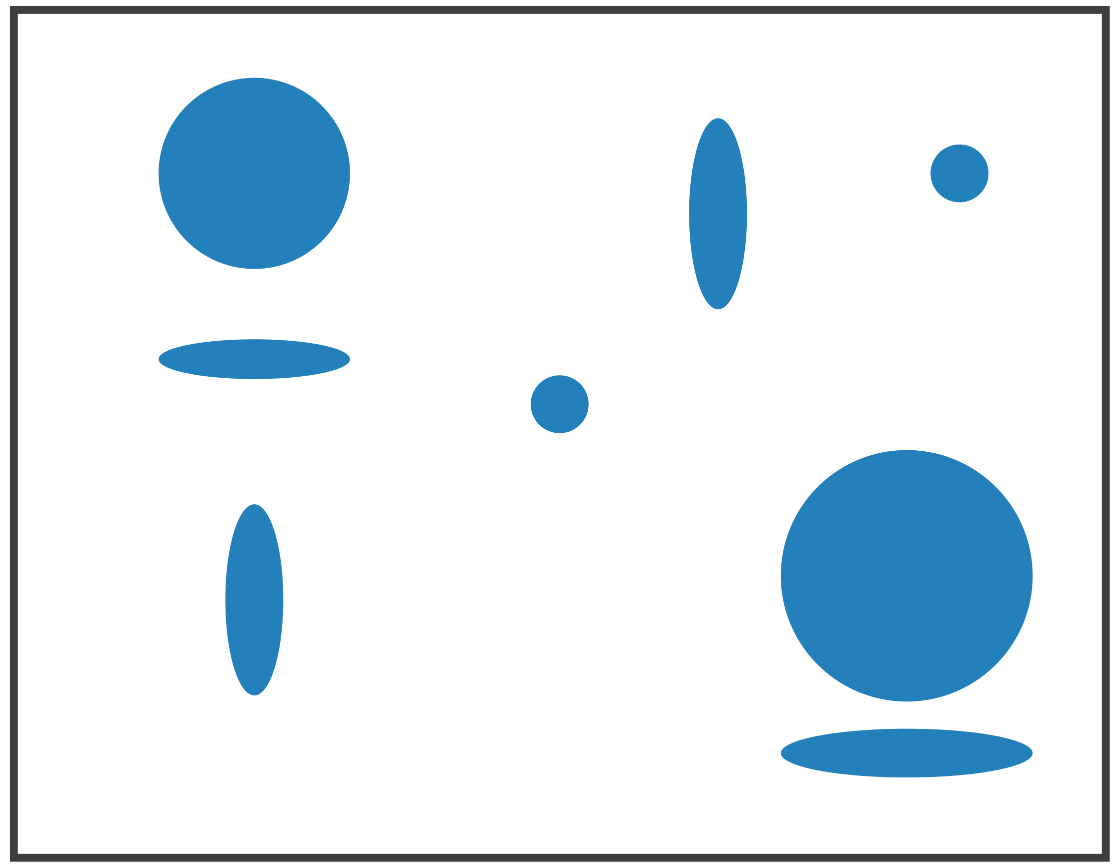
Size
+ Hue (Color)



Some interference

2 groups each

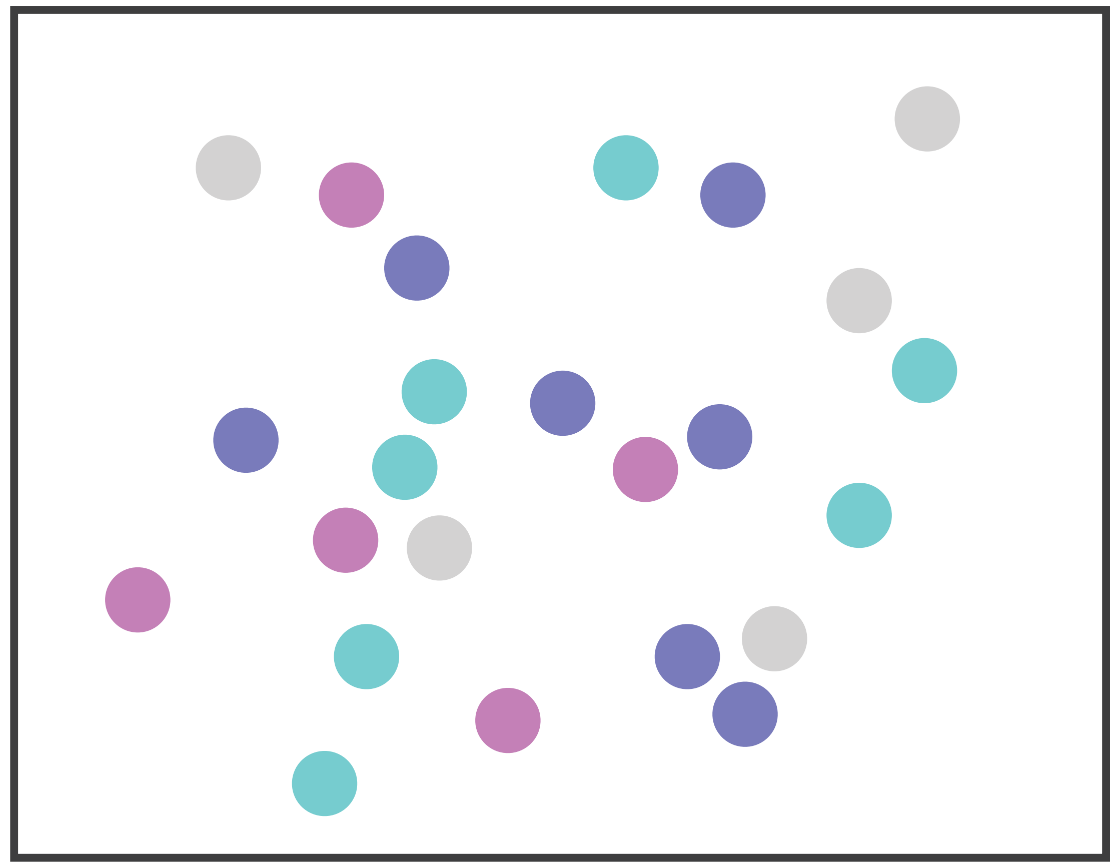
Width
+ Height



Some/significant interference

3 groups total: integral area

Red
+ Green



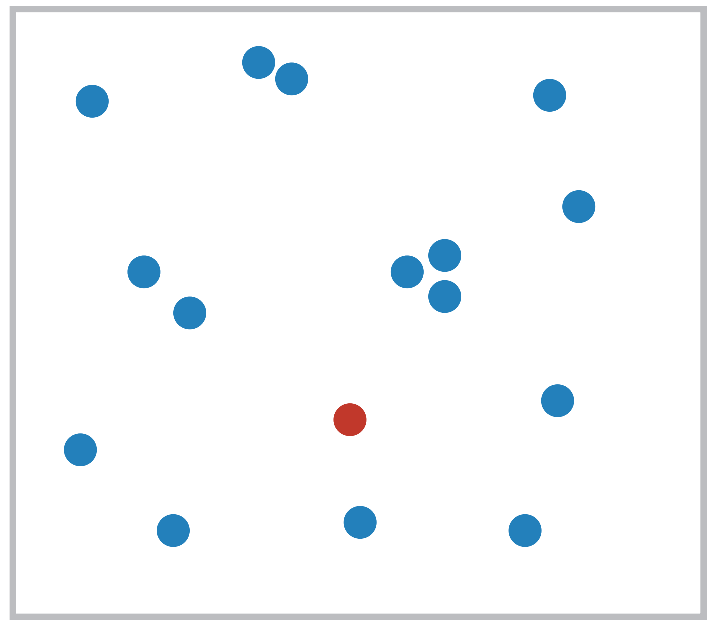
Major interference

4 groups total: integral hue

Popout

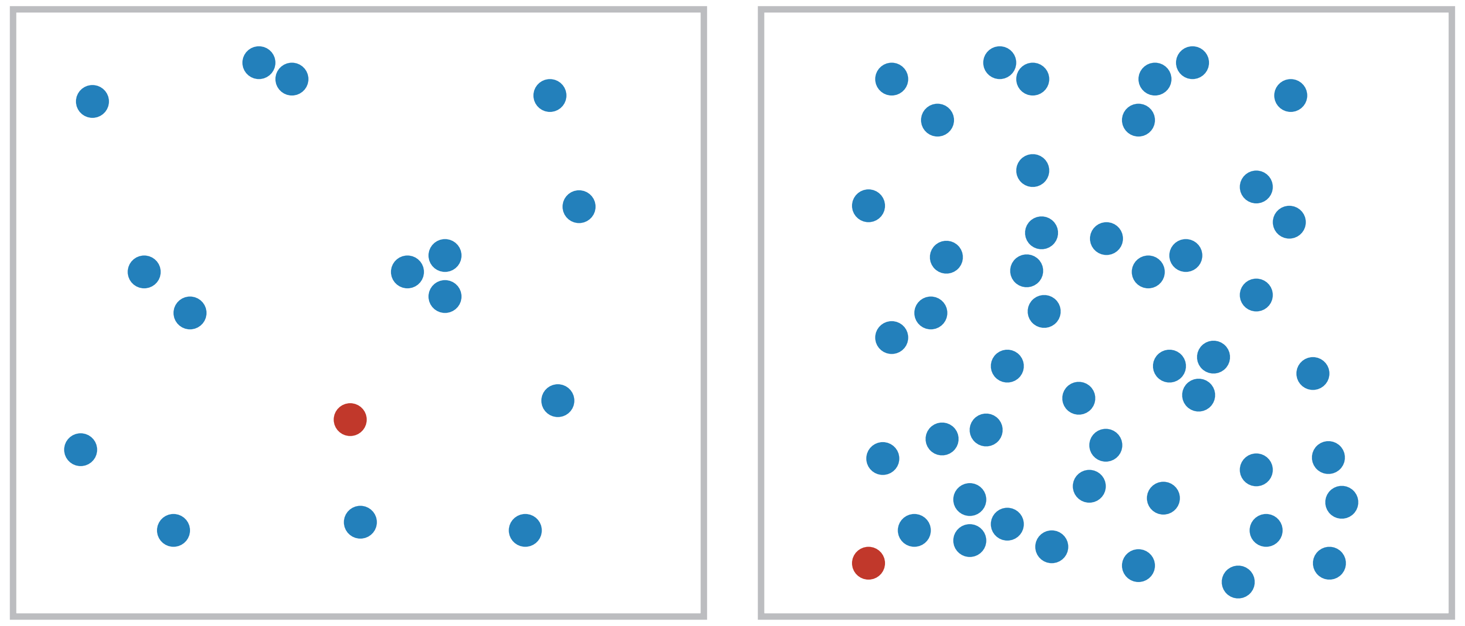
- find the red dot
  - how long does it take?

Popout



- find the red dot
  - how long does it take?

Popout



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Popout

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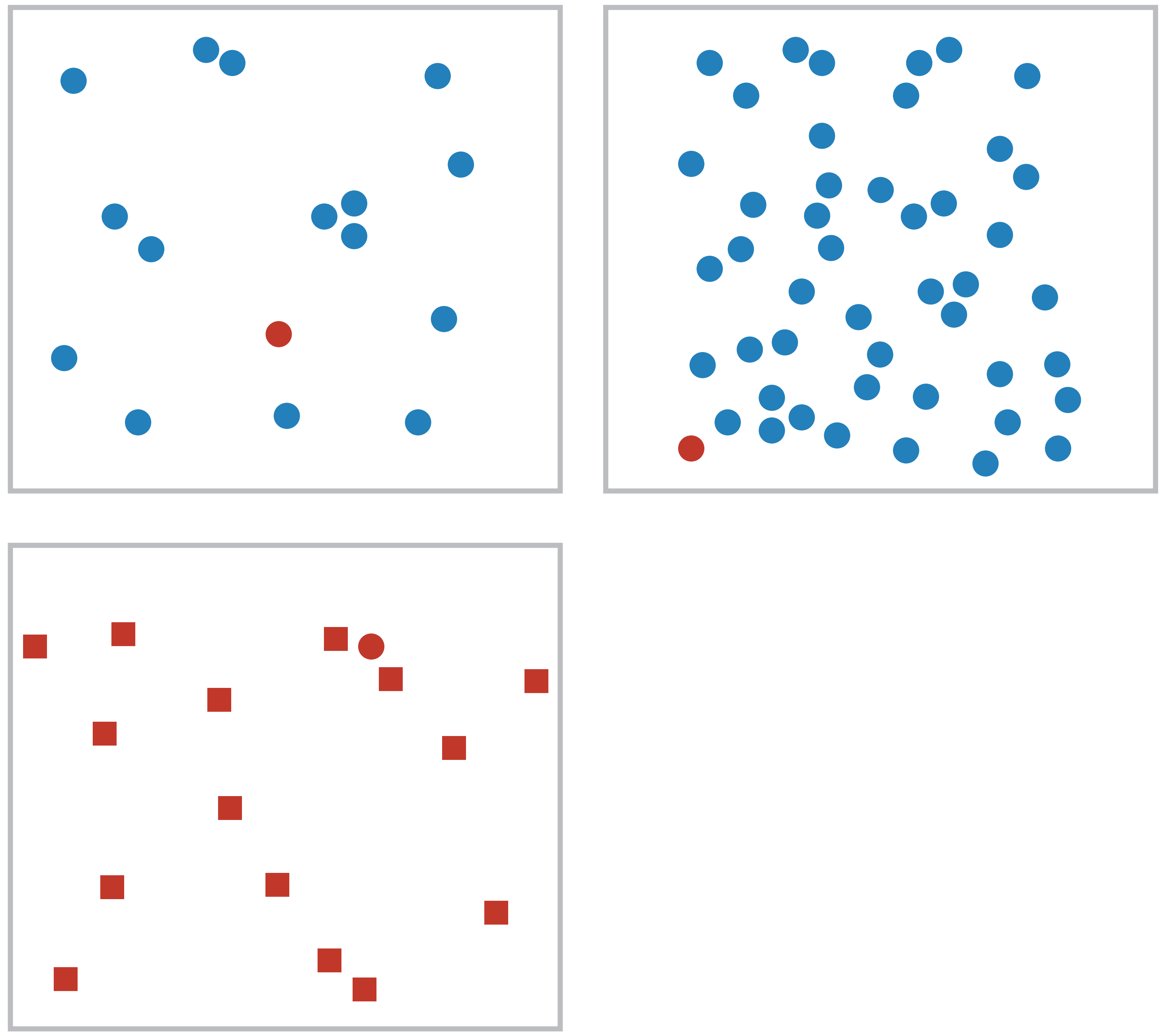
  - how long does it take?



Popout

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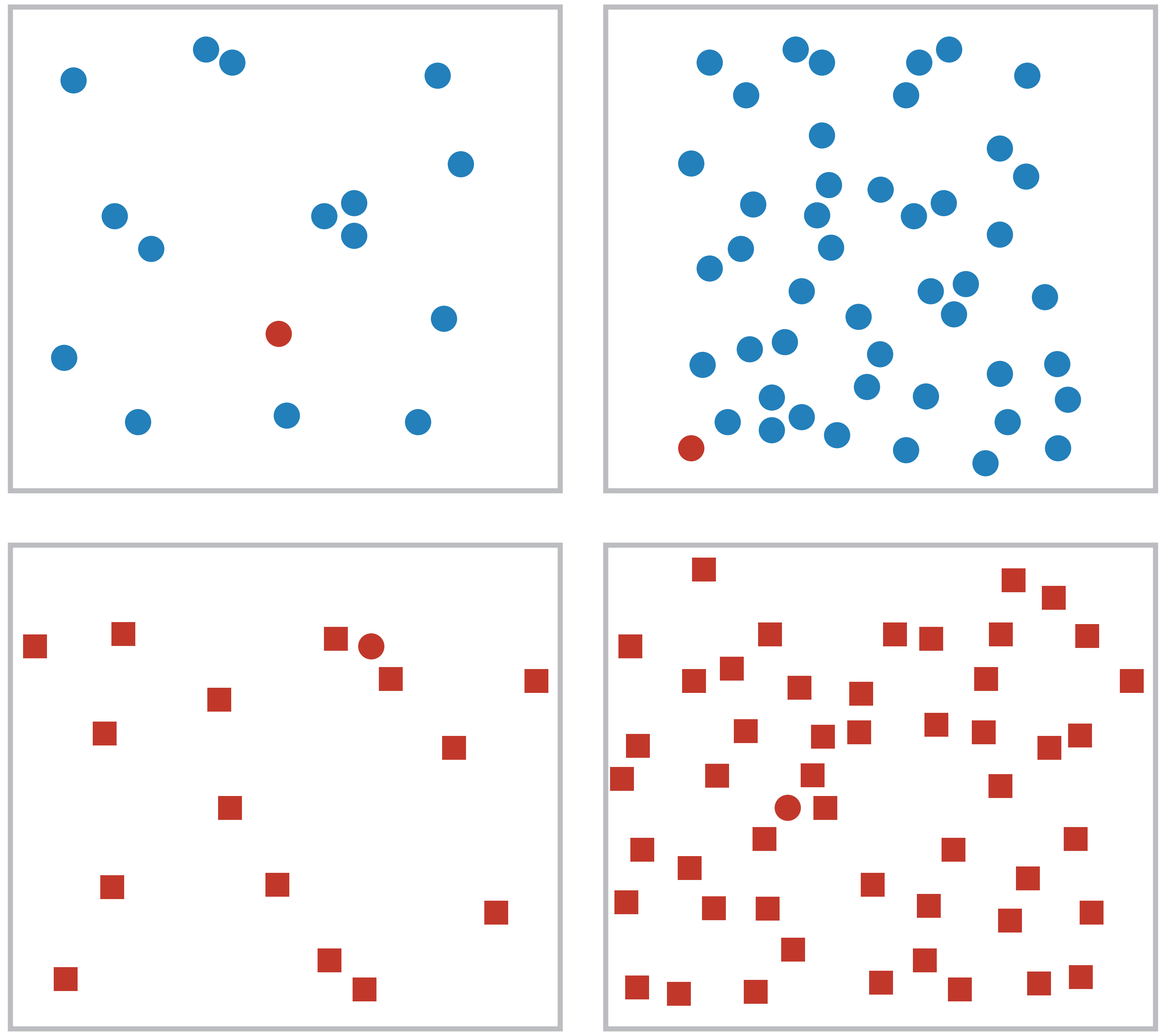

Popout

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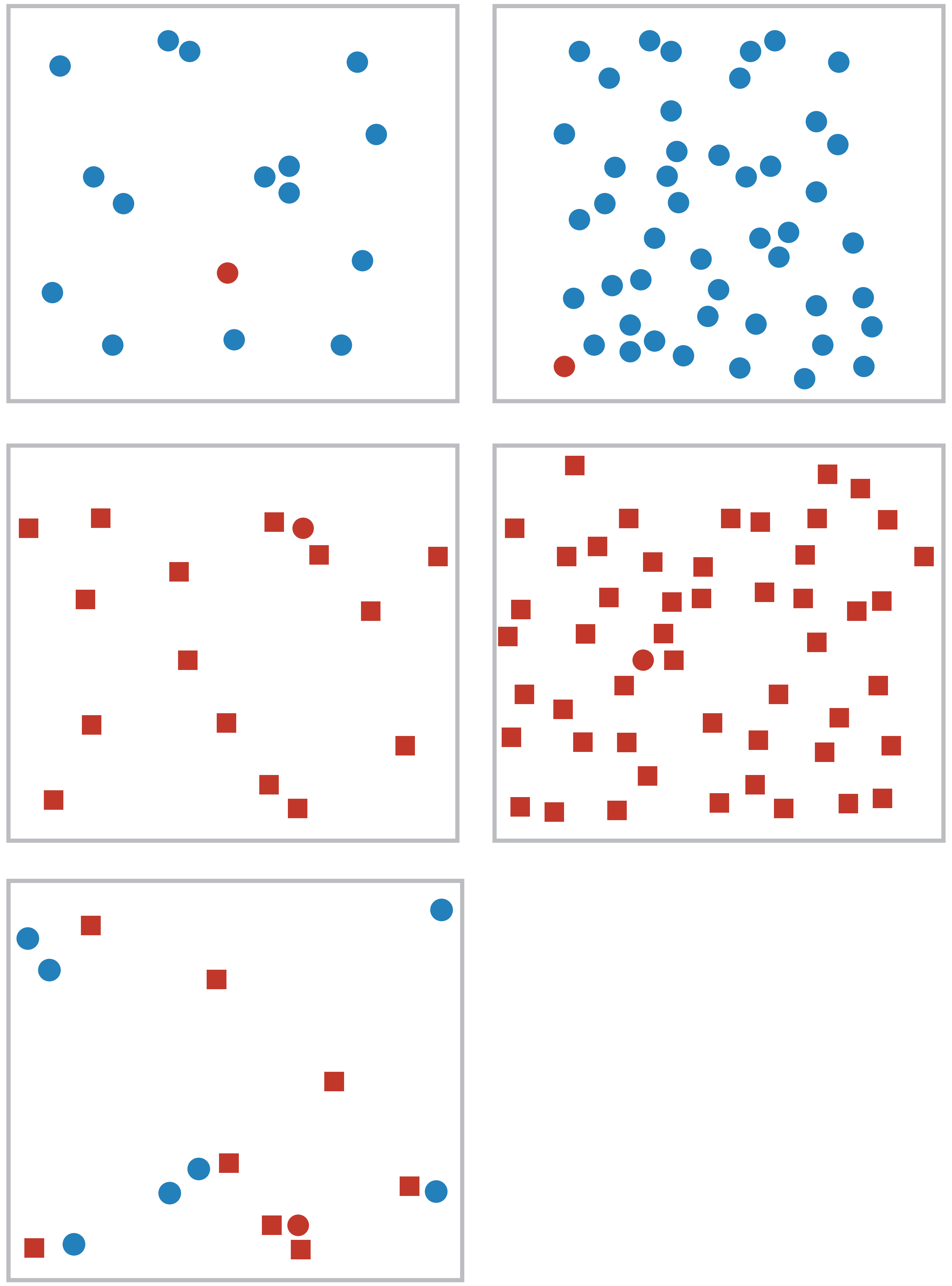

Popout

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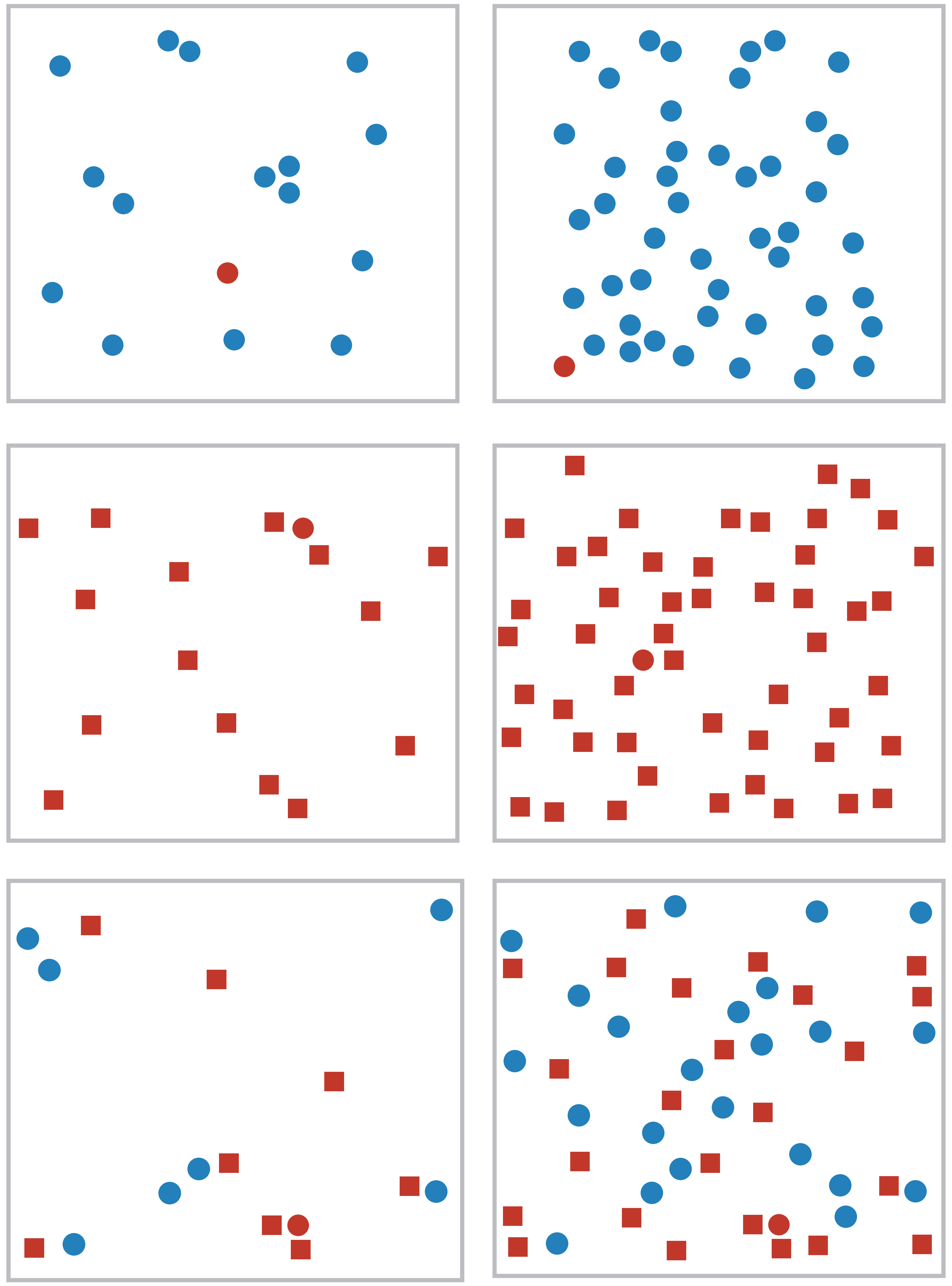
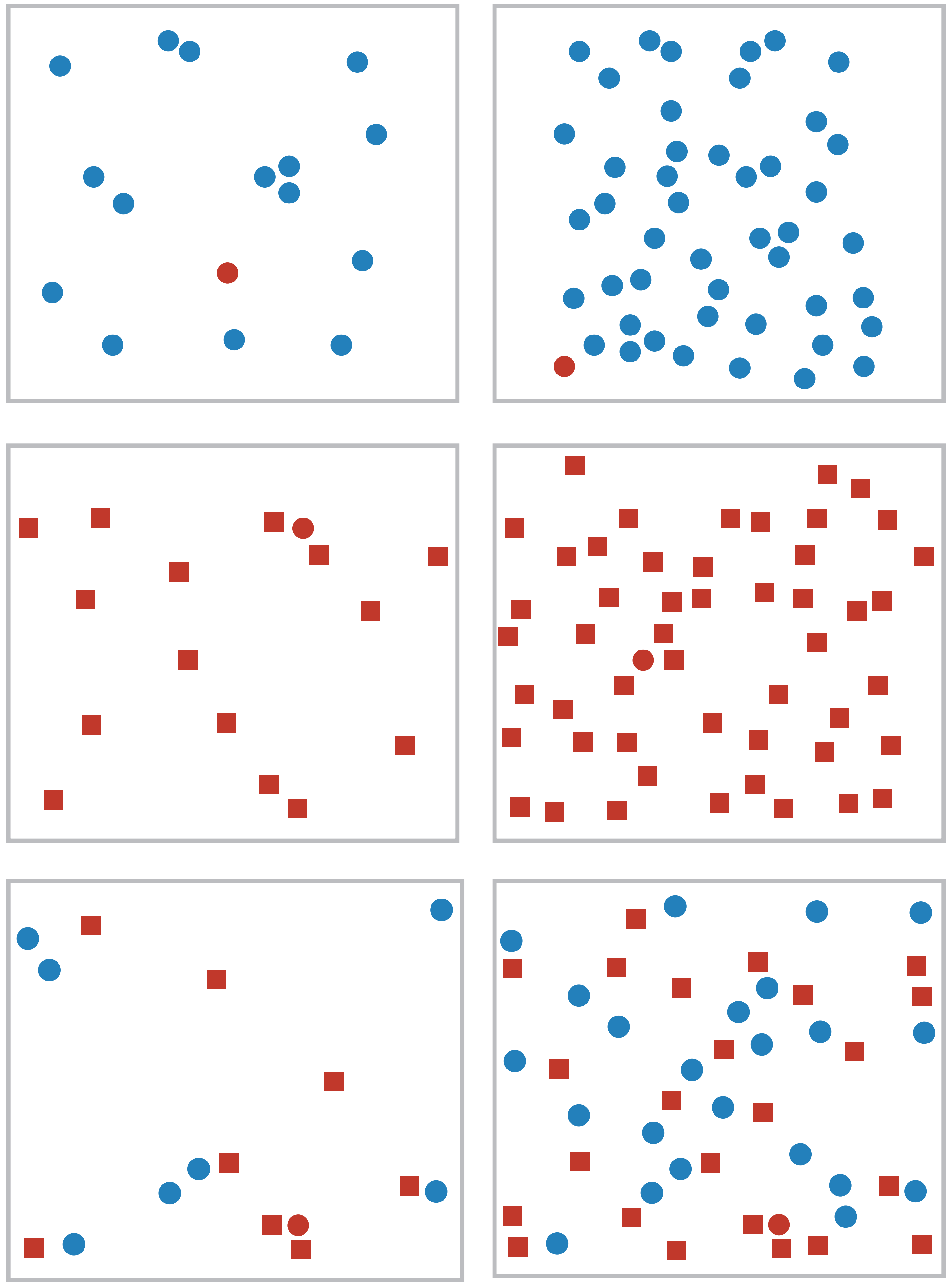
  - how long does it take?



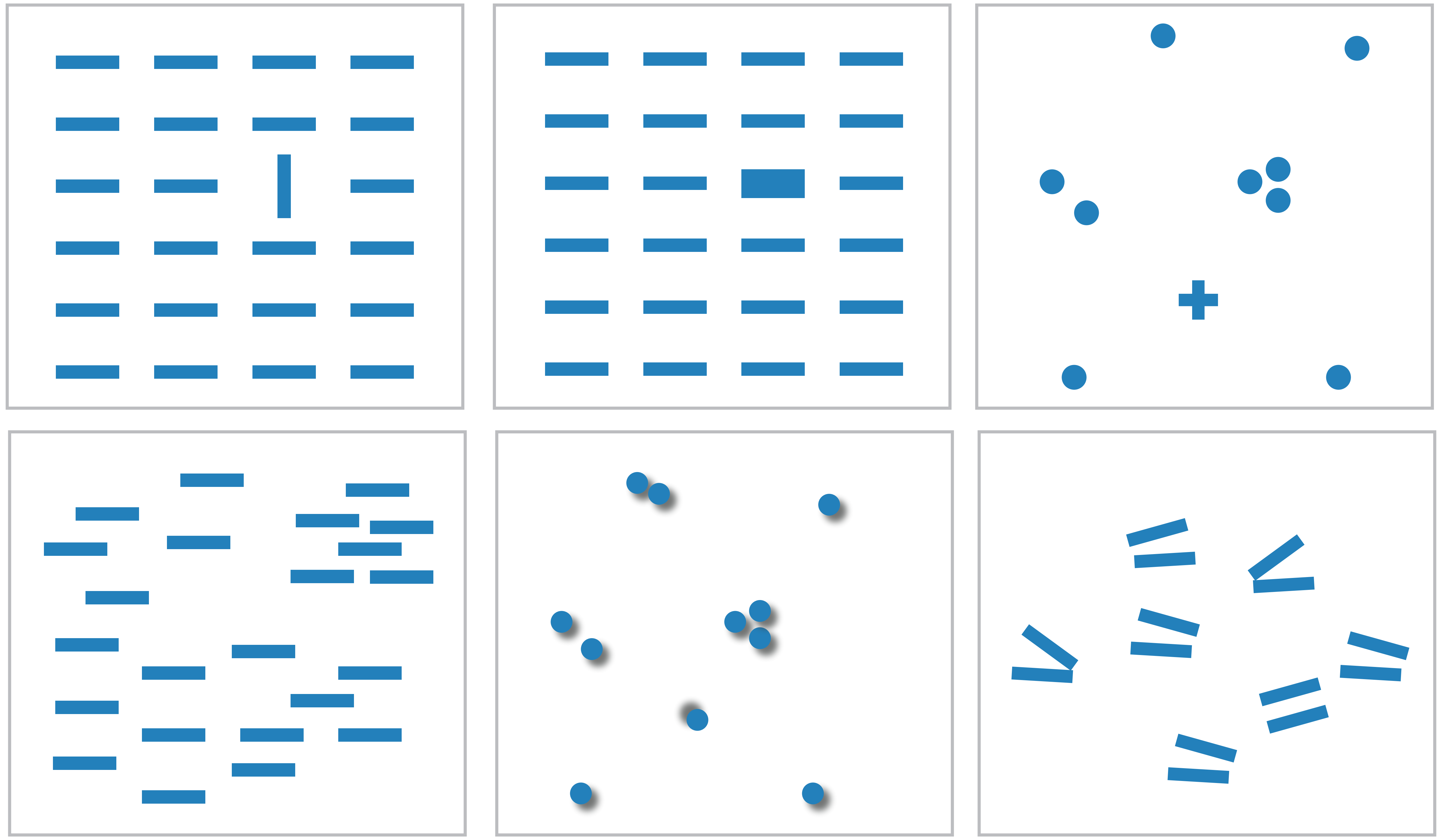
Popout

- find the red dot
  - how long does it take?
- parallel processing on many individual channels
  - speed independent of distractor count
  - speed depends on channel and amount of difference from distractors
- serial search for (almost all) combinations
  - speed depends on number of distractors



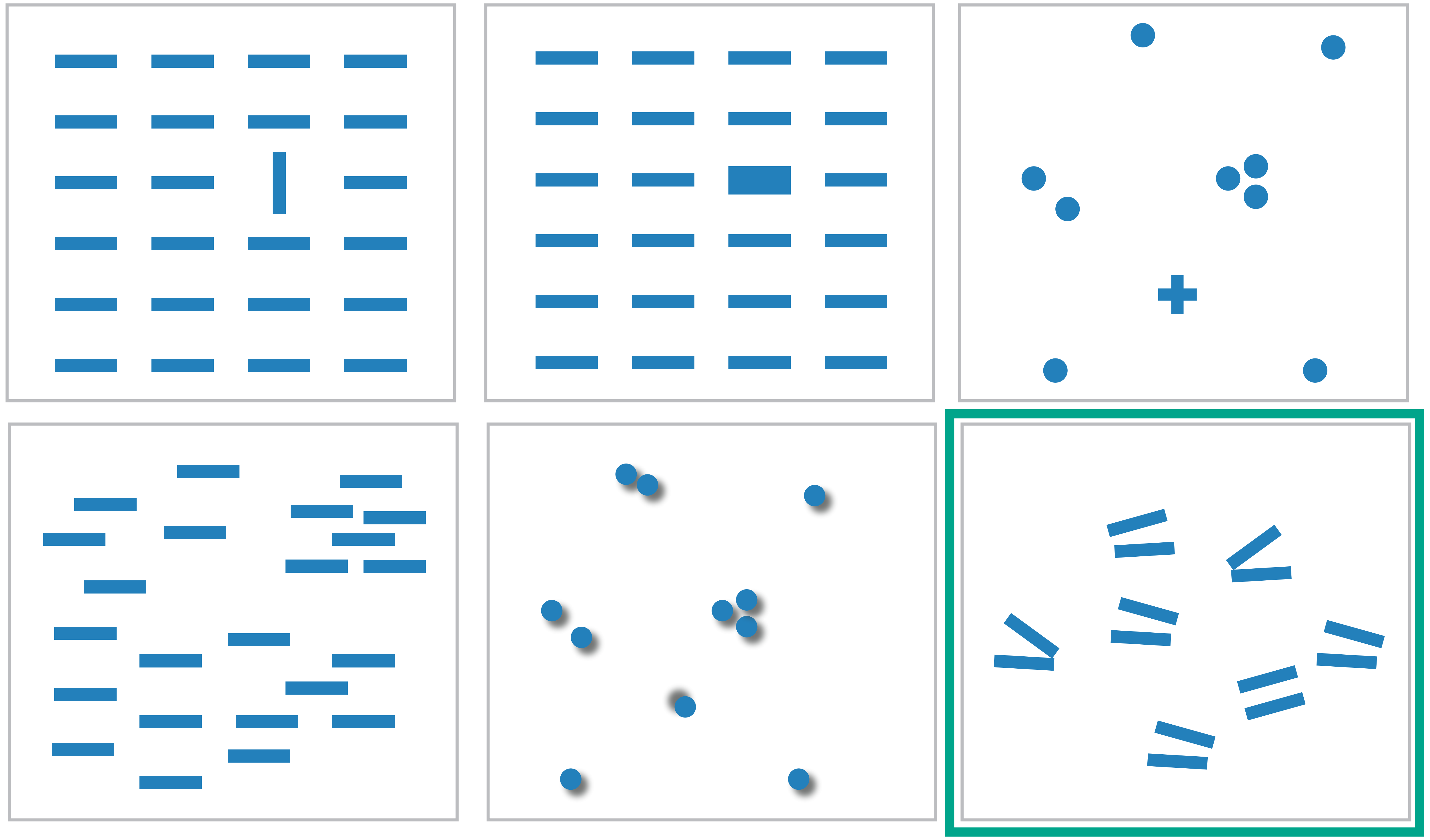
Popout

- many channels
  - tilt, size, shape, proximity, shadow direction, ...



Popout

- many channels
  - tilt, size, shape, proximity, shadow direction, ...
- but not all!
  - parallel line pairs do not pop out from tilted pairs

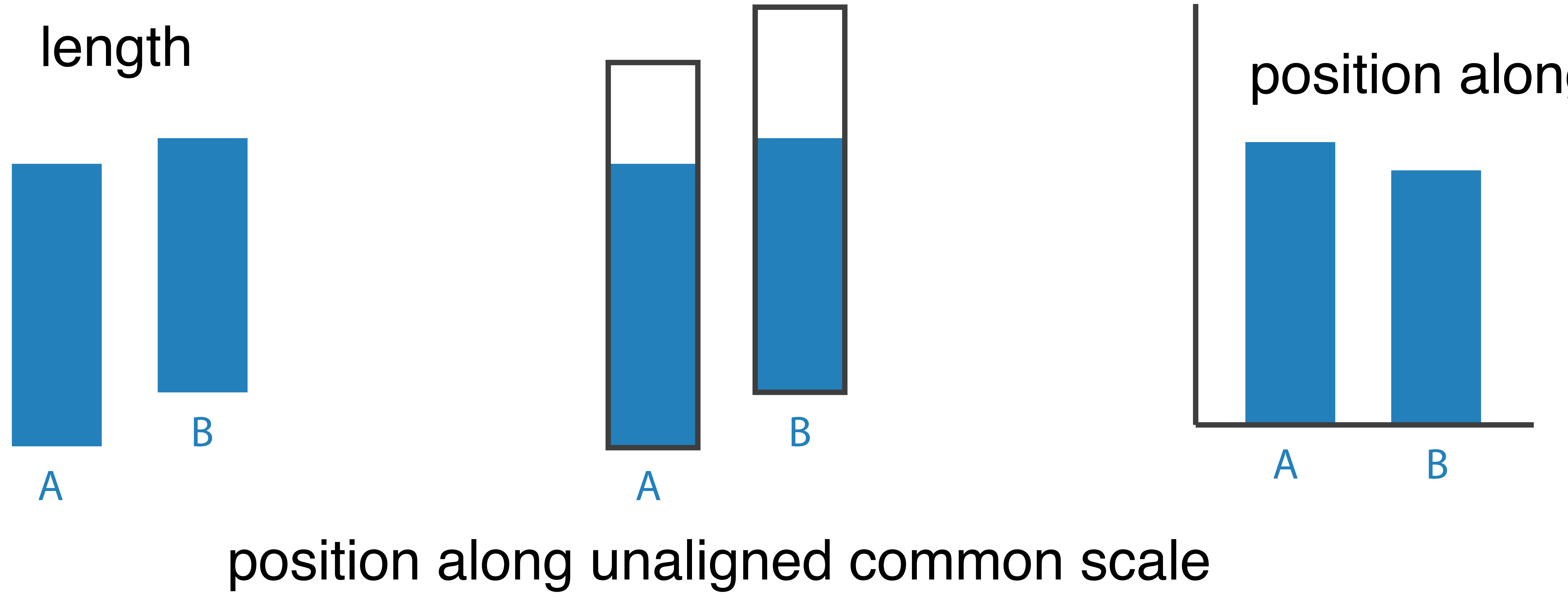


Factors affecting accuracy

- alignment
- distractors
- distance
- common scale

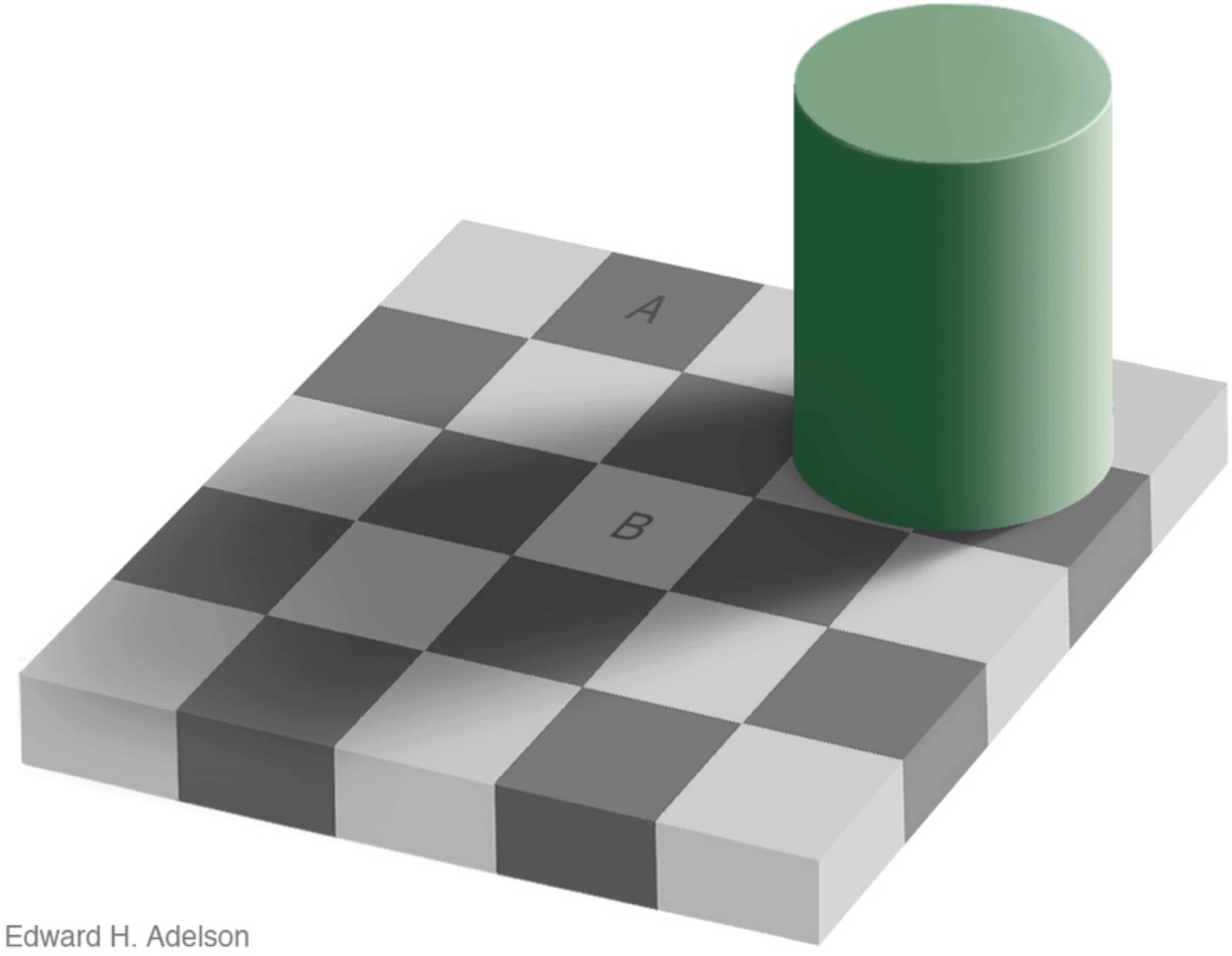
Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that’s why accuracy increases with common frame/scale and alignment
  - Weber’s Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement



Relative luminance judgements

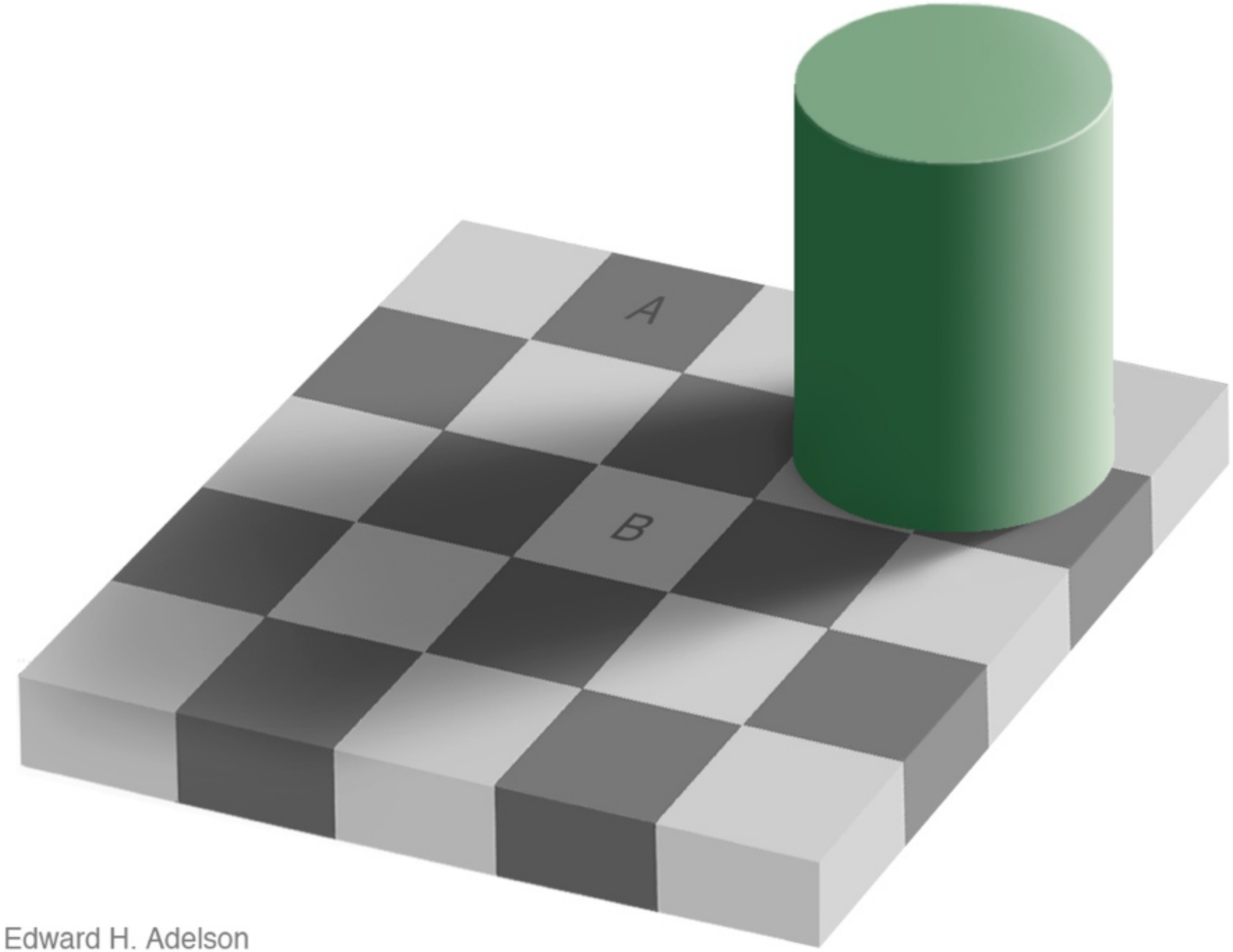
- perception of luminance is contextual based on the contrast with surroundings



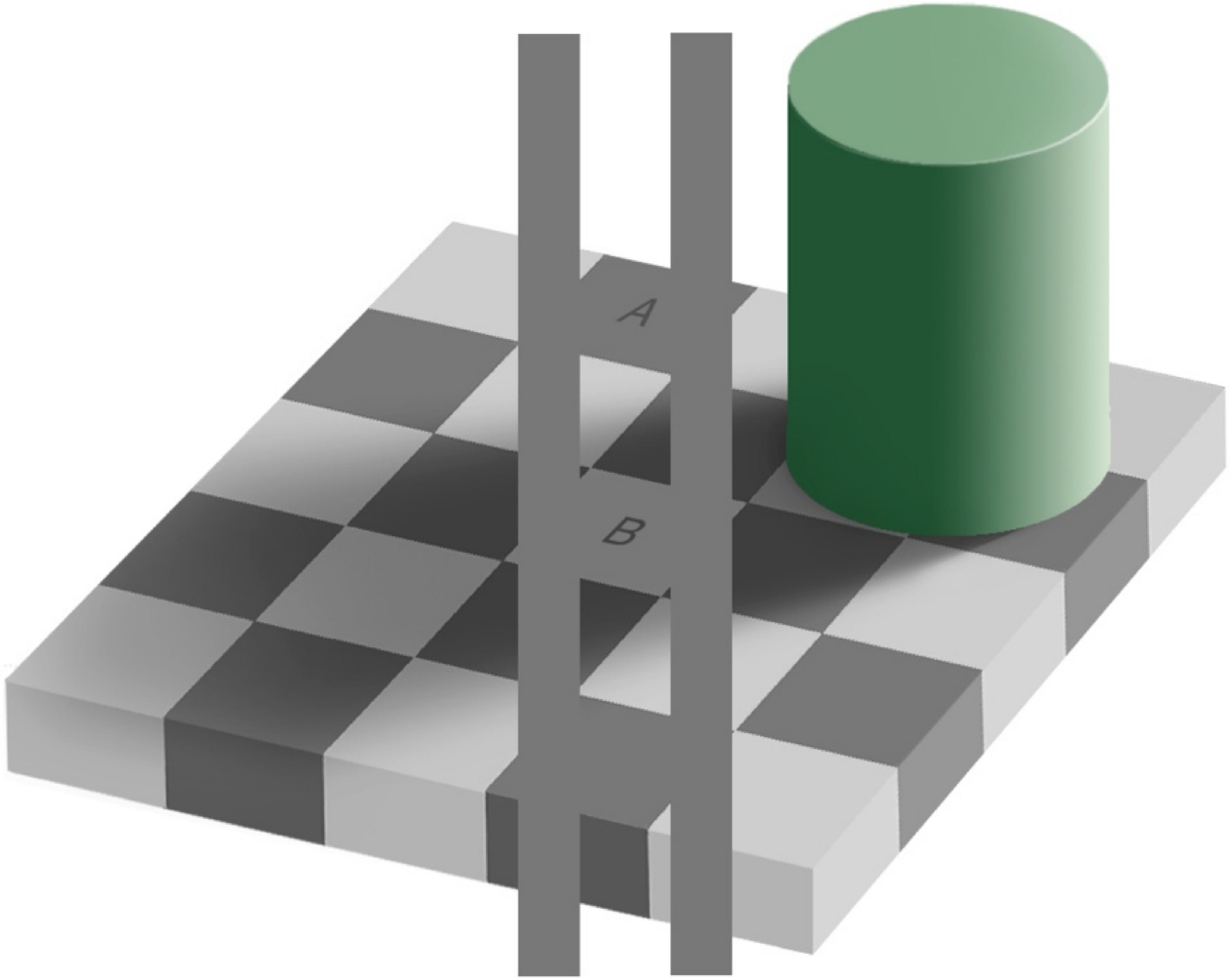
http://persci.mit.edu/gallery/checkershadow

Relative luminance judgements

- **perception of luminance is contextual based on the contrast with surroundings**



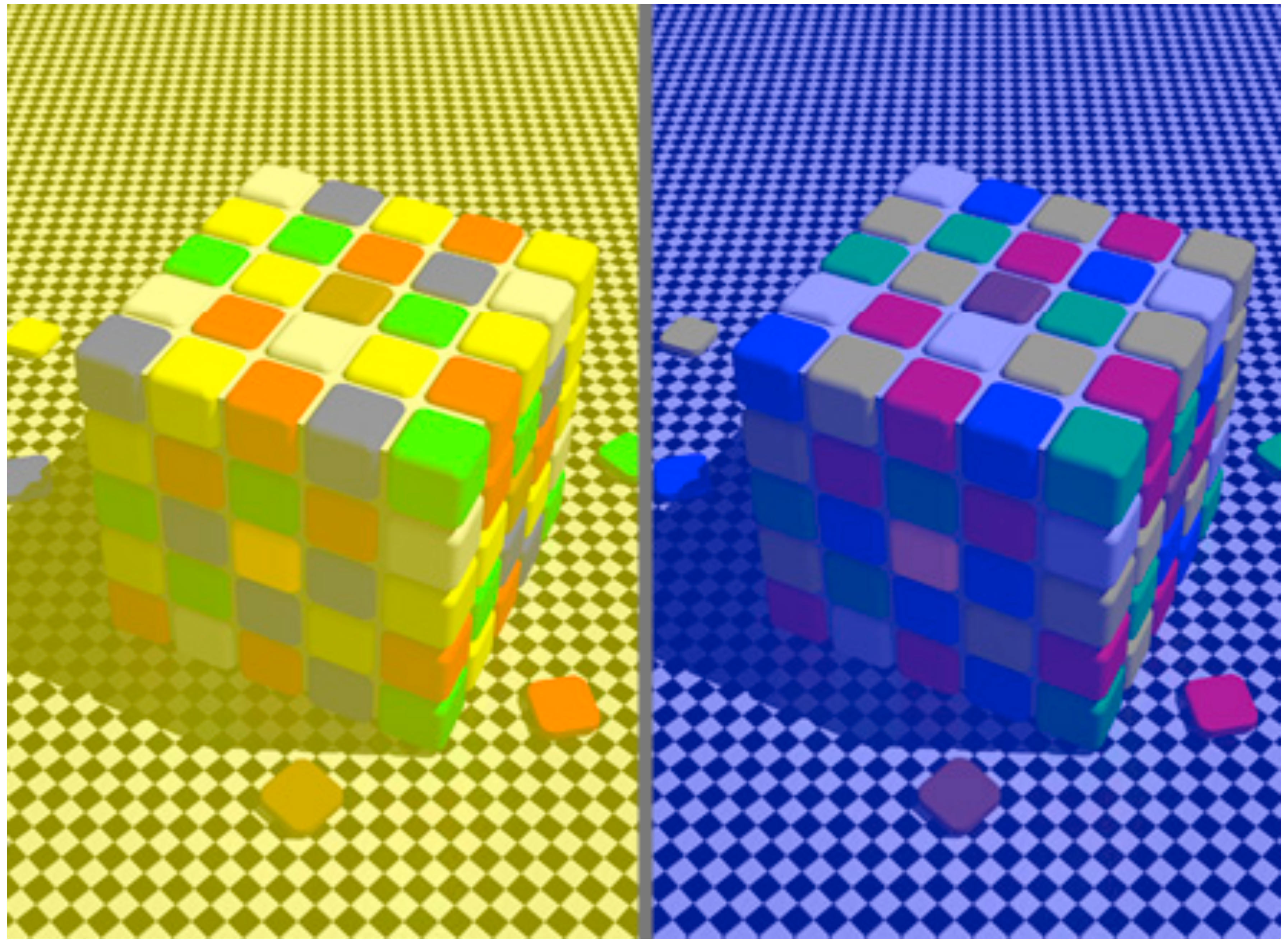
Edward H. Adelson



http://persci.mit.edu/gallery/checkershadow

Relative color judgements

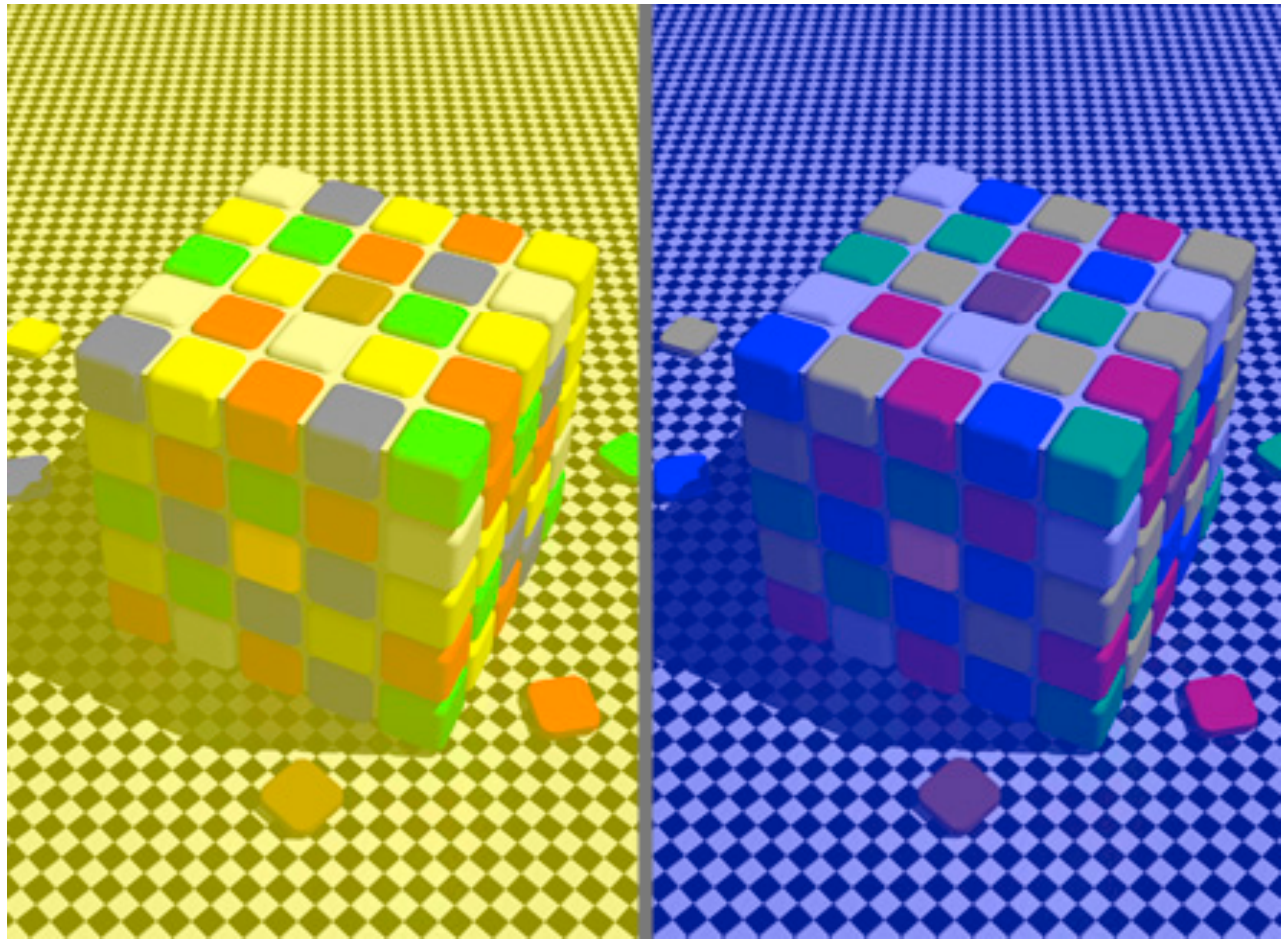
- color constancy across broad range of illumination conditions

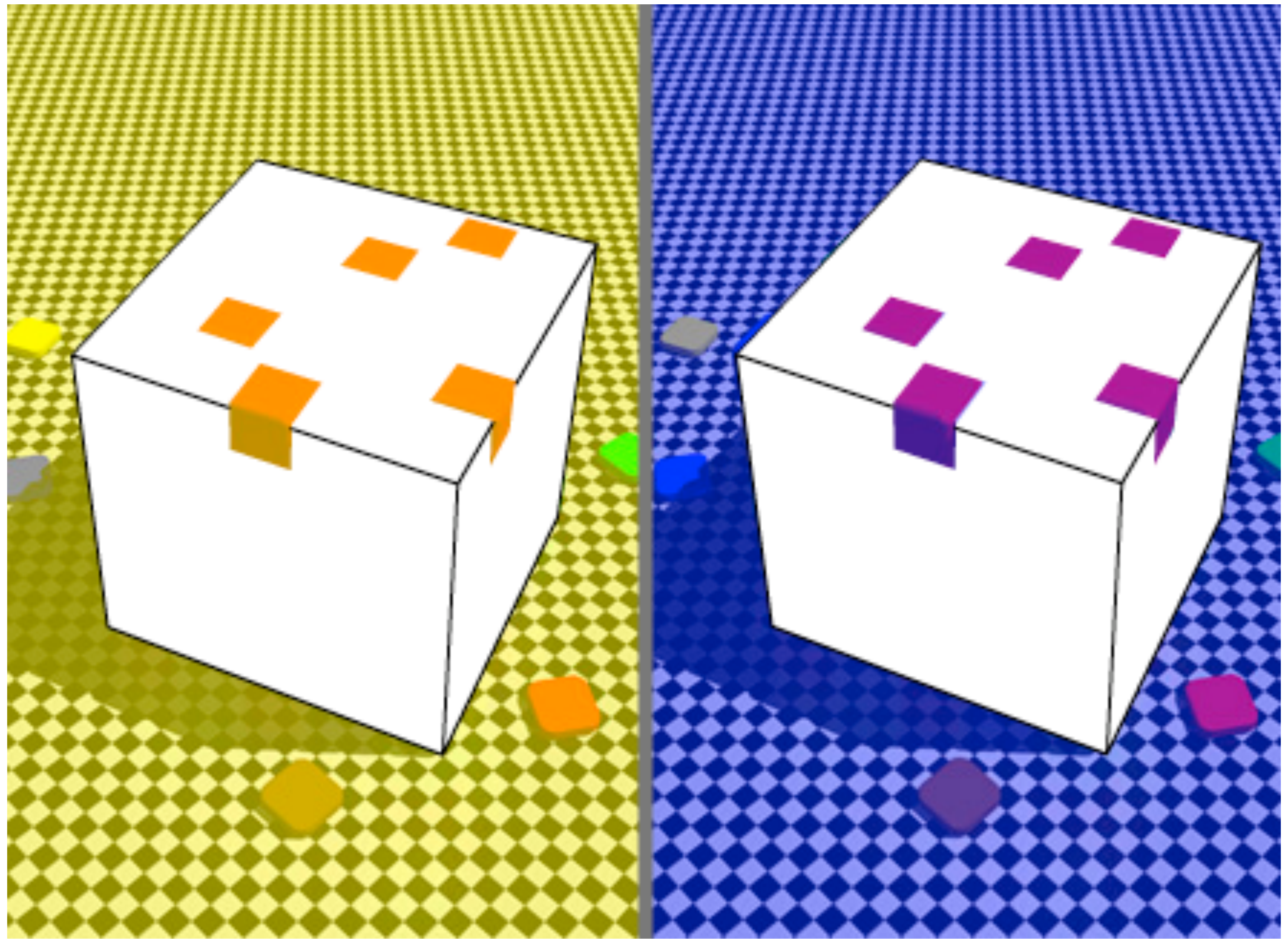


http://www.purveslab.net/seeforyourself/

Relative color judgements

- color constancy across broad range of illumination conditions



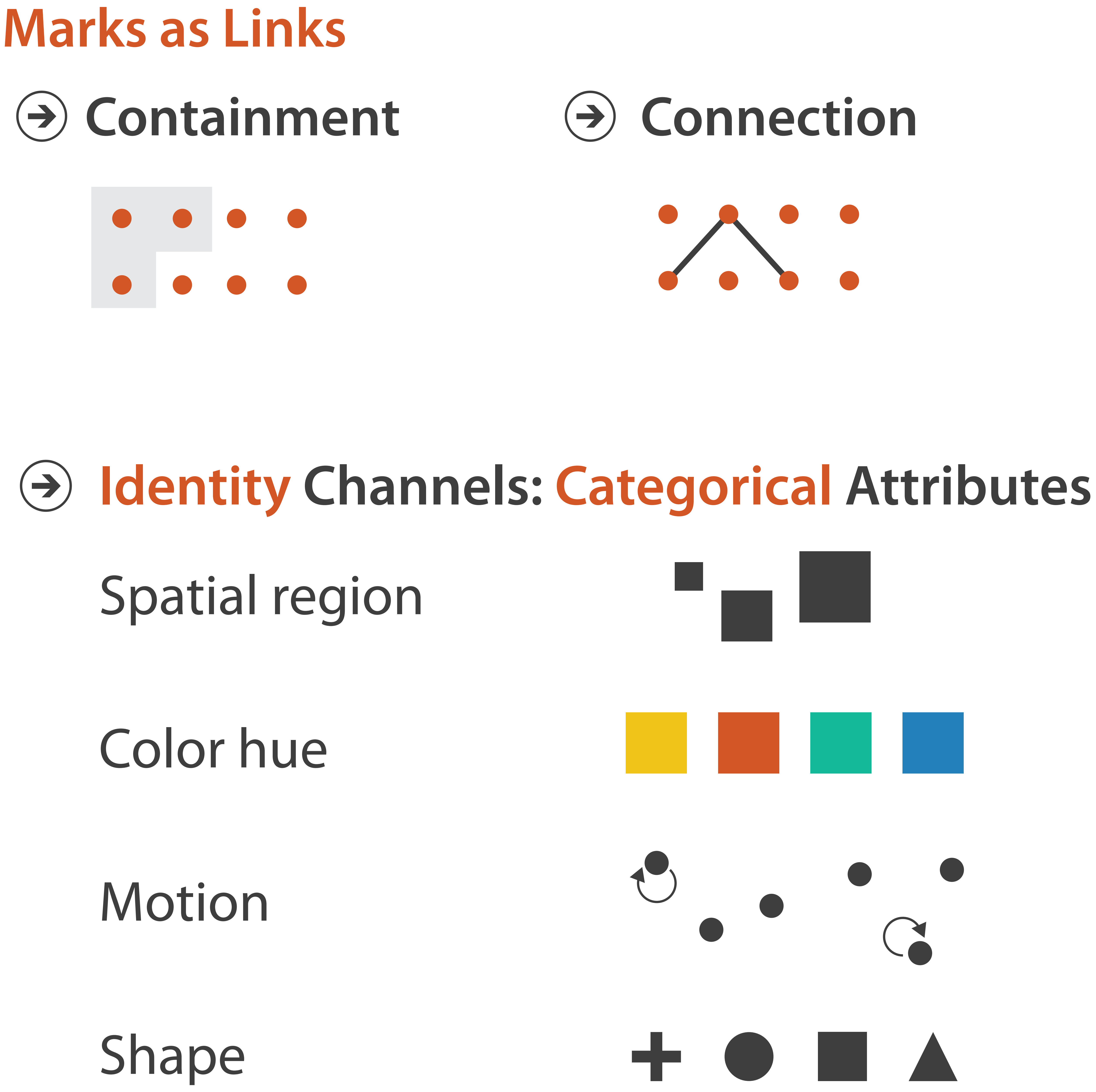


http://www.purveslab.net/seeforyourself/

Grouping

- containment
- connection

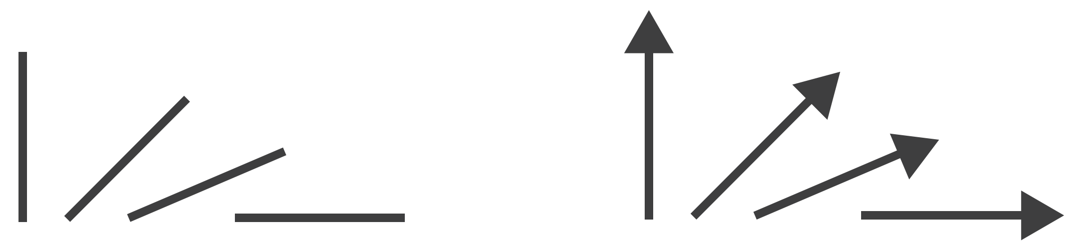
- proximity
  - same spatial region
- similarity
  - same values as other categorical channels



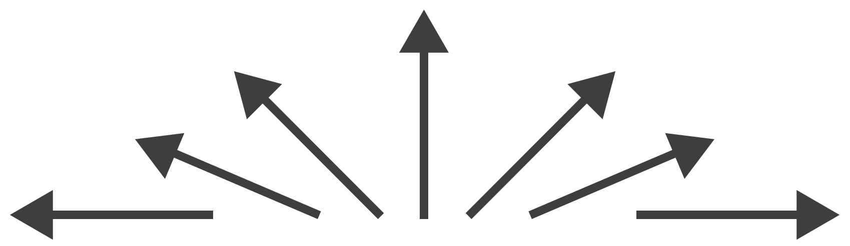
Map Other Channels

Angle / tilt / orientation channel

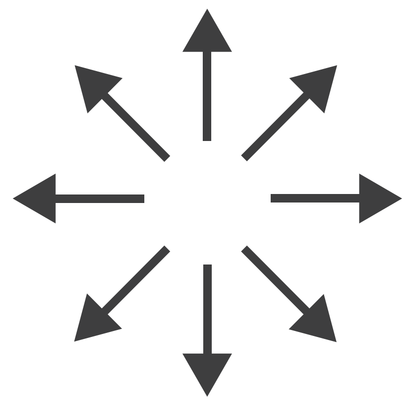
- different mappings depending on range used



Sequential ordered
line mark or arrow glyph



Diverging ordered
arrow glyph

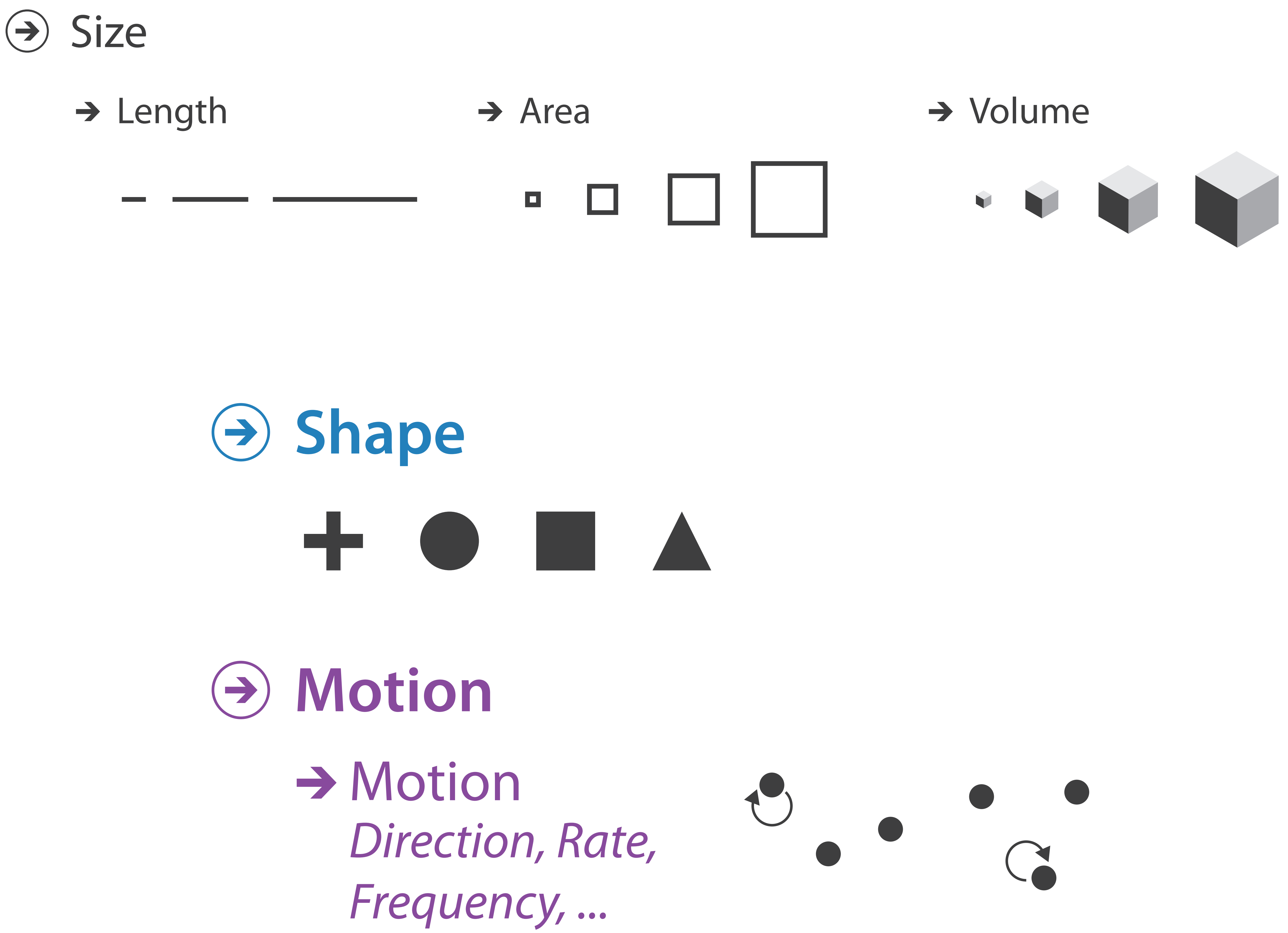


Cyclic ordered
arrow glyph

- 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
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - great for highlighting (binary)
  - use with care to avoid irritation



Reading Material

[dv3] **Chapter 5 - Marks and Channels**

Color

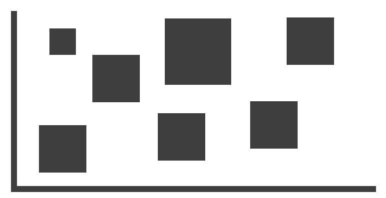
Idiom design choices: Beyond spatial arrangement

Encode

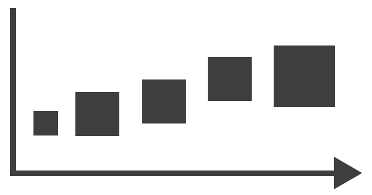
Arrange

→ Express

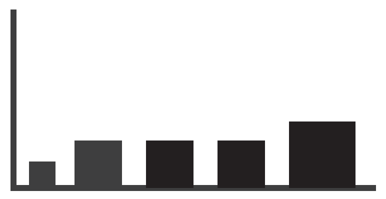
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

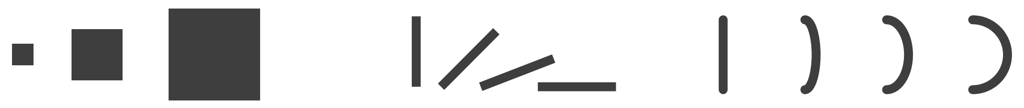
→ Color

→ *Hue*

→ *Saturation*

→ *Luminance*

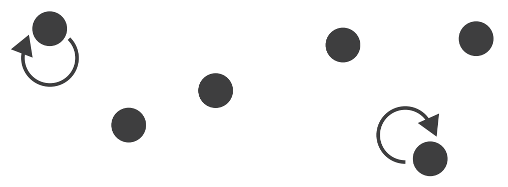
→ Size, Angle, Curvature, ...



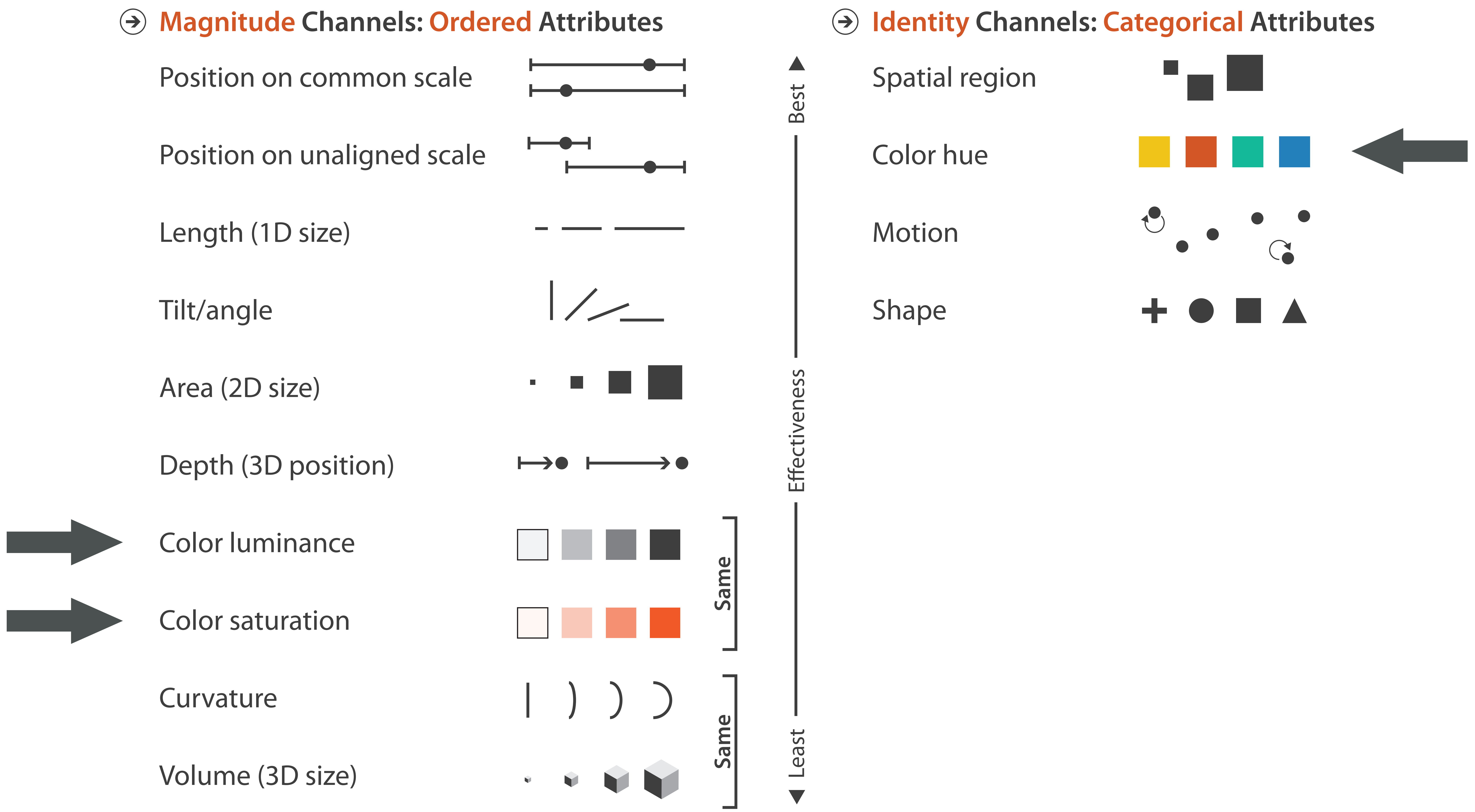
→ Shape

→ Motion

Direction, Rate, Frequency, ...

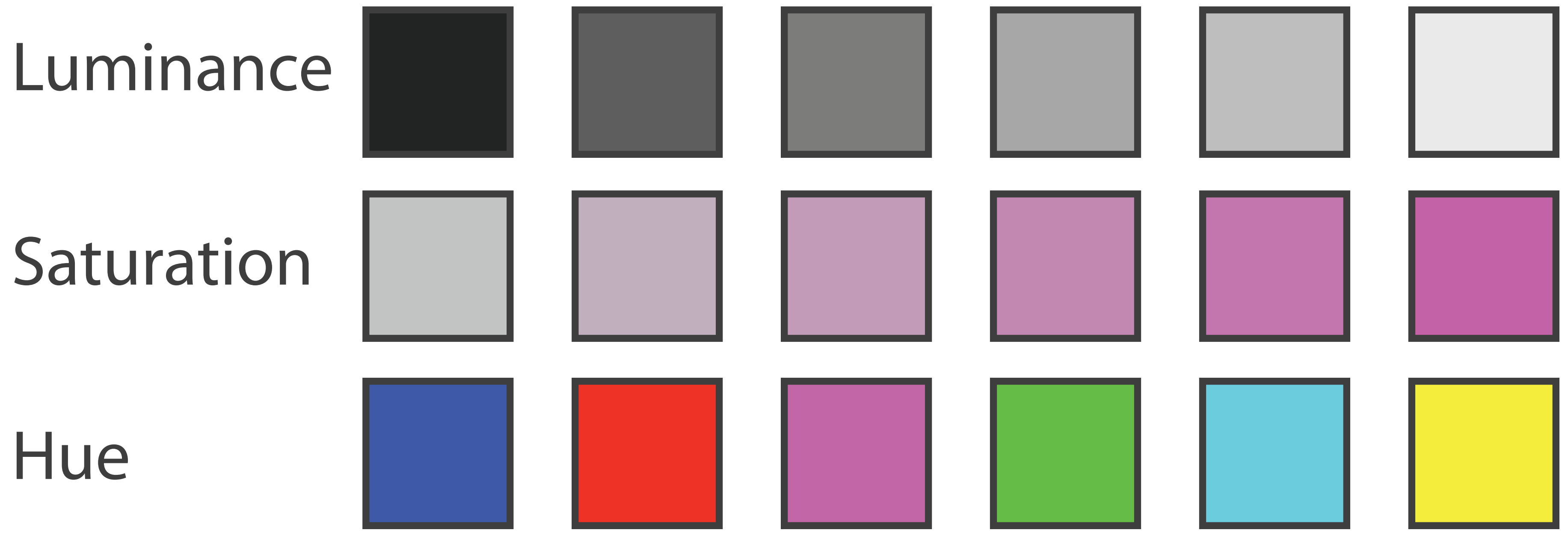


Channels: What's up with color?



Decomposing color

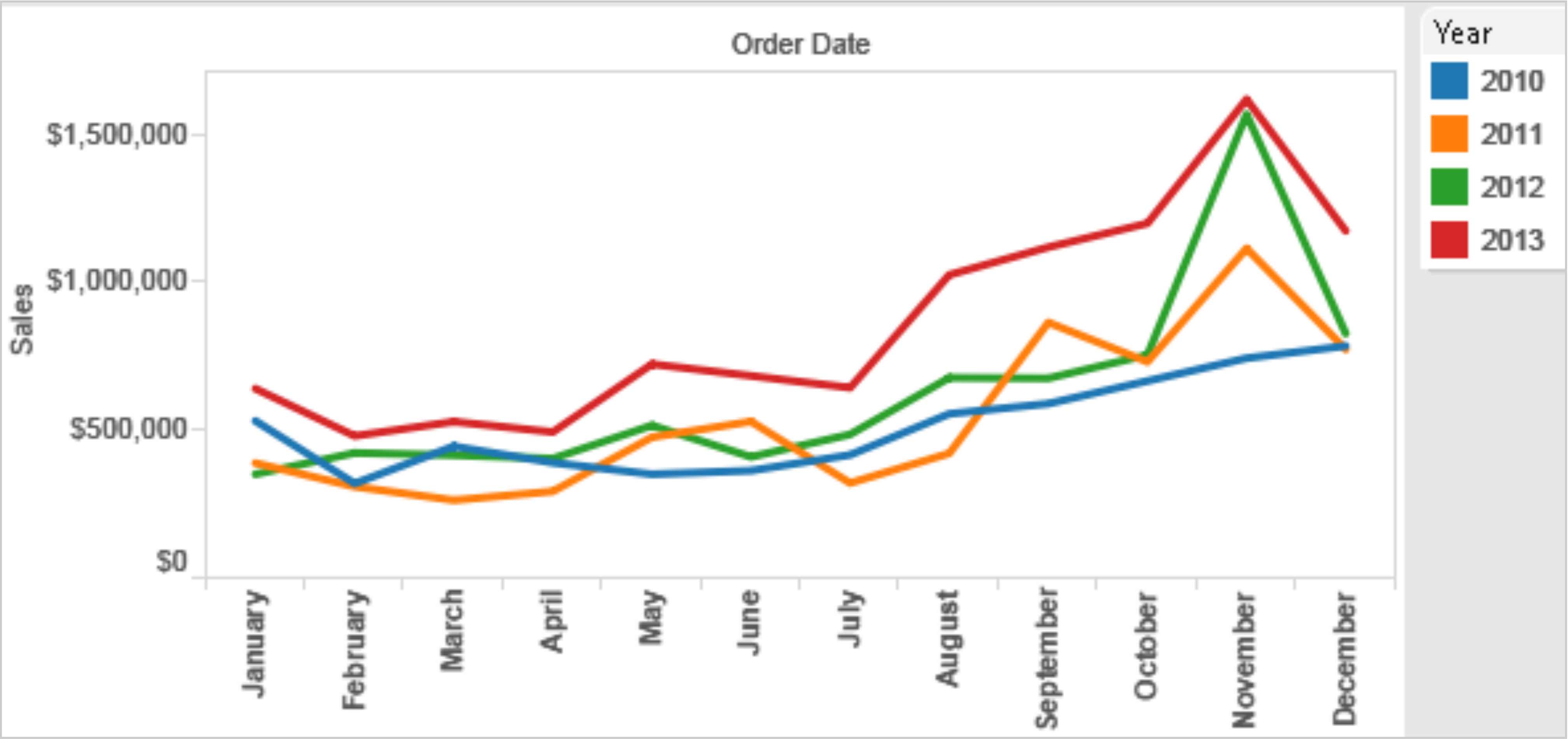
- first rule of color: do not (just) talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance: how bright (B/W)
    - saturation: how colourful
  - categorical can show identity
    - hue: what color

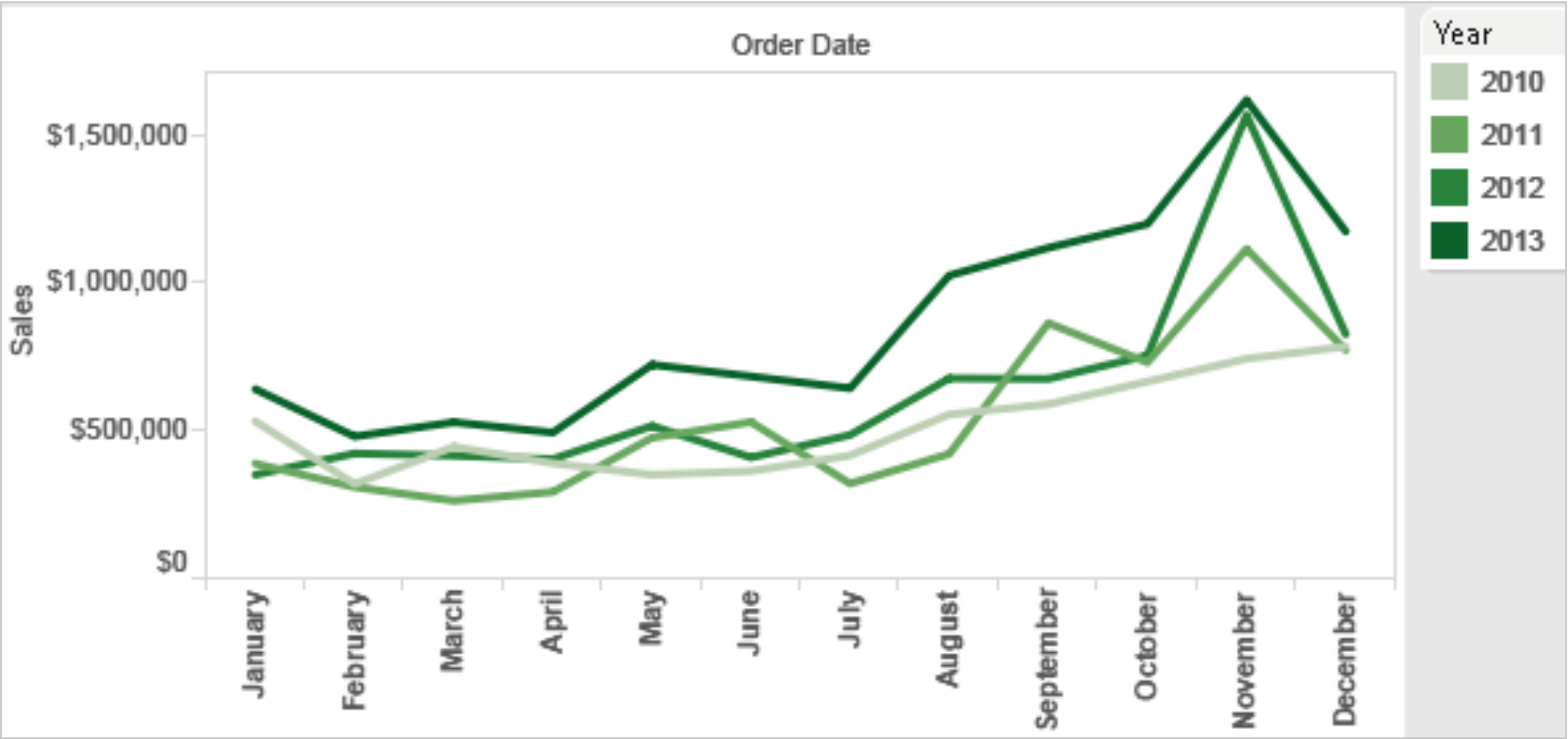


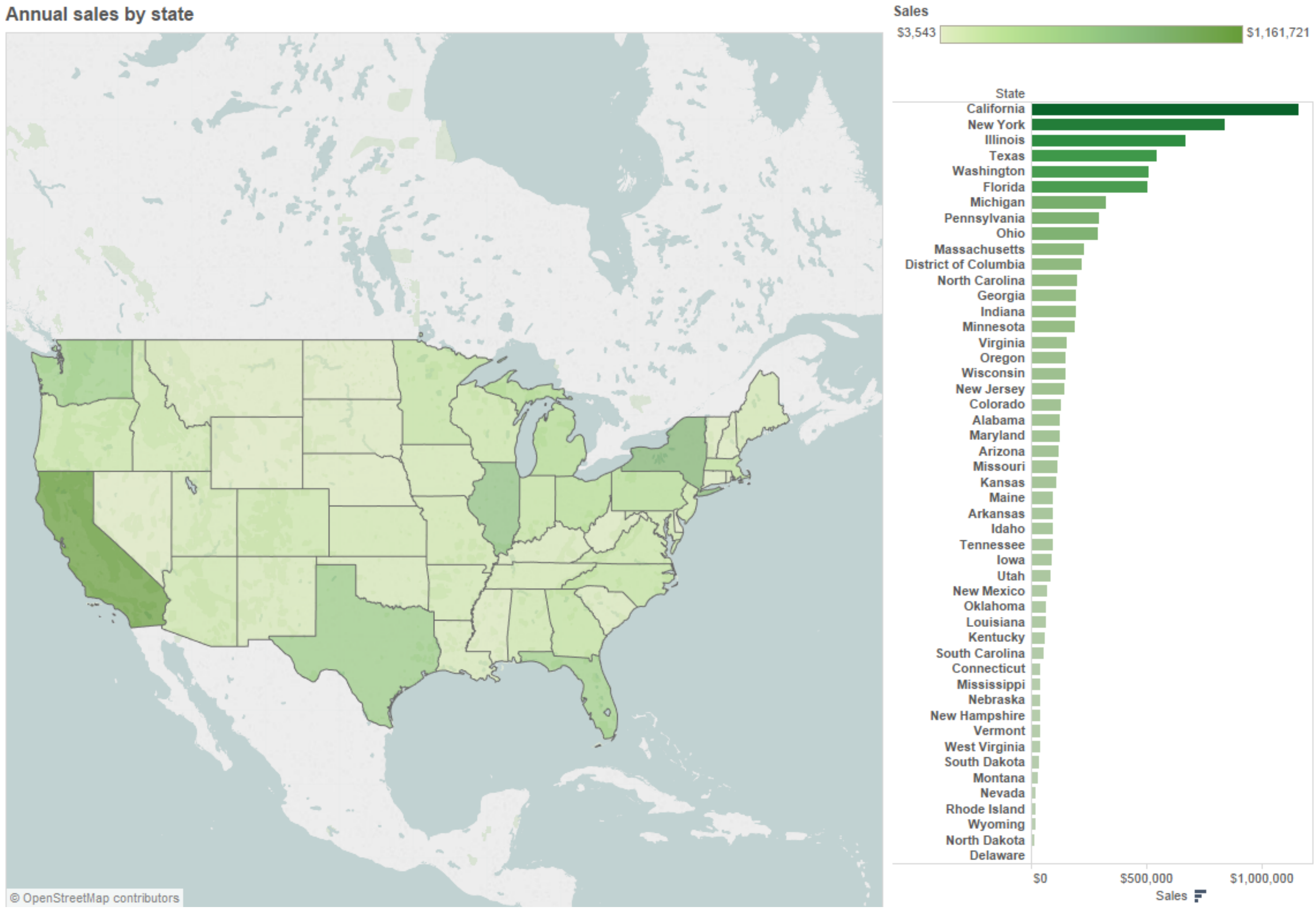
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable bins can we use?

Color Channels in Visualization

Categorical vs ordered color



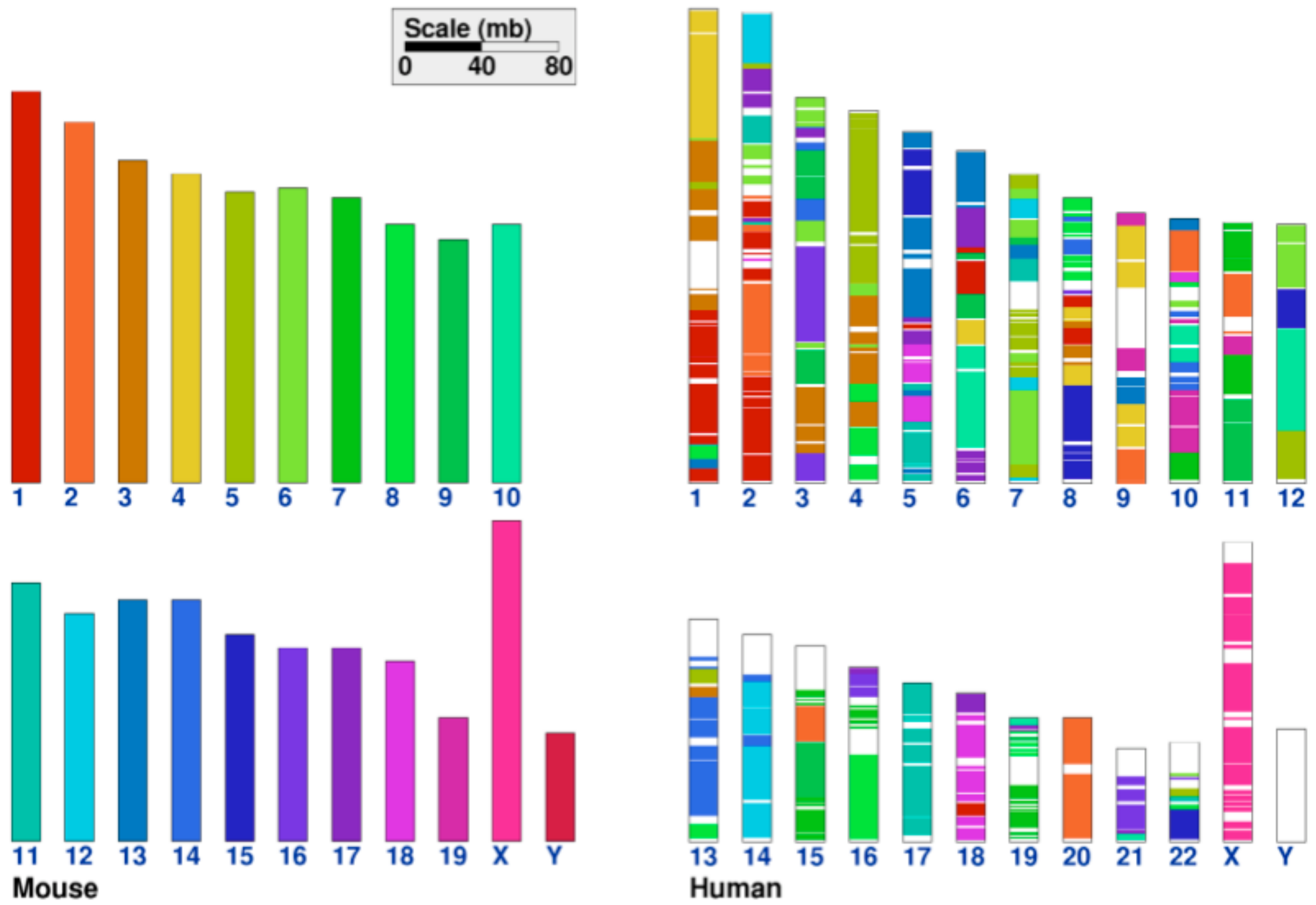




[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Categorical color: limited number of discriminable bins

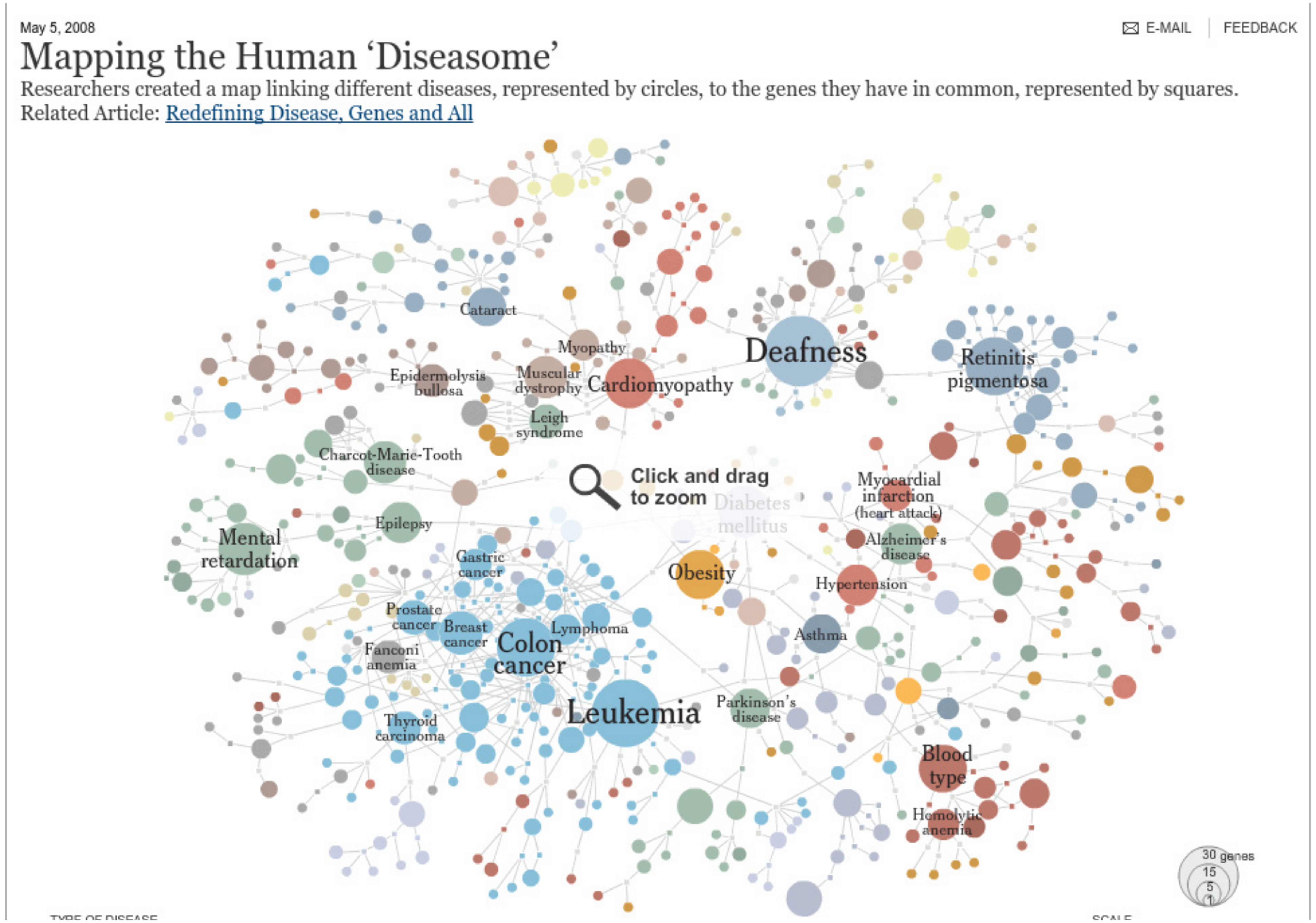
- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights

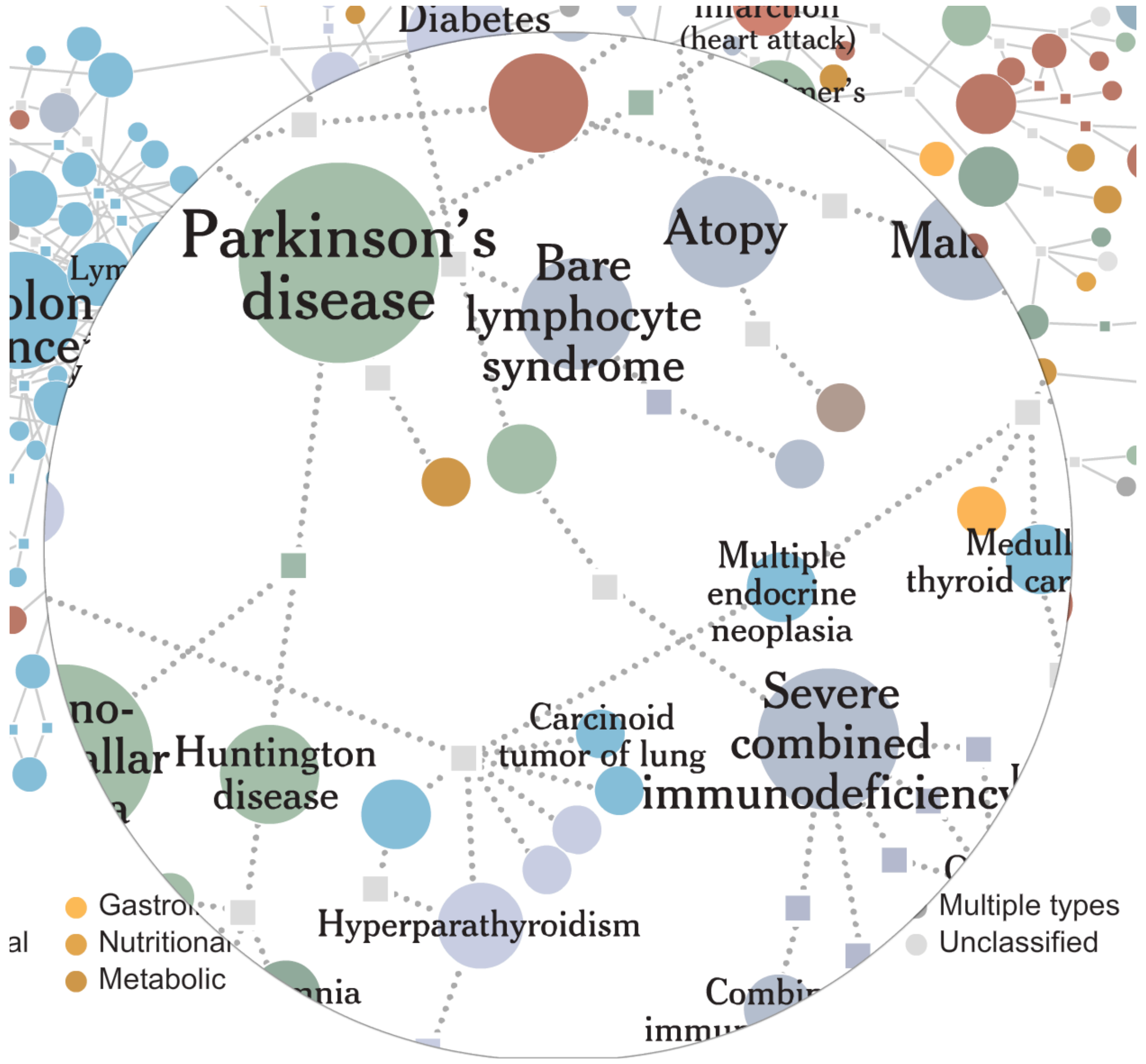


[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Categorical color: limited number of discriminable bins

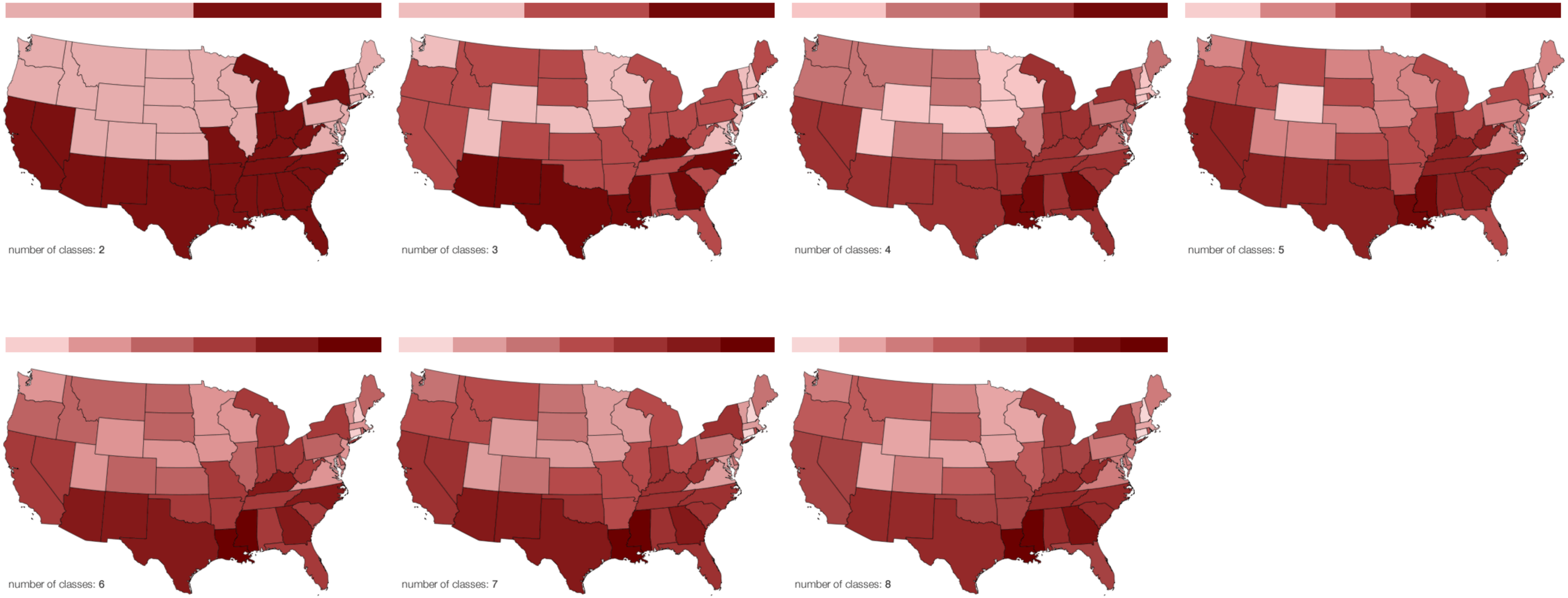
Cancer, Bone, Skeletal
Connective tissue, Muscular, Dermatological
Cardiovascular, Hematological, Renal
Endocrine, Immunological
Gastrointestinal, Nutritional, Metabolic
Ear, nose, throat, Ophthalmological, Respiratory
Developmental, Neurological, Psychiatric
Multiple types, Unclassified





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

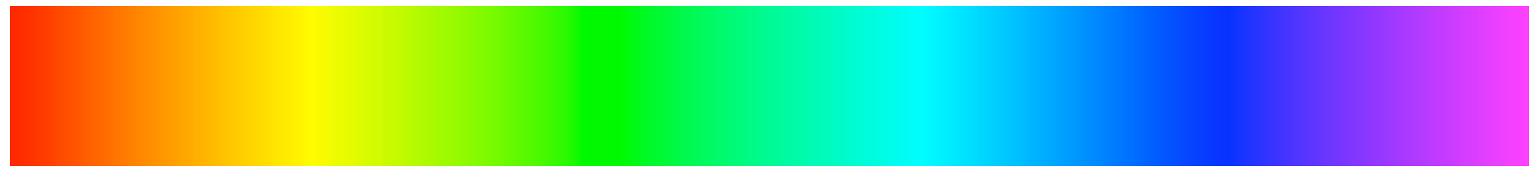
Ordered color: limited number of discriminable bins

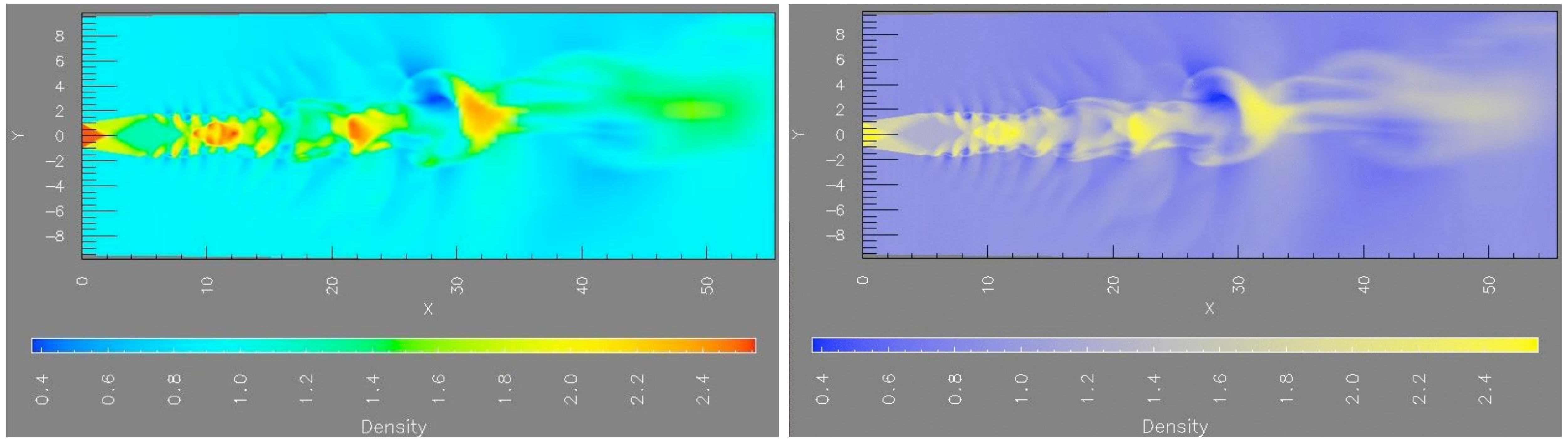


Gregor Aisch, vis4.net/blog/posts/choropleth-maps/

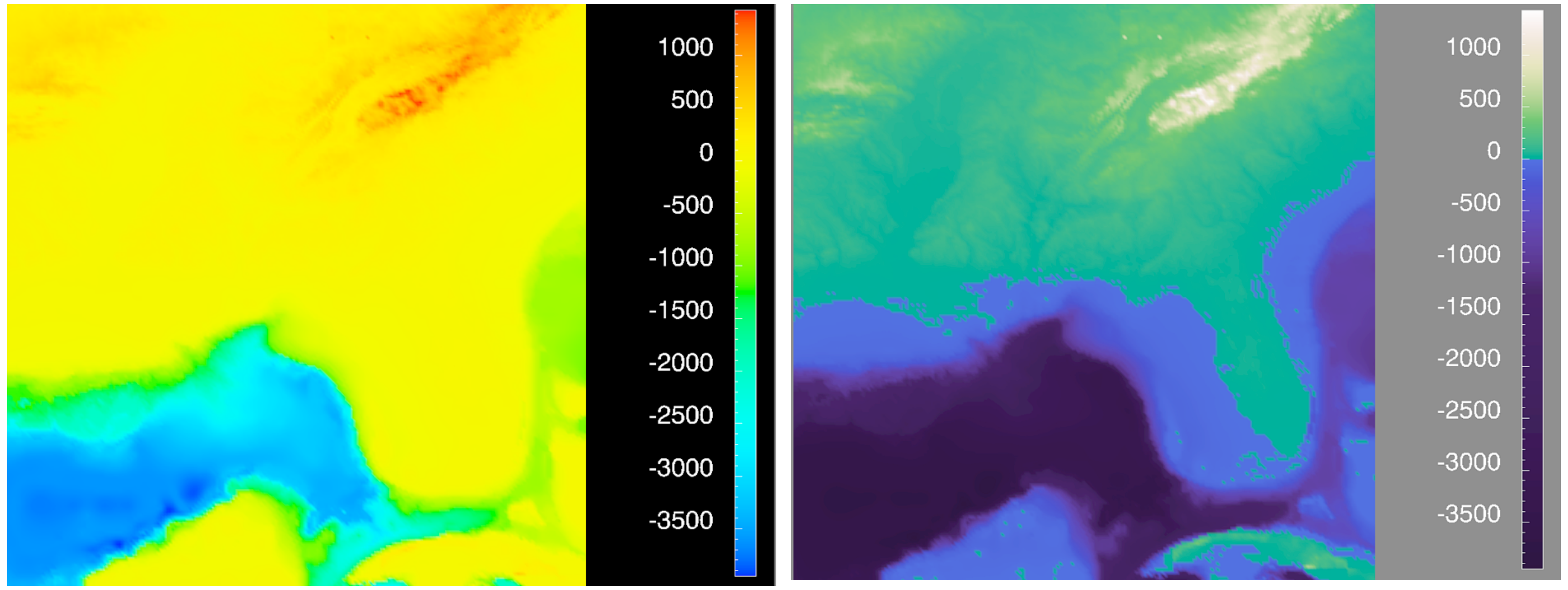
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]





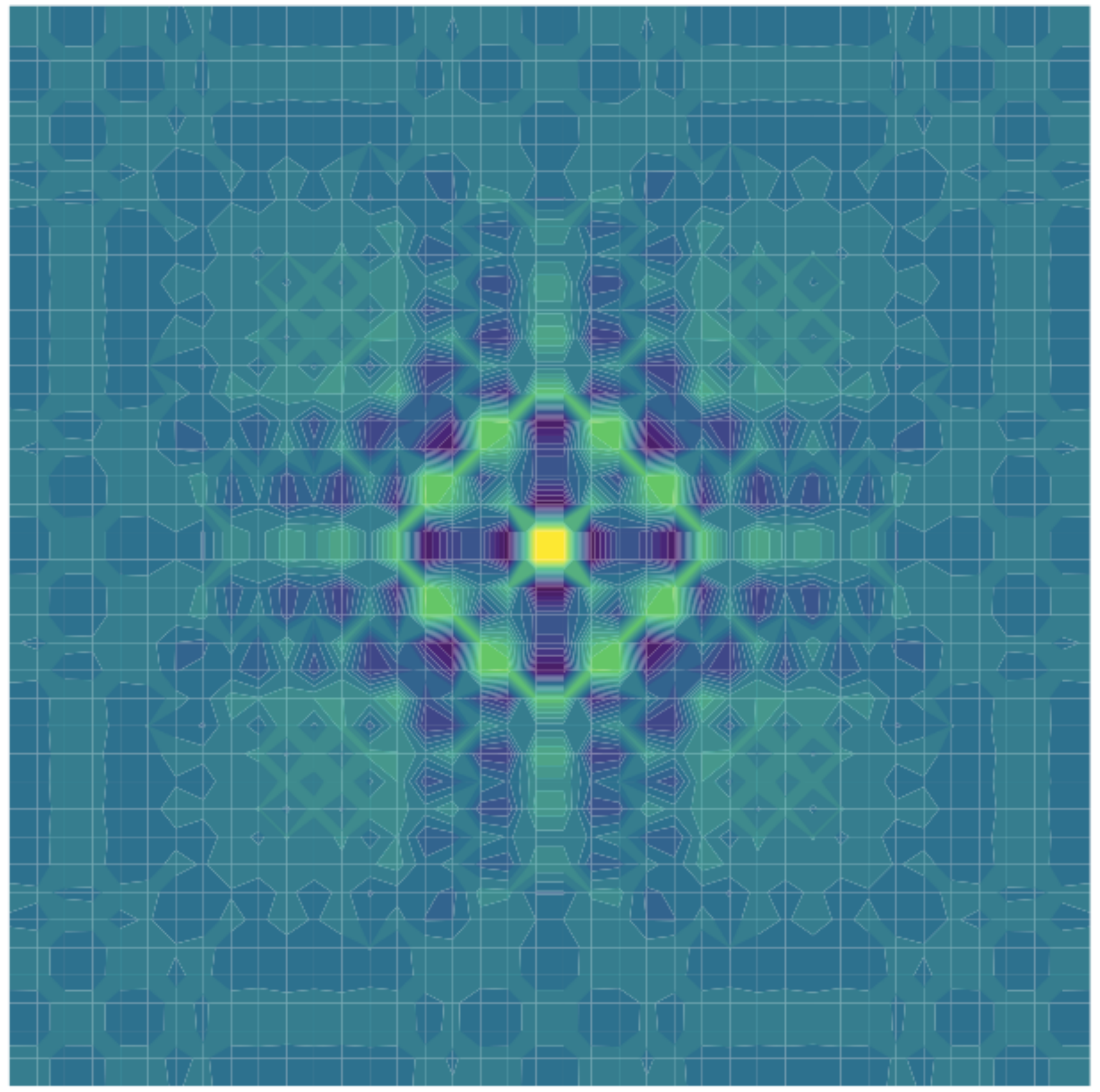
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis). pp. 118–125. 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM] https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

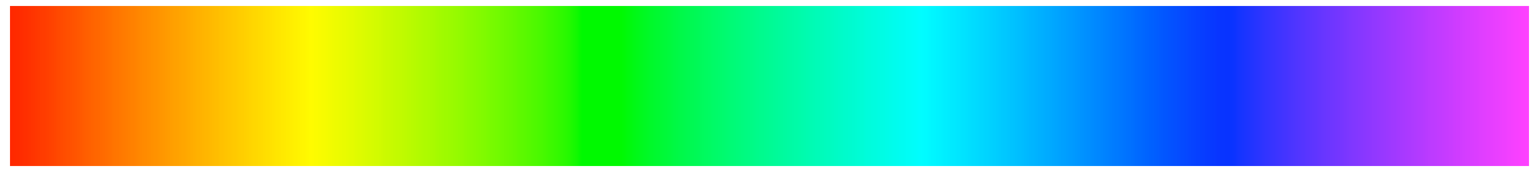
Viridis / Magma: sequential colormaps

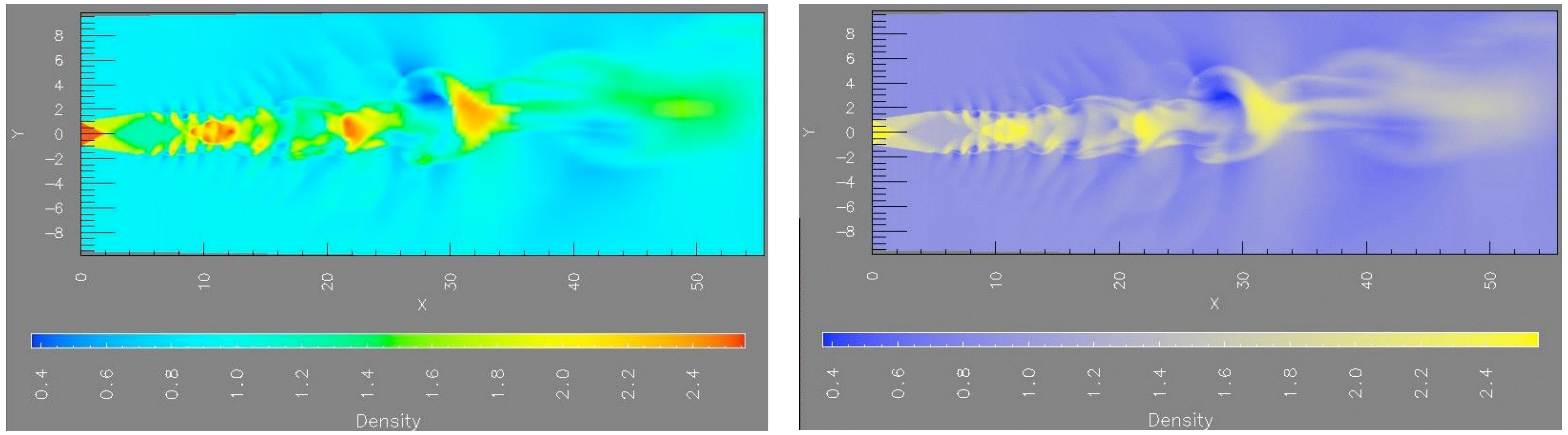
- monotonically increasing luminance, perceptually uniform
- colorful, colorblind-safe
  - R, python, D3



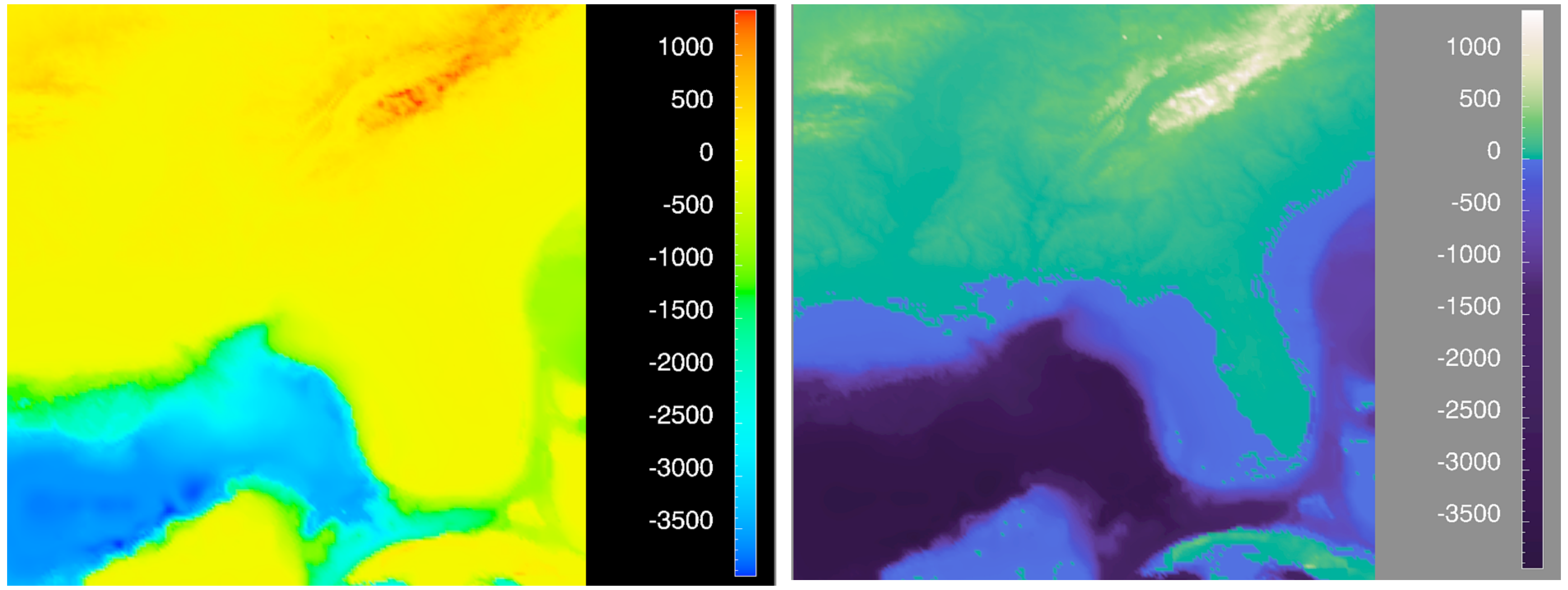
Ordered color: Rainbow is poor default

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

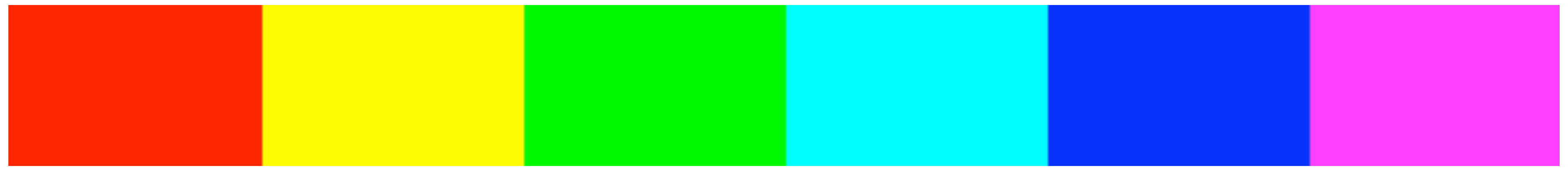




[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



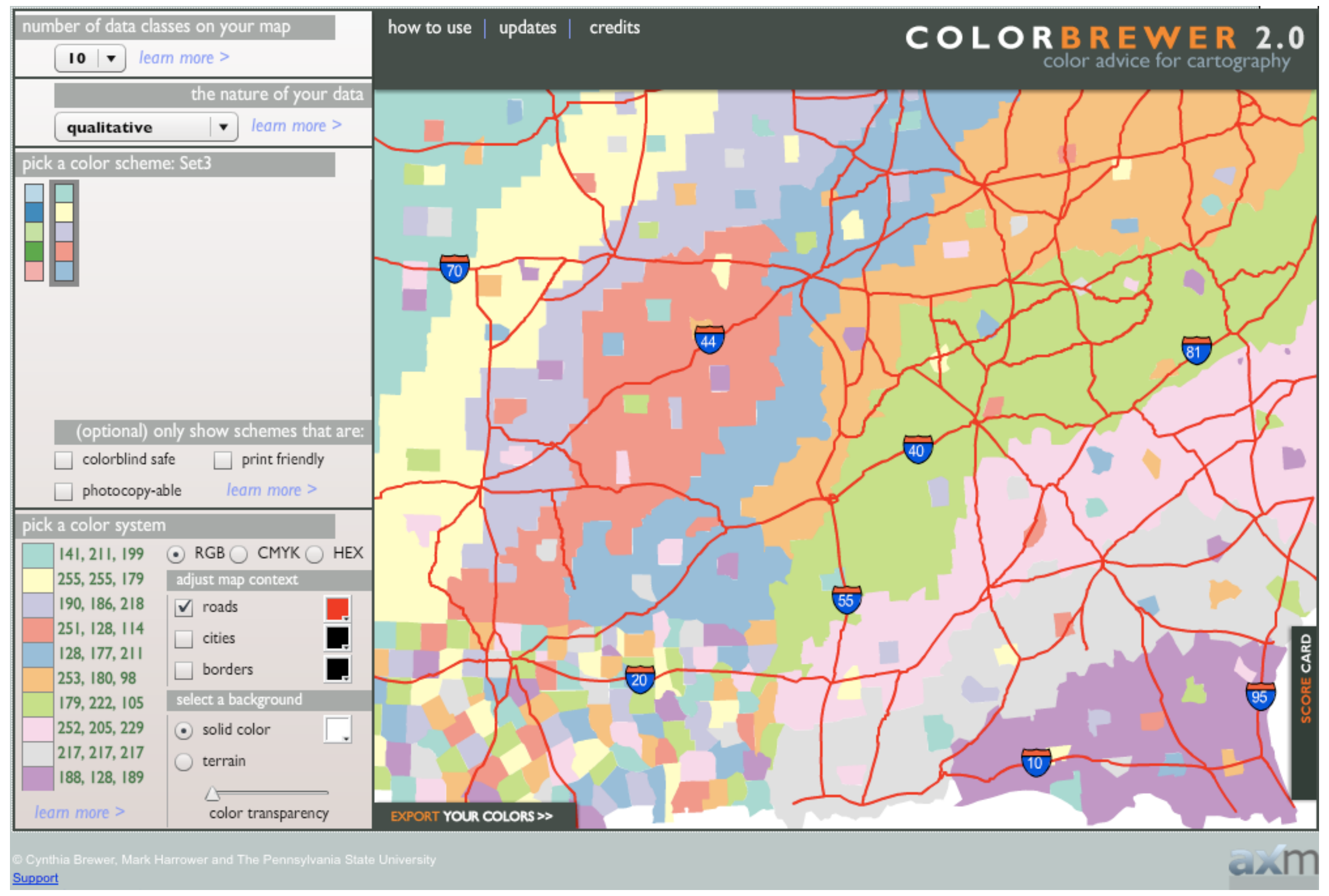
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://

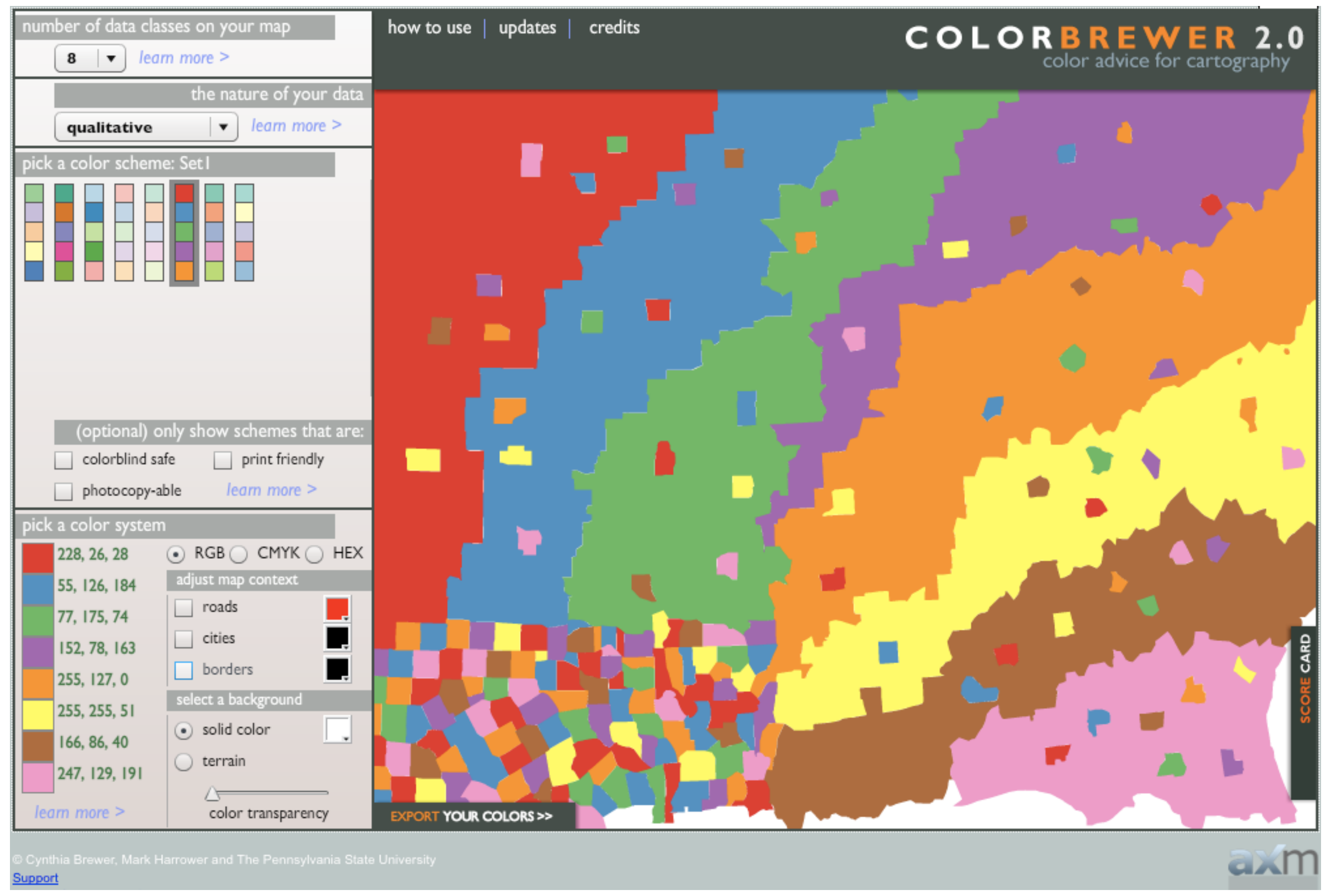


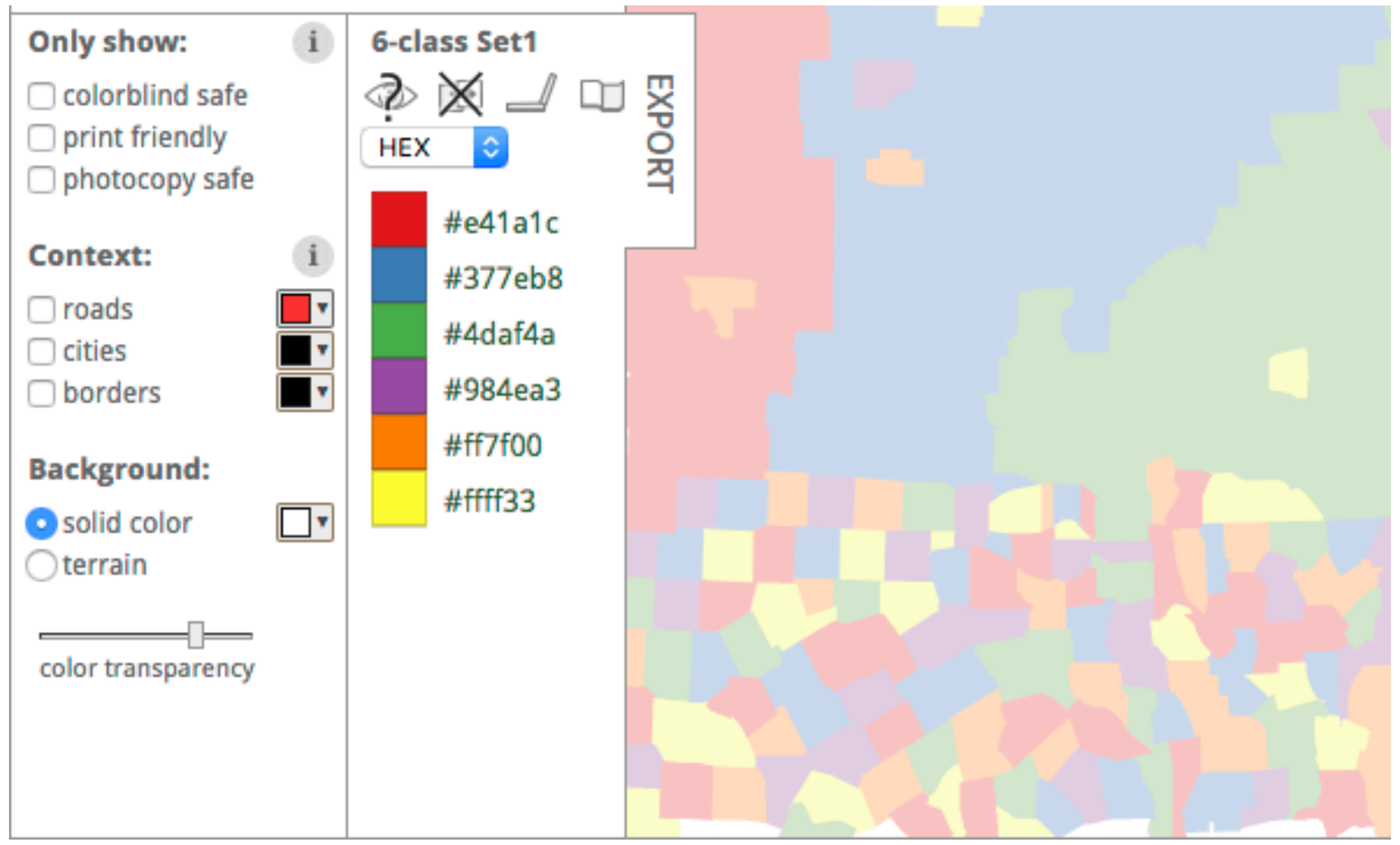
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

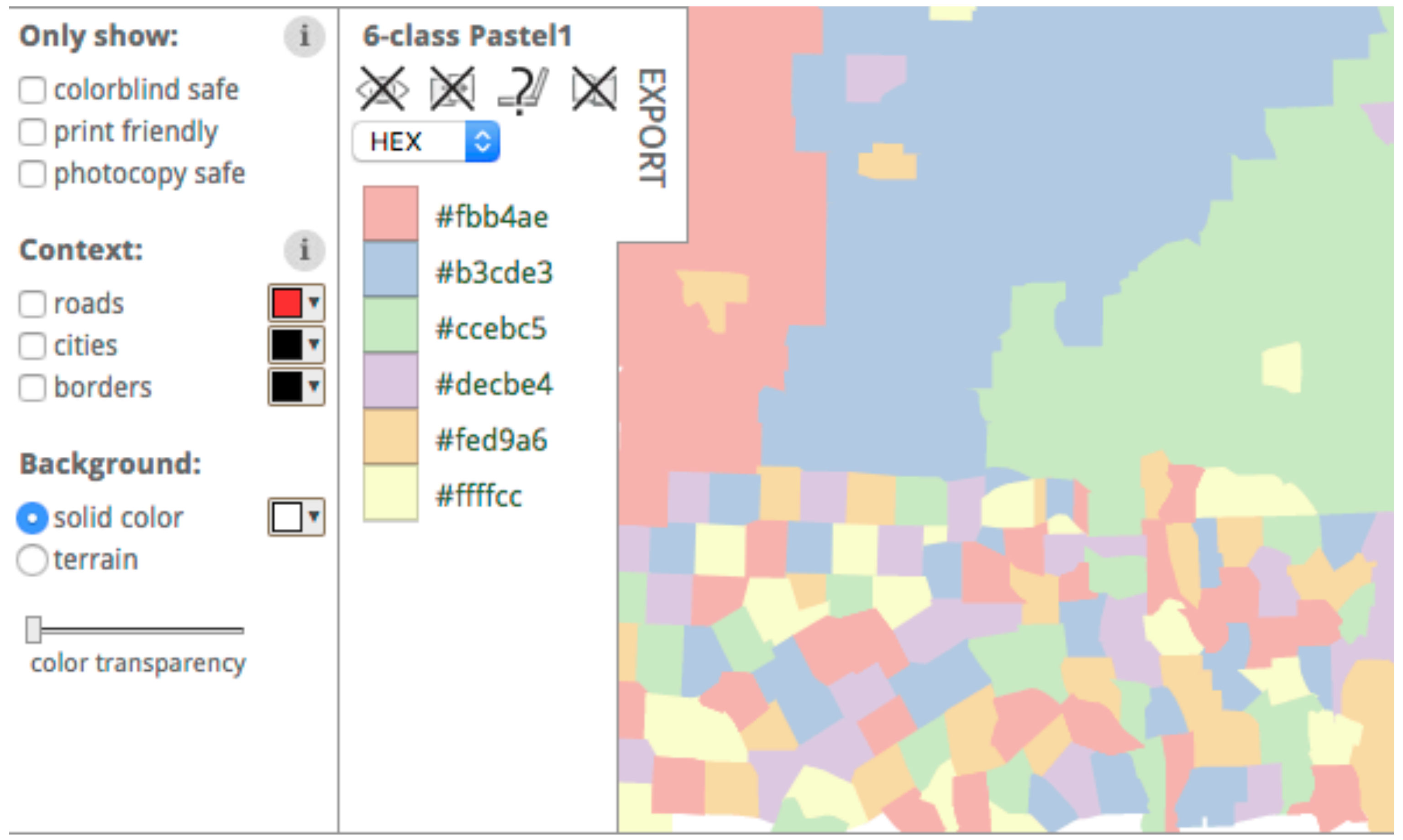
Interaction between channels: Not fully separable

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



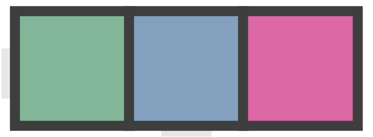






http://colorbrewer2.org/

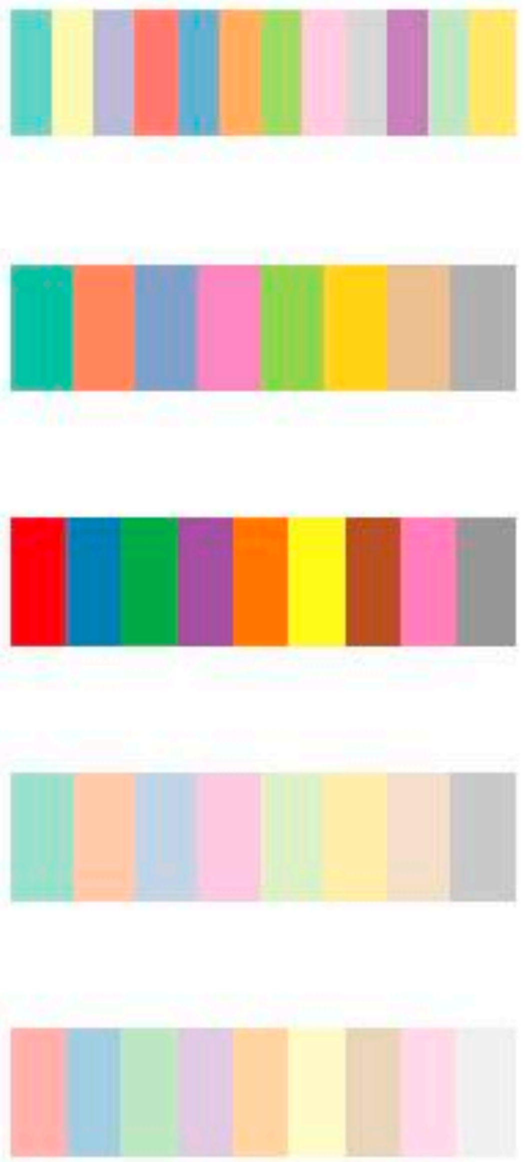
Color Palettes



Categorical

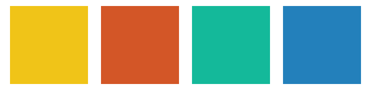
Color palettes: univariate

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



categorical

➔ Categorical



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

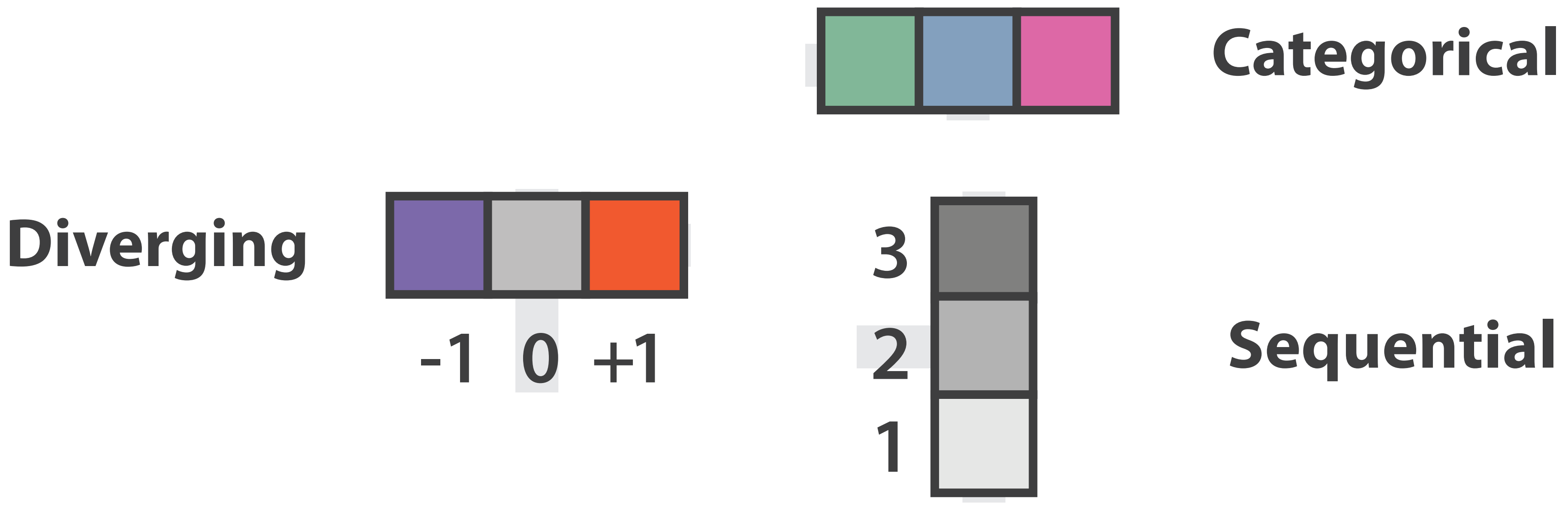
Color palettes: univariate

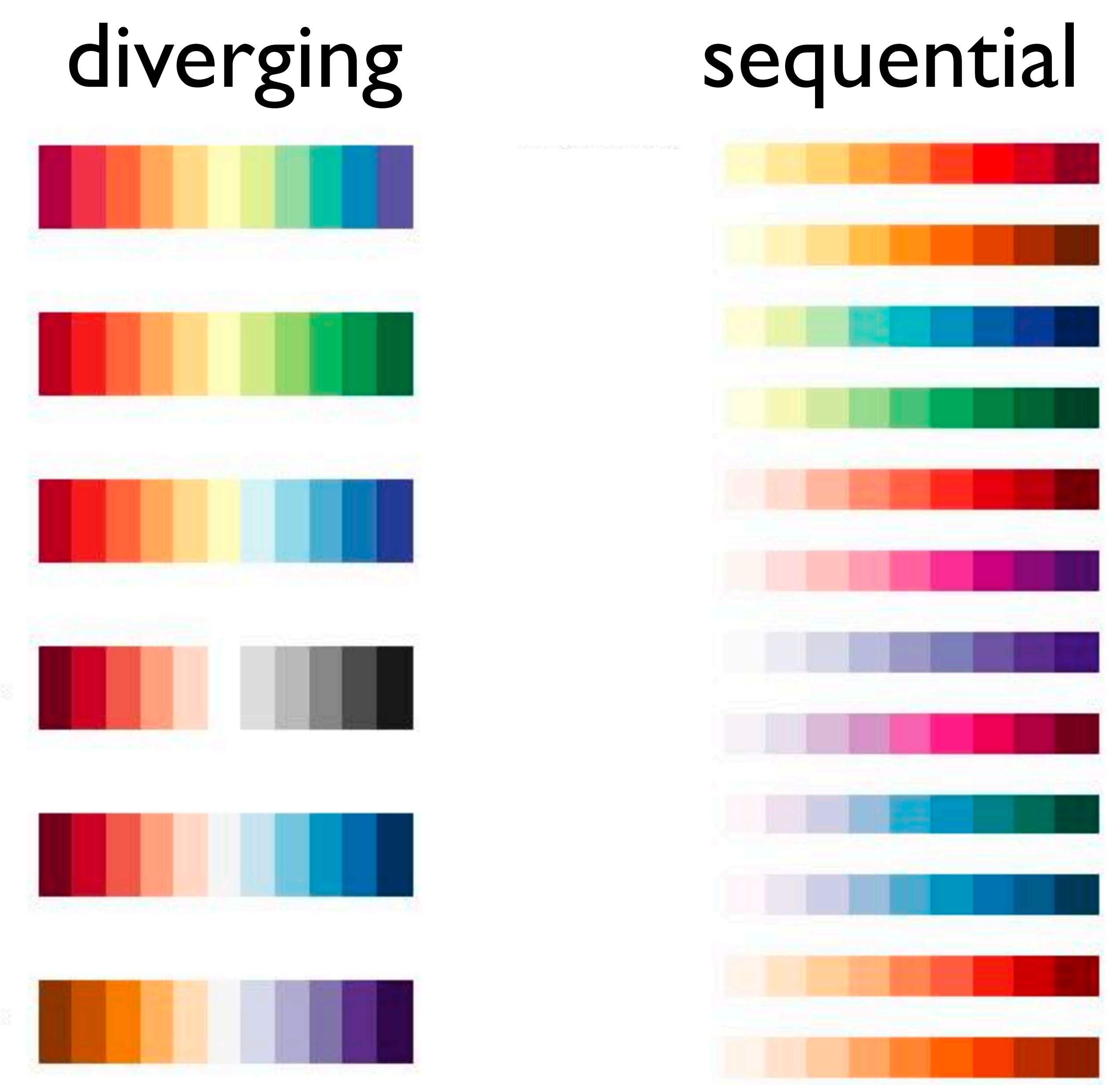
➔ Categorical

➔ 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



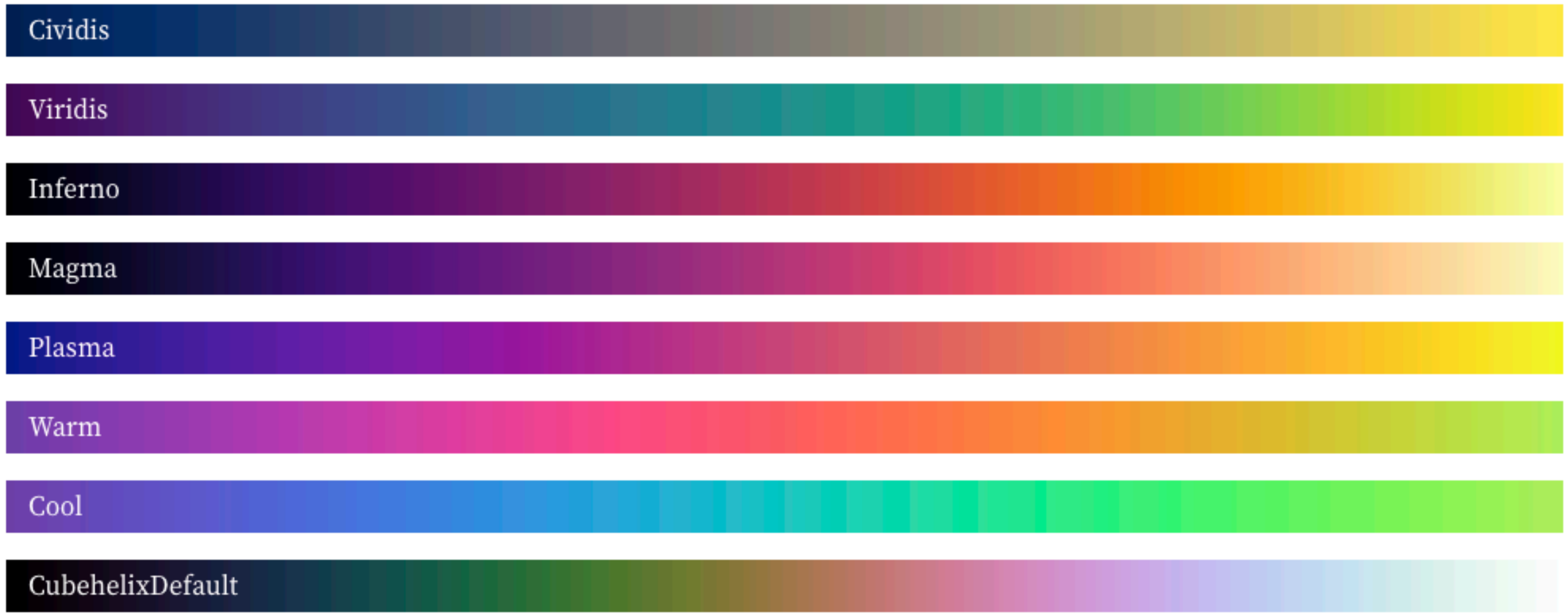


Color palettes: univariate

- Categorical

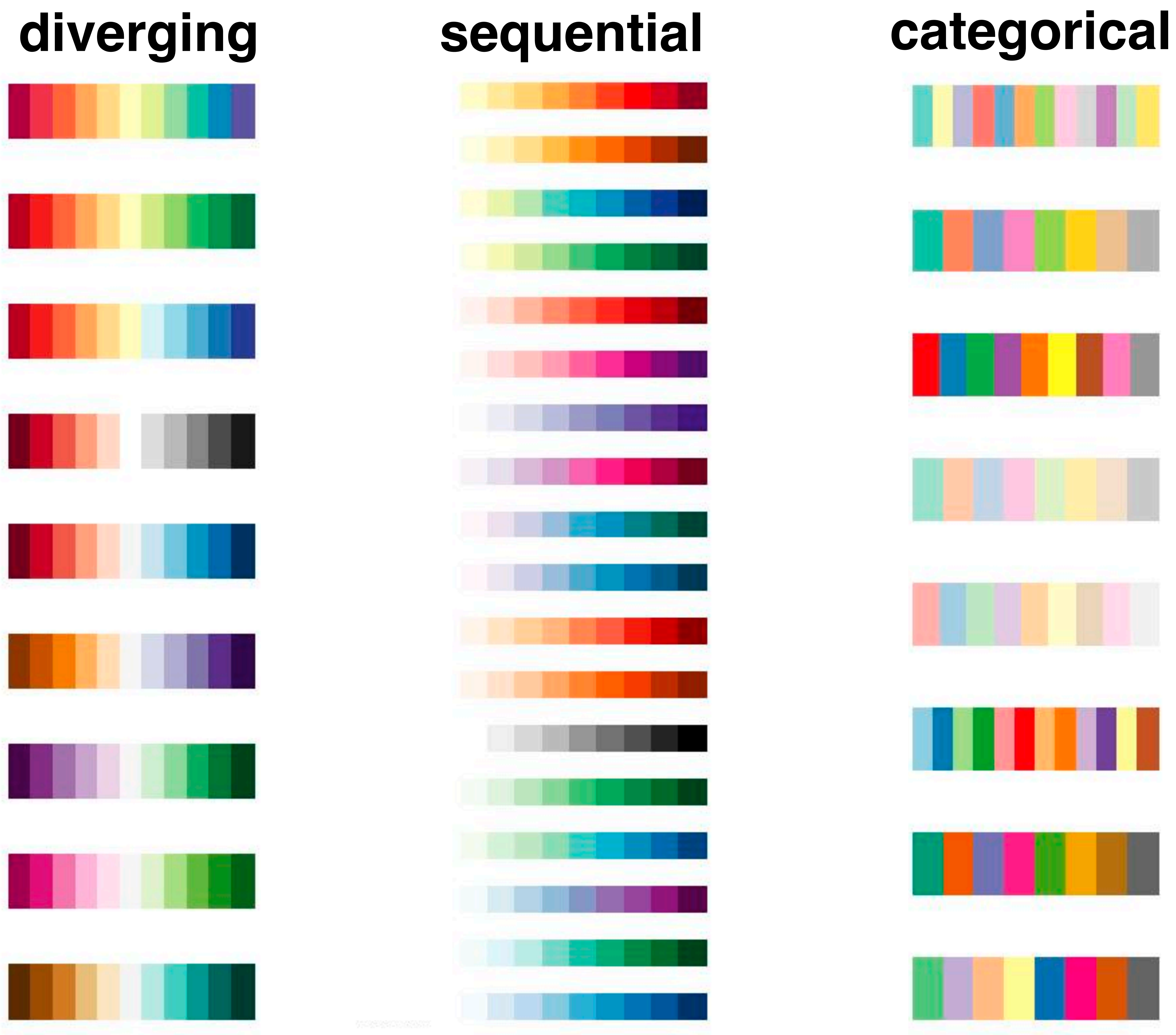
- Ordered
  - *Sequential*
  - *Diverging*

- 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

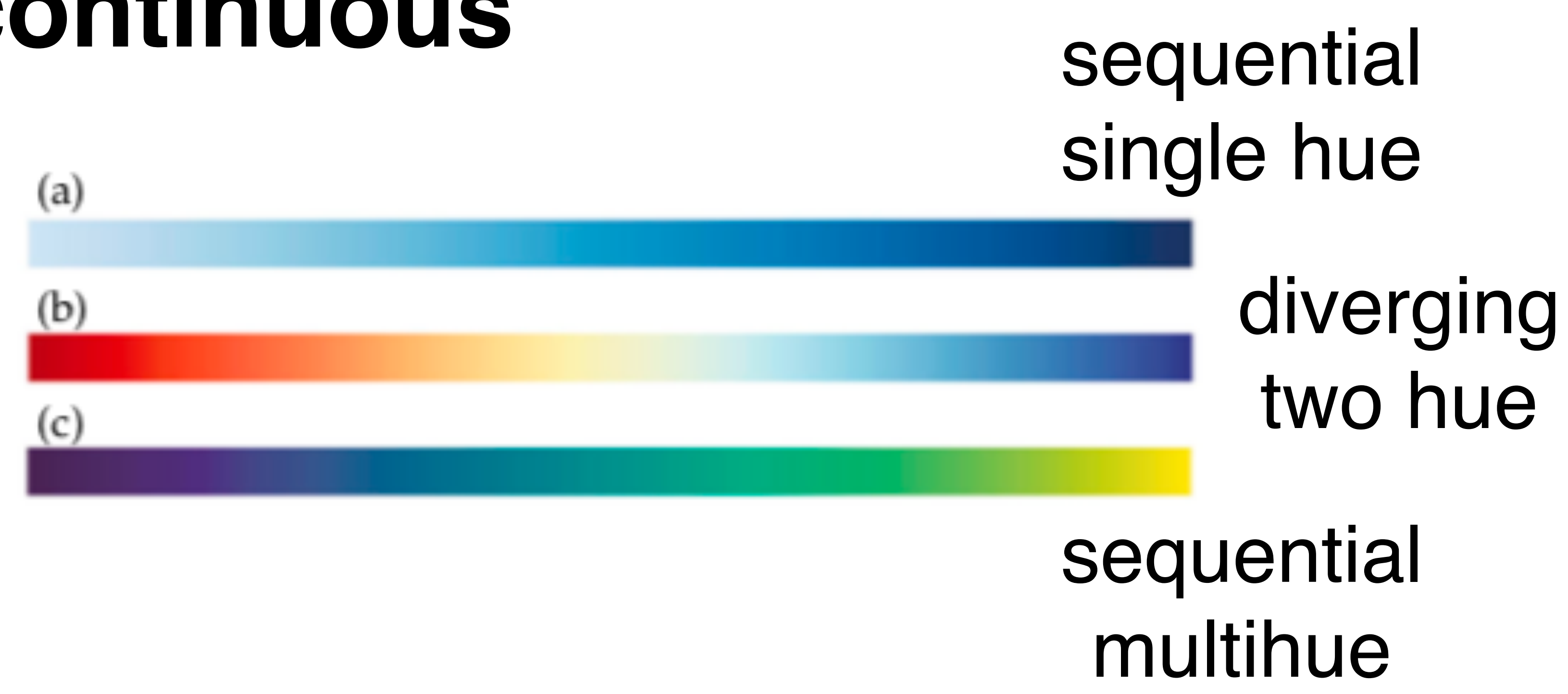


Color palette design considerations: univariate

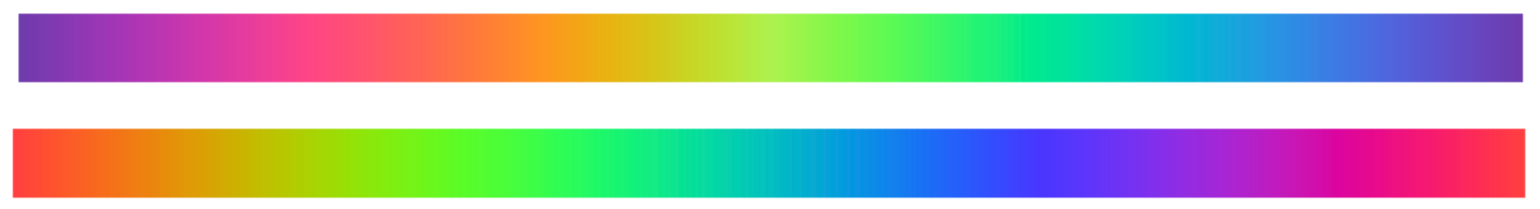
segmented



continuous



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

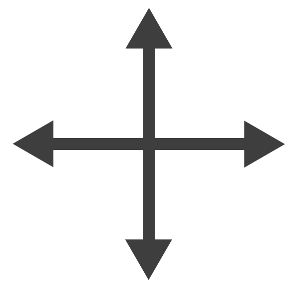
Colormaps

- Categorical

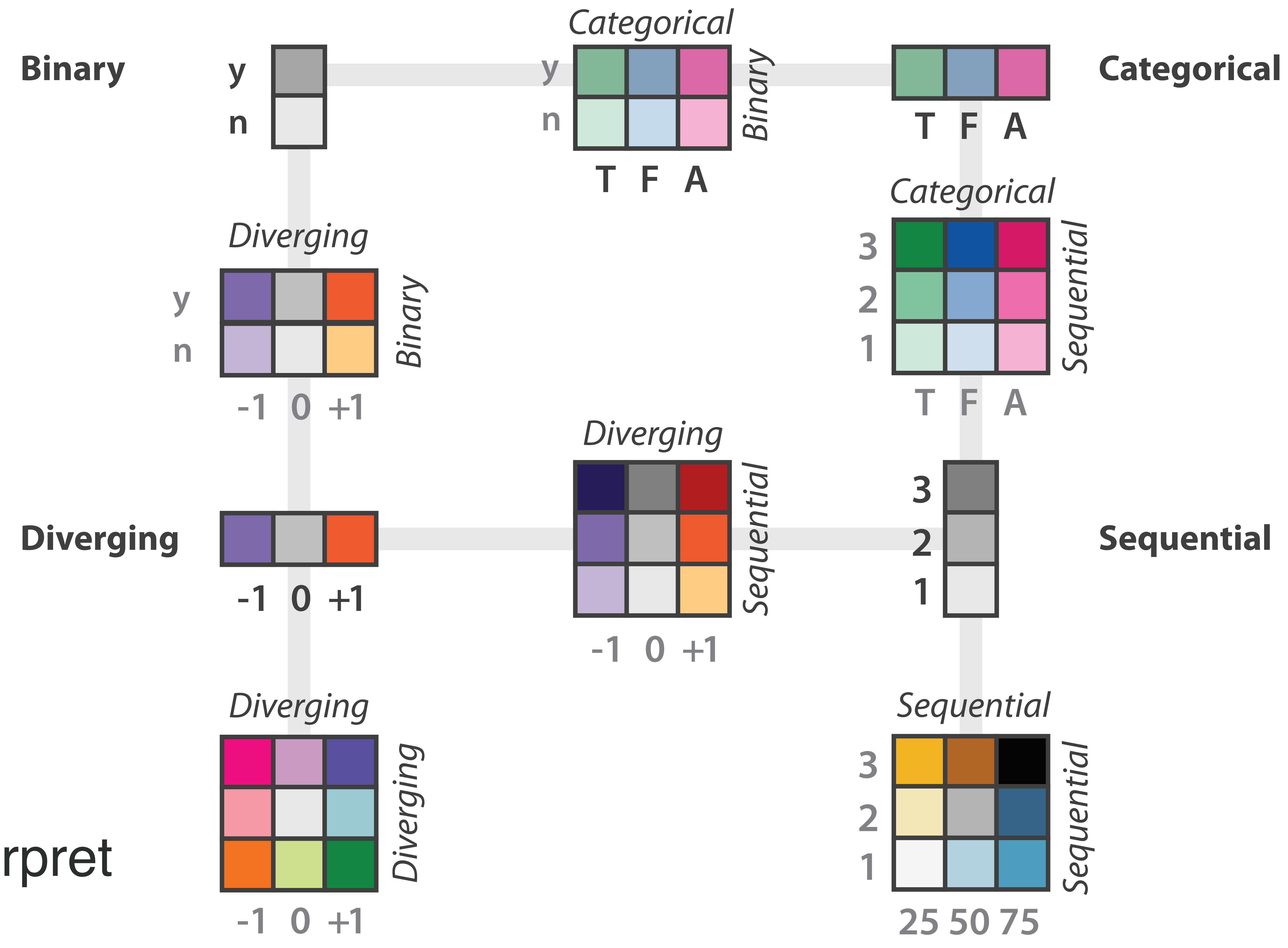
- Ordered
  - *Sequential*

  - *Diverging*

- Bivariate



use with care!

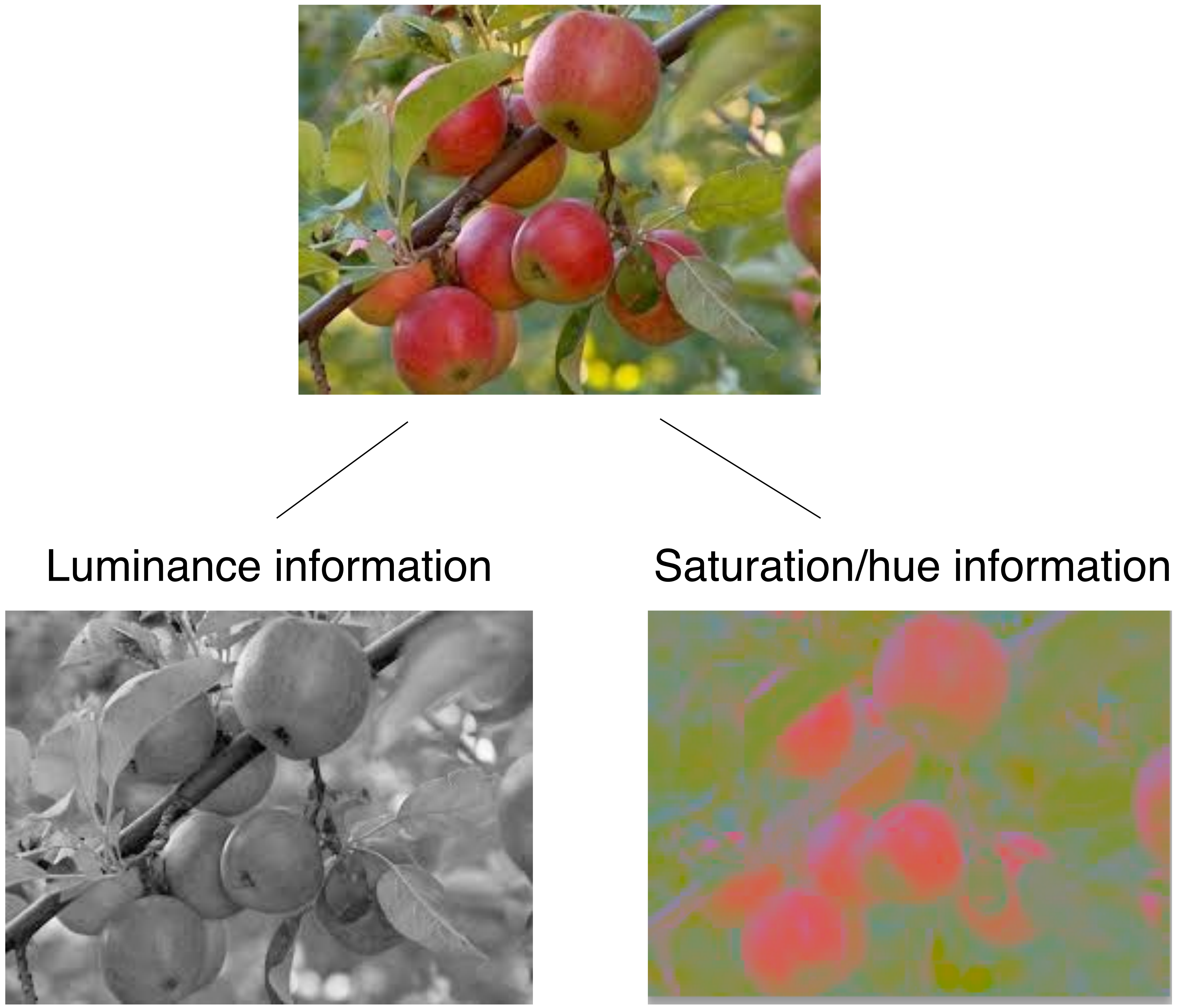


- bivariate can be very difficult to interpret
  - when multiple levels in each direction

Color Deficiency

Luminance

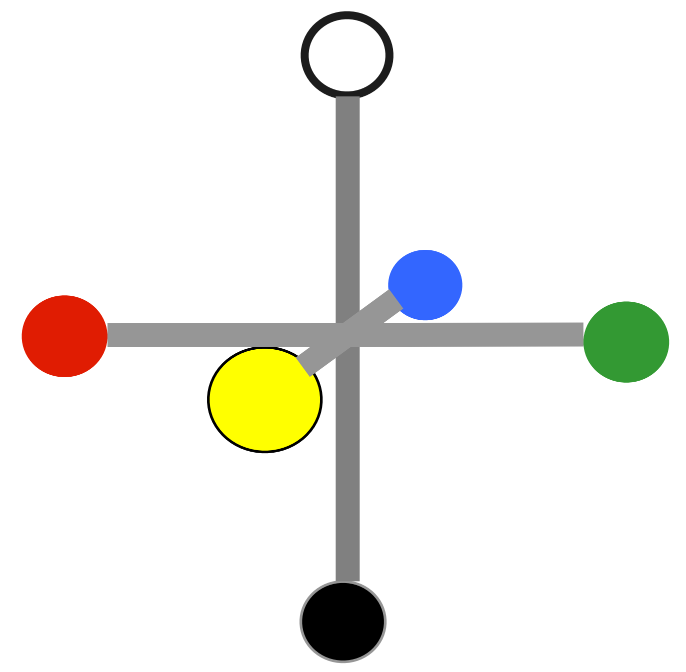
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!

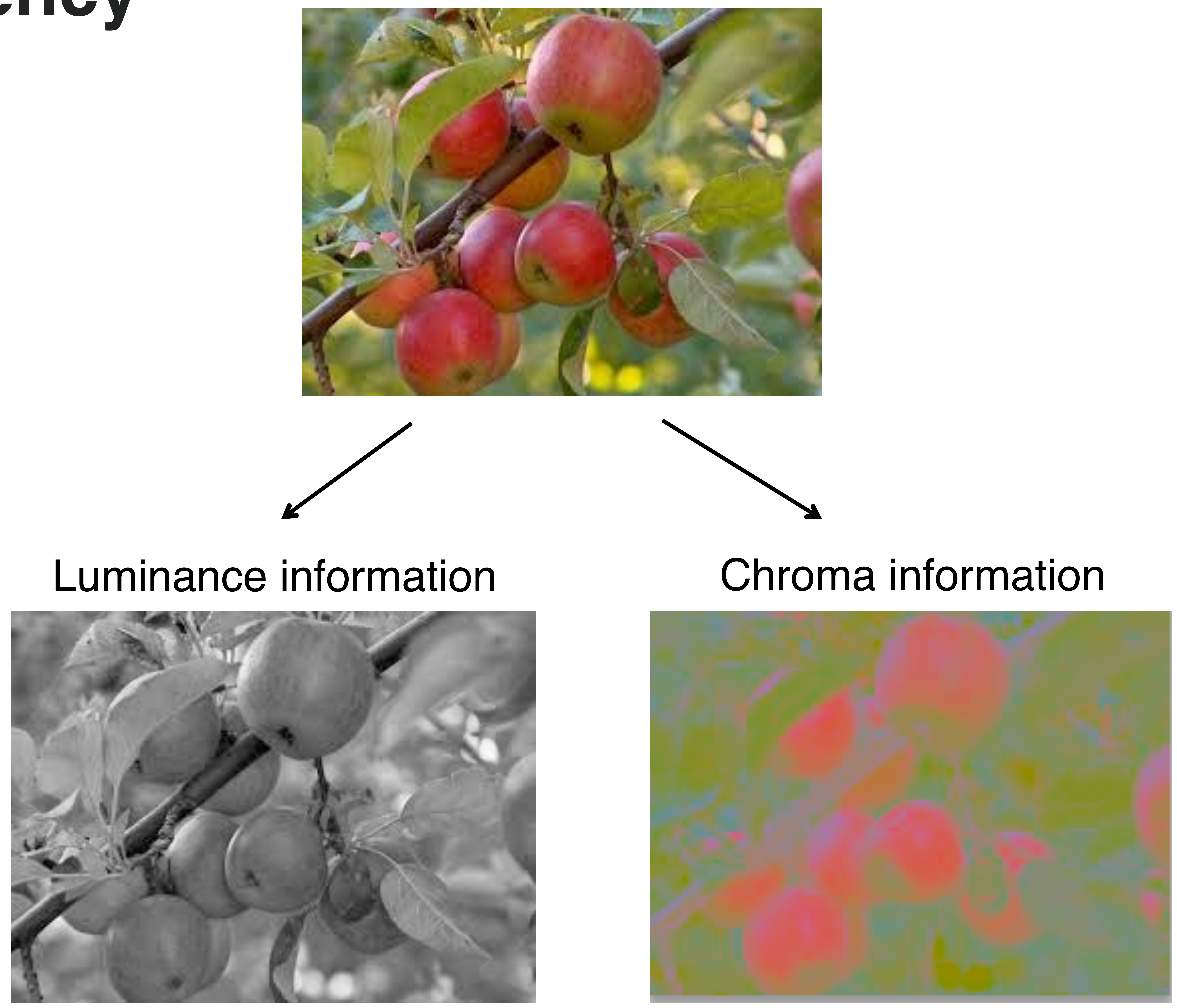


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Opponent color and color deficiency

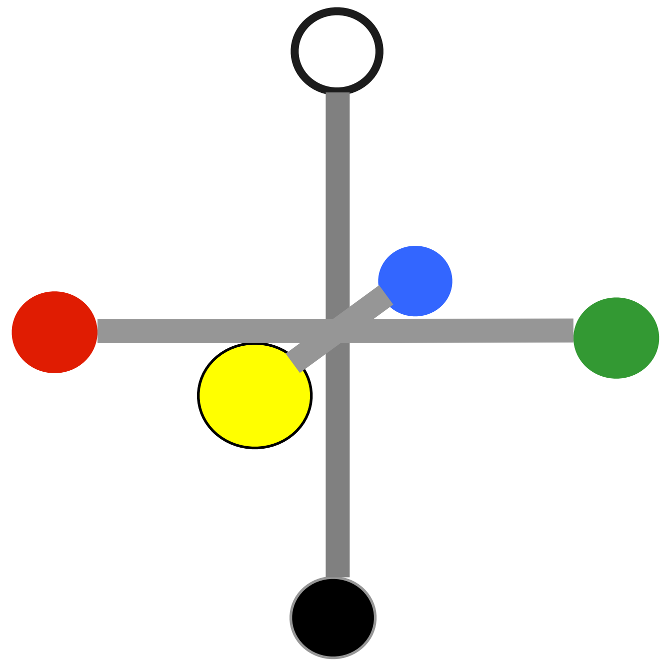
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

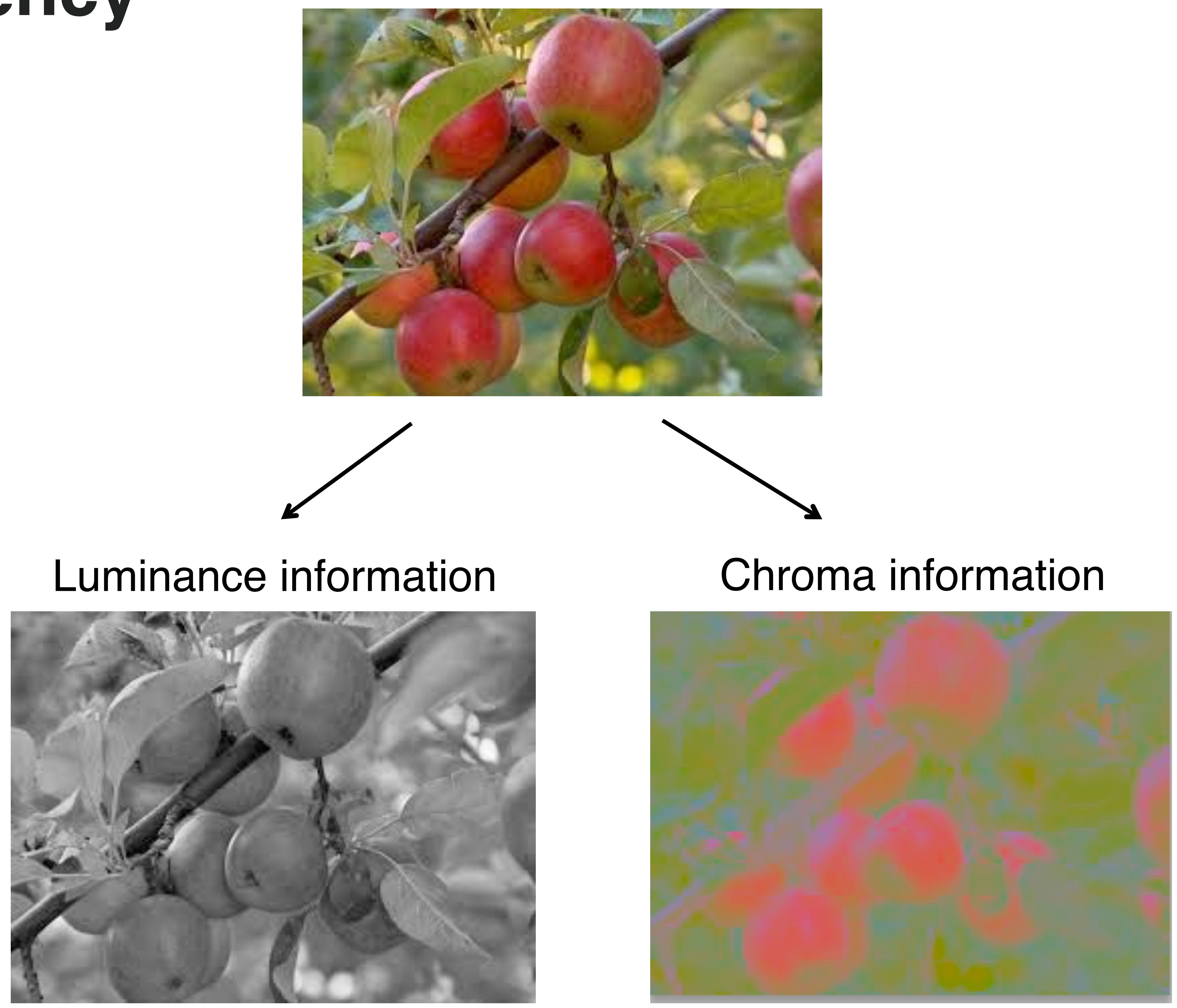




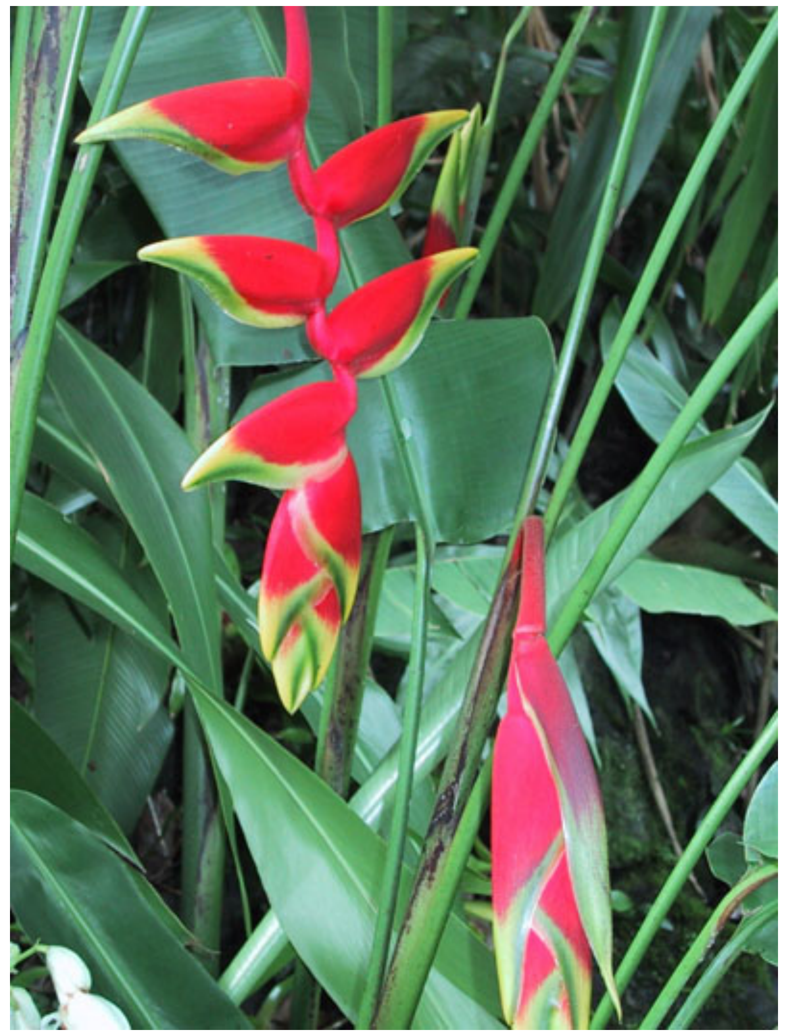
Opponent color and color deficiency

- 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

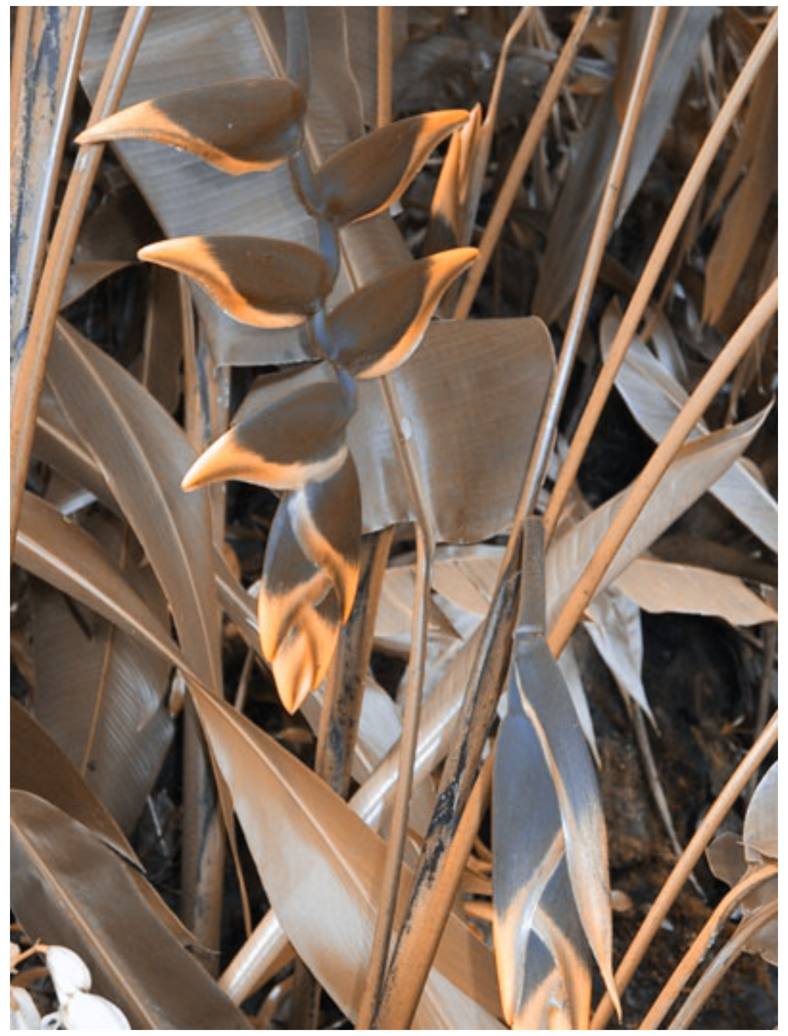




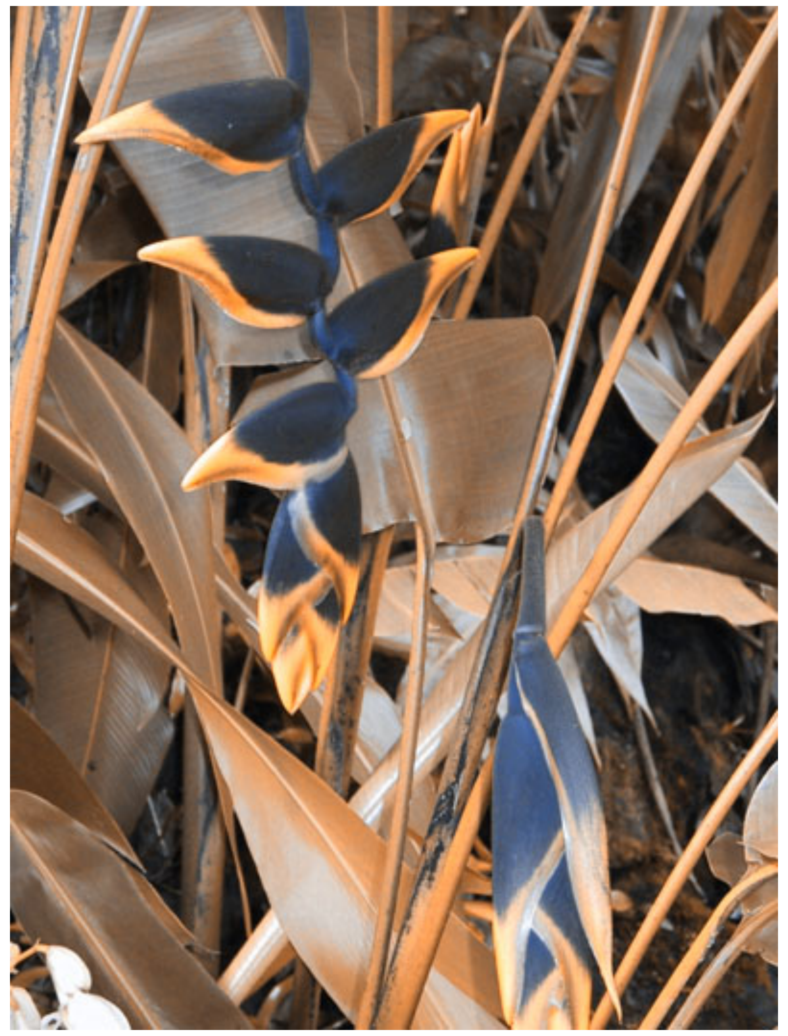
Designing for color deficiency: Check with simulator



Normal vision

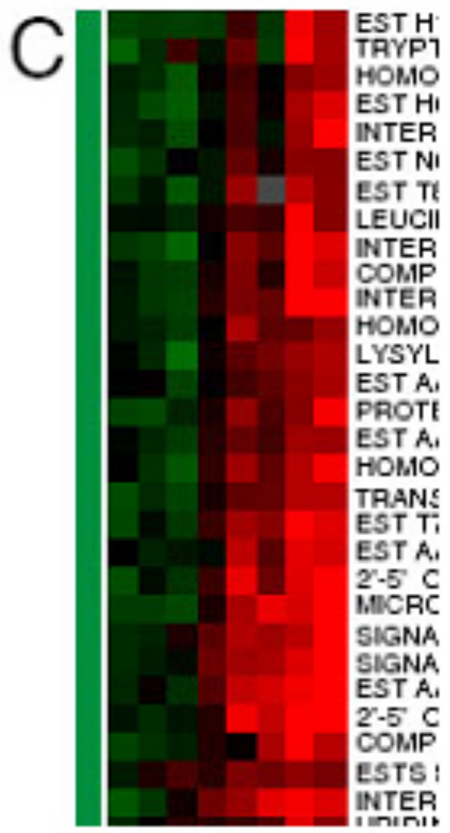


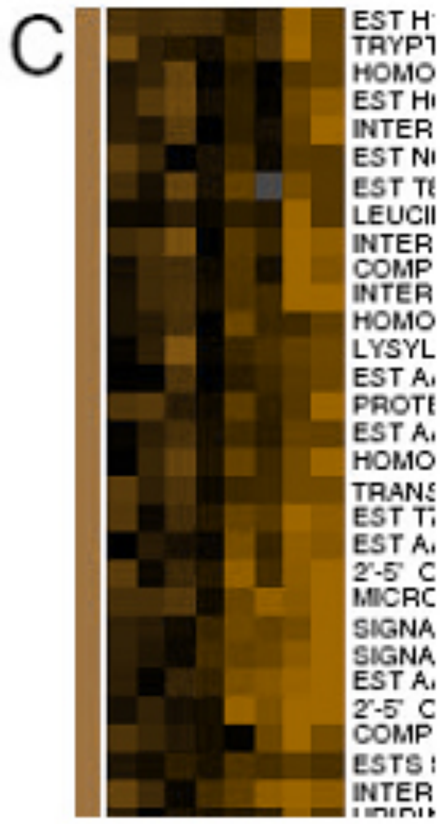
Deuteranope
green-weak

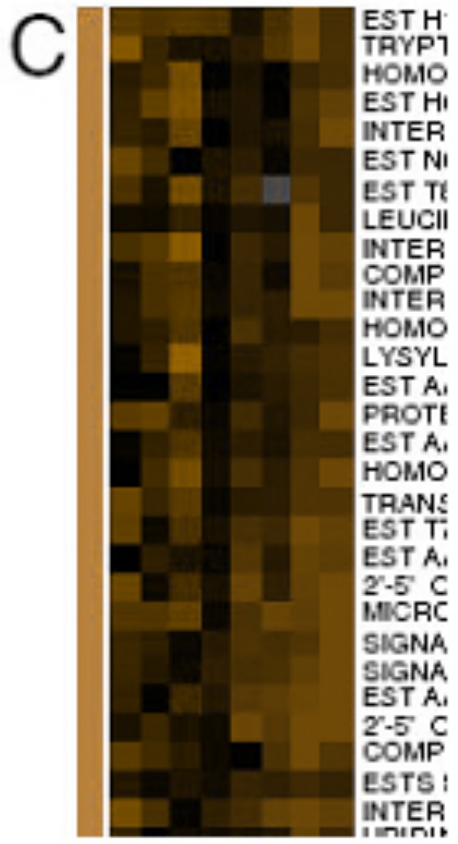


Protanope
red-weak

Tritanope
blue-weak







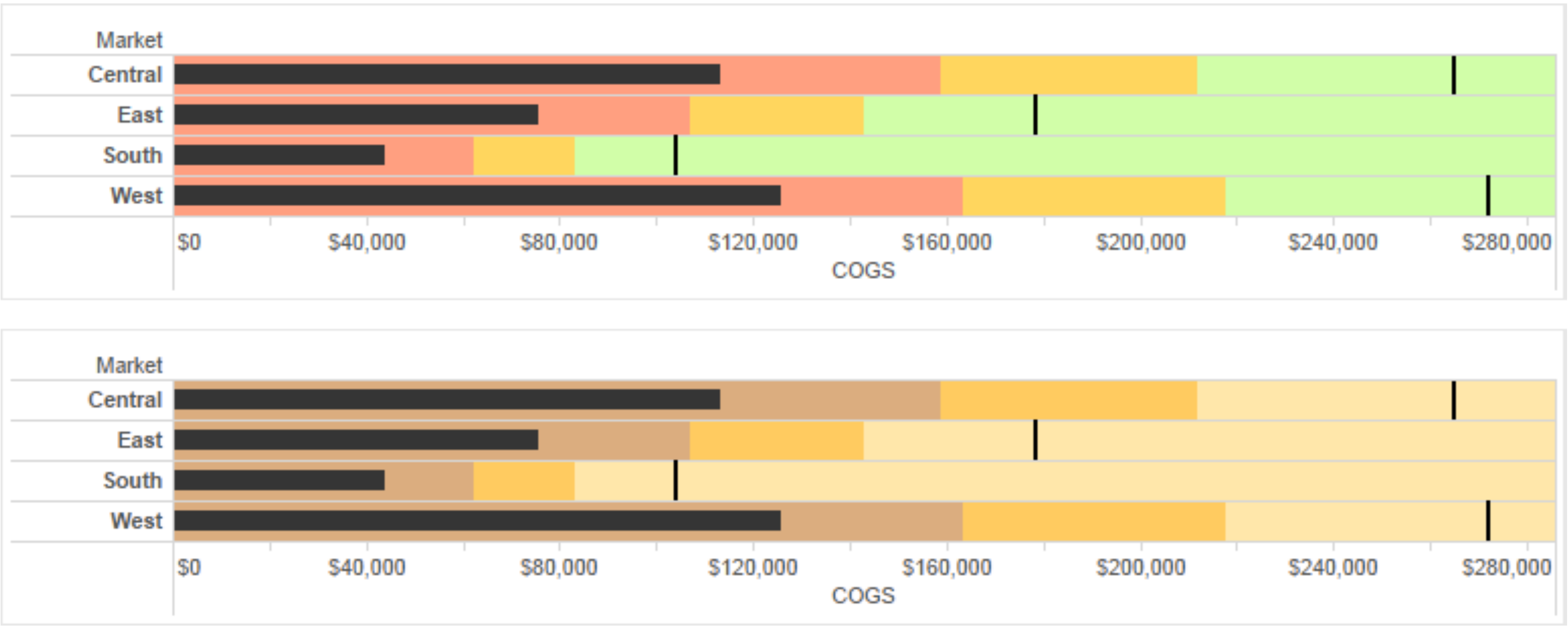
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

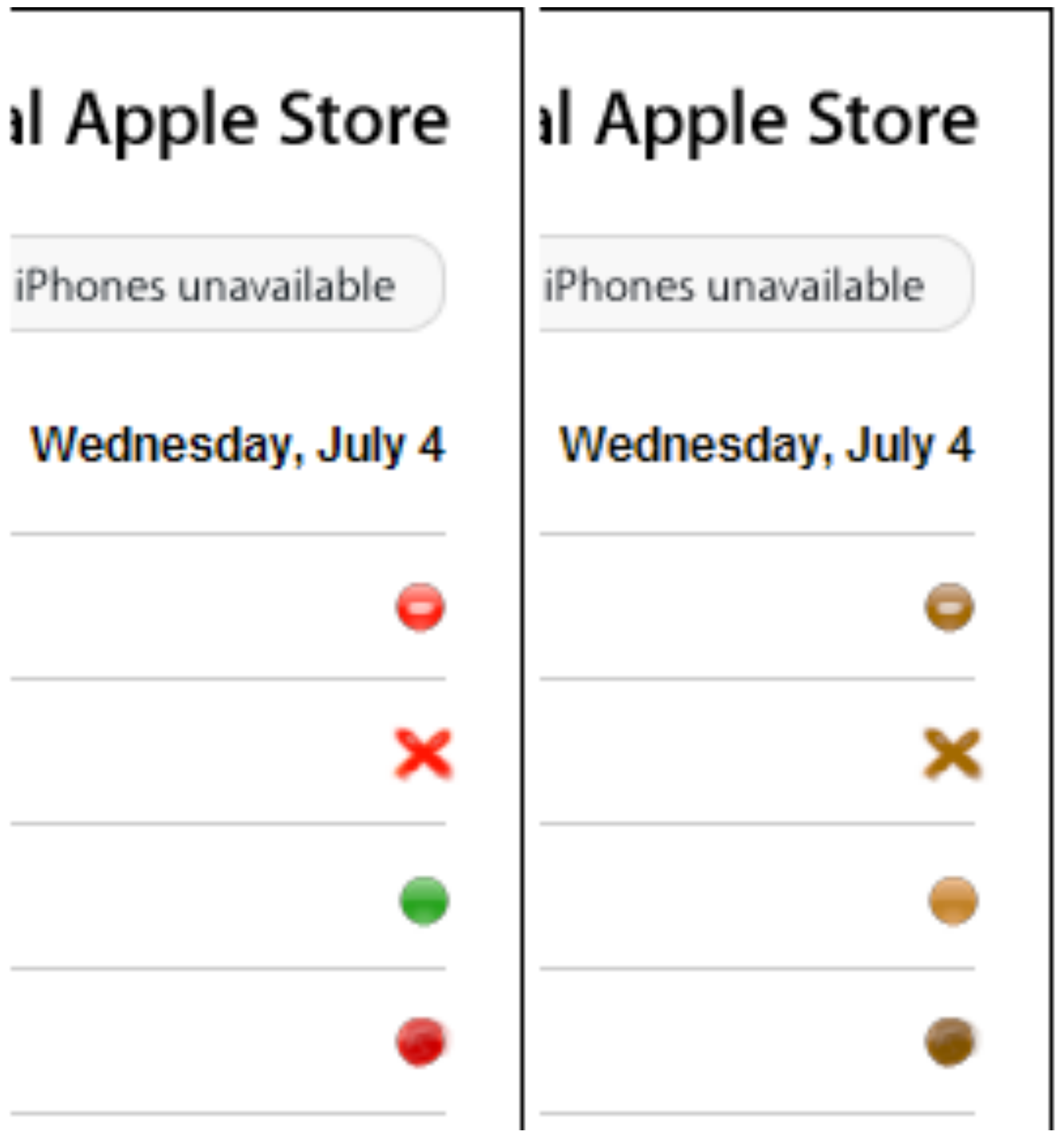
https://www.color-blindness.com/coblis-color-blindness-simulator/

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape

Deuteranope simulation

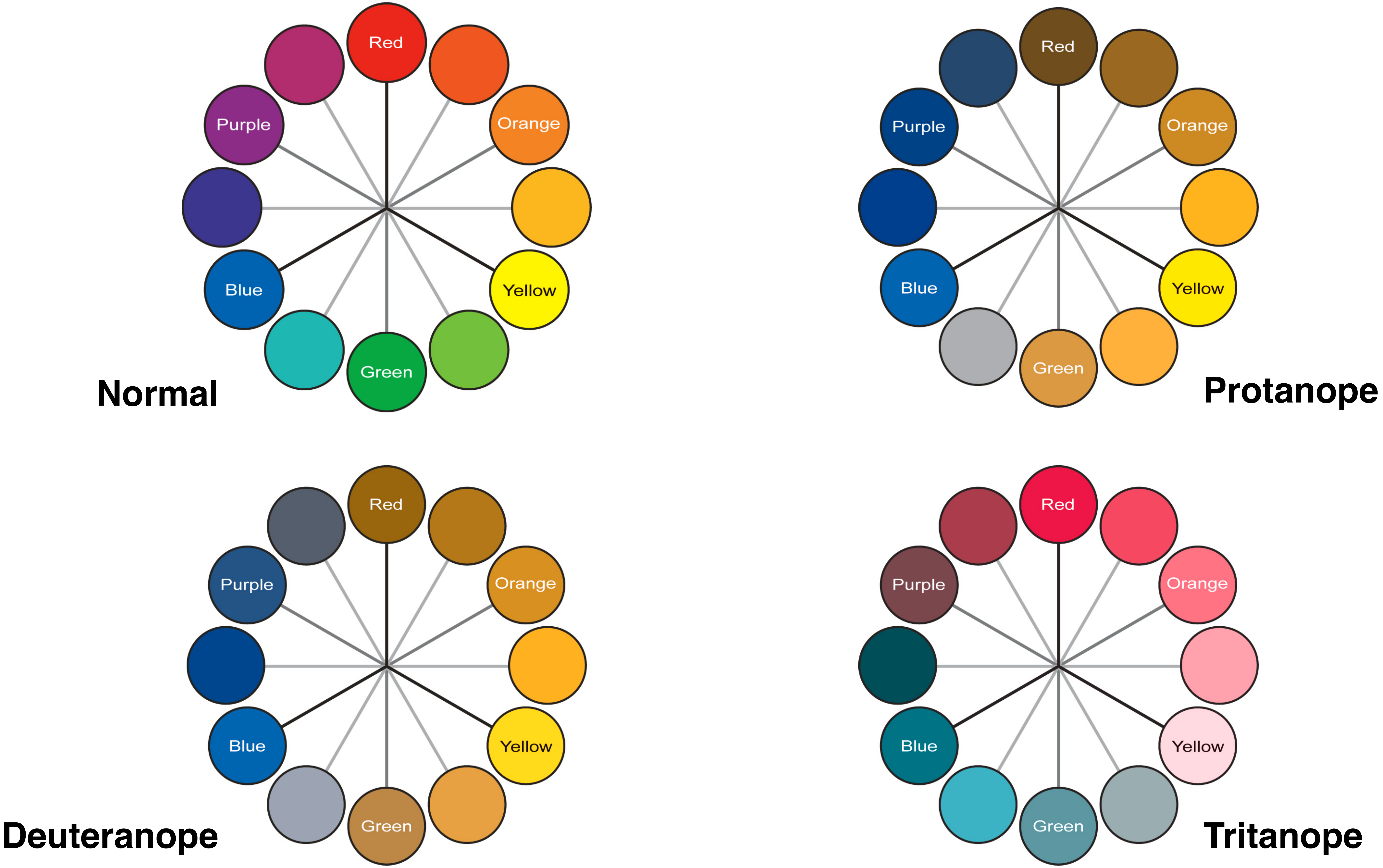




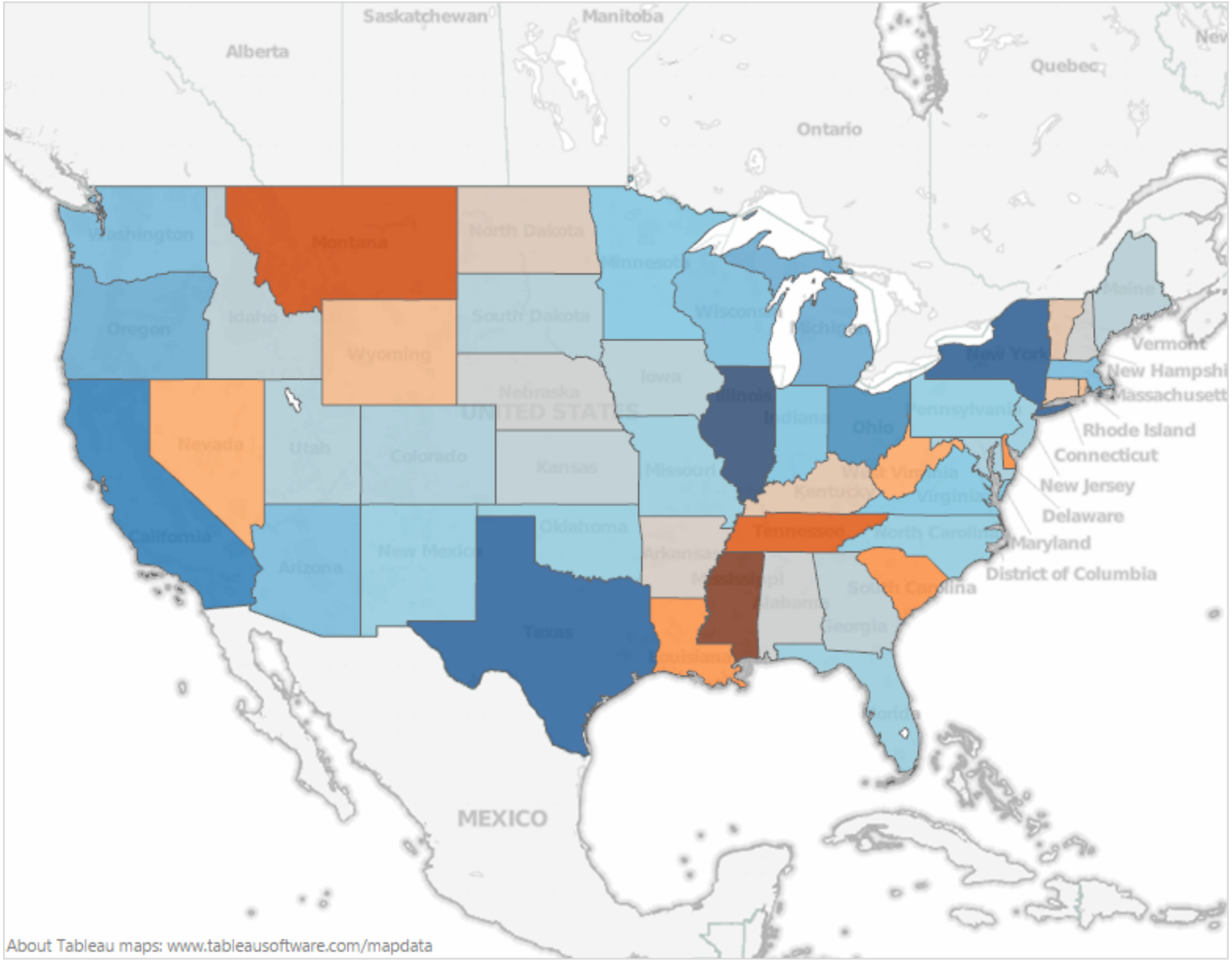
Change the shape

Vary luminance

Color deficiency: Reduces color to 2 dimensions



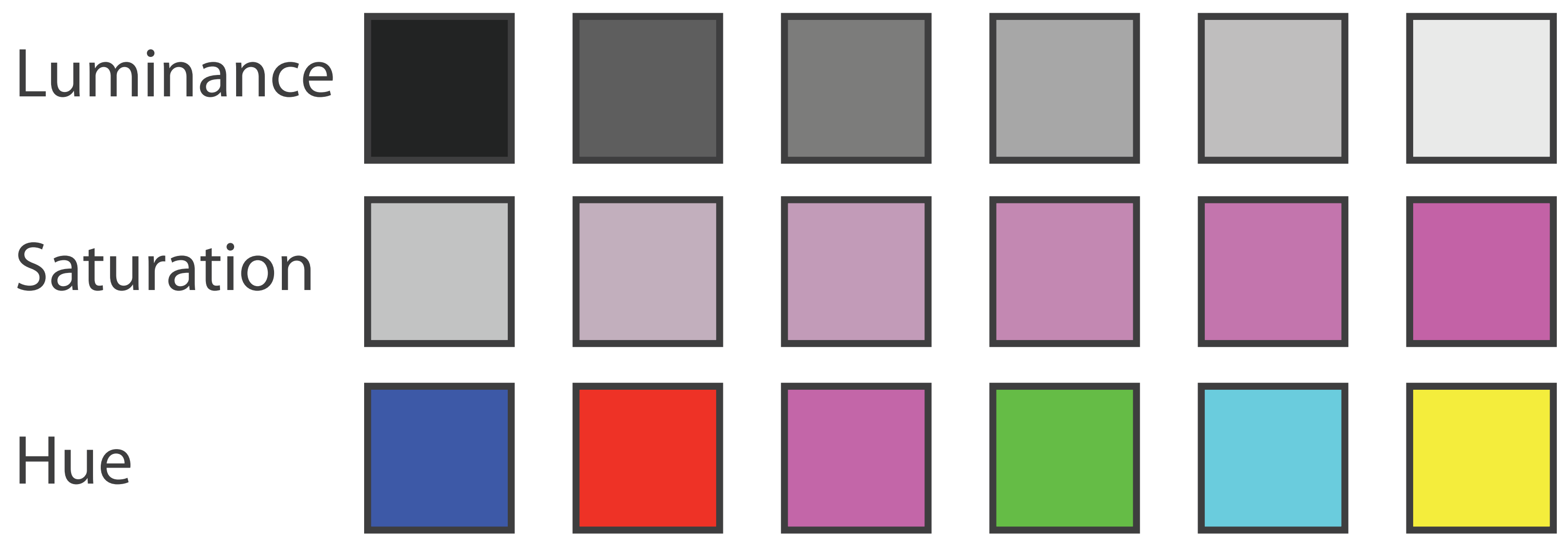
Designing for color deficiency: Blue-Orange is safe

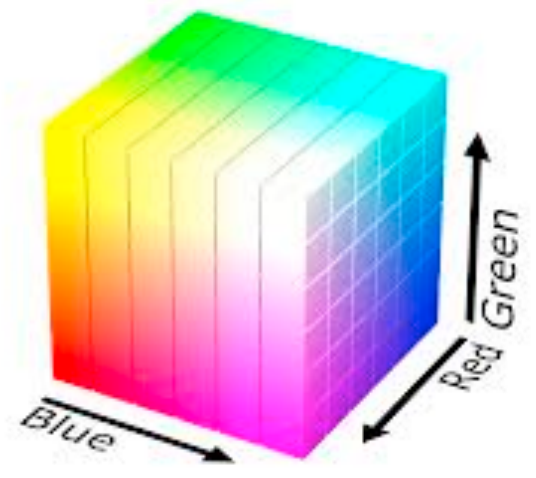


Color Spaces

Many color spaces

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

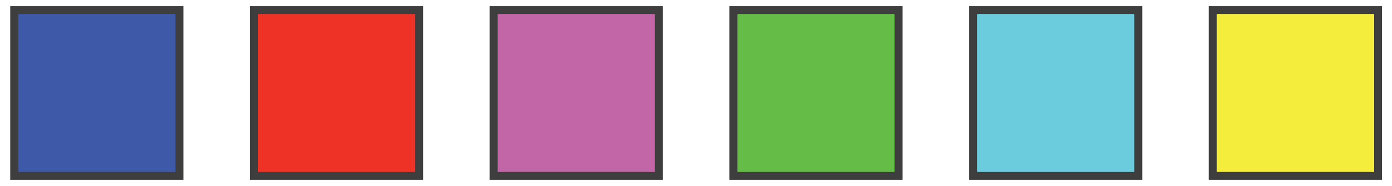


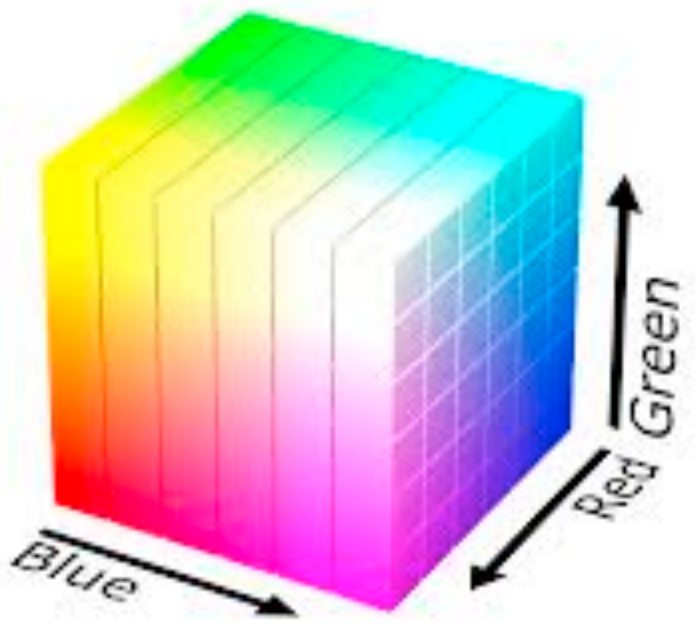


RGB

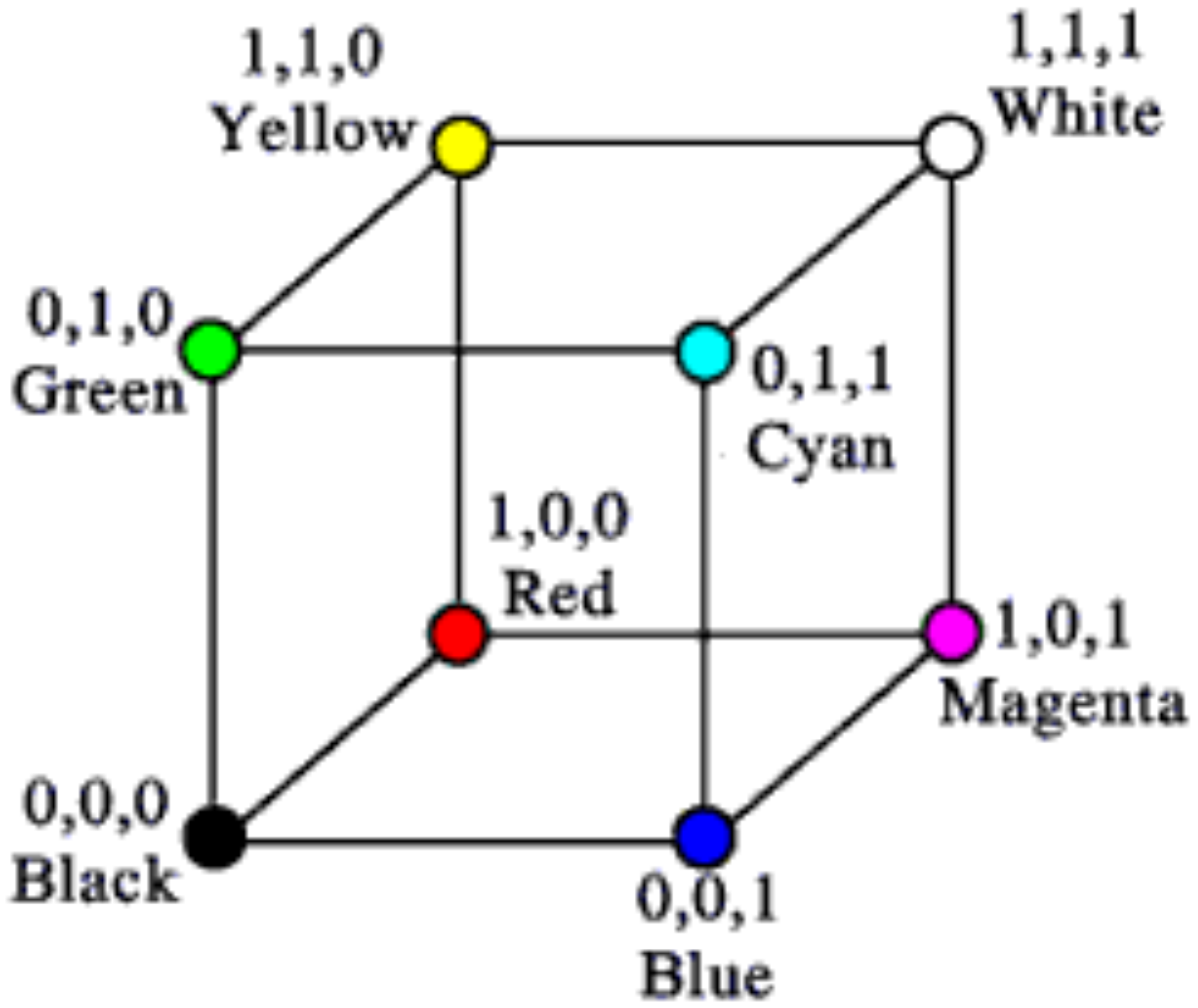
- RGB: good for display hardware

Corners of the RGB color cube



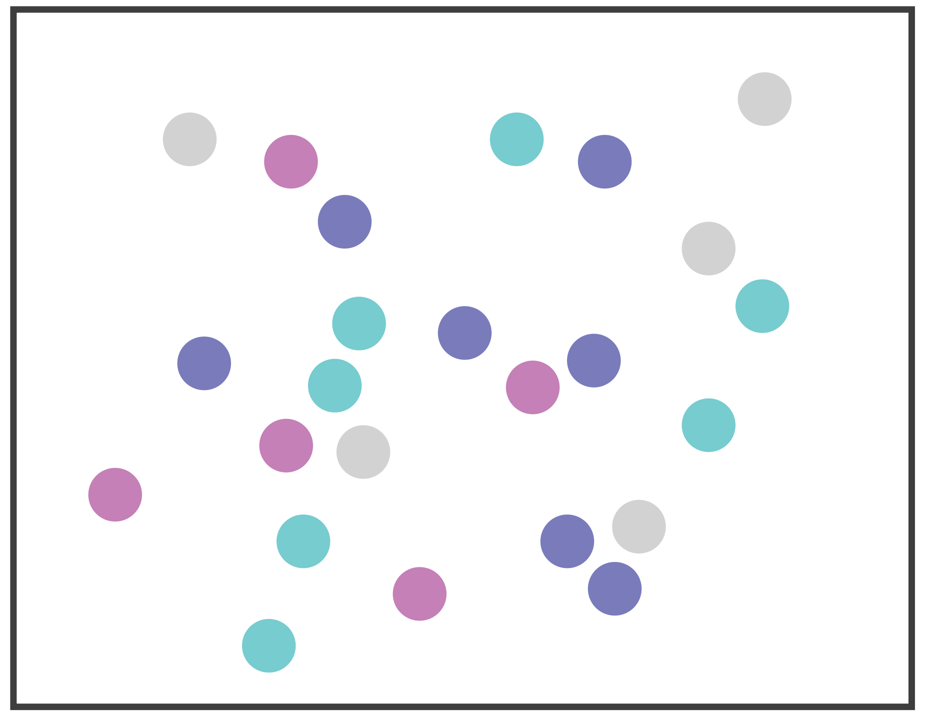


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png



- poor for encoding & interpolation

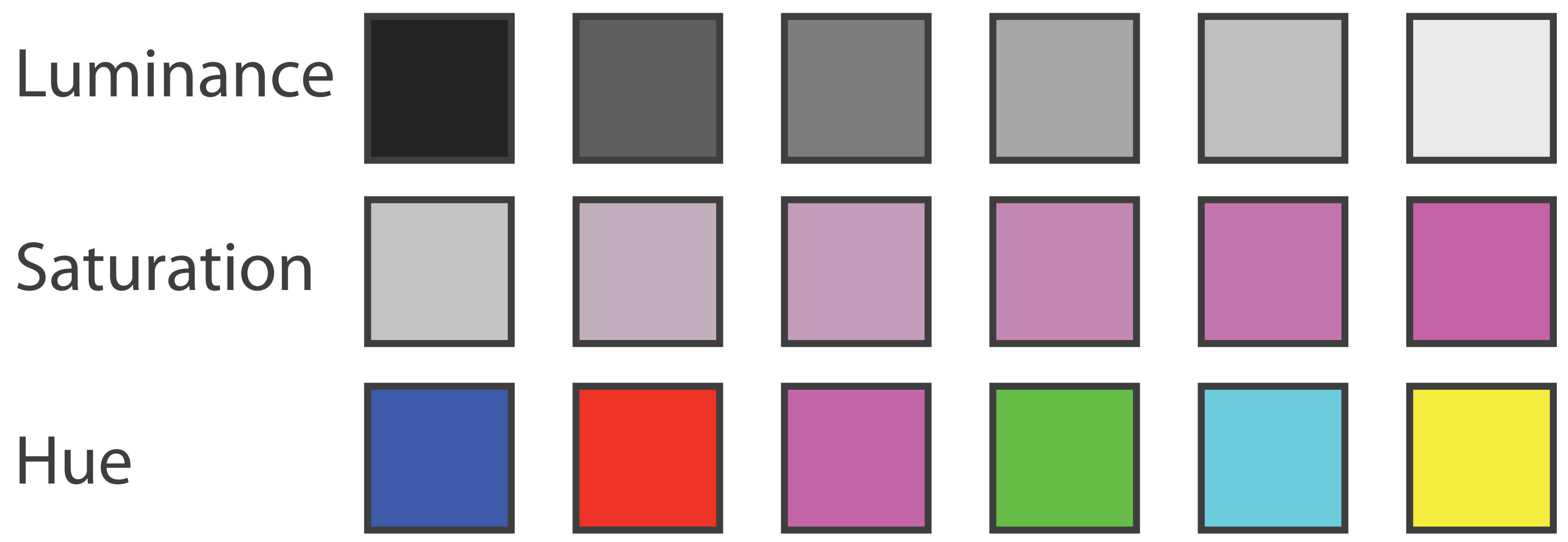
Red
+ Green

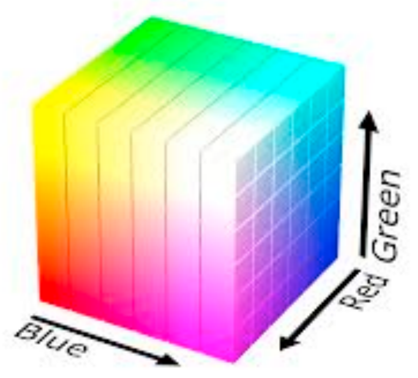


Major interference

Many color spaces

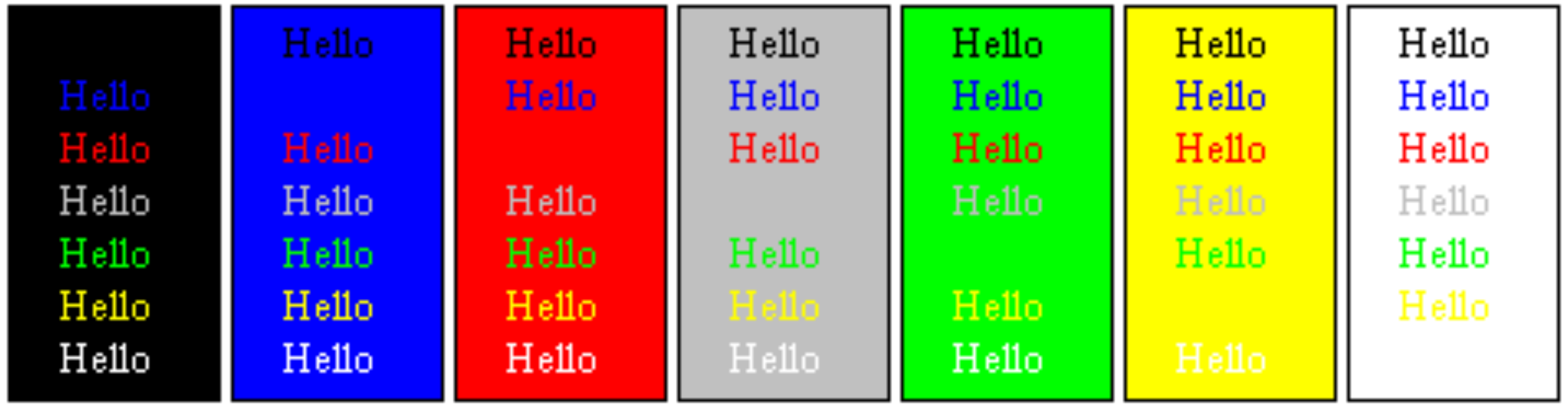
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding





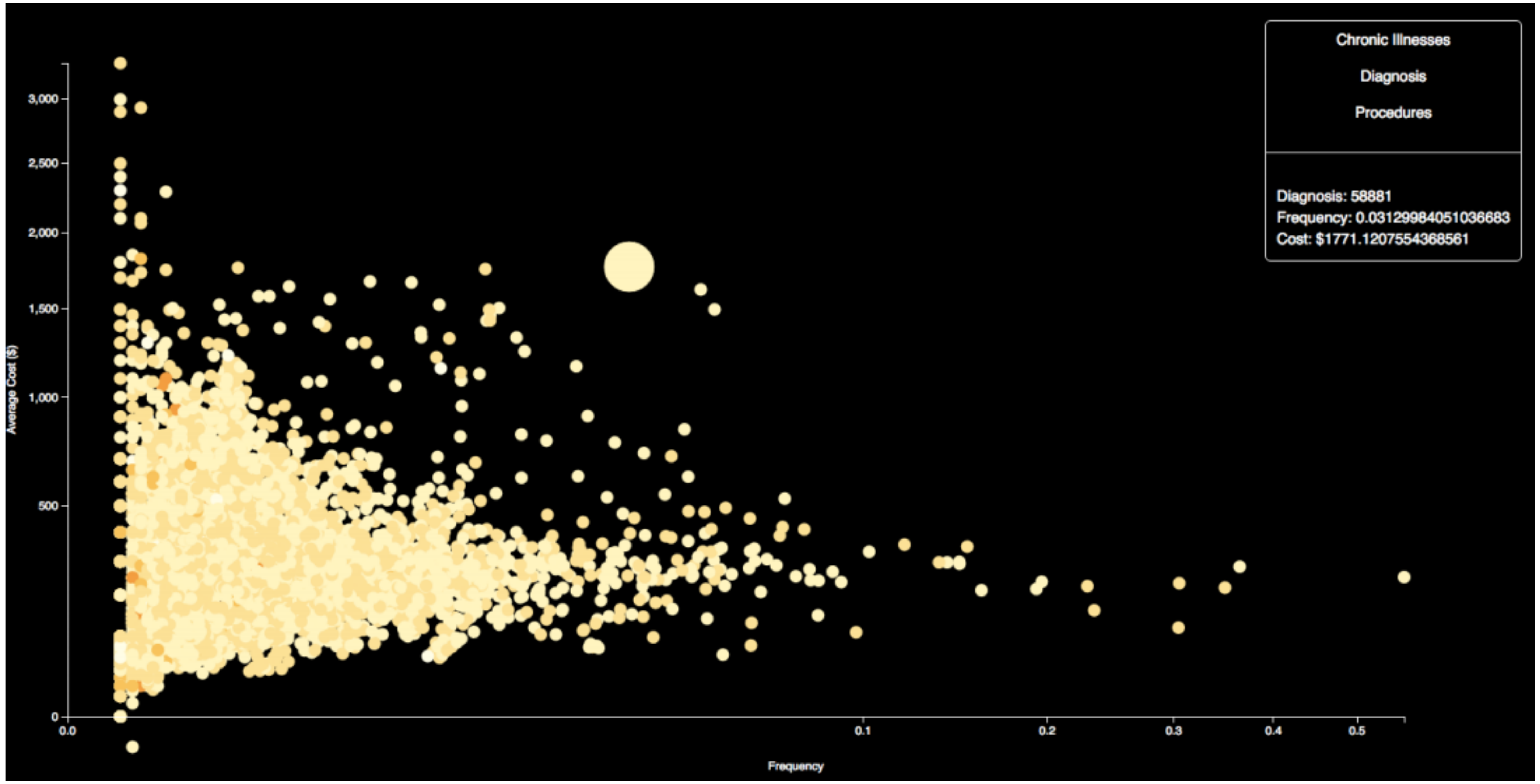
Color Constrast & Naming

Interaction with the background



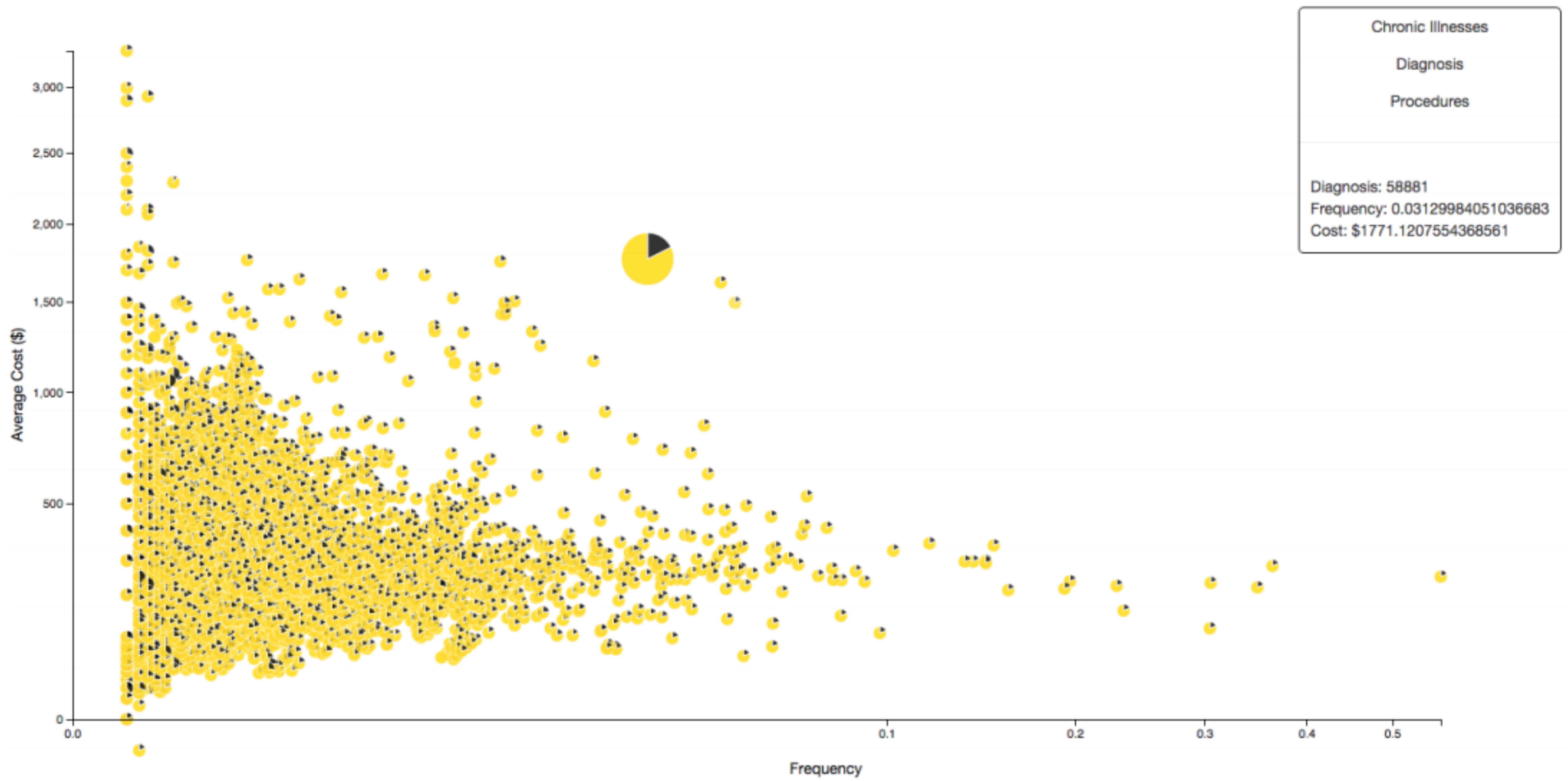
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



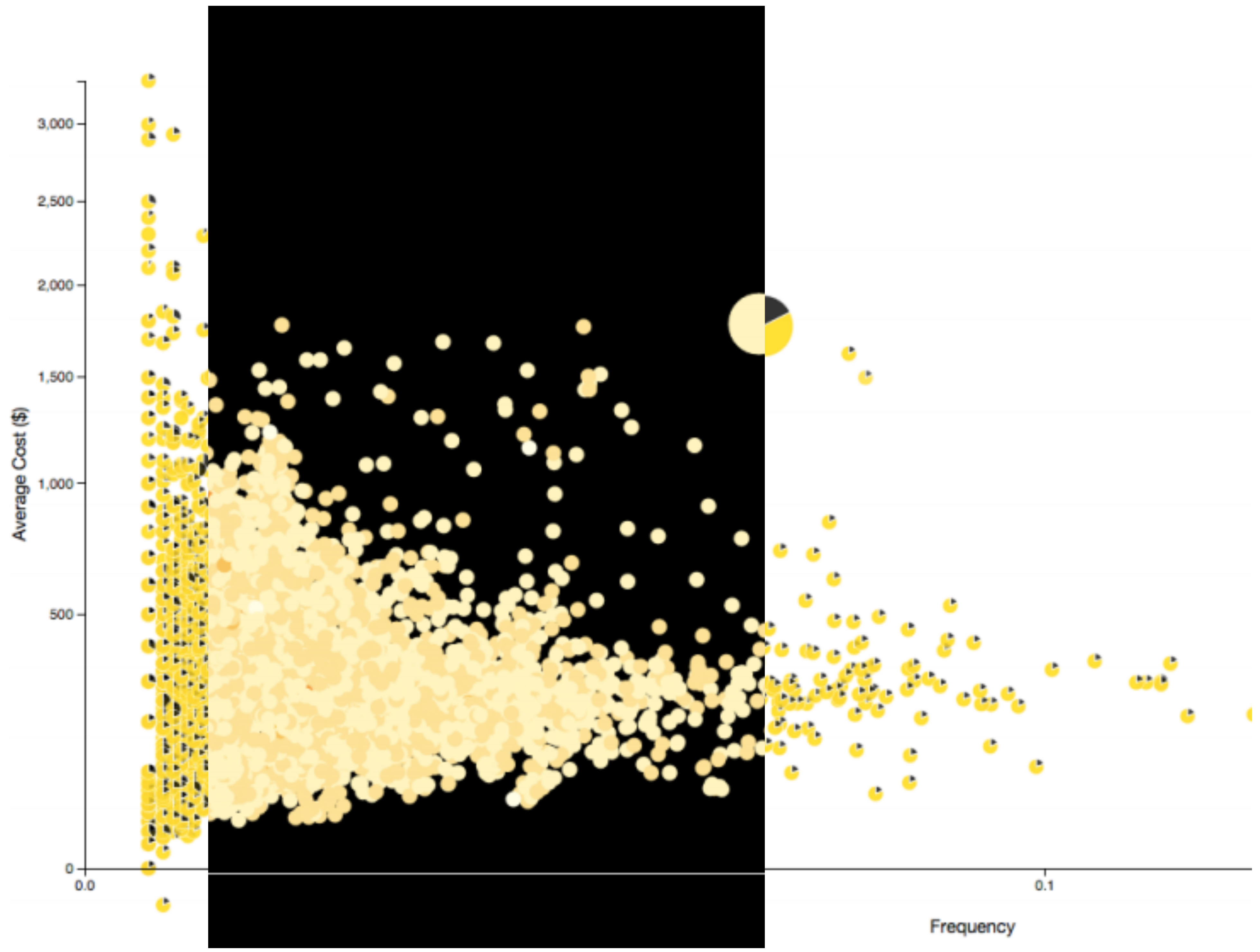
Interaction with the background: tweaking yellow for visibility

- 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

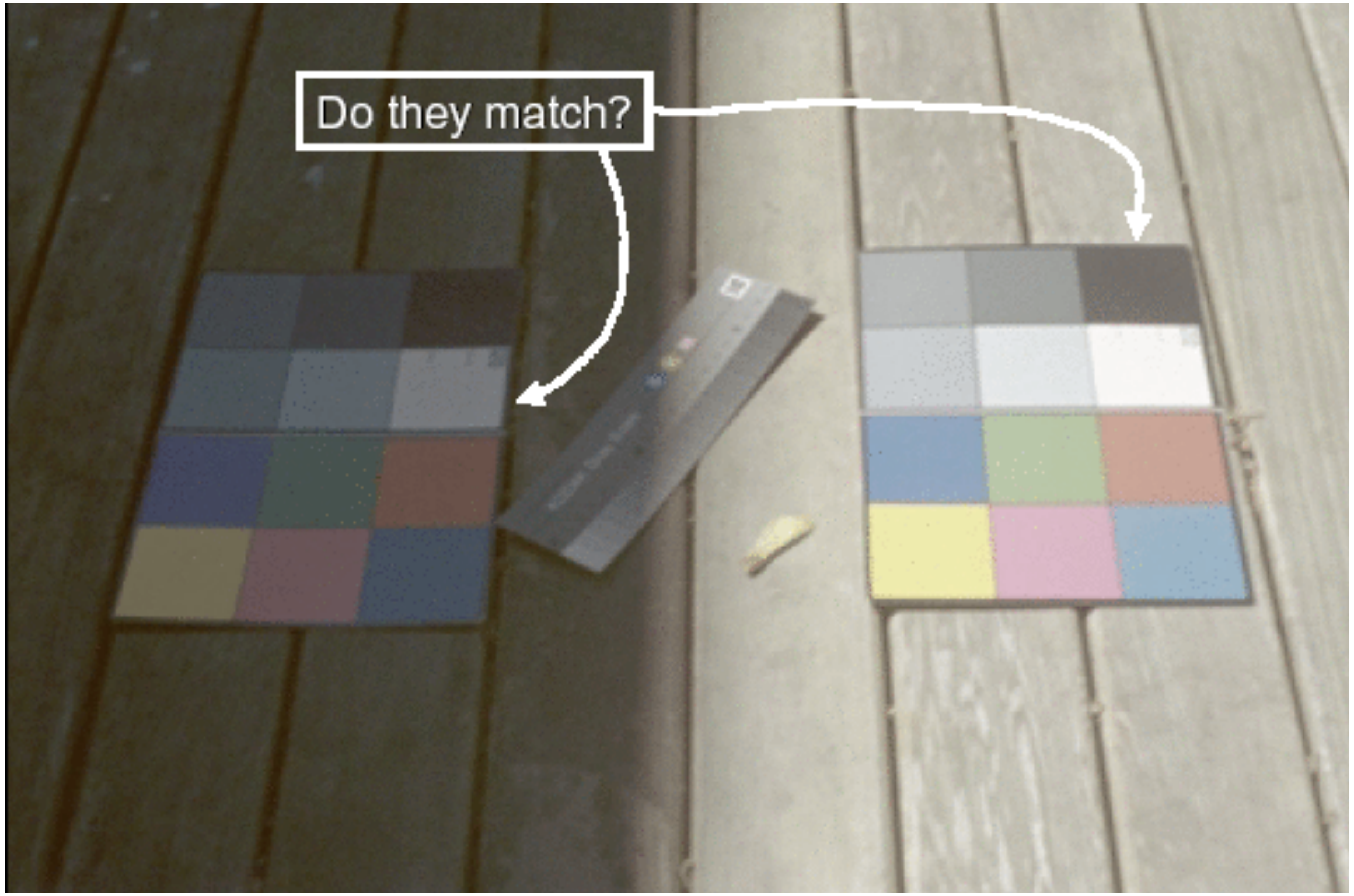


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

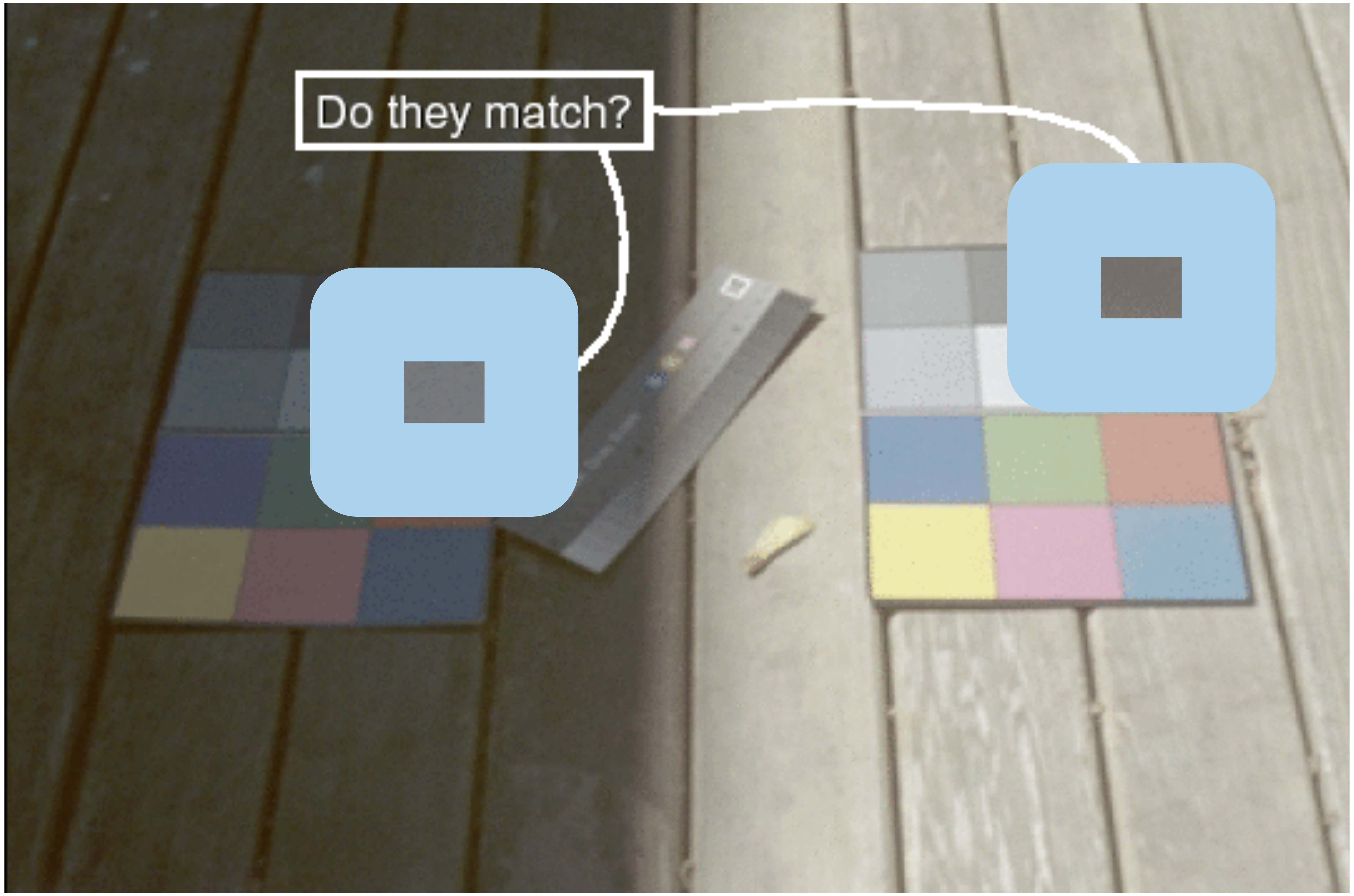
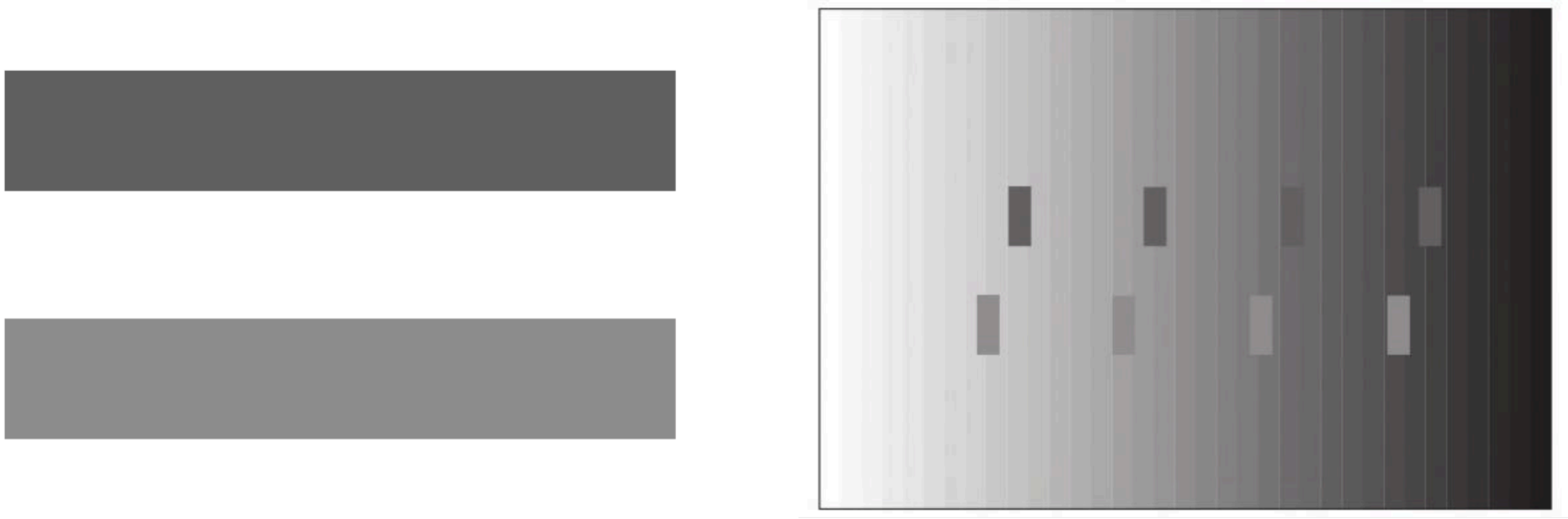
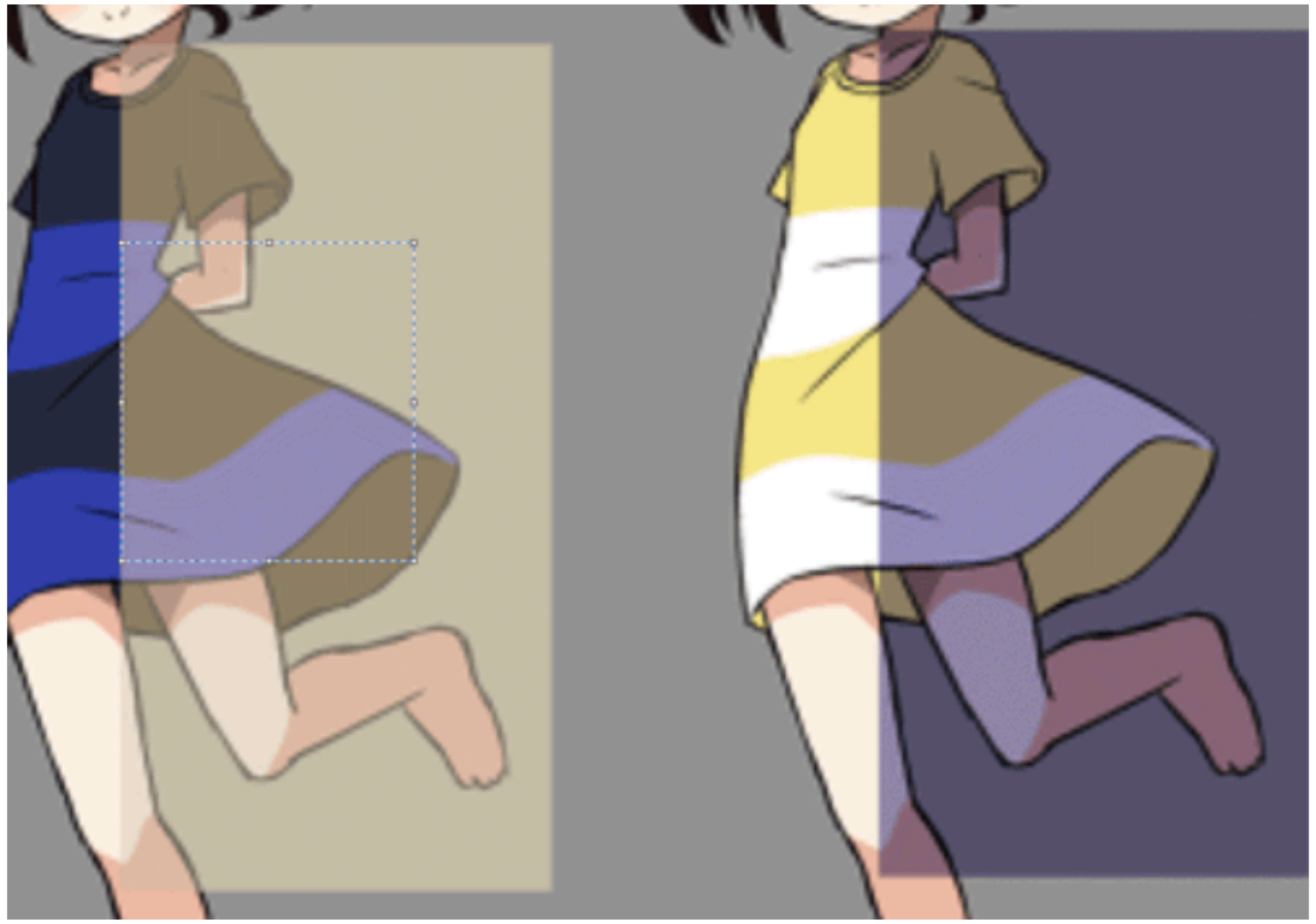


Image courtesy of John McCann via Maureen Stone

Contrast with background



Contrast with background

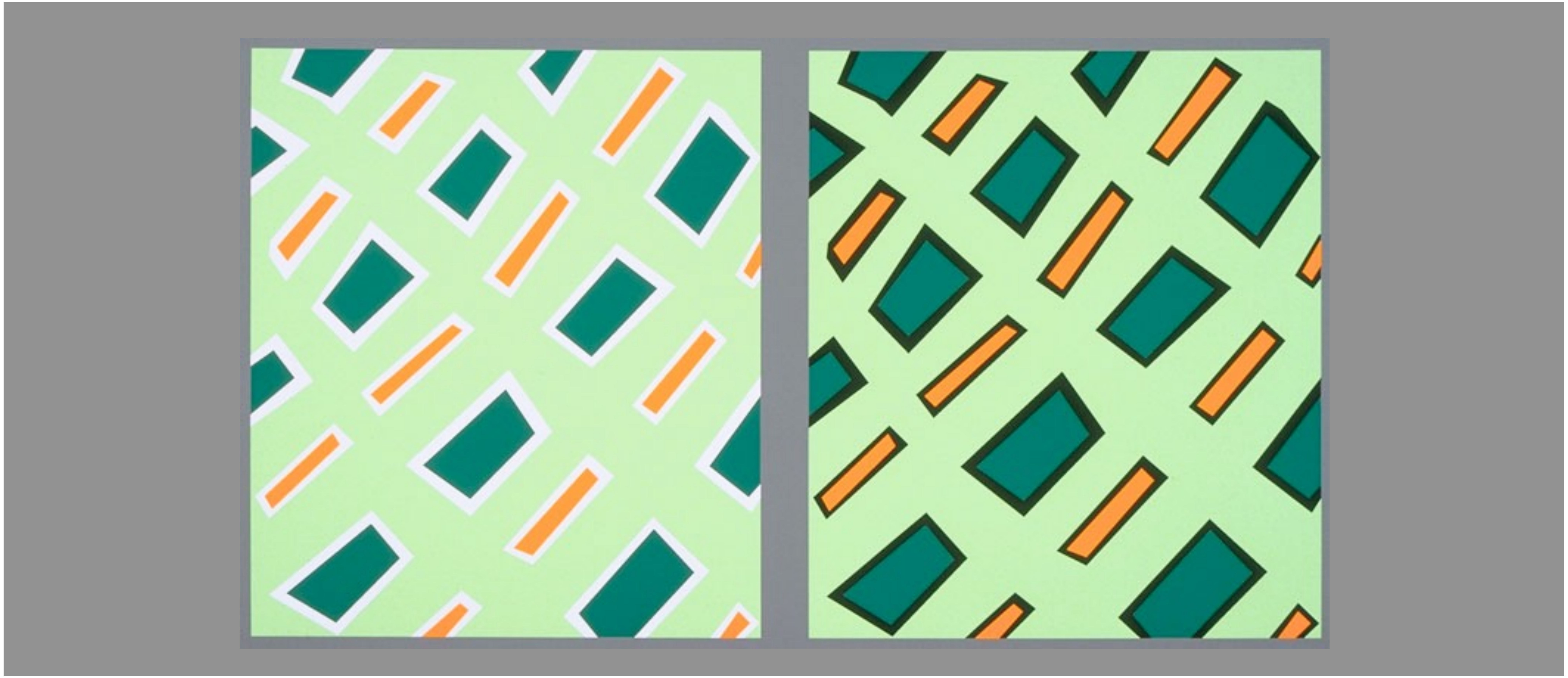


Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

Bezold Effect: Outlines matter



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
  - …

Reading Material

[dv3] **Chapter 10 - Map Color and other channels**

Questions?

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