

# Analisi e Visualizzazione di Reti Complesse

DV03 Marks and Channels  
Color

Prof. Rossano Schifanella

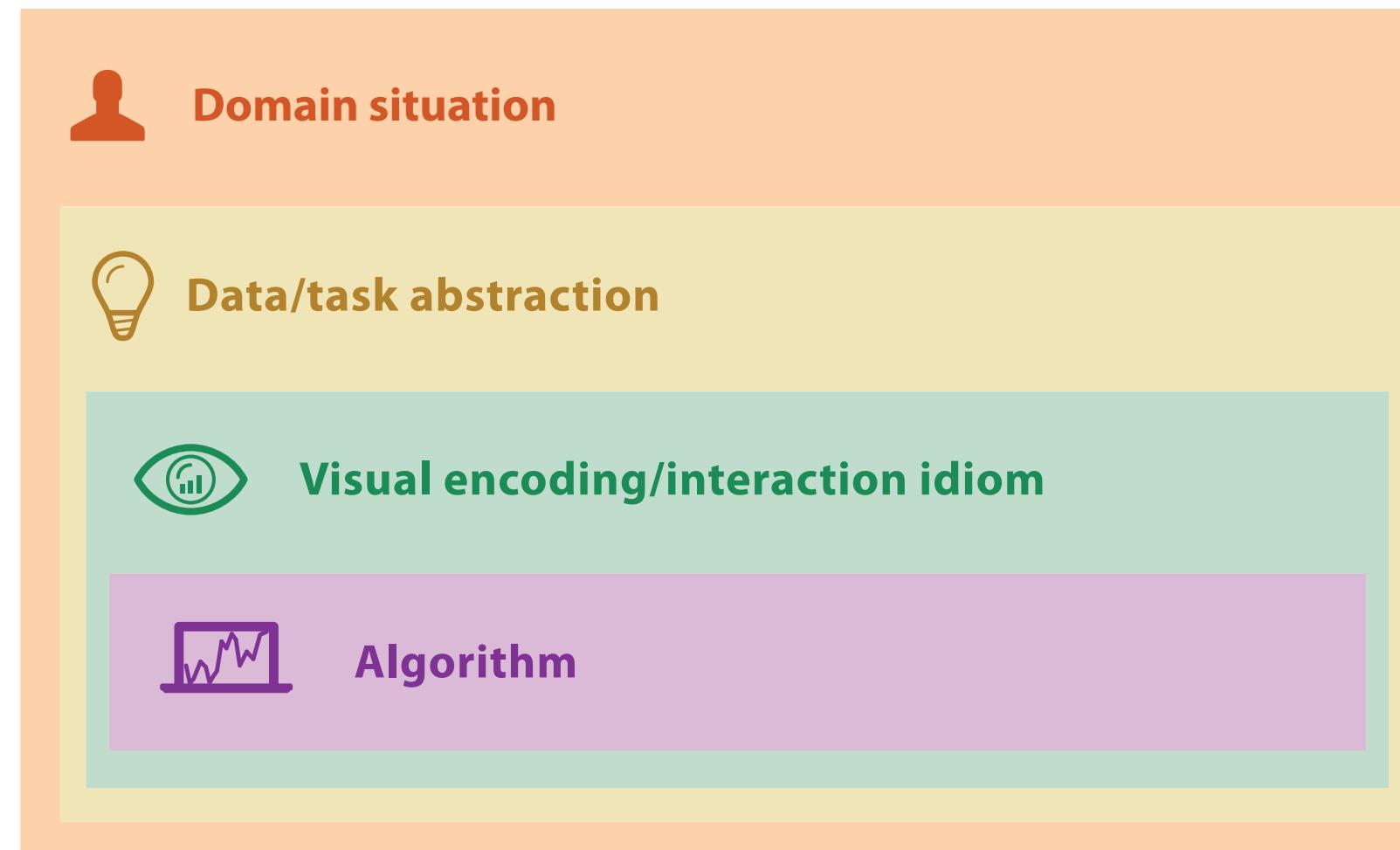
DV03 - Marks and Channels | Color



# Marks and Channels

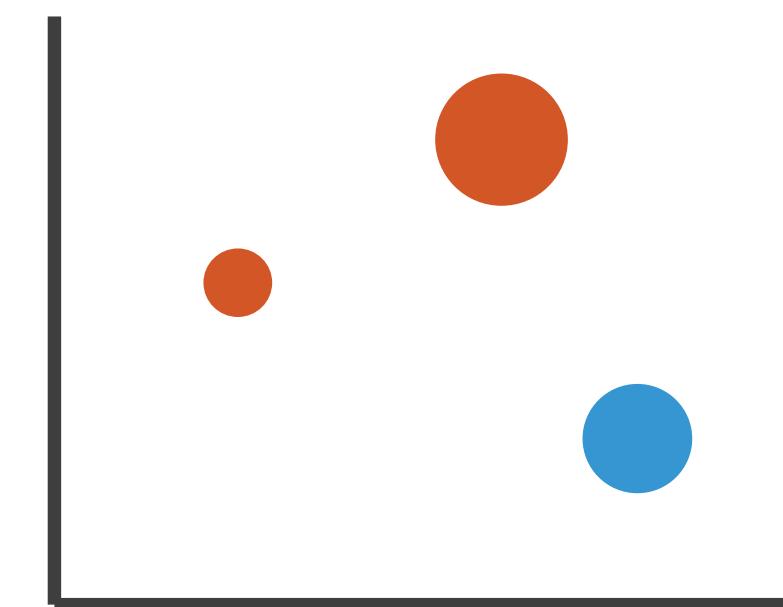
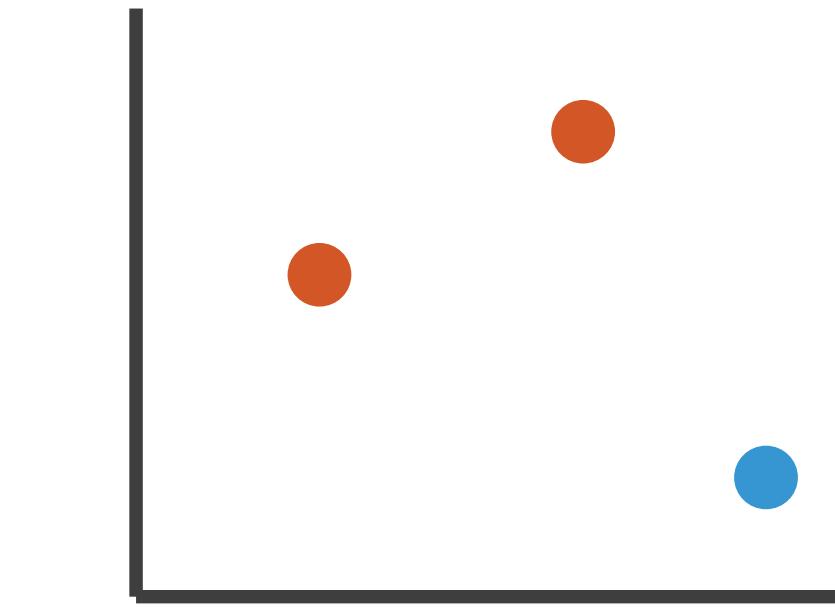
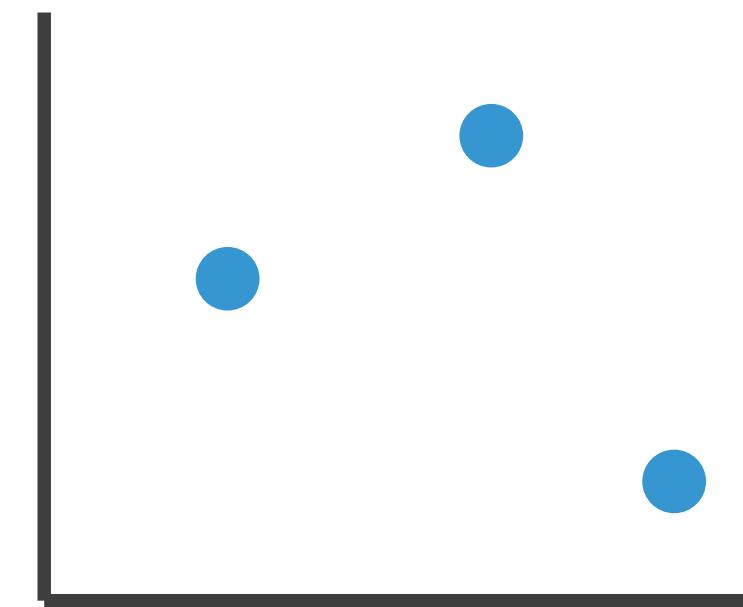
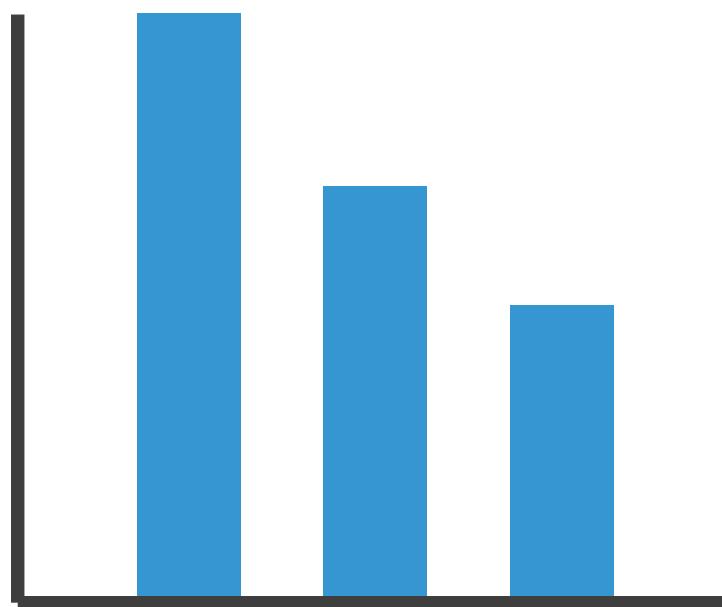
# Visual encoding

- How to systematically analyze the idiom structure?



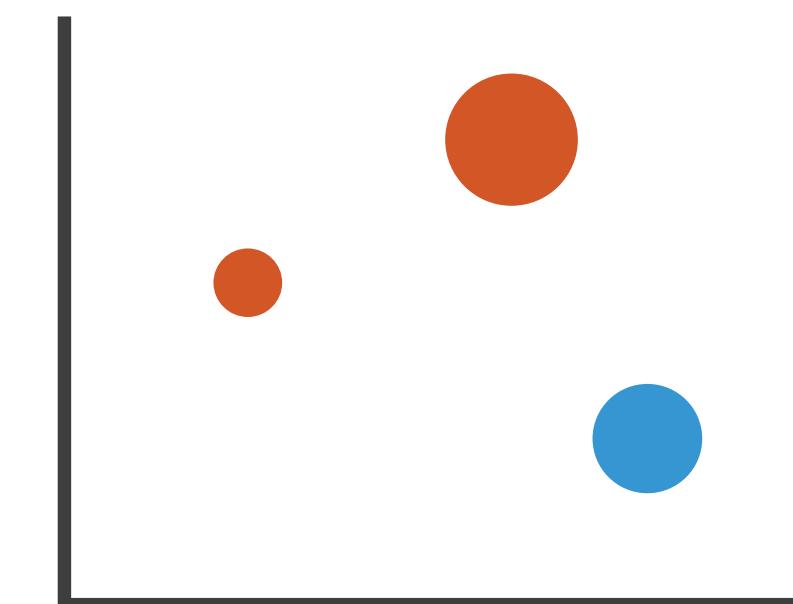
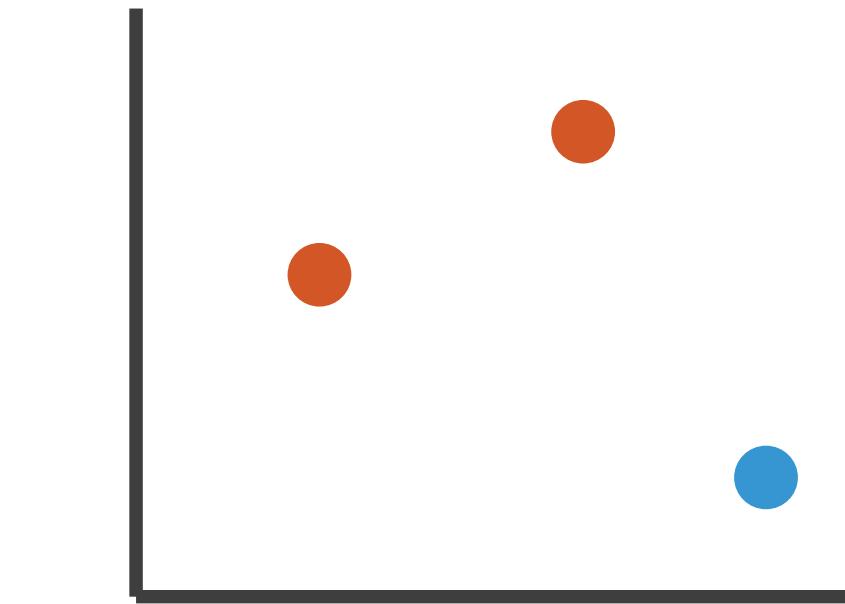
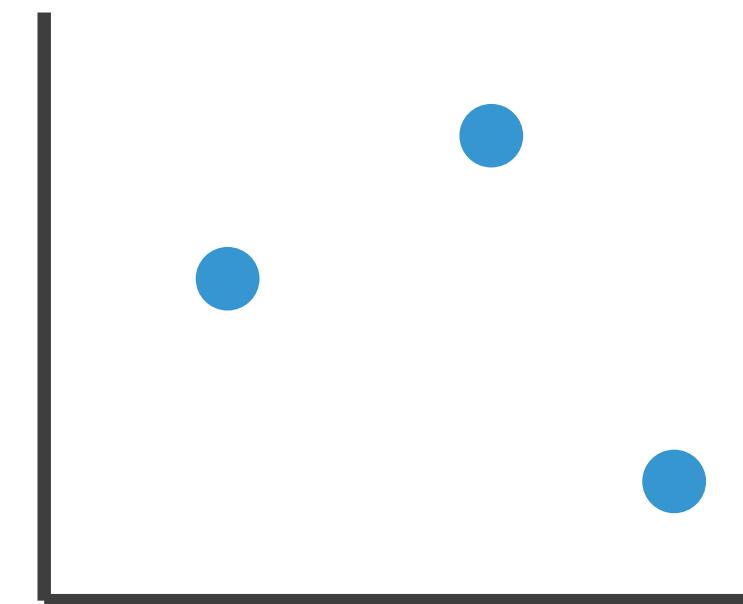
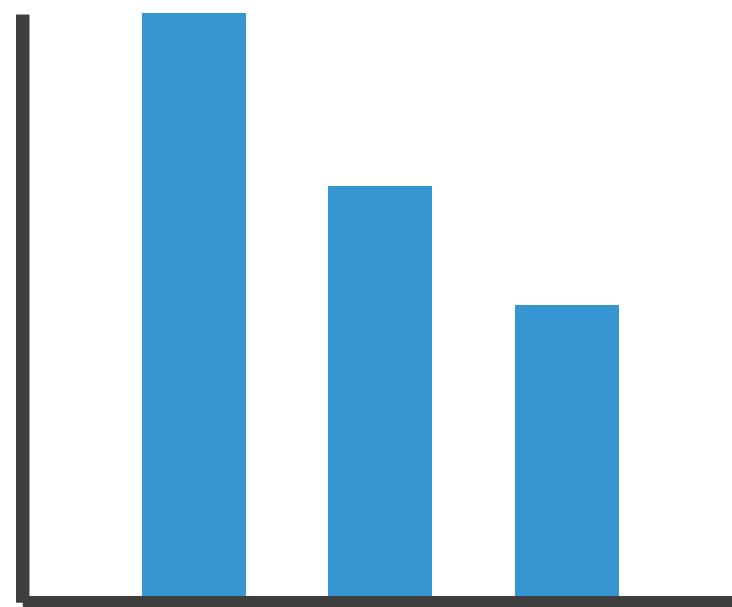
# Visual encoding

- How to systematically analyze the idiom structure?



# Visual encoding

- How to systematically analyze the idiom structure?

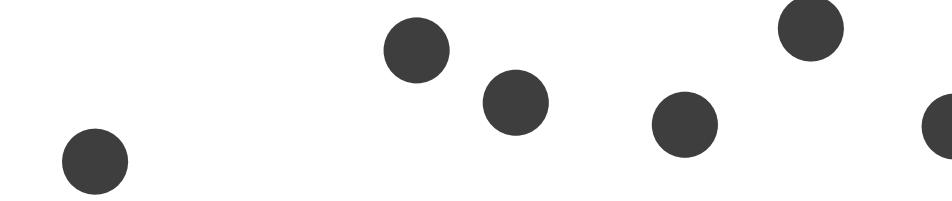


- **marks & channels**
  - **marks**: represent items or links
  - **channels**: change the appearance of marks based on attributes

# Marks for items

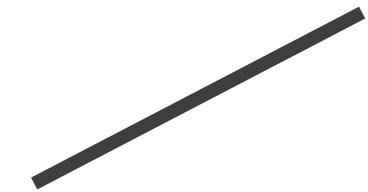
- basic geometric elements

→ Points



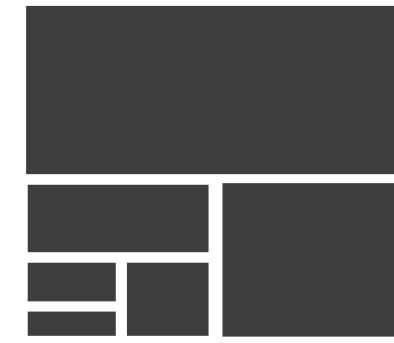
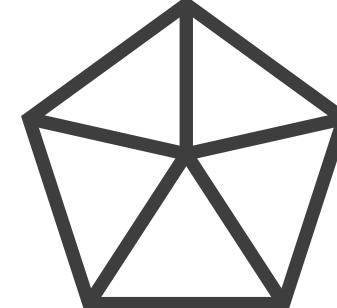
0D

→ Lines



1D

→ Interlocking Areas

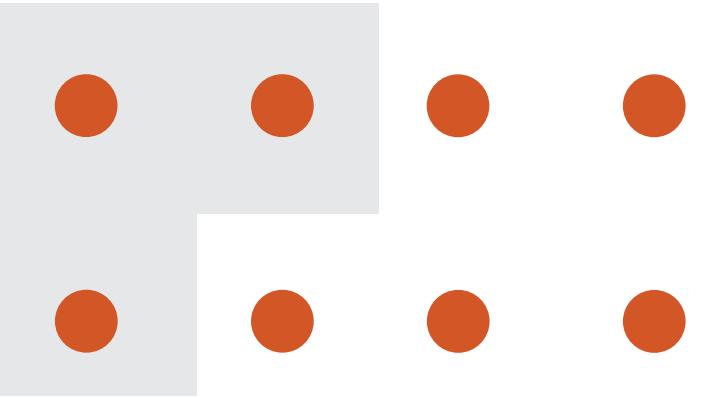


2D

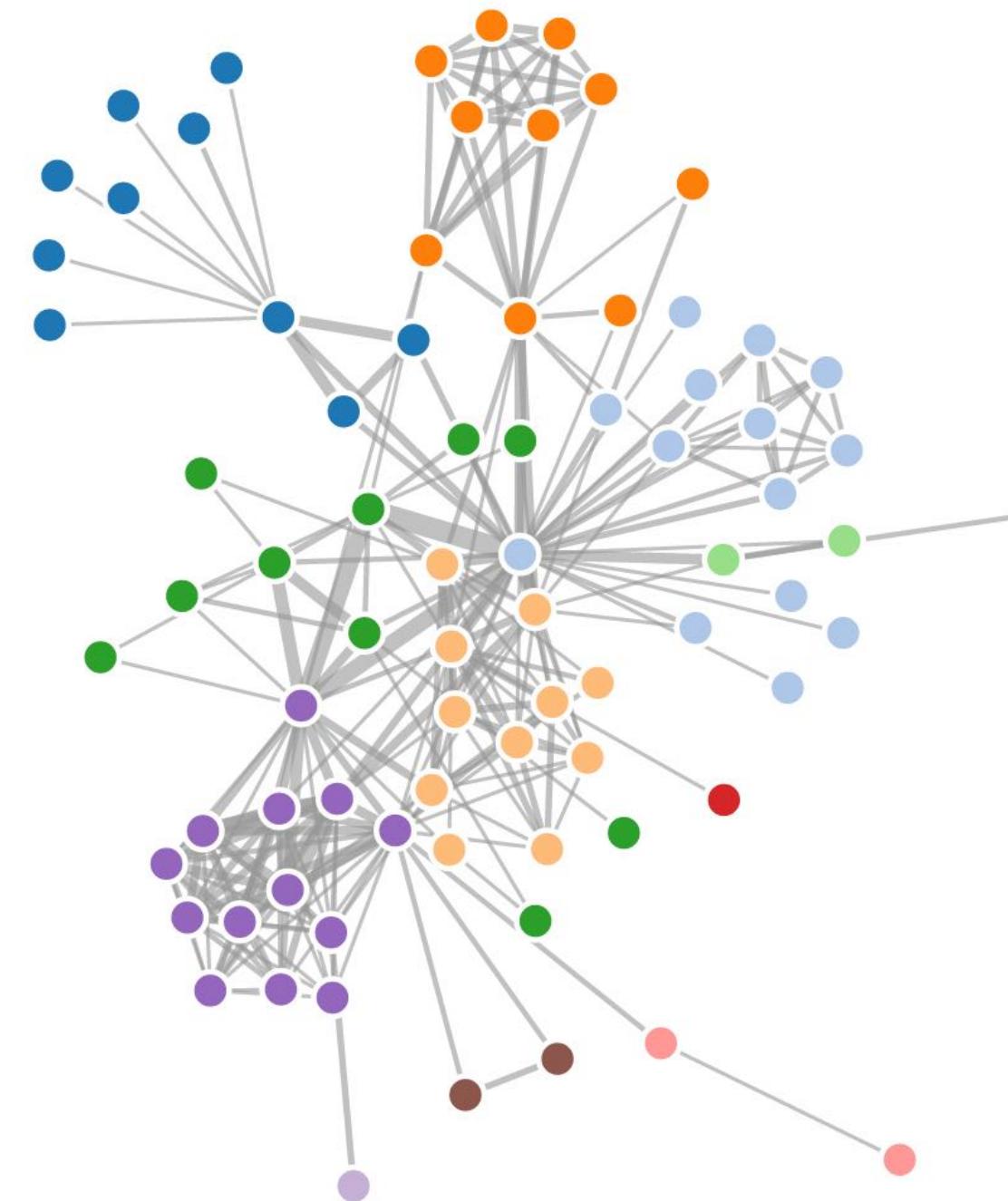
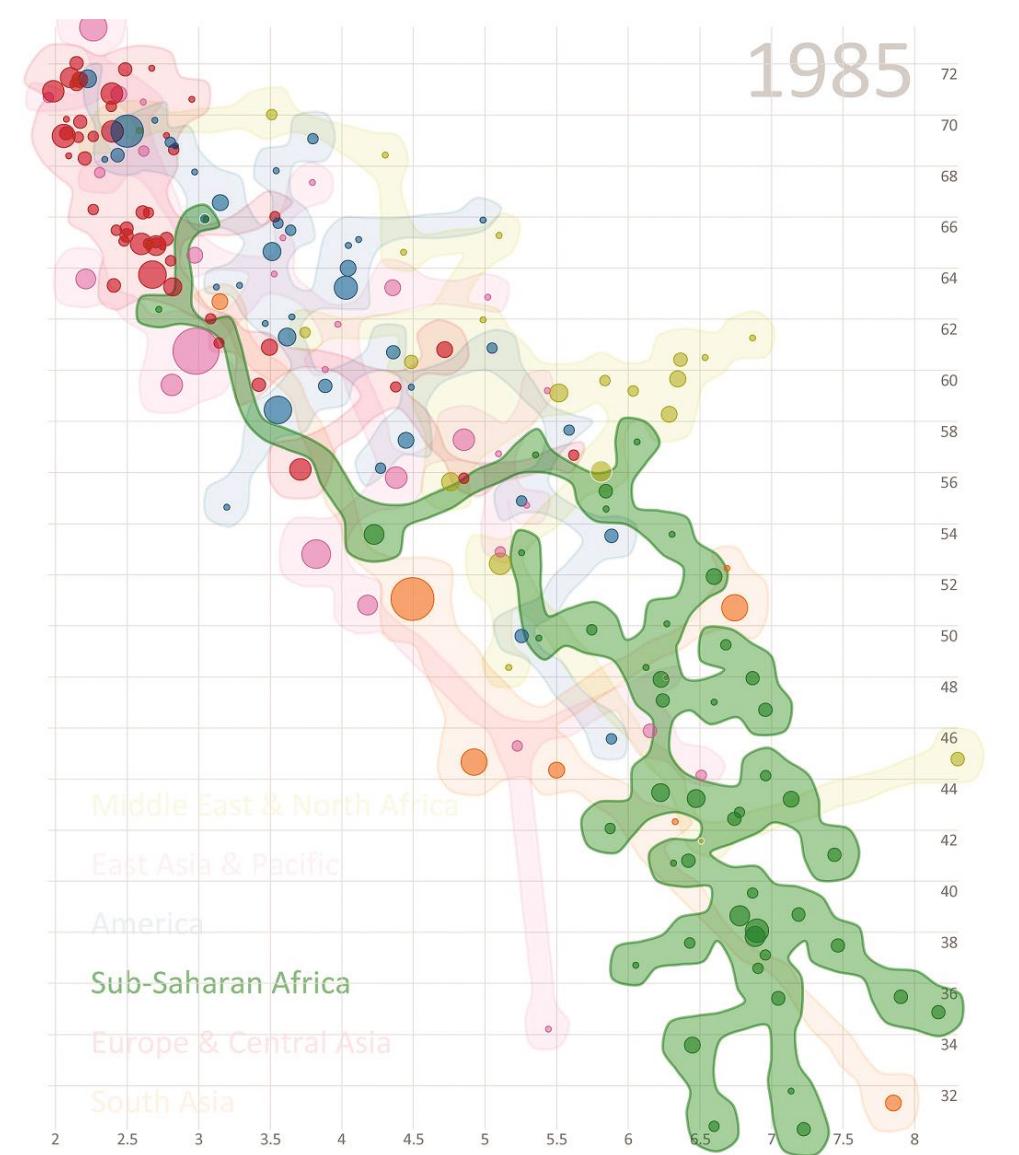
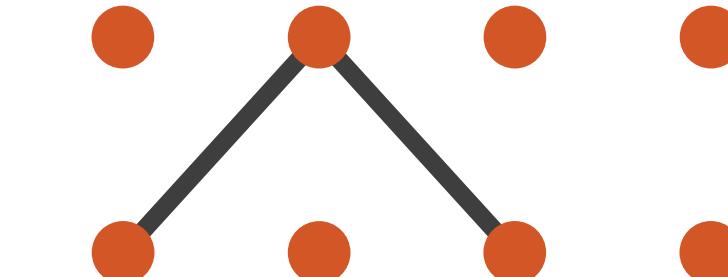
- 3D mark: volume, rarely used

# Marks for links

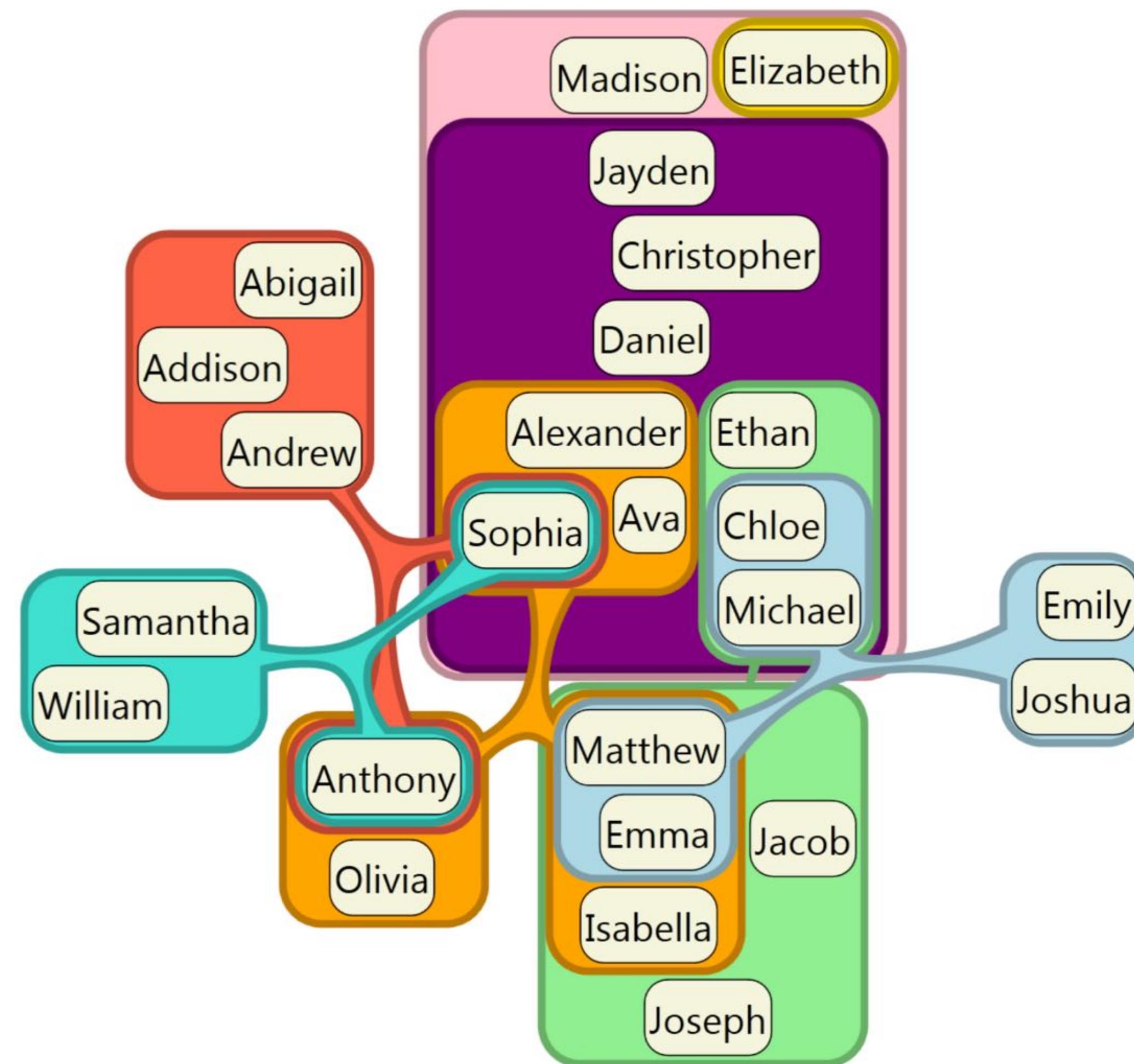
→ Containment



→ Connection



# 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

➔ Position

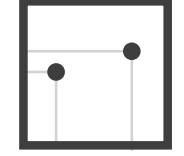
→ Horizontal



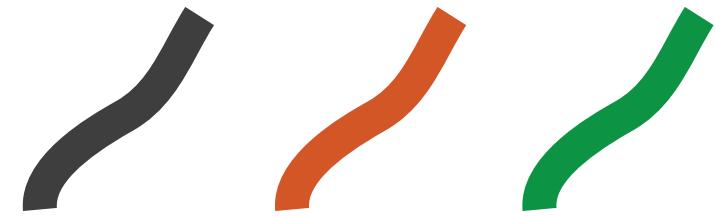
→ Vertical



→ Both



➔ Color



➔ Shape



➔ Tilt



➔ Size

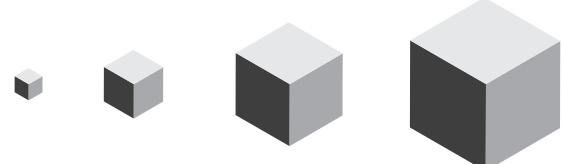
→ Length



→ Area



→ Volume



# 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

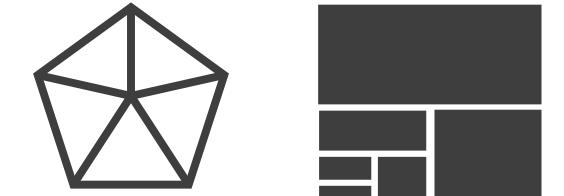
→ Points



→ Lines



→ Interlocking Areas



→ Position

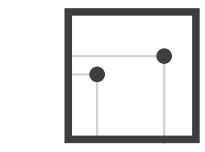
→ Horizontal



→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

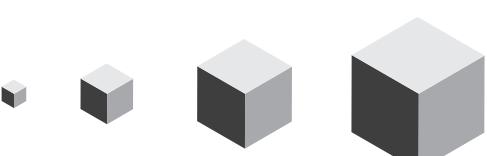
→ Length



→ Area

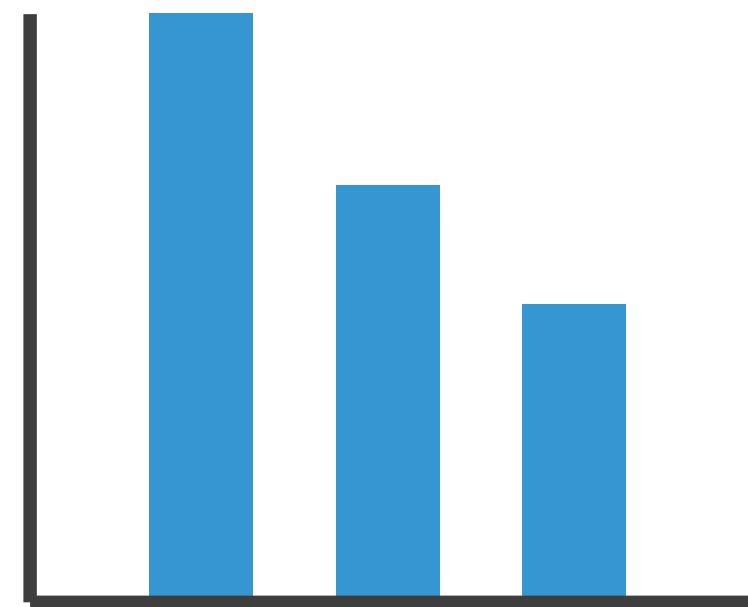


→ Volume



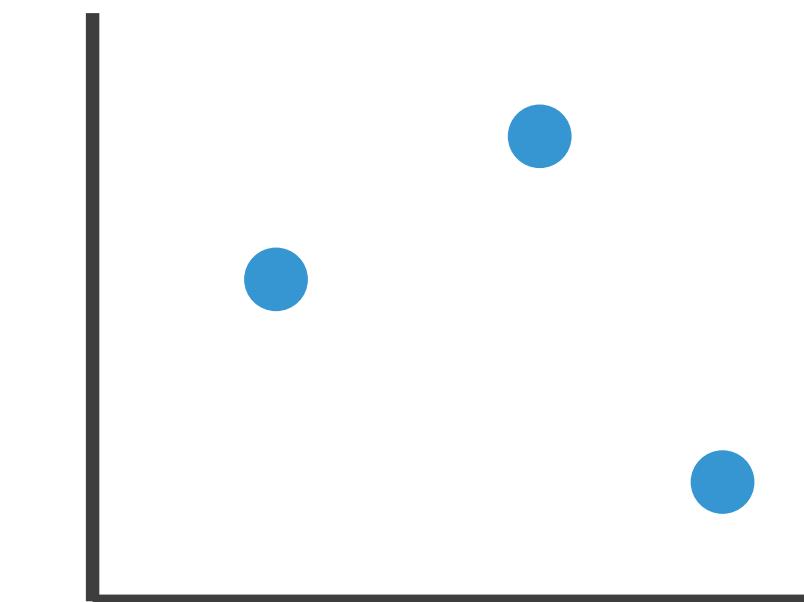
# Visual encoding

- analyze idiom structure as combination of marks and channels



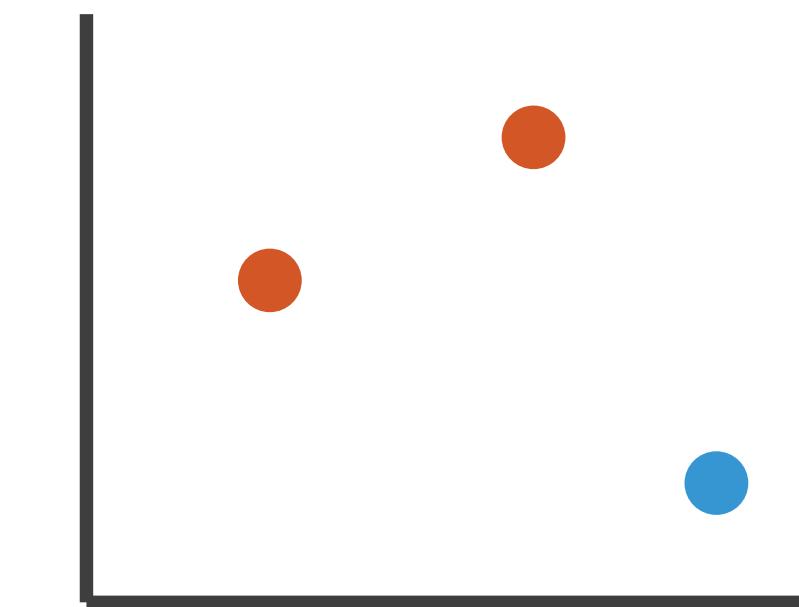
1:  
**vertical position**

**mark: line**



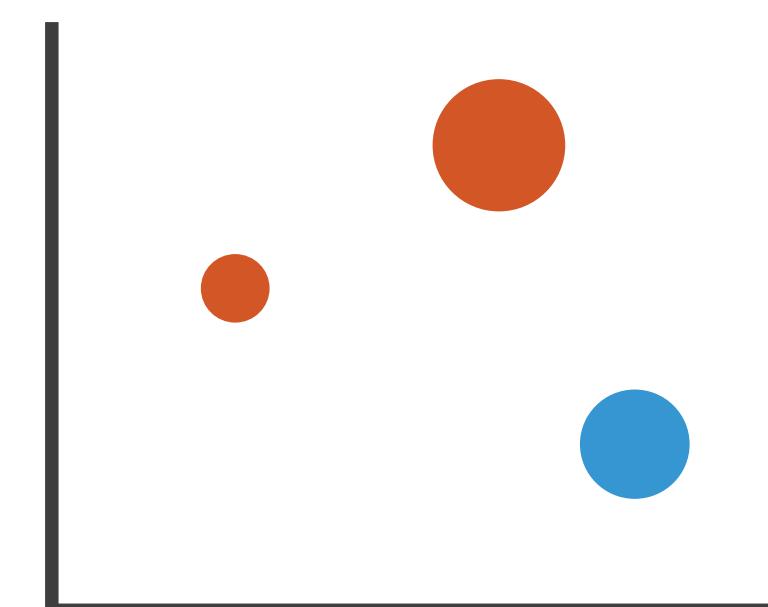
2:  
**vertical position**  
**horizontal position**

**mark: point**



3:  
**vertical position**  
**horizontal position**  
**color hue**

**mark: point**

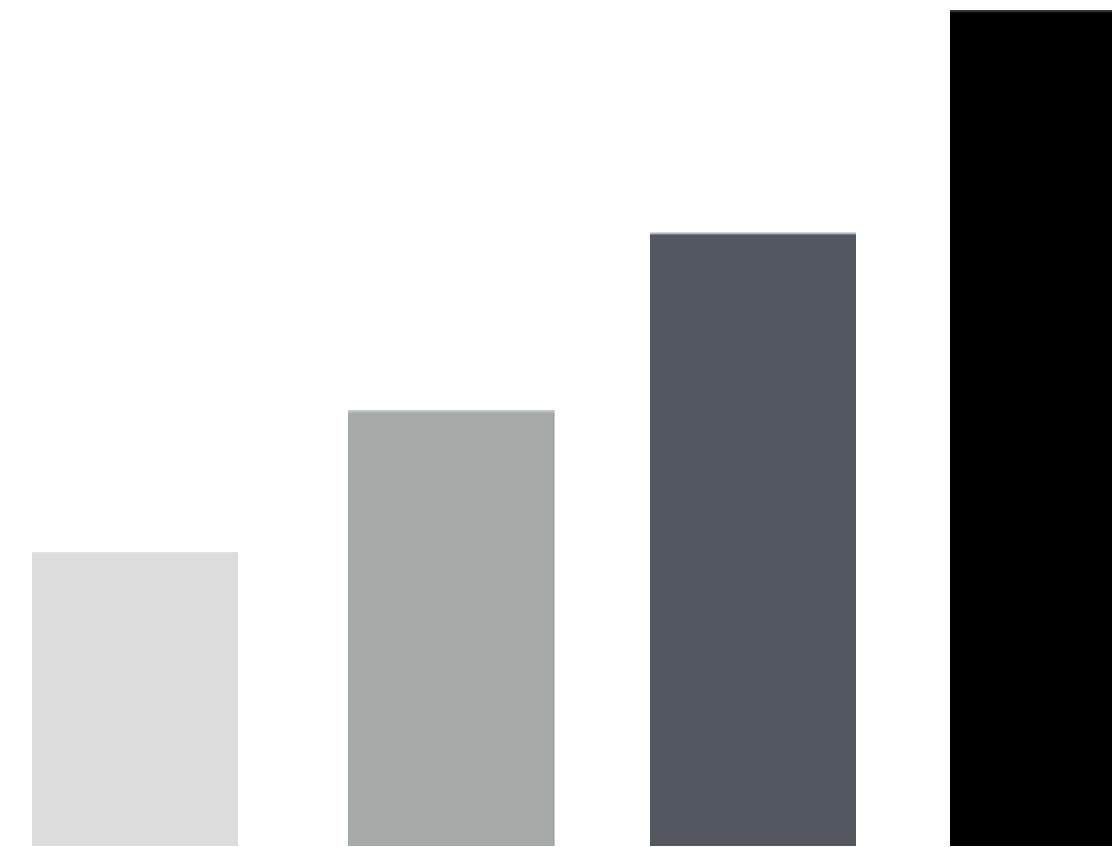


4:  
**vertical position**  
**horizontal position**  
**color hue**  
**size (area)**

**mark: point**

# Redundant encoding

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



Length, Position, and Luminance

# Scope of analysis

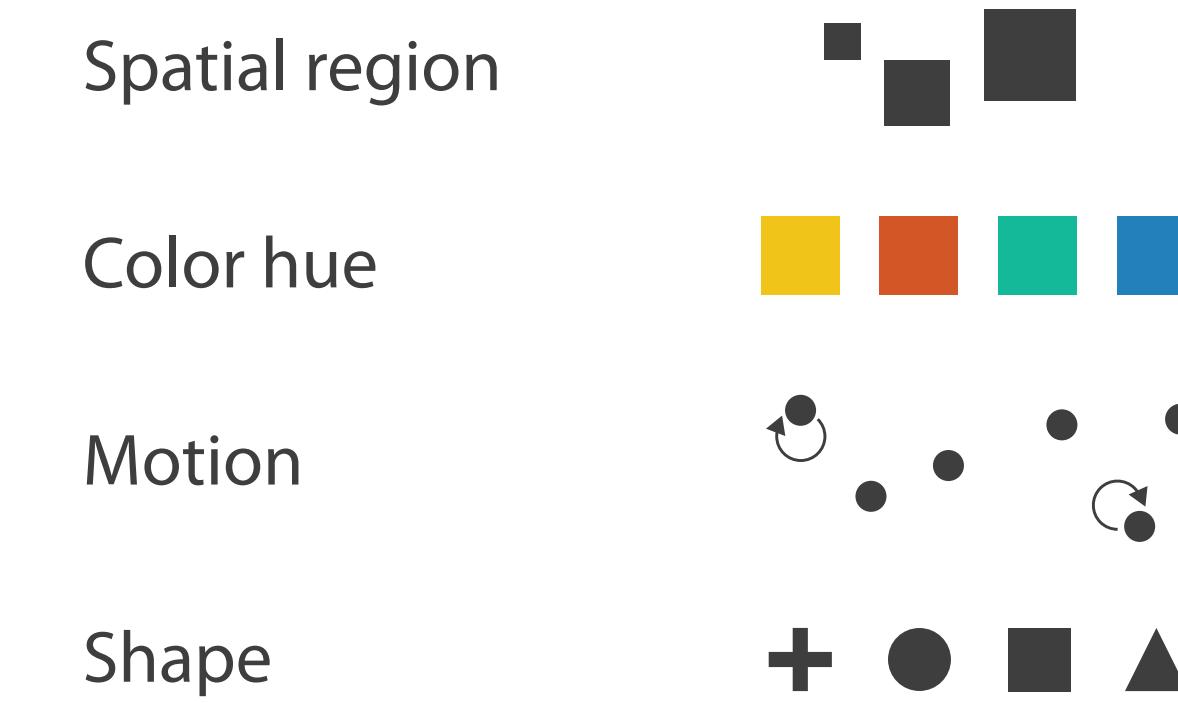
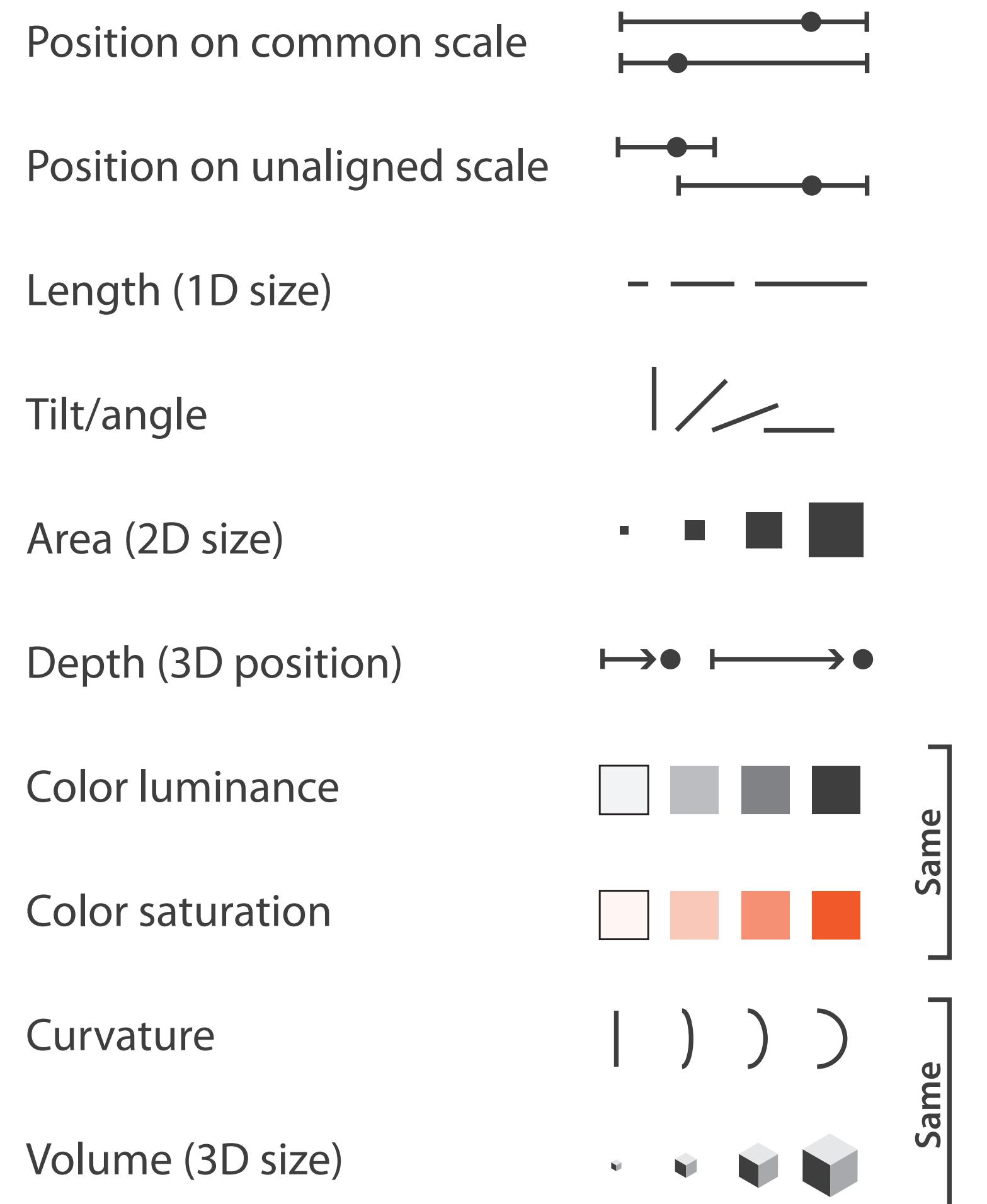
- simplifying assumptions: one mark per item, single view
- later on
  - multiple views
  - multiple marks in a region (glyph)
  - some items not represented by marks (aggregation and filtering)

# When to use which channel?

When should you use which channel?

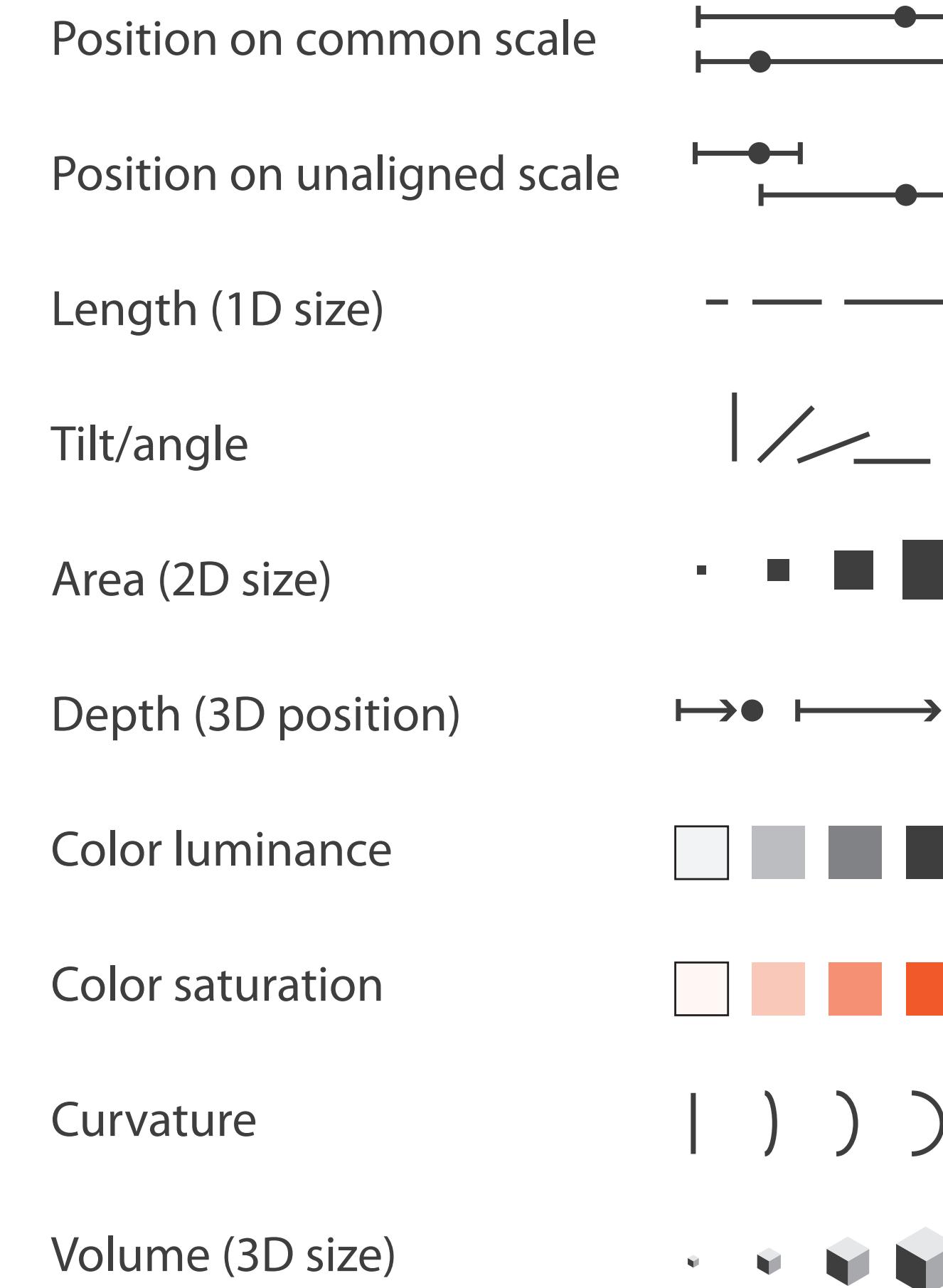
- **expressiveness**
  - match channel type to data type
- **effectiveness**
  - some channels are better than others

# Channels: Rankings

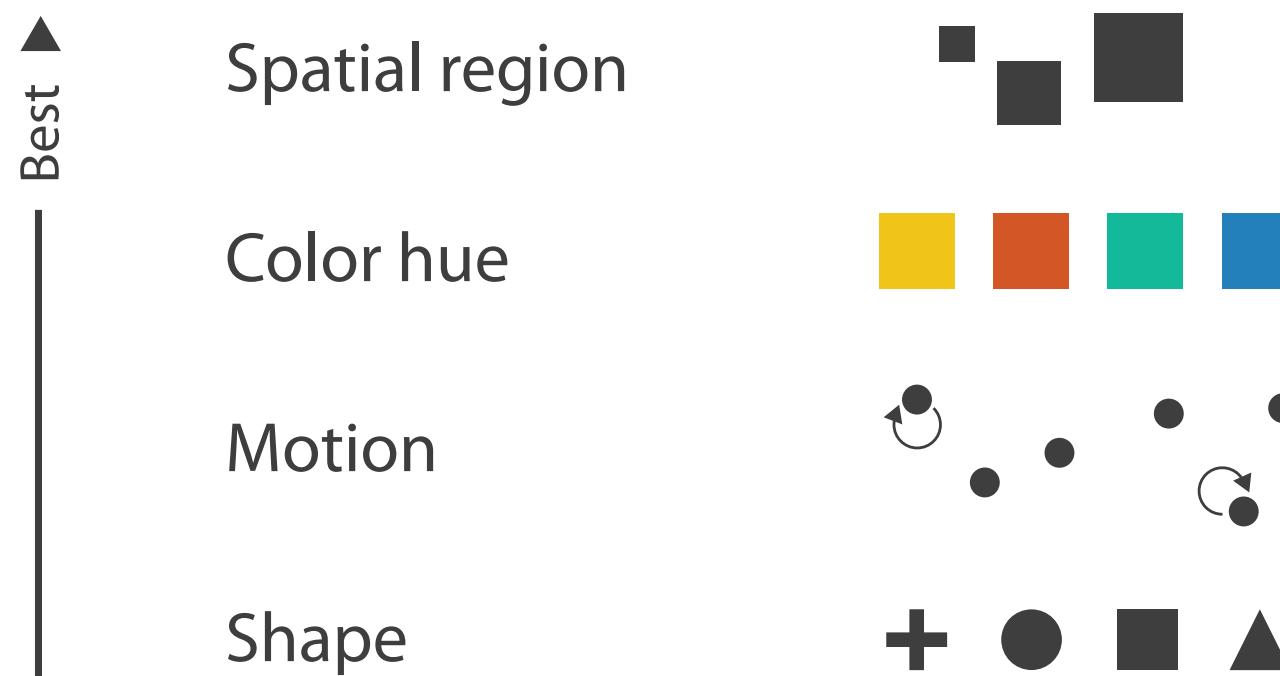


# Channels: Rankings

## → **Magnitude Channels: Ordered Attributes**



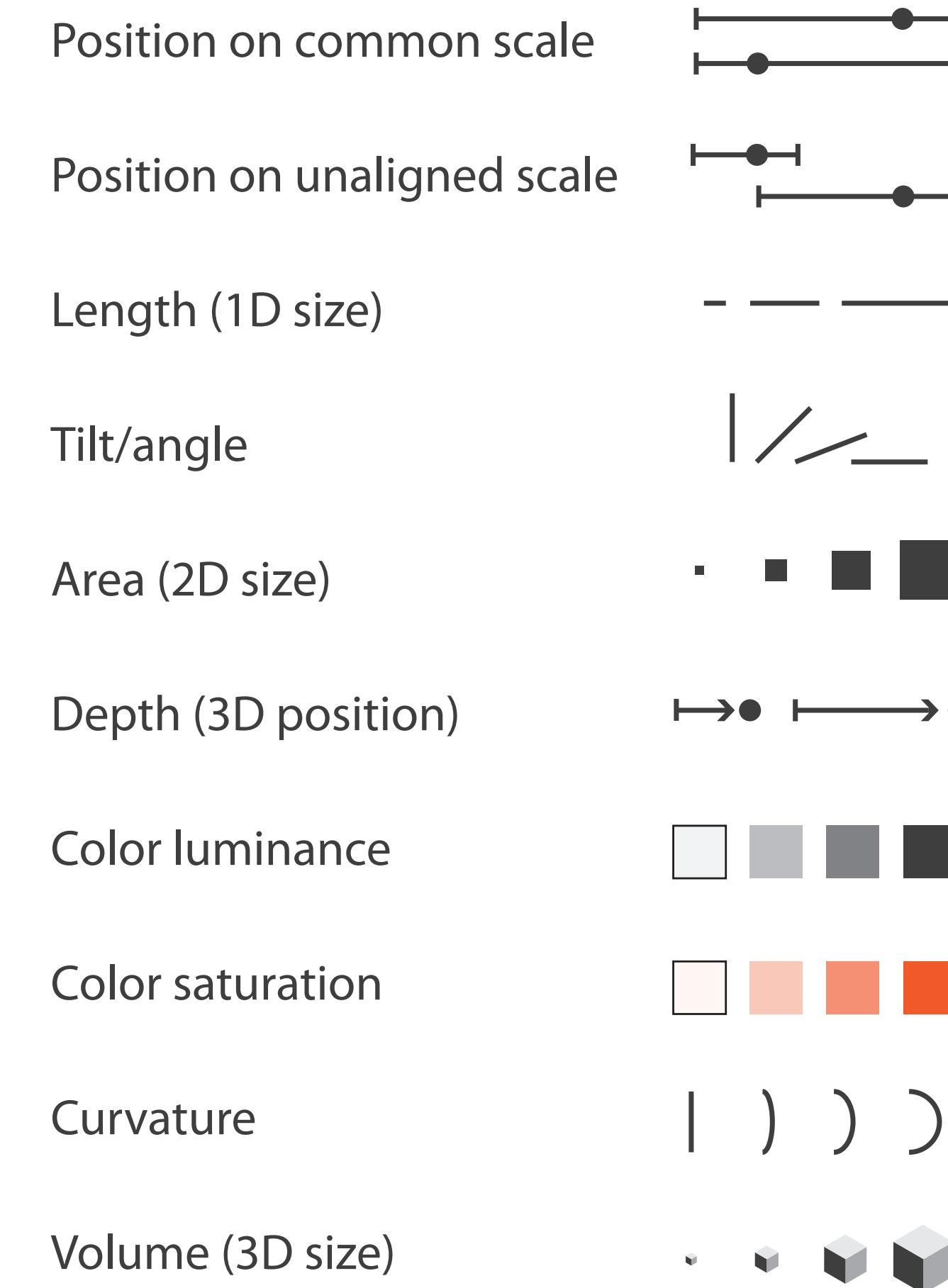
## → **Identity Channels: Categorical Attributes**



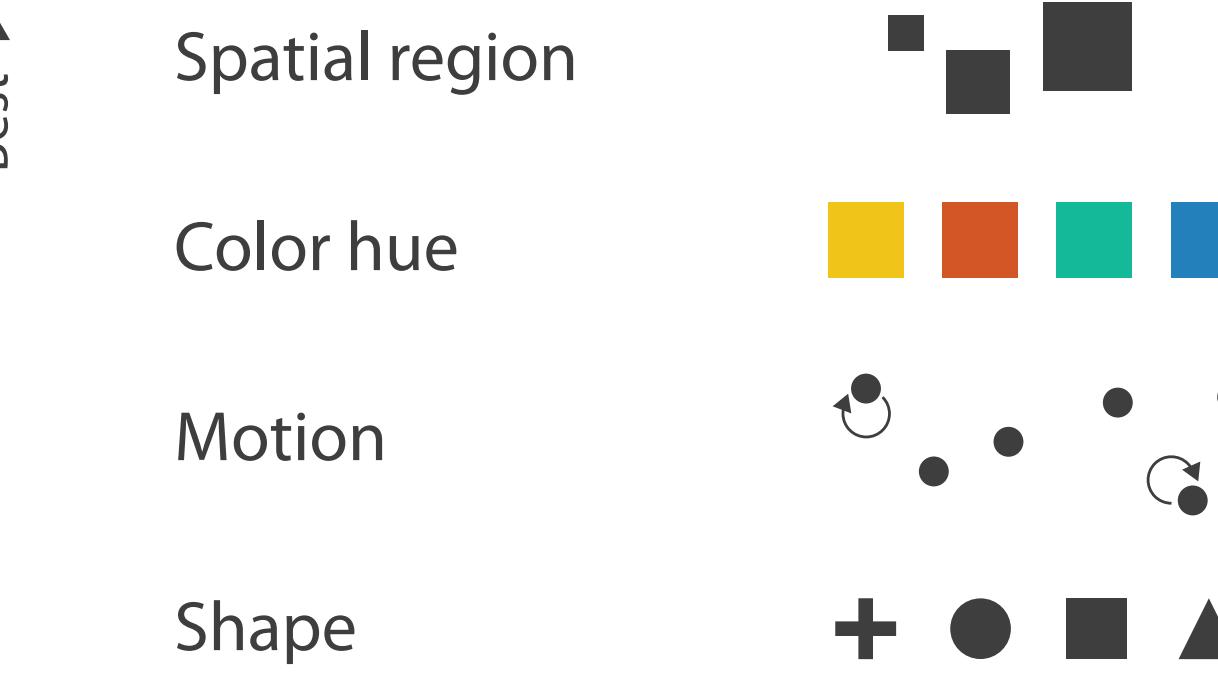
- **expressiveness**
  - match channel and data characteristics
  - **magnitude for ordered**
    - how much? which rank?
  - **identity for categorical**
    - what?

# Channels: Rankings

## → Magnitude Channels: Ordered Attributes



## → Identity Channels: Categorical Attributes



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

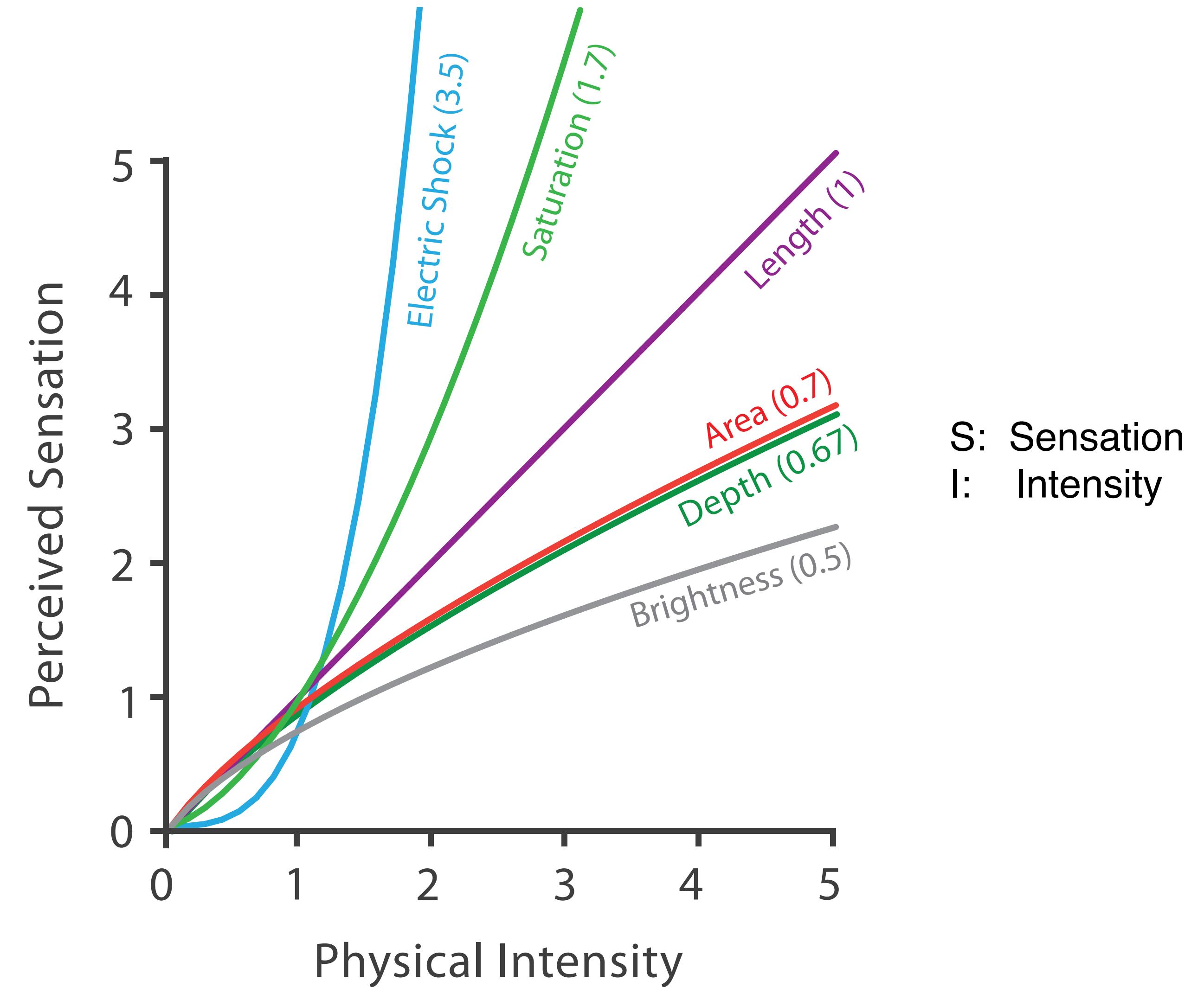
# Channel effectiveness

- **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

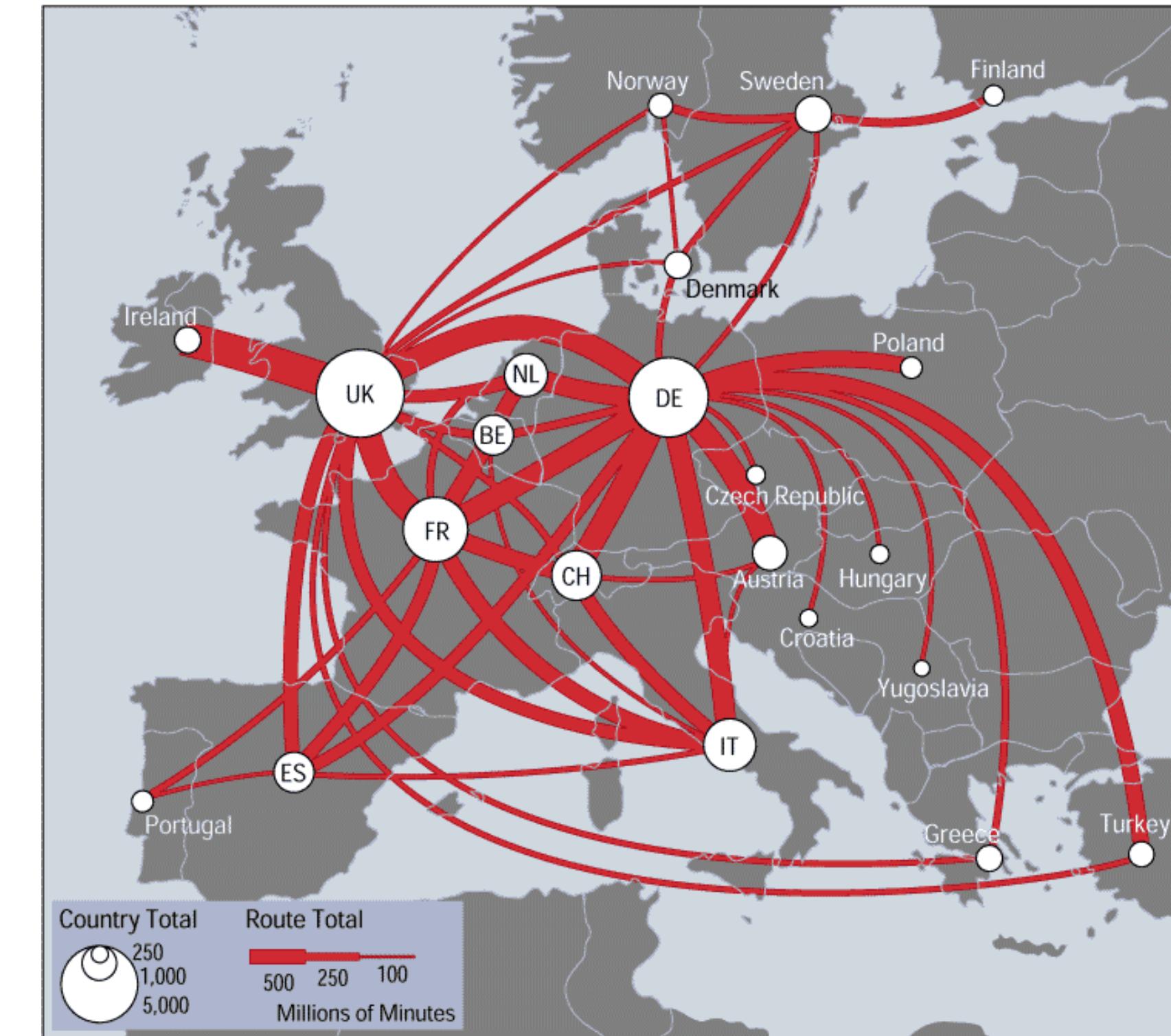
- length is accurate: linear
- others magnified or compressed
  - exponent characterizes

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



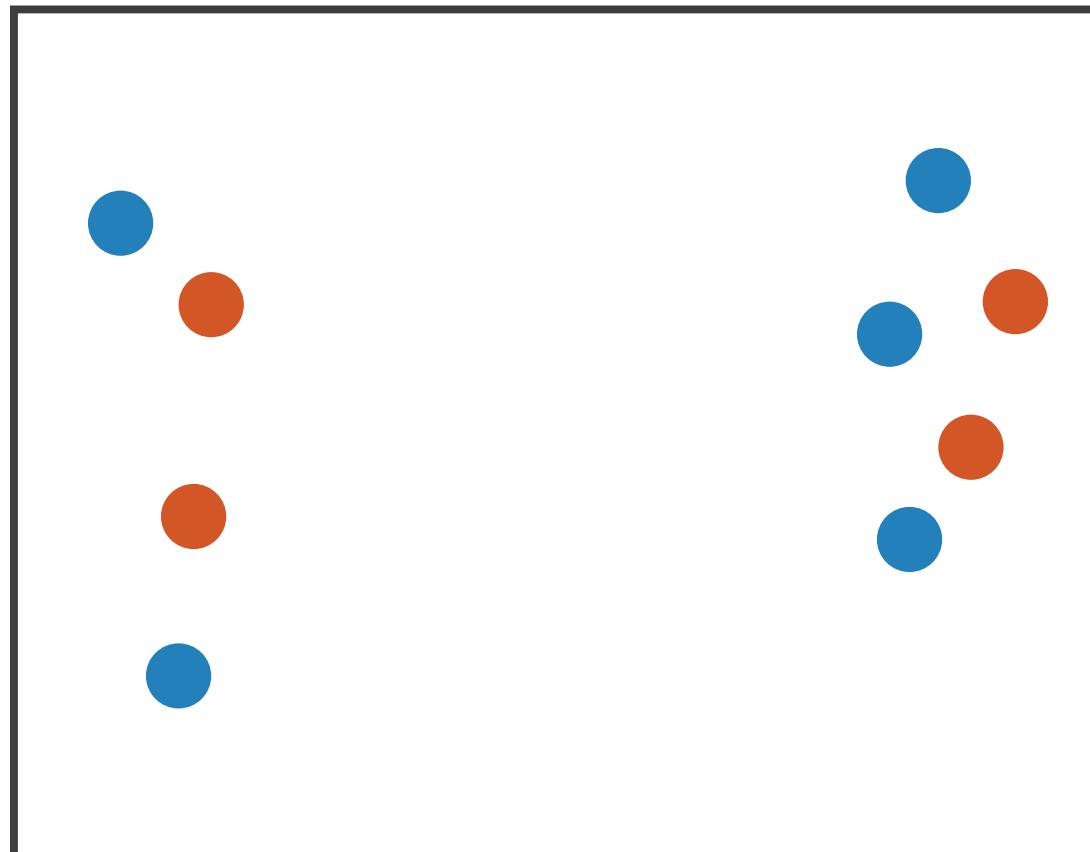
# Discriminability: How many usable steps?

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



# Separability vs. Integrality

Position  
+ Hue (Color)

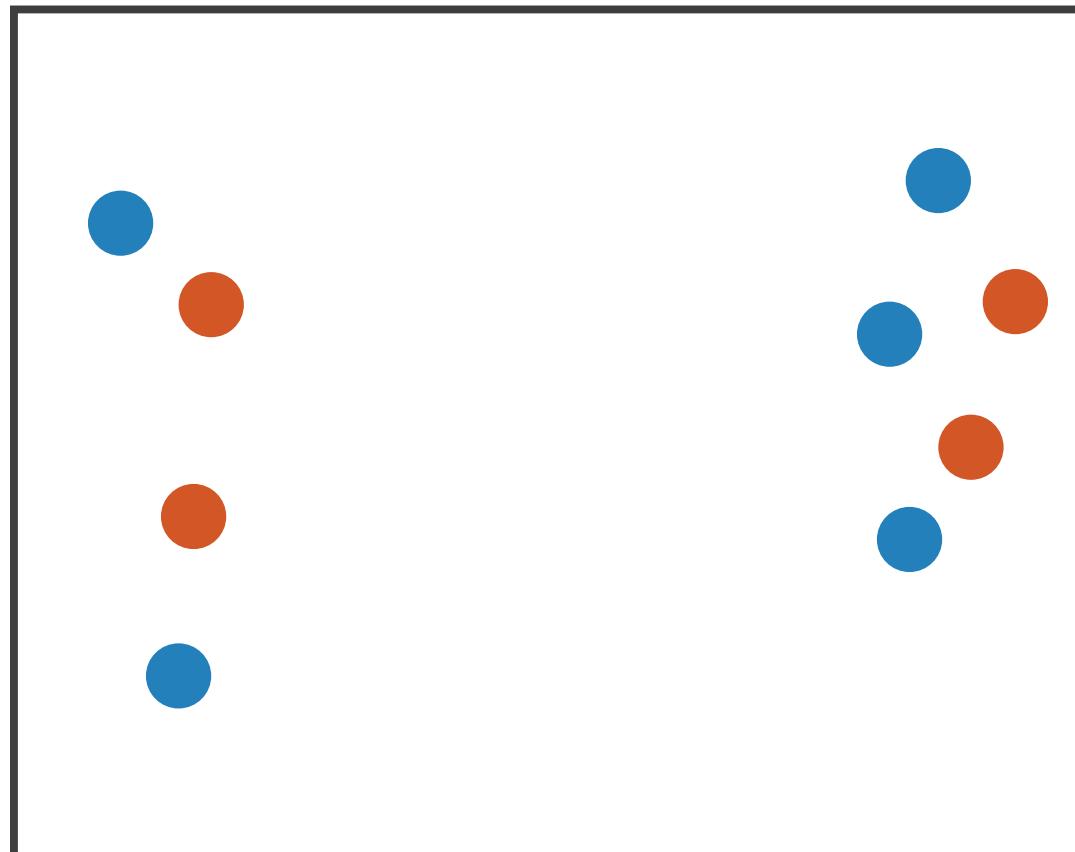


**Color (hue) and position can be used independently**

Fully separable

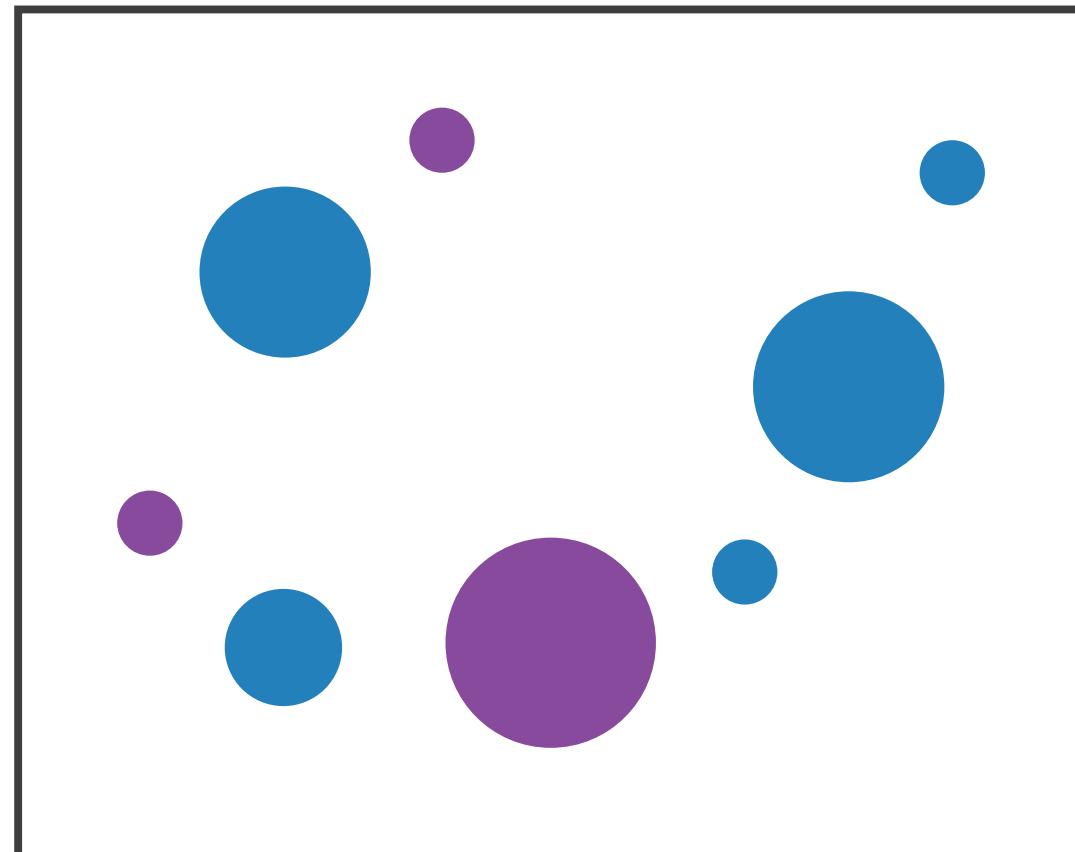
# Separability vs. Integrality

Position  
+ Hue (Color)



Fully separable

Size  
+ Hue (Color)

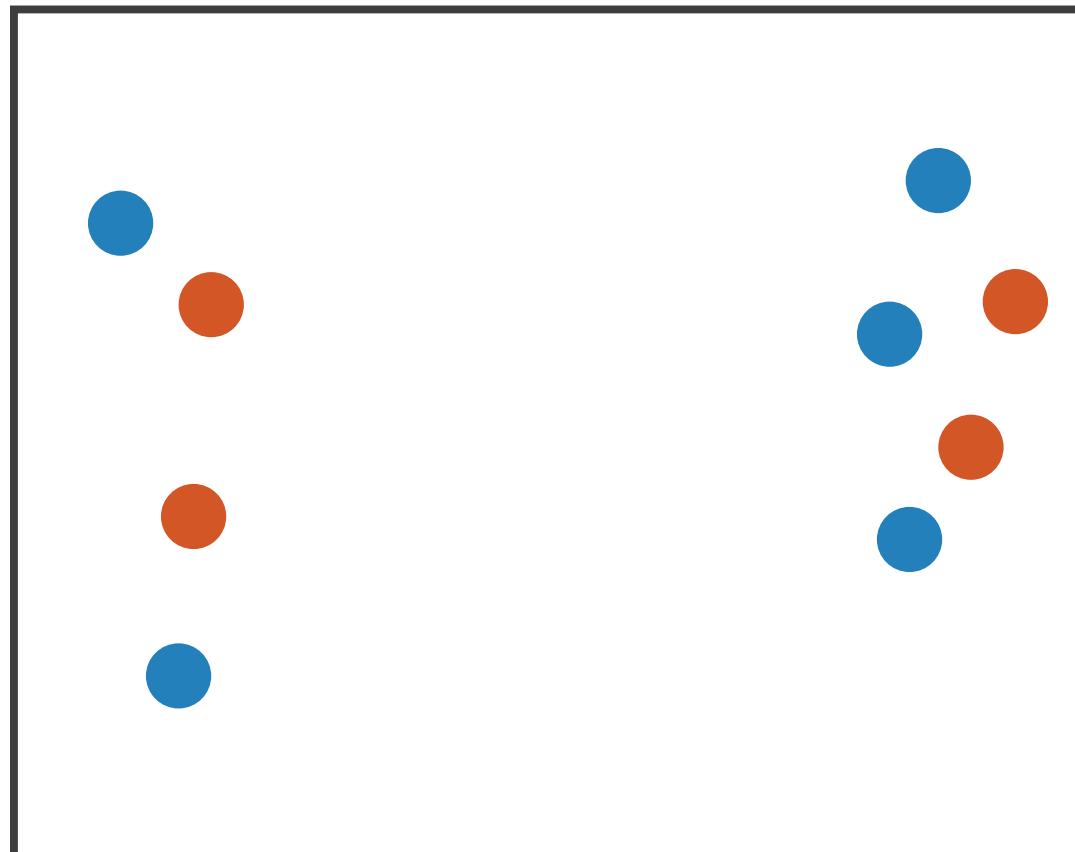


Some interference

**Size and hue interfere somewhat; hue is harder to perceive on smaller objects.**

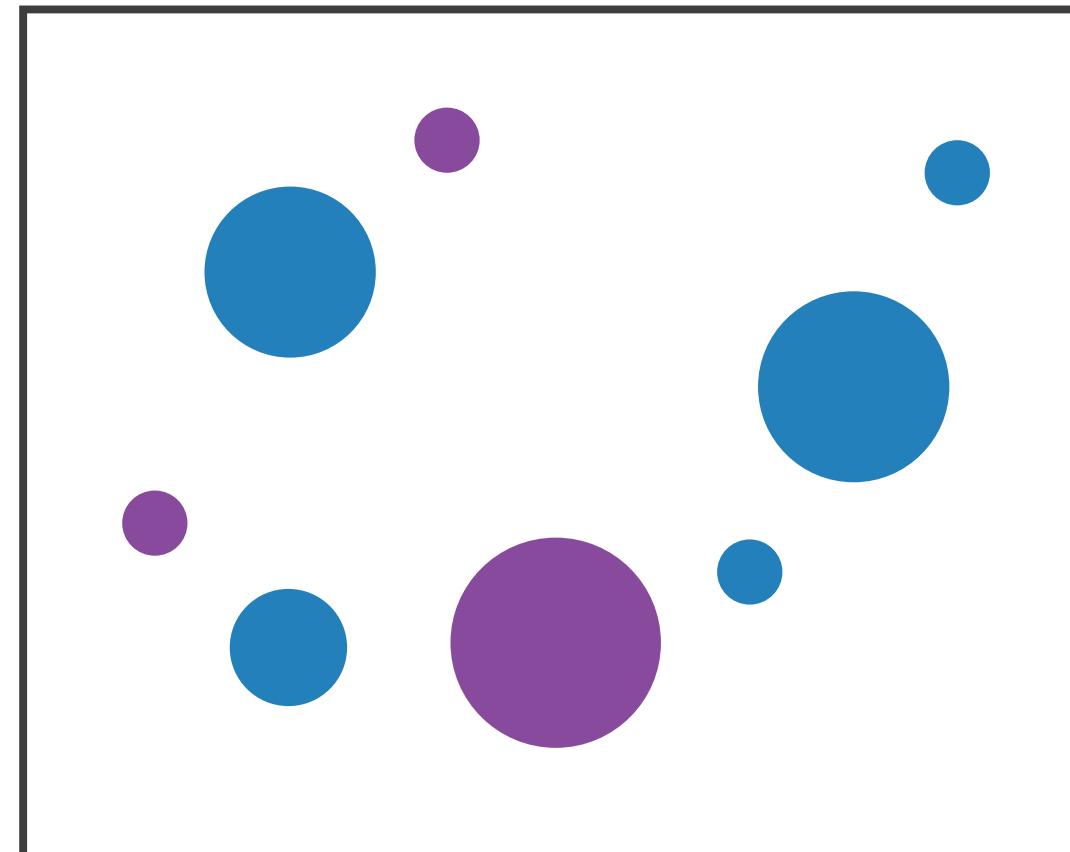
# Separability vs. Integrality

Position  
+ Hue (Color)



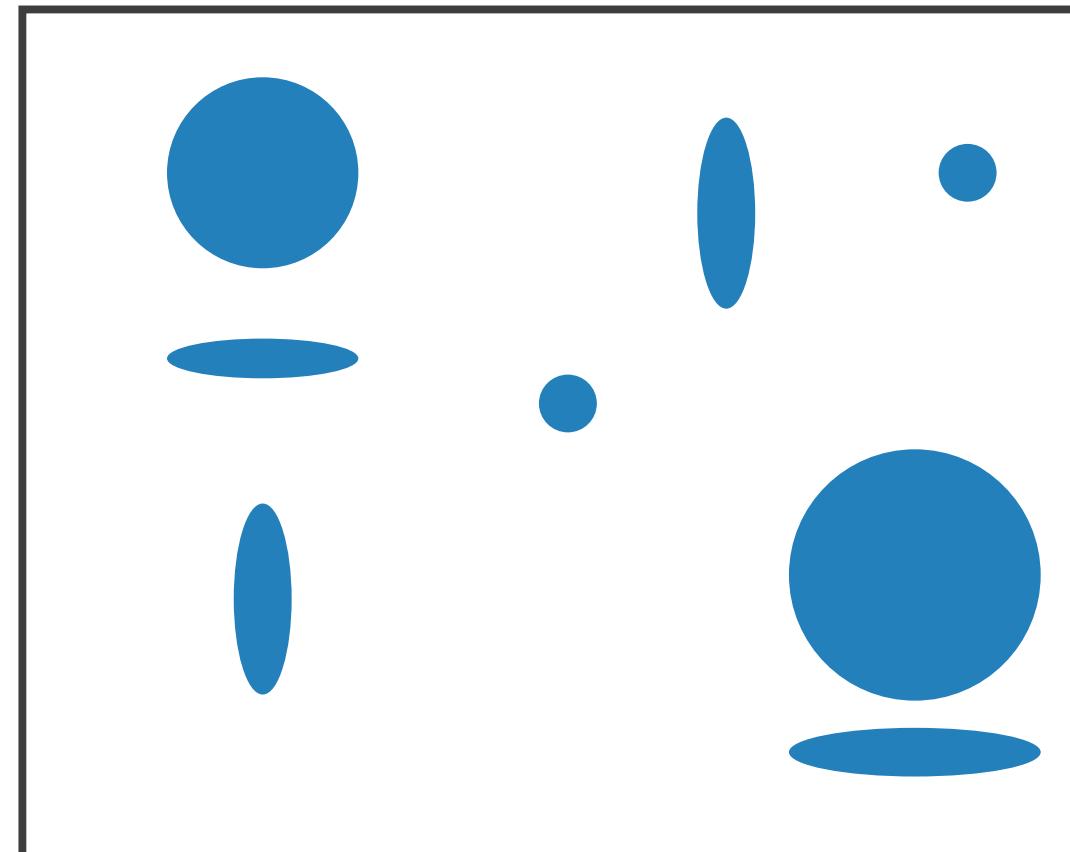
Fully separable

Size  
+ Hue (Color)



Some interference

Width  
+ Height



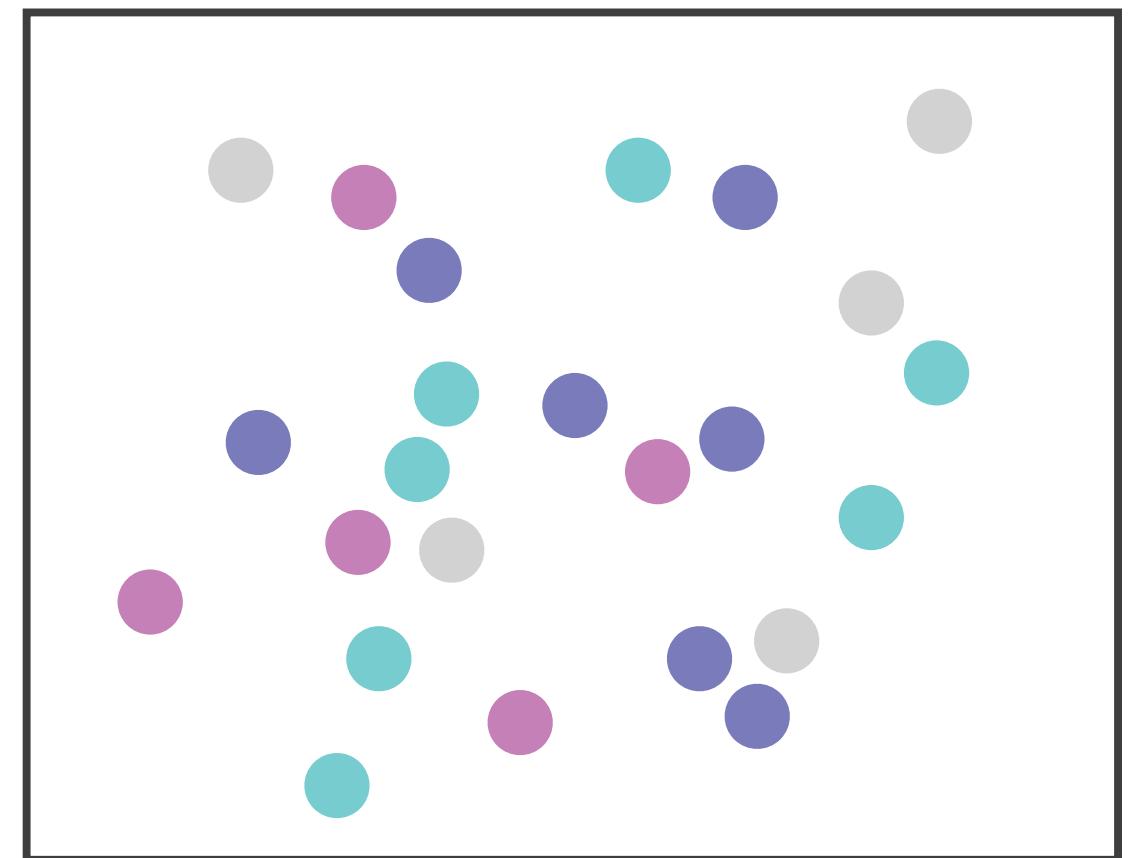
Some/significant  
interference

**Width and height do not function well independently; the result is perceived primarily as shape.**

# Separability vs. Integrality

**Encoding two different values in the red and green channels as a hue does not work at all.**

Red  
+ Green

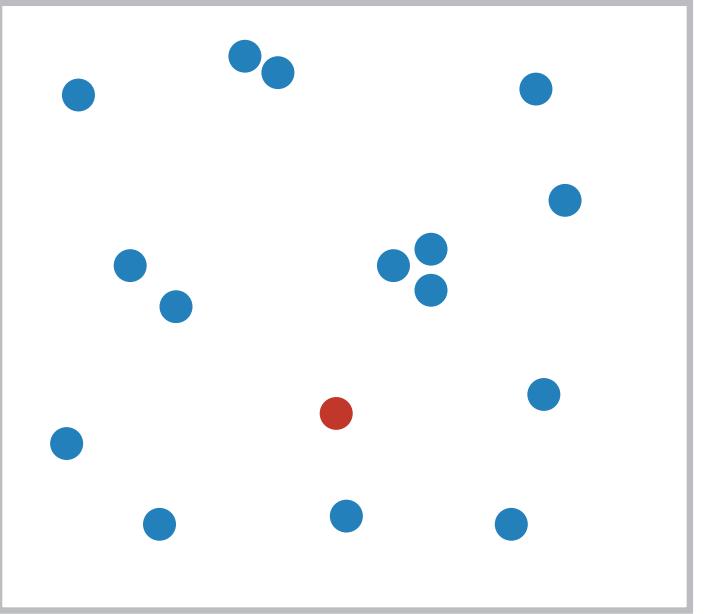


Major interference

# Popout

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

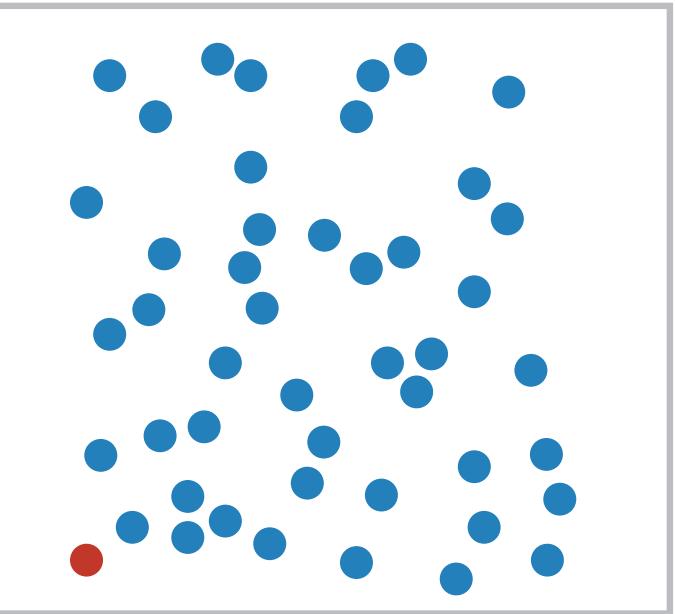
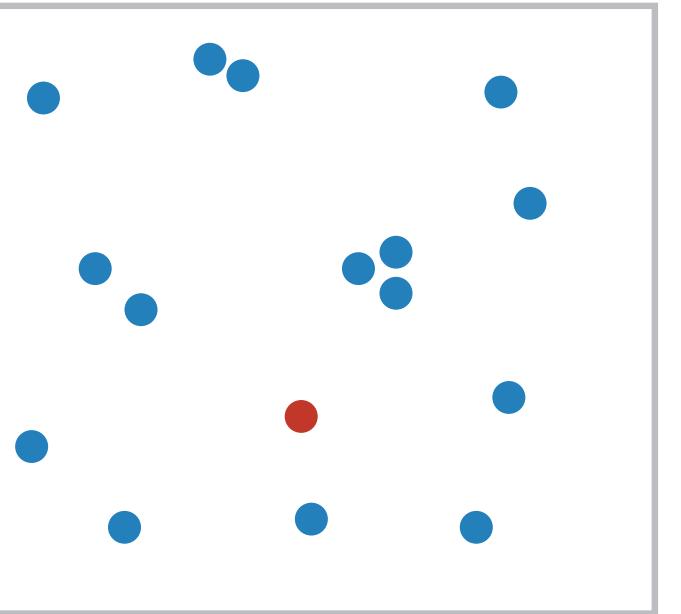
# Popout



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

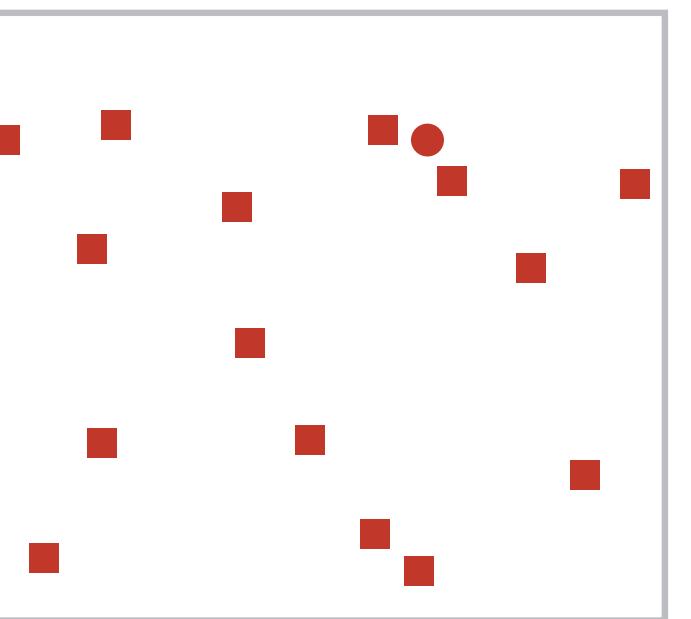
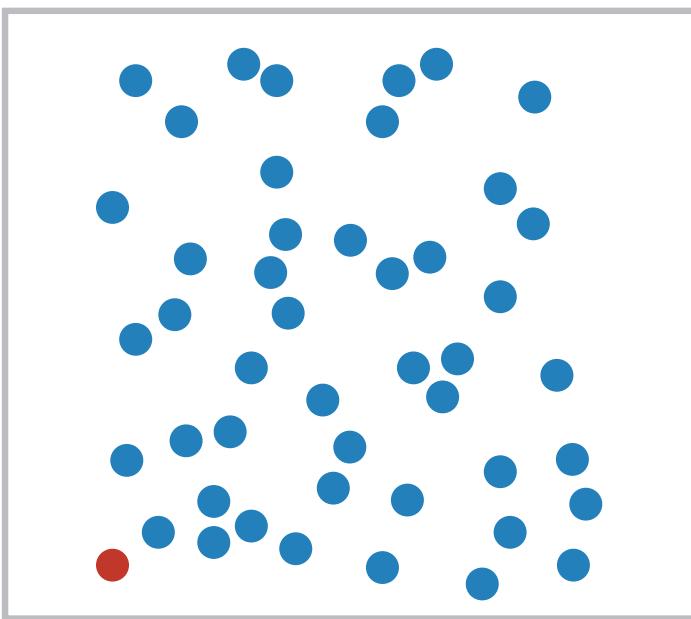
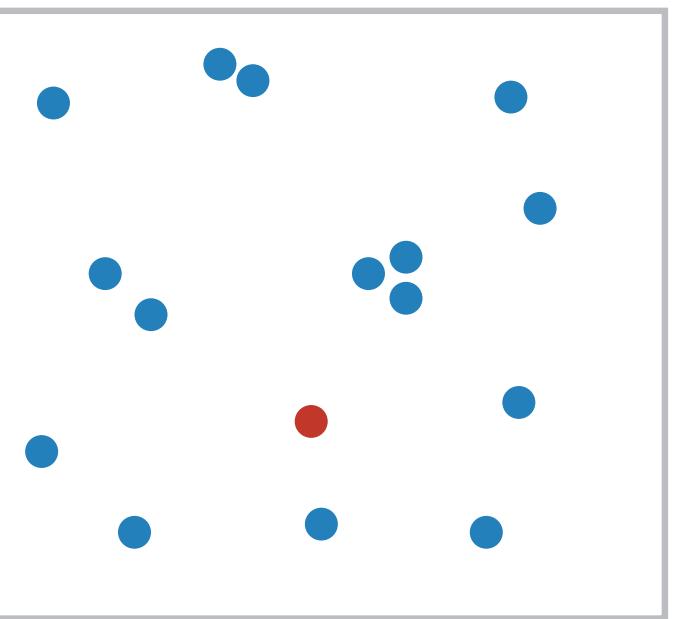
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  - how long does it take?



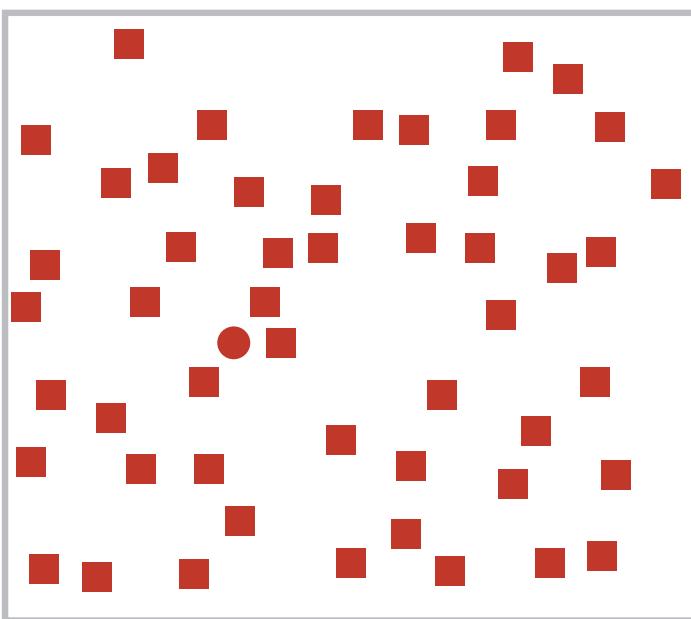
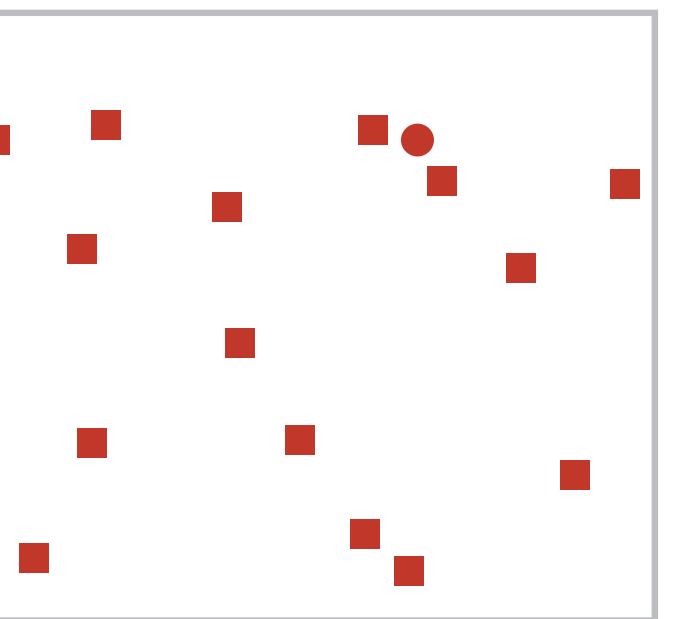
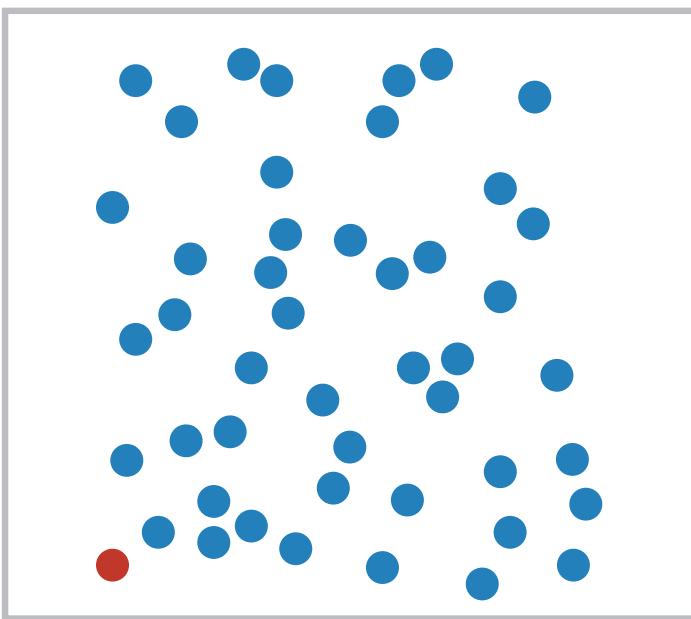
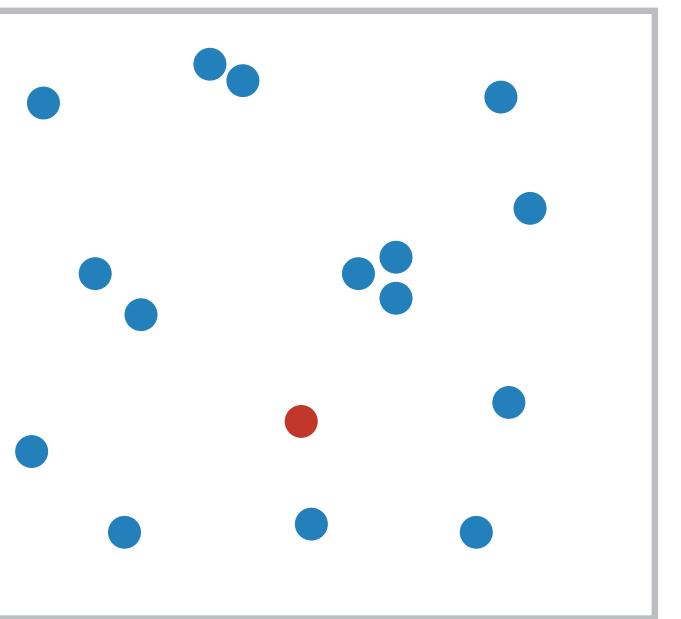
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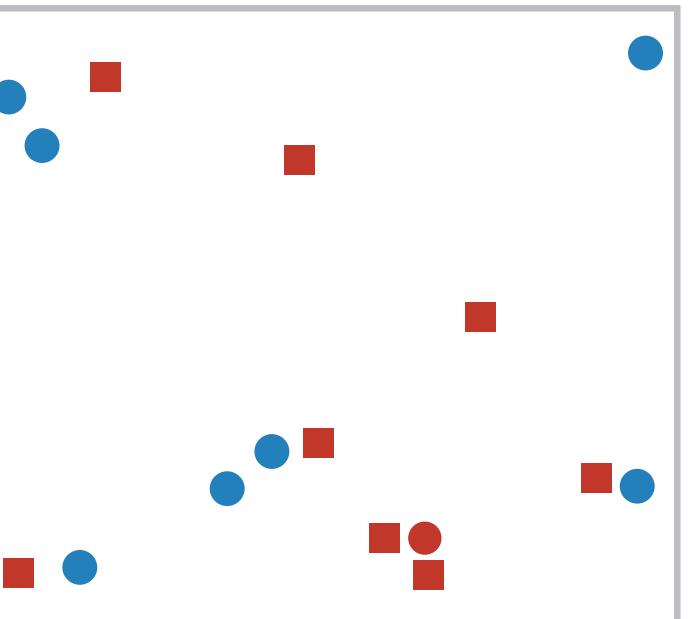
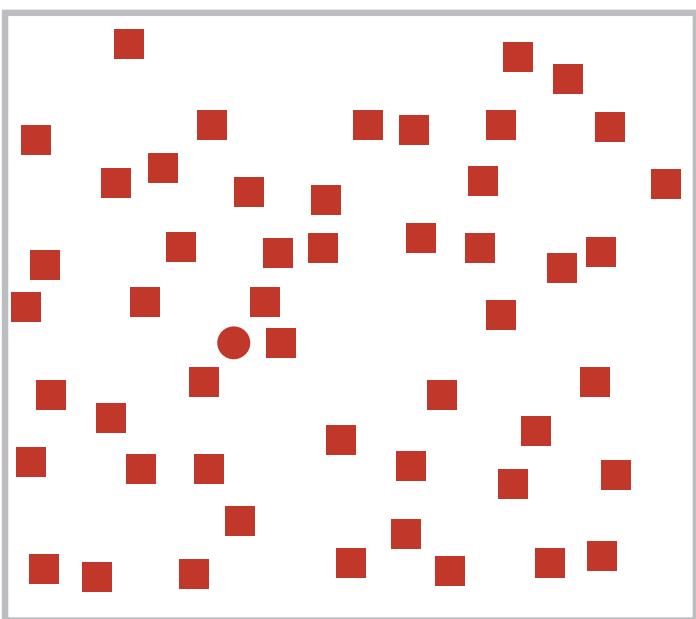
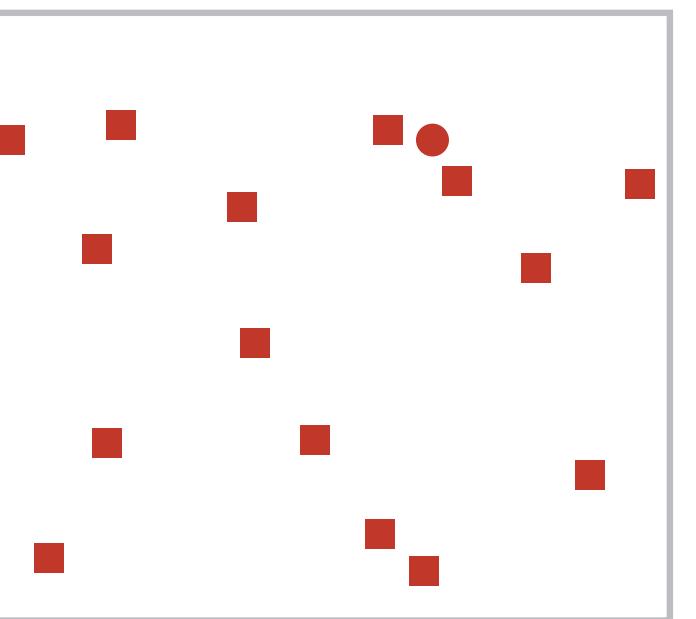
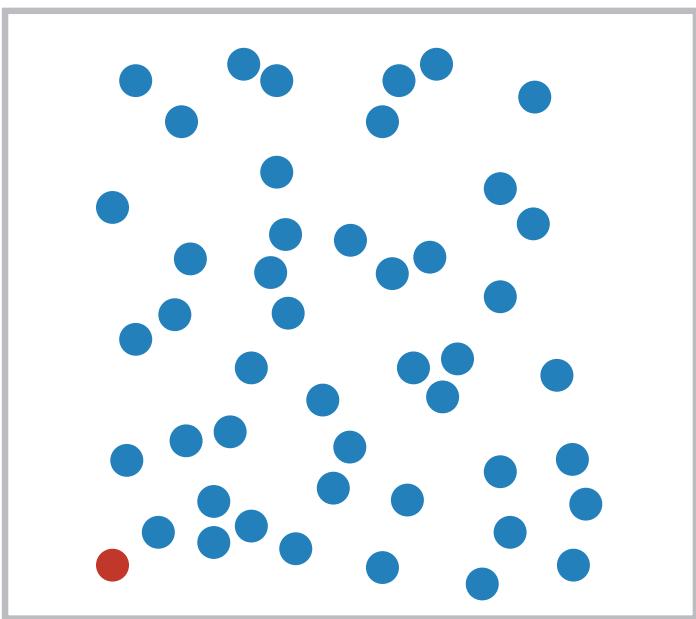
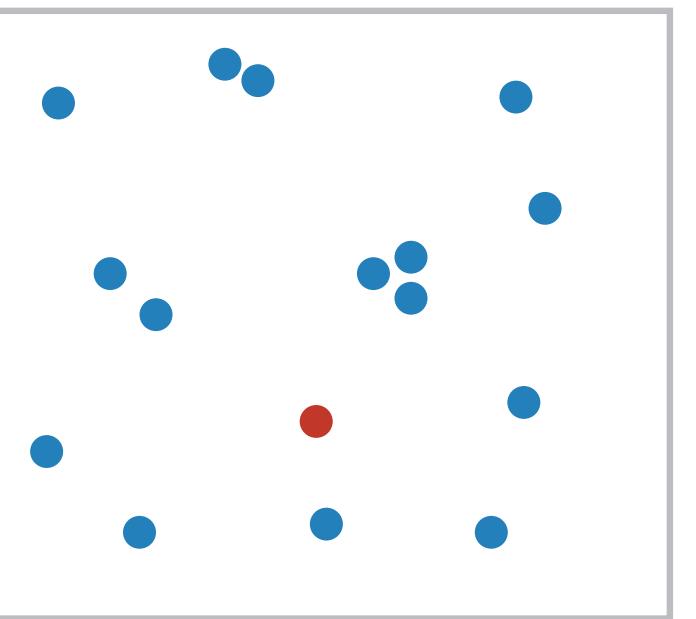
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- find the red dot
  - how long does it take?



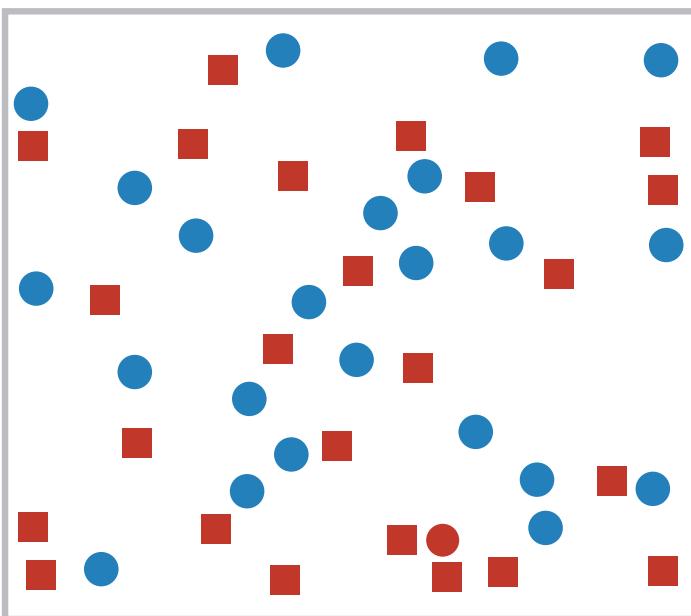
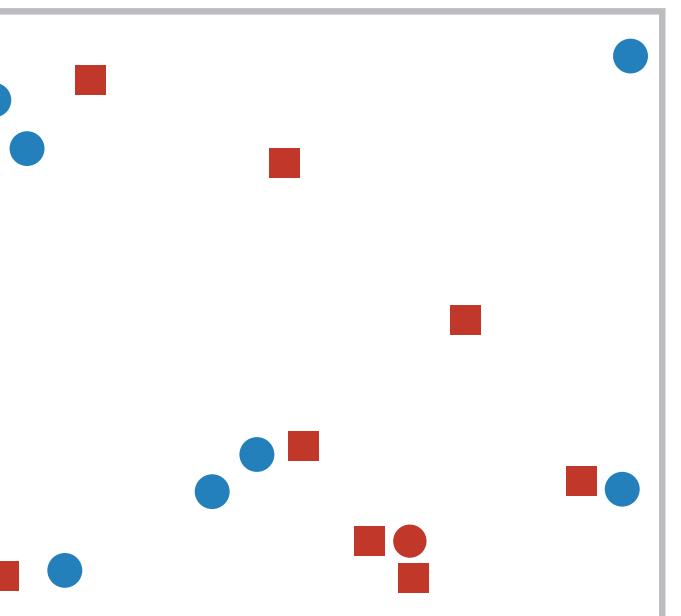
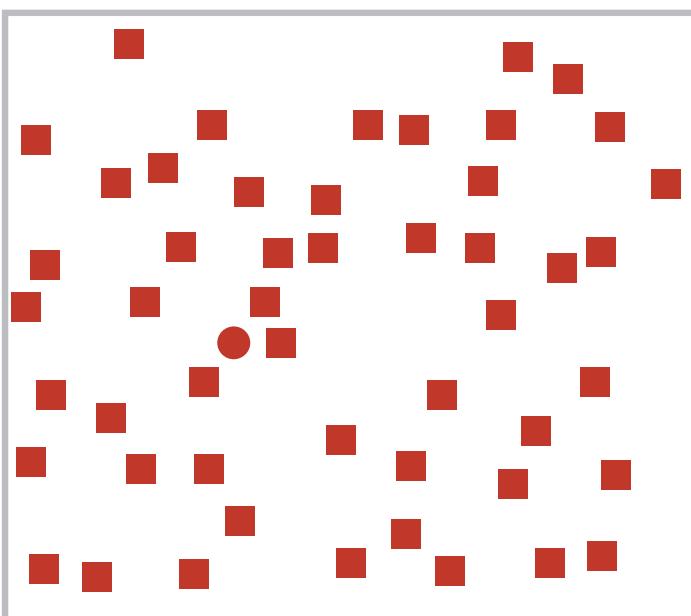
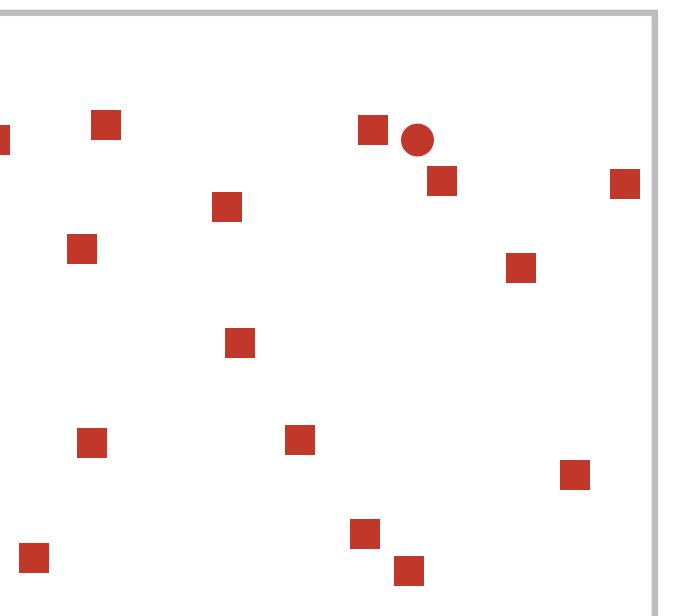
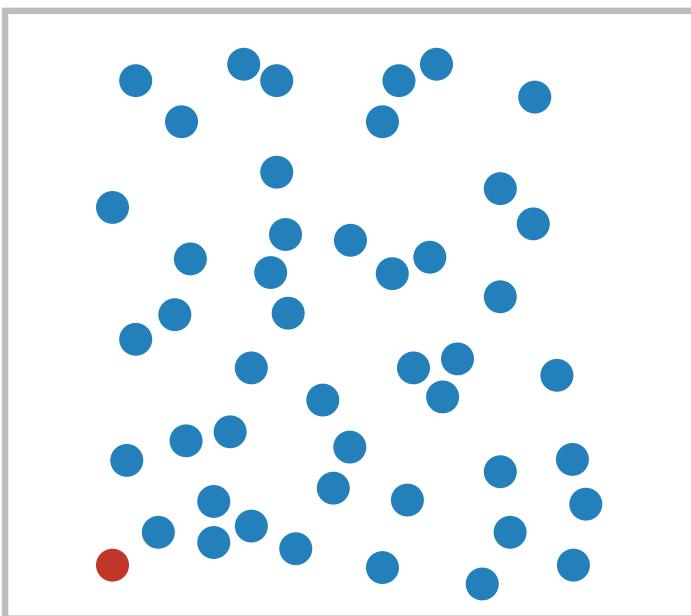
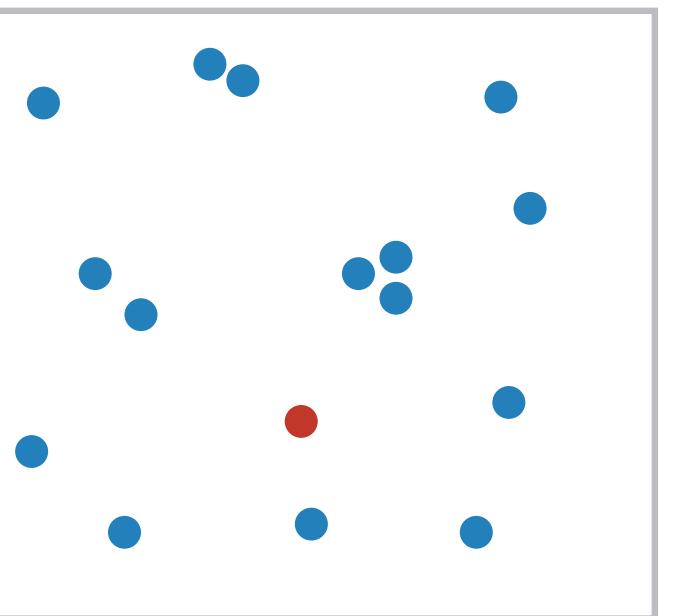
# Popout

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



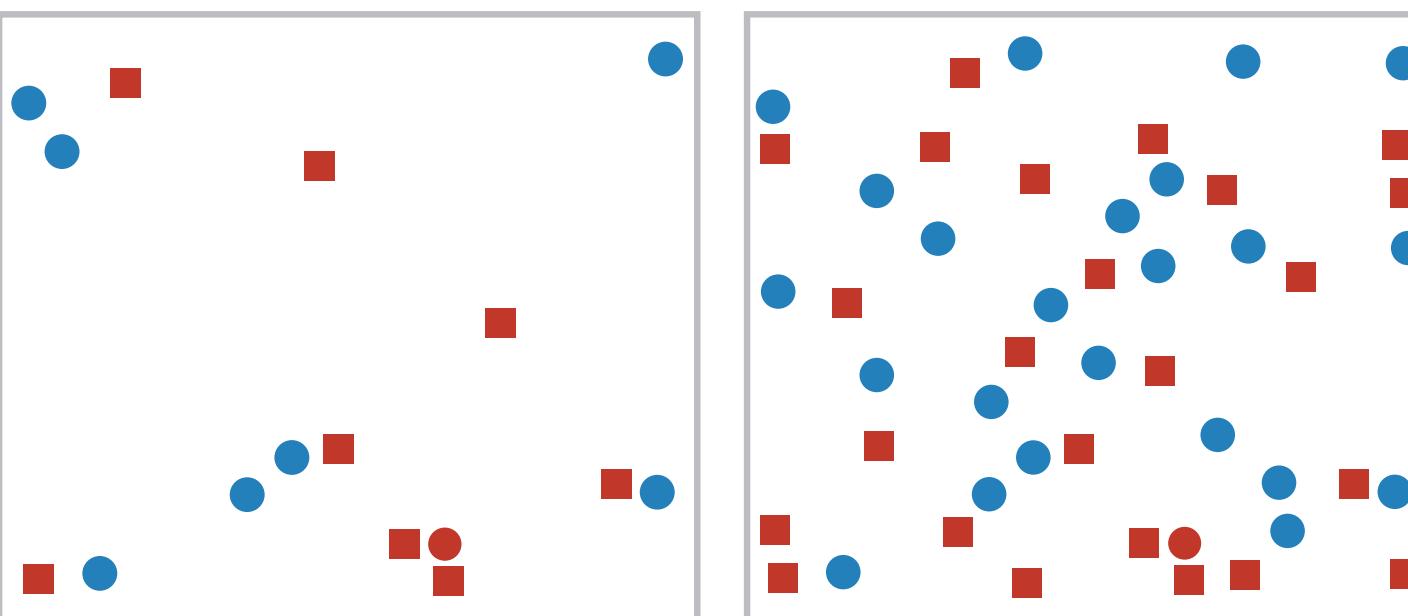
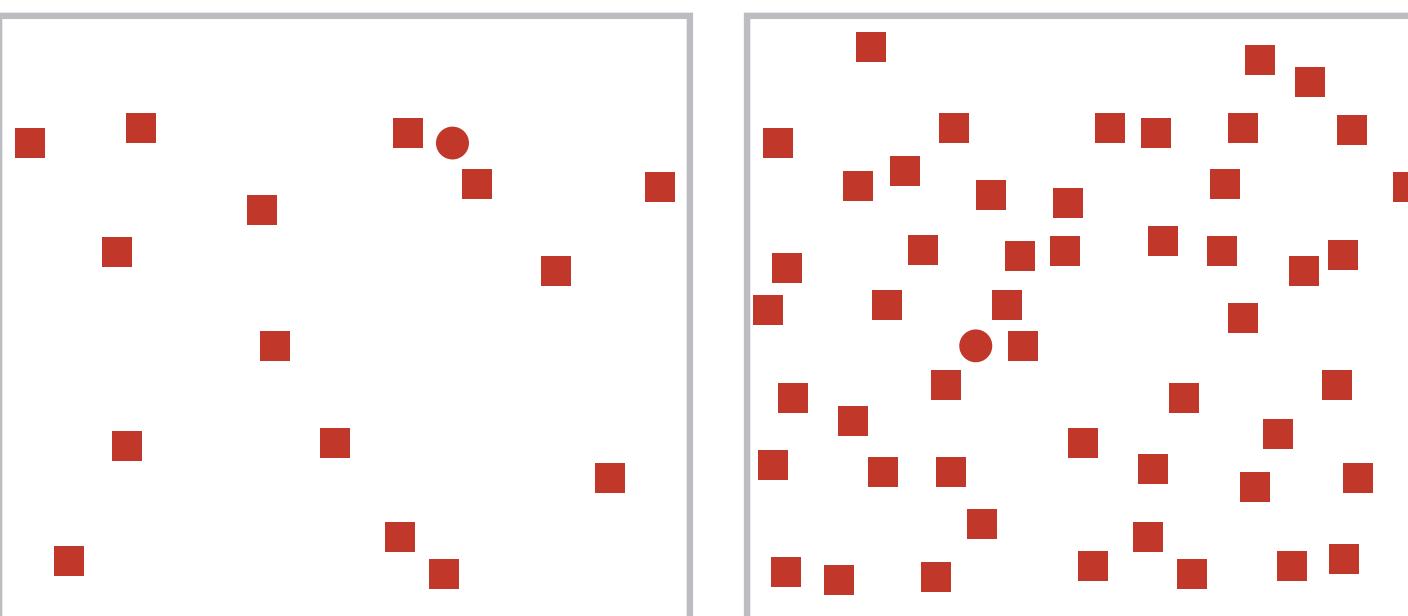
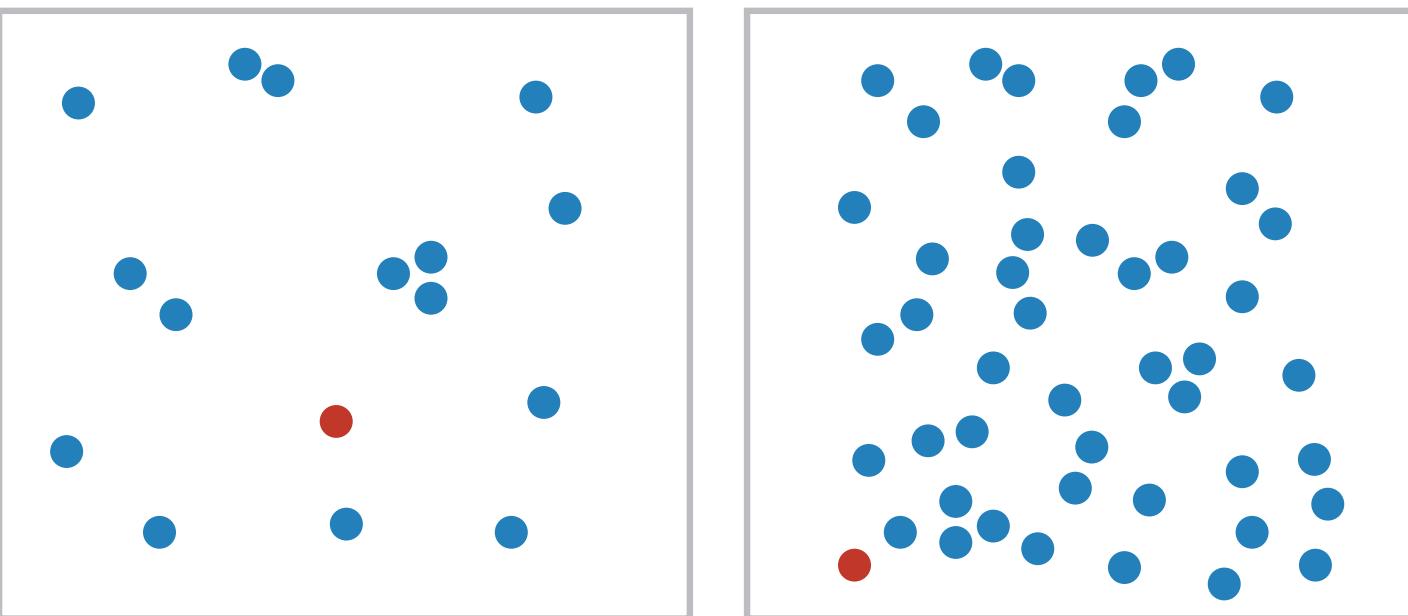
# Popout

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



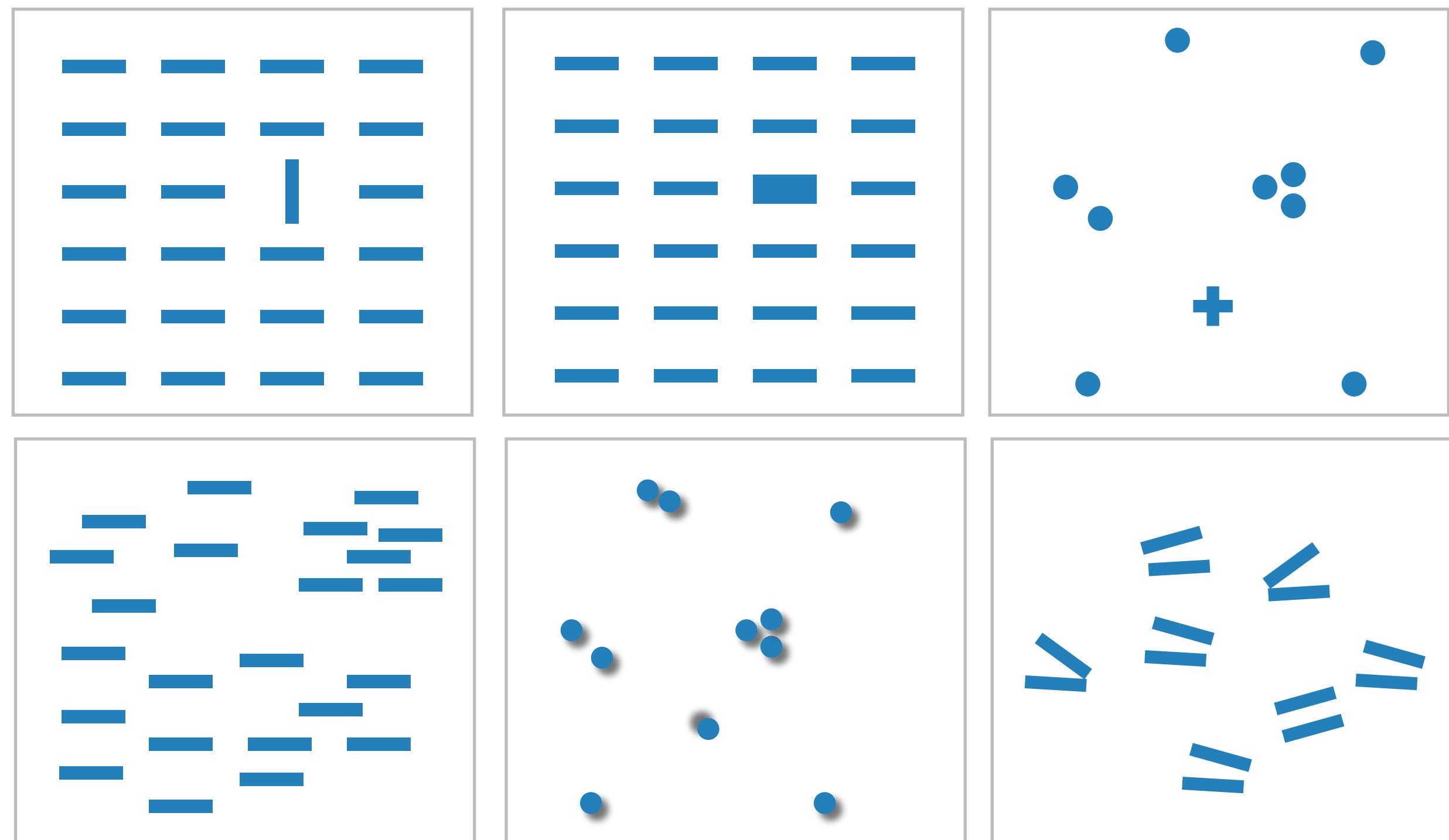
# Popout

- 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



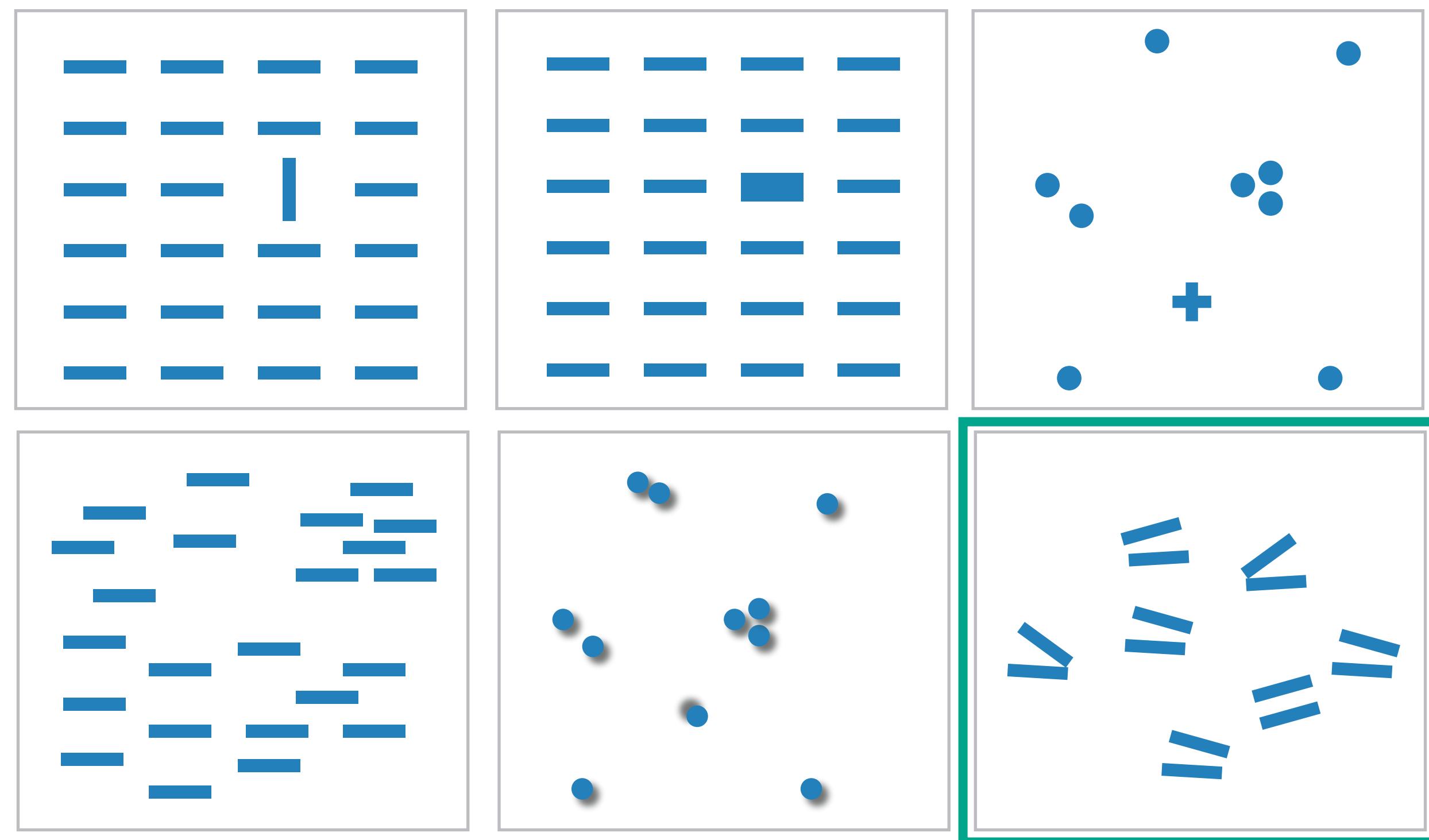
# Popout

- 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



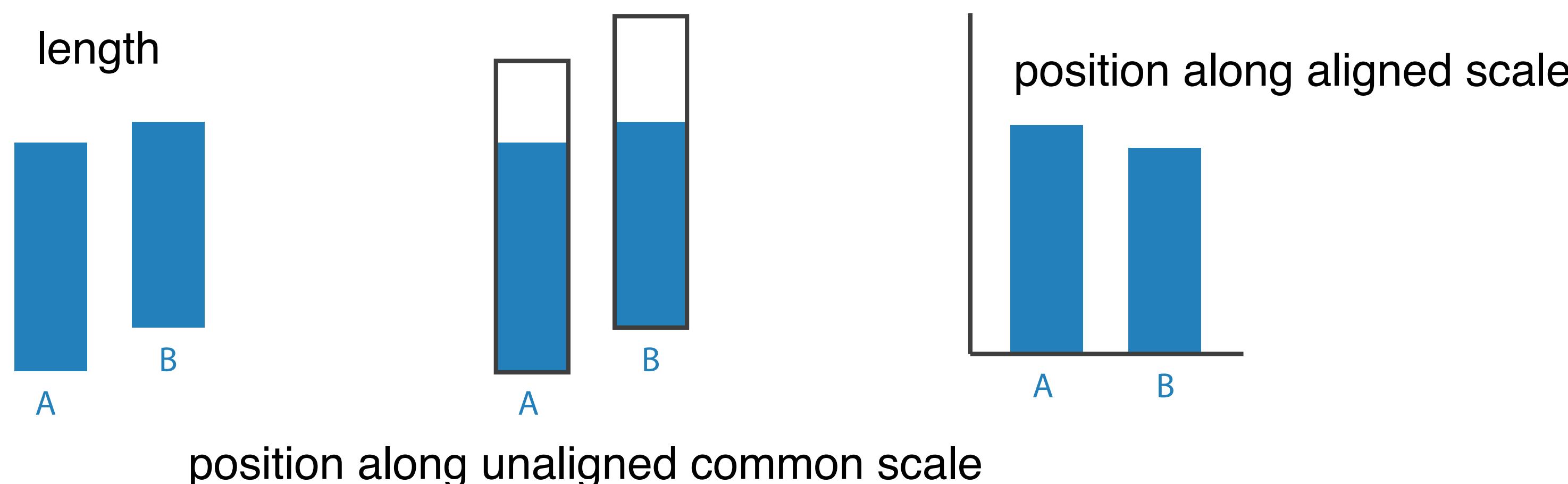
# Factors affecting accuracy

- alignment
- distractors
- distance
- common scale



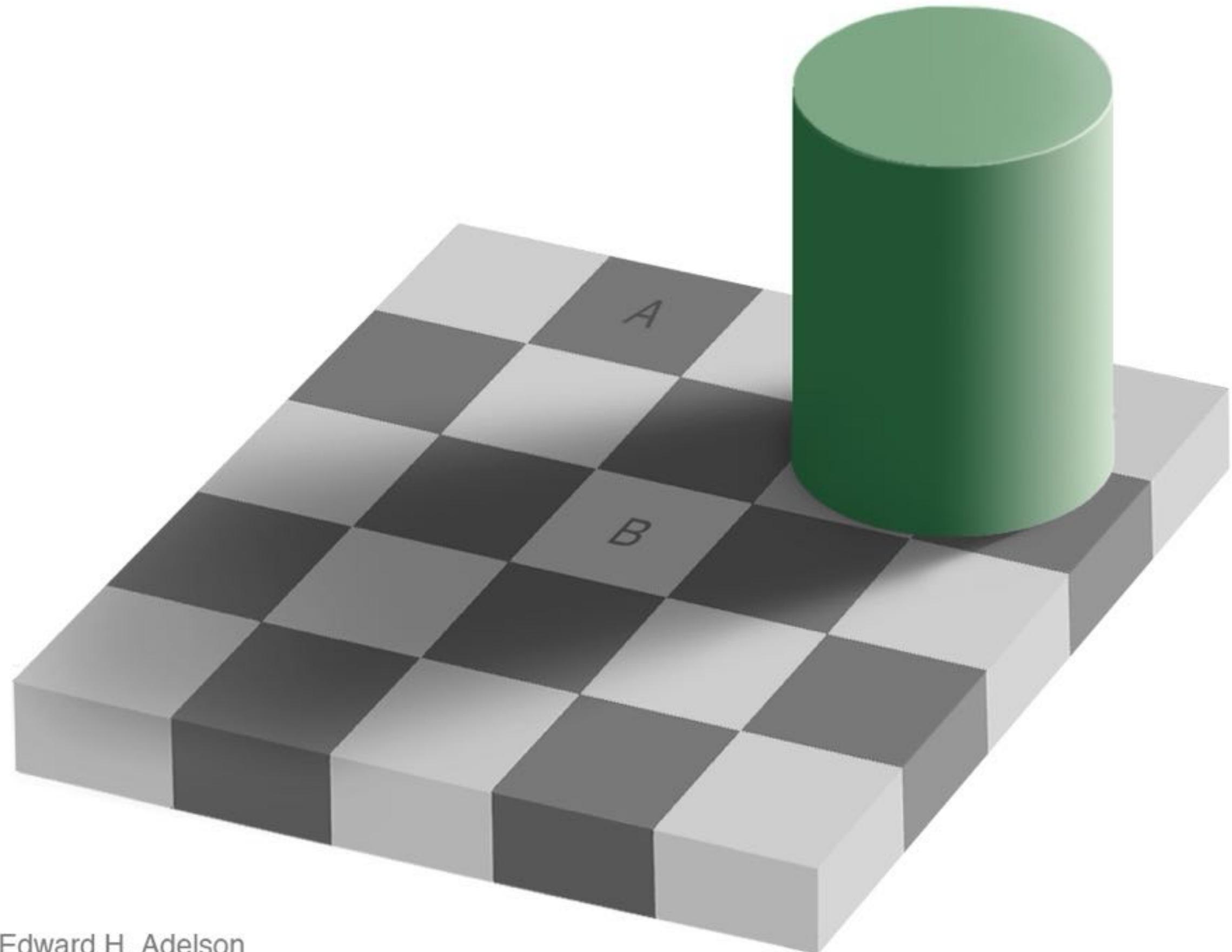
# Relative vs. absolute judgements

- 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 ( $\Delta S/S=k$  that depends on the type of stimulus)
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement



# Relative luminance judgements

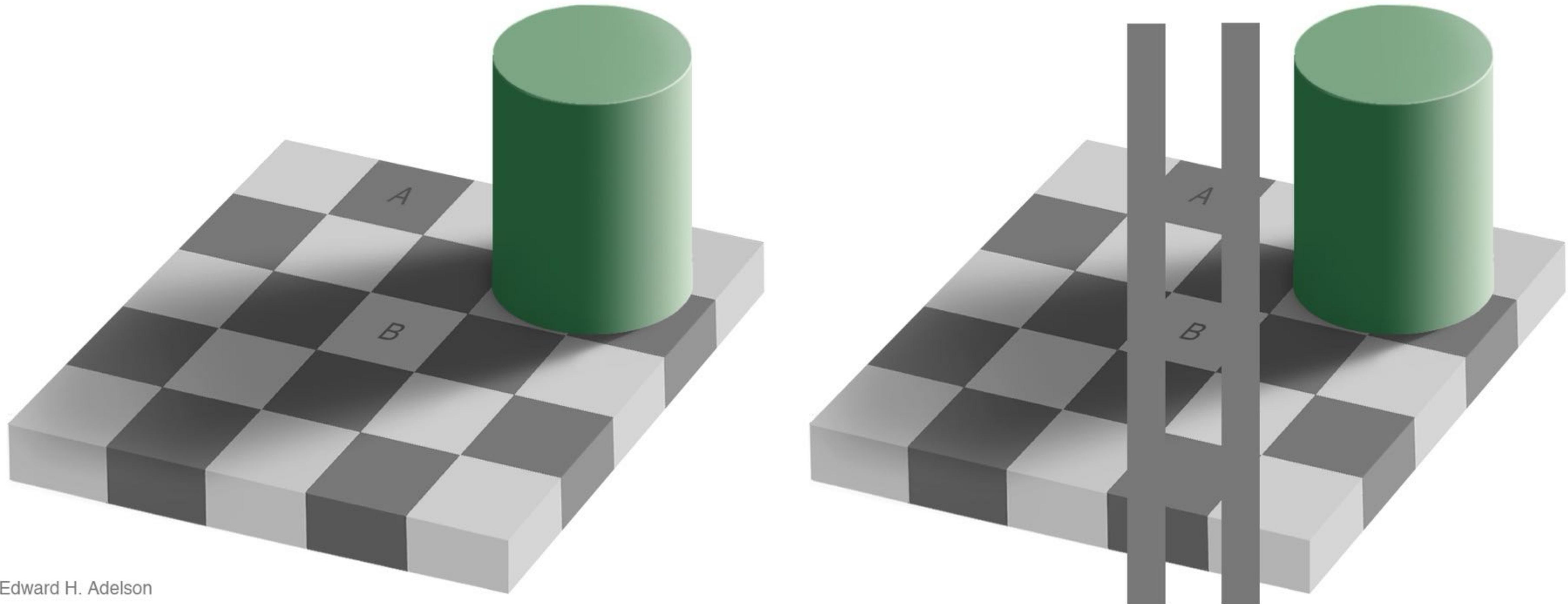
- perception of luminance is contextual based on the contrast with surroundings



Edward H. Adelson

# Relative luminance judgements

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

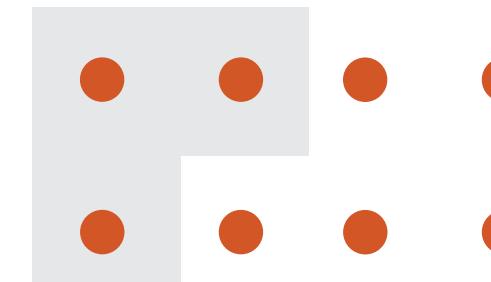


# Grouping

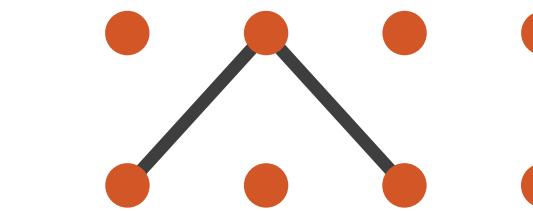
- containment
  - connection
- 
- proximity
    - same spatial region
  - similarity
    - same values as other categorical channels

## Marks as Links

### → Containment

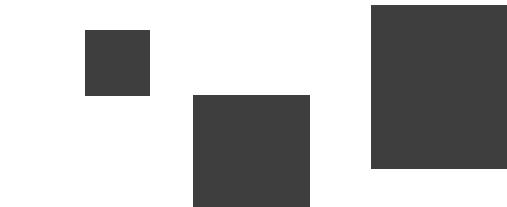


### → Connection

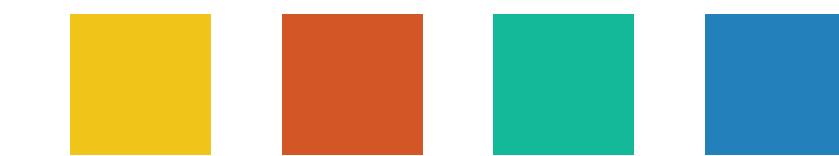


## Identity Channels: Categorical Attributes

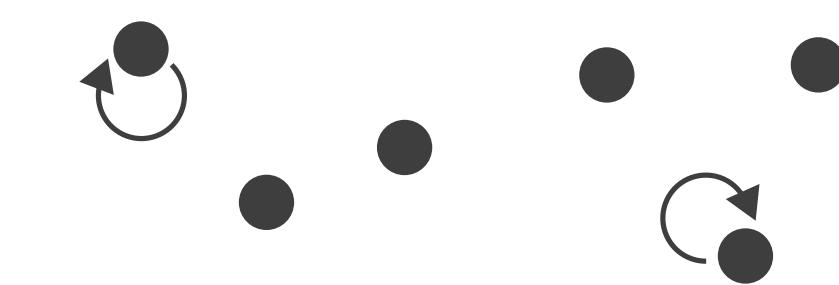
Spatial region



Color hue



Motion



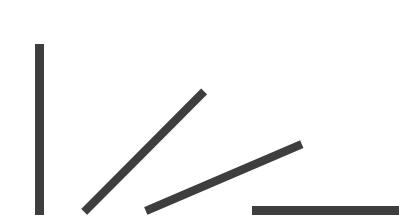
Shape



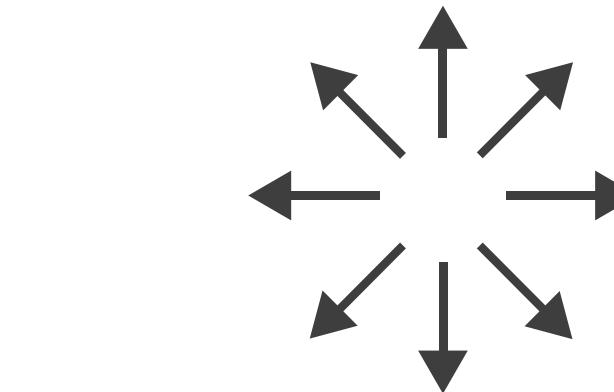
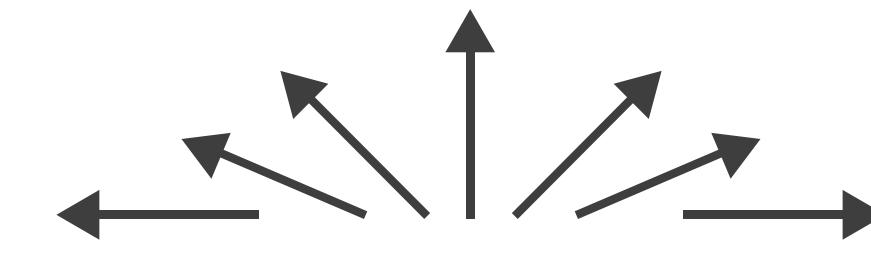
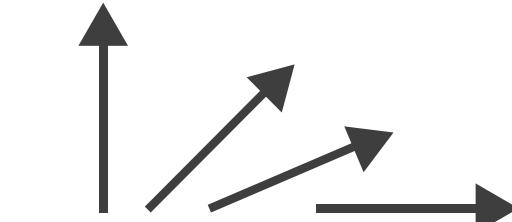
# Map Other Channels

# Angle / tilt / orientation channel

- different mappings depending on range used



Sequential ordered  
line mark or 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

## → Size

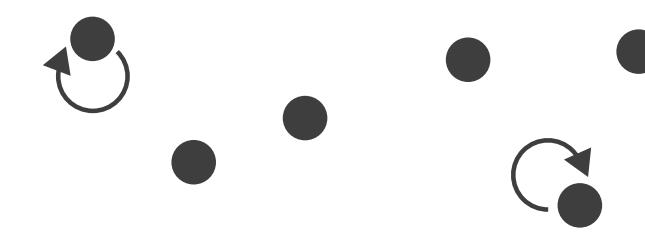


## → Shape



## → Motion

→ Motion  
*Direction, Rate,  
Frequency, ...*



# **Reading Material**

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

# Color

# Idiom design choices: Beyond spatial arrangement

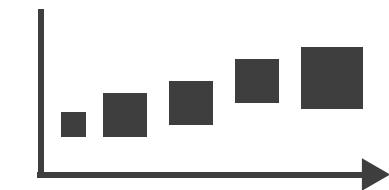
## Encode

### ④ Arrange

→ Express



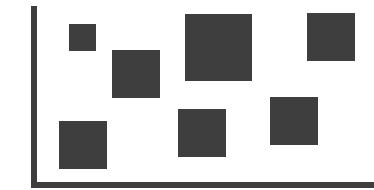
→ Order



→ Use



→ Separate



→ Align



### ④ Map

from **categorical** and **ordered** attributes

→ Color

→ Hue



→ Saturation



→ Luminance



→ Size, Angle, Curvature, ...

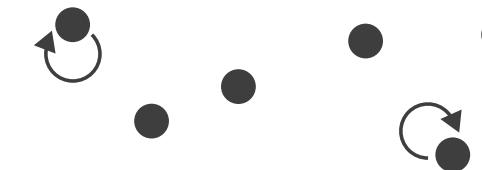


→ Shape



→ Motion

*Direction, Rate, Frequency, ...*



# Channels: What's up with color?

## → Magnitude Channels: Ordered Attributes

Position on common scale



Position on unaligned scale



Length (1D size)



Tilt/angle



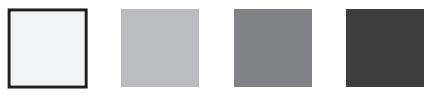
Area (2D size)



Depth (3D position)



Color luminance



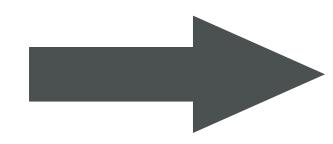
Color saturation



Curvature



Volume (3D size)

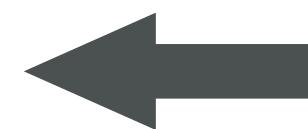


## → Identity Channels: Categorical Attributes

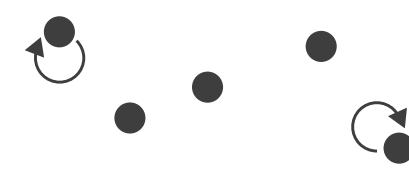
Spatial region



Color hue



Motion



Shape

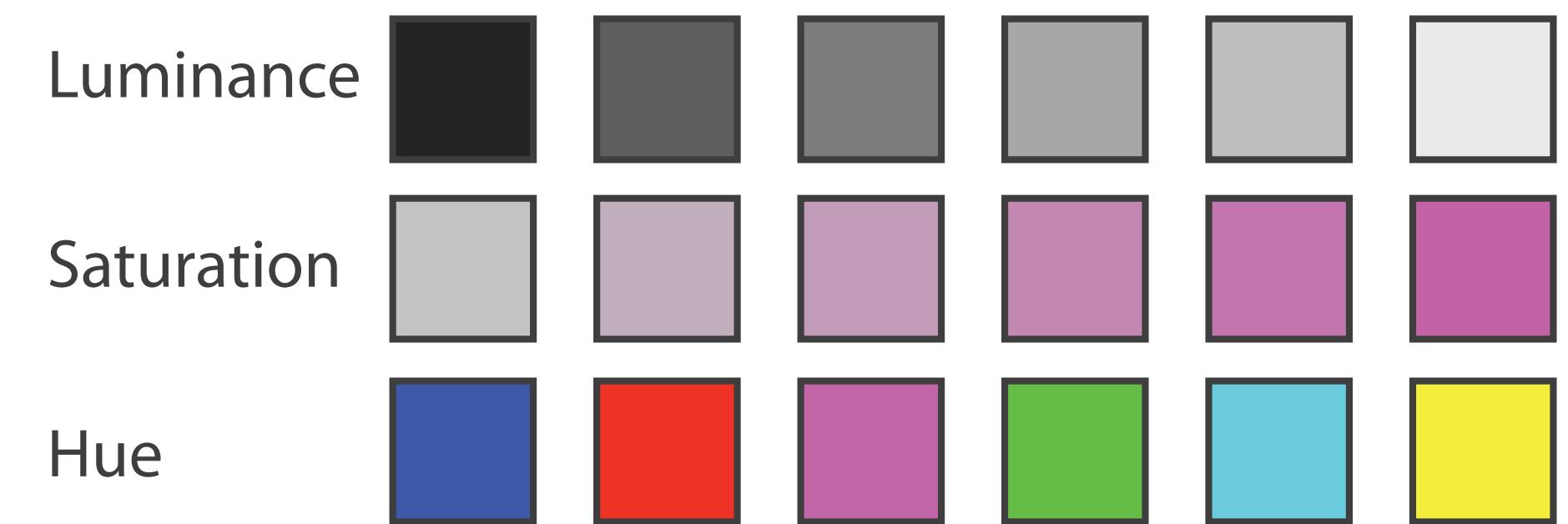


▲ Best  
Effectiveness  
Least ▼

[ Same ] [ Same ]

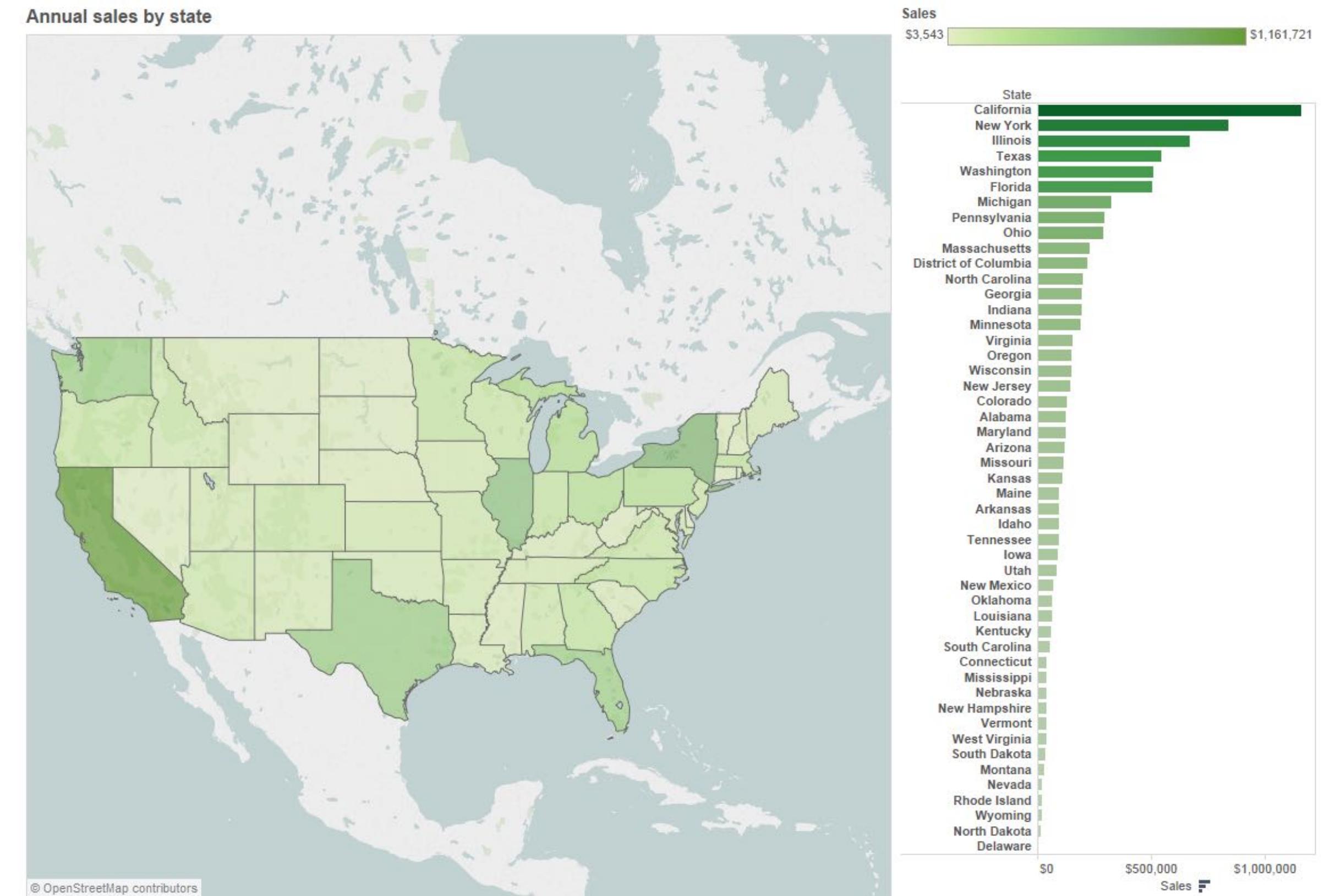
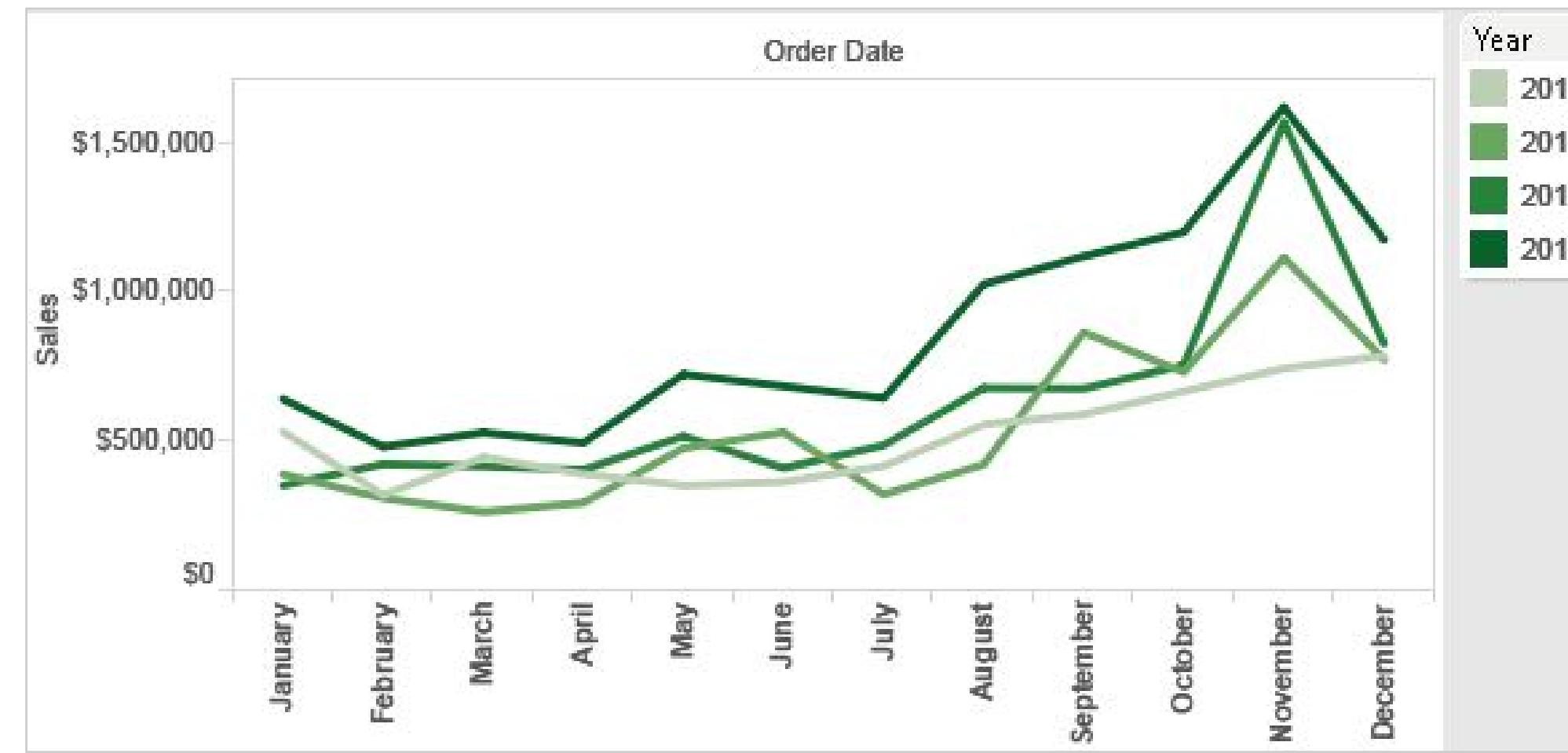
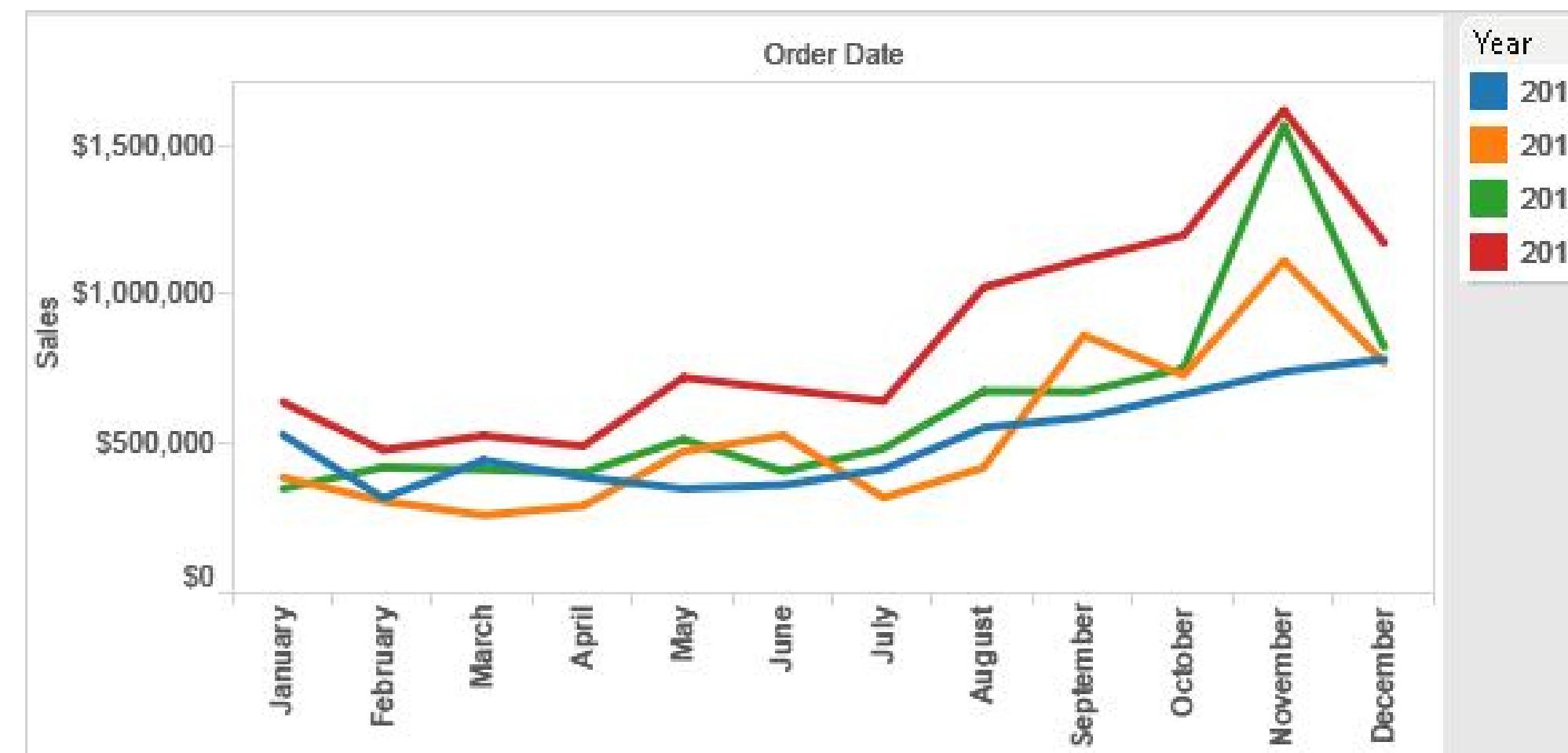
# Decomposing color

- 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?



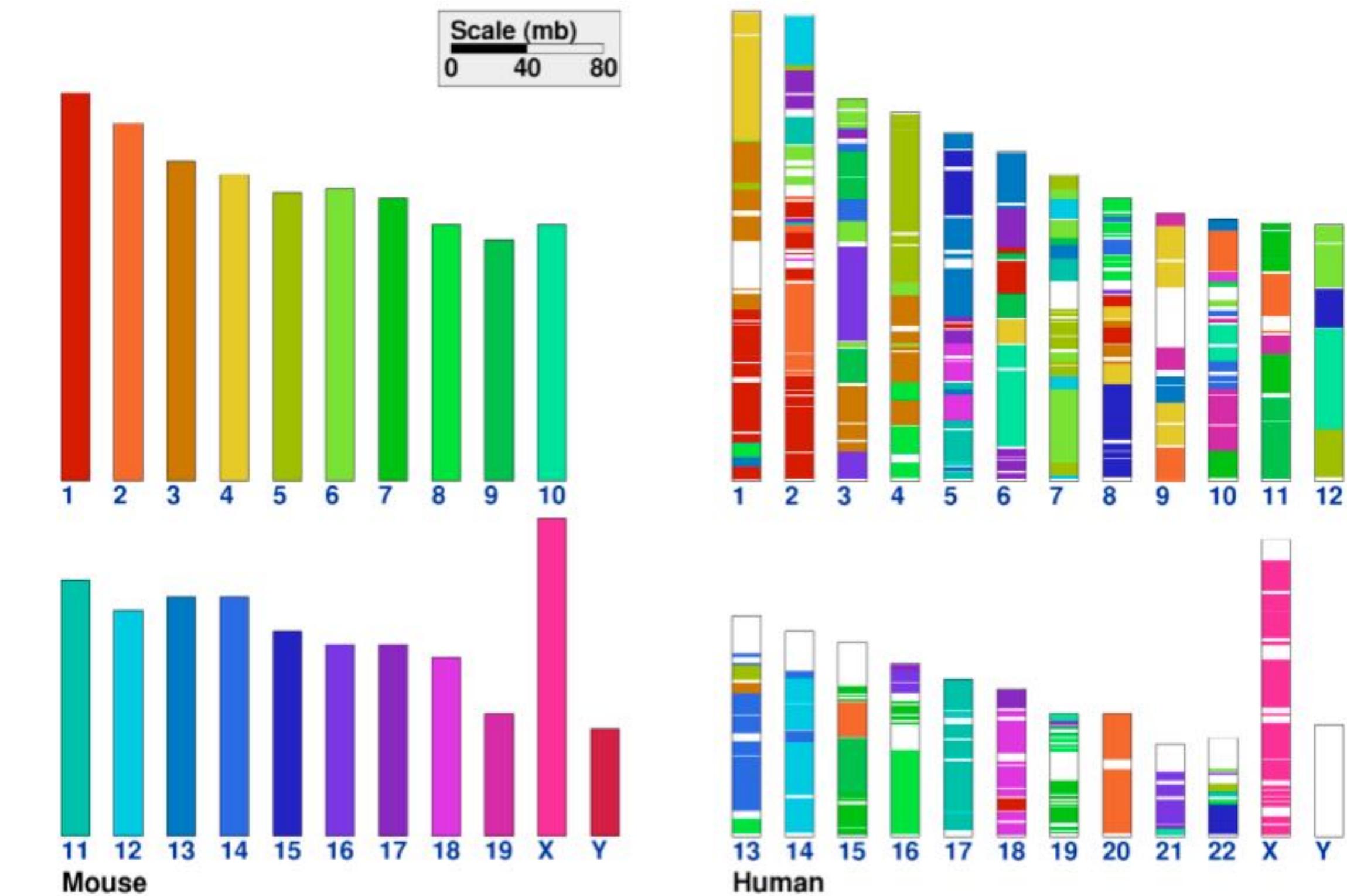
# Color Channels in Visualization

# Categorical vs ordered color



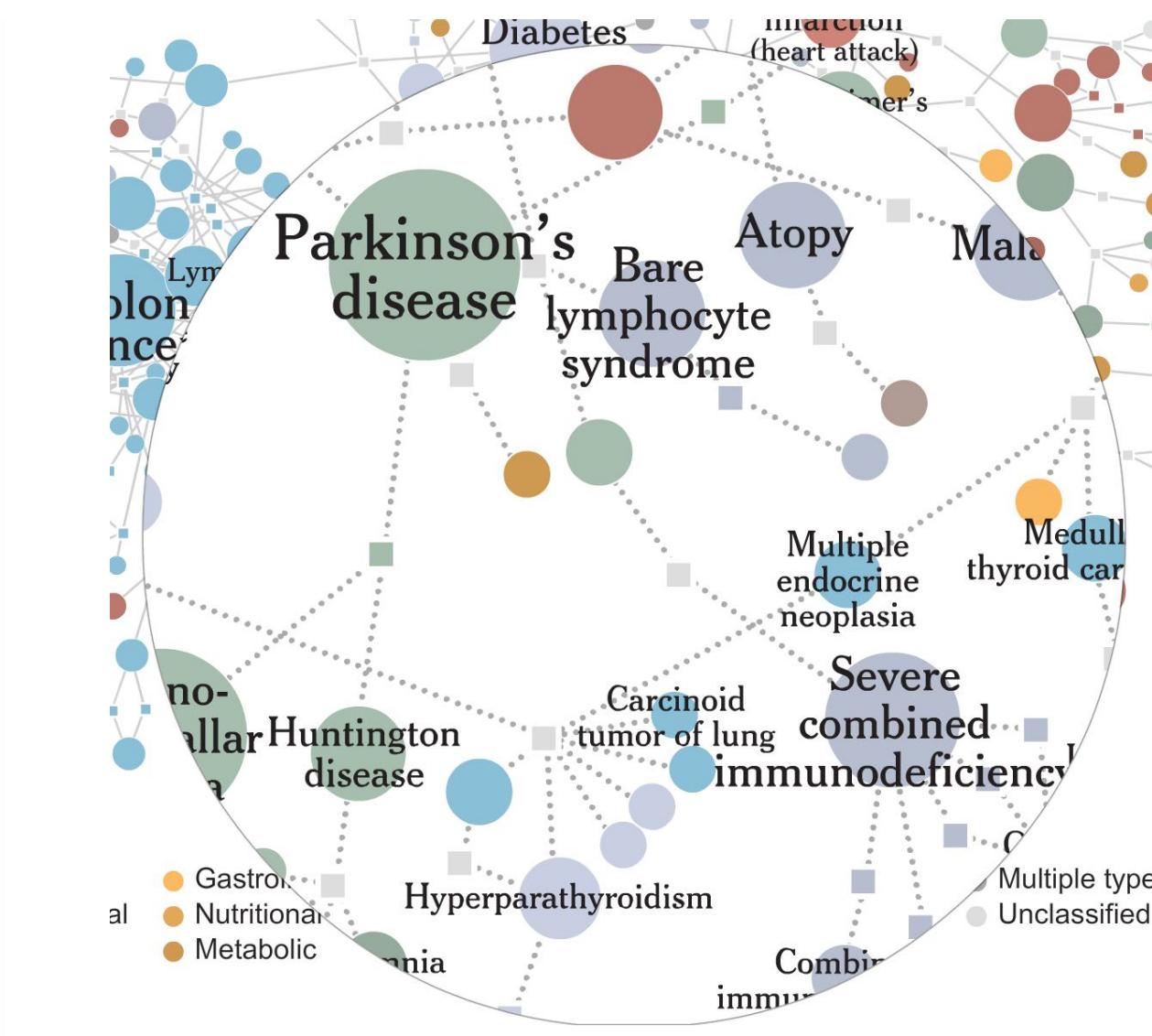
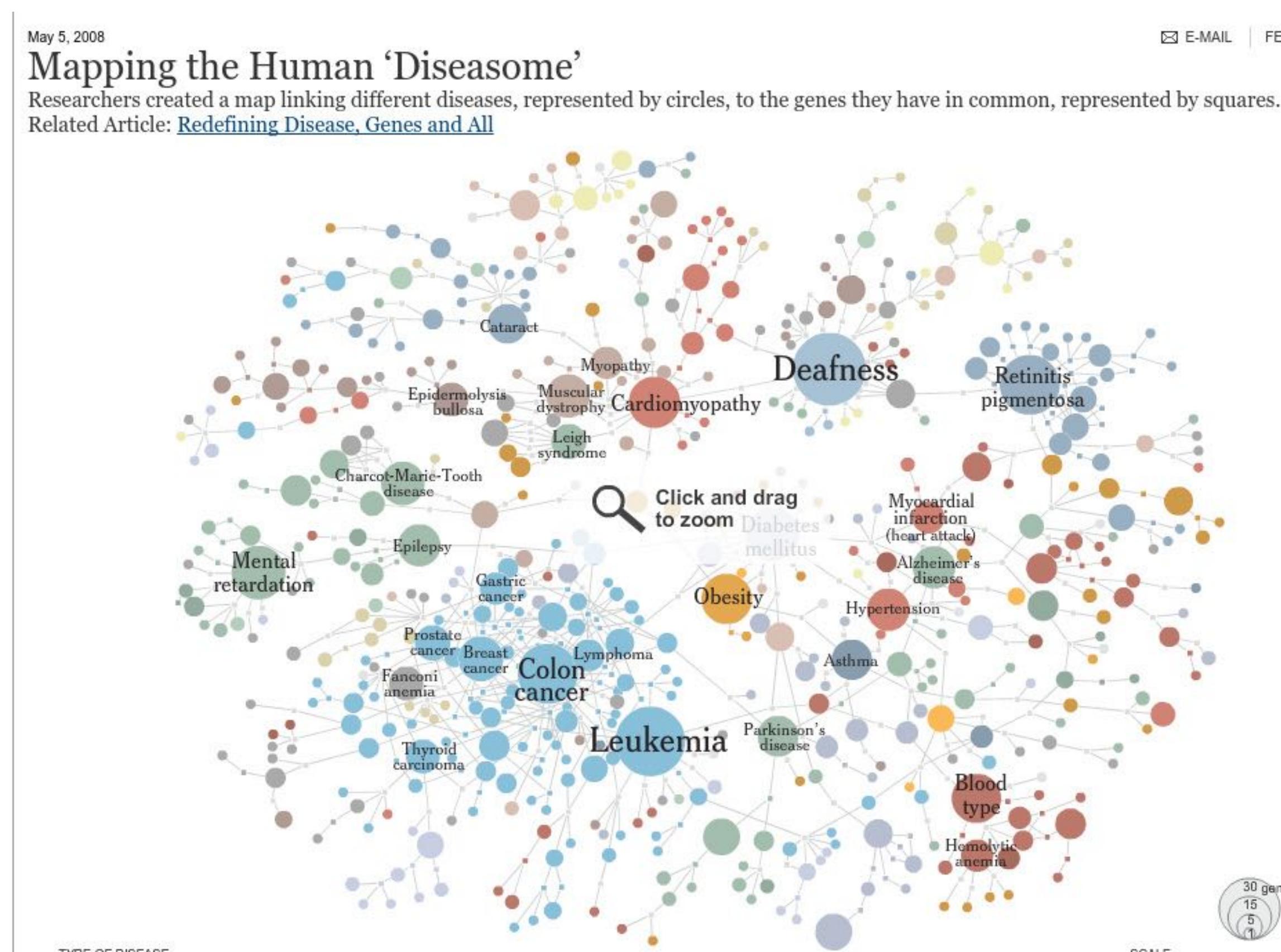
# Categorical color: limited number of discriminable bins

- 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

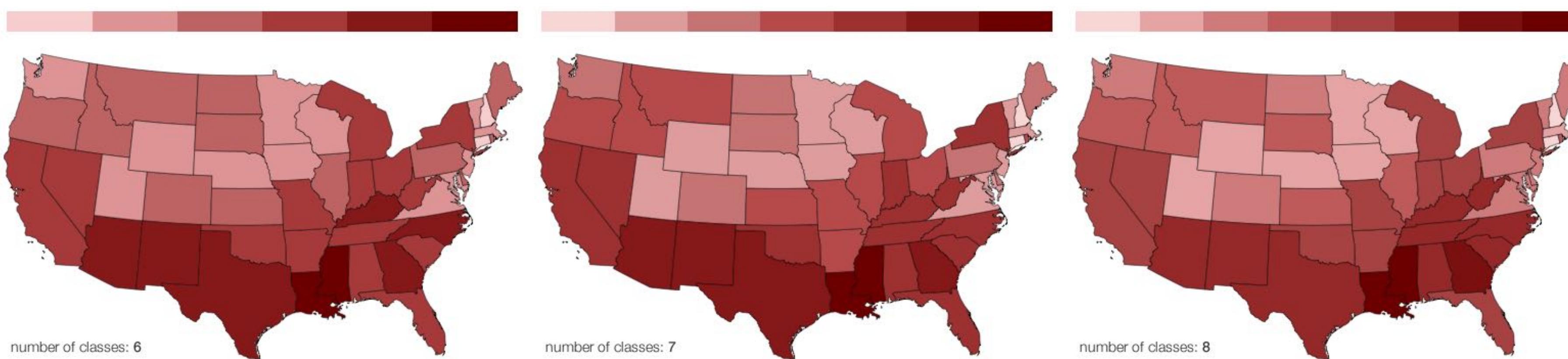
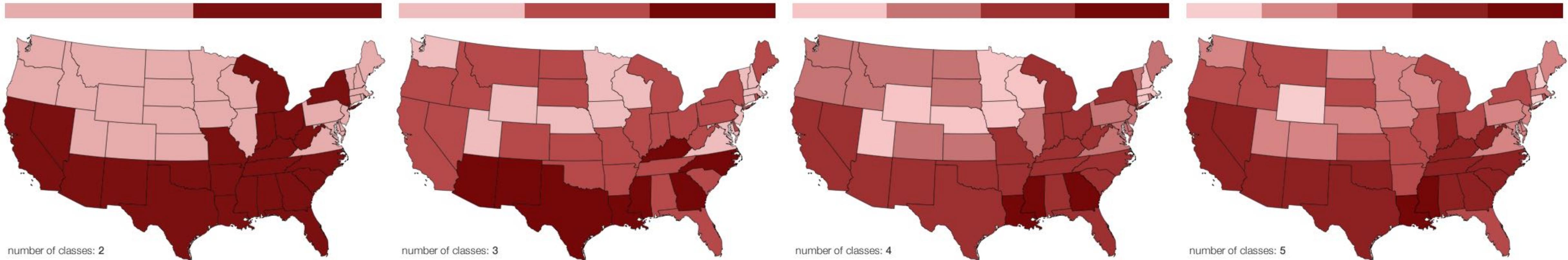


# Categorical color: limited number of discriminable bins

- Cancer
- Connective tissue
- Cardiovascular
- Endocrine
- Gastrointestinal
- Ear, nose, throat
- Developmental
- Multiple types
- Bone
- Muscular
- Hematological
- Immunological
- Nutritional
- Ophthalmological
- Neurological
- Unclassified
- Skeletal
- Dermatological
- Renal
- Myopathy
- Muscular dystrophy
- Leigh syndrome
- Epidermolysis bullosa
- Charcot-Marie-Tooth disease
- Mental retardation
- Epilepsy
- Prostate cancer
- Breast cancer
- Thyroid carcinoma
- Leukemia
- Colon cancer
- Lymphoma
- Gastric cancer
- Fanconi anemia
- Cataract
- Deafness
- Retinitis pigmentosa
- Myocardial infarction (heart attack)
- Hypertension
- Asthma
- Parkinson's disease
- Blood type
- Hemolytic anemia
- Diabetes mellitus
- Obesity
- Atopy
- Bare lymphocyte syndrome
- Multiple endocrine neoplasia
- Carcinoid tumor of lung
- Hyperparathyroidism
- Combin immunodeficiency
- Multiple types
- Unclassified

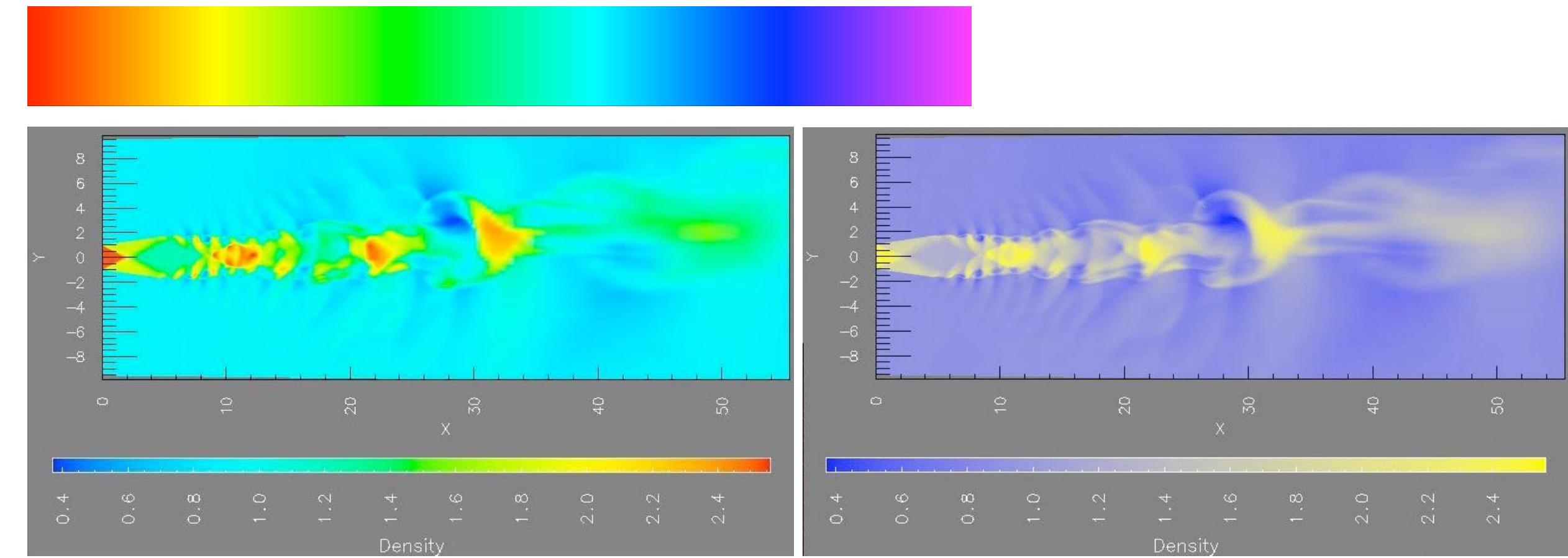


# Ordered color: limited number of discriminable bins

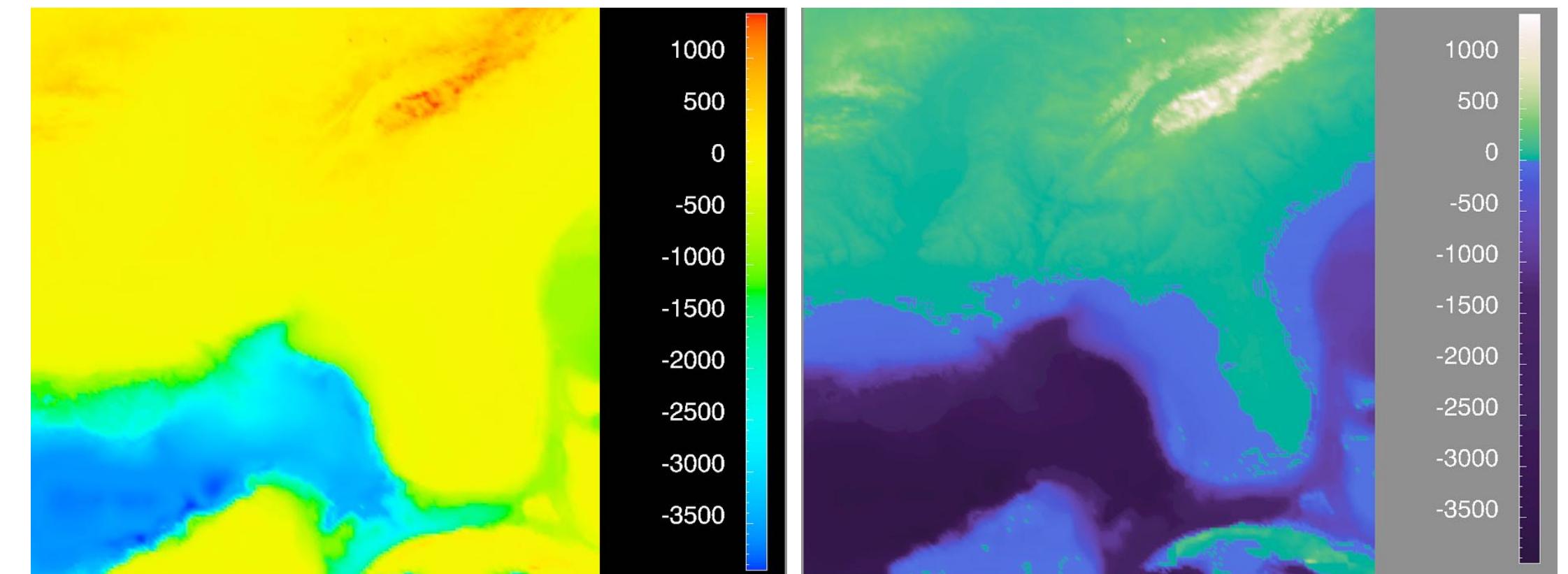


# Ordered color: Rainbow is poor default

- 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]



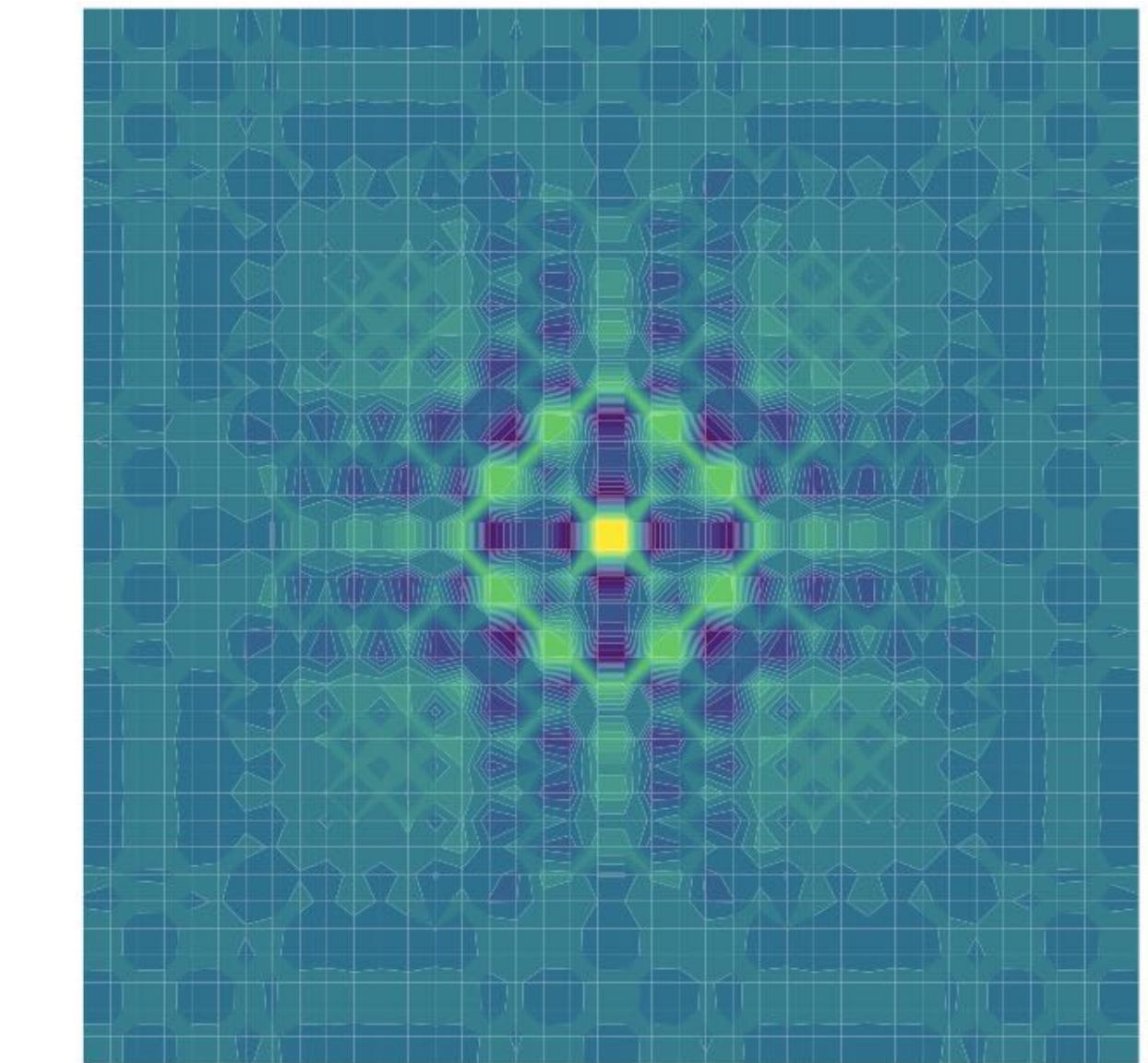
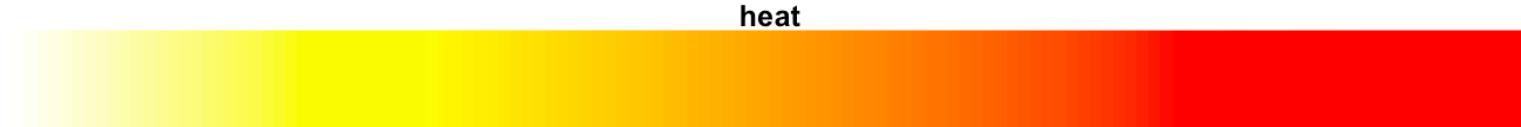
[A Rule-based Tool for Assisting Colormap Selection. Bergman., Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis). pp. 118–125. 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998]

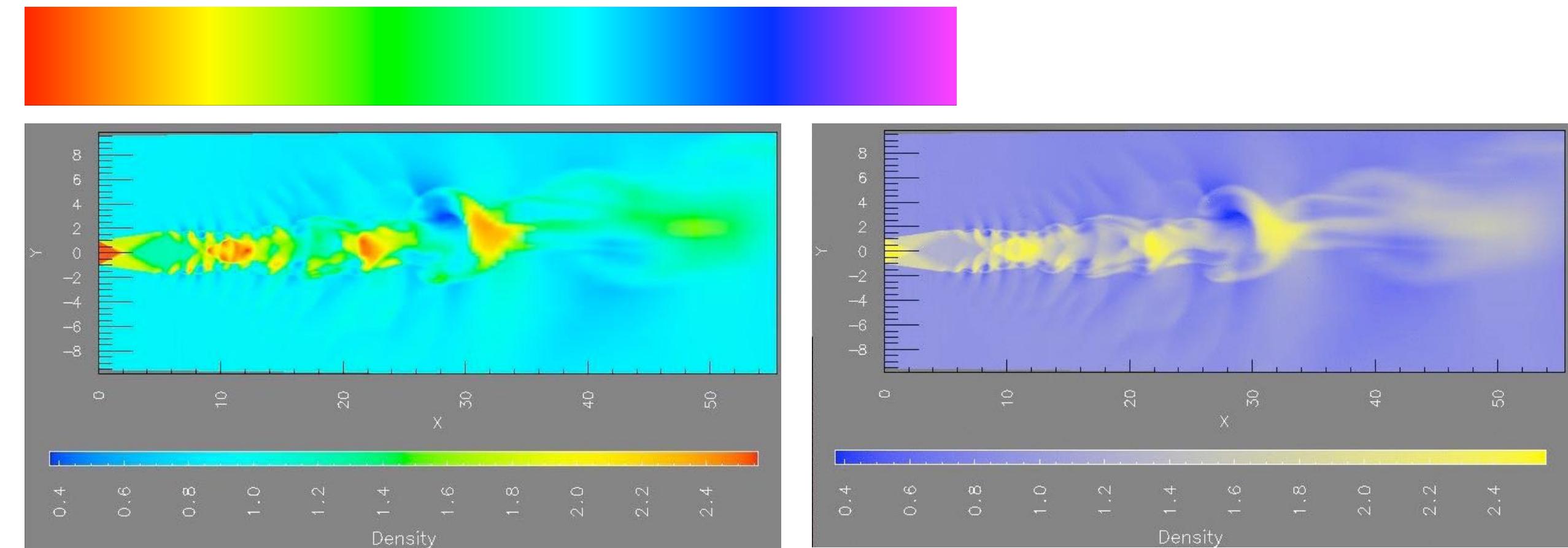
# Viridis / Magma: sequential colormaps

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

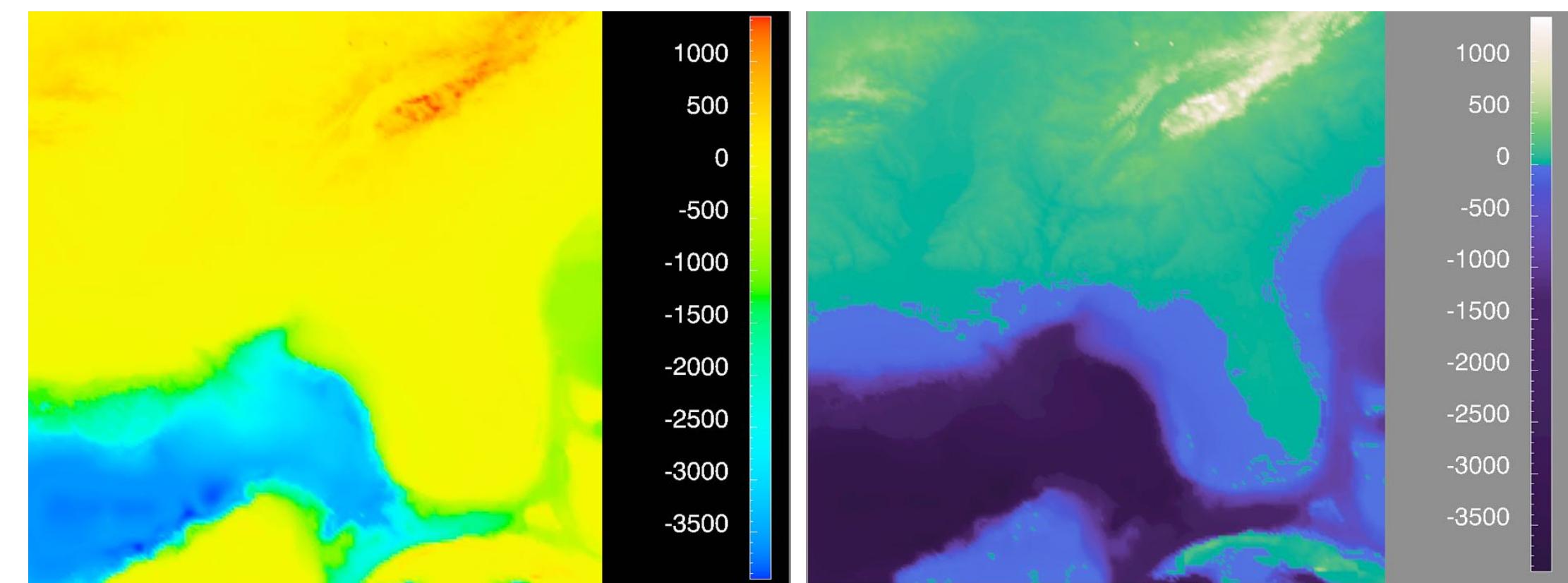


# Ordered color: Rainbow is poor default

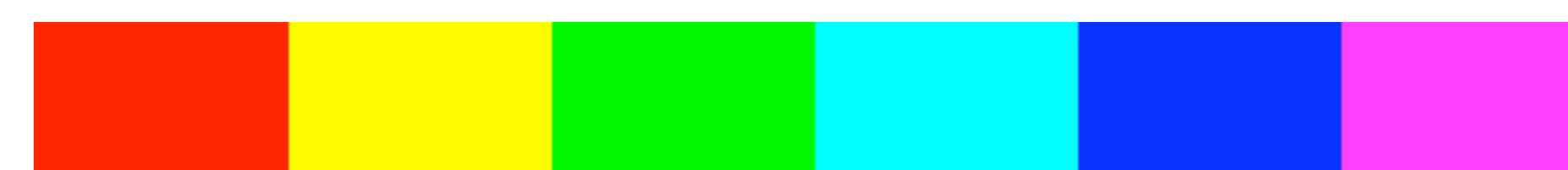
- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented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



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



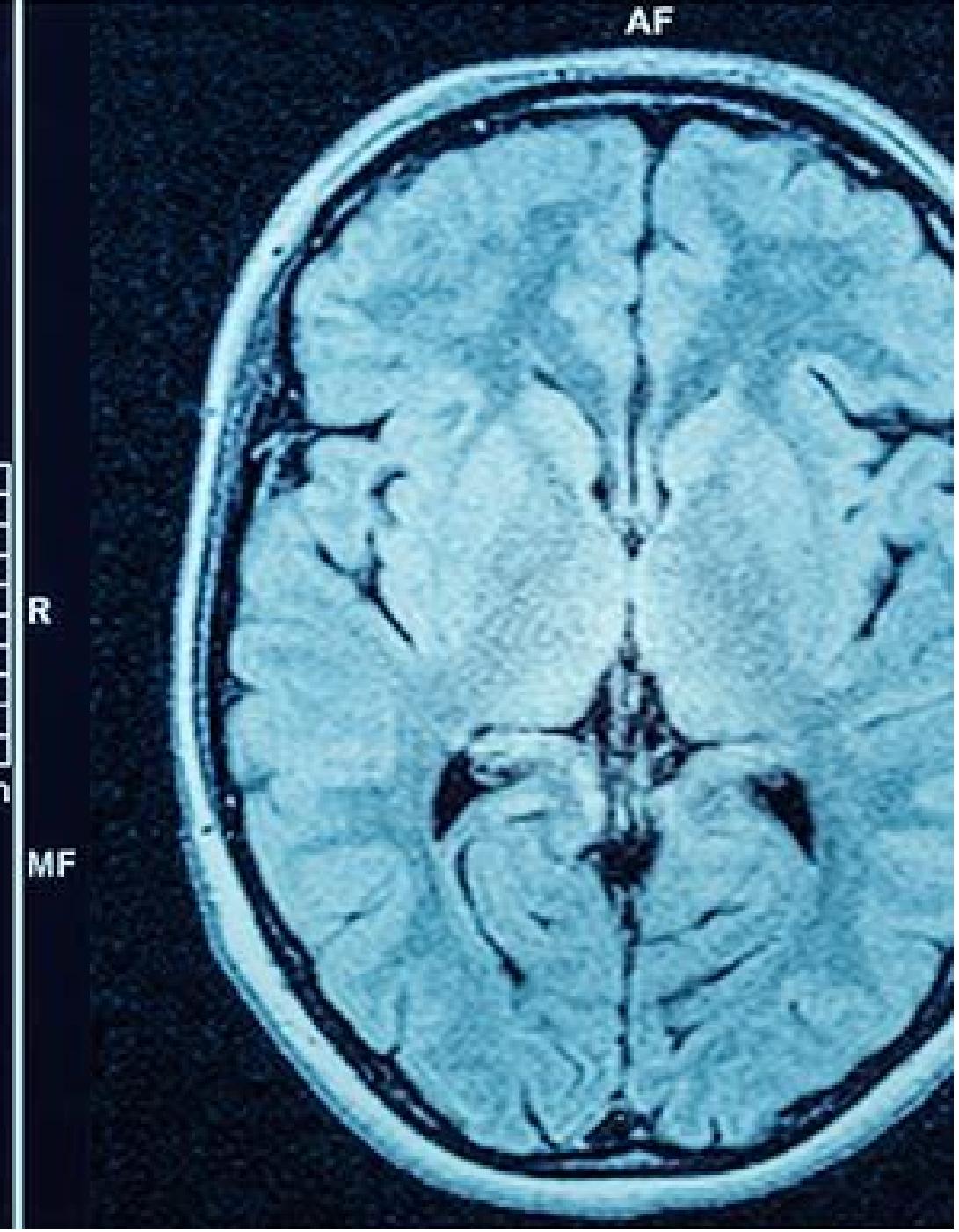
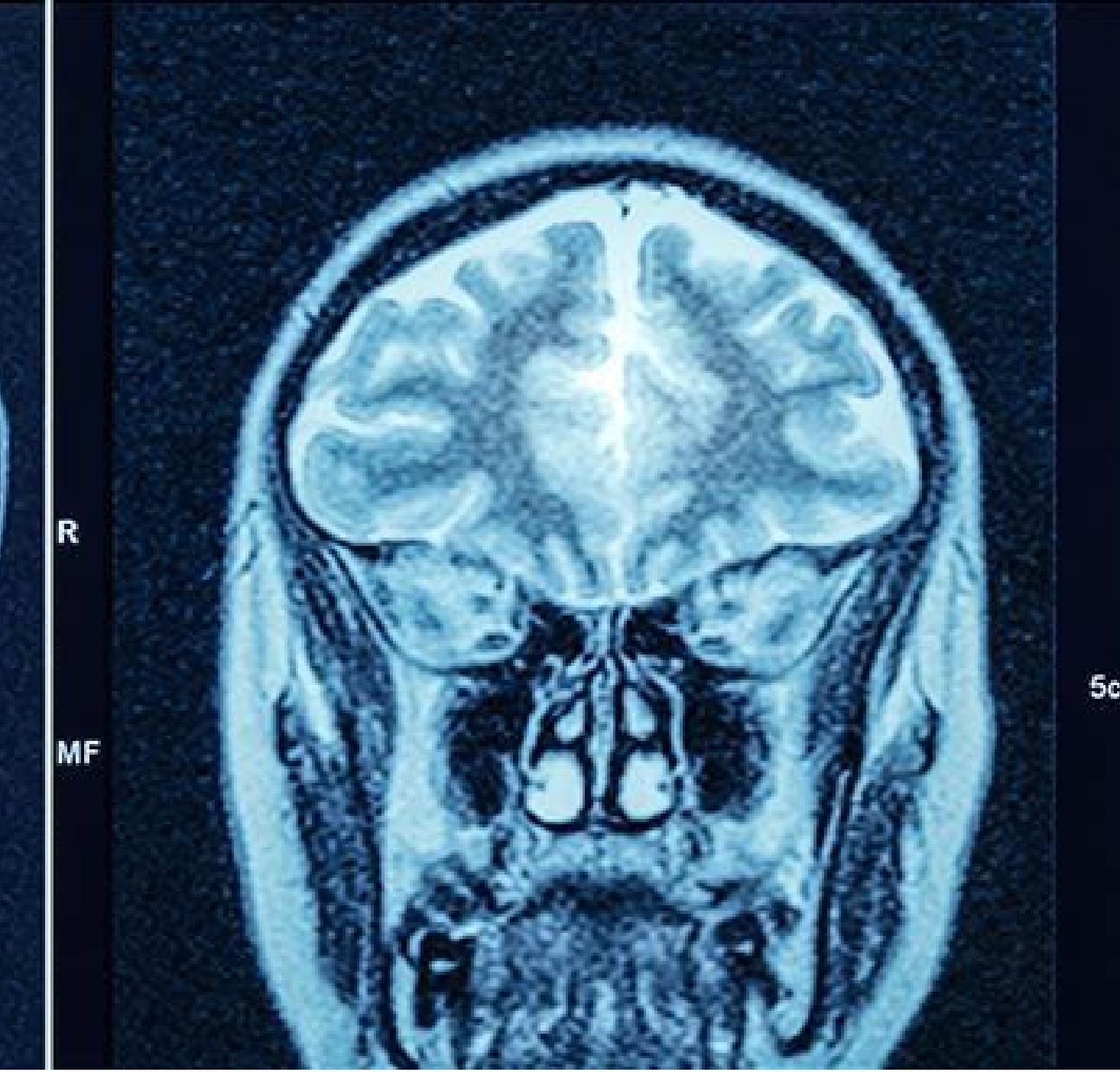
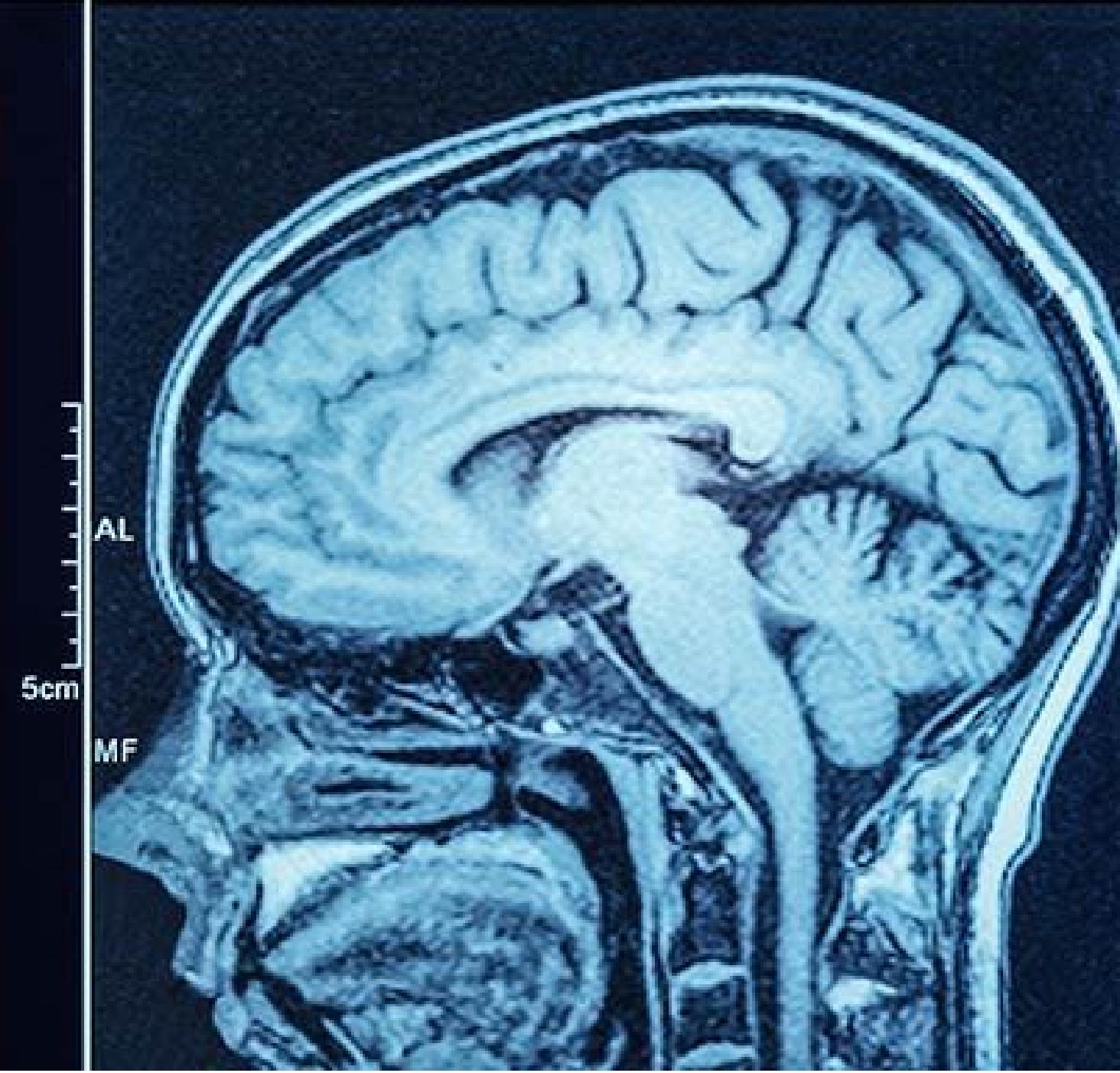
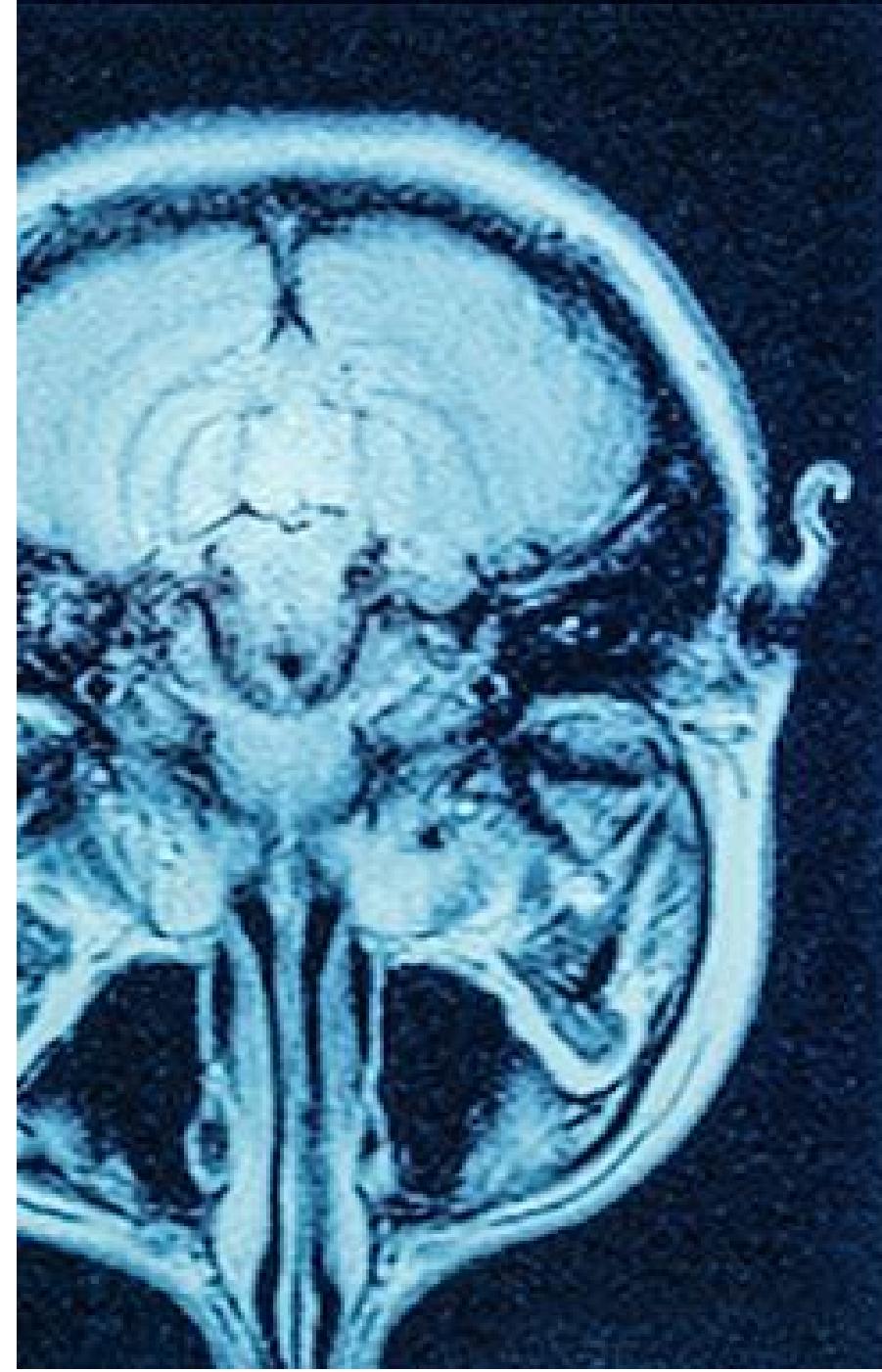
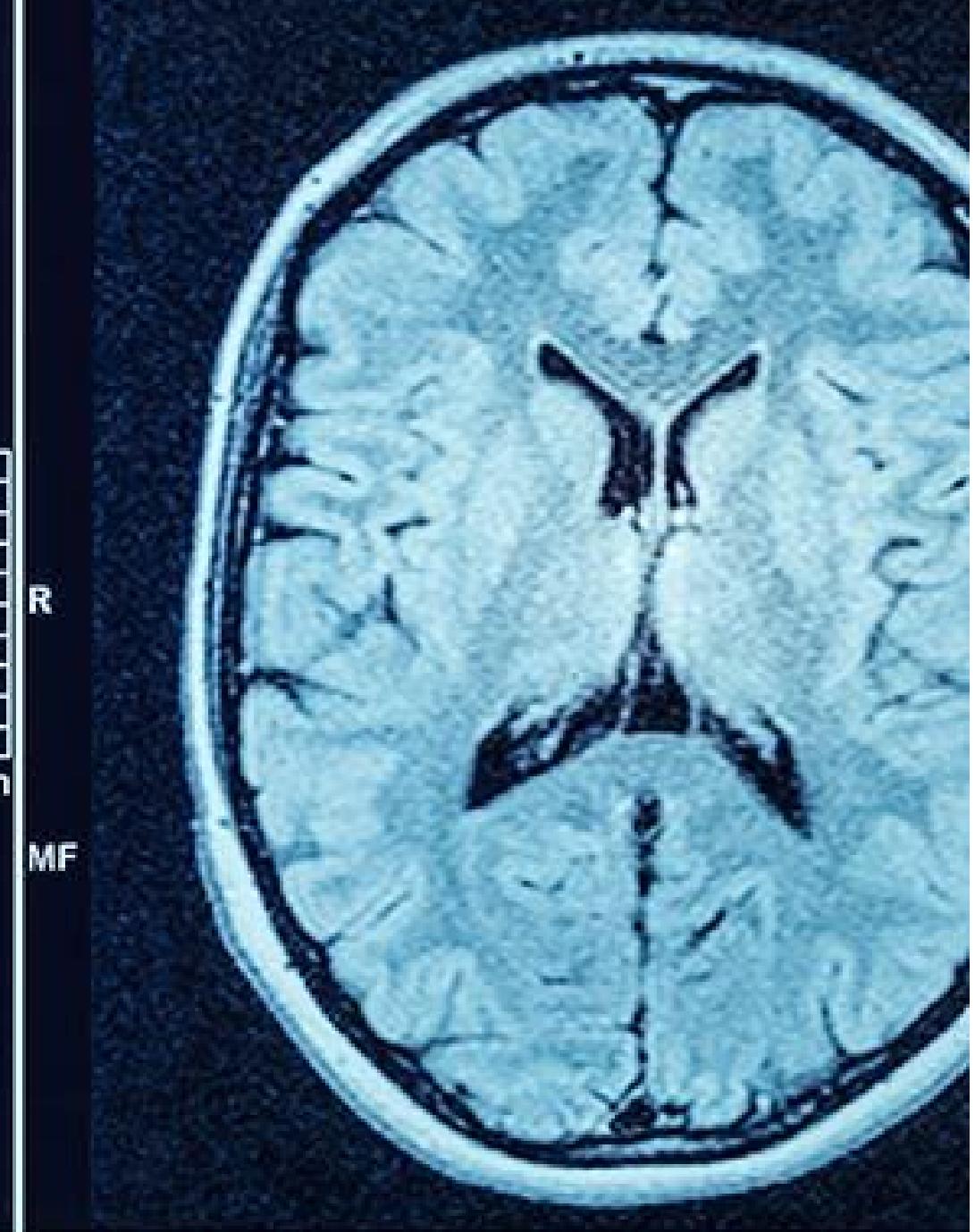
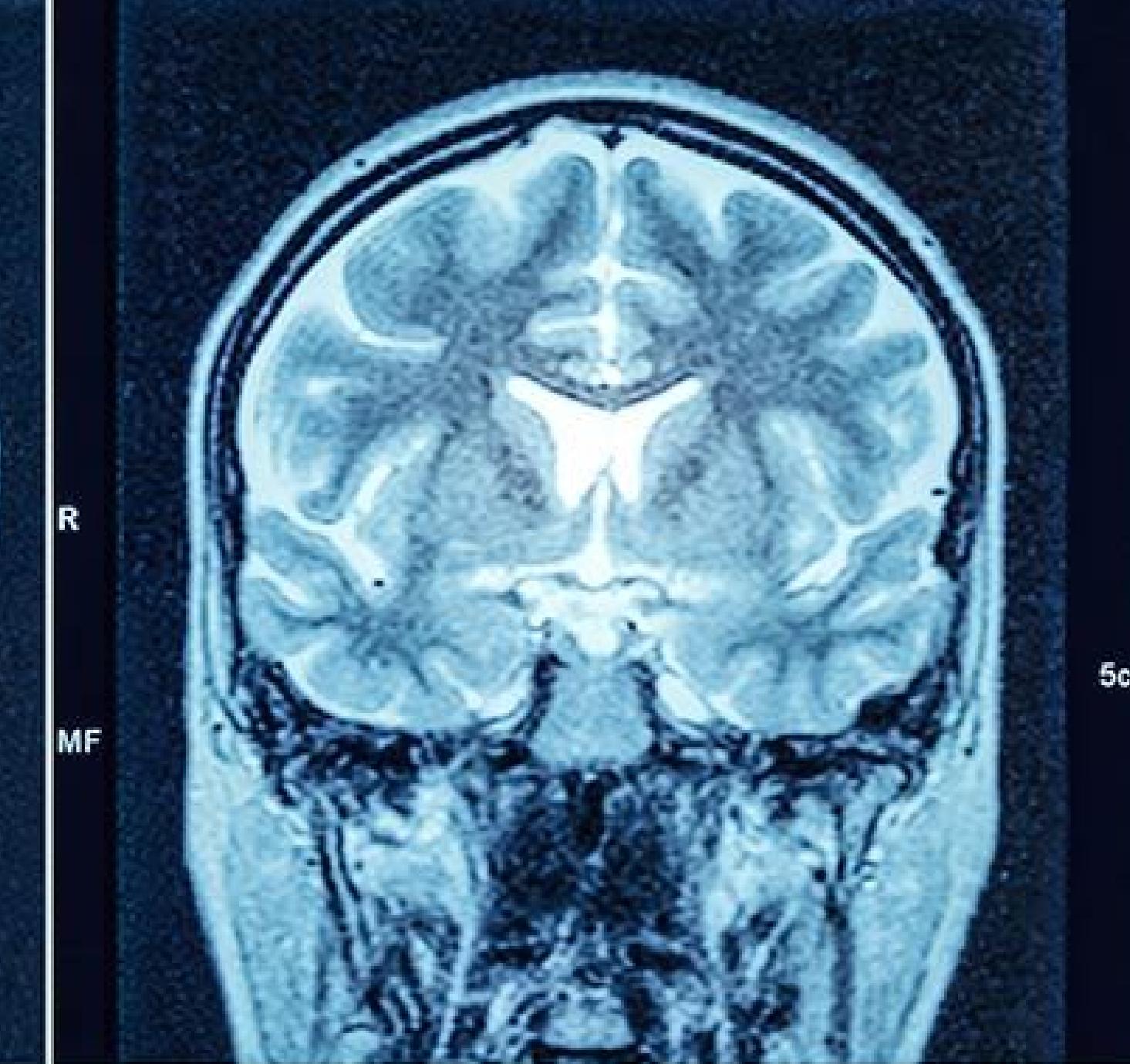
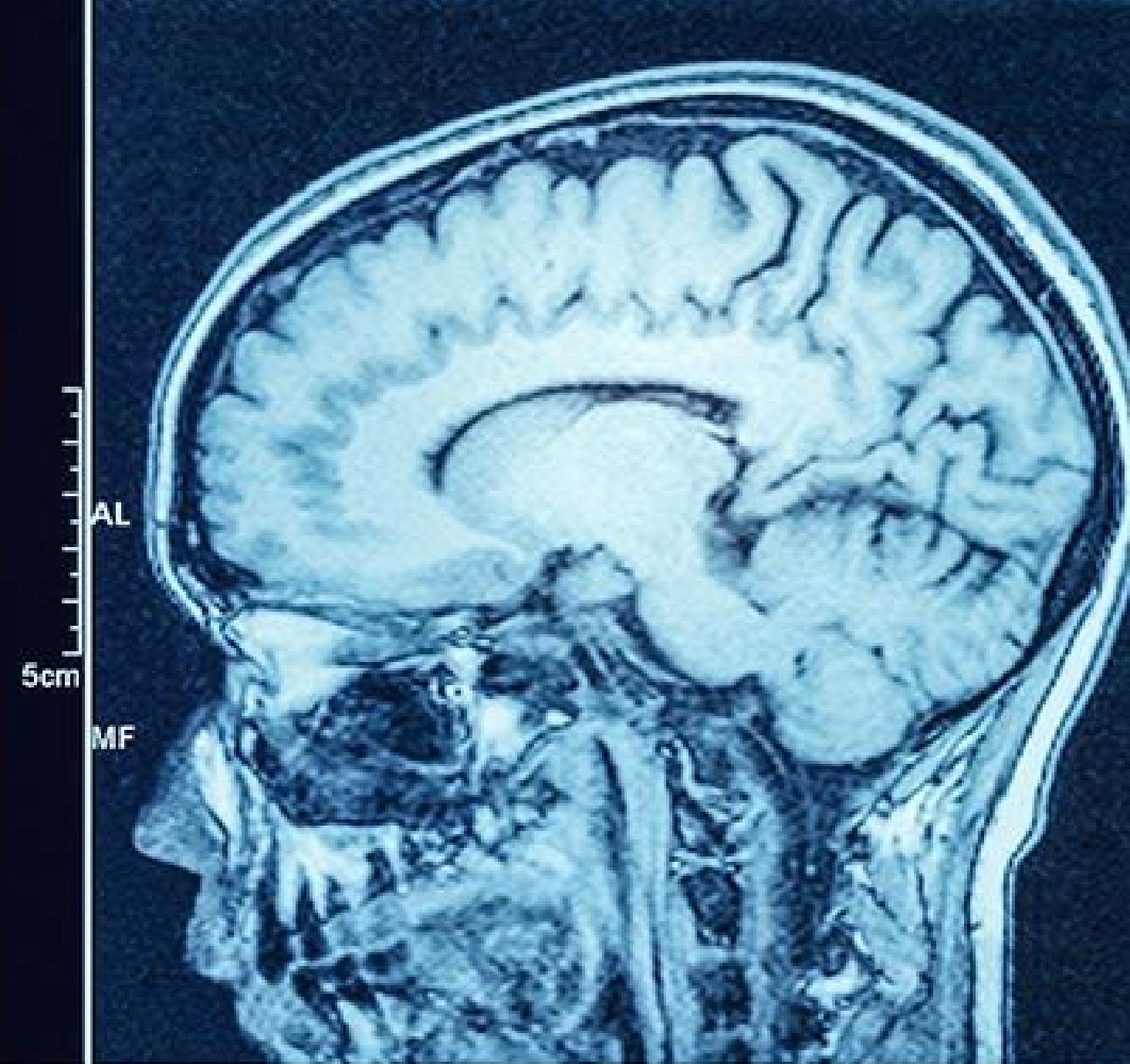
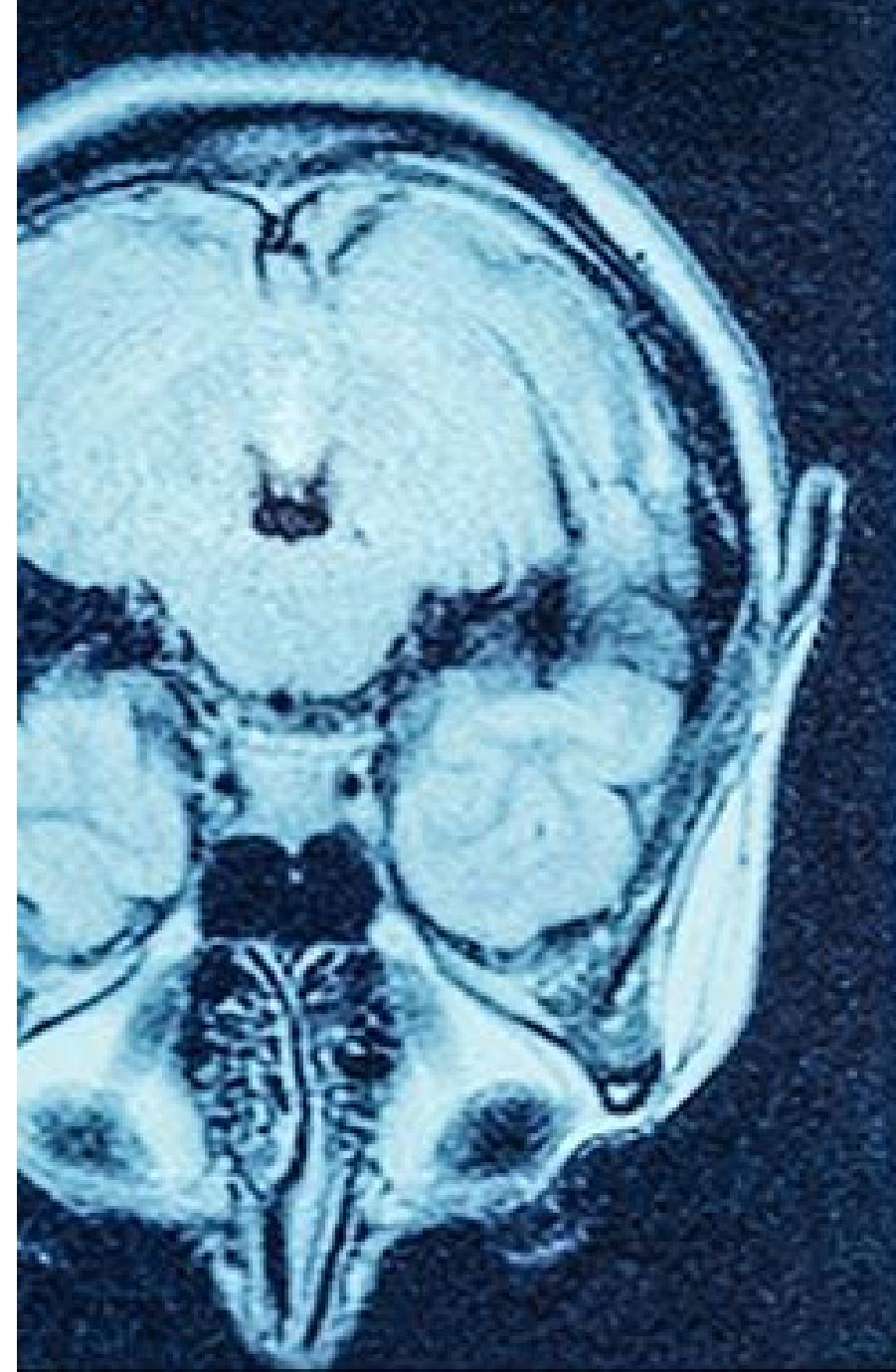
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <http://>



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

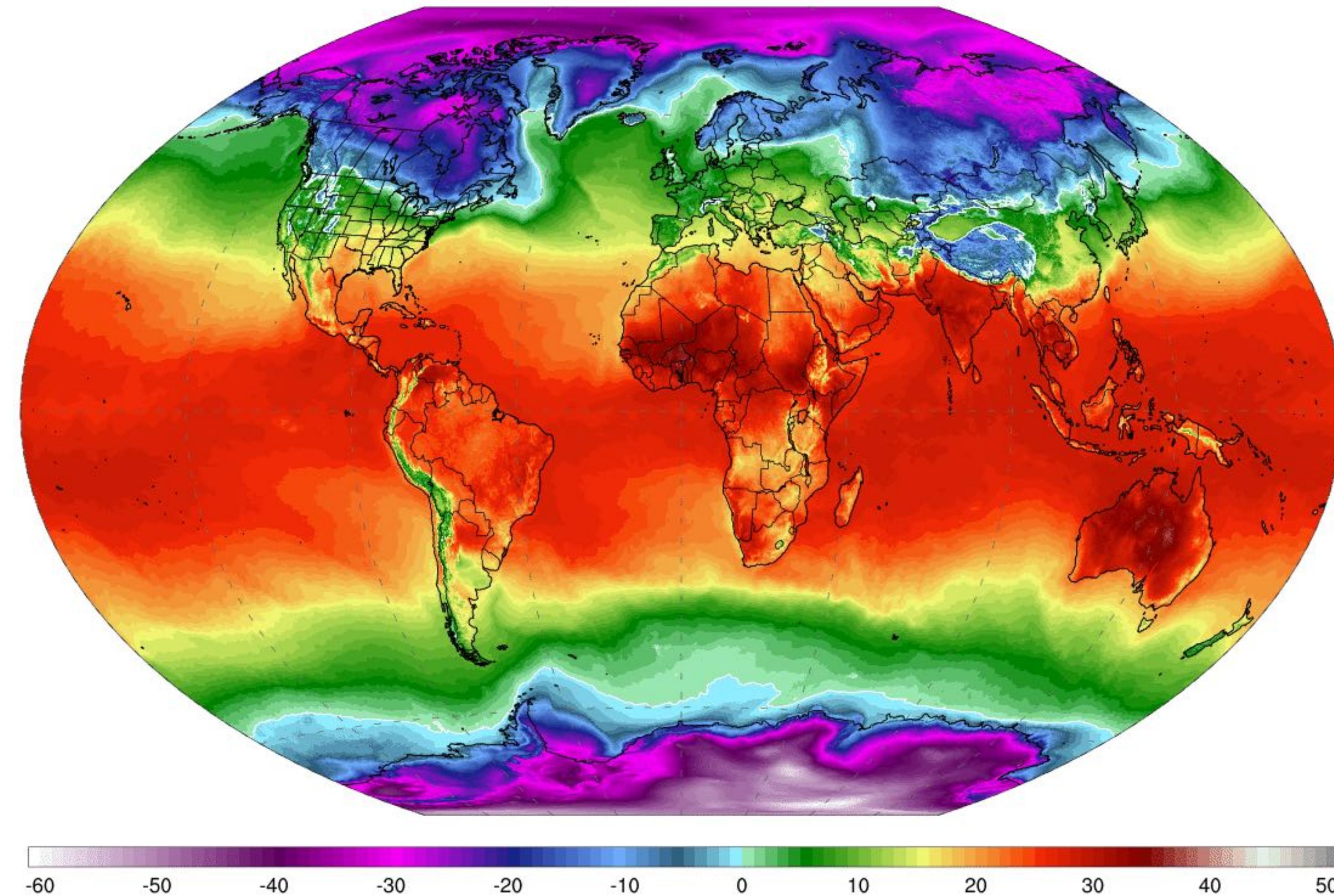
# In other words

- The **luminance** component in a color (the brightness/darkness component) **is critical for carrying information about high spatial frequency** variations in the data.
- The **saturation** and **hue components of color are critical for conveying information about low spatial frequency variations** in the data.
- **High spatial frequency information calls for a monotonic scale with a strong luminance component.**
- **Low-spatial-frequency information calls for a monotonic scale with a strong saturation component**



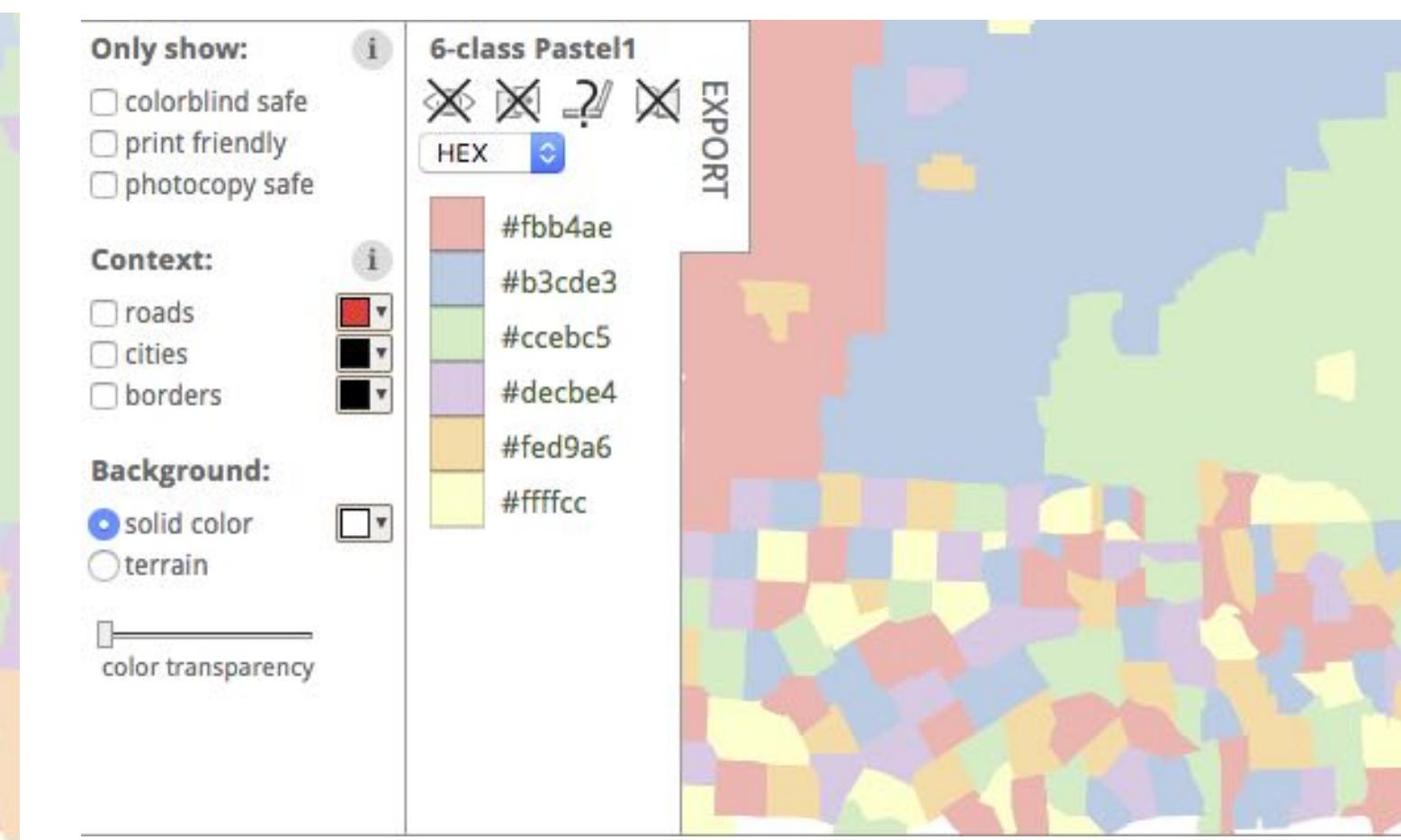
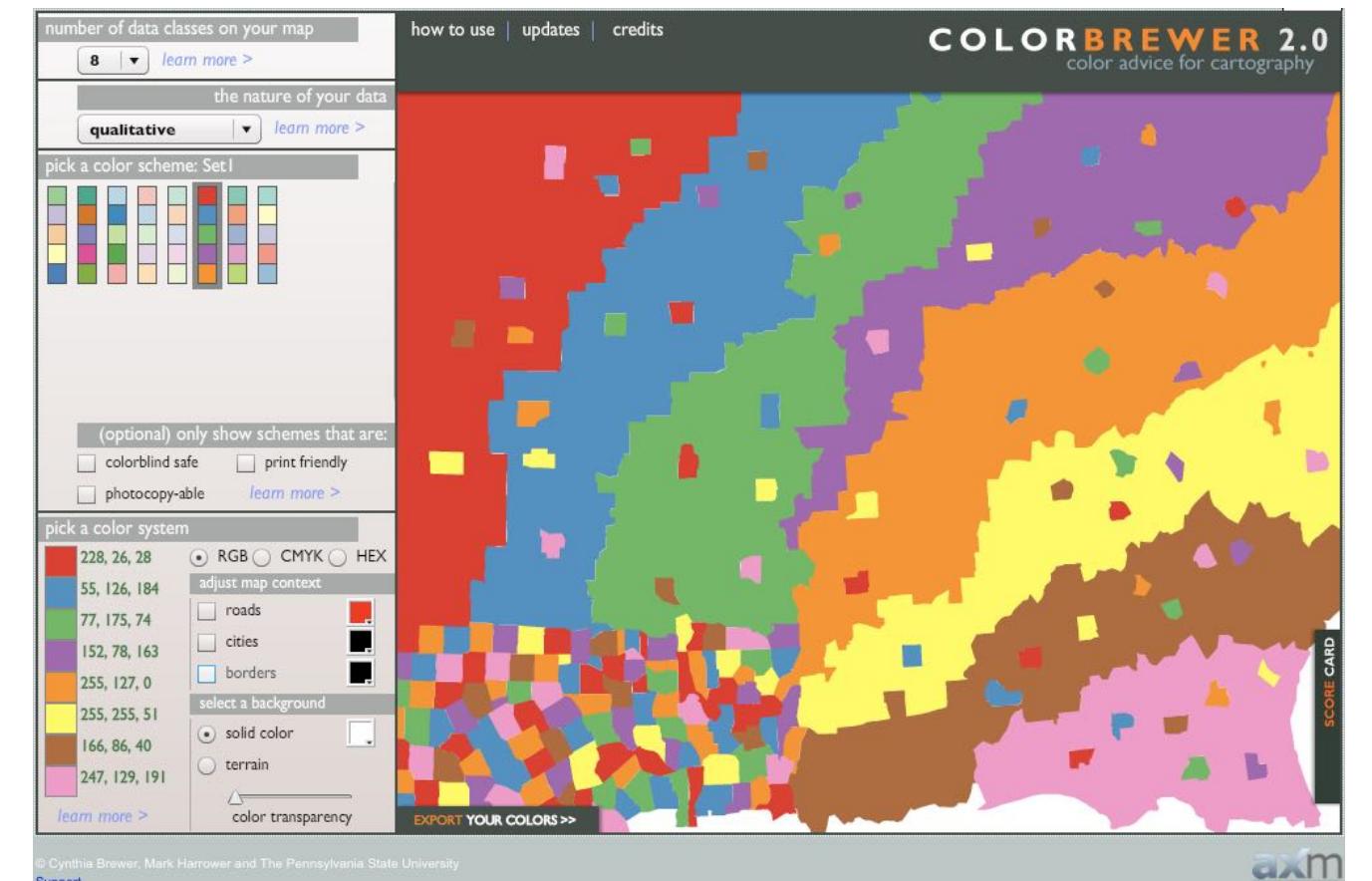
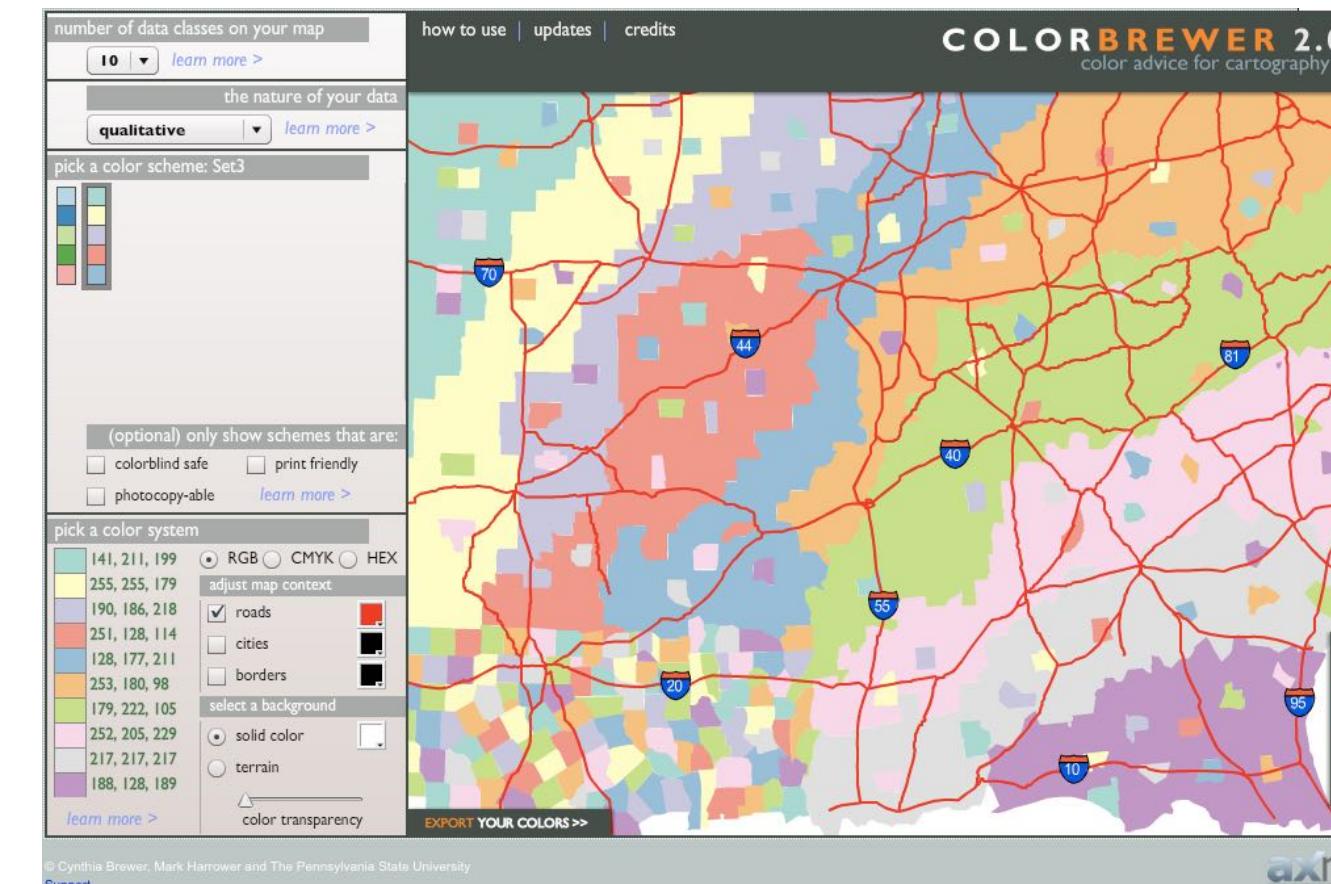
**GFS 2m Temperature (°C)**  
1-day Avg | Wed, Mar 12, 2025

**ClimateReanalyzer.org**  
Climate Change Institute | University of Maine



# 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)



# Color Palettes

# Color palettes: univariate

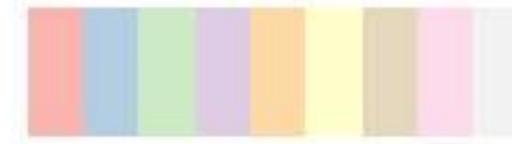
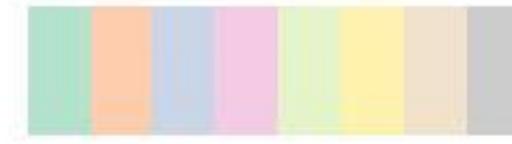
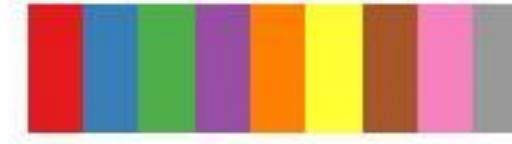


- categorical
  - aim for maximum distinguishability
  - aka *qualitative, nominal*

→ Categorical



categorical



# Color palettes: univariate

→ Categorical



→ Ordered

→ *Sequential*

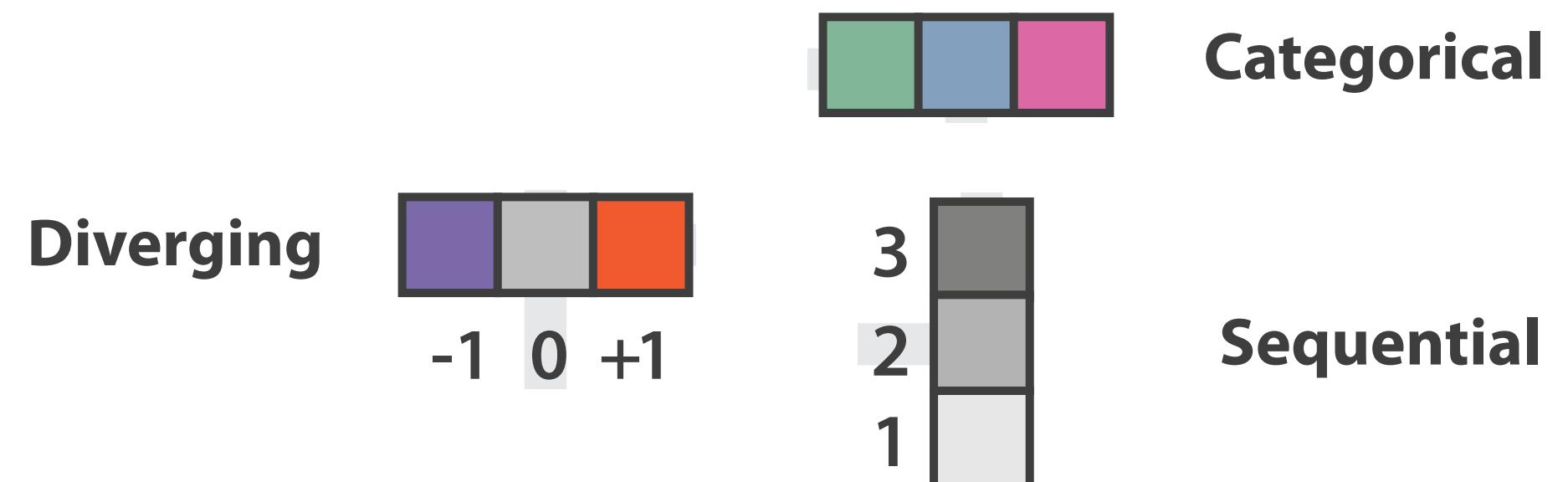


→ *Diverging*



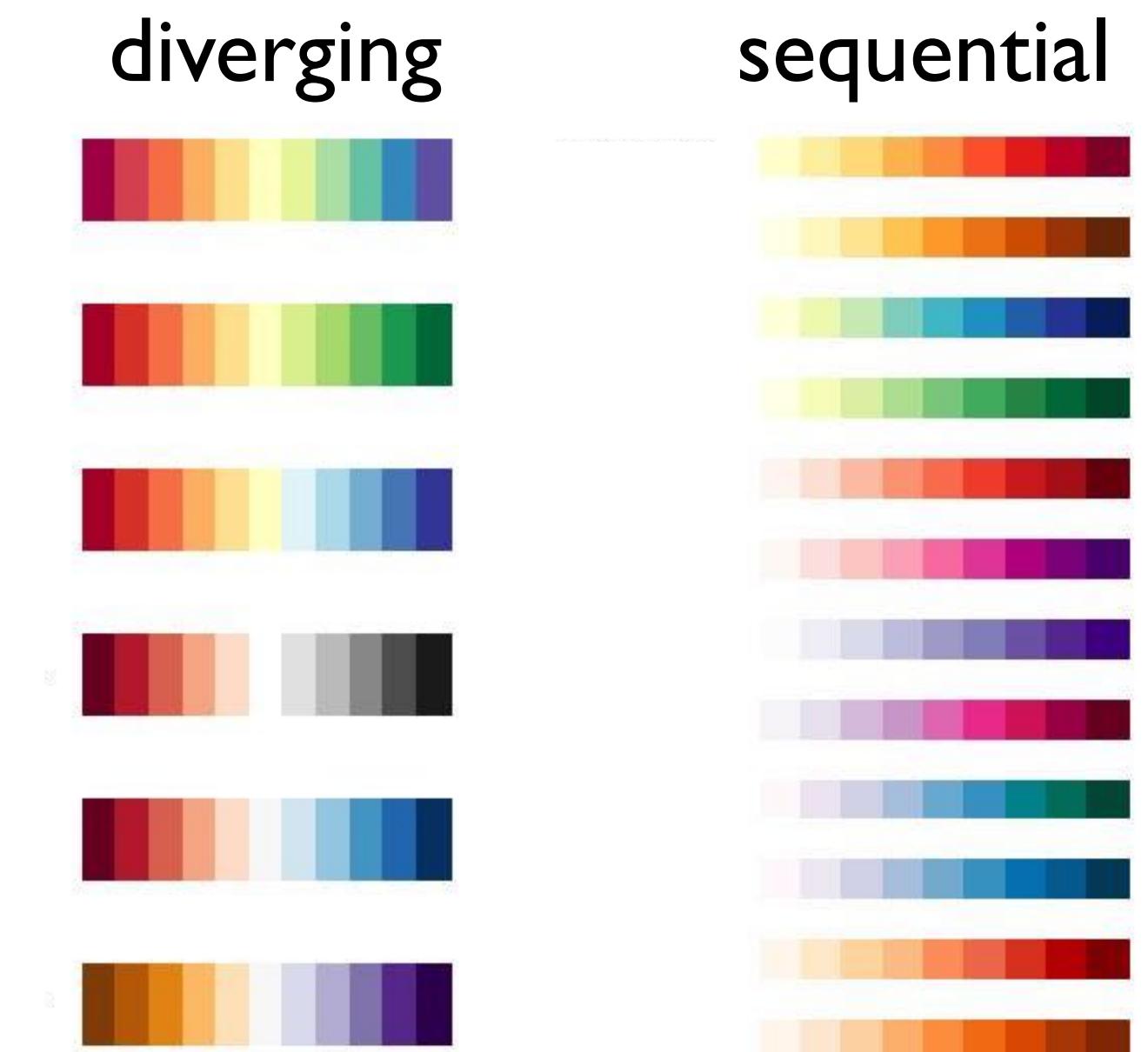
- **diverging**

- 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*

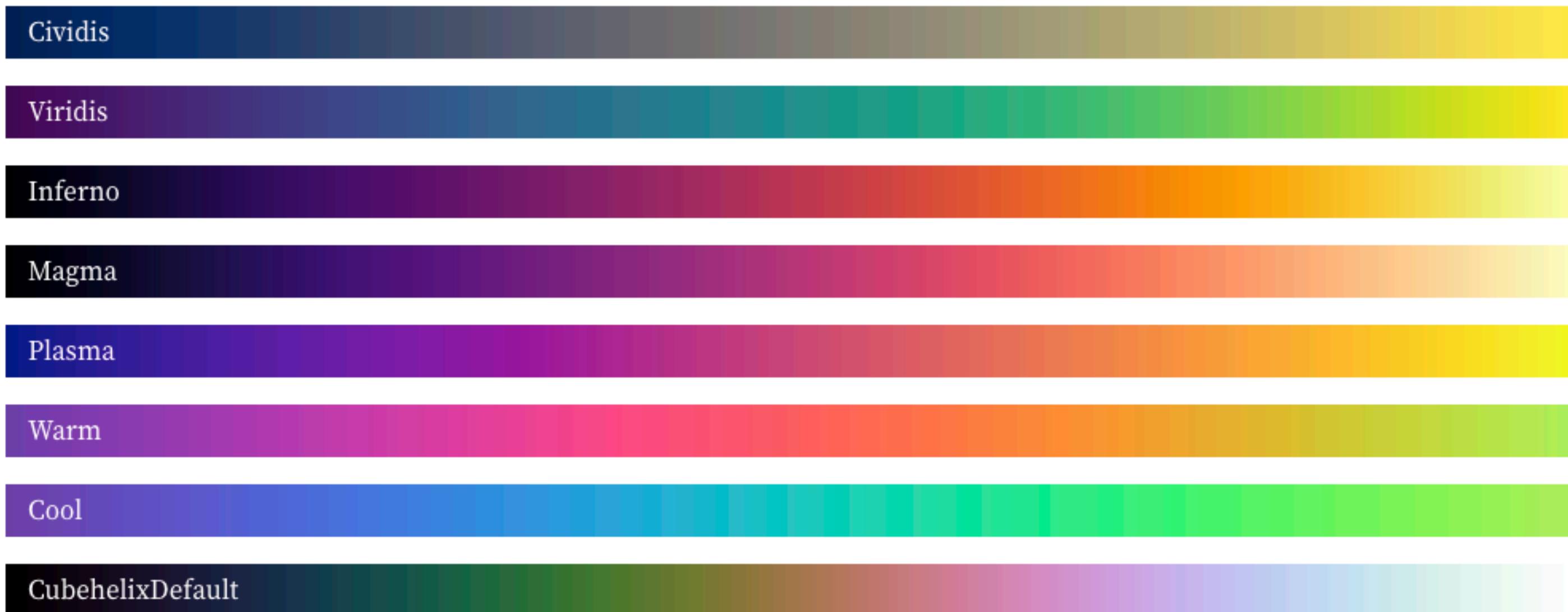


- **diverging**

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

- **sequential**

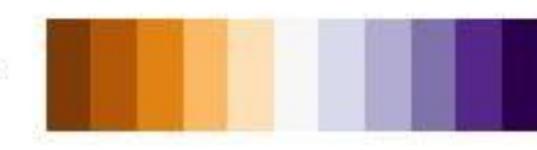
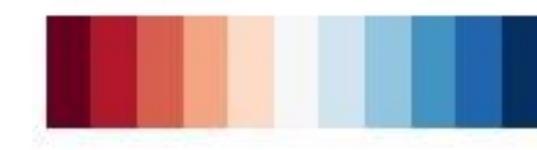
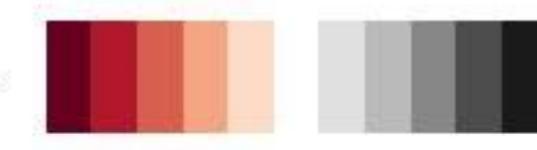
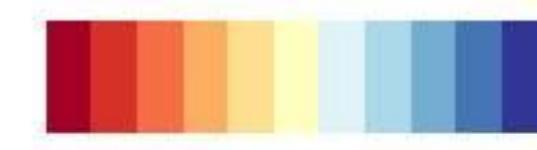
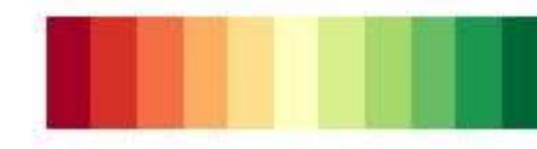
- ramp luminance or saturation
- if multi-hue, good to order by luminance



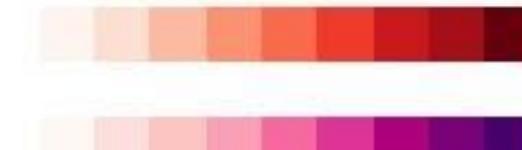
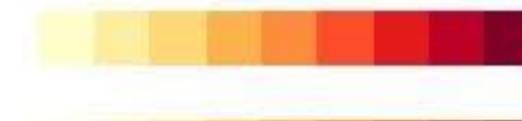
# Color palette design considerations: univariate

**segmented**

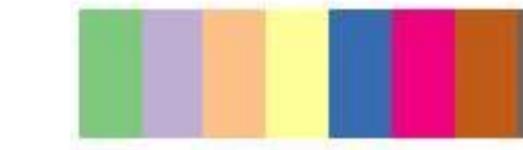
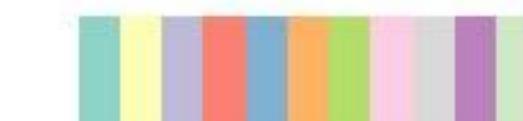
**diverging**



**sequential**



**categorical**



**continuous**

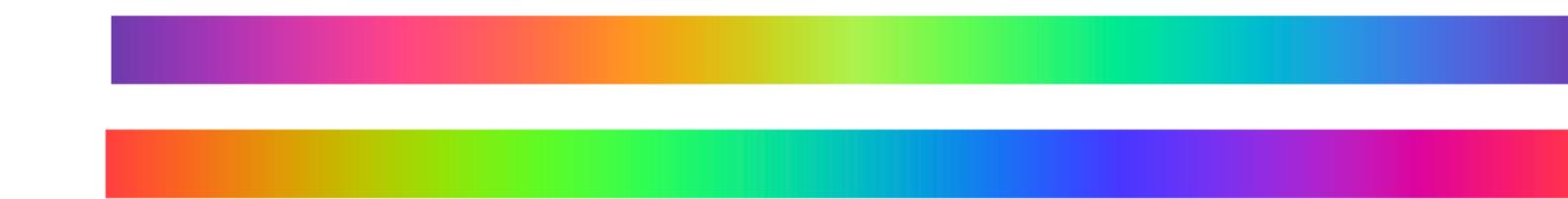


sequential  
single hue

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?

# Colormaps

→ Categorical



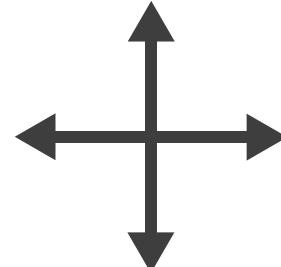
→ Ordered

→ Sequential

→ Diverging



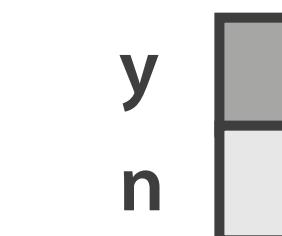
→ Bivariate



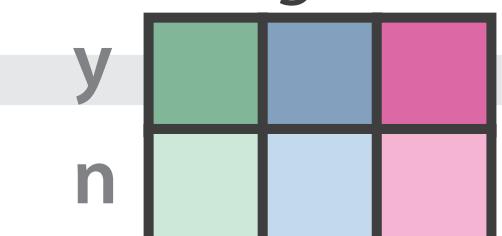
**use with care!**

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

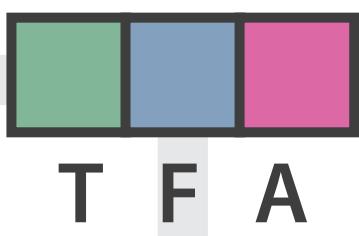
Binary



Categorical

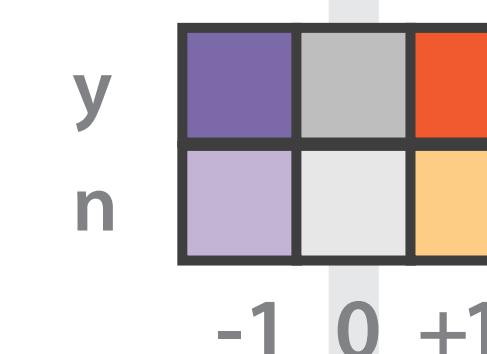


Binary

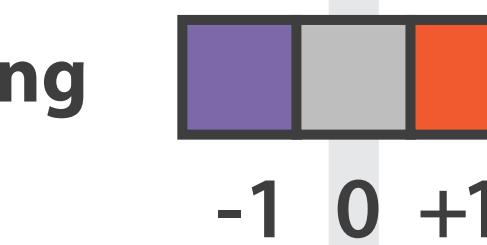


Categorical

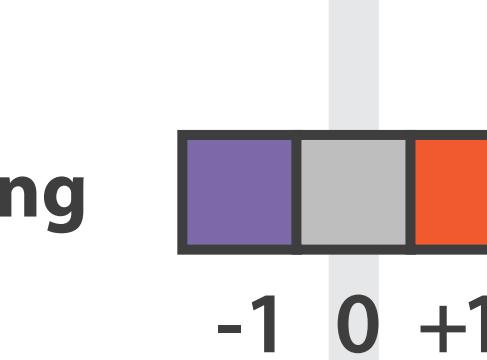
Diverging



Diverging

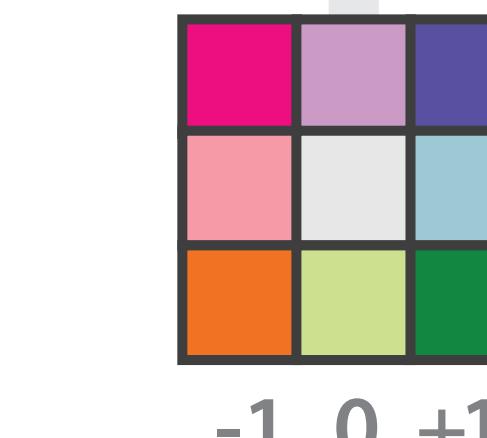


Diverging

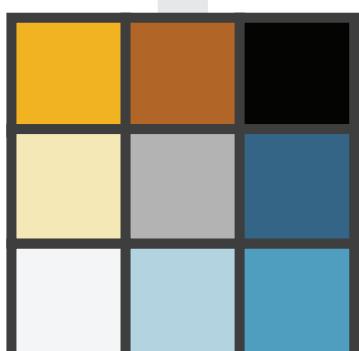


Sequential

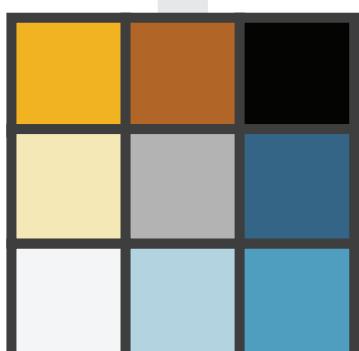
Diverging



Diverging



Sequential



Sequential

# Color Deficiency

# Luminance

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



Luminance information

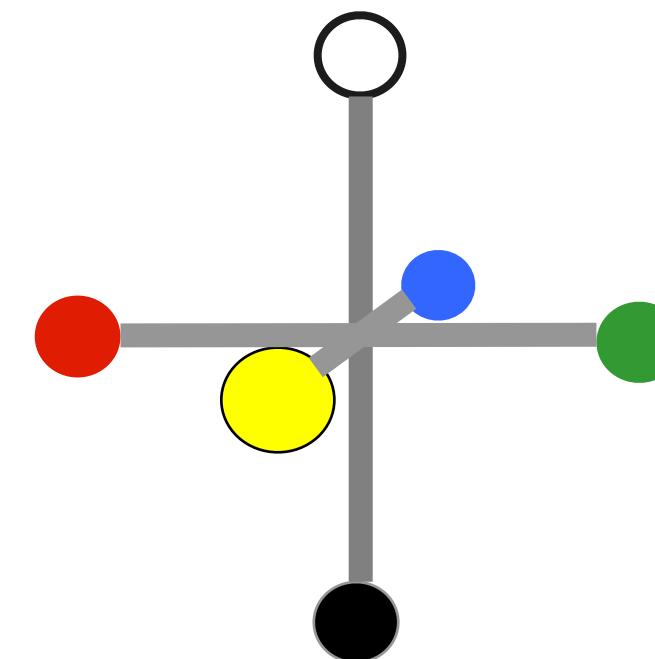


Saturation/hue information



# 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 ( $b^*$ )



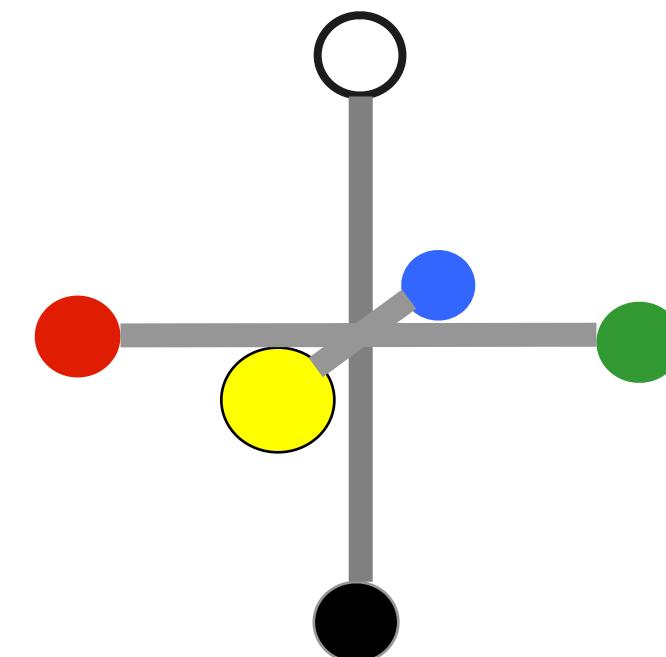
Luminance information



Chroma information

# 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



Luminance information



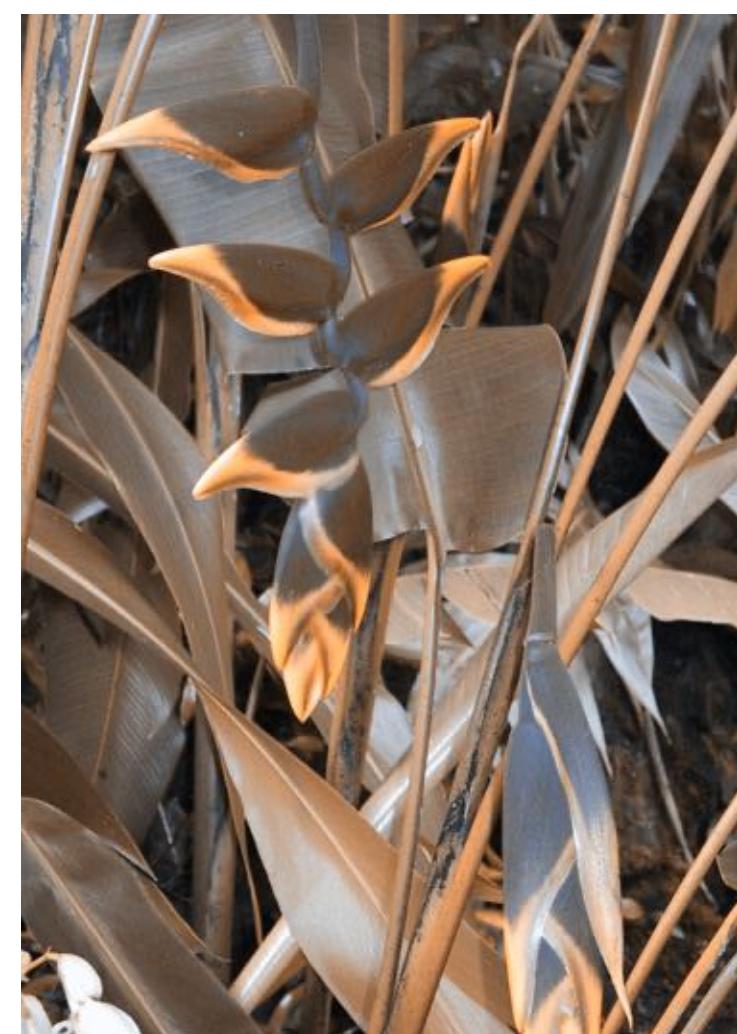
Chroma information



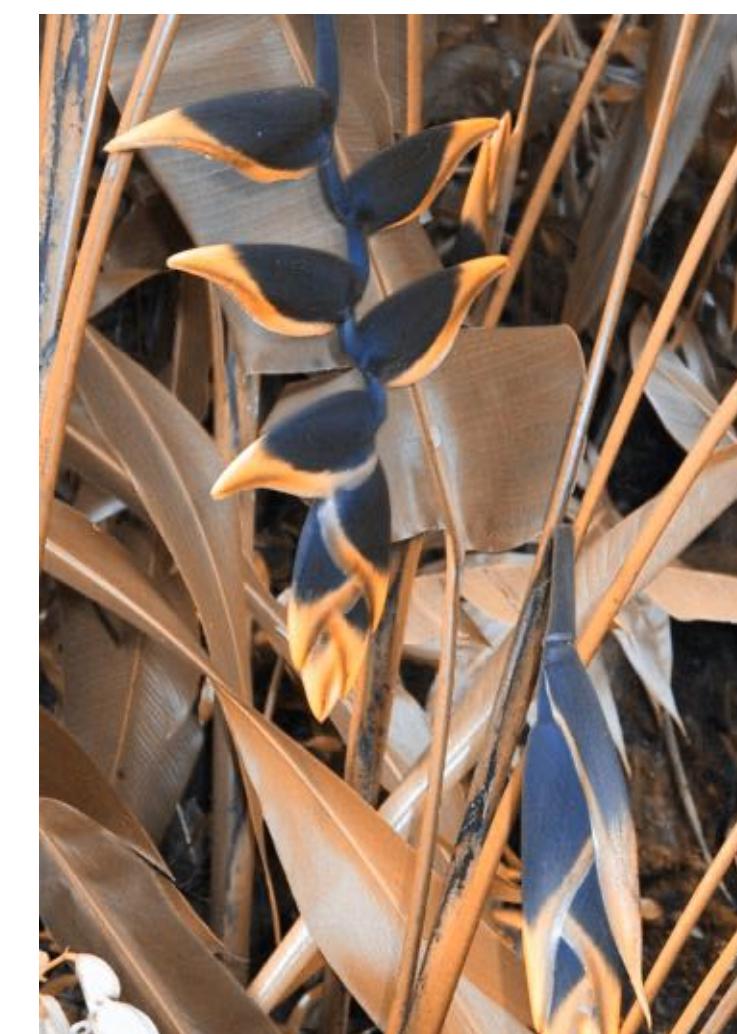
# Designing for color deficiency: Check with simulator



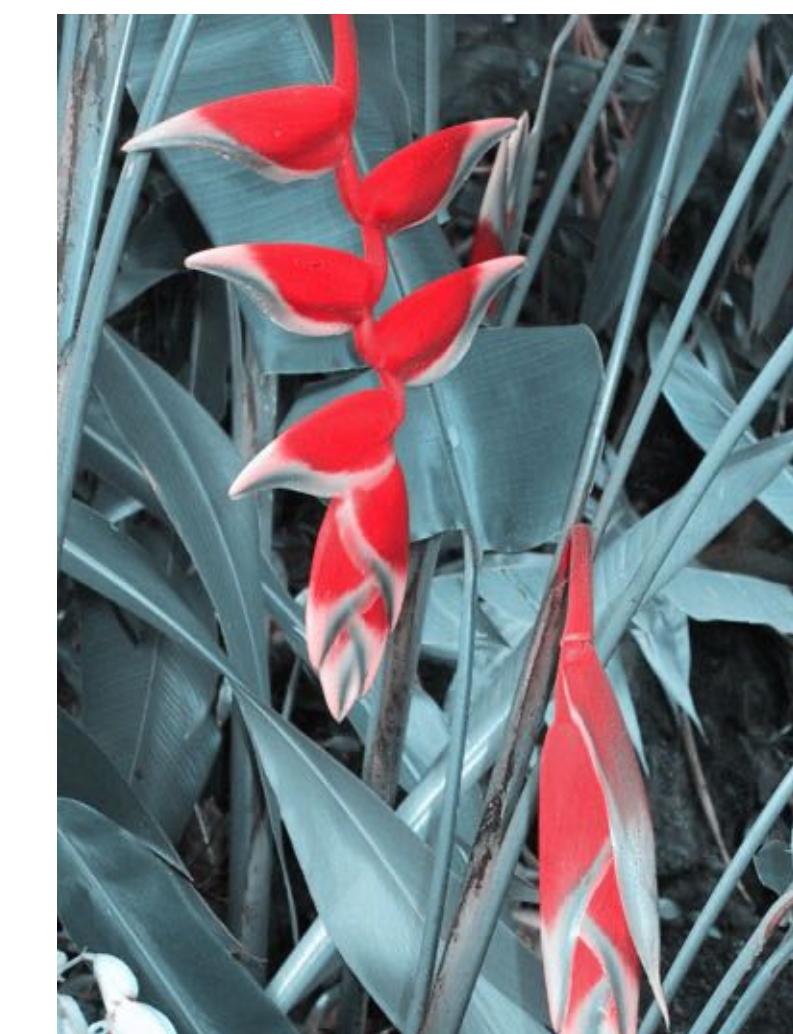
**Normal vision**



**Deutanope**  
green-weak



**Protanope**  
red-weak

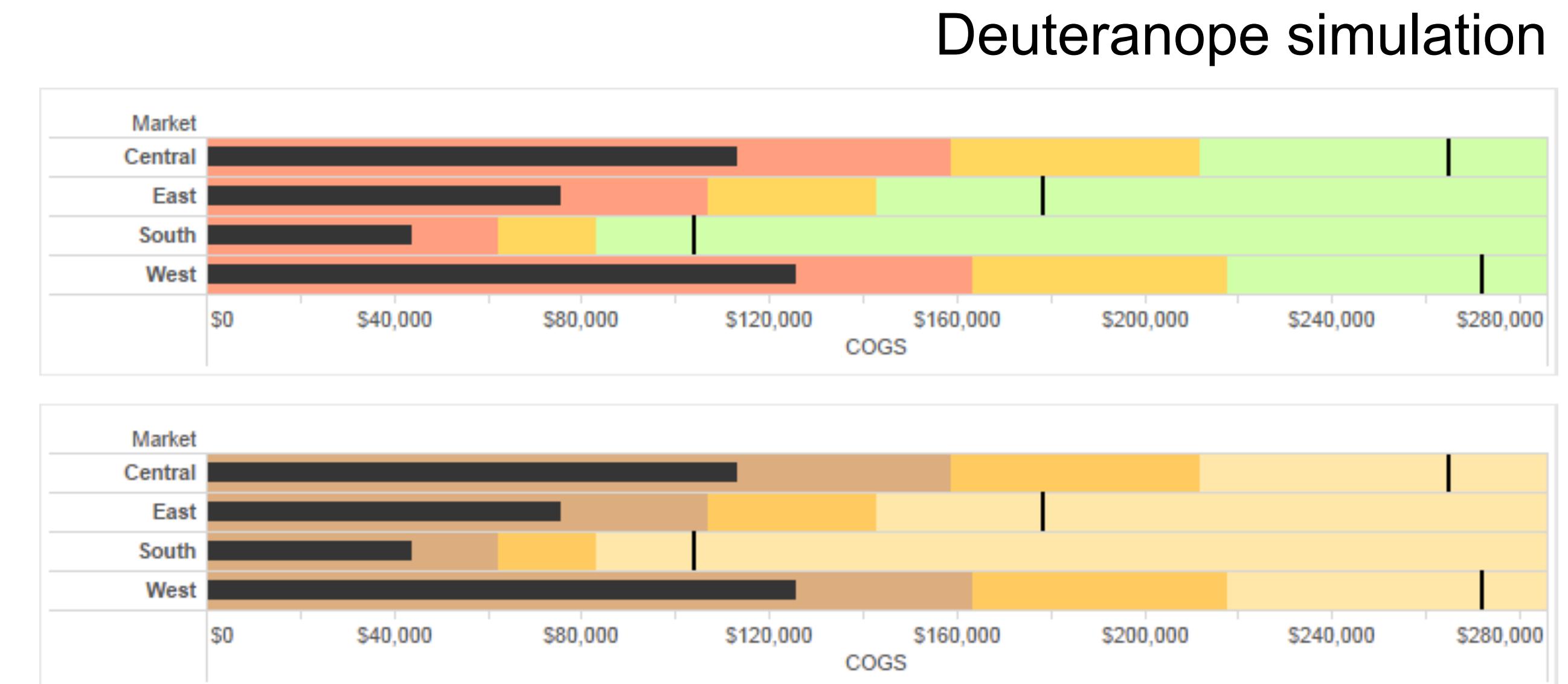
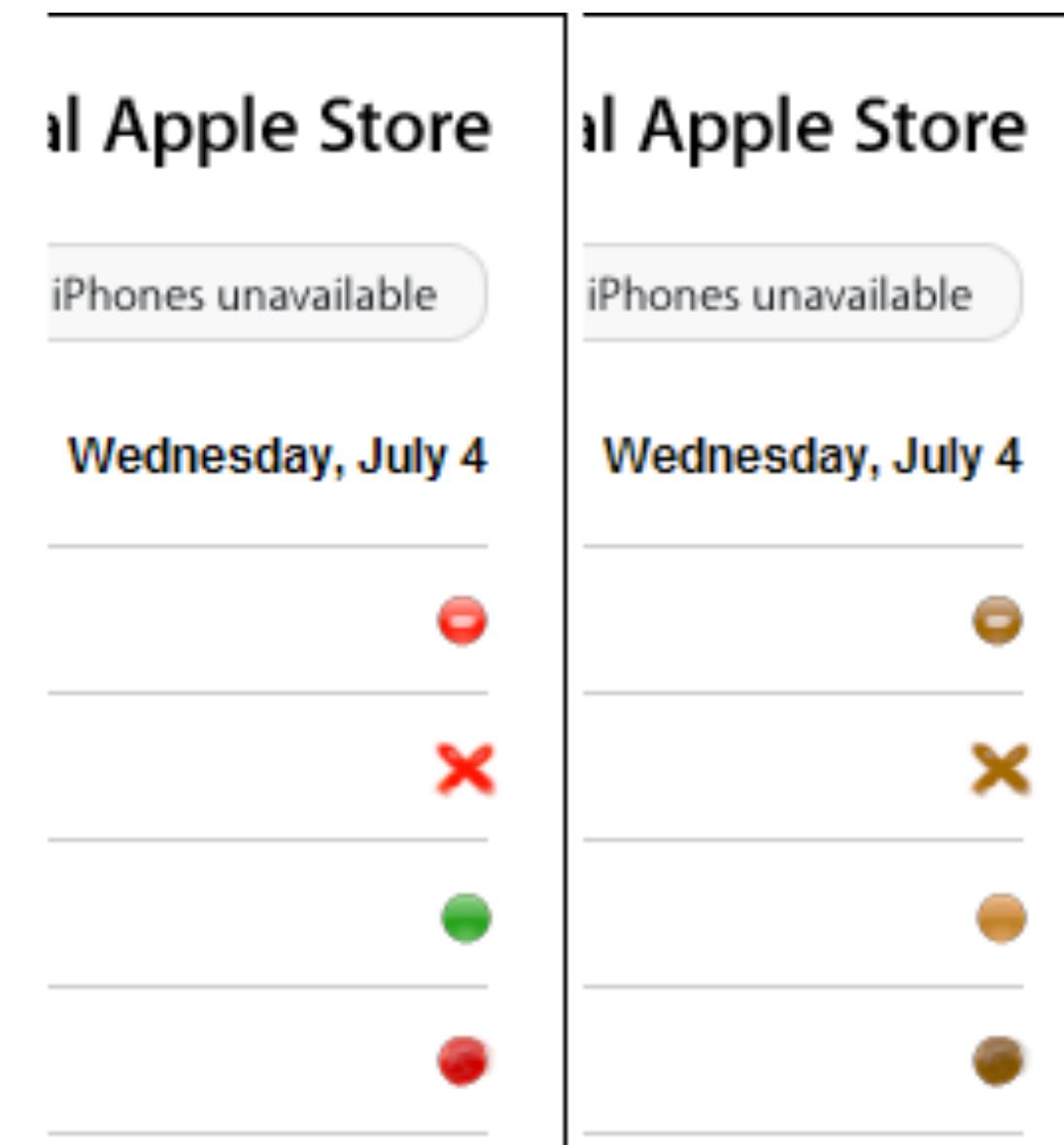


**Tritanope**  
blue-weak



# Designing for color deficiency: Avoid encoding by hue alone

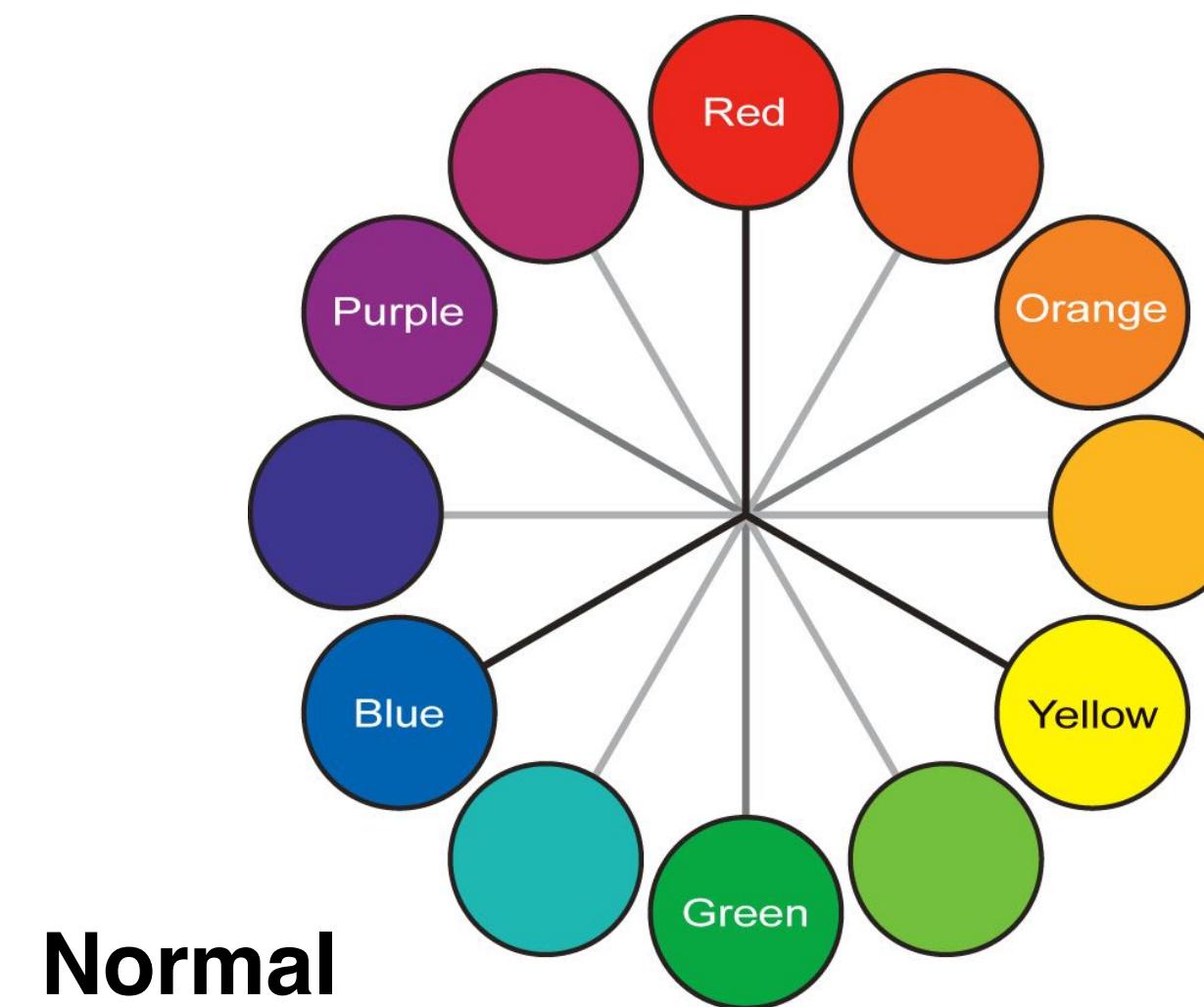
- redundantly encode
  - vary luminance
  - change shape



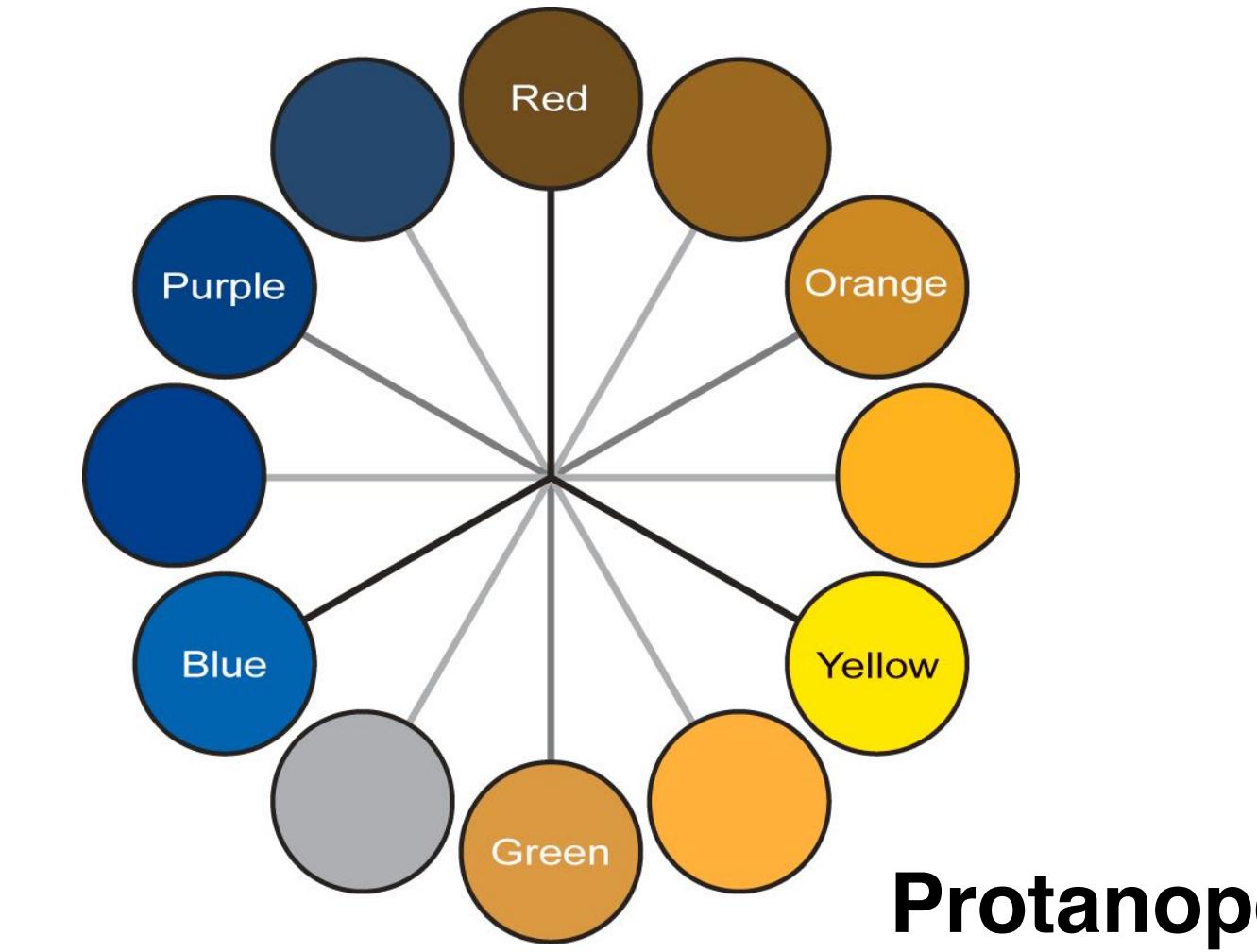
Change the shape

Vary luminance

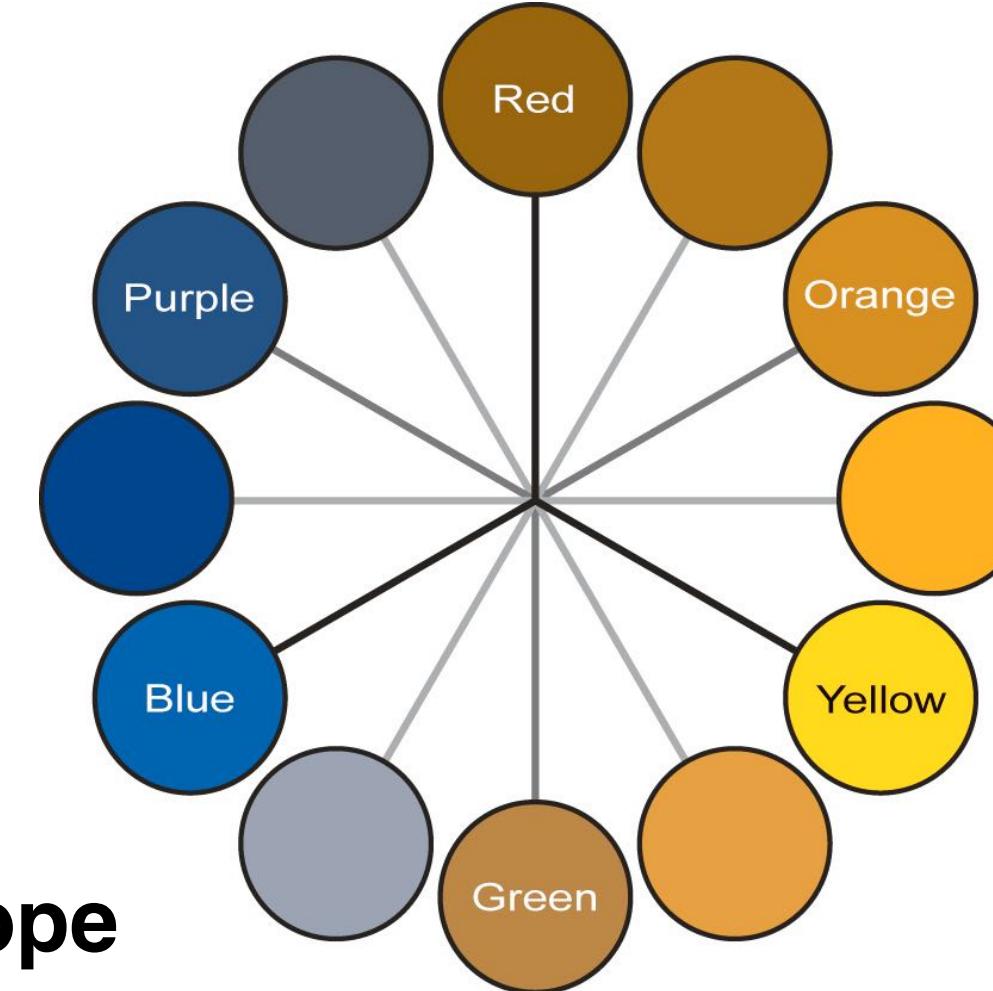
# Color deficiency: Reduces color to 2 dimensions



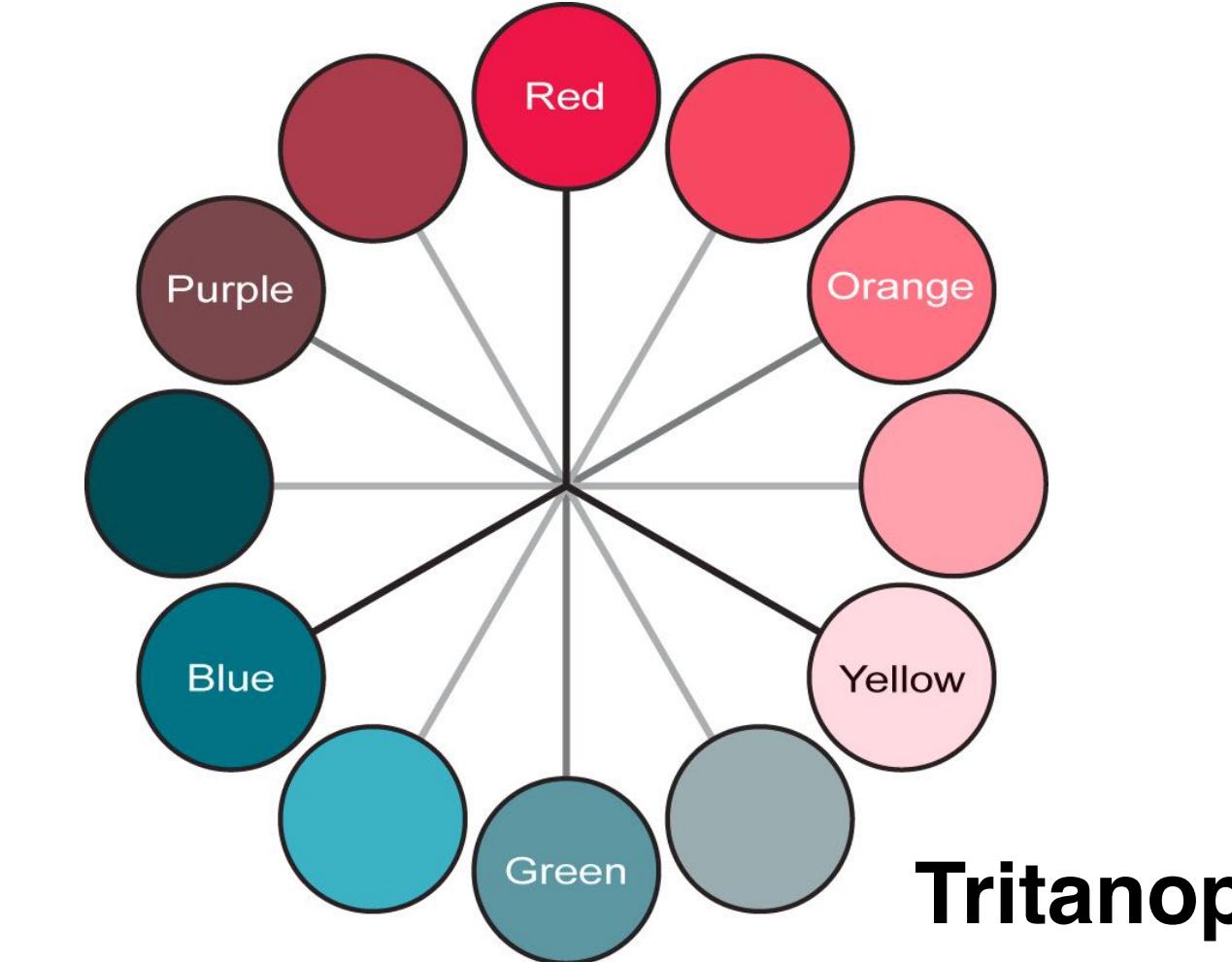
**Normal**



**Protanope**

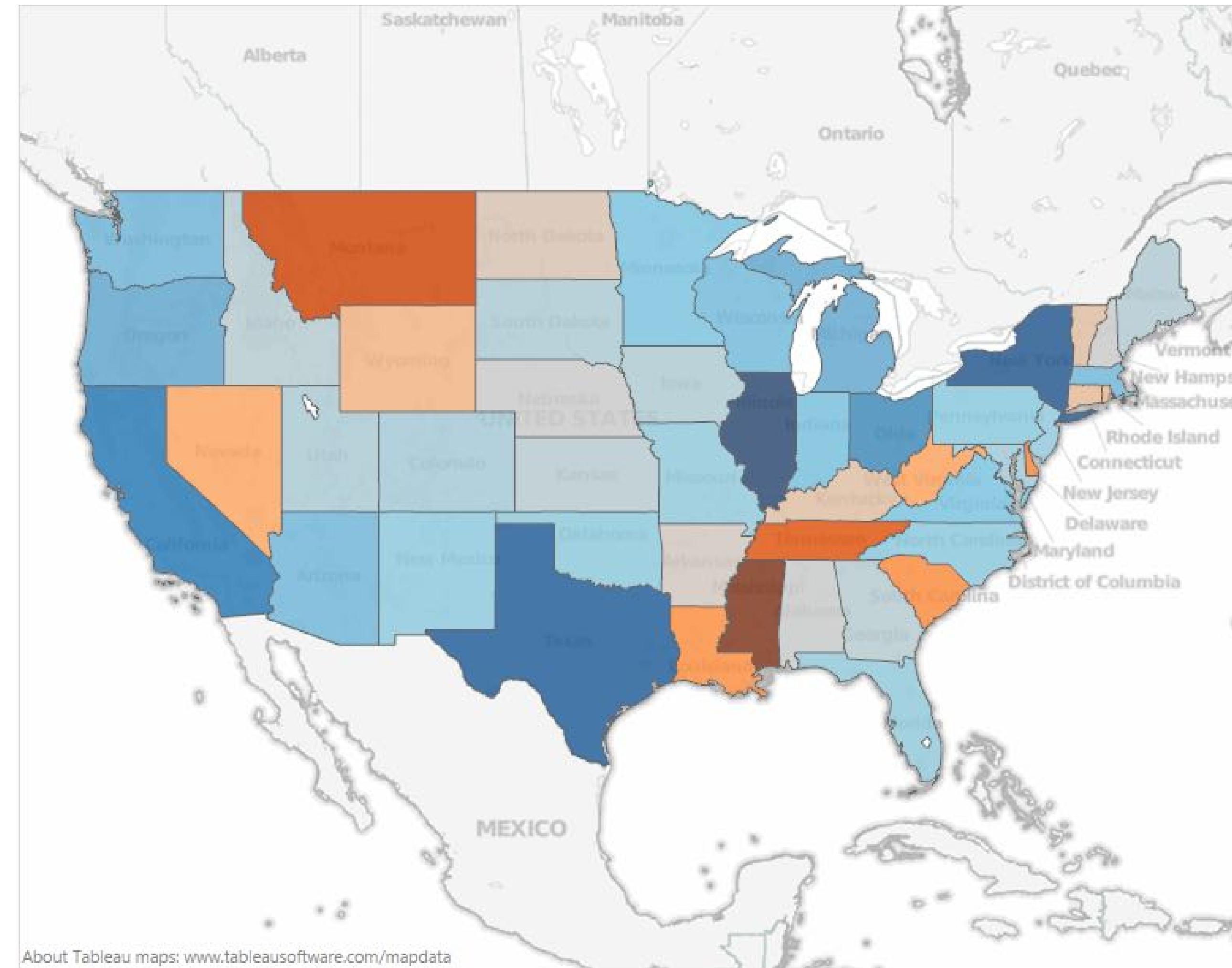


**Deutanope**



**Tritanope**

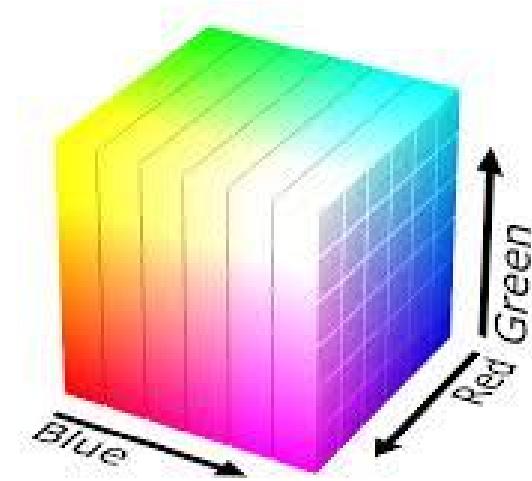
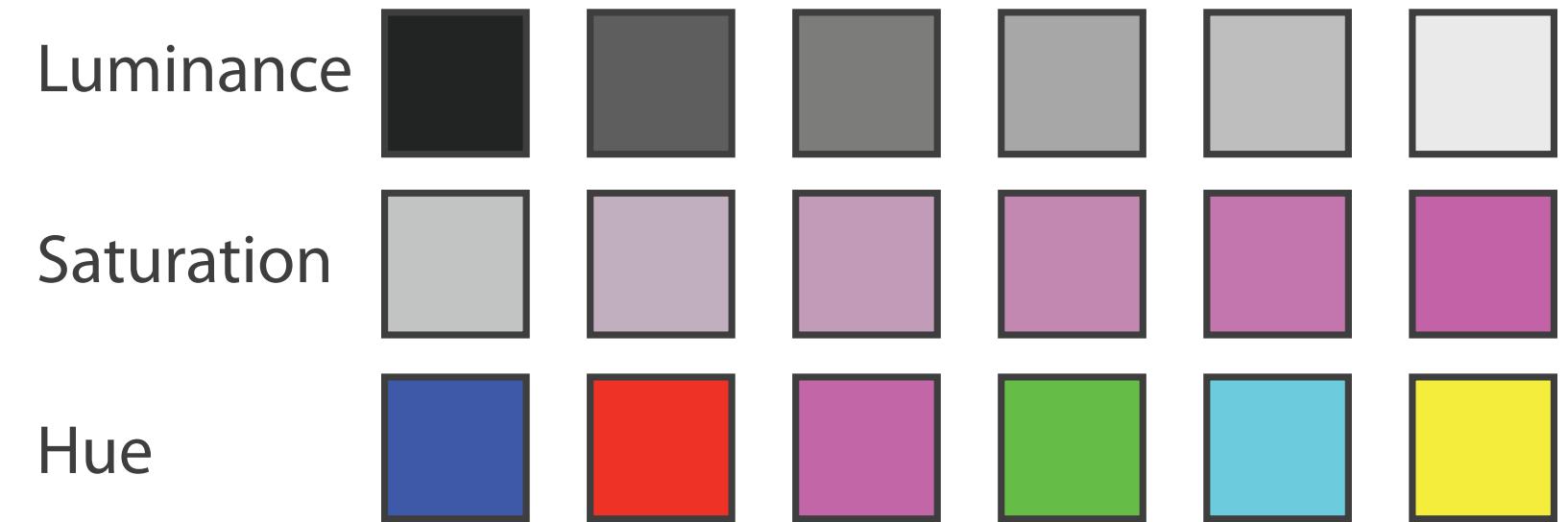
# Designing for color deficiency: Blue-Orange is safe



# Color Spaces

# Many color spaces

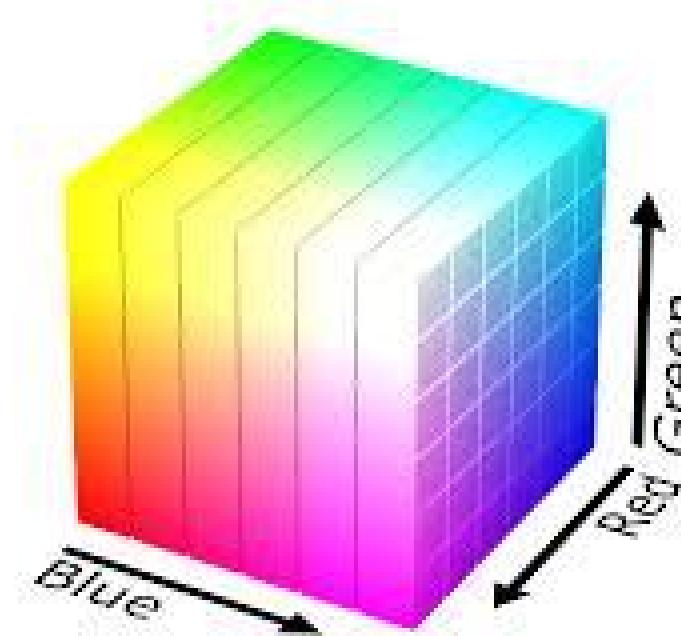
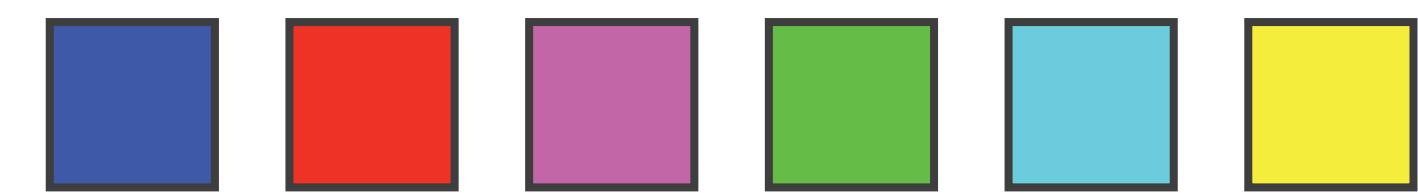
- Luminance ( $L^*$ ), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware



# RGB

- RGB: good for display hardware

Corners of the RGB color cube

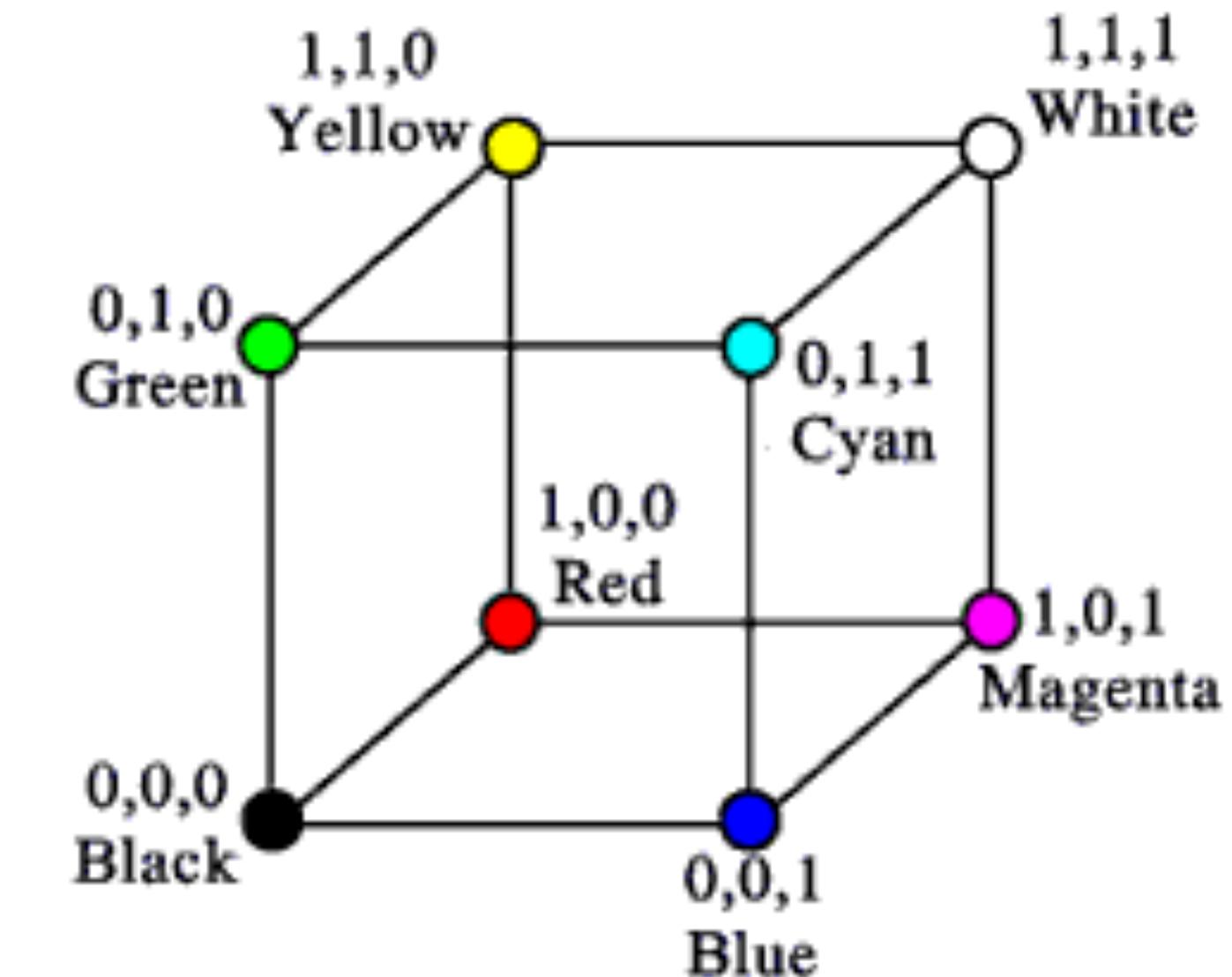


[https://commons.wikimedia.org/wiki/File:RGB\\_color\\_solid\\_cube.png](https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png)

Red  
+ Green

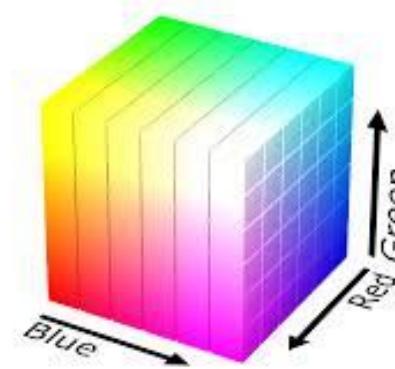
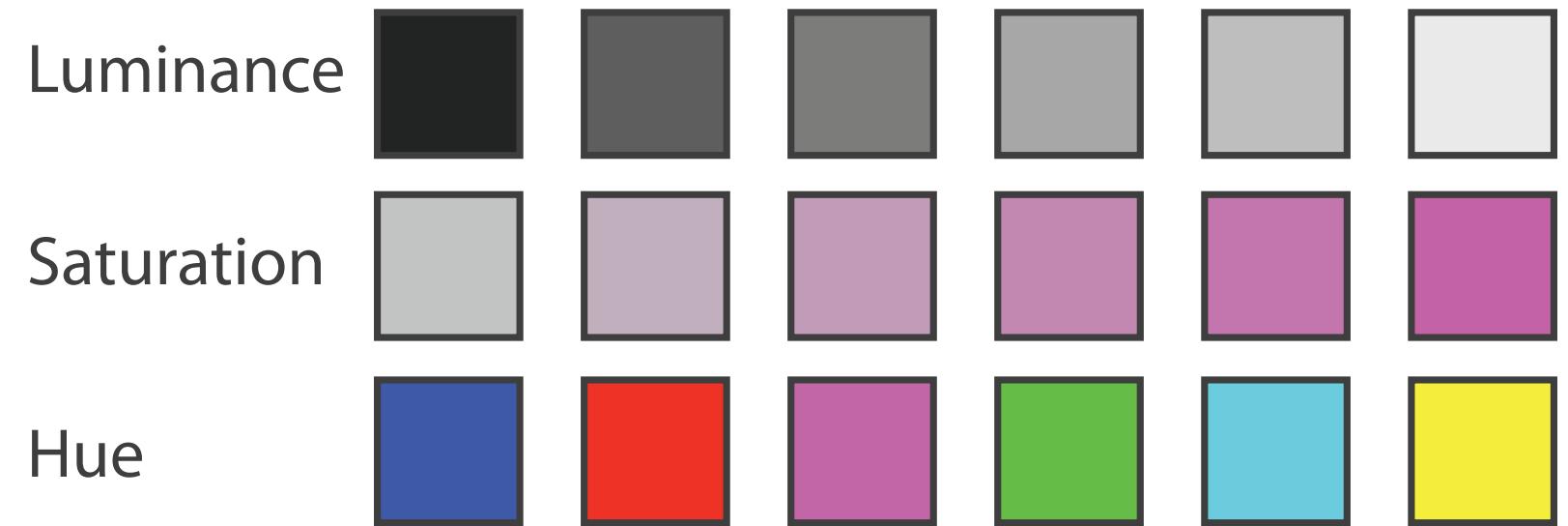


Major interference



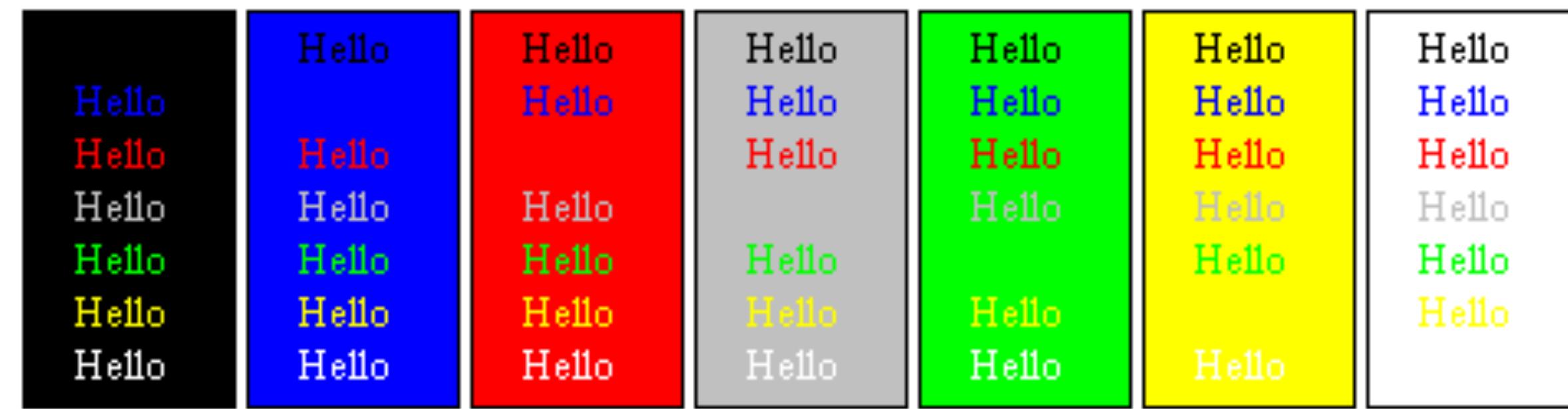
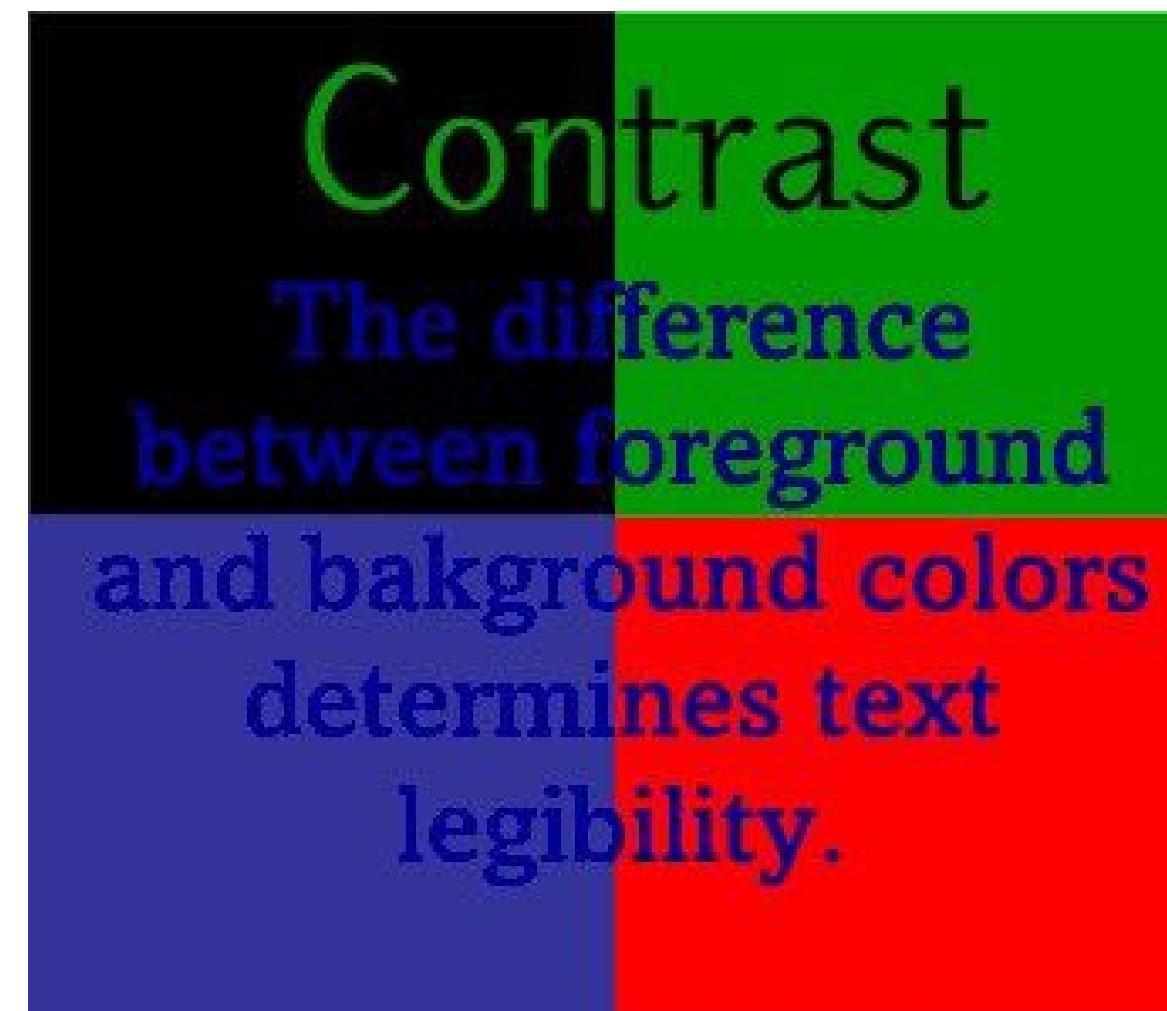
# Many color spaces

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



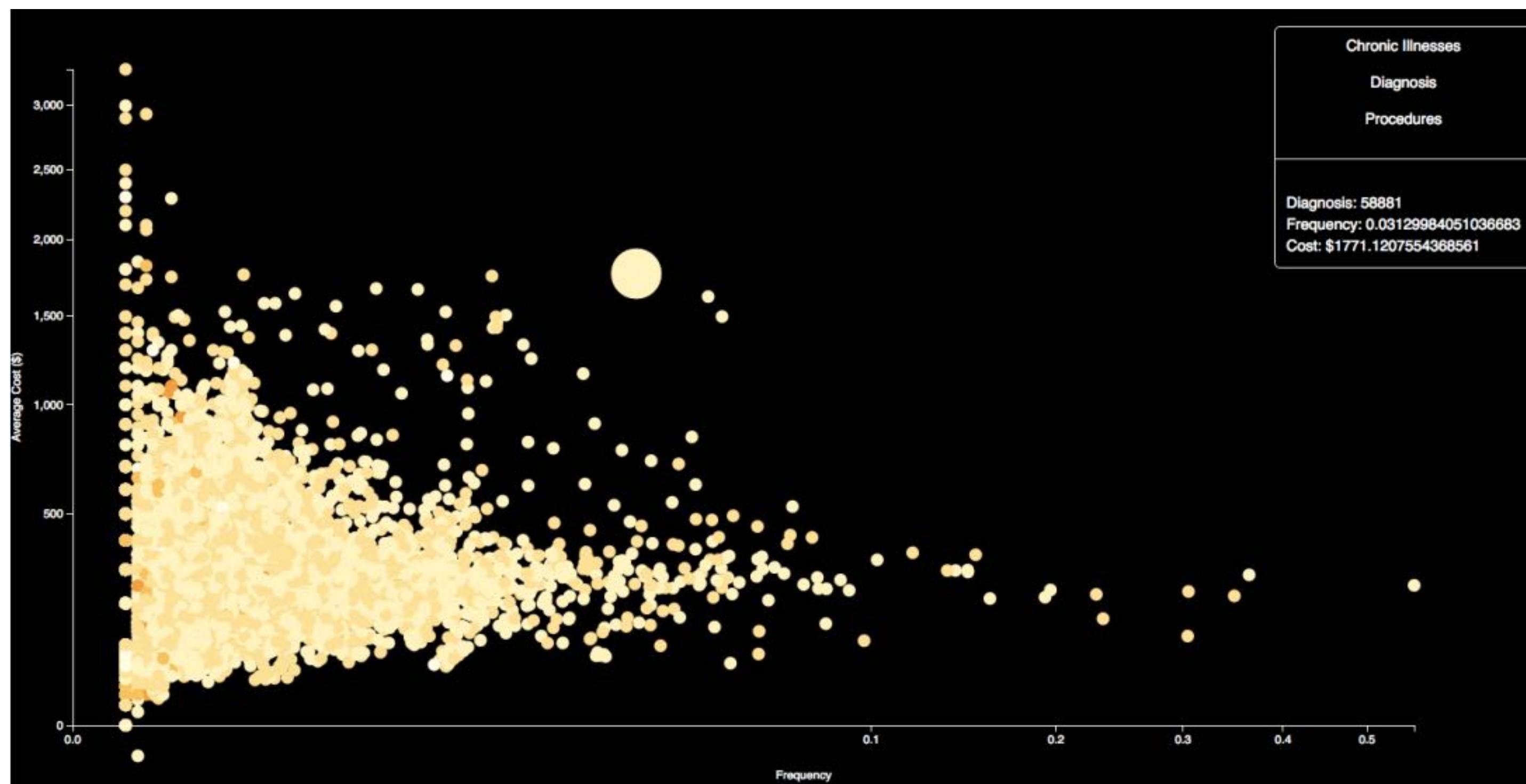
# Color Contrast & Naming

# Interaction with the background



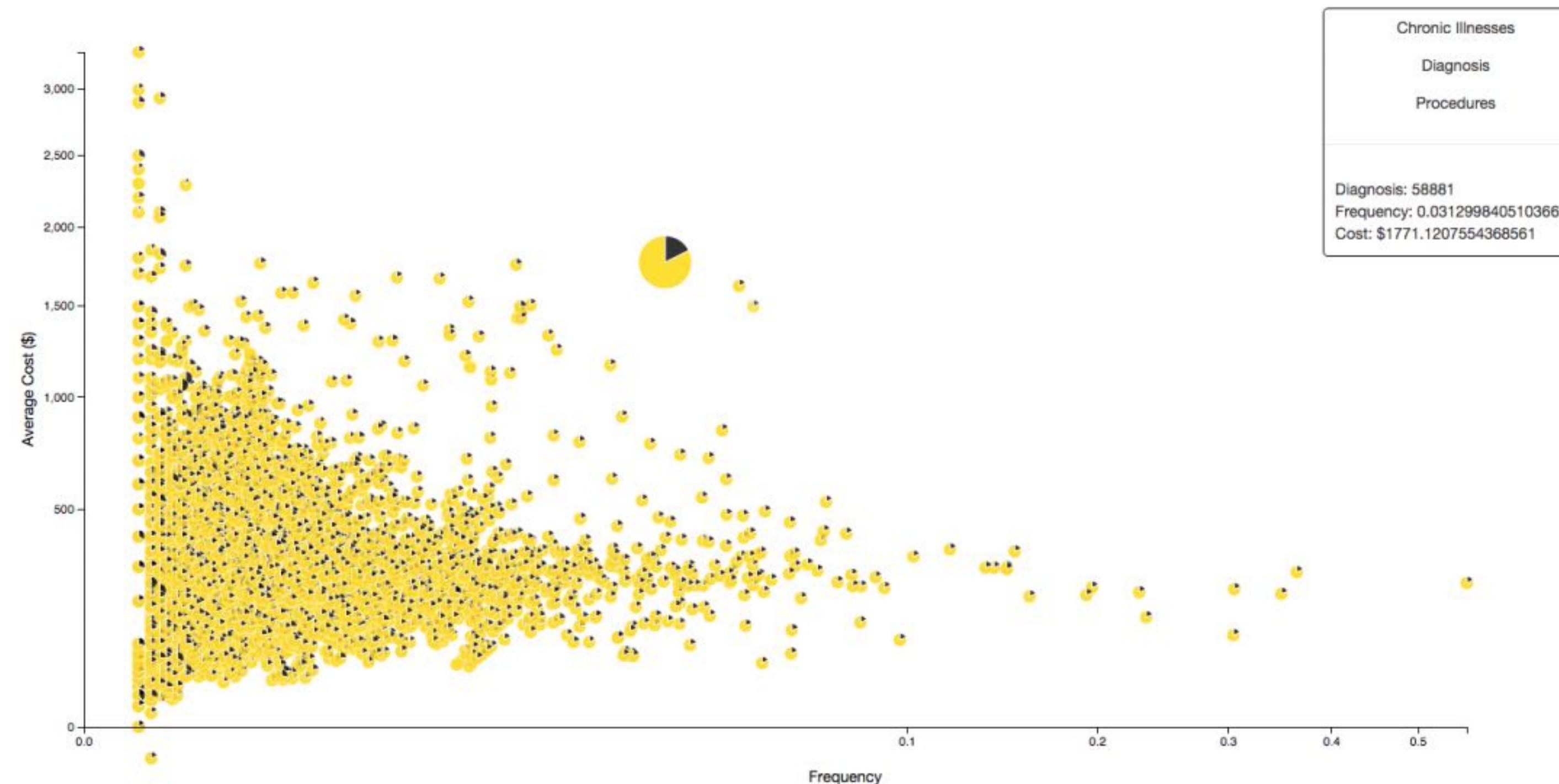
# Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



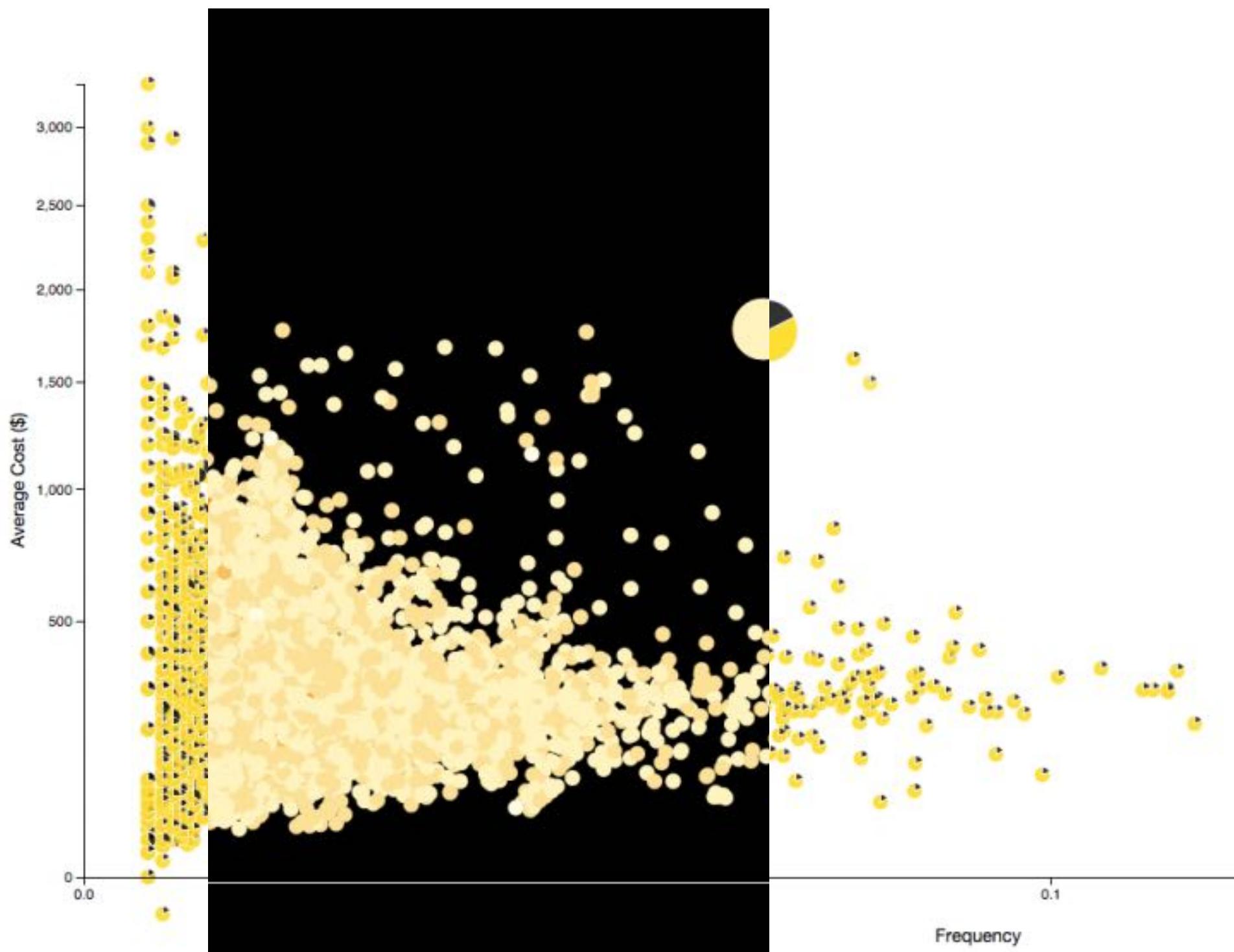
# Interaction with the background: tweaking yellow for visibility

- 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

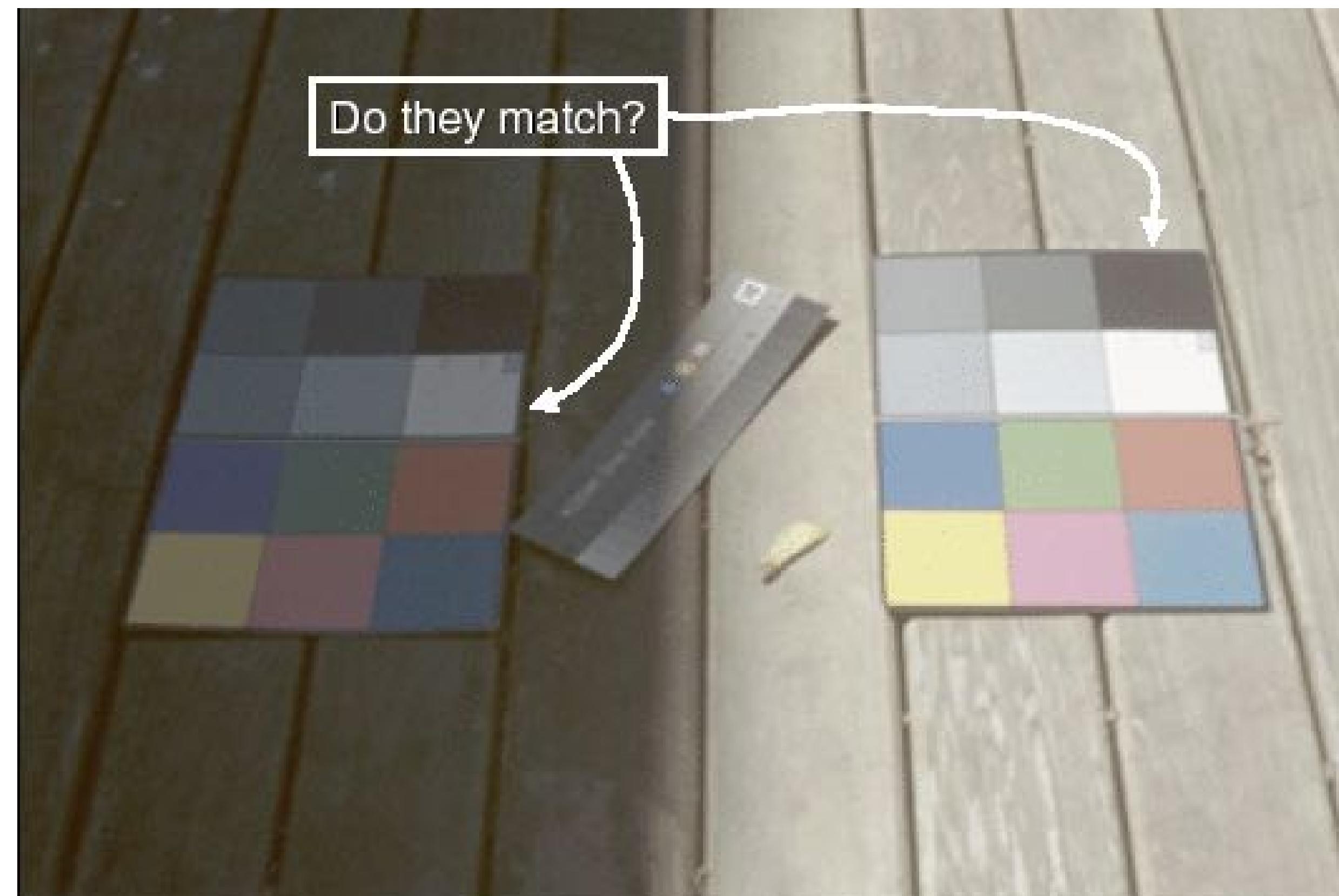


Image courtesy of John McCann via Maureen Stone

# Color/Lightness constancy: Illumination conditions

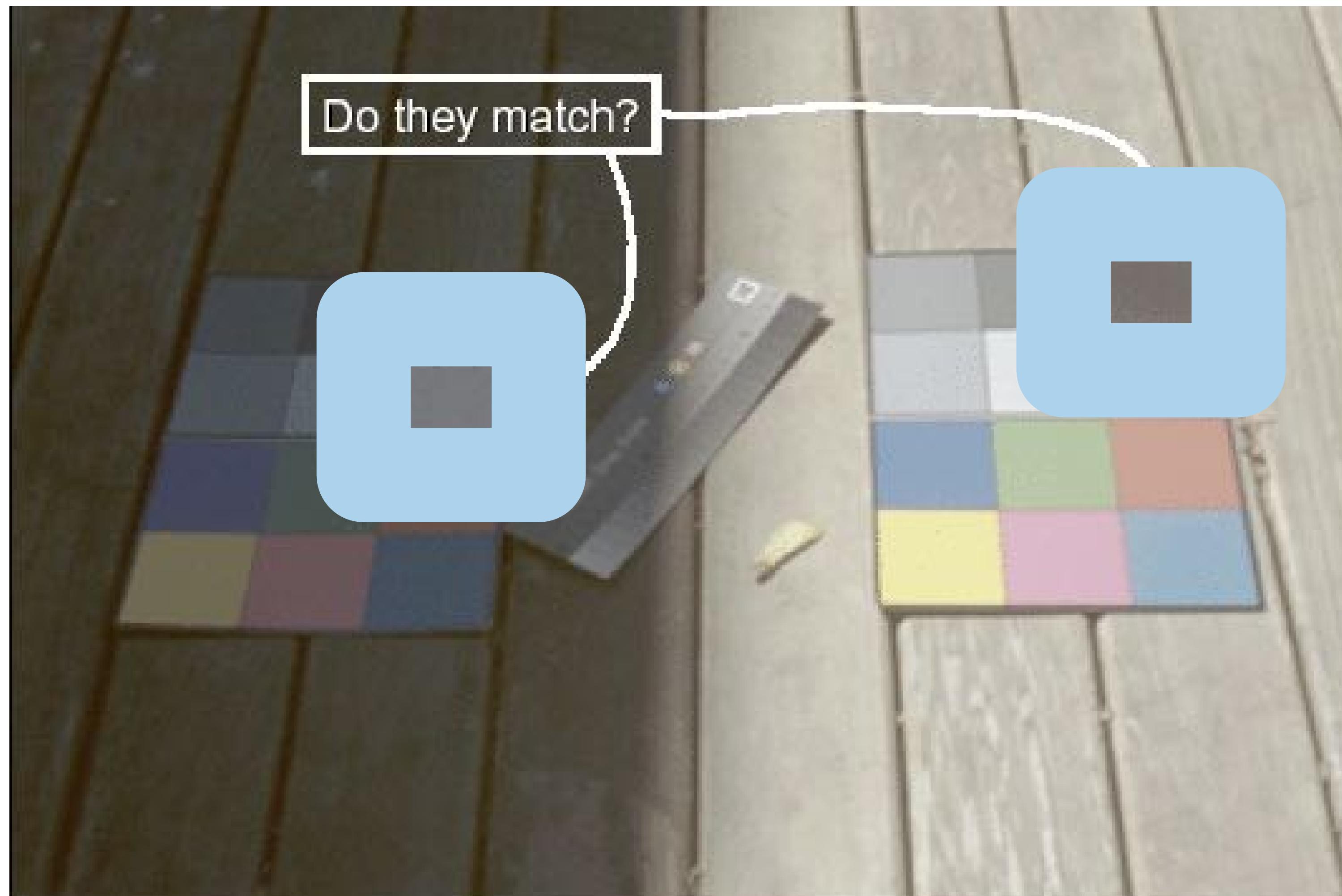
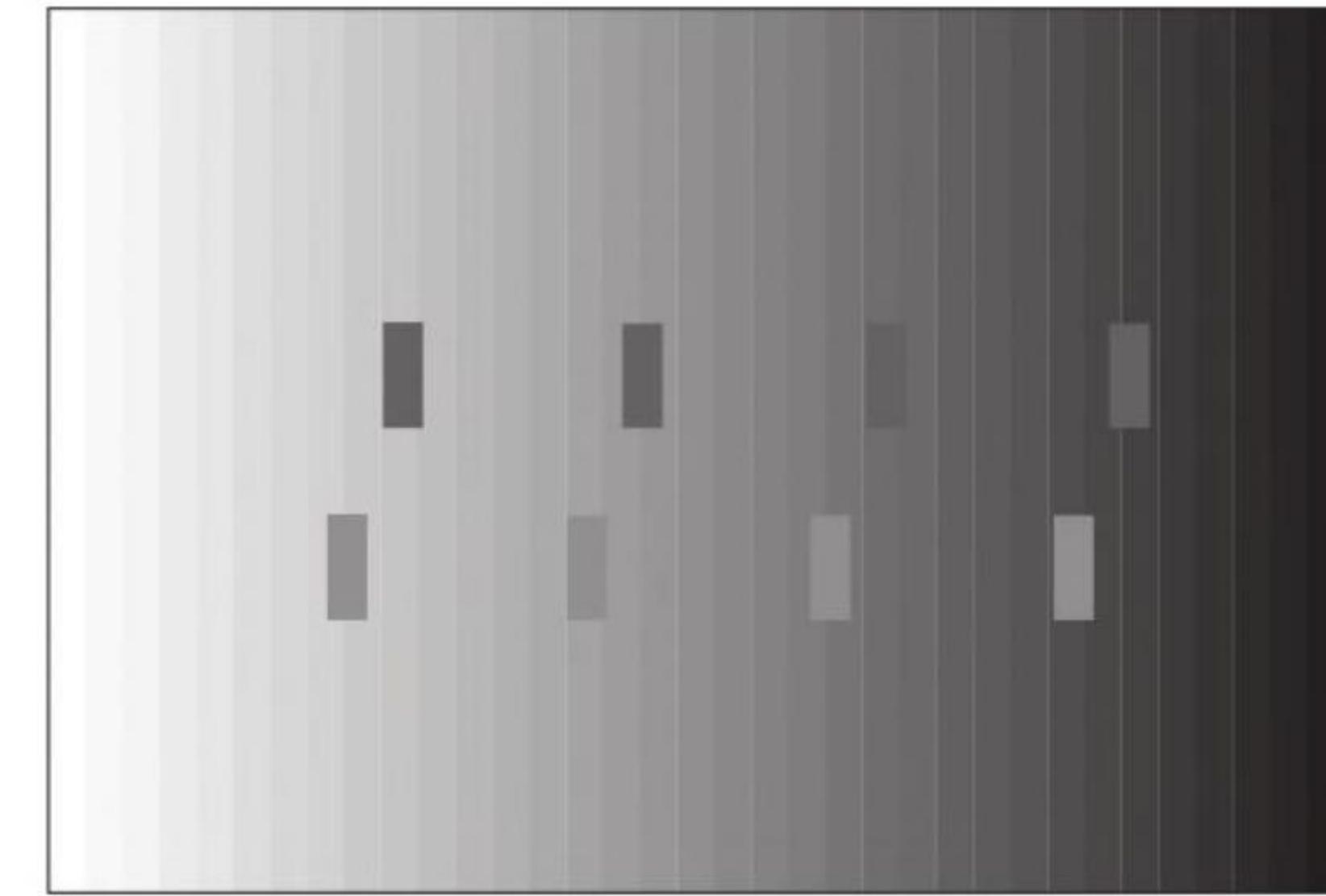
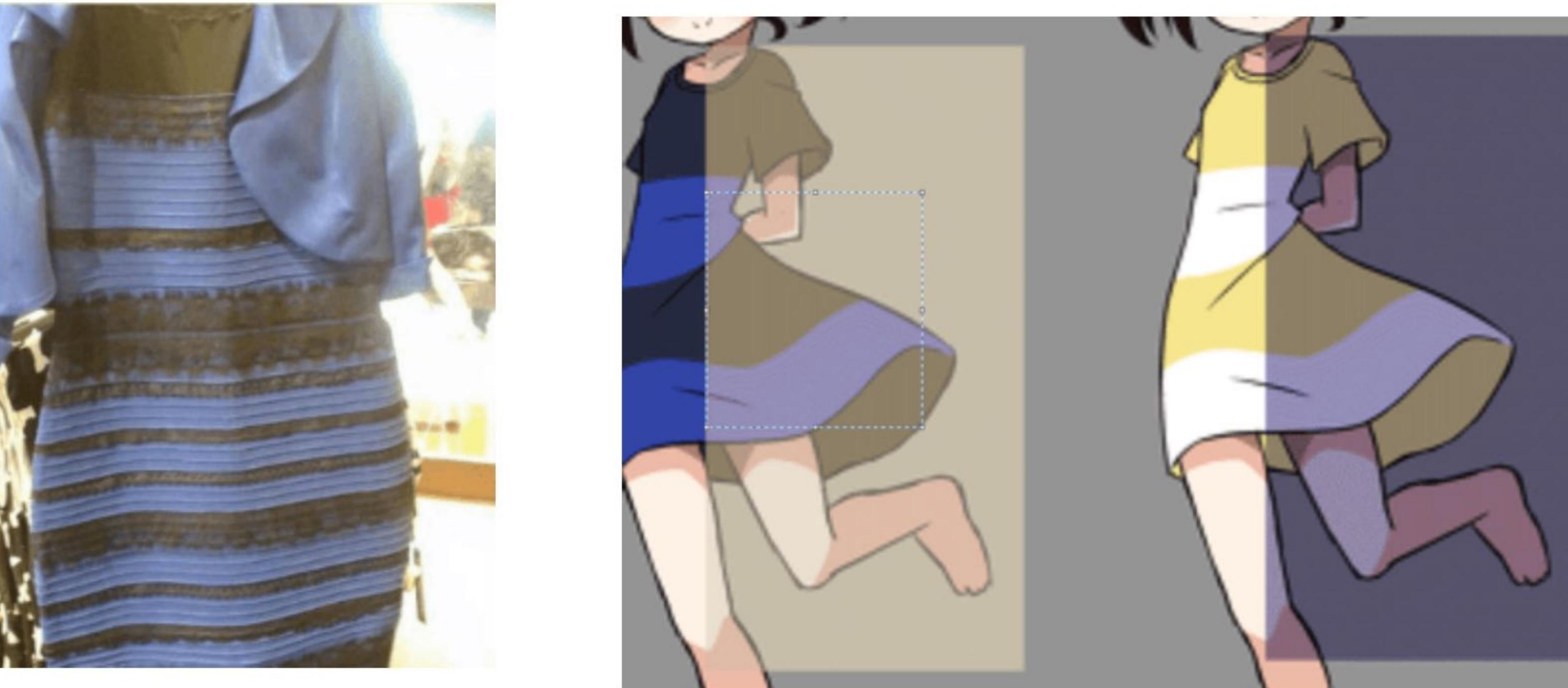


Image courtesy of John McCann via Maureen Stone

# Contrast with background



# Contrast with background

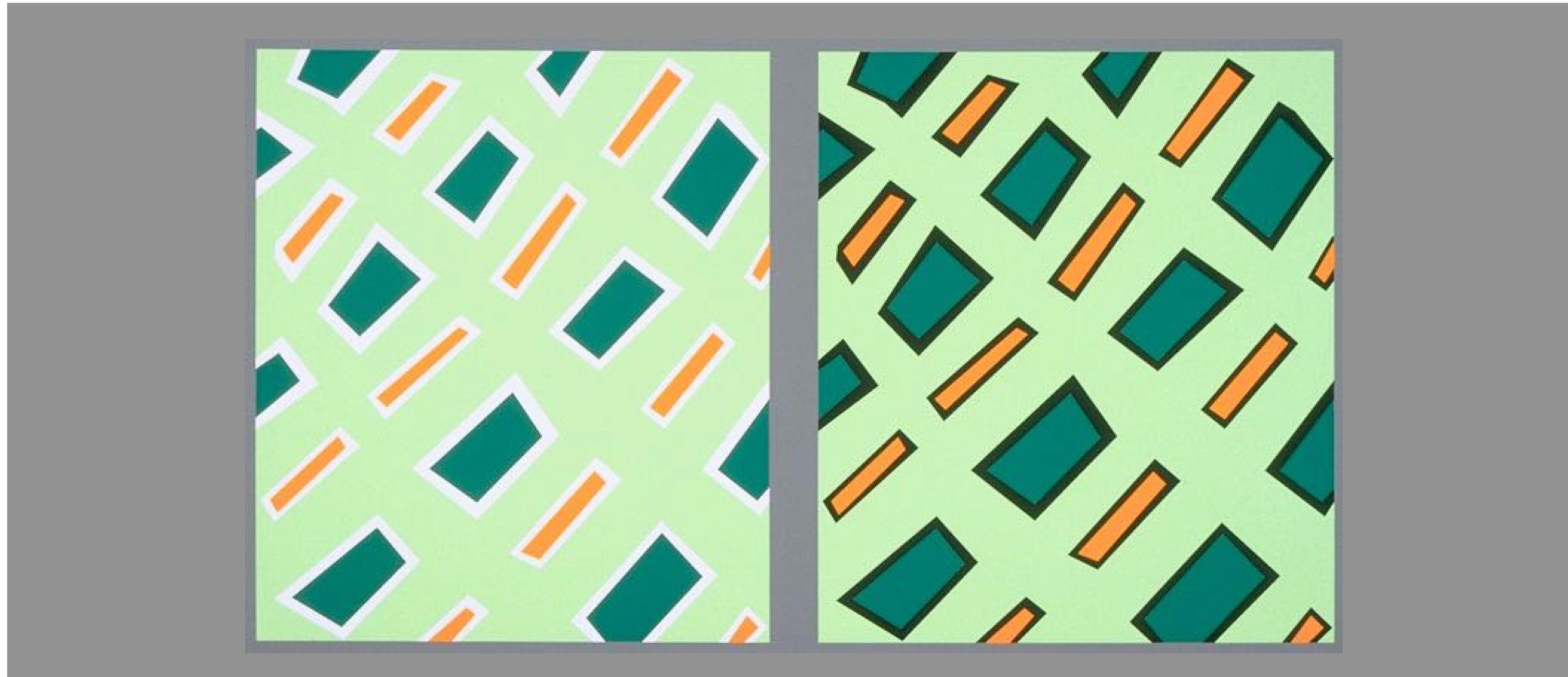


Black and blue? White and gold?

<https://imgur.com/hxJjUQB>

[https://en.wikipedia.org/wiki/The\\_dress](https://en.wikipedia.org/wiki/The_dress)

# Bezold Effect: Outlines matter



# Color naming



# Color naming

Color names if  
you're a girl...



Color names if  
you're a guy...

Doghouse Diaries  
"We take no as an answer."

# Color naming

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



# Color naming

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

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



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

# Color is just part of vision system

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

# Reading Material

[dv3] Chapter 10 - Map Color and other channels

# Questions?

:::::::



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