

Analisi e Visualizzazione di Reti Complesse

DV03 Marks and Channels
Color

Prof. Rossano Schifanella

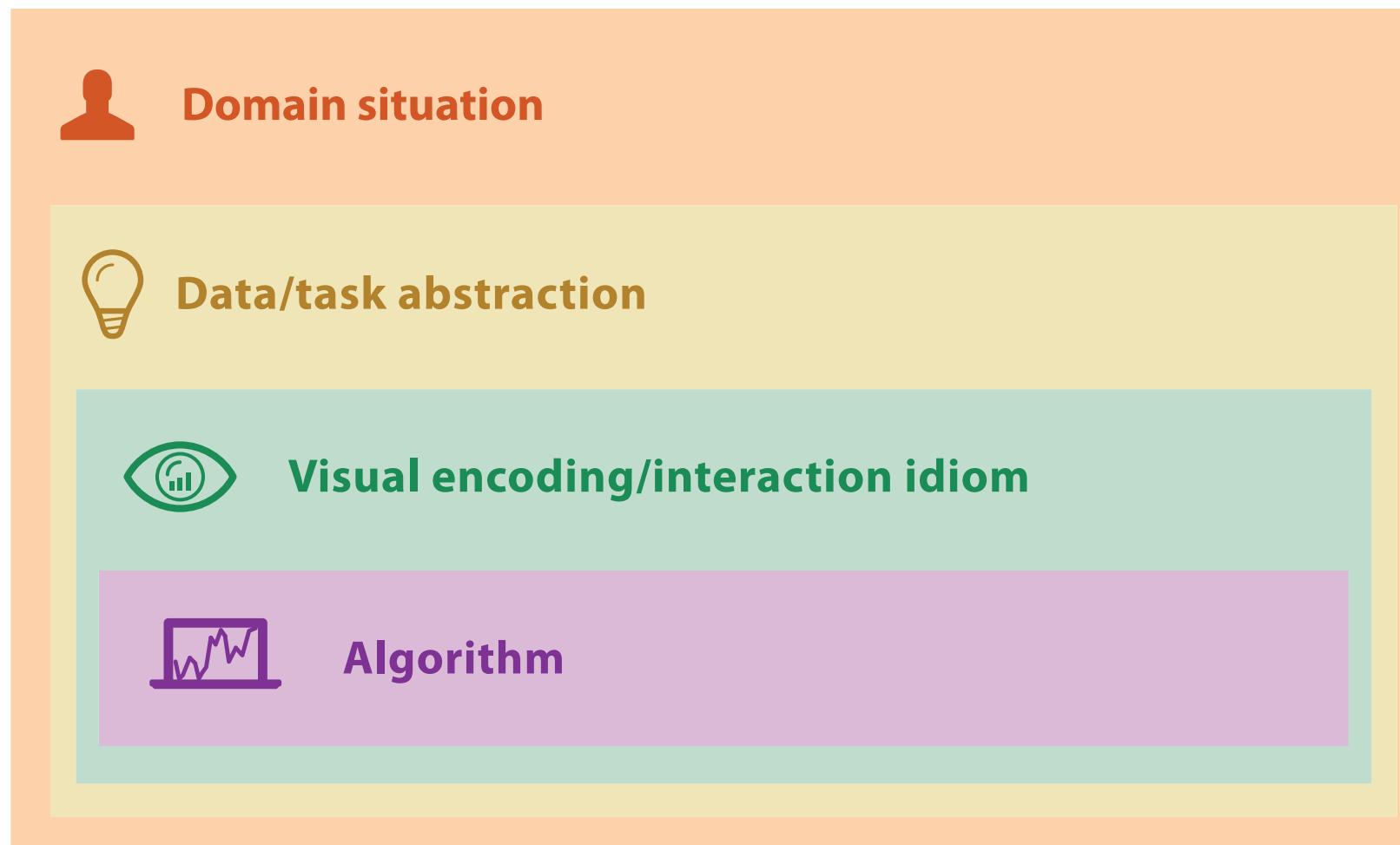
DV03 - Marks and Channels | Color



Marks and Channels

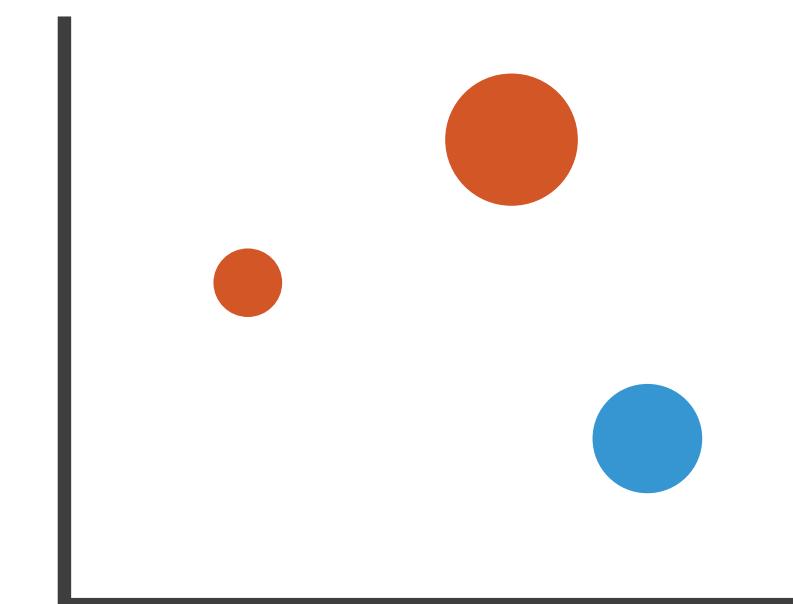
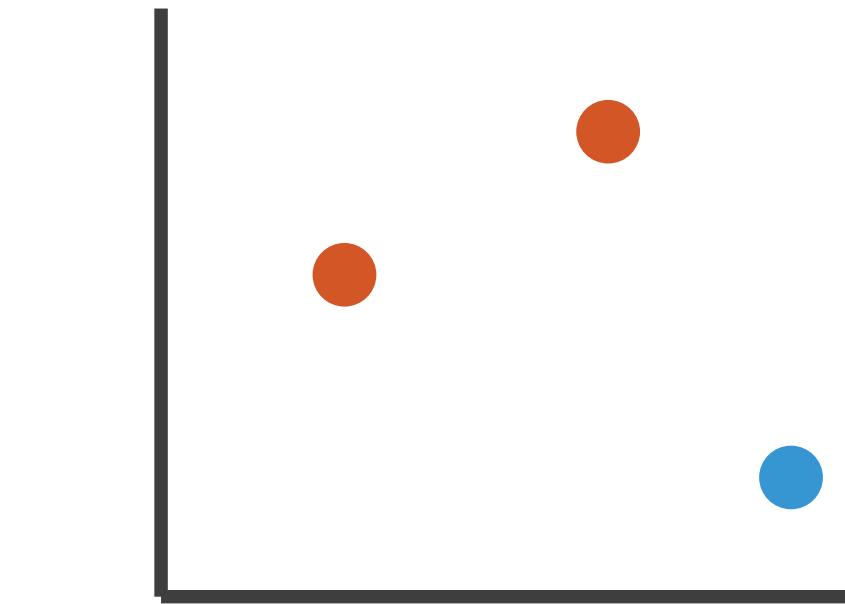
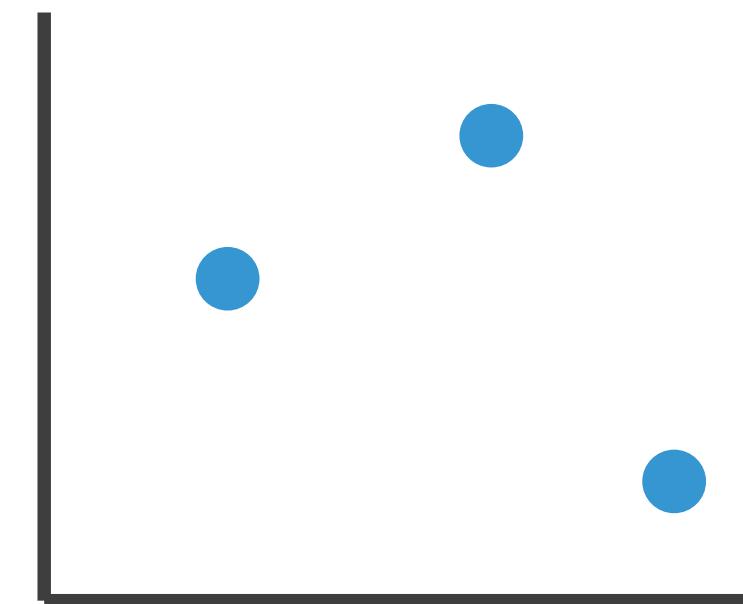
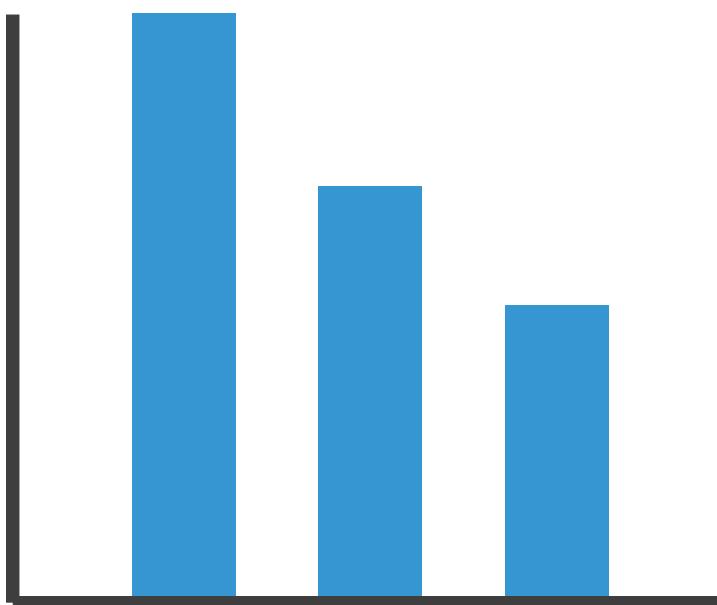
Visual encoding

- How to systematically analyze the idiom structure?



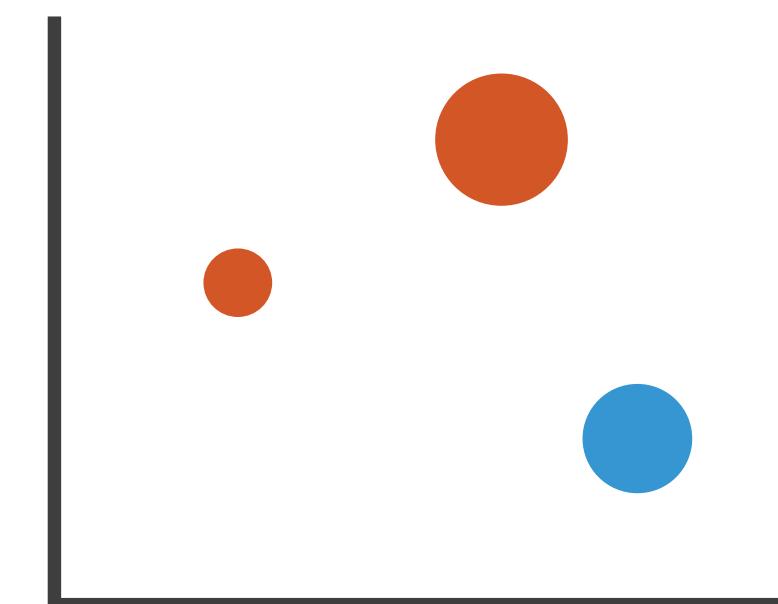
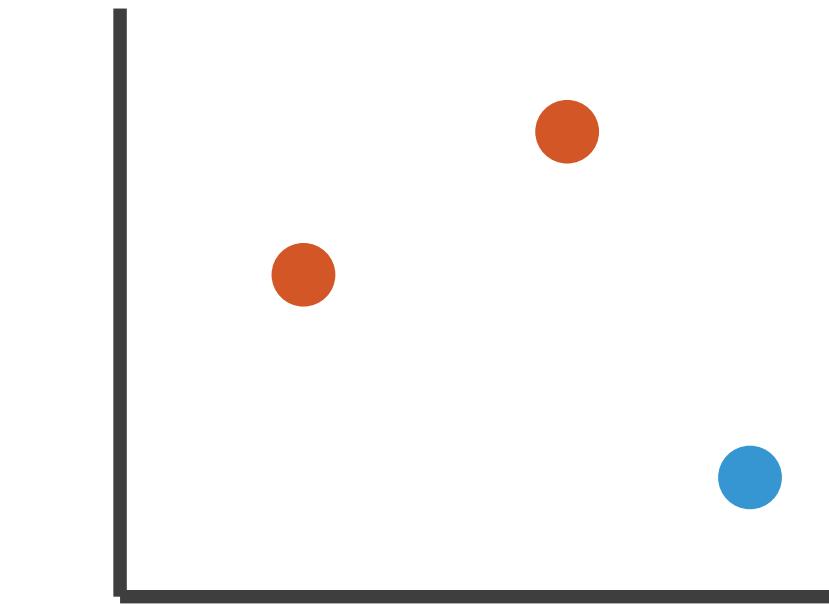
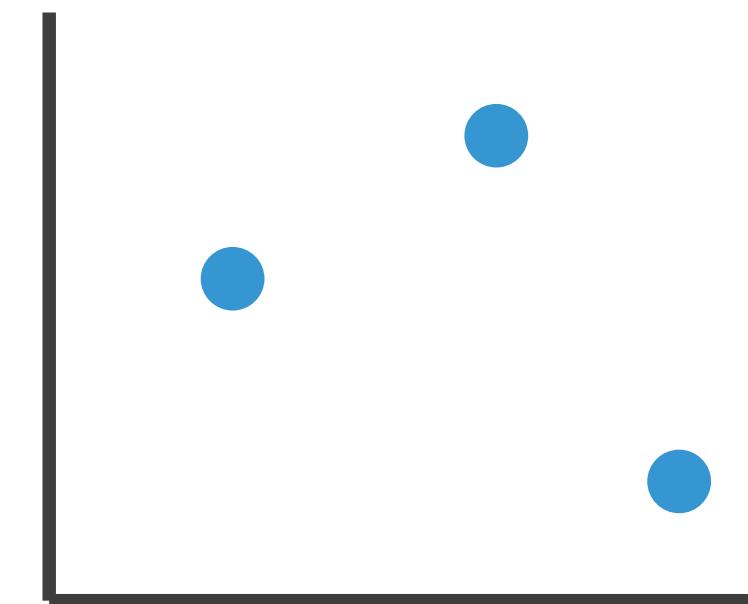
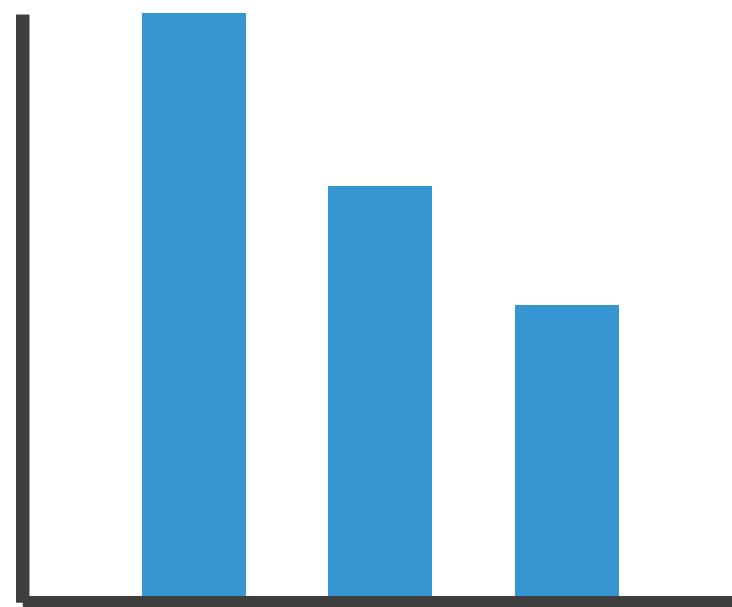
Visual encoding

- How to systematically analyze the idiom structure?



Visual encoding

- How to systematically analyze the idiom structure?

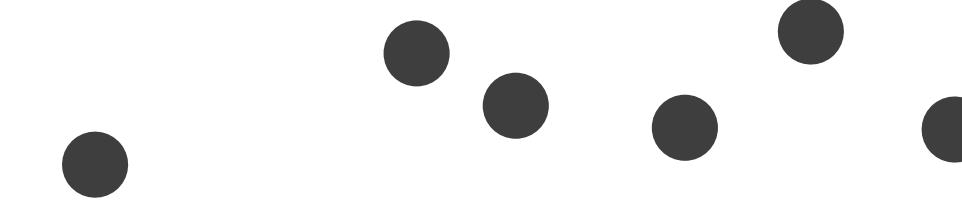


- **marks & channels**
 - **marks**: represent items or links
 - **channels**: change the appearance of marks based on attributes

Marks for items

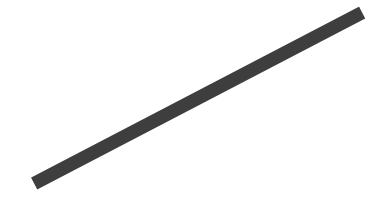
- basic geometric elements

→ Points



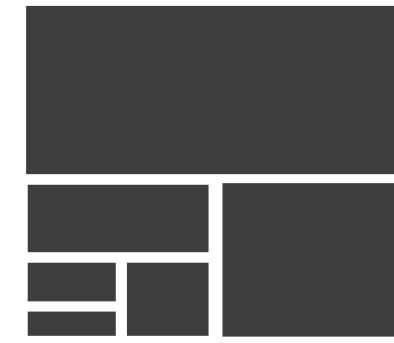
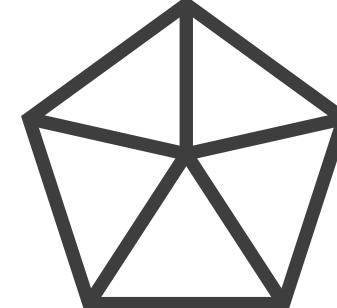
0D

→ Lines



1D

→ Interlocking Areas

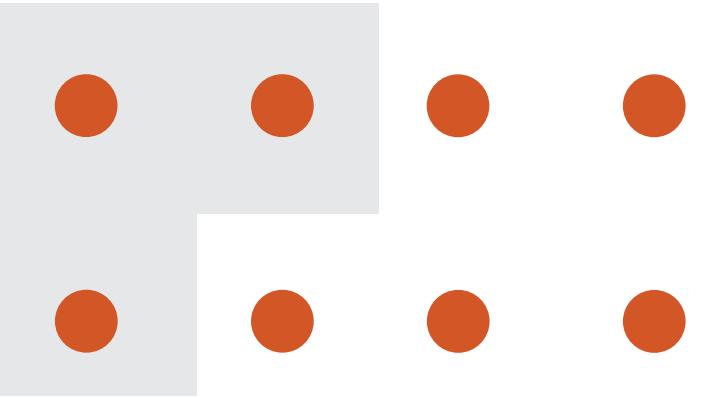


2D

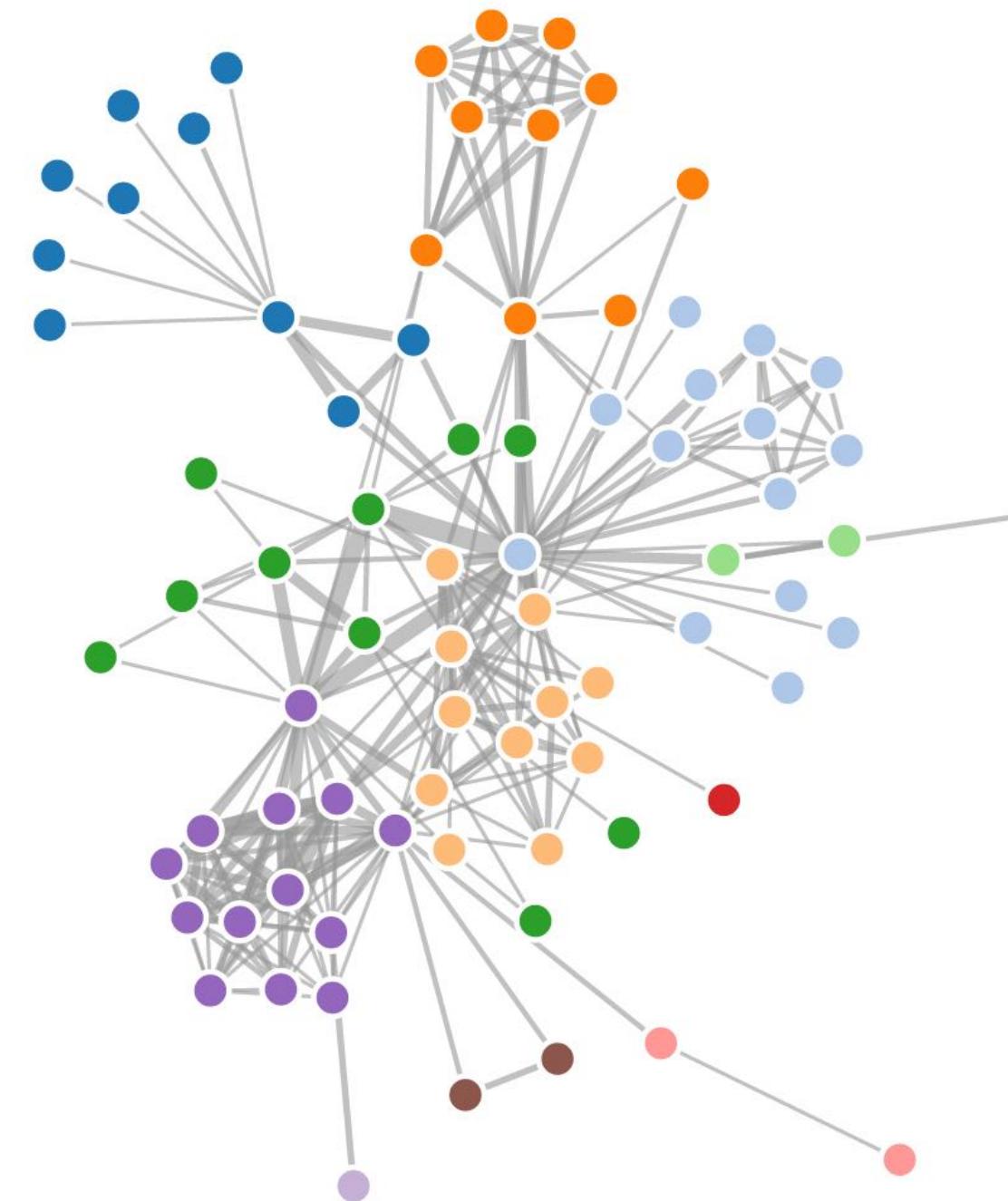
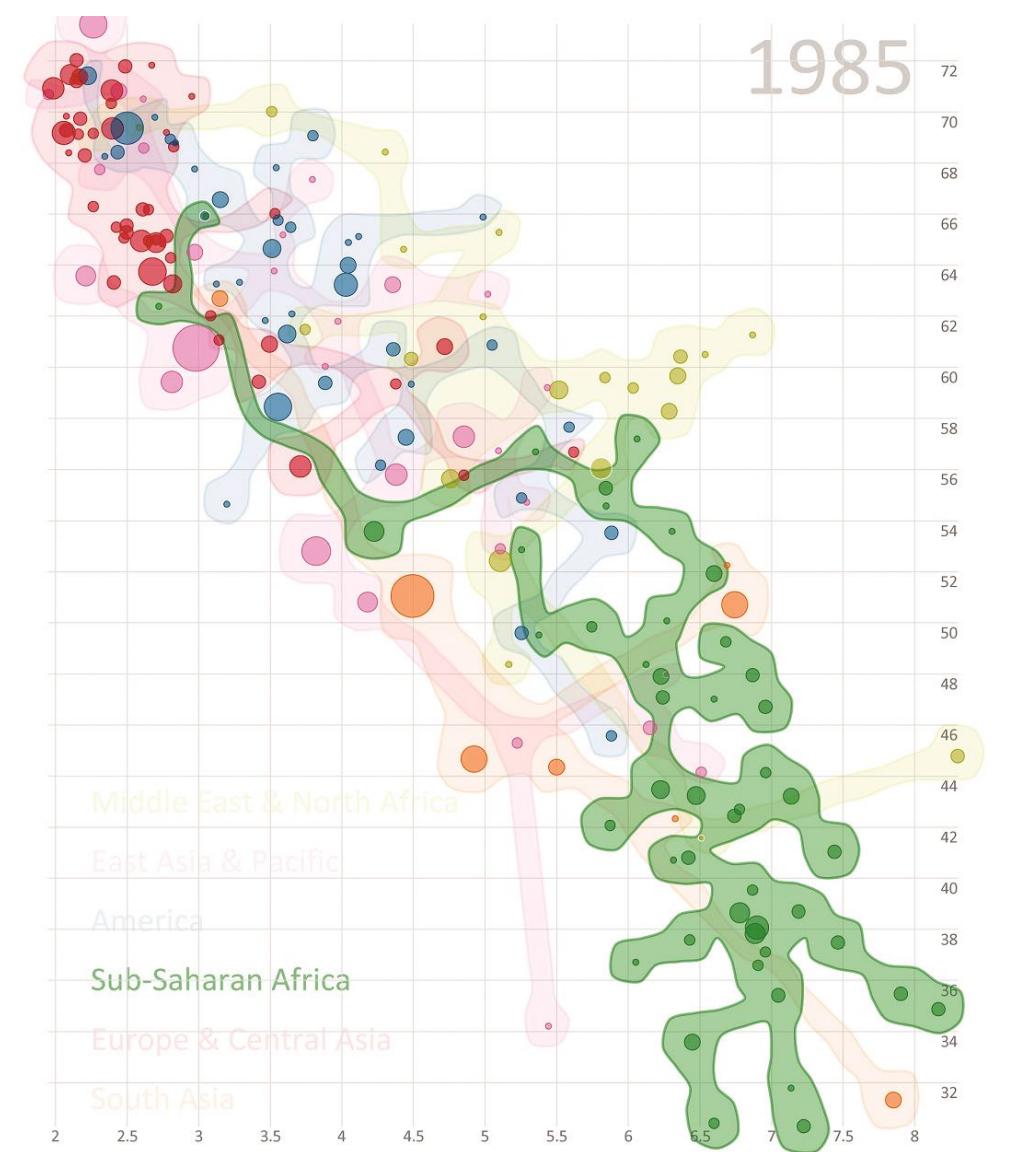
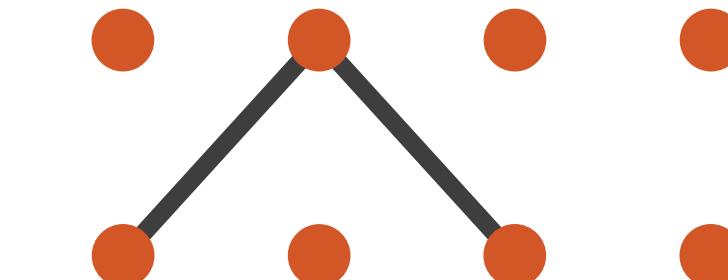
- 3D mark: volume, rarely used

Marks for links

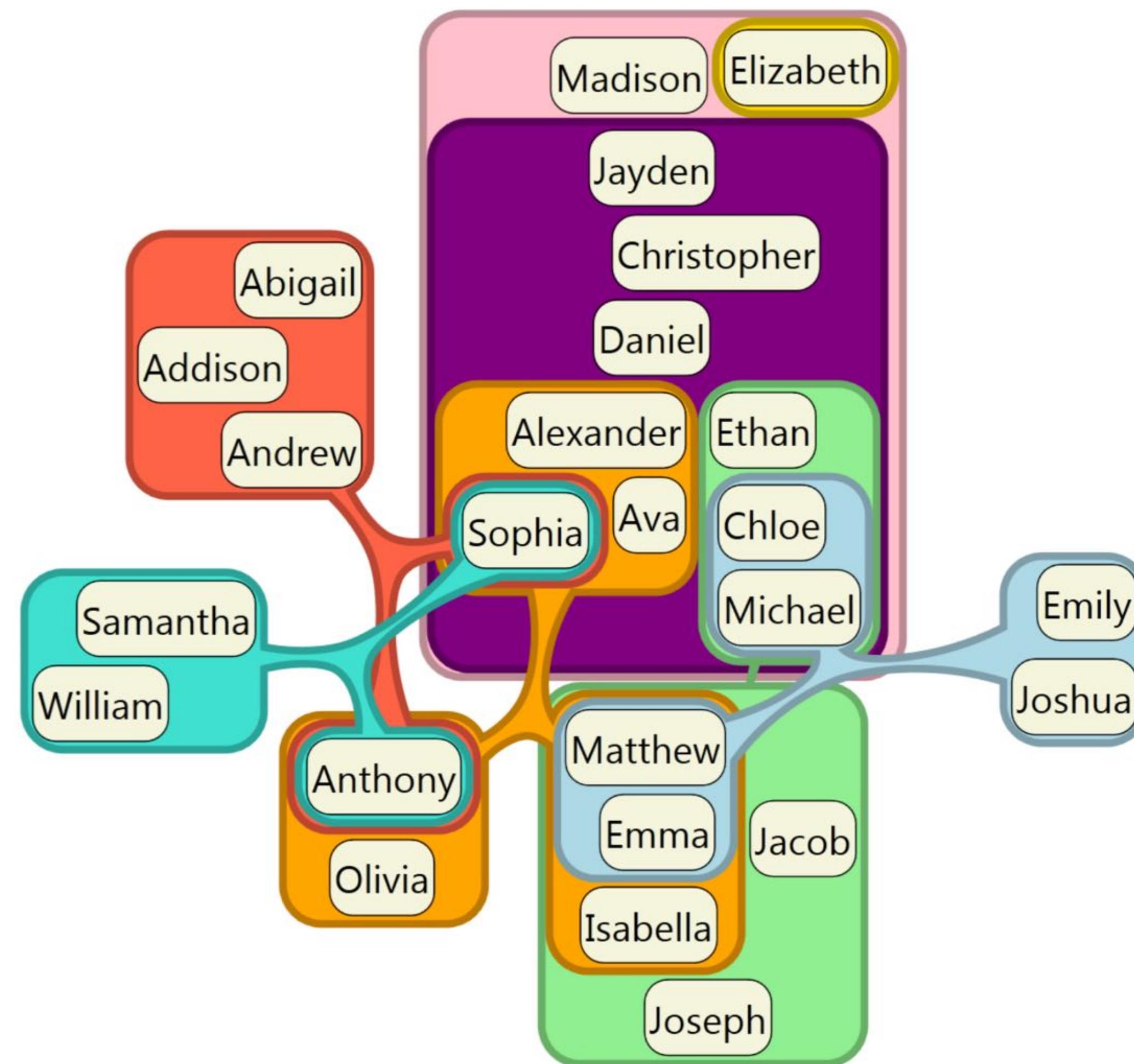
→ Containment



→ 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

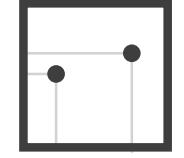
→ Horizontal



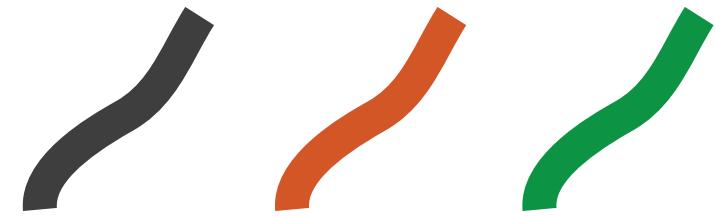
→ Vertical



→ Both



➔ Color



➔ Shape



➔ Tilt



➔ Size

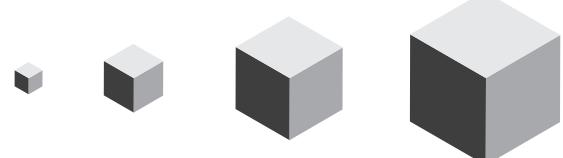
→ Length



→ Area



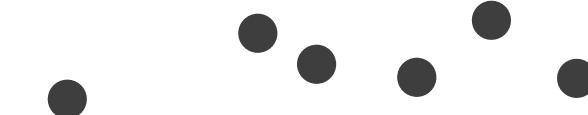
→ Volume



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

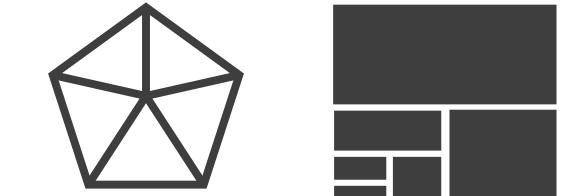
→ Points



→ Lines



→ Interlocking Areas

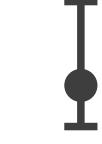


→ Position

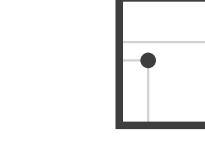
→ Horizontal



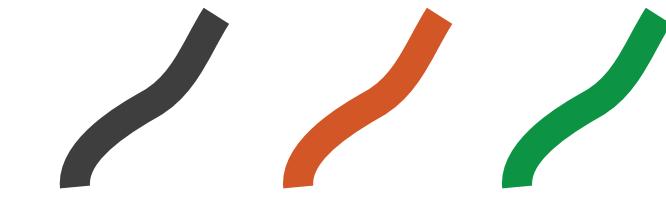
→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

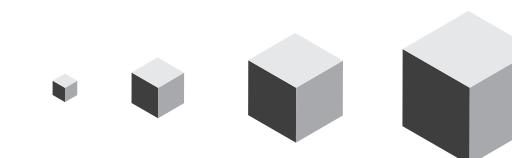
→ Length



→ Area

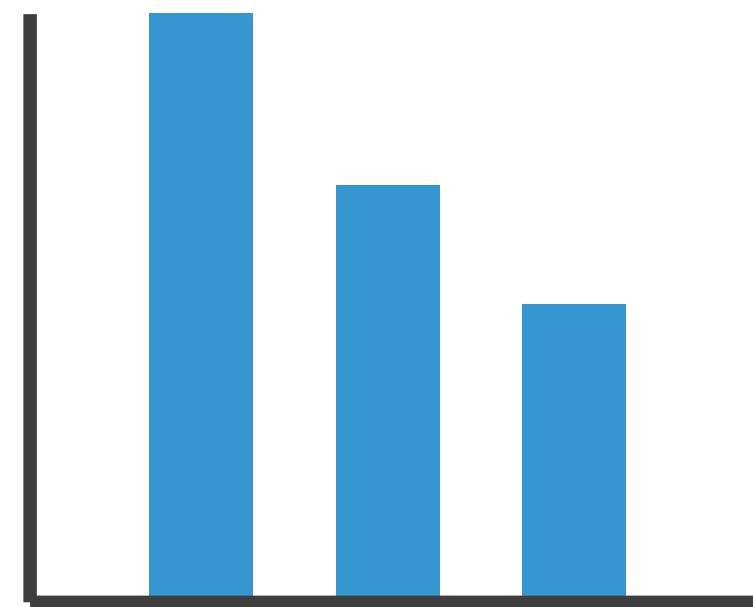


→ Volume



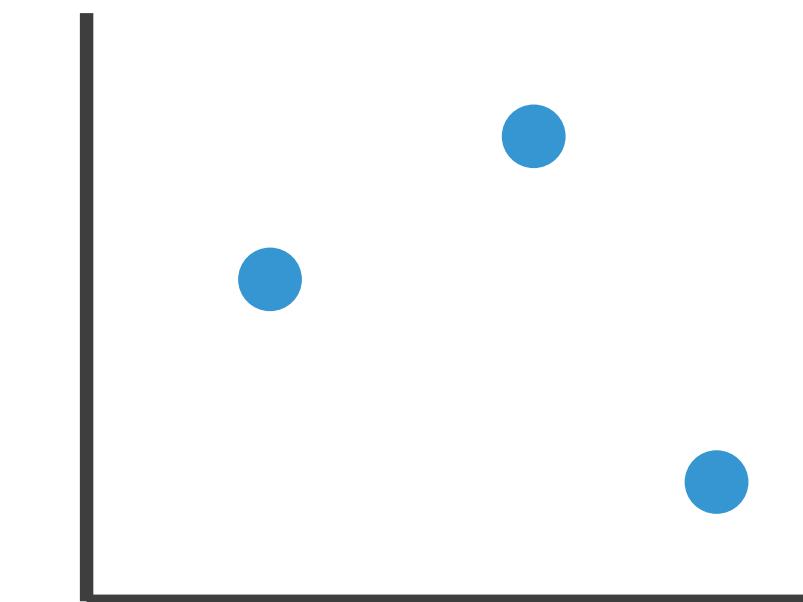
Visual encoding

- analyze idiom structure as combination of marks and channels



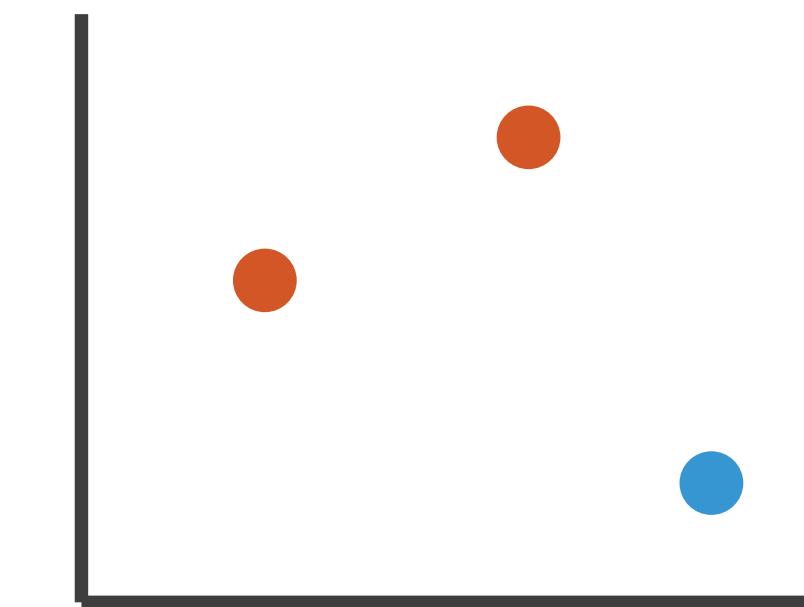
1:
vertical position

mark: line



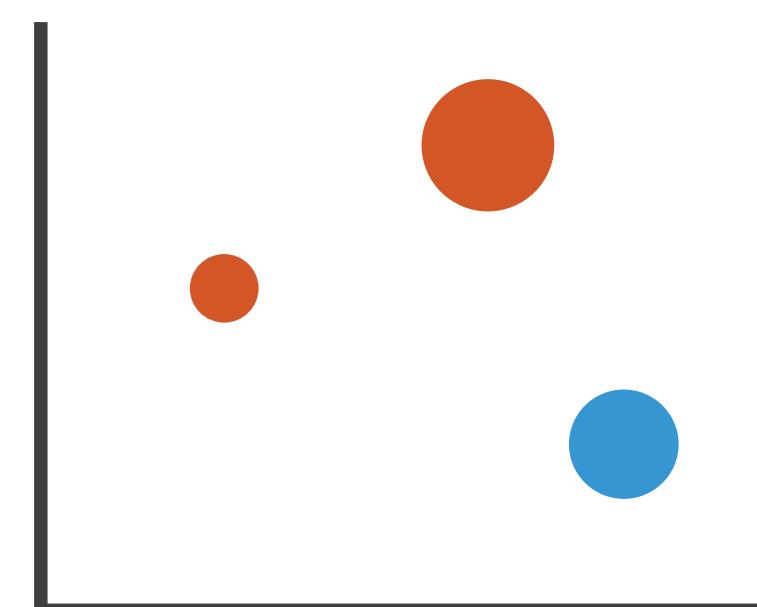
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

mark: point

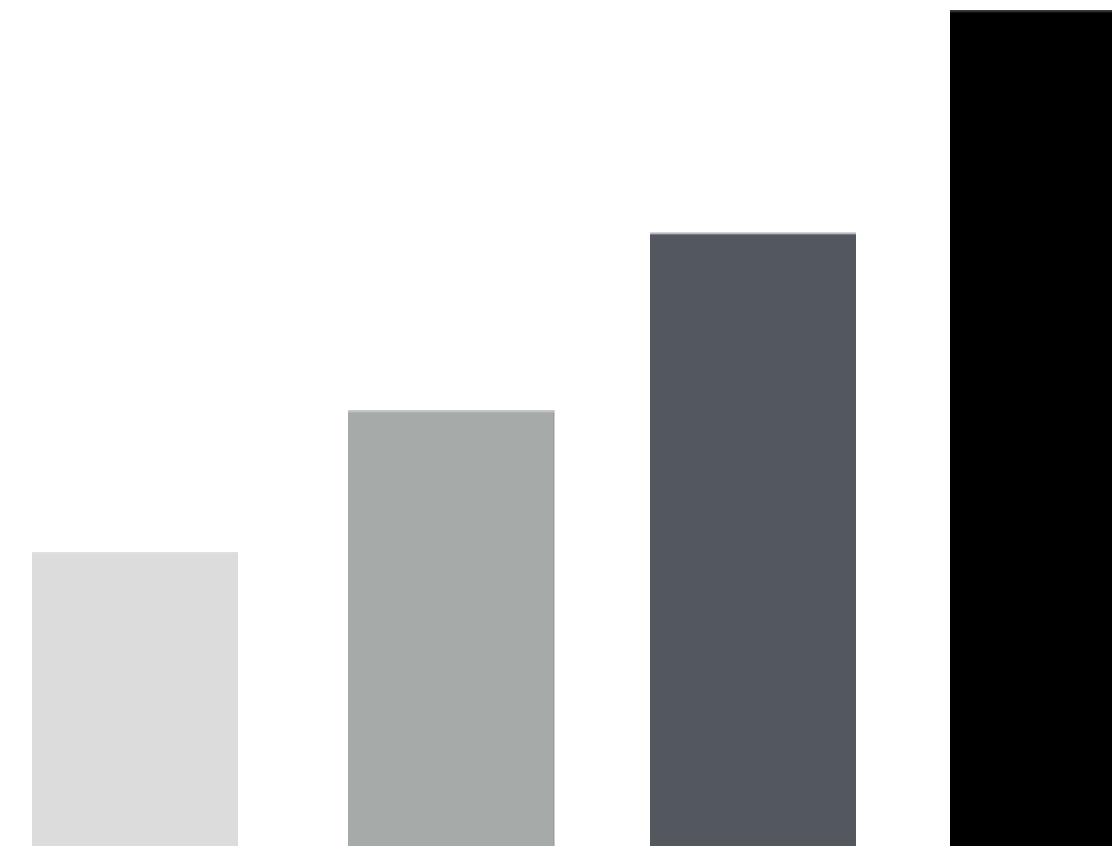


4:
vertical position
horizontal position
color hue
size (area)

mark: point

Redundant encoding

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



Length, Position, and Luminance

Scope of analysis

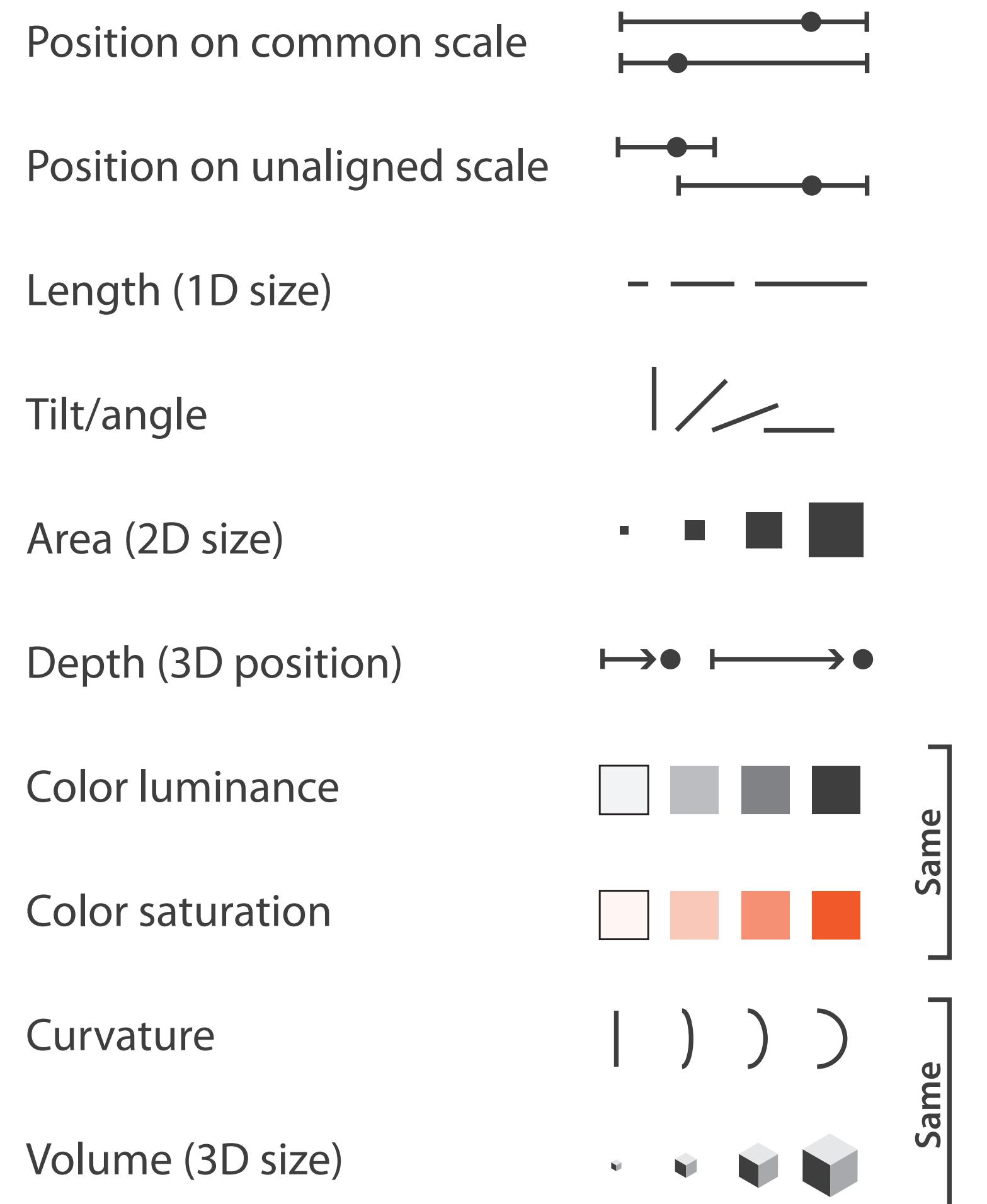
- simplifying assumptions: one mark per item, single view
- later on
 - multiple views
 - multiple marks in a region (glyph)
 - some items not represented by marks (aggregation and filtering)

When to use which channel?

When should you use which channel?

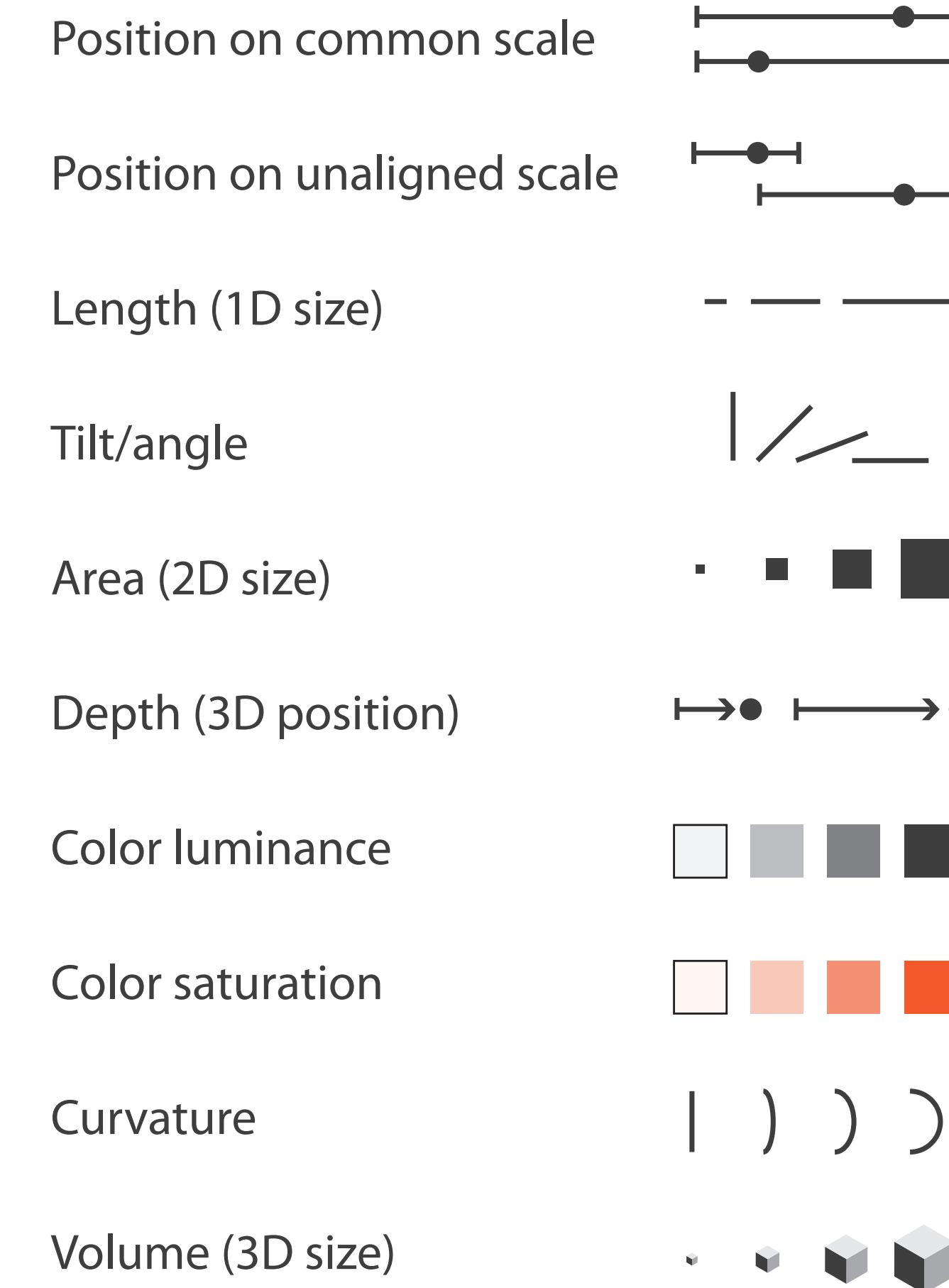
- **expressiveness**
 - match channel type to data type
- **effectiveness**
 - some channels are better than others

Channels: Rankings

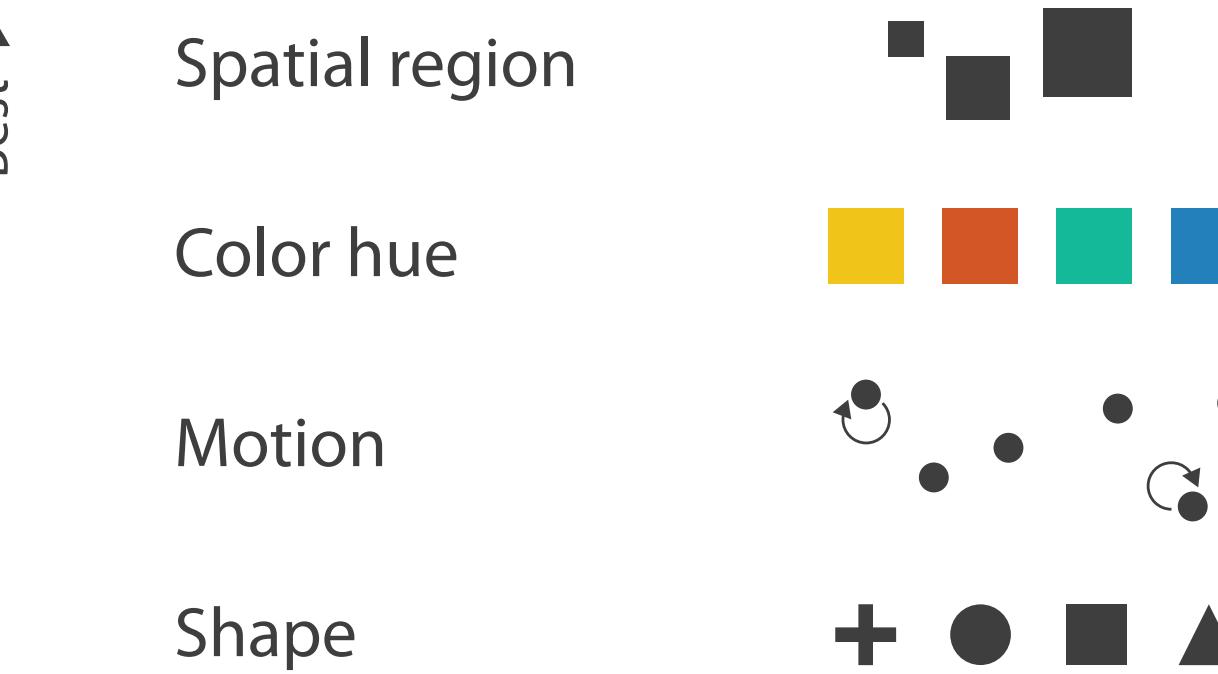


Channels: Rankings

→ **Magnitude Channels: Ordered Attributes**



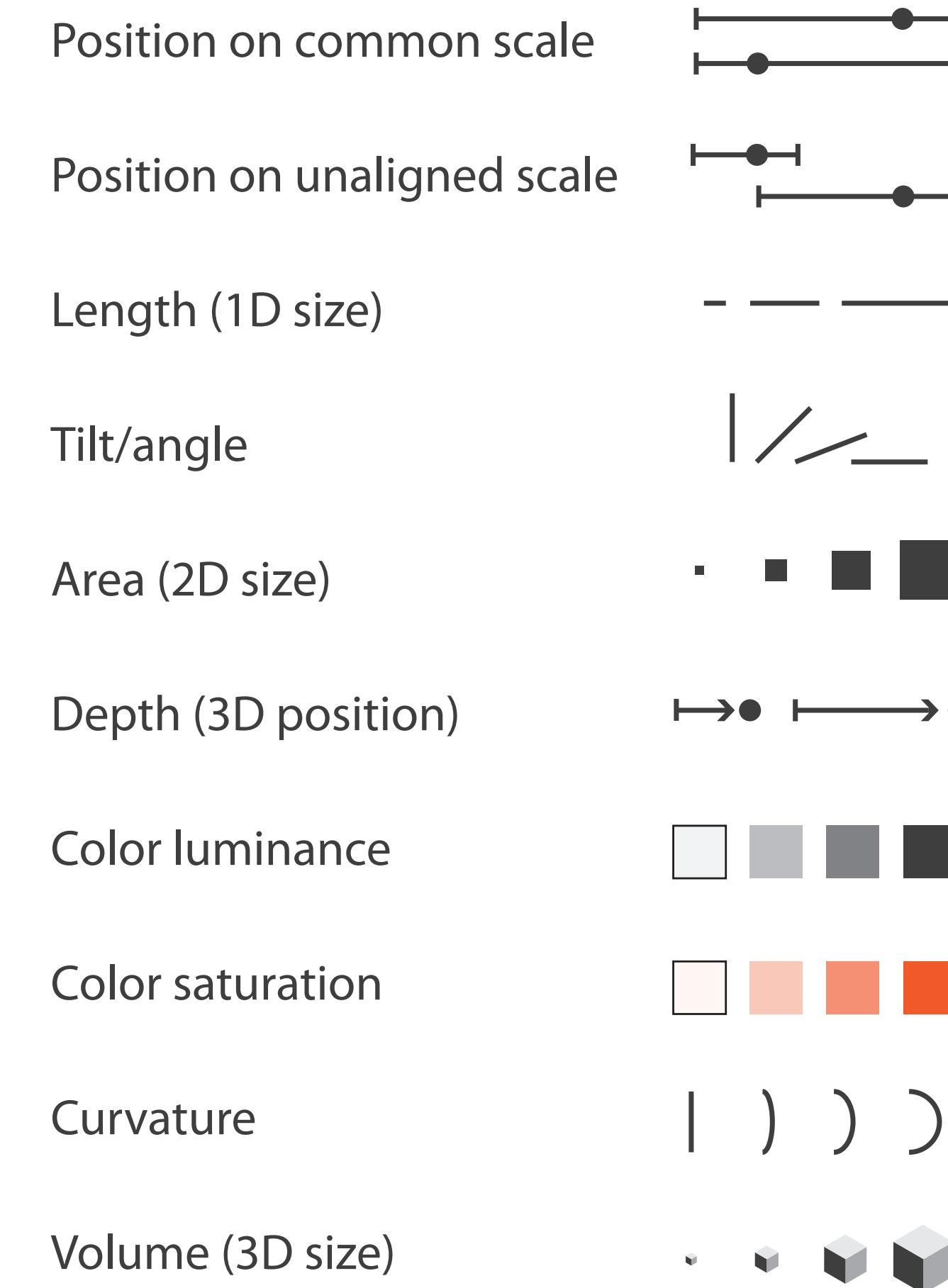
→ **Identity Channels: Categorical Attributes**



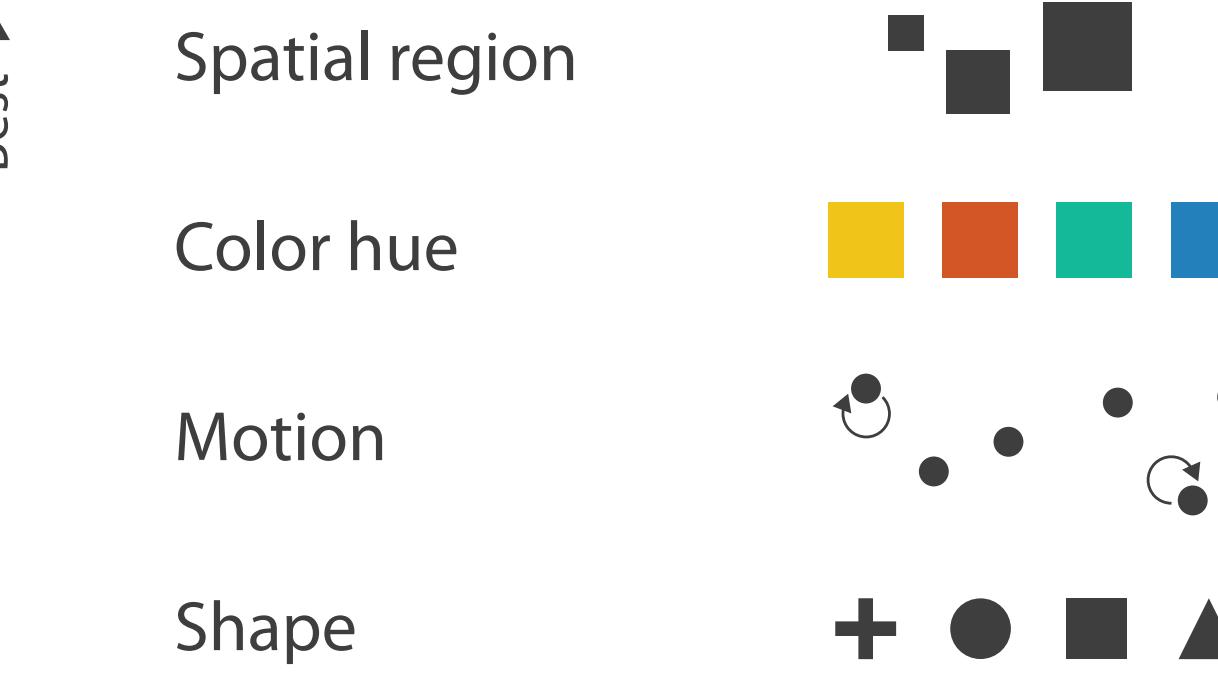
- **expressiveness**
 - match channel and data characteristics
 - **magnitude for ordered**
 - how much? which rank?
 - **identity for categorical**
 - what?

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

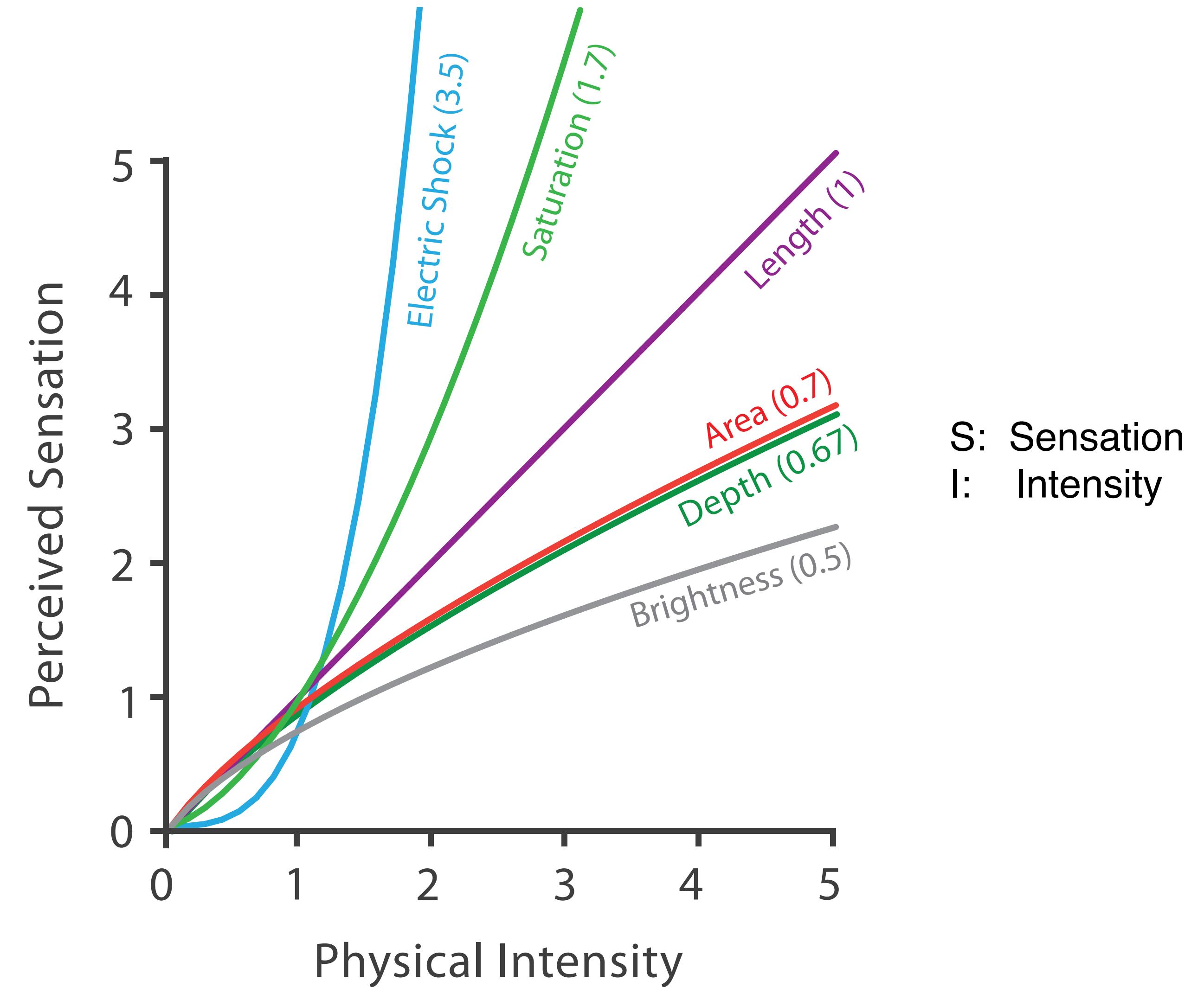
Channel effectiveness

- **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

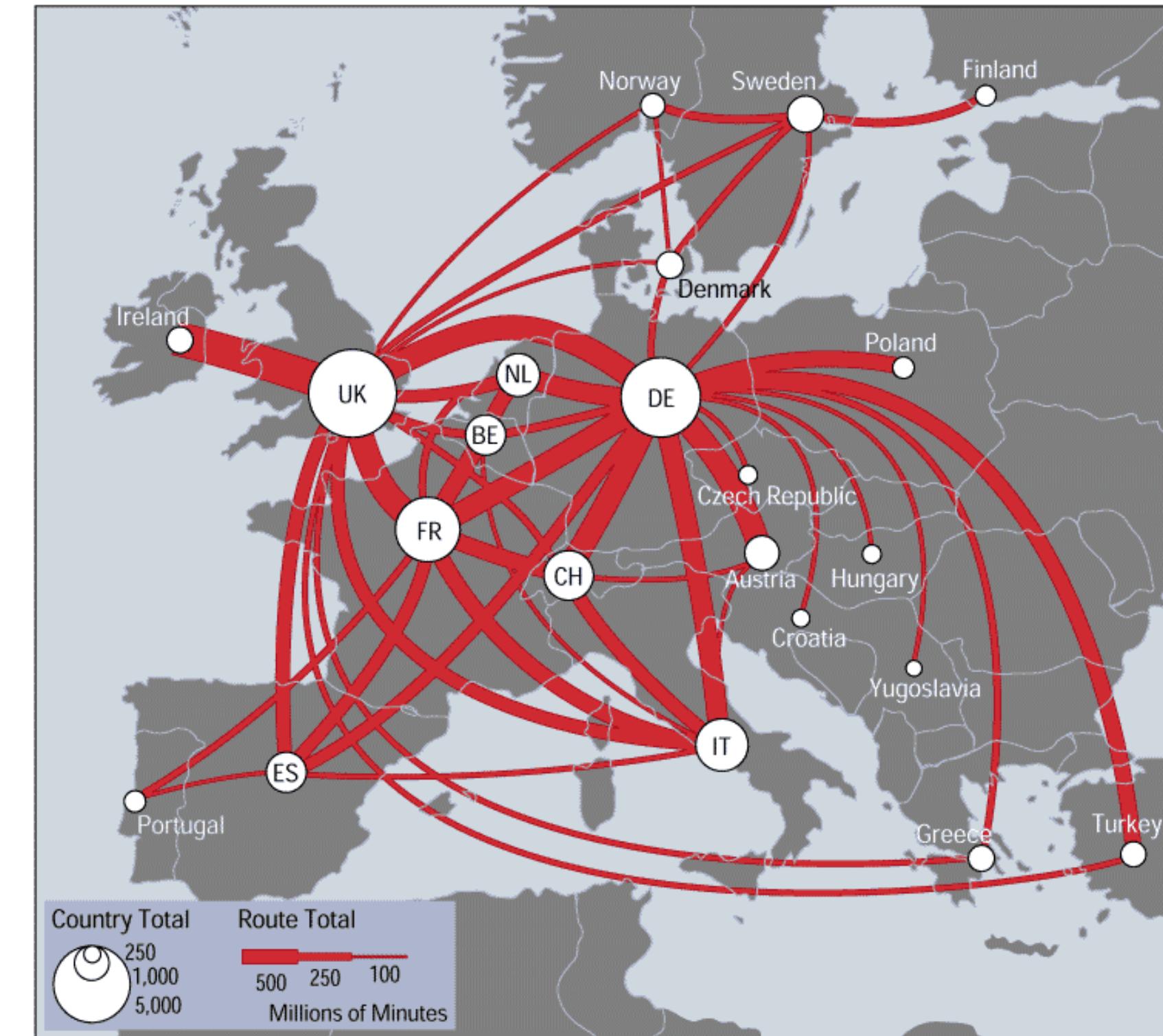
- length is accurate: linear
- others magnified or compressed
 - exponent characterizes

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



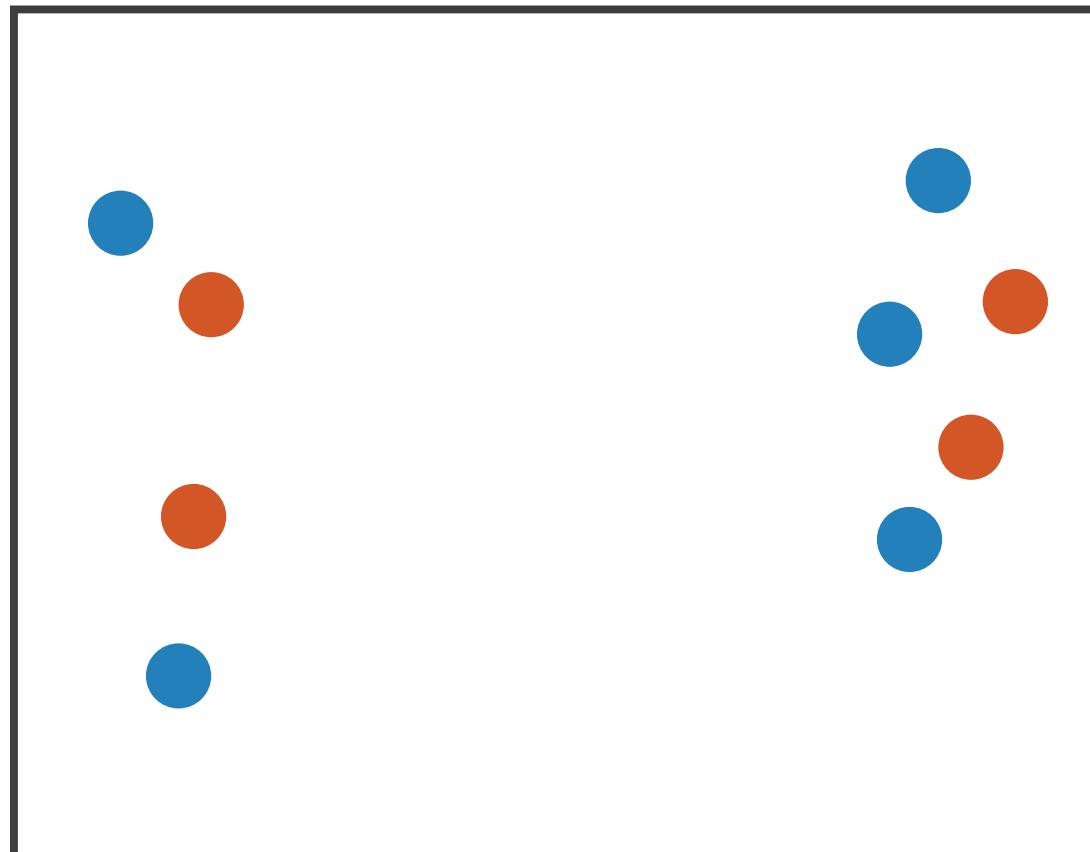
Discriminability: How many usable steps?

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



Separability vs. Integrality

Position
+ Hue (Color)

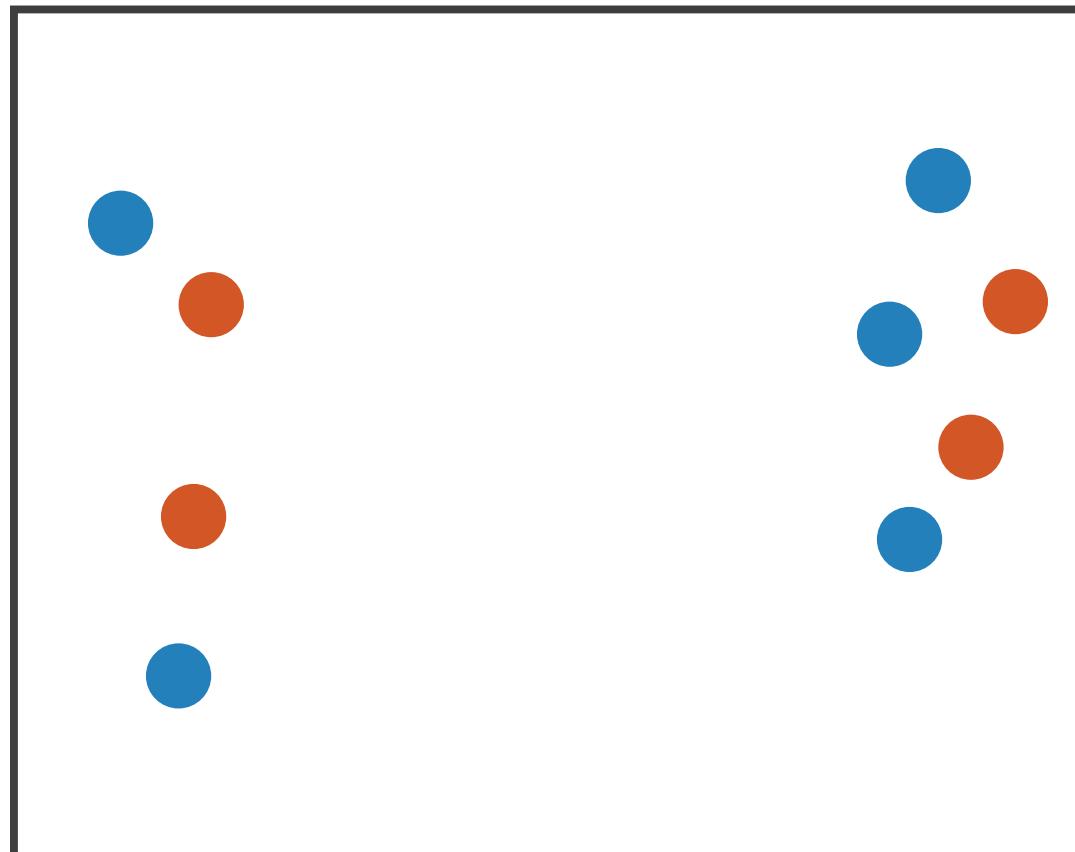


Color (hue) and position can be used independently

Fully separable

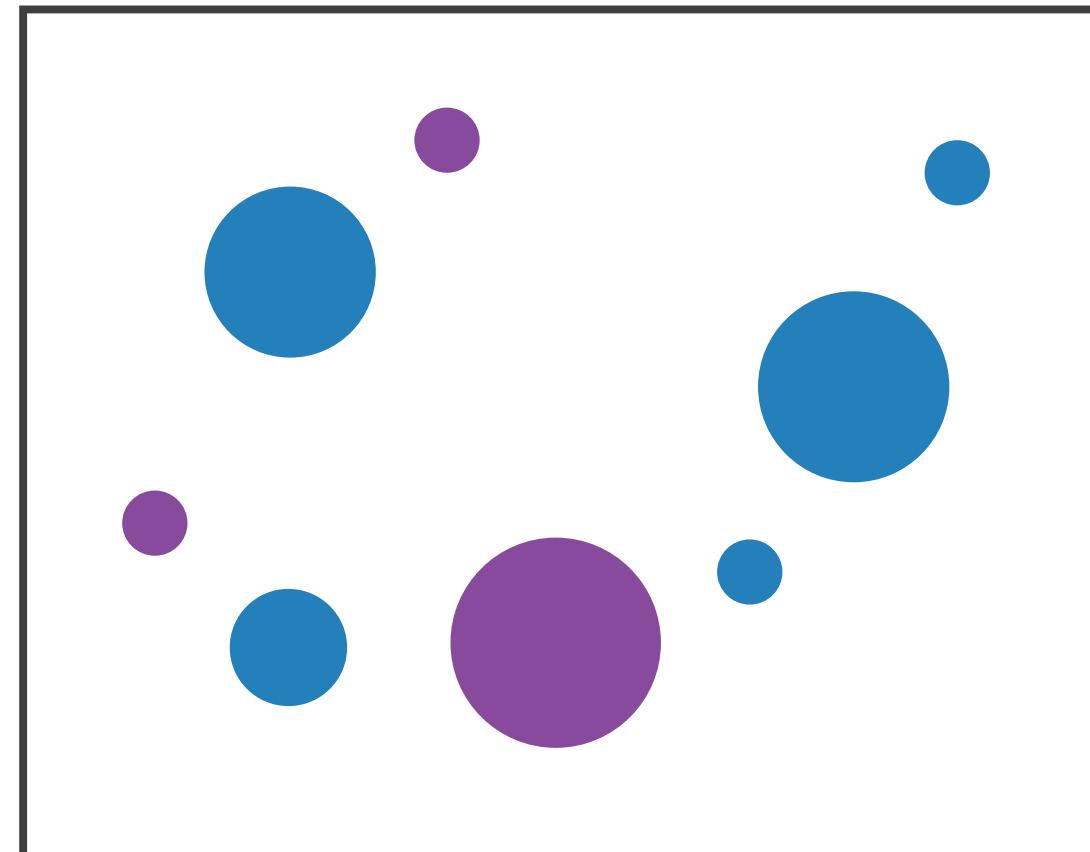
Separability vs. Integrality

Position
+ Hue (Color)



Fully separable

Size
+ Hue (Color)

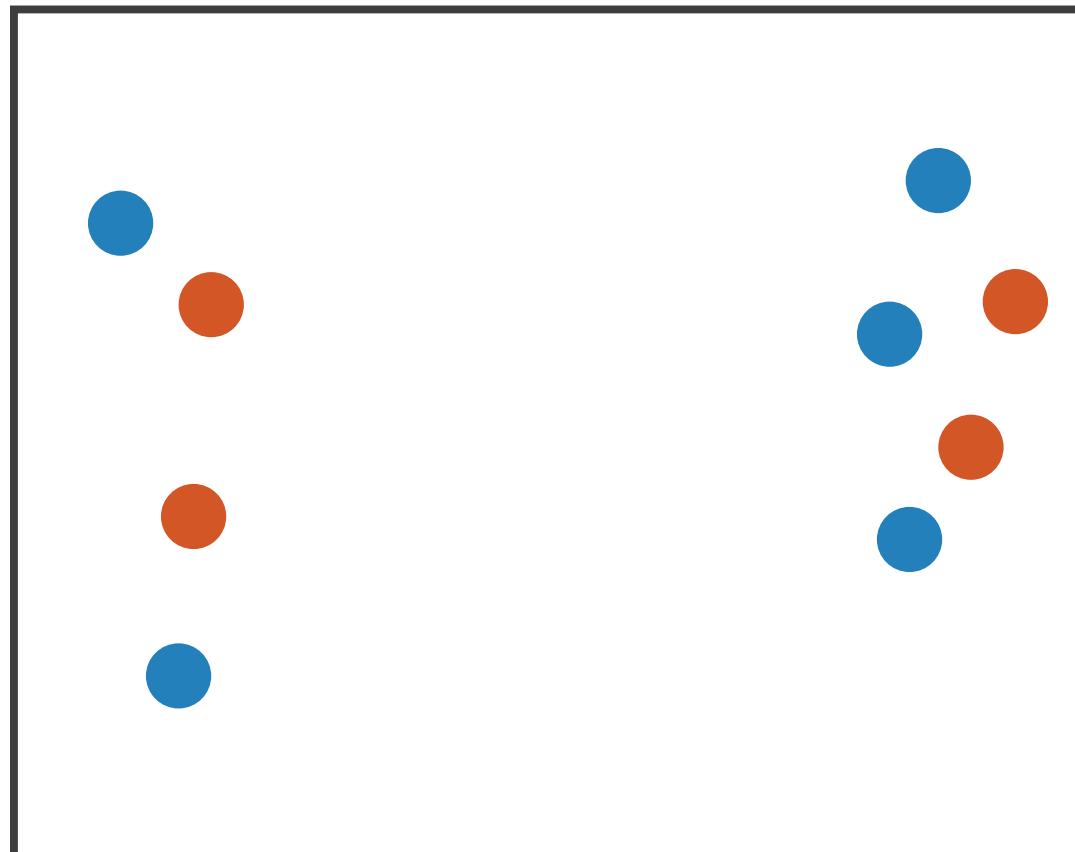


Some interference

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

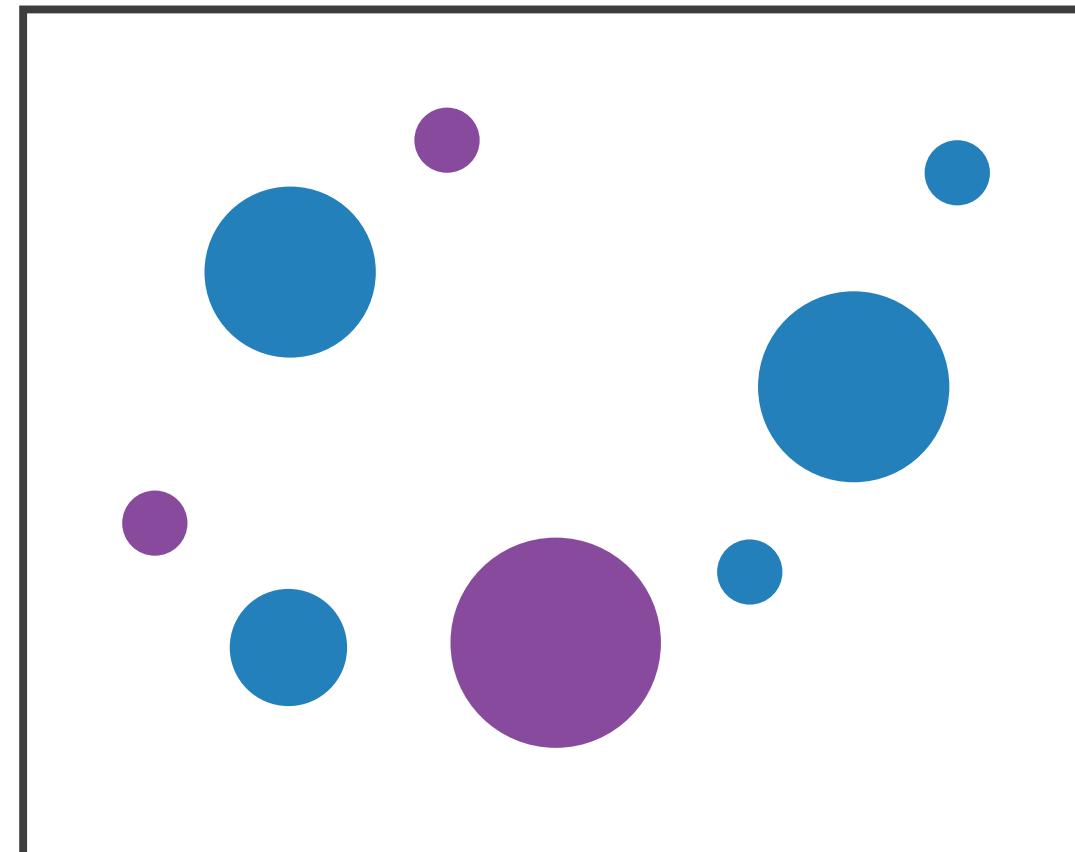
Separability vs. Integrality

Position
+ Hue (Color)



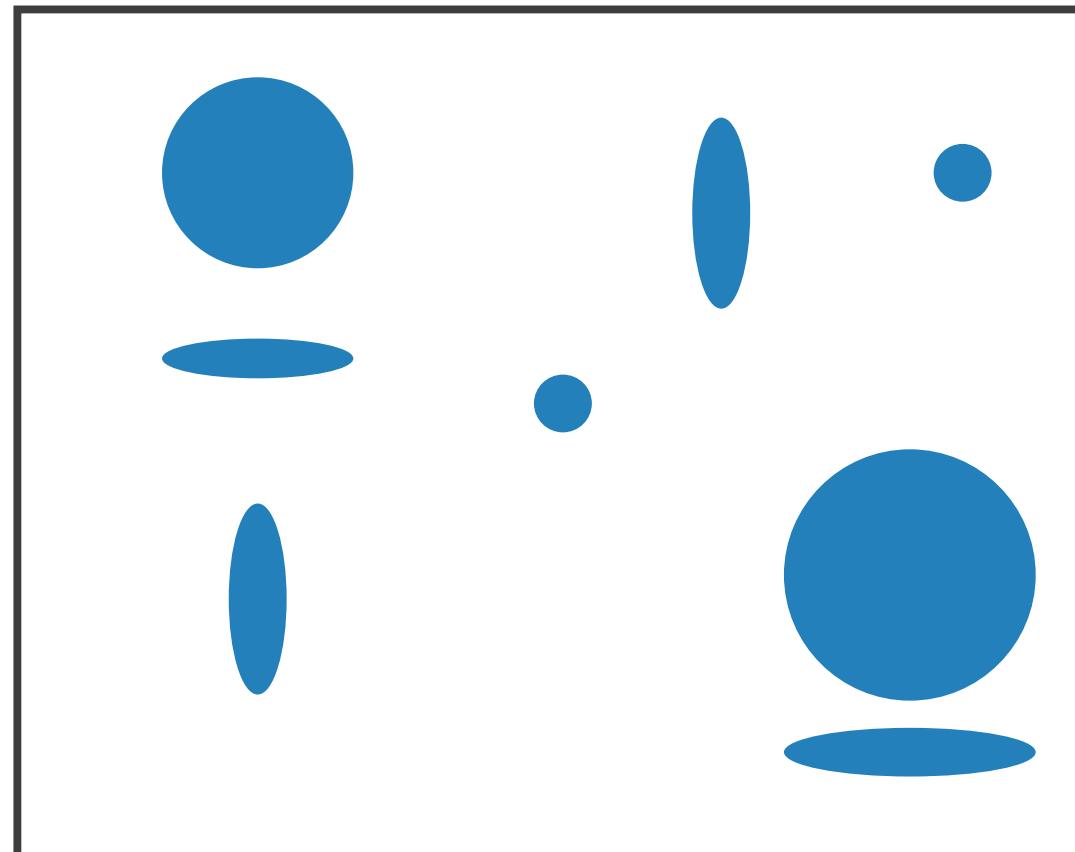
Fully separable

Size
+ Hue (Color)



Some interference

Width
+ Height



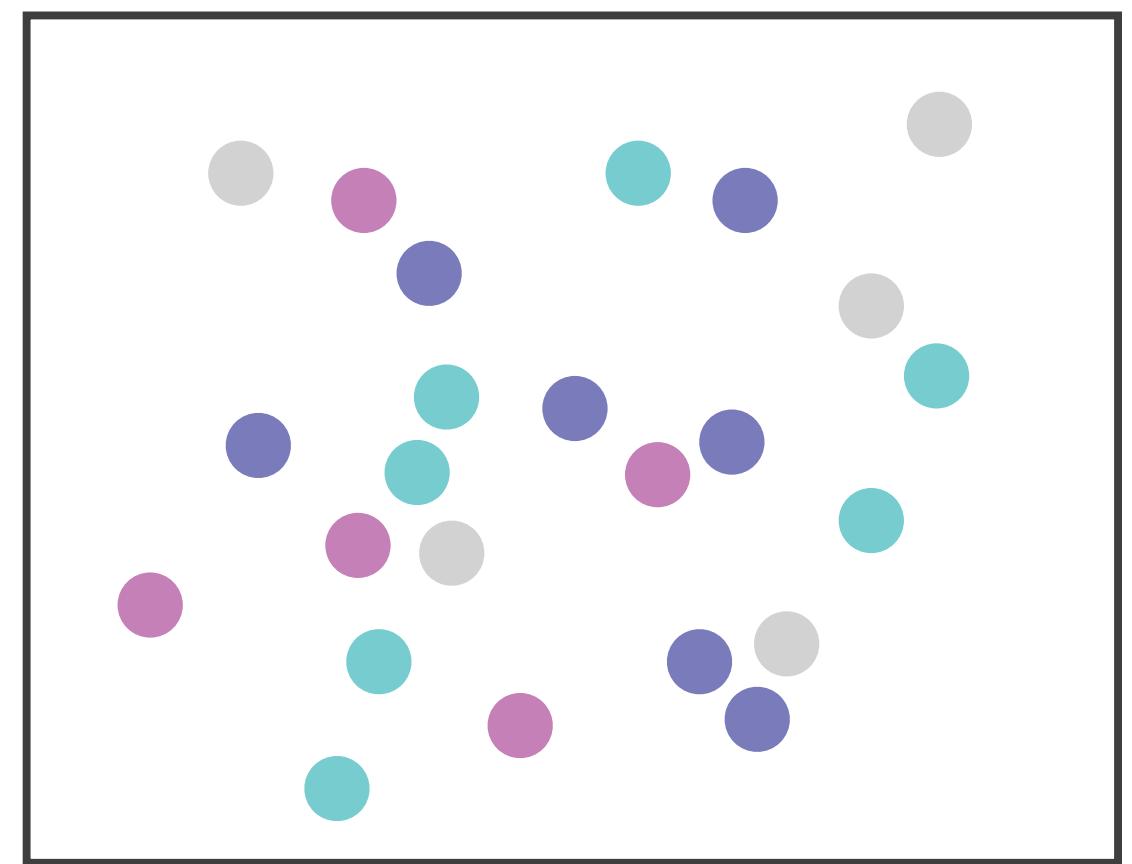
Some/significant
interference

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

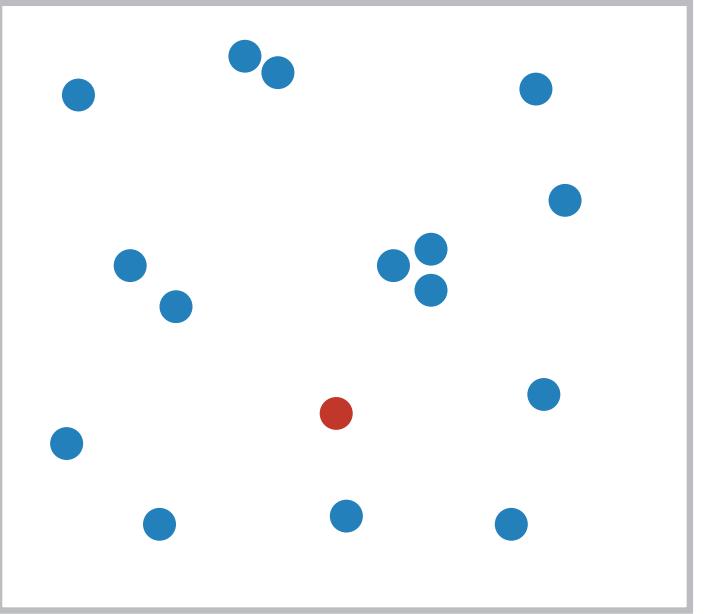


Major interference

Popout

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

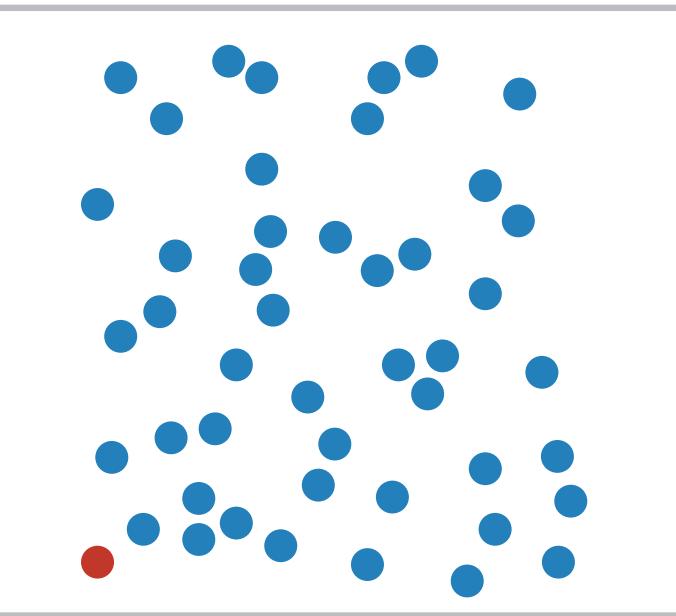
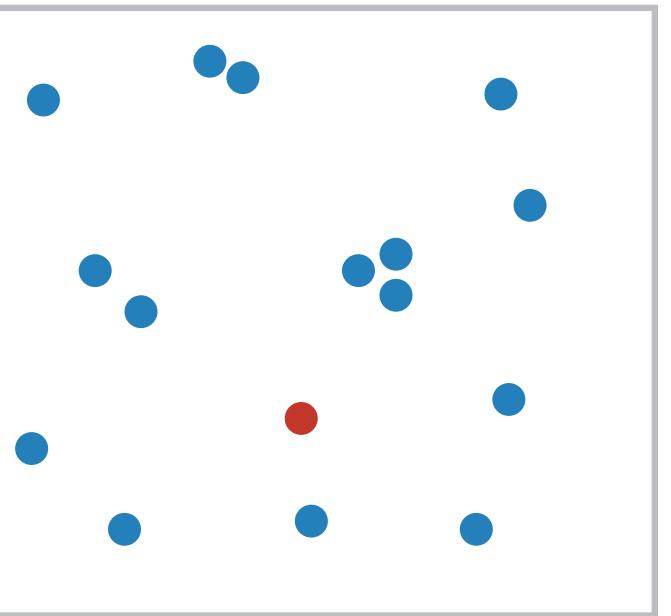
Popout



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

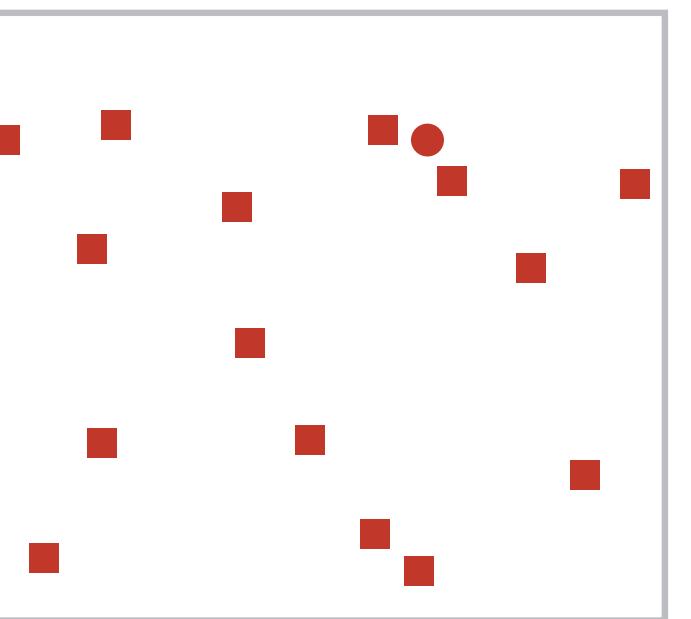
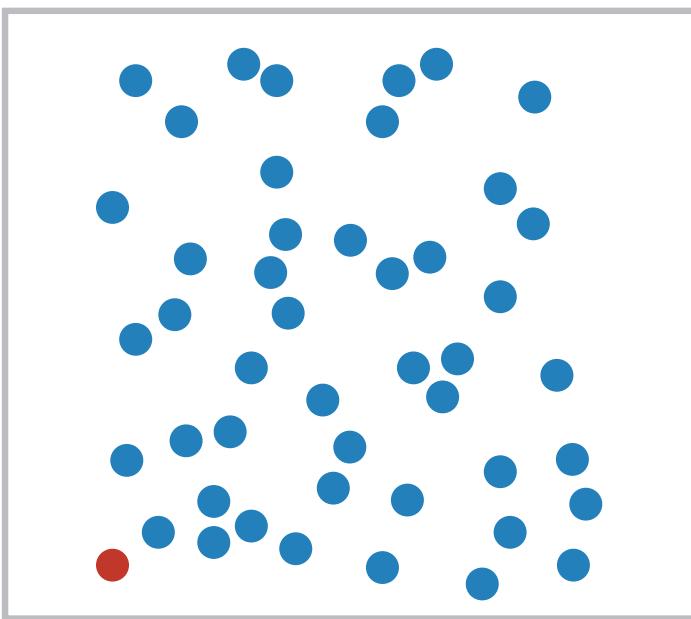
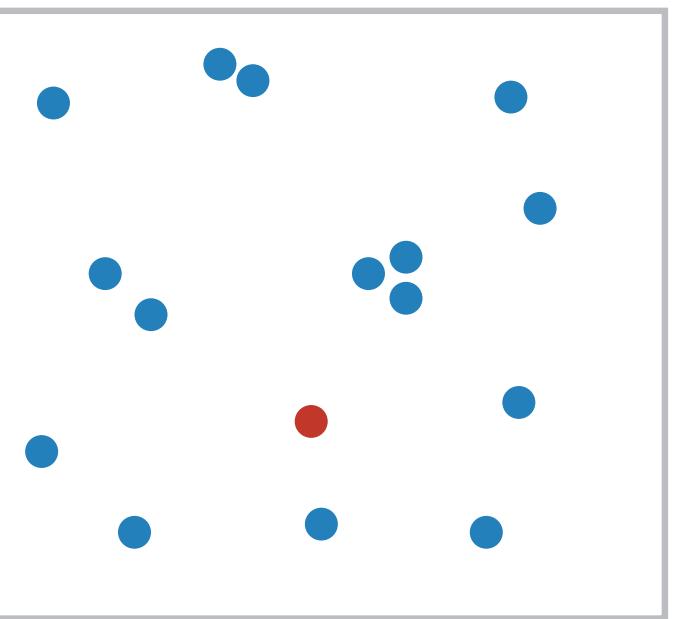
Popout

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



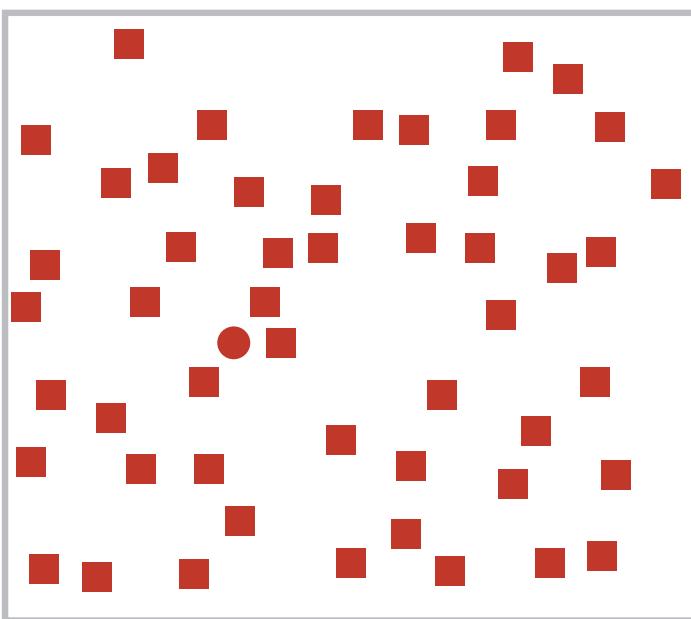
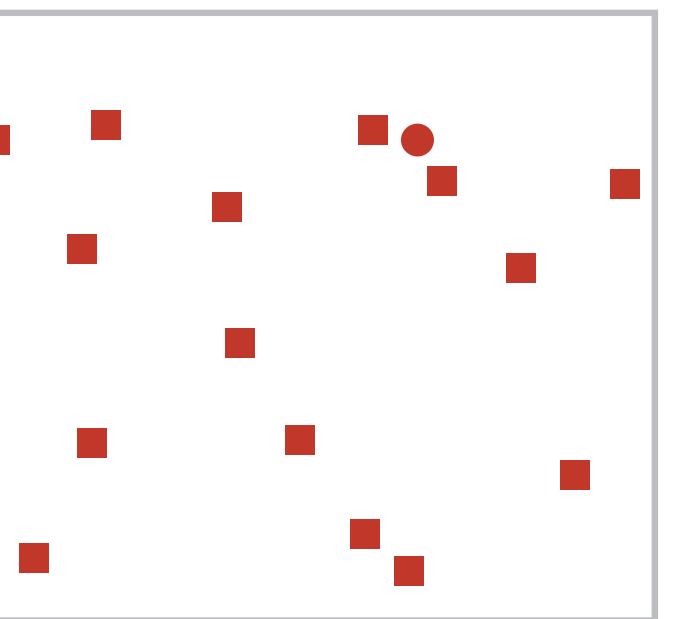
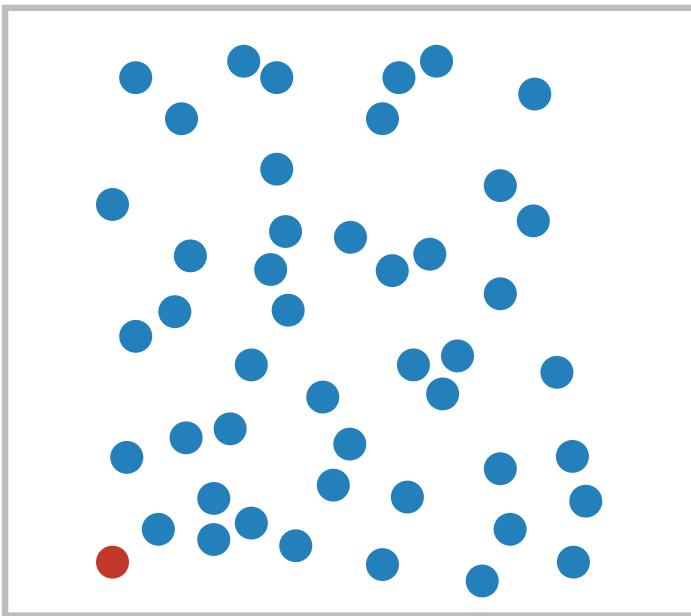
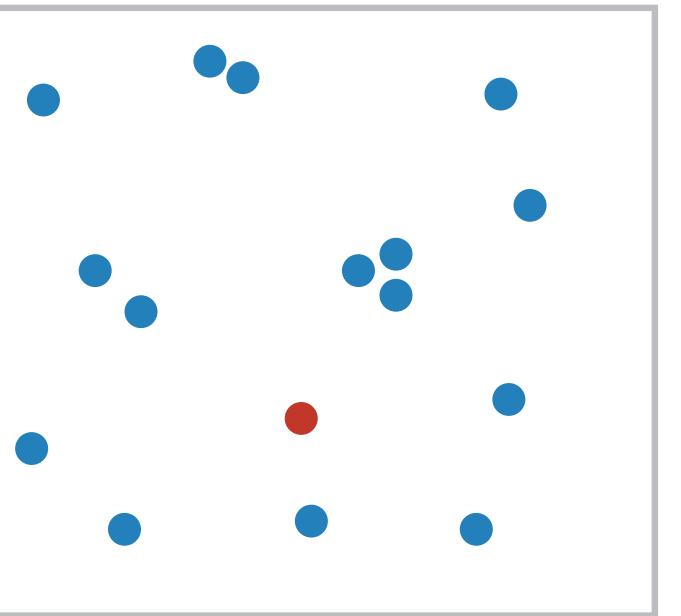
Popout

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



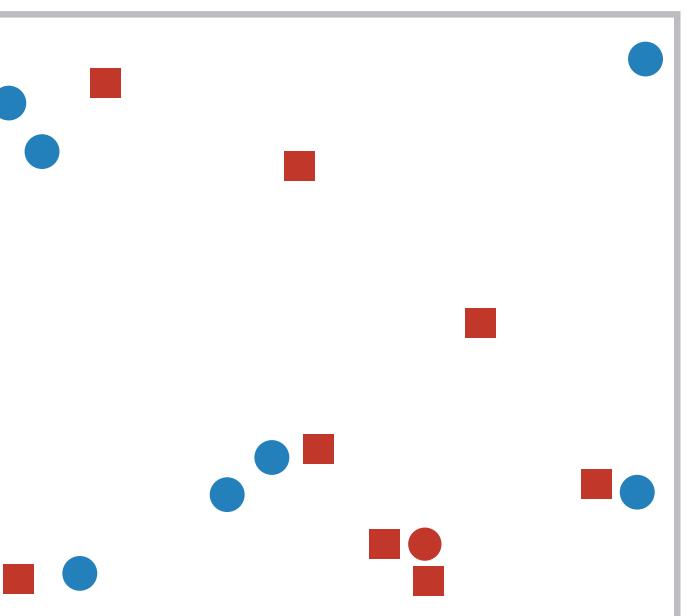
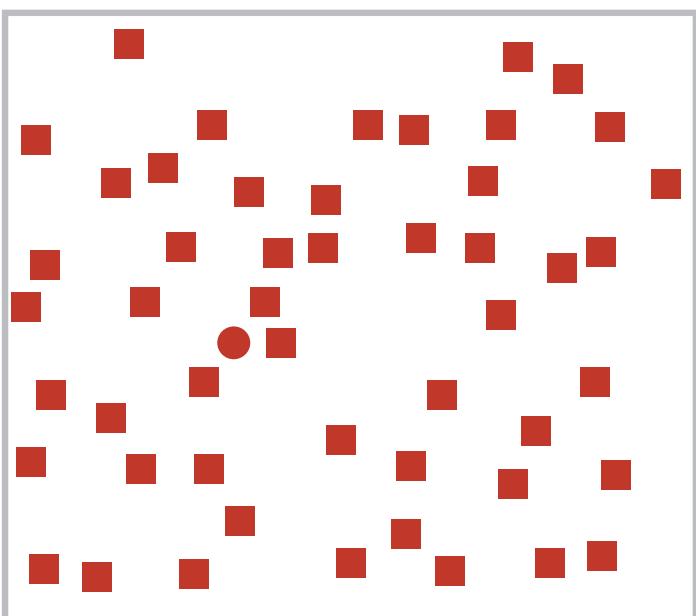
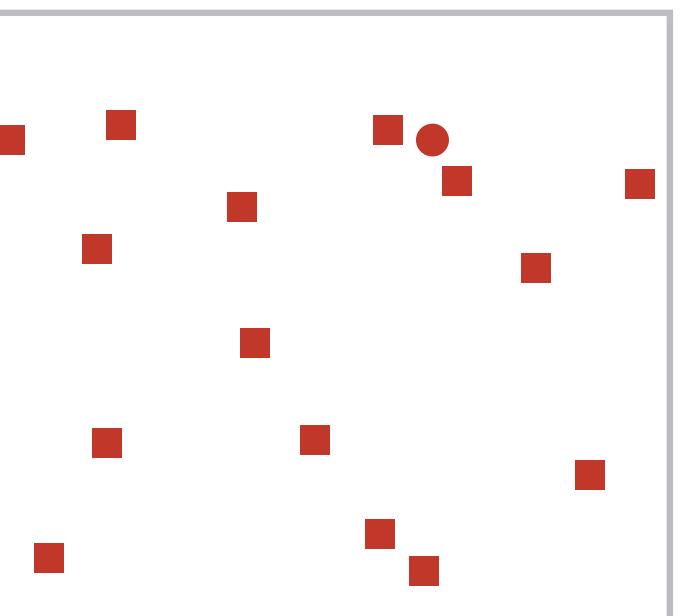
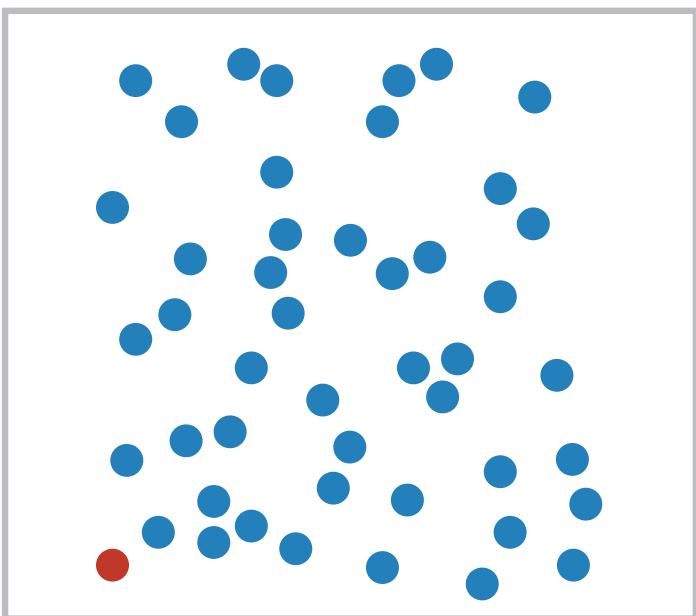
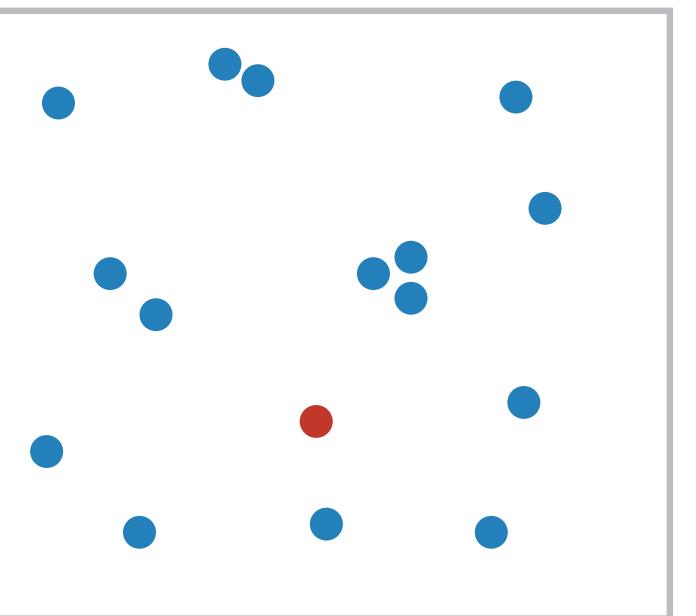
Popout

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



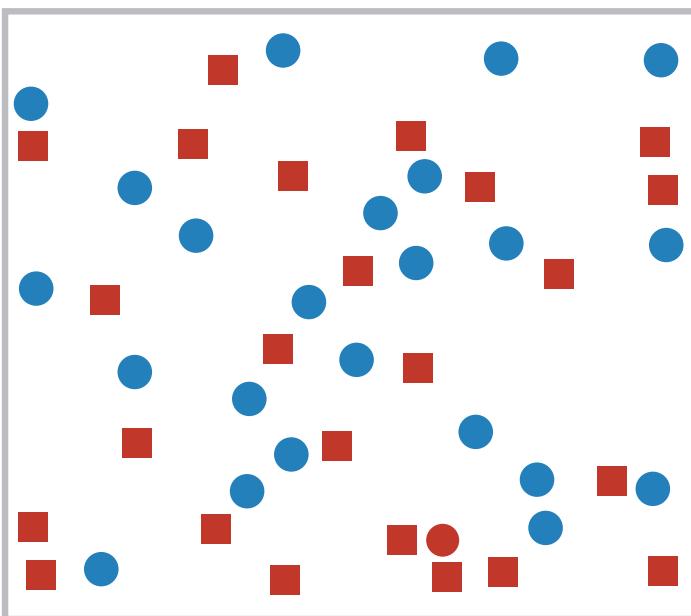
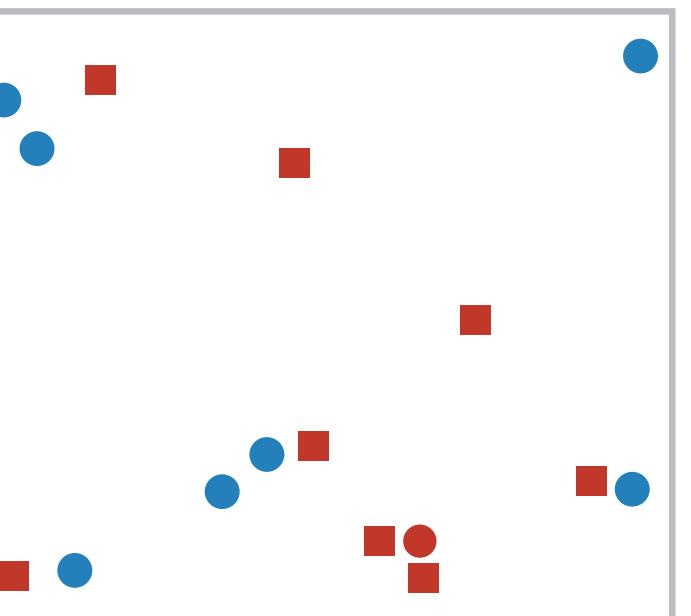
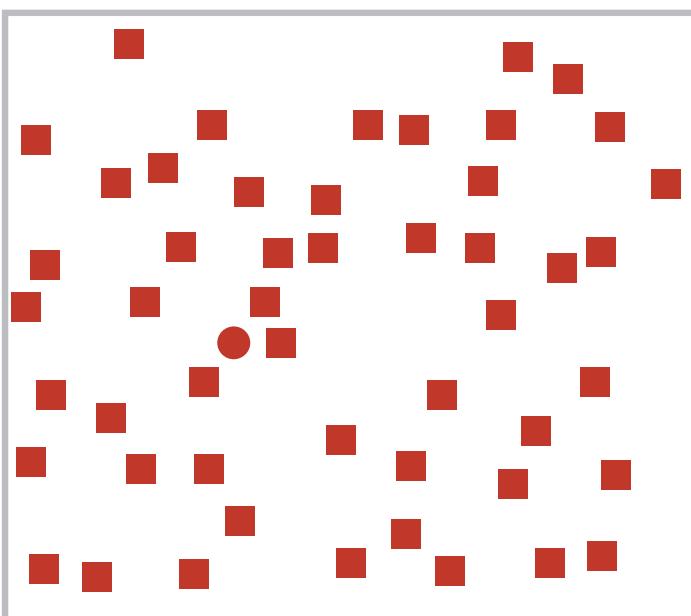
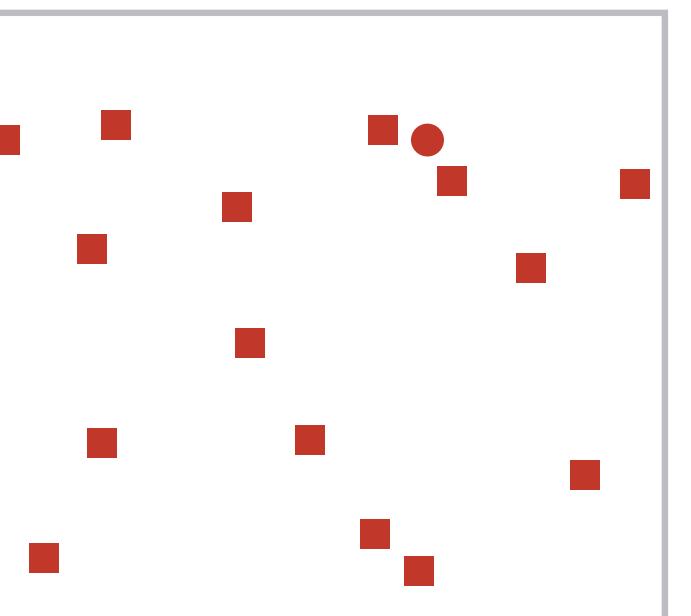
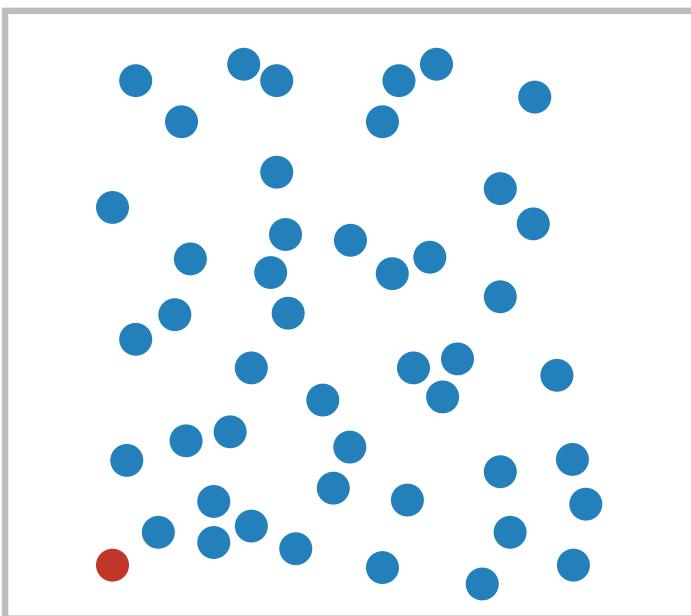
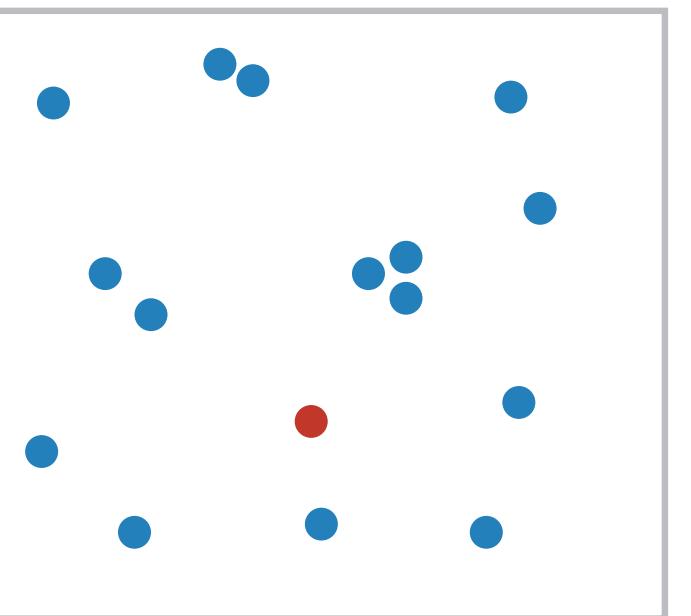
Popout

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



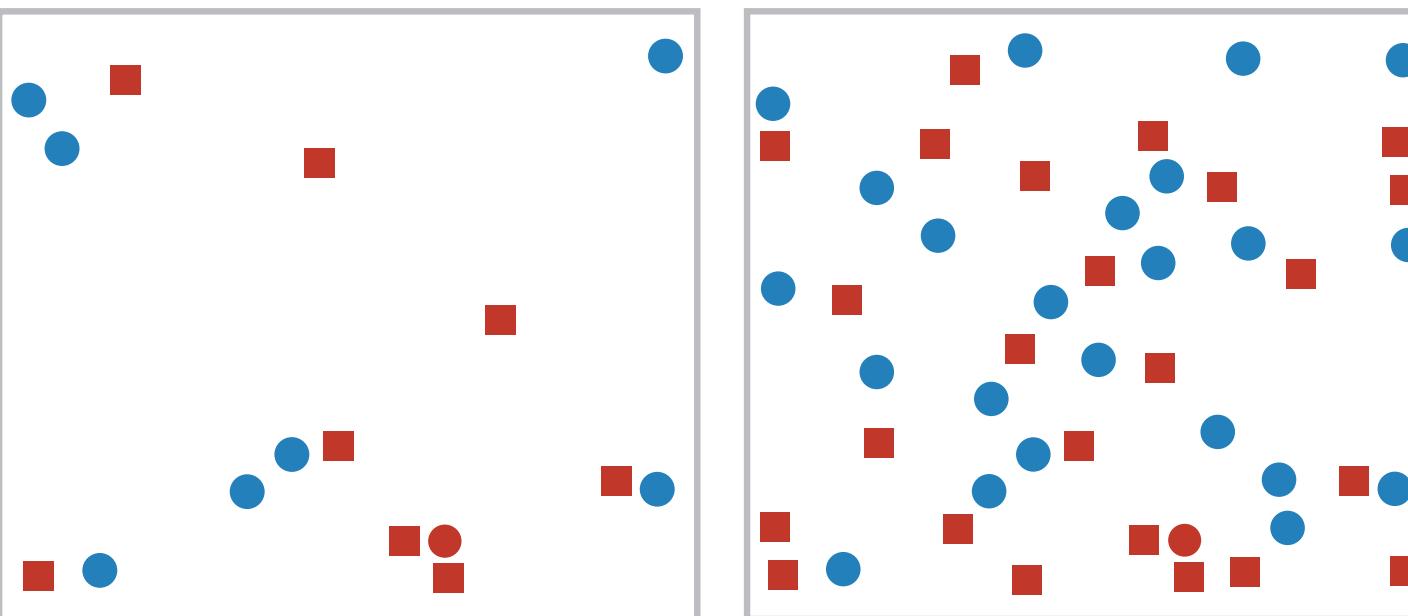
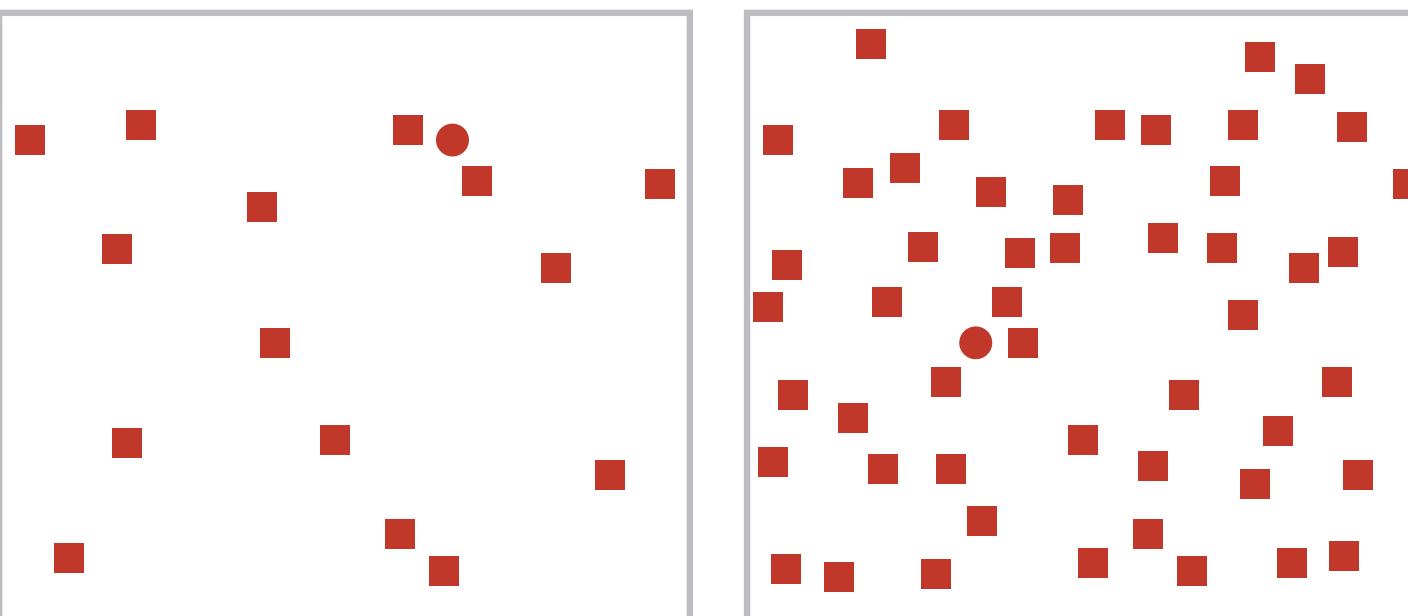
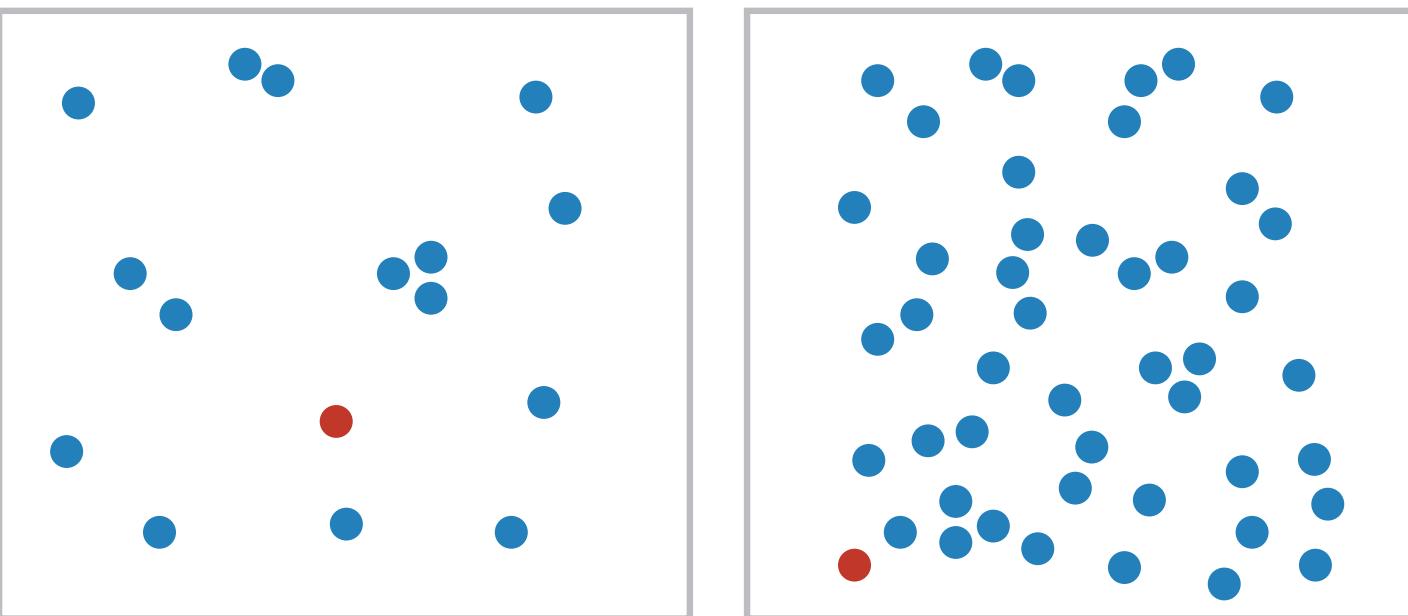
Popout

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



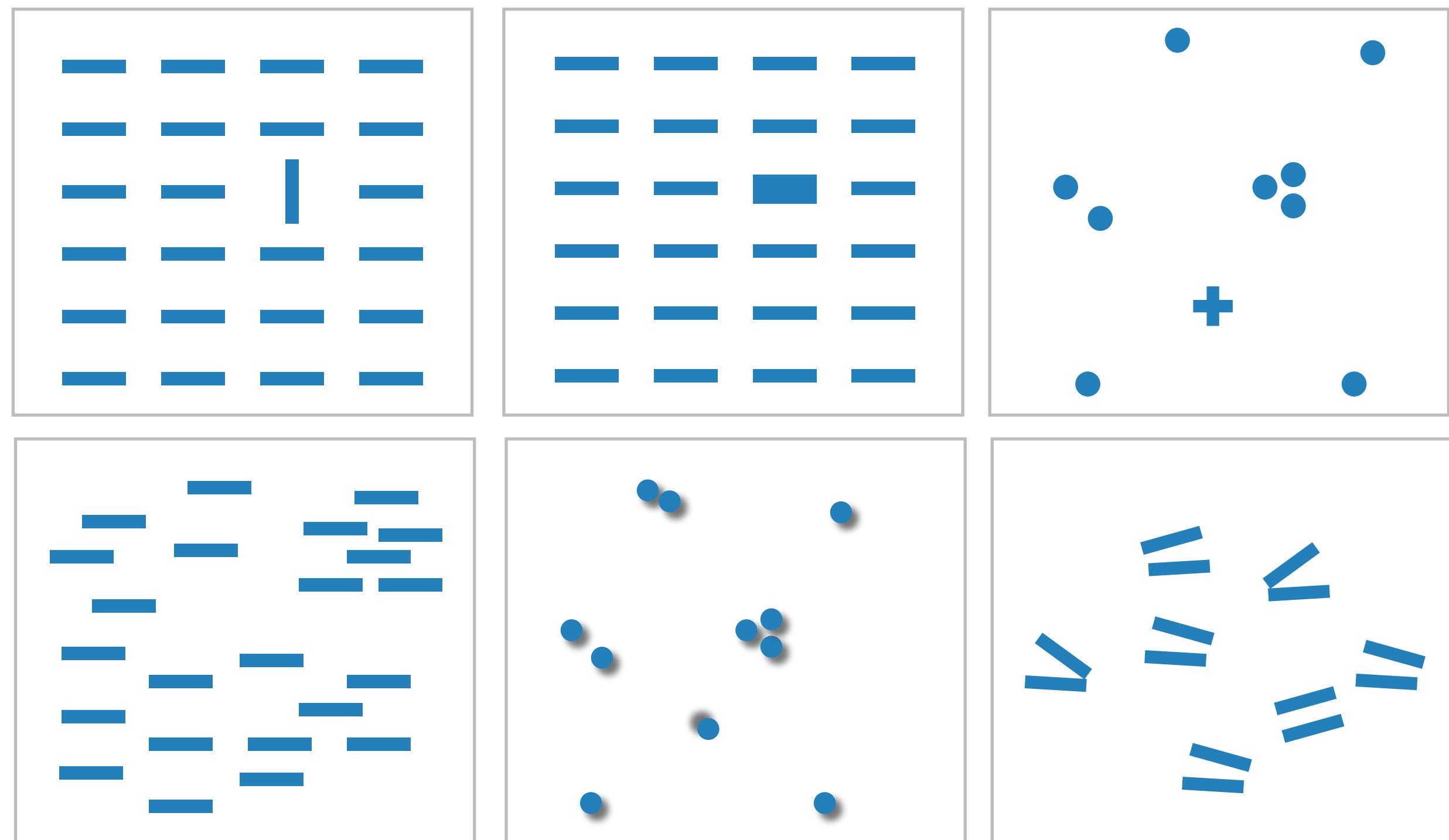
Popout

- 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



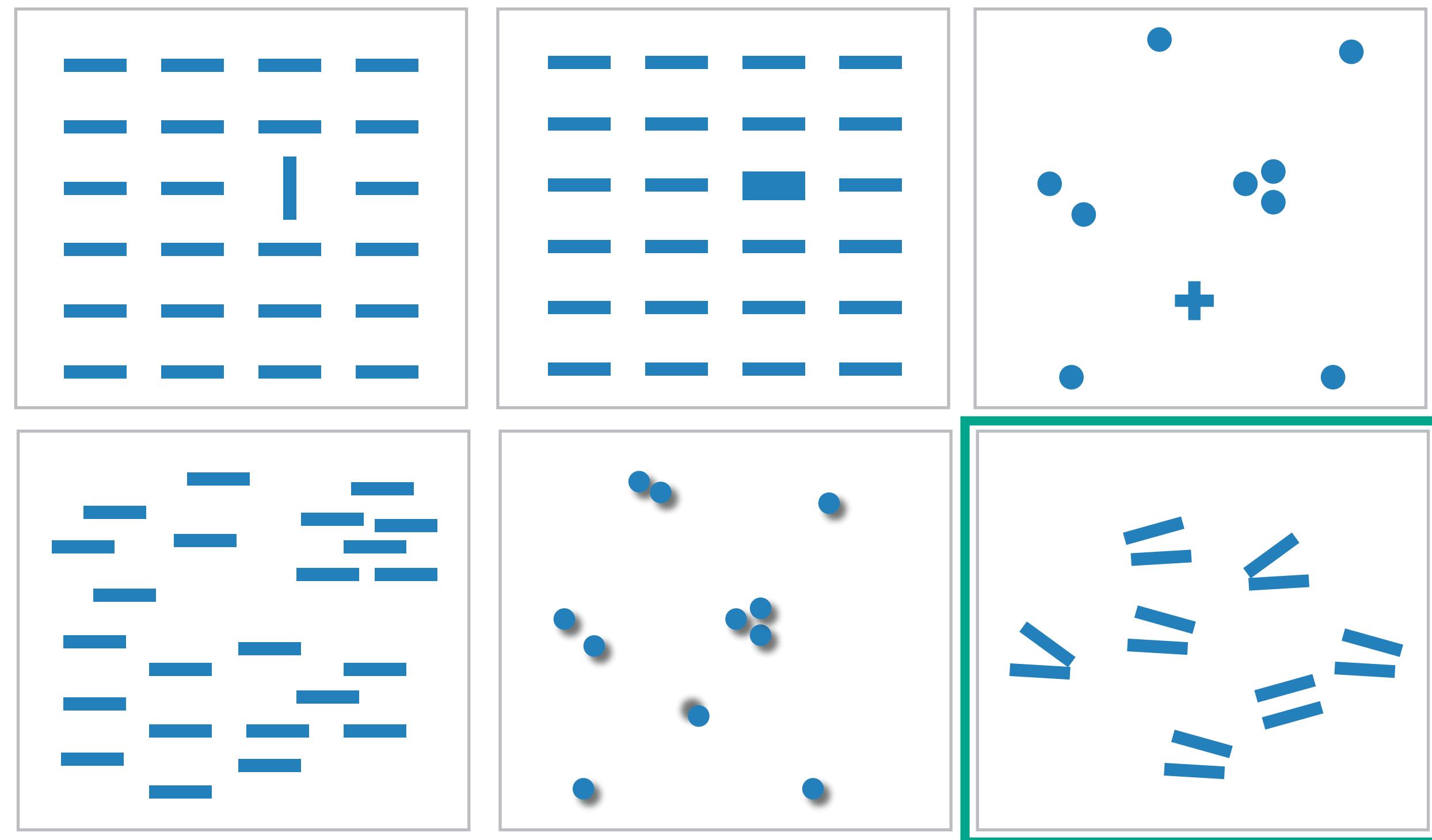
Popout

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



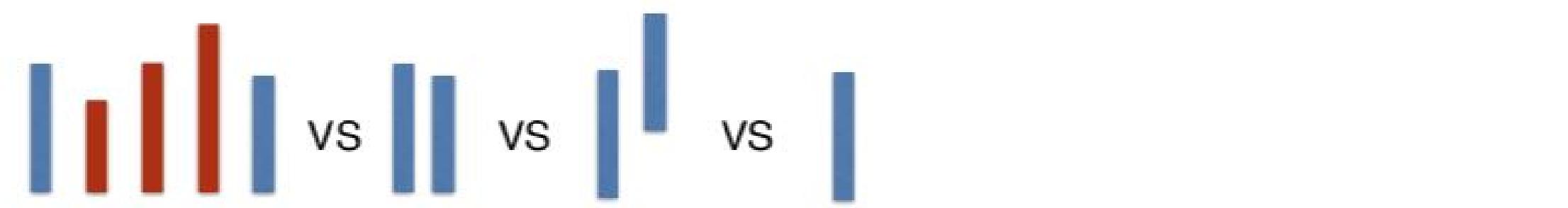
Popout

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



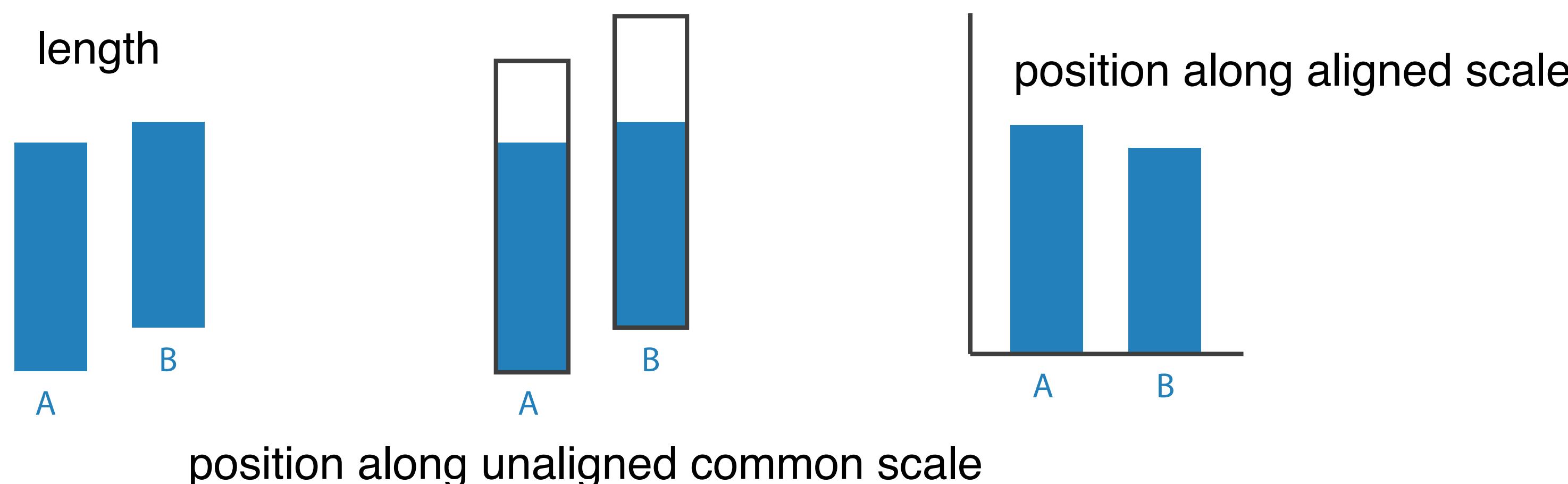
Factors affecting accuracy

- alignment
- distractors
- distance
- common scale



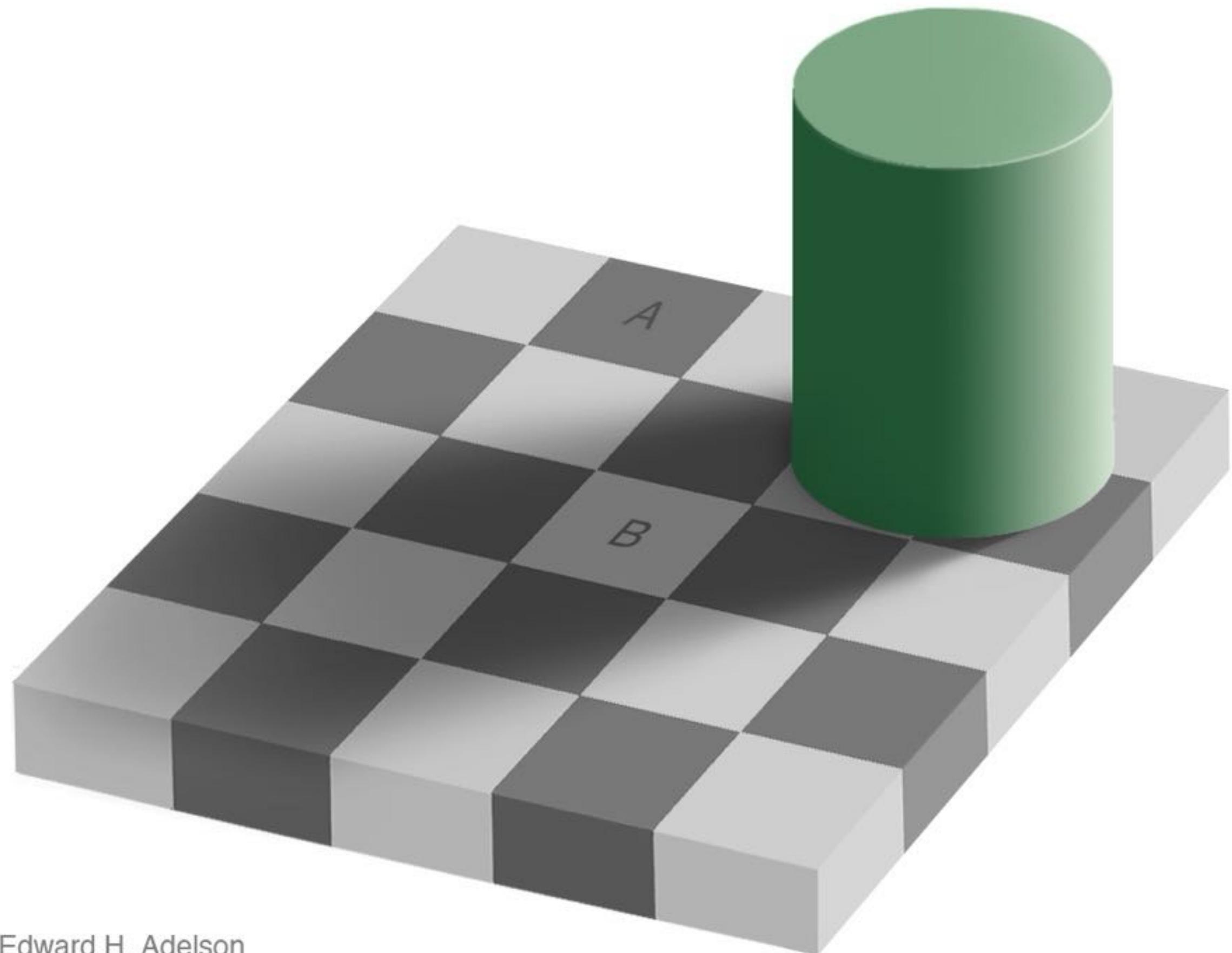
Relative vs. absolute judgements

- 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

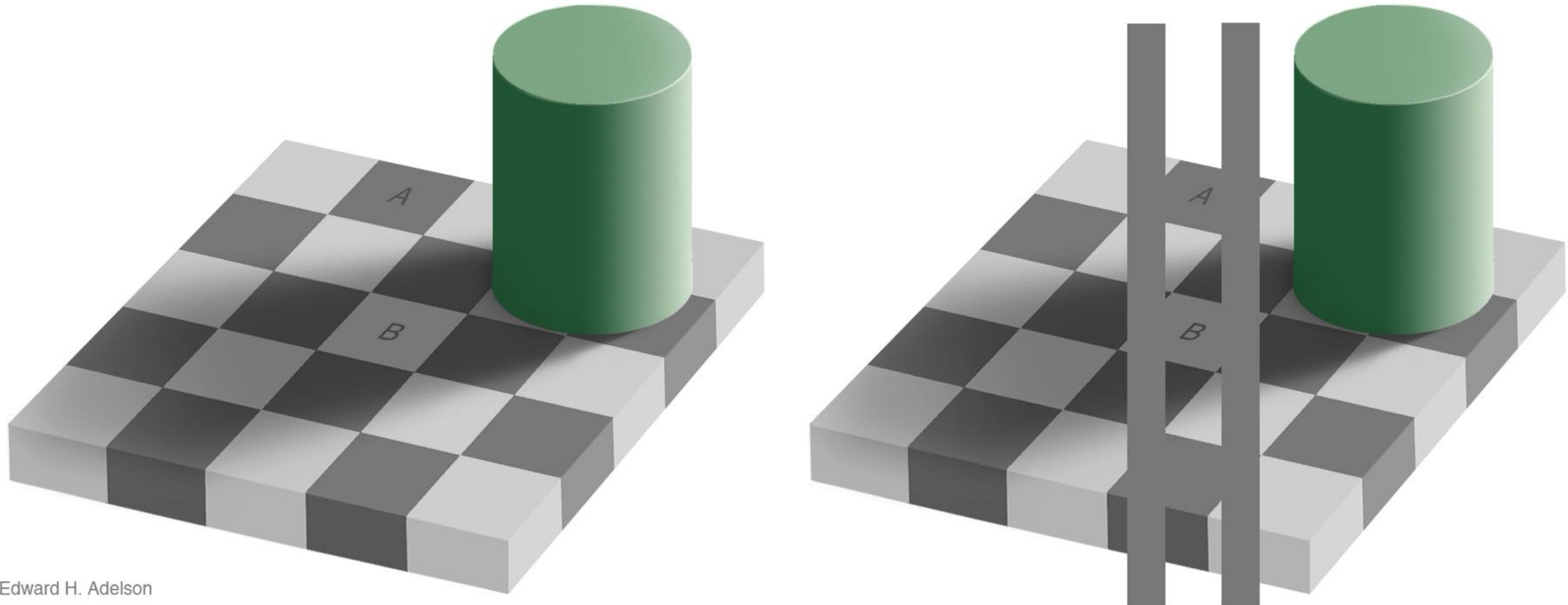
- perception of luminance is contextual based on the contrast with surroundings



Edward H. Adelson

Relative luminance judgements

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



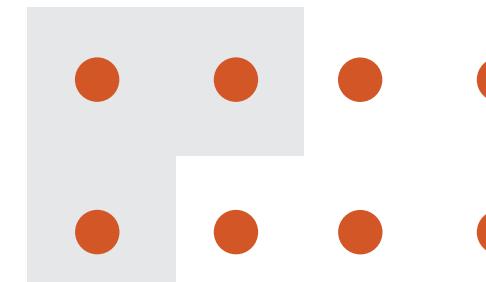
Edward H. Adelson

Grouping

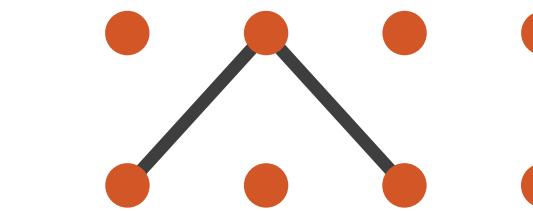
- containment
 - connection
-
- proximity
 - same spatial region
 - similarity
 - same values as other categorical channels

Marks as Links

→ Containment

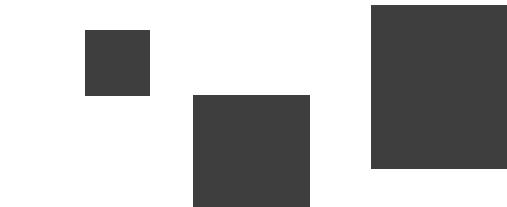


→ Connection

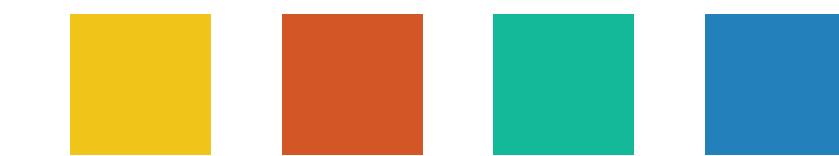


Identity Channels: Categorical Attributes

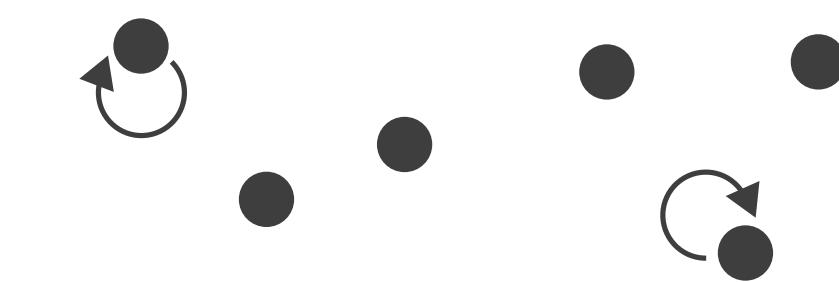
Spatial region



Color hue



Motion



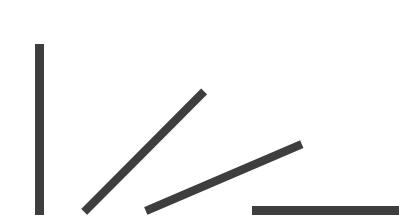
Shape



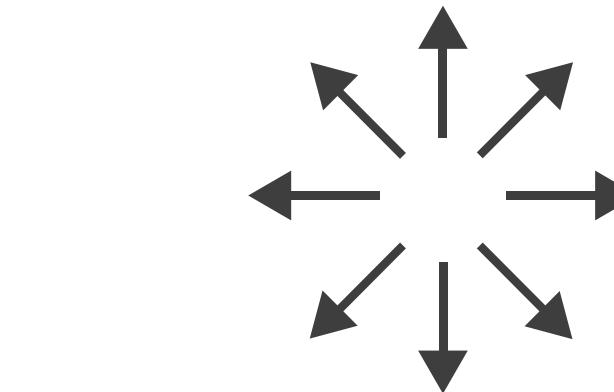
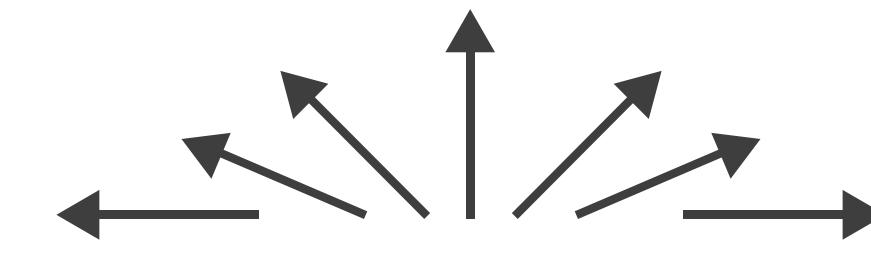
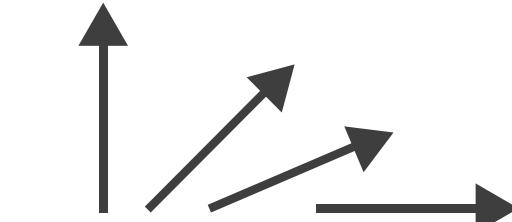
Map Other Channels

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



→ Length

→ Area

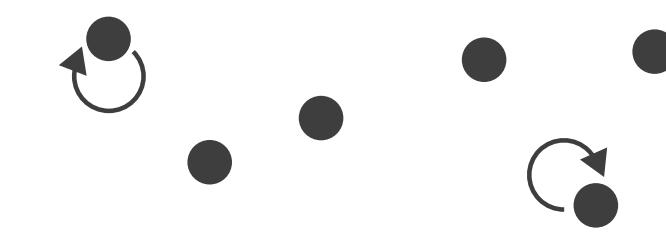
→ Volume

→ 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



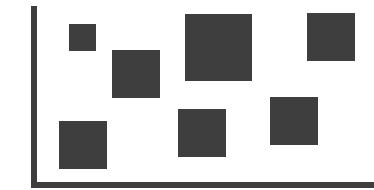
→ Order



→ Use



→ Separate



→ Align



④ Map

from categorical and ordered attributes

→ Color

→ Hue



→ Saturation



→ Luminance



→ Size, Angle, Curvature, ...

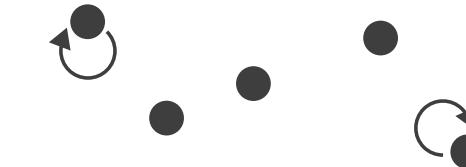


→ Shape



→ Motion

Direction, Rate, Frequency, ...



Channels: What's up with color?

→ Magnitude Channels: Ordered Attributes

Position on common scale



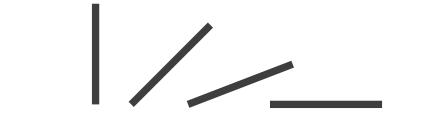
Position on unaligned scale



Length (1D size)



Tilt/angle



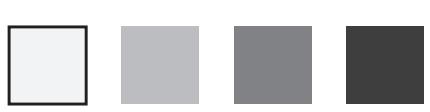
Area (2D size)



Depth (3D position)



Color luminance



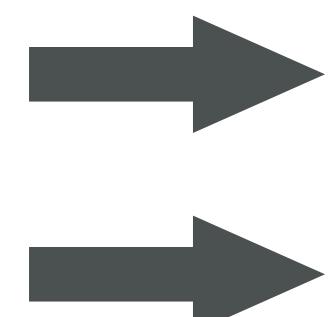
Color saturation



Curvature



Volume (3D size)

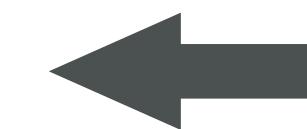


→ Identity Channels: Categorical Attributes

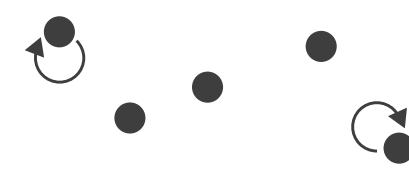
Spatial region



Color hue



Motion



Shape

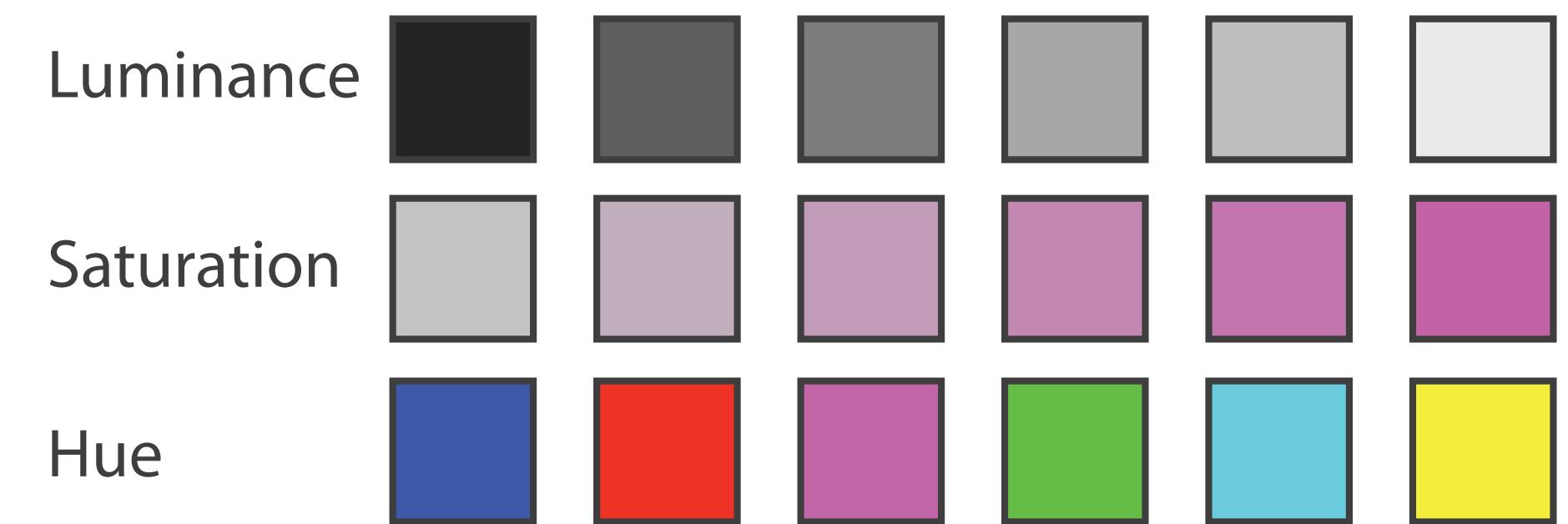


↑ Best
Effectiveness
↓ Least

[Same] [Same]

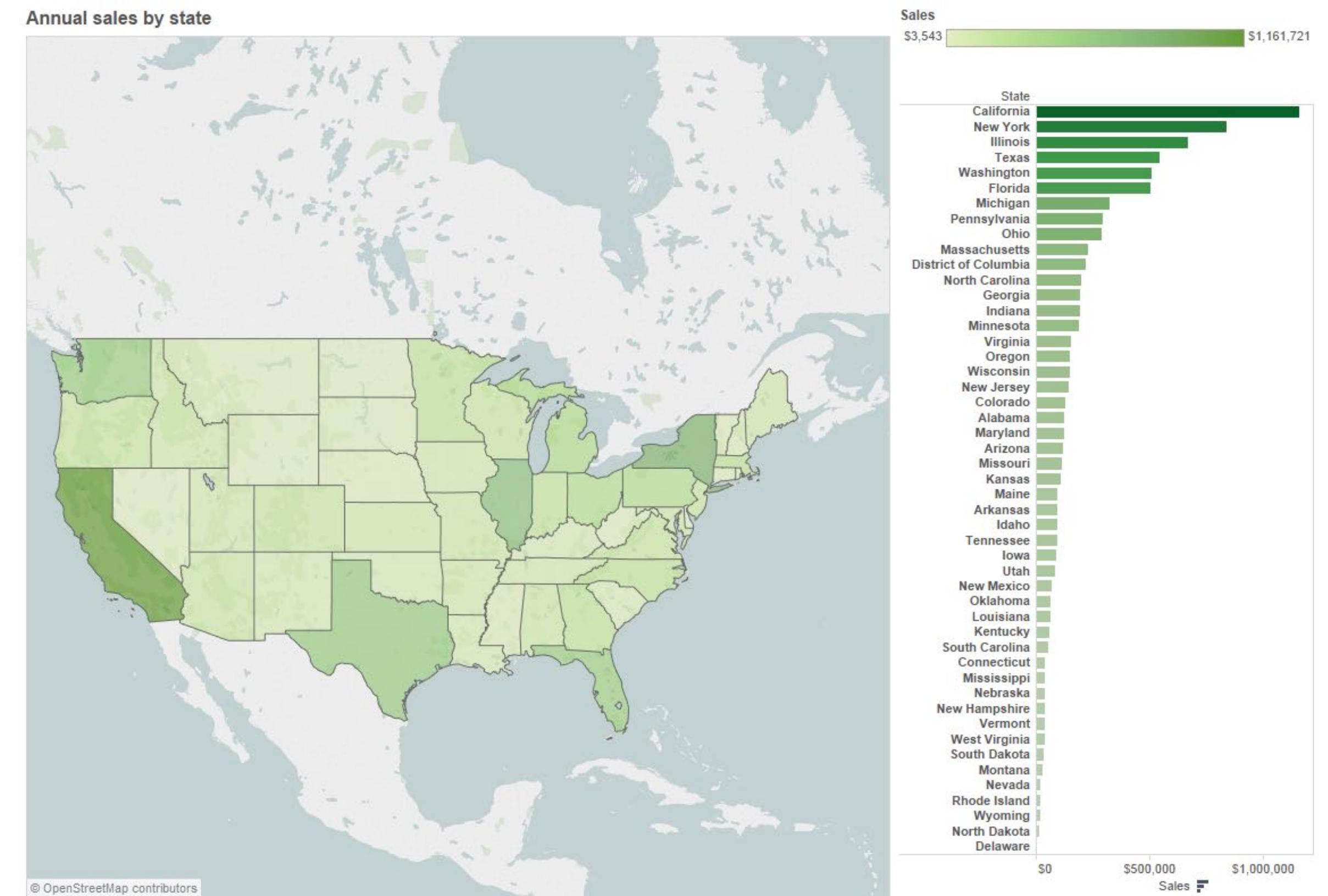
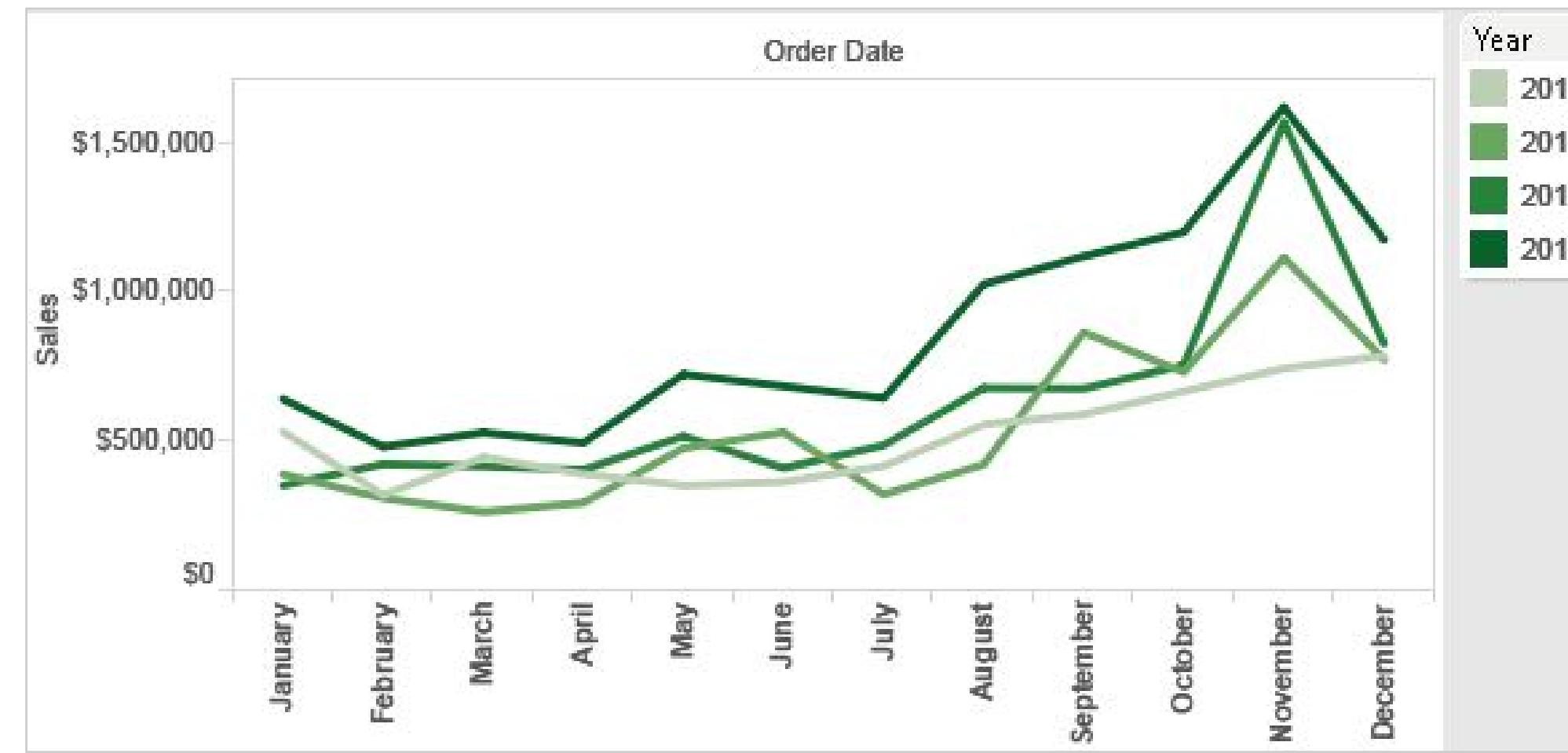
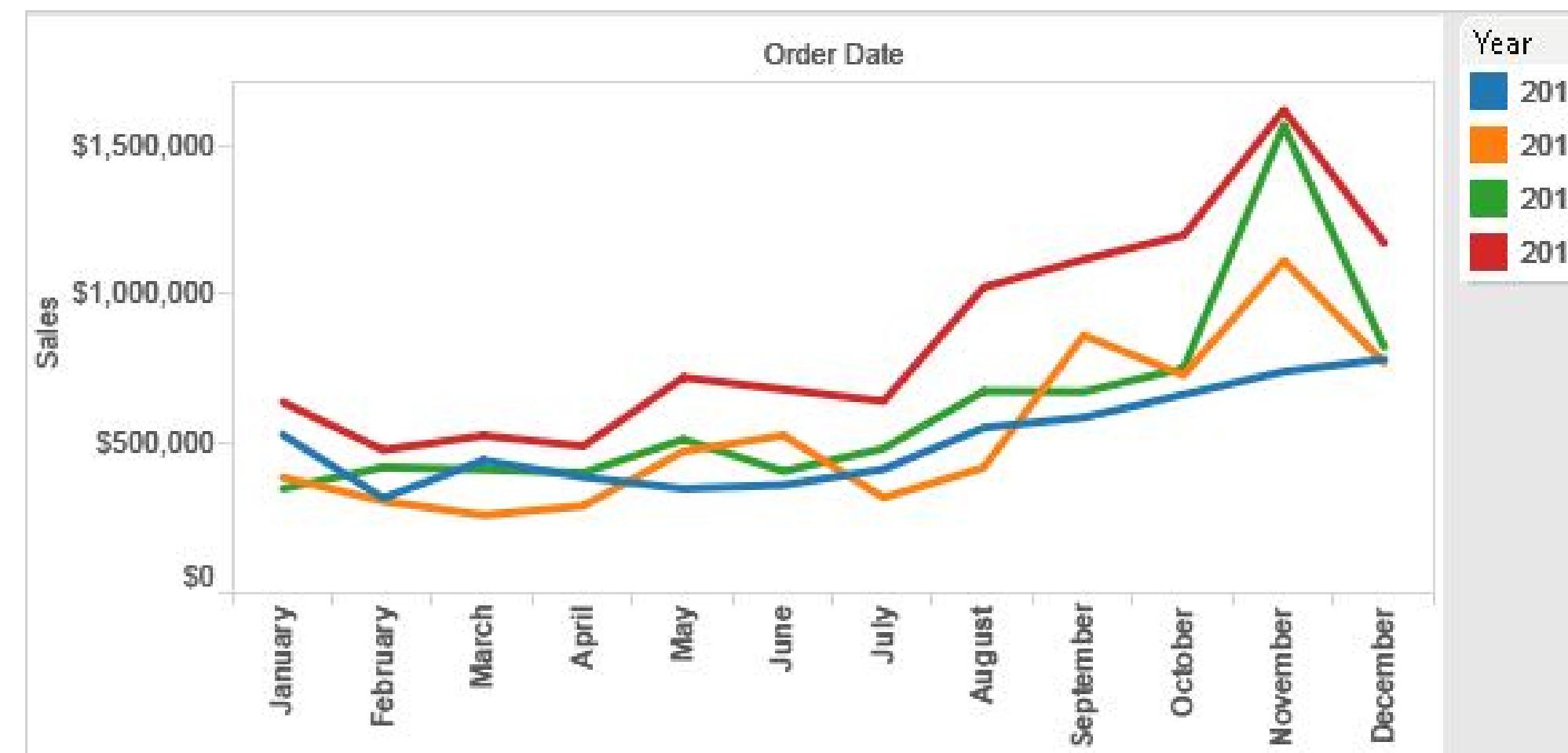
Decomposing color

- 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?



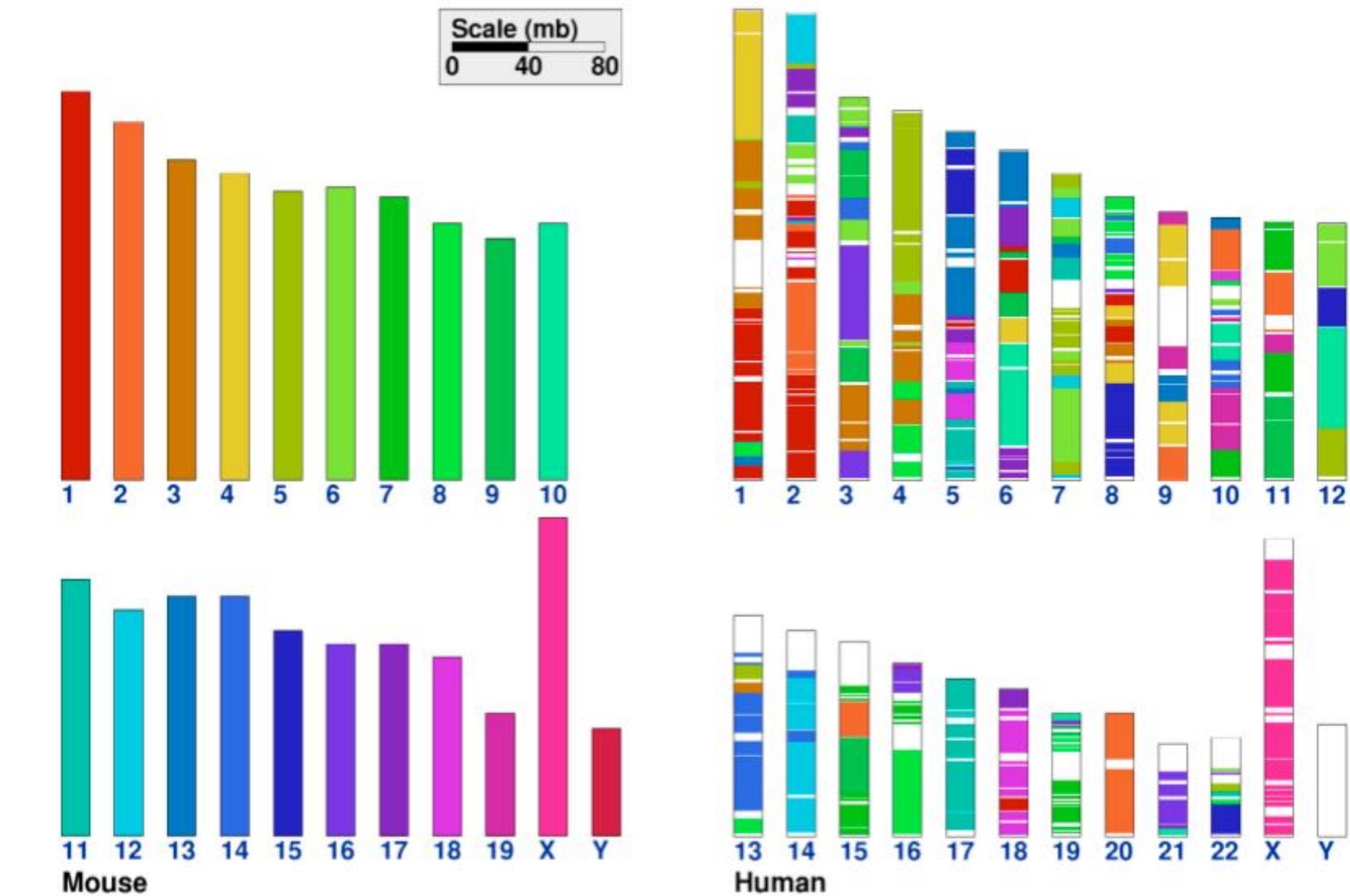
Color Channels in Visualization

Categorical vs ordered color



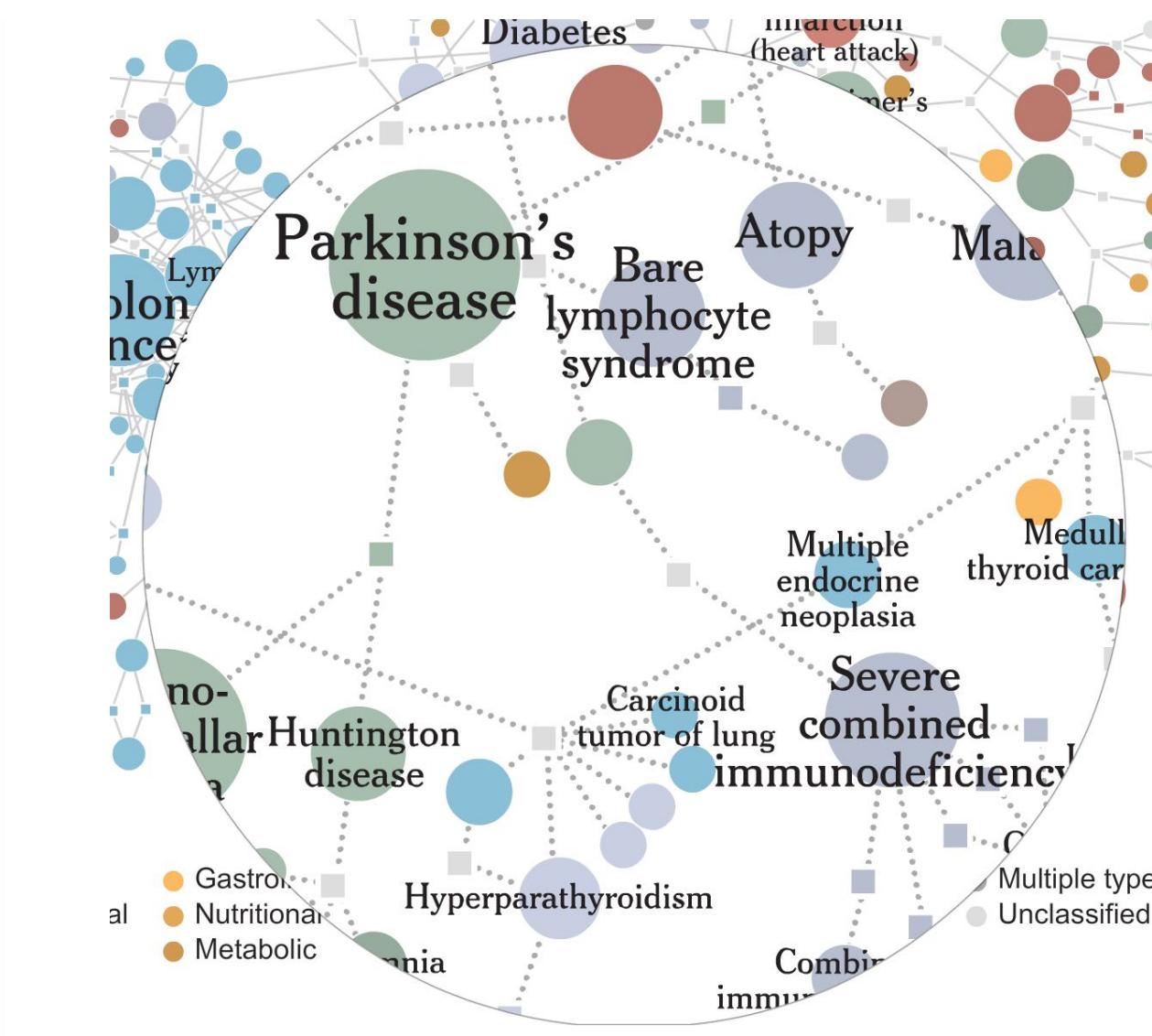
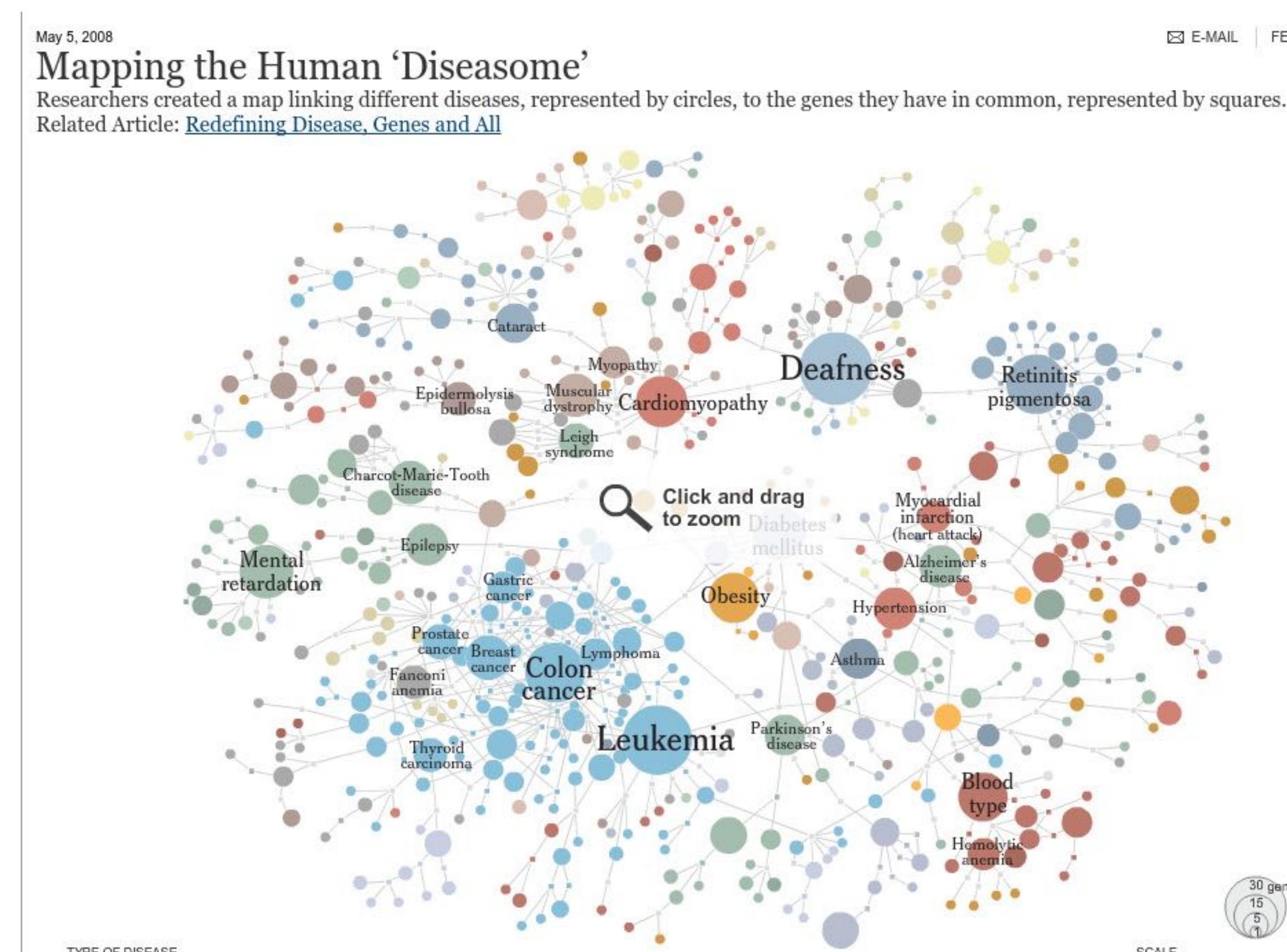
Categorical color: limited number of discriminable bins

- 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

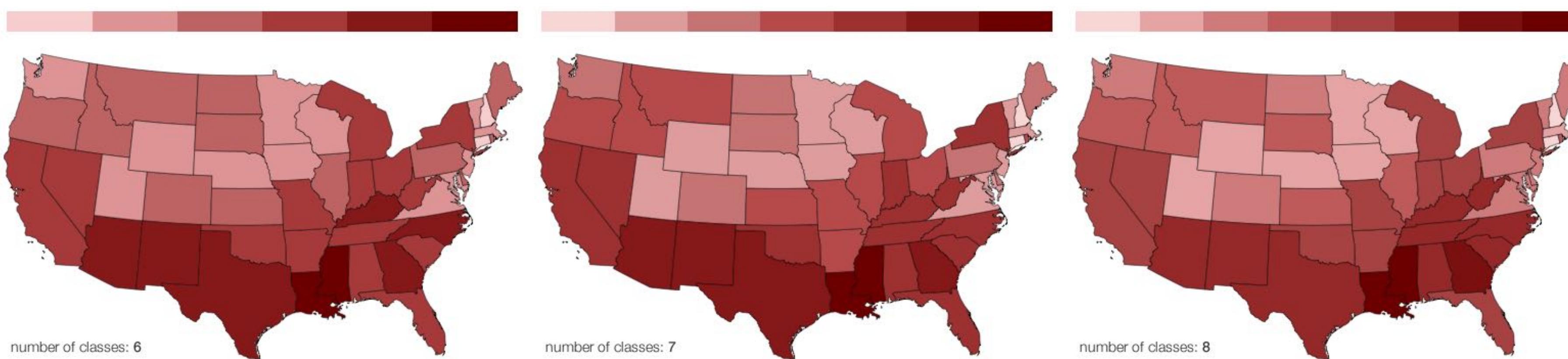
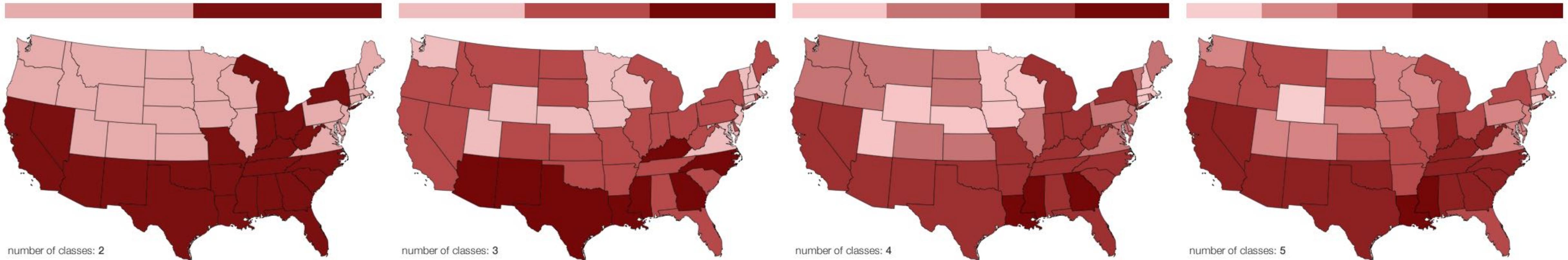


Categorical color: limited number of discriminable bins

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

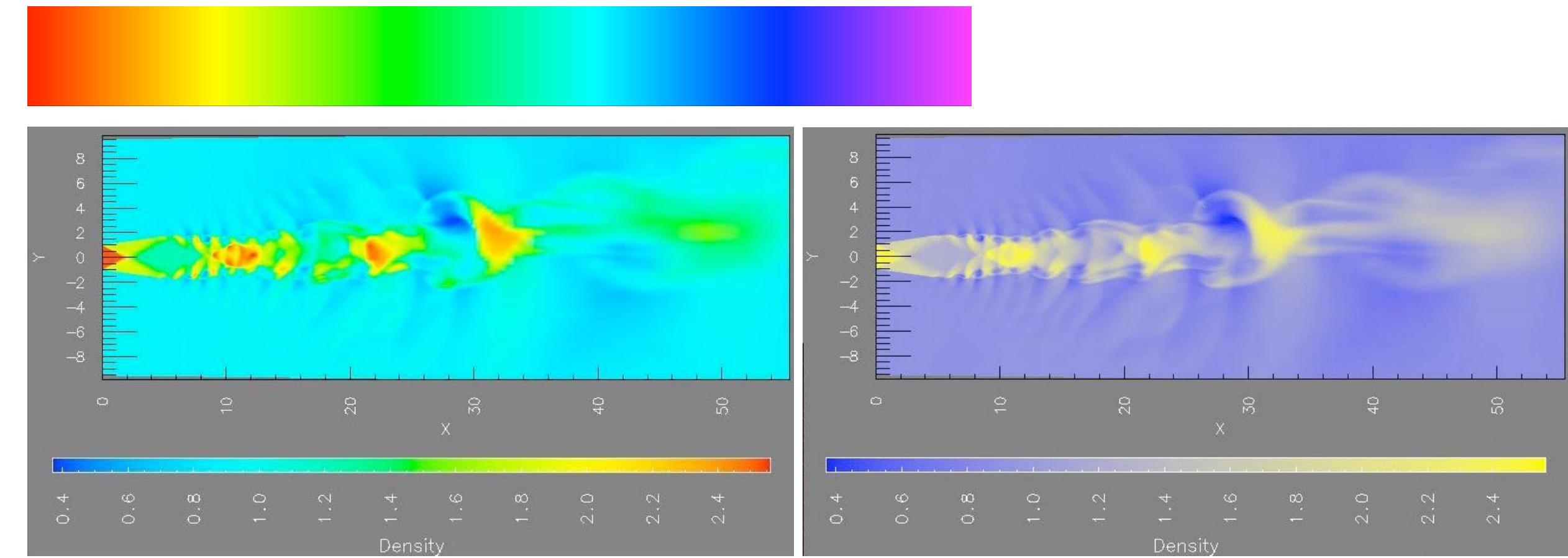


Ordered color: limited number of discriminable bins

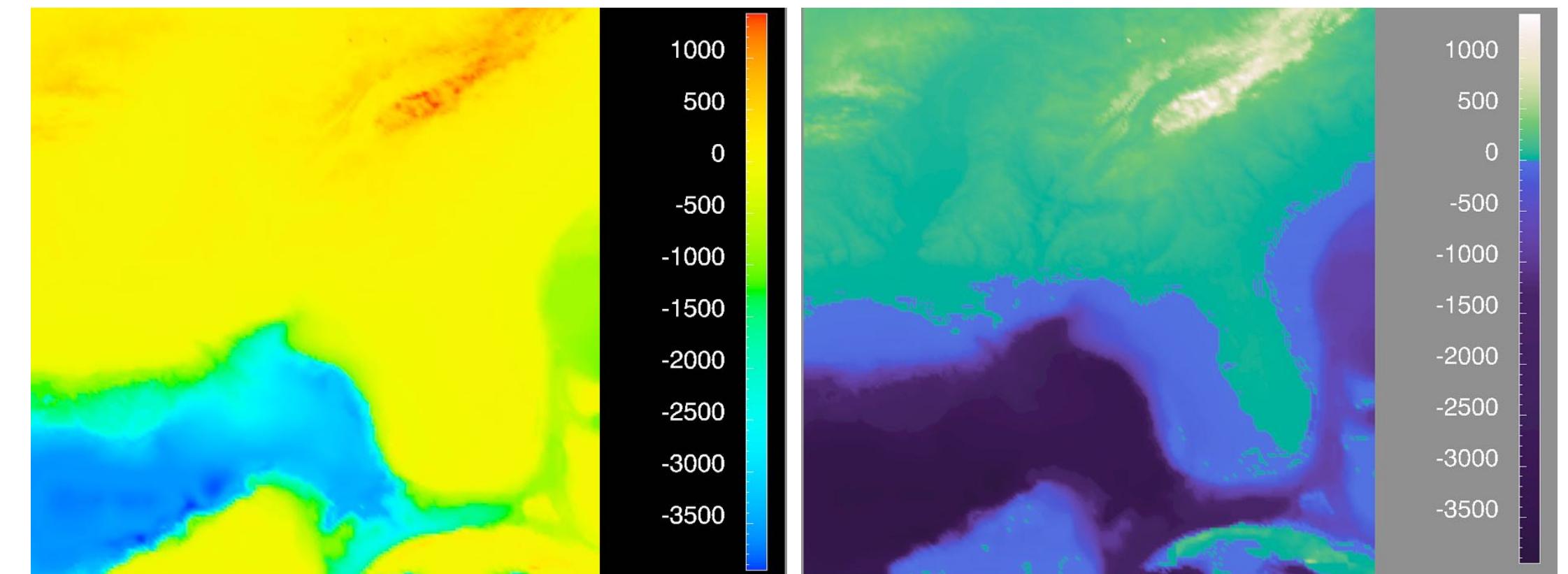


Ordered color: Rainbow is poor default

- 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]



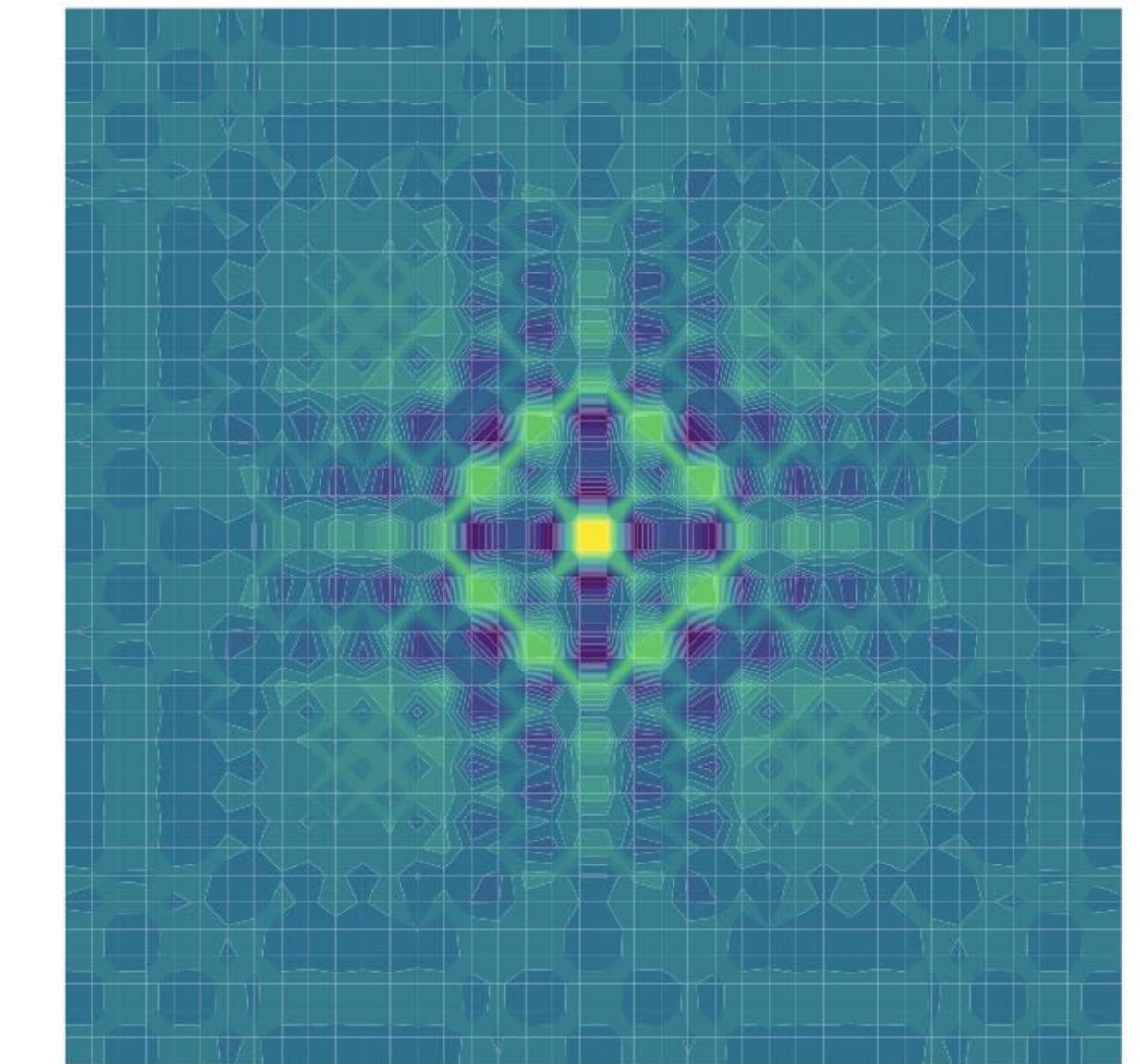
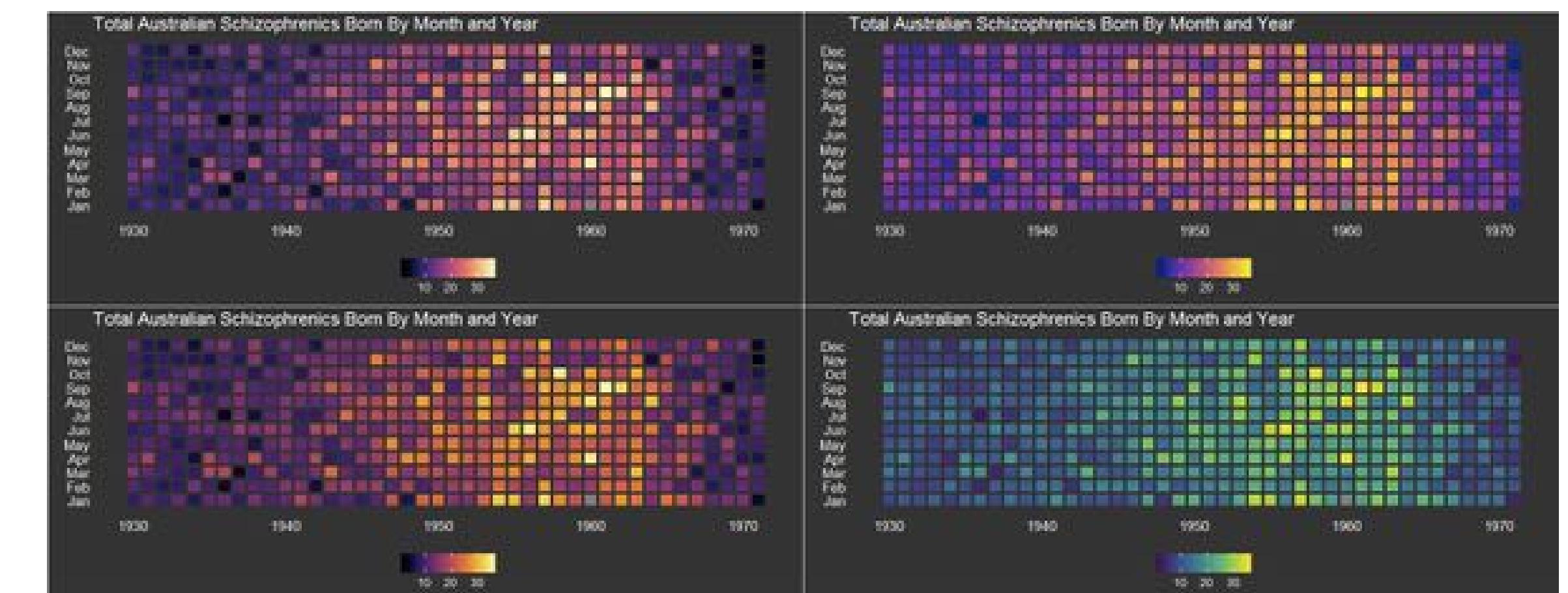
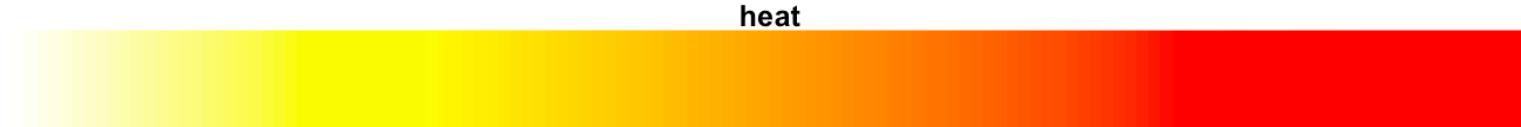
[A Rule-based Tool for Assisting Colormap Selection. Bergman,.. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis). pp. 118–125. 1995.]



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

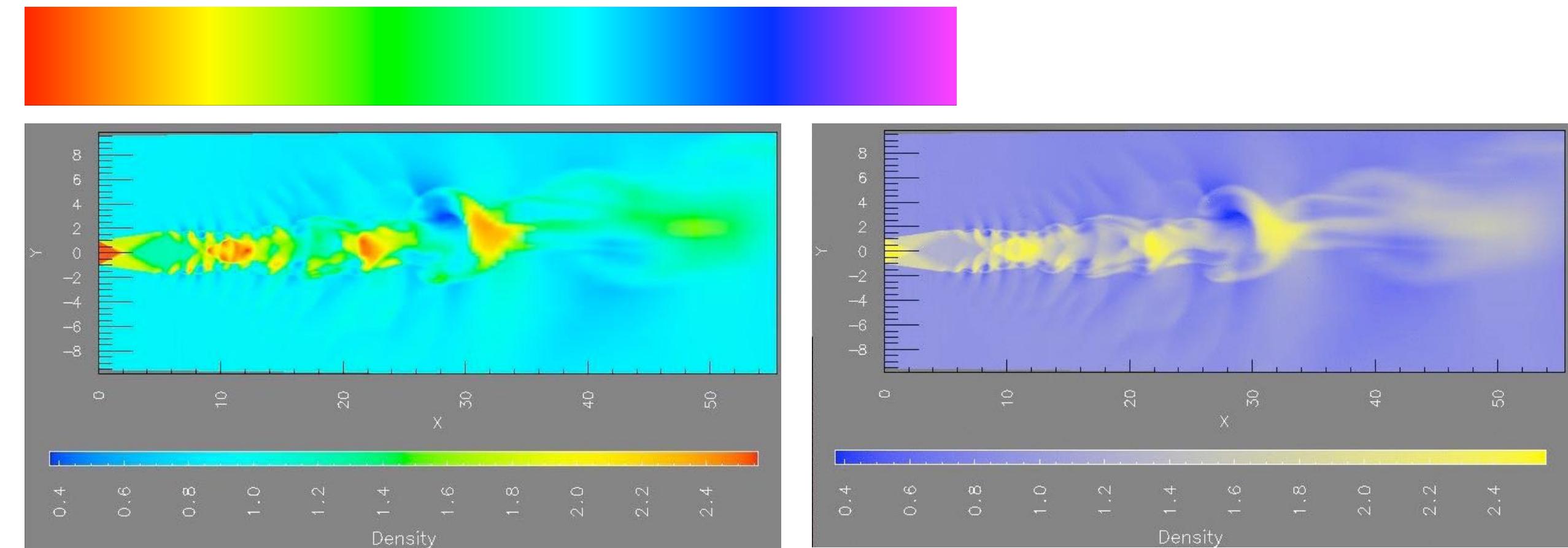
Viridis / Magma: sequential colormaps

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

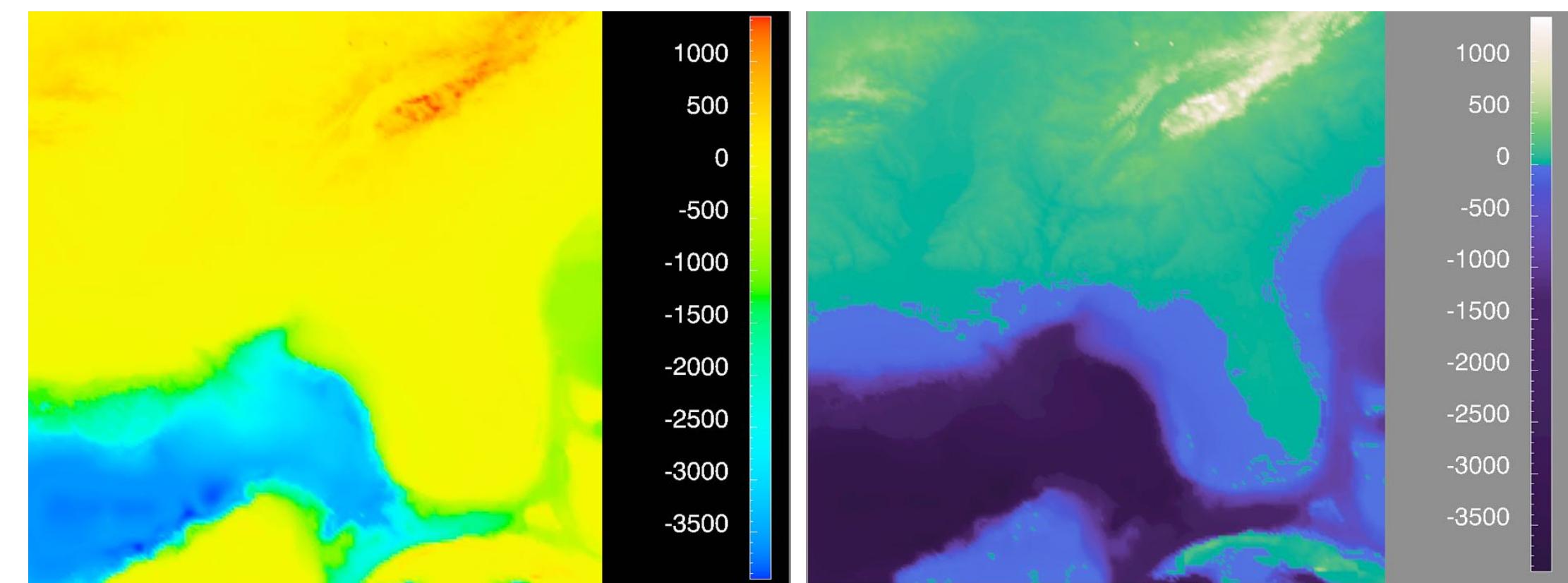


Ordered color: Rainbow is poor default

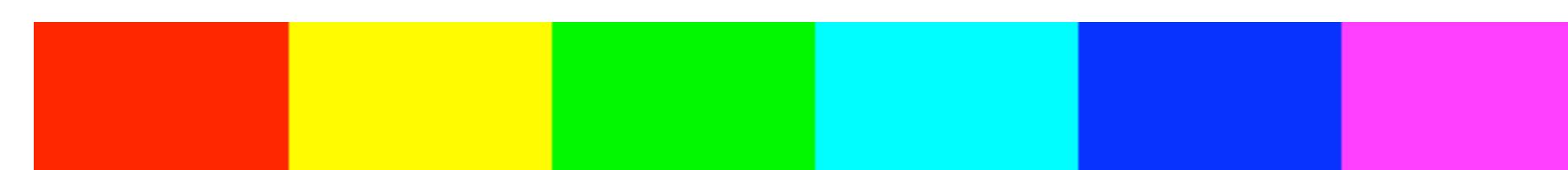
- problems
 - perceptually unordered
 - perceptually nonlinear
- benefits
 - fine-grained structure visible and nameable
- alternatives
 - large-scale structure: fewer hues
 - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
 - segmented saturated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



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



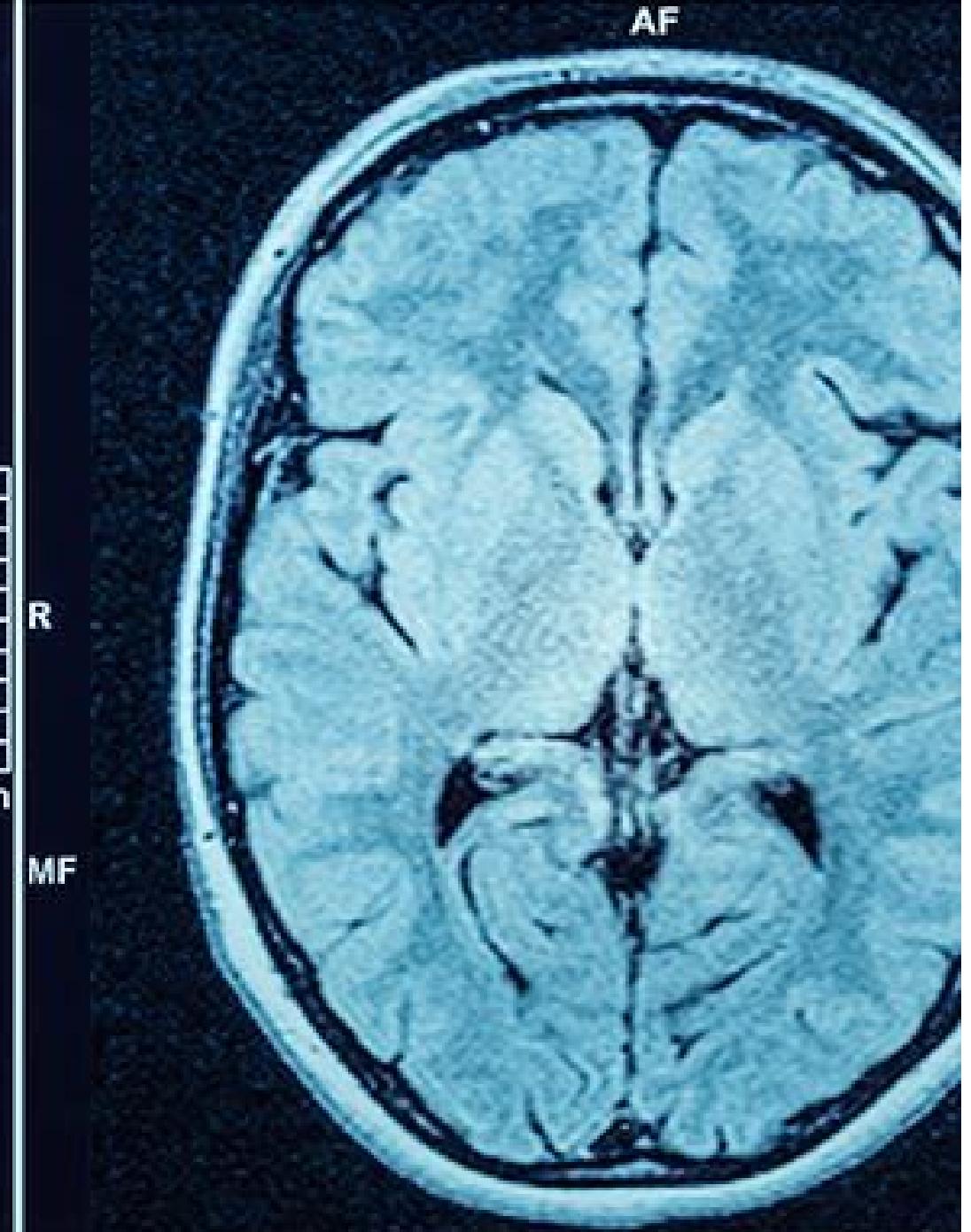
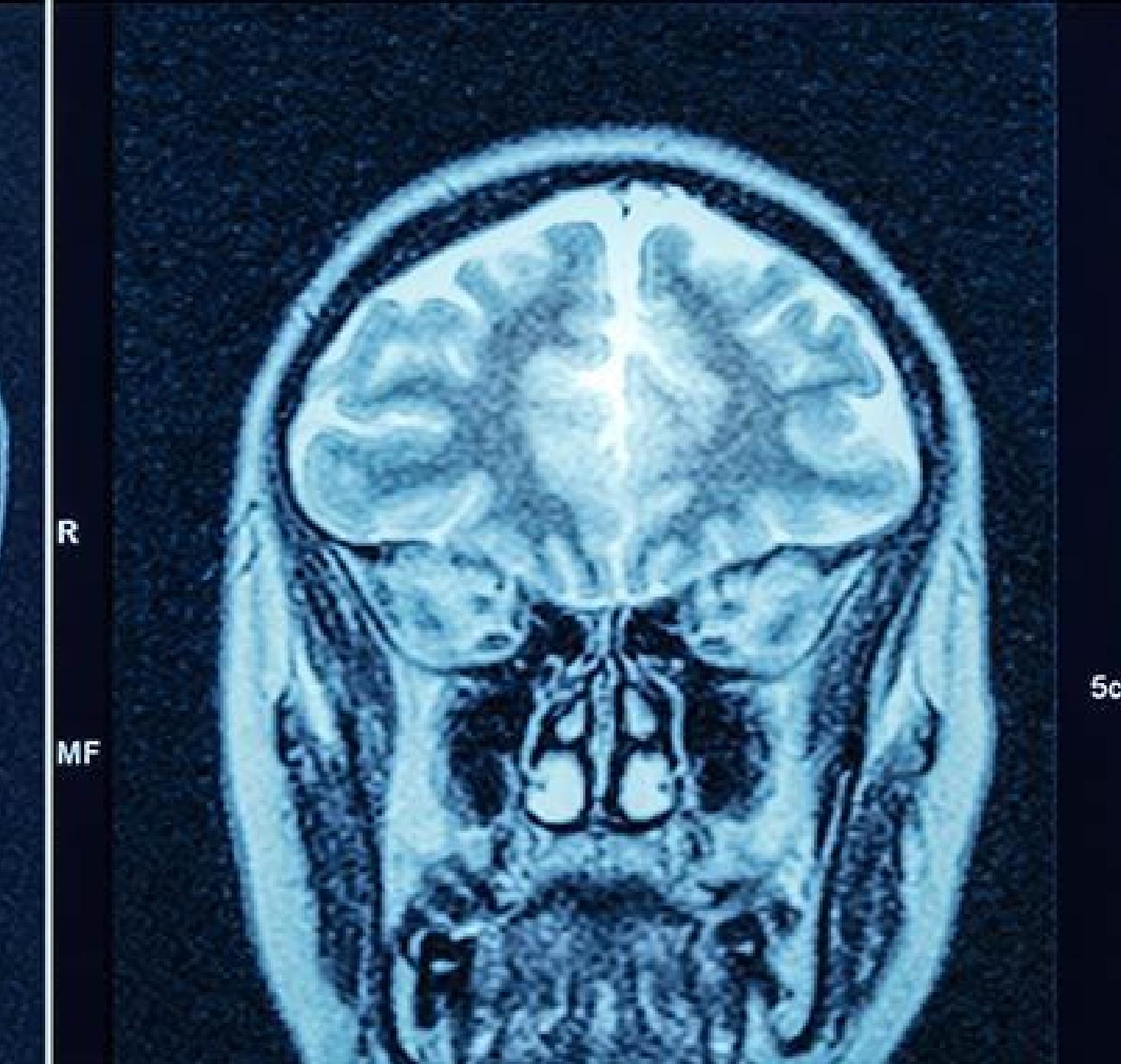
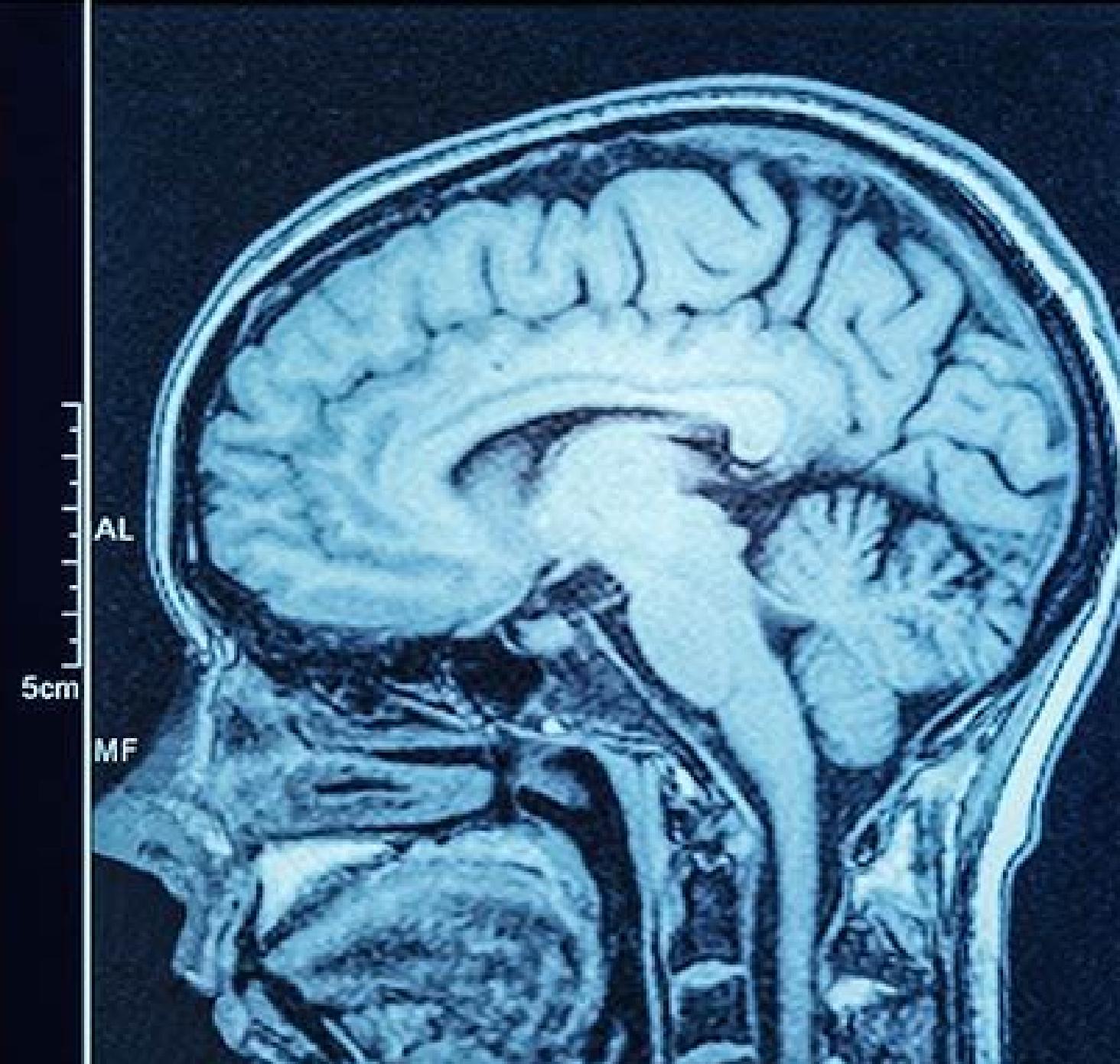
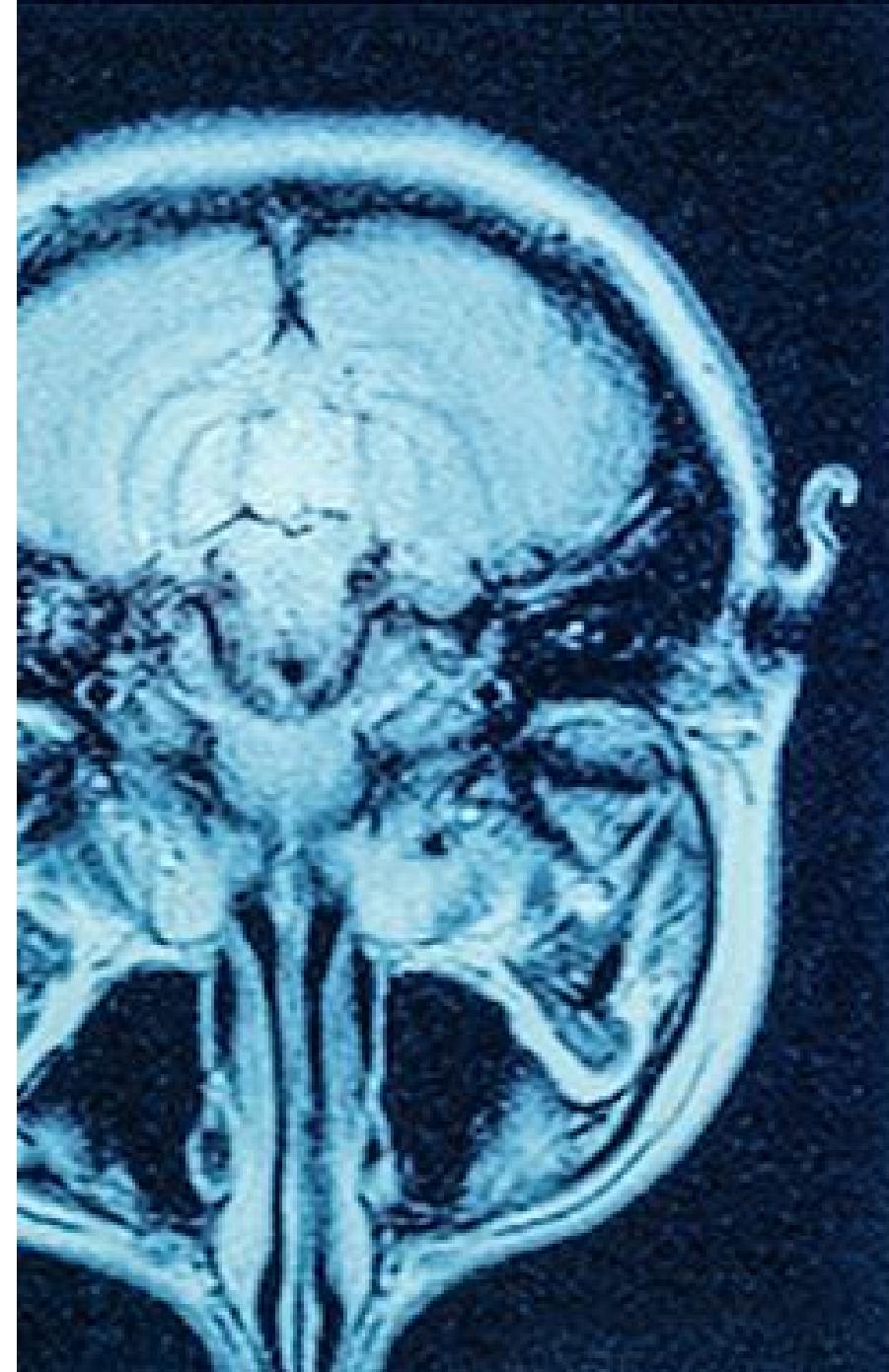
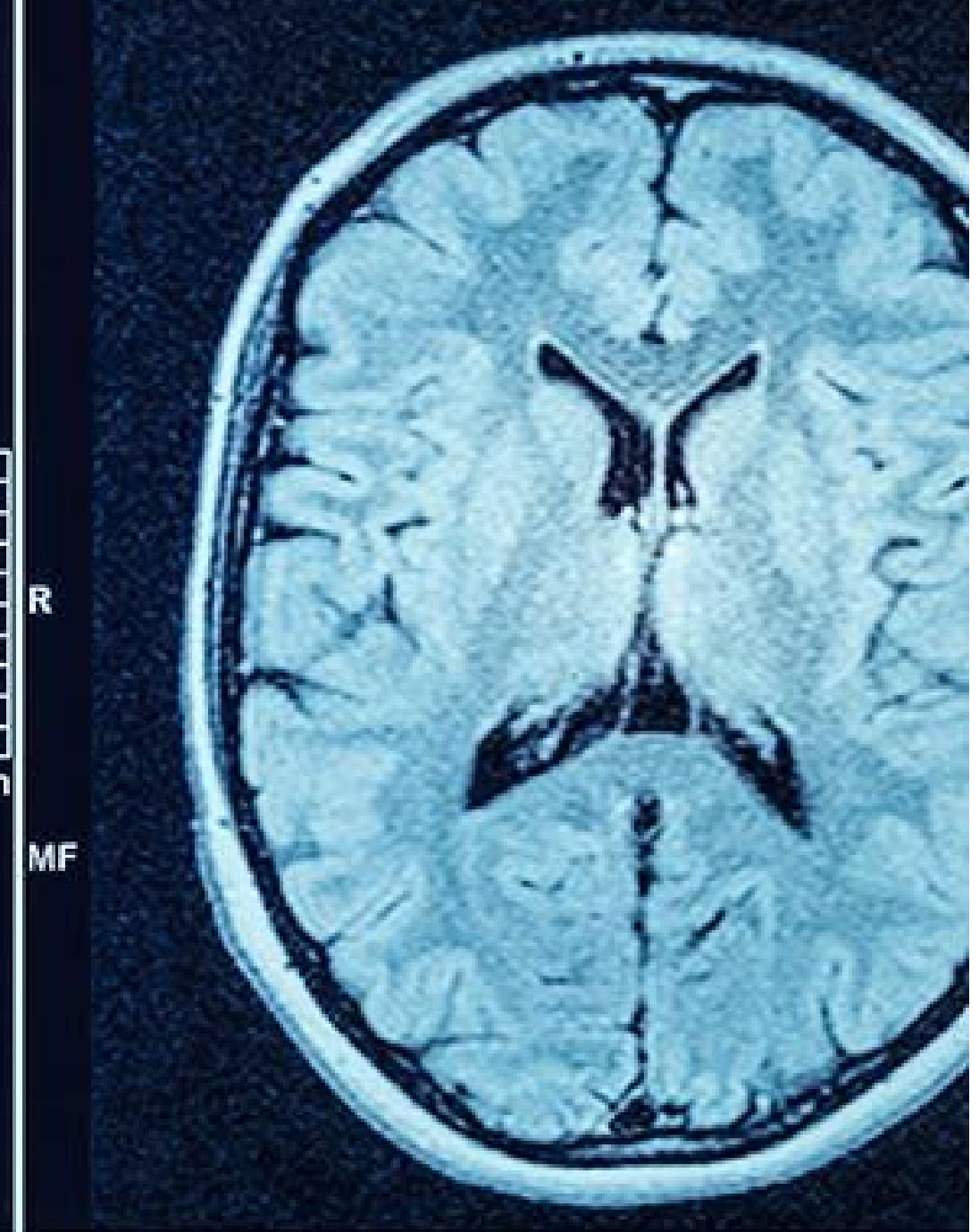
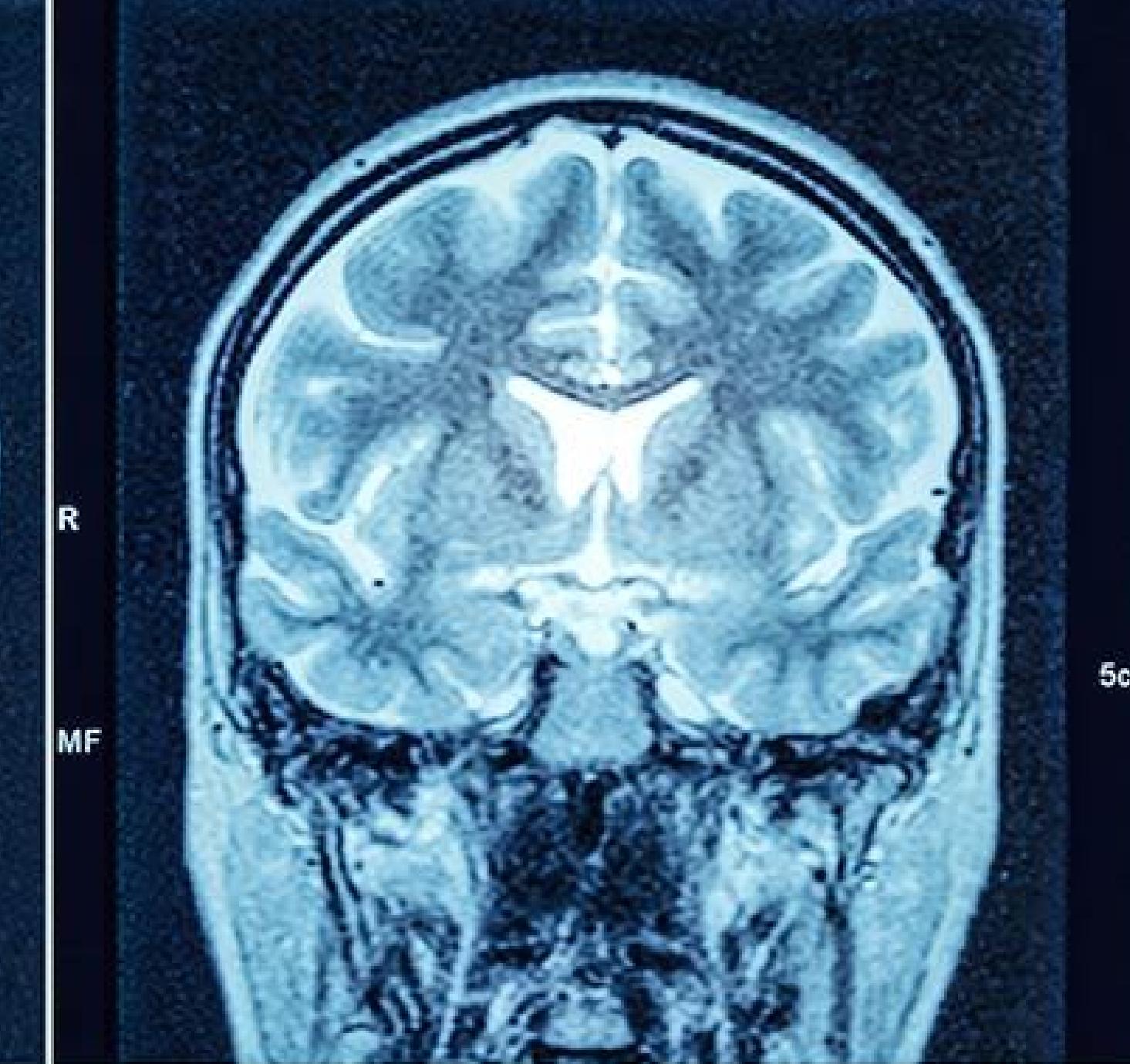
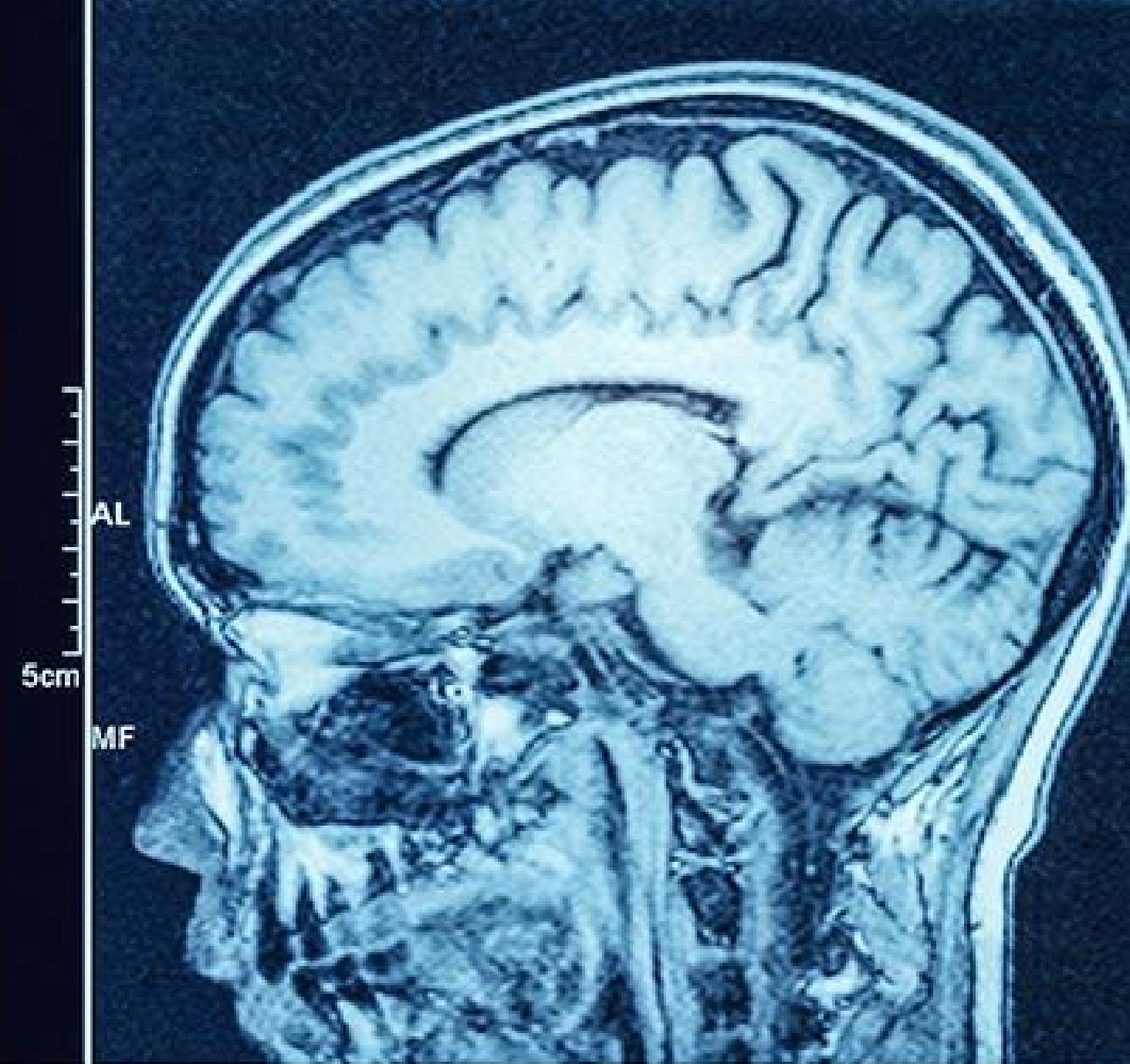
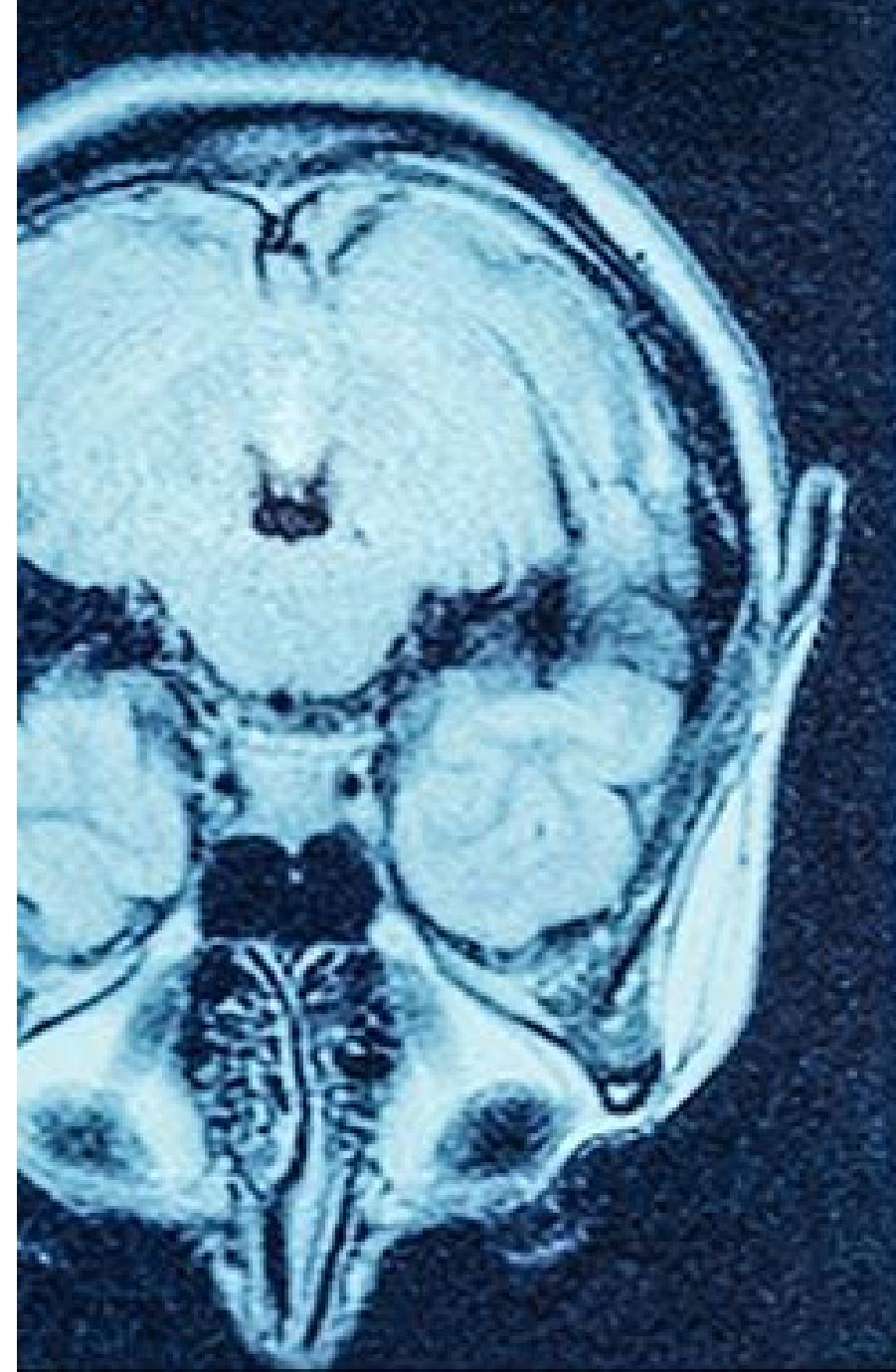
[Why Should Engineers Be Worried About Color?
Treinish and Rogowitz 1998. <http://>



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

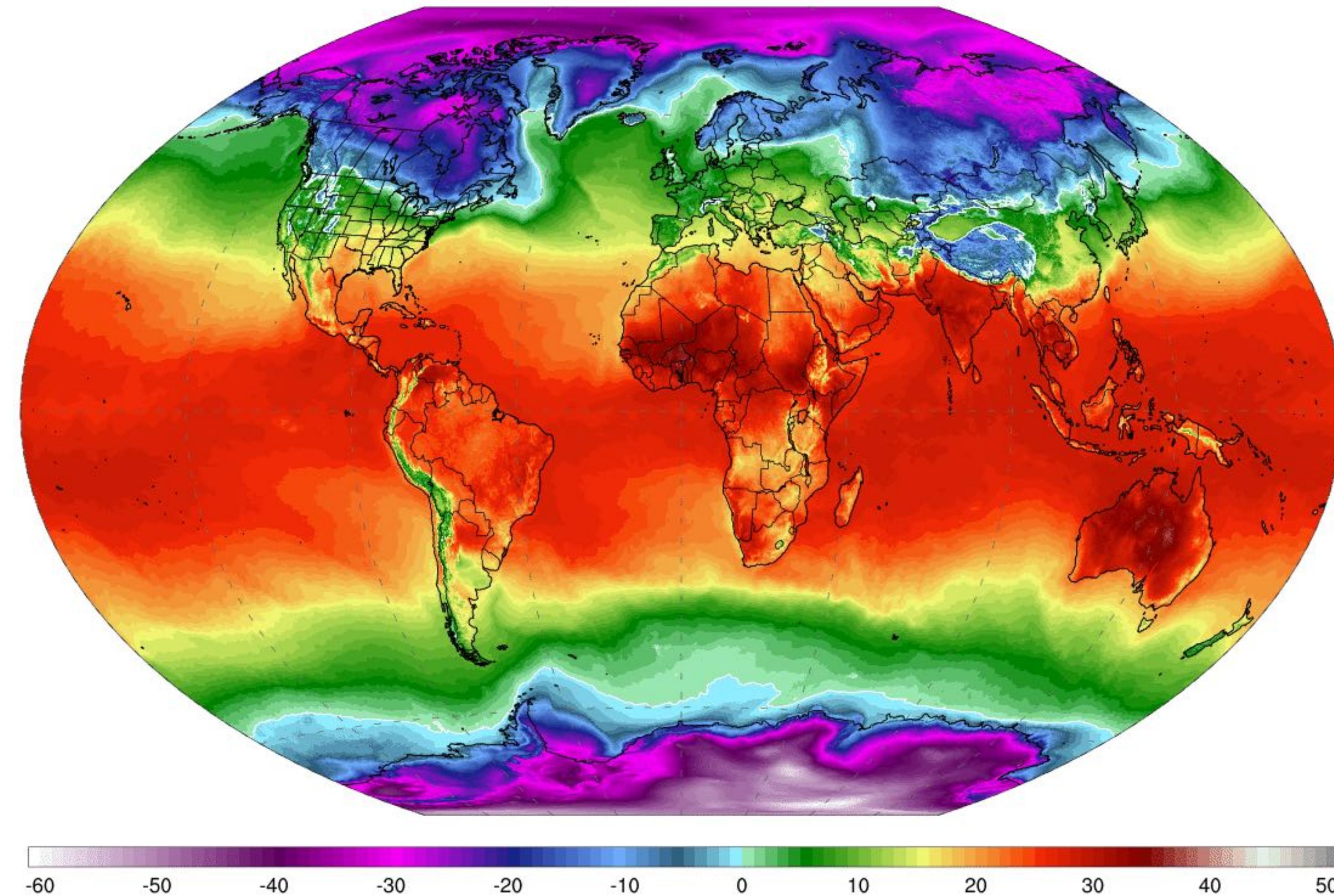
In other words

- 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**



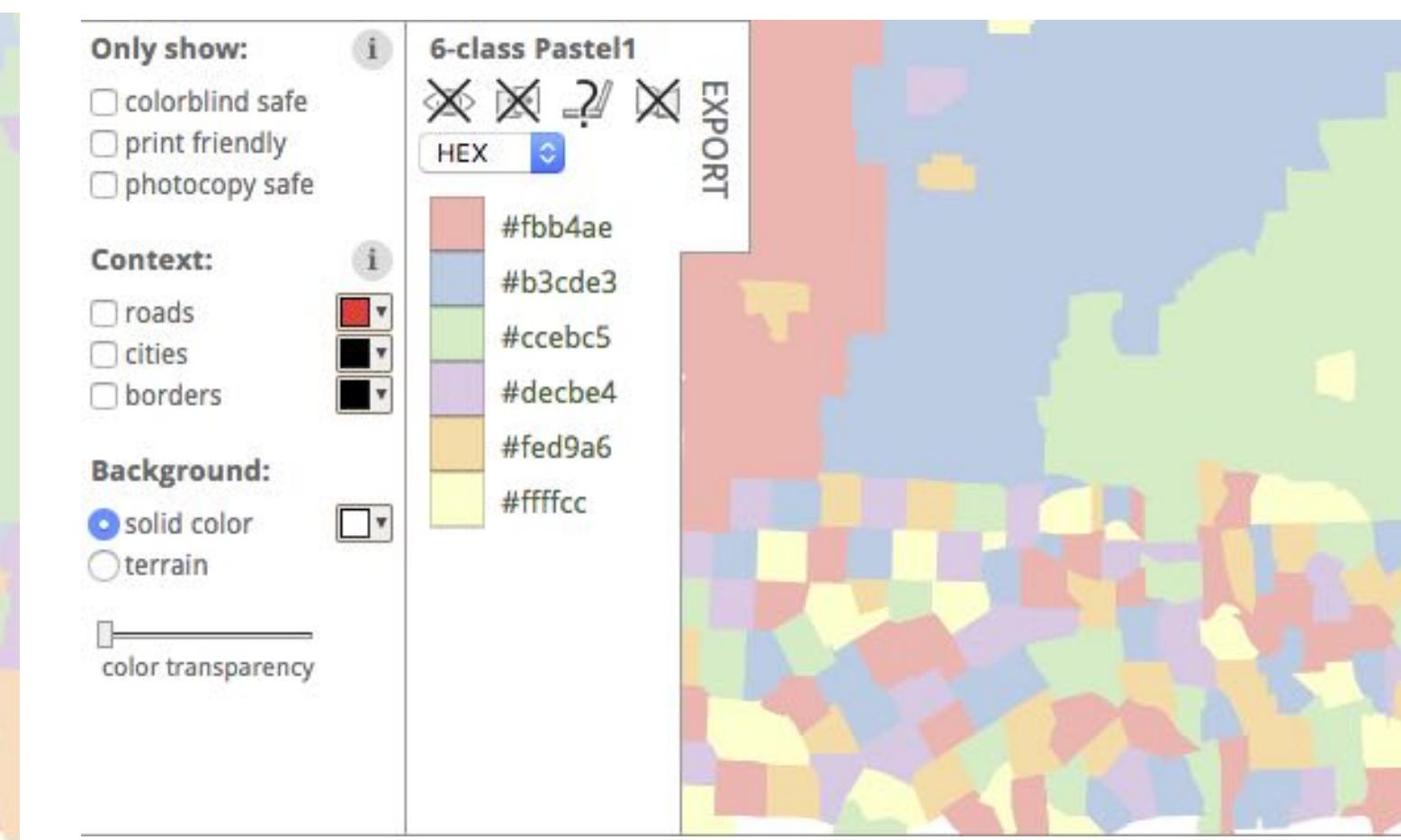
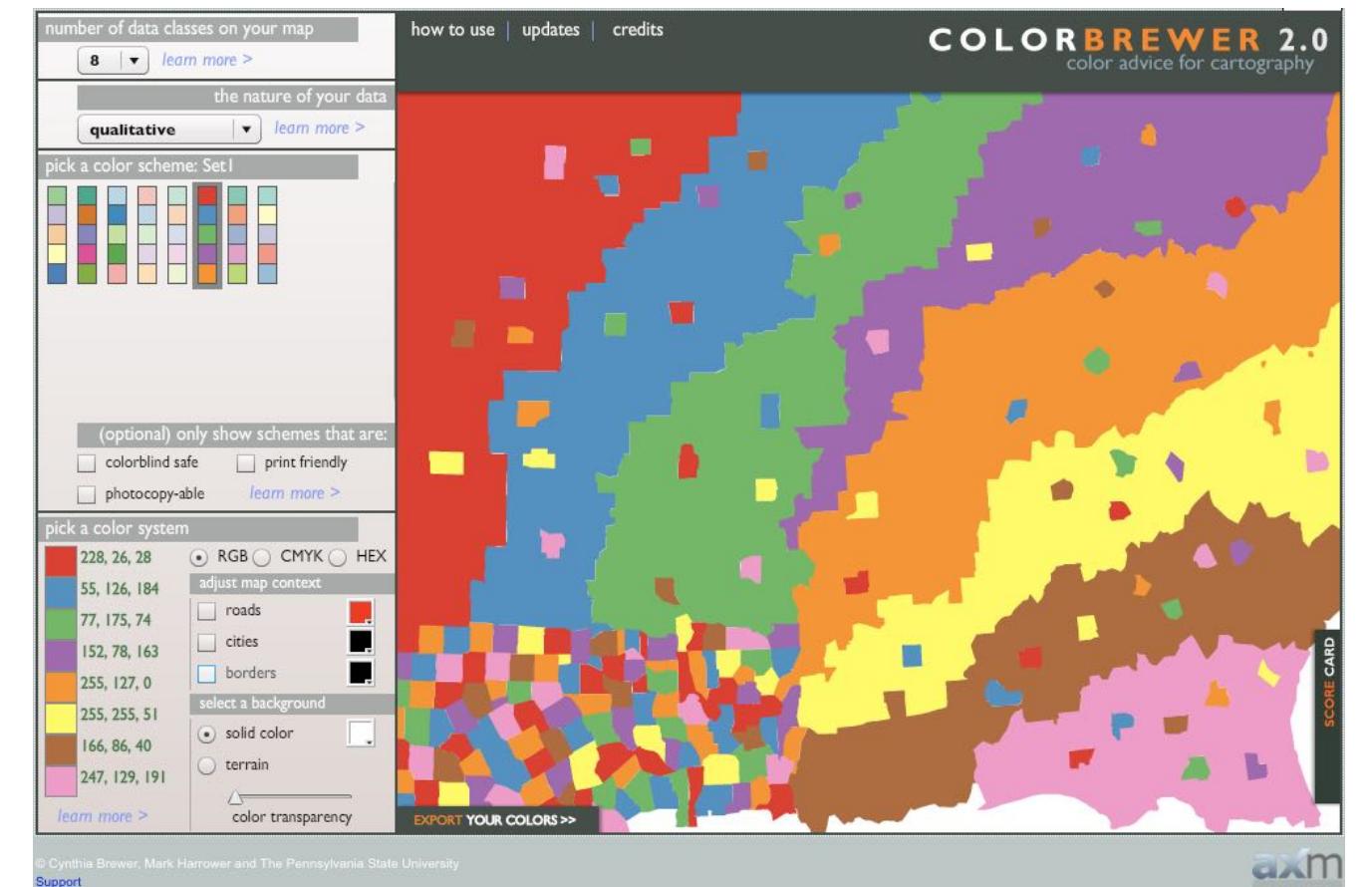
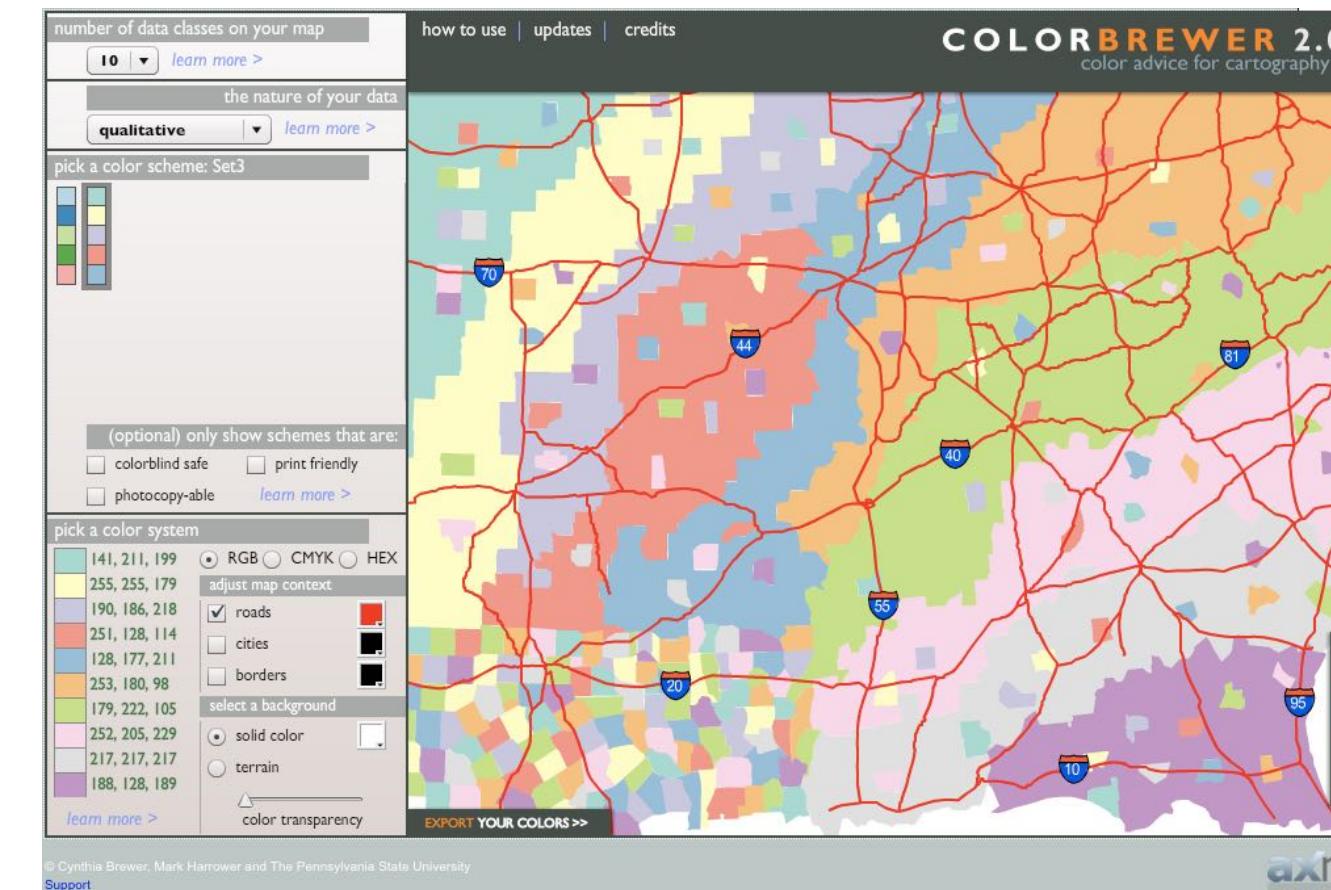
GFS 2m Temperature (°C)
1-day Avg | Wed, Mar 12, 2025

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

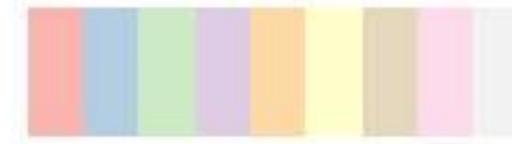
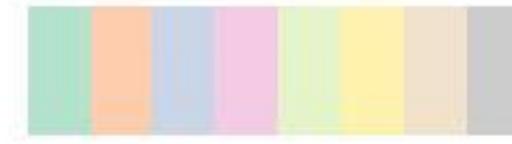
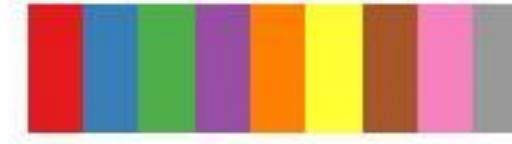


- categorical
 - aim for maximum distinguishability
 - aka *qualitative, nominal*

→ Categorical



categorical



Color palettes: univariate

→ Categorical



→ Ordered

→ *Sequential*

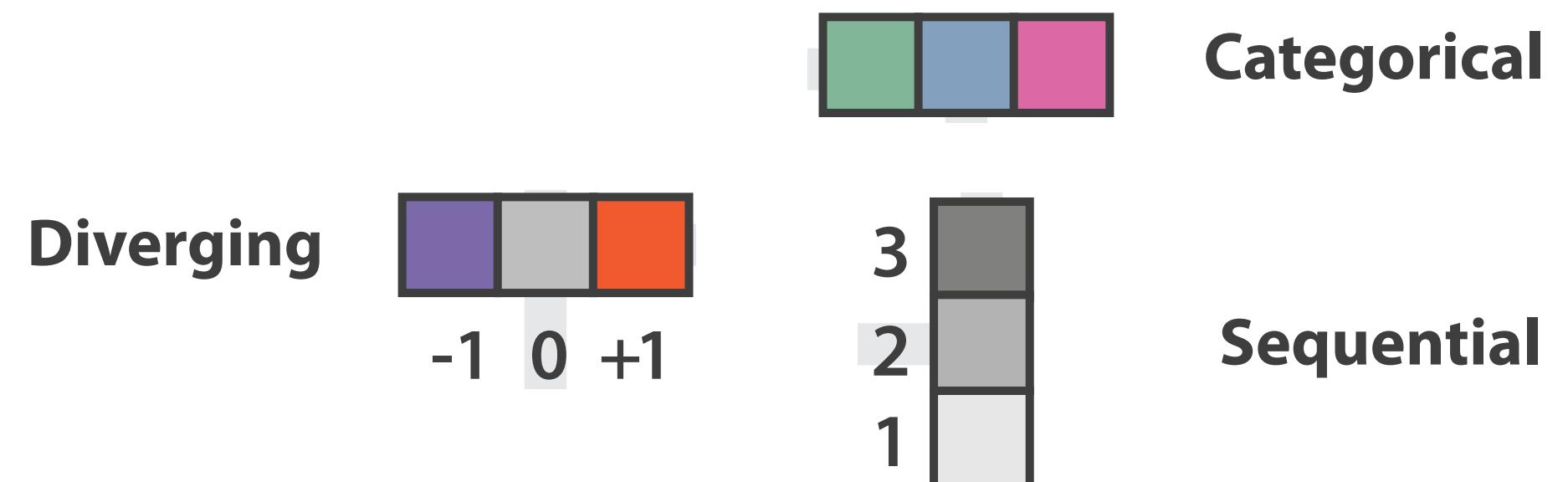


→ *Diverging*



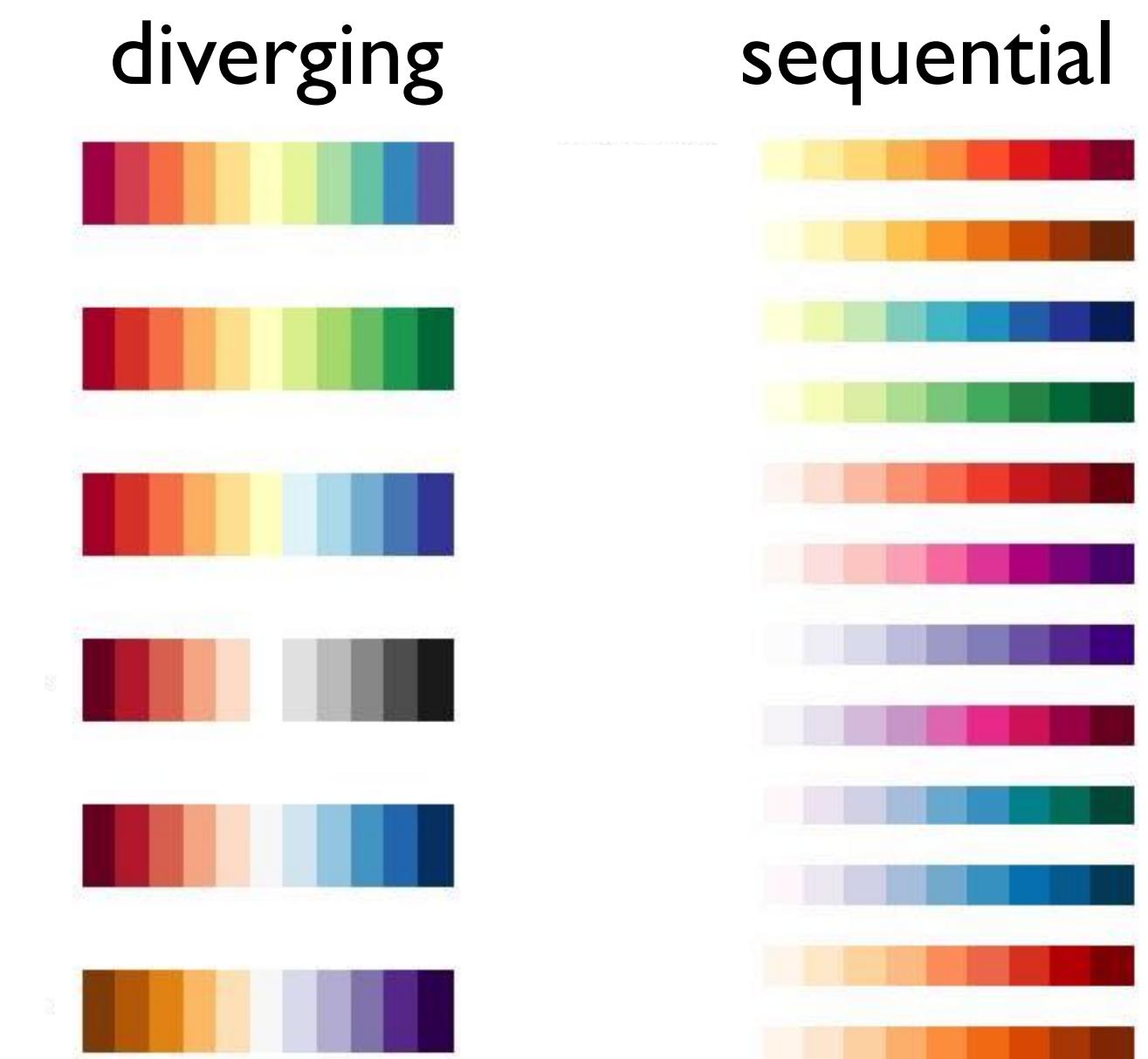
- **diverging**

- 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*

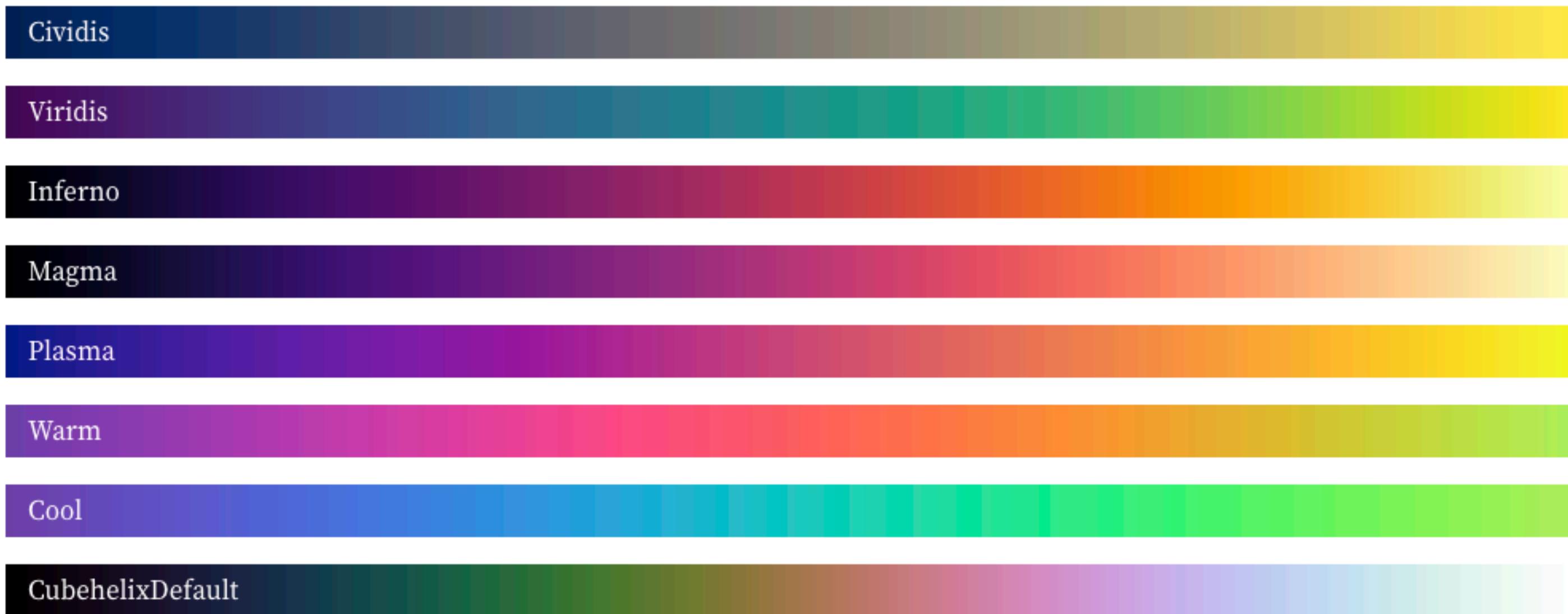


- **diverging**

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

- **sequential**

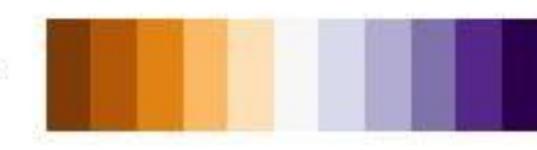
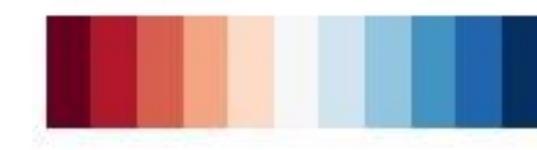
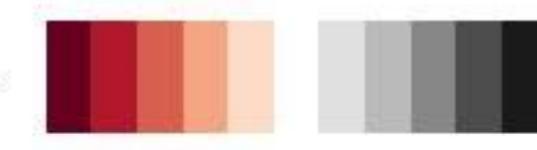
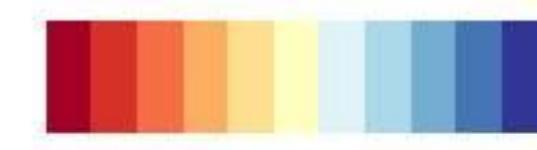
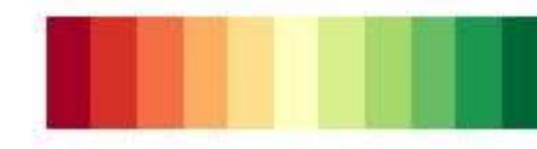
- ramp luminance or saturation
- if multi-hue, good to order by luminance



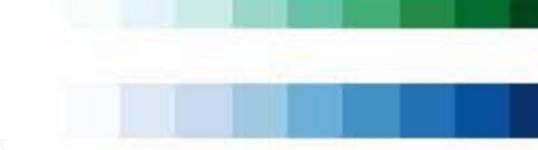
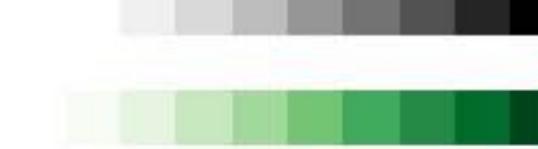
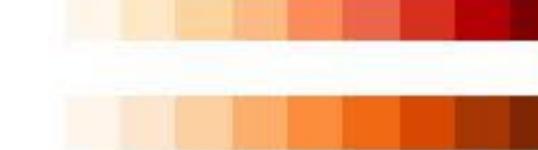
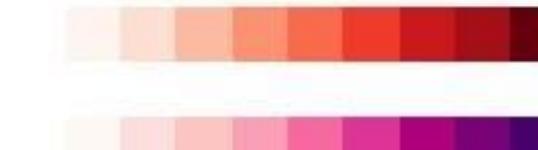
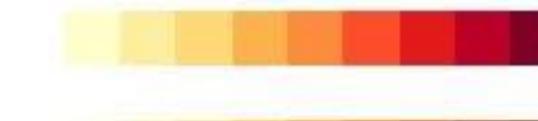
Color palette design considerations: univariate

segmented

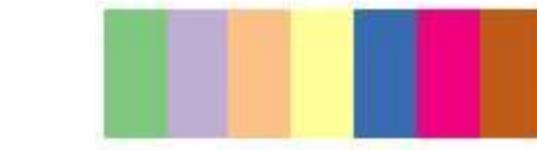
diverging



sequential



categorical



continuous

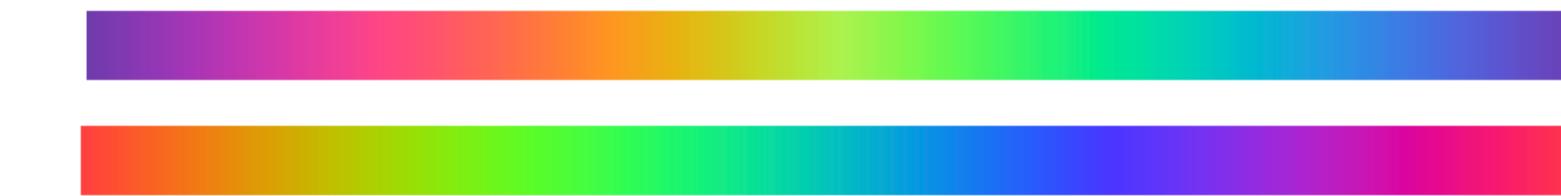


sequential
single hue

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



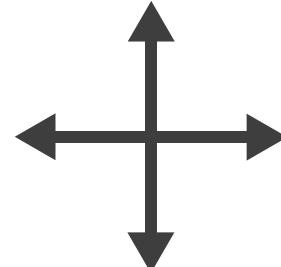
→ Ordered

→ Sequential

→ Diverging



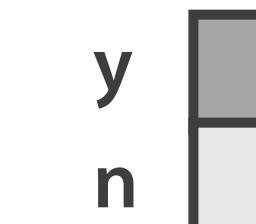
→ Bivariate



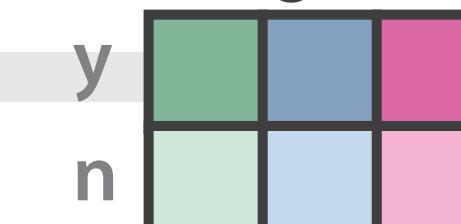
use with care!

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

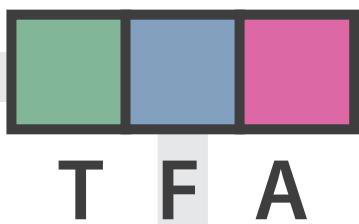
Binary



Categorical

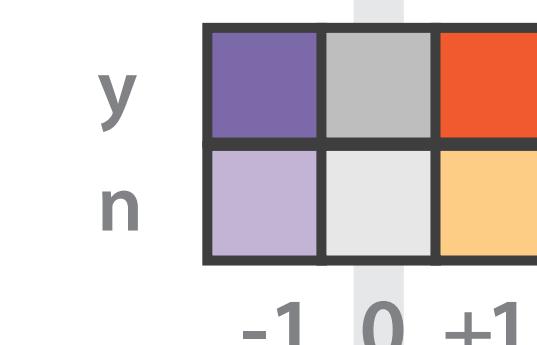


Binary

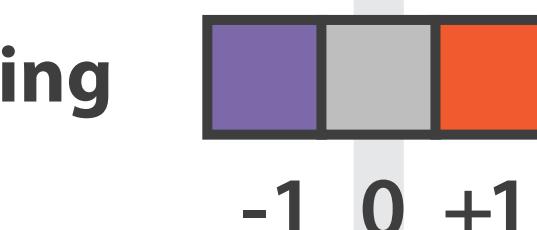


Categorical

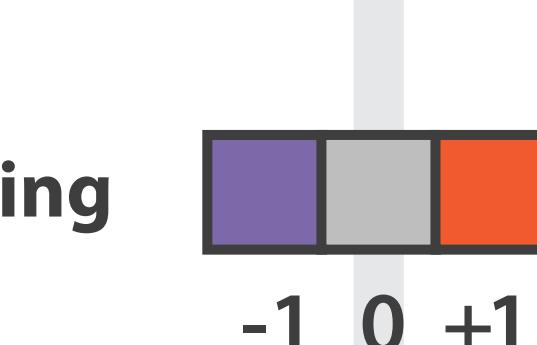
Diverging



Diverging

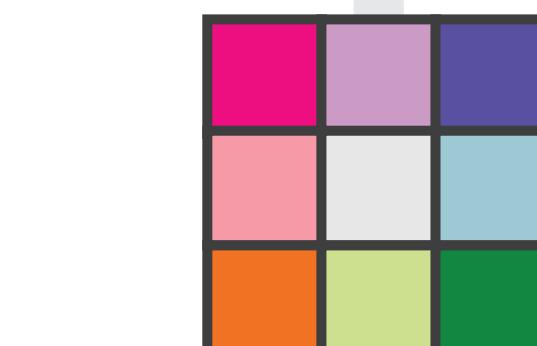


Diverging

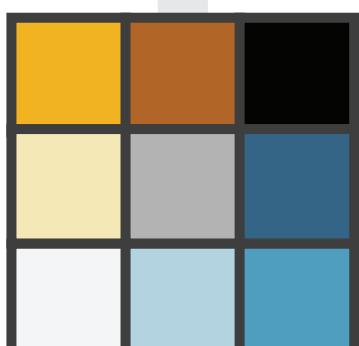


sequential

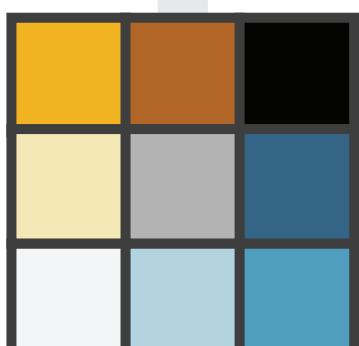
Diverging



Diverging



Sequential



Sequential



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

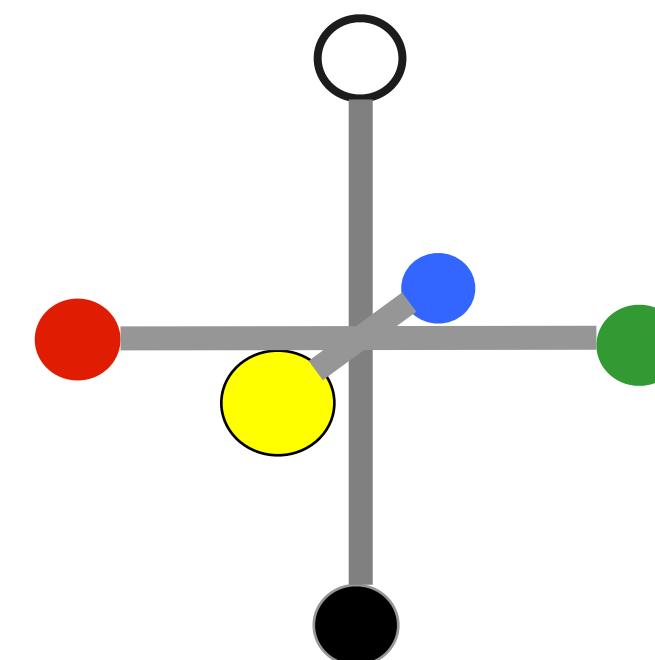


Saturation/hue information



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

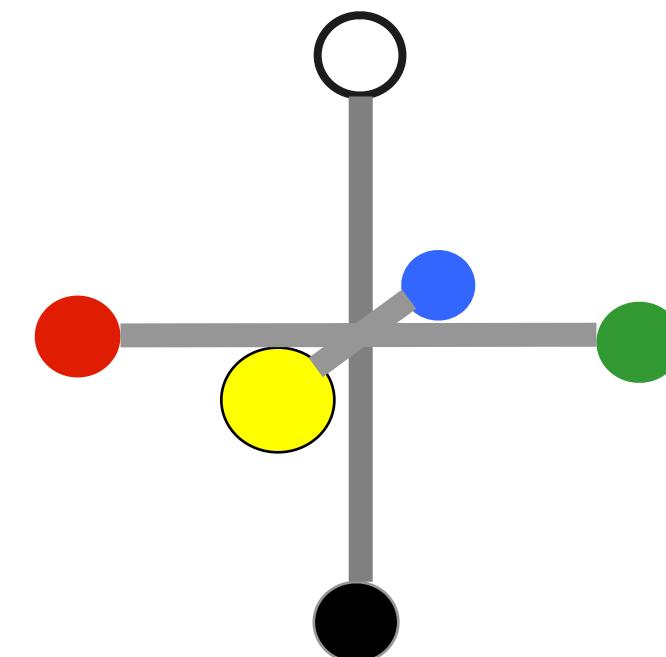


Chroma information



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



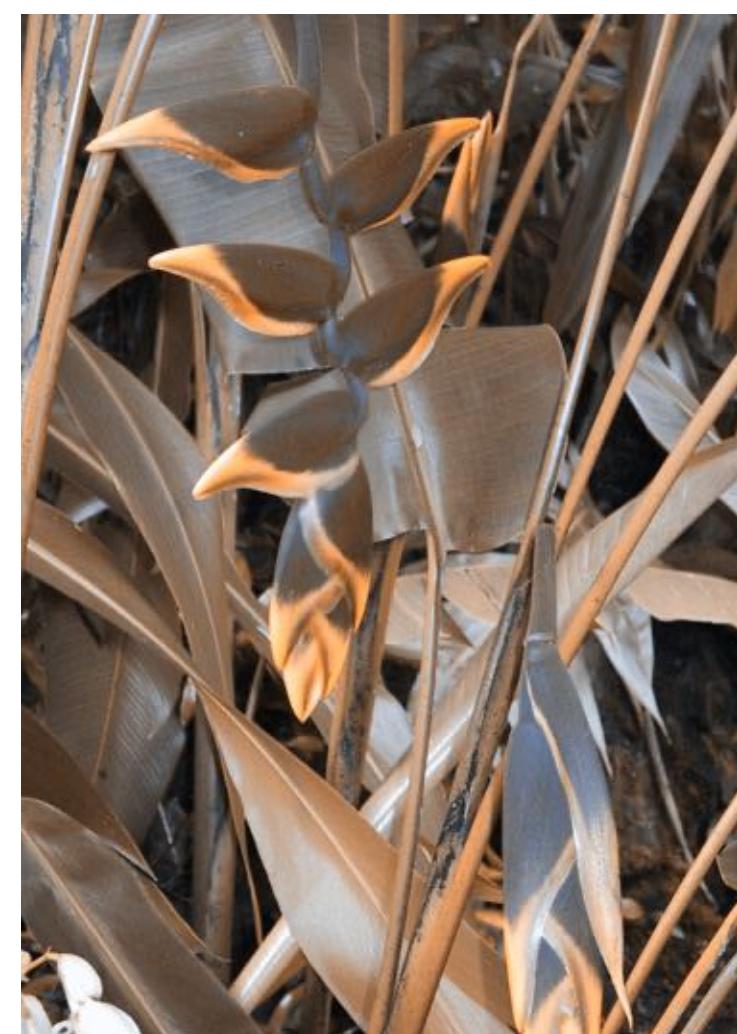
Chroma information



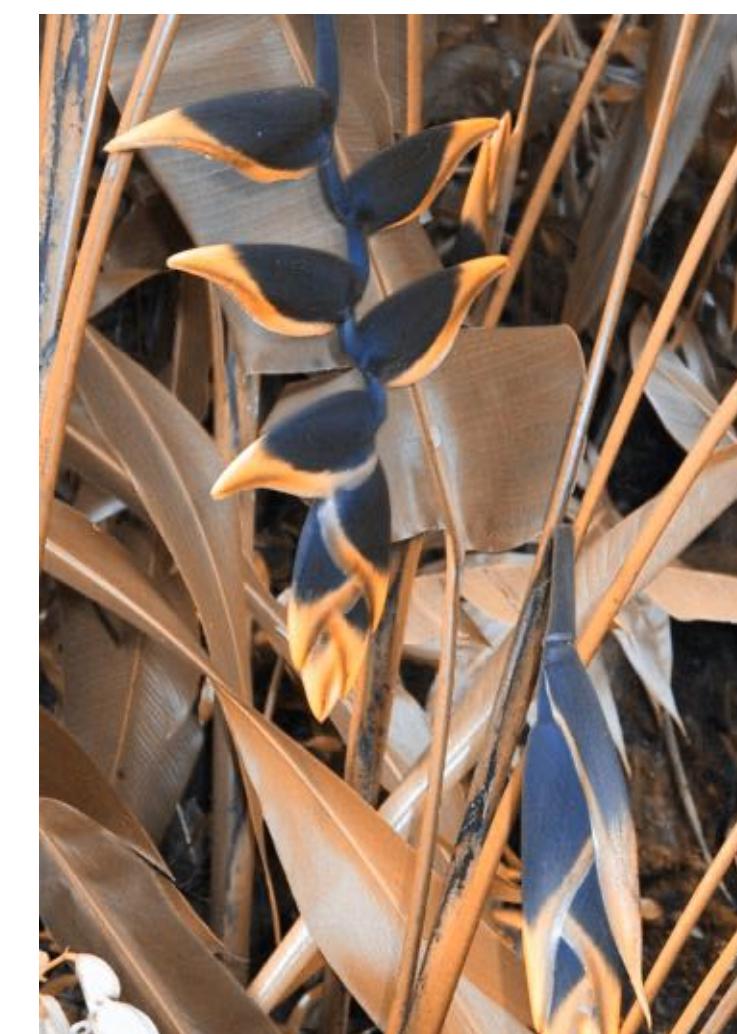
Designing for color deficiency: Check with simulator



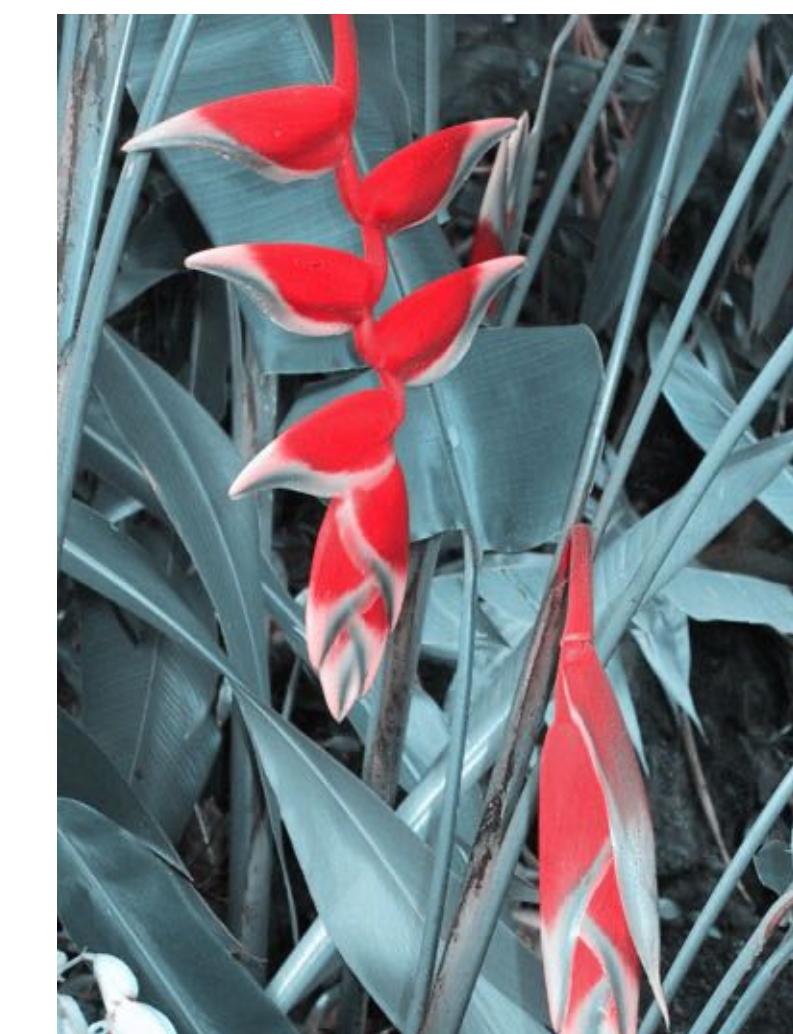
Normal vision



Deutanope
green-weak



Protanope
red-weak

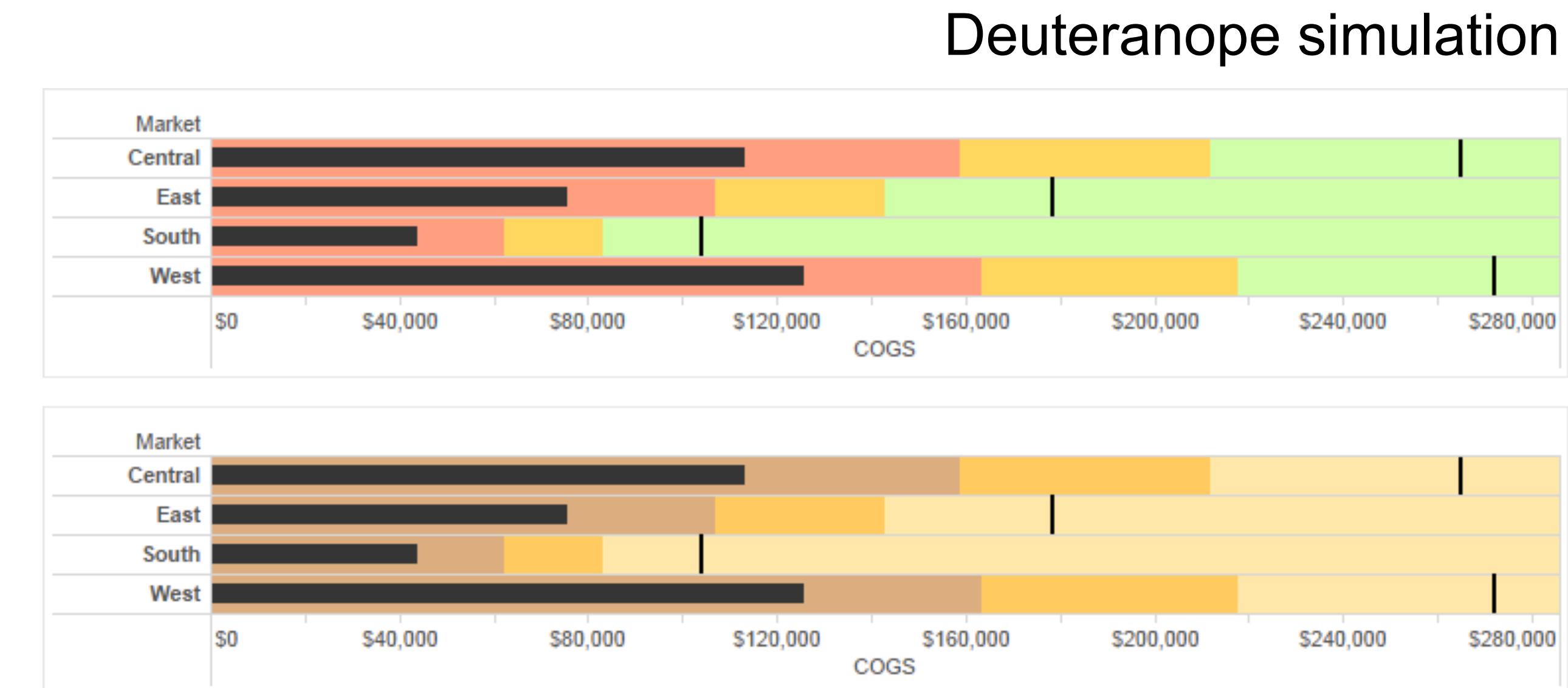
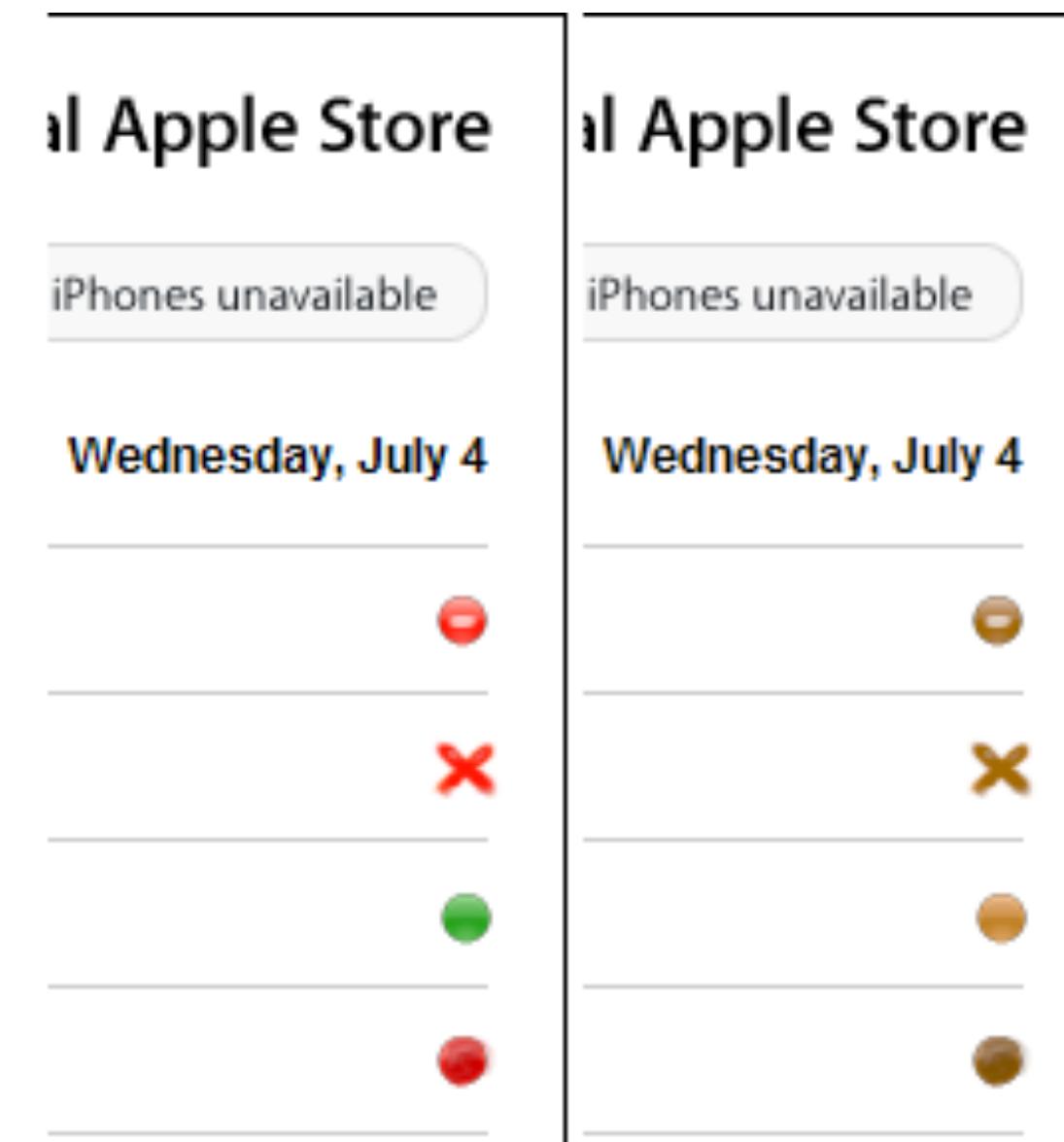


Tritanope
blue-weak



Designing for color deficiency: Avoid encoding by hue alone

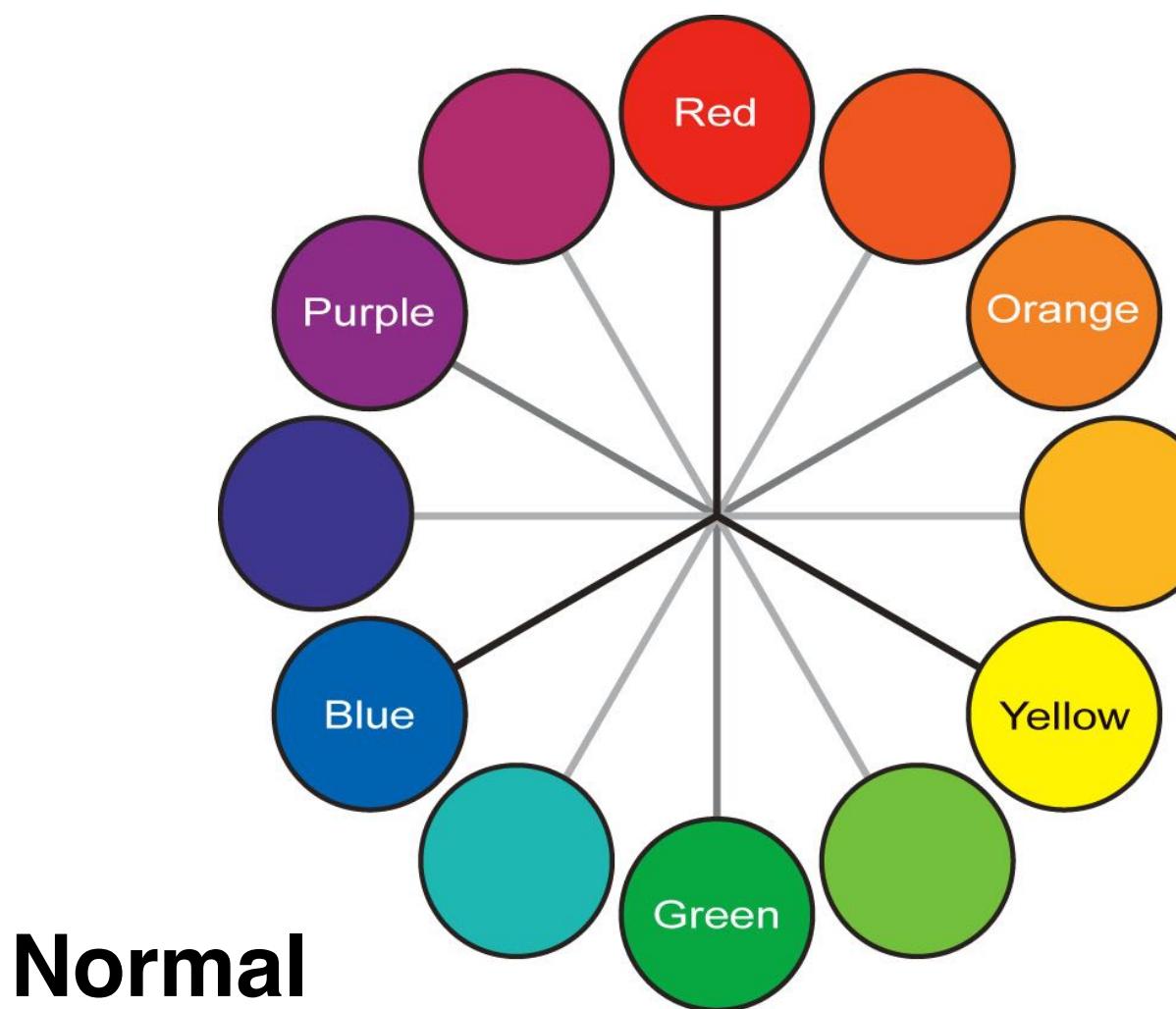
- redundantly encode
 - vary luminance
 - change shape



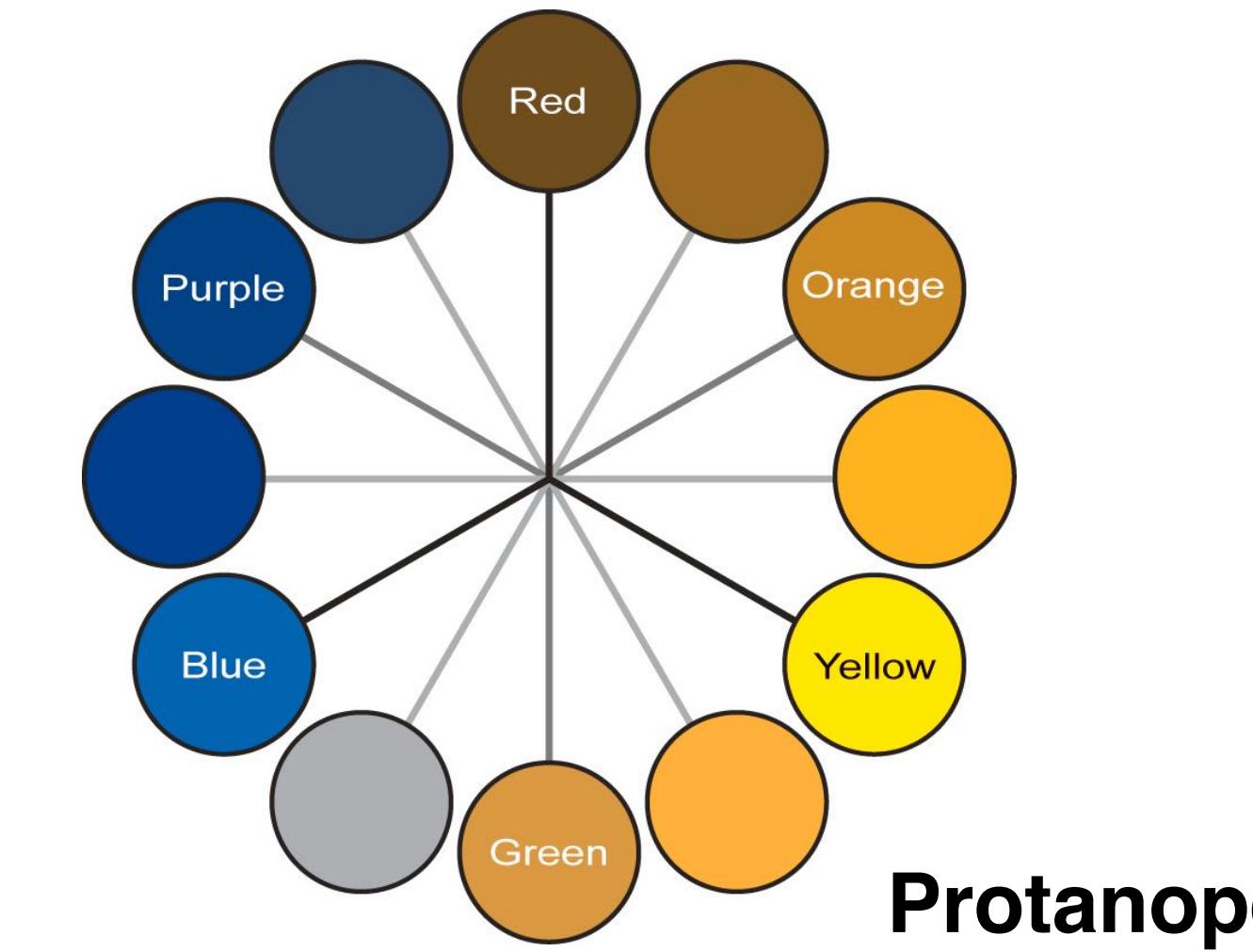
Change the shape

Vary luminance

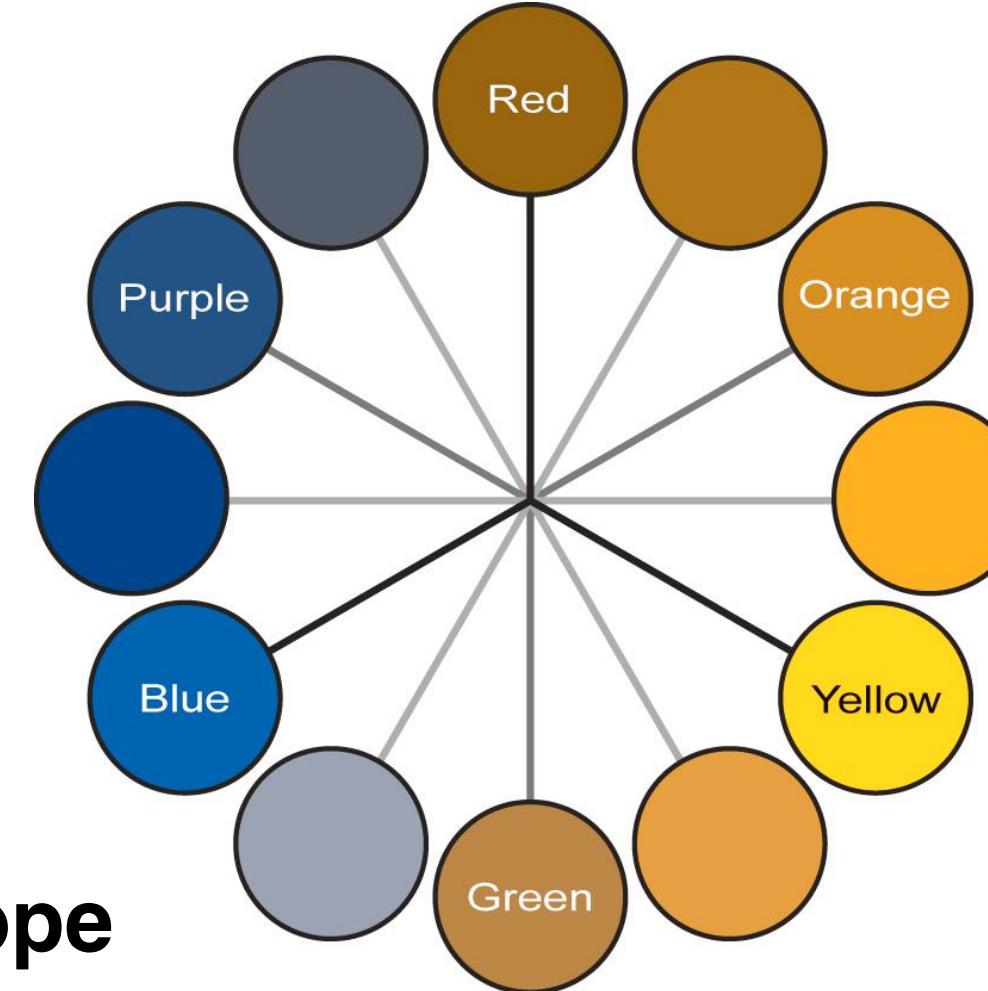
Color deficiency: Reduces color to 2 dimensions



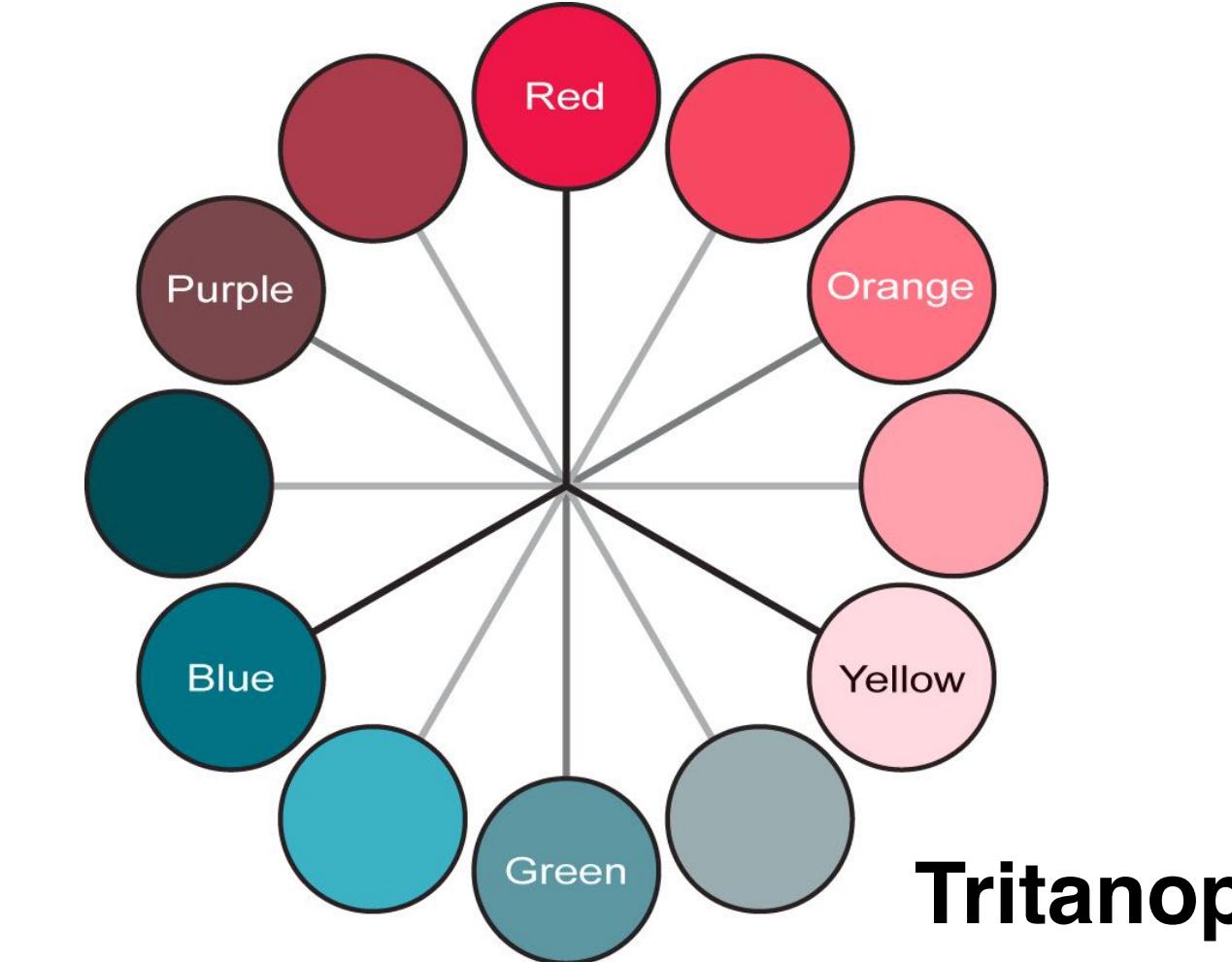
Normal



Protanope

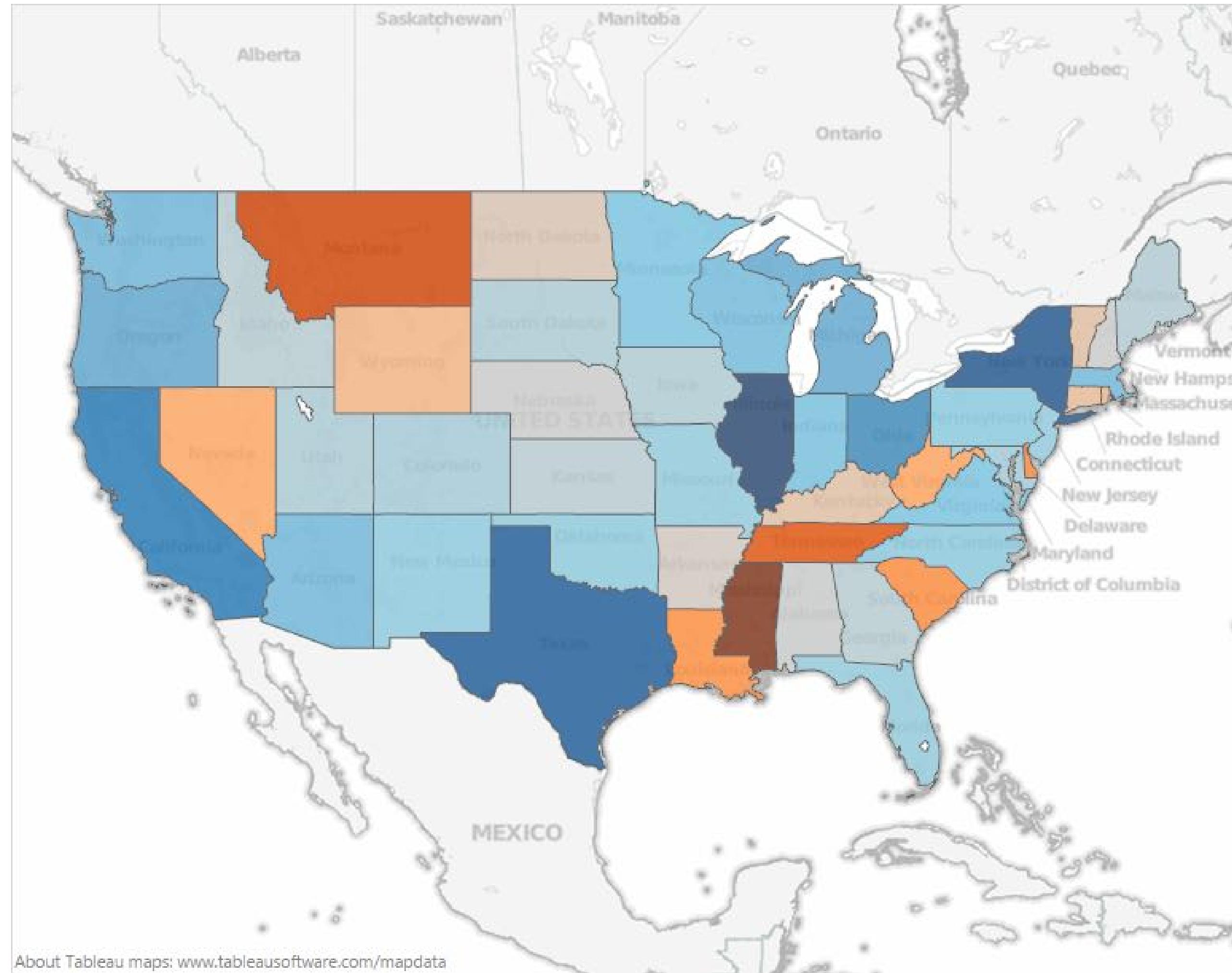


Deutanope



Tritanope

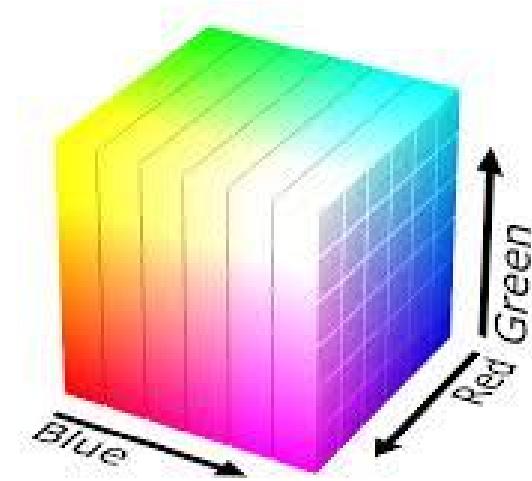
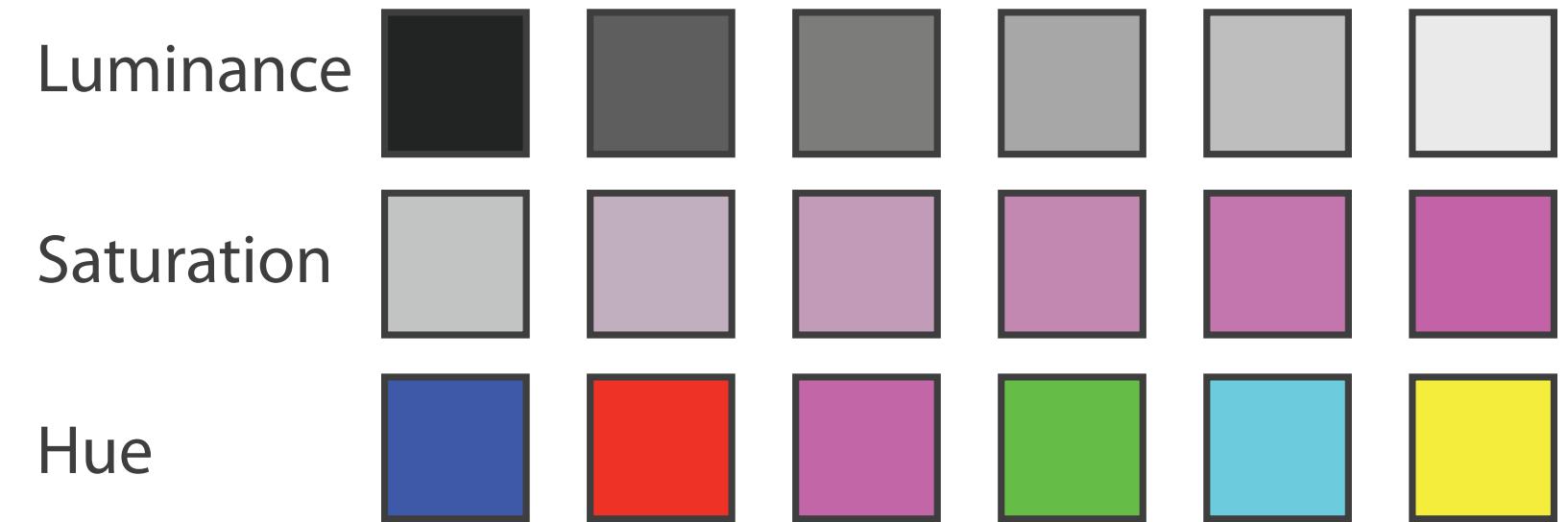
Designing for color deficiency: Blue-Orange is safe



Color Spaces

Many color spaces

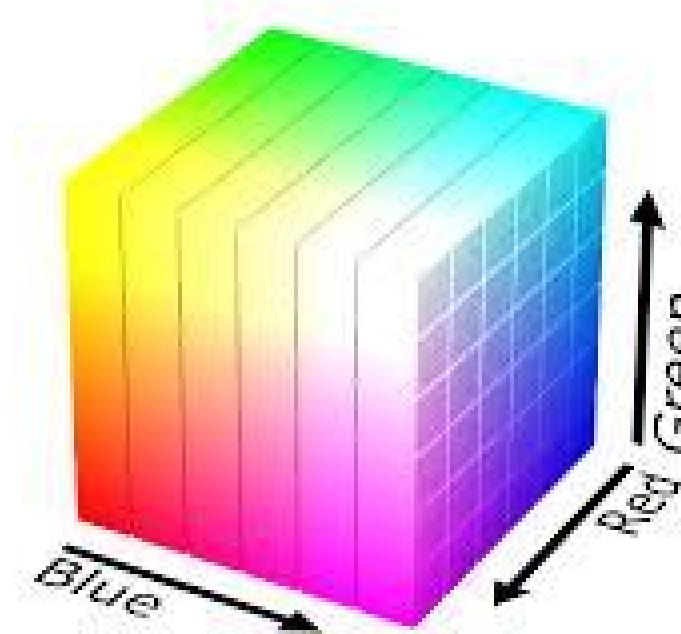
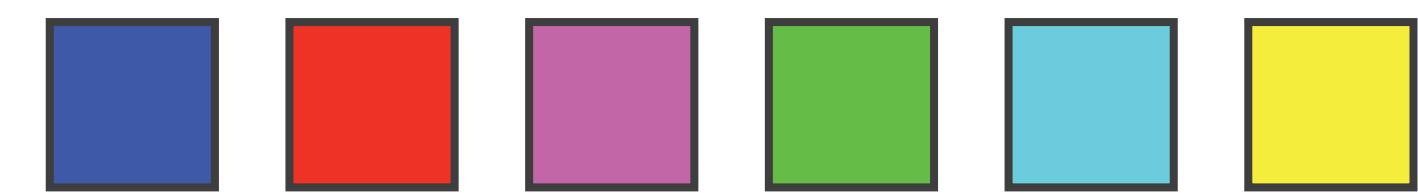
- Luminance (L^*), hue (H), saturation (S)
 - good for encoding
 - but not standard graphics/tools colorspace
- RGB: good for display hardware



RGB

- RGB: good for display hardware

Corners of the RGB color cube

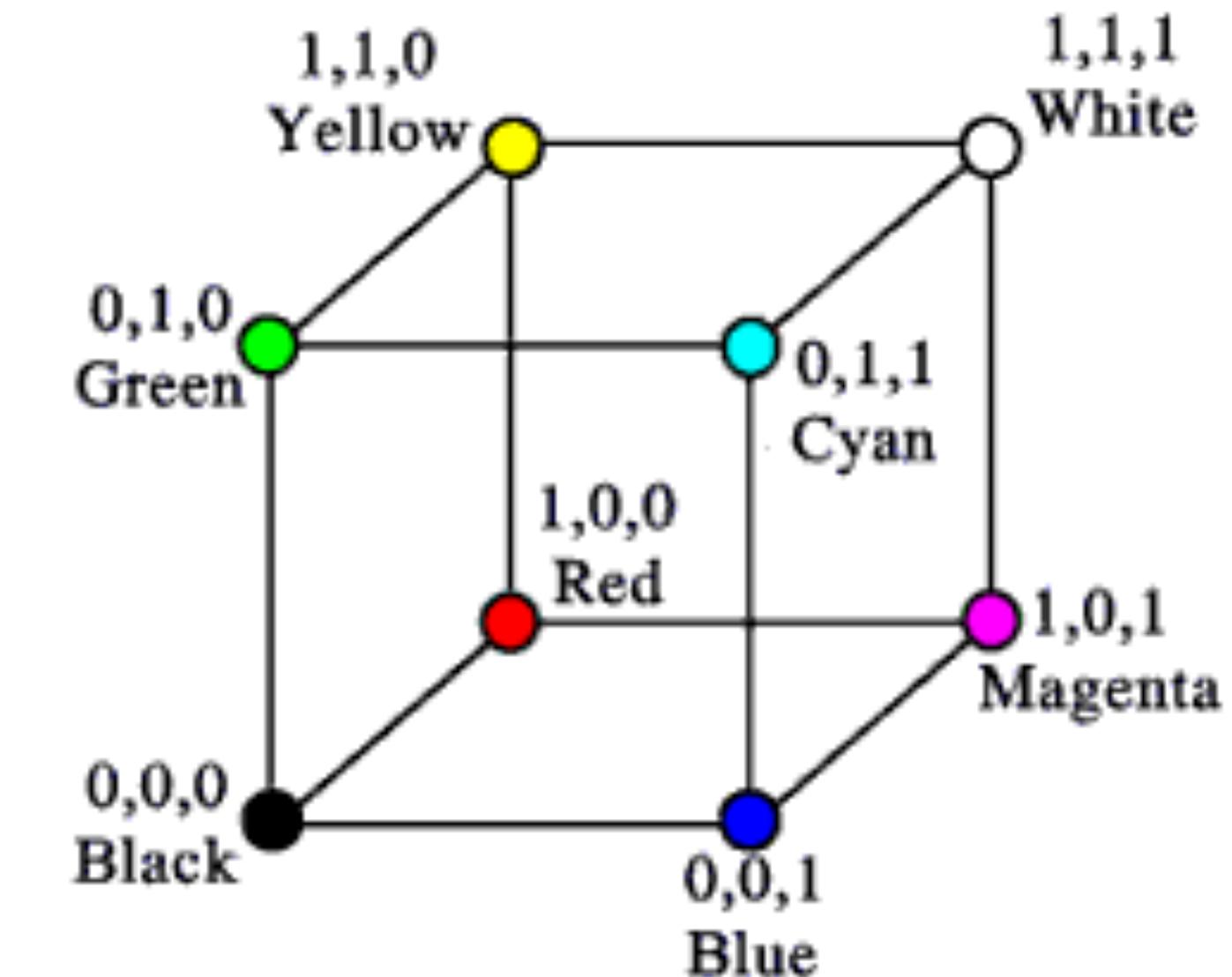


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Red
+ Green

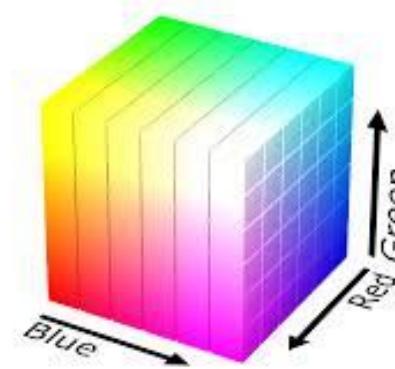
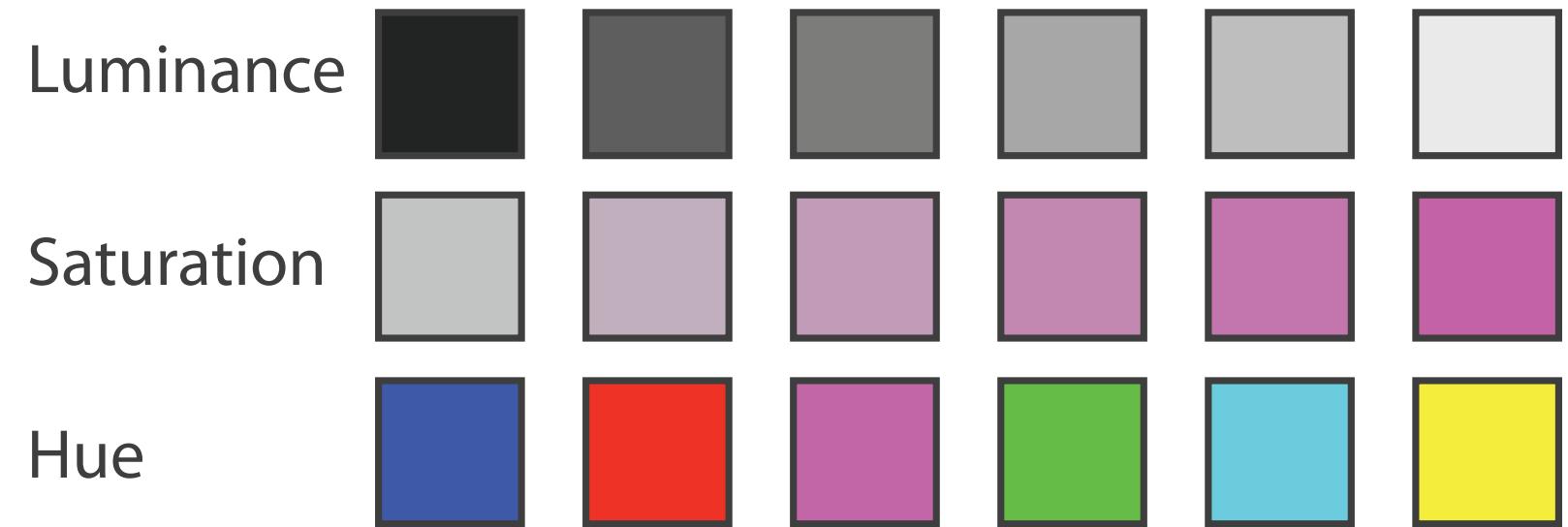


Major interference



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

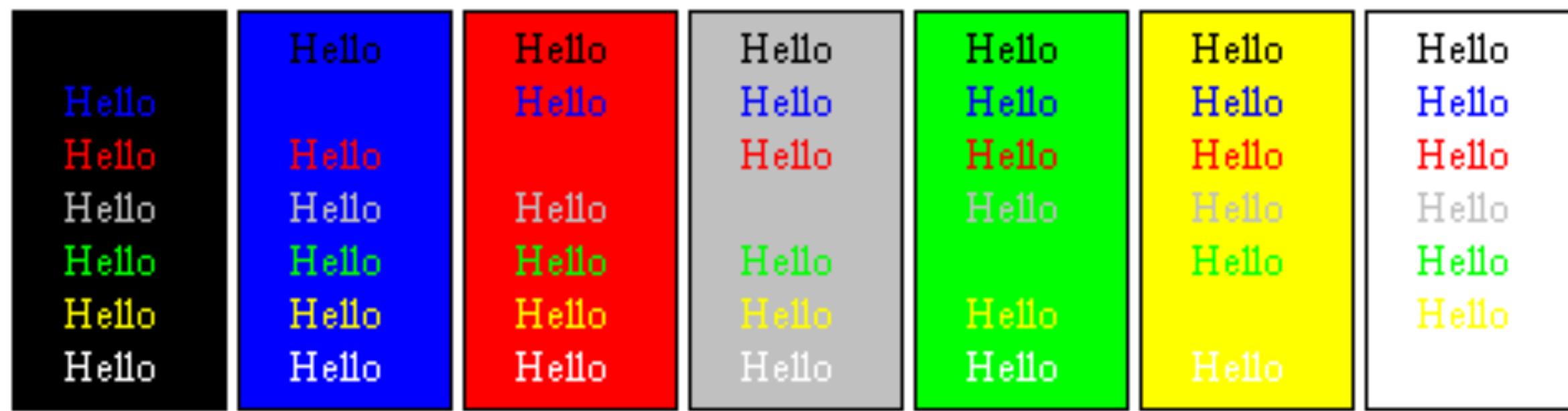


Color Contrast & Naming

Interaction with the background

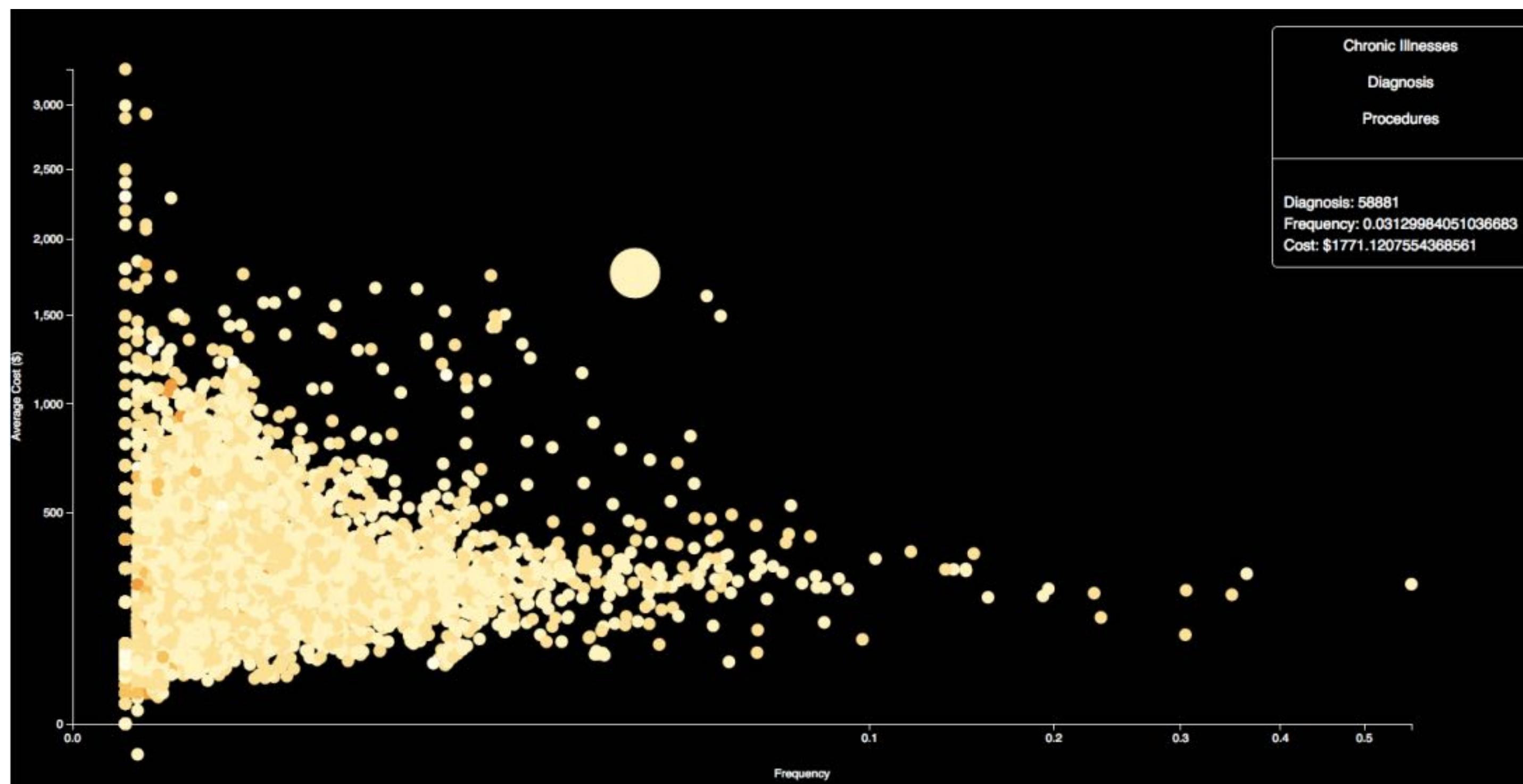
Contrast

The difference between foreground and background colors determines text legibility.



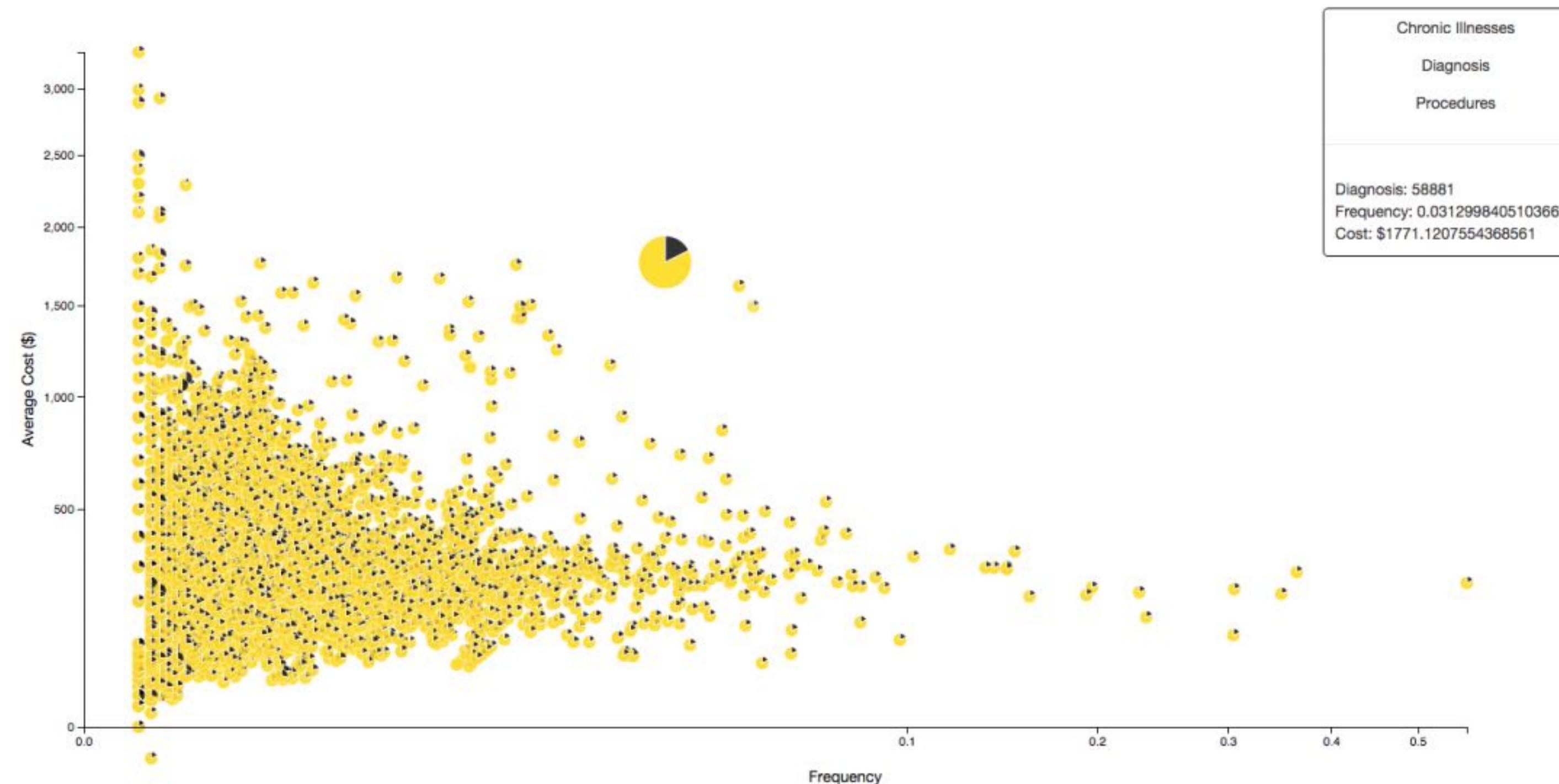
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



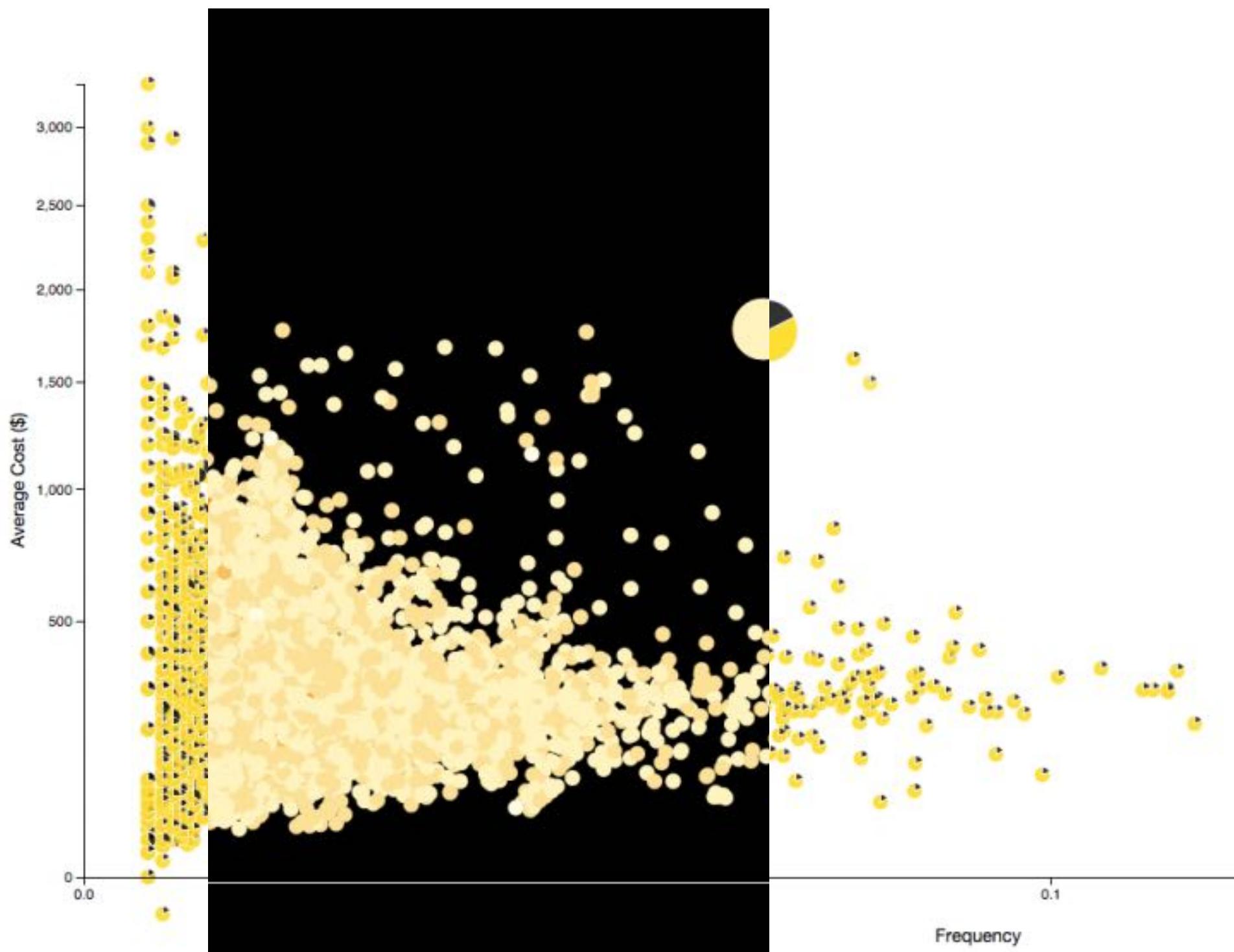
Interaction with the background: tweaking yellow for visibility

- 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

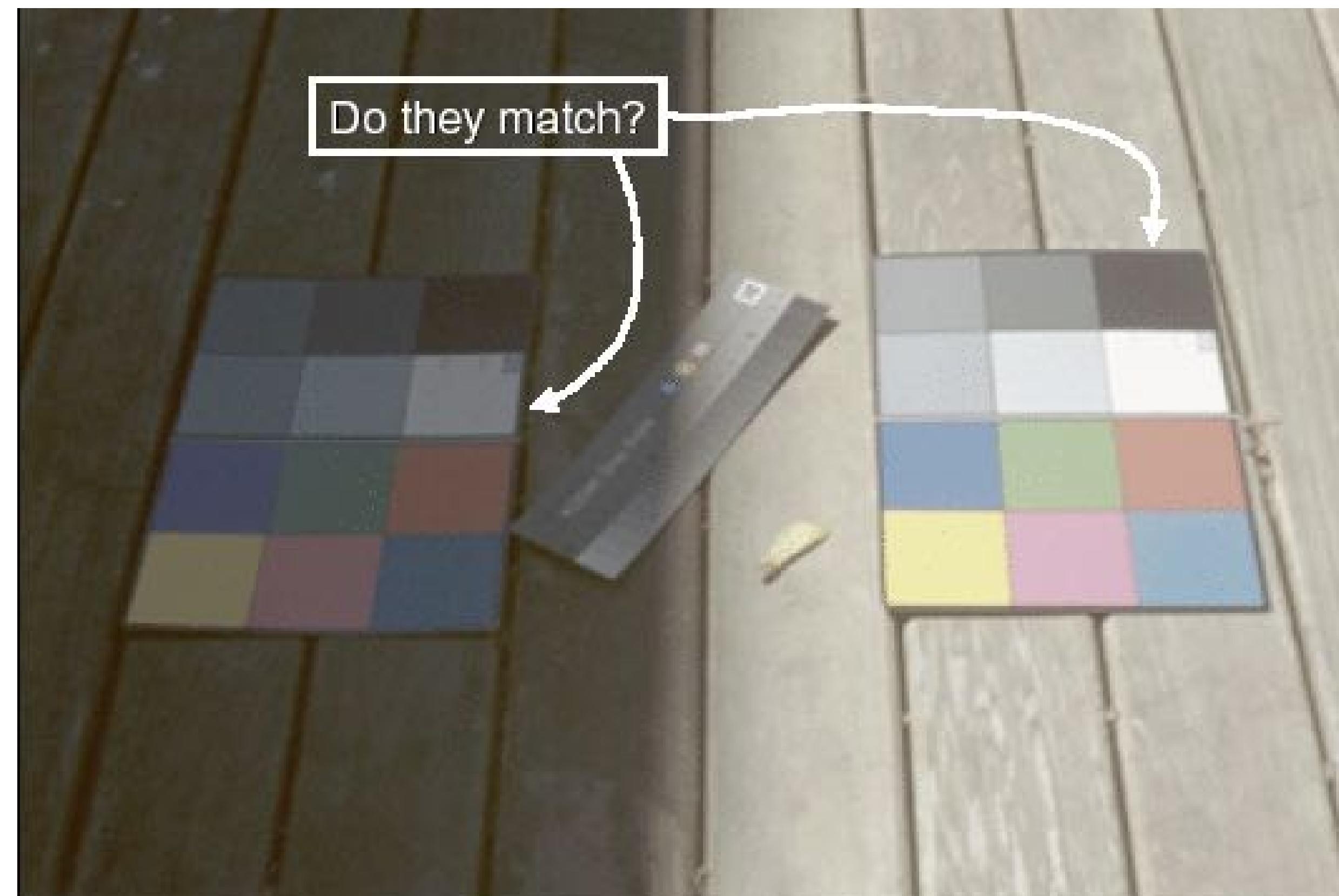


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

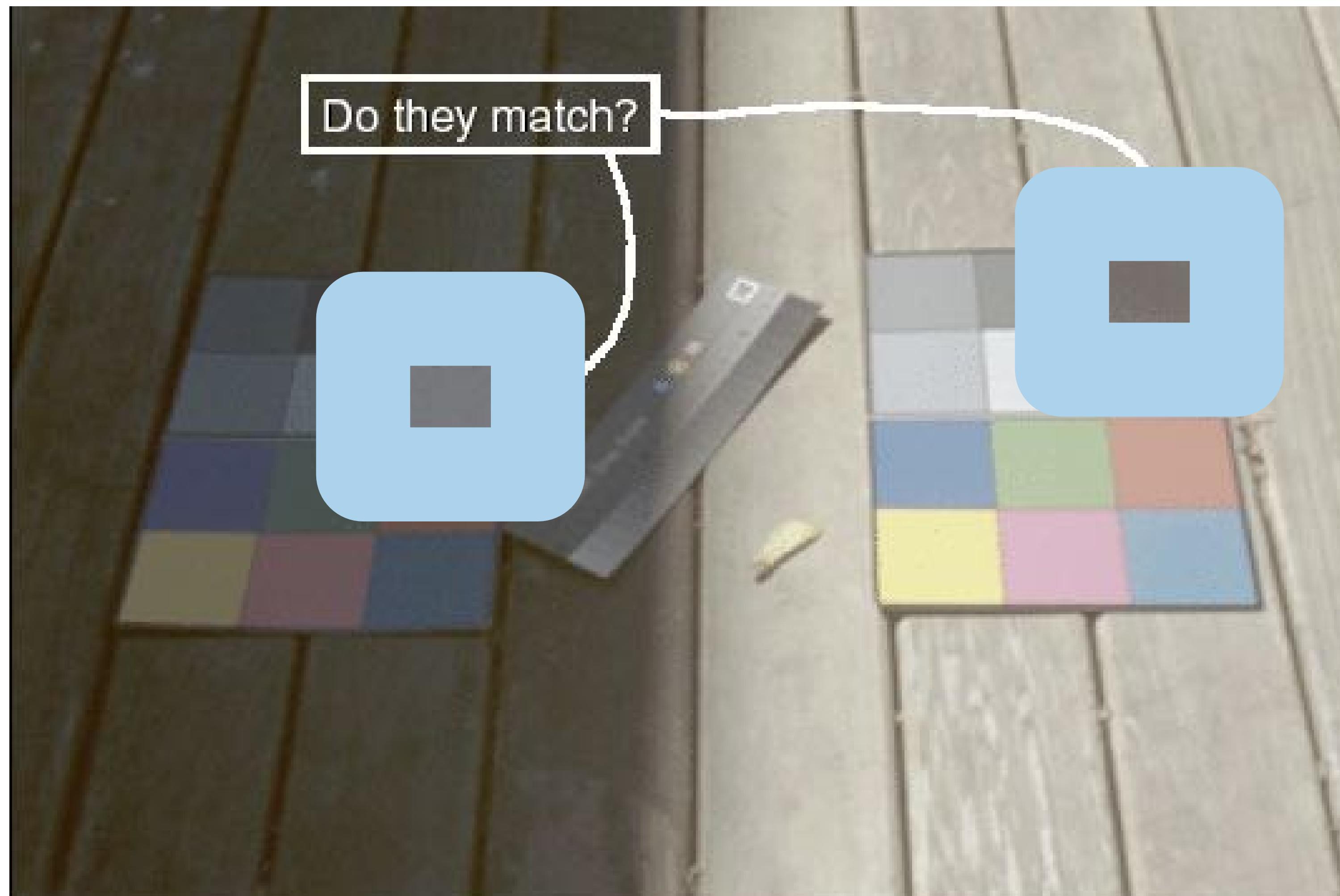
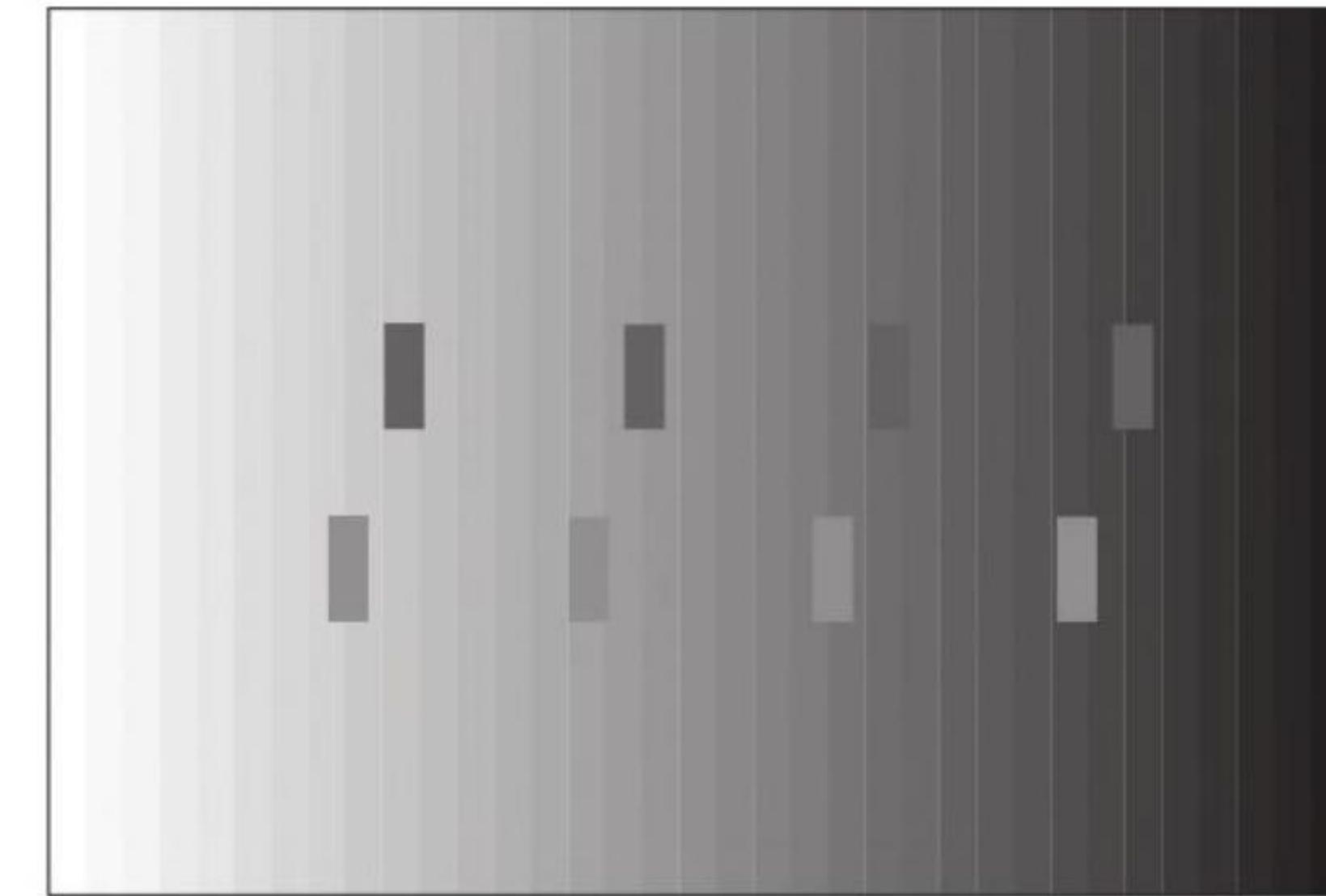
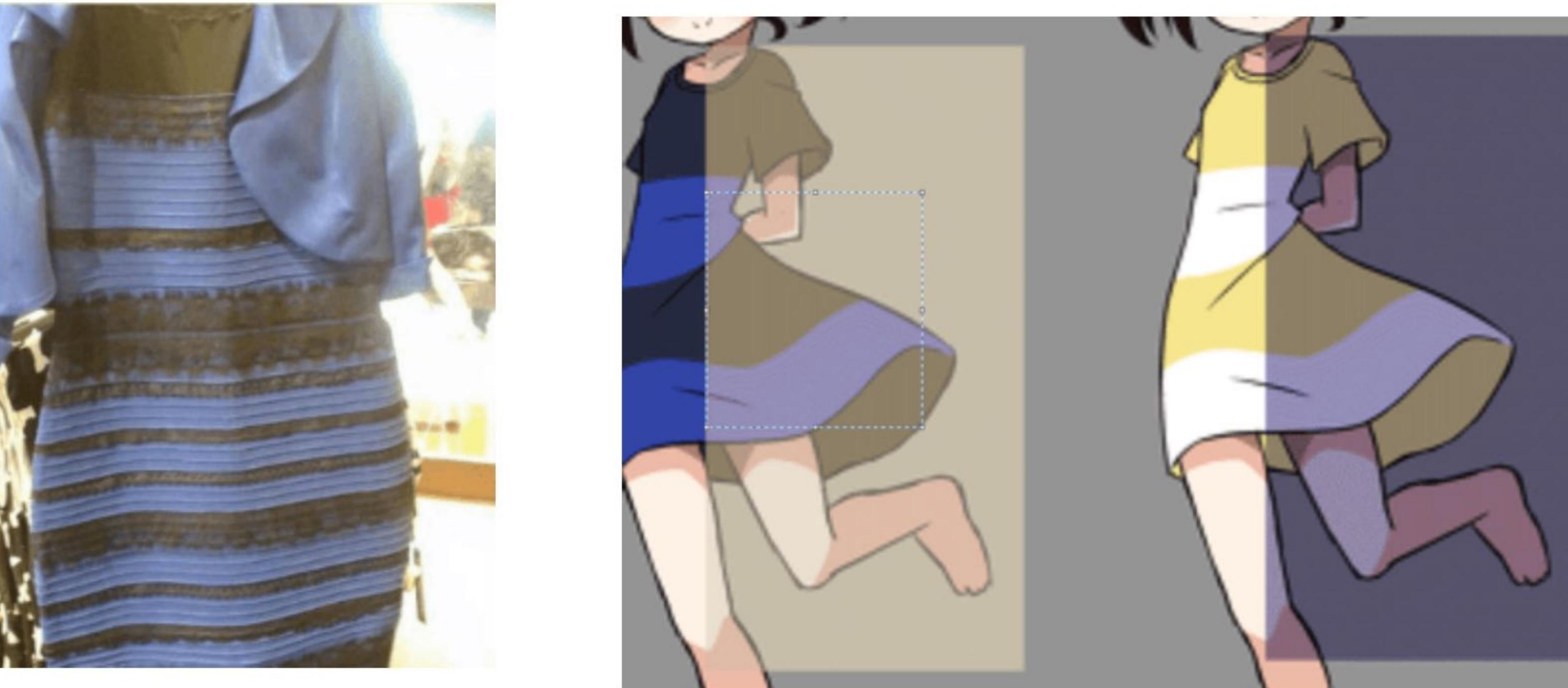


Image courtesy of John McCann via Maureen Stone

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

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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