NYU

CS-GY 6313 B: Information Visualization

9/26/2024

Logistics

- Assignment 1 due next week
- Google Colab okay
  - Export final notebook to a Jupyter file or python script
- Dataset sources coming soon
  - Will be an announcement on Brightspace, after class today.

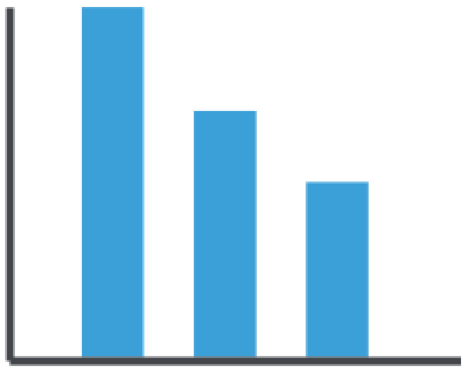
Encoding Data Visually

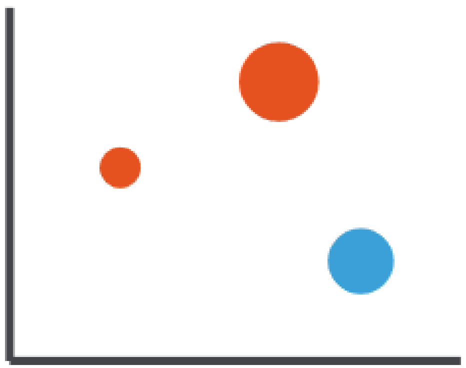
Visual Encoding

- We know how vision works (mostly)
- What is the best way to present information visually?
  - Image-based representations, symbols
- Goals:
  - Efficient extraction of information
  - Minimal ambiguity

Visual Encoding

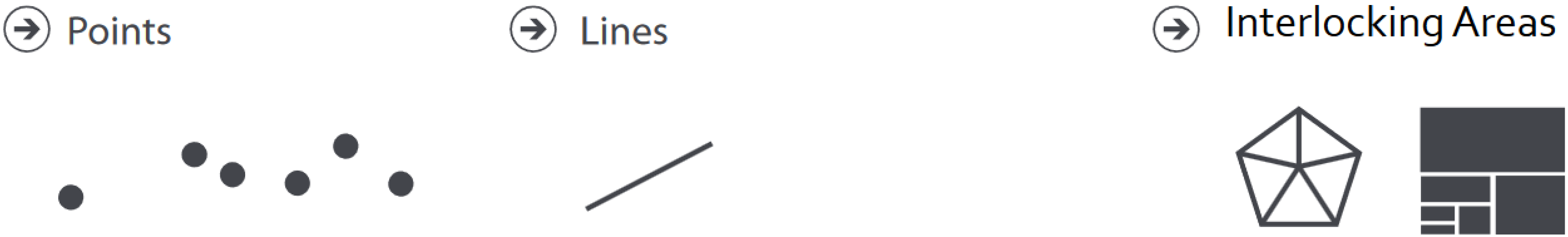
- How do we systematically analyze these charts?
- Marks and channels
  - Marks: represent entities or links between entities
  - Channels: change the appears of marks based on attribute values



Marks for items

- Marks are basic geometric elements

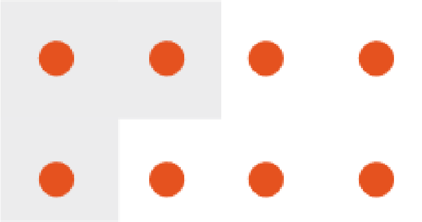


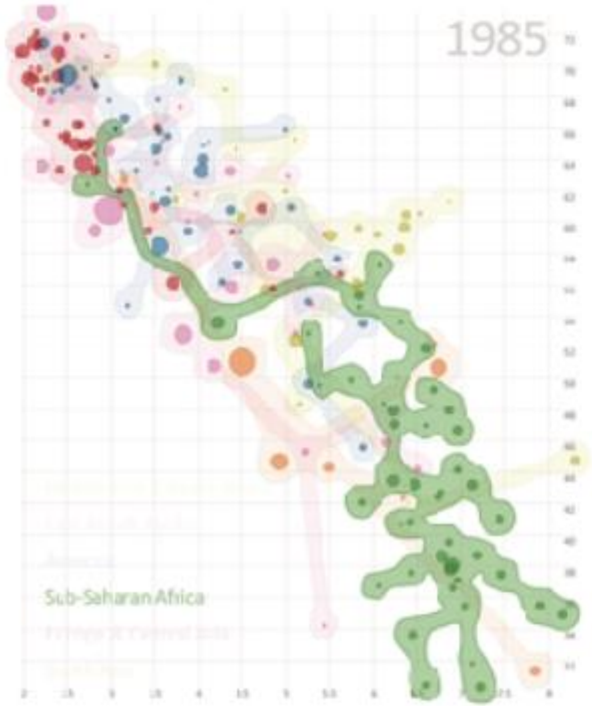
0D 1D 2D

- 3D marks are rare

Marks for links

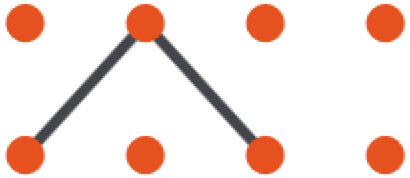
- Containment





https://vialab.ca/research/bubble-sets

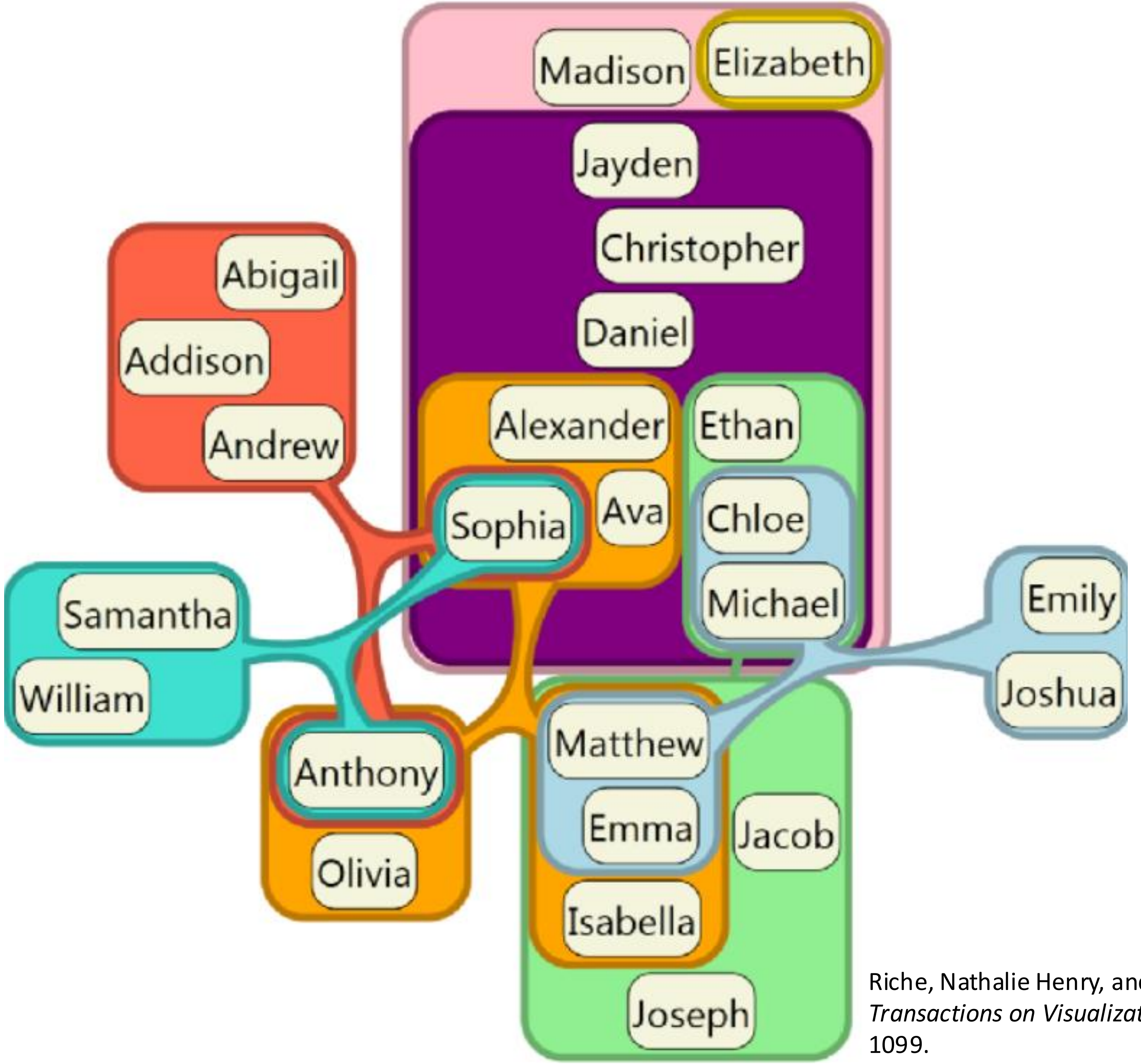
- Connection



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

Containments can be nested

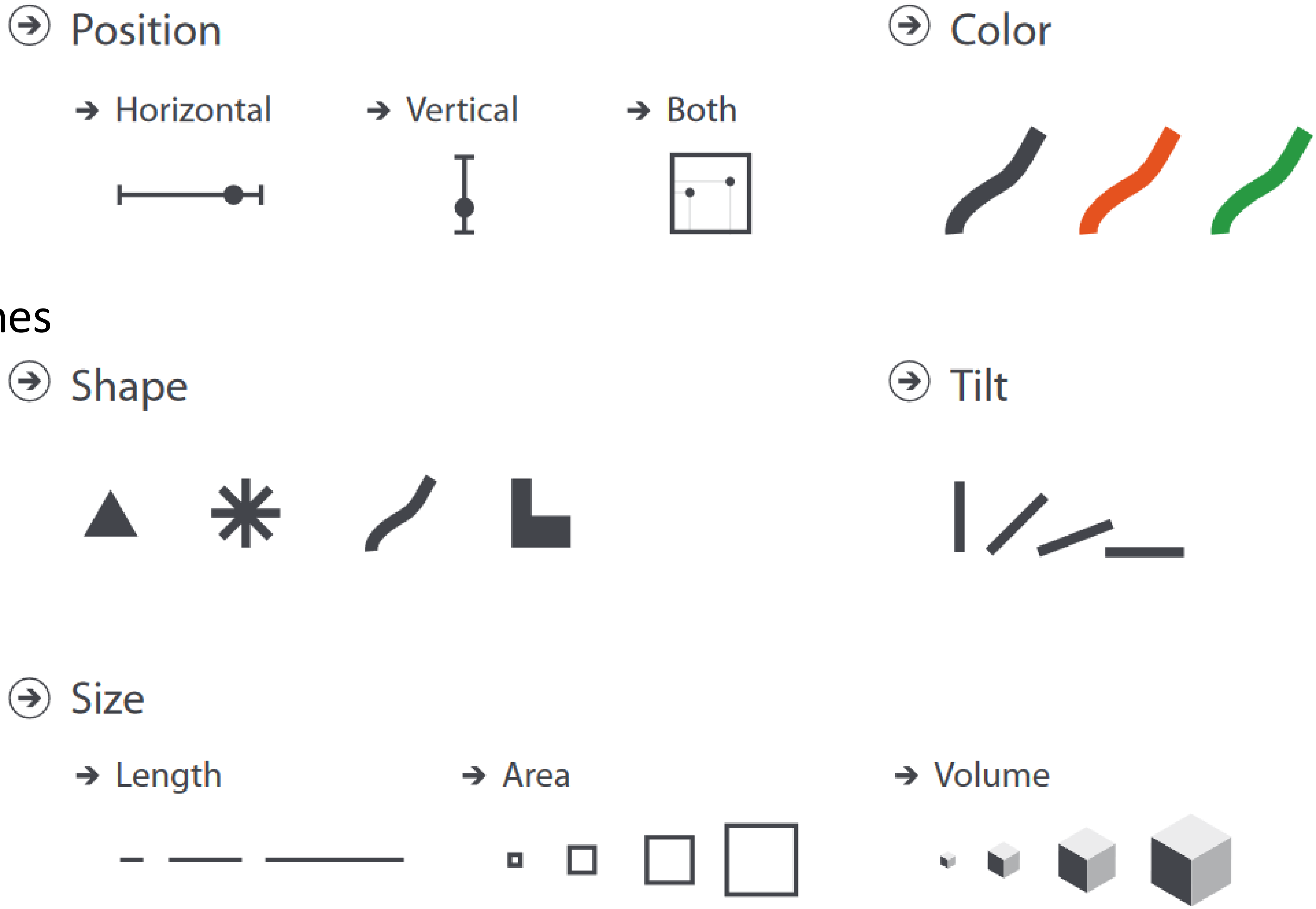
- Hierarchical!



Riche, Nathalie Henry, and Tim Dwyer. "Untangling euler diagrams." *IEEE Transactions on Visualization and Computer Graphics* 16.6 (2010): 1090-1099.

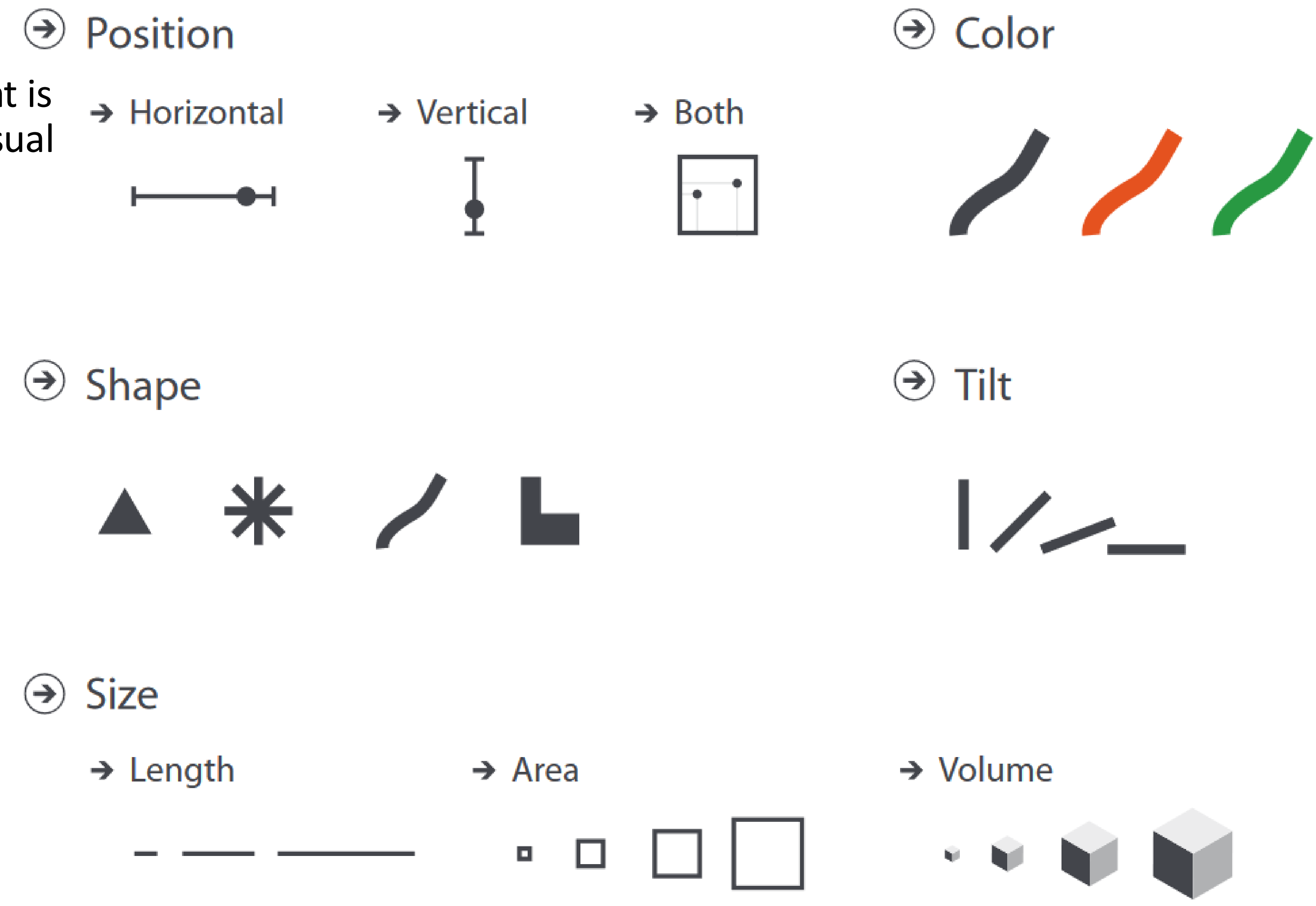
Channels

- Control the appearance of marks
  - Proportional to or based on attributes
- Goes by many different names
  - Visual channels
  - Visual variable
  - Retinal channel
  - Visual dimension
  - …



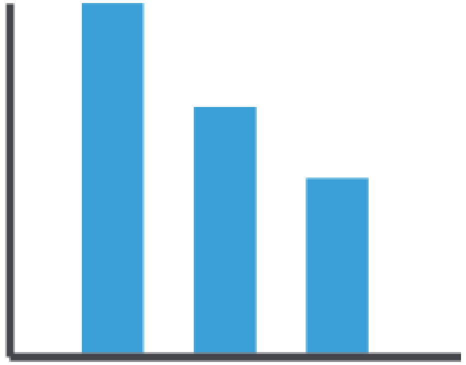
Channels

- Channel properties differ
  - Type and amount of info that is conveyed to the human's visual system
  - Not all channels are equal



Visual Encoding

- Analyze charts as a **combination of marks and channels**



1 channel:

Vertical position

Mark: line

2 channels:

Vertical position

Horizontal position

Mark: point

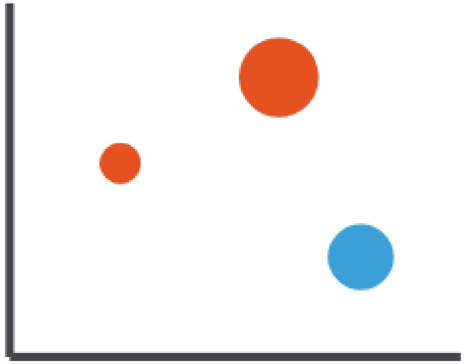
3 channels:

Vertical position

Horizontal position

Color hue

Mark: point



4 channels:

Vertical position

Horizontal position

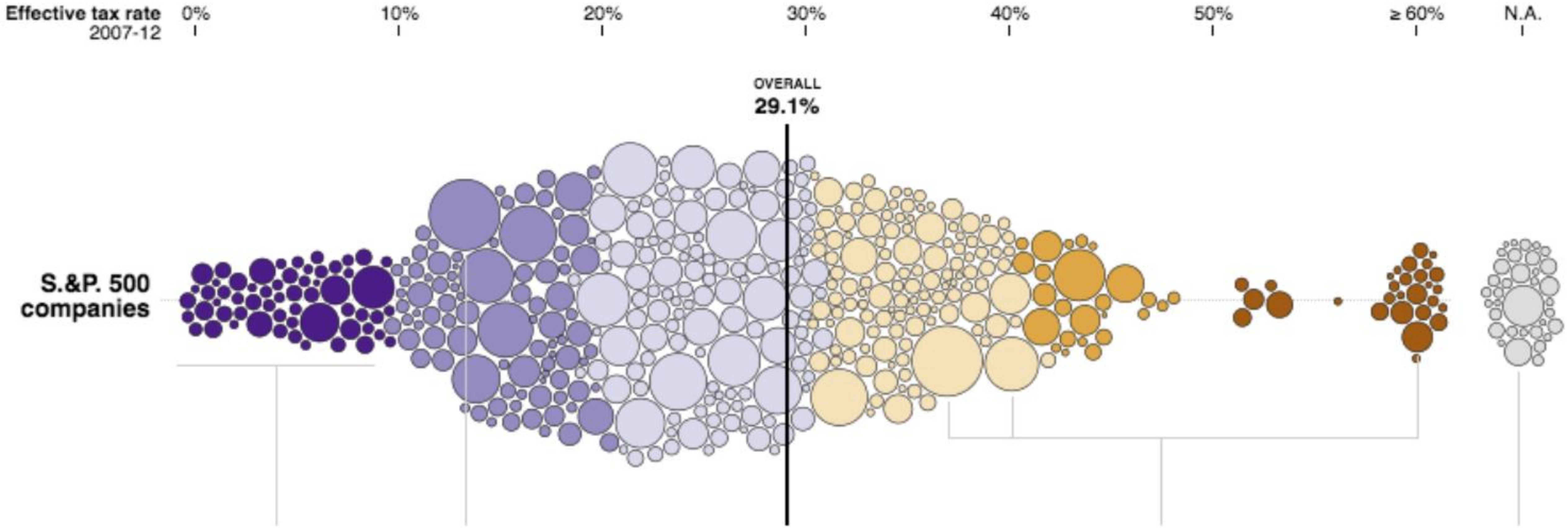
Color hue

Size (area)

Mark: point

Exercise: Name the marks and channels

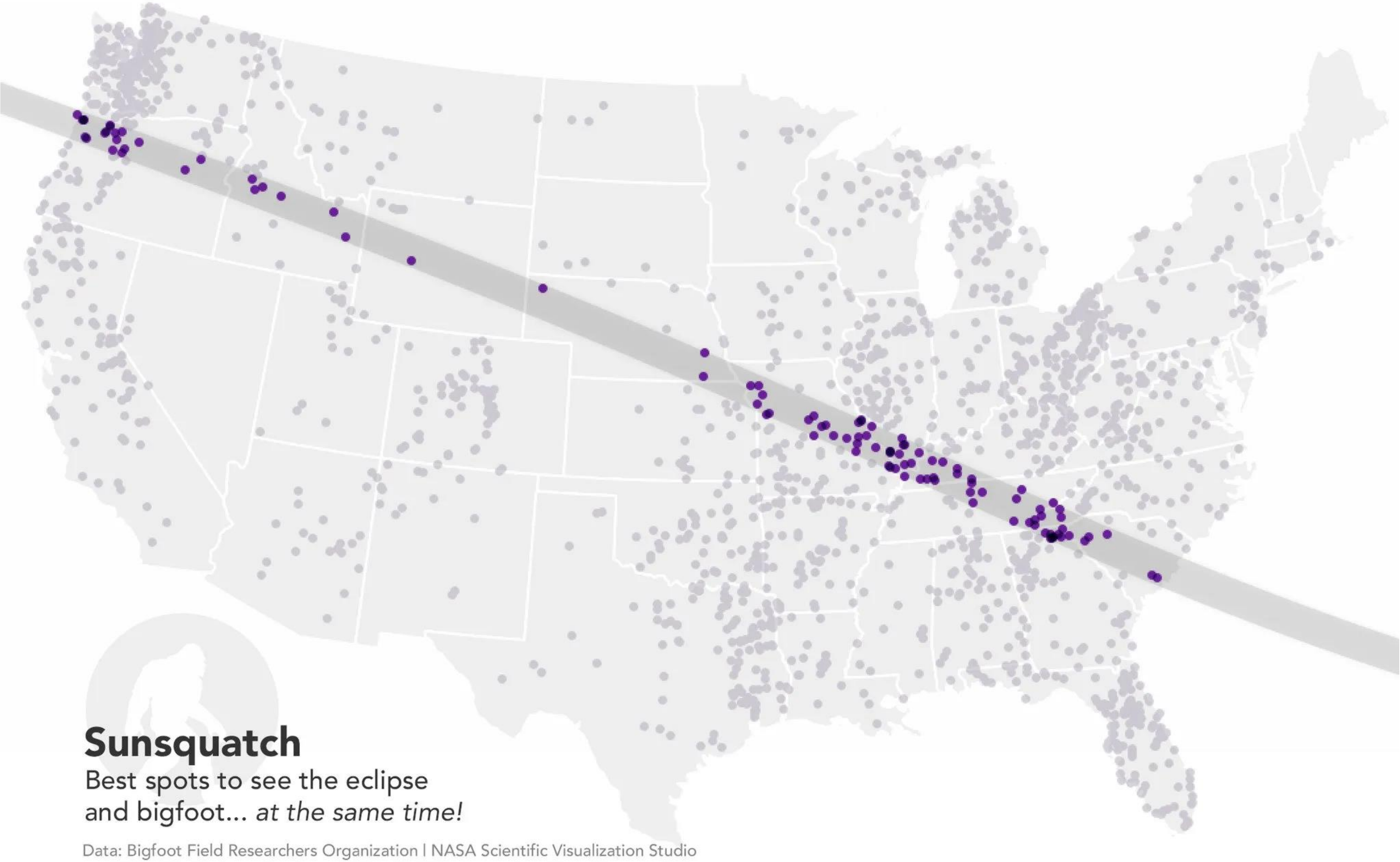
- Tax rates



https://archive.nytimes.com/www.nytimes.com/interactive/2013/05/25/sunday-review/corporate-taxes.html

Exercise: Name the marks and channels

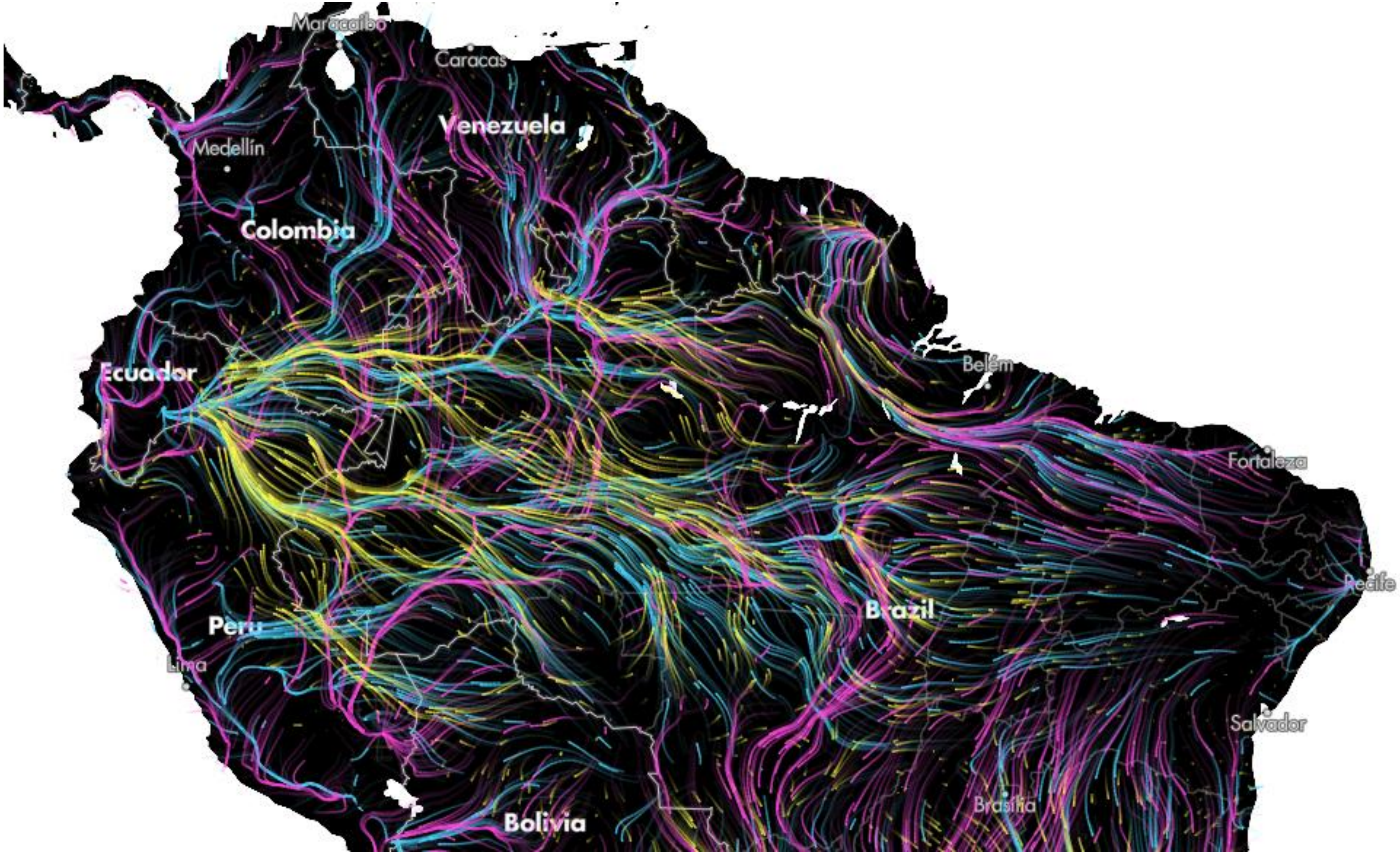
- Sunsquatch



https://flowingdata.com/2017/08/20/sunsquatch-the-only-eclipse-map-you-need/

Exercise: Name the marks and channels

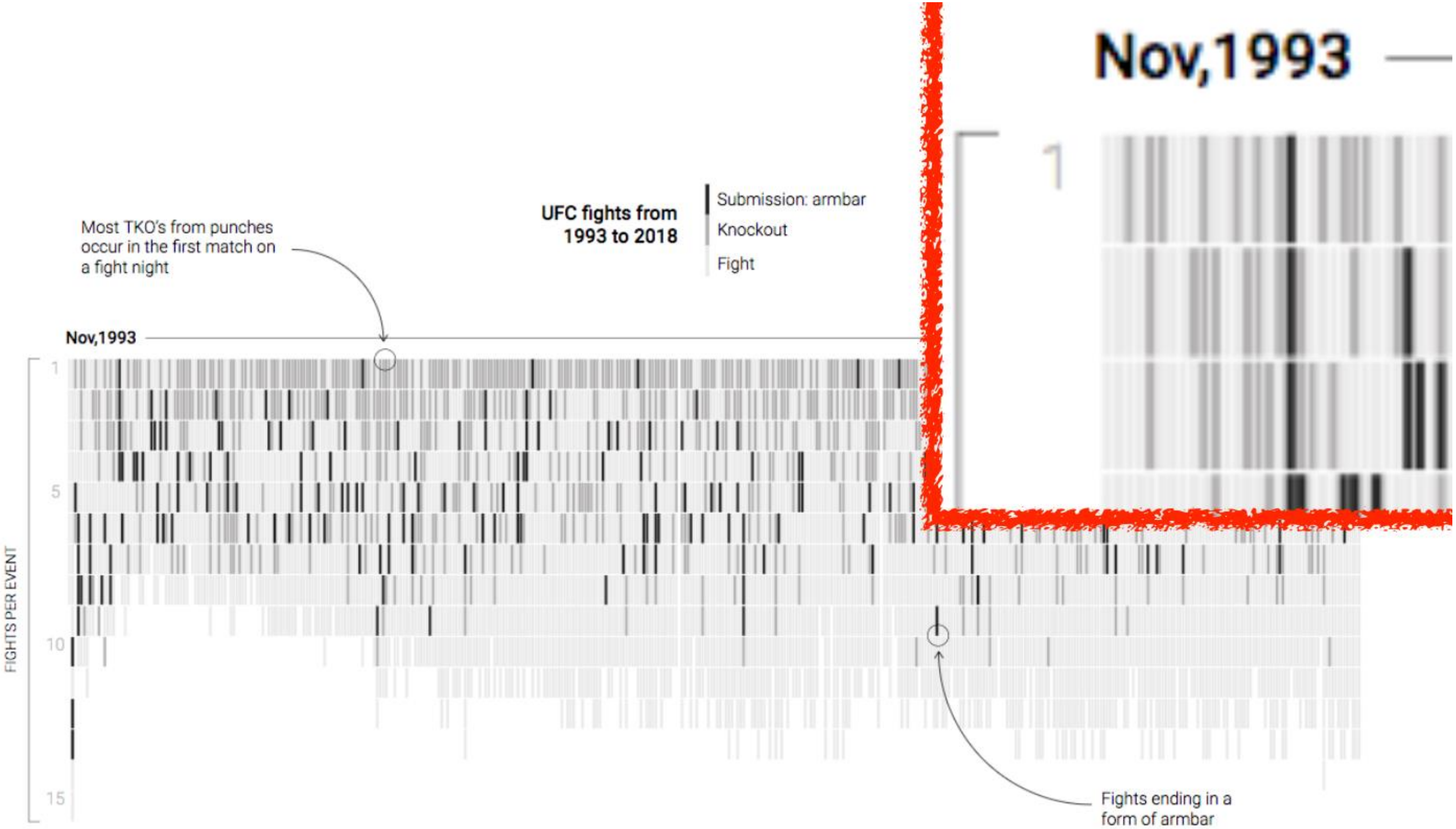
- Migration



https://www.maps.tnc.org/migrations-in-motion/#5/-7.1/-67.94

Exercise: Name the marks and channels

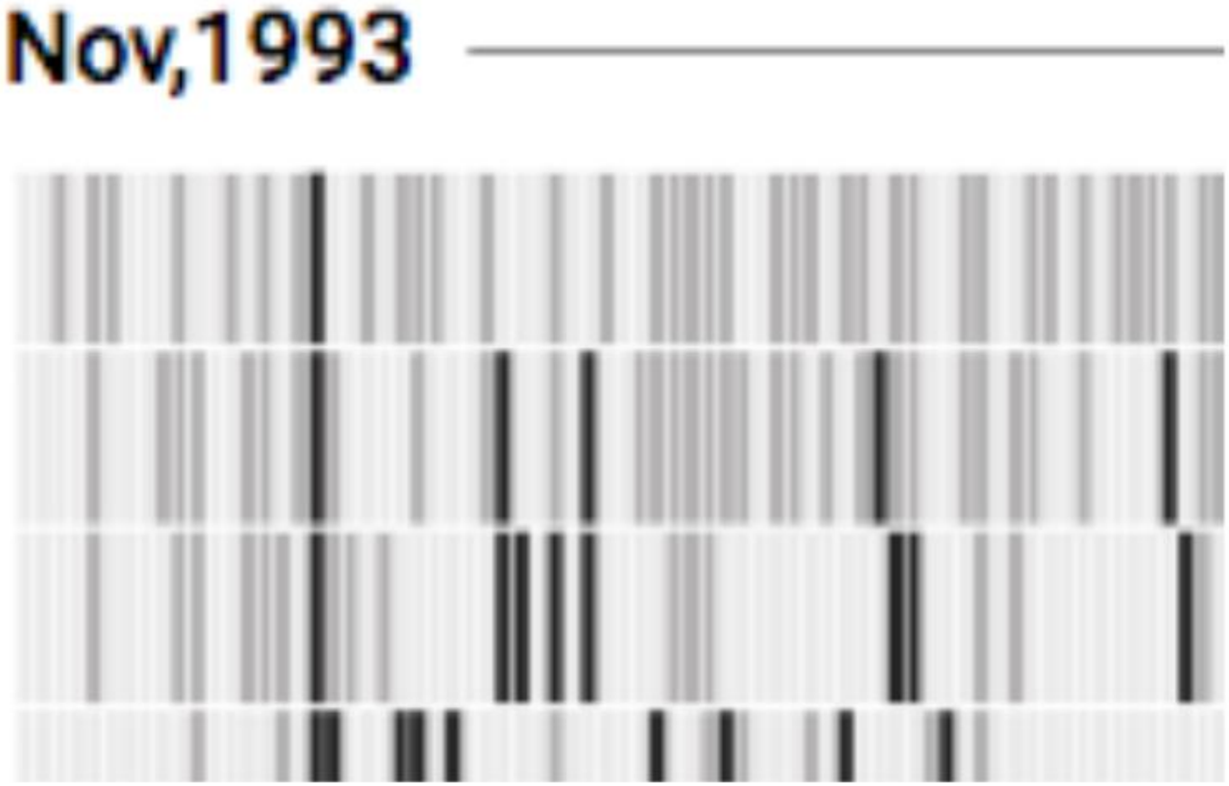
- UFC fights



https://multimedia.scmp.com/infographics/sport/article/3010883/bruce-lee-and-mixed-martial-arts/ (updated, this graphic no longer exists)

Exercise: Name the marks and channels

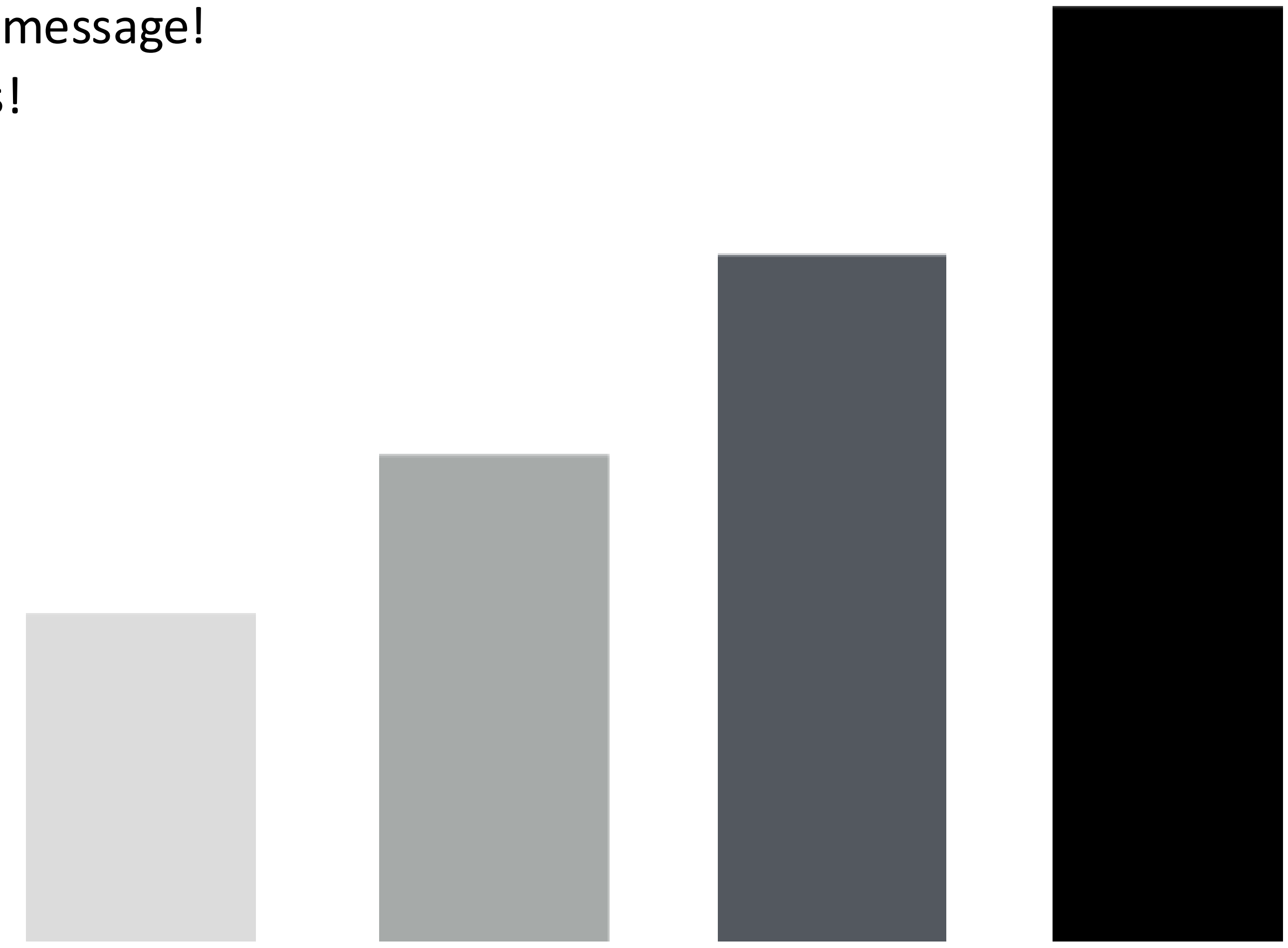
- UFC fights
  - Line?
    - No, not length encoded
  - Area?
    - No, area/shape does not convey any meaning
  - Point?
    - Yes! Just has a rectangular shape



https://multimedia.scmp.com/infographics/sport/article/3010883/bruce-lee-and-mixed-martial-arts/ (updated, this graphic no longer exists)

Redundant Encoding

- Multiple channels can encode the same information
  - Sends a stronger message!
  - Uses up channels!



Length and Luminance

Marks as constraints

- Math view: marks are geometric primitives

- Constraints view: Mark type constrains what else can be encoded
  - Points: 0 constraints on size, can encode more attributes with size & shape
  - Lines: 1 constraint on size (length), can encode something else another way (width)
  - Areas: 2 constraints on size (length & width), can’t encode using size or shape

- Quick check: ask “Can I size-encode another attribute?”
  - If shape/size is already in use, the answer is “no”

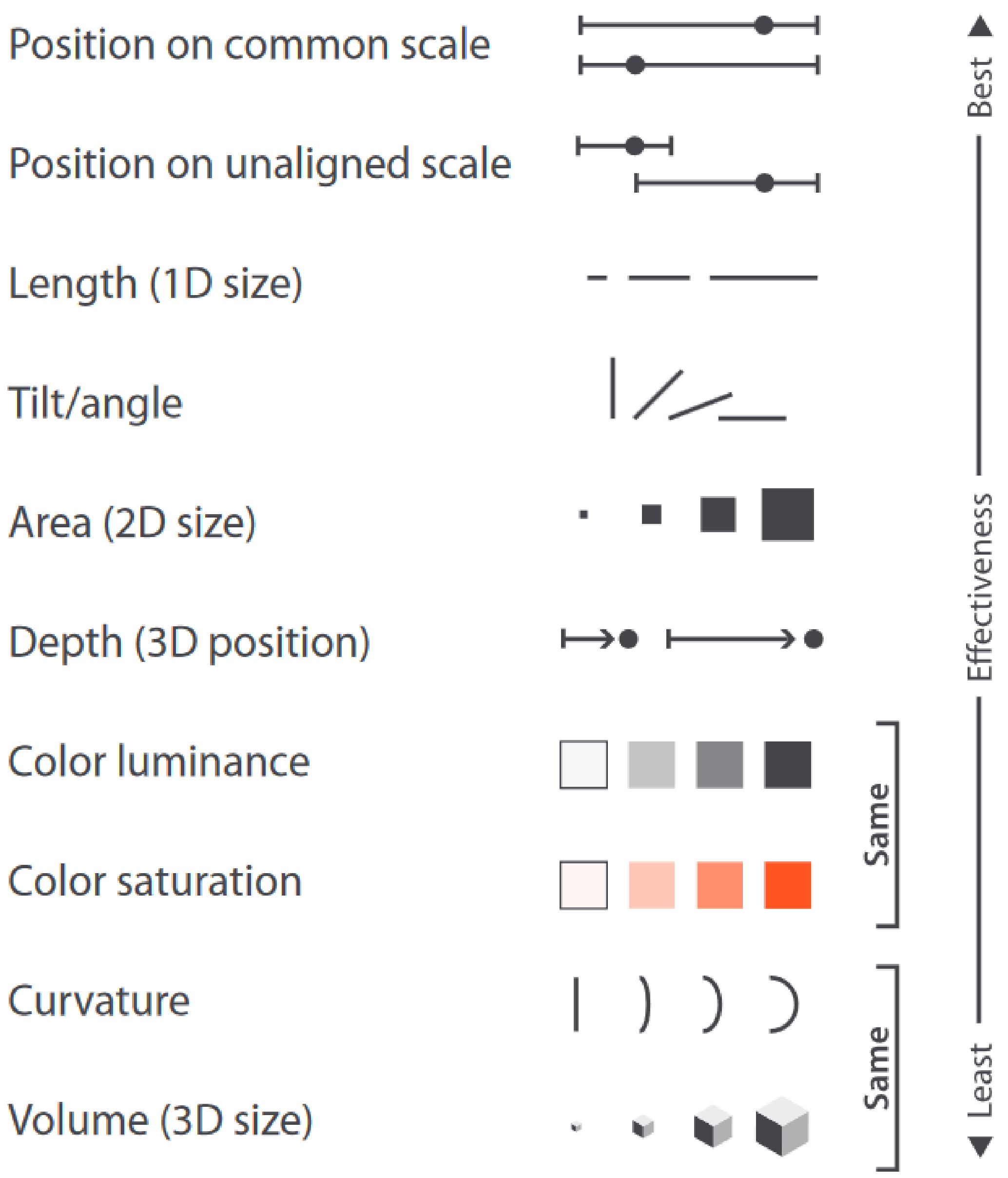
When to use which channel?

- **Expressiveness:** Match channel type to data type

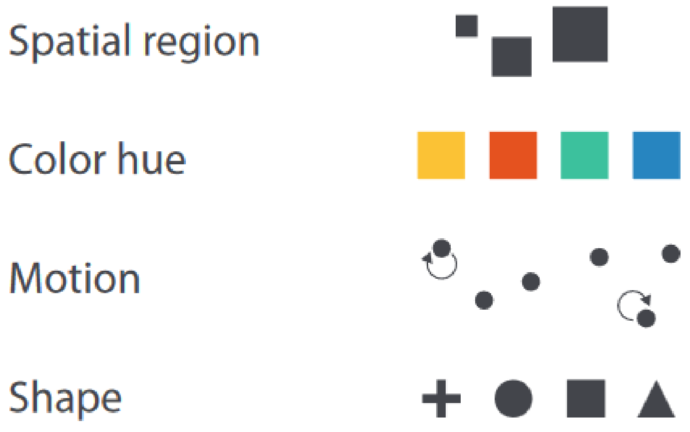
- **Effectiveness:** Some channels are better than others

Channel ranking

- **Magnitude channels:** have an ordering

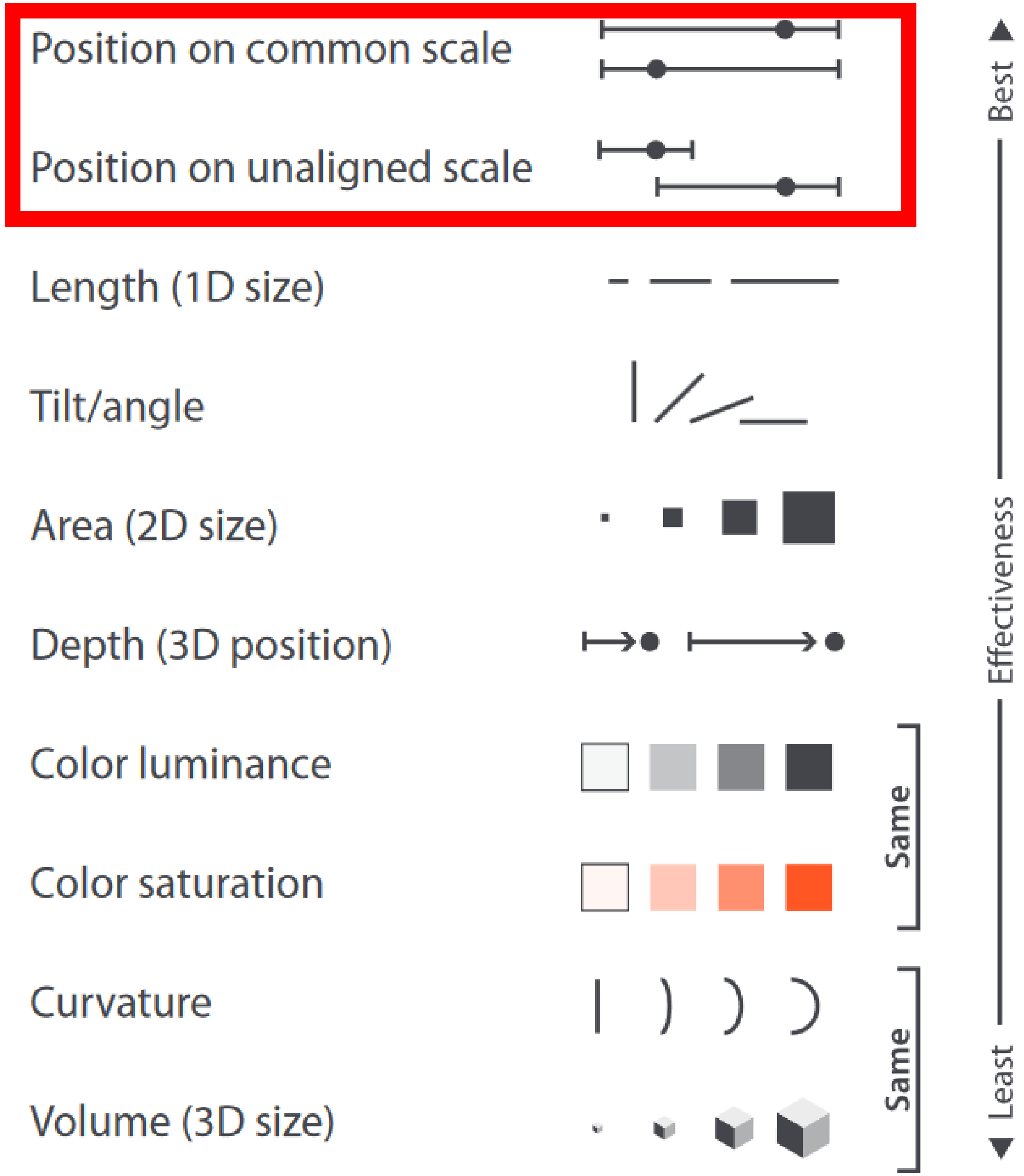


- **Identity channels:** no ordering

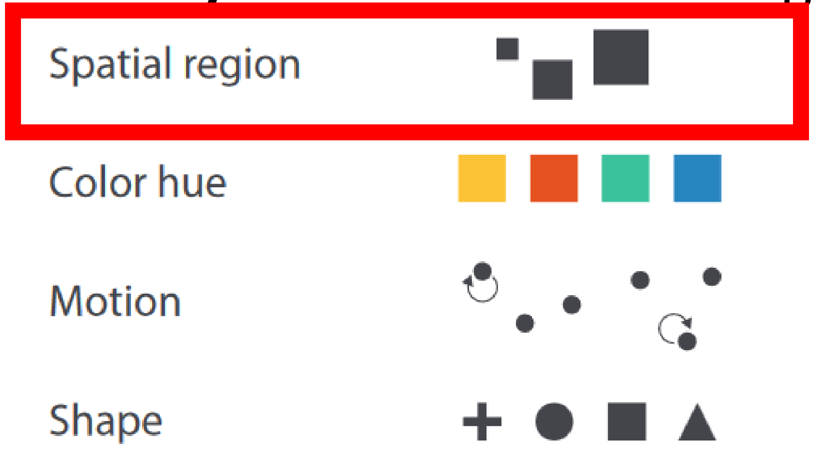


Channel ranking

- **Magnitude channels:** have an ordering

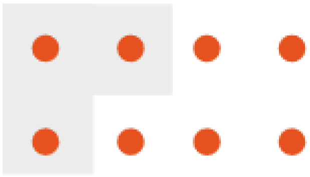


- **Identity channels:** no ordering

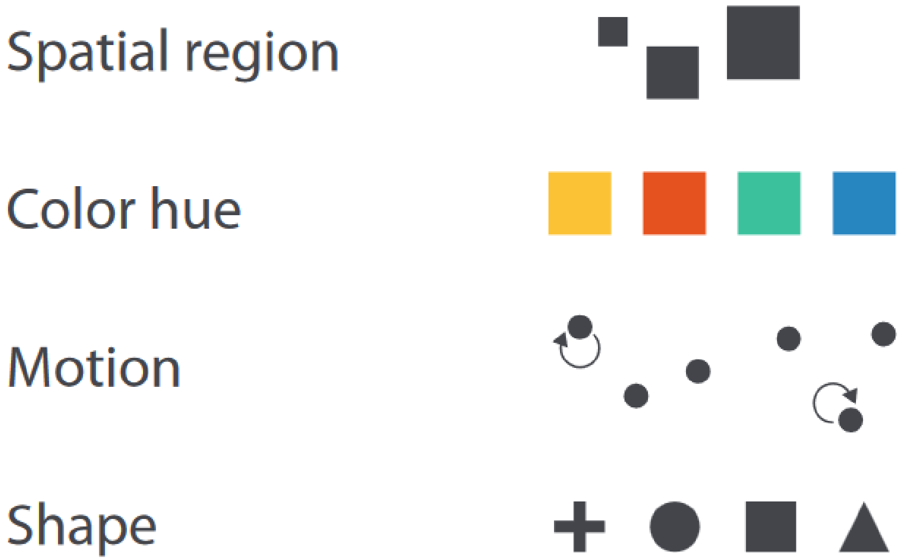


Grouping

- Marks as links:
    - Containment
    - Connection



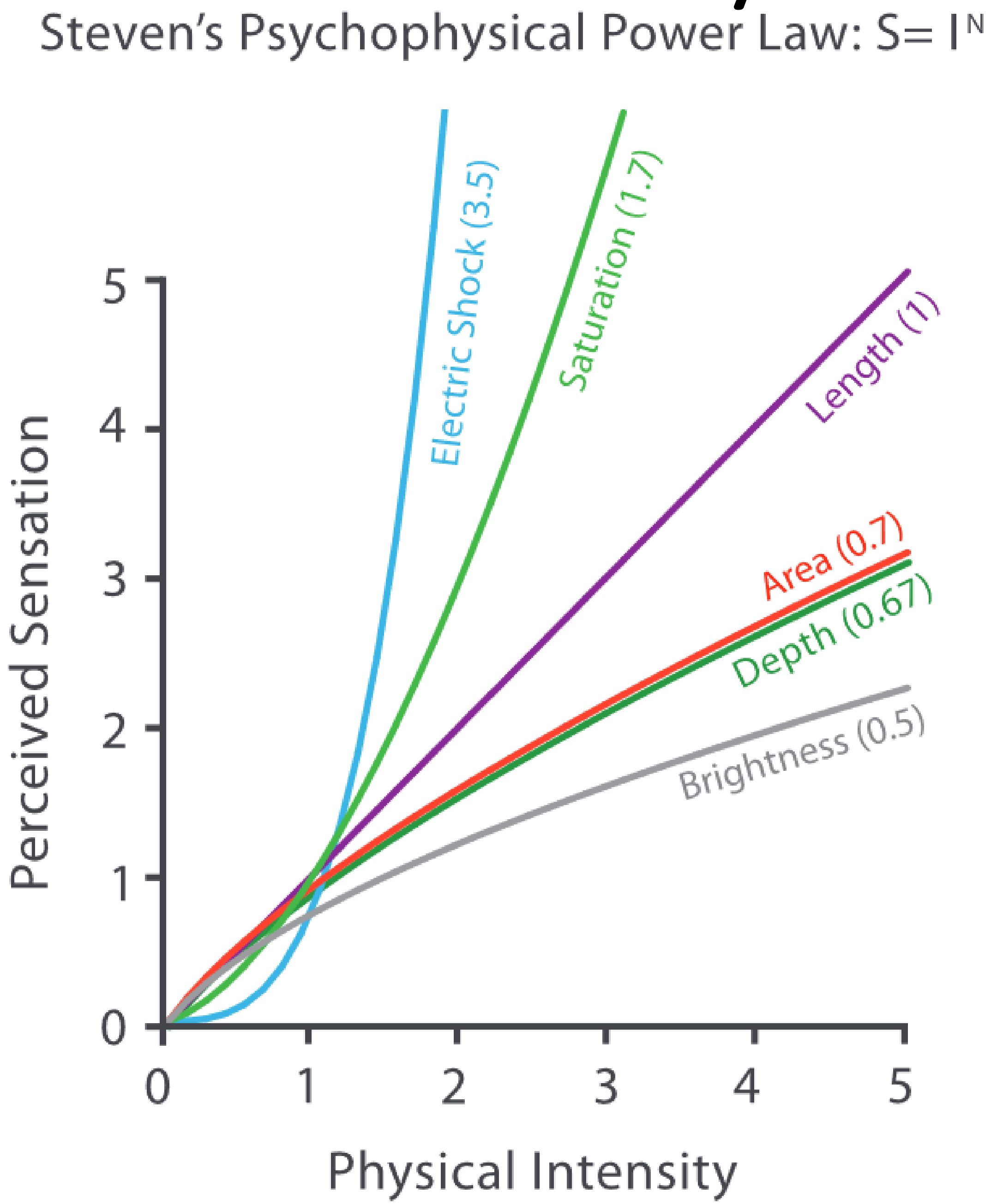
- Identity channels:
    - Proximity
    - Similarity



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?

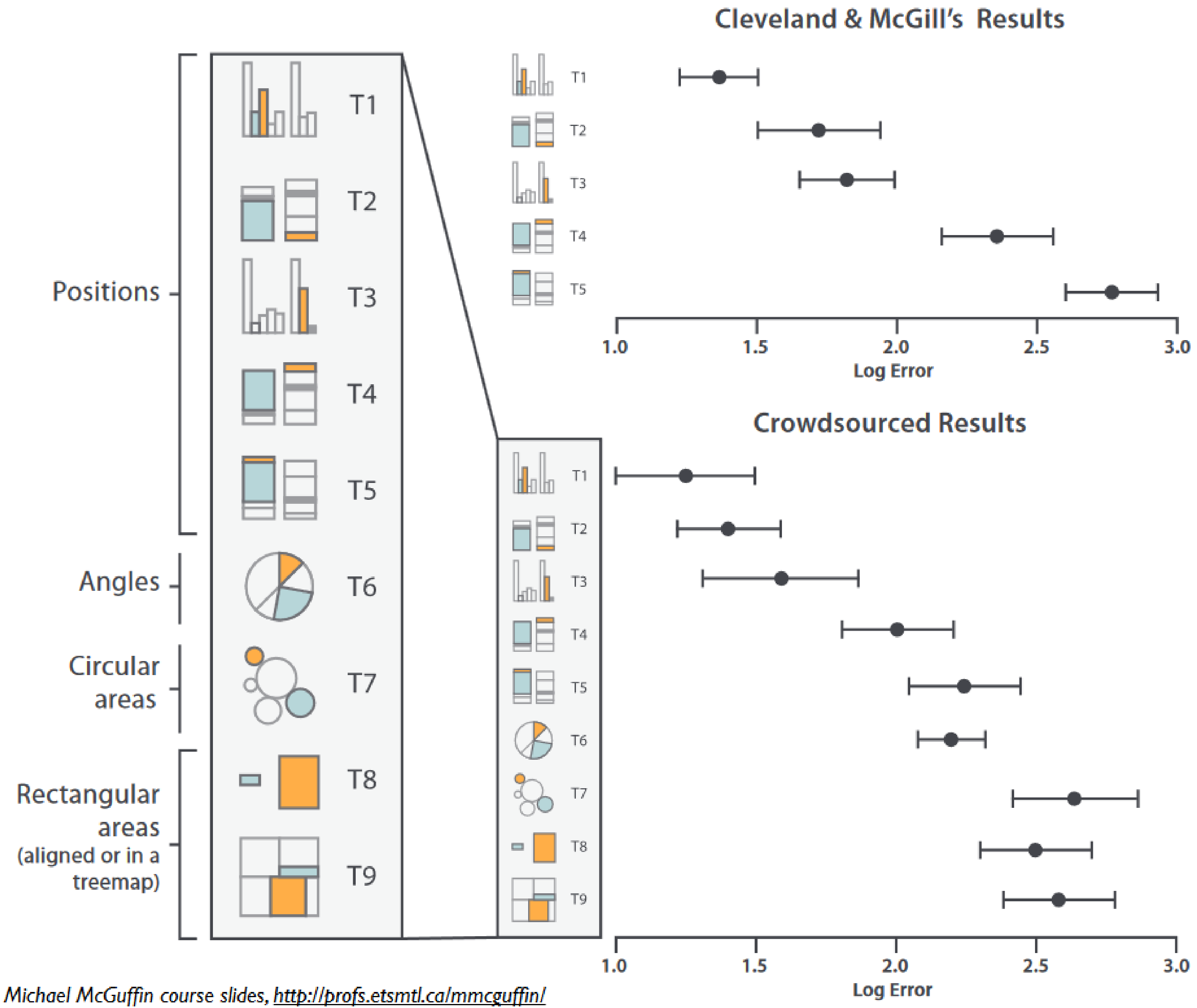
Accuracy: Fundamental Theory



S = sensation

I = intensity

Accuracy: Viz experiments

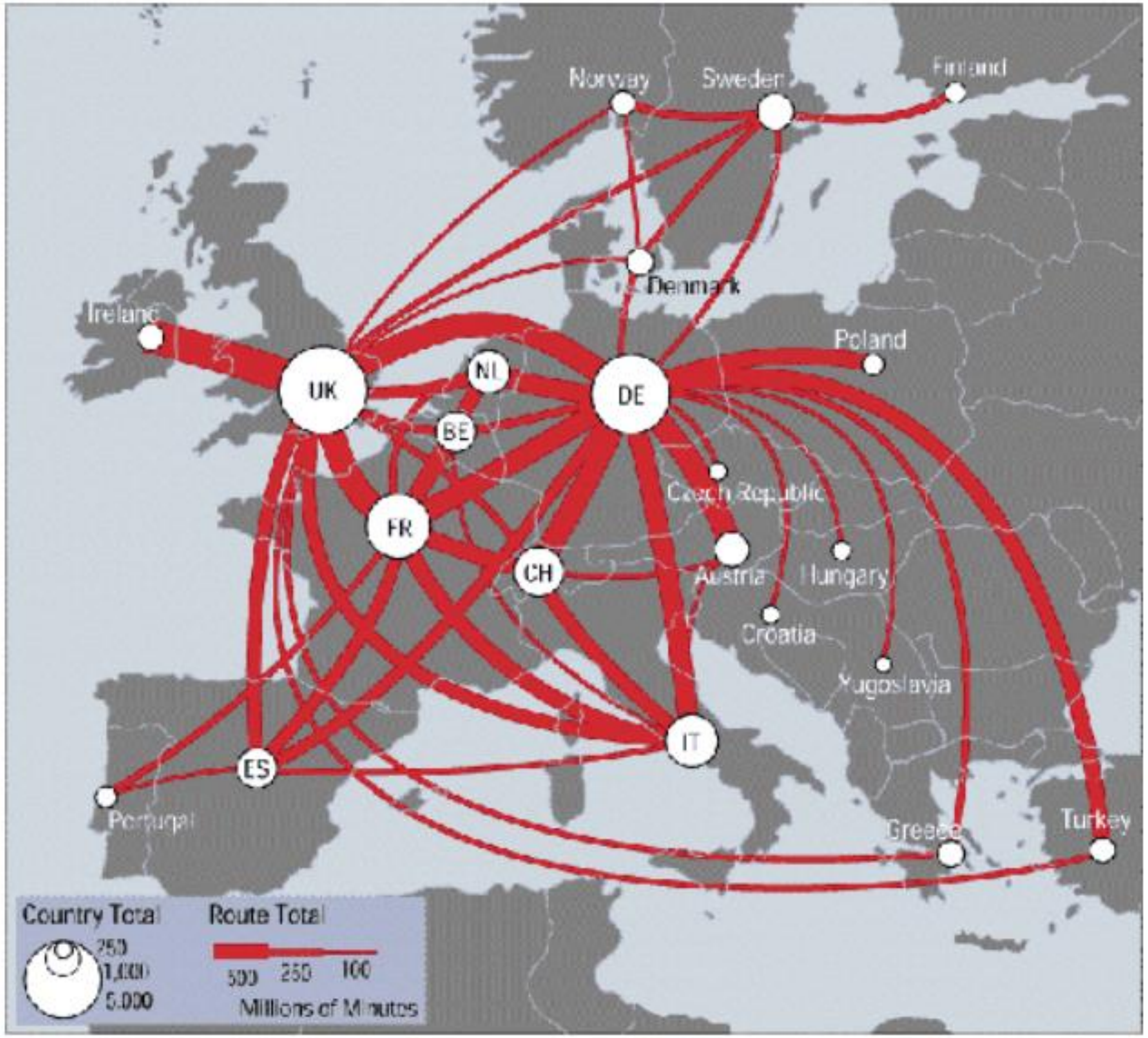


Heer, Jeffrey, and Michael Bostock. "Crowdsourcing graphical perception: using mechanical turk to assess visualization design." *Proceedings of the SIGCHI conference on human factors in computing systems*. 2010.

after Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/

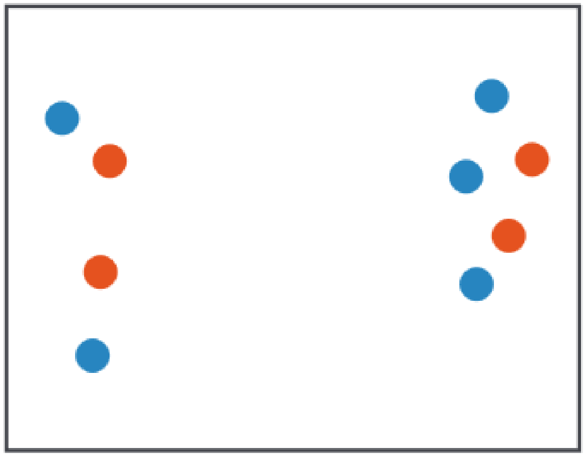
Discriminability: How many usable dimensions?

- Need a sufficient number of attribute levels to show details of the data
  - E.g.: Line width has only a few bins → can't make lines arbitrarily wide



Separability vs Integrality

Position
+ Hue (Color)



Fully separable

2 groups each

2 groups each

3 groups total:
Integral area

4 groups total:
Integral hue

Popout

45929078059772098775972655665110049836645
27107462144654207079014738109743897010971
43907097349266847858715819048630901889074
25747072354745666142018774072849875310665

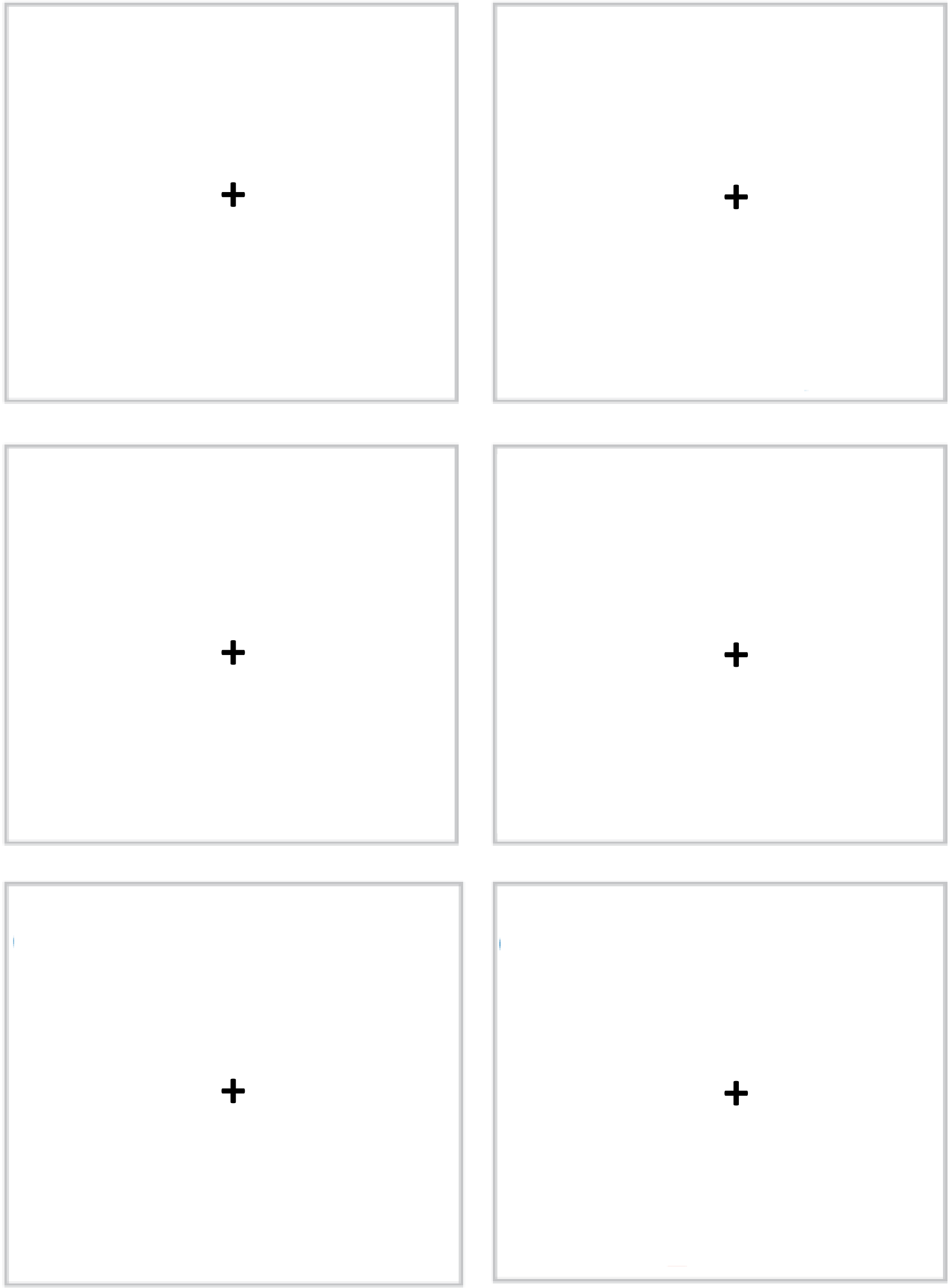
(a)

4592907805977209877597265566511004983**3**6645
271074621446542070790147**3**8109743897010971
4**3**907097**3**49266847858715819048630901889074
2574707**3**54745666142018774072849875**3**10665

(b)

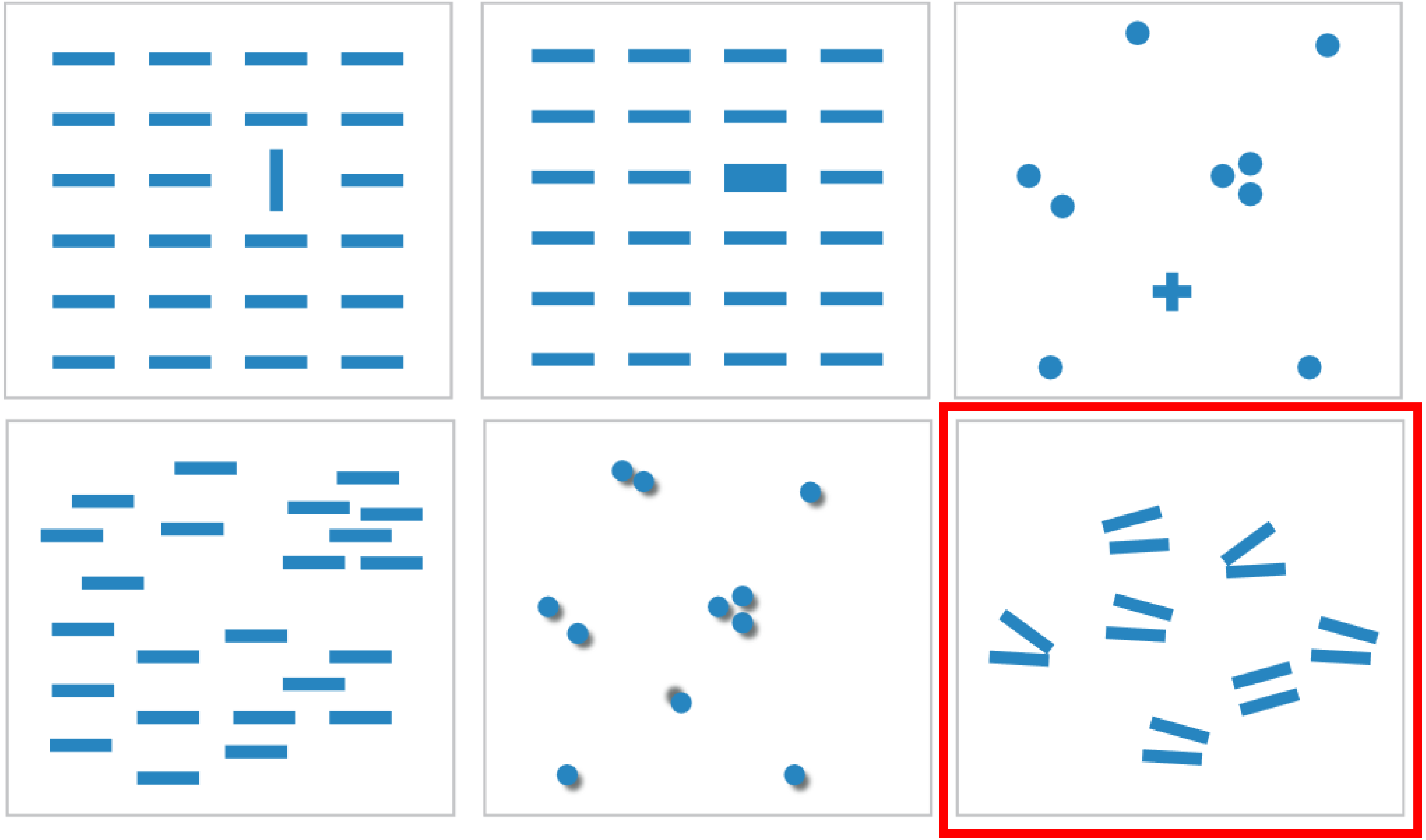
Popout

- Find the red dot
  - How long does it take?
- Parallel processing on individual channels
  - Popout → speed independent of distractor count
  - Speed depends on channel and similarity to distractors
- Serial search for combined channels
  - Speed depends on the number of distractors



Popout

- Works for many different channels



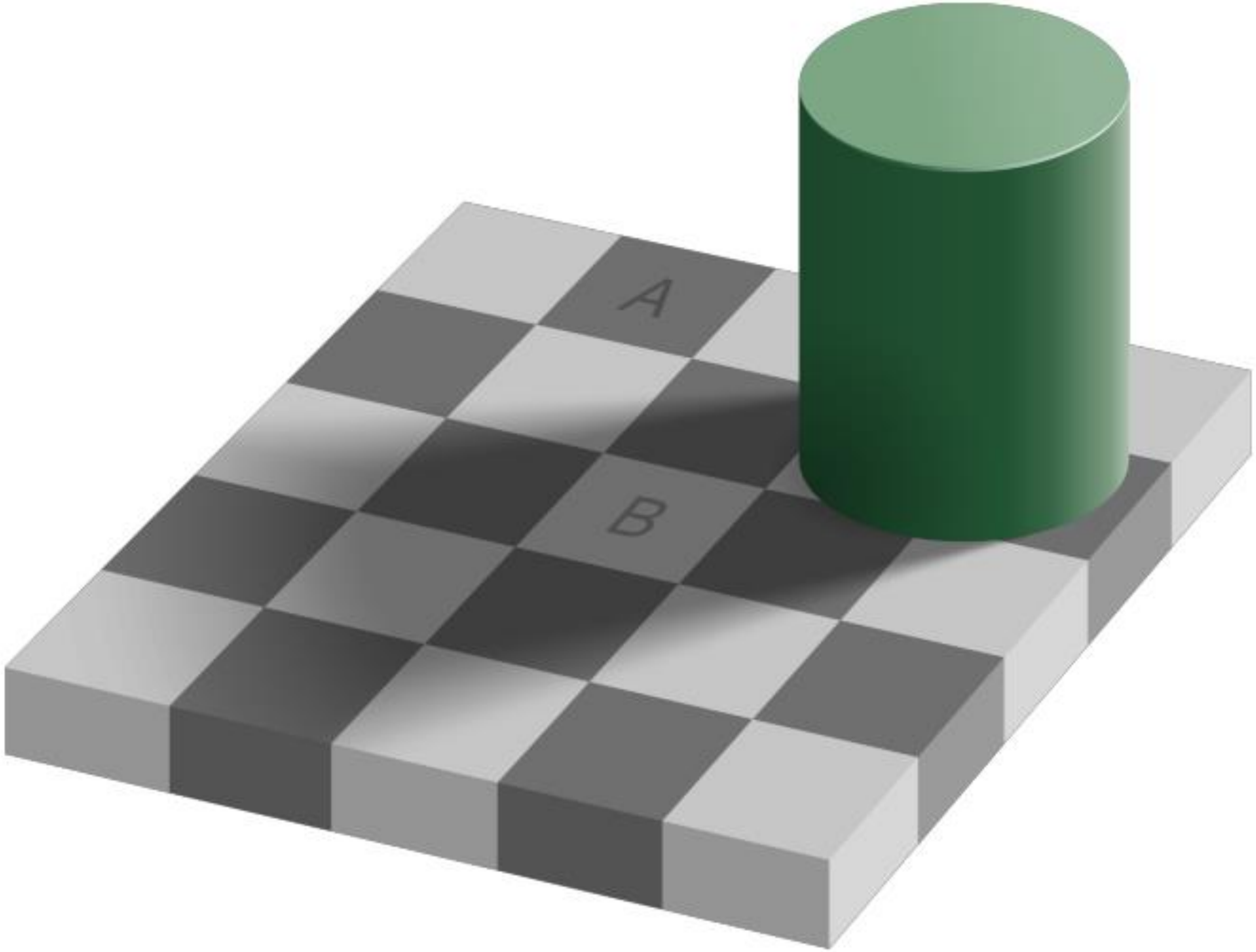
- Parallel lines don’t pop out from tilted lines

Factors affecting accuracy

- Alignment
- Distractors
- Distance

Relative vs absolute judgements

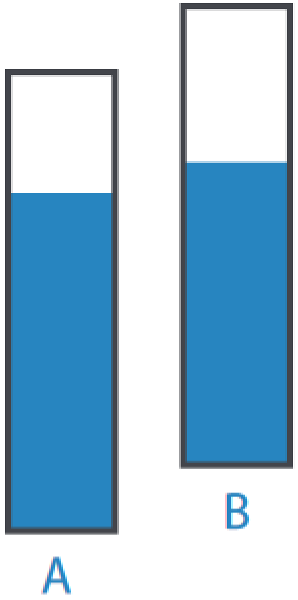
- Visual system mostly operates using relative judgements



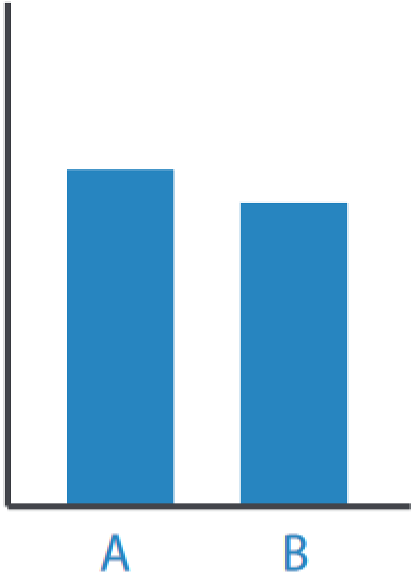
Relative vs absolute judgements

- Visual system mostly operates using relative judgements

Length



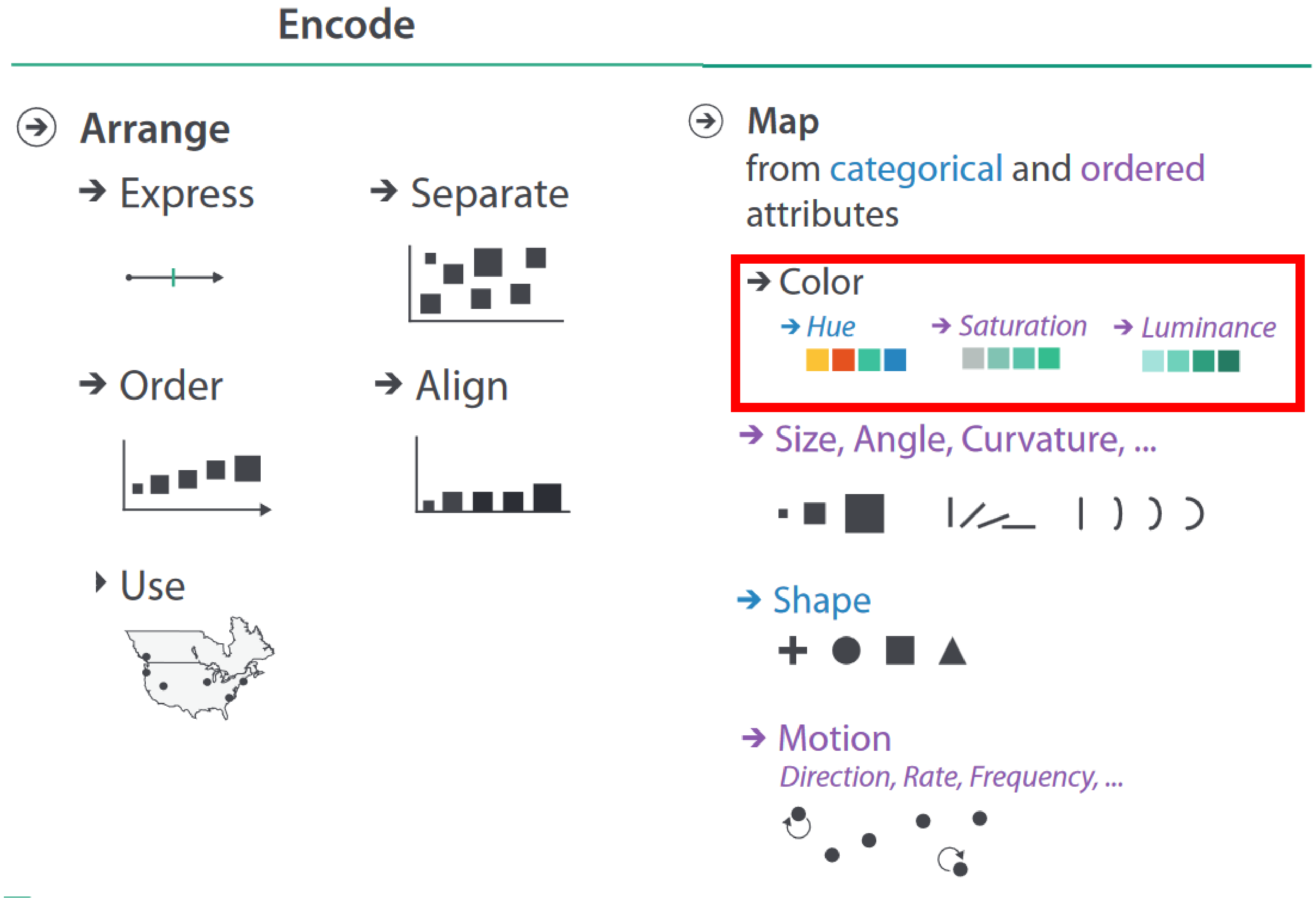
Position along **unaligned** common scale



Position along **aligned** common scale

Color

- Focus so far has been on spatial arrangement

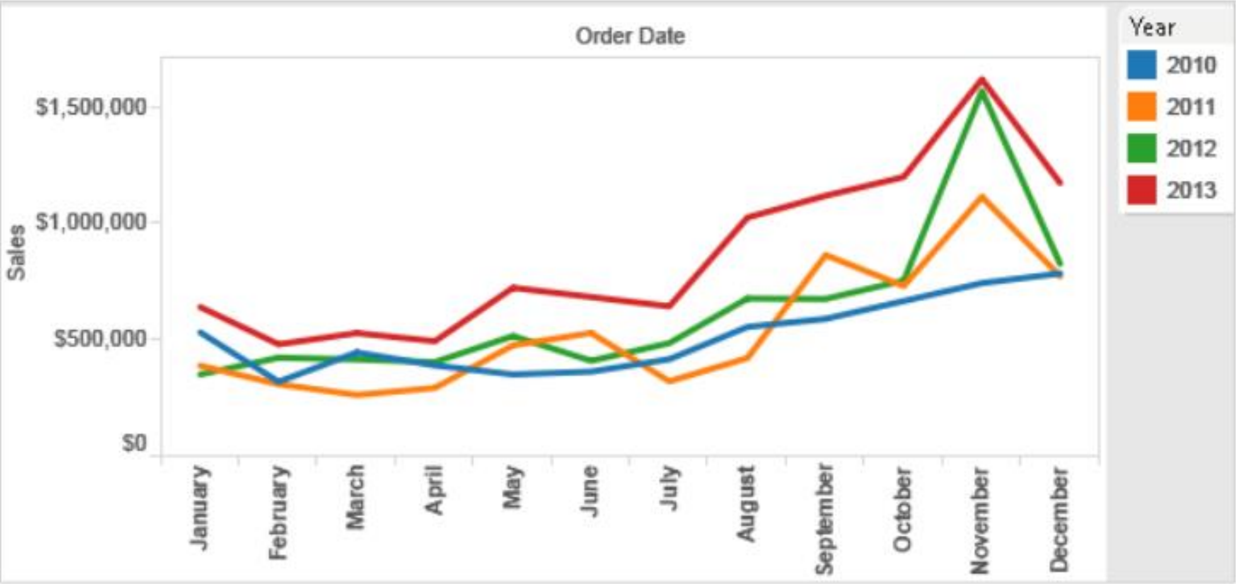


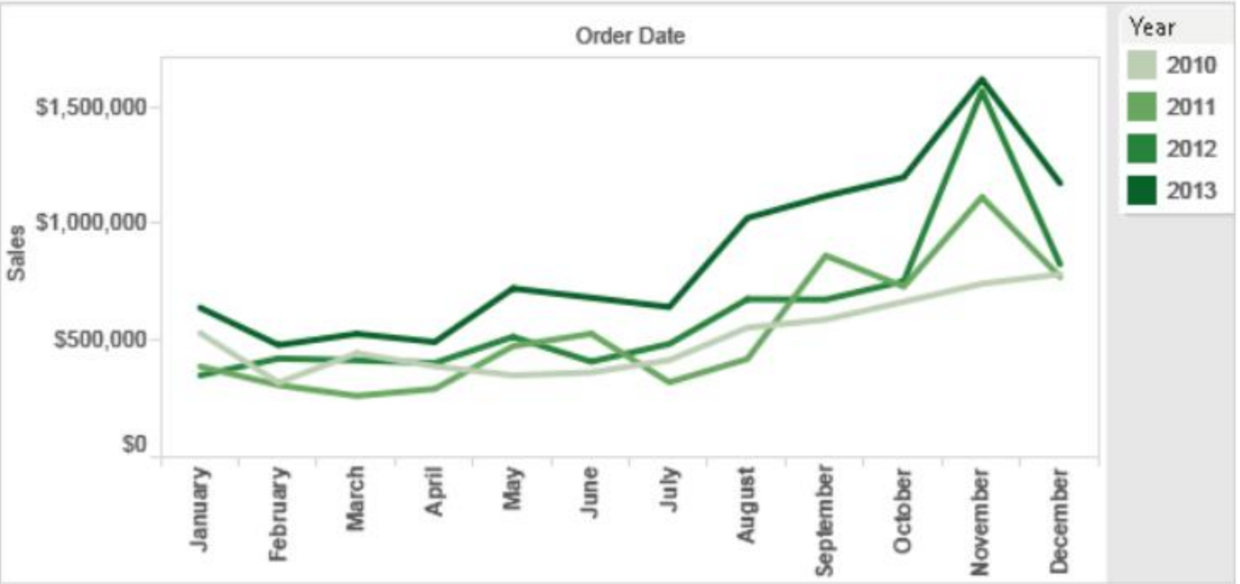
Decomposing color

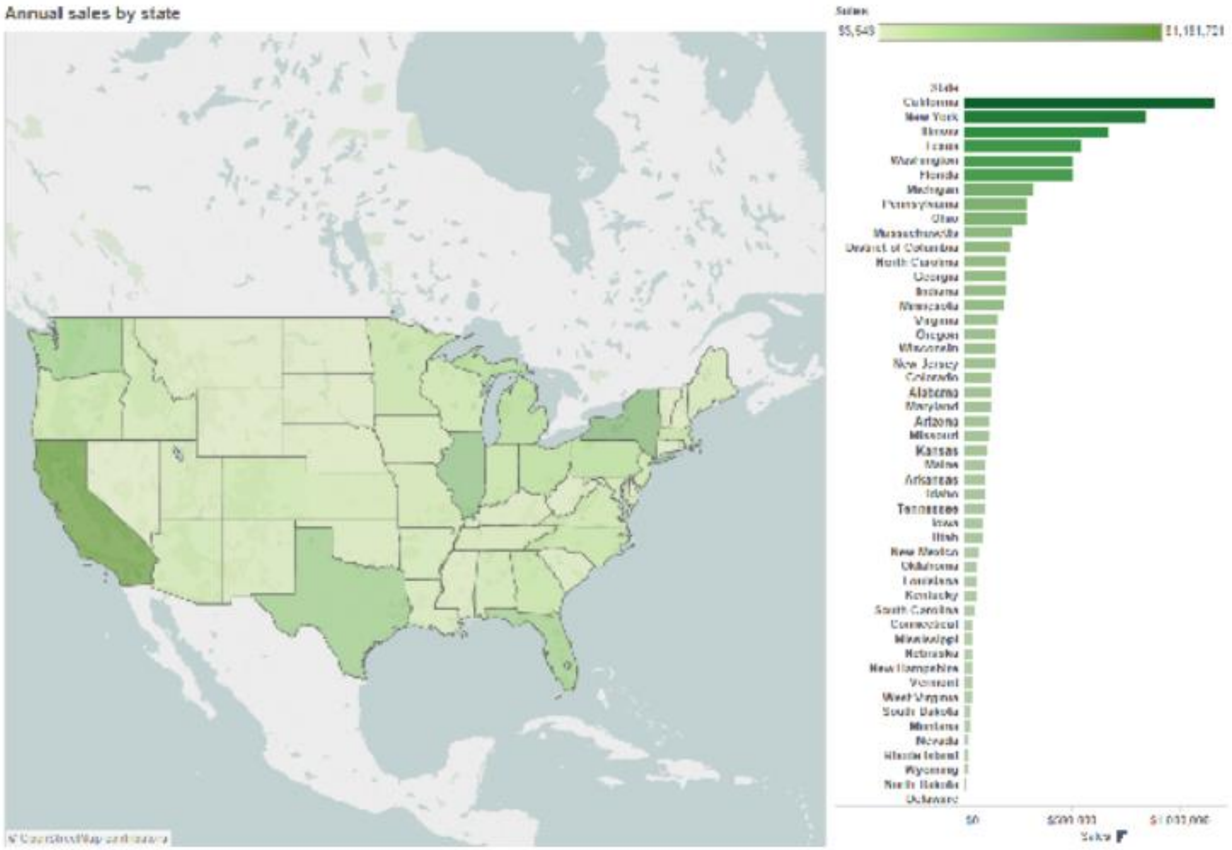
- Do not just talk about color!
  - It's confusing if treated as monolithic
- Recall the three channels of color:
  - Ordered (can show magnitude)
    - **Luminance:** how bright (black/white)
    - **Saturation:** how colorful
  - Categorical (can show identity)
    - **Hue:** what color

- Color channels have different properties
  - What they convey directly to the visual system
  - How much they can convey
    - How many discriminable bins can we use

Categorical vs ordered color



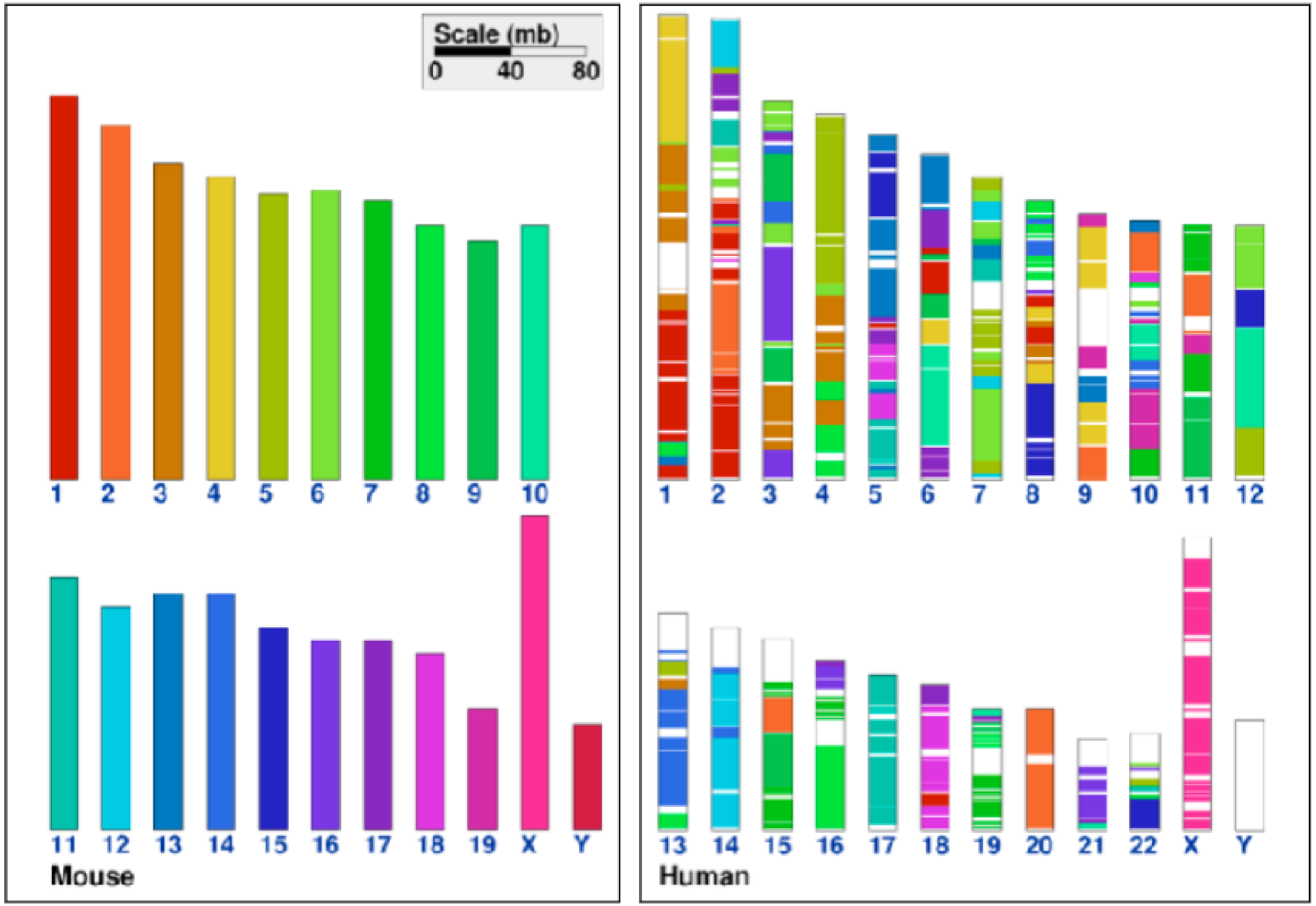




Categorical color: limited # of discriminable bins

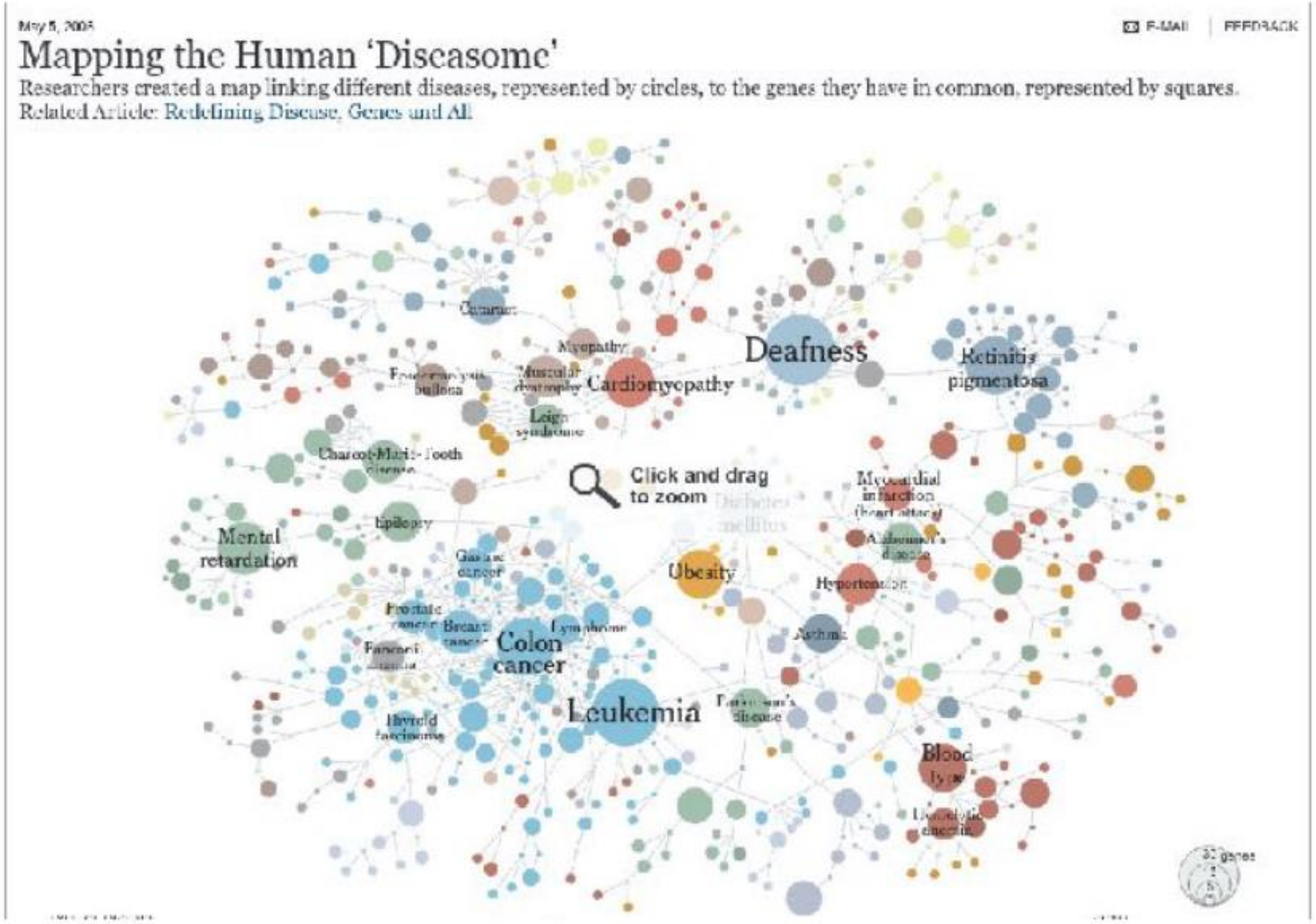
- Human perception uses *relative* comparisons
  - Good if colors appear contiguously
  - Bad for absolute comparisons

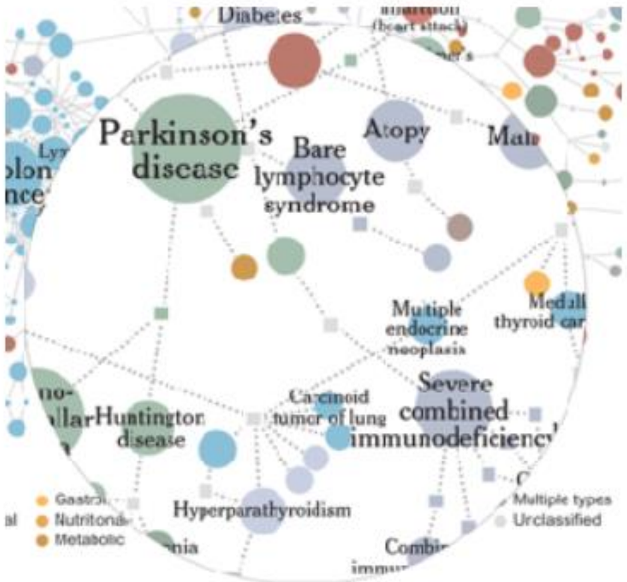
- Noncontiguous small regions of color:
  - Rule of thumb: Can only use 6 – 12 different colors (bins), **including** background and highlights
  - Advice: deliberately, manually bin categories first, then map them to colors



Sinha, Amit U., and Jaroslaw Meller. "Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms." *BMC bioinformatics* 8 (2007): 1-9.

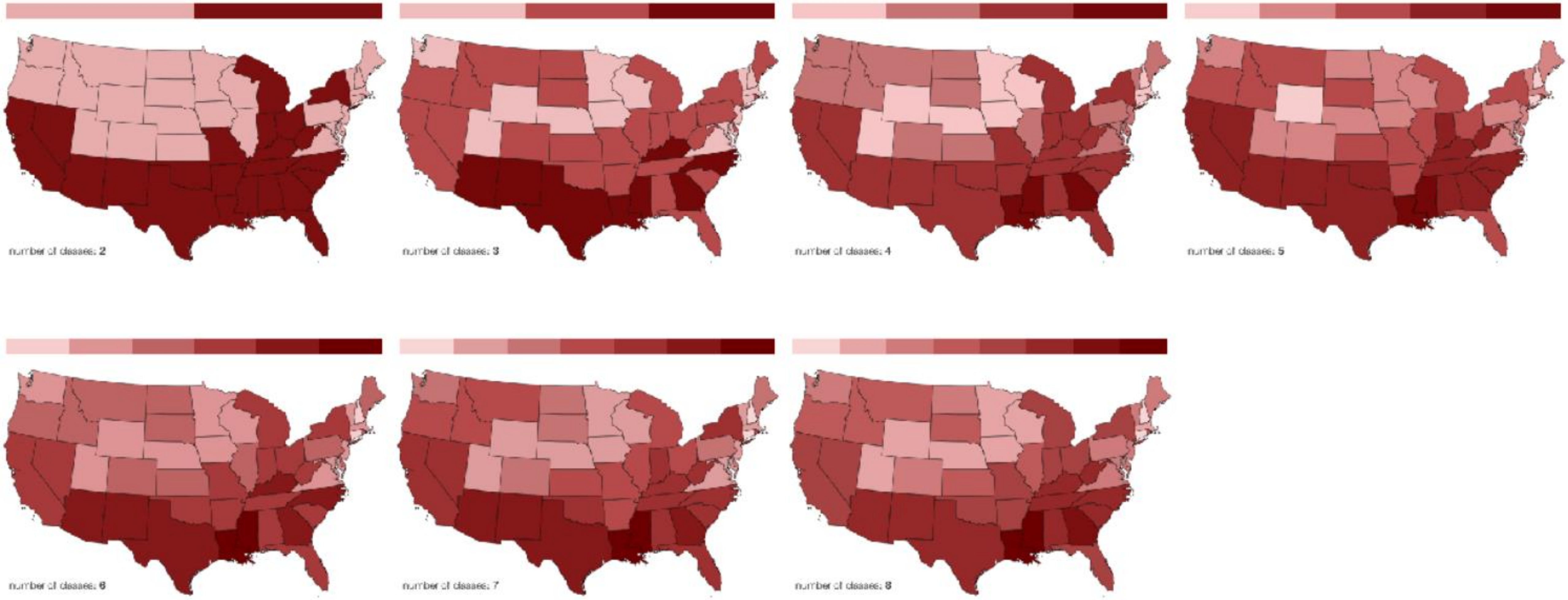
Categorical color: limited # of discriminable bins





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

Ordered color: limited # of discriminable bins



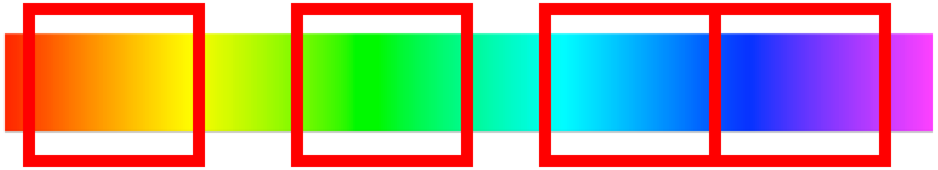
https://www.vis4.net/blog/choropleth-maps/

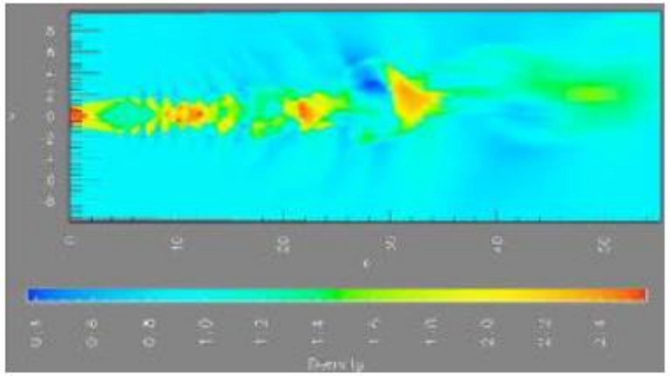
Ordered color: rainbow color map is often bad

- Problems:
  - Perceptually unordered
  - Perceptually nonlinear

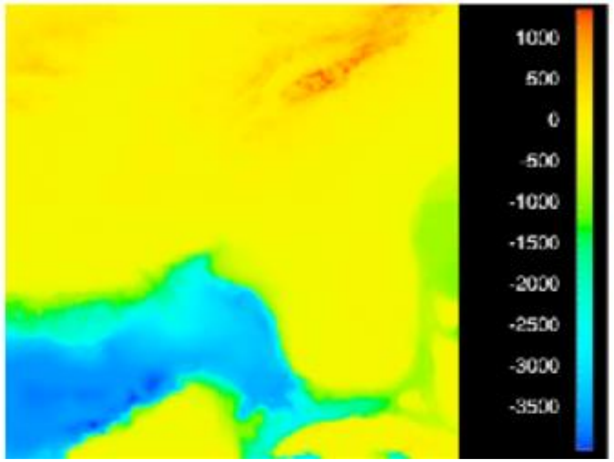
- Not all bad:
  - Fine-grained structure is easily visible

- Alternatives:
  - Large-scale structure: use fewer hues
  - Fine structure: multiple hues with monotonically increasing luminance (e.g. viridis color map)





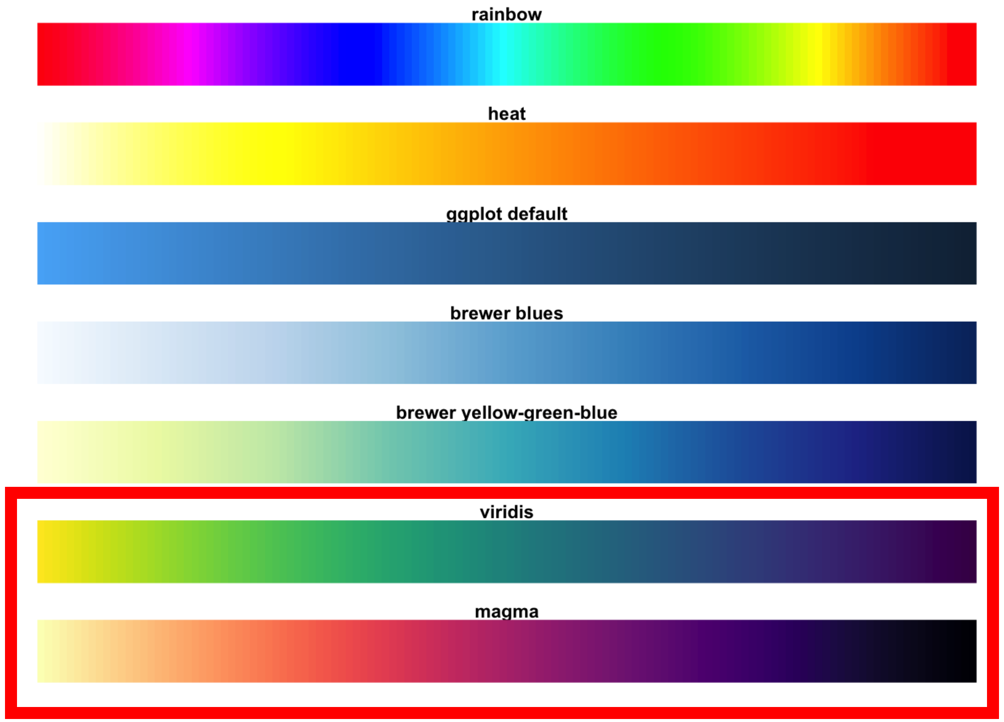
Bergman, Lawrence D., Bernice E. Rogowitz, and Lloyd A. Treinish. "A rule-based tool for assisting colormap selection." *Proceedings Visualization'95*. IEEE, 1995.

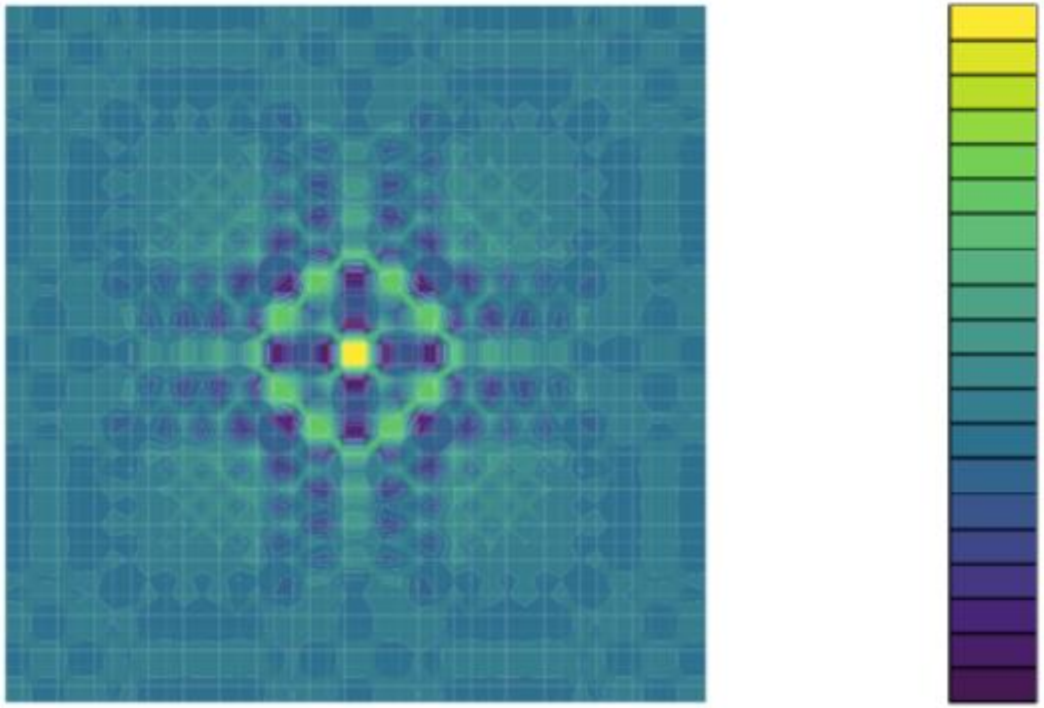


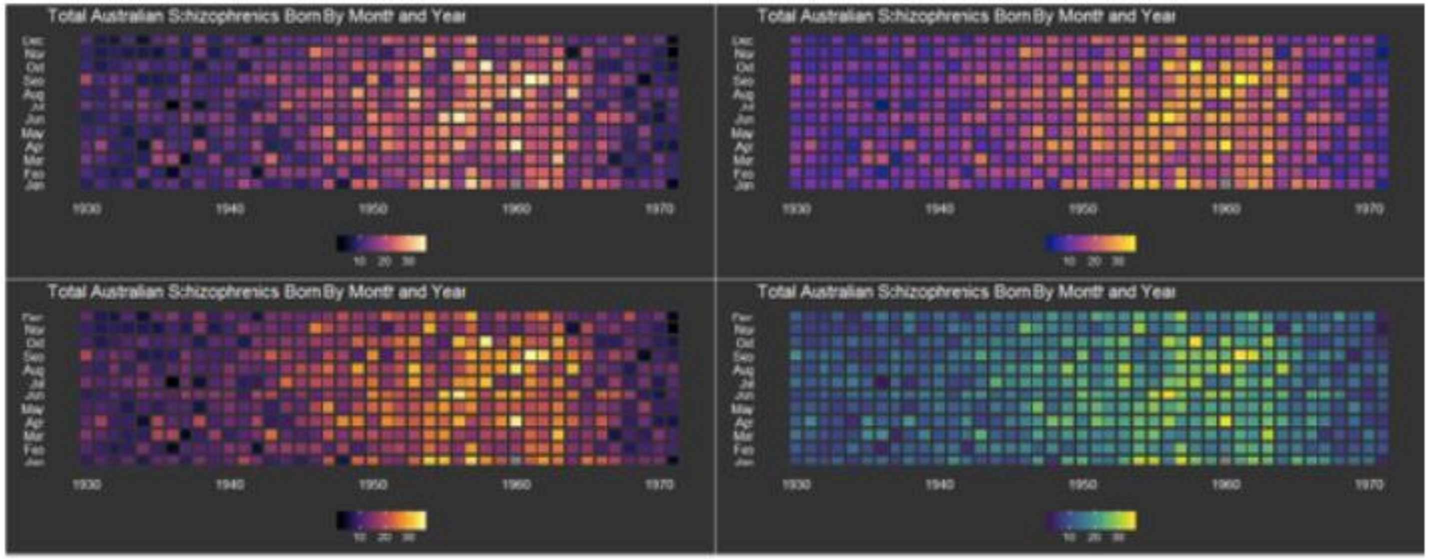
Rogowitz, Bernice E., and Lloyd A. Treinish. "Why should engineers and scientists be worried about color." *See URL http://www. research. ibm. com/people/l/lloydt/color/color. HTM* (1996).

Viridis / Magma: sequential colormaps

- Monotonically increasing luminance, perceptually uniform
- Colorblind-safe, too







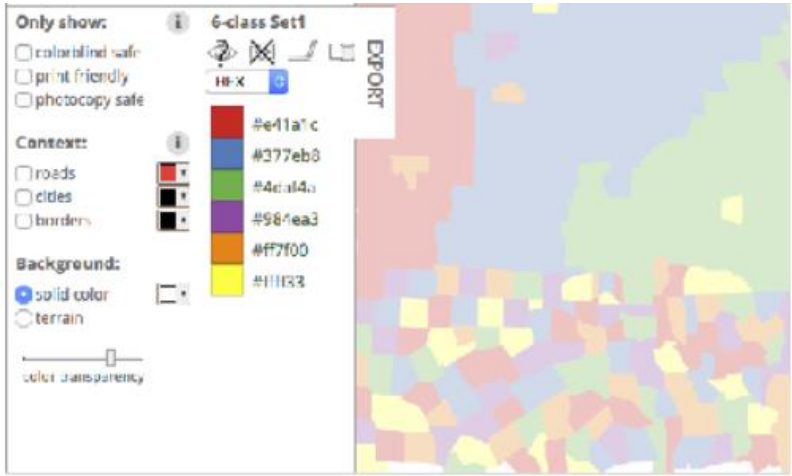
https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

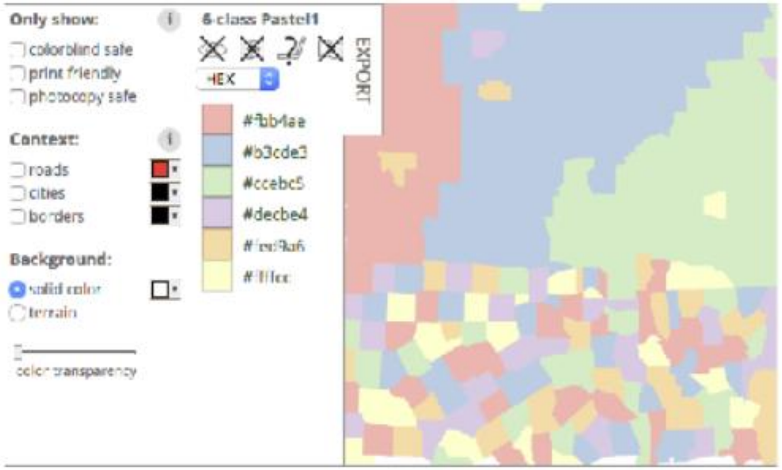
Interaction between channels: Not fully separable

- Color channel interactions
  - Size heavily influences salience
  - Rule of thumb: small regions need high saturation, large regions need low saturation

- Saturation & luminance
  - Not separable from each other!
  - Also not separable from transparency
  - Rule of thumb: Small separated regions → use 2 bins (3-4 max)
  - Rule of thumb: Only use one of saturation, luminance, or transparency

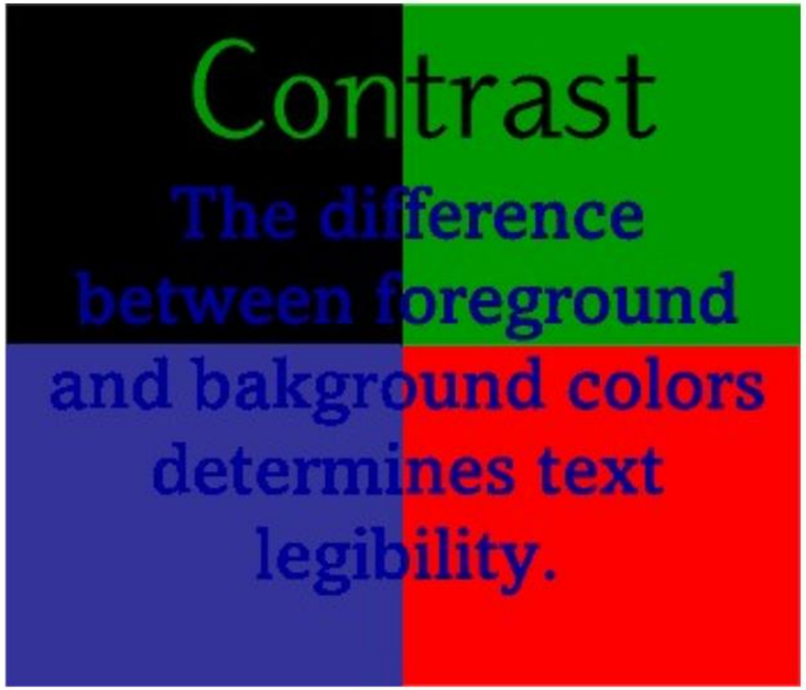
https://colorbrewer2.org

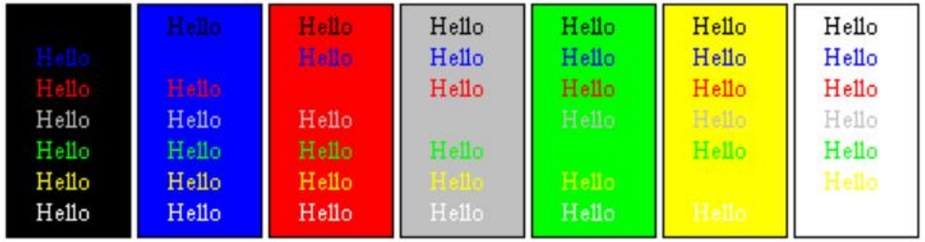




Color deficiency: Luminance

- We need luminance for edge detection
  - Fine-grained details only visible via luminance contrast
  - Legible text requires luminance contrast!



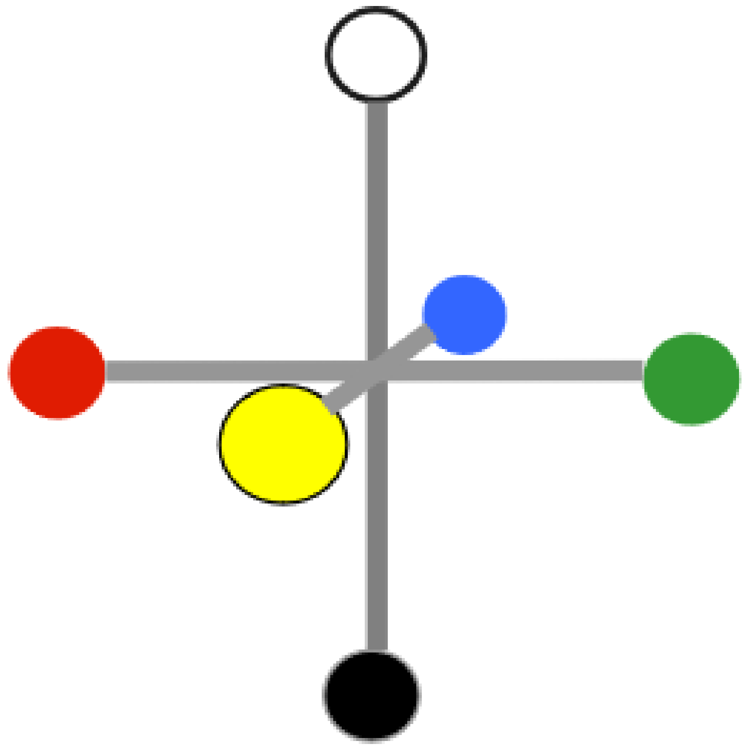


Luminance information

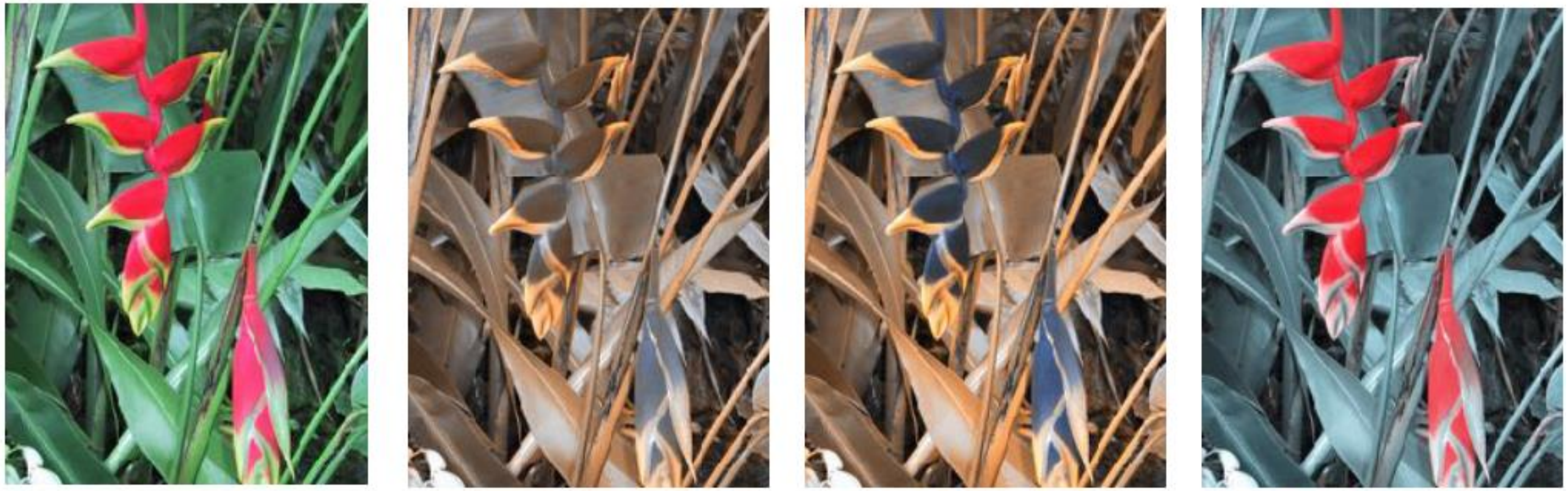
Saturation/hue information

Color deficiency

- “Colorblind” → degraded acuity along one axis
  - 8% of men are red/green color deficient
  - Blue/yellow deficiency is rare



Color deficiency: Check with simulator

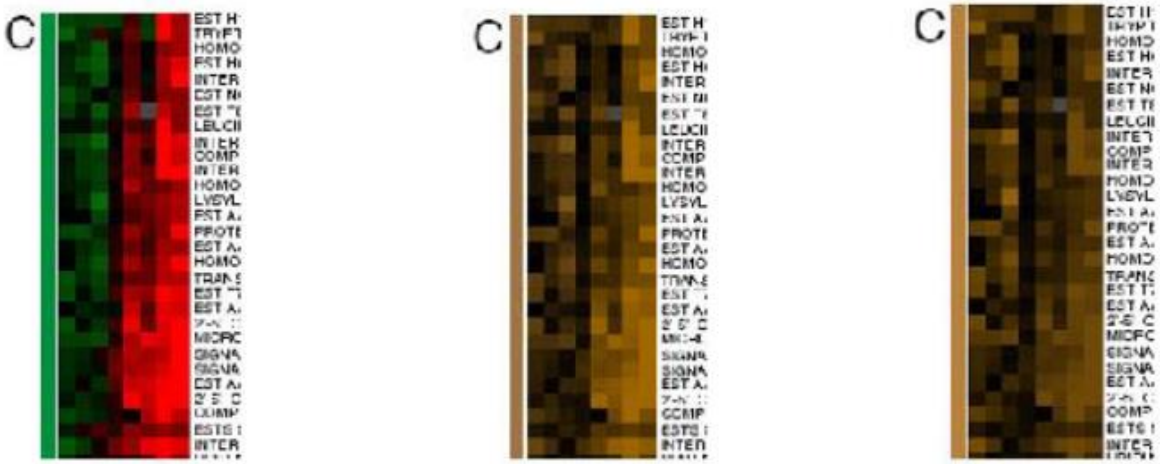


Normal vision

Deuteranope *green-weak*

Protanope *red-weak*

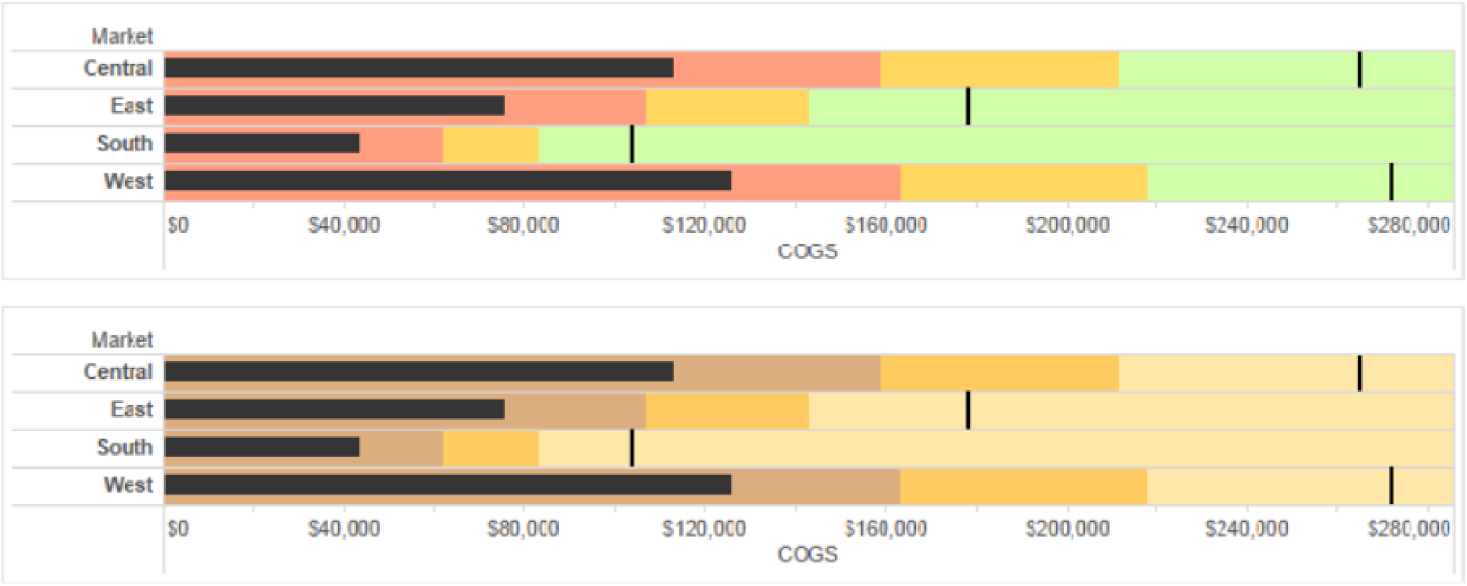
Tritanope *blue-weak*



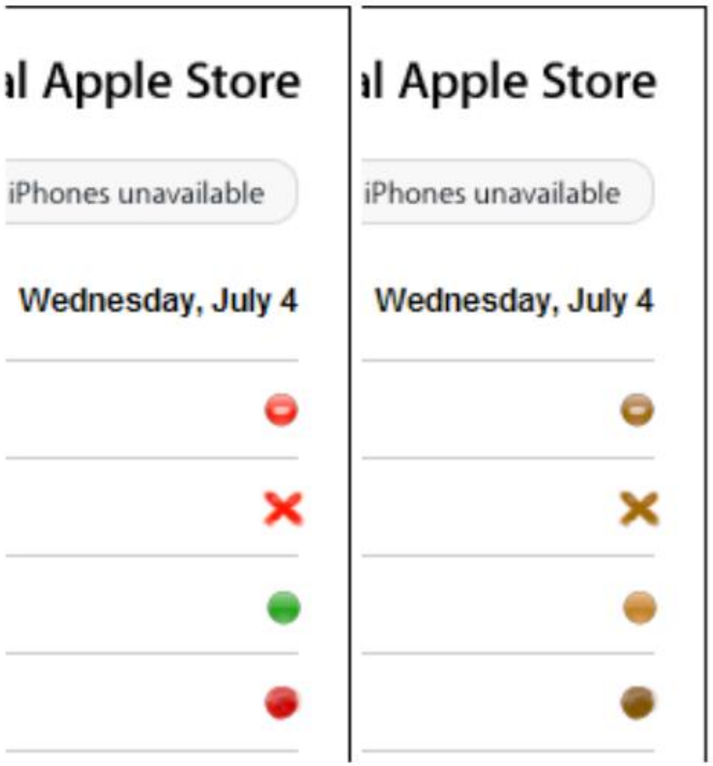
https://www.color-blindness.com/coblis-color-blindness-simulator/

Color deficiency: avoid encoding by hue alone

- Redundantly encode information!
  - Vary luminance
  - Change shape



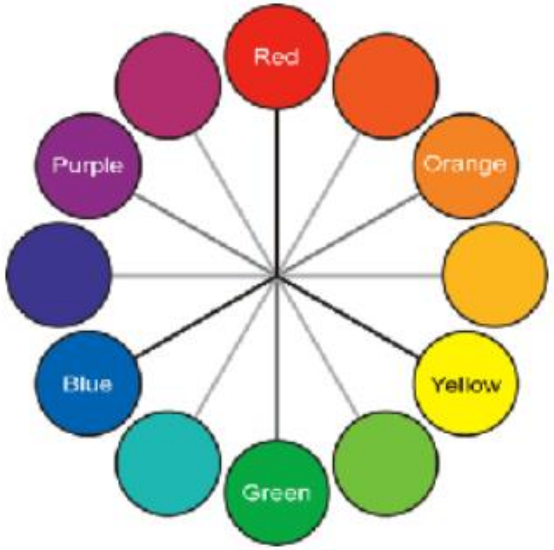
Deuteranope simulation



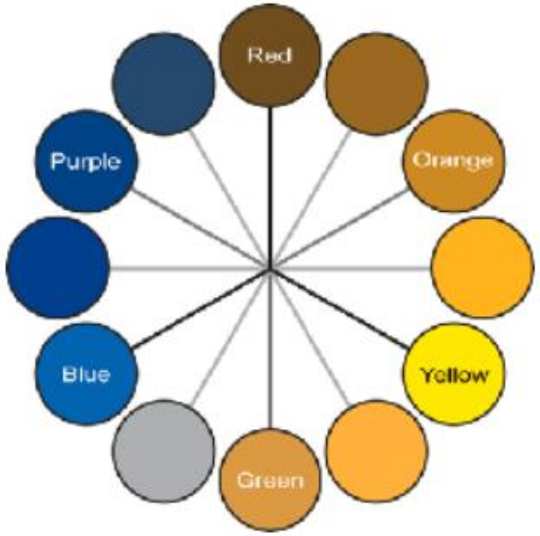
Change the shape

Vary the luminance

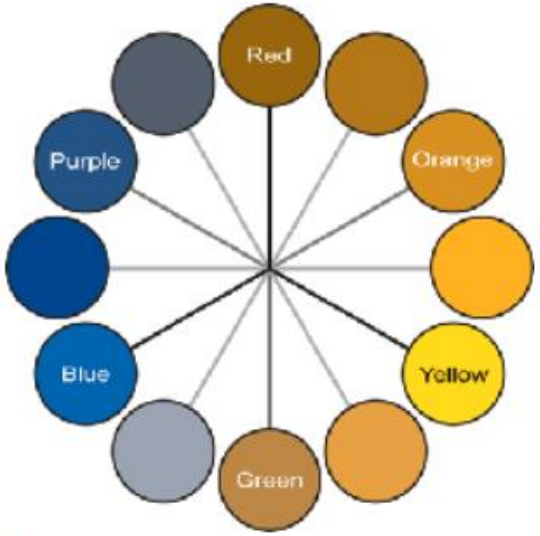
Color deficiency: Reduces color to 2 dimensions



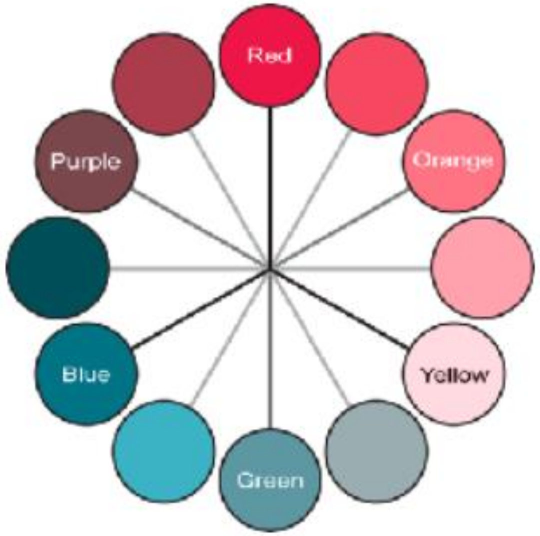
Normal



Protanope

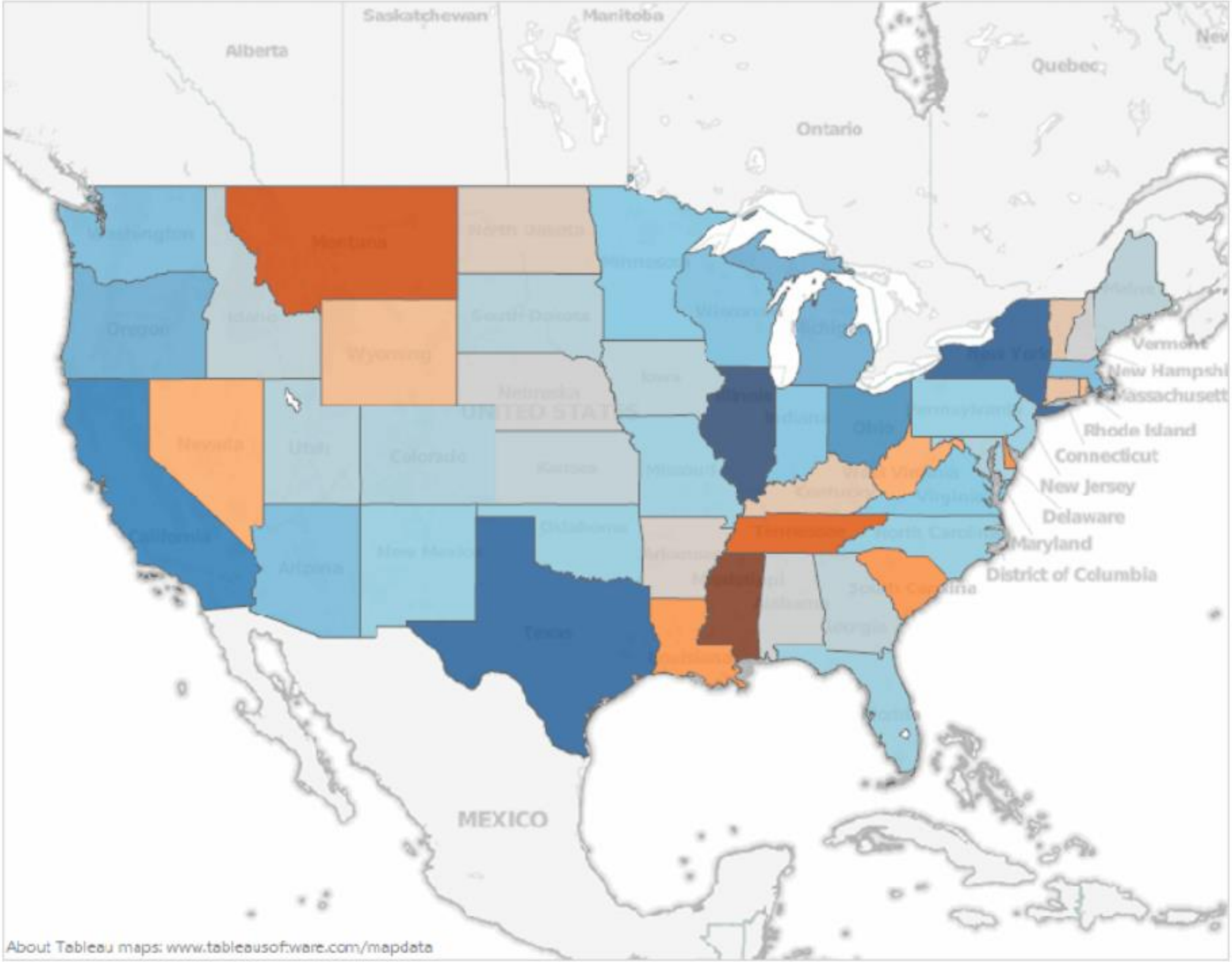


Deuteranope

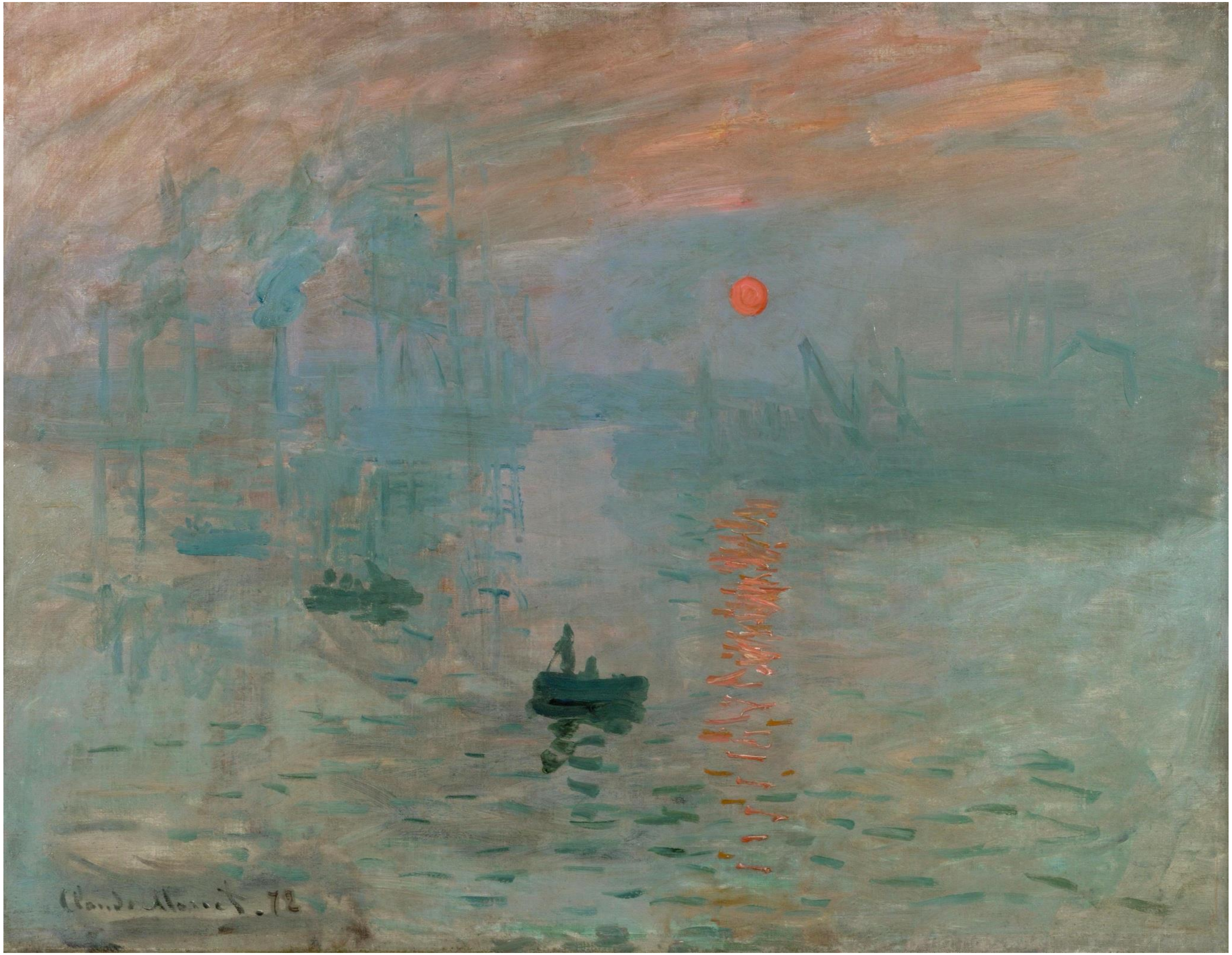


Tritanope

Color deficiency: Blue/orange is safe



Impression, Sunrise,
Claude Monet, 1872



Impression, Sunrise,
Claude Monet, 1872

NYU

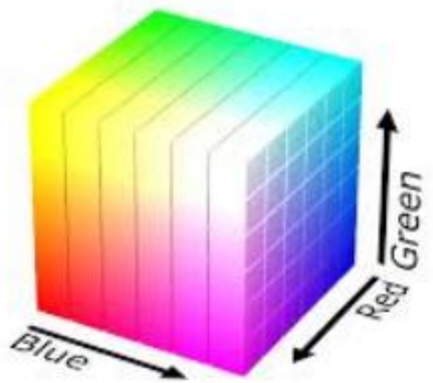
Break
back at 12:31pm

Color spaces

- There are many color spaces

- Luminance (L*), hue (H), saturation (S)
  - Good for encoding
  - Not standard in graphics and tooling

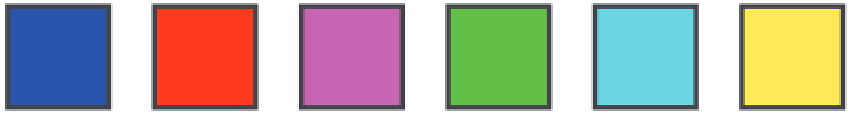
- RGB
  - Good for display hardware

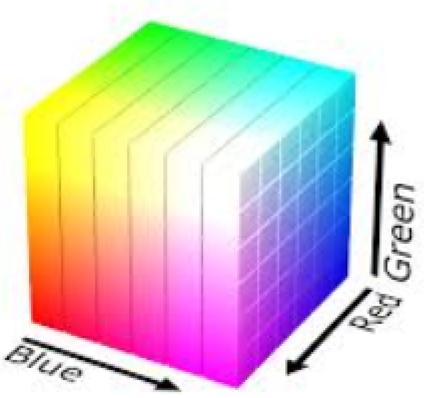


Color spaces: RGB

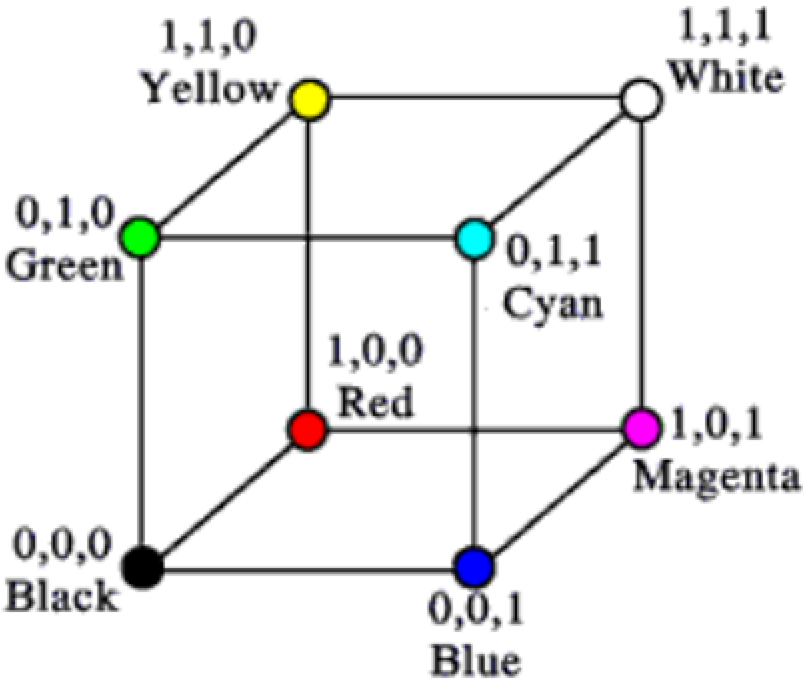
- RGB
  - Good for display hardware

Corners of the RGB color cube





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



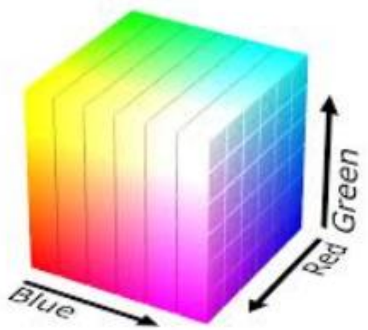
  - Bad for encoding & interpolating

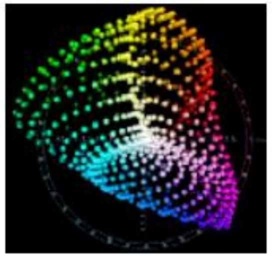
Red
+ Green

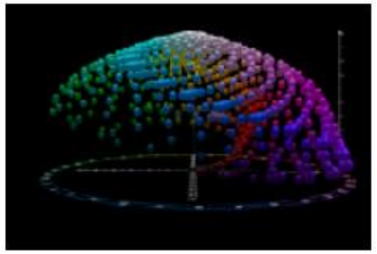
Major interference

Color spaces

- There are many color spaces
- Luminance (L*), hue (H), saturation (S)
  - Good for encoding
  - Not standard in graphics and tooling
- RGB
  - Good for display hardware
- CIE LAB (L*a*b*)
  - Good for interpolation
  - Hard to interpret, poor for encoding



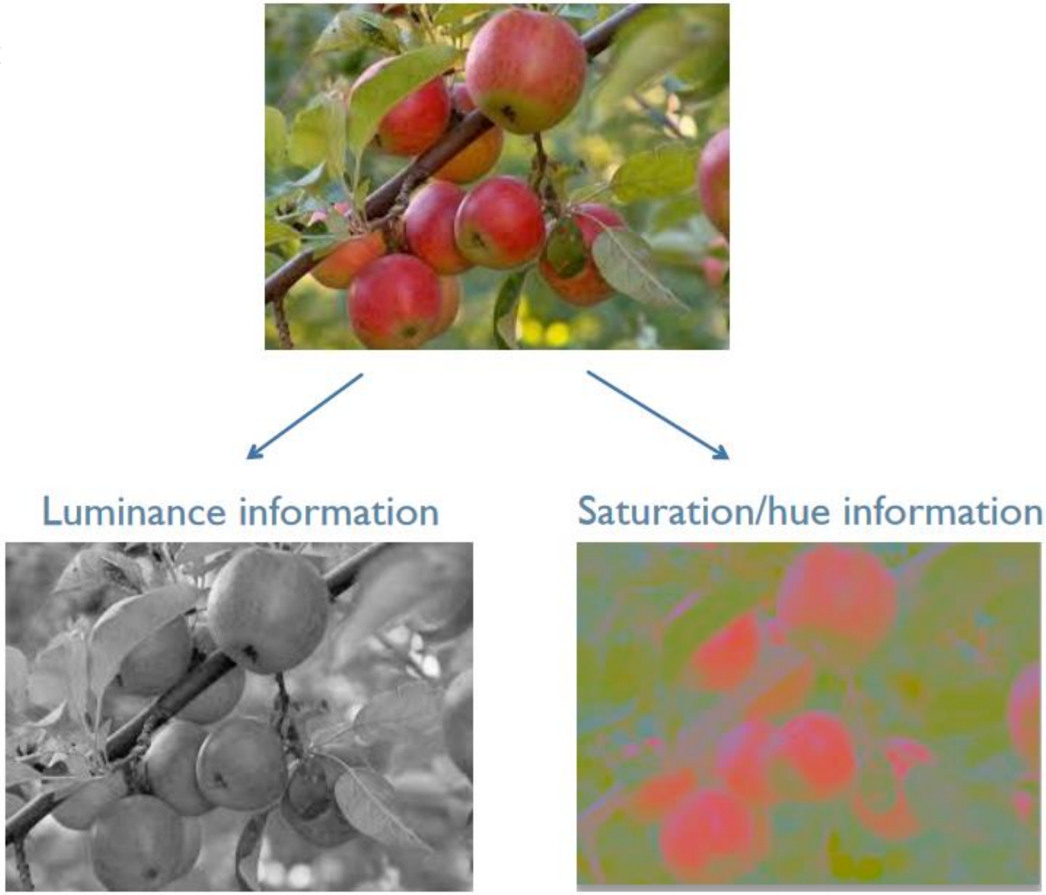


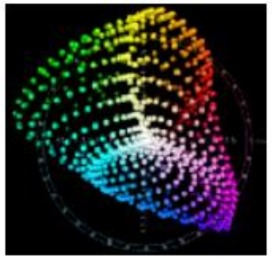


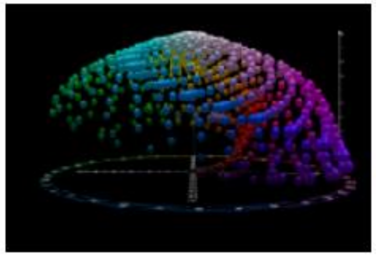
Perceptual color space: L*a*b*

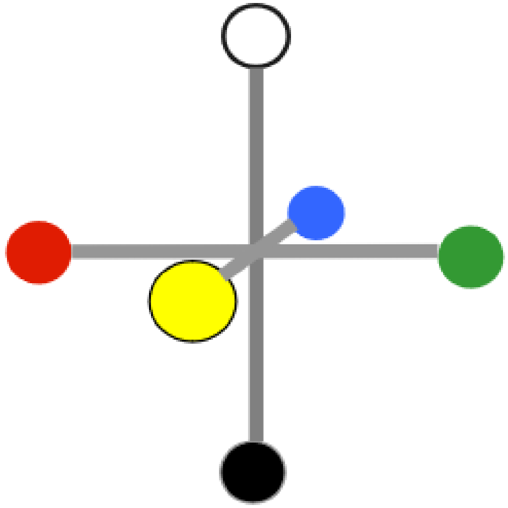
- Visual processing:
  - one achromatic luminance channel (L*)
- 2 chroma channels
  - Red-green (a*) & yellow-blue axis (b*)

- CIE LAB
  - Perceptually uniform
  - Great for interpolating
  - Complex shape
    - Poor for encoding (hard to understand)



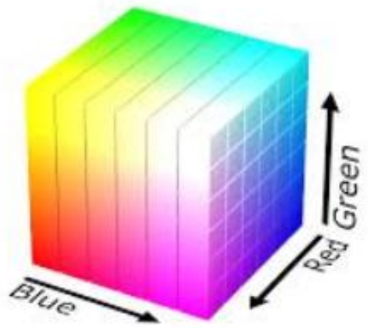


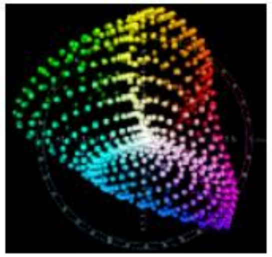


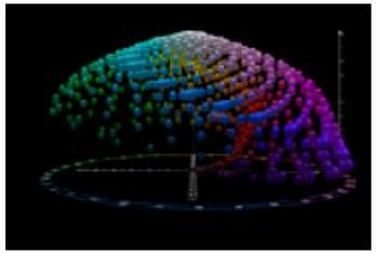


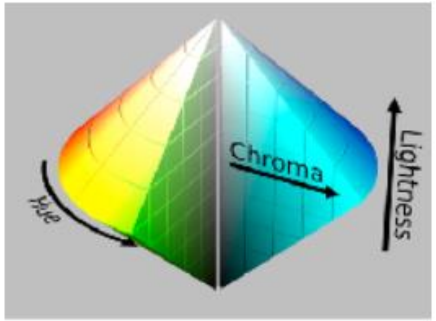
Color spaces

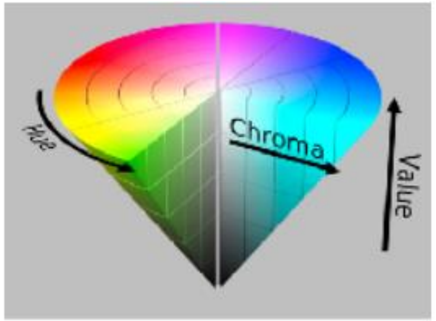
- There are many color spaces
- Luminance (L*), hue (H), saturation (S)
  - Good for encoding
  - Not standard in graphics and tooling
- RGB
  - Good for display hardware
- CIE LAB (L*a*b*): good for interpolation
  - Hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - Hue/saturation wheel is intuitive
  - Beware: only pseudo-perceptual
  - Lightness (L) or Value (V) ≠ Luminance (L*)





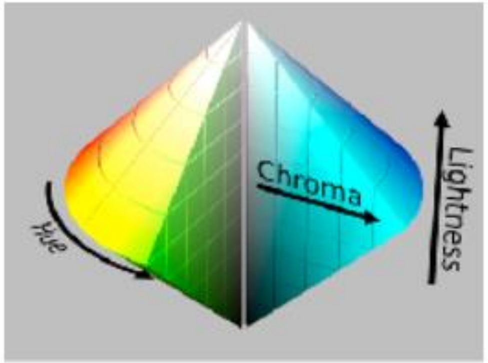


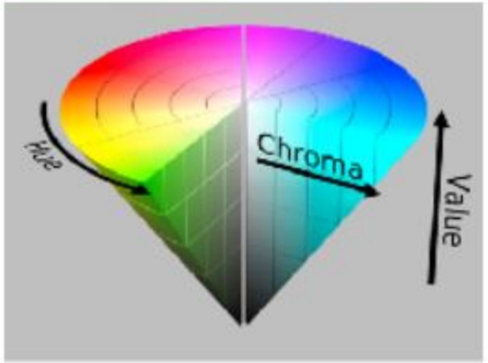


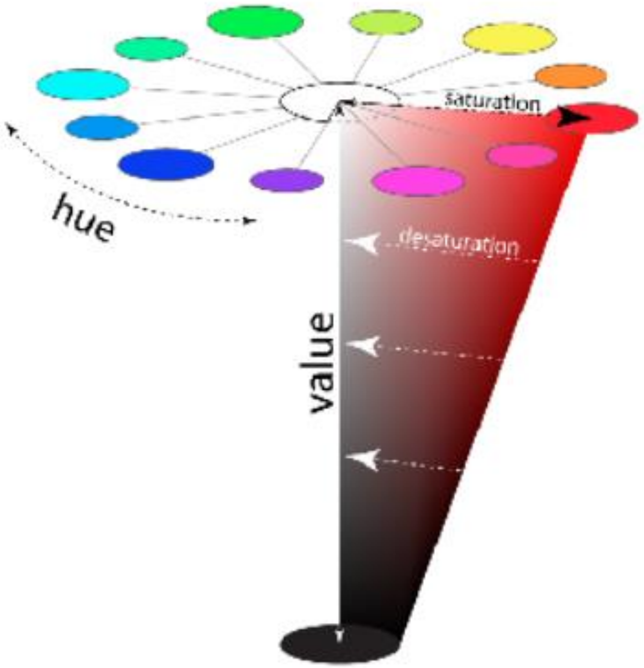


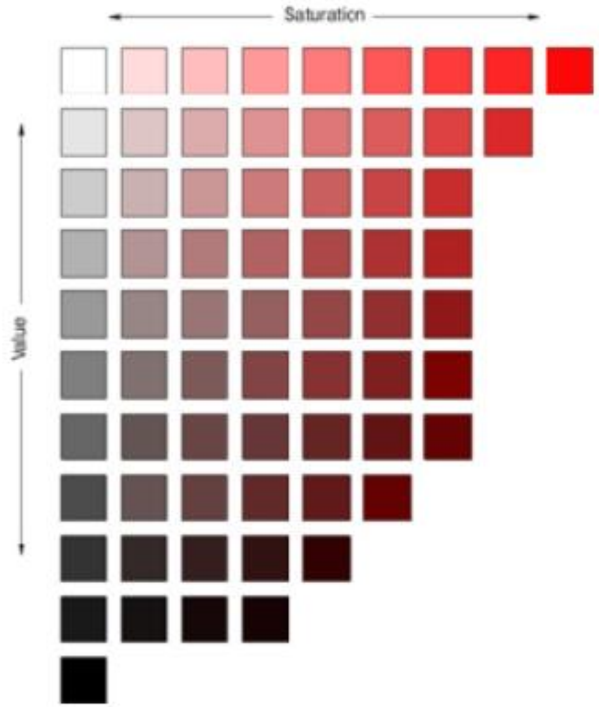
HSL/HSV

- Somewhat better for encoding
  - Hue/saturation wheel intuitive
- Saturation
  - In HSV (single cone): desaturated = white
  - In HSL (double cone): desaturated = grey
- Luminance vs saturation
  - These channels are not separable
  - We care about hue vs luminance/saturation for viz





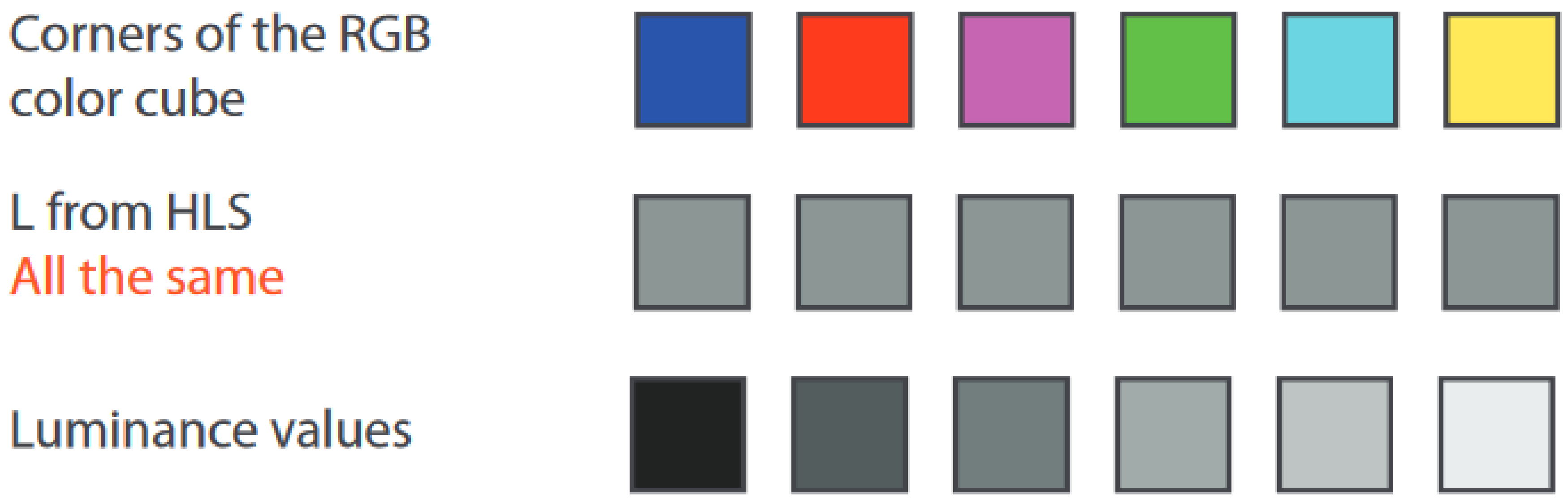




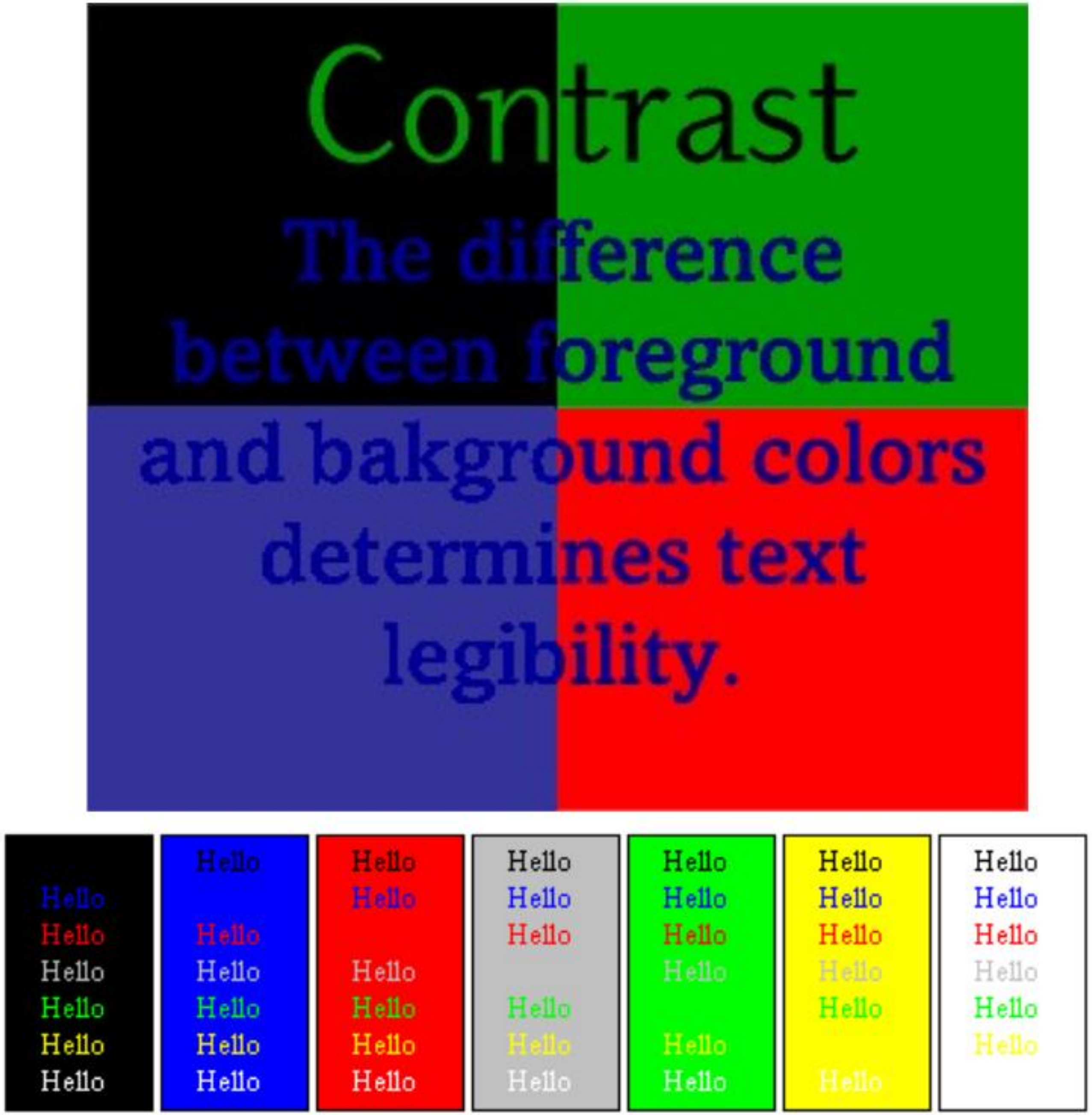
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV: Pseudo-perceptual

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

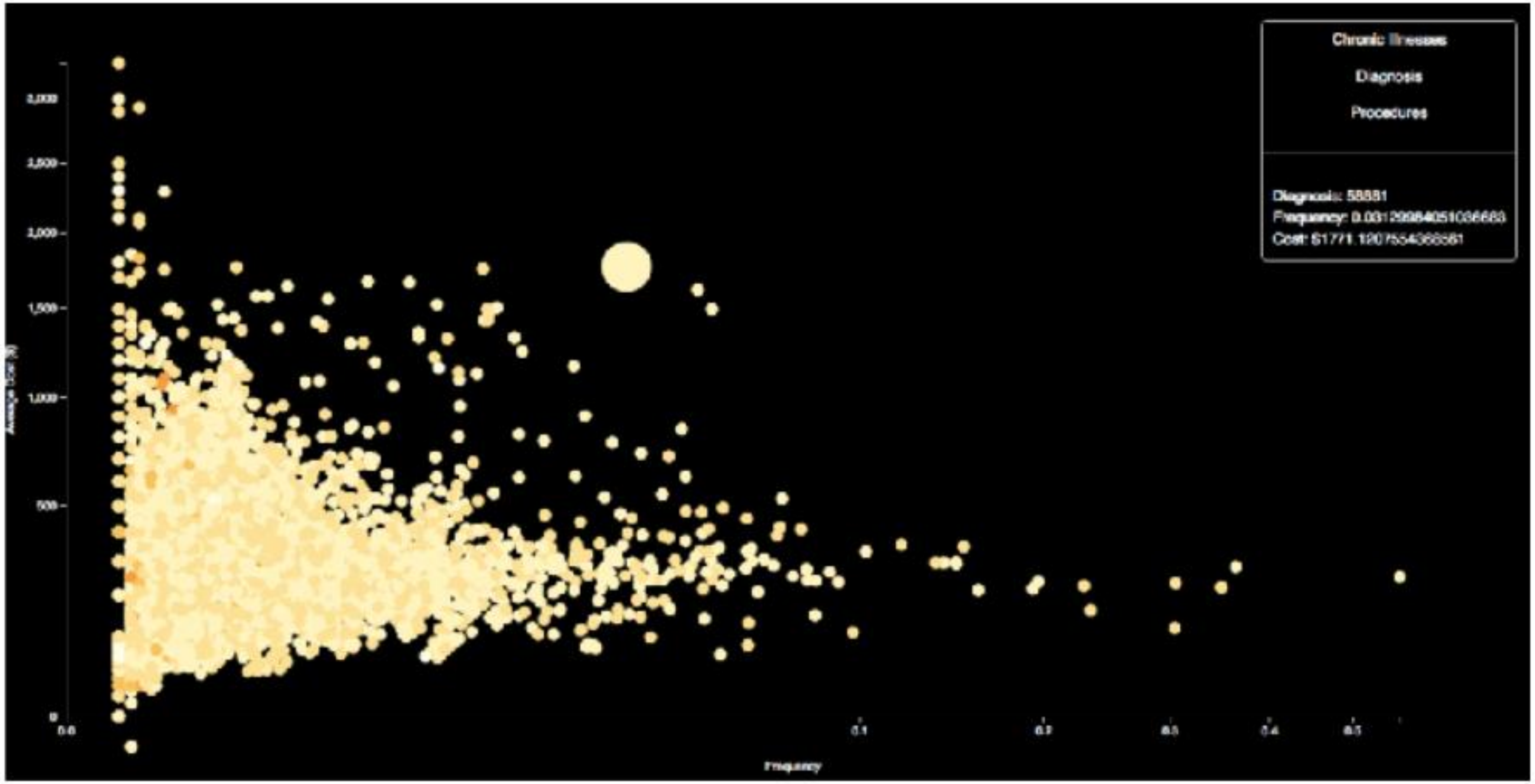


Color Contrast



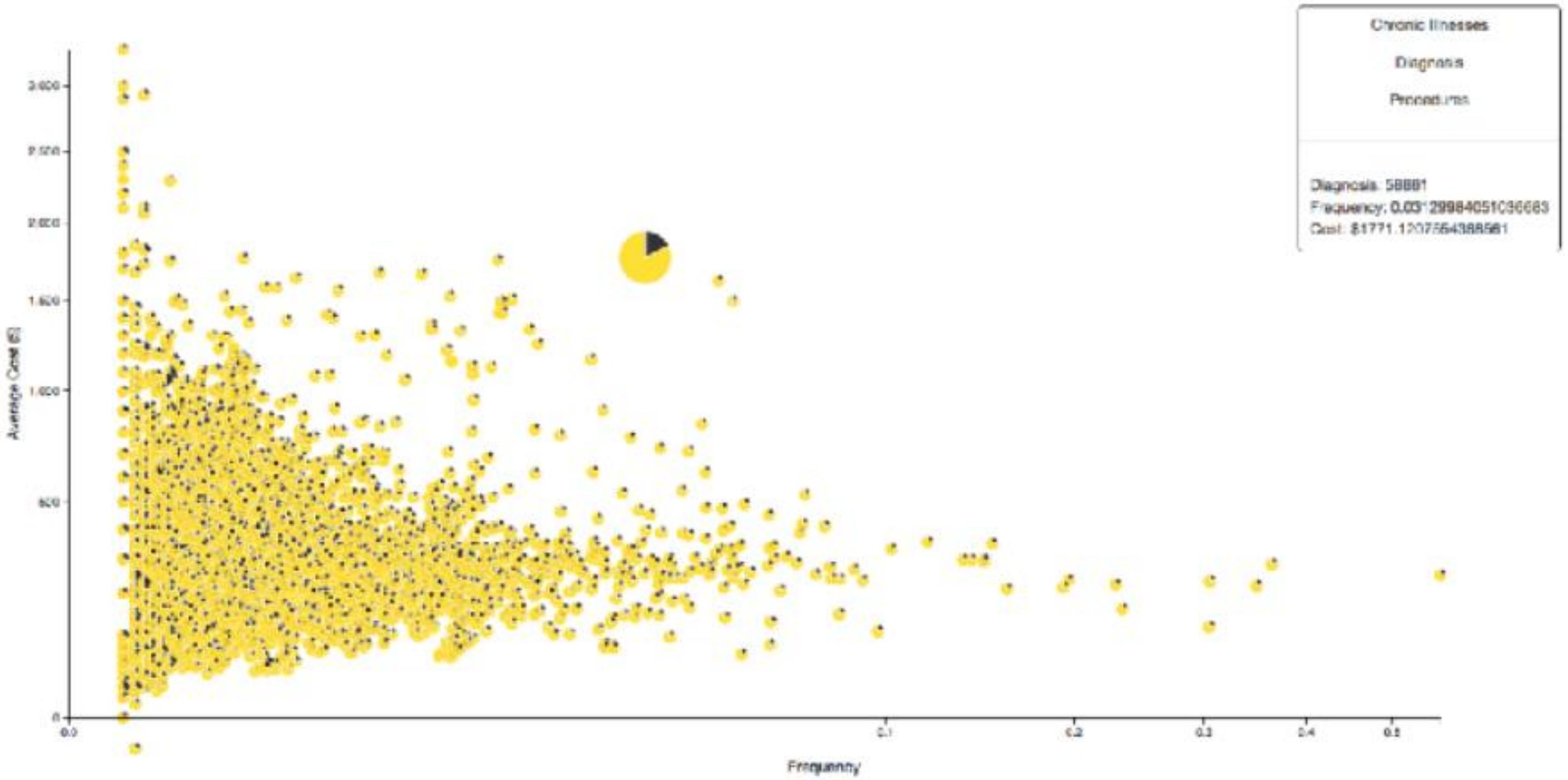
Color contrast: interaction with background

- Marks with high luminance on a background with low luminance



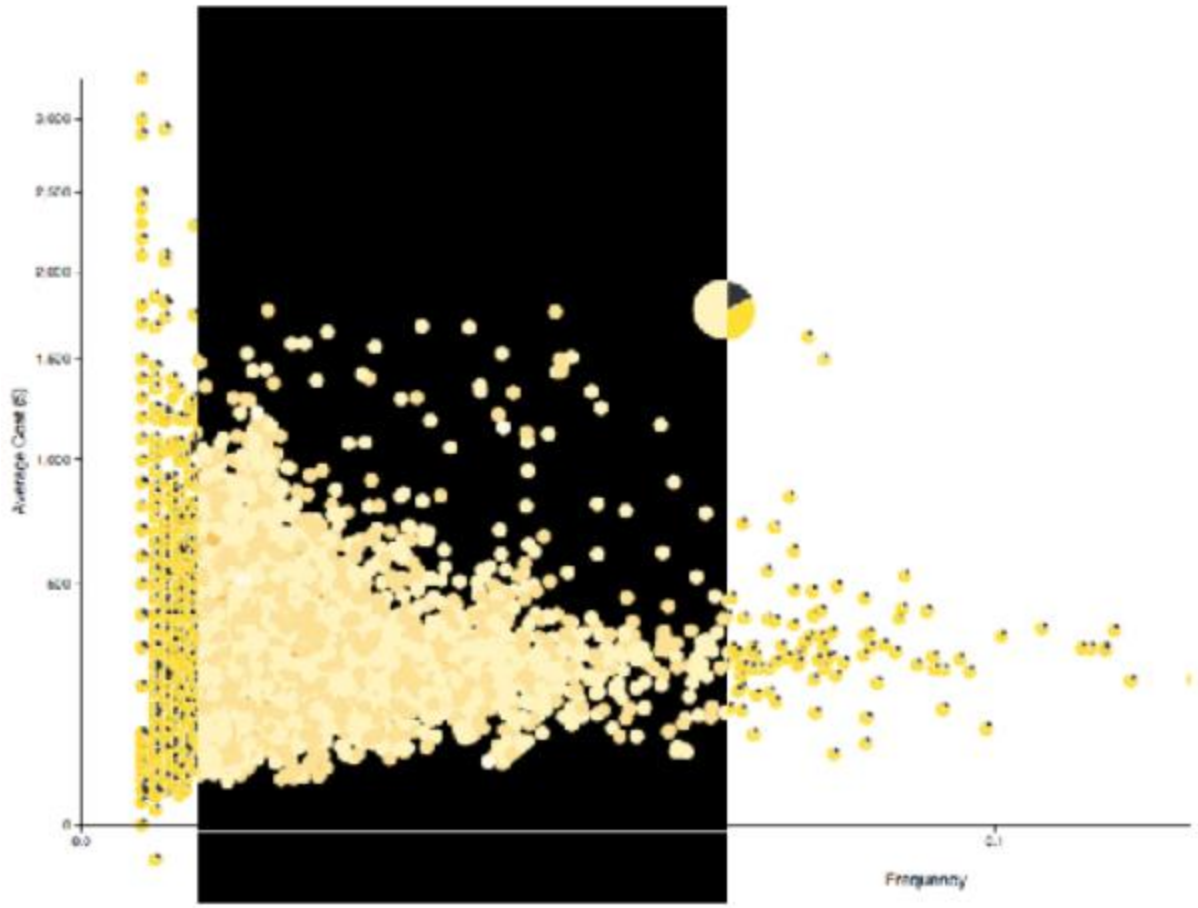
Color contrast: interaction with background

- Marks with medium luminance on a background with high luminance

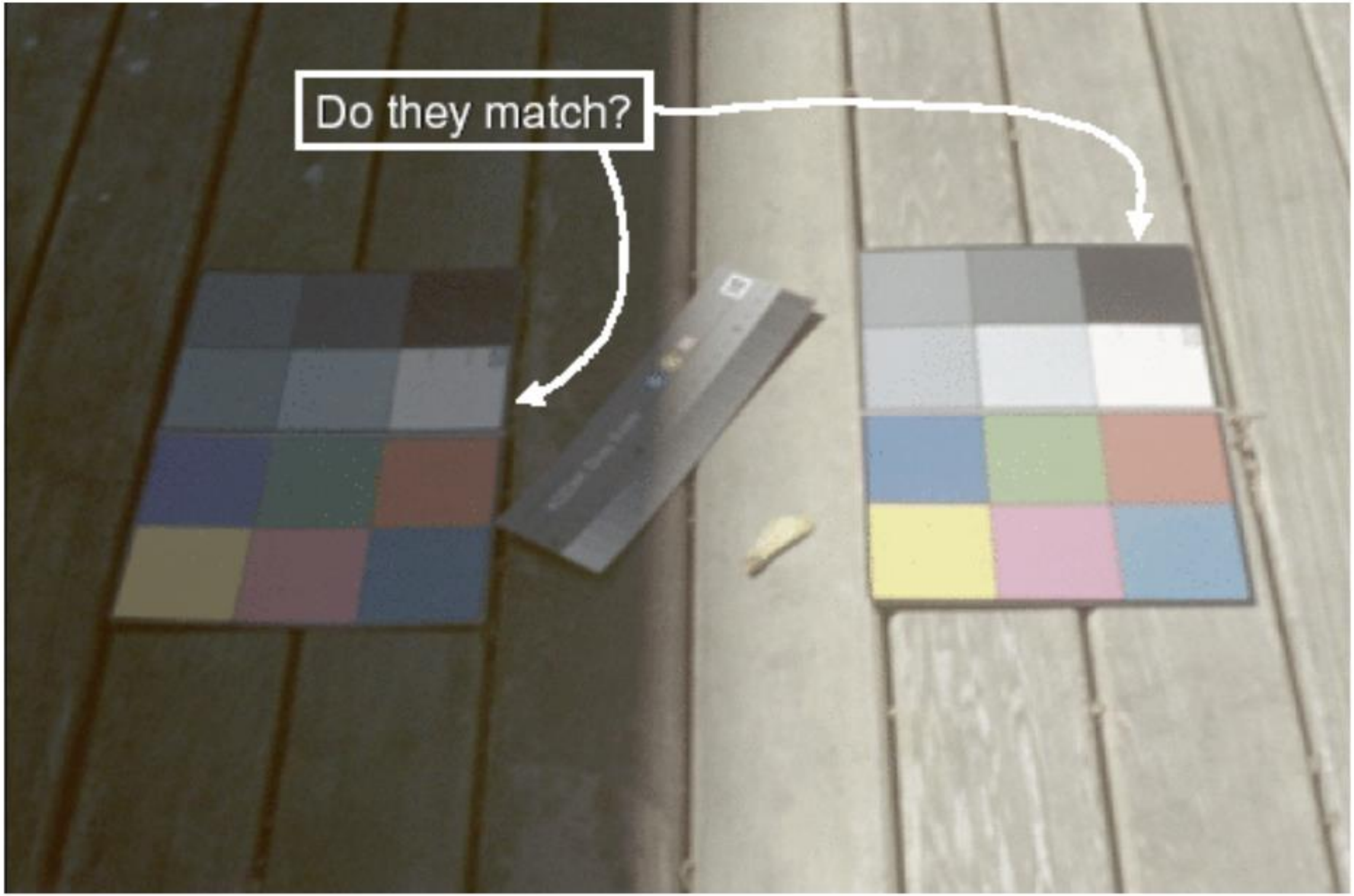


Color contrast: interaction with background

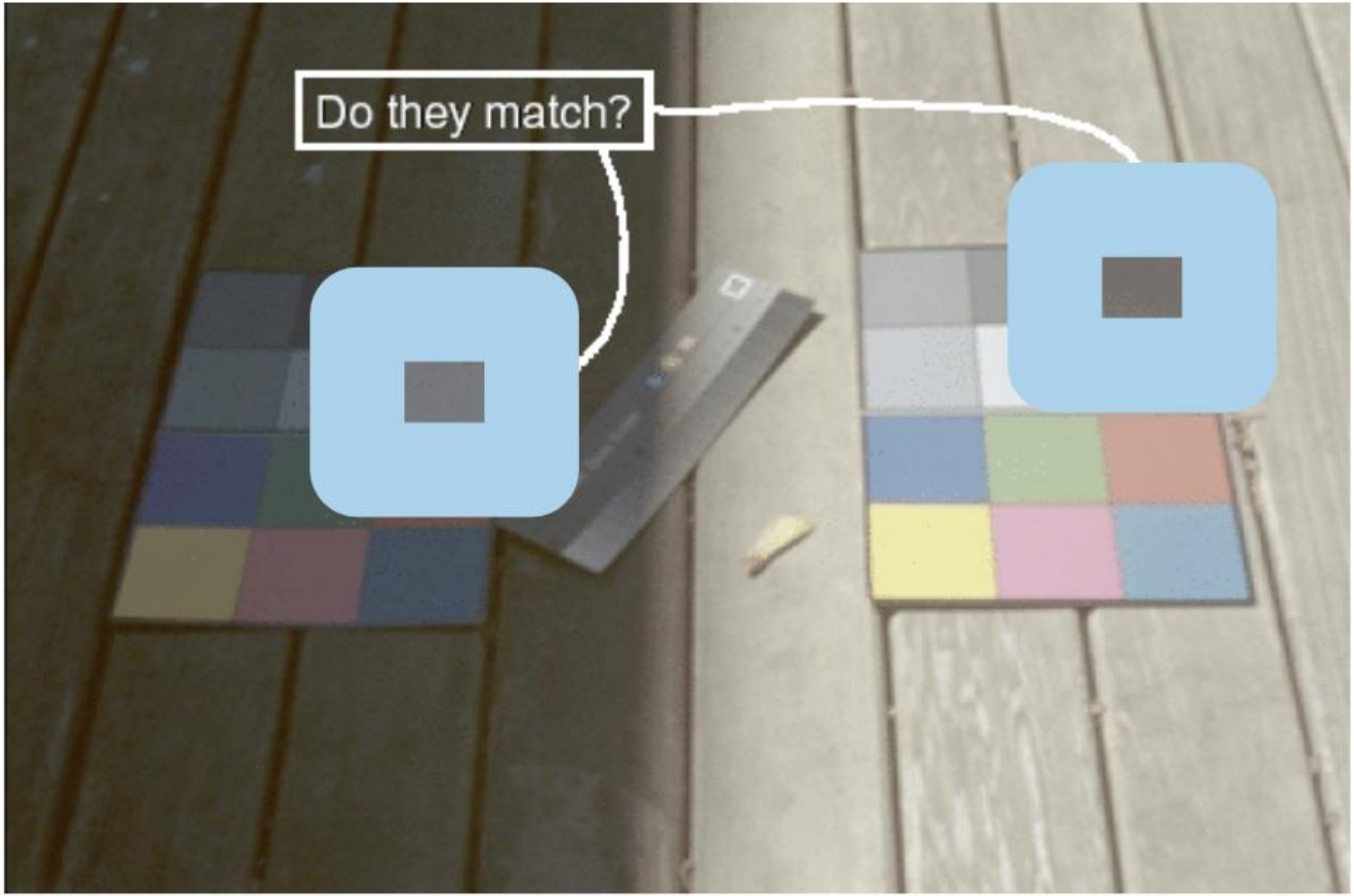
- Change the mark luminance based on the background!



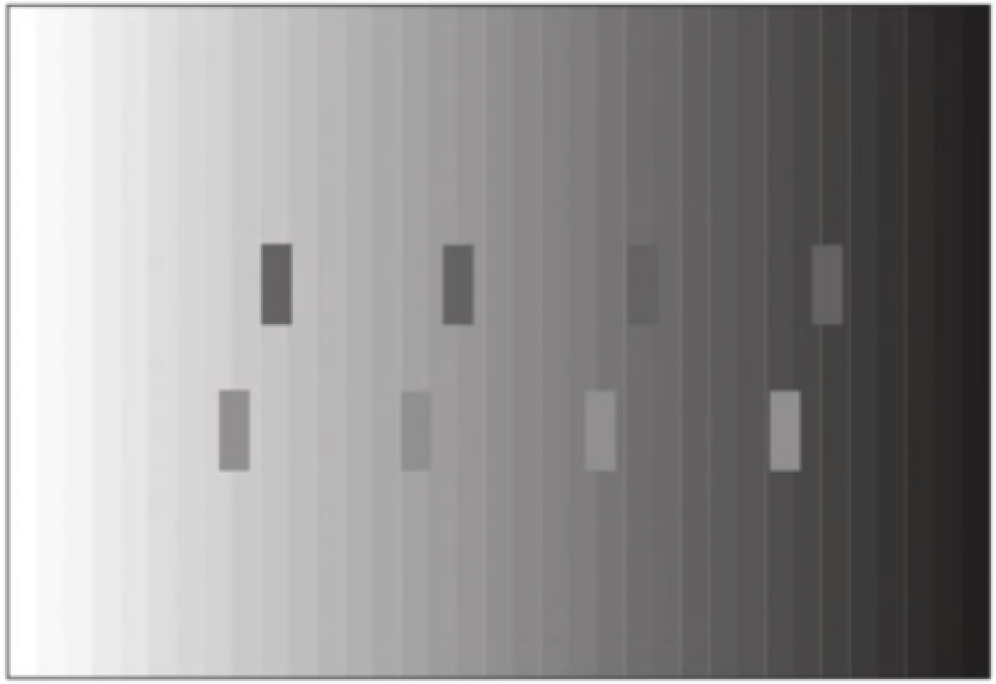
Color/lightness constancy



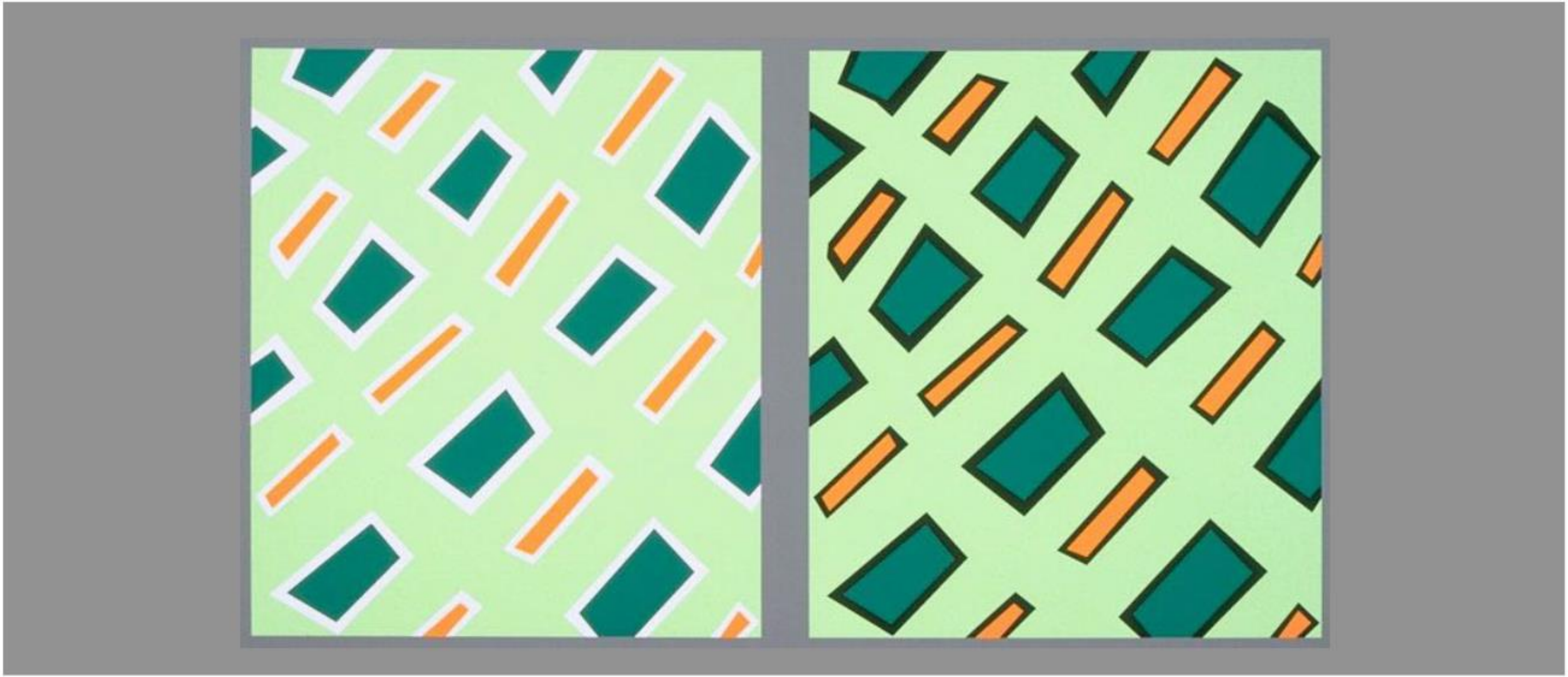
Color/lightness constancy



Color/lightness constancy: contrast w/background



Color contrast: outlines matter (Bezold Effect)



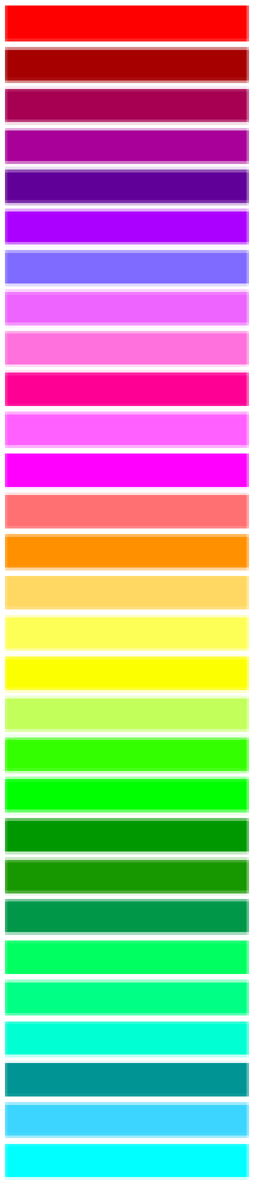
Color appearance

- Not fully specified by any color space

- Depends on the surrounding context!
  - Chromatic adaptation
  - Luminance adaptation
  - Simultaneous contrast
  - Spatial effects
  - Viewing angle
  - …

Color names

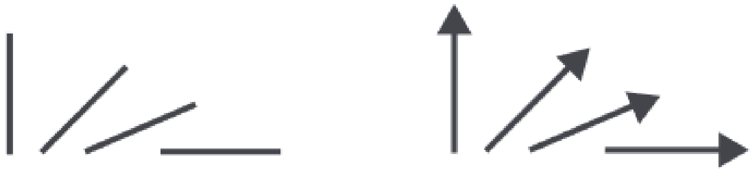
- Has implications on communication and memorability



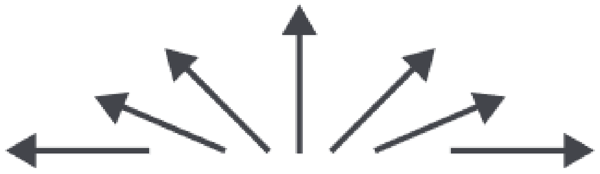
https://blog.xkcd.com/2010/05/03/color-survey-results/

Angle/tilt/orientation channel

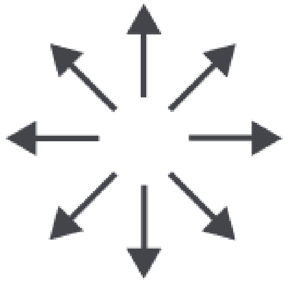
- Angle can also be used for encoding information
- Choose a different mapping based on the data range



Sequential ordered
line mark or arrow glyph



Diverging ordered
arrow glyph



Cyclic ordered
arrow glyph

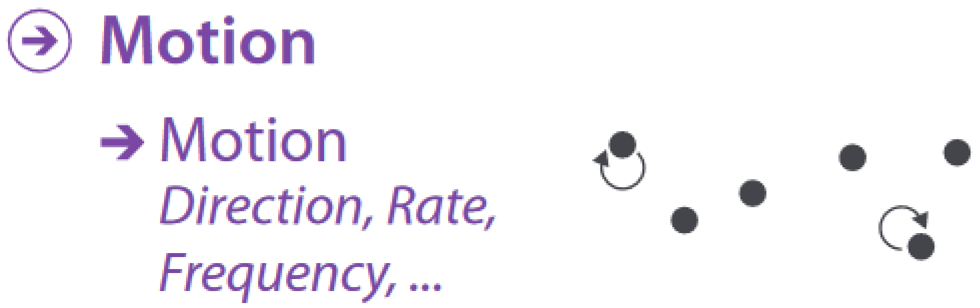
- Nonlinear accuracy:
  - High: exact horizontal, vertical, diagonal
  - Lower: other orientations (eg 23 vs 24 degrees)

Mapping other channels

- Size
  - Aligned lengths is best
  - Length is good in general
  - 2D area ok
  - 3D volume is bad

- Shape
  - Complex combination of lower-level primitives
  - Many bins

- Motion
  - Highly separable against static elements
    - Great for highlighting (binary)
  - Use carefully to avoid annoying the user

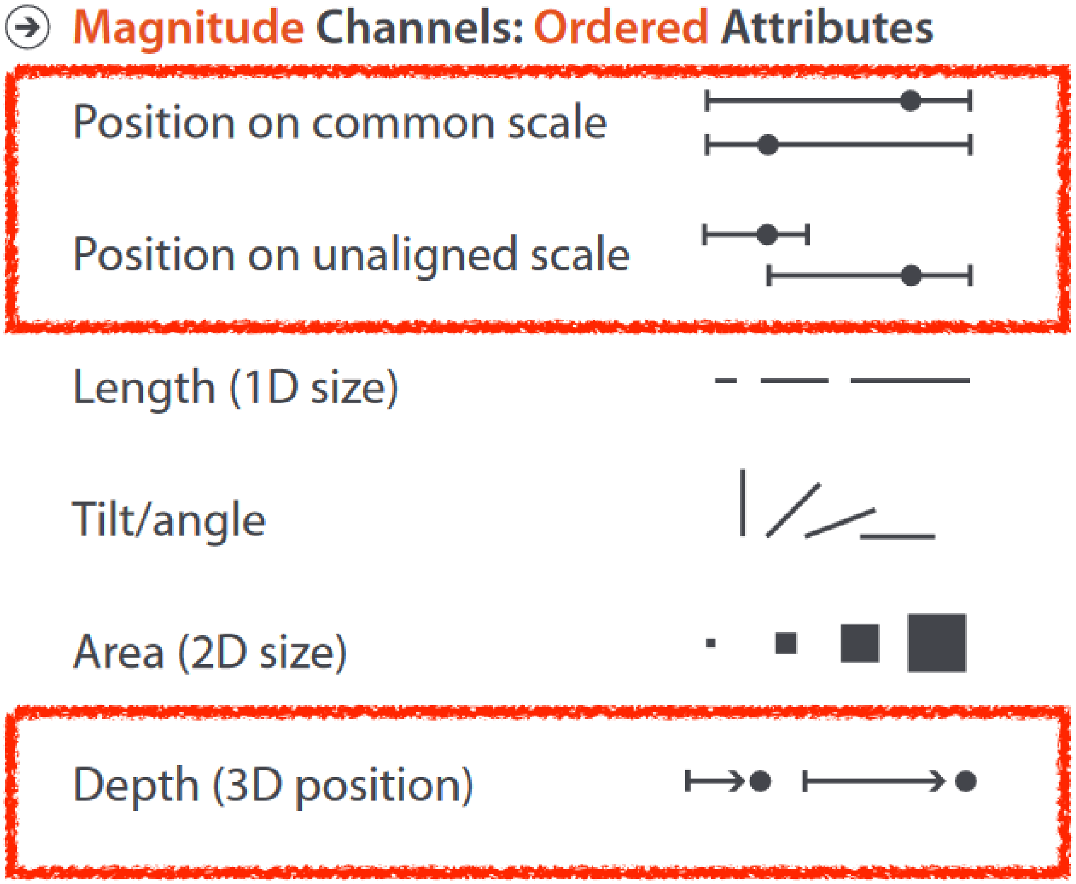


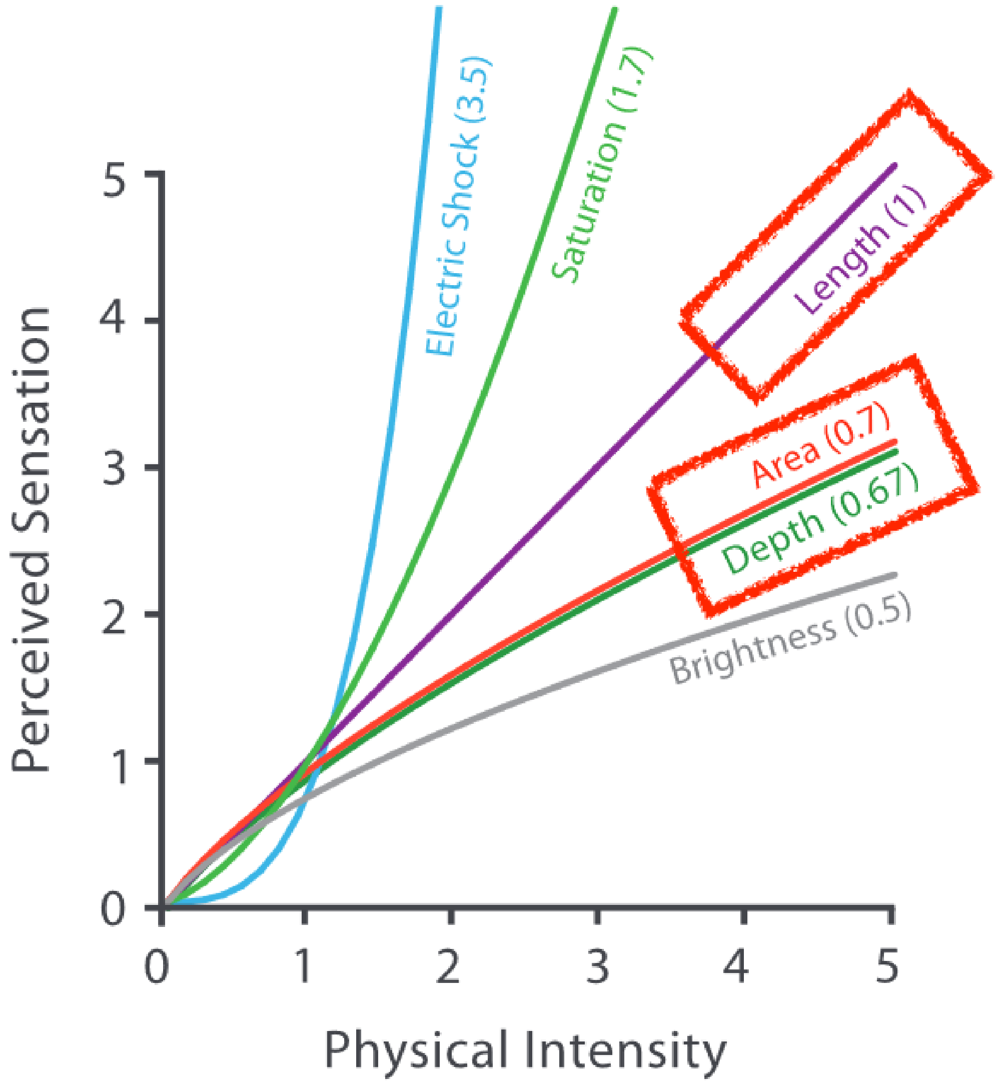
Rules of thumb

- No unjustified 3D
- Eyes beat memory
- Resolution over immersion
- Overview first, zoom and filter, details on demand
- Responsiveness is required
- Function first, form next

No unjustified 3D

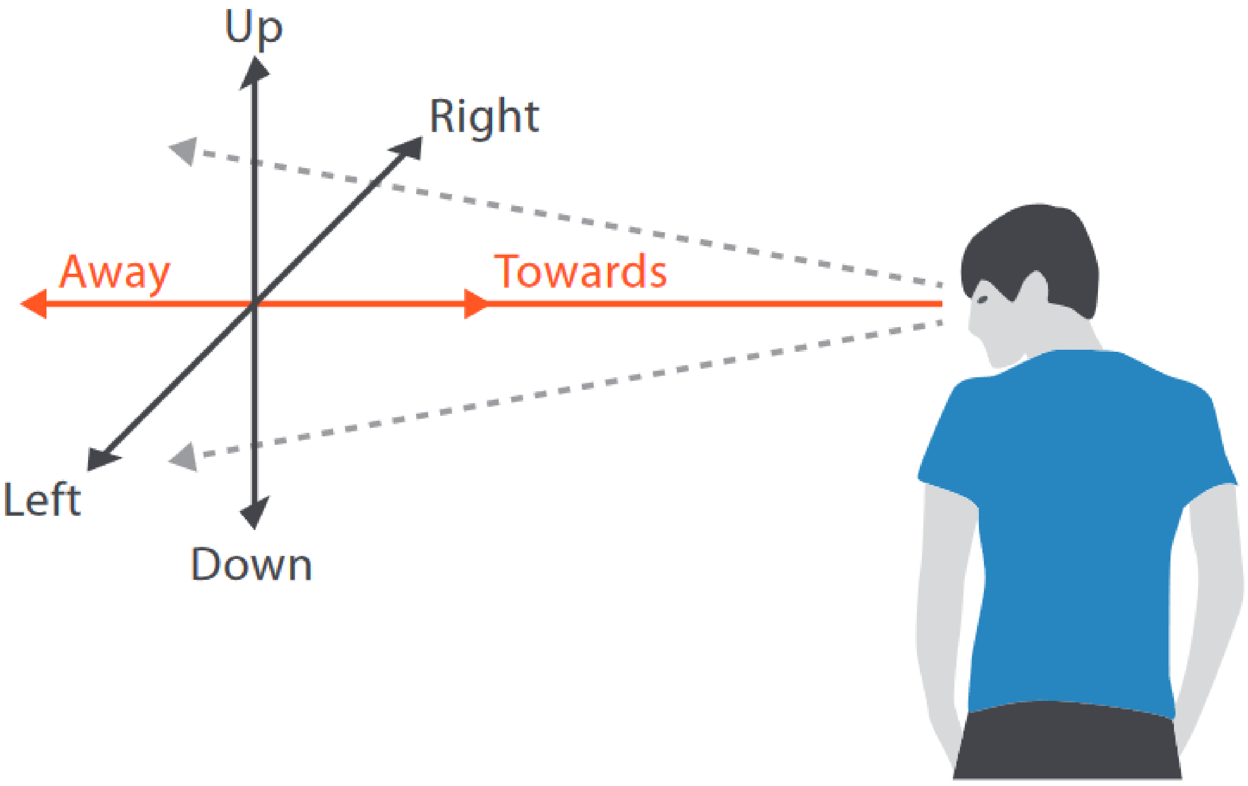
- **Planar** spatial position is good
  - Depth (3D position) is bad!

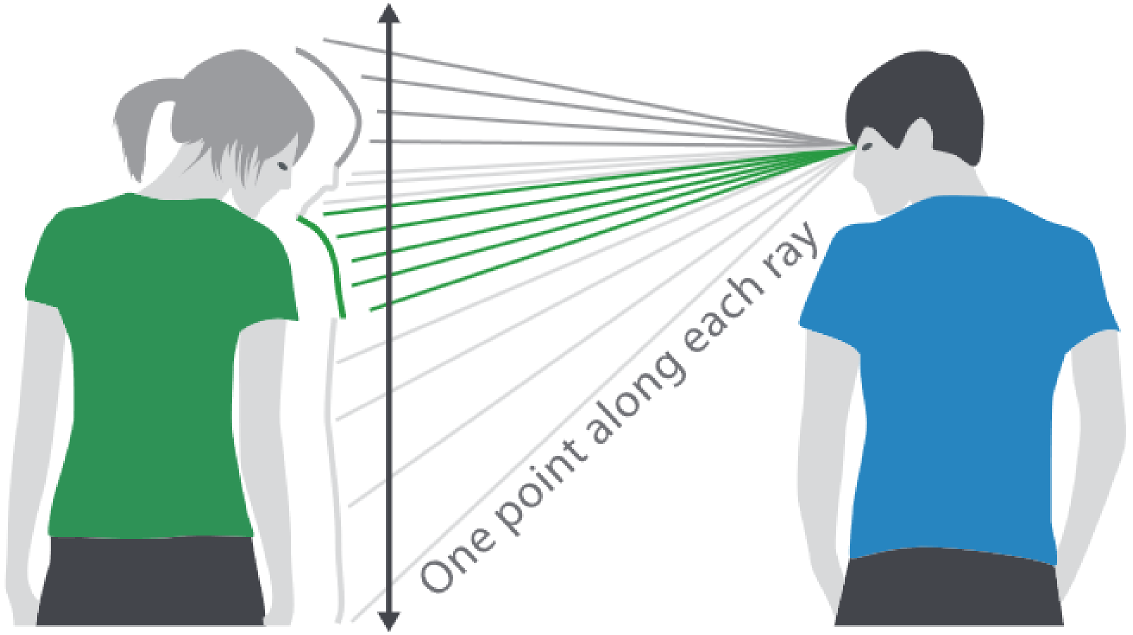




No unjustified 3D

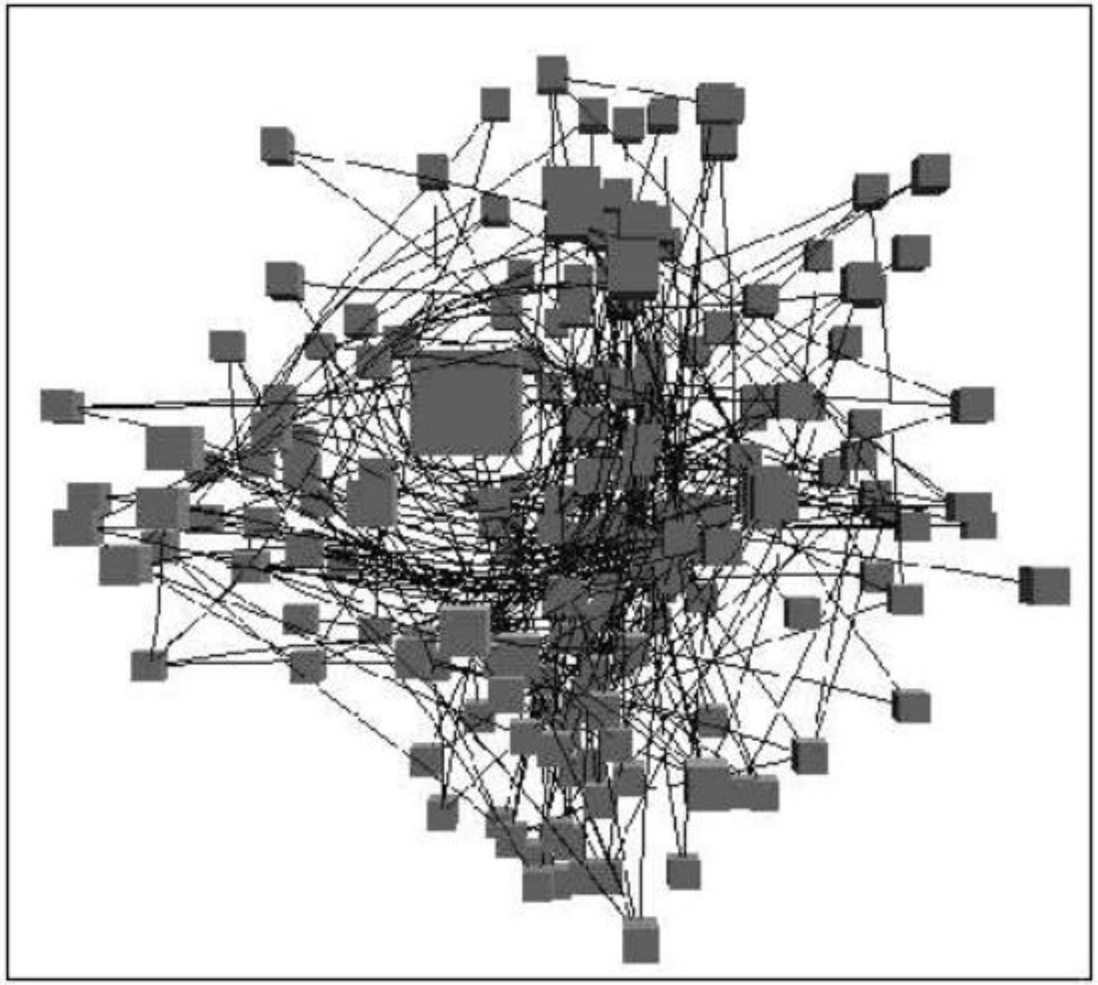
- 3D visual processing is slower
  - A simple fact of the visual system





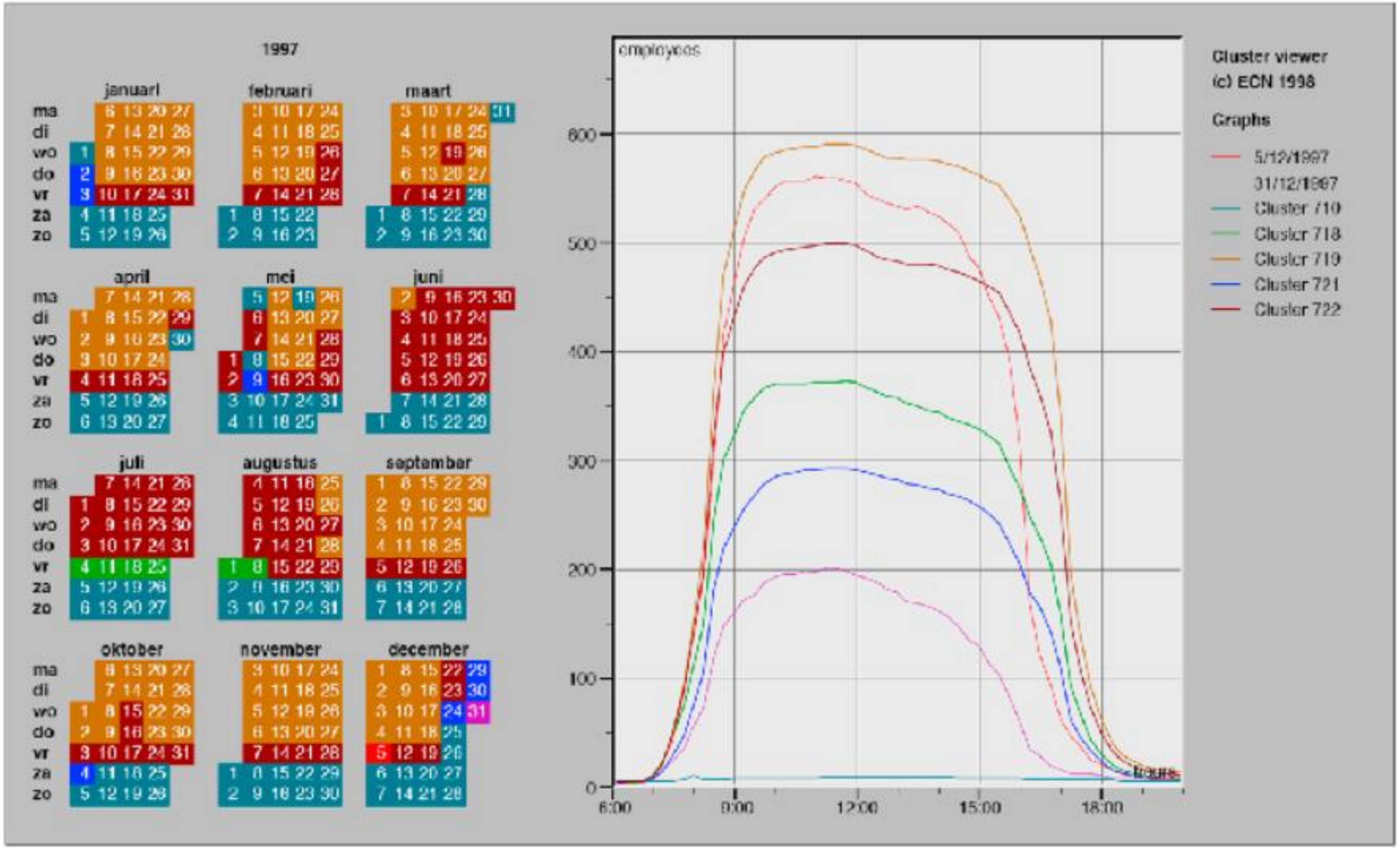
No unjustified 3D

- Occlusions hide information
- Interaction can solve this, but it costs time and cognitive load



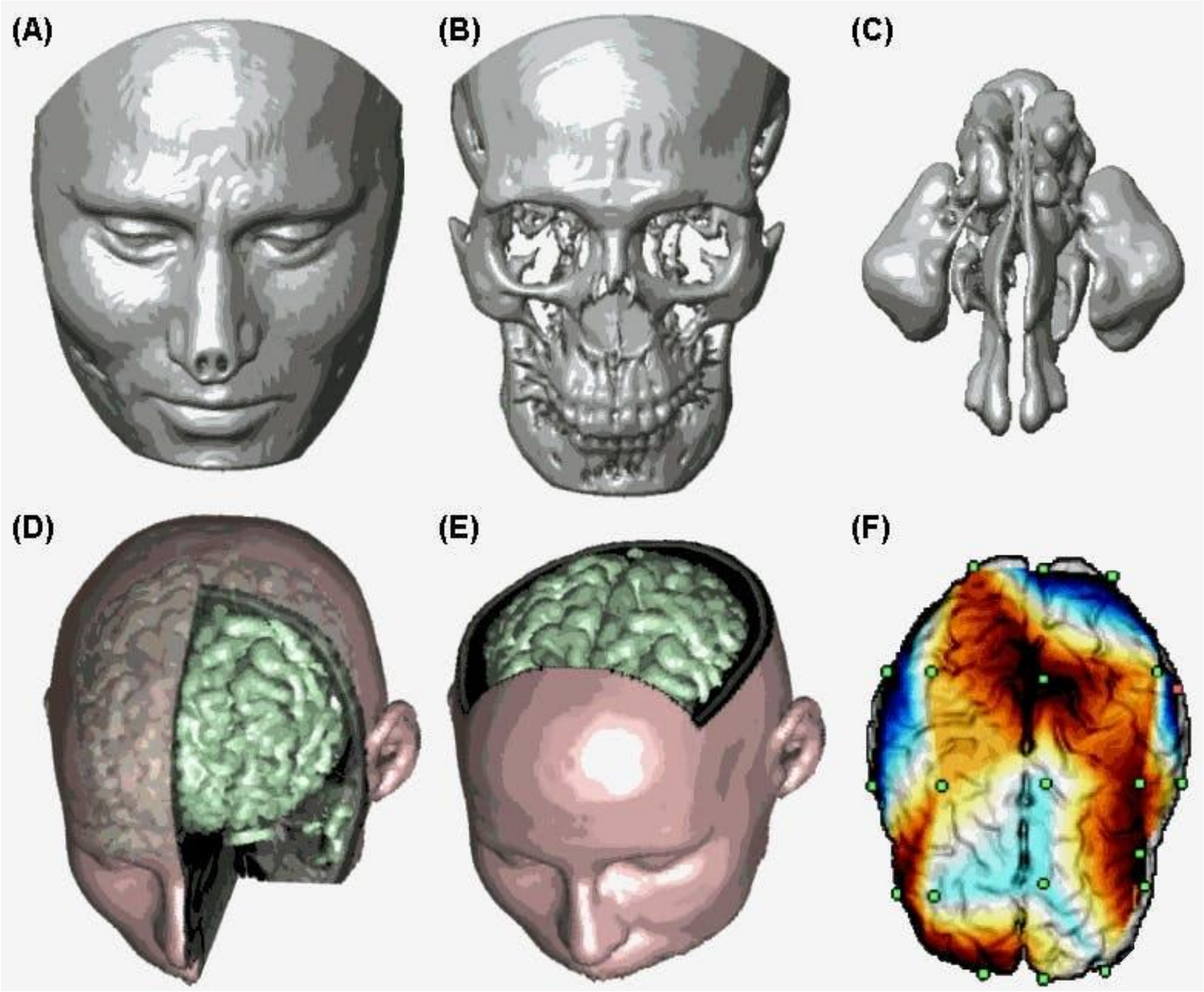
No unjustified 3D: solutions

- Juxtapose multiple views
  - E.g. calendar, superimposed 2D curves



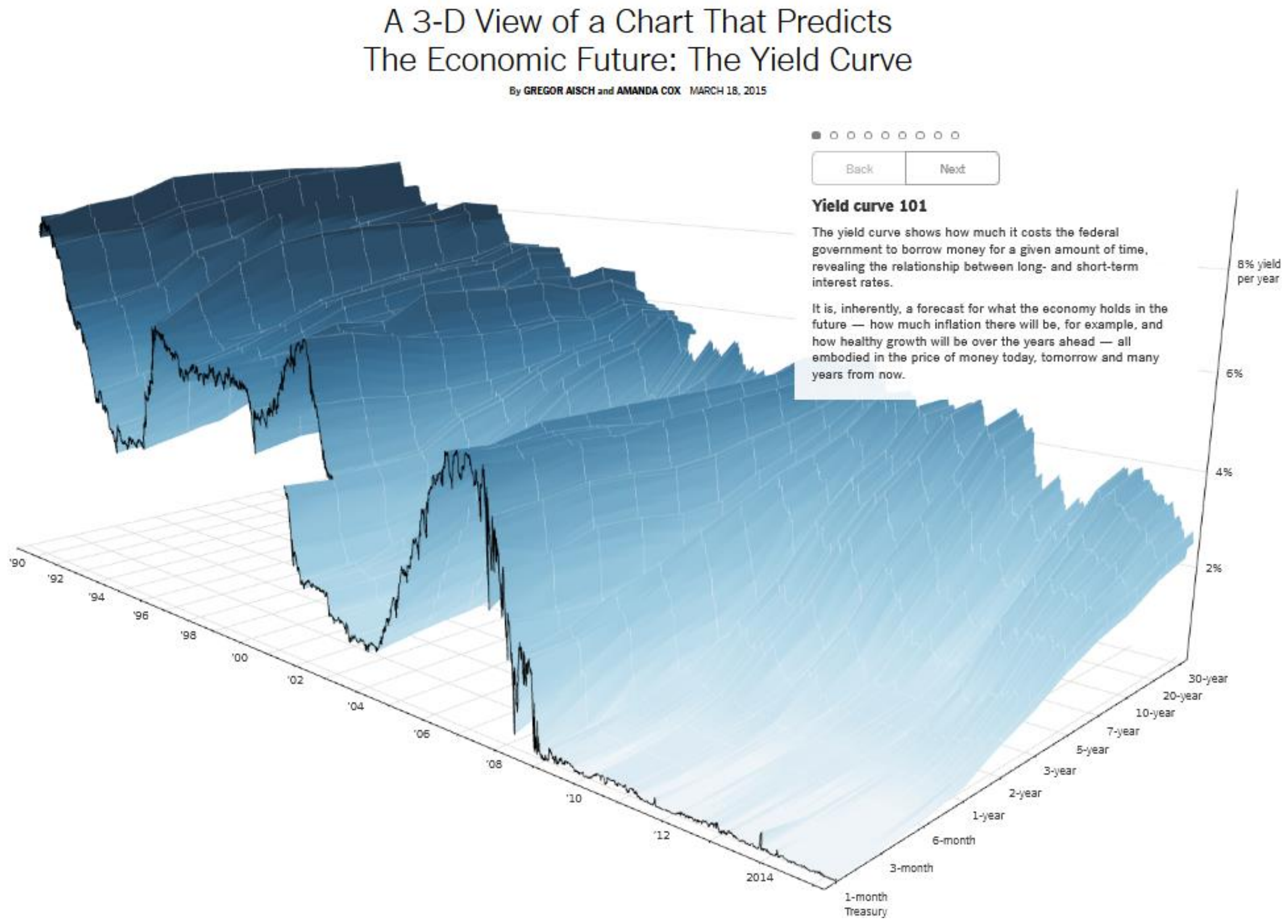
Justified 3D: Shape Perception

- If shape perception is the main task, 3D is often justified



Justified 3D: controlled views

- Carefully controlled viewpoints
- Optimized for the best views of the 3D data



https://www.nytimes.com/interactive/2015/03/19/upshot/3d-yield-curve-economic-growth.html

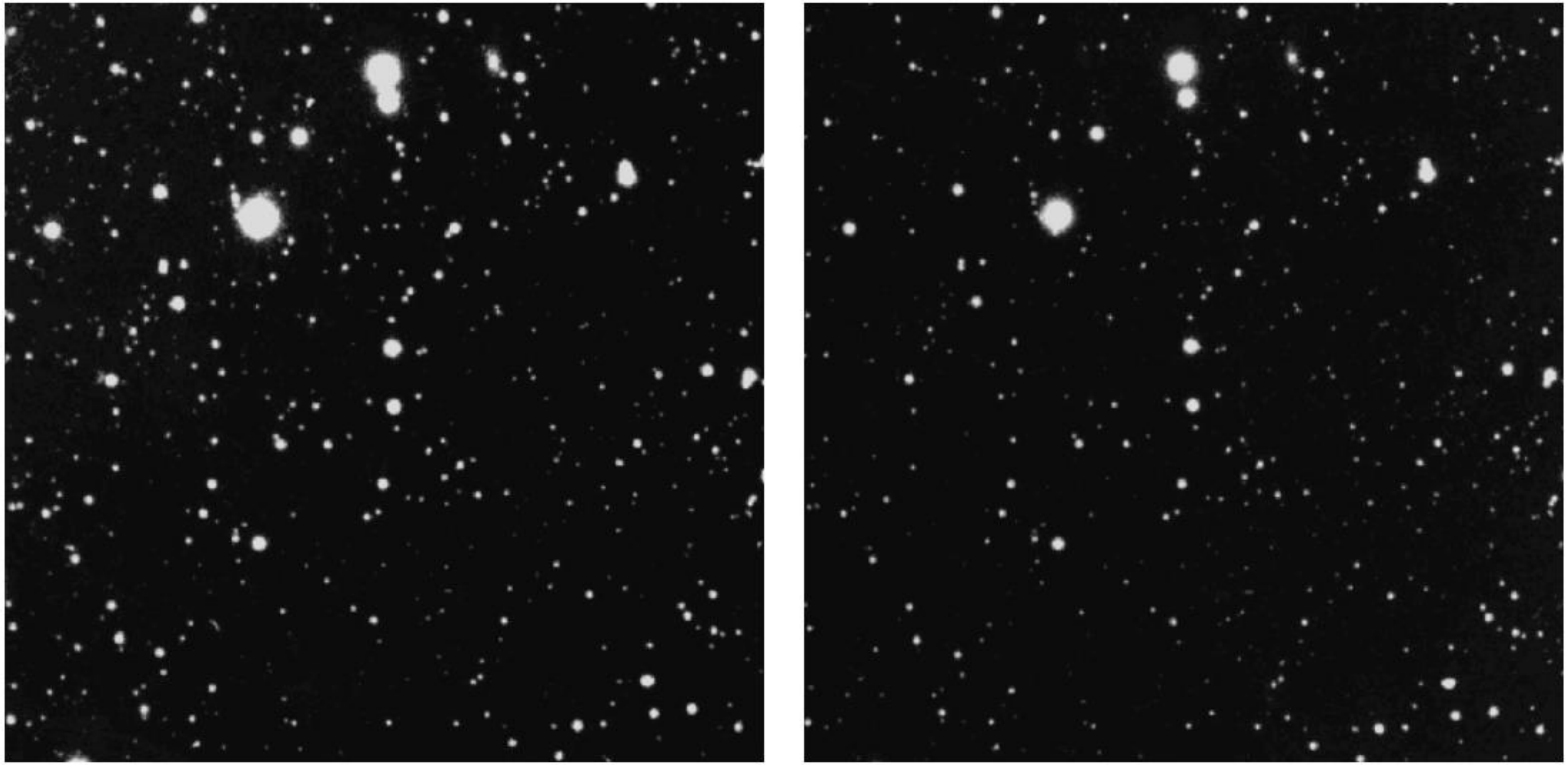
Eyes beat memory

- Principle: external cognition vs internal memory
  - Easy to compare side-by-side items
  - Hard to compare a visible item to your memory of another item

- Implications for animation:
  - Good for transitions and choreographed storytelling
  - Bad for data with many states/views

Eyes beat memory? Blink comparison

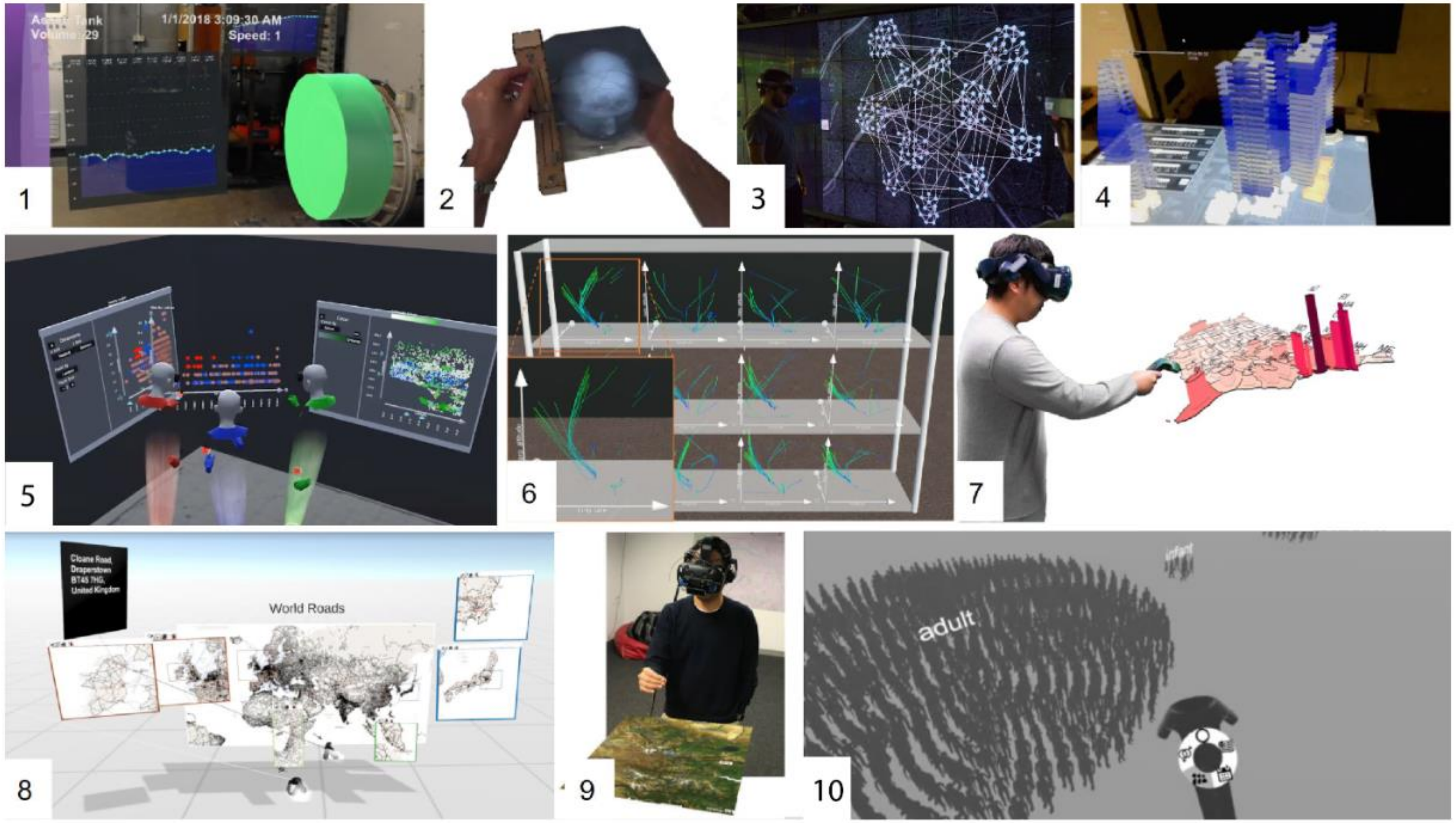
- Special case where animation (memory) beats side-by-side comparison (eyes)
  - Blink comparator used to discover Pluto
  - Change blindness!



https://www.sightsize.com/the-blink-comparator/

Resolution beats immersion

- Immersion is usually not needed **for abstract data**
  - No need for things like virtual reality
- Resolution is more important
  - Pixels are a scarce resource
- Not completely useless, though…
  - Spatial data (augmented reality)
  - Collaborative analytics
  - Complex interactions with data



Ens, Barrett, et al. "Grand challenges in immersive analytics." *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 2021.

Overview first, zoom and filter, details on demand

- Provide a summary/high-level view of the data
- Allow users to zoom into specific views of the data
    - Requires filtering the dataset to only render specified data
- Show more details when the users asks for it
    - Tooltips and other interactions

- Influential paper: Shneiderman, Ben. "The eyes have it: A task by data type taxonomy for information visualizations." *The craft of information visualization*. Morgan Kaufmann, 2003. 364-371.

Responsiveness is required

- Three categories of visual feedback:
  - 0.1 seconds: perceptual response
    - subsecond response for mouseover highlighting - ballistic motion
  - 1 second: immediate response
    - fast response after mouse click, button press - Fitts' Law limits on motor control
  - 10 seconds: brief tasks
    - bounded response after dialog box - mental model of heavyweight operation (file load)

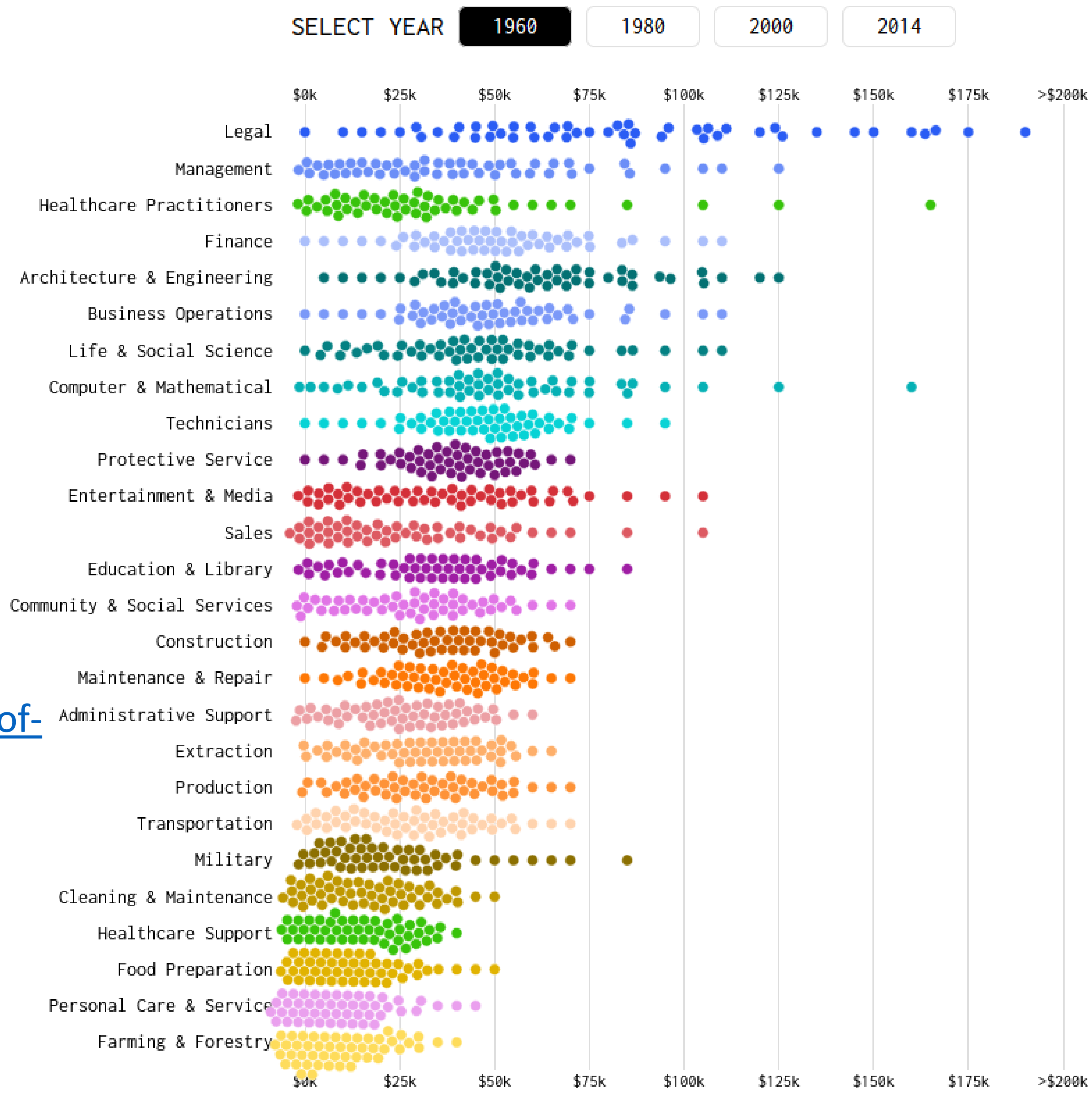
- Considerations:
  - Need 60 FPS rendering! → computationally expensive
  - Visual indicators for interactions: hourglass, progress bar, etc.

Function first, form next

- Start with functionality
  - Aesthetics can be changed afterwards, as refinement
  - Aesthetics are still important!
    - Secondary level of function
- Don’t start with aesthetics
  - Can’t retrofit functionality

Exercise

- Visual channels used?
  - E.g. channel X encodes attribute Y
- Marks used?
  - E.g. mark of type X encodes item Y
- Any suggested improvements?



https://flowingdata.com/2016/06/28/distributions-of-annual-income/

Exercise

- Visual channels used?
  - E.g. channel X encodes attribute Y
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- Any suggested improvements?

https://project-ukko.net/map.html

Exercise

- Visual channels used?
  - E.g. channel X encodes attribute Y
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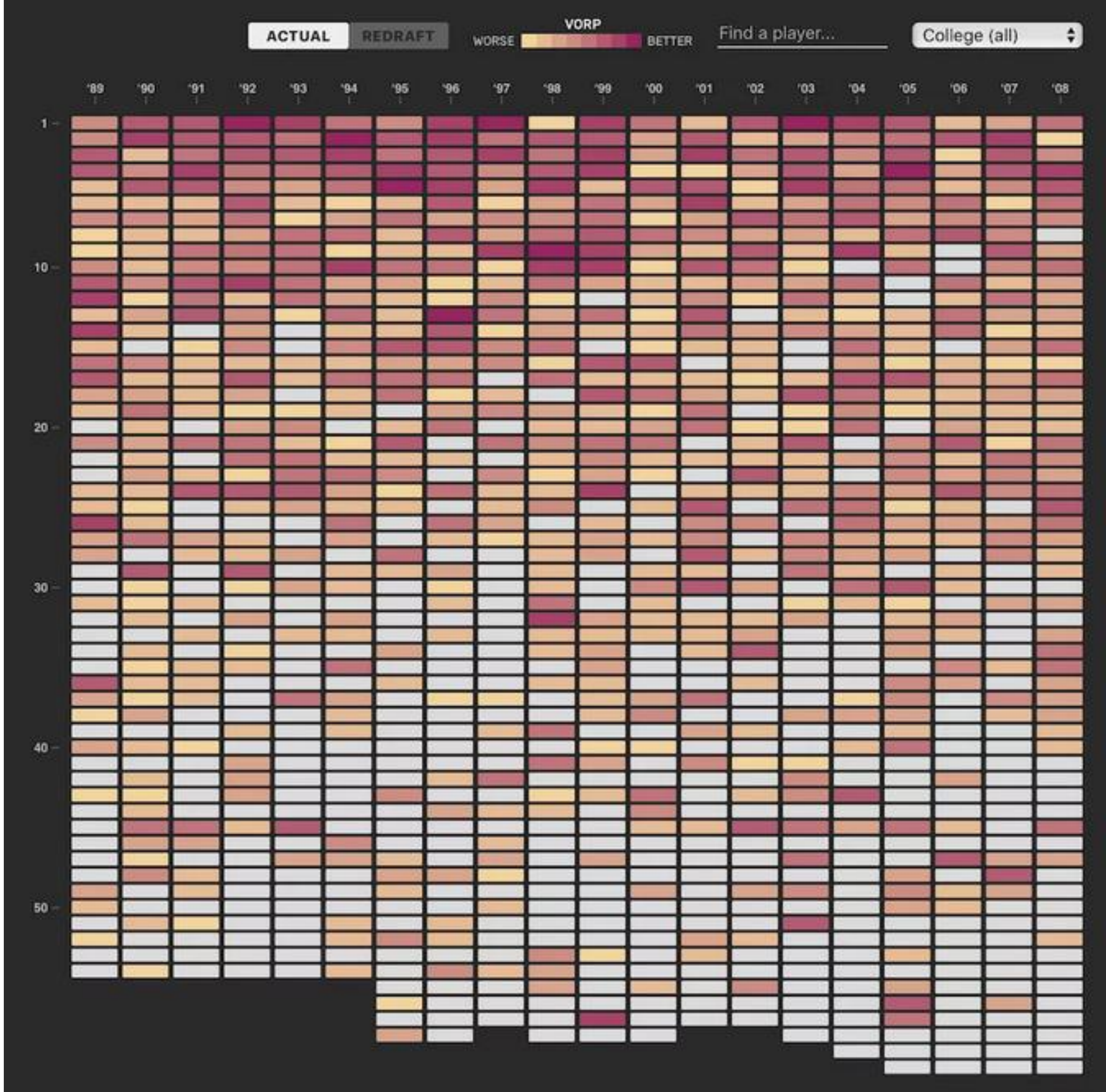
  - E.g. mark of type X encodes item Y
- Any suggested improvements?

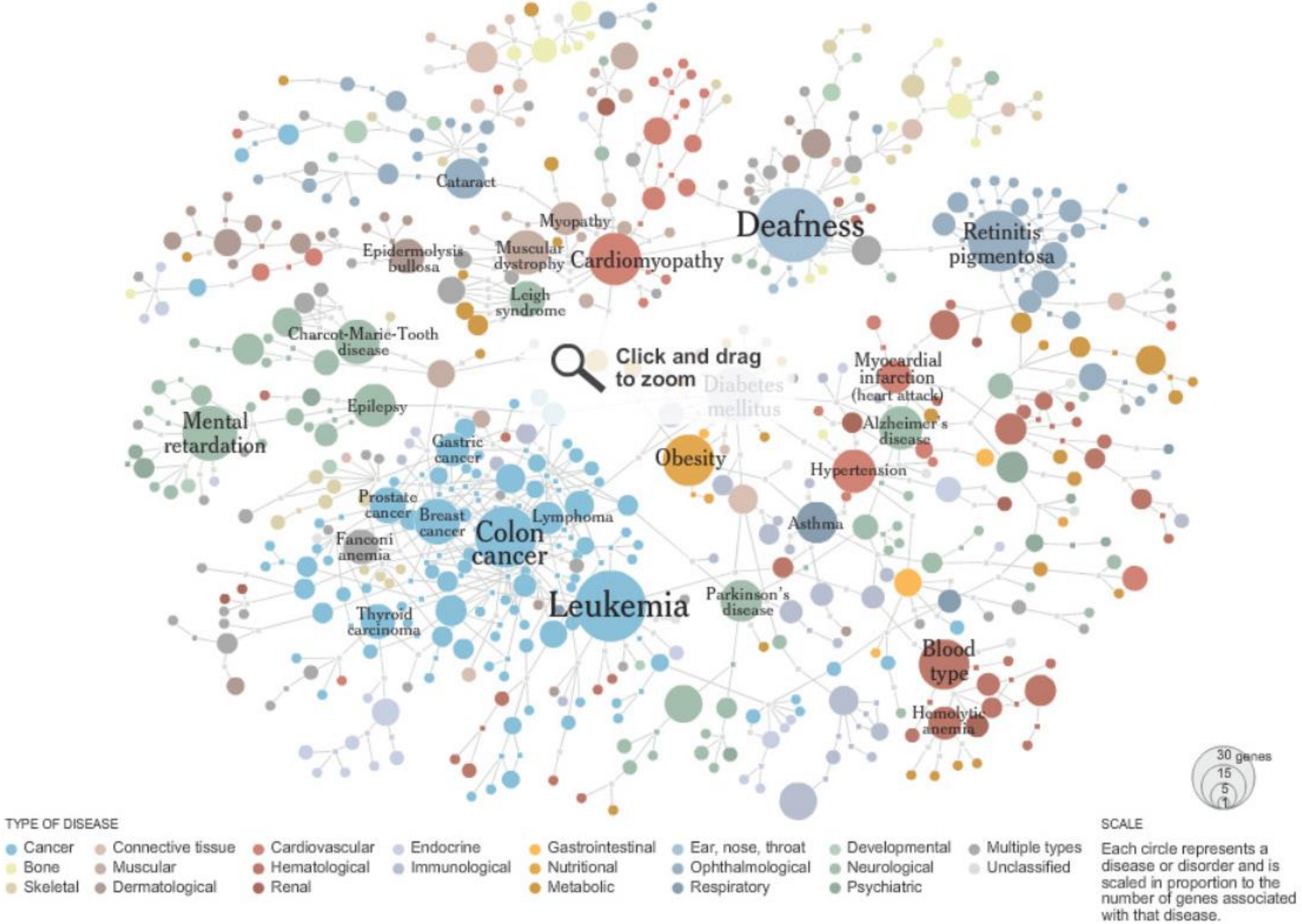
https://pudding.cool/2017/03/redraft/



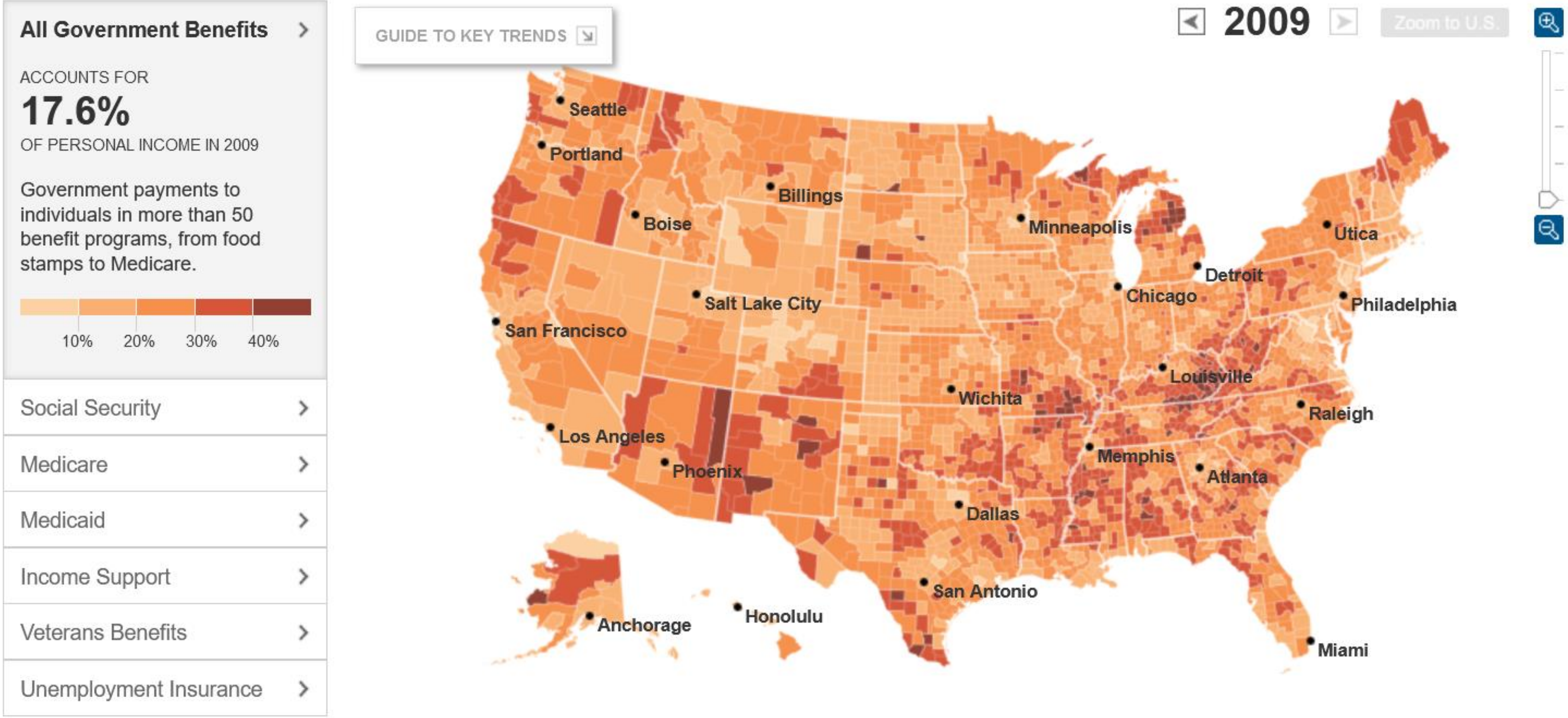
Exercise

- Visual channe
  - E.g. channe
- Marks used?
  - E.g. mark of
- Any suggeste

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



Exercise



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