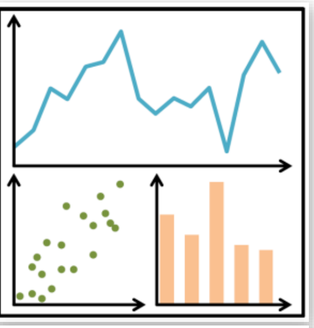
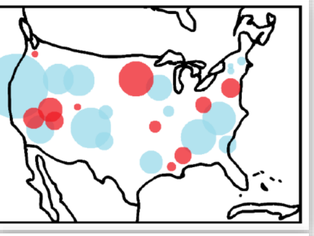
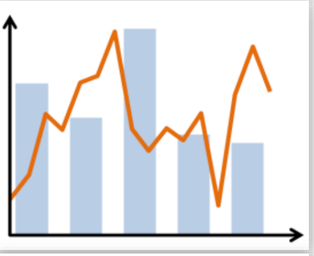
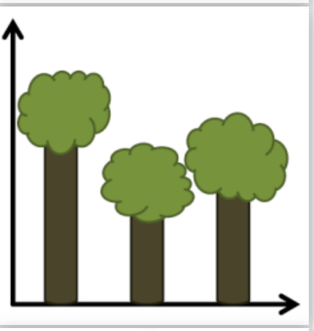
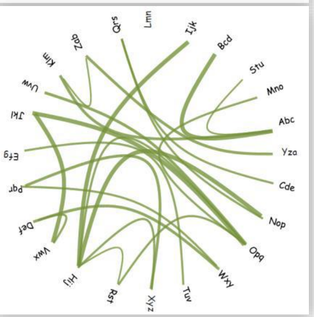






Color, Popout, Illusions

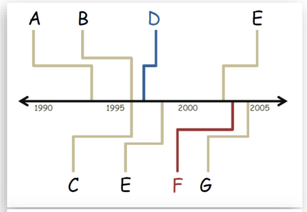
CS 7250

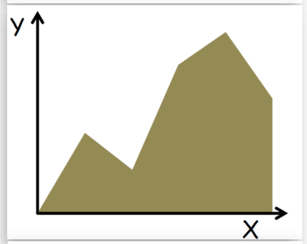
SPRING 2020

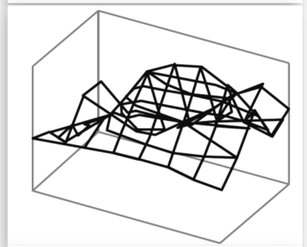
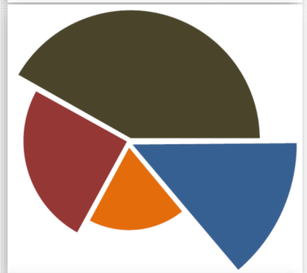
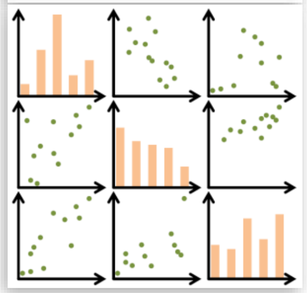
Prof. Cody Dunne

NORTHEASTERN UNIVERSITY

Slides and inspiration from Michelle Borkin, Krzysztof Gajos, Hanspeter Pfister, Miriah Meyer, Jonathan Schwabish, and David Sprague





Burning Questions?

Previously, on CS 7250…

“…avoiding catastrophe becomes the first principle in bringing color to information: above all, do no harm.”

-Edward Tufte

Color Maps

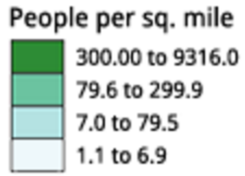
Three Main Types:

Categorical

Does not imply magnitude differences (categorical/nominal data)

Distinct hues with similar emphasis

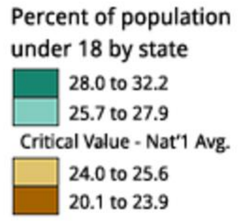
Sequential



Best for ordered data that progresses from low to high (ordinal, quantitative data)

Darkness (lightness) channel effectively employed

Diverging

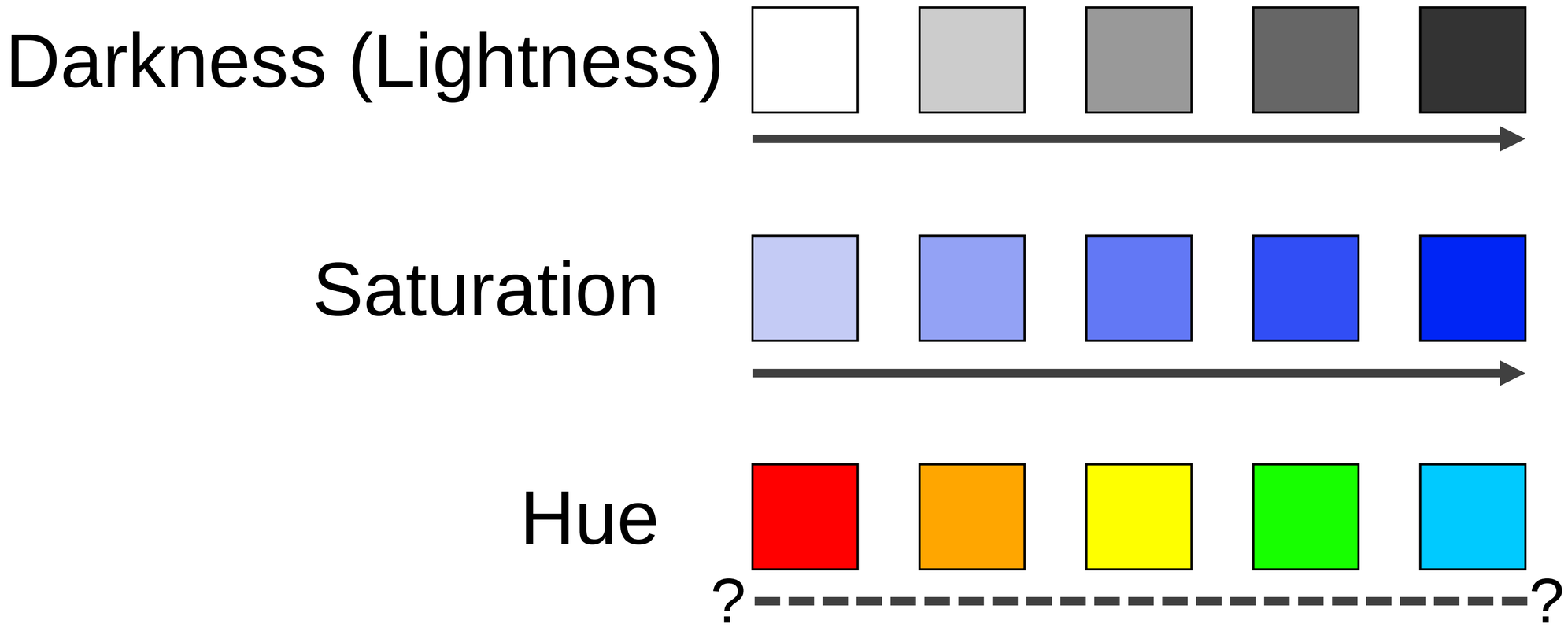


For data with a “diverging” (mid) point (quantitative data)

Equal emphasis on mid-range critical values and extremes at both ends of the data range

Brewer, 1994

Color Vocabulary and Perceptual Ordering

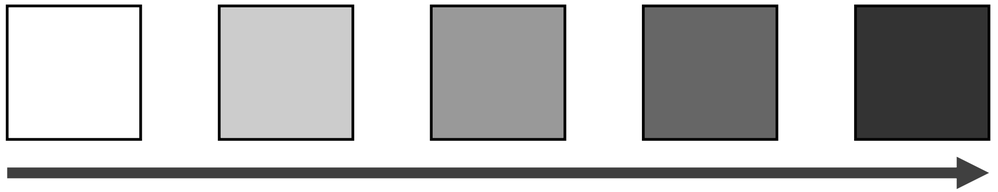


“Get it right in black and white.”

-Maureen Stone

Stone, 2010

Darkness (Lightness) Channel



- No edges without darkness difference
- No shading without darkness variation
- Has higher spatial sensitivity than color channels
- Contrast defines legibility, attention, layering
- Controlling darkness is primary rule of design

Based on Slide by Hanpseter Pfister

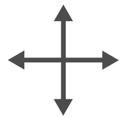
Color

- Color Encoding
  - Hue
  - Saturation
  - Luminance

- Color Map
  - Categorical

  - Ordered
    - *Sequential*
    - *Diverging*

  - Bivariate



Size, Angle, Curvature, ...

- Length

- Angle

- Area

- Curvature

- Volume

Shape

Motion

- Motion
  Direction, Rate, Frequency, ...

Now, on CS 7250…

COLOR

GOALS FOR TODAY: LEARN HOW…

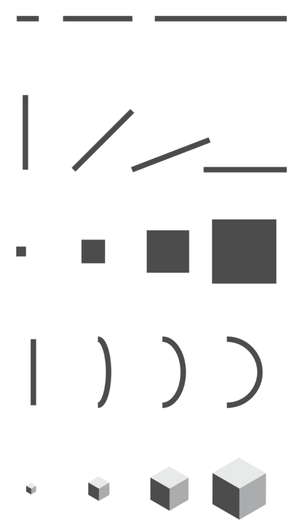
- …to effectively use color as a channel for visual encodings including different colormap types.
- …we process color in the visual system.
- …individual color differences (i.e., colorblindness) should be accommodated in visualizations.
- …interactions can occur between colors and with lighting.
- …illusions and tricks can affect perception.

Color

- Color Encoding
  - Hue
  - Saturation
  - Luminance
    ≈Lightness (Darkness)
- Color Map
  - Categorical
  - Ordered
    - *Sequential*
    - *Diverging*
  - Bivariate

Size, Angle, Curvature, ...

- Length
- Angle
- Area
- Curvature
- Volume

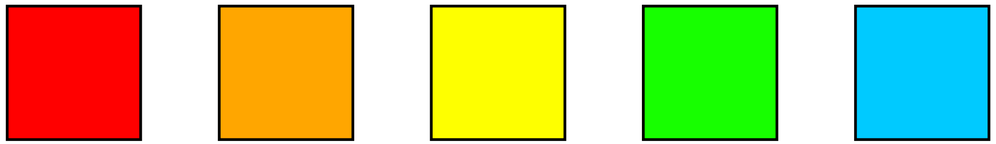


Shape

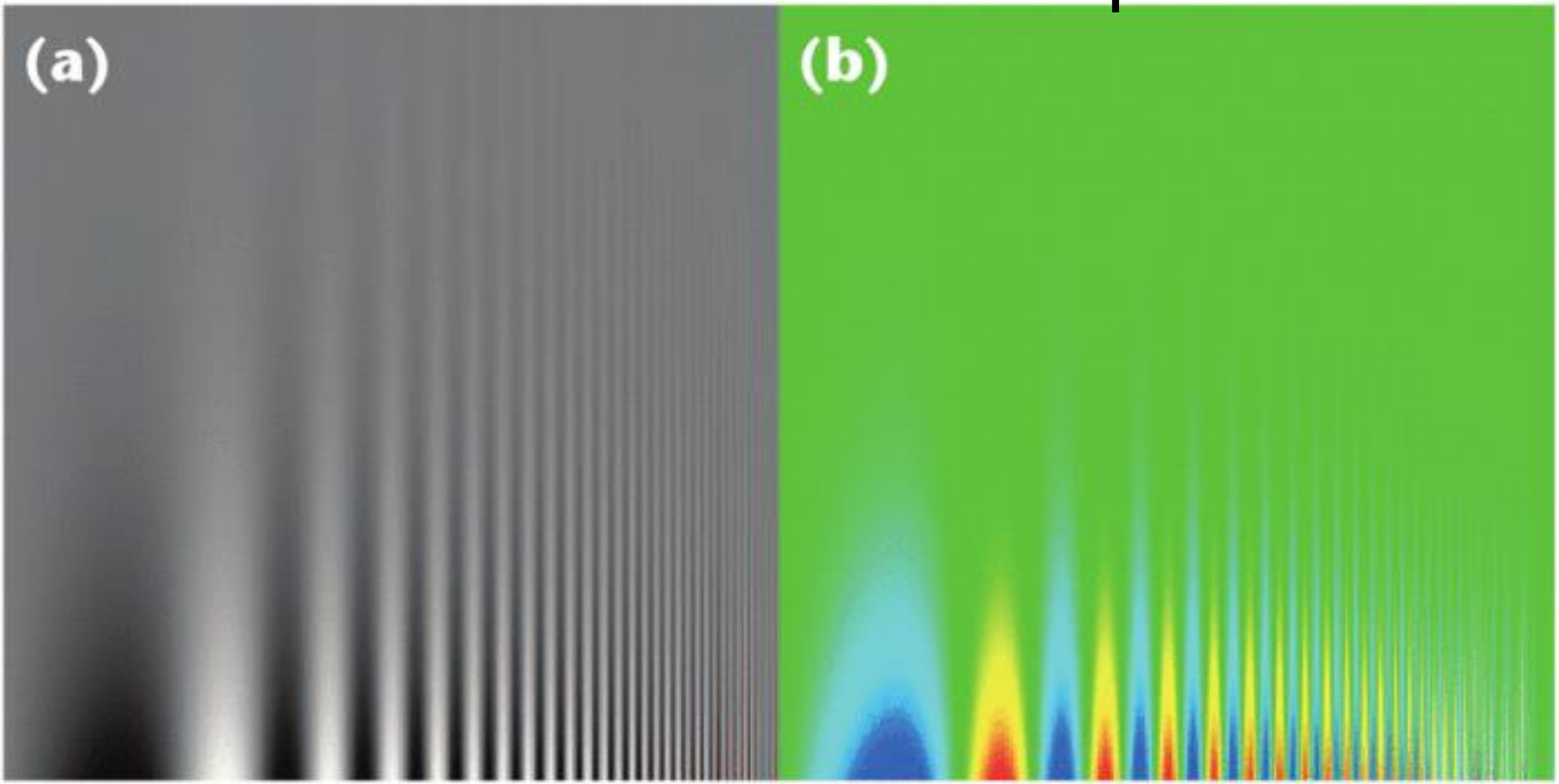
Motion

- Motion
  Direction, Rate, Frequency, ...

Rainbow Color Map (Hue)

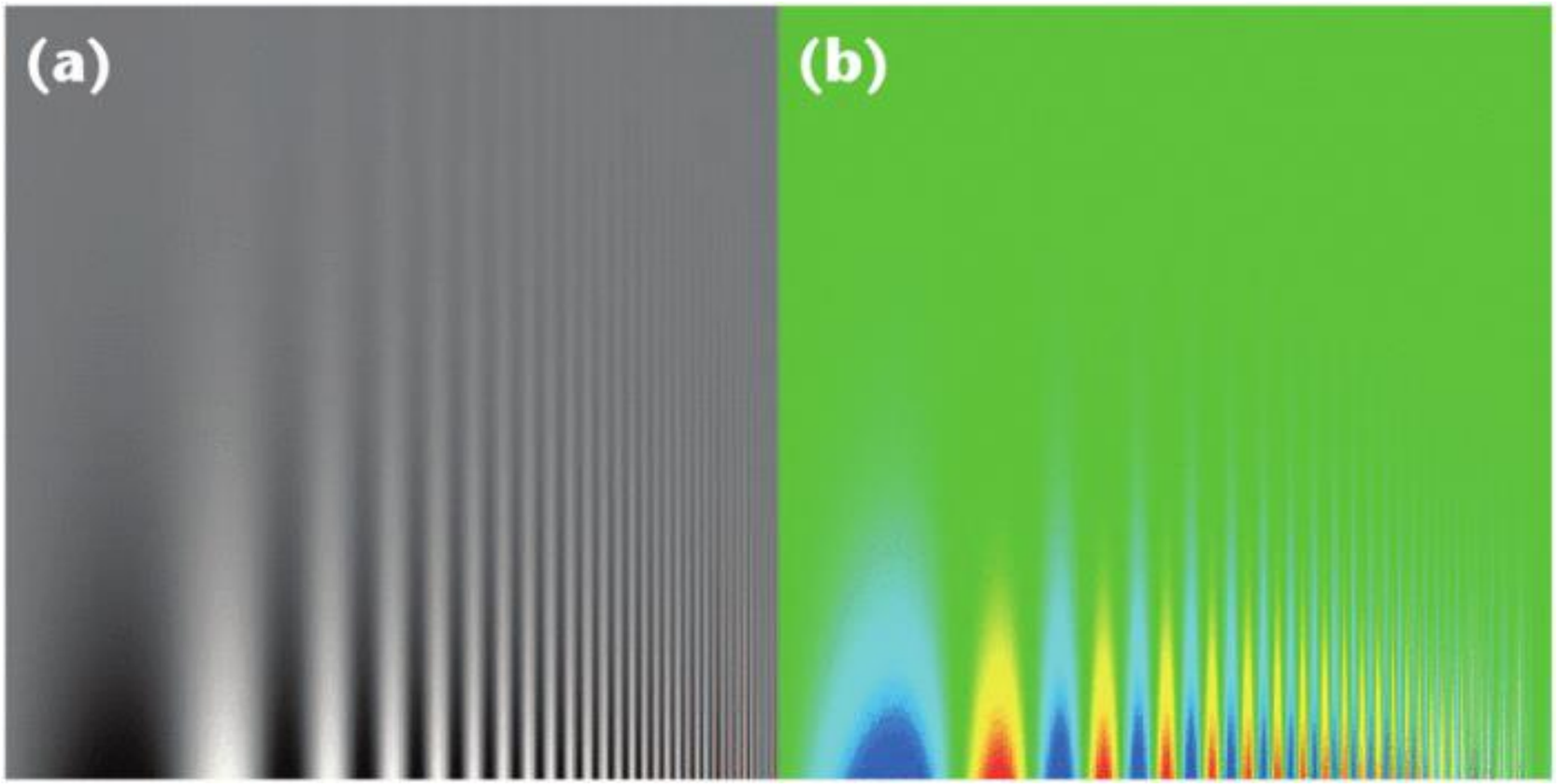


Rainbow Color Map



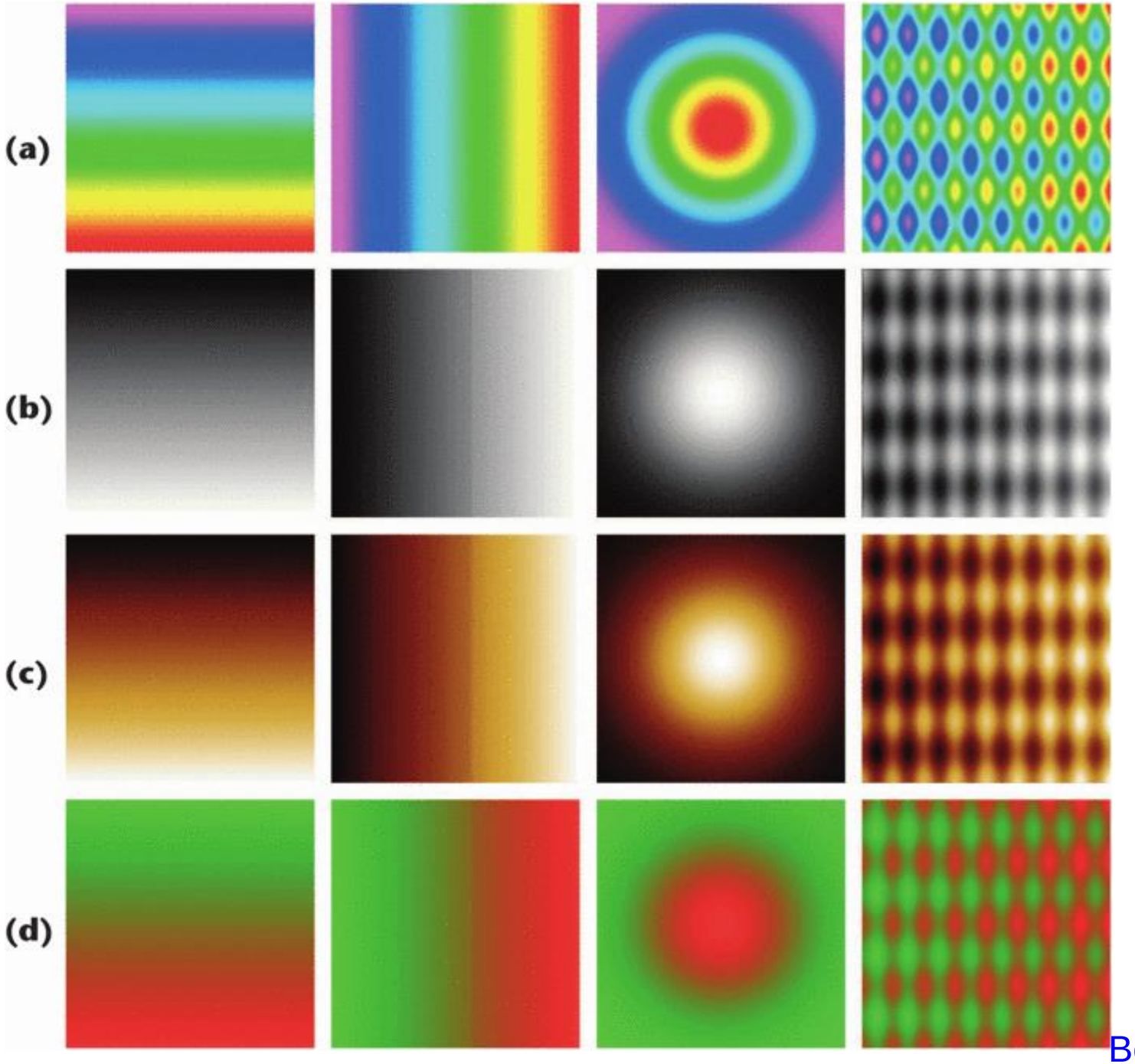
Borkin et al., 2011

Rainbow Color Map



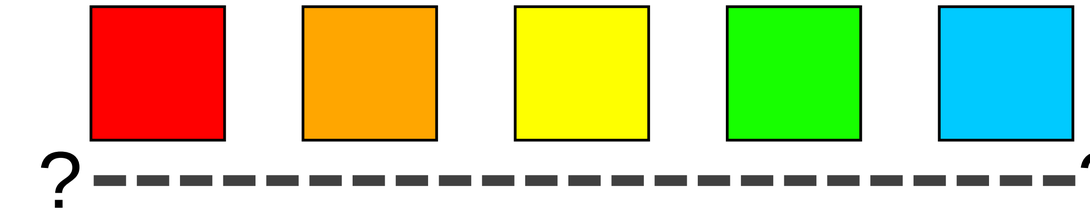
- No darkness variation (obscures details)
- Viewers perceive sharp transitions in color as sharp transitions in the data, even when this is not the case (misleading)

Borkin et al., 2011

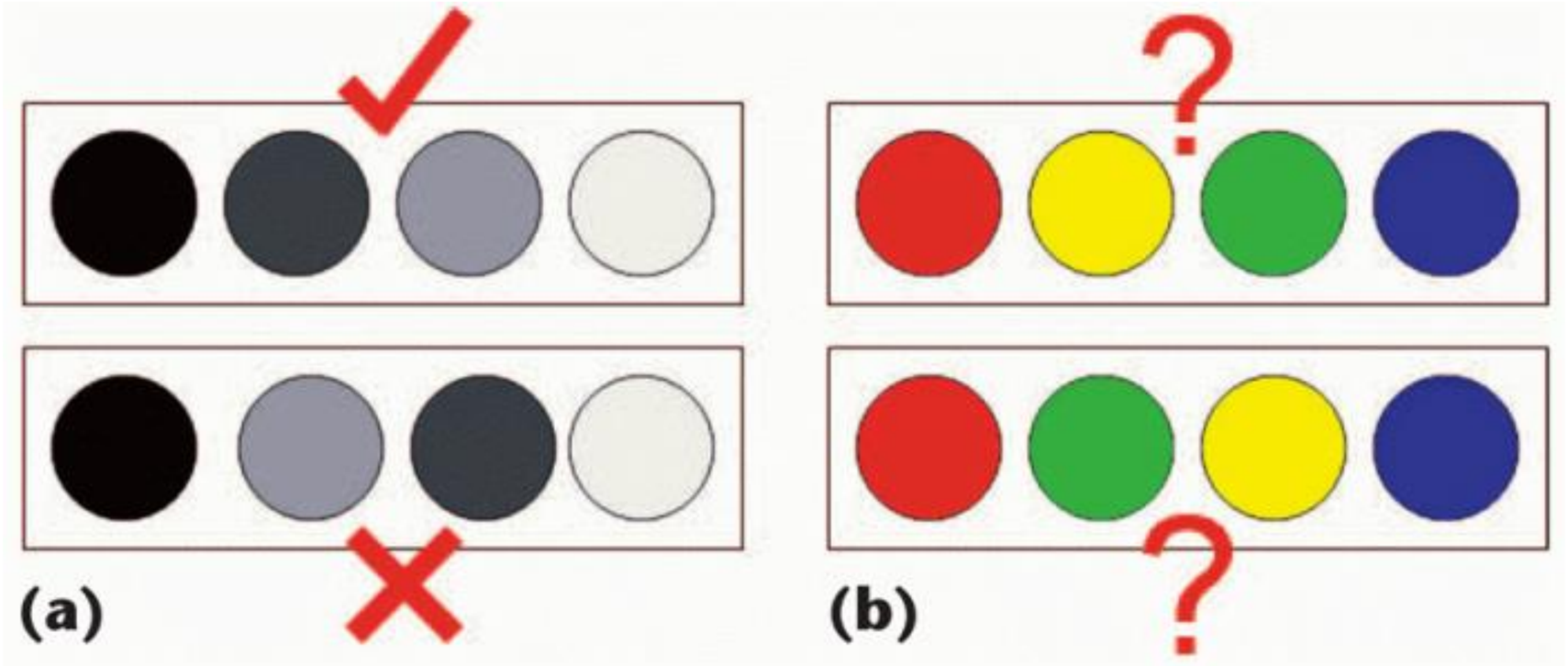


Borland & Russell, 2007

Rainbow Color Map (Hue)



No perceptual ordering (confusing)



Borland & Russell, 2007

Rainbow Color Map

Rainbow:

3D: 39%

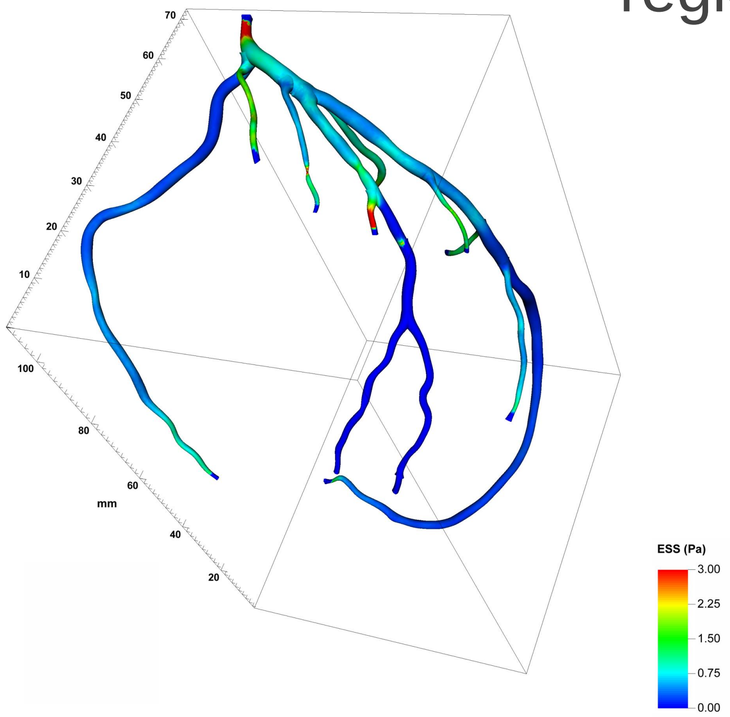
2D: 62%

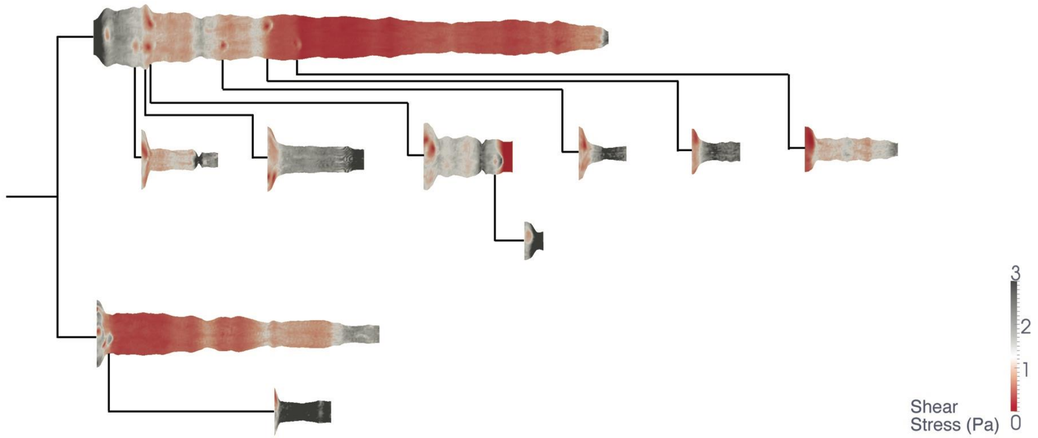
How many diseased regions found?

Diverging:

3D: 71% (*Δ +31%*)

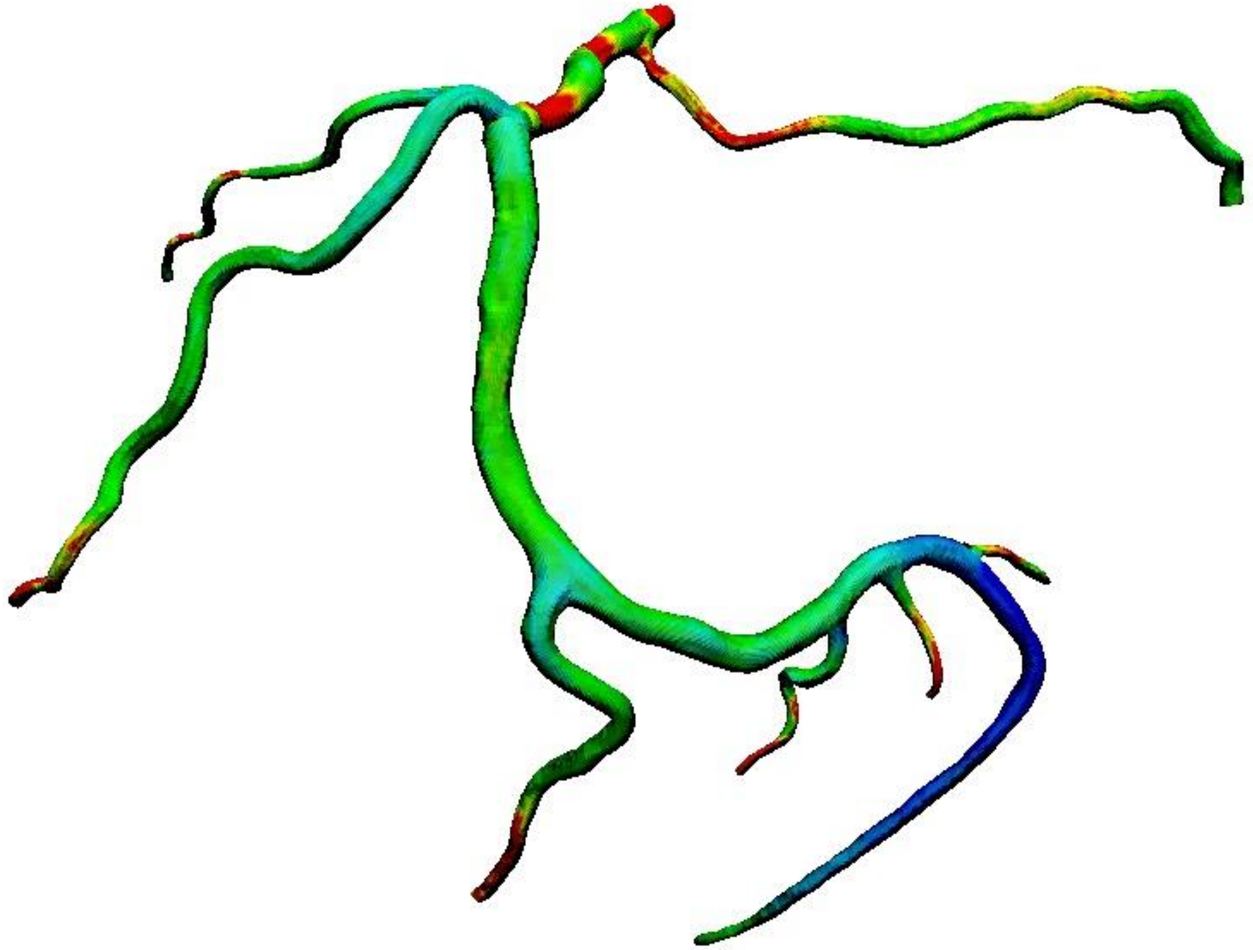
2D: 91% (*Δ +29%*)





[Borkin et al., 2011]

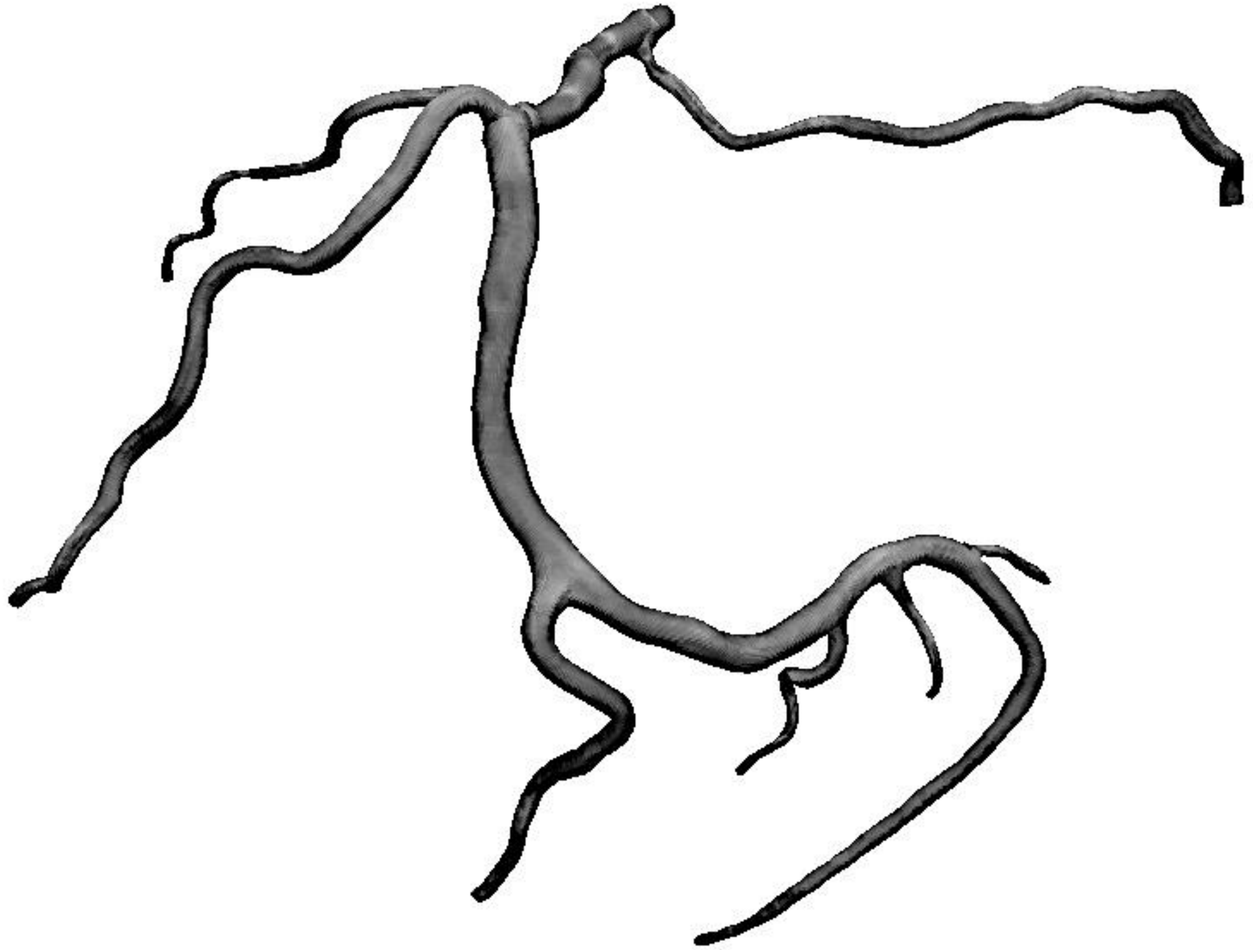
“Get it right in black and white.”



39% Diseased Regions Found

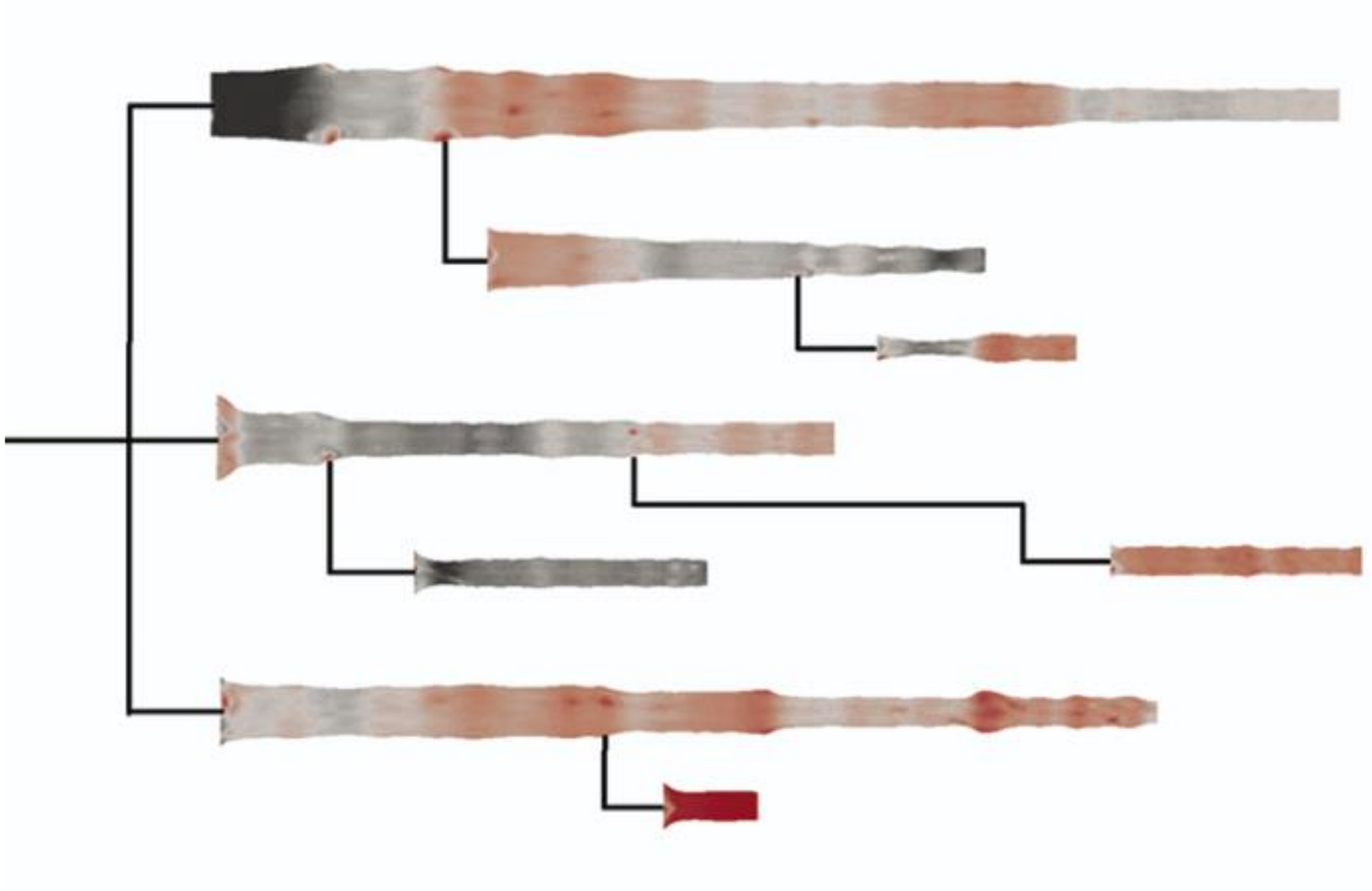
Borkin et al., 2011

“Get it right in black and white.”



Borkin et al., 2011

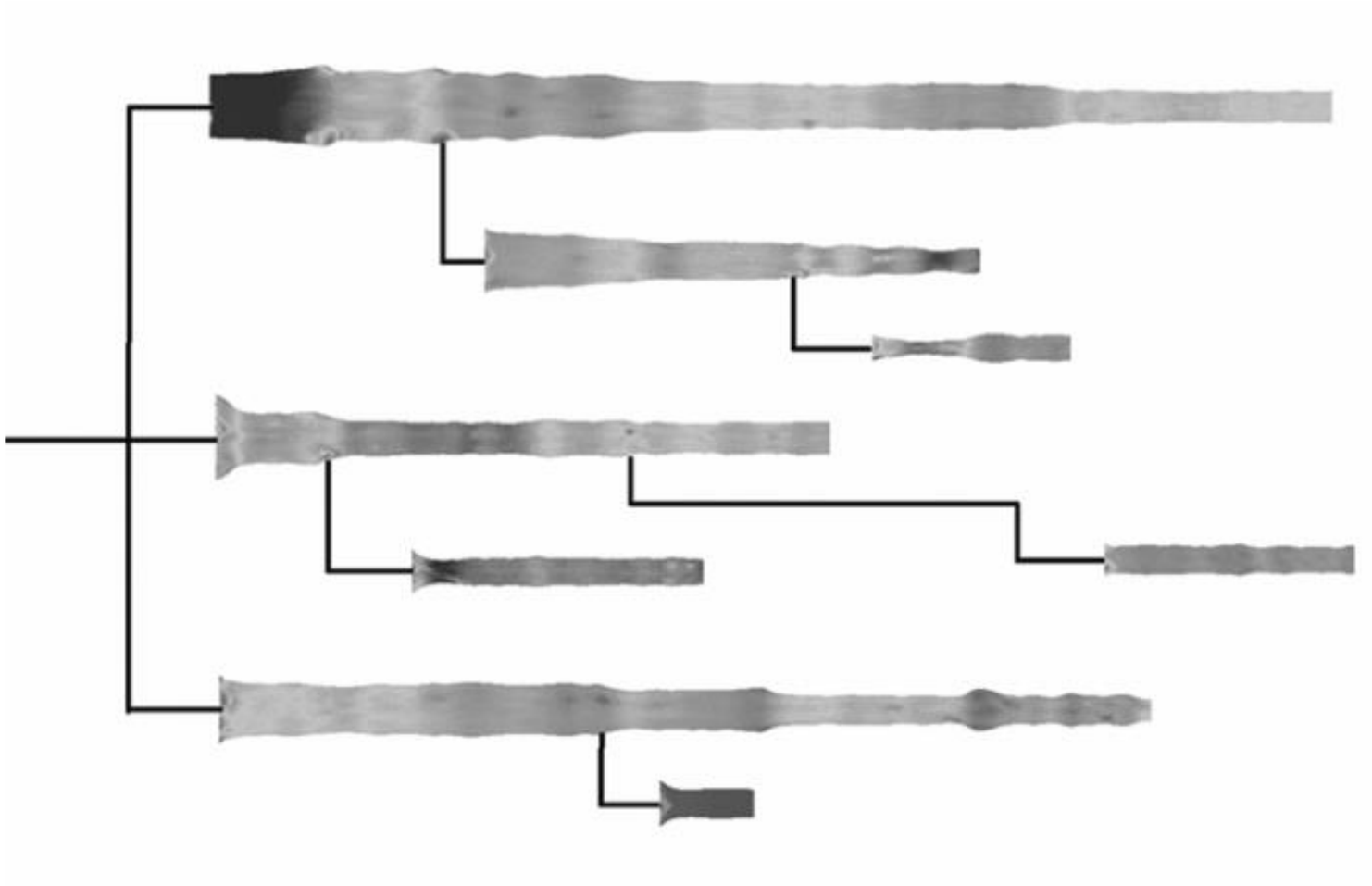
“Get it right in black and white.”



91% Diseased Regions Found

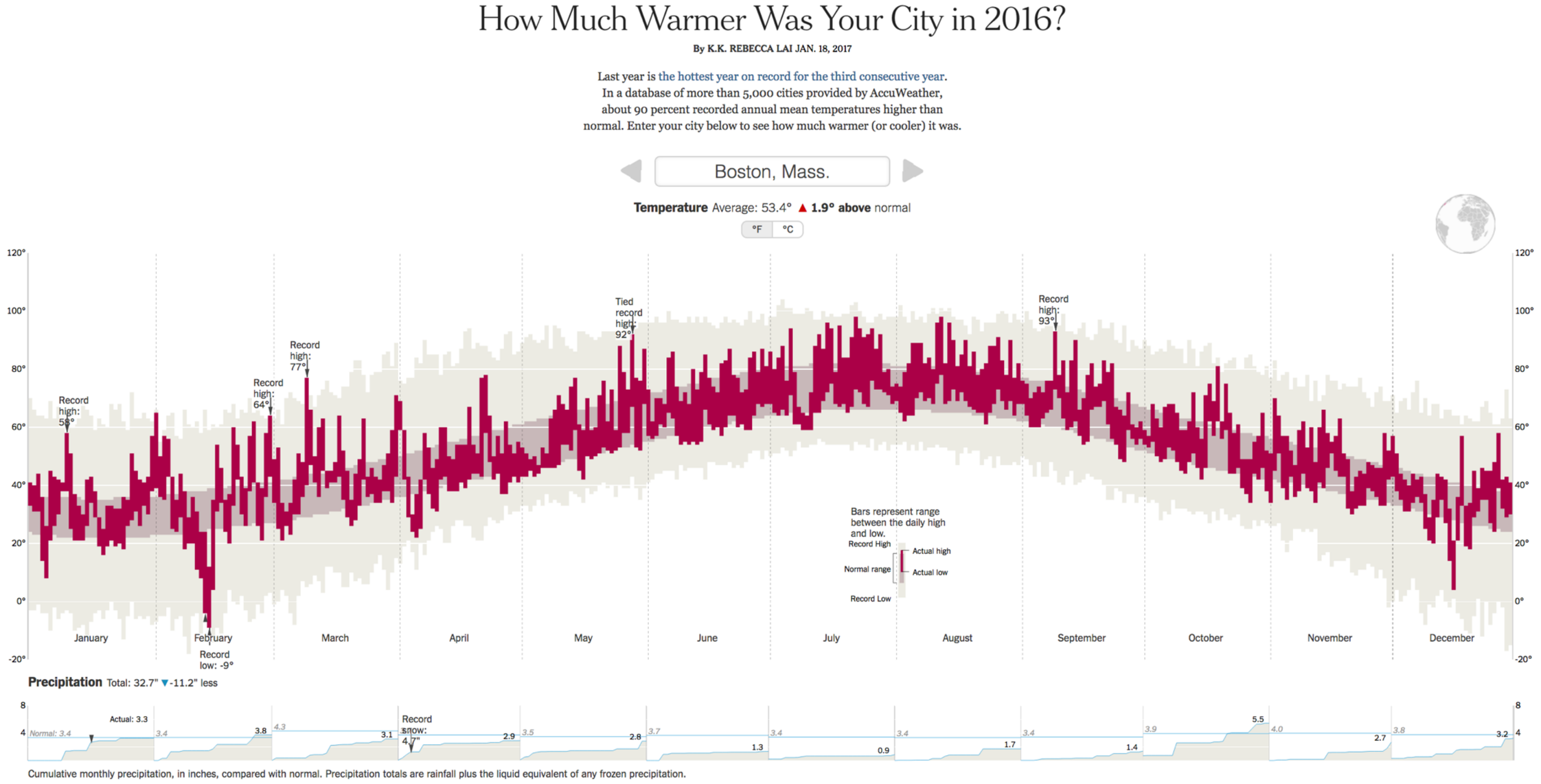
Borkin et al., 2011

“Get it right in black and white.”



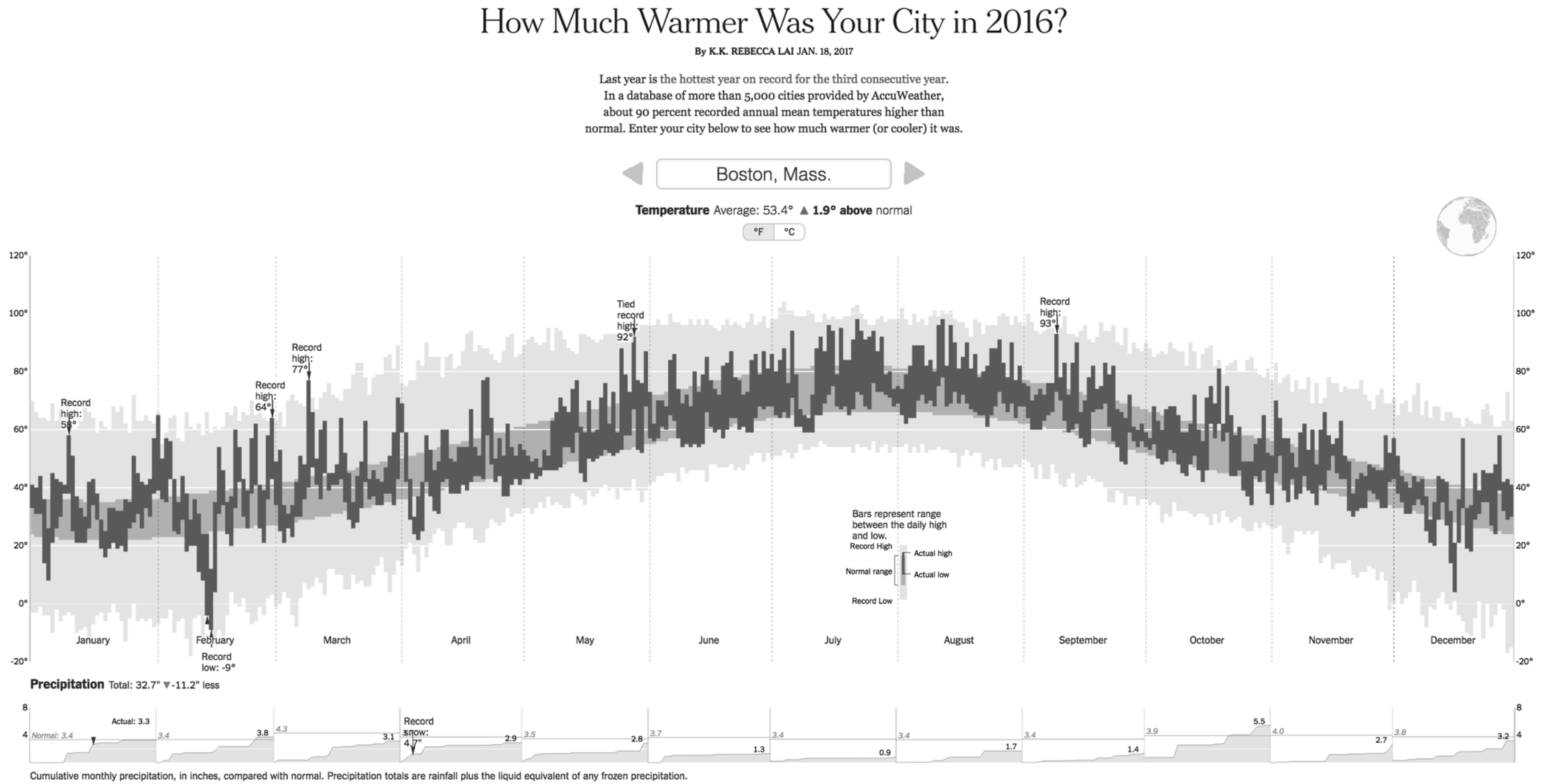
Borkin et al., 2011

“Get it right in black and white.”



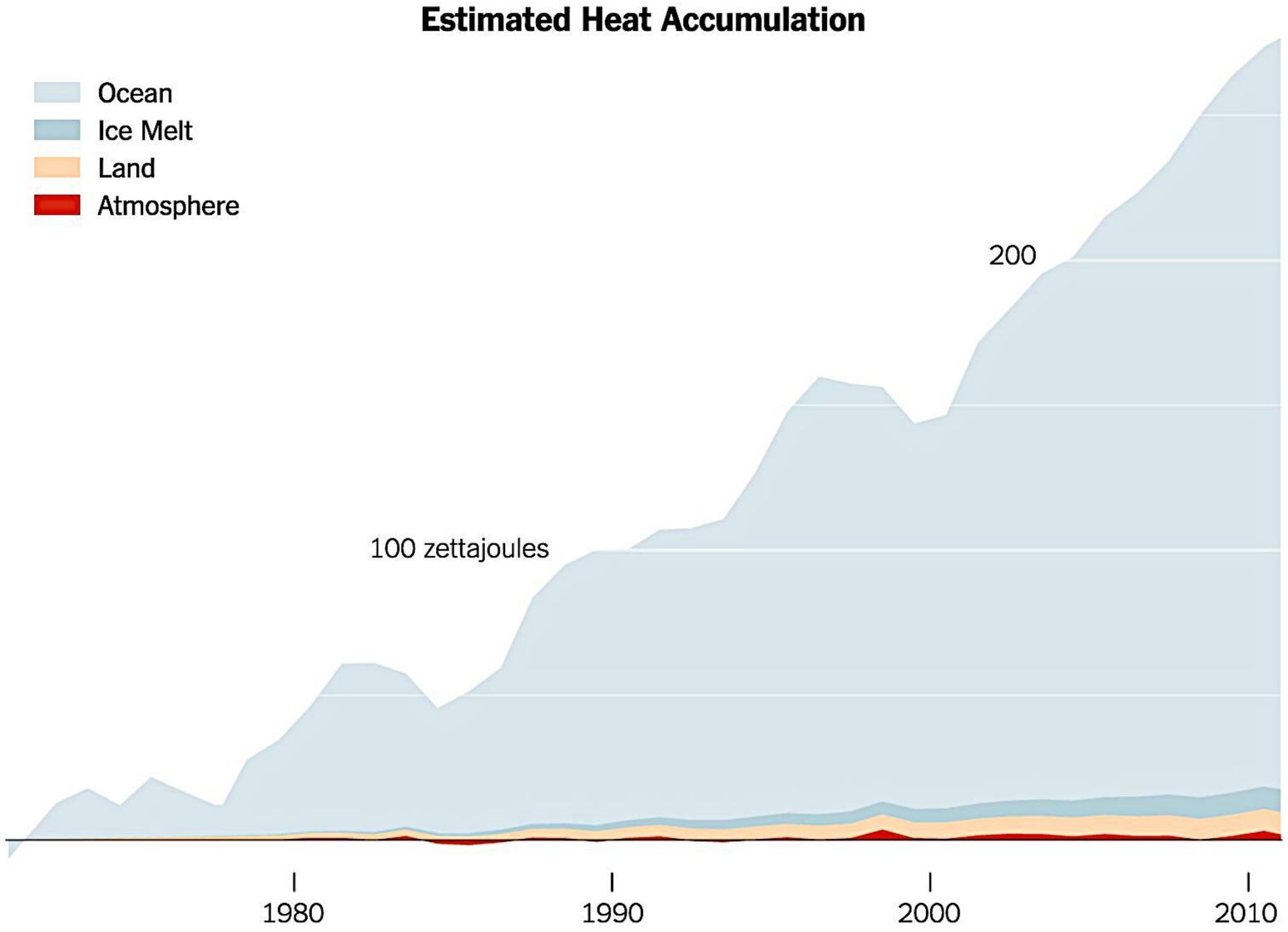
NY Times, 2017

“Get it right in black and white.”

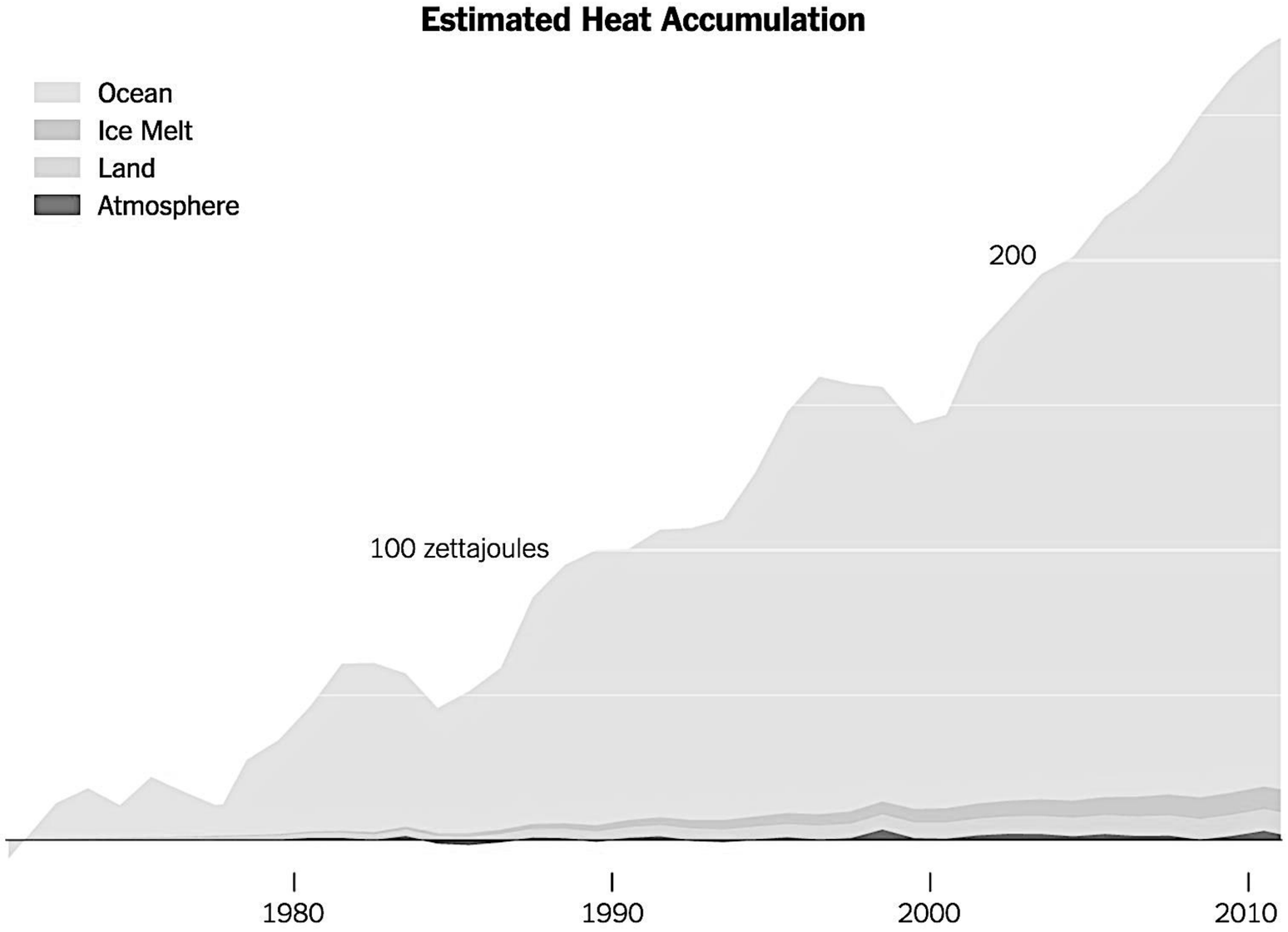


NY Times, 2017

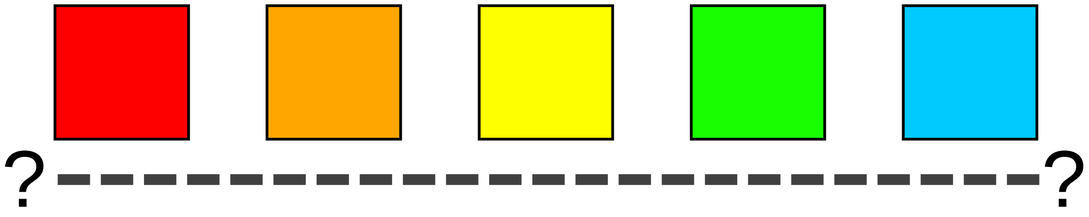
“Get it right in black and white.”



“Get it right in black and white.”



Rainbow Color Map (Hue)

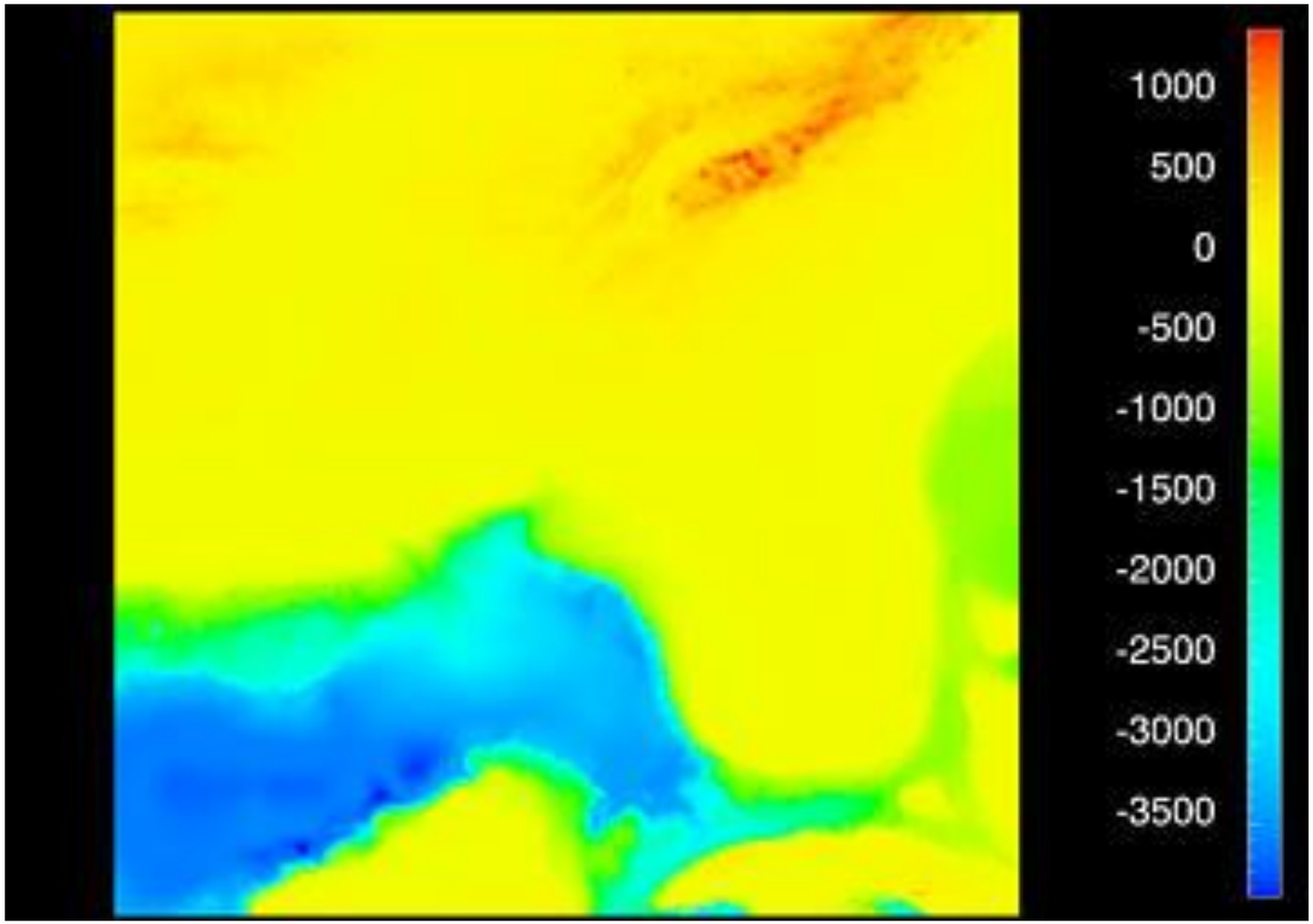


Why this color map is a poor choice for quantitative data…

- No perceptual ordering (confusing)
- No darkness variation (obscures details)
- Viewers perceive sharp transitions in color as sharp transitions in the data, even when this is not the case (misleading)

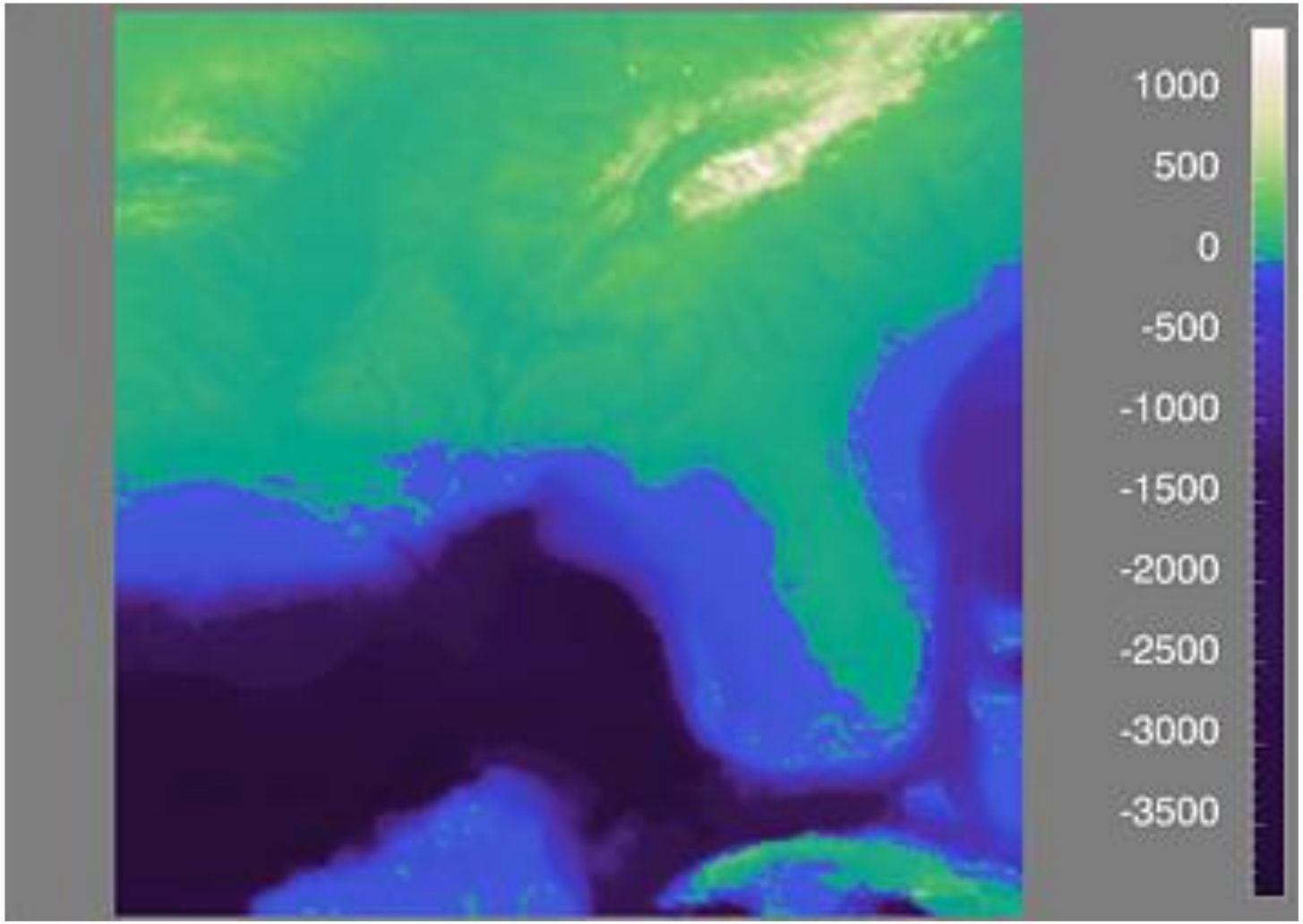
Borland & Russell, 2007)

Color Maps



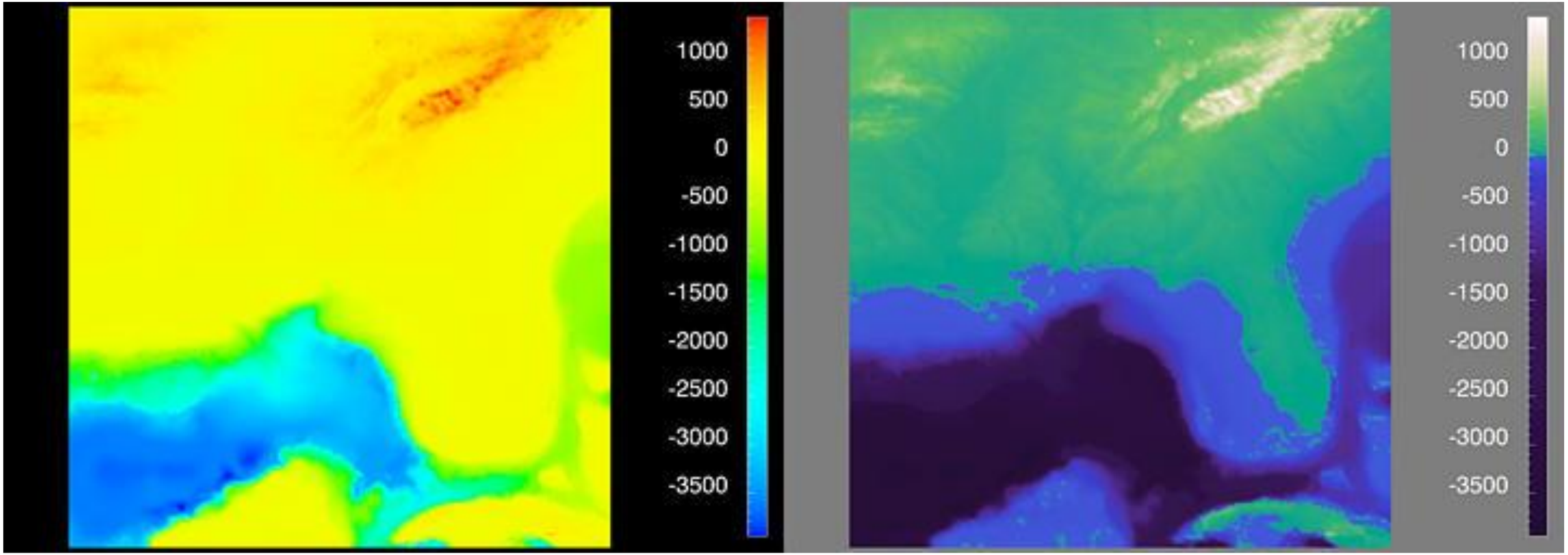
Rogowitz & Treinish, 1996

Color Maps



Rogowitz & Treinish, 1996

Color Maps



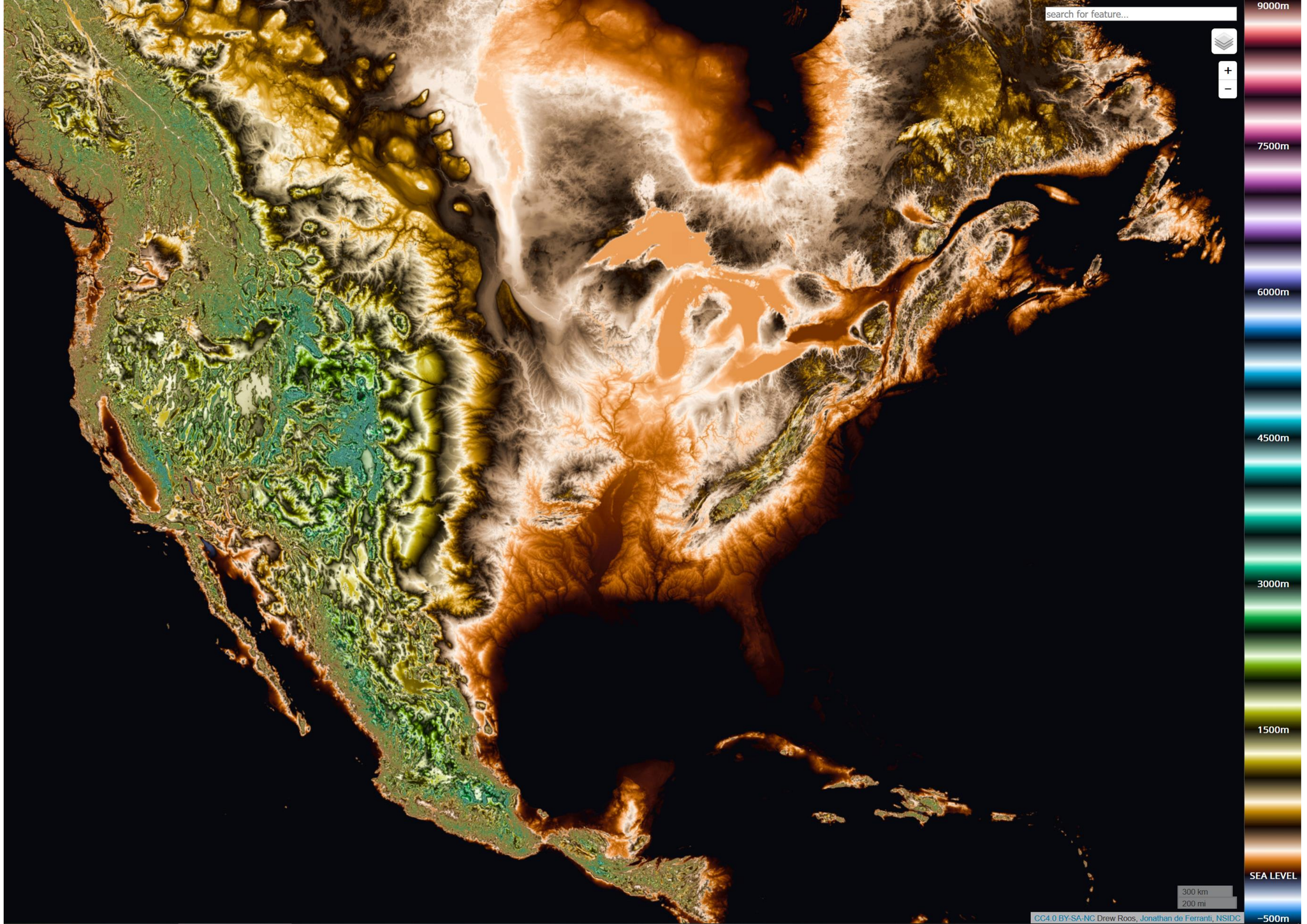
Sequential (possibly wrong)

Diverging

Sequential rainbow (wrong!)

Rogowitz & Treinish, 1996

Roos, 2015

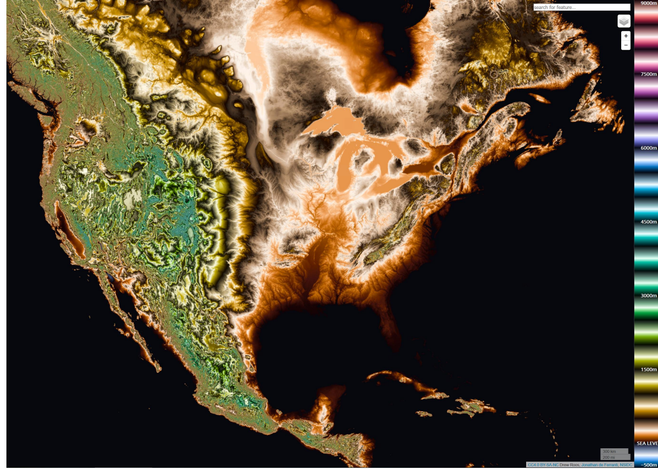

search for feature...
9000m
7500m
6000m
4500m
3000m
1500m
SEA LEVEL
−500m
300 km
200 mi
CC4.0 BY-SA-NC Drew Roos, Jonathan de Ferranti, NSIDC

Roos, 2015

IN-CLASS EXERCISE

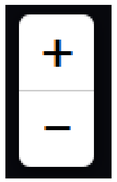
In-class exercise: Oilslick

10m



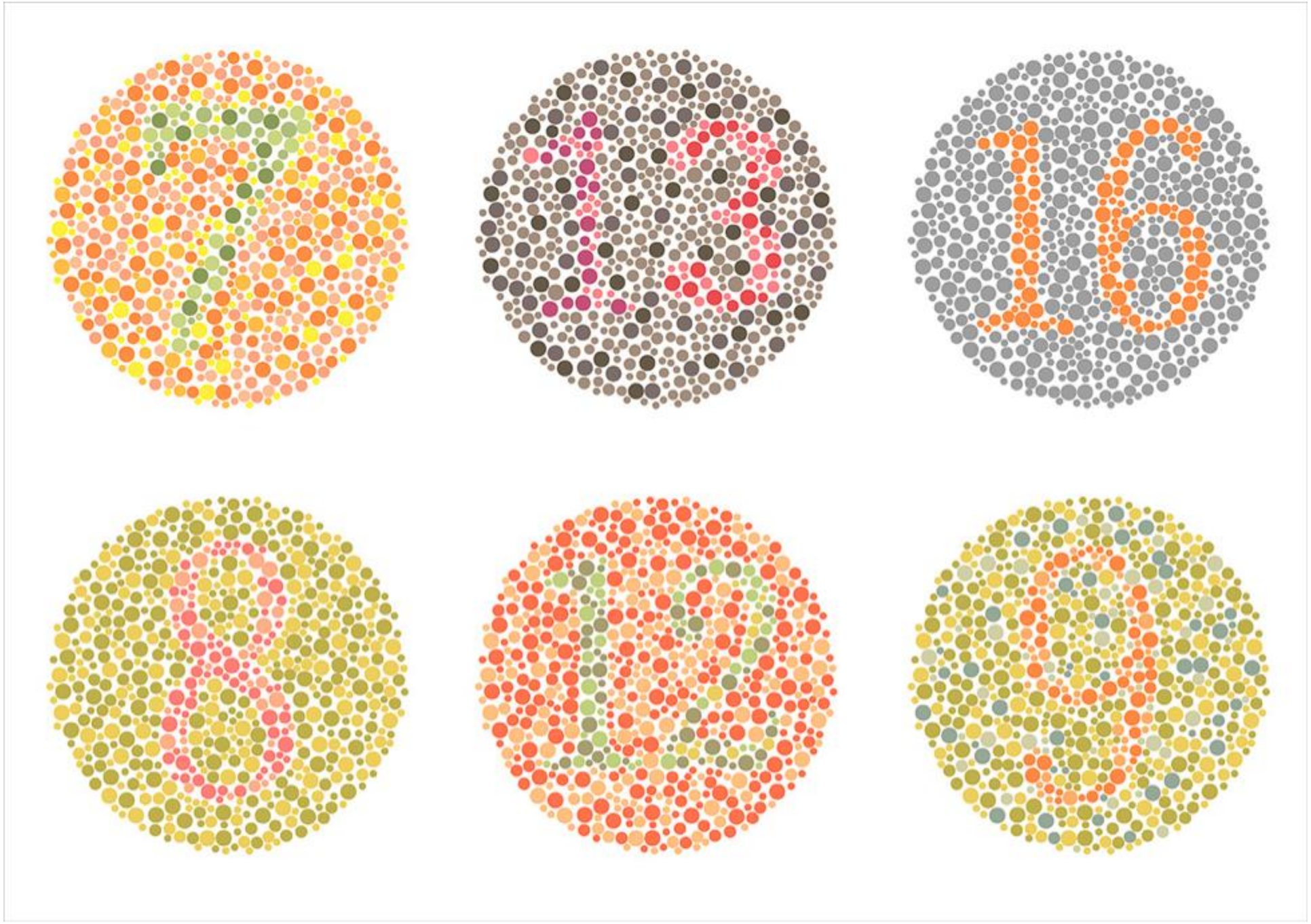
INSTRUCTIONS:

- Working individually, go to https://mrgris.com/projects/oilslick/
- Experiment with the different layers, different zoom levels, and different locations



- Think of answers to these questions:
  - What areas are particularly interesting?
  - Which layer / color scale works best, and for which tasks?

- Several of you will be asked to share your findings.

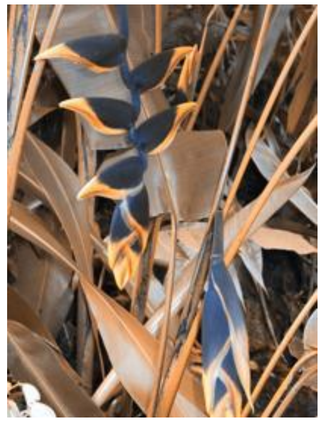


Those with deuteranope color blindness (red/green) will have difficulty seeing the numbers.

Color Deficiencies (Color Blindness)

Person with faulty cones (or faulty pathways):

Protanope = faulty red cones



Deuteranope = faulty green cones

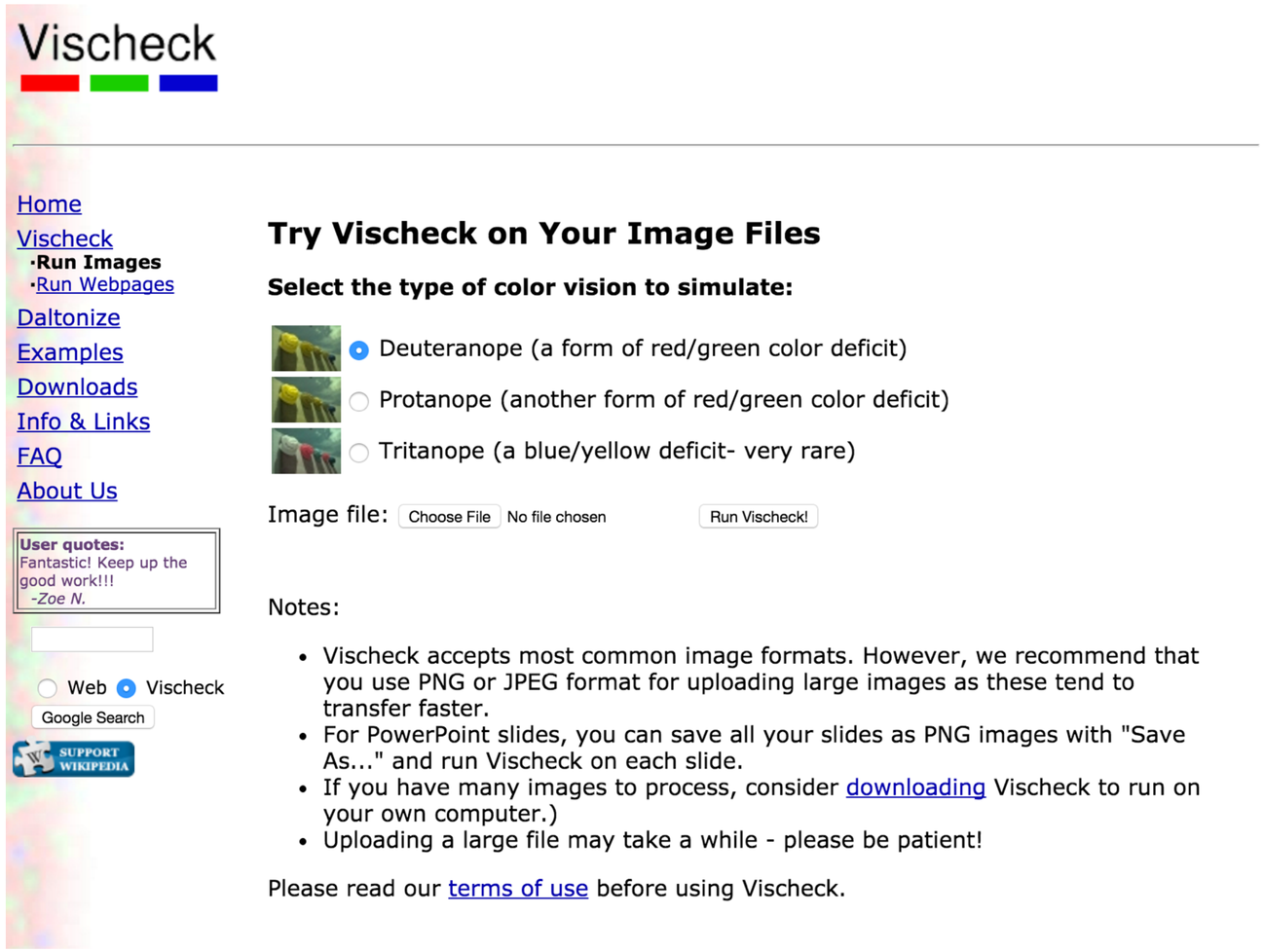
normal

Tritanope = faulty blue cones

Color Deficiencies (Color Blindness)

Based on Slides by Hanspeter Pfister, Maureen Stone

Check your images/colormaps for issues!



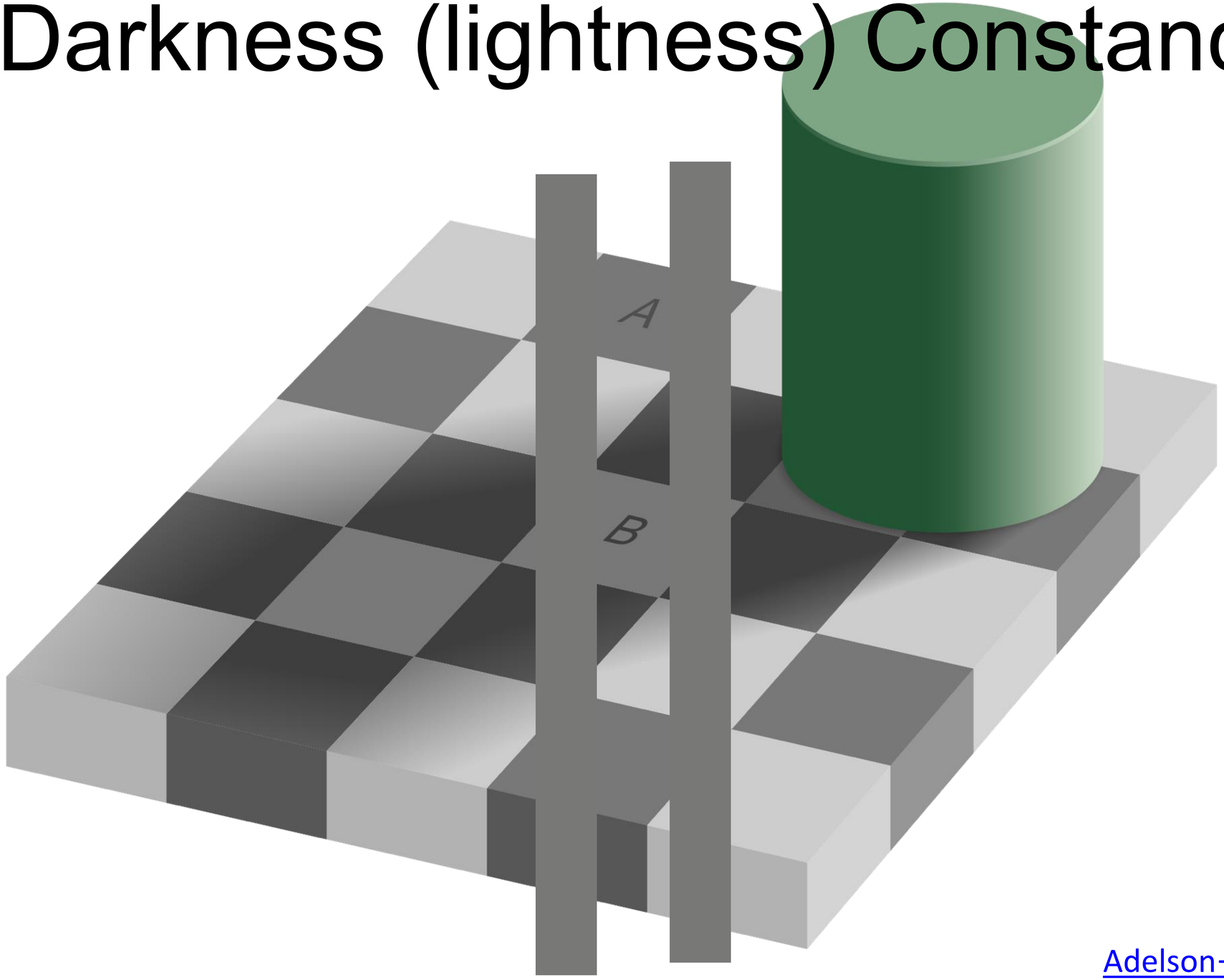
http://www.vischeck.com/vischeck/vischeckImage.php https://www.color-blindness.com/coblis-color-blindness-simulator/

Interactions between Colors and with Lighting

“Lightness Constancy”

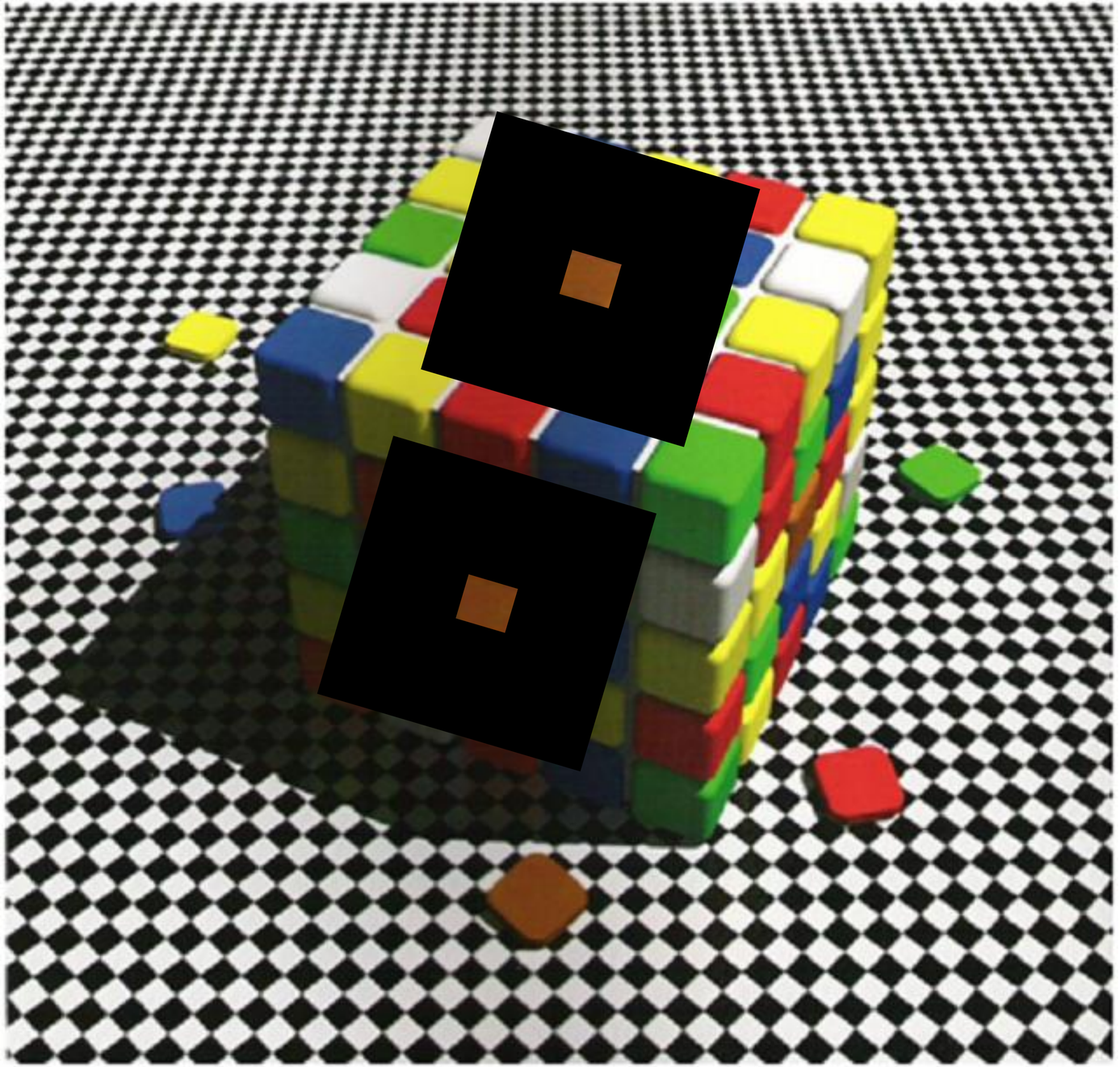
The perception that the apparent brightness of light and dark surfaces remains more or less the same under different luminance conditions is called **darkness (lightness) constancy**.

“Darkness (lightness) Constancy”



Adelson→Pingstone, 2015

“Color Constancy”



Lotto, 2009

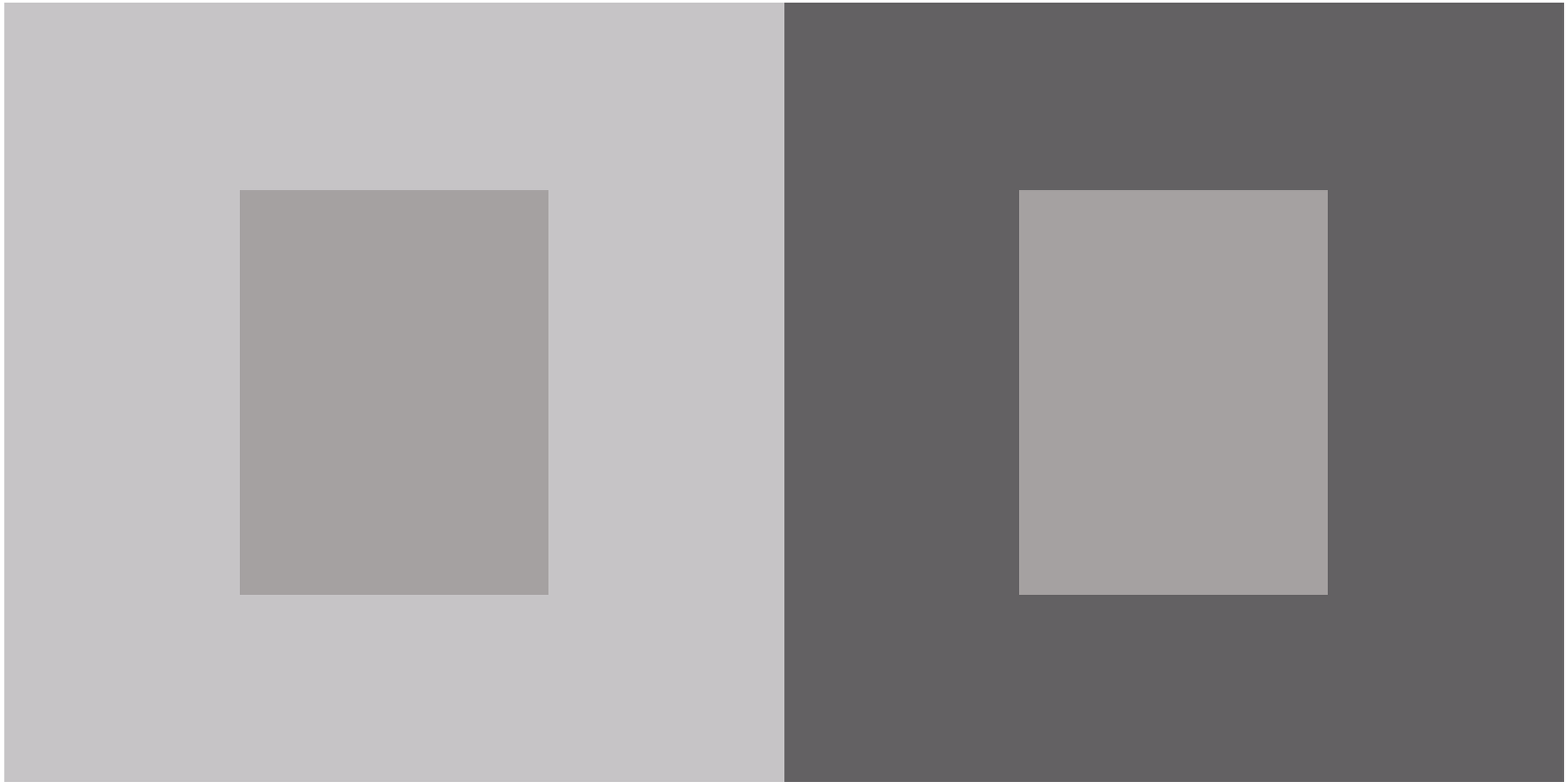
“Simultaneous Contrast”

“Simultaneous Contrast”

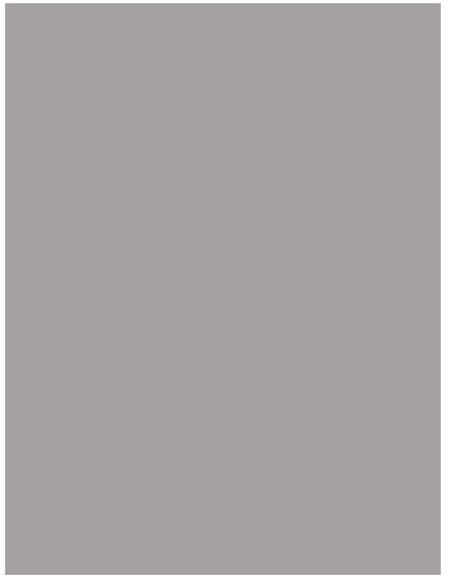
“Simultaneous Contrast”

Avoid gradients as backgrounds or bars!

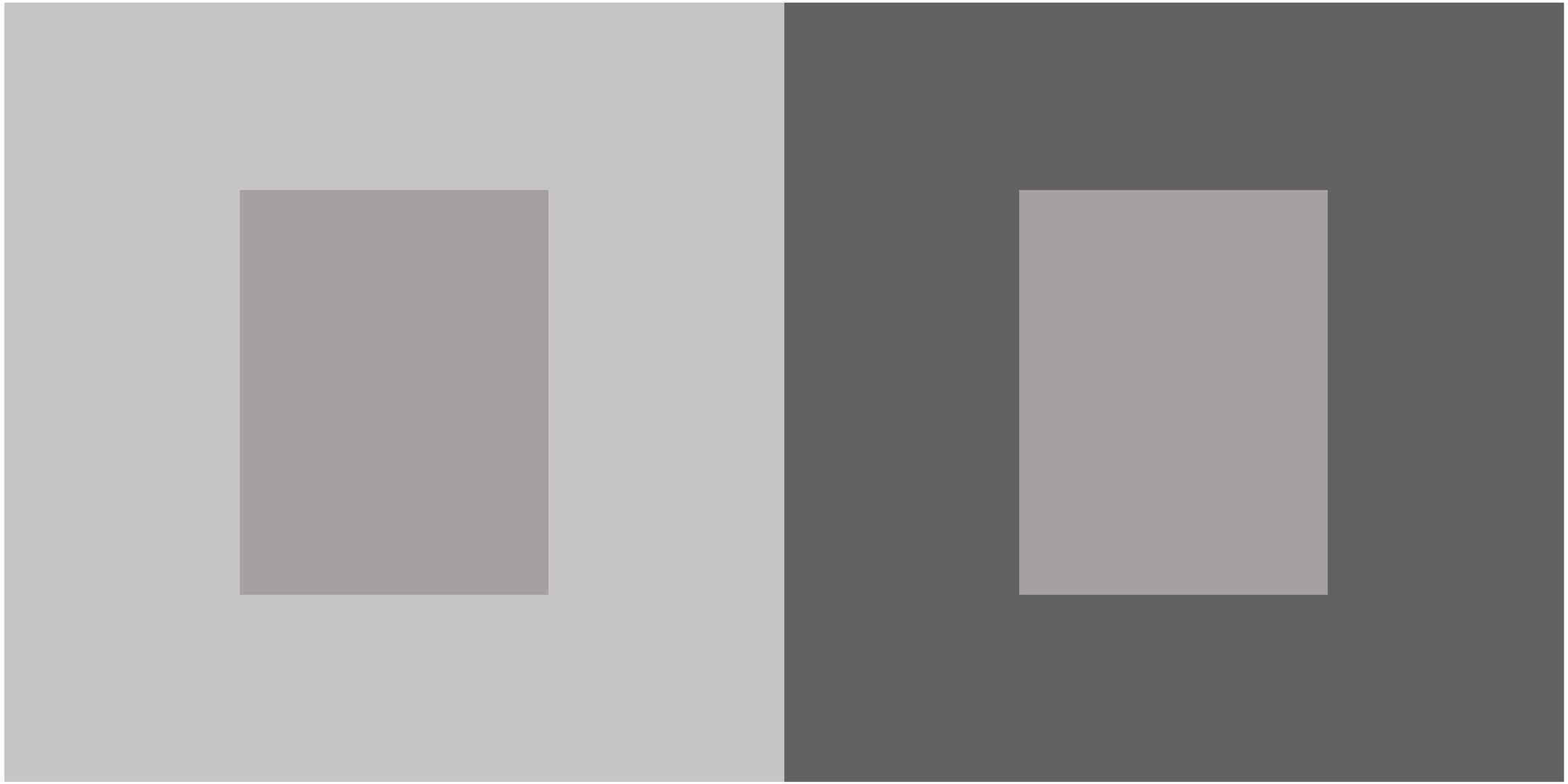
“Simultaneous Contrast”



“Simultaneous Contrast”

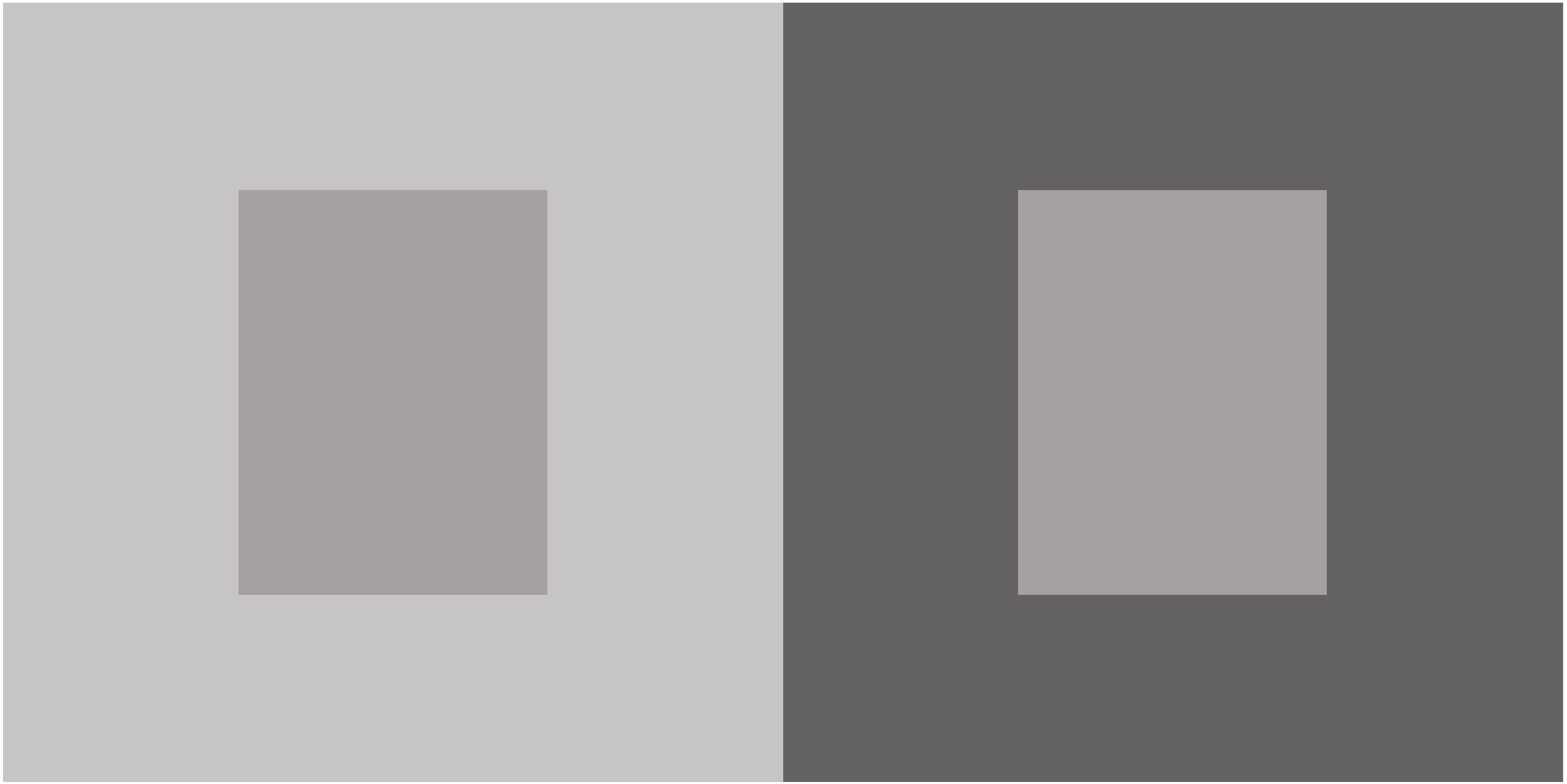


“Simultaneous Contrast”

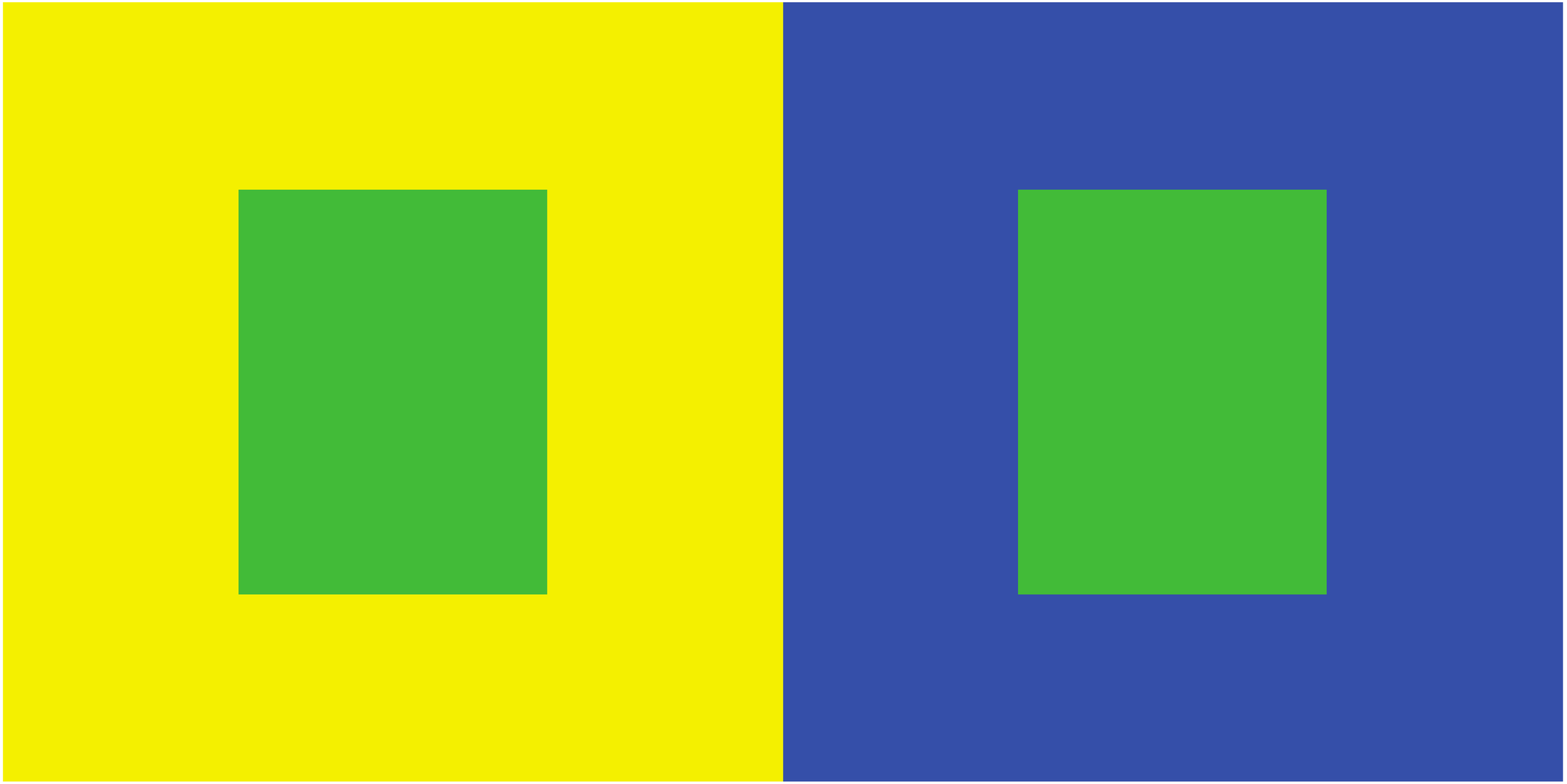


“Simultaneous Contrast”

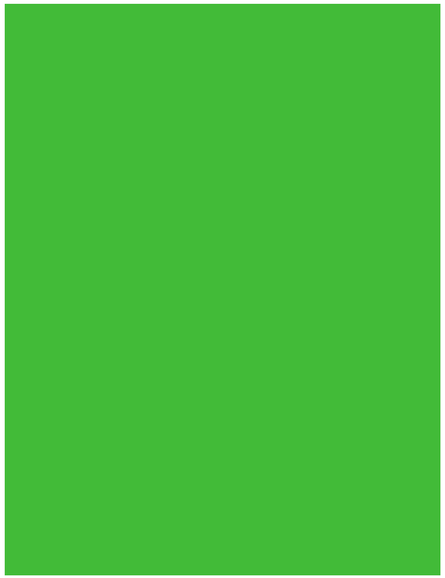
“Simultaneous Contrast”

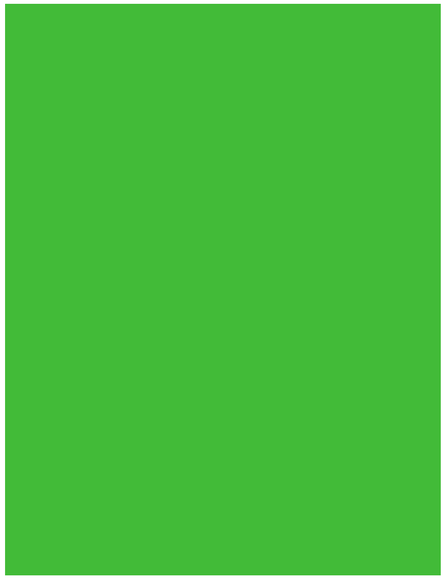


“Simultaneous Contrast”



“Simultaneous Contrast”





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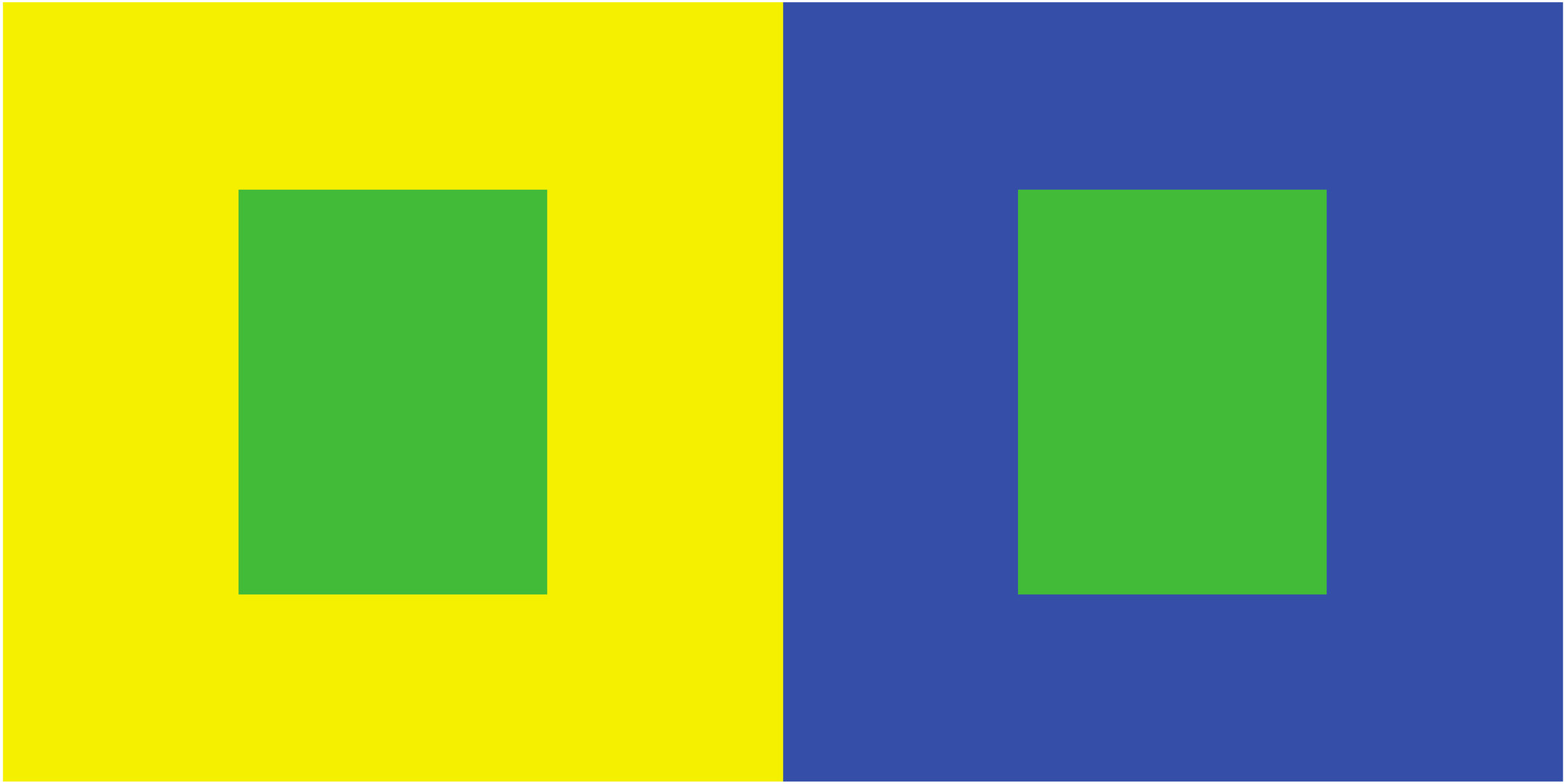
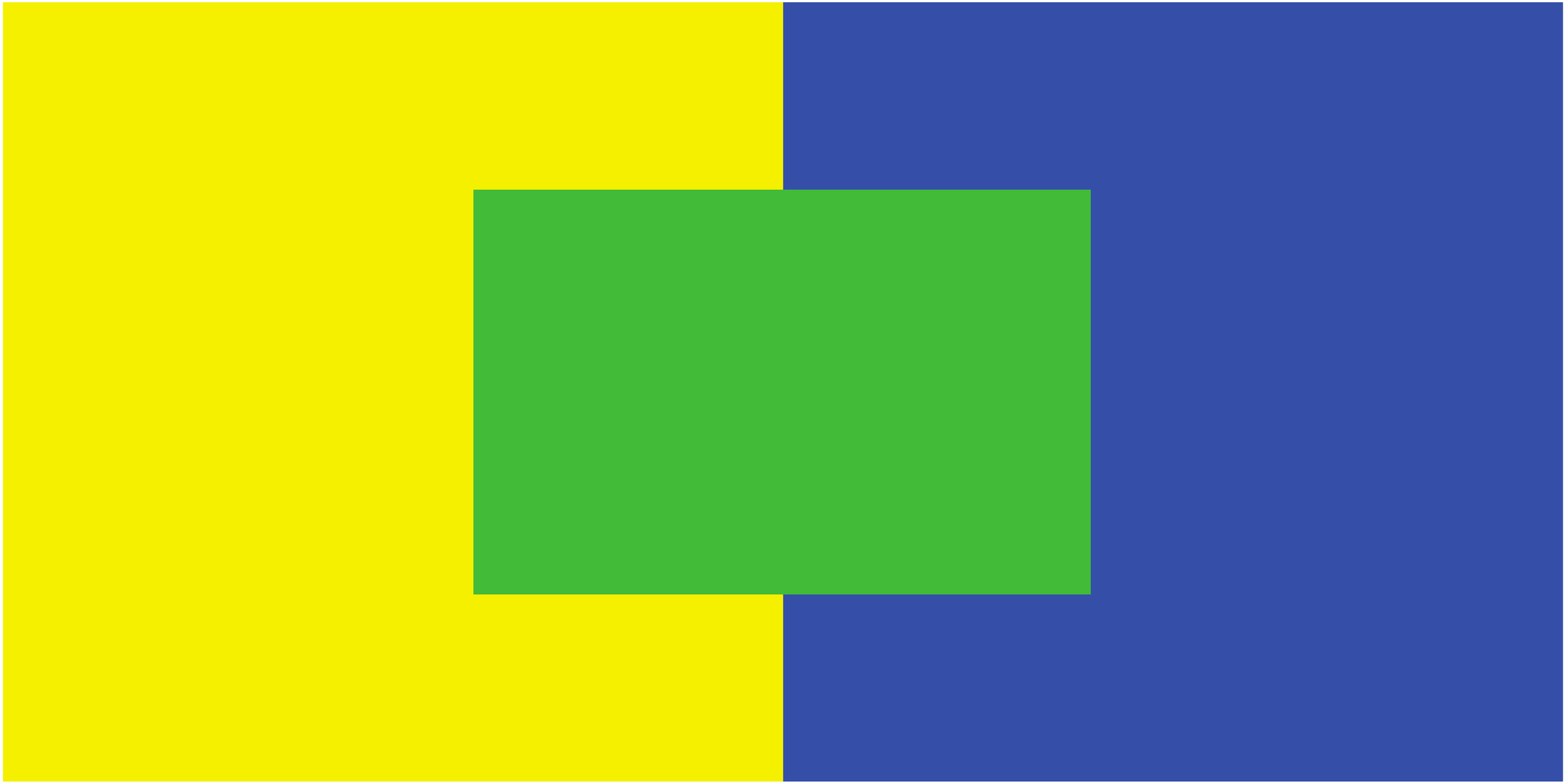
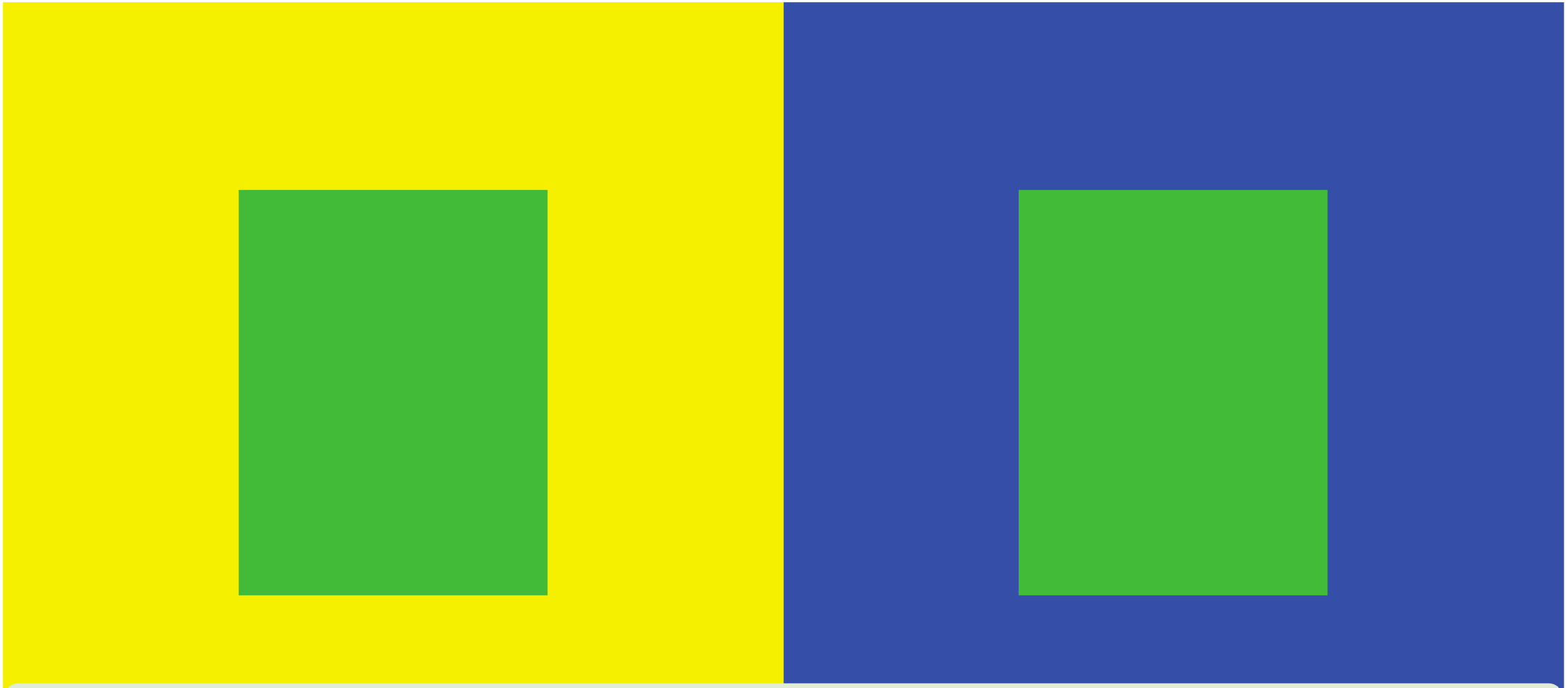


“Simultaneous Contrast”



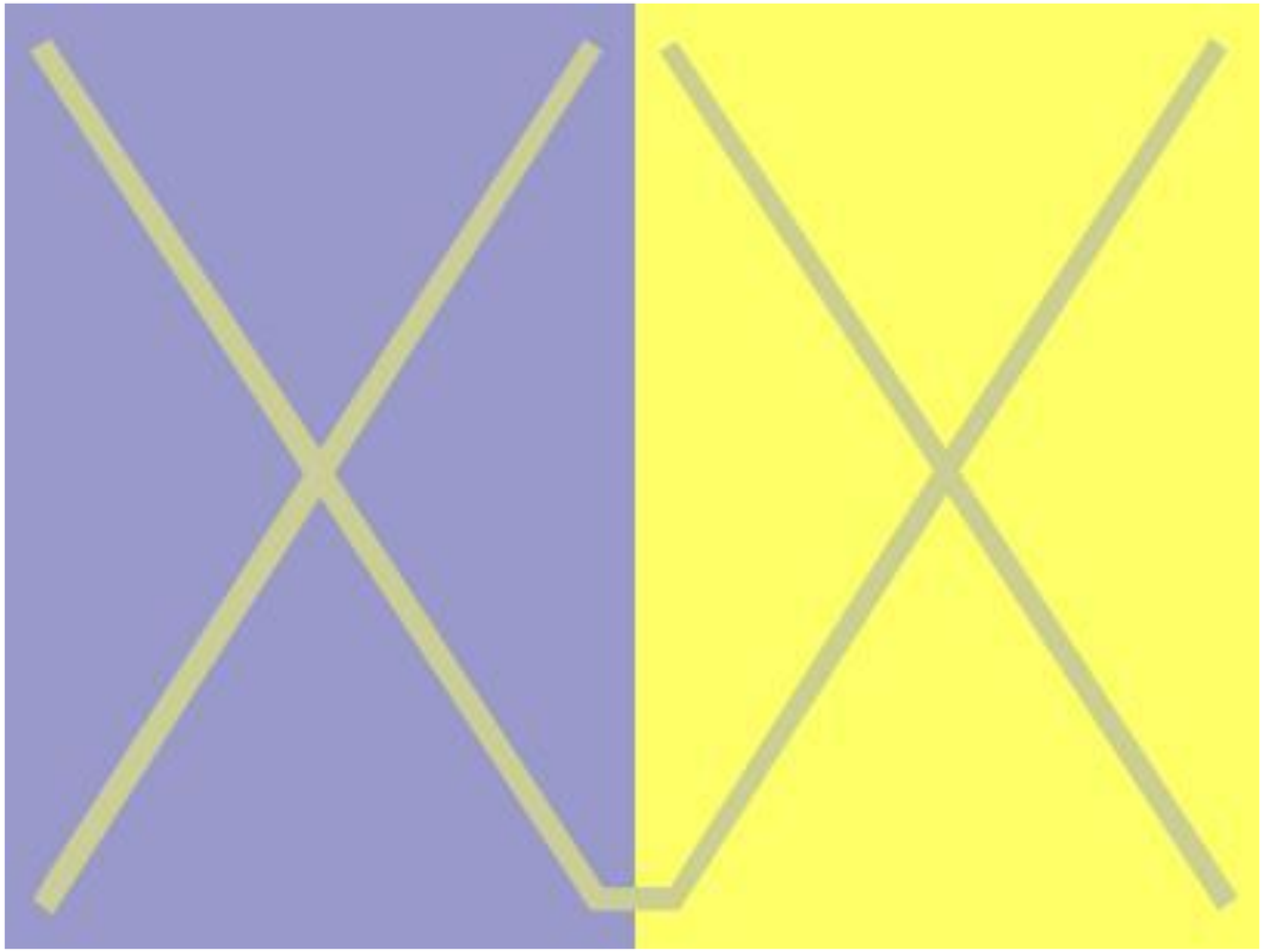
“Simultaneous Contrast”



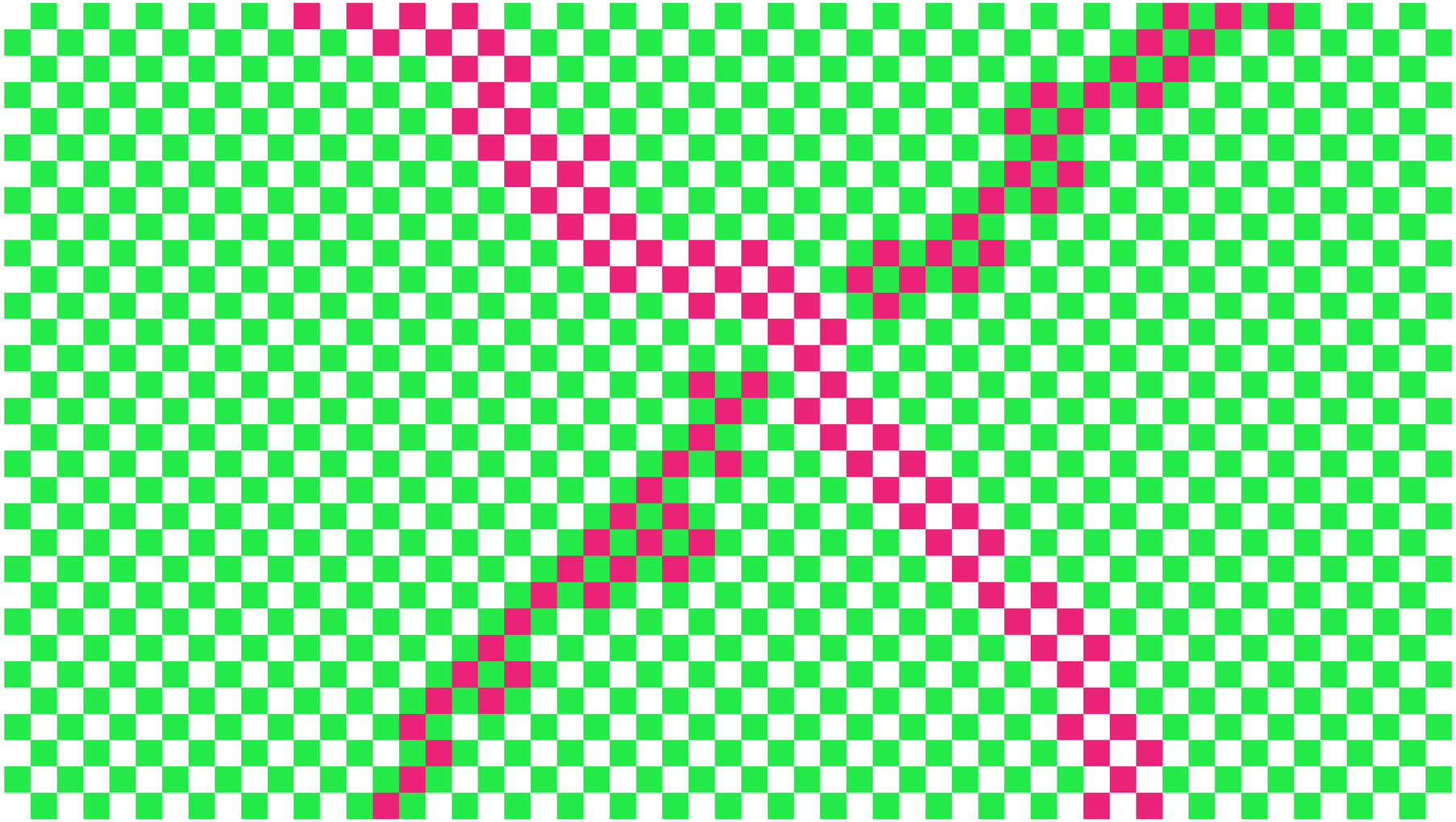
Be careful with bars and scatter plot points - the colors may appear differently with different background colors and neighboring colors!

Be aware that colors in legends may appear different than on the plot!

“Simultaneous Contrast”

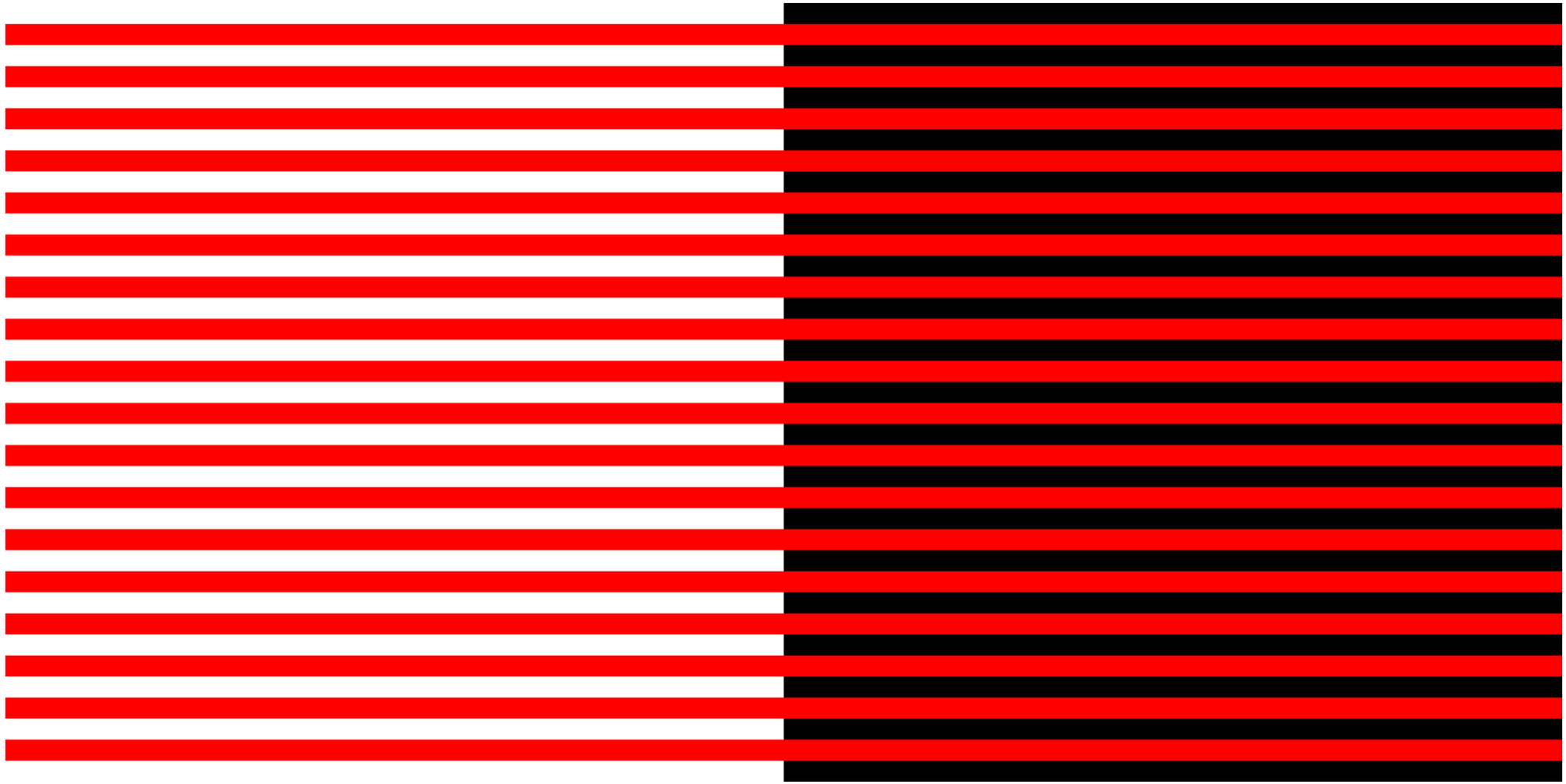


“Simultaneous Contrast”

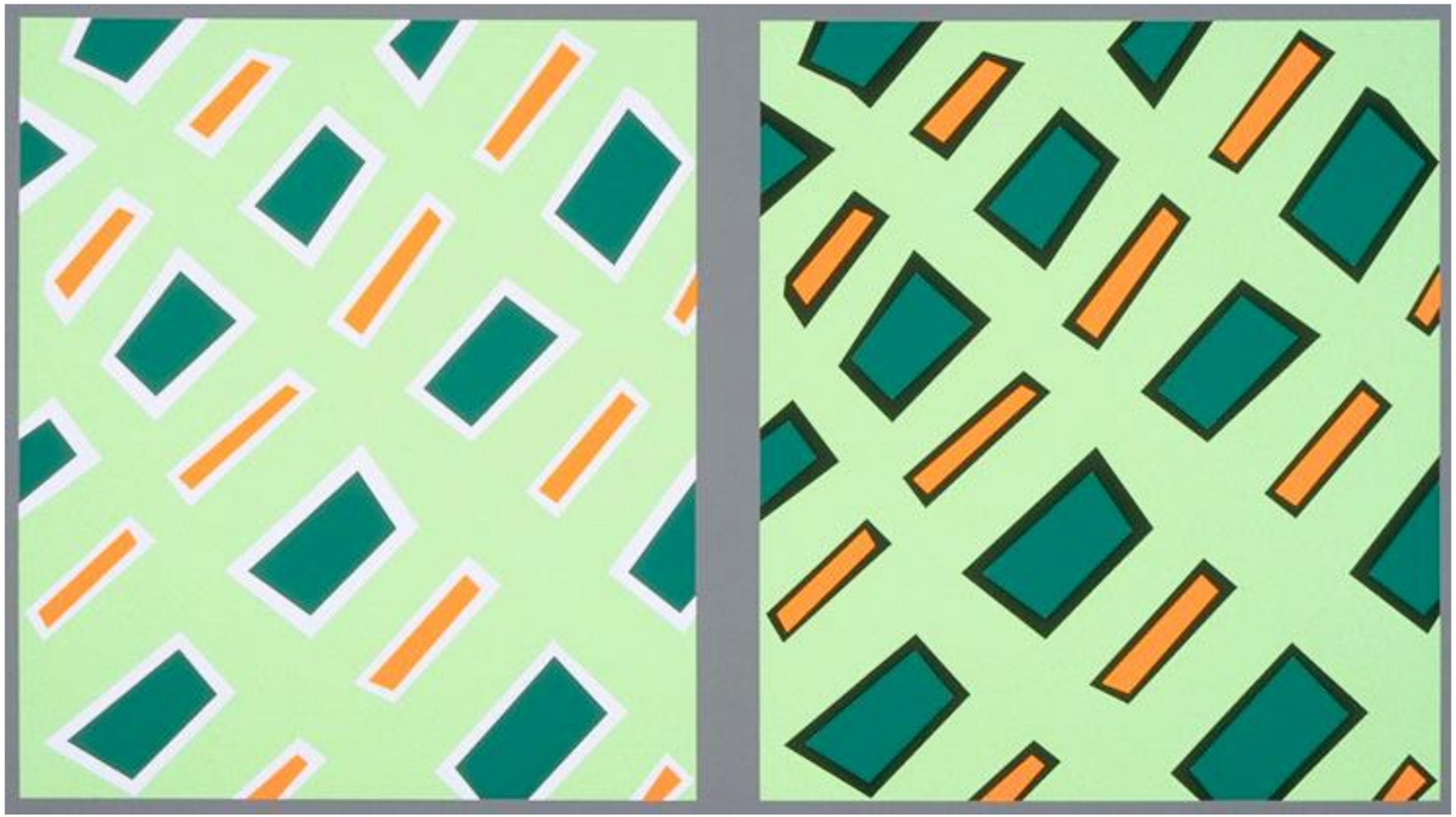


Griffin, 2015

“von Bezold Spreading Effect”



“von Bezold Spreading Effect”



Be careful with colors in scatter plots!
Be aware of color changes when adding borders around bars and plots!
Be aware that colors in legends may appear different than on the plot!

Which area is larger (green or red)?

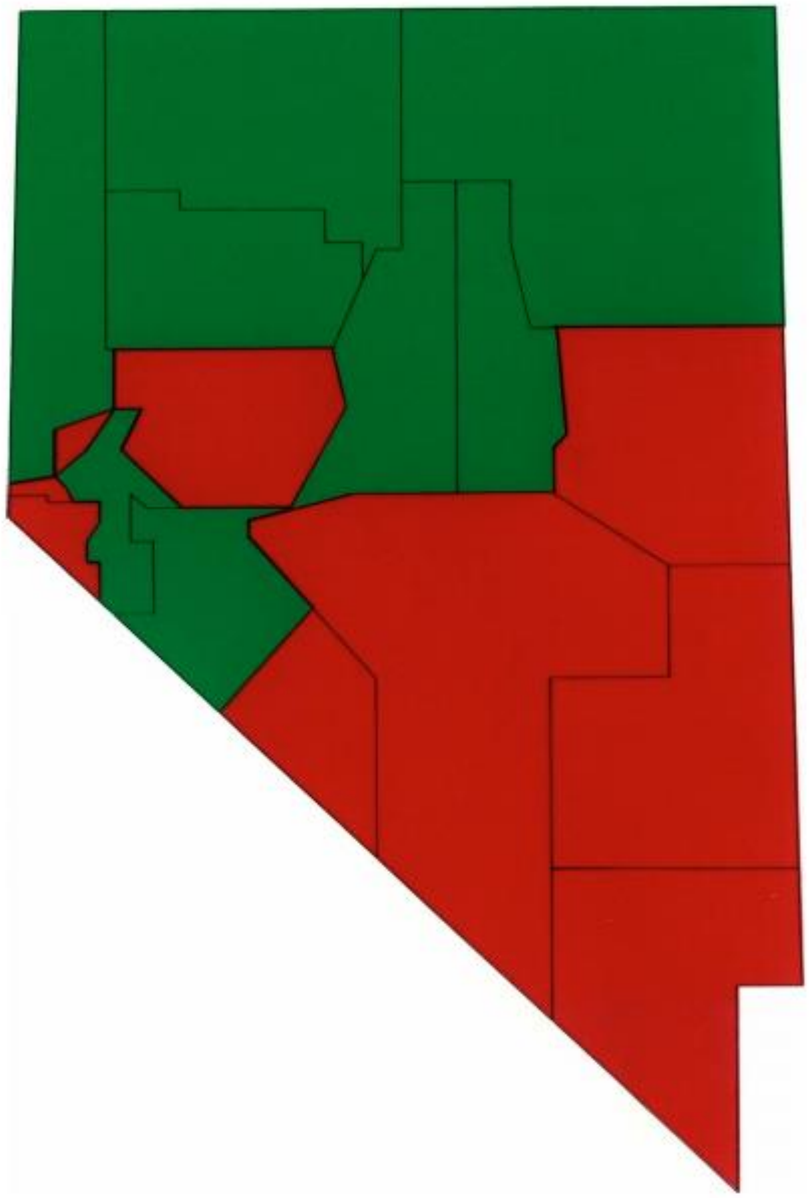


Figure 1. Stimulus From the High-Saturation Group

Cleveland & McGill, 1983

Which area is larger?

Areas are equal(!).

Study participants favored red in the highly saturated case (left) but were more correct with the desaturated case (right)

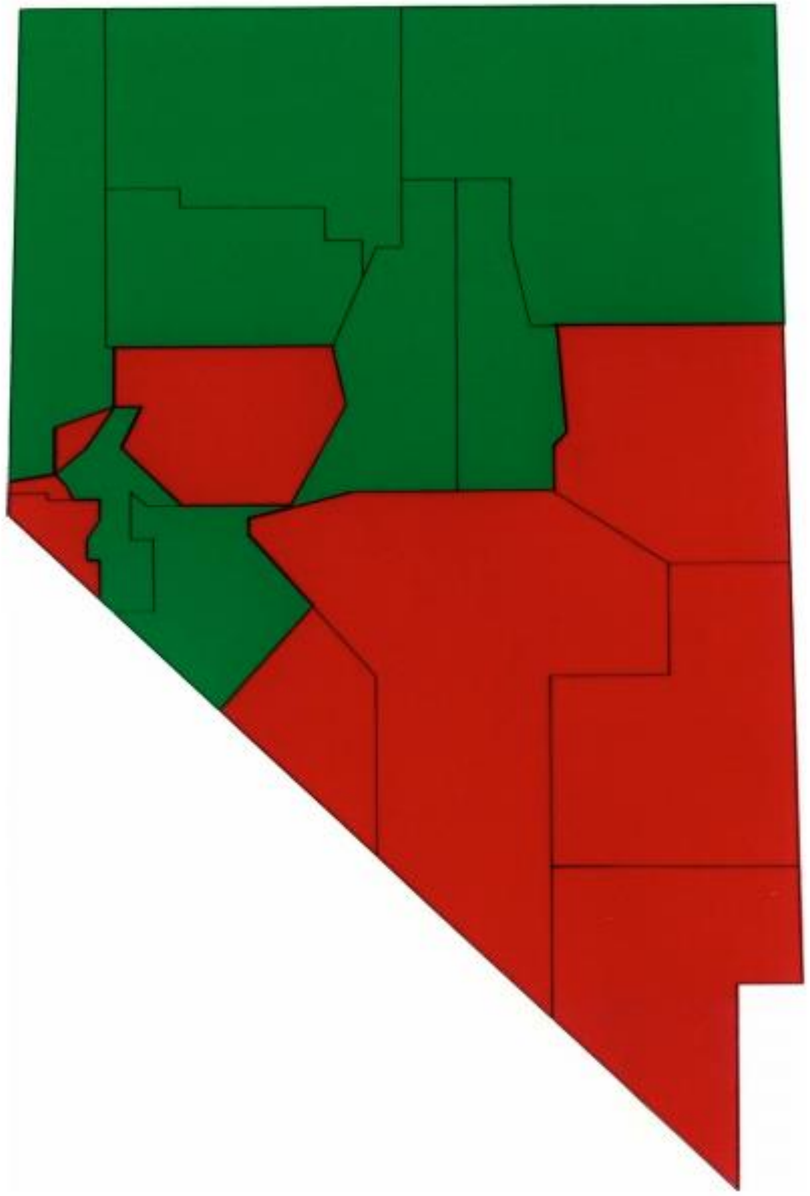


Figure 1. Stimulus From the High-Saturation Group

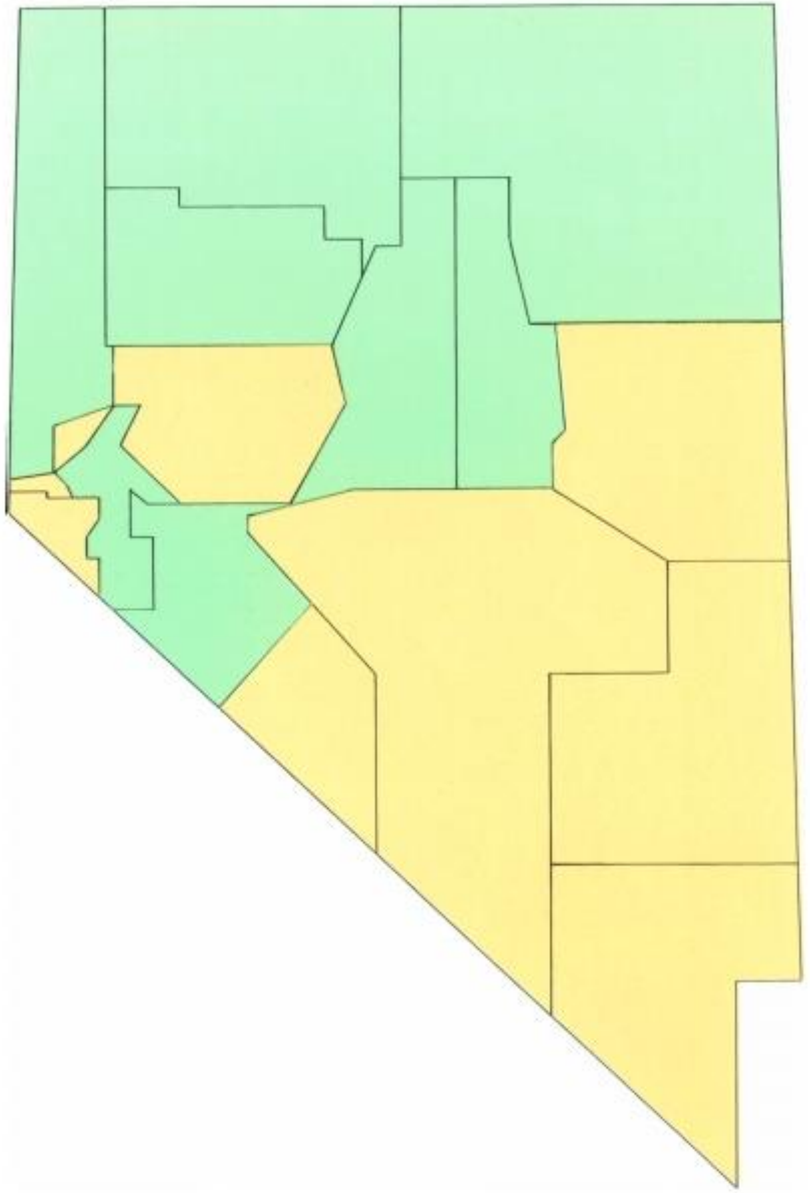
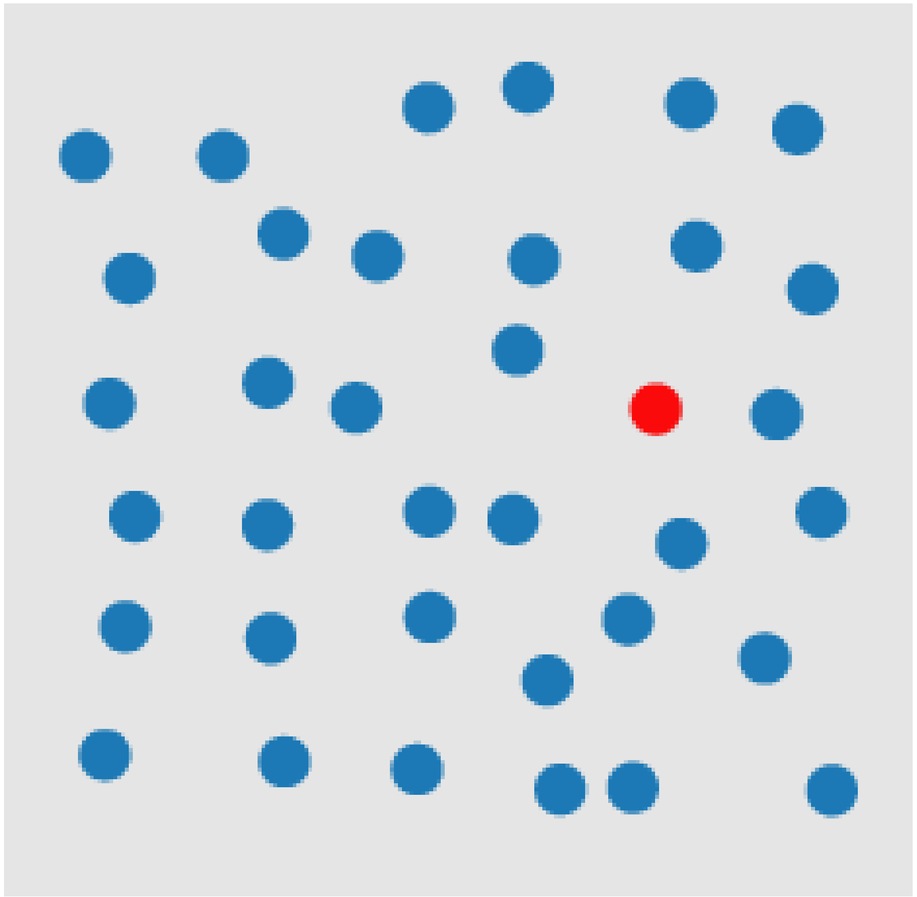
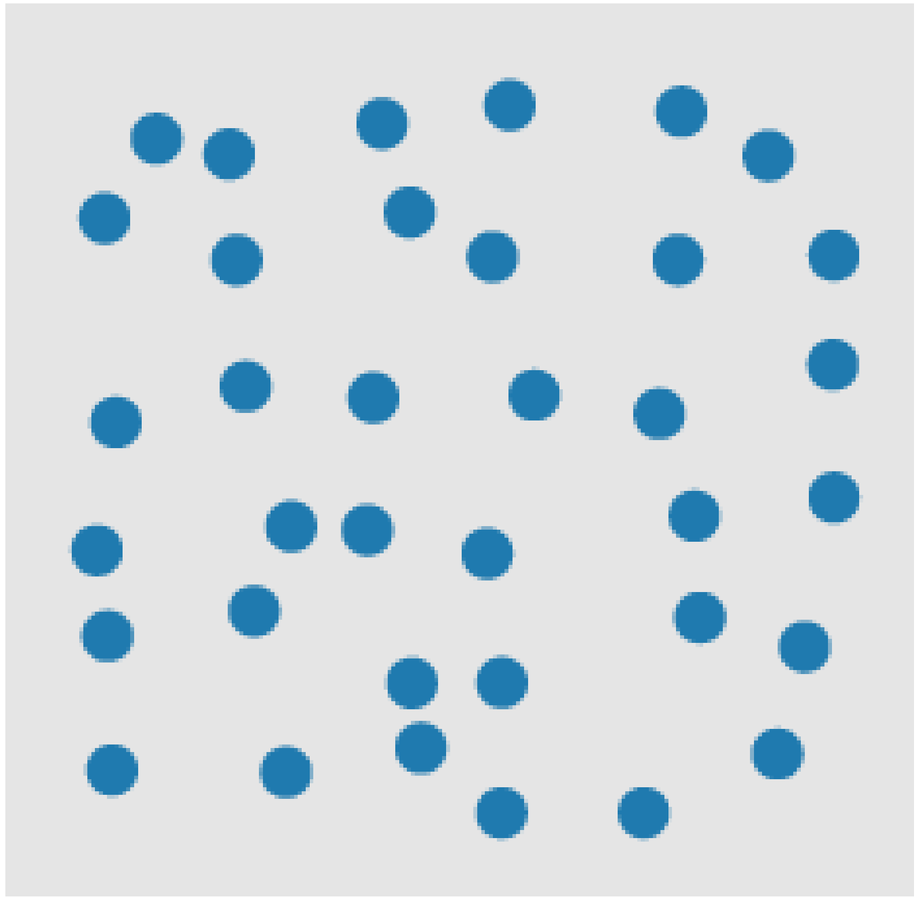


Figure 2. Stimulus From the Low-Saturation Group

Cleveland & McGill, 1983

POP-OUT EFFECTS



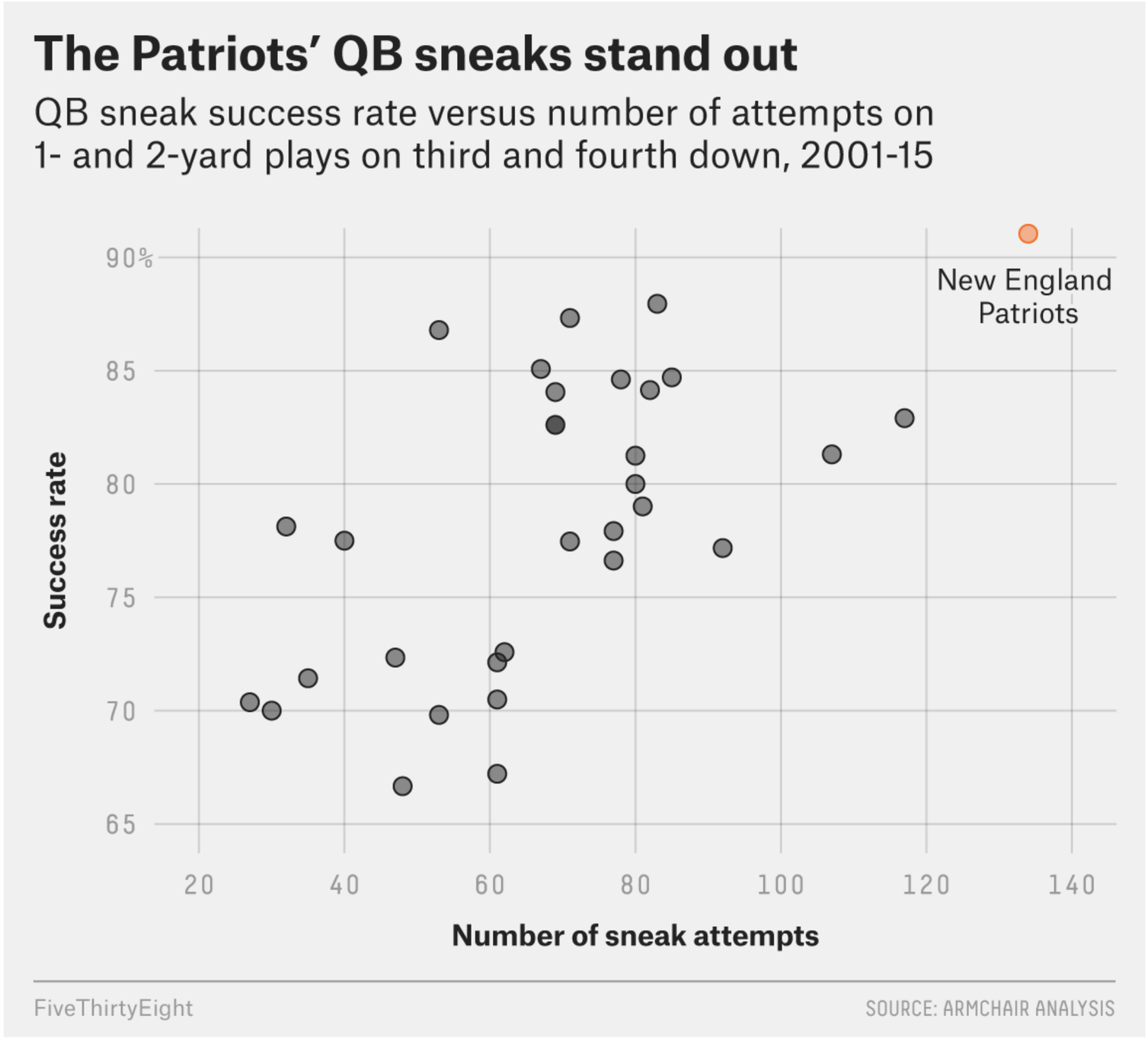


COLOR

A quarterback sneak is a play in American football and Canadian football in which the quarterback, upon taking the center snap, dives ahead while the offensive line surges forward. It is usually only used in very short yardage situations.

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

Which pop-out effects are used in this example visualization?



https://fivethirtyeight.com/features/the-patriots-are-even-sneakier-than-you-think/

Desaturated background, light blue

**NASA has an amazing collection of visualization and imaging experts. As in the example above, background colors are always selected to be desaturated thus making the foreground have a pop-out effect. The preferred background color is generally light blue which is desaturated and gives a 3D depth effect (i.e., blue sky in the distant background).

https://www.nasa.gov/content/goddard/hubble-goes-high-definition-to-revisit-iconic-pillars-of-creation

Color Mixing Pitfalls

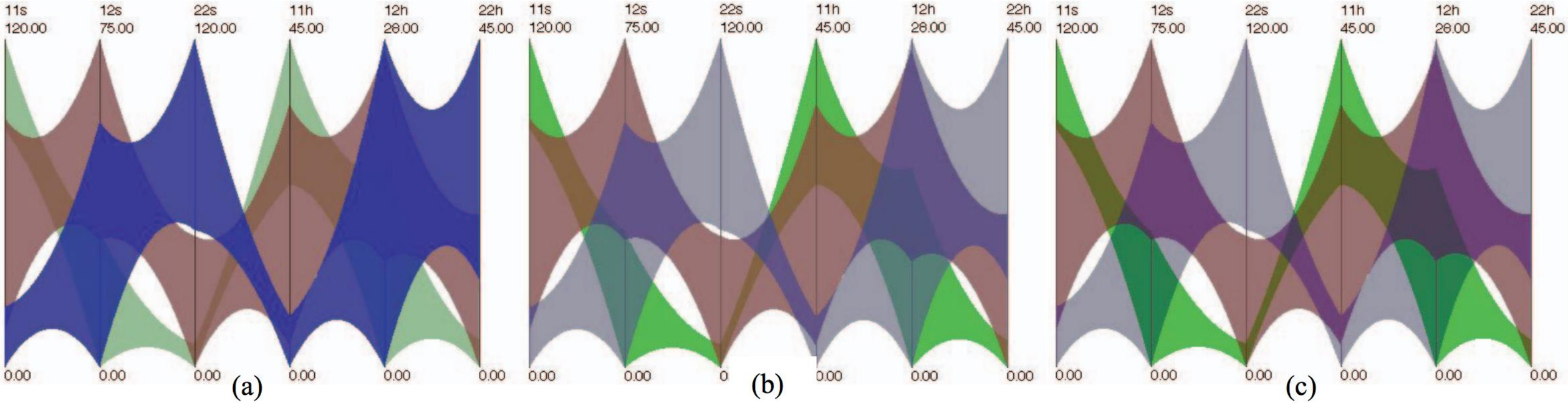


Fig. 12: Illustrative visualizations of a six-dimensional dataset using illustrative parallel coordinates. (a) Ideal visualization with appropriate weightings and color choices, and the use of the local model in overlapping areas. (b) Improper weightings are employed. The blue cluster no longer seems to be in front. (c) The use of improper weightings and the disabling of the local model results in a confusing visualization.

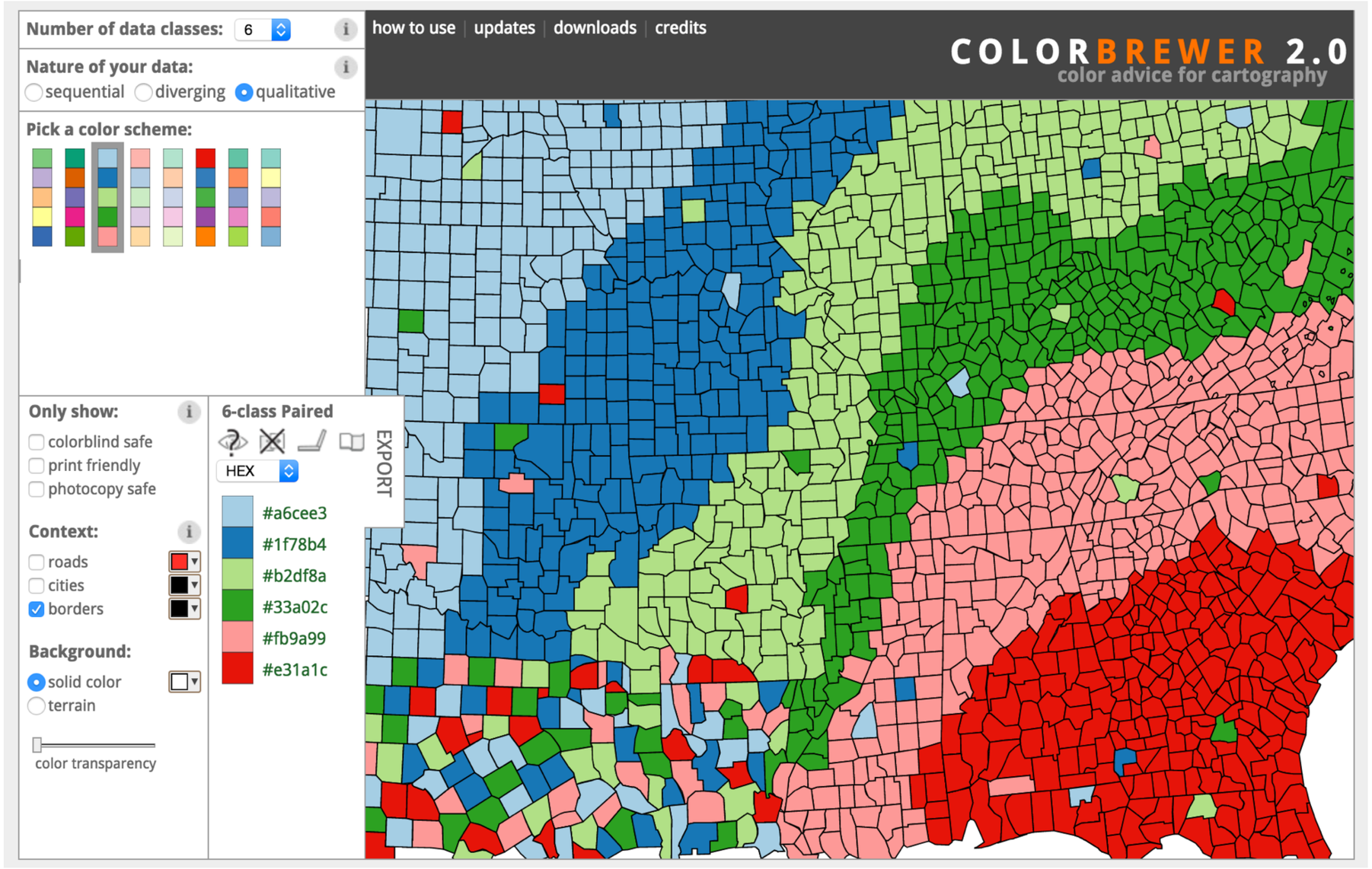
"Aimed at reducing false colors in the overlap regions. …[Reduce] saturation of the color in the rear object only in the overlap region while keeping its lightness."

Note the swap in blue/red for foreground/background vs. NASA

Wang et al., 2008

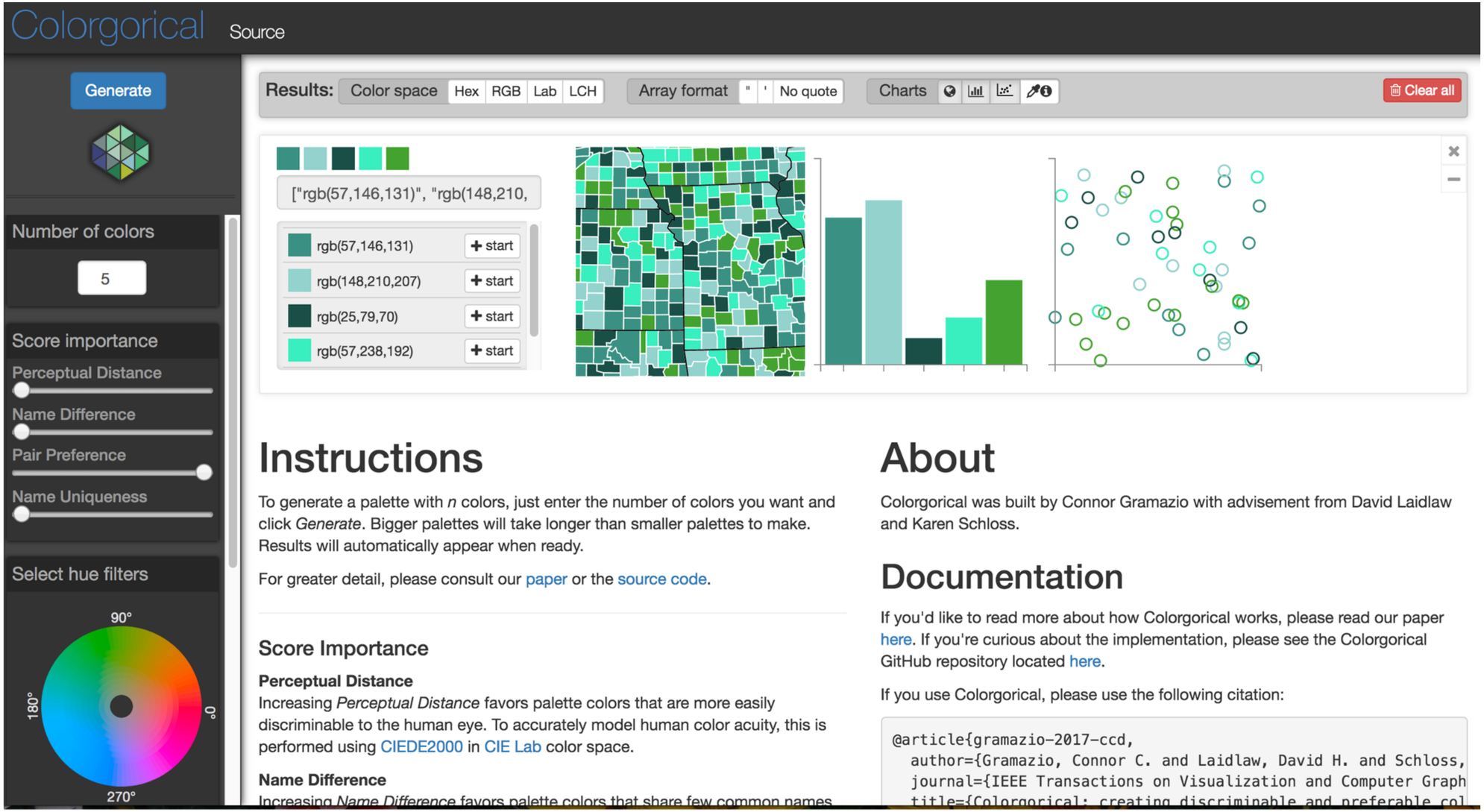
Tools for Picking Colormaps

Color Brewer



http://colorbrewer2.org/

Colorgorical



http://vrl.cs.brown.edu/color

Other Useful Tools

- Get a list of colors from an image: https://html-color.codes/color-from-image
- Analyze your palette: https://projects.susielu.com/viz-palette
- Analyze the name similarity of colors in your palette: http://vis.stanford.edu/color-names/analyzer/
- Details on multi-hued color scales: https://www.vis4.net/blog/2013/09/mastering-multi-hued-color-scales/#combining-bezier-interpolation-and-lightness-correction
- Easy picking a multi-hued color scale: http://tristen.ca/hcl-picker/
- Easily correcting darkness (lightness) for a scale: http://gka.github.io/palettes/
- Do a ton programmatically: https://gka.github.io/chroma.js/
- virdis colors: https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

Color Advice Summary

Use a limited hue palette

- Control color “pop out” with low-saturation colors
- Avoid clutter from too many competing colors

Use neutral backgrounds

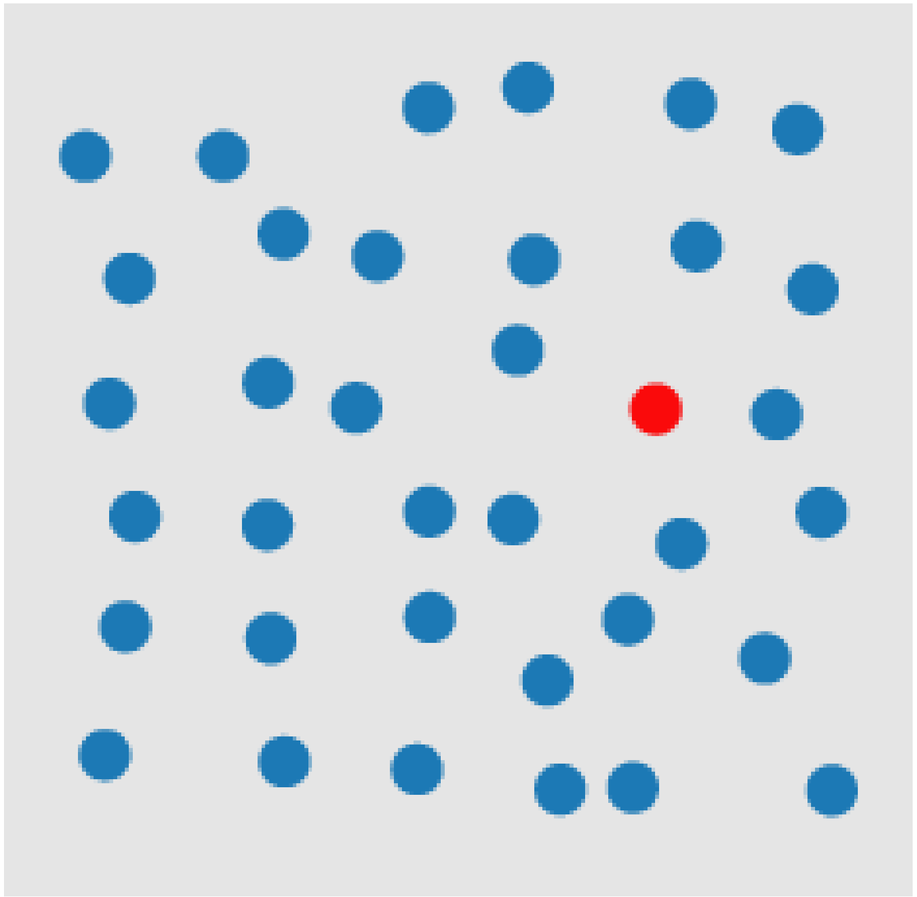
- Control impact of color
- Minimize simultaneous contrast

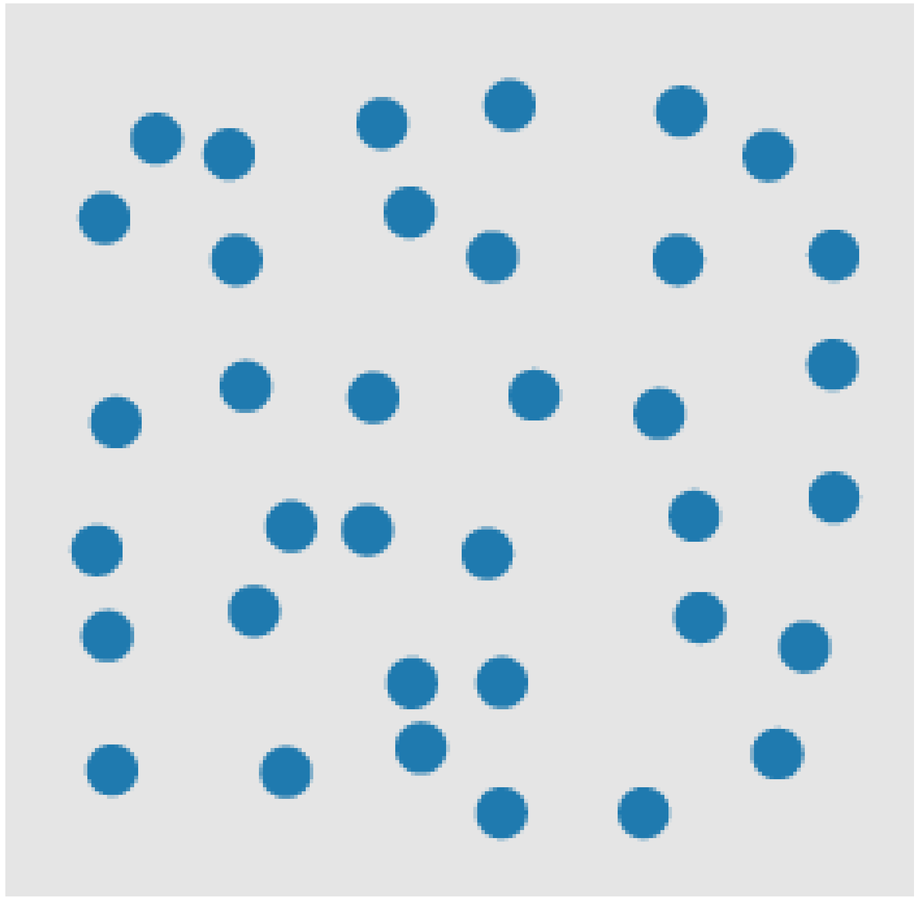
Use Color Brewer etc. for picking scales

Don’t forget aesthetics!

Pop-out Effects

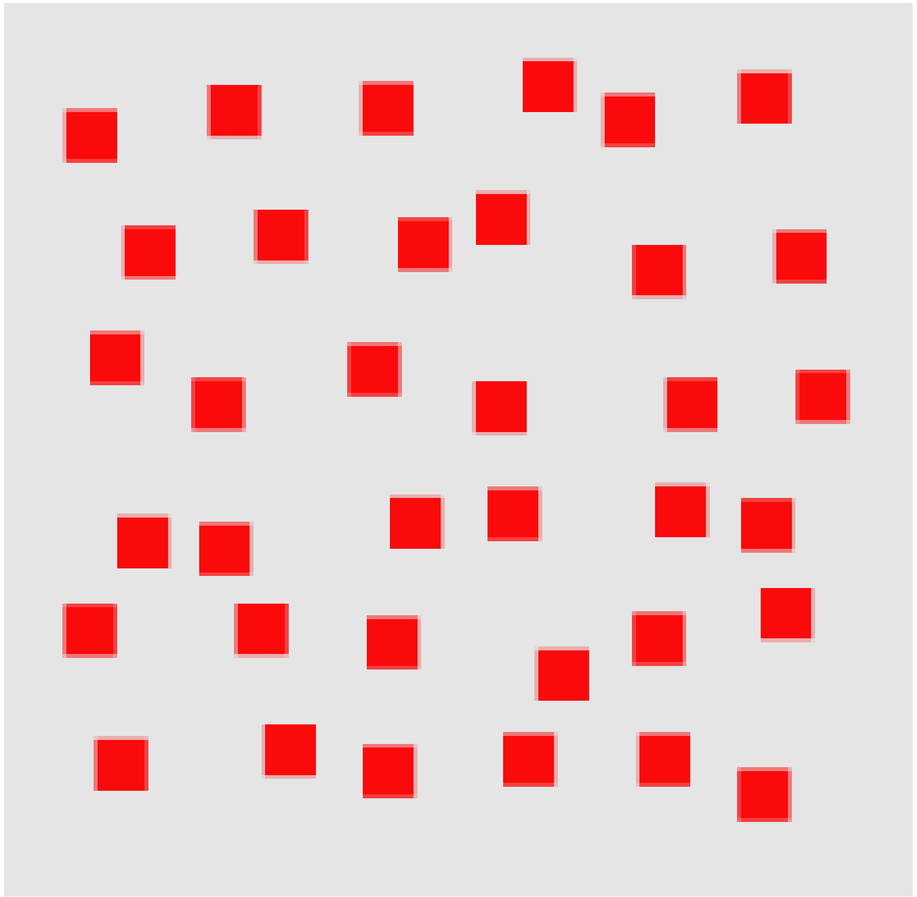
Pop-Out Effects

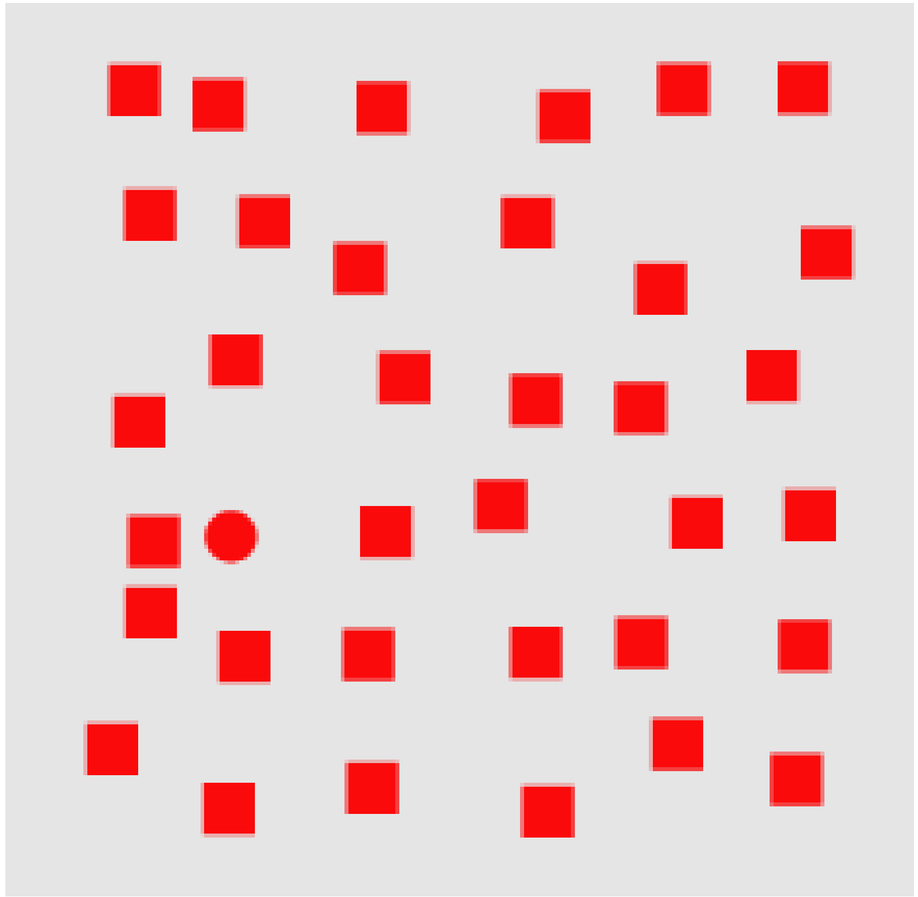




Color

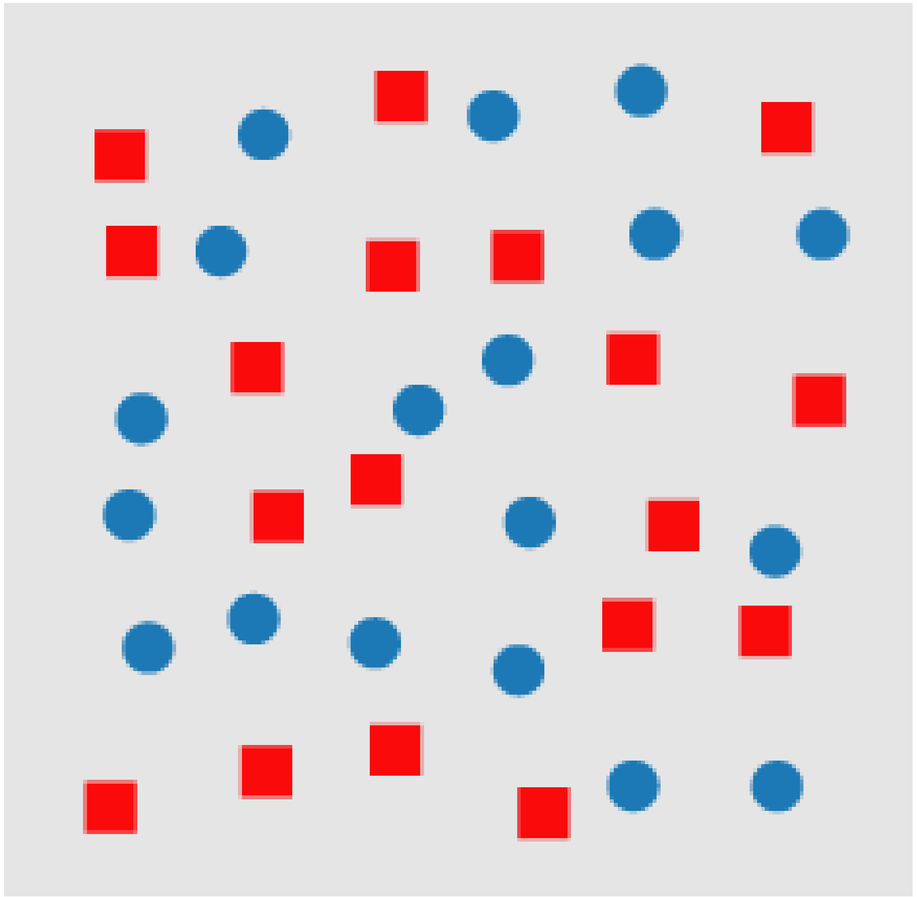
POP-OUT EFFECTS

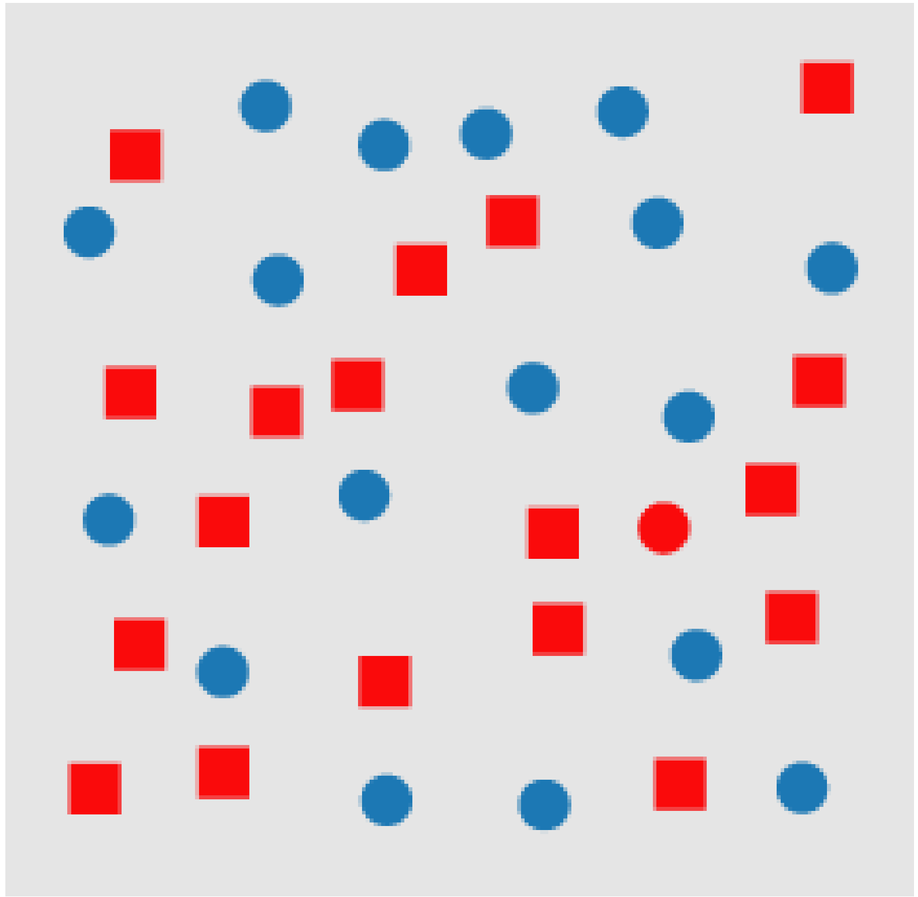




SHAPE

POP-OUT EFFECTS

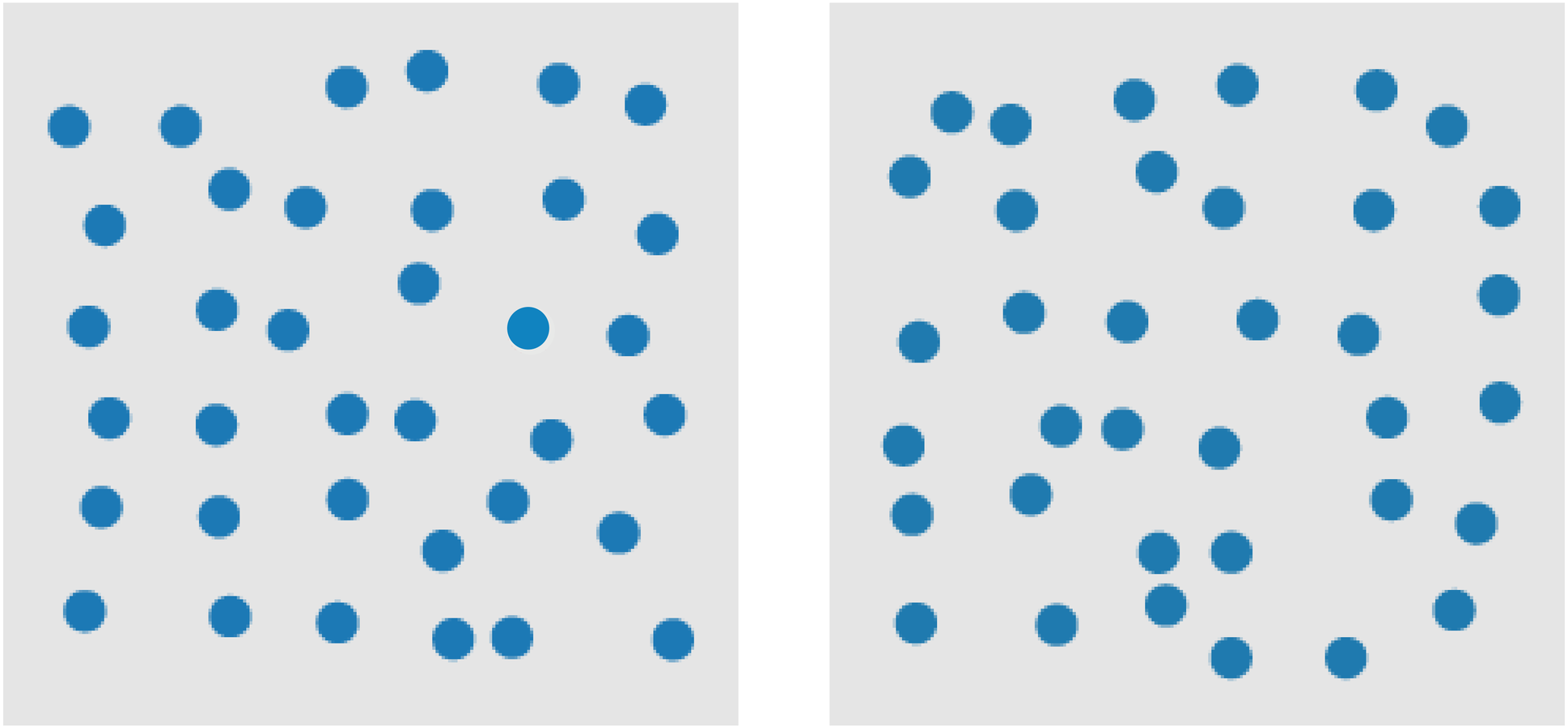




"CONJUNCTION" (HARDER TO FIND RED CIRCLE!)

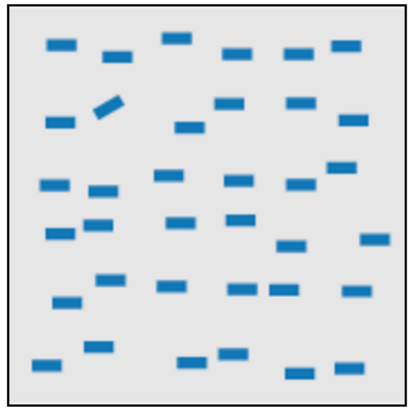
Healey, 2012

POP-OUT EFFECTS

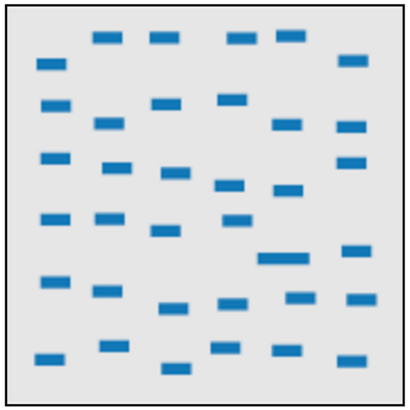


MOTION

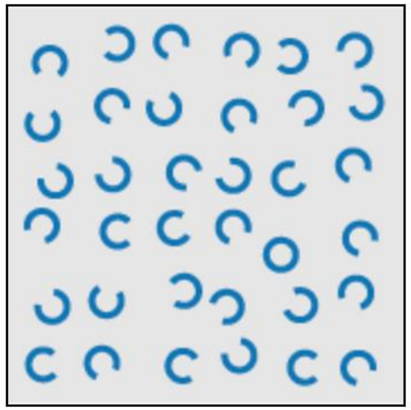
Pop-Out Effects



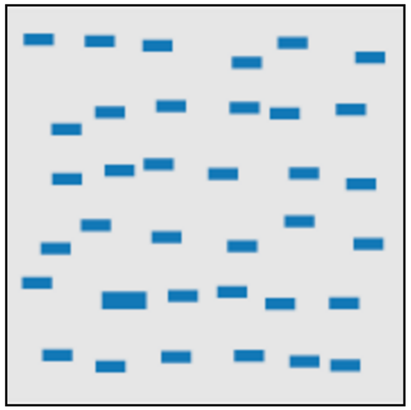
line (blob) orientation
Julész & Bergen 83; Sagi & Julész 85a, Wolfe et al. 92; Weigle et al. 2000



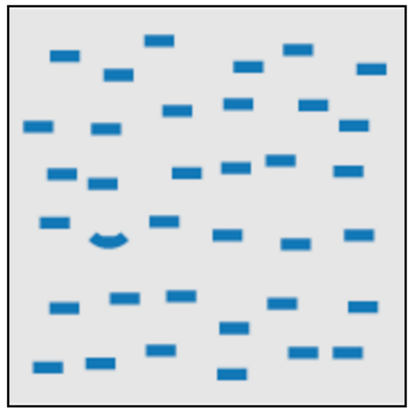
length, width
Sagi & Julész 85b; Treisman & Gormican 88



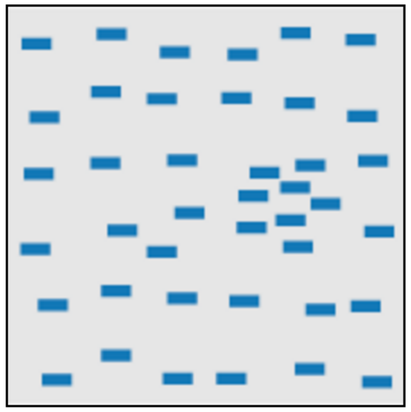
closure
Julész & Bergen 83



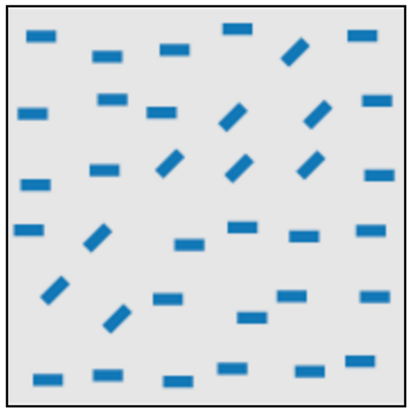
size
Treisman & Gelade 80; Healey & Enns 98; Healey & Enns 99



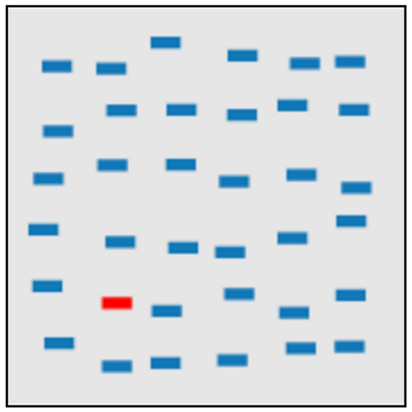
curvature
Treisman & Gormican 88



density, contrast
Healey & Enns 98; Healey & Enns 99



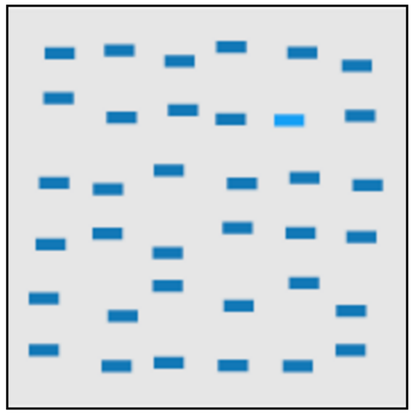
number, estimation
Sagi & Julész 85b; Healey et al. 93; Trick & Pylyshyn 94



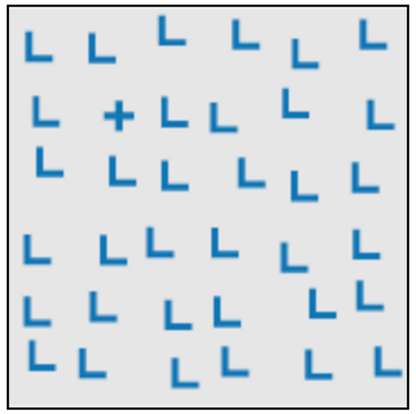
colour (hue)
Nagy & Sanchez 90; Nagy et al. 90; D'Zmura 91; Kawai et al. 95; Bauer et al. 96; Healey 96; Bauer et al. 98; Healey & Enns 99

Healey, 2012

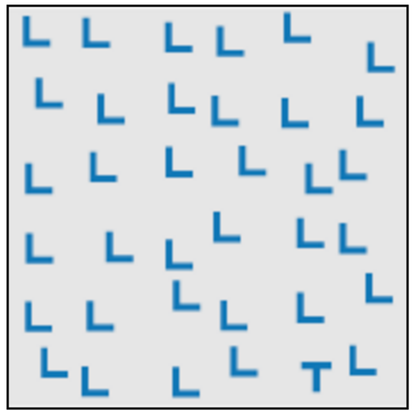
POP-OUT EFFECTS



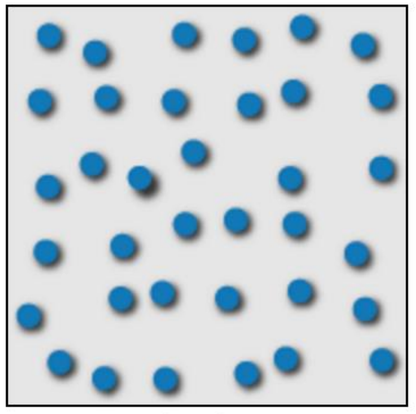
intensity, binocular lustre
Beck et al. 83; Treisman & Gormican 88; Wolfe & Franzel 88



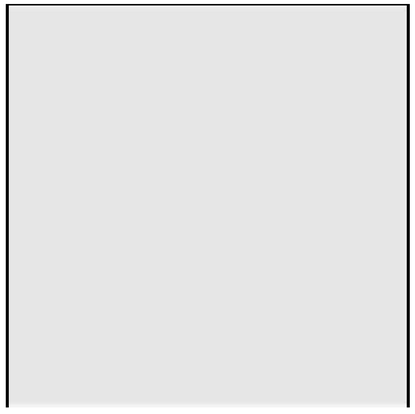
intersection
Julész & Bergen 83



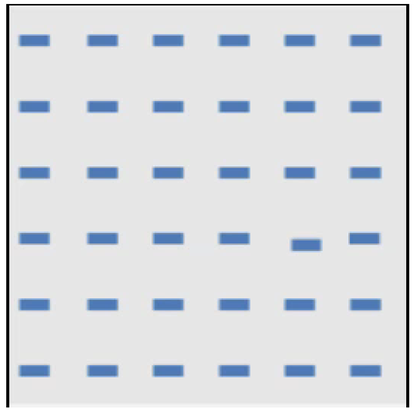
terminators
Julész & Bergen 83



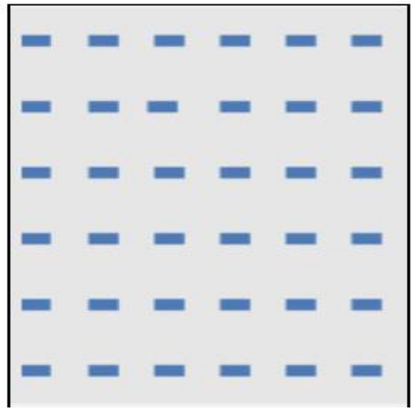
3D depth cues
Enns 90b; Nakayama & Silverman 86



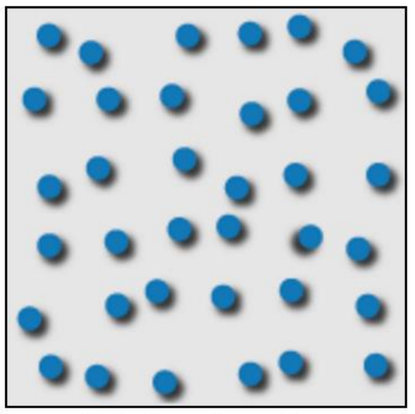
flicker
Gebb et a. 55; Mowbray & Gebhard 55; Brown 65; Julész 71; Huber & Healey 2005



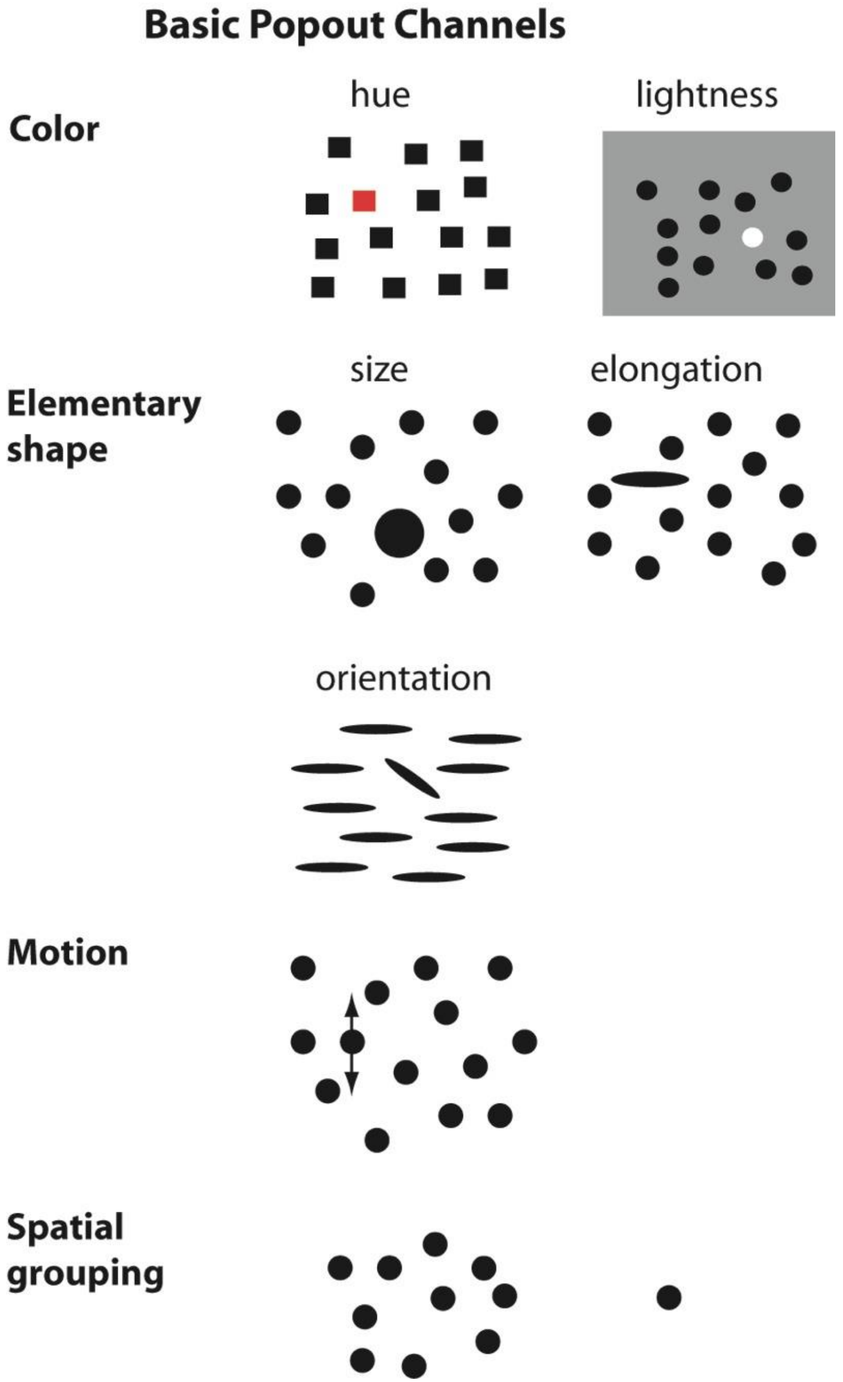
direction of motion
Nakayama & Silverman 86; Driver & McLeod 92; Huber & Healey 2005



velocity of motion
Tynan & Sekuler 82; Nakayama & Silverman 86; Driver & McLeod 92; Hohnsbein & Mateeff 98; Huber & Healey 2005



lighting direction
Enns 90a



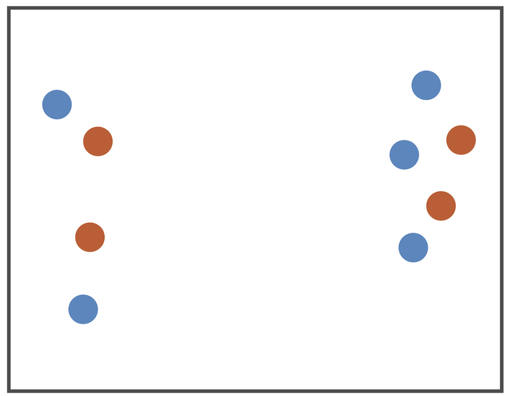
Use these "popout" effects to help design effective visualizations!

(E.g., draw viewer's attention to main points, effective redundant encodings, etc.)

Discriminability and Separability

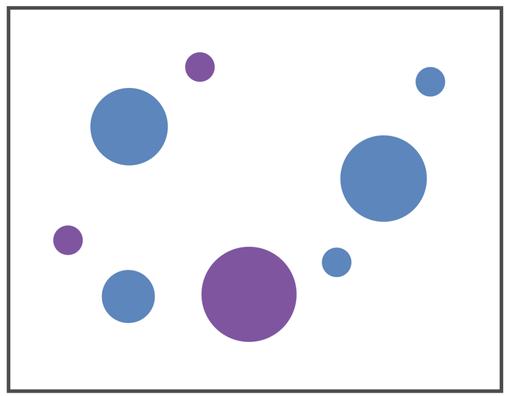
The question of discriminability is: if you encode data using a particular visual channel, are the differences between items perceptible to the human as intended?

Position
+ Hue (Color)



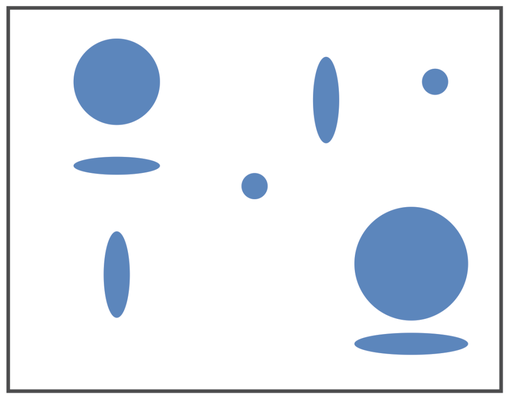
Fully separable

Size
+ Hue (Color)



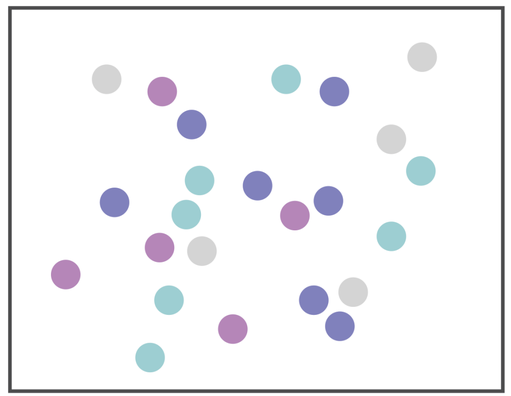
Some interference

Width
+ Height



Some/significant interference

Red
+ Green



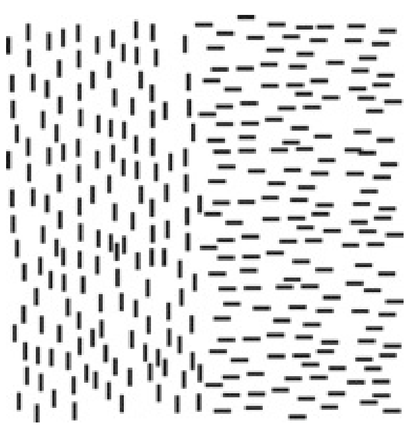
Major interference

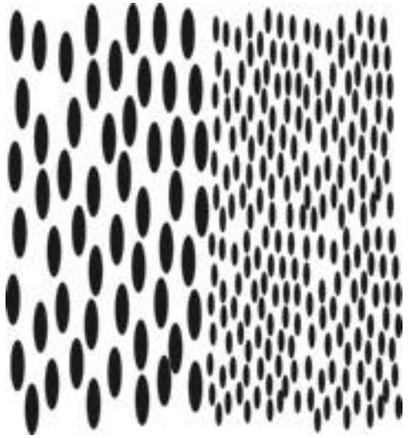
Discriminability and Separability

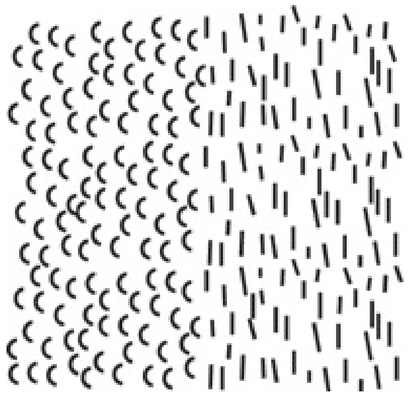
Ware, "Information Visualization"

Textures

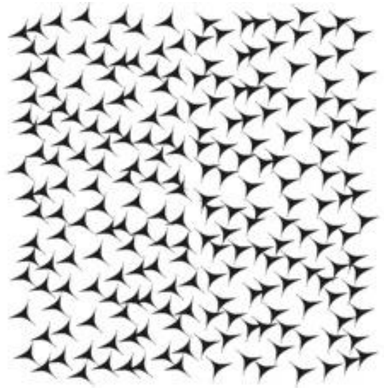
easy

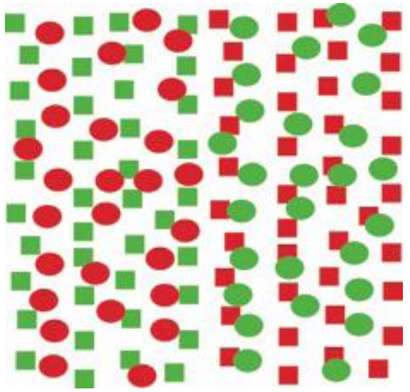


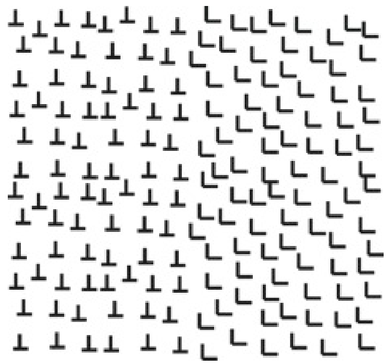




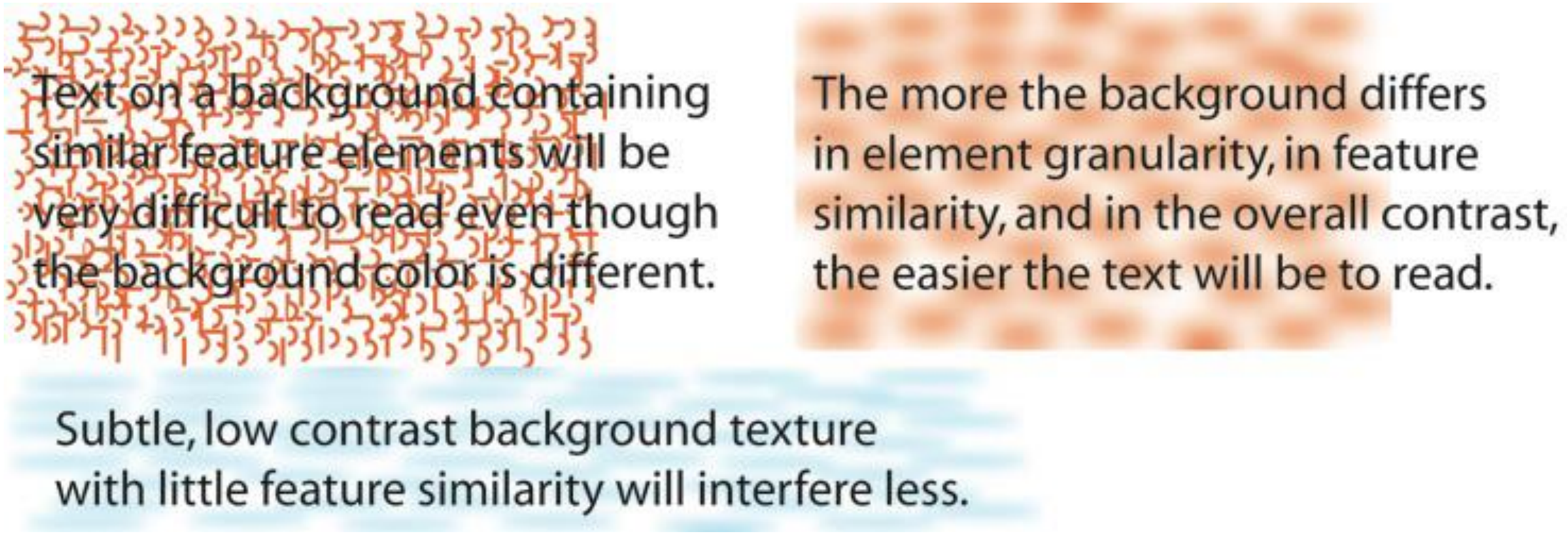
hard







Textures: Interference



More (13!) Color Design Tips

R1: Vivid colors (bright, saturated colors) stand out. They guide attention to a particular feature, generating the pop-out effect.

R2: An excessive amount of vivid colors is perceived as unpleasant and overwhelming; use them between duller background tones.

R3: Foreground-background separation works best if the foreground color is bright and highly saturated, while the background is de-saturated.

R4: Colors can be better discriminated if they differ simultaneously in hue, saturation and darkness.

R5: The low-end darkness steps should be very small, while the high end requires larger steps (Weber's Law).

R6: Discrimination is poorer for small objects. Hue, saturation and darkness discrimination all decrease.

R7: Complementary (opponent) colors are located opposite on the color wheel and have the highest chromatic contrast. When mixing opponent colors they may cancel each other, giving neutral grey.

R8: Some hues appear inherently more saturated than others. Yellow has the least number of perceived saturation steps (10). For hues on both sides of yellow, the saturation steps increase linearly.

R9: An opposite effect of R8 is that the brightest lights fall in the yellow range, while blues, violets (purples) and reds are least bright.

R10: For labeling, apart from black, white, grey, there are 4 primary colors (red, green, blue, yellow) and 4 secondary colors (brown, orange, purple, pink). Also, the number of color labels should be ≤ 6-7.

R11: Warm colors (red, orange, yellow) excite emotions, grab attention. Cold colors (green to violet) create openness and distance.

R12: Important for hue-based labeling is the fact that increasing the darkness (and saturation) does not change the perceived hue.

R13: Also important for labeling is that objects of similar hue are perceived as a group, while objects of different hues are perceived as belonging to different groupings.

Wang et al., 2008

ILLUSIONS AND TRICKS

Visual Attention & Change Blindness


How many passes does the team in white make?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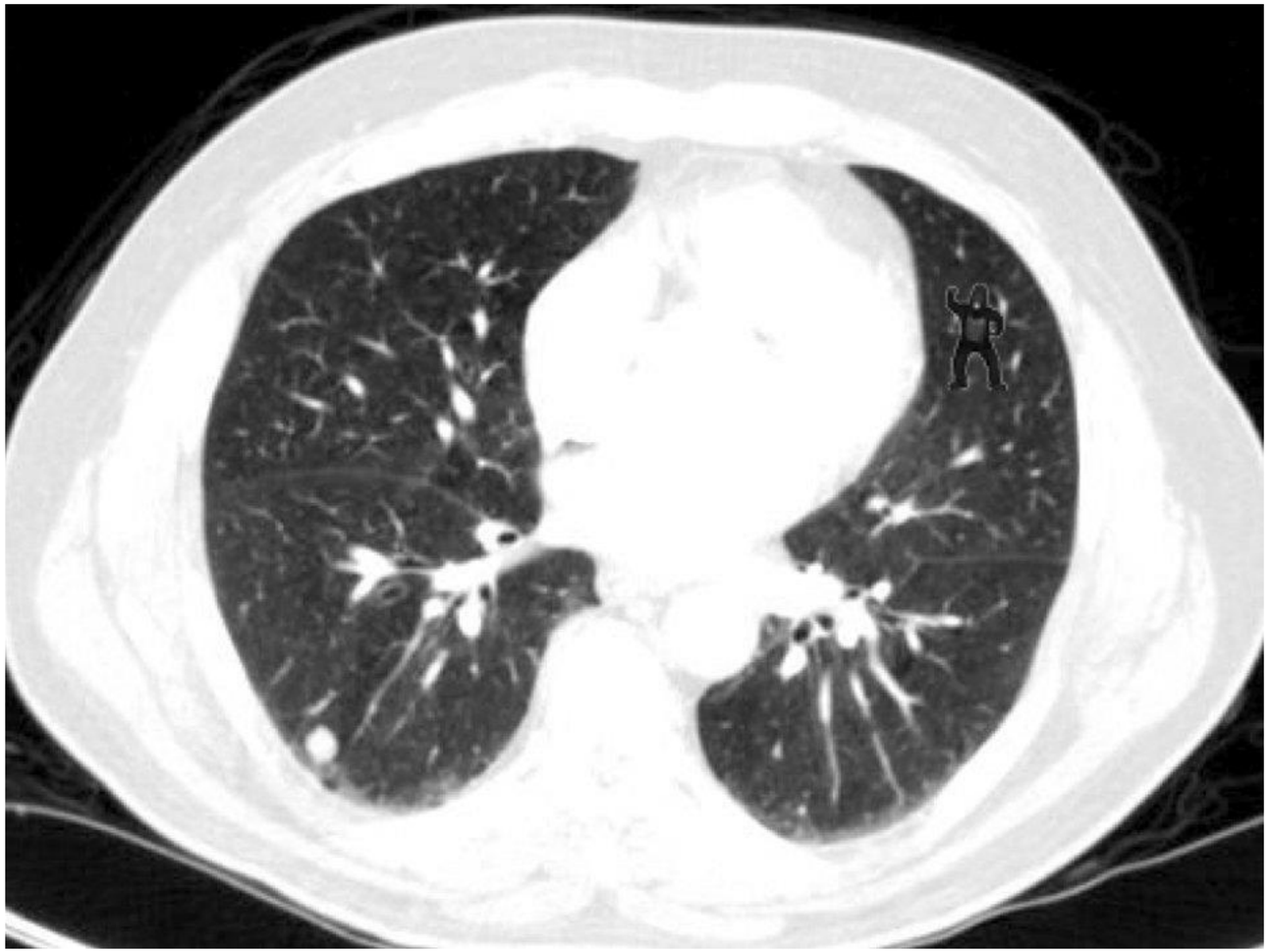
Visual Attention & Change Blindness

Task: Identify the lumps/nodules in the patient's lungs to look for cancer or abnormal growth.



83% of the radiologists missed the gorilla!

http://search.bwh.harvard.edu/new/pubs/DrewVoWolfe13.pdf

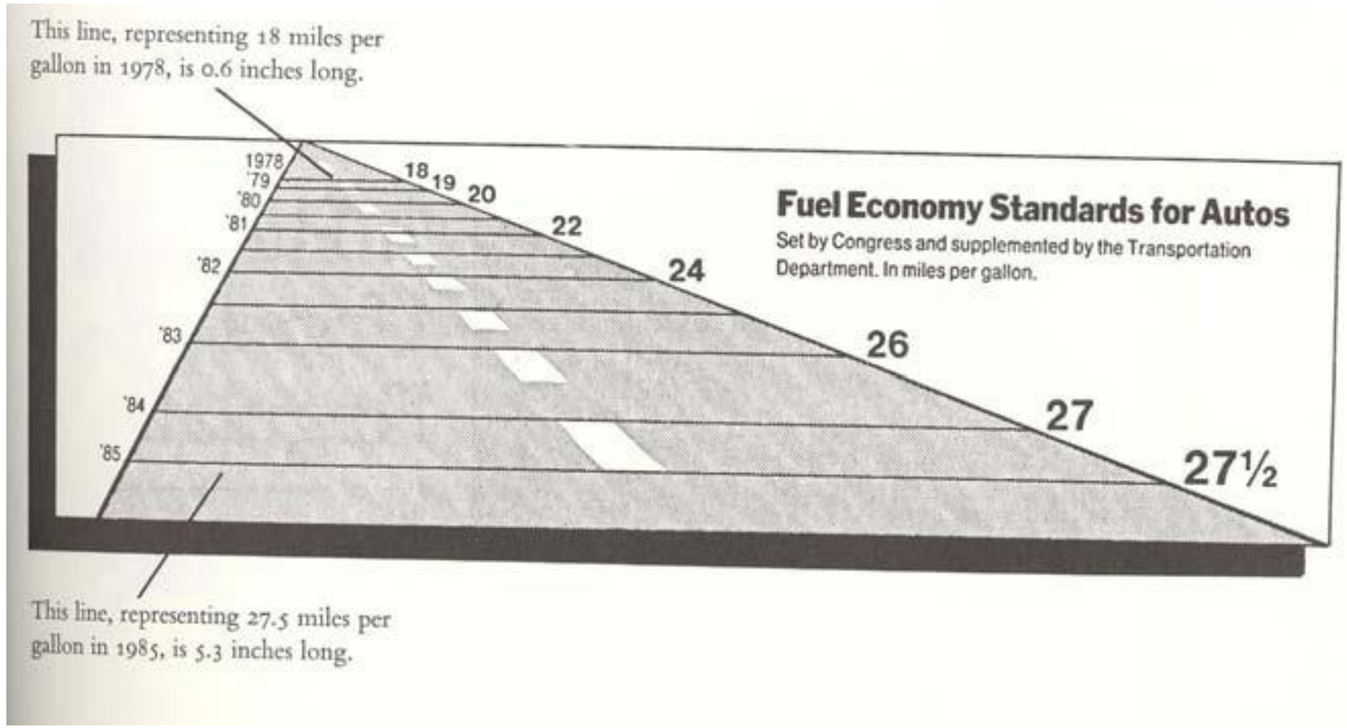
Lie Factor

$$\text{Lie Factor} = \frac{\text{(Size of effect in graphic)}}{\text{(Size of effect in data)}}$$

Lie Factor = >1, overstating

Lie Factor = 1, accurate :)

Lie Factor = <1, understating

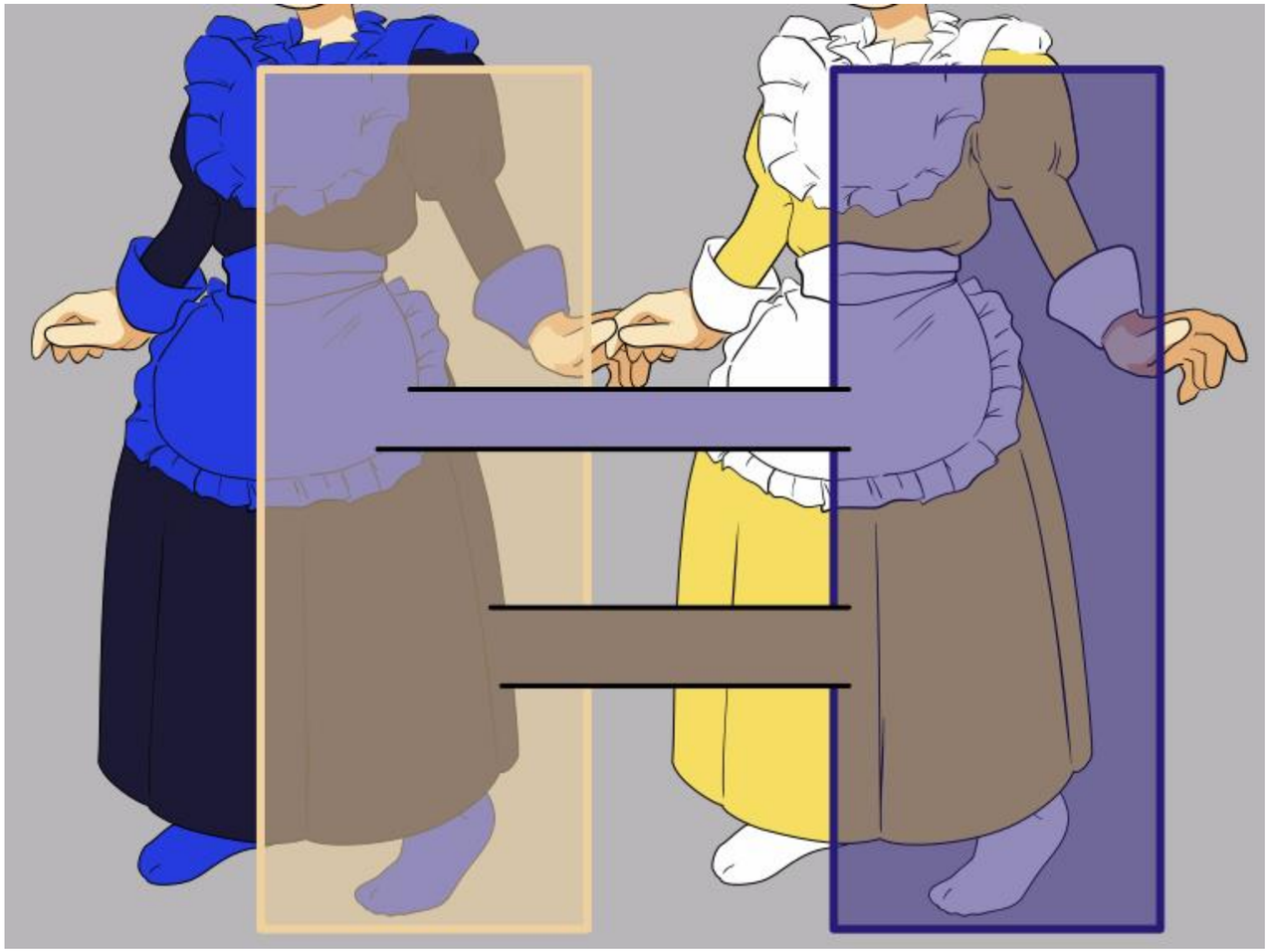


"The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities measured."

Tufte, "Visual Display of Quantitative Information" (1983)

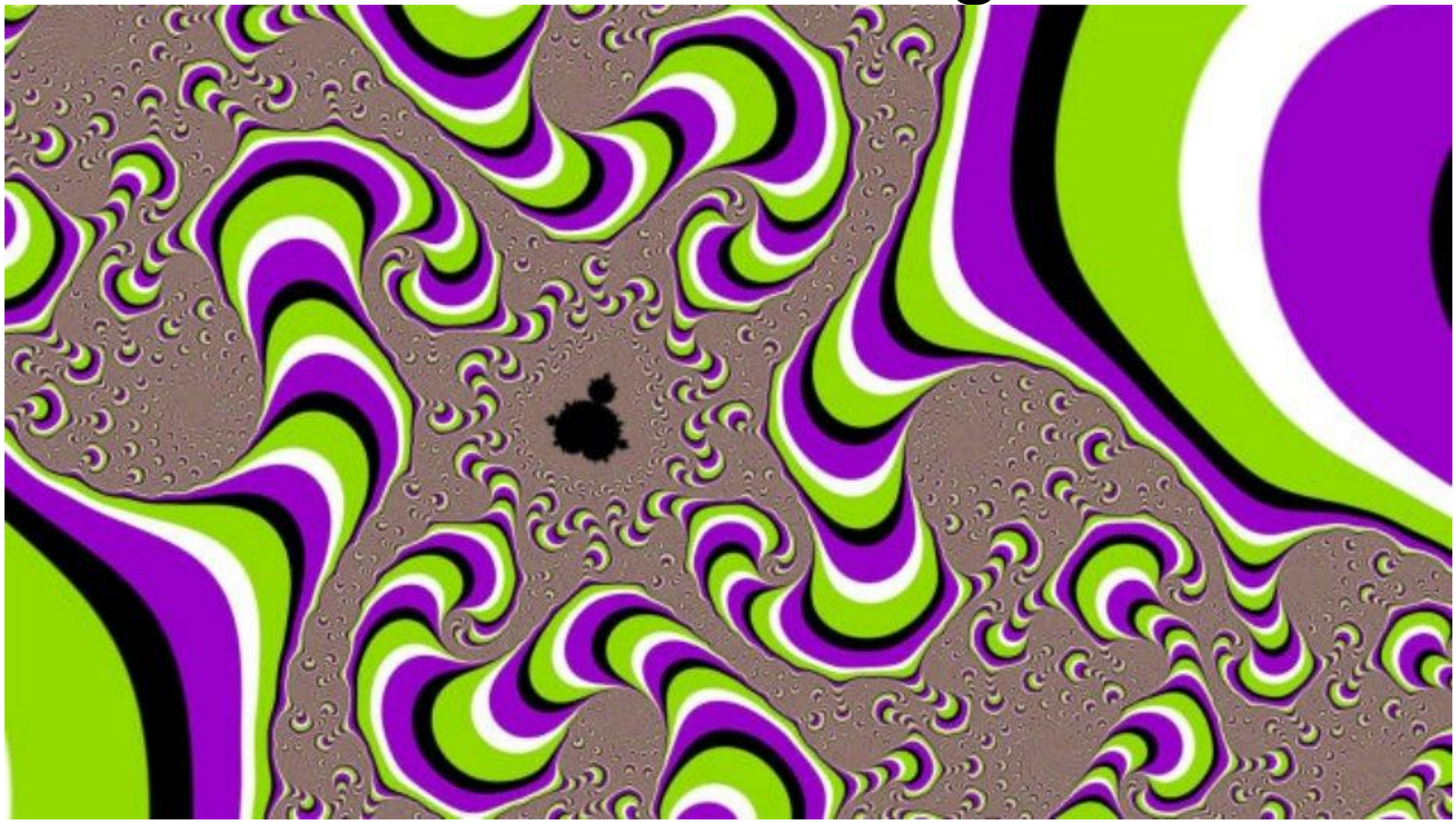
The Dress:

blue/black or yellow/white?



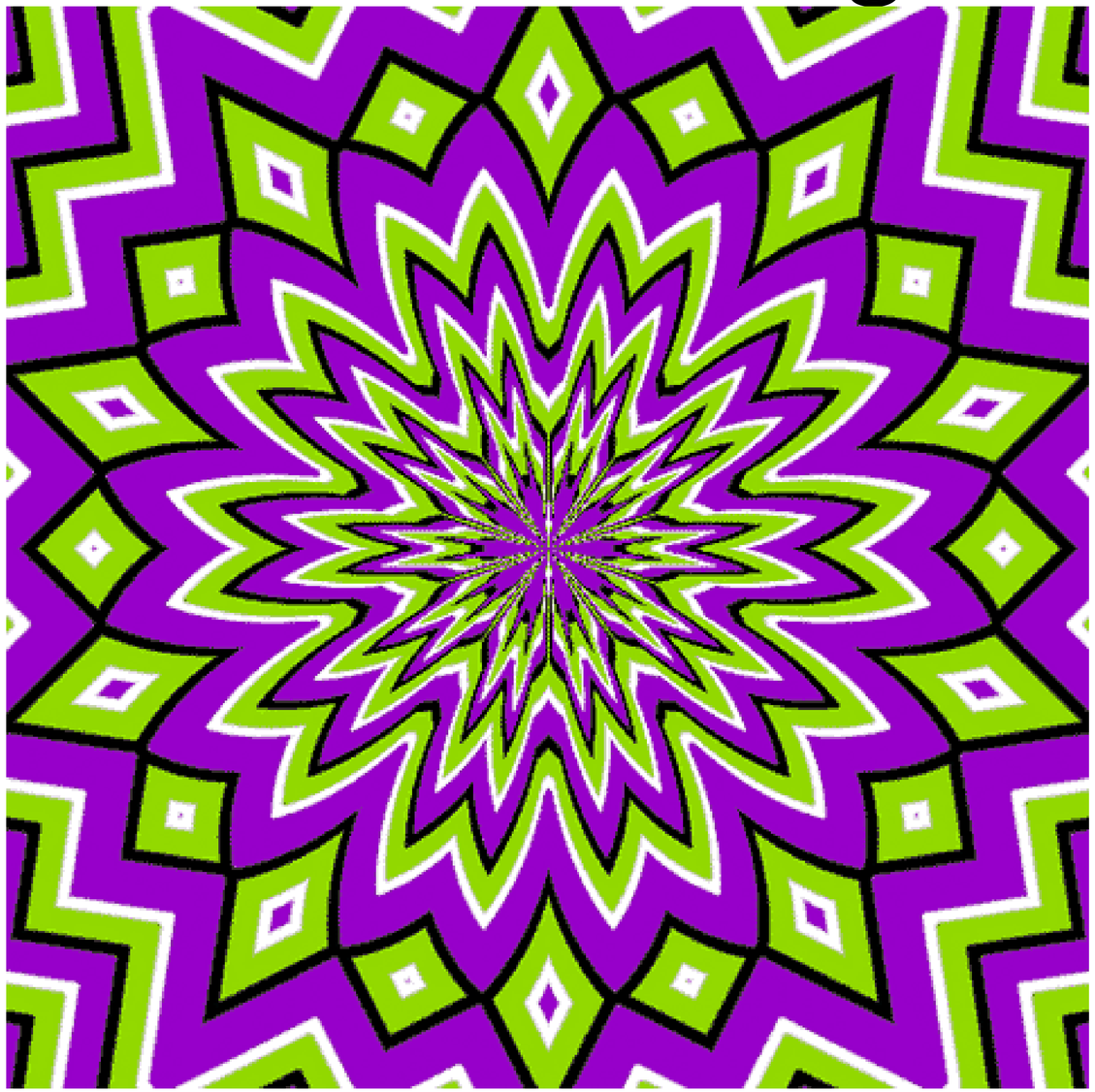
https://en.wikipedia.org/wiki/The_dress

Still or moving?



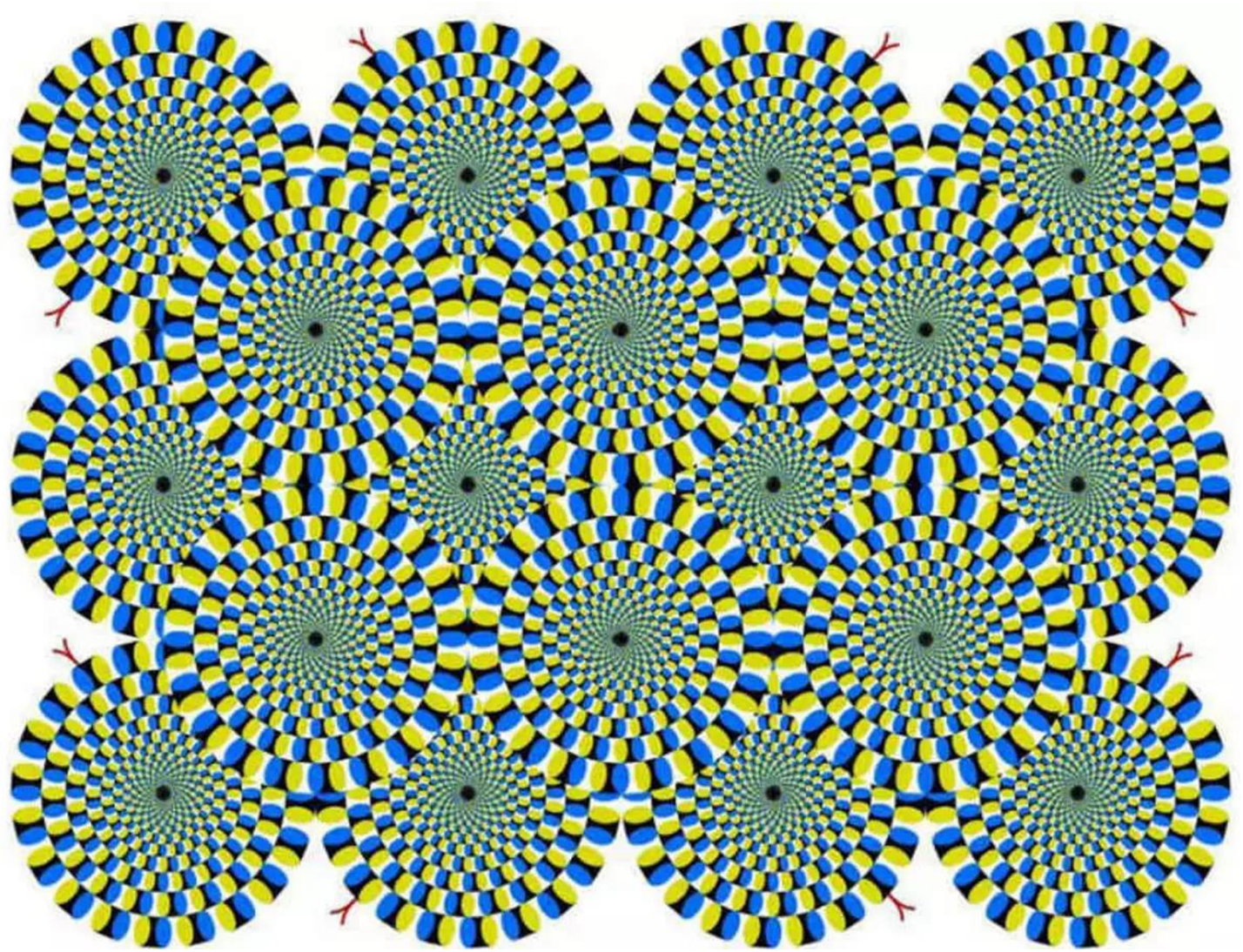
Griffin, 2015

Still or moving?



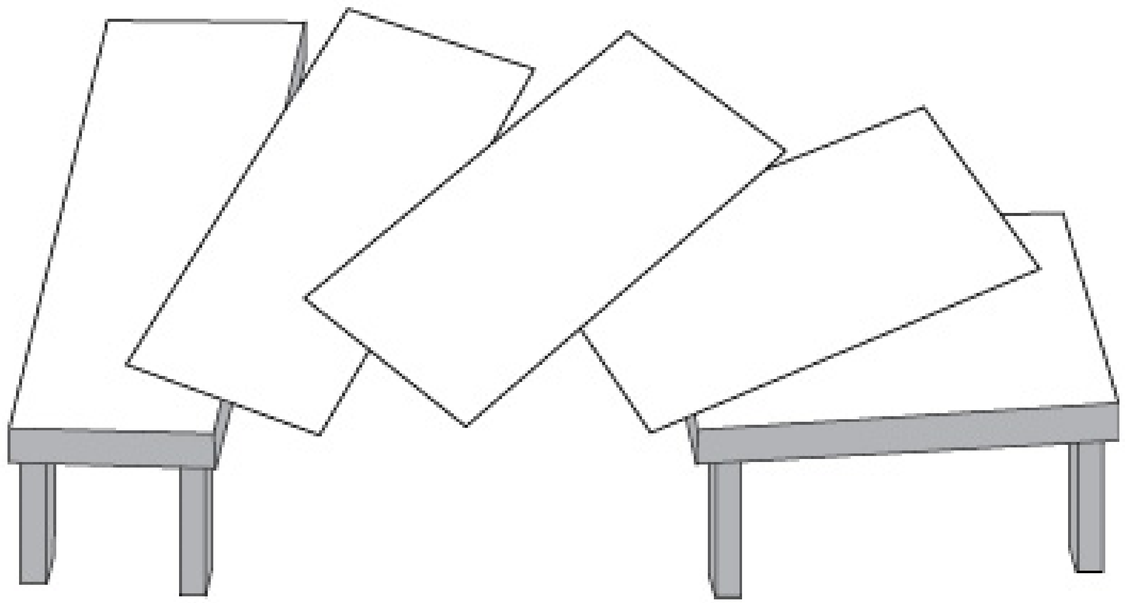
Griffin, 2015

Still or moving?



Griffin, 2015

Shepherd's Table Illusion



Illusion based on how we perceive depth/perspective...

http://mentalfloss.com/article/28862/brainworks-explaining-optical-illusions-and-other-mental-tricks