

# Lecture 10: Color

CS 7250

SPRING 2021

*Prof. Cody Dunne*

*NORTHEASTERN UNIVERSITY*

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

# CHECKING IN

# READING QUIZ

Quiz — Color

Password: “drats\_another\_quiz”

ACCEPT ASSIGNMENT 7 — D3

EVENT HANDLING NOW!

# VISUALIZATION IDEAS



# Visualization Taxonomy

In order to address the variety of visualization types in the MassVis database, we created a taxonomy for static (i.e., non-interactive) visualizations. The taxonomy classifies static visualizations according to the underlying data structures, the visual encoding of the data, and the perceptual tasks enabled by these encodings. It contains twelve visualization categories and several popular subtypes for each category. In addition, we supply a set of properties that aid in the characterization of the visualizations. This taxonomy was created originally to classify the **2k dataset**, and we continue to use this terminology in our **papers**. For more information about the taxonomy, please read this document: **taxonomy details**

If you use this taxonomy, please cite this paper:  **Bibtex**

<http://massvis.mit.edu/>

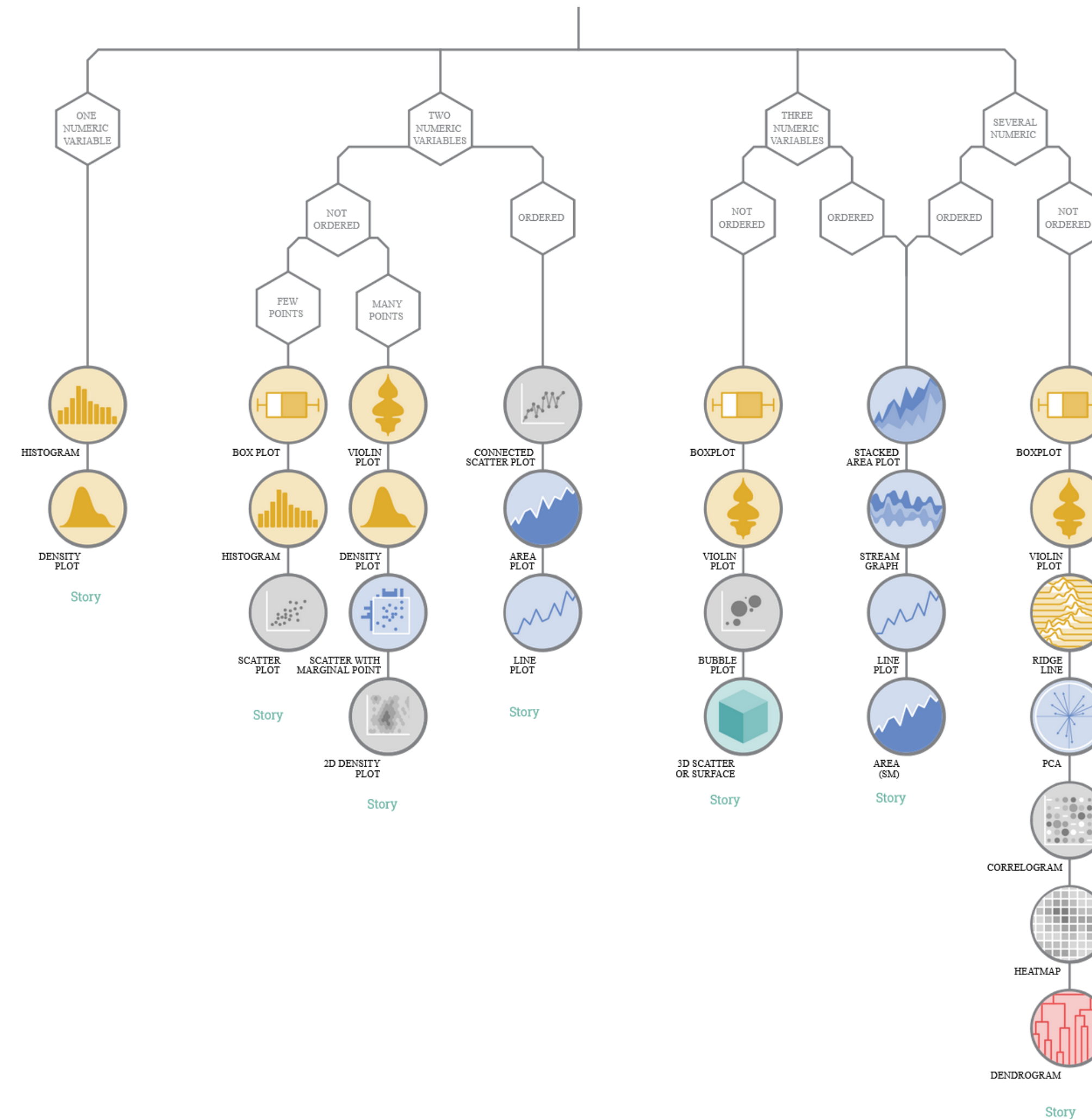
Borkin, M., Vo, A., Bylinskii, Z., Isola, P., Sunkavalli, S., Oliva, A., & Pfister, H., 2013, "[What Makes a Visualization Memorable?](#)", IEEE Transactions on Visualization and Computer Graphics (Proceedings of InfoVis 2013), 19, 12, 2306-2315.

# More visualization “catalogs”

What kind of data do you have? Pick the main type using the buttons below. Then let the decision tree guide you toward your graphic possibilities.

## Data to Viz

<https://www.data-to-viz.com/>



# More visualization “catalogs”

DataVizProject

<http://datavizproject.com/>

The Data Visualization Catalogue

<http://www.datavizcatalogue.com/>





# More visualization ideas

<https://matplotlib.org/gallery.html>

<https://github.com/d3/d3/wiki/Gallery>

<https://plot.ly/python/>

This screenshot shows the 'Gallery' page of the D3.js GitHub repository. The page features a 'Visual Index' grid with 16 categories of charts: Box Plots, Bubble Chart, Bullet Charts, Calendar View, Non-contiguous Cartogram, Chord Diagram, Dendrogram, Force-Directed Graph, Circle Packing, Population Pyramid 2000, Stacked Bars, Streamgraph, Sunburst, Node-Link Tree, Treemap, and Voronoi Diagram. On the right side, there is a 'Data-Driven Documents' section with links to Home, Gallery, Examples, Tutorials, and Plugins, and a 'Help' section with links to Stack Overflow, Slack, Google Group, and Gitter. The top of the page shows repository statistics: 3,611 watches, 72,156 stars, and 18,630 forks.

This screenshot shows the Plotly Python Open Source Graphing Library website. The header includes the Python logo and the text 'Plotly Python Open Source Graphing Library'. Below the header, there is a search bar and a section titled 'Plotly Fundamentals' with five links: 'Dash - Interactive Python Apps', 'Static Image Export', 'Updating Plotly Graphs', 'Jupyter Notebook Tutorial', and 'More Plotly Fundamentals'. Below this is a 'Basic Charts' section with four chart thumbnails and a 'More Plotly Fundamentals' button. The text on the page describes Plotly's capabilities: 'Plotly's Python graphing library makes interactive, publication-quality graphs online. Examples of how to make line plots, scatter plots, area charts, bar charts, error bars, box plots, histograms, heatmaps, subplots, multiple-axes, polar charts, and bubble charts.'

This screenshot shows the Matplotlib website. The main heading is 'matplotlib' with a logo. Below the heading, there is a section titled 'Lines, bars, and markers' which displays a grid of 12 different chart examples. The examples are labeled as follows: 'barh\_demo', 'fill\_demo', 'fill\_demo\_features', 'line\_demo\_dash\_control', 'line\_styles\_reference', 'linestyles', 'marker\_fillstyle\_reference', 'marker\_reference', 'filled markers', and 'unfilled markers'. Each example shows a different combination of line styles, markers, and fill colors.

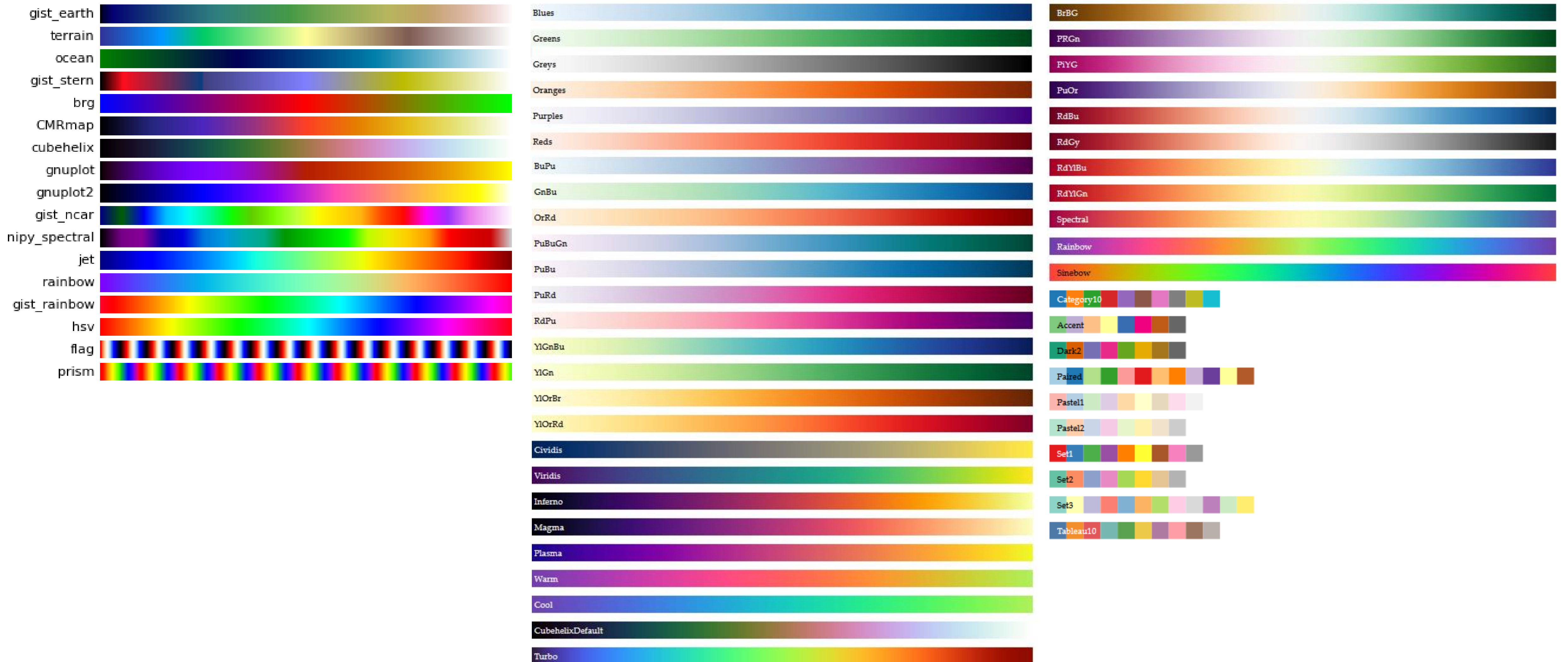
COLOR

# 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 Maps

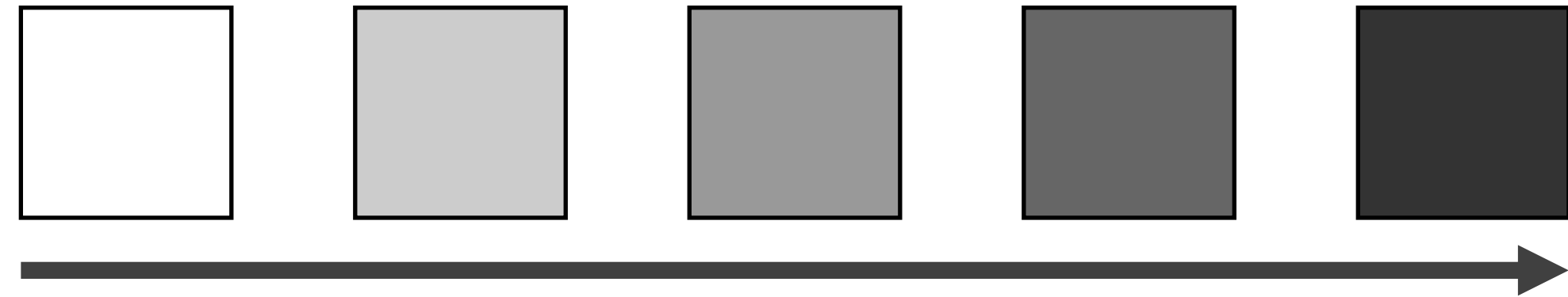
Color Map = map between value (domain) and color (range)



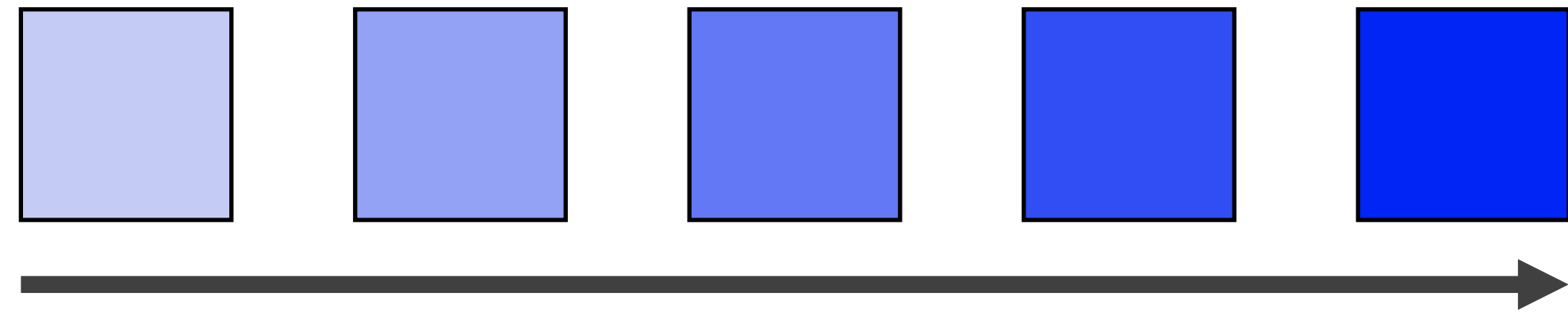
“...avoiding catastrophe becomes the first principle in bringing color to information: above all, do no harm.”  
-Edward Tufte

# Color Vocabulary and Perceptual Ordering

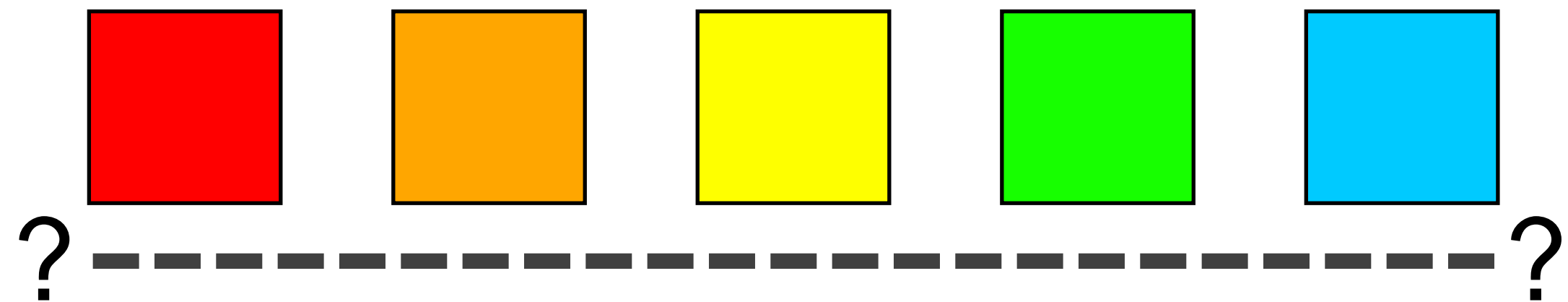
Darkness (Lightness)



Saturation



Hue



# Encode > Map

## → Color

→ Color Encoding

→ Hue



→ Saturation



→ Luminance



≈ Darkness  
(Lightness)

→ Color Map

→ Categorical



→ Ordered

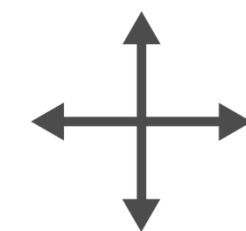
→ Sequential



→ Diverging



→ Bivariate



## → Size, Angle, Curvature, ...

→ Length



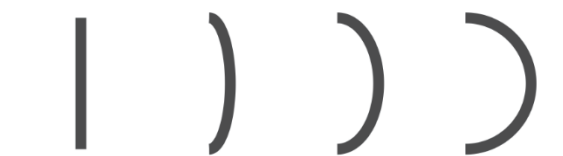
→ Angle



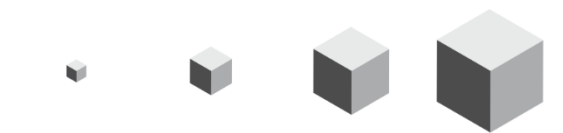
→ Area



→ Curvature



→ Volume



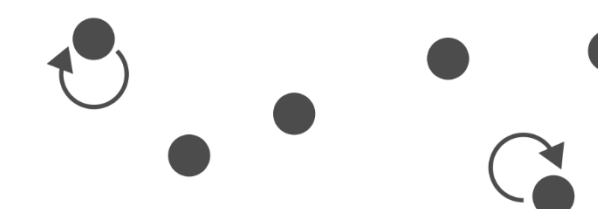
## → Shape



## → Motion

→ Motion

Direction, Rate,  
Frequency, ...



# Color Maps

## THREE MAIN TYPES:

### Categorical

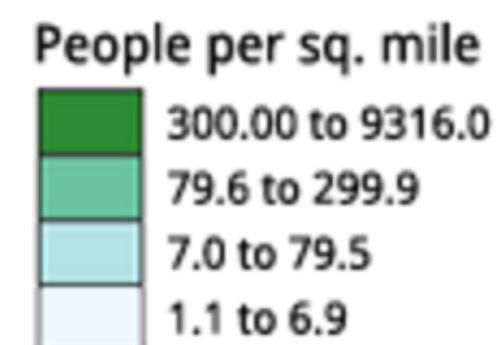


Does not imply magnitude differences (categorical/nominal data)

Distinct hues with similar emphasis

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### Sequential

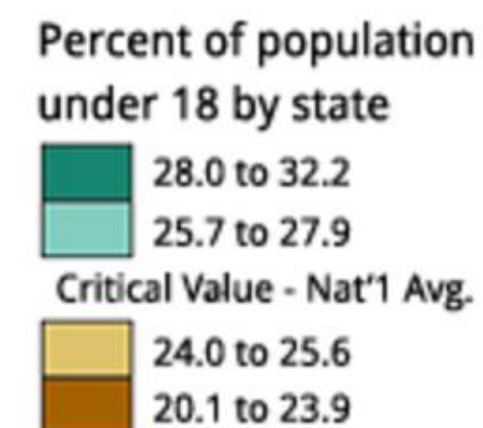


Best for ordered data that progresses from low to high (ordinal, quantitative data)

Darkness (lightness) channel effectively employed

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### 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



# Color Maps

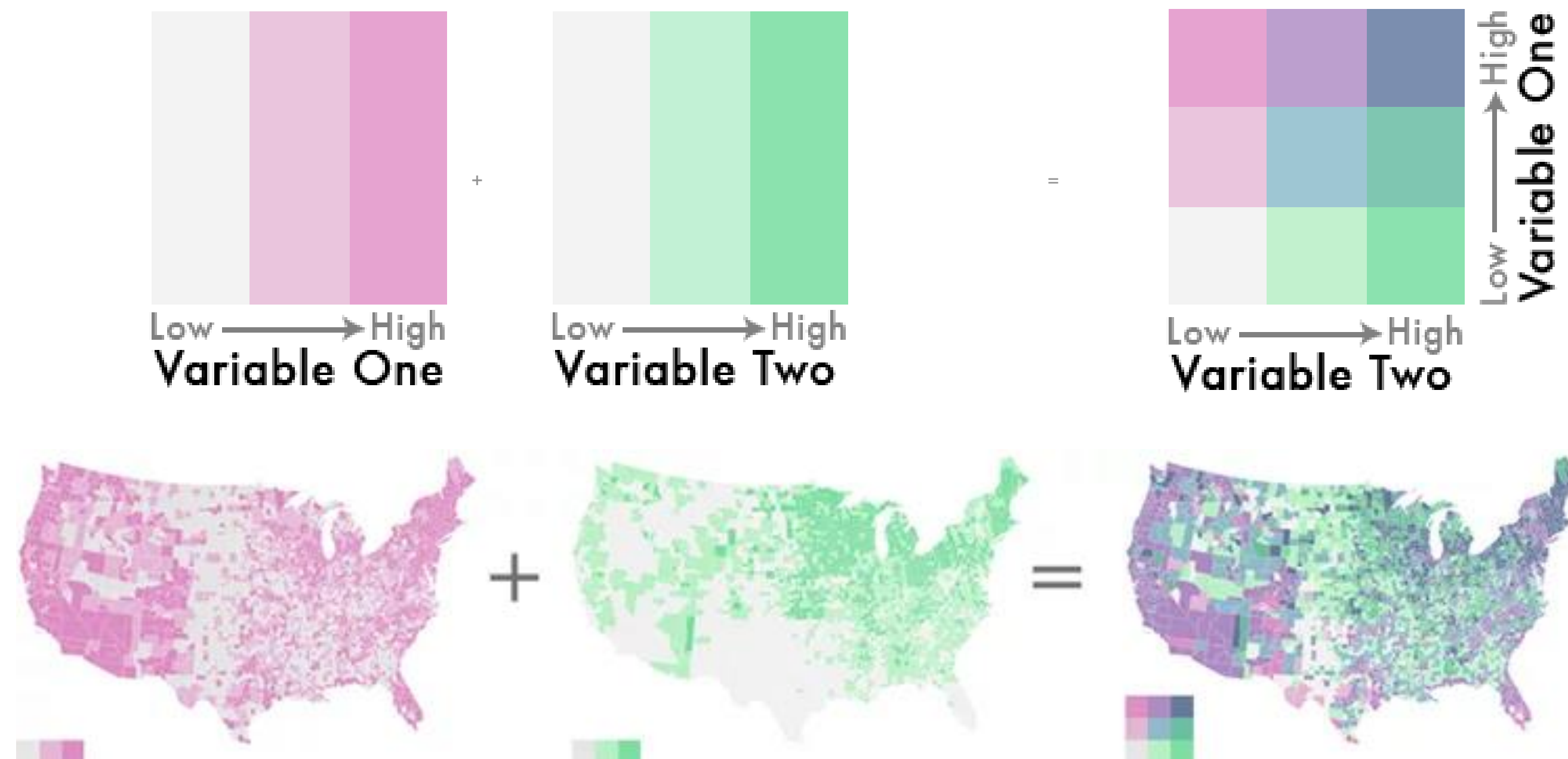
ALSO...

Bivariate

Displays two variables

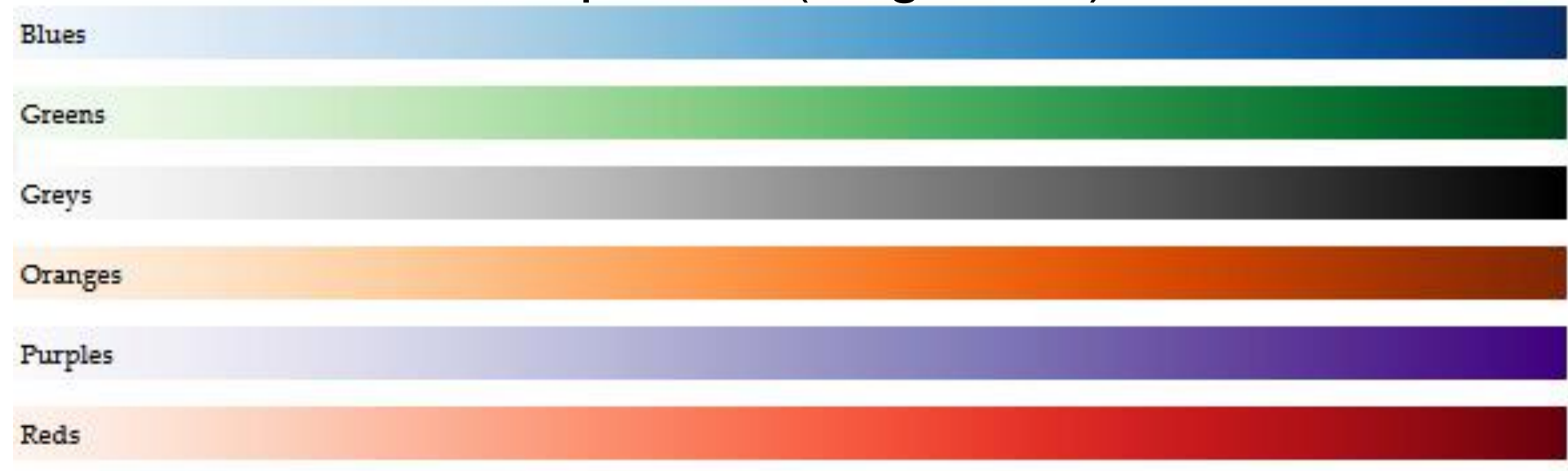
Combination of two sequential color schemes

*These are very difficult to design effectively, make intelligible, and be color blind friendly.*



# Types of Color Maps

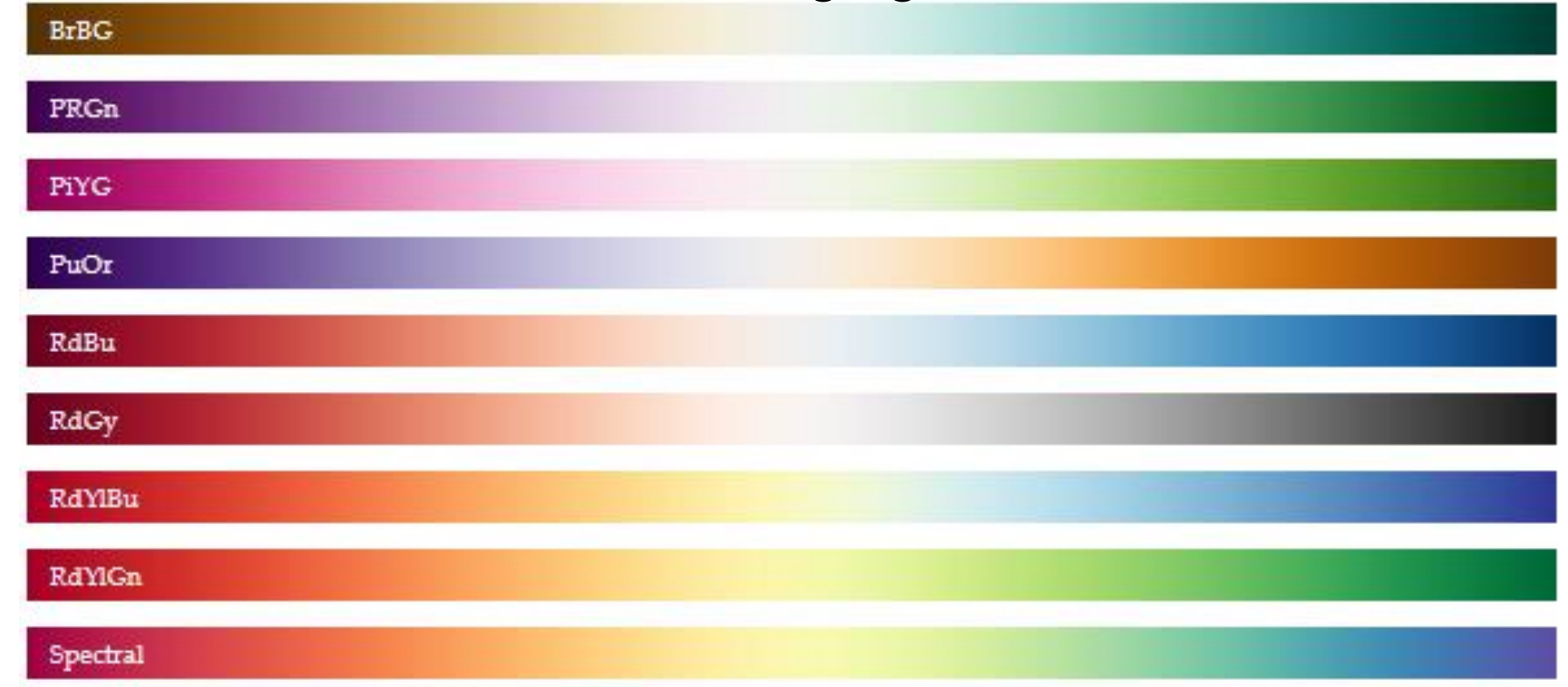
Sequential (single hue)



Sequential (multiple hue)



Diverging



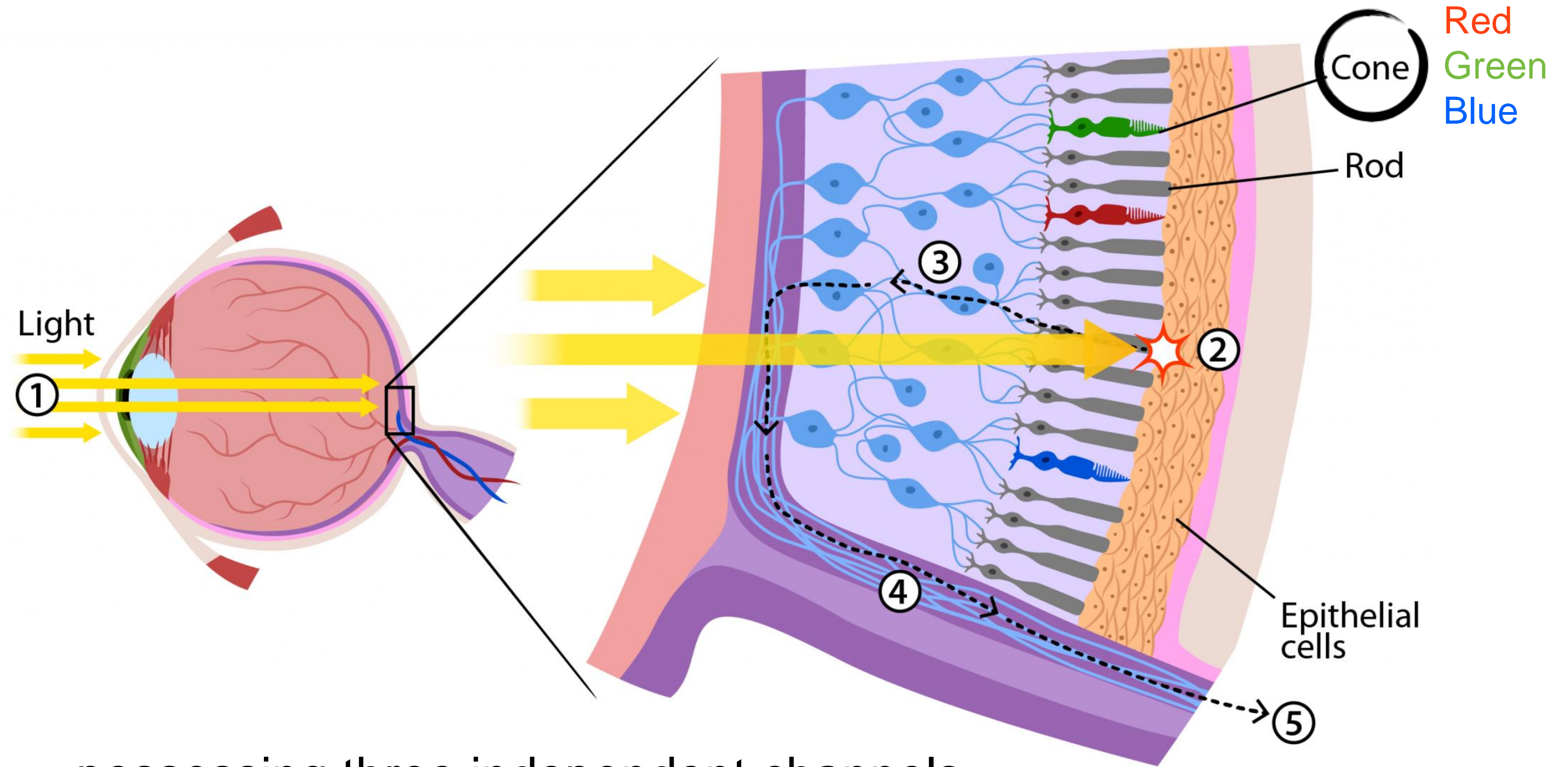
Categorical



Cyclical

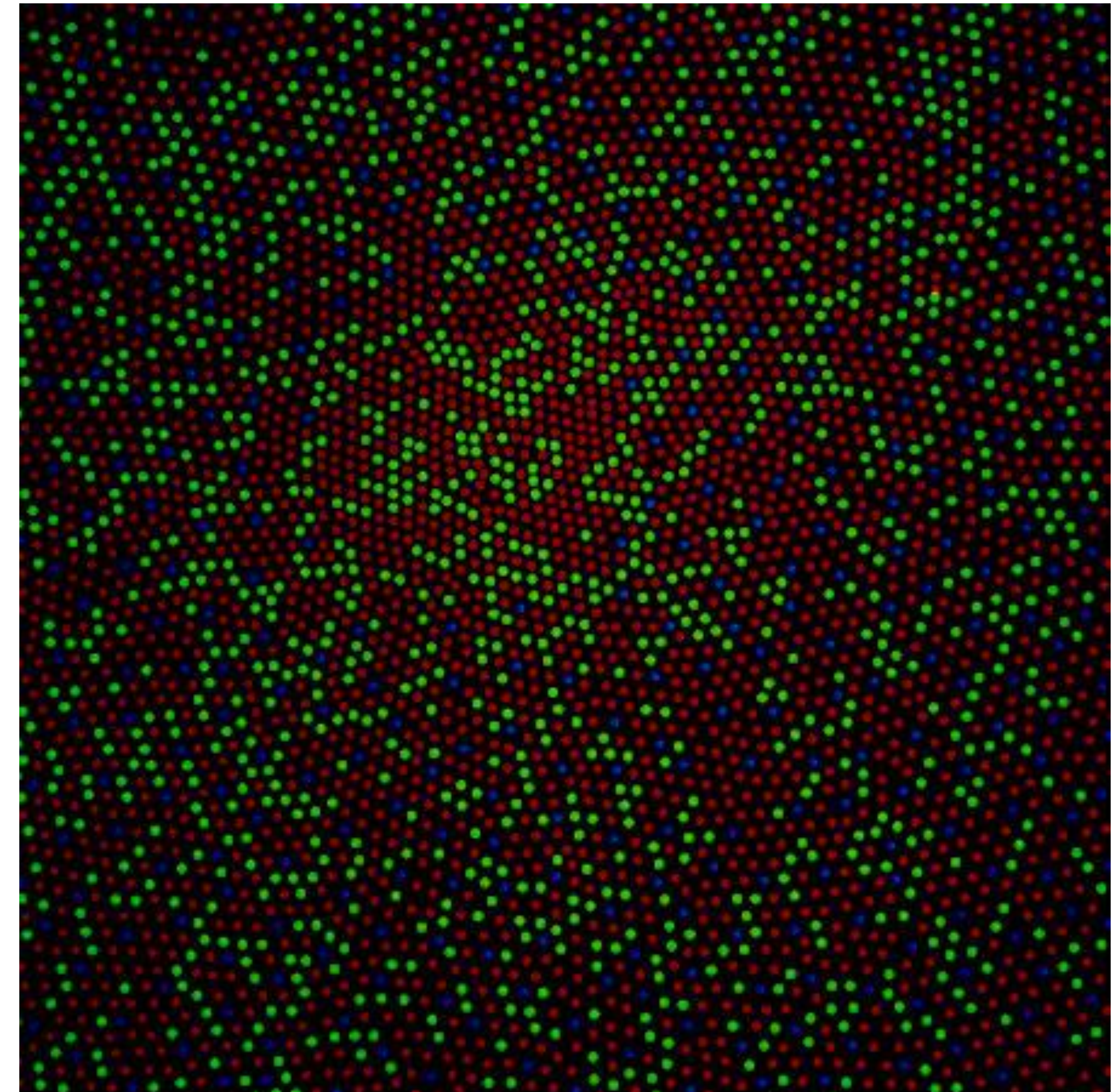
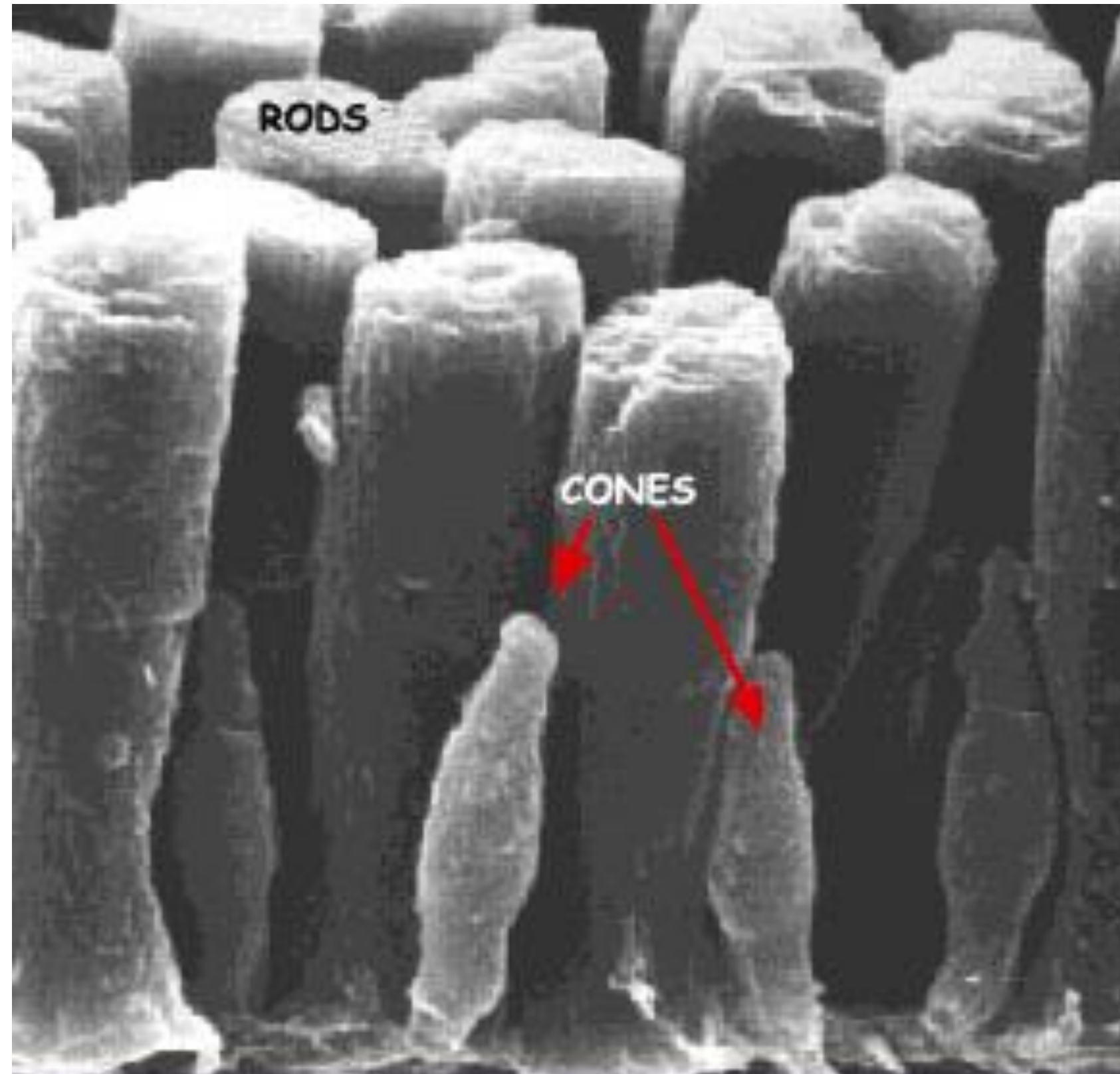


# RODS & CONES

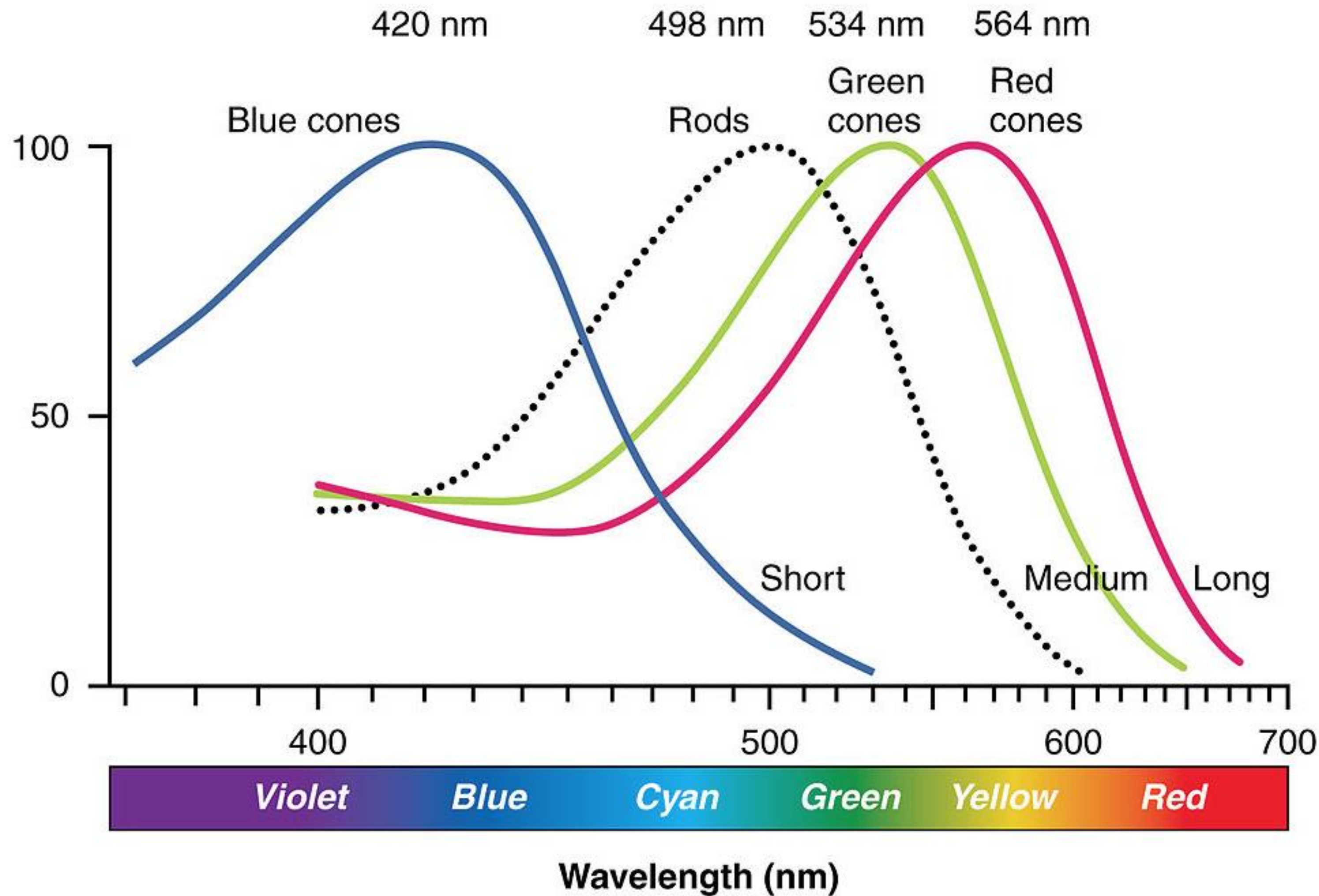


trichromacy = possessing three independent channels for conveying color information

# RODS & CONES



# CONES & RODS



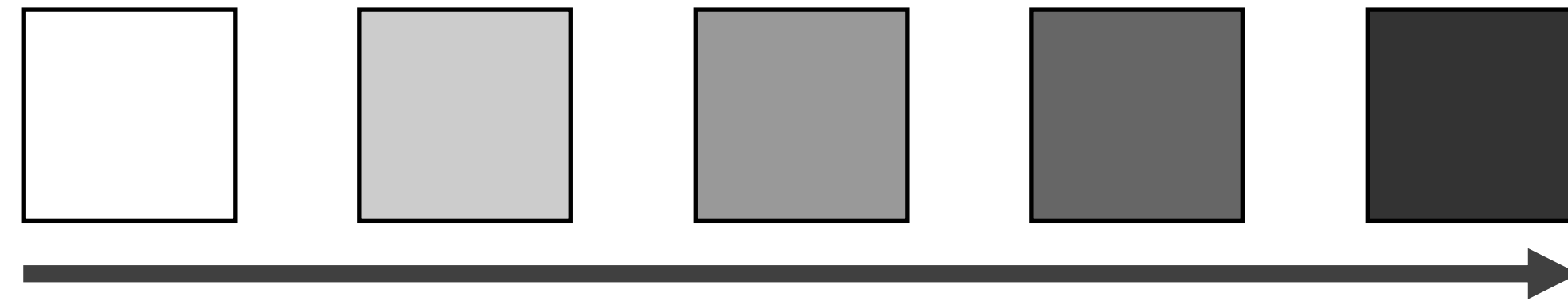
This is why darkness (lightness) is an effective encoding channel!

Rods: 120 million  
Cones: 5-6 million

This is why we are so sensitive to red!

Cones:  
64% red-sensitive  
32% green-sensitive  
2% blue-sensitive.

# 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

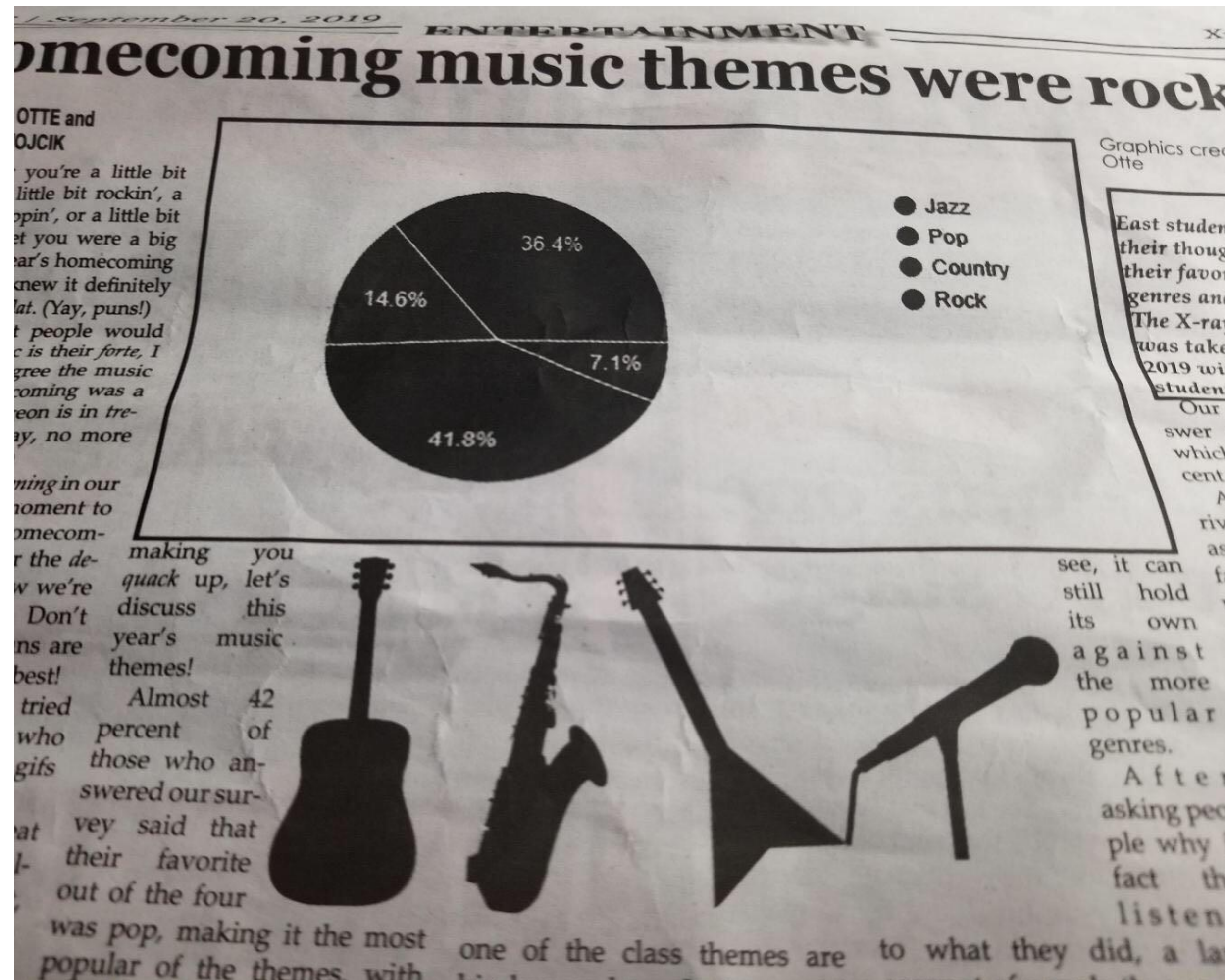
“Get it right in black and white.”

-Maureen Stone





# Understanding your medium matters



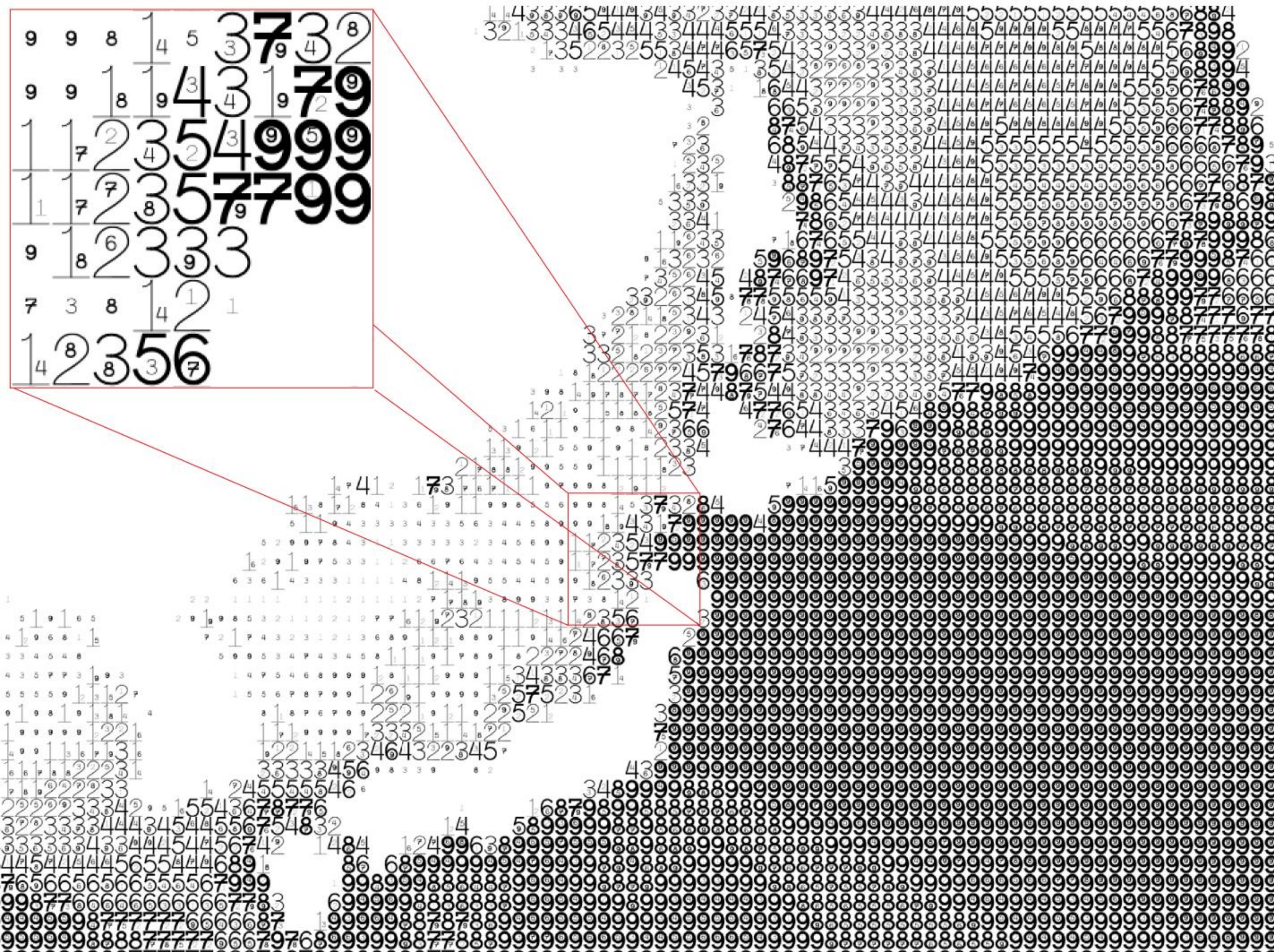
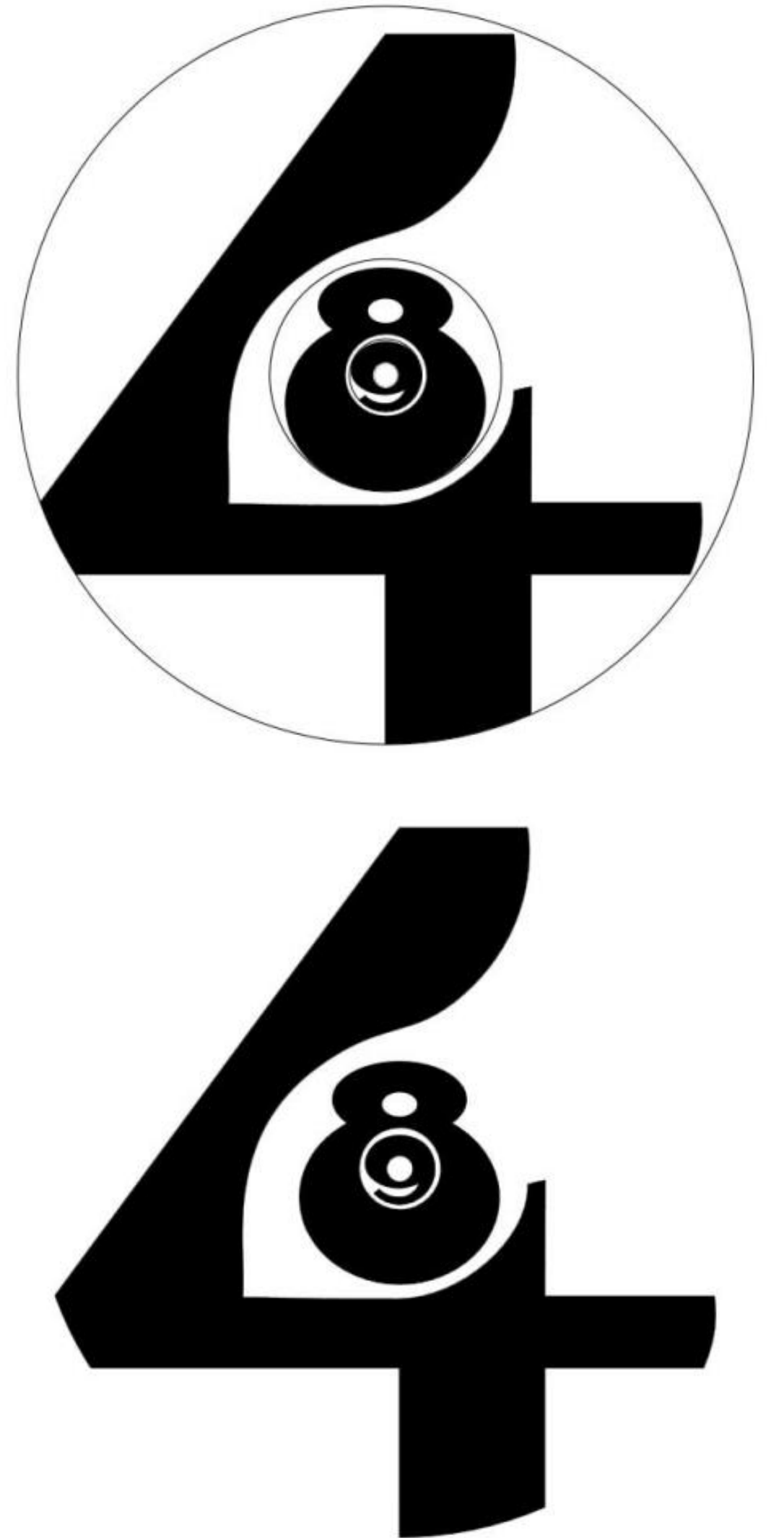
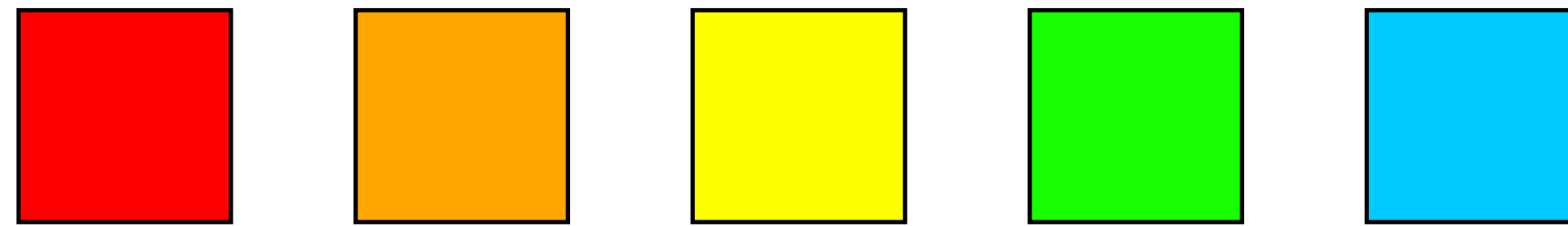


Figure 8: Maximum wave amplitudes for the Japan 2011 tsunami. Amplitudes were clipped at 99cm. Data adapted from NOAA; <http://www.noaa.gov/>.

# FatFonts



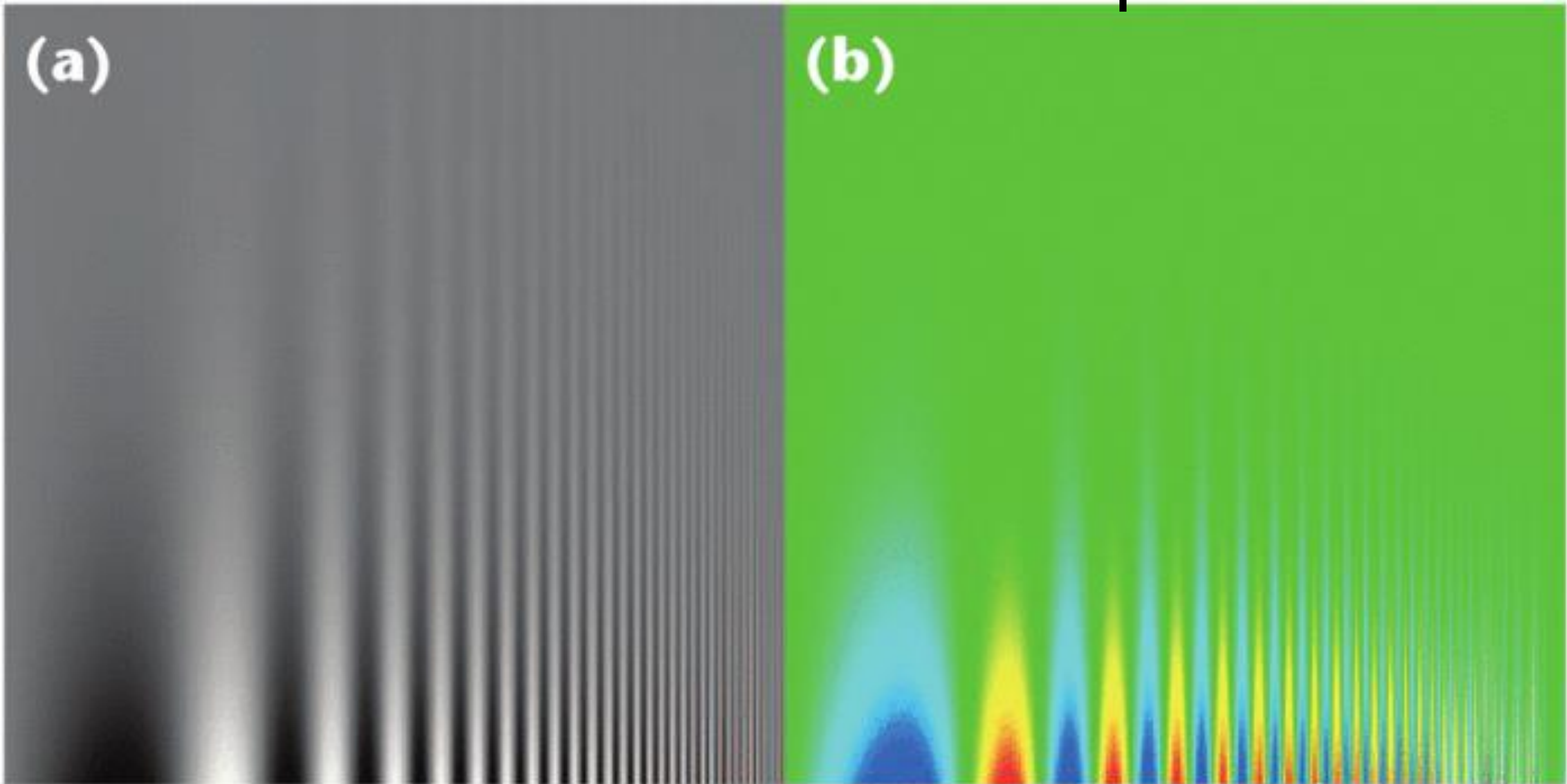
# Rainbow Color Map (Hue)



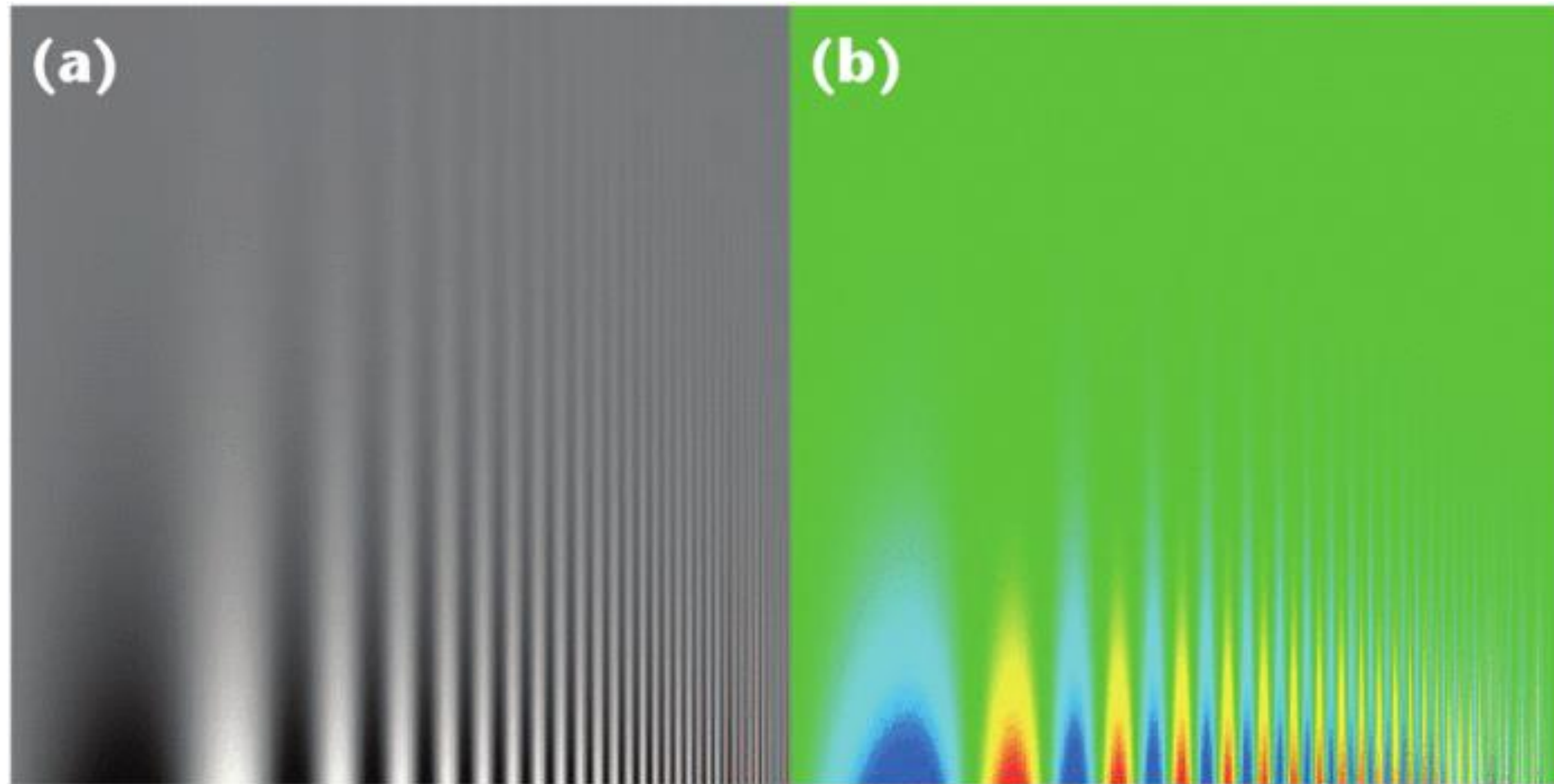
# Rainbow Color Map

(a)

(b)



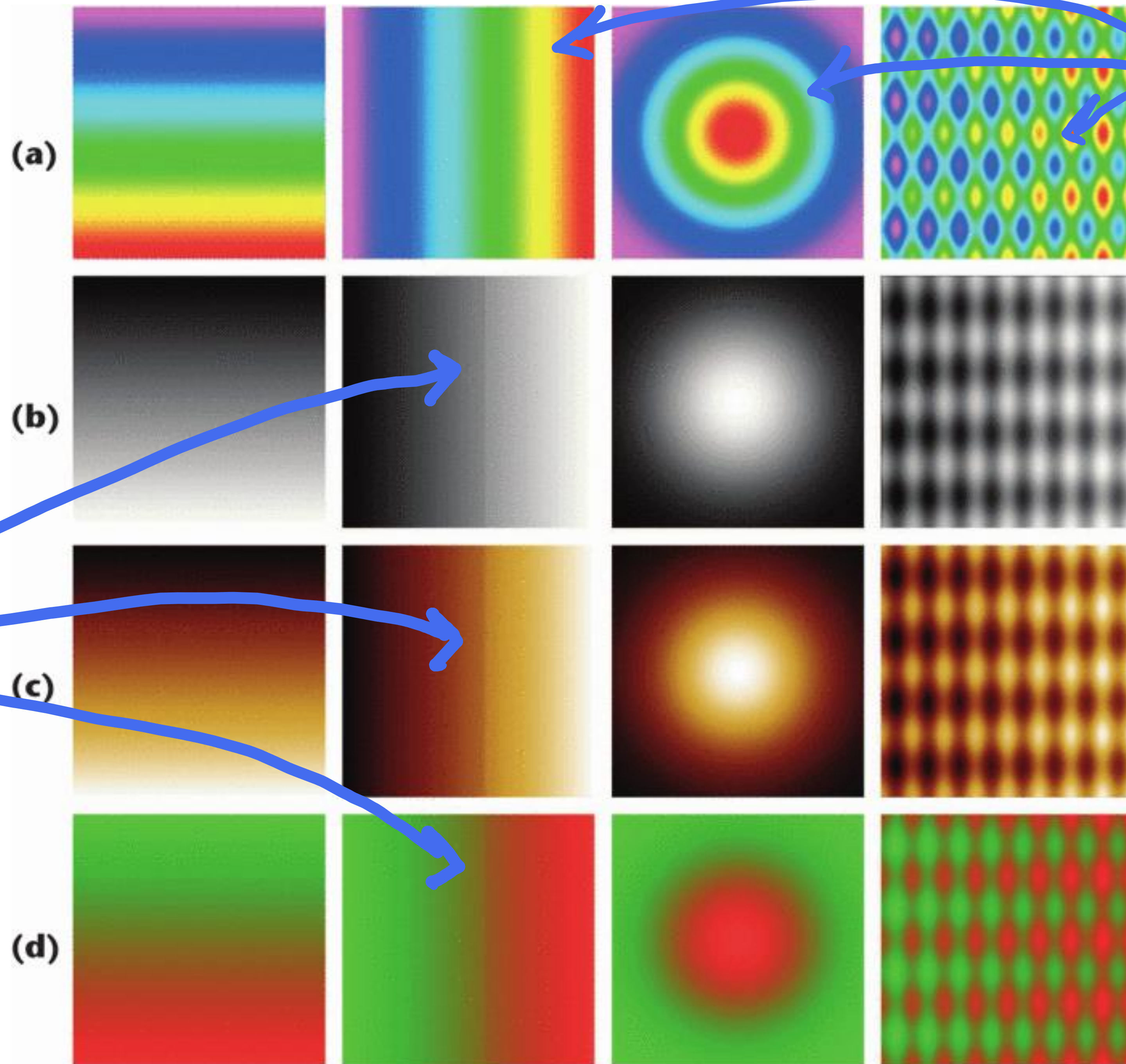
# Rainbow Color Map



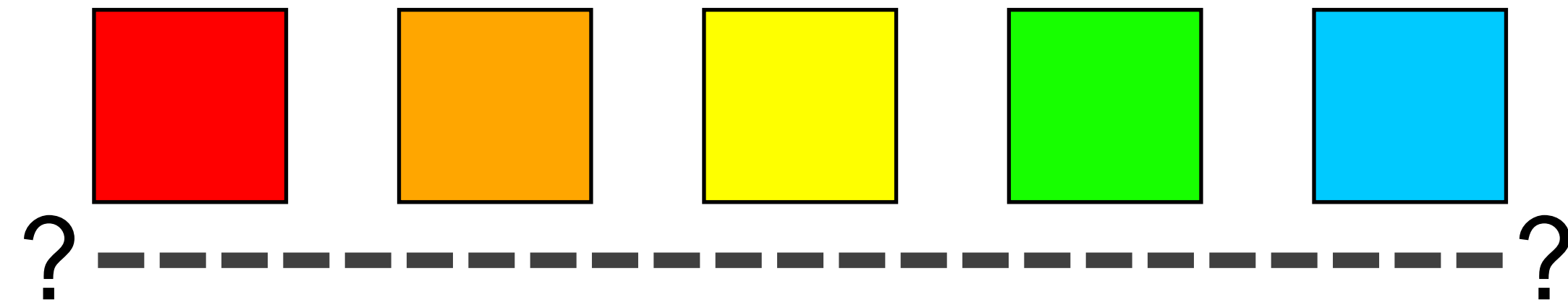
- No darkness variation (obscures details)
- Viewers perceive sharp transitions in color as sharp transitions in the data, even when this is not the case (misleading)

Real!

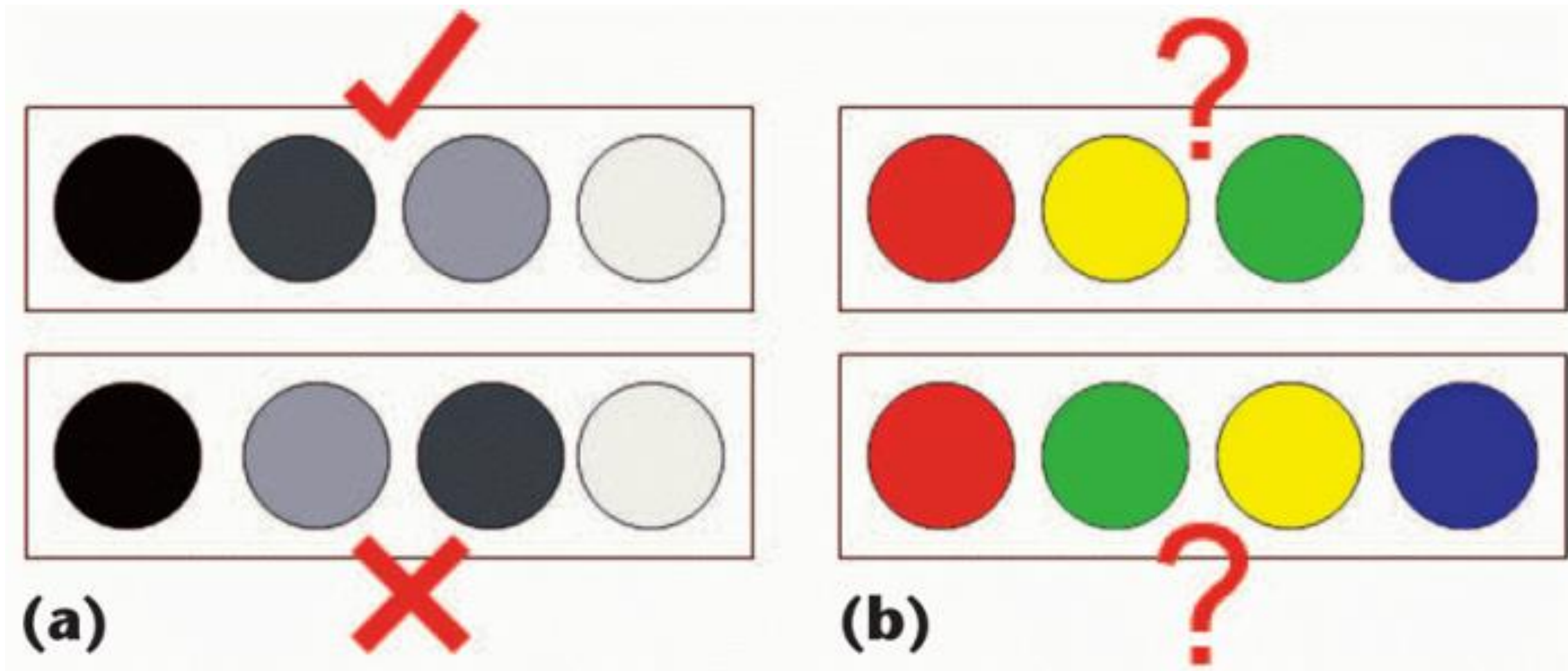
False



# Rainbow Color Map (Hue)



No perceptual ordering (confusing)

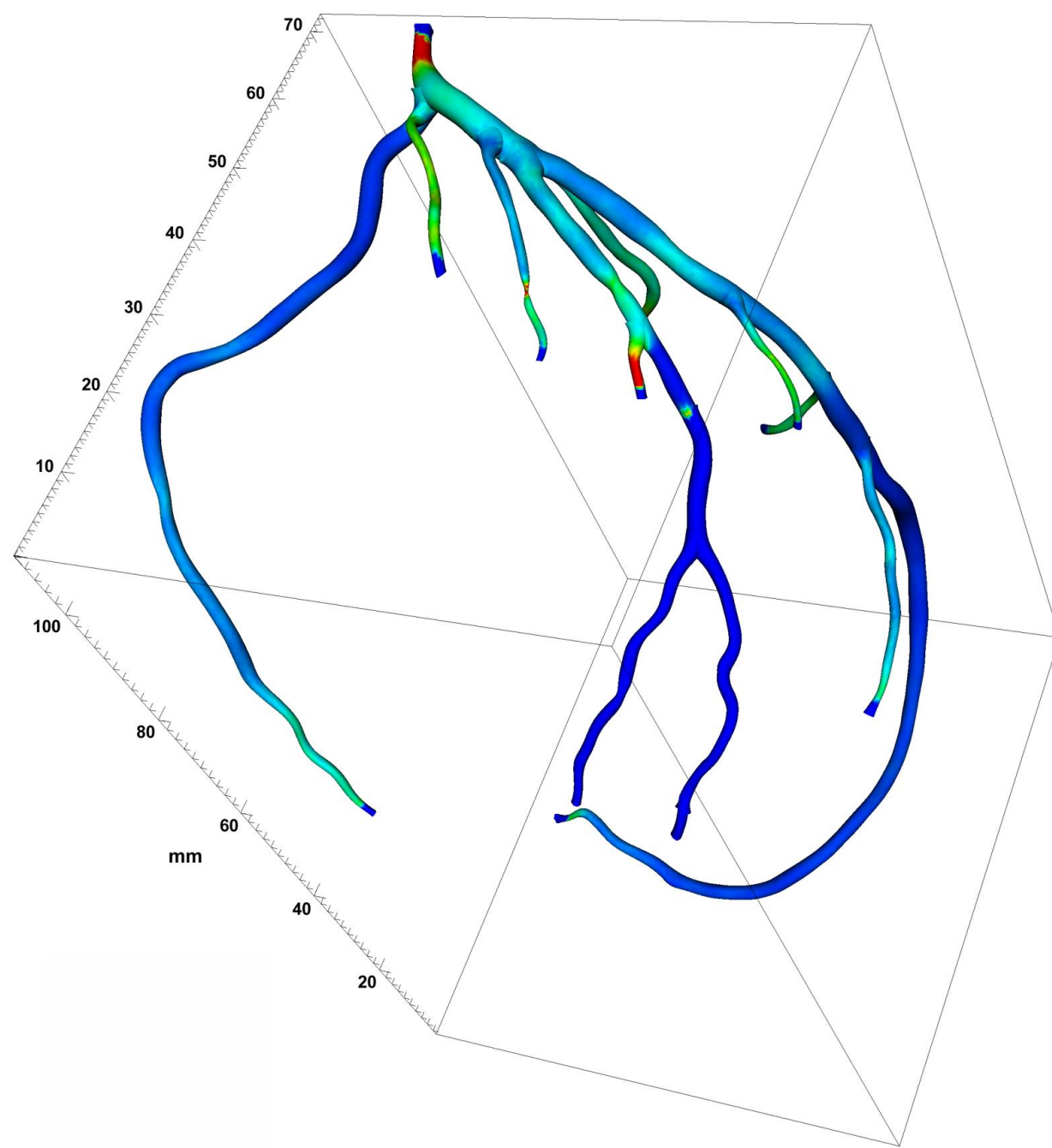


# Rainbow Color Map

Rainbow:

3D: 39%

2D: 62%

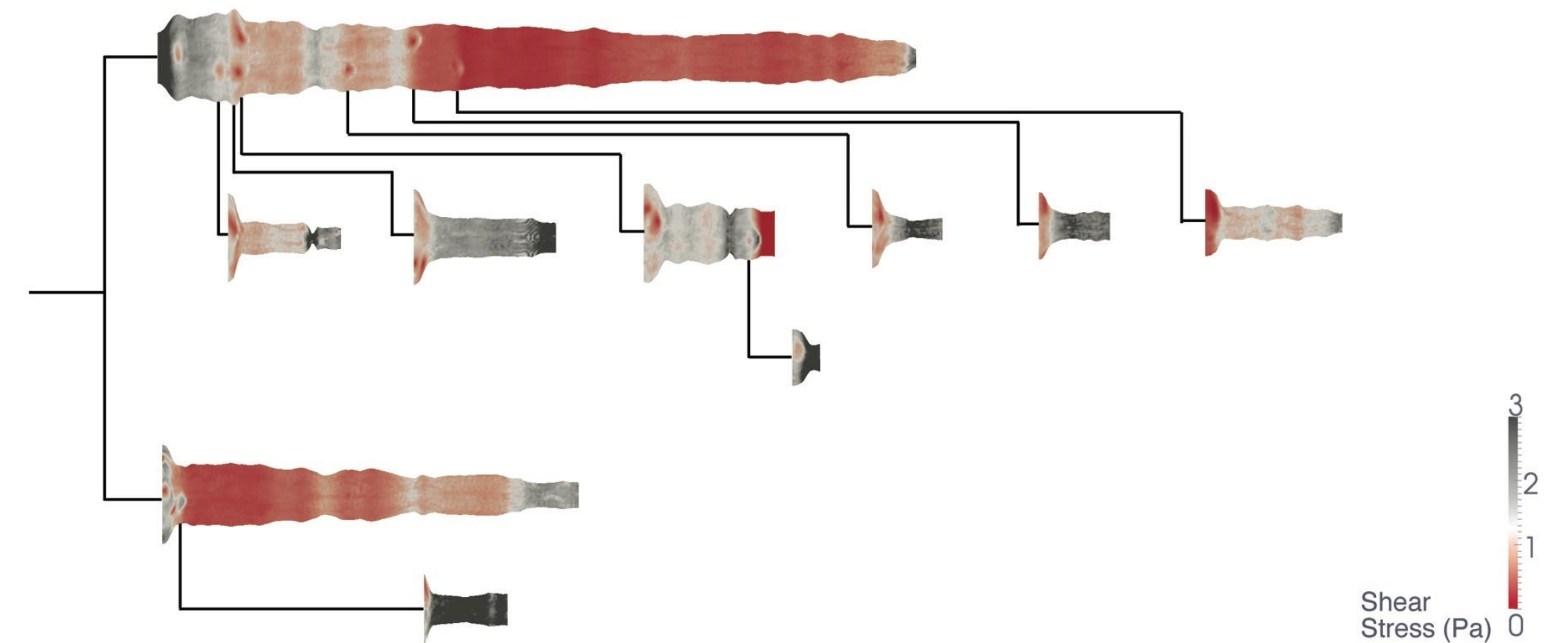


How many diseased regions found?

Diverging:

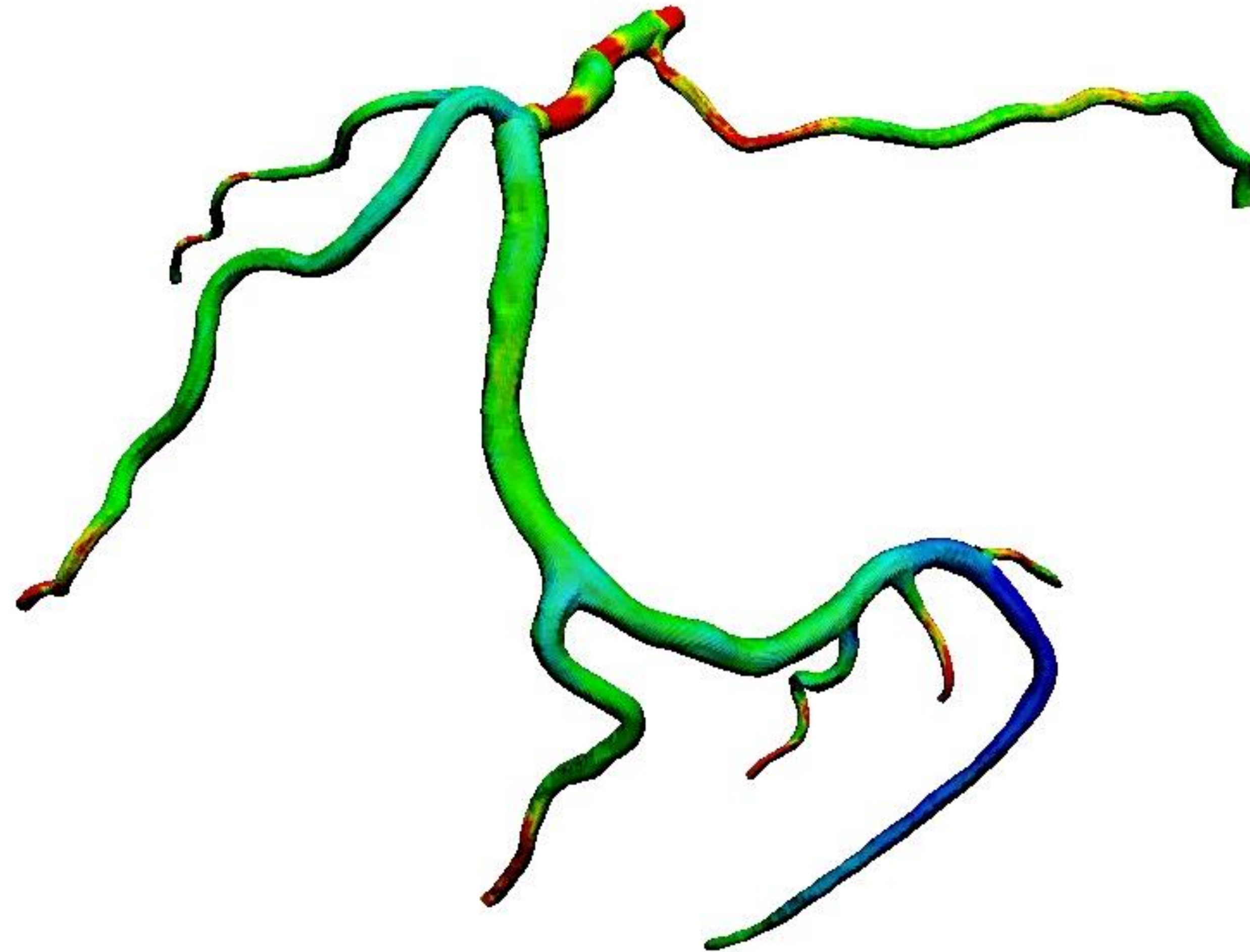
3D: 71% ( $\Delta$  +31%)

2D: 91% ( $\Delta$  +29%)



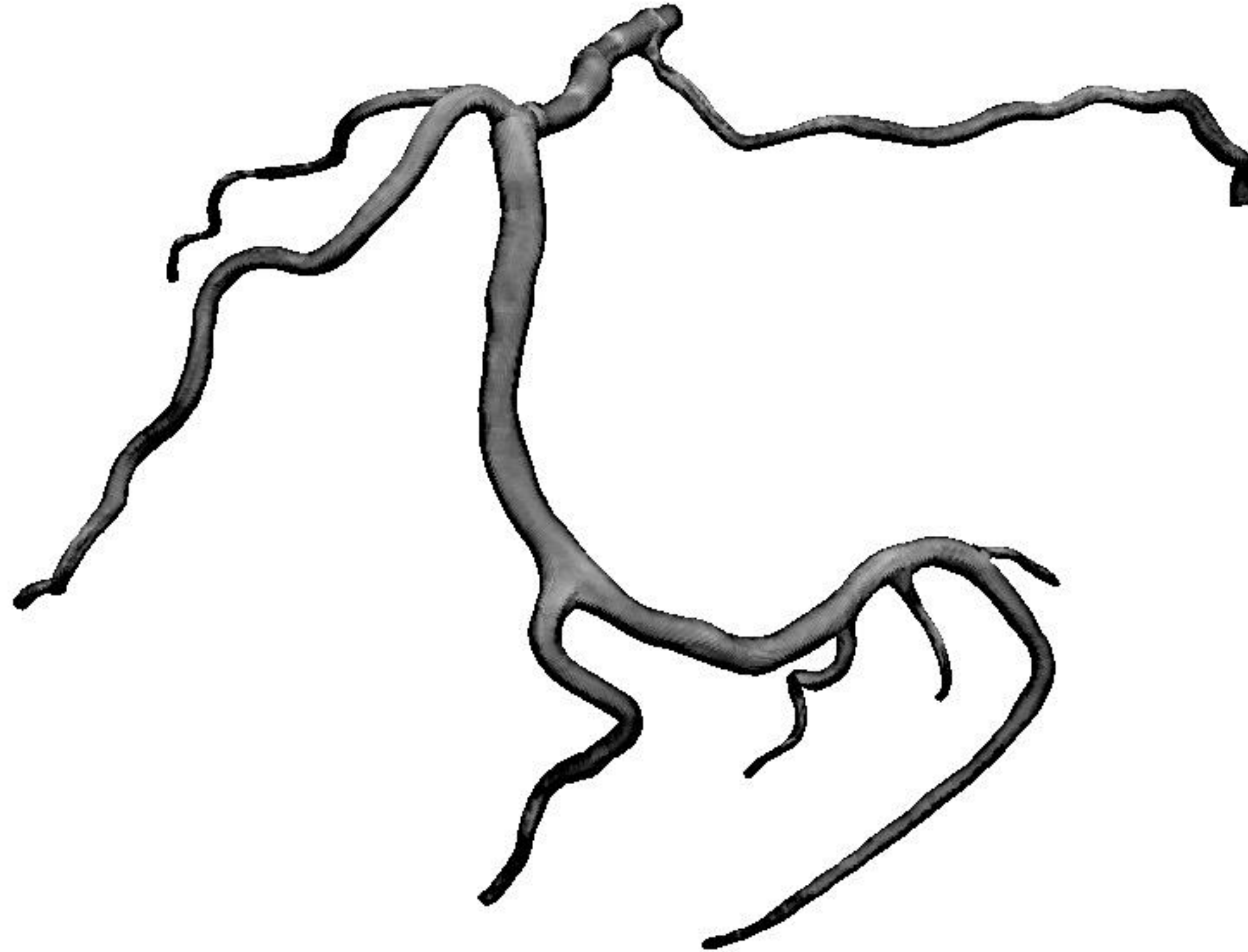


“Get it right in black and white.”

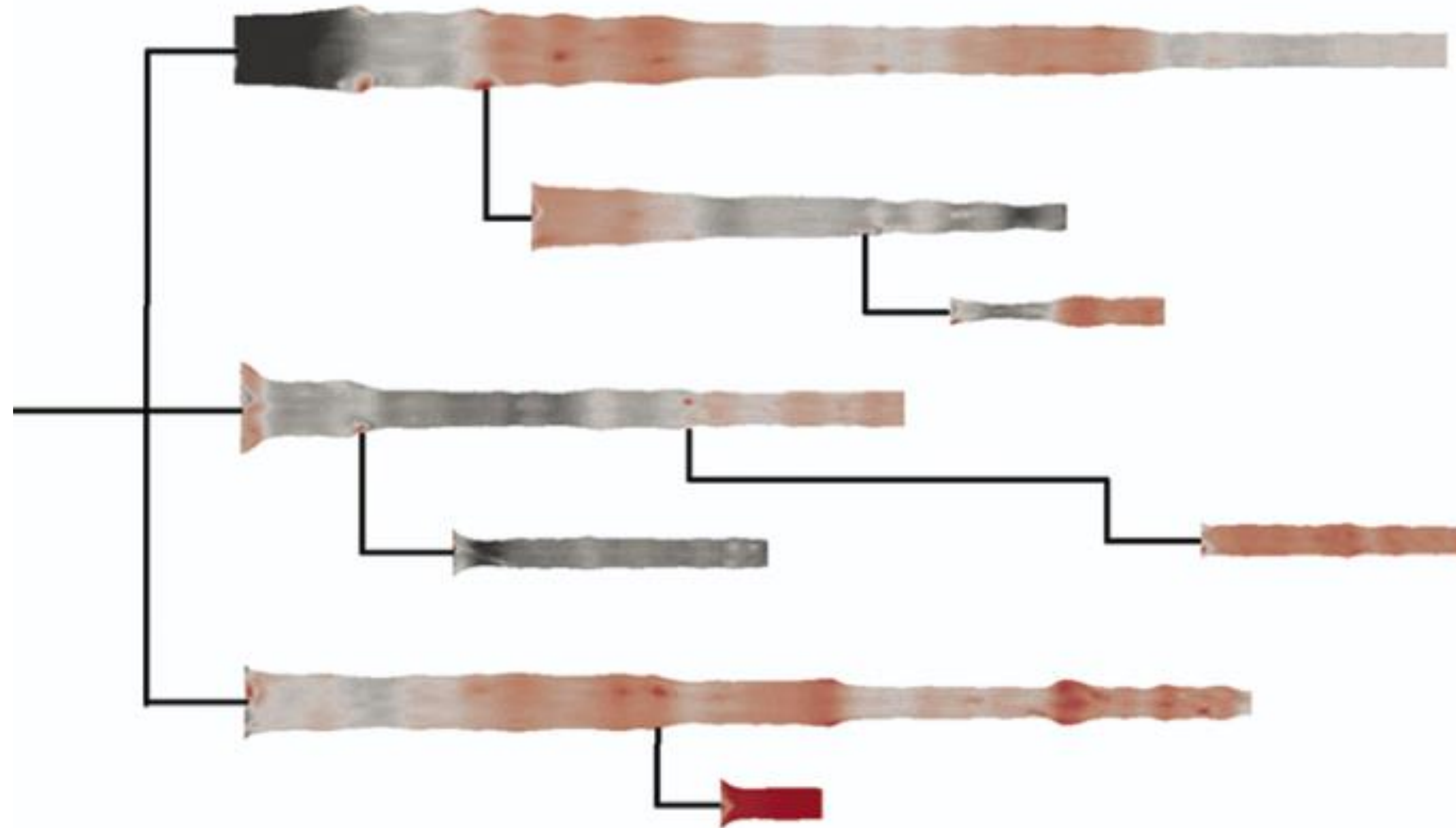


39% Diseased Regions Found

“Get it right in black and white.”

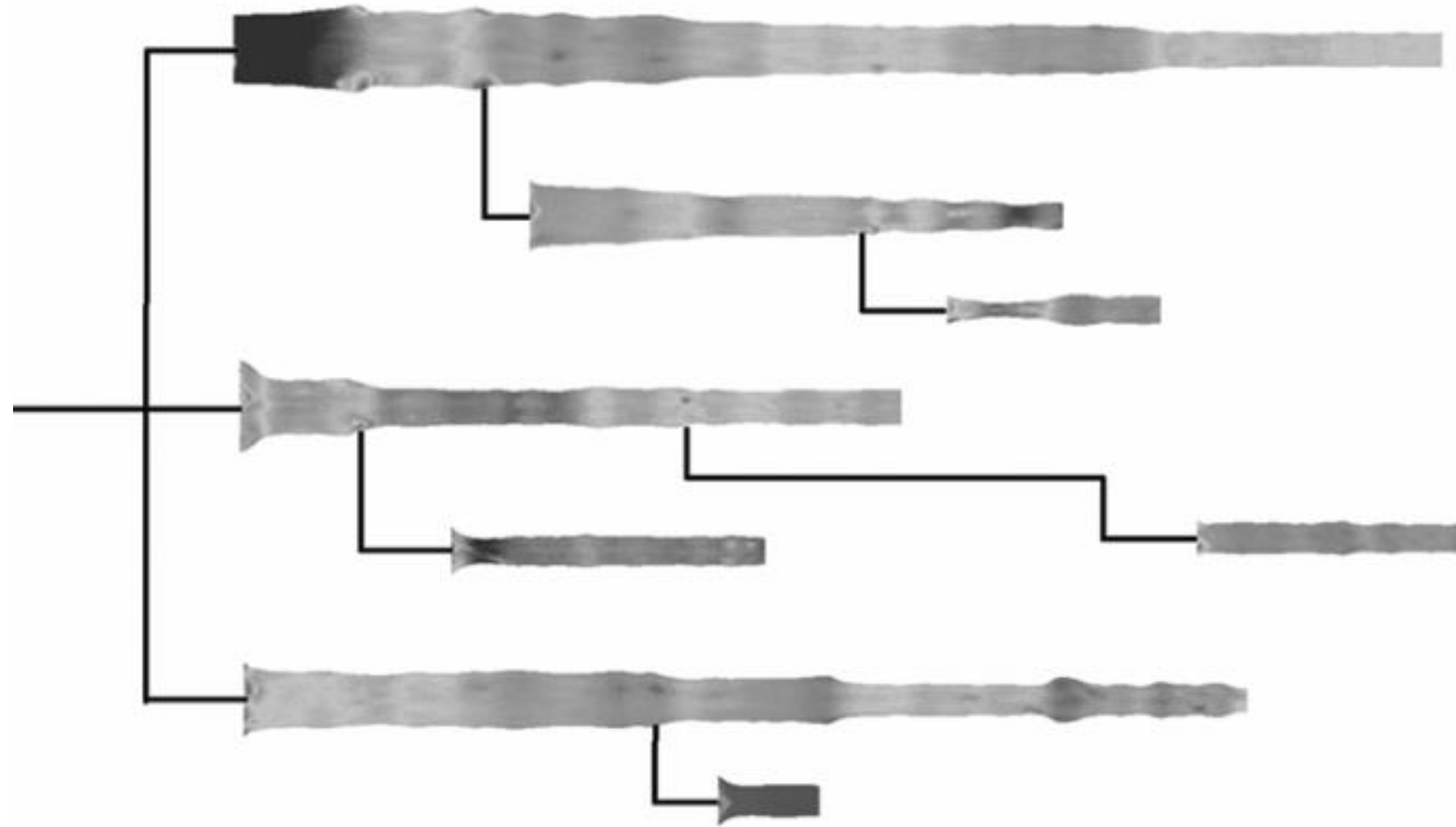


“Get it right in black and white.”



91% Diseased Regions Found

“Get it right in black and white.”



# “Get it right in black and white.”

## How Much Warmer Was Your City in 2016?

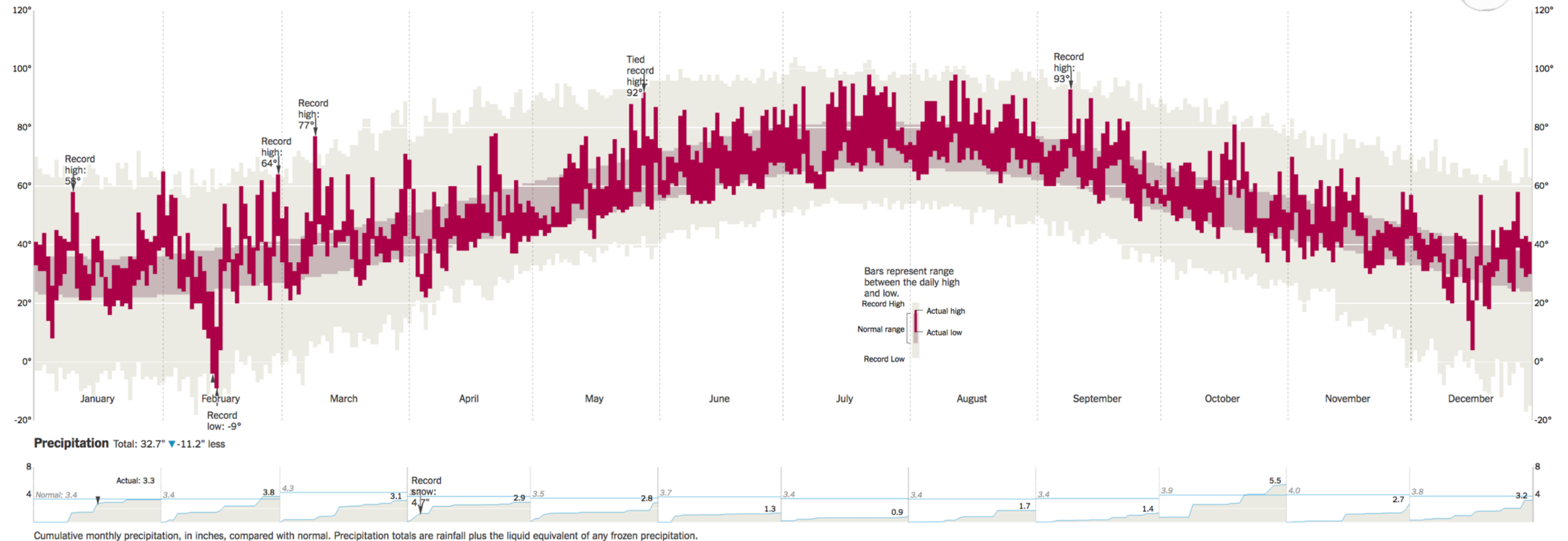
By K.K. REBECCA LAI JAN. 18, 2017

Last year is the hottest year on record for the third consecutive year. In a database of more than 5,000 cities provided by AccuWeather, about 90 percent recorded annual mean temperatures higher than normal. Enter your city below to see how much warmer (or cooler) it was.

◀ Boston, Mass. ▶

Temperature Average: 53.4° ▲ 1.9° above normal

°F °C



# “Get it right in black and white.”

## How Much Warmer Was Your City in 2016?

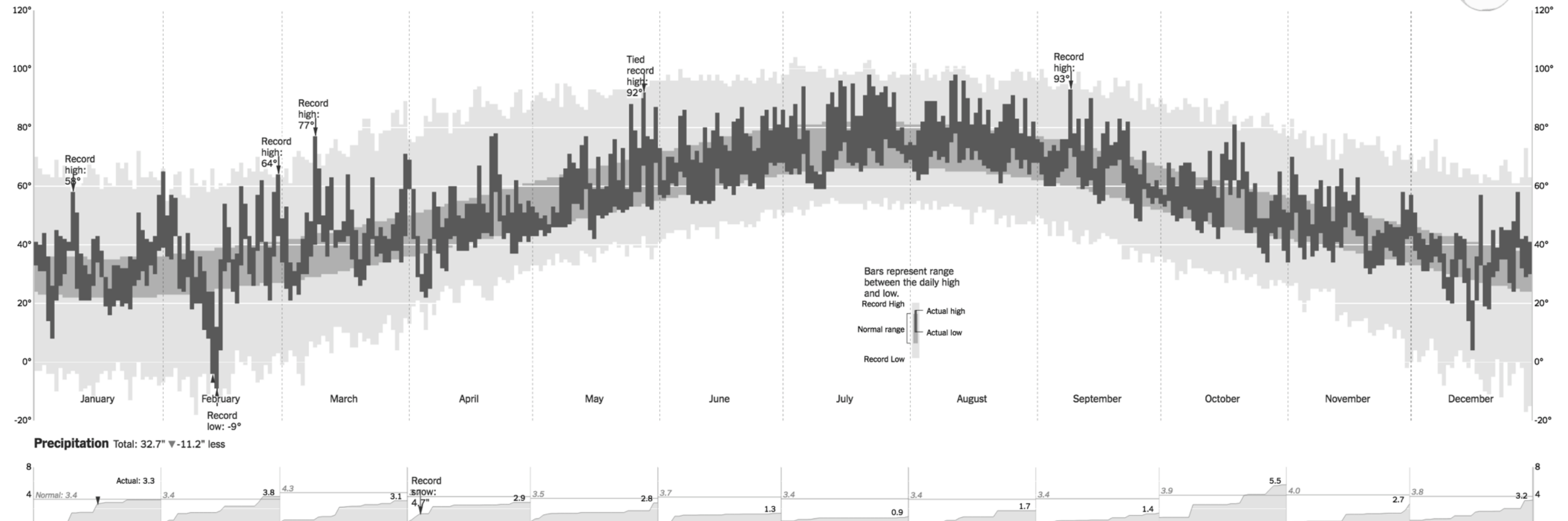
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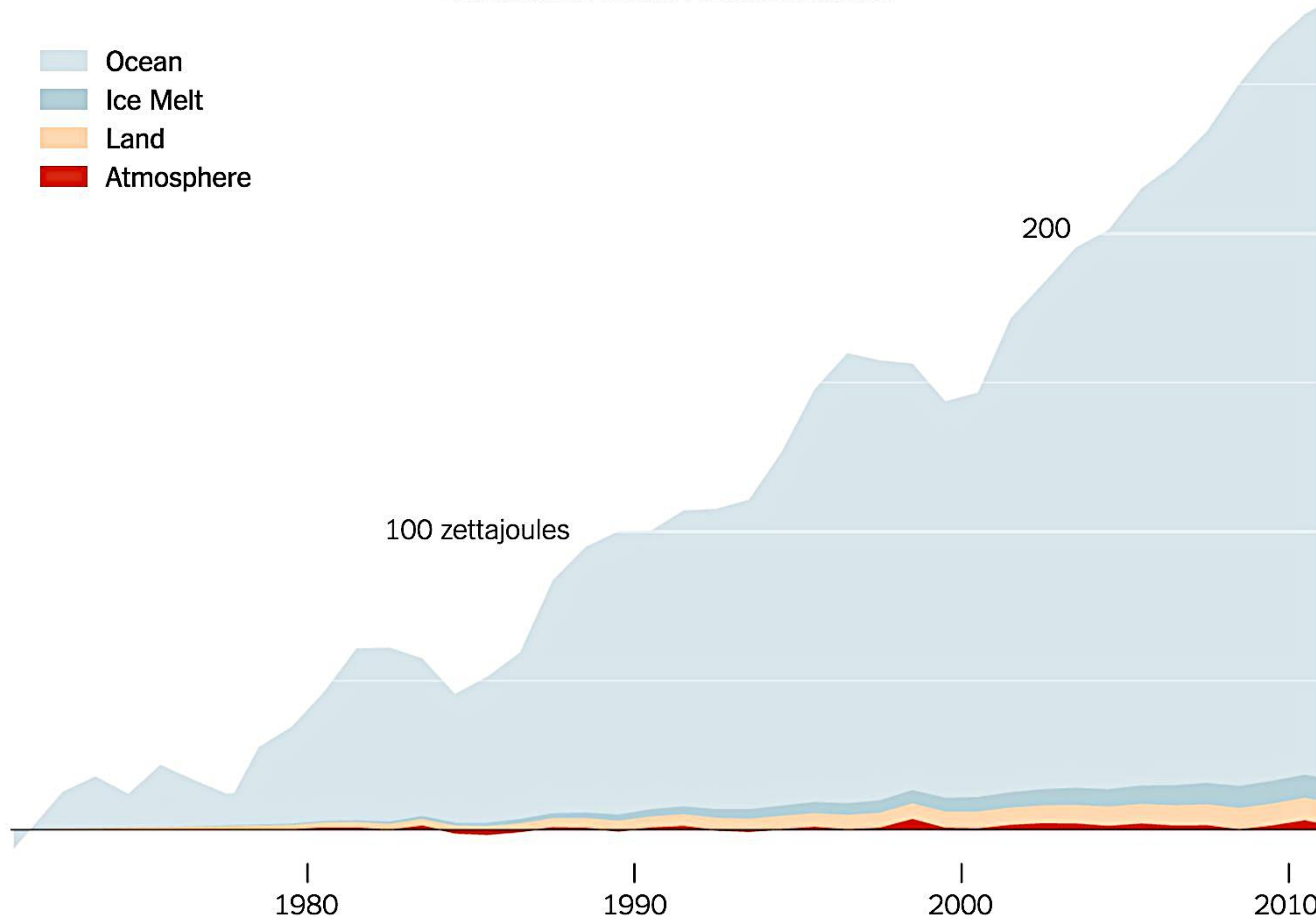


Cumulative monthly precipitation, in inches, compared with normal. Precipitation totals are rainfall plus the liquid equivalent of any frozen precipitation.

# “Get it right in black and white.”

## Estimated Heat Accumulation

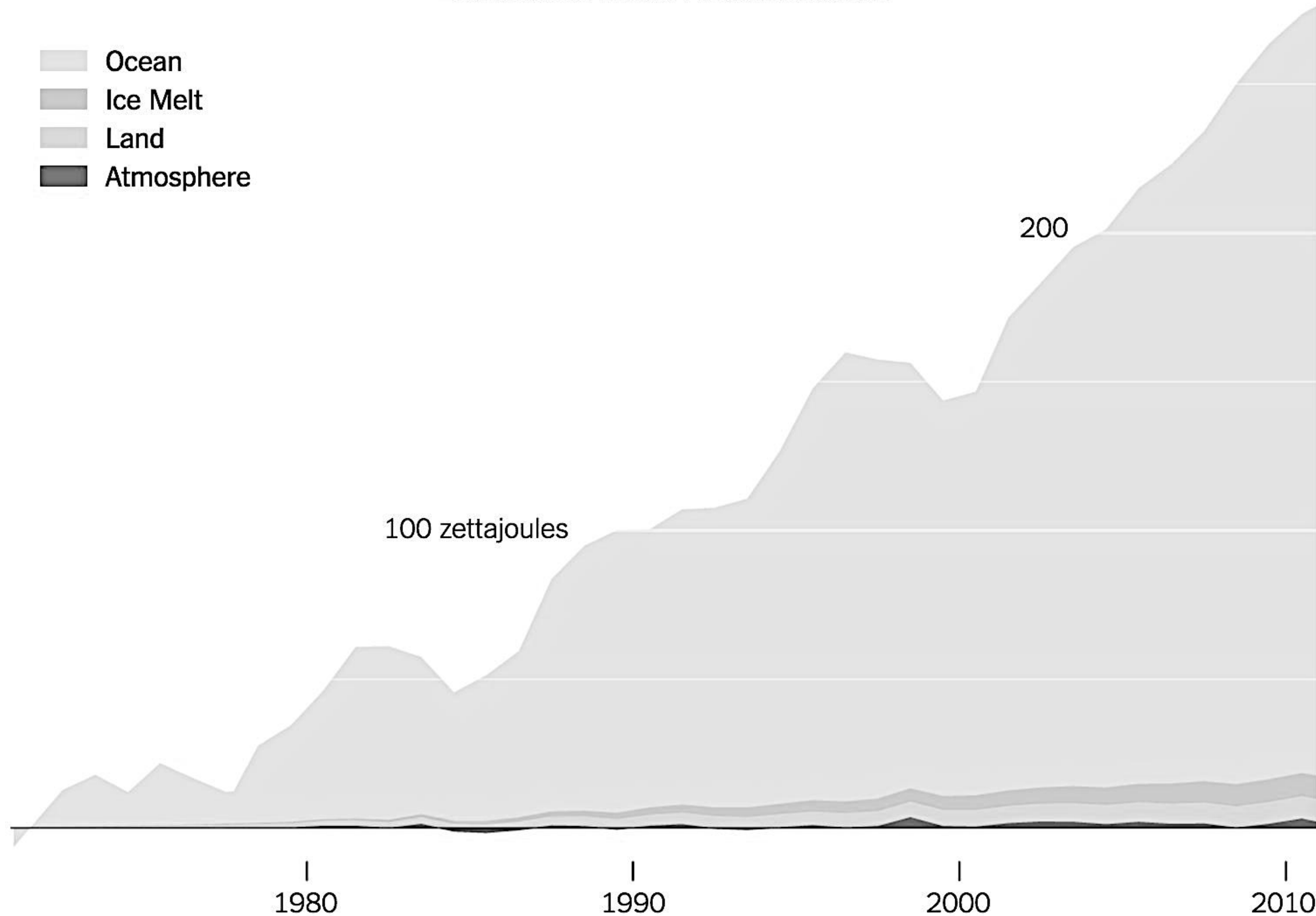
- Ocean
- Ice Melt
- Land
- Atmosphere



# “Get it right in black and white.”

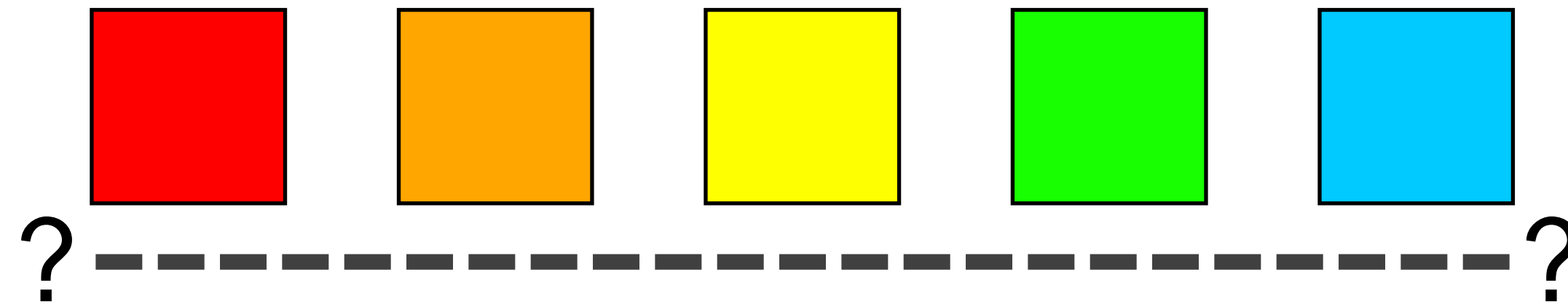
## Estimated Heat Accumulation

- Ocean
- Ice Melt
- Land
- Atmosphere





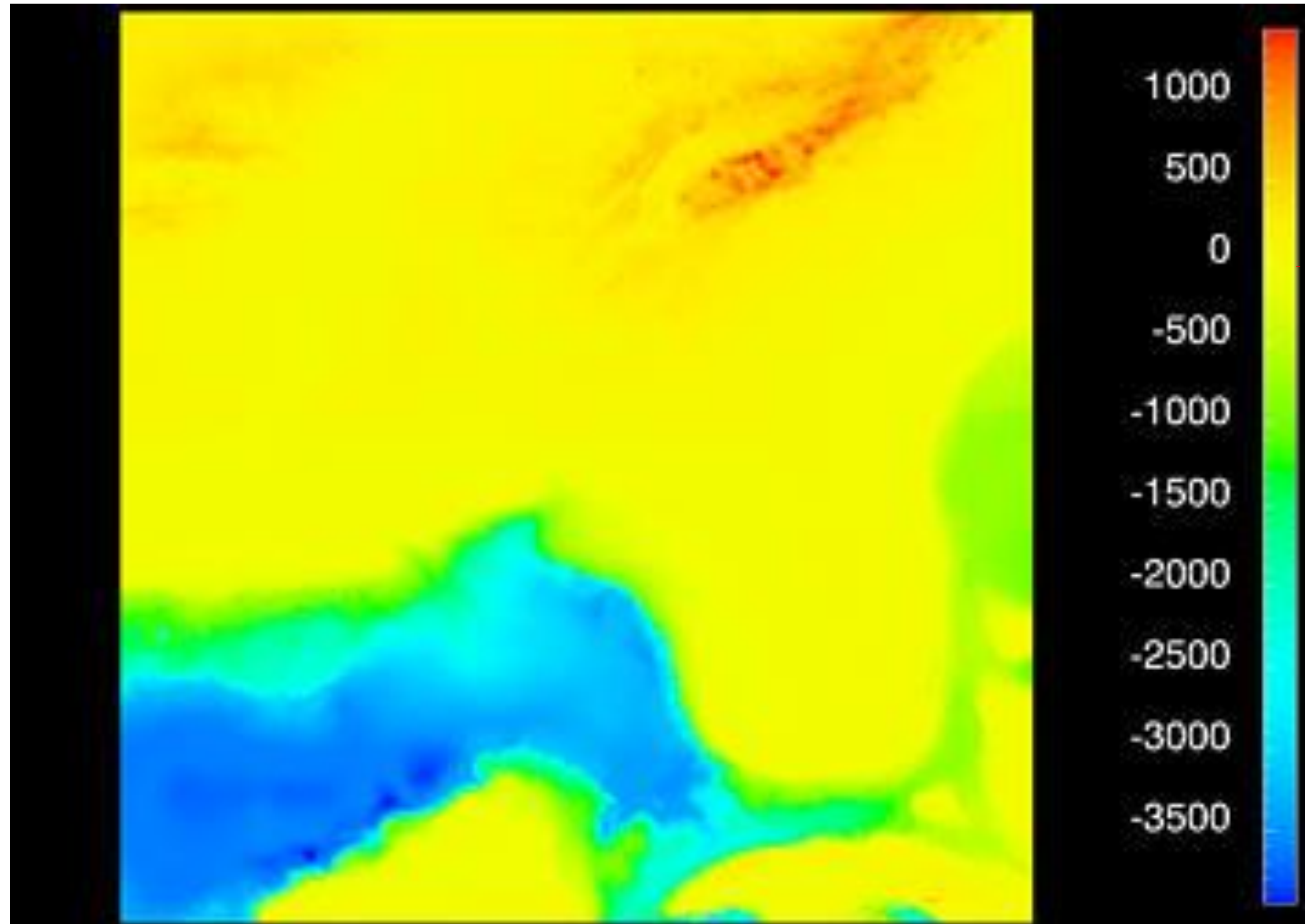
# Rainbow Color Map (Hue)



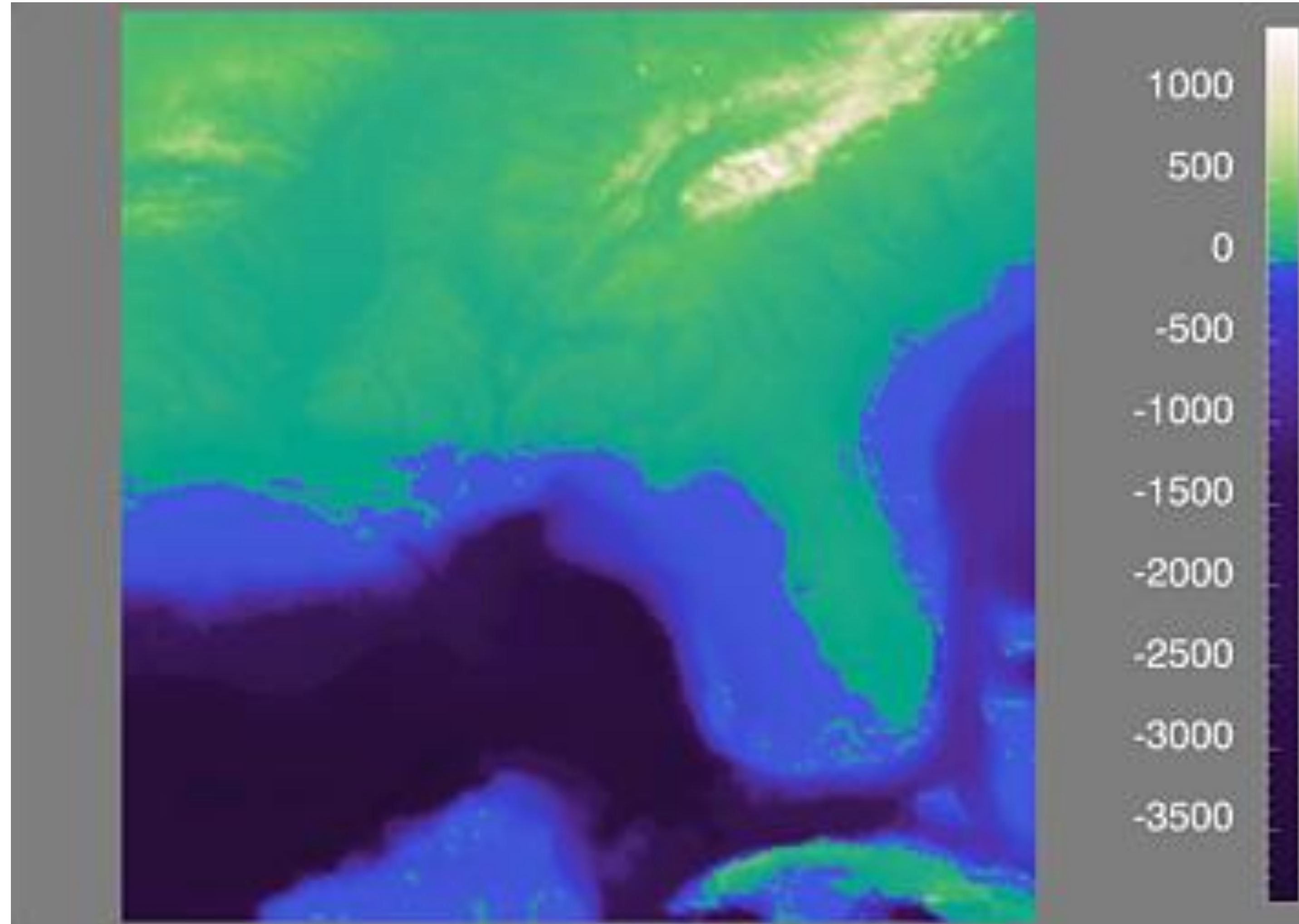
Why this color map is a poor choice for quantitative data...

- 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)

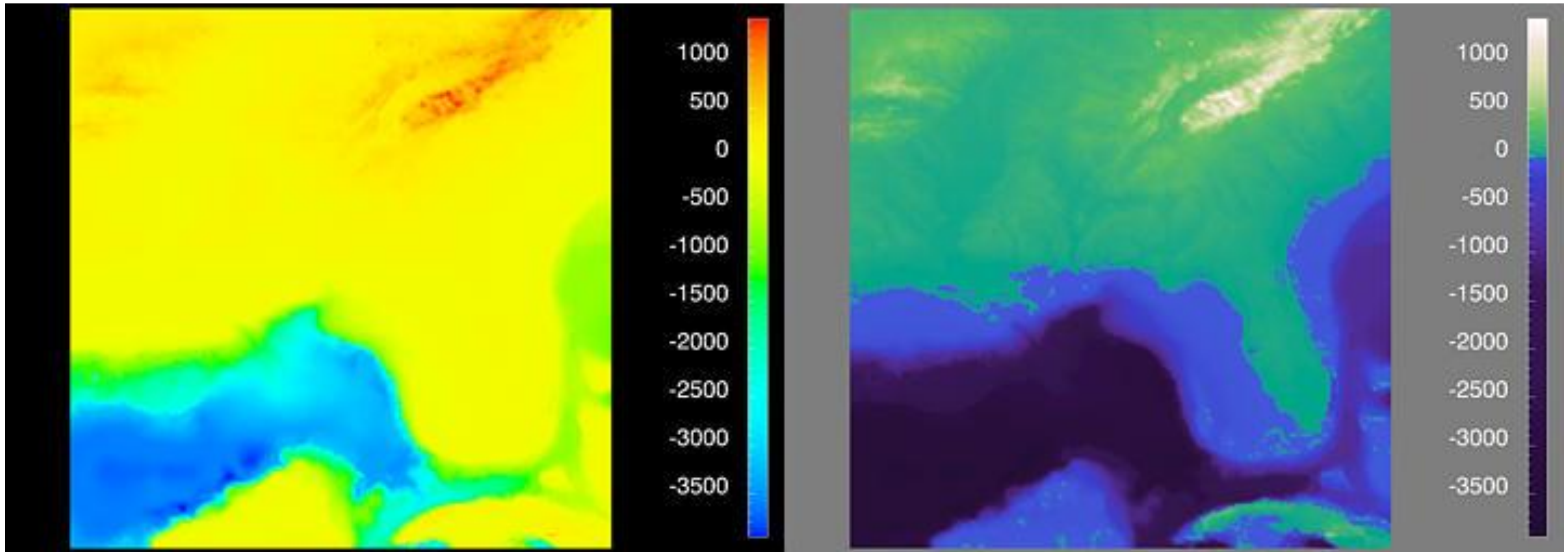
# Color Maps



# Color Maps



# Color Maps

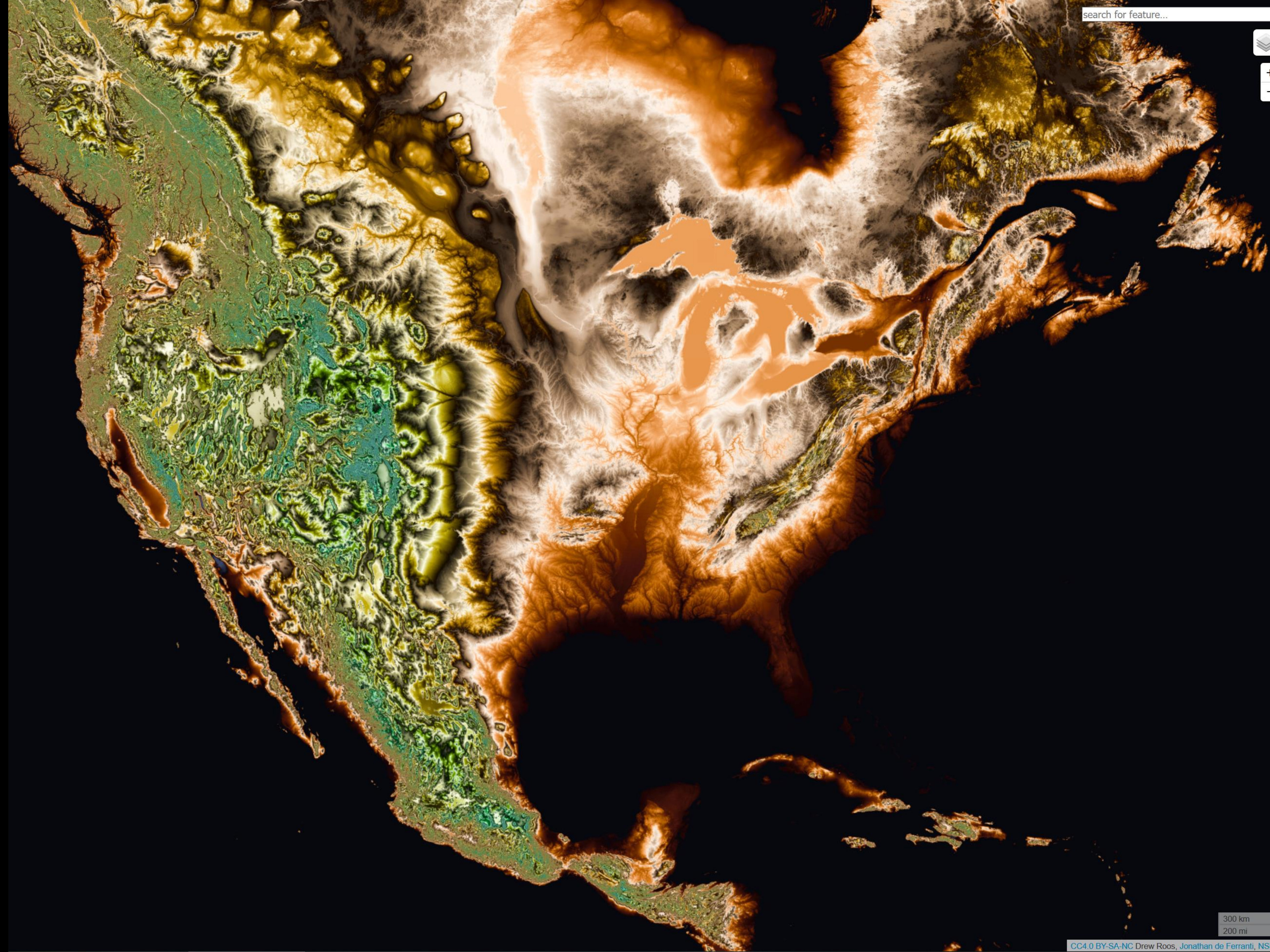


*Sequential (possibly wrong)*

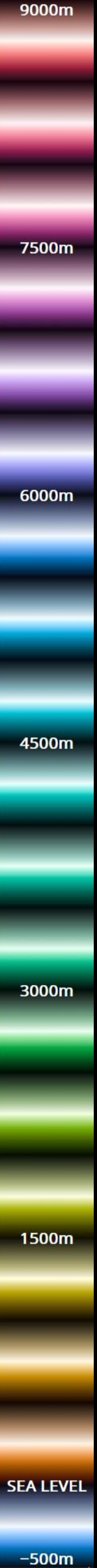
*Diverging*

*Sequential rainbow (wrong!)*





search for feature...



300 km  
200 mi

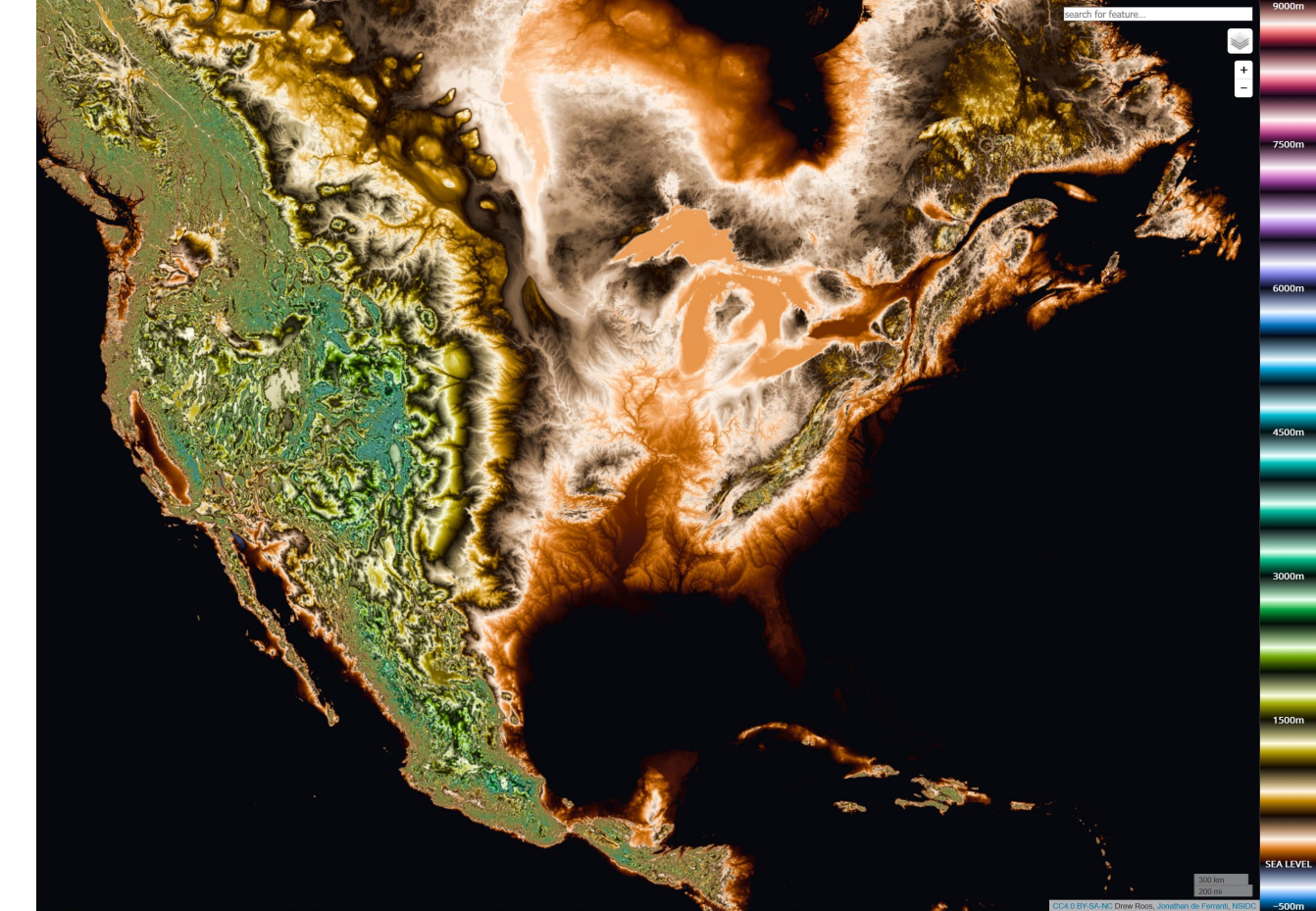
CC4.0 BY-SA-NC Drew Roos, Jonathan de Ferranti, NSIDC

[Roos, 2015](#)

# IN-CLASS EXERCISE

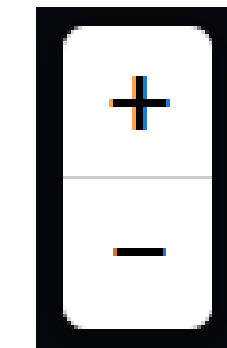
# In-class exercise: Oilslick

*10m*



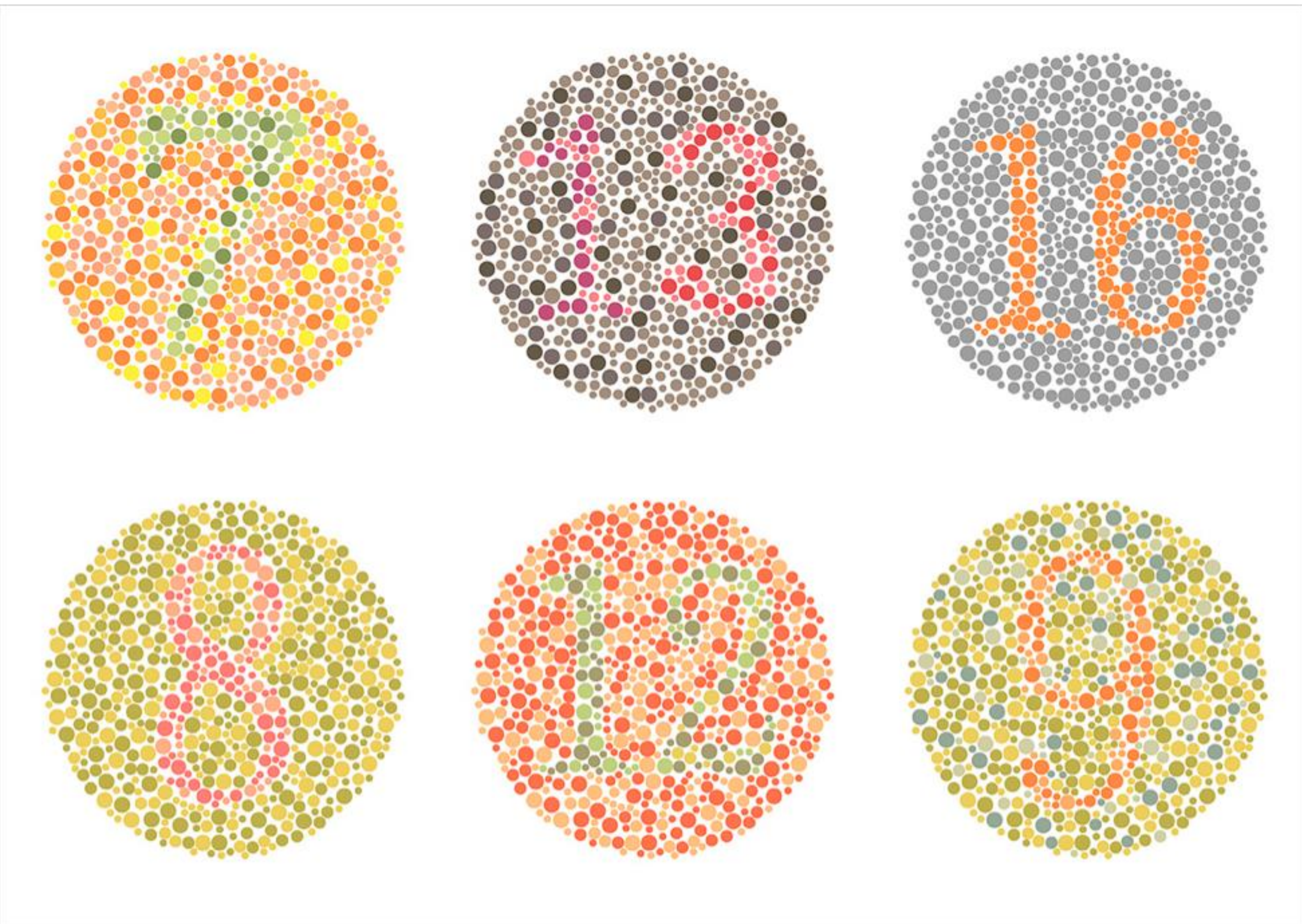
## INSTRUCTIONS:

- 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*



*Tritanope = faulty blue cones*

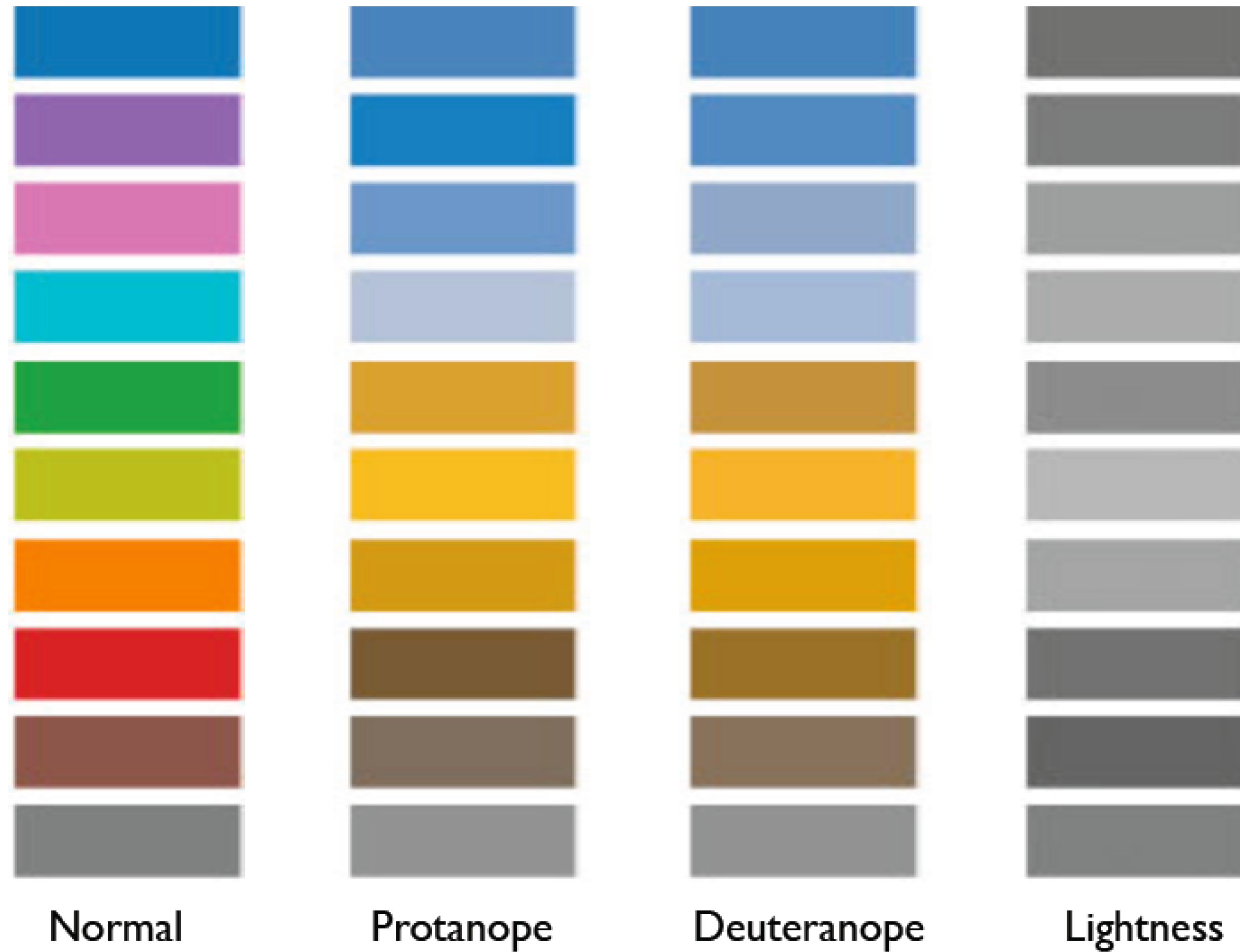


*Deuteranope = faulty green cones*

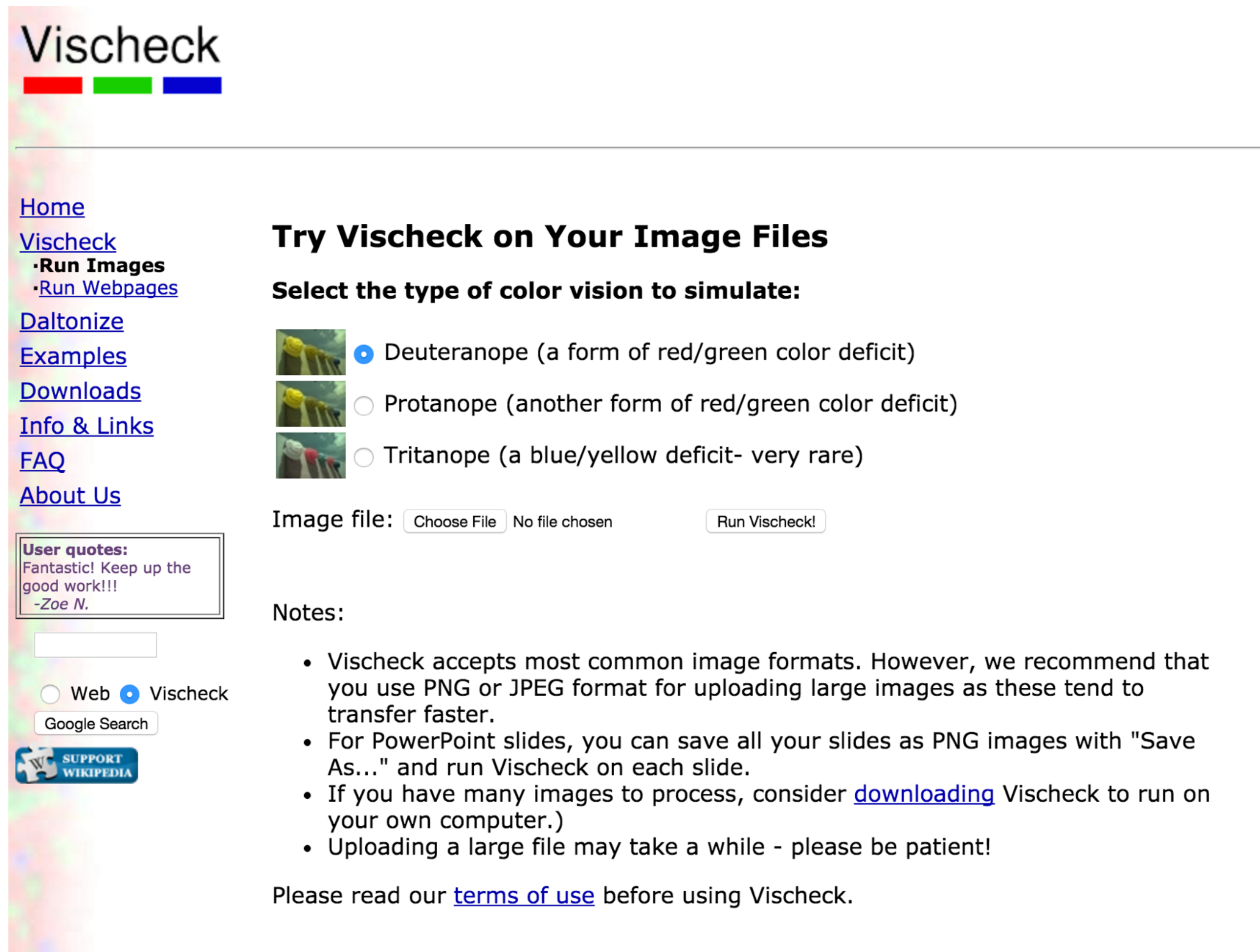


*normal*

# Color Deficiencies (Color Blindness)



# Check your images/colormaps for issues!



The screenshot shows the Vischeck website. At the top left is the logo with three colored bars (red, green, blue). Below it is a navigation menu with links: Home, Vischeck, Run Images, Run Webpages, Daltonize, Examples, Downloads, Info & Links, FAQ, and About Us. A 'User quotes' box contains a testimonial from Zoe N. There are radio buttons for 'Web' and 'Vischeck', and a 'Google Search' button. The main content area is titled 'Try Vischeck on Your Image Files' and includes a section 'Select the type of color vision to simulate:' with three options: Deuteranope (selected), Protanope, and Tritanope. Below this is an 'Image file:' section with a 'Choose File' button, 'No file chosen' text, and a 'Run Vischeck!' button. A 'Notes:' section contains three bullet points about image formats, saving PowerPoint slides, and file size. At the bottom, it says 'Please read our terms of use before using Vischeck.'

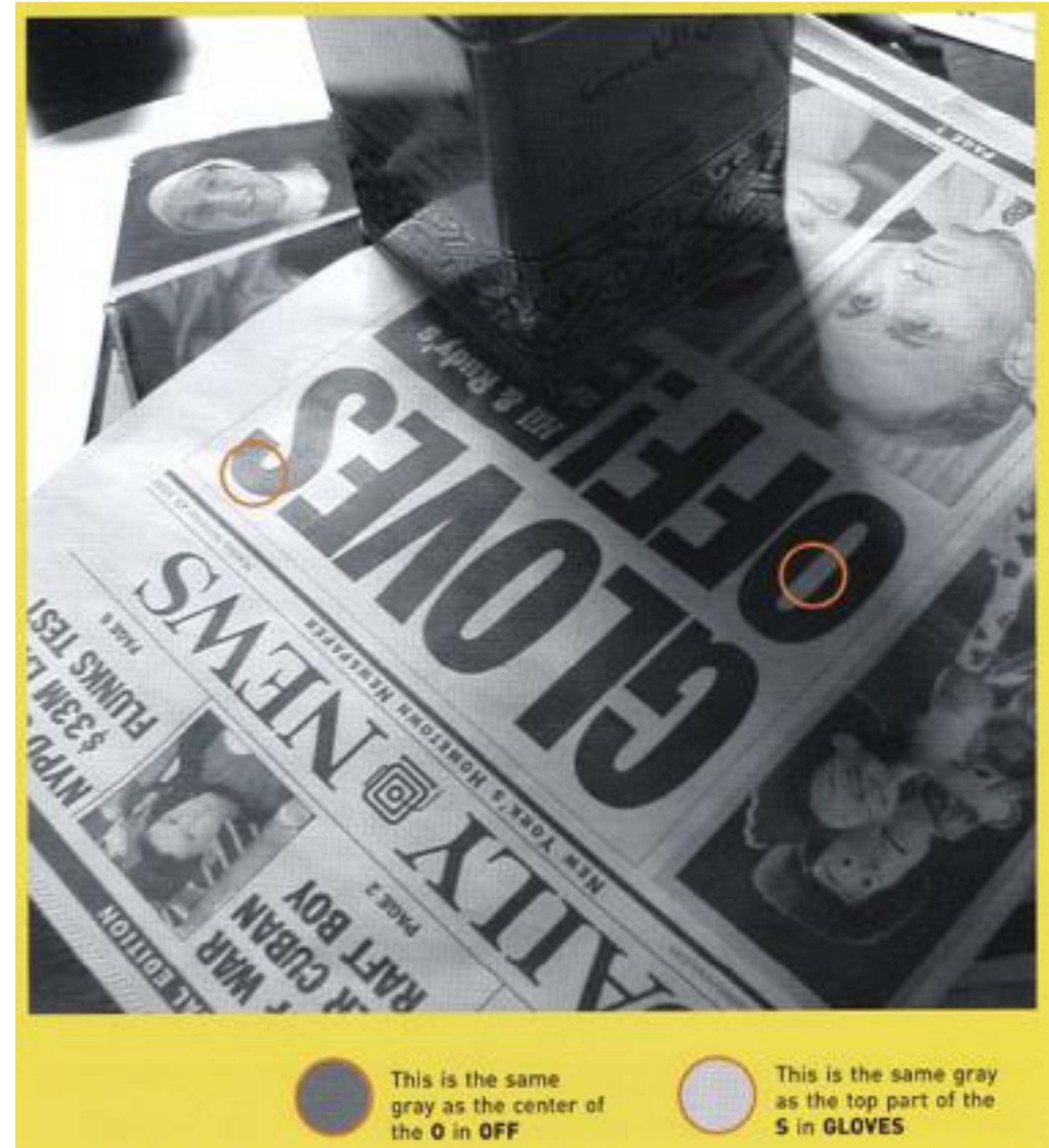


The screenshot shows the Coblis website. At the top is the logo and a navigation menu with links: Home, CVD Essentials, Color Blindness Tests, Color Tools, and Contact. The main heading is 'Coblis — Color Blindness Simulator'. Below this is a search bar, an email subscription form, and a rainbow color bar. The text explains that the simulator is used to understand color blindness and that calculations are done locally. It includes instructions on how to use the simulator and a list of simulation options: Trichromatic view (Normal, Anomalous Trichromacy), Dichromatic view (Red-Blind/Protanopia, Green-Blind/Deuteranopia, Blue-Blind/Tritanopia), and Monochromacy (Monochromacy, Blue Cc). There are also options for 'Use lens to compare with normal view' (No Lens, Normal Lens, Inverse Lens) and a 'Reset View' button. On the right side, there is a 'FREE Color Blind Check' section with a target icon and text encouraging users to test their vision.

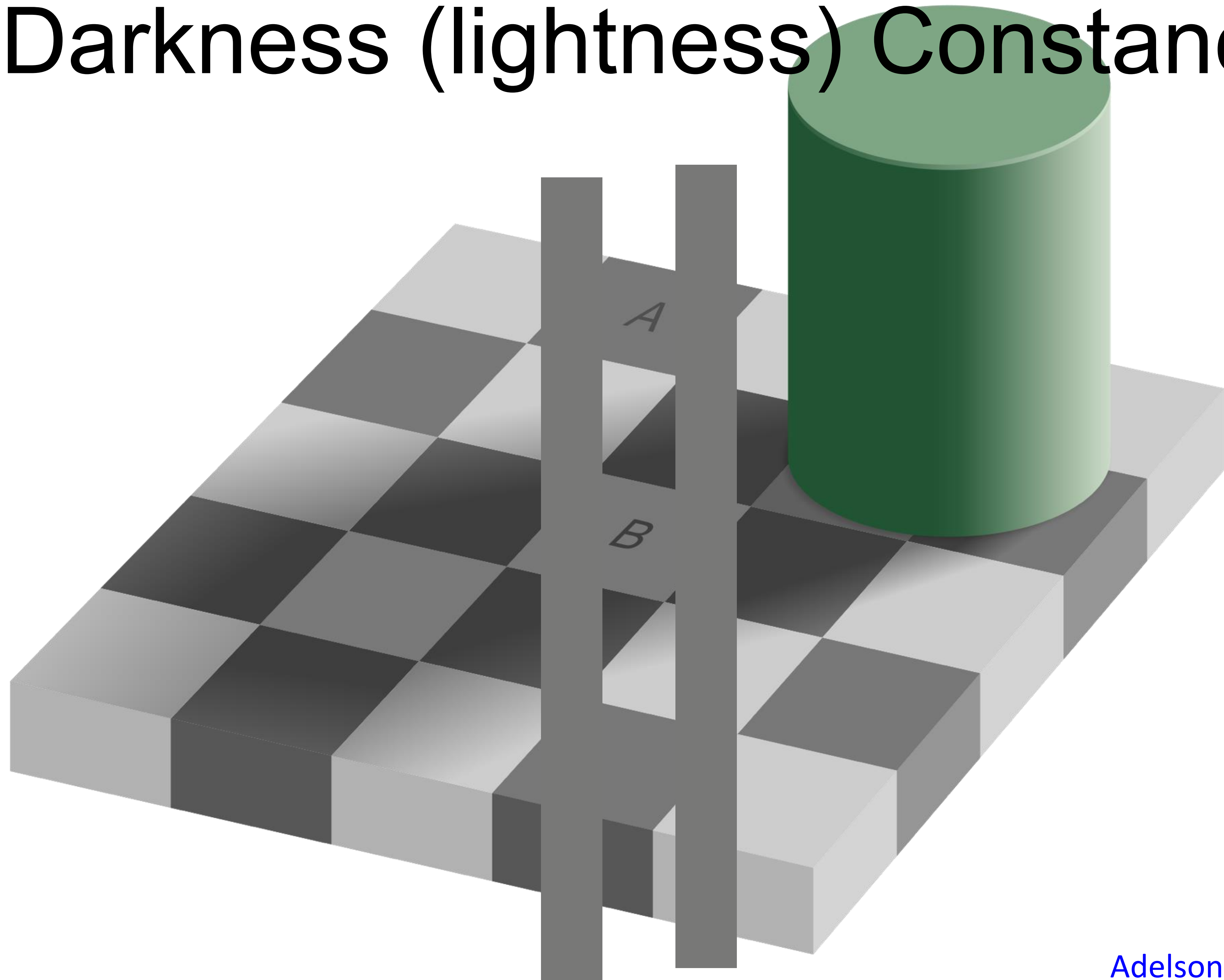
# INTERACTIONS BETWEEN COLORS AND WITH LIGHTING

# “Lightness Constancy”

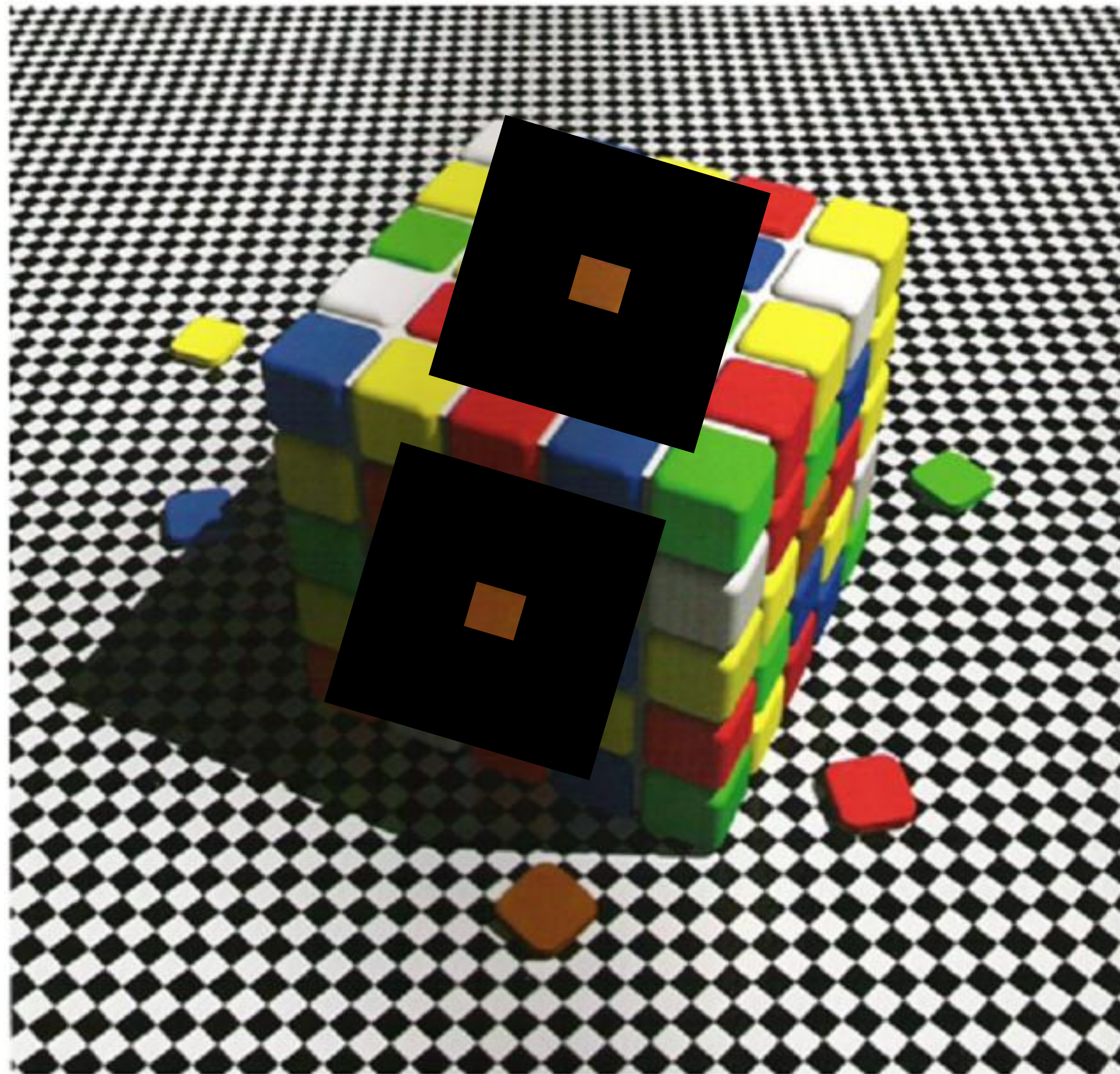
The perception that the apparent brightness of light and dark surfaces remains more or less the same under different luminance conditions is called **darkness (lightness) constancy**.



# “Darkness (lightness) Constancy”



# “Color Constancy”





# “Simultaneous Contrast”



# “Simultaneous Contrast”

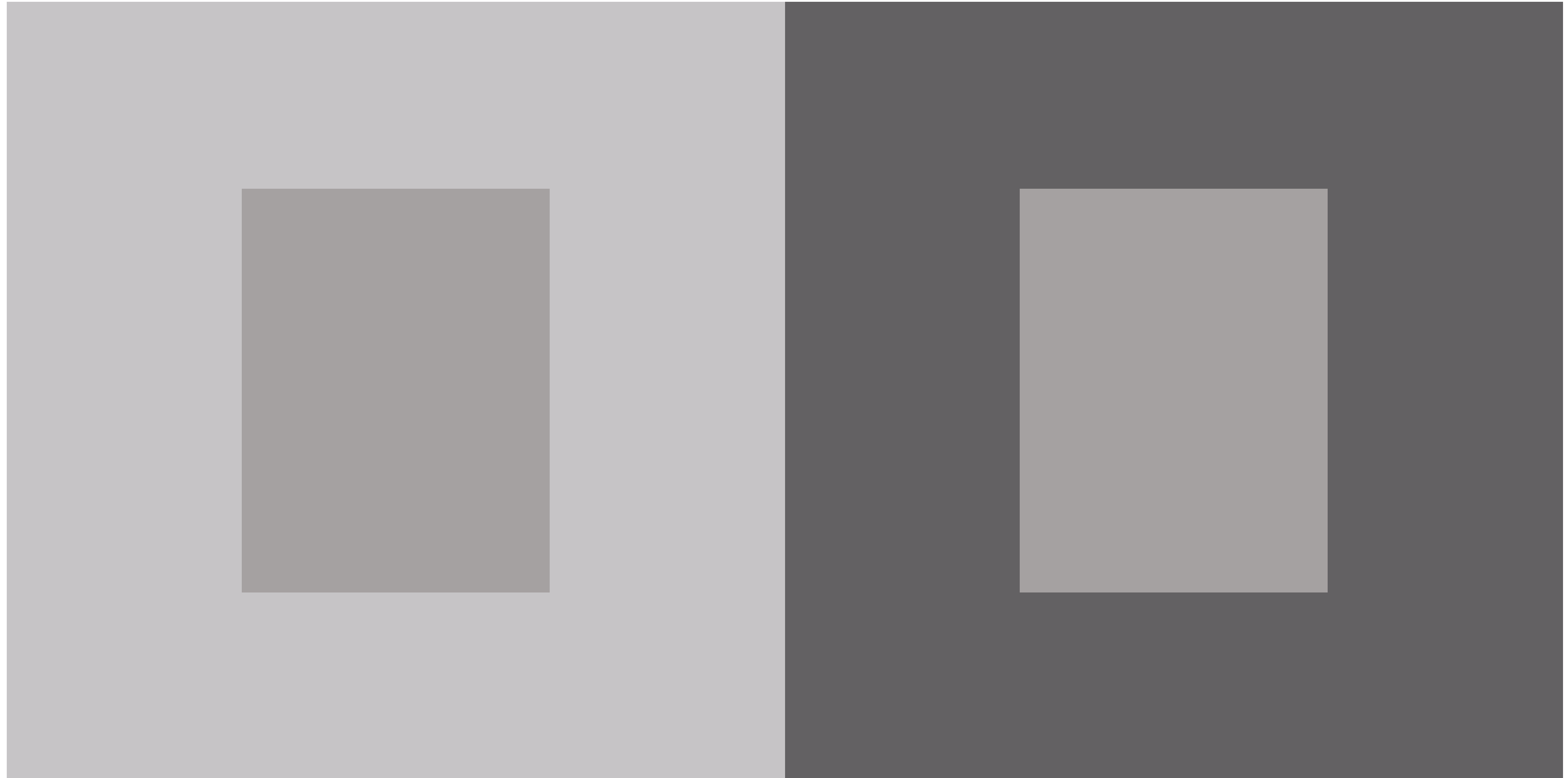


# “Simultaneous Contrast”

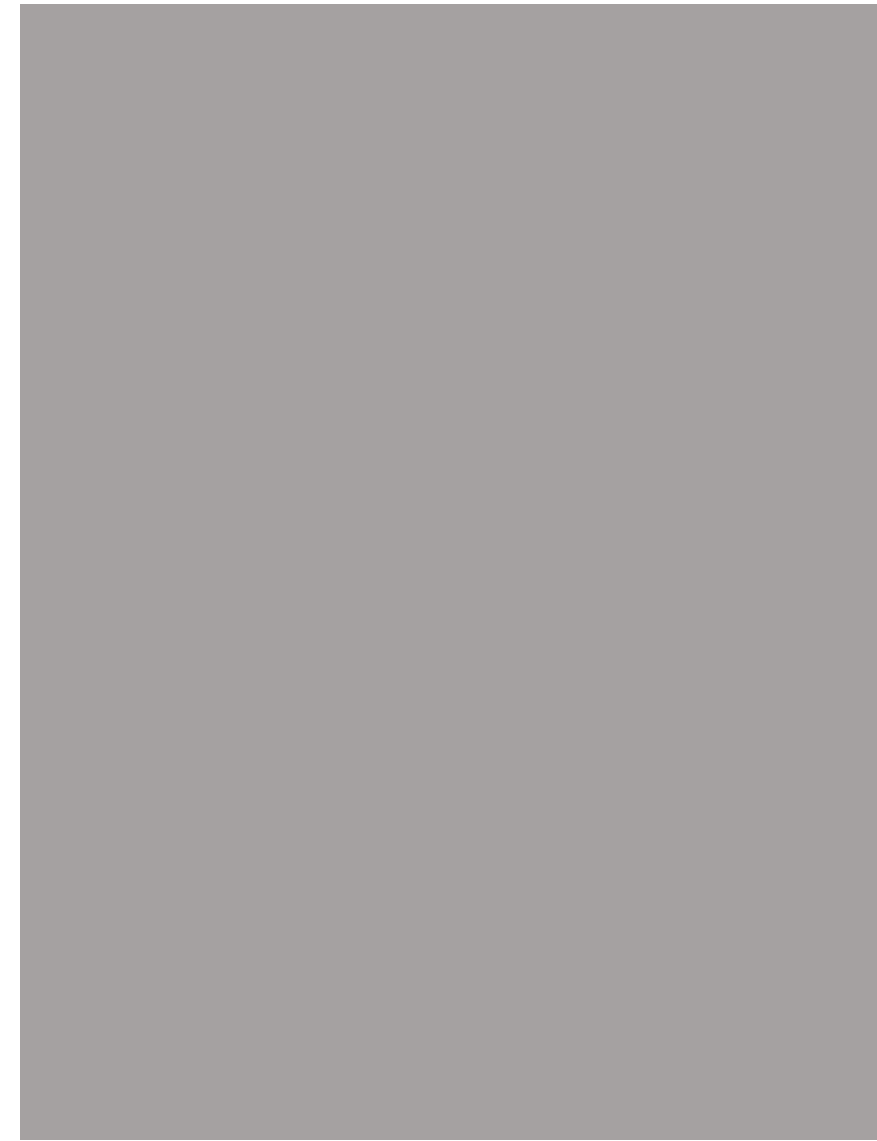
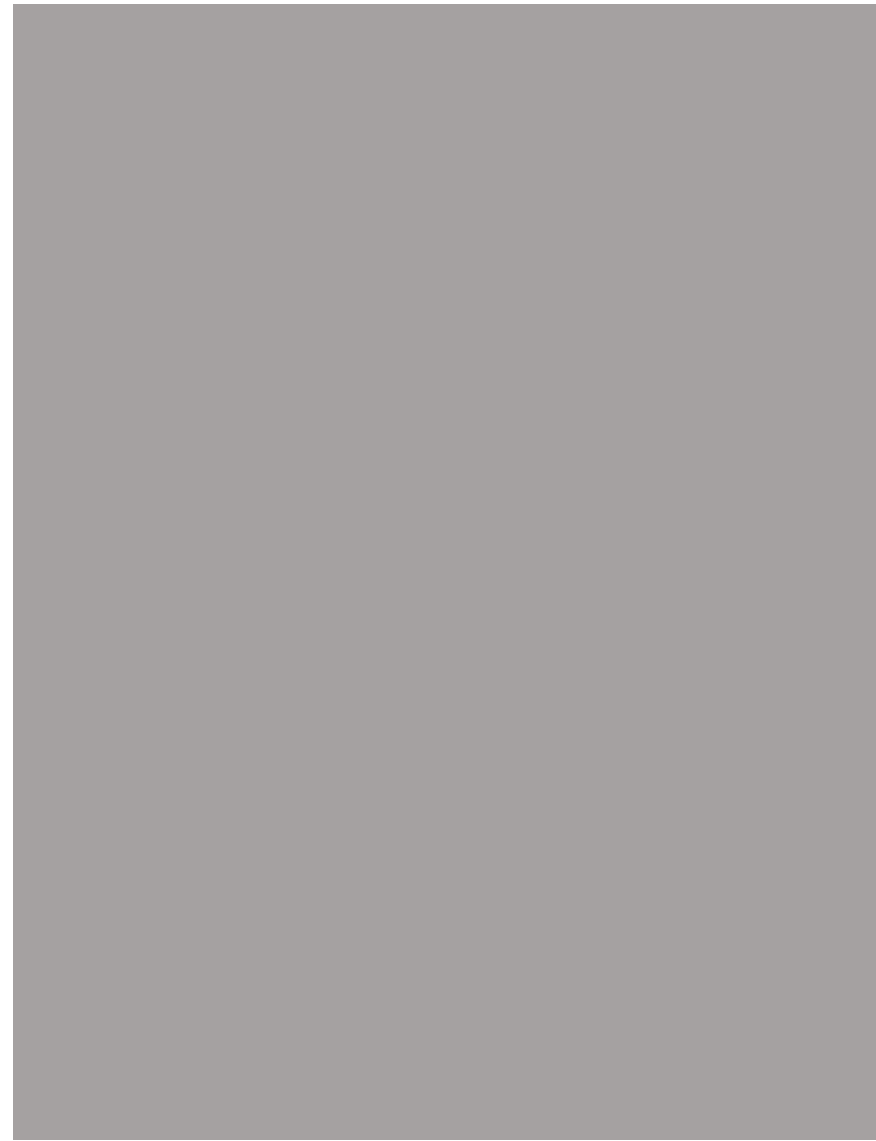


*Avoid gradients as backgrounds or bars!*

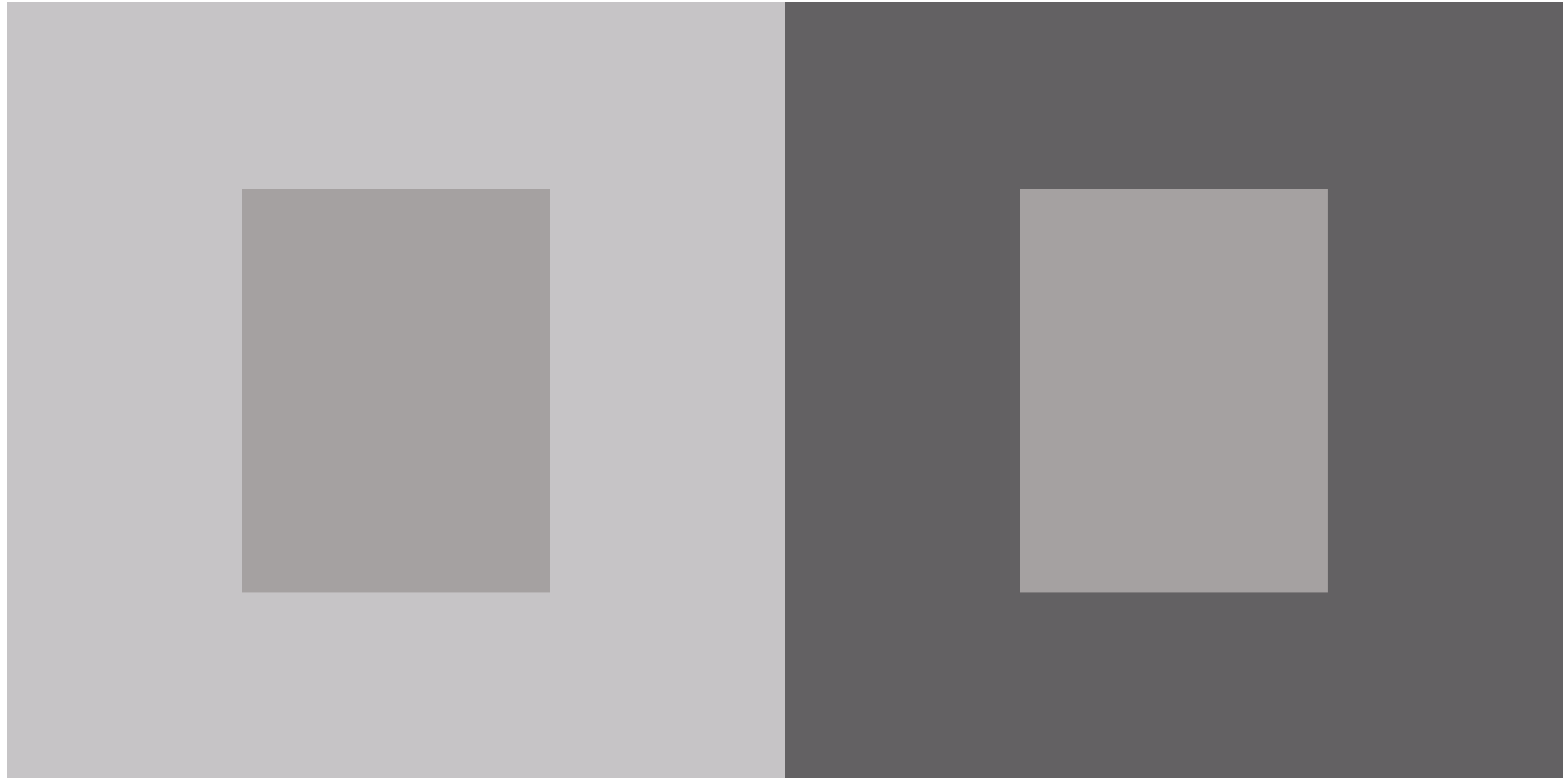
# “Simultaneous Contrast”



# “Simultaneous Contrast”



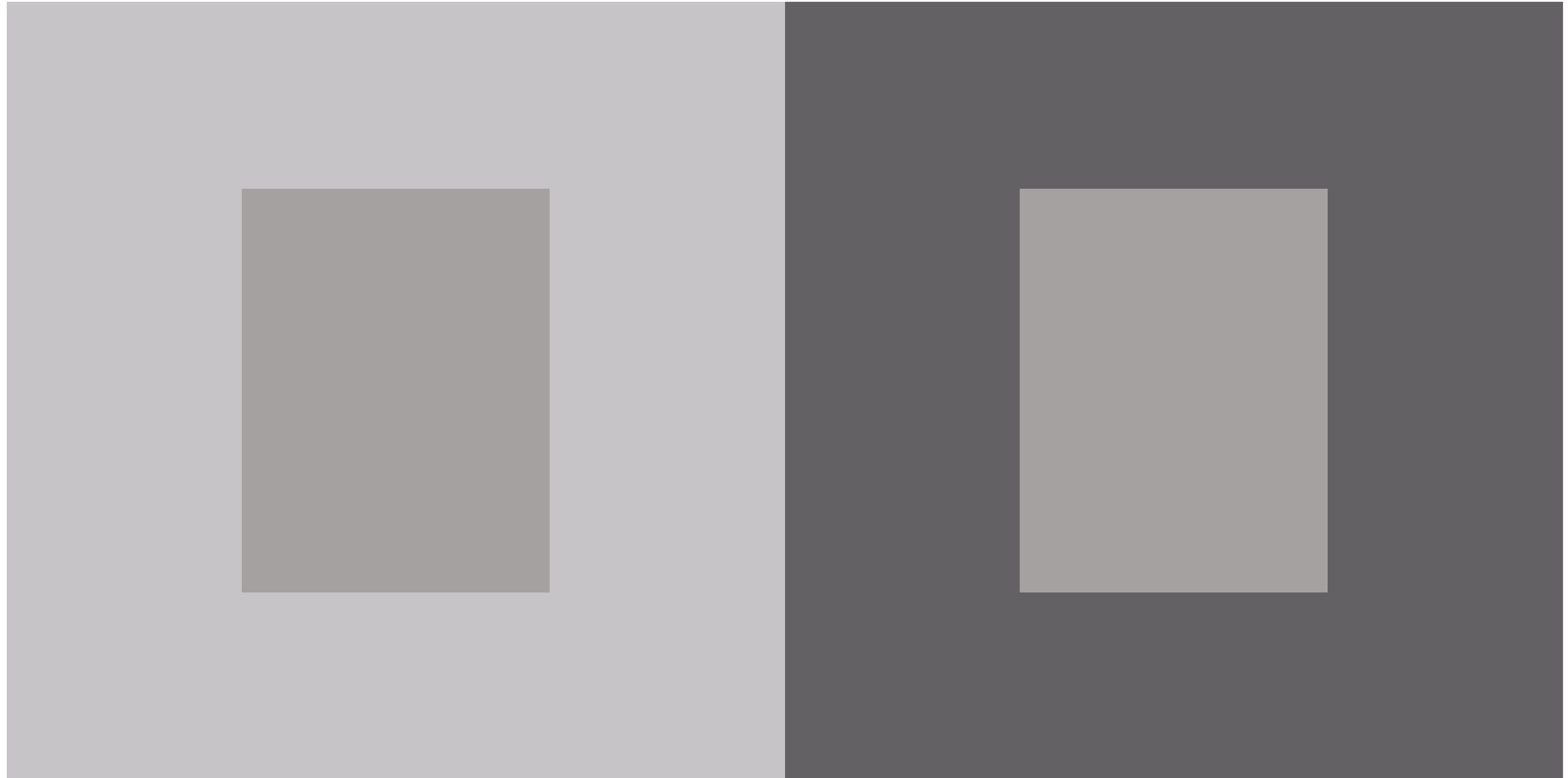
# “Simultaneous Contrast”



# “Simultaneous Contrast”

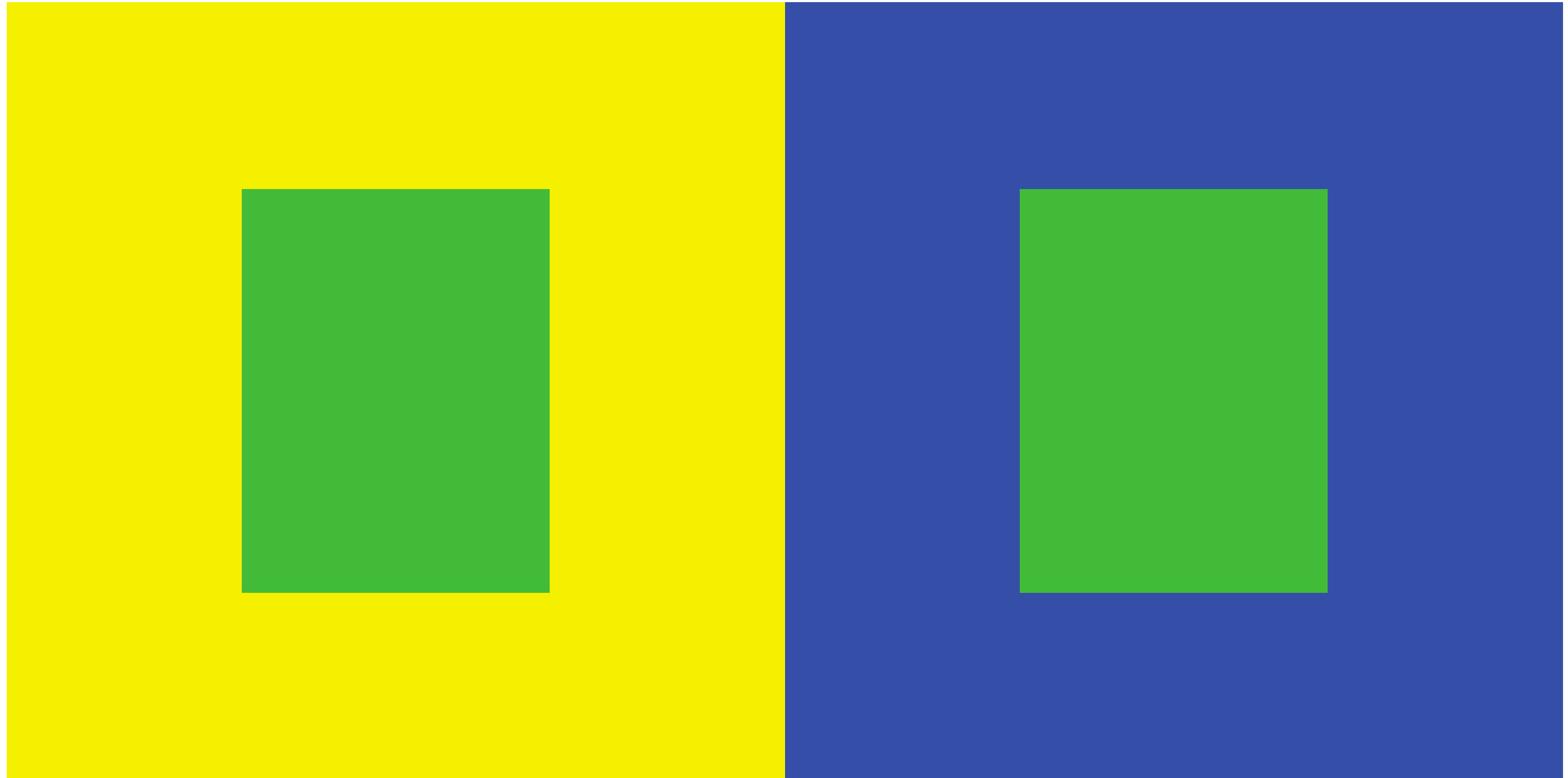


# “Simultaneous Contrast”





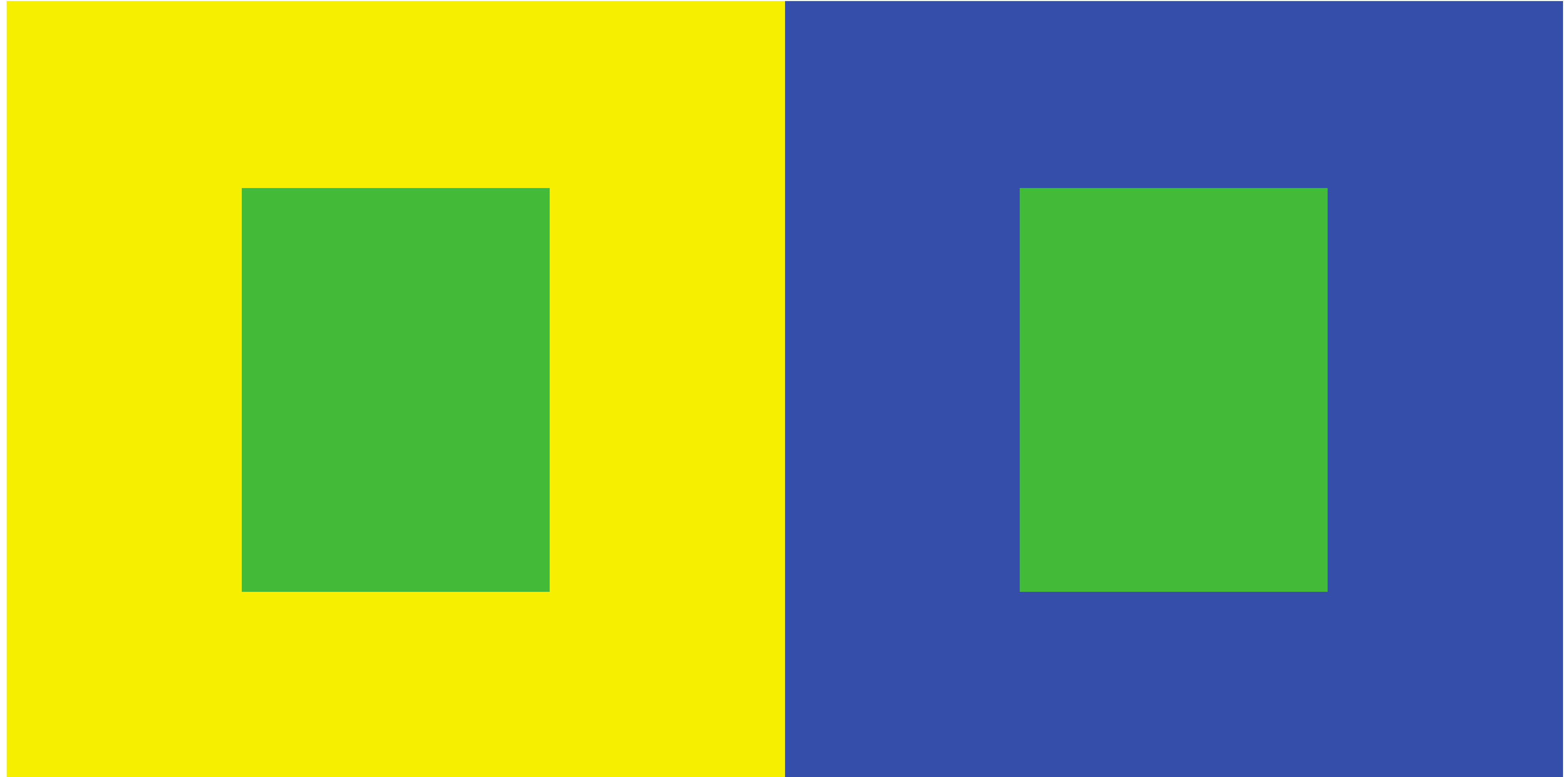
# “Simultaneous Contrast”



# “Simultaneous Contrast”



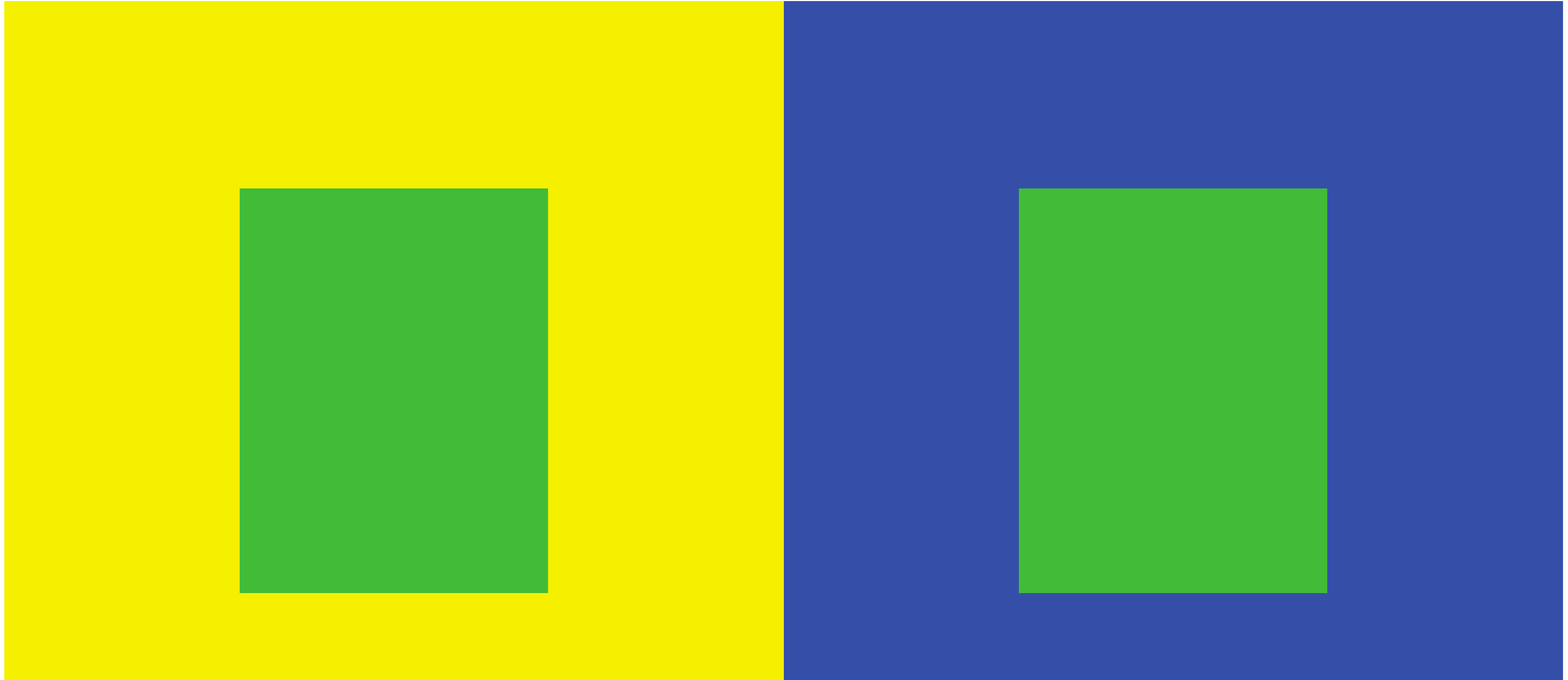
# “Simultaneous Contrast”



# “Simultaneous Contrast”



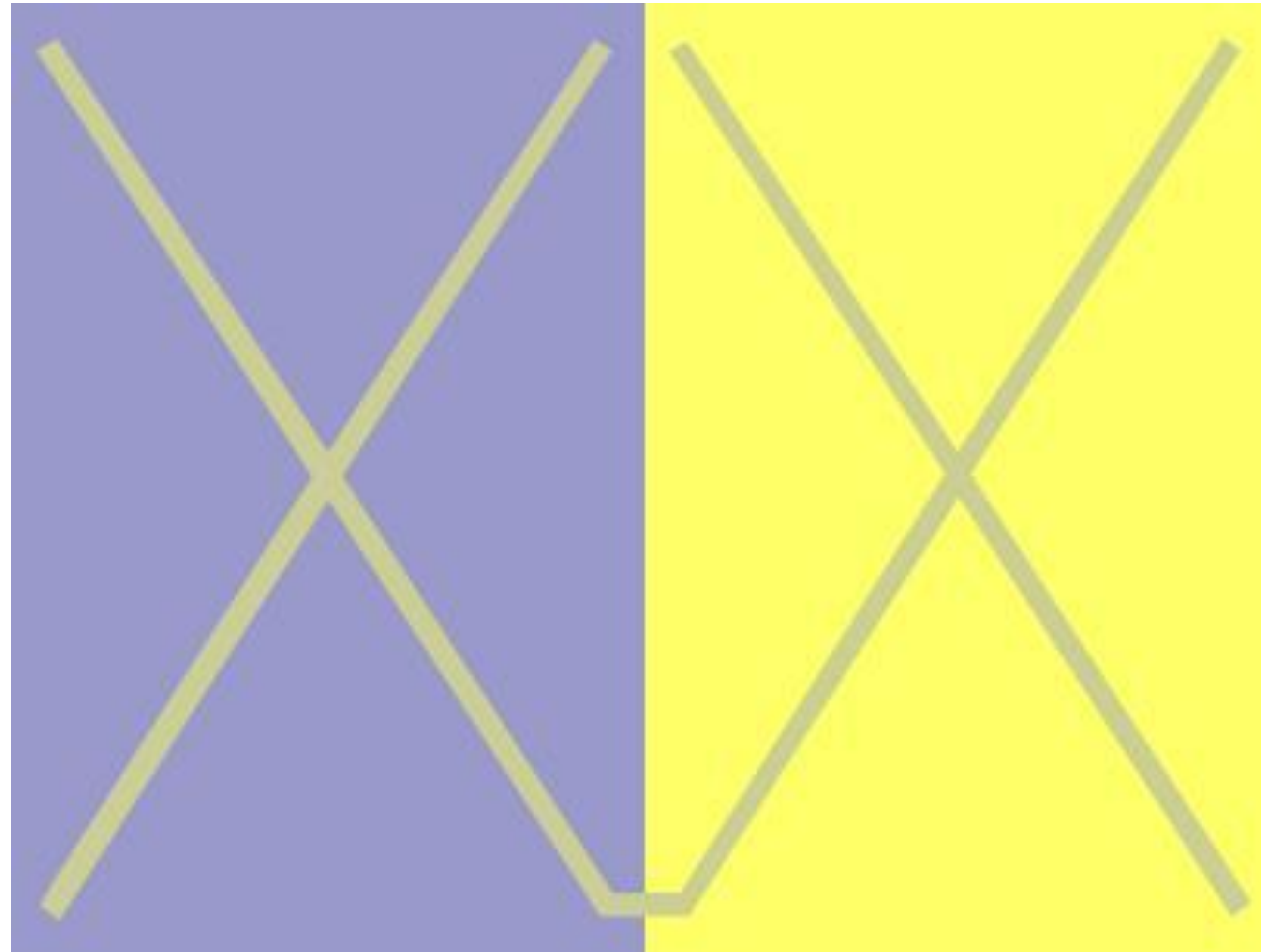
# “Simultaneous Contrast”



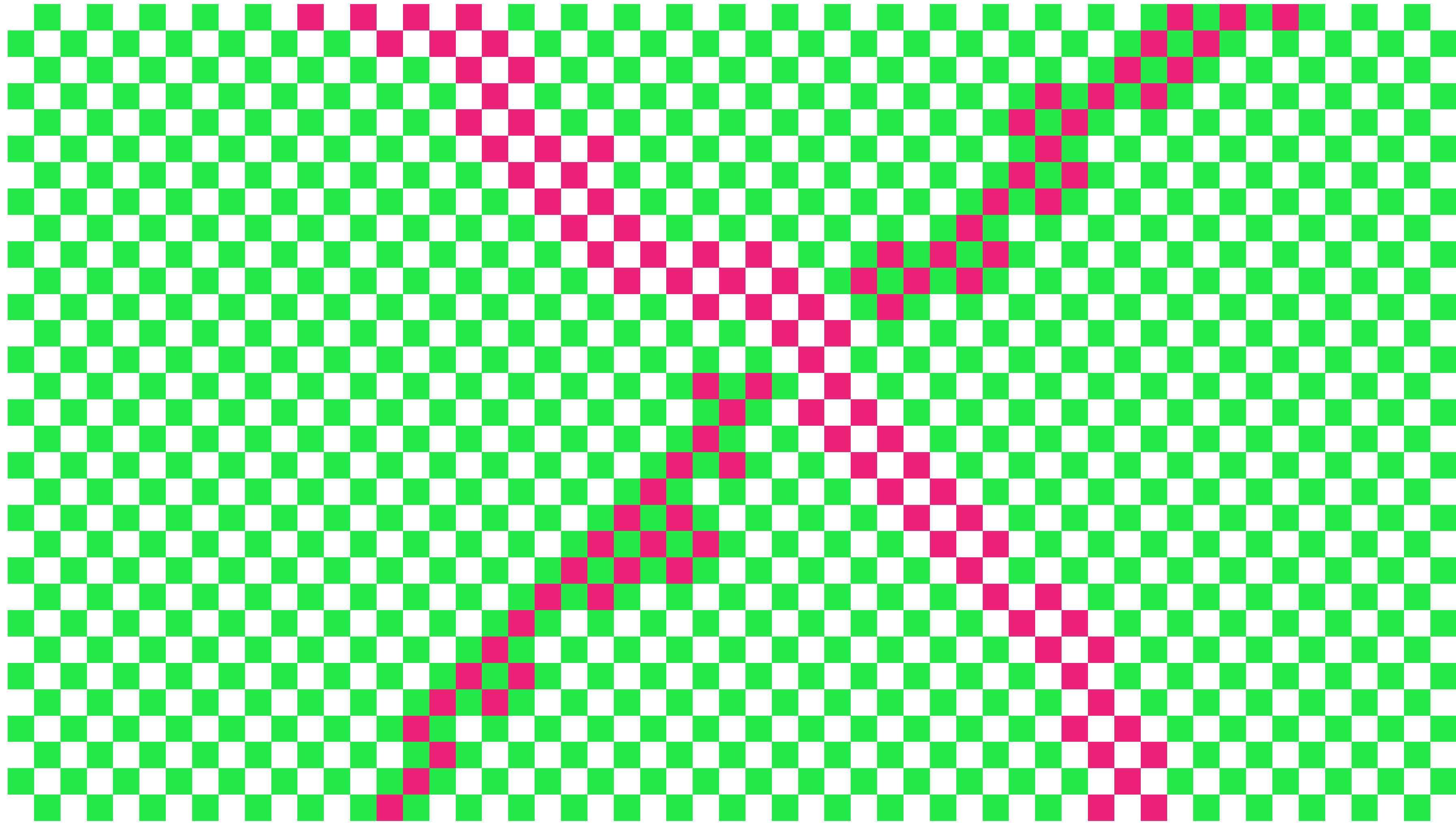
*Be careful with bars and scatter plot points - the colors may appear differently with different background colors and neighboring colors!*

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

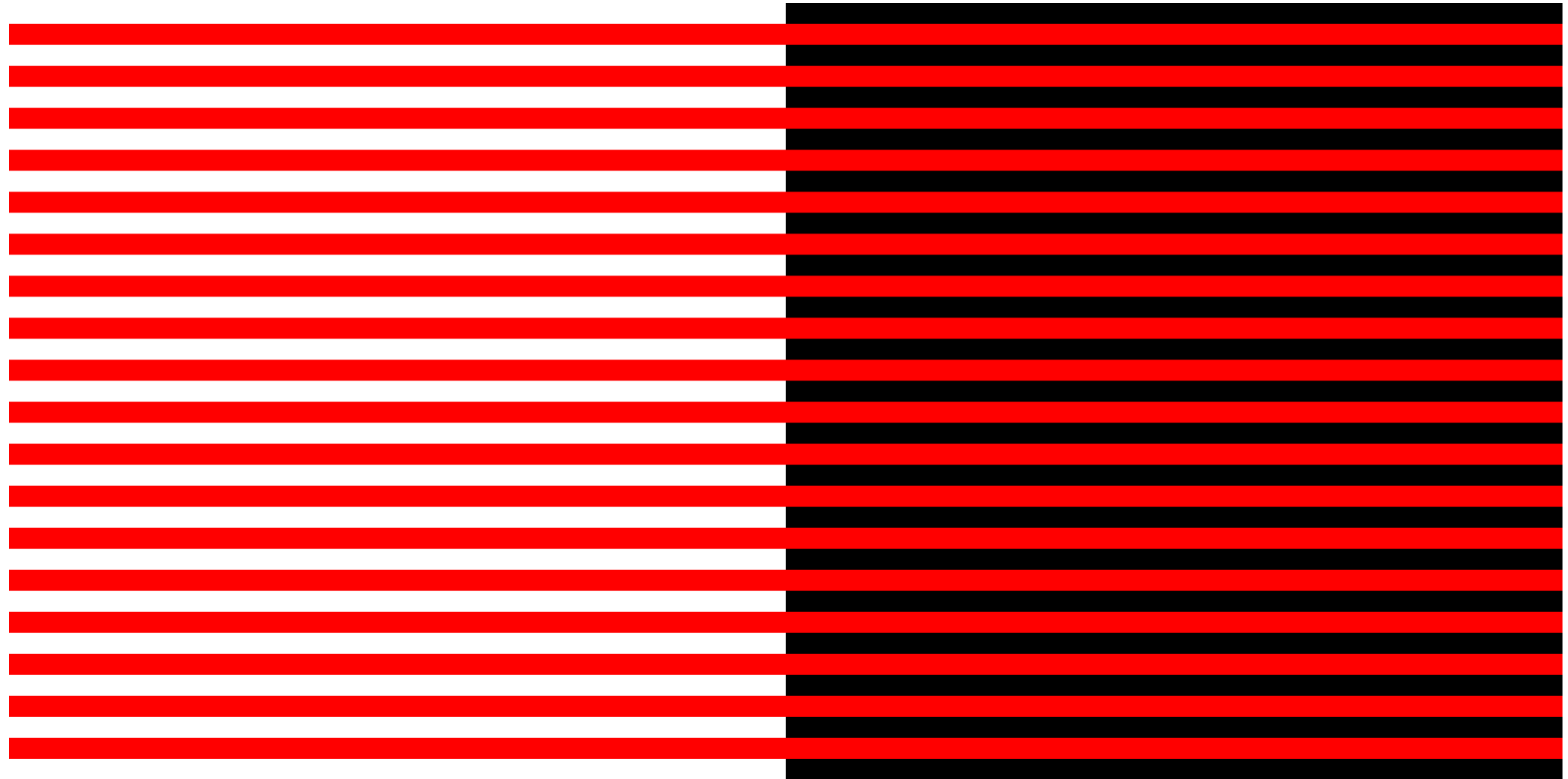
# “Simultaneous Contrast”



# “Simultaneous Contrast”

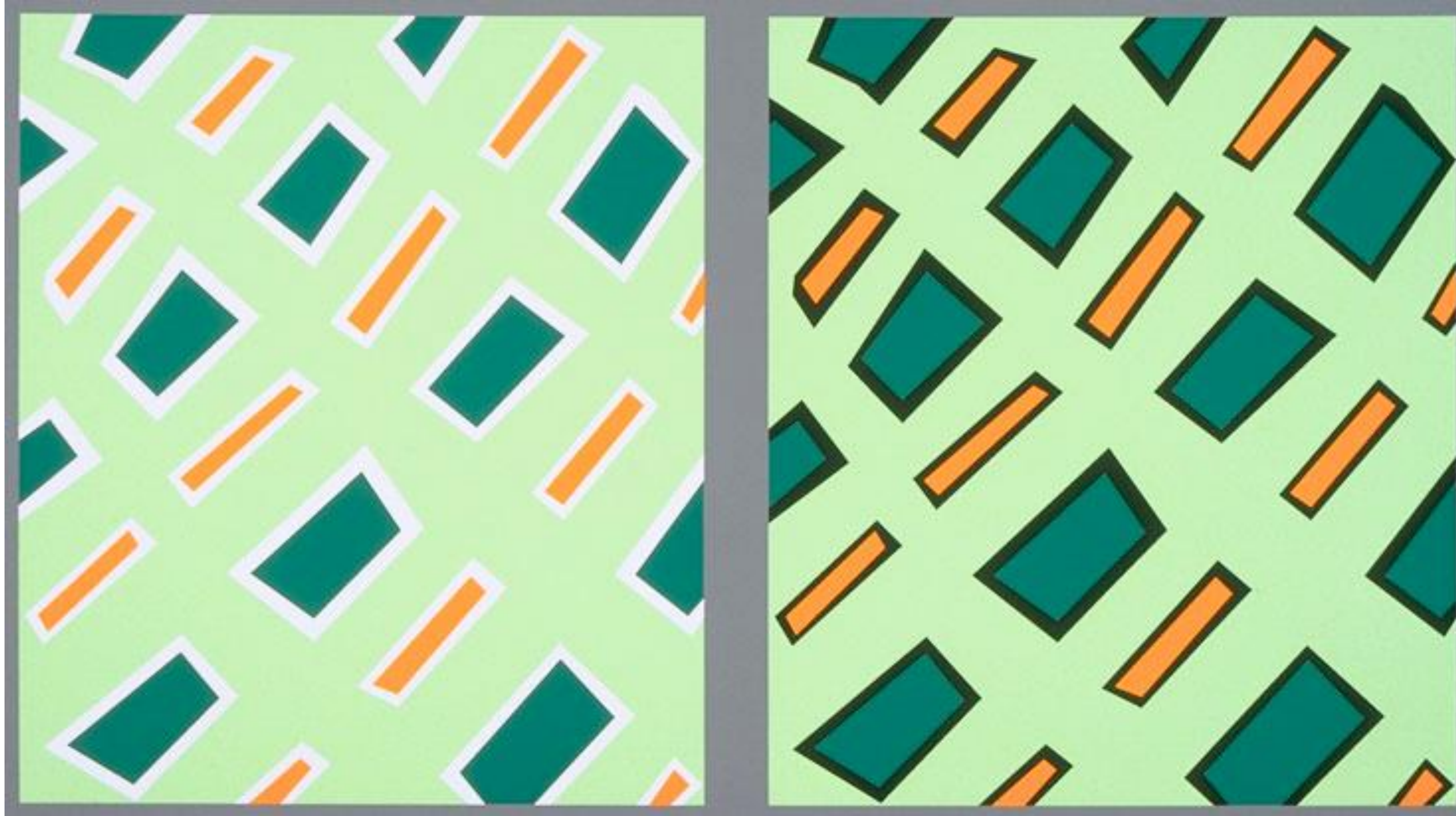


# “von Bezold Spreading Effect”





# “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)?

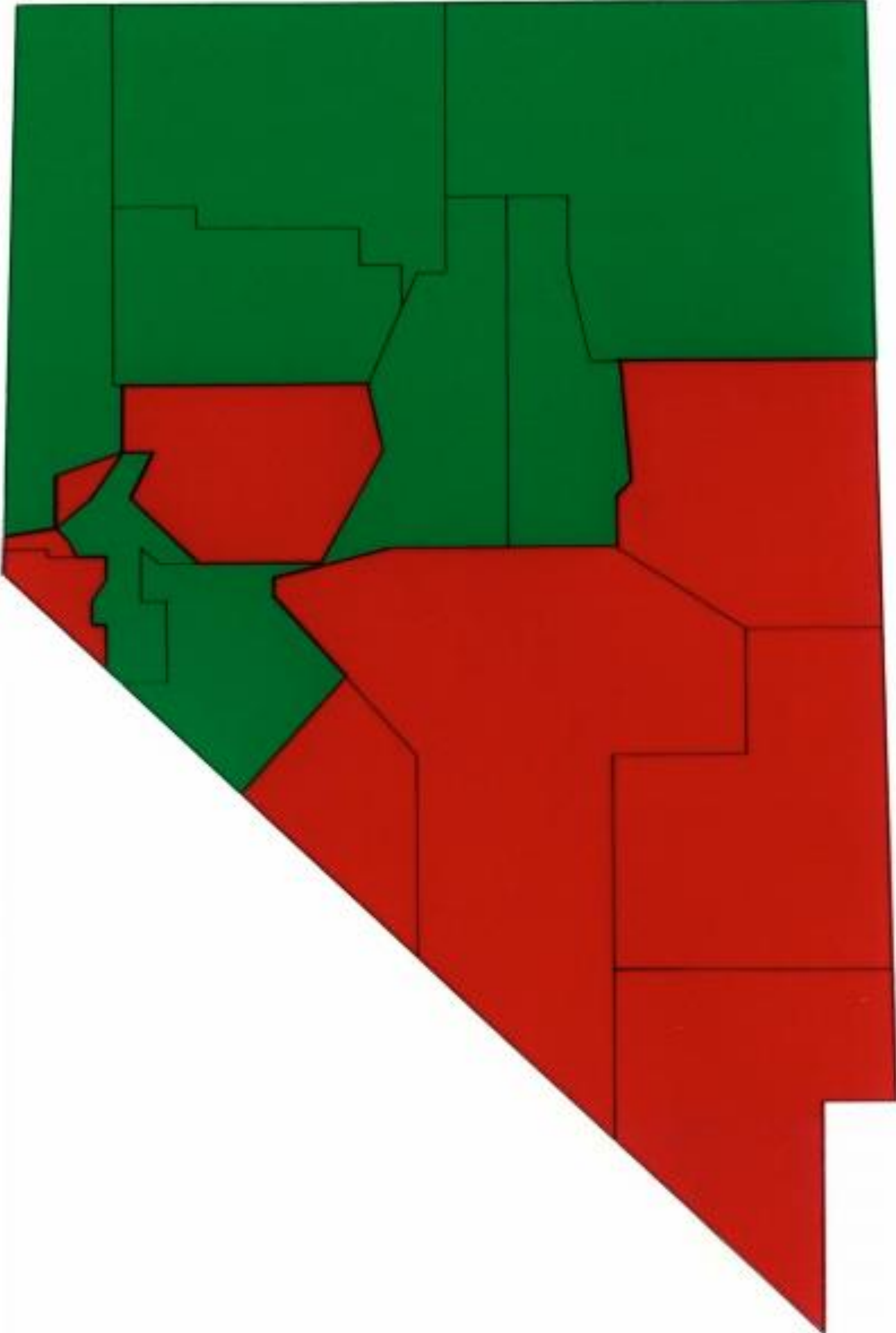


Figure 1. Stimulus From the High-Saturation Group

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)*

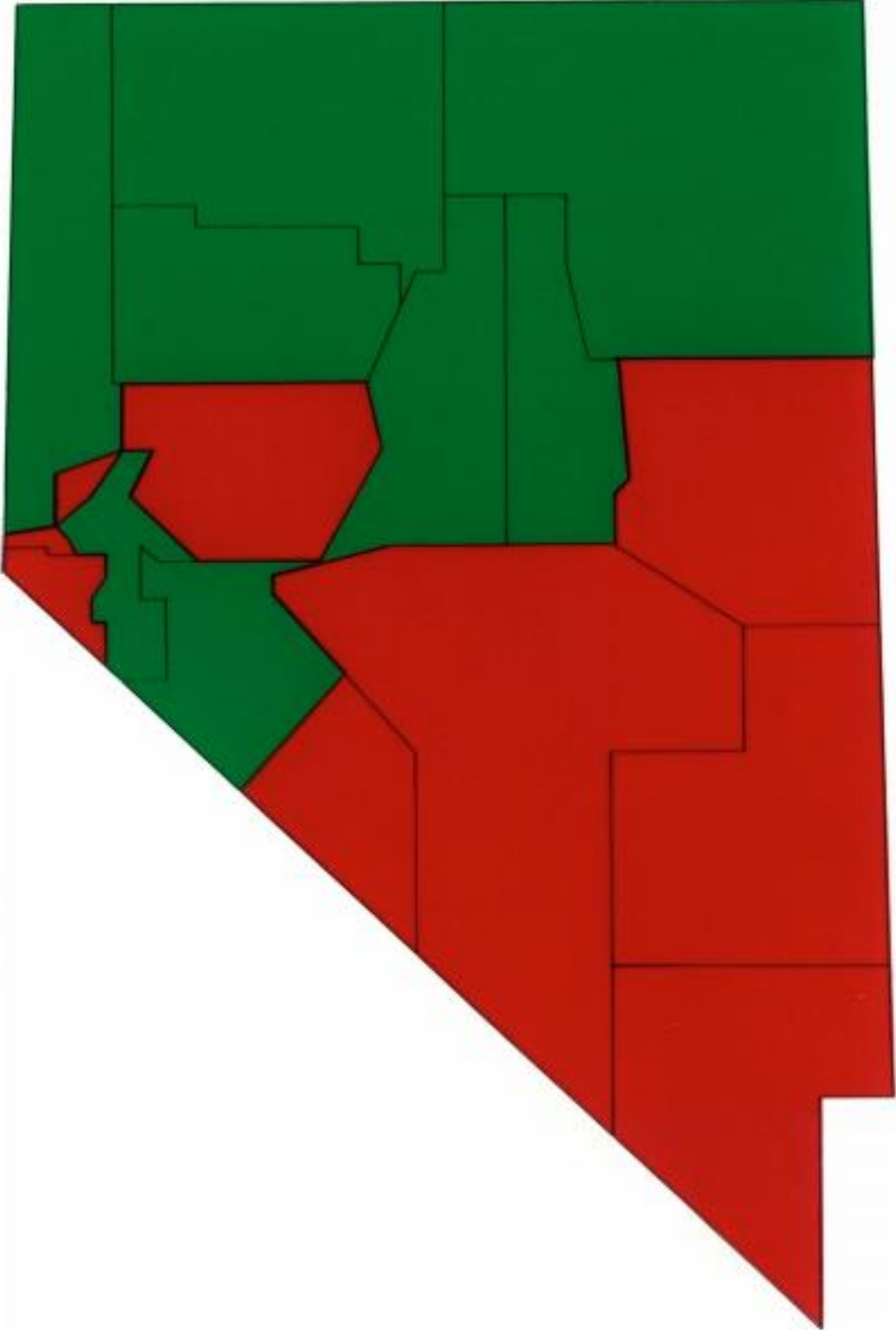


Figure 1. Stimulus From the High-Saturation Group

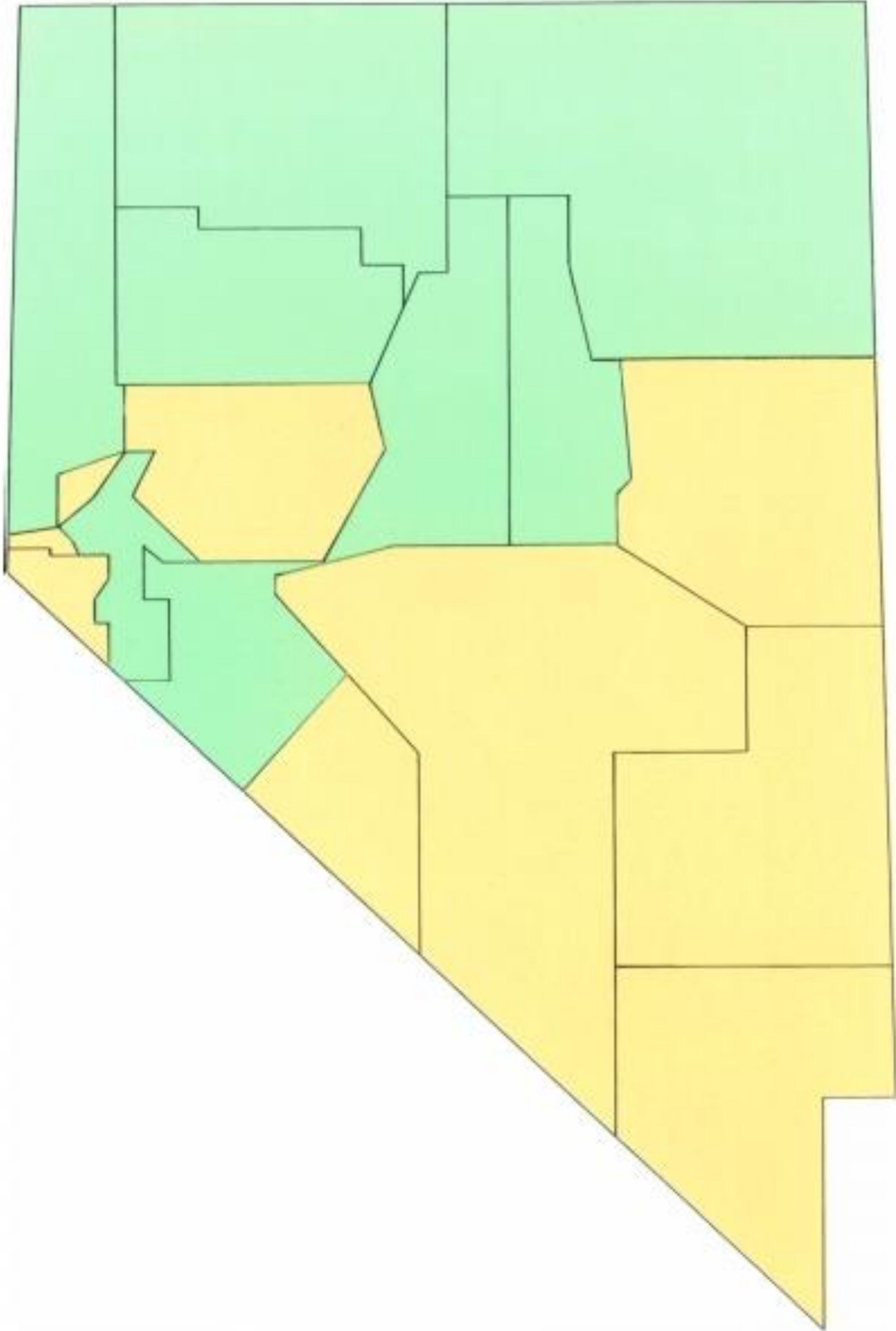
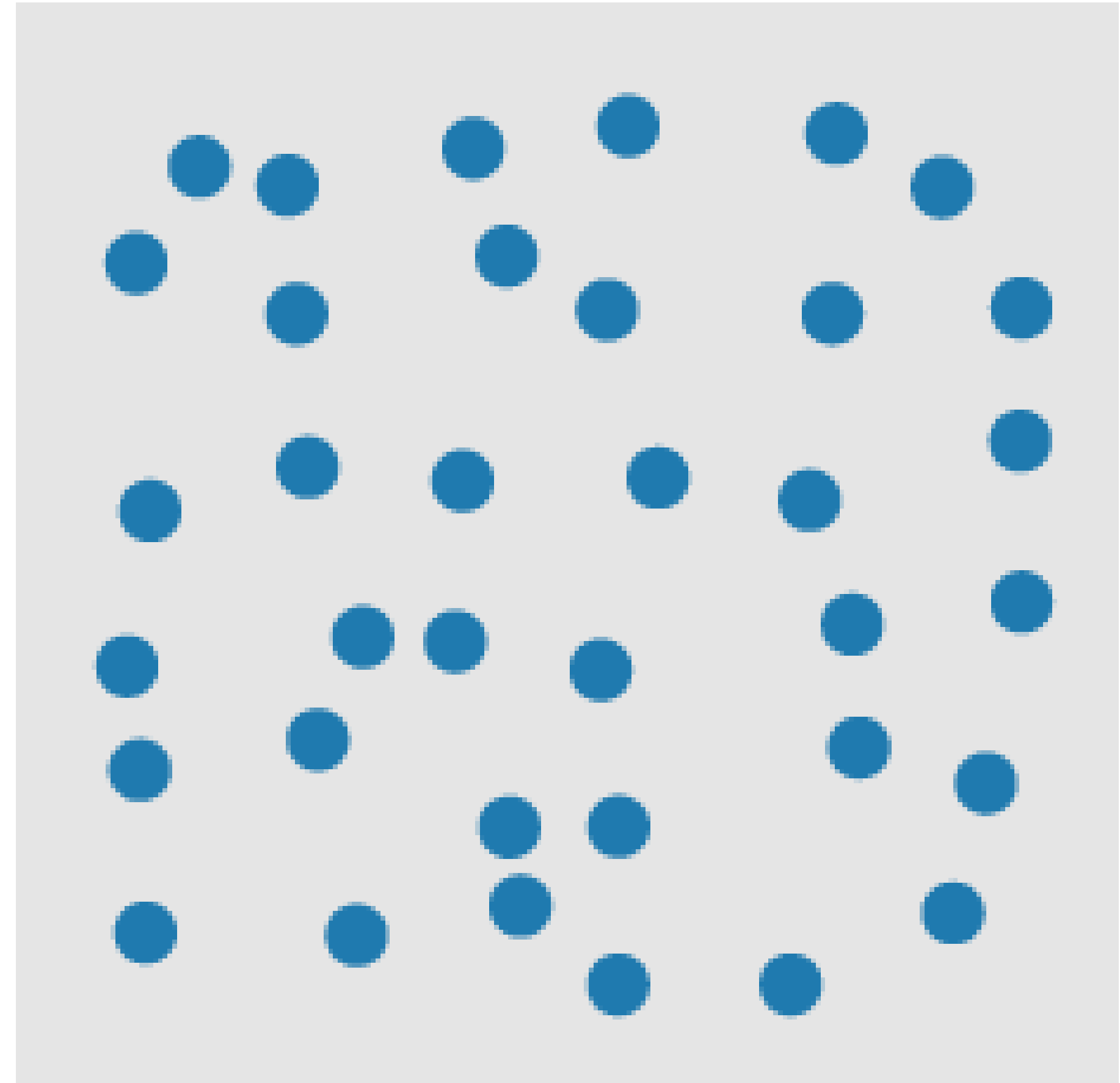
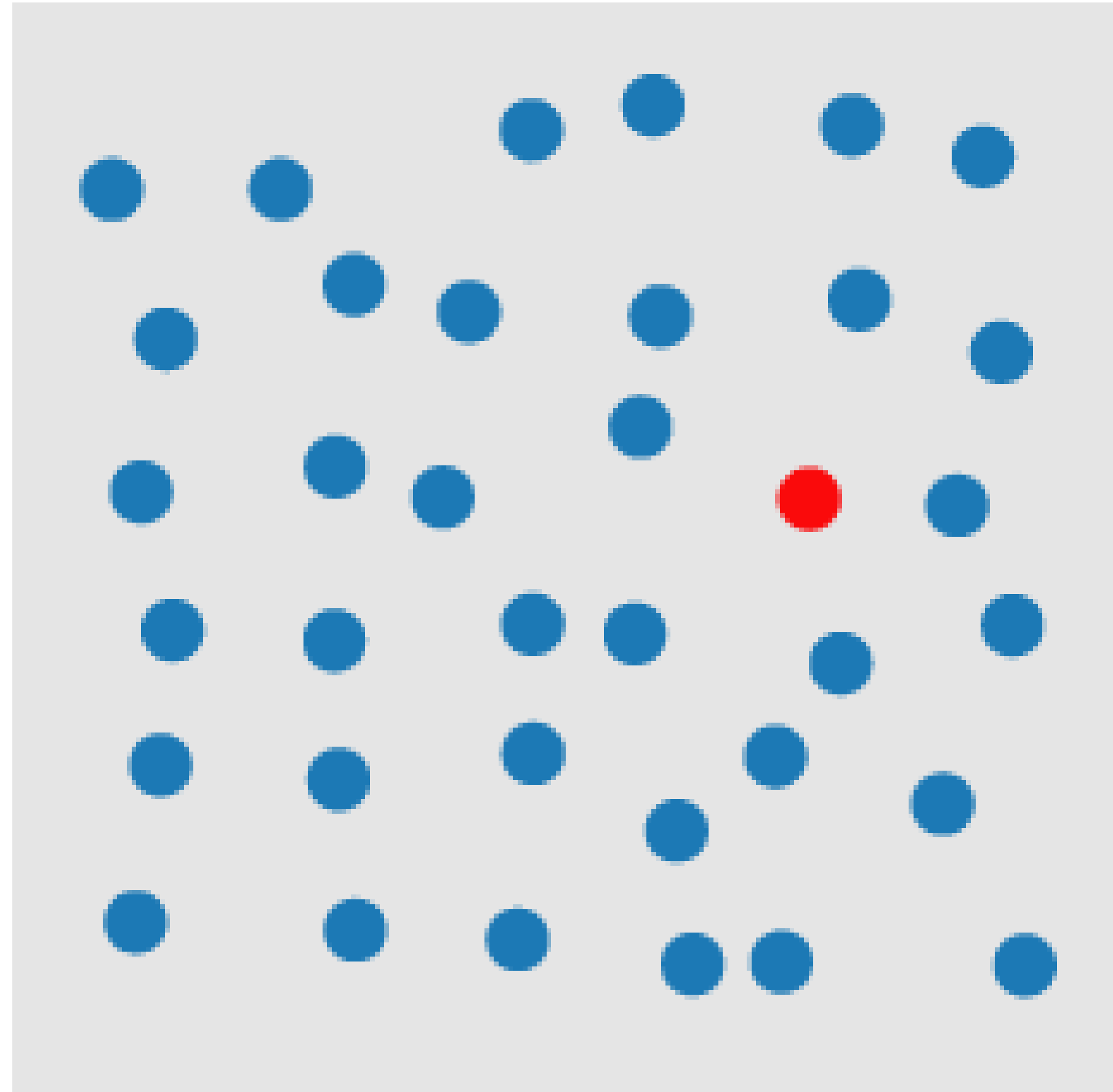


Figure 2. Stimulus From the Low-Saturation Group

# POP-OUT EFFECTS



COLOR

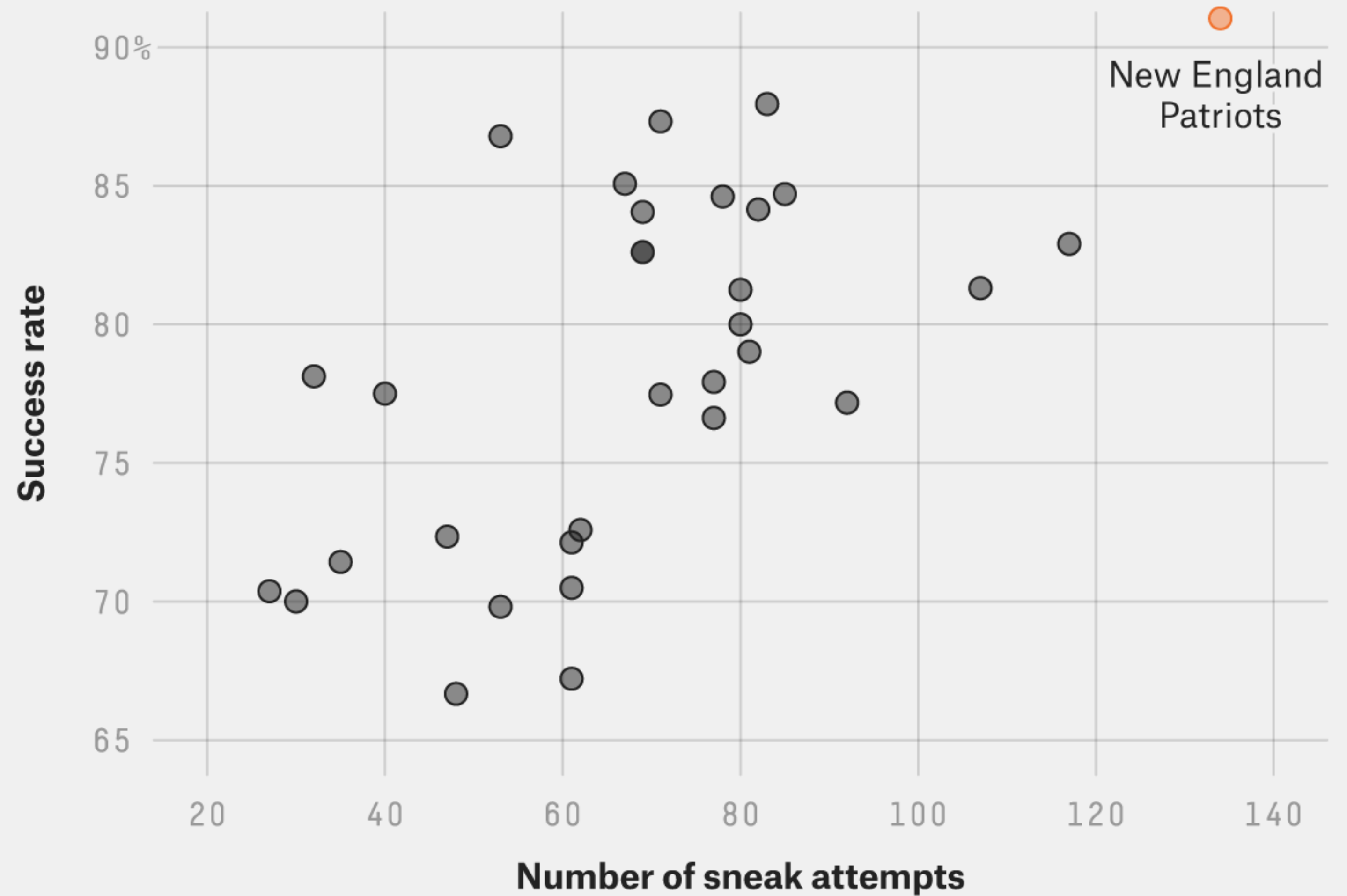
A quarterback sneak is a [play](#) in [American football](#) and [Canadian football](#) in which the [quarterback](#), upon taking the center snap, dives ahead while the offensive line surges forward. It is usually only used in very short yardage situations.

[https://en.wikipedia.org/wiki/Quarterback\\_sneak](https://en.wikipedia.org/wiki/Quarterback_sneak)

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

## The Patriots' QB sneaks stand out

QB sneak success rate versus number of attempts on 1- and 2-yard plays on third and fourth down, 2001-15



FiveThirtyEight

SOURCE: ARMCHAIR ANALYSIS



Desaturated  
background,  
light blue

NASA/ESA/Hubble  
Heritage Team (STScI/AURA) /  
Hester & Scowen

# Color Mixing Pitfalls

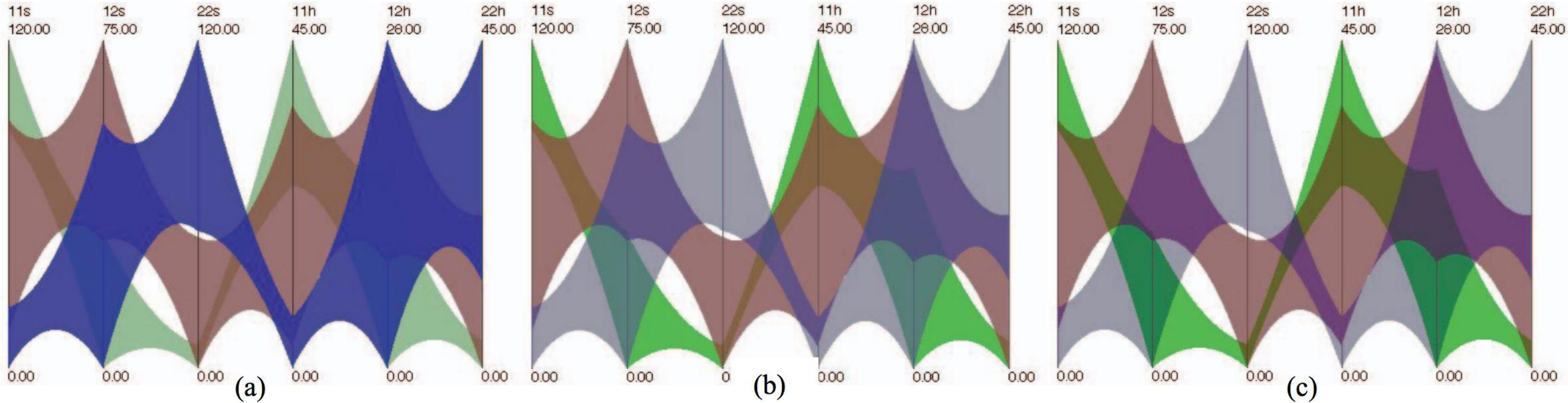


Fig. 12: Illustrative visualizations of a six-dimensional dataset using illustrative parallel coordinates. (a) Ideal visualization with appropriate weightings and color choices, and the use of the local model in overlapping areas. (b) Improper weightings are employed. The blue cluster no longer seems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

# TOOLS FOR PICKING COLOORMAPS

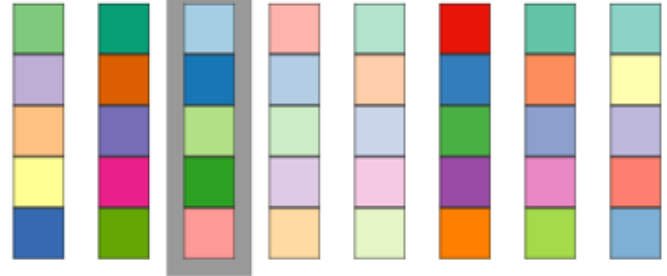


# Color Brewer

Number of data classes: 6 how to use | updates | downloads | credits

Nature of your data:  sequential  diverging  qualitative

Pick a color scheme:



Only show:  colorblind safe  print friendly  photocopy safe

Context:  roads  cities  borders

Background:  solid color  terrain

color transparency

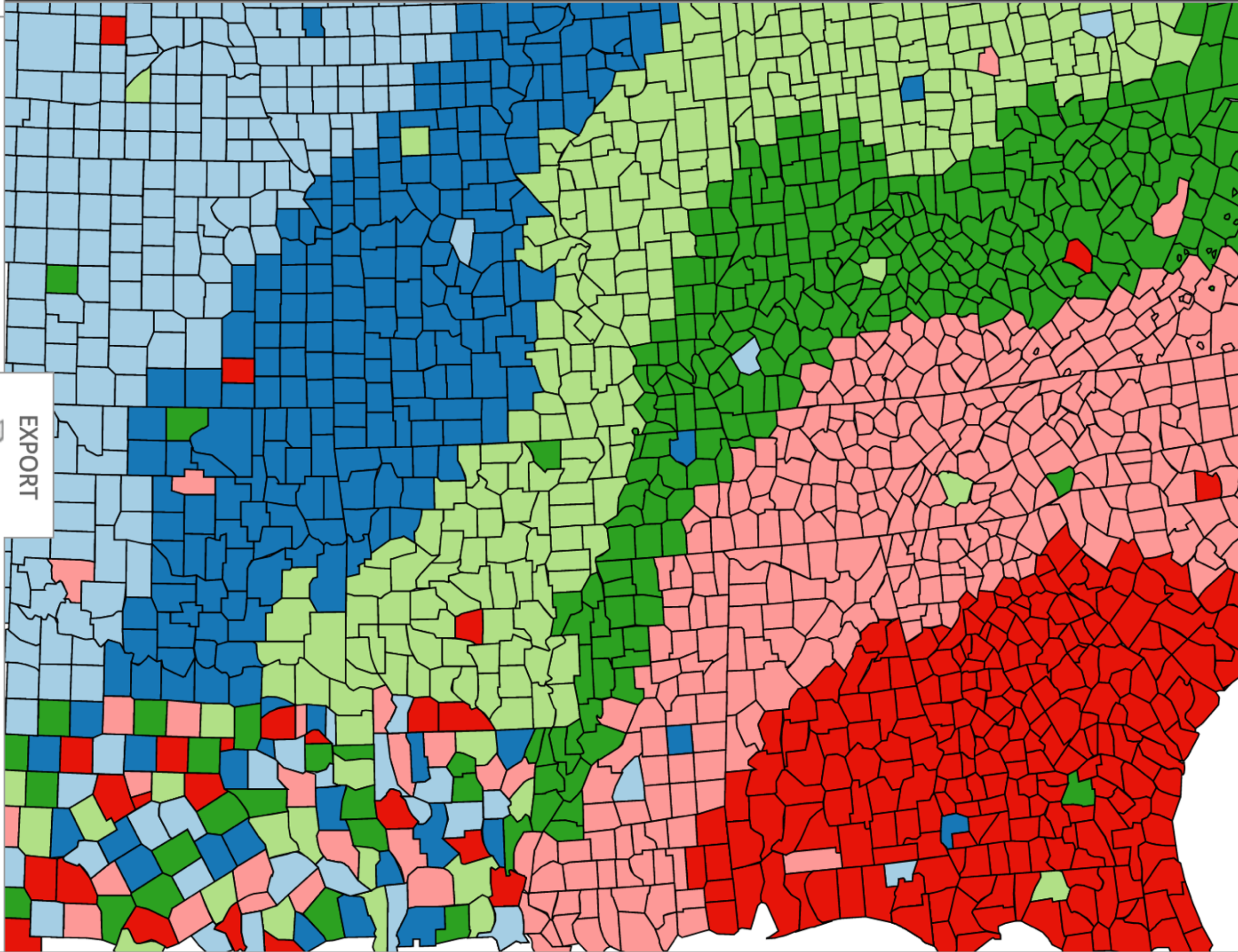
6-class Paired

EXPORT

HEX

- #a6cee3
- #1f78b4
- #b2df8a
- #33a02c
- #fb9a99
- #e31a1c

**COLORBREWER 2.0**  
color advice for cartography



<http://colorbrewer2.org>

# Colorgorical

Colorgorical Source

Generate

Results: Color space Hex RGB Lab LCH Array format " ' No quote Charts Clear all

Number of colors: 5

Score importance: Perceptual Distance, Name Difference, Pair Preference, Name Uniqueness

Select hue filters: 90°, 180°, 270°, 0°

Results: ["rgb(57,146,131)", "rgb(148,210,207)", "rgb(25,79,70)", "rgb(57,238,192)"]

rgb(57,146,131) + start

rgb(148,210,207) + start

rgb(25,79,70) + start

rgb(57,238,192) + start

## Instructions

To generate a palette with  $n$  colors, just enter the number of colors you want and click *Generate*. Bigger palettes will take longer than smaller palettes to make. Results will automatically appear when ready.

For greater detail, please consult our [paper](#) or the [source code](#).

## Score Importance

### Perceptual Distance

Increasing *Perceptual Distance* favors palette colors that are more easily discriminable to the human eye. To accurately model human color acuity, this is performed using CIEDE2000 in CIE Lab color space.

### Name Difference

Increasing *Name Difference* favors palette colors that share few common names.

## About

Colorgorical was built by Connor Gramazio with advisement from David Laidlaw and Karen Schloss.

## Documentation

If you'd like to read more about how Colorgorical works, please read our paper [here](#). If you're curious about the implementation, please see the Colorgorical GitHub repository located [here](#).

If you use Colorgorical, please use the following citation:

```
@article{gramazio-2017-ccd,
  author={Gramazio, Connor C. and Laidlaw, David H. and Schloss, Karen},
  journal={IEEE Transactions on Visualization and Computer Graphics},
  title={Colorgorical: creating discriminable and preferable color palettes}
```

# 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/>
- viridis 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!*

# Upcoming Assignments & Communication

Look at the upcoming assignments and deadlines regularly!

- Textbook, Readings, & Reading Quizzes — Variable days
- In-Class Activities — 11:59pm same day as class
  - T: Lecture, F: In-class project feedback meetings & work
  - Next T: Lecture, Next F: Lecture
- Assignments & Projects— Generally due **R 11:59pm**
  - R (6 days):**
    - Assignment 7 (D3 Events)
    - Project 3 — Interview & Task Analysis**
  - Next R (13 days):** Project 4 — Data Collection & Exploration, Sketches
  - Next-next R (20 days):**
    - Assignment 8 — Brushing and Linking in D3
    - Project 5 — Final "Interactive" Visualization Sketch, Implementation Plan, & Group Charter

Use Canvas Discussions for general questions, email the TAs/S-LTA/instructor for questions specific to you: [codydunne-and-tas@ccs.neu.edu](mailto:codydunne-and-tas@ccs.neu.edu). Include links!

If you're emailing about a particular assignment, please **include the URL of the Submission Details page**. ([Canvas documentation](#).)

If you have a project question, **give us your group number**. E.g., include: `Group ## — Topic` with `##` replaced by your group number and `Topic` replaced by your topic.