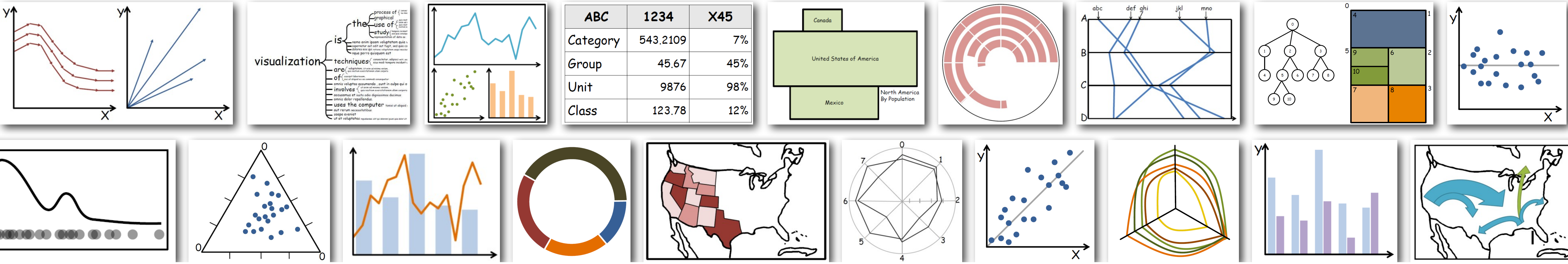


Lecture : Color in Visualization Design

(Color gamut and models)

DATA ANALYSIS & VISUALIZATION

FALL 2020

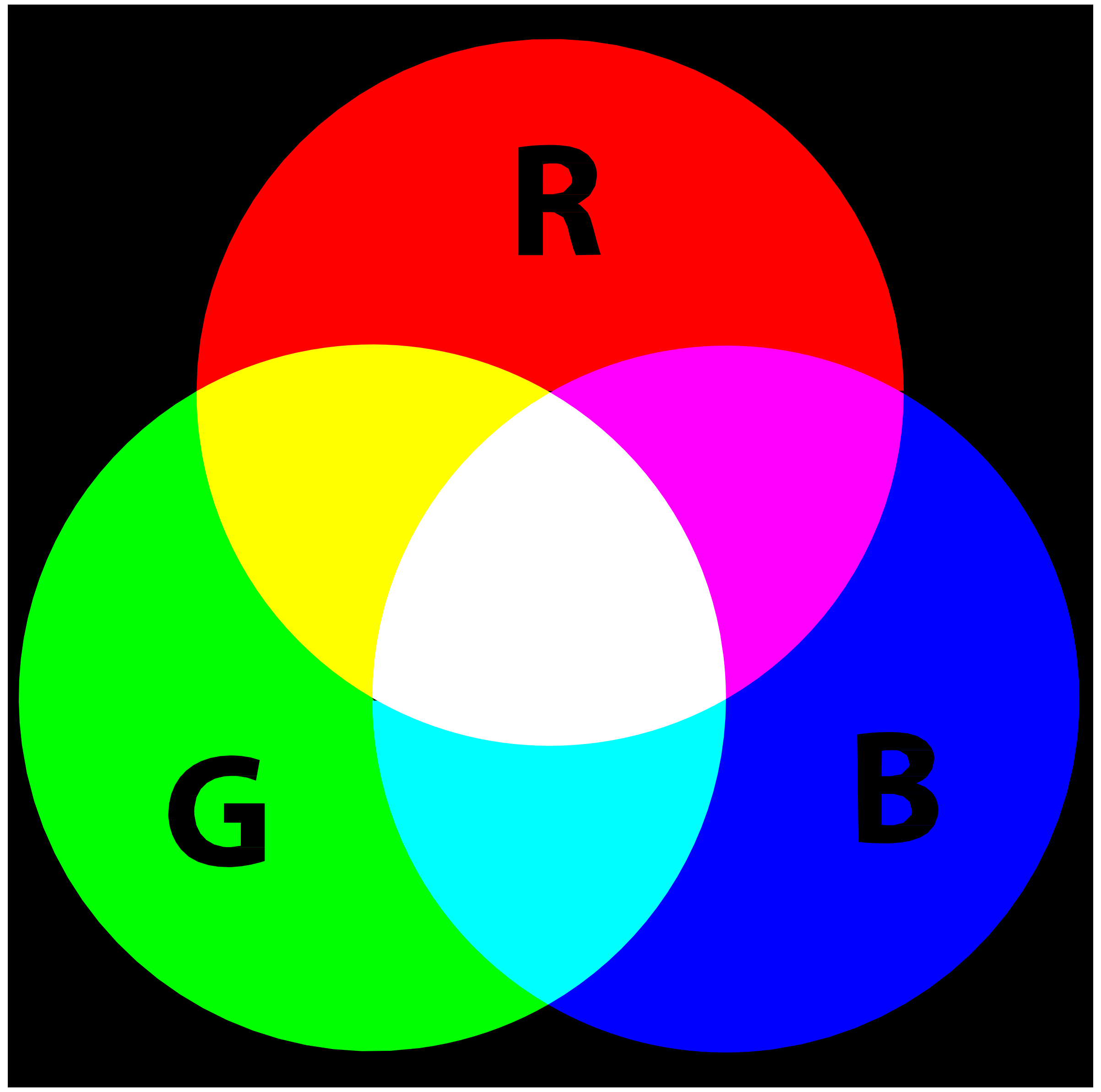
Dr. Muhammad Faisal Cheema

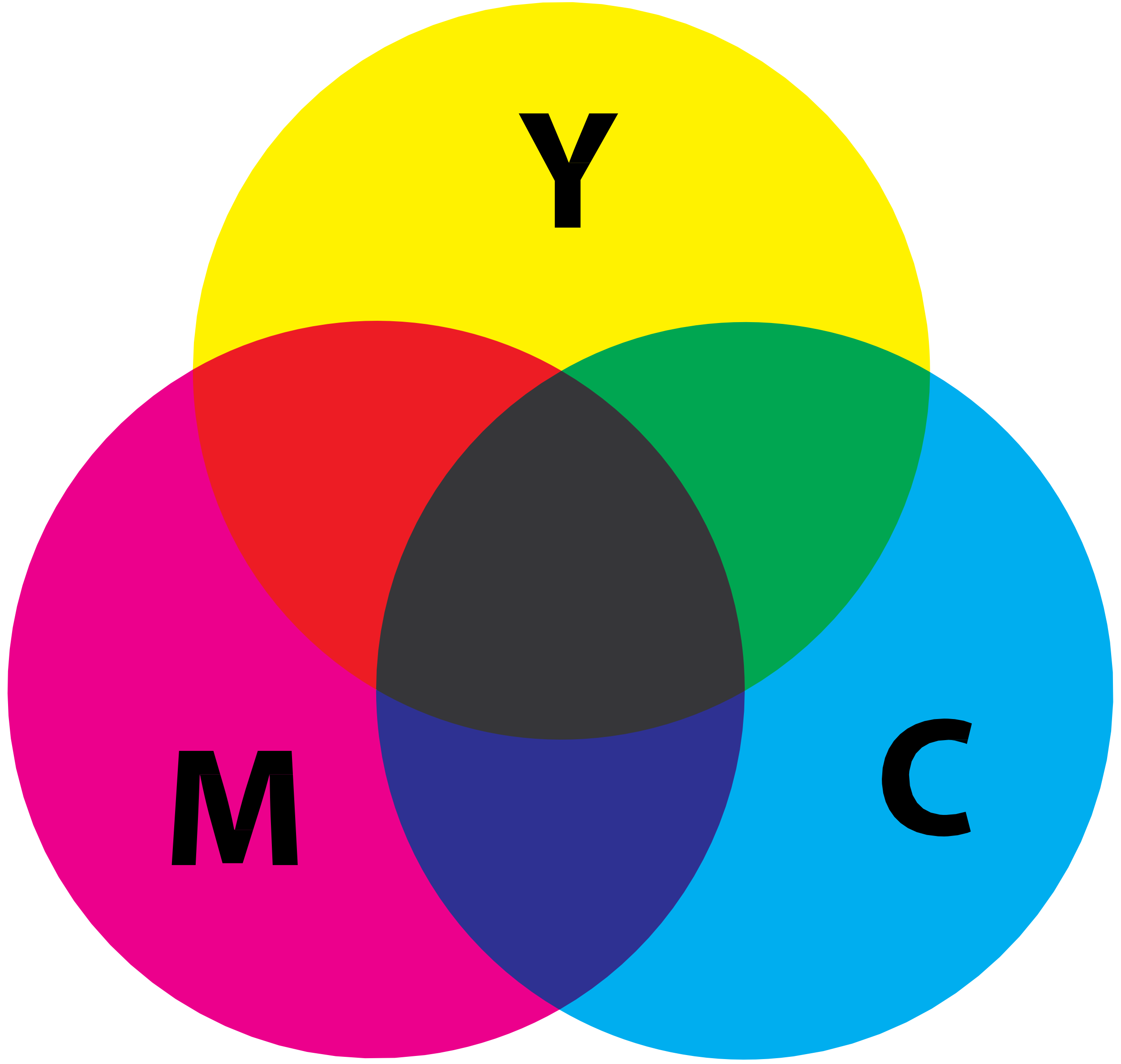
FAST NU

Primary Colors?

- Red, Green, and Blue
- Red, Yellow, and Blue
- Orange, Green, and Violet
- Cyan, Magenta, and Yellow
- All of the above!

Color Addition and Subtraction

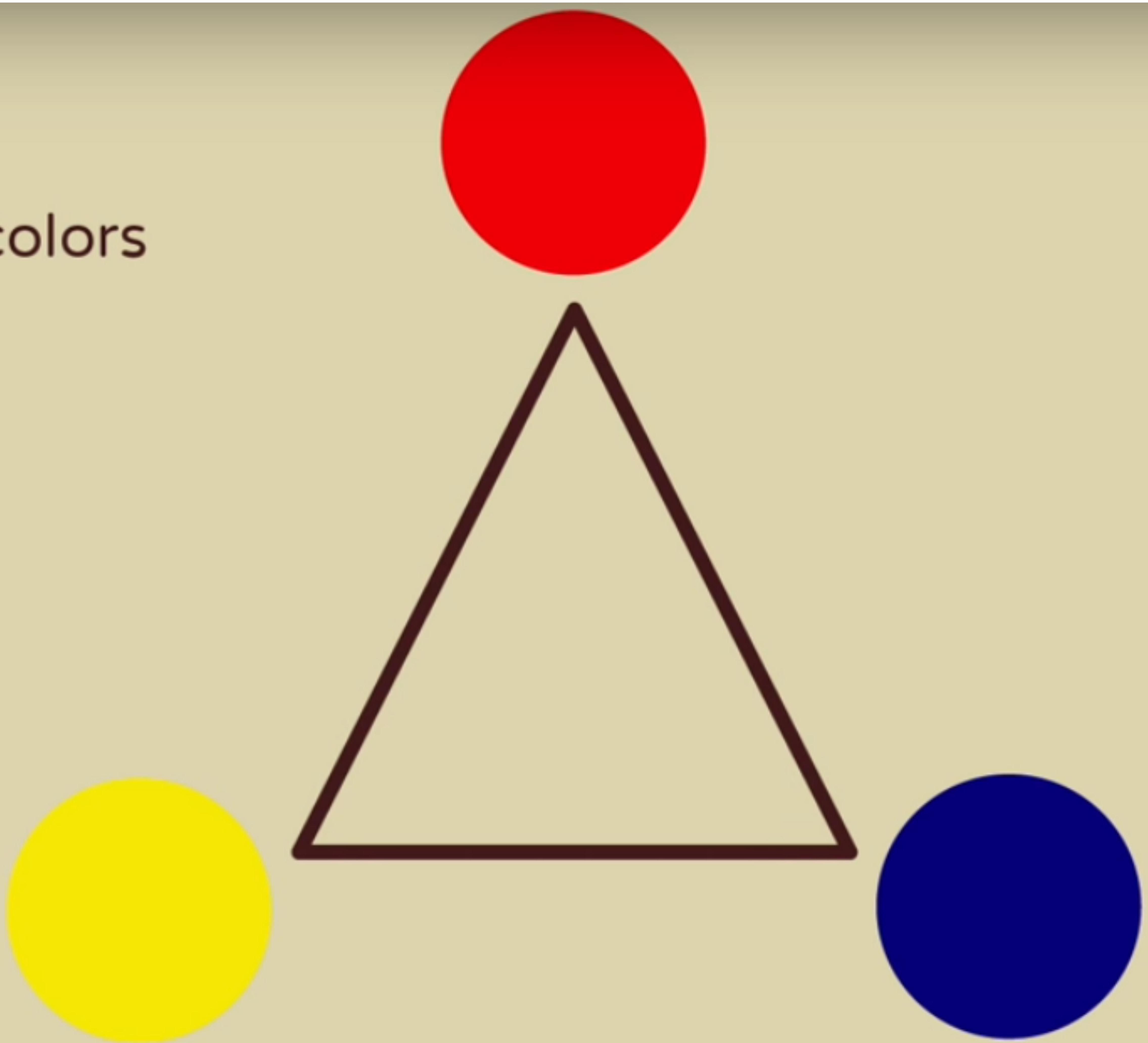




Primary colors

can be mixed to create all other colors

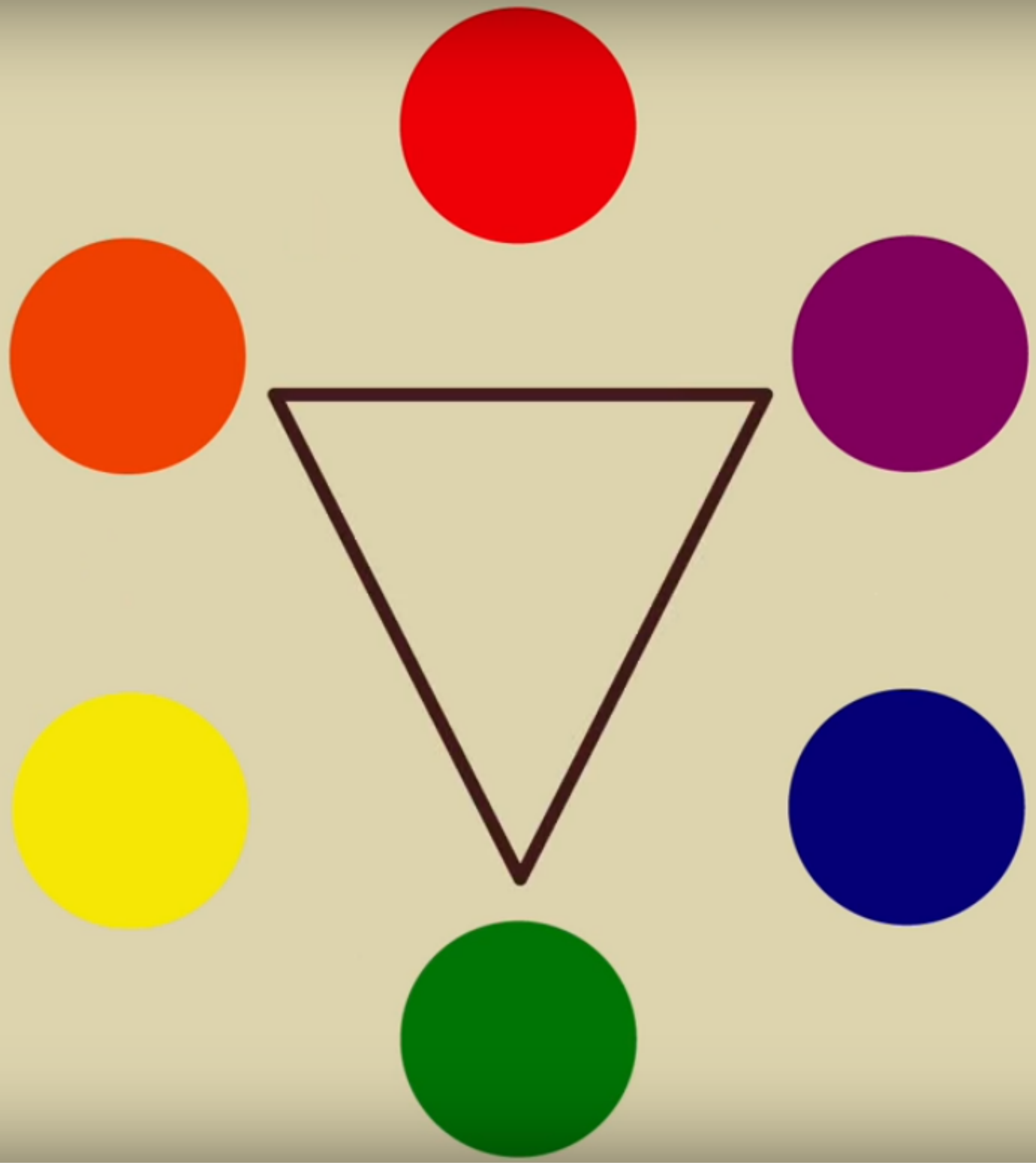
-Red
-Blue
-Yellow



Secondary colors

created by mixing primaries

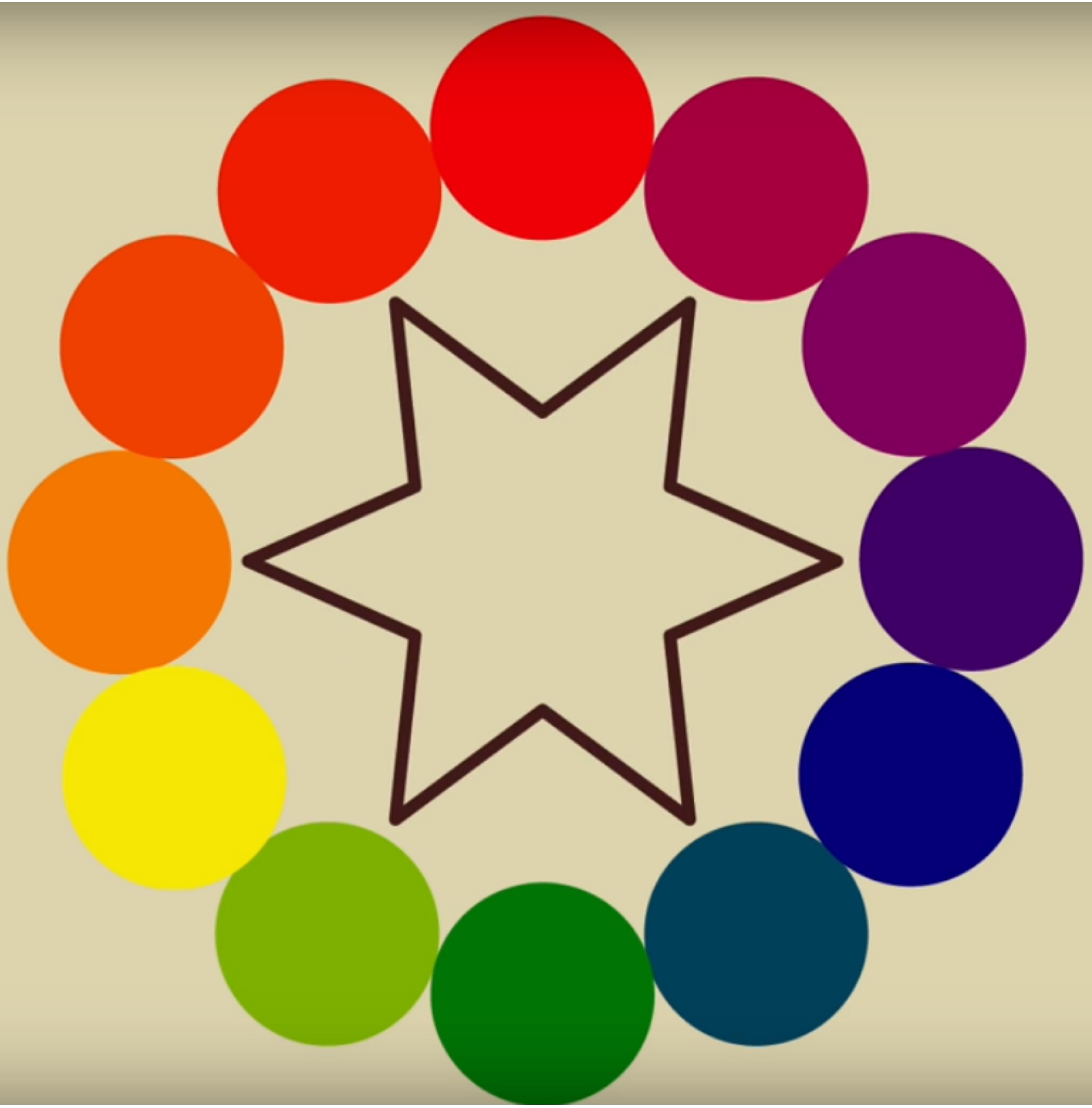
-Purple (red + blue)
-Green (blue + yellow)
-Orange (yellow + red)



Tertiary colors

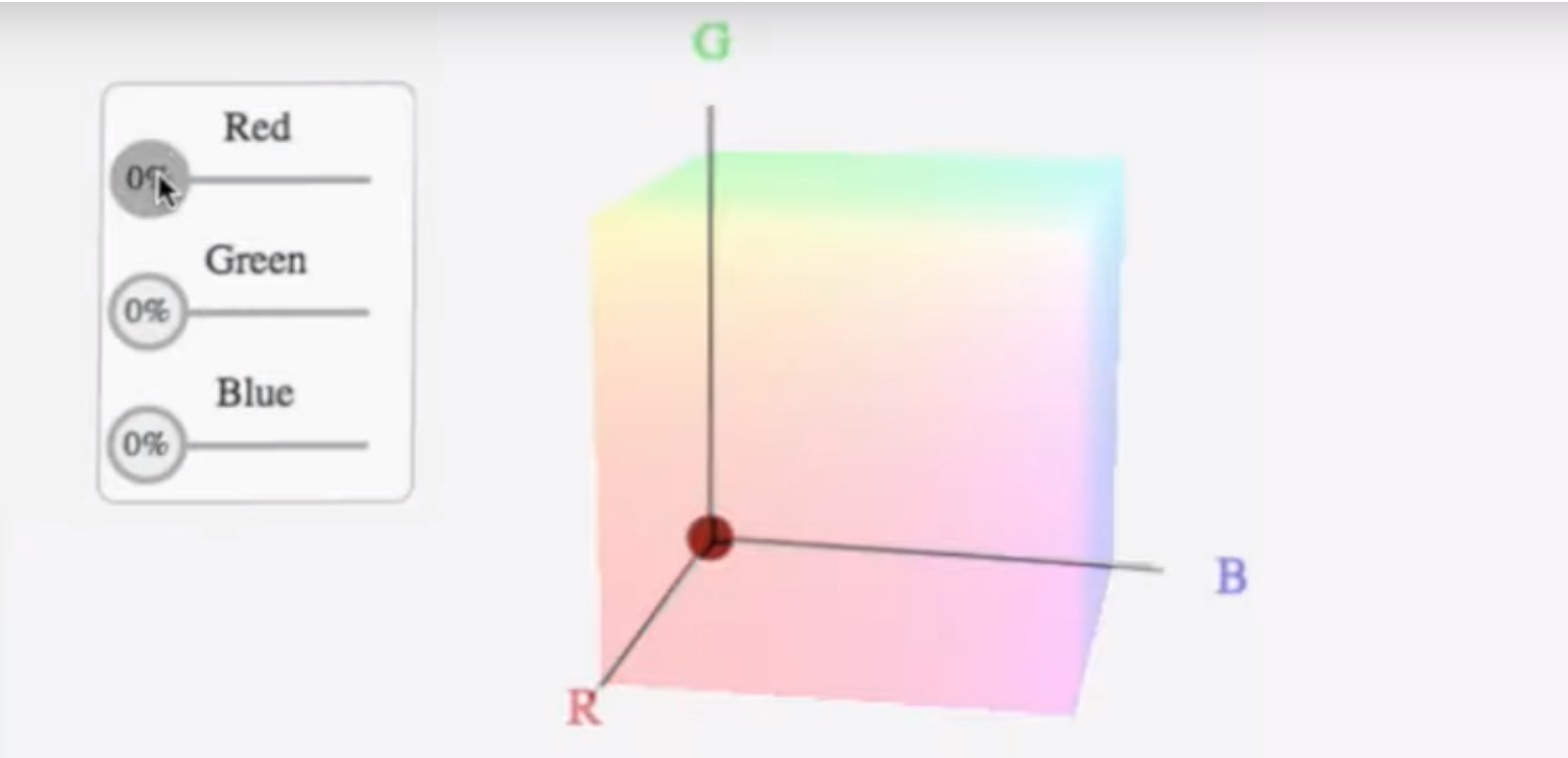
created by mixing
primaries & secondaries

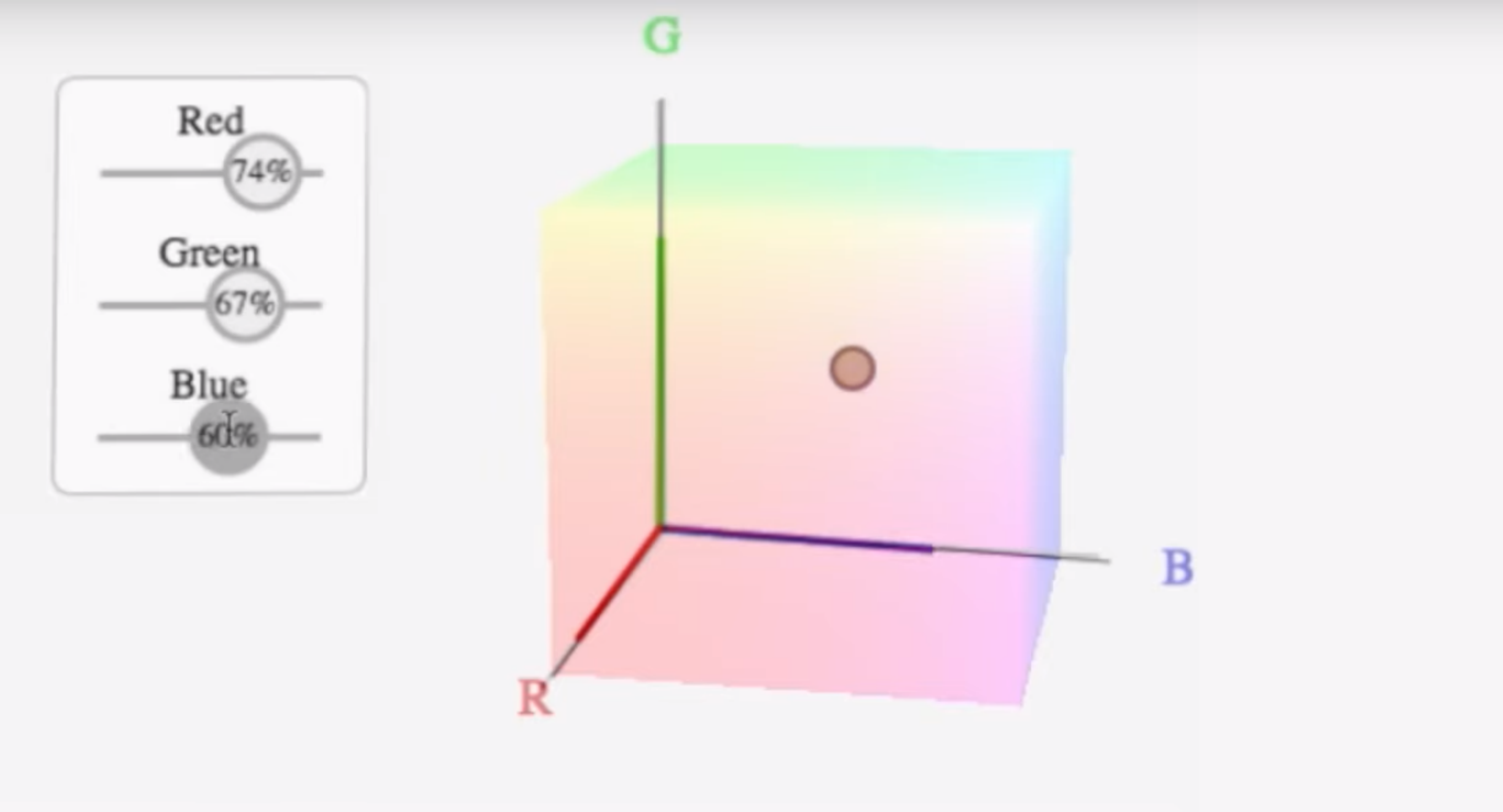
-Red-Orange
-Red-Purple
-Blue-Purple
-Blue-Green
-Yellow-Green
-Yellow-Orange



What is a Color Space and Color cube?

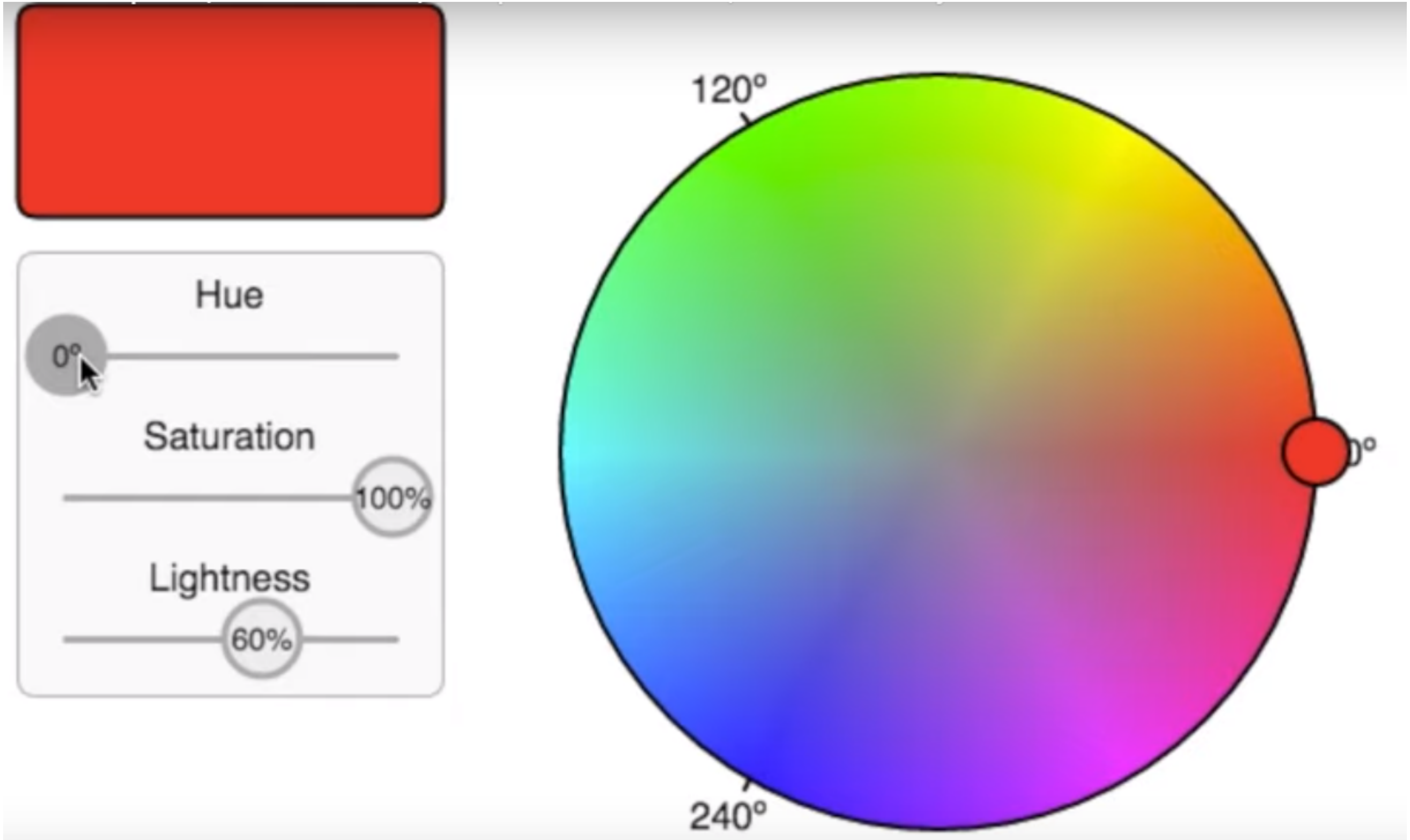
And their relation?


Red
0%
Green
0%
Blue
0%
G
B
R


Red
74%
Green
67%
Blue
60%
G
B
R

But in Computer programs

We see a Color wheel (not a cube)

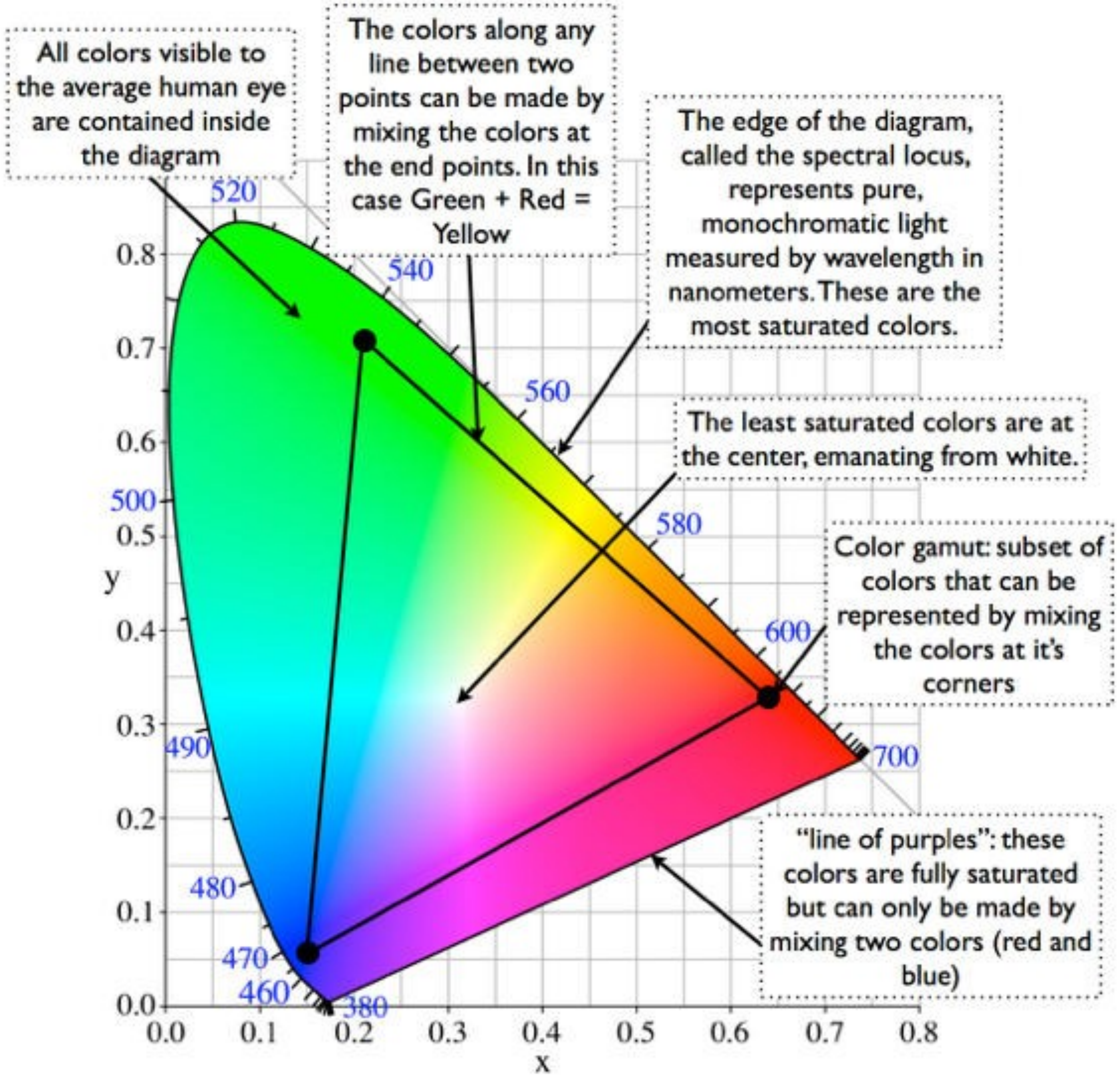


Hue
0°
Saturation
100%
Lightness
60%
120°
0°
240°

Redefine Color Spaces (w.r.t. human eye)?

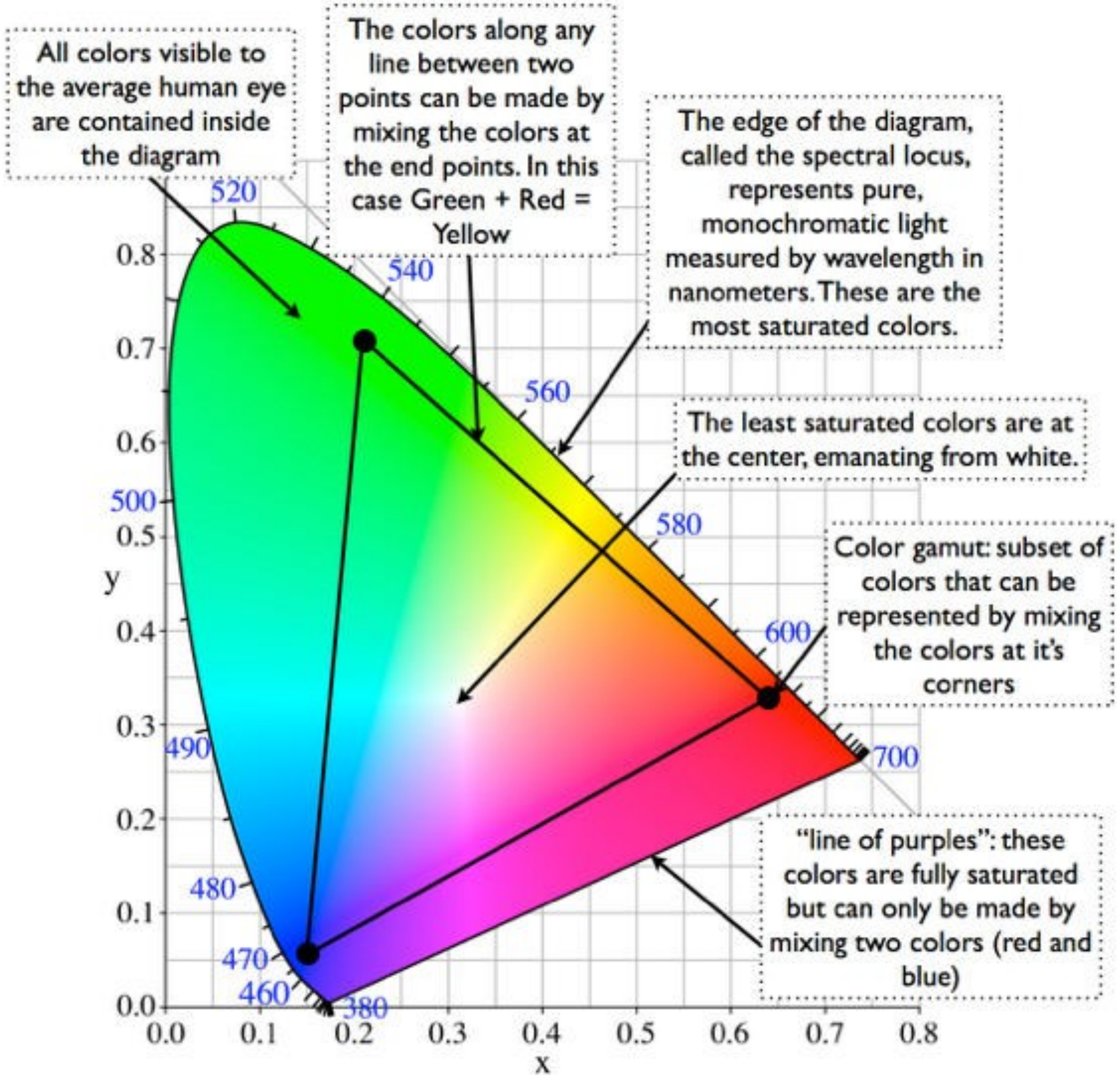
Color spaces: All Spectral colors perceivable by human eye (NOT just by RGB / CMYK etc.)

Color Spaces and Gamuts



[http://dot-color.com/2012/08/14/color-space-confusion/]

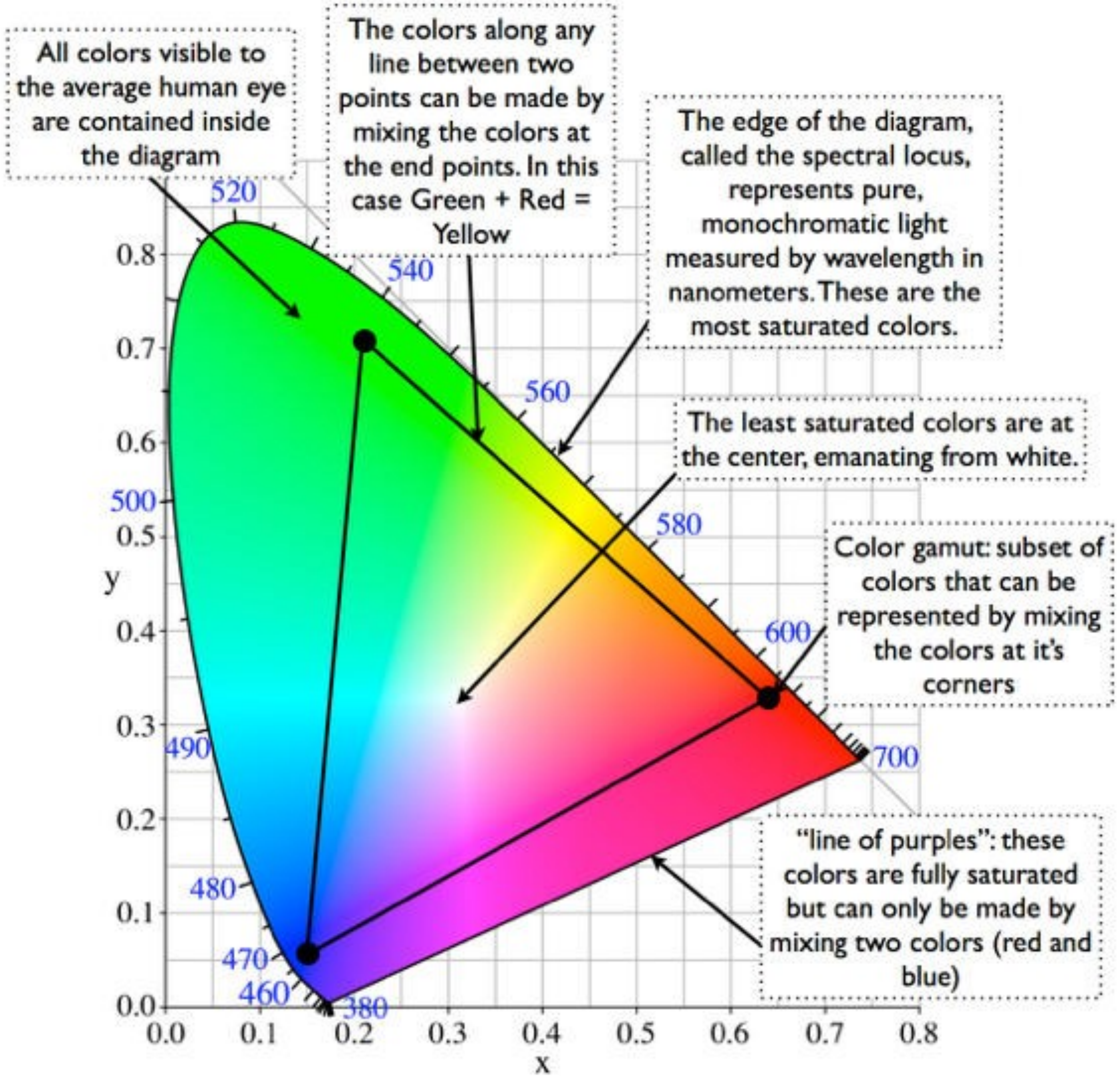
Why this strange shape to represent all colors?



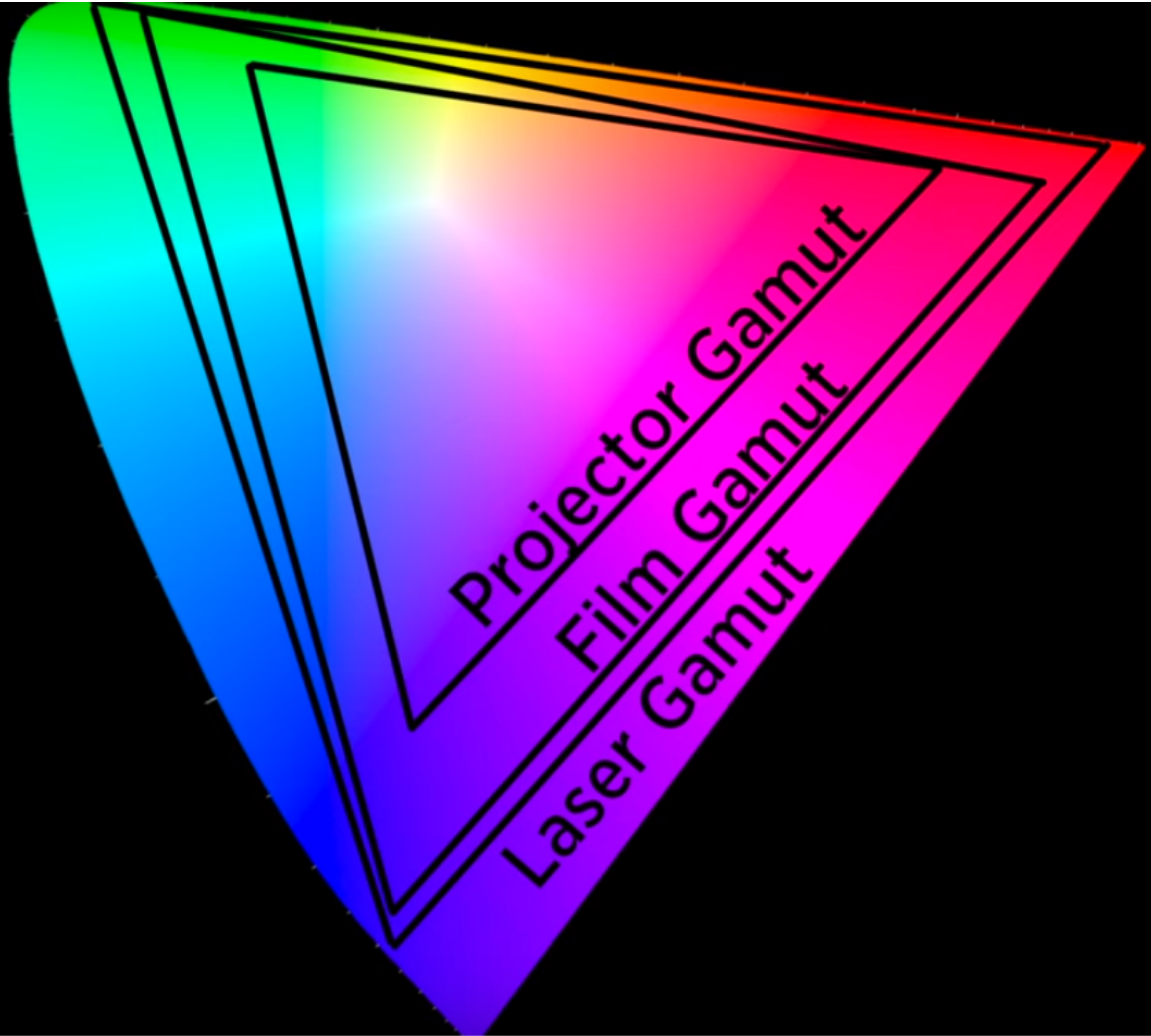
[http://dot-color.com/2012/08/14/color-space-confusion/]

Why this strange shape to represent all colors?

Reason:
PERCEPTUAL
UNIFORMITY



[http://dot-color.com/2012/08/14/color-space-confusion/]



Projector Gamut
Film Gamut
Laser Gamut

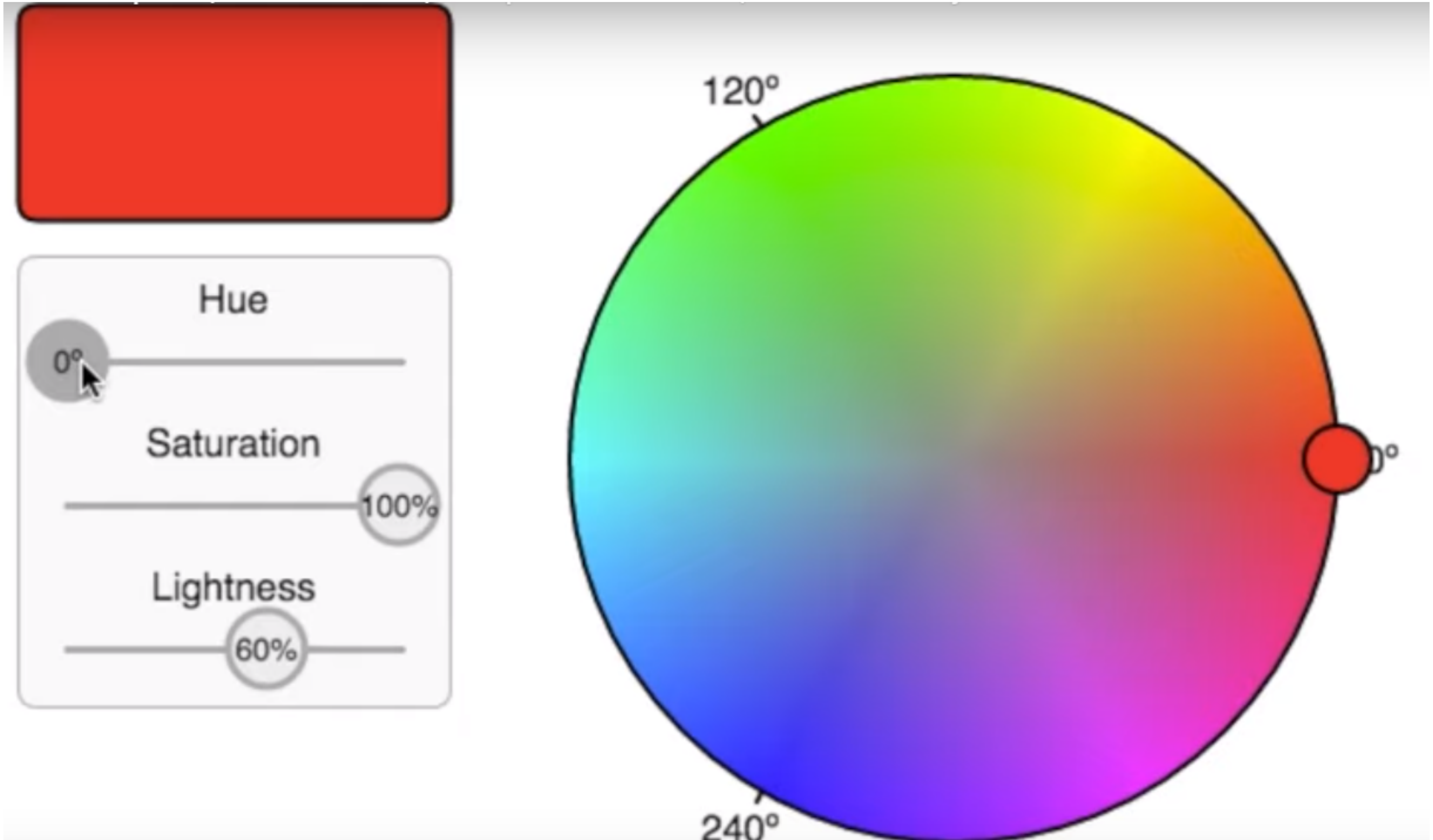
Color Spaces and Gamuts

- Color space: the organization of all colors in space
  - Often human-specific, what we can see (e.g. CIELAB)
- Color gamut: a subset of colors
  - Defined by corners on in the color space
  - What can be produced on a monitor (e.g. using RGB)
  - What can be produced on a printer (e.g. using CMYK)
  - The gamut of your monitor != the gamut of someone else's != the gamut of a printer

Color Models

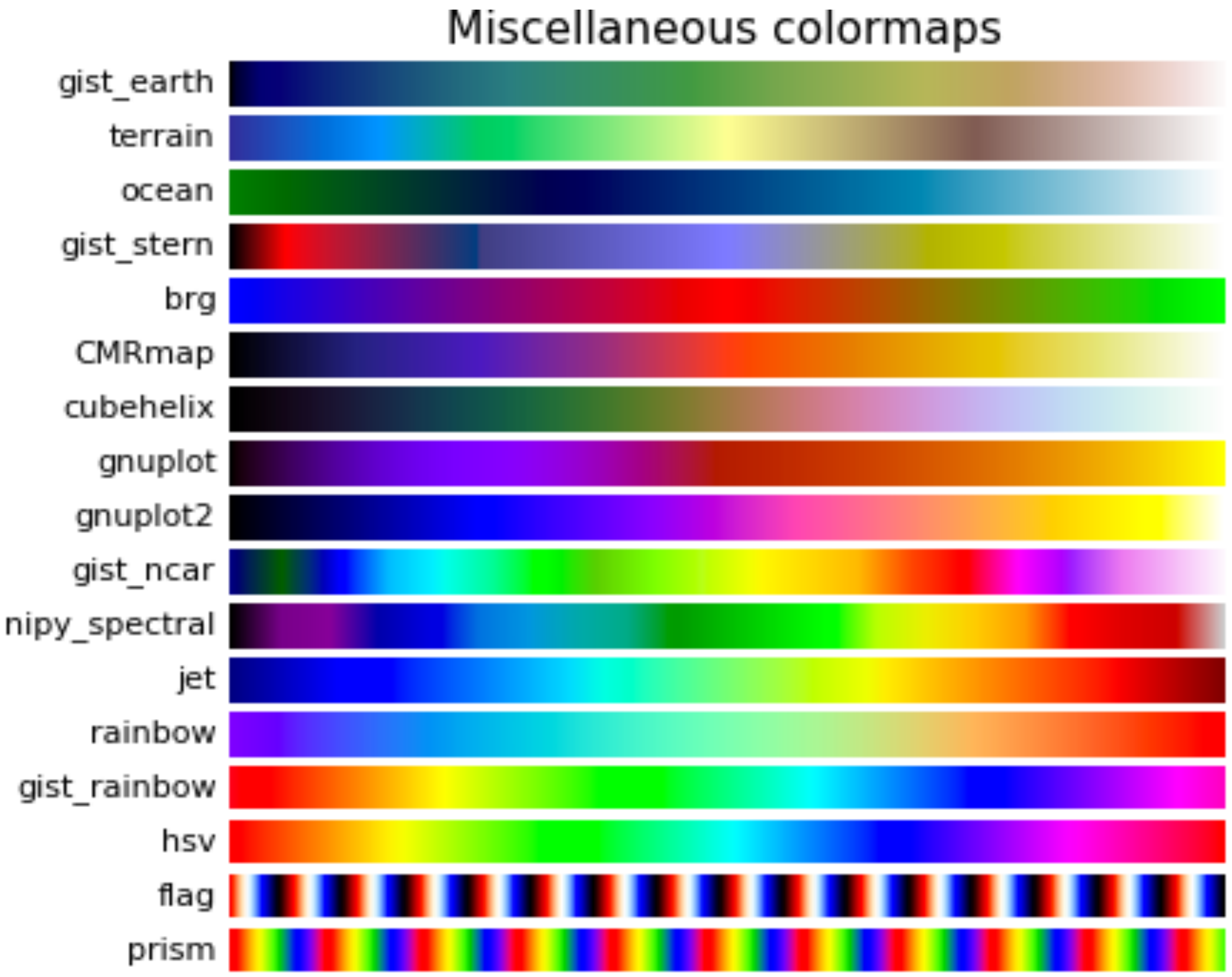
- A color model is a representation of color using some basis
- RGB uses three numbers (red, blue, green) to represent color
- Color space ~ color model, but there can be many color models used in the same color space (e.g. OGV)
- Hue-Saturation-Lightness (HSL) is more intuitive and useful
  - Hue captures pure colors
  - Saturation captures the amount of white mixed with the color
  - Lightness captures the amount of black mixed with a color
  - HSL color pickers are often circular
- Hue-Saturation-Value (HSV) is similar (swap black with gray for the final value), linearly related

HSL Model



Color Maps

Color Map = mapping between color and value



http://matplotlib.org/mpl_examples/color/colormaps_reference_05.png

Rainbow Color Map

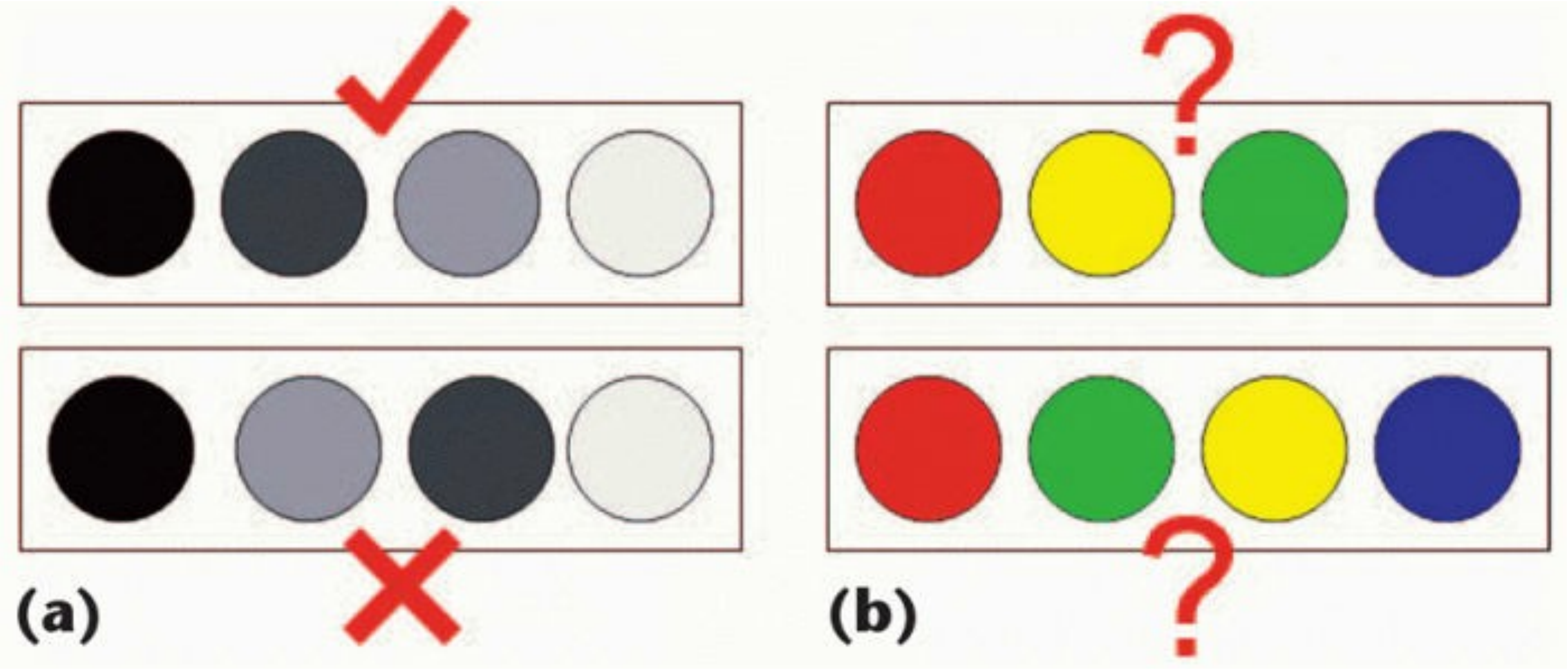
Why this color map is a poor choice...

- No perceptual ordering (confusing)
- No luminance 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)

Rainbow Color Map

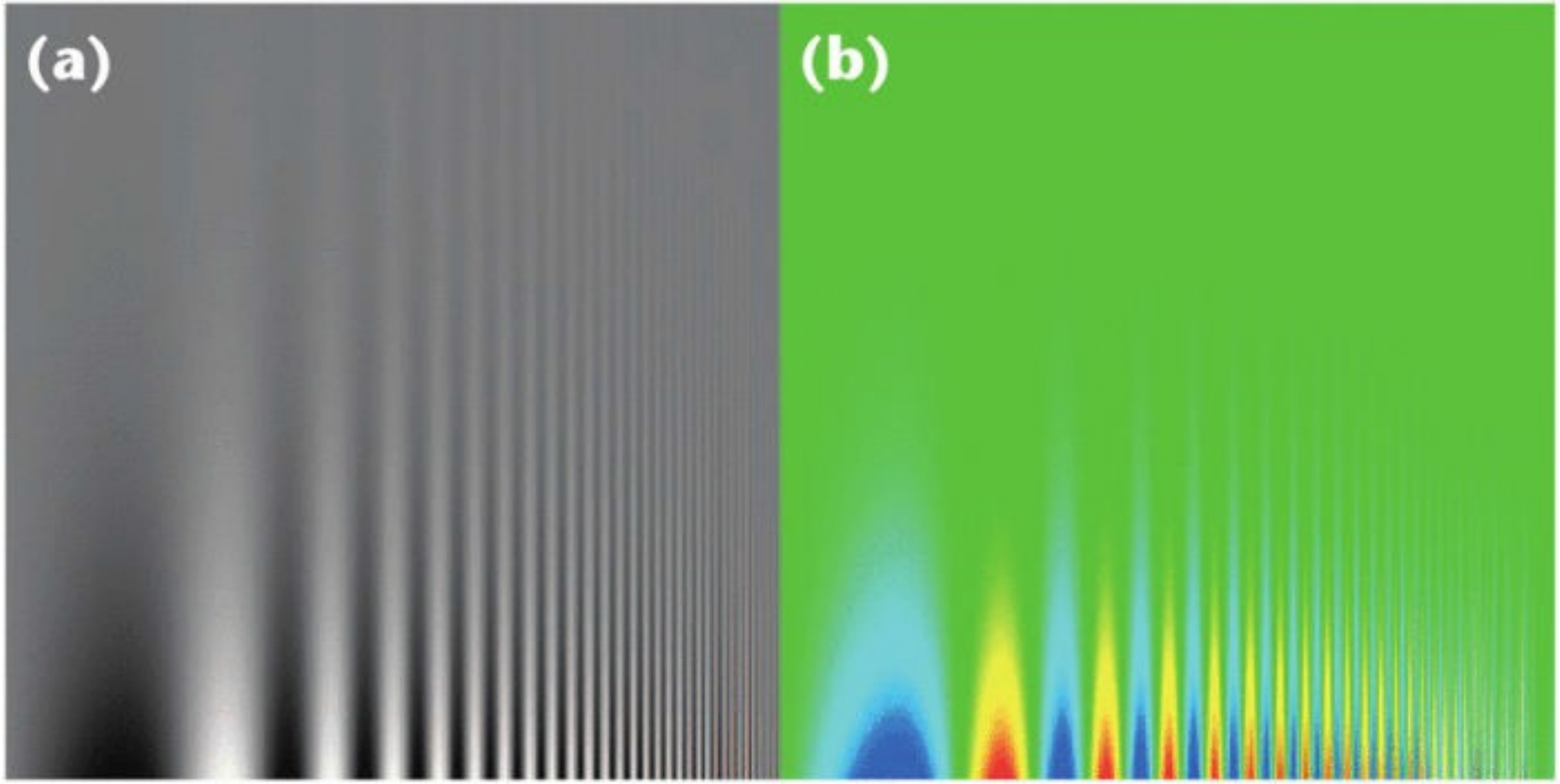
- No perceptual ordering (confusing)



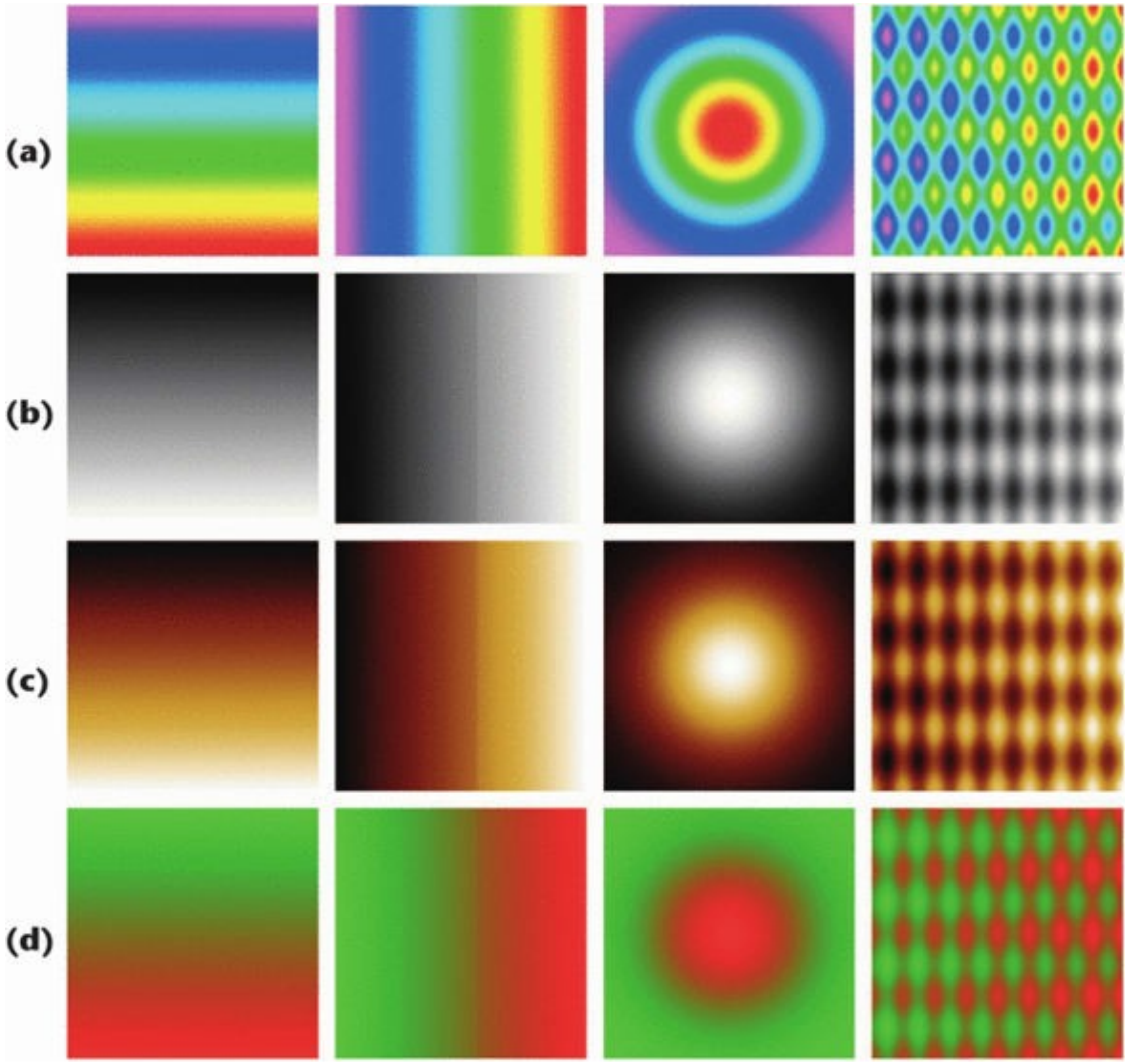
Borland & Russell (2007)

Rainbow Color Map

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

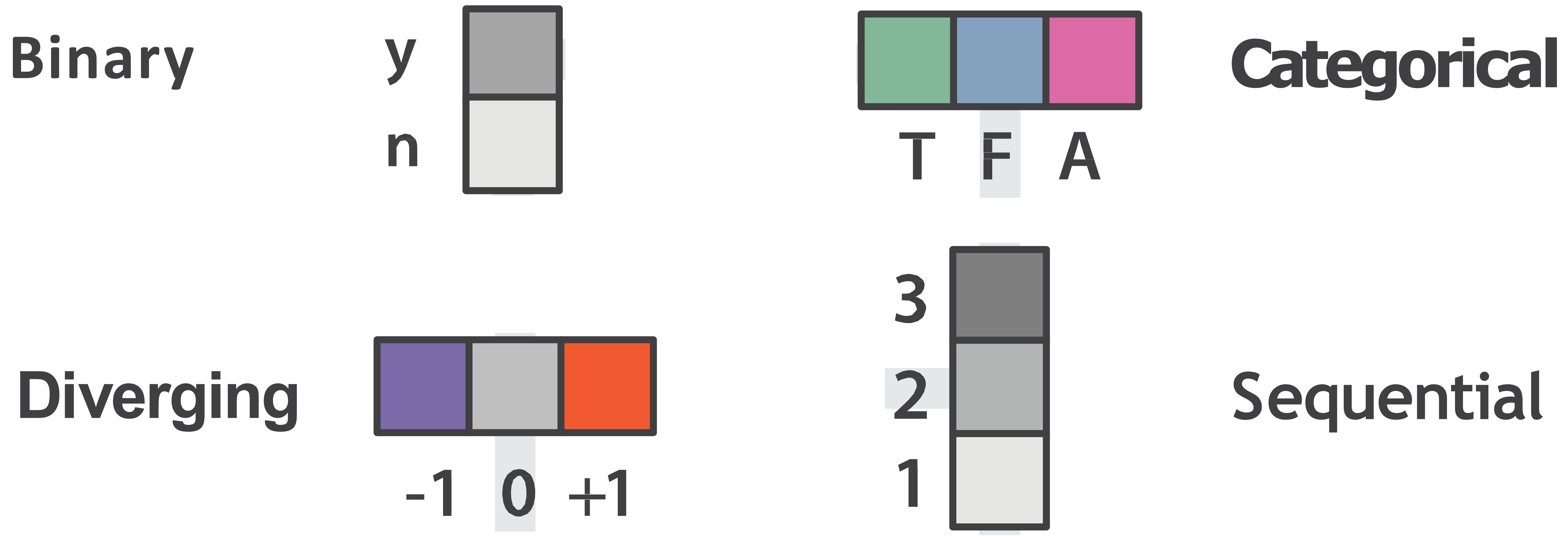


Artifacts from Rainbow Colormaps



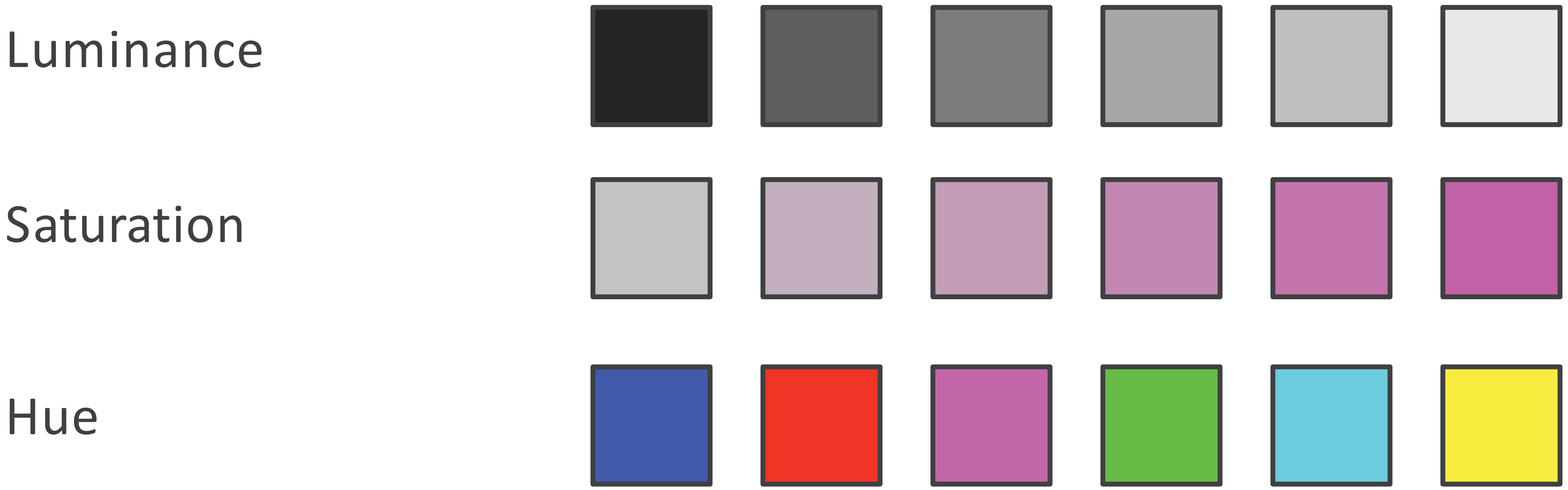
Colormap

- A colormap specifies a mapping between colors and data values
- Colormap should follow the expressiveness principle
- Types of colormaps:



Categorical vs. Ordered

- Hue has no implicit ordering: use for categorical data
- Saturation and luminance do: use for ordered data



[Munzner (ill. Maguire), 2014]

Color Maps

THREE MAIN TYPES:

Categorical

Does not imply magnitude differences (categorical/ nominal data)

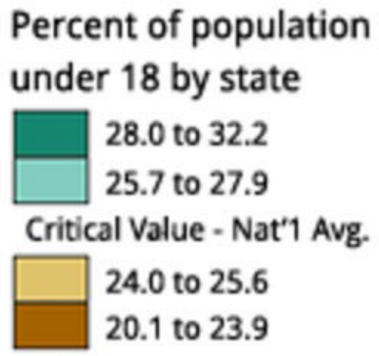
Distinct hues with similar emphasis

Sequential

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

Luminosity 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, Cynthia A. 1994. Color use guidelines for mapping and visualization. Chapter 7 (pp. 123-147) in Visualization in Modern Cartography

Color Maps

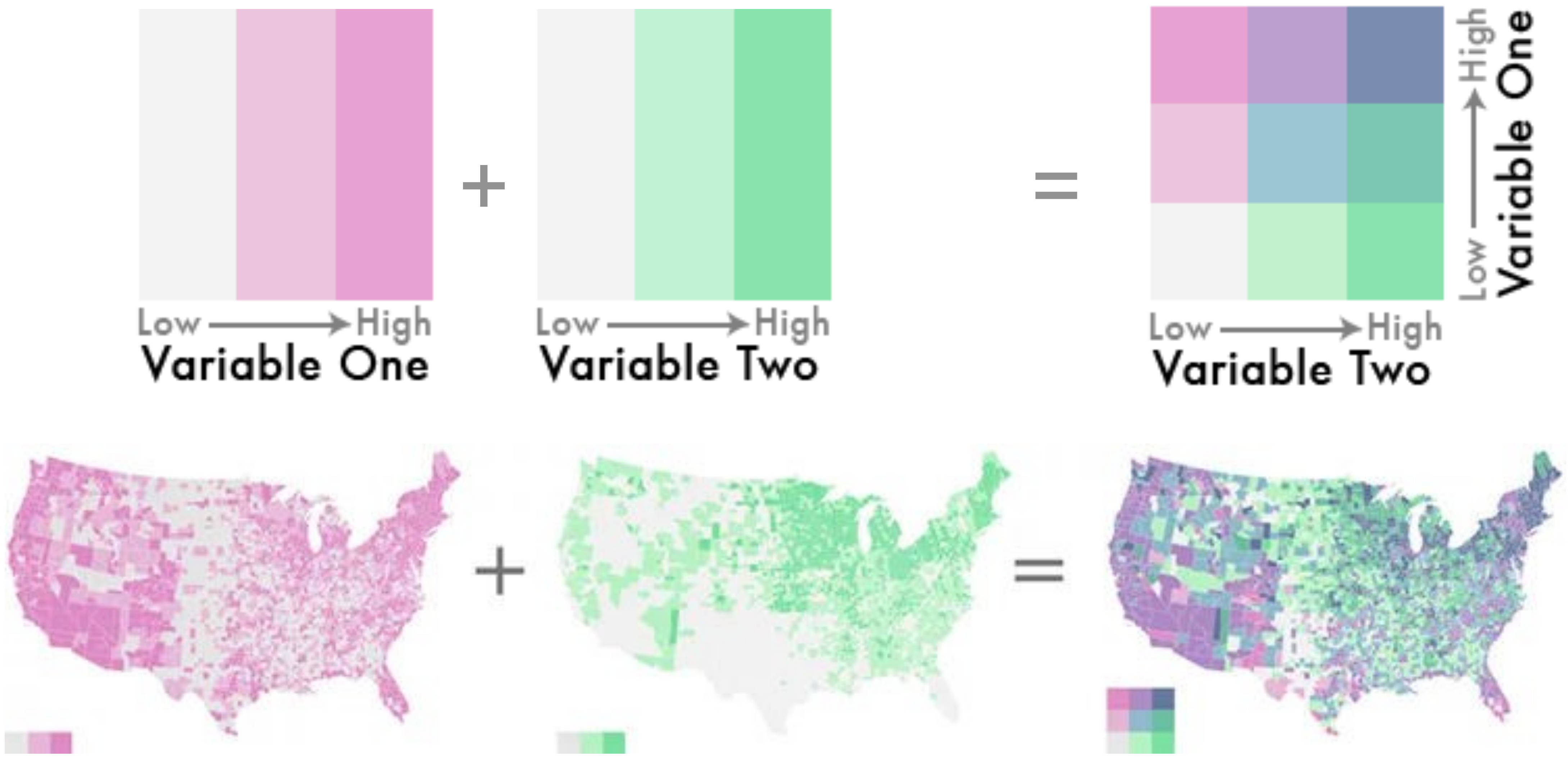
Also...

Bivariate

Displays two variables

Combination of two sequential color schemes

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

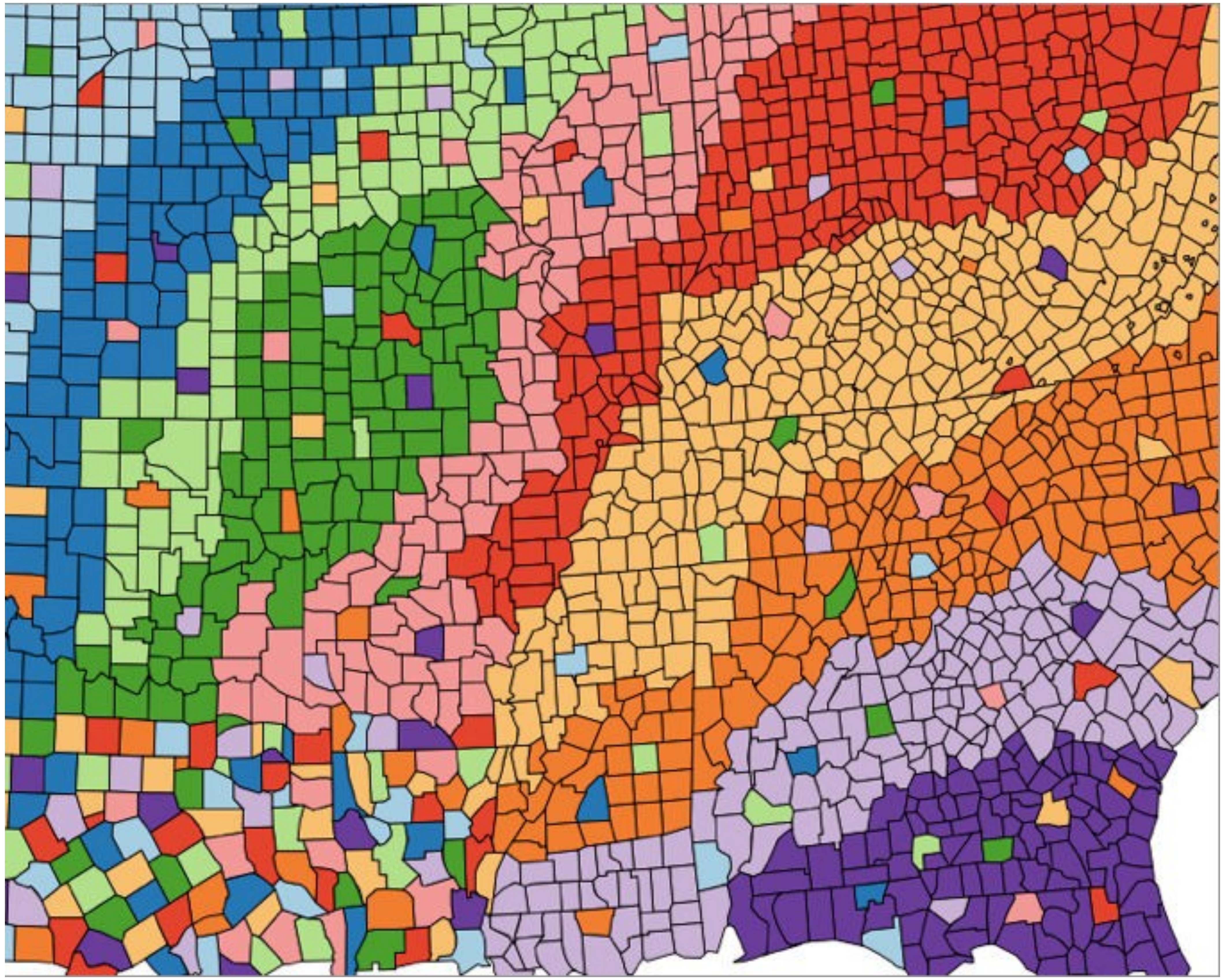


http://www.joshuastevens.net/cartography/make-a-bivariate-choropleth-map/

Categorical Colormap Guidelines

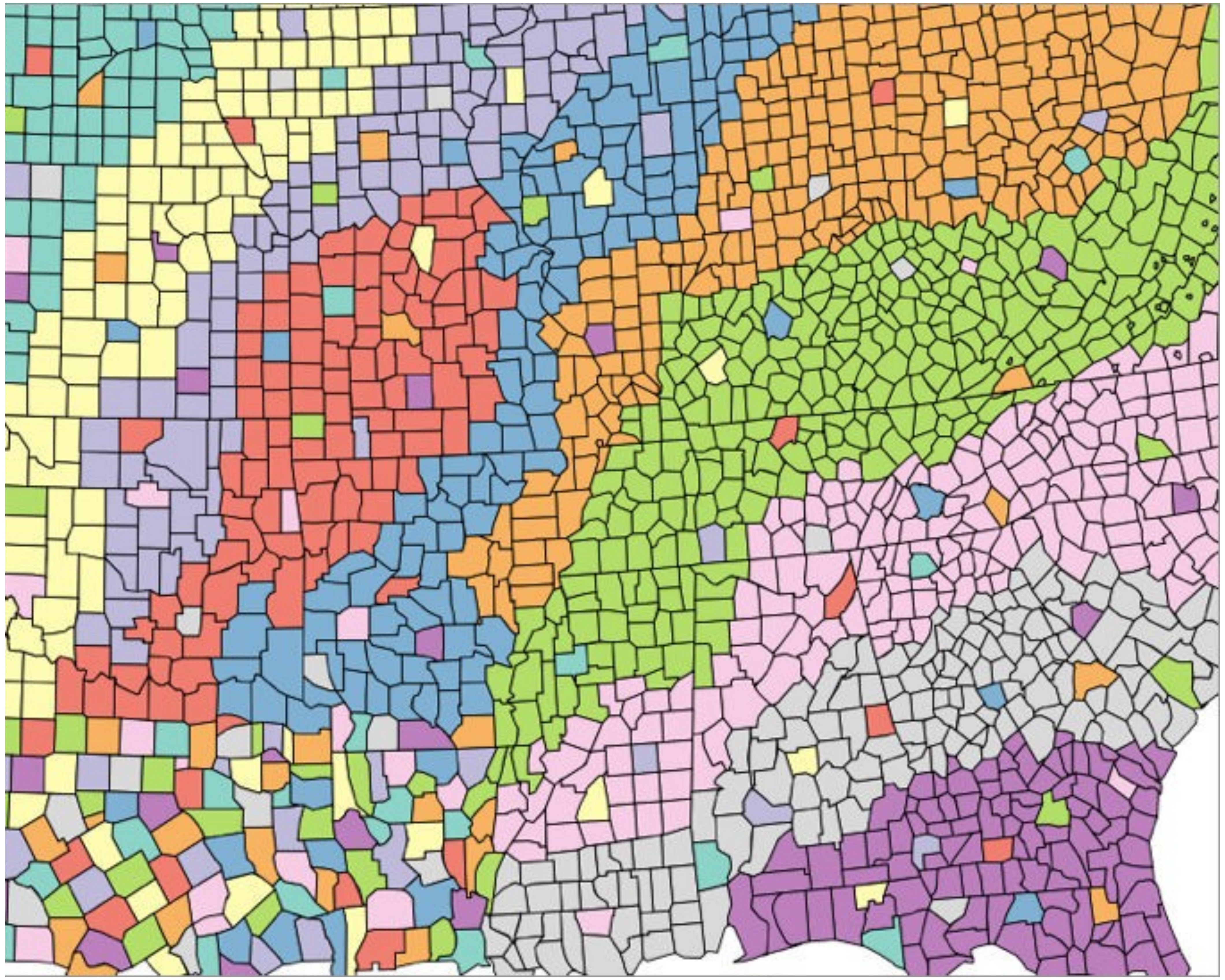
- Don't use too many colors (~12)
- Remember your background has a color, too
- Nameable colors help
- Be aware of luminance (e.g. difference between blue and yellow)
- Think about other marks you might wish to use in the visualization

Categorical Colormaps



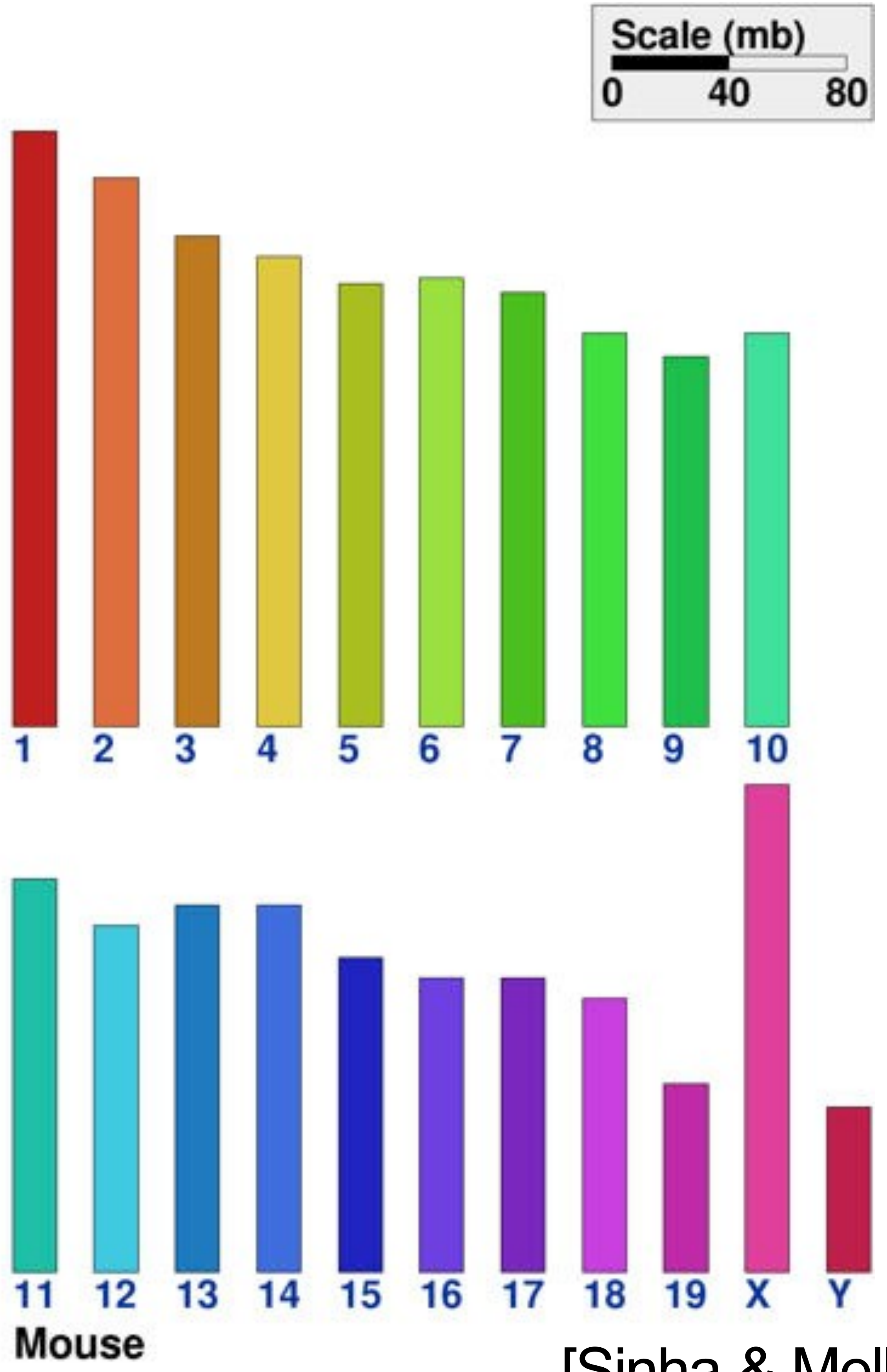
[colorbrewer2.org]

Categorical Colormaps



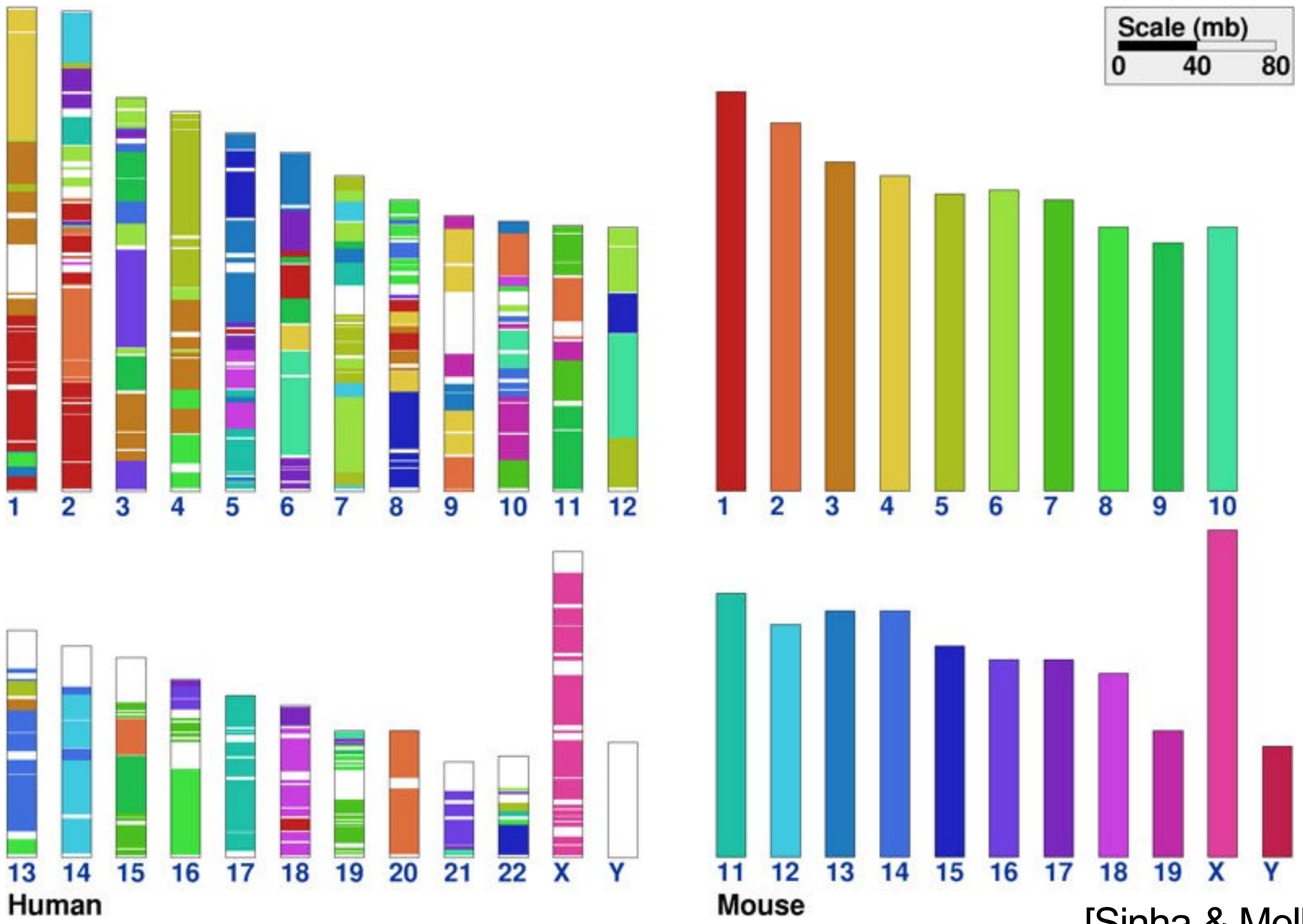
[colorbrewer2.org]

Number of distinguishable colors?



[Sinha & Meller, 2007]

Number of distinguishable colors?



[Sinha & Meller, 2007]

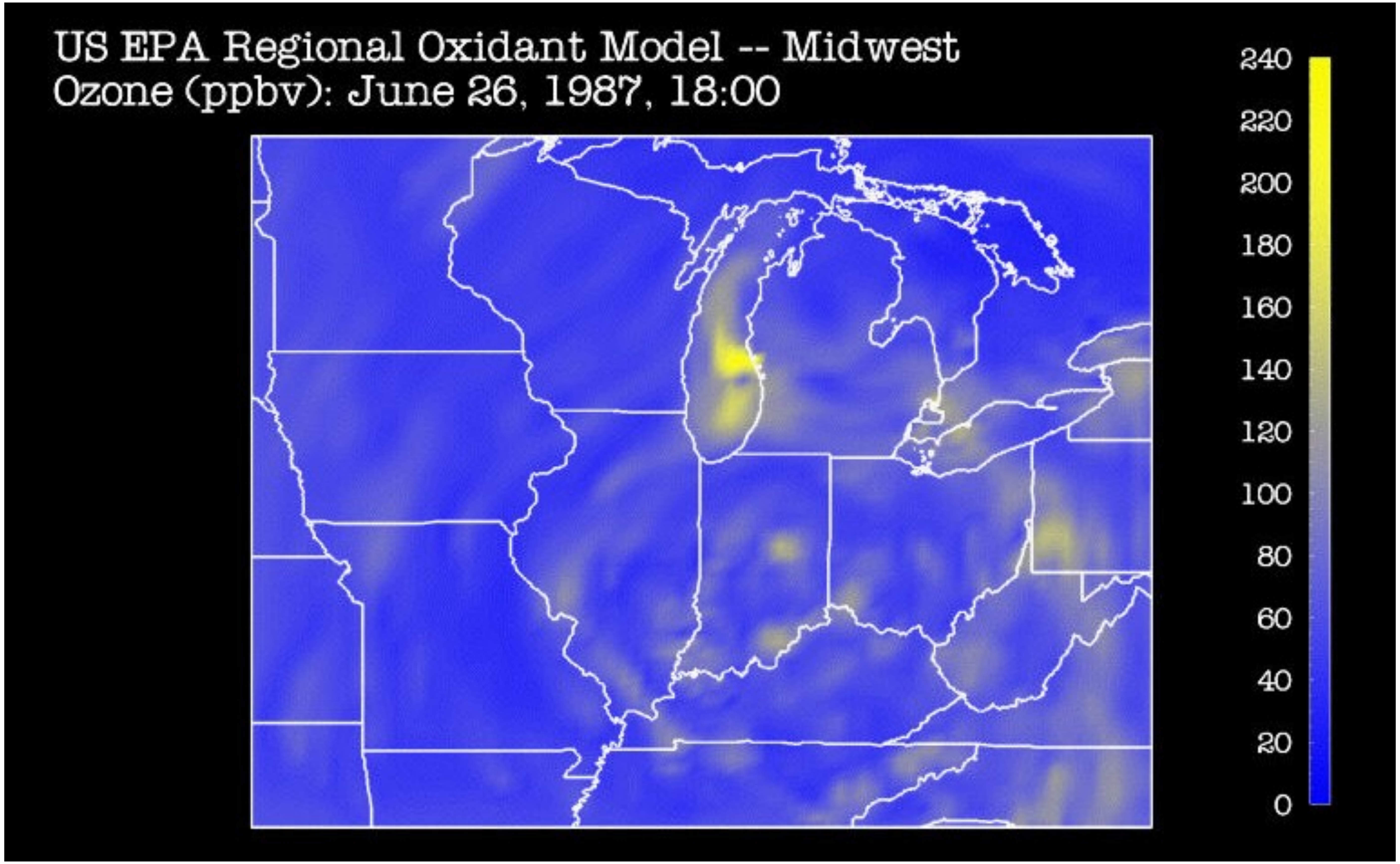
Discriminability

- Often, fewer colors are better
- Don't let viewers combine colors because they can't tell the difference
- Make the combinations yourself
- Also, can use the "Other" category to reduce the number of colors

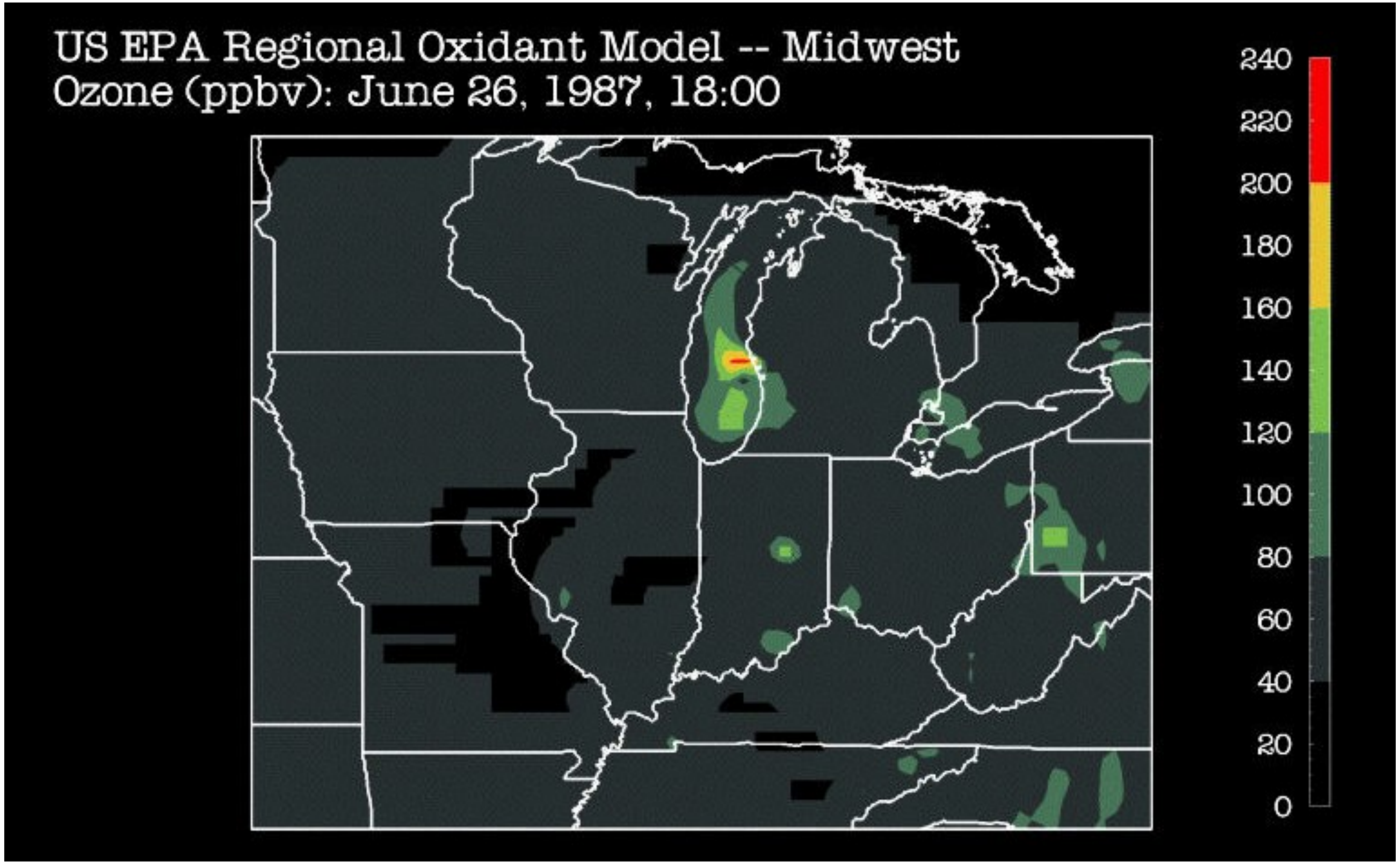
Ordered Colormaps

- Used for ordinal or quantitative attributes
- [0, N]: Sequential
- [-N, 0, N]: Diverging (has some meaningful midpoint)
- Can use hue, saturation, and luminance
- Remember hue is not a magnitude channel so be careful
- Can be continuous (smooth) or segmented (sharp boundaries)
  - Segmented matches with ordinal attributes
  - Can be used with quantitative data, too.

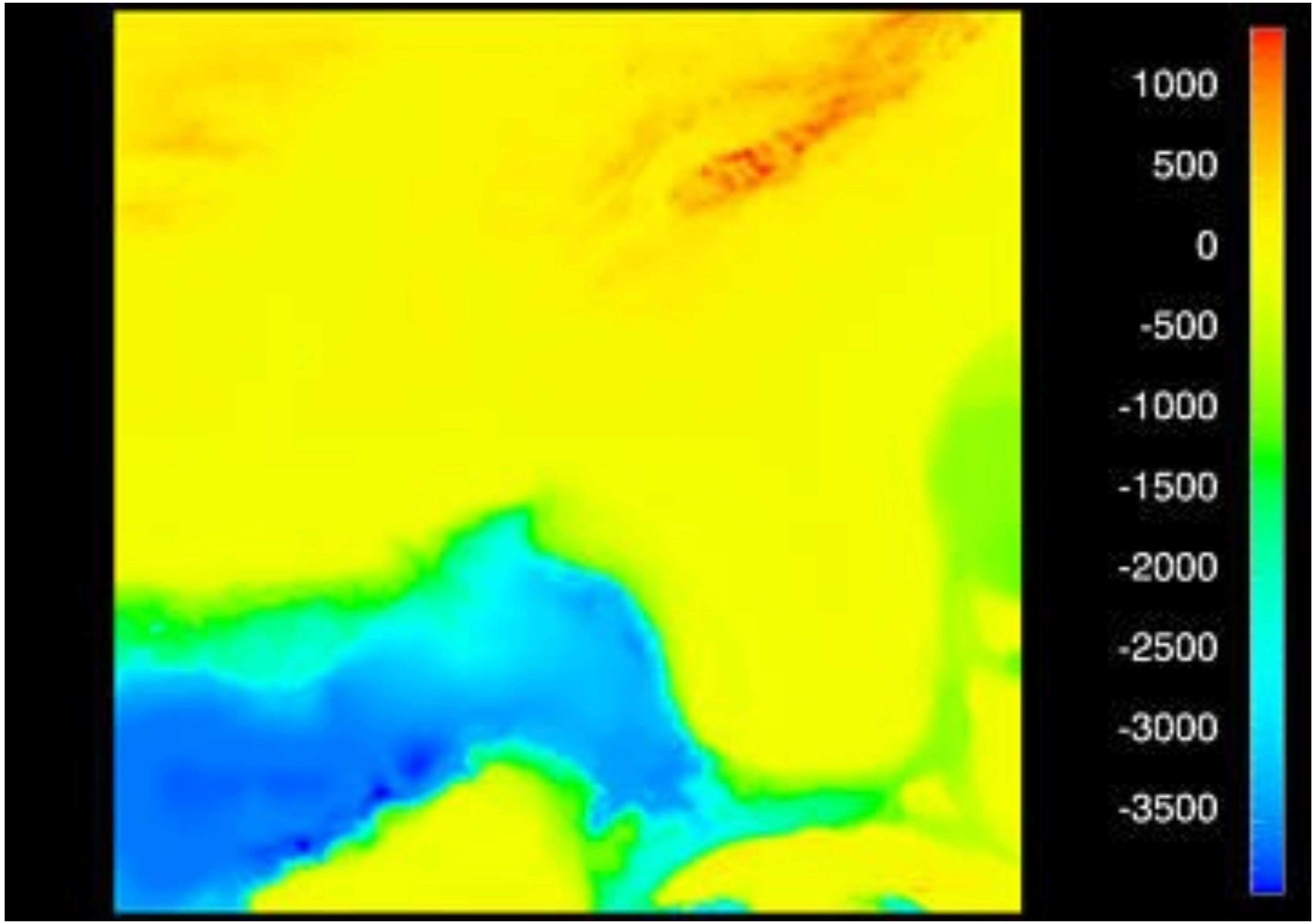
Continuous Colormap



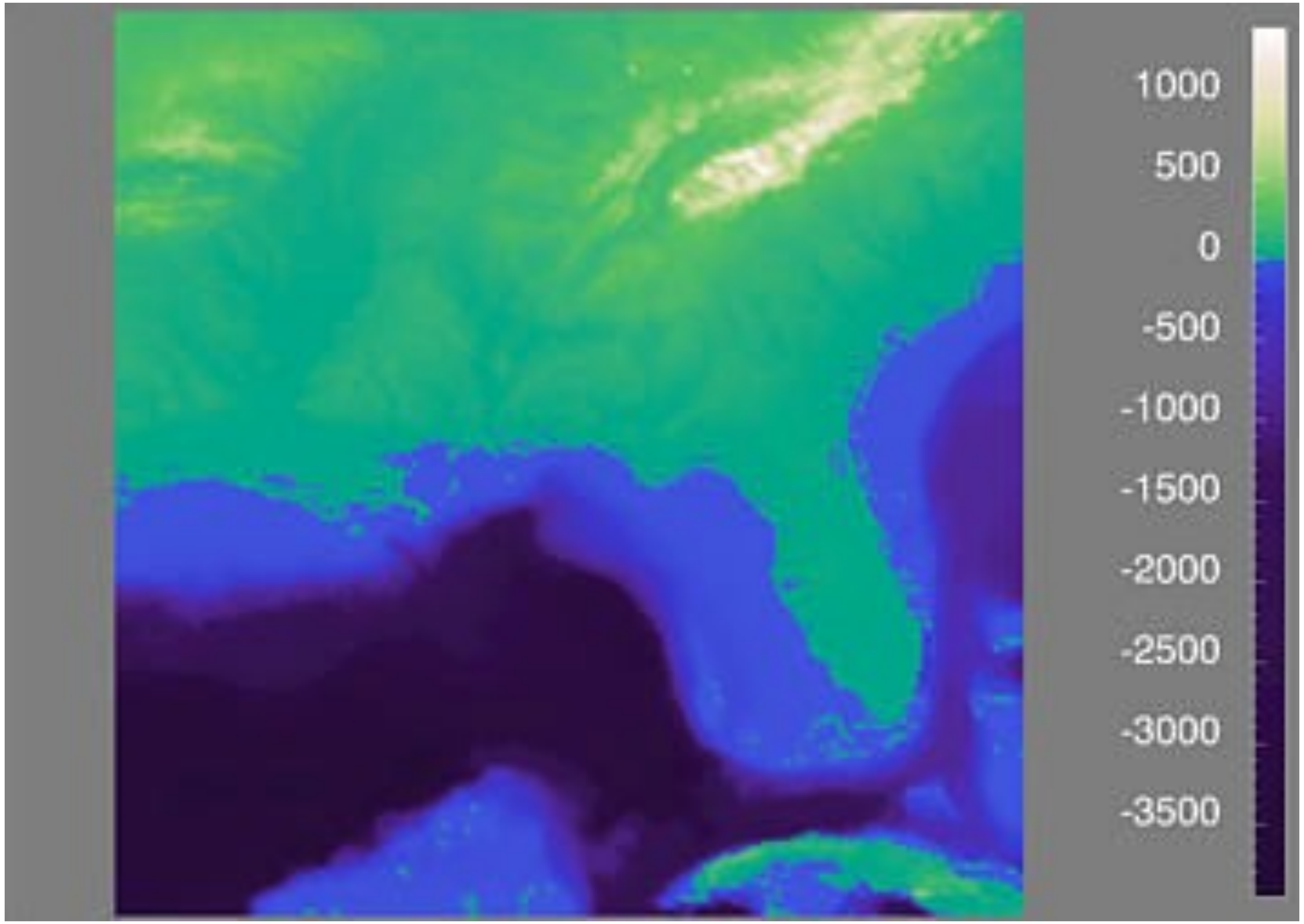
Sequential Colormap



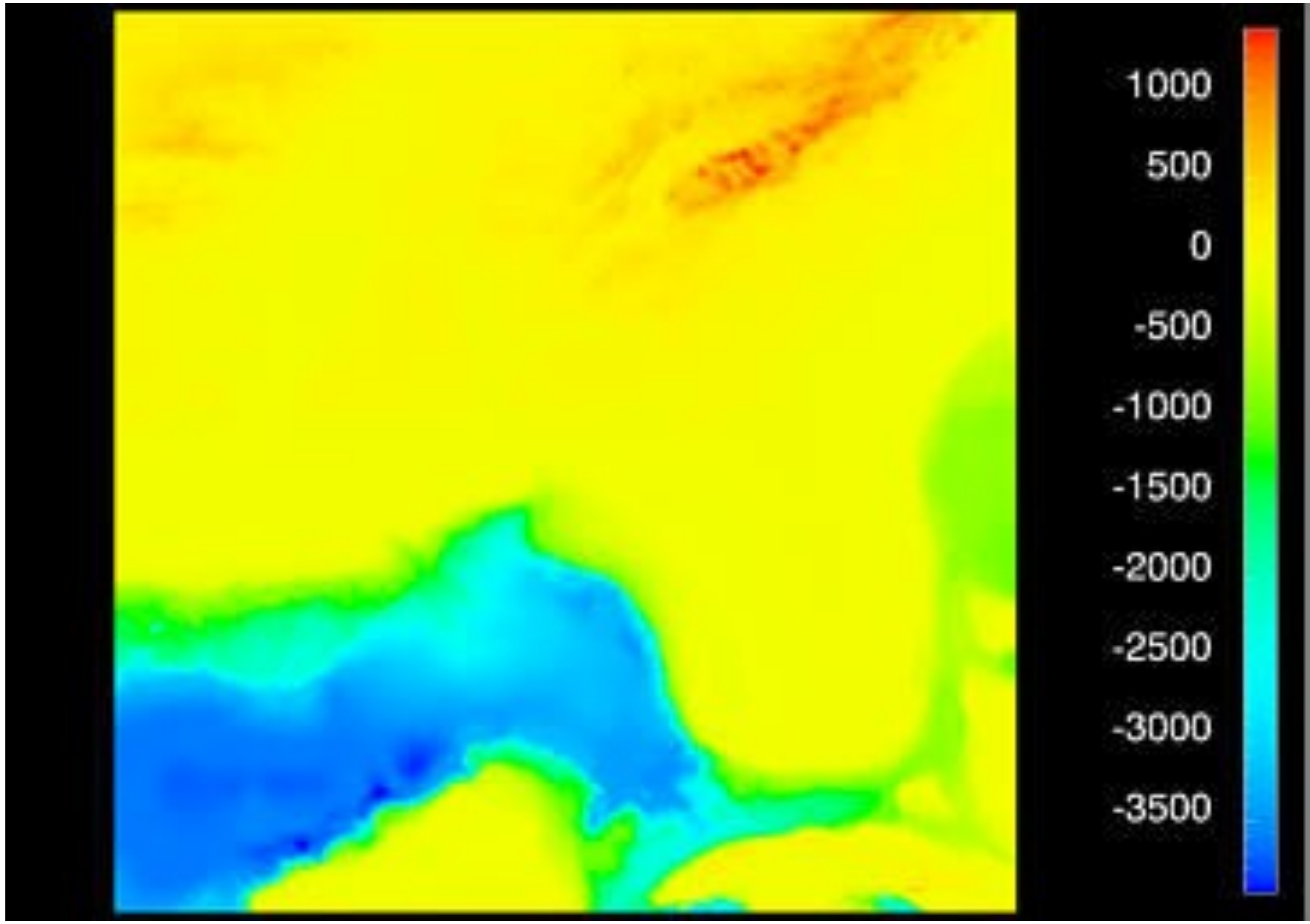
Color Maps



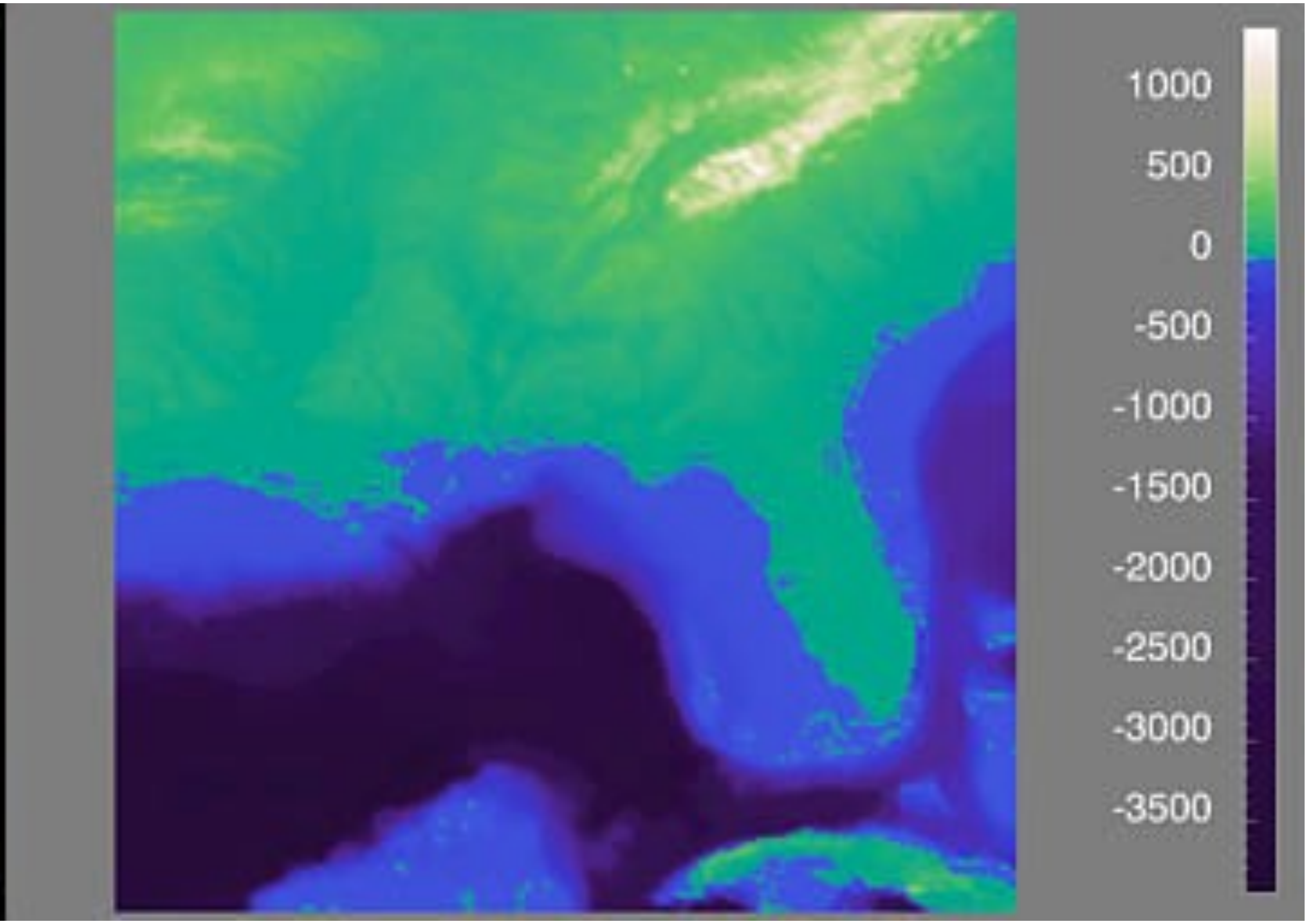
Color Maps



Color Maps



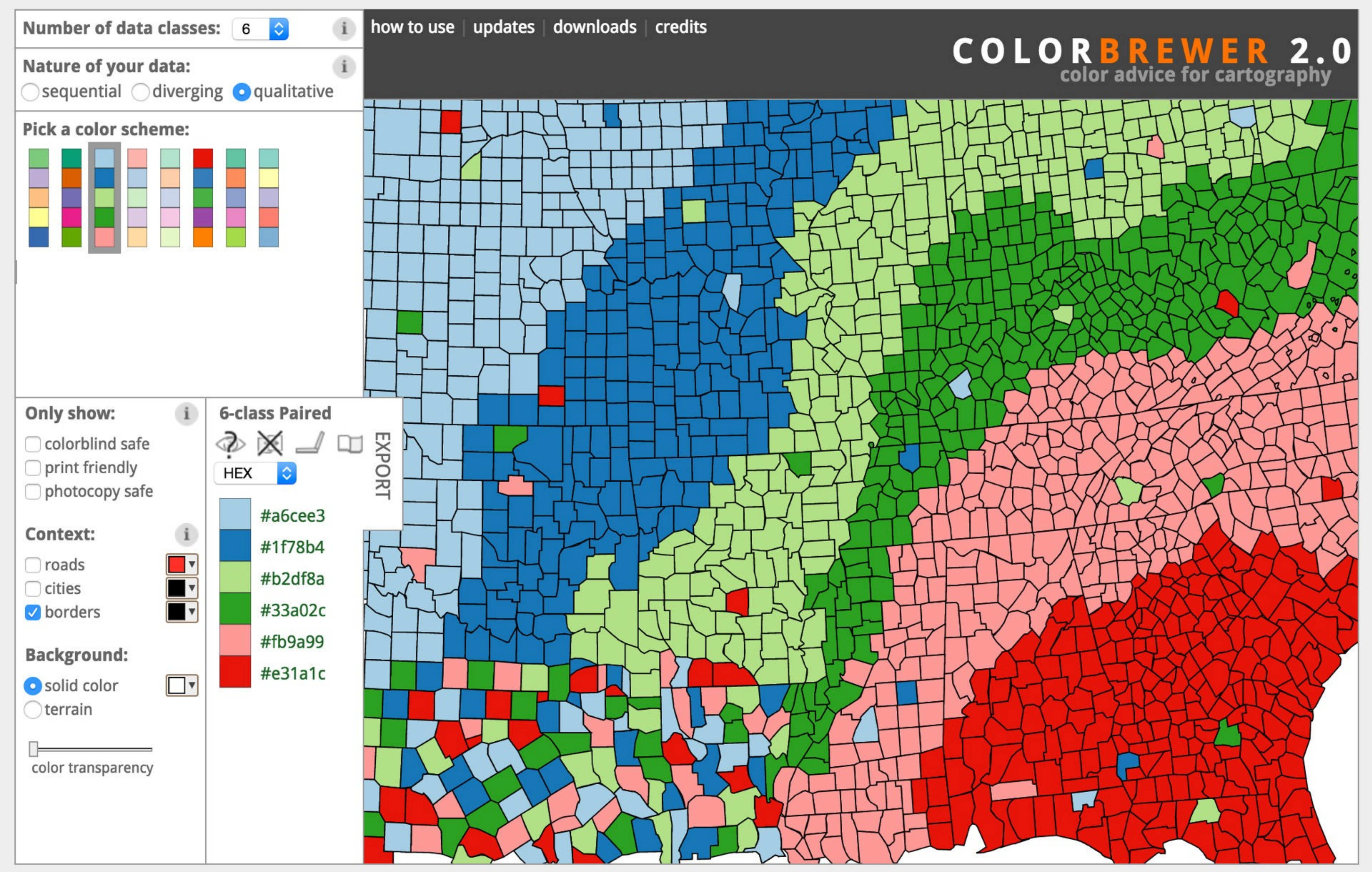
Sequential (wrong!)
Sequential rainbow (wrong!)



Diverging

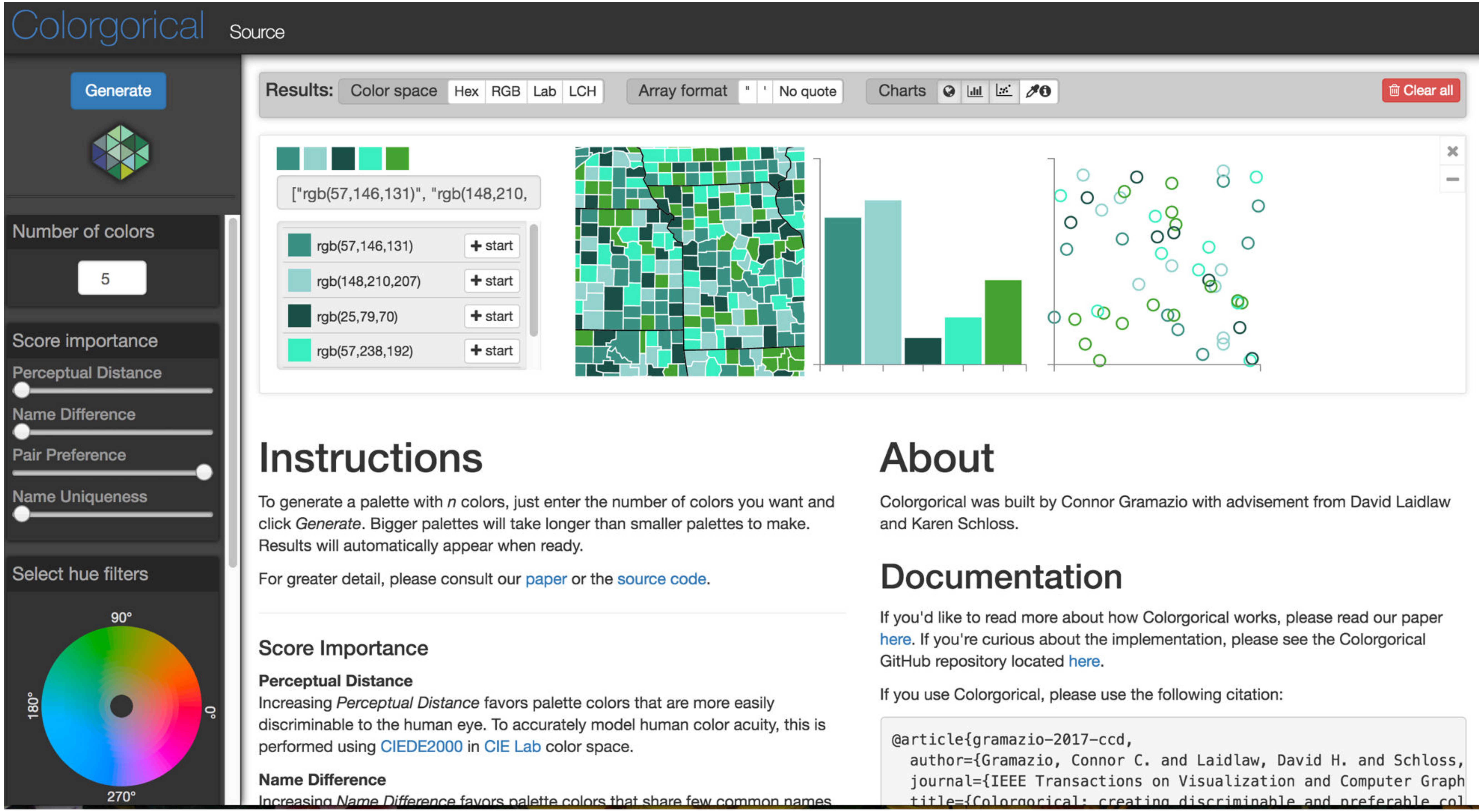
https://www.research.ibm.com/people/l/lloydt/color/color.HTM

Color Brewer



http://colorbrewer2.org/

Colorgorical



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

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 for scales

Don’t forget aesthetics!

Color Design Rules

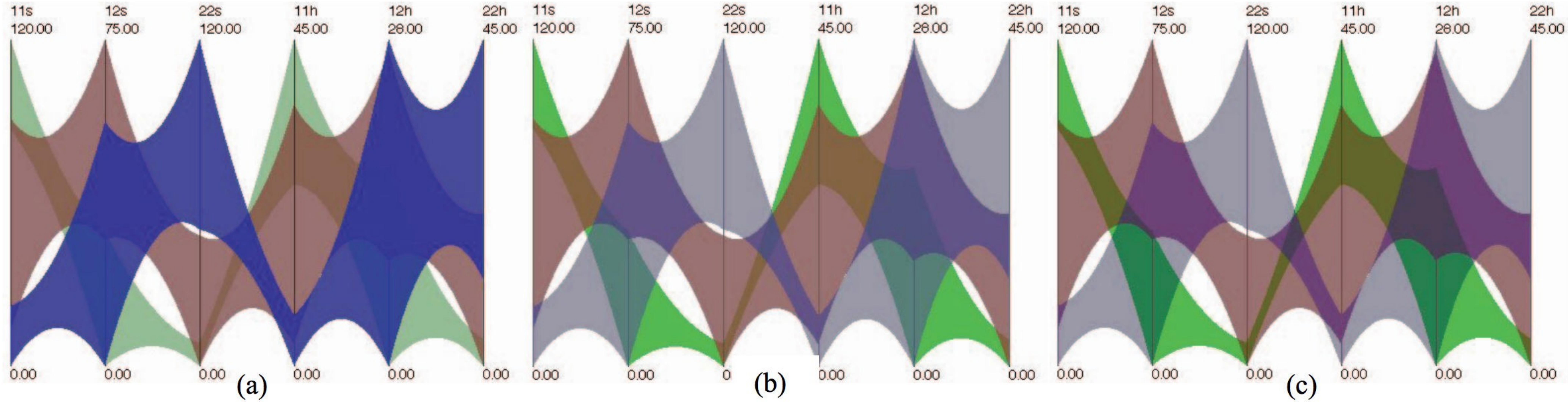


Fig. 12: Illustrative visualizations of a six-dimensional dataset using illustrative parallel coordinates. (a) Ideal visualization with appropriate weightings and color choices, and the use of the local model in overlapping areas. (b) Improper weightings are employed. The blue cluster no longer seems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

Wang, et al., "Color Design for Illustrative Visualization" (2008)

Color Design Rules

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 lightness.

R5: The low end lightness 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 lightness 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 lightness (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., "Color Design for Illustrative Visualization" (2008)

Color Design Rules

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

Weber's Law

Our ability to detect a difference between two objects with a certain attribute is related to the percent difference in the attribute, not the absolute difference.

$$\frac{\Delta S}{S} = \text{constant}$$

where S is the initial stimulus and ΔS the difference between stimuli ("**just noticeable difference**").

*Ratios are more important than magnitude differences.

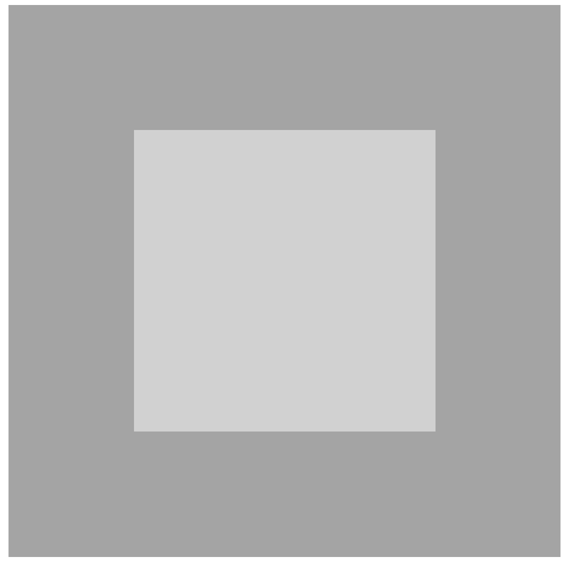
Color Design Rules

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

Weber's Law

Our ability to detect a difference between two objects with a certain attribute is related to the percent difference in the attribute, not the absolute difference.

$$\frac{\textit{Just-noticeable Difference}}{\textit{Background Intensity}} \qquad \frac{\Delta S}{S} = \text{constant} \quad \sim 1\%$$



where S is the initial stimulus and ΔS the difference between stimuli ("**just noticeable difference**").

*Ratios are more important than magnitude differences.

Color Design Rules

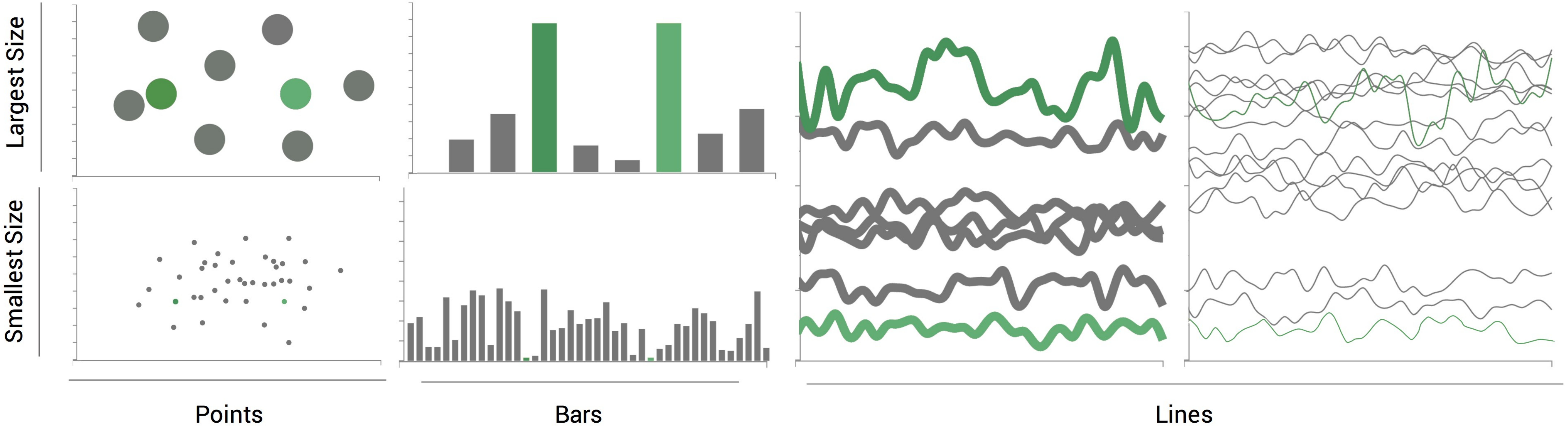
R5: The low end lightness steps should be very small, while the high end requires larger steps (Weber's Law).

Weber's Law

We tend to perceive discrete steps in continuous variations in magnitude.

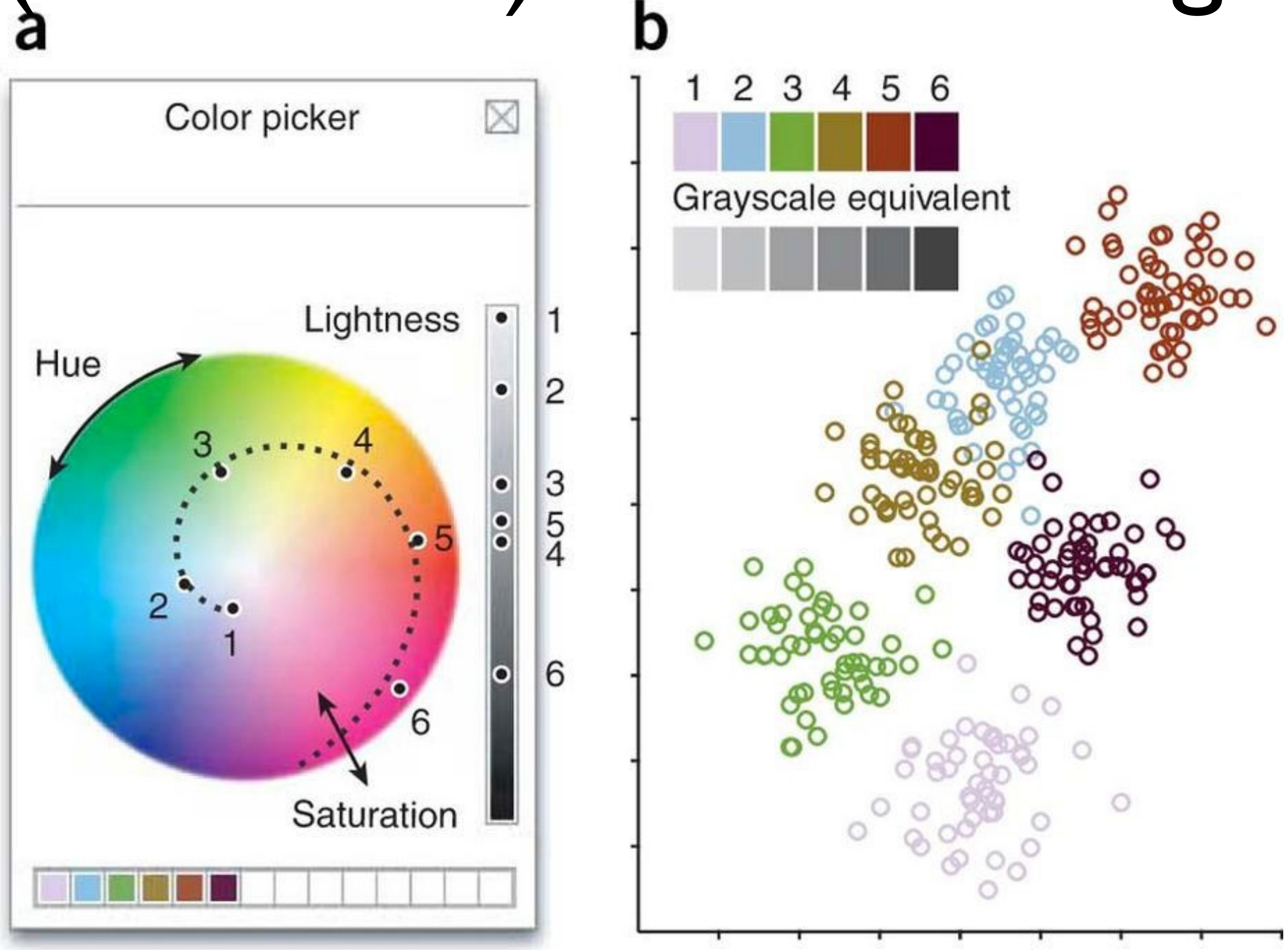
Color Design Rules

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



Szafir "Modeling Color Difference for Visualization Design" (2017)

More (Advanced) Color Picking Advice



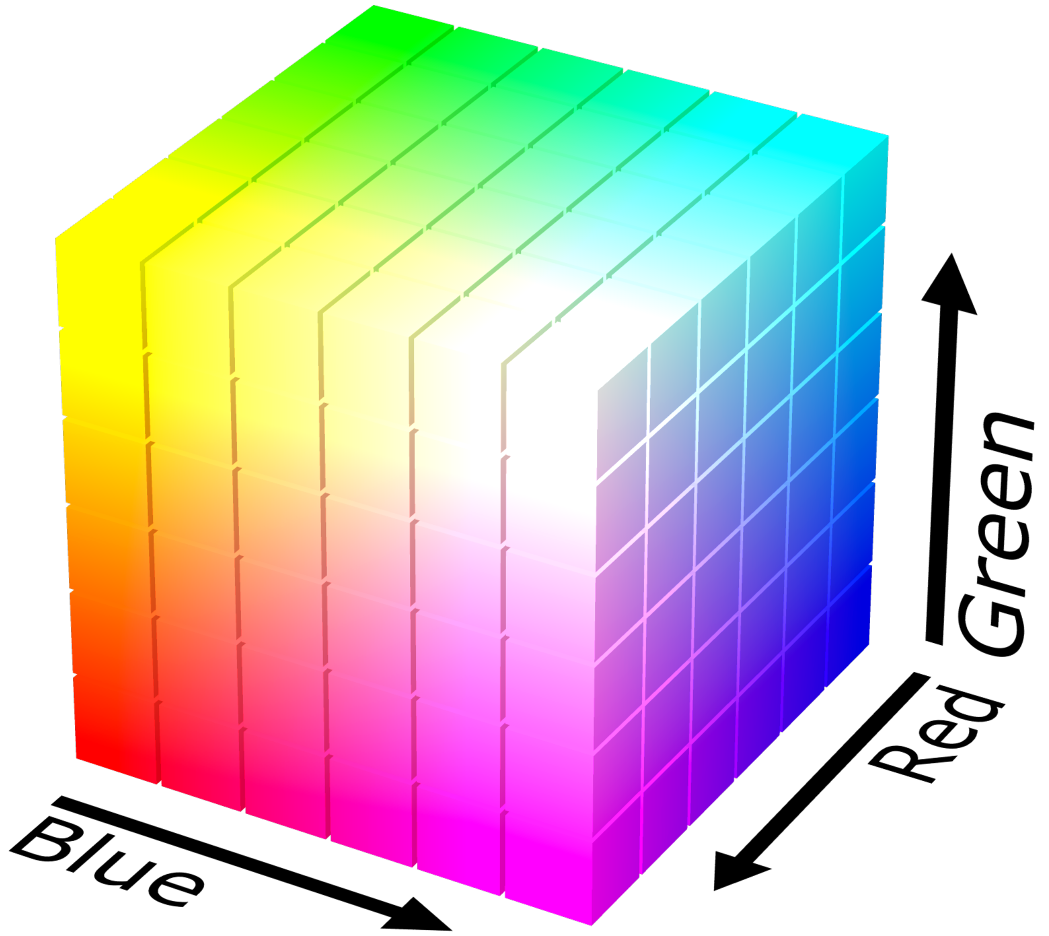
If picking colors and making your own palette, make sure to transition through and pick dimcriminatable colors that vary in hue and brightness.

Wong "Points of view: Color coding" (2010)

More (Advanced) Color Picking Advice

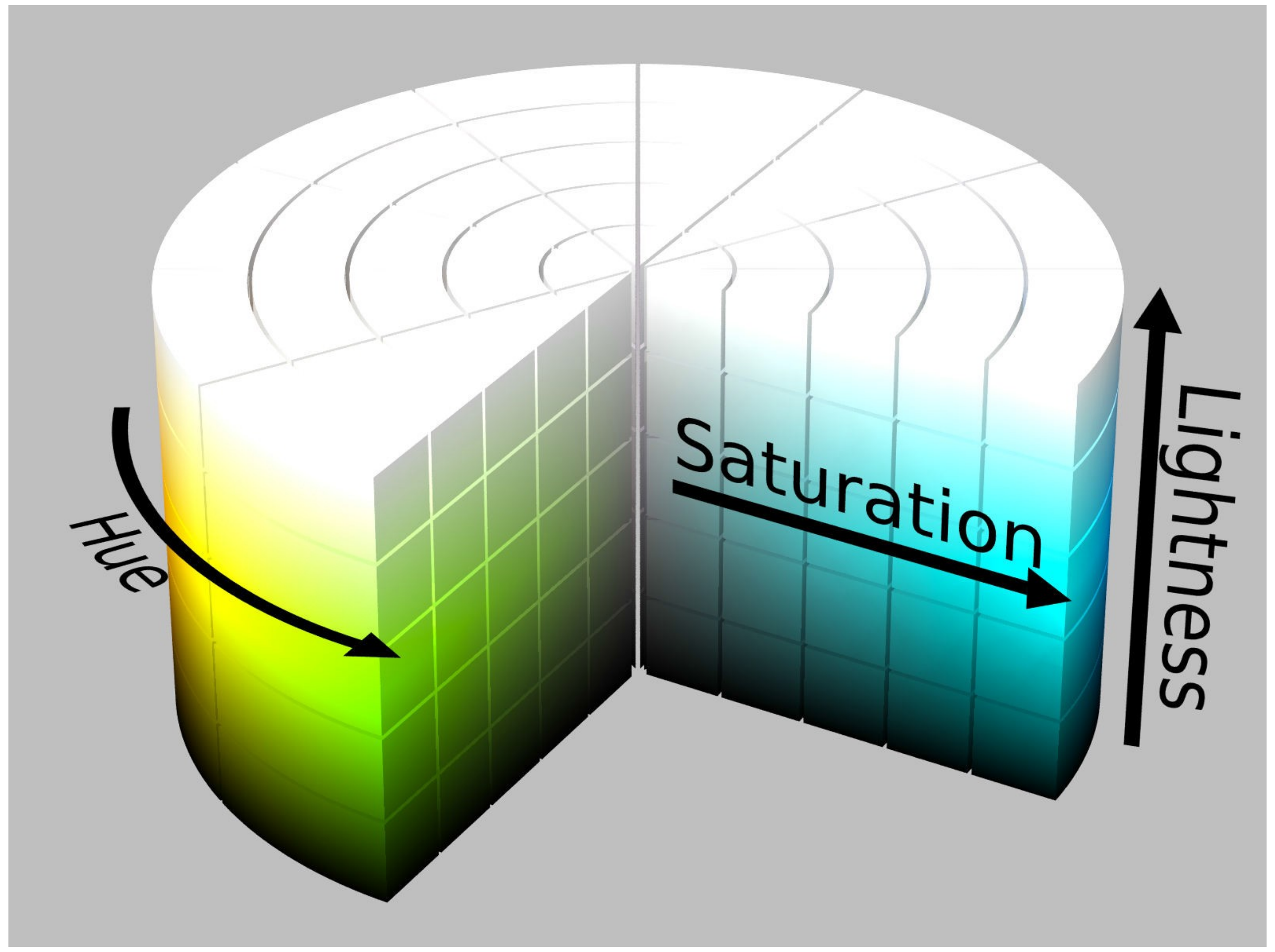
Color Spaces

RGB



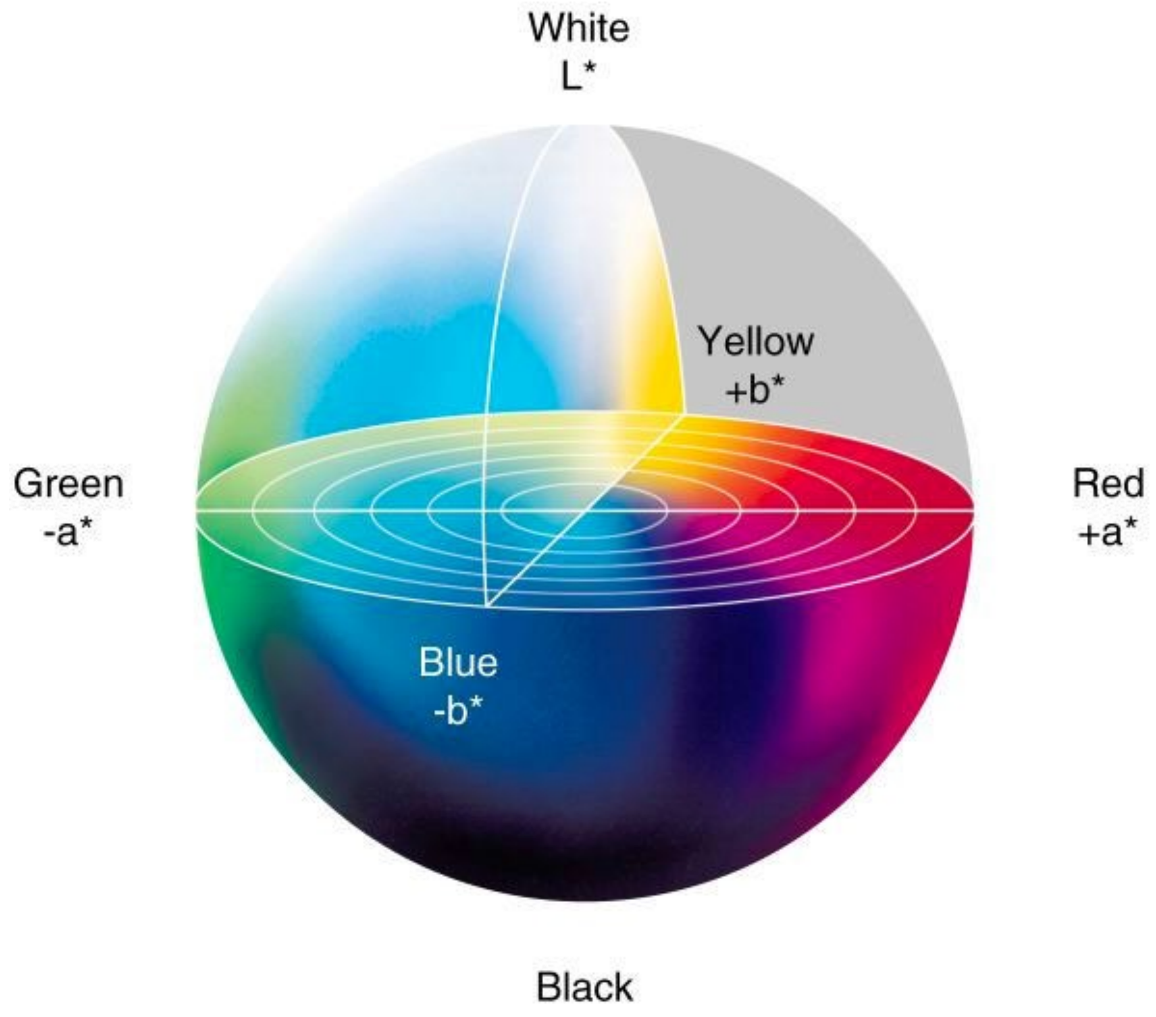
Great for monitor display
Not perceptually uniform

HSL



Intuitive: Hue, Saturation, Lightness
Not perceptually uniform
(HSV is a variation on HSL)

Lab



Perceptually Uniform!
(L approximates human perception of lightness)
a = R/G and b = Y/B channel

Perceptually uniform: a change of the same amount in a color value should produce a change of about the same visual importance

More (Advanced) Color Picking Advice

Luminance is tricky…