

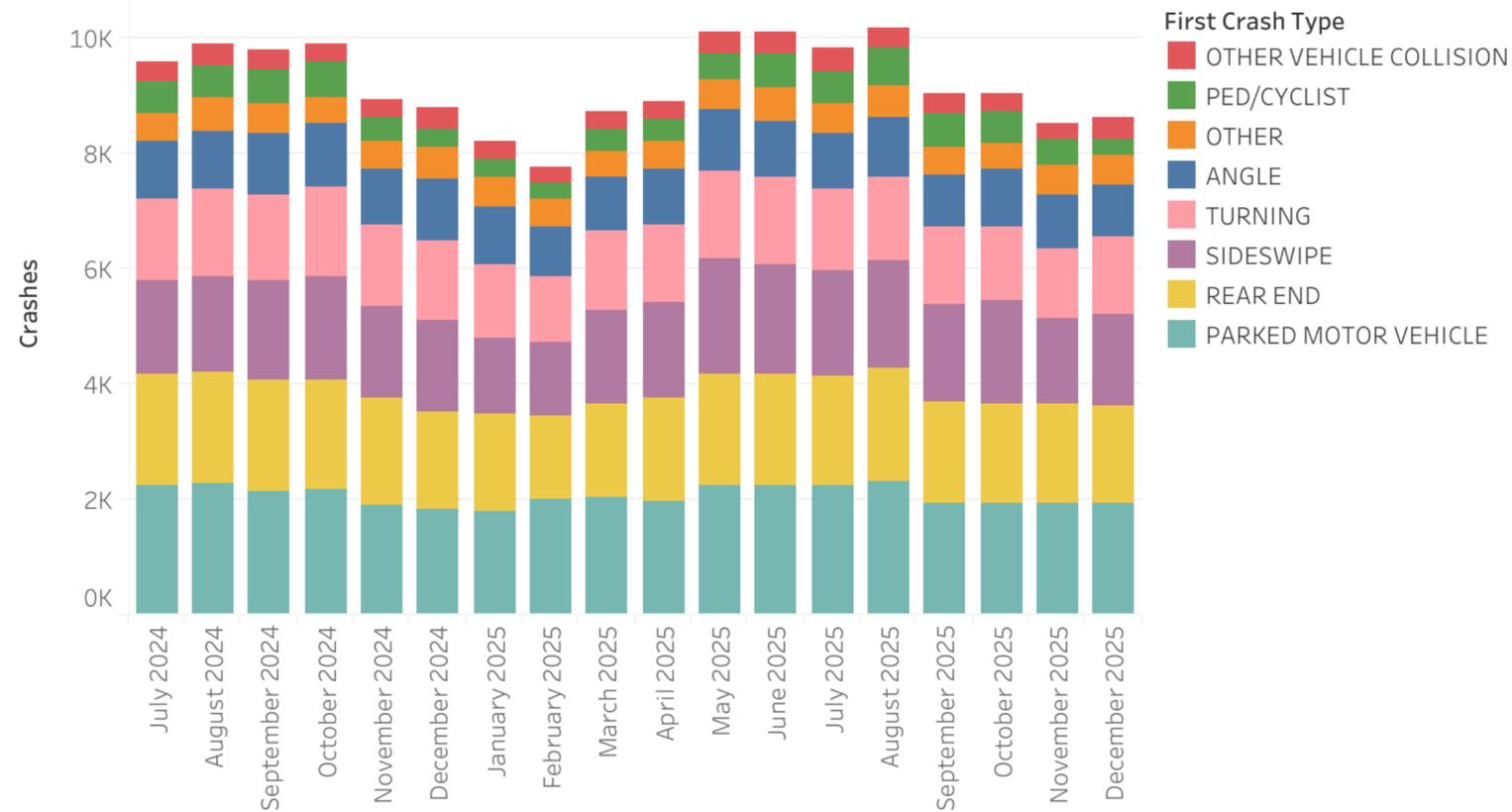
Data Visualization (CSCI 627/490)

Color & Colormaps

Dr. David Koop

Assignment 3

Chicago Traffic Crashes 2024-2025



- Due next week
- Chicago Traffic Crashes Data
- Create same stacked bar chart with
 - Tableau Public
 - Observable Plot
 - D3
- D3 Stacked Bar Chart:
 - Required for CSCI 627 students
 - Extra credit for CSCI 490 students

Courselets

- Educational resources for visualization using notebooks
- Reviewed charts over the last couple of classes, how do we construct them?
- How do we use visualization libraries, including those in other contexts like Python?
 - matplotlib: charts-matplotlib.ipynb
 - pyobsplot: charts-obsplot.ipynb

Midterm

- In-class, Wednesday, March 4, 12:30-1:45pm
- Only need writing utensil (+eraser)
- Format:
 - Multiple Choice
 - Free Response
- CSCI 627 students will have an extra double-sided page with more research-focused questions

Color



Color



Color

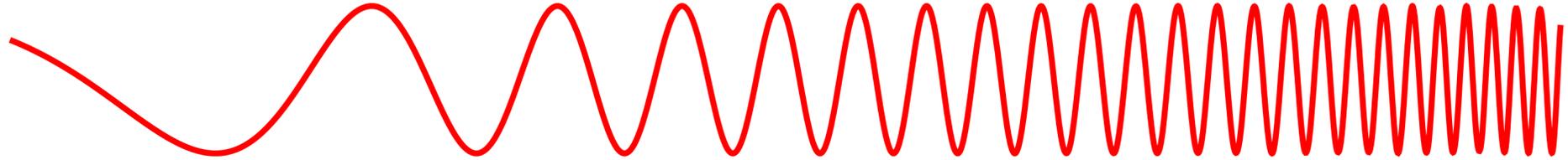


Color and Light

- Color is a **perceptive** property: color depends on the eyes and brain
- Visible light is a small portion of the **electromagnetic spectrum** which is composed of waves that at various frequencies (wavelengths), all traveling at the speed of light

Electromagnetic Spectrum

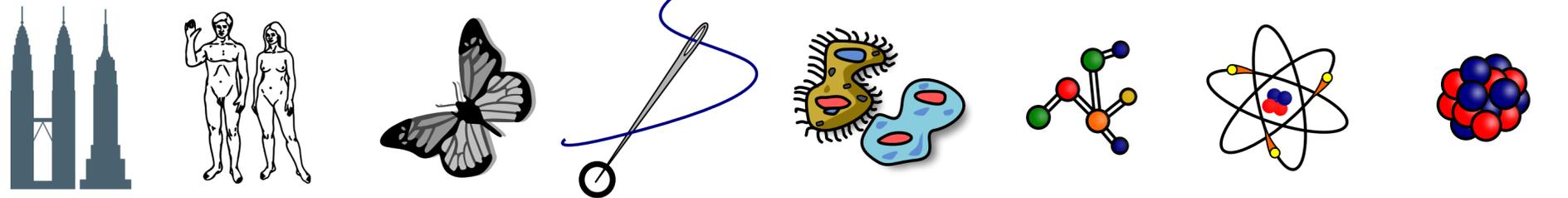
Penetrates Earth's Atmosphere?



Radiation Type
Wavelength (m)

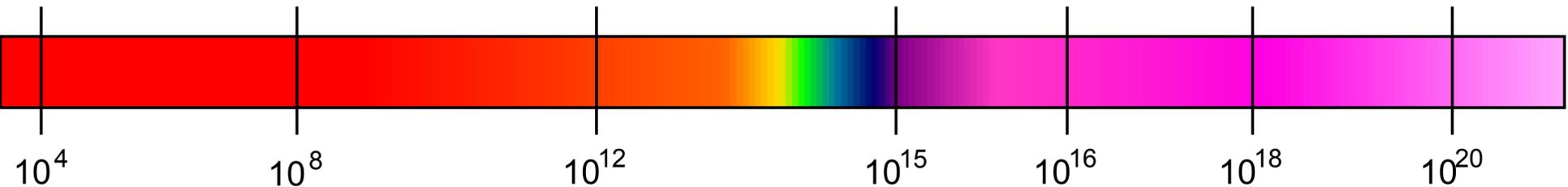


Approximate Scale
of Wavelength

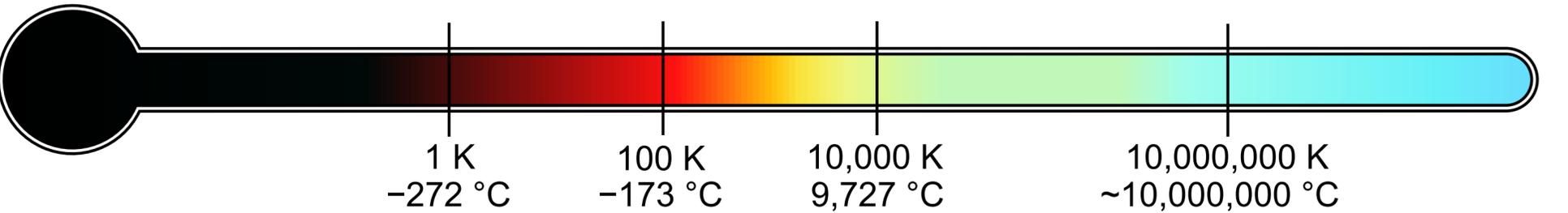


Buildings Humans Butterflies Needle Point Protozoans Molecules Atoms Atomic Nuclei

Frequency (Hz)

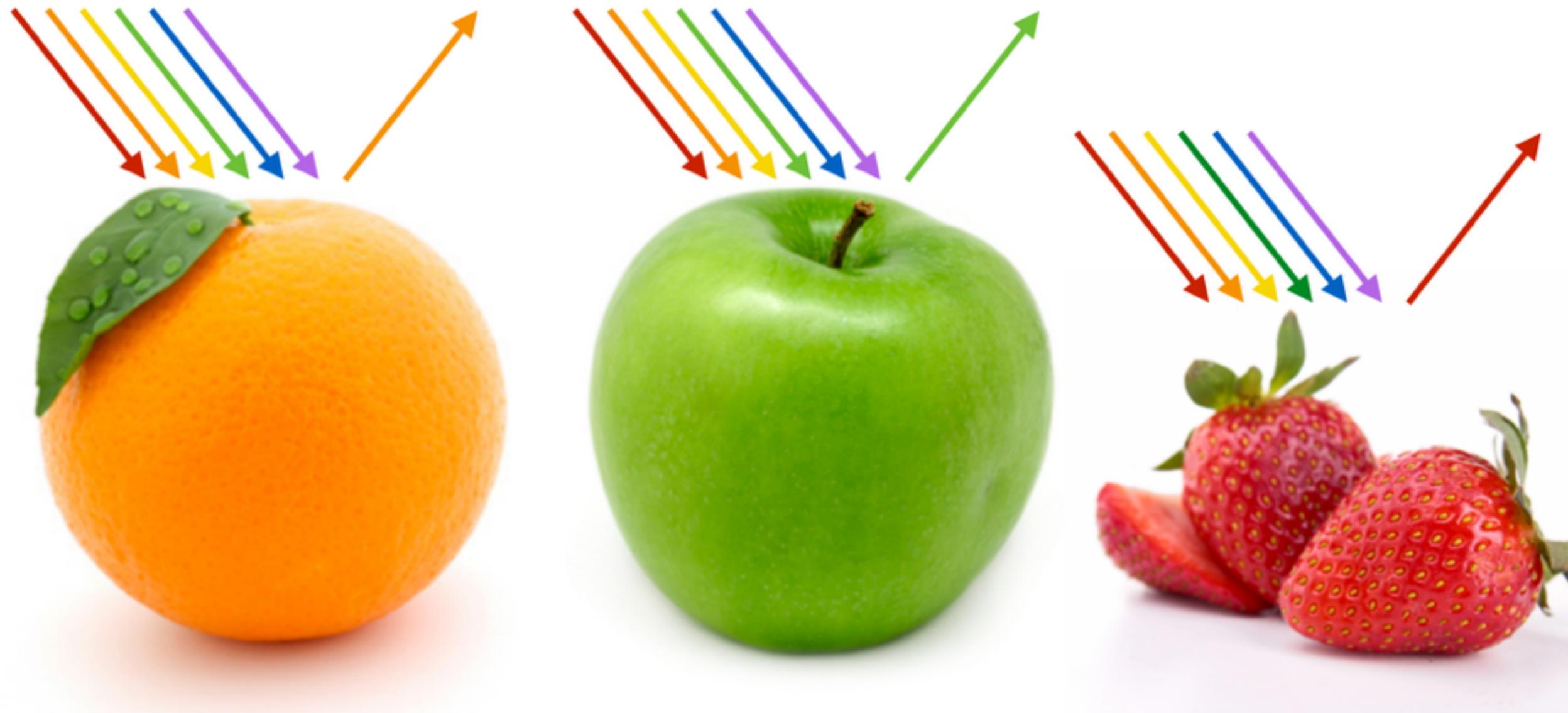


Temperature of
objects at which
this radiation is the
most intense
wavelength emitted



[Wikimedia, NASA]

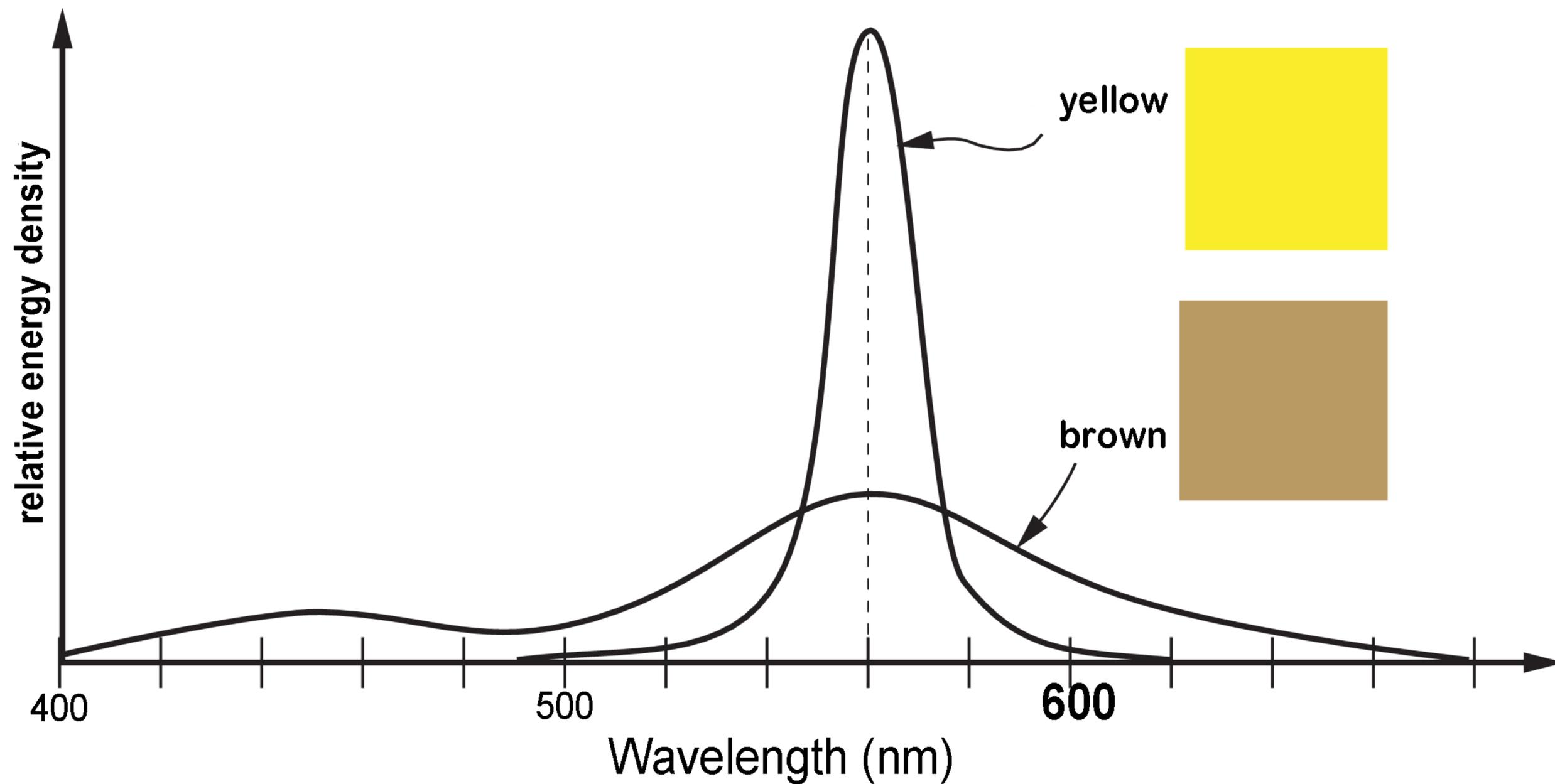
Light Reflection & Absorption



Wavelength (nm)

[via M. Meyer]

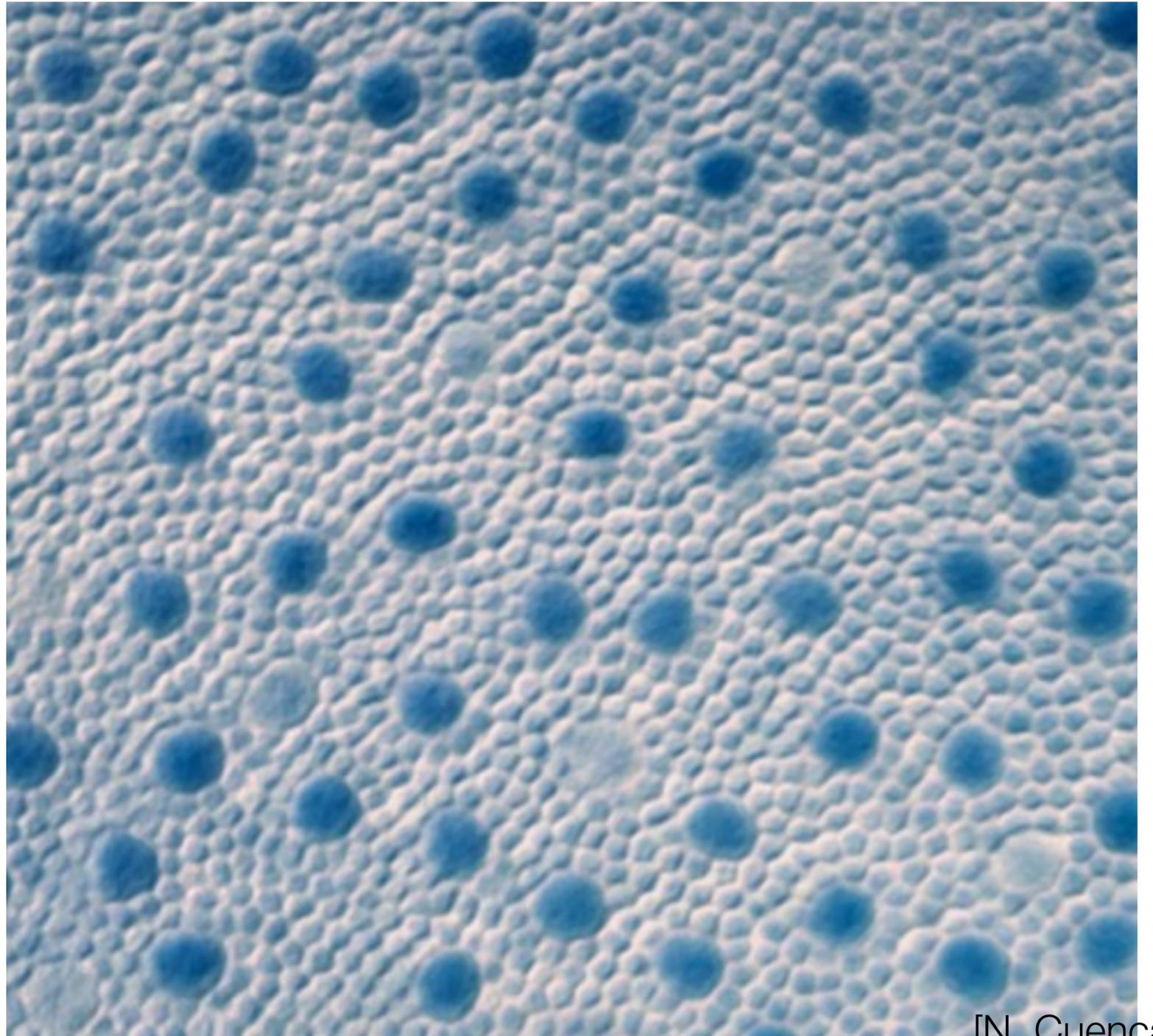
Color \neq Wavelength



[via M. Meyer]

Human Color Perception

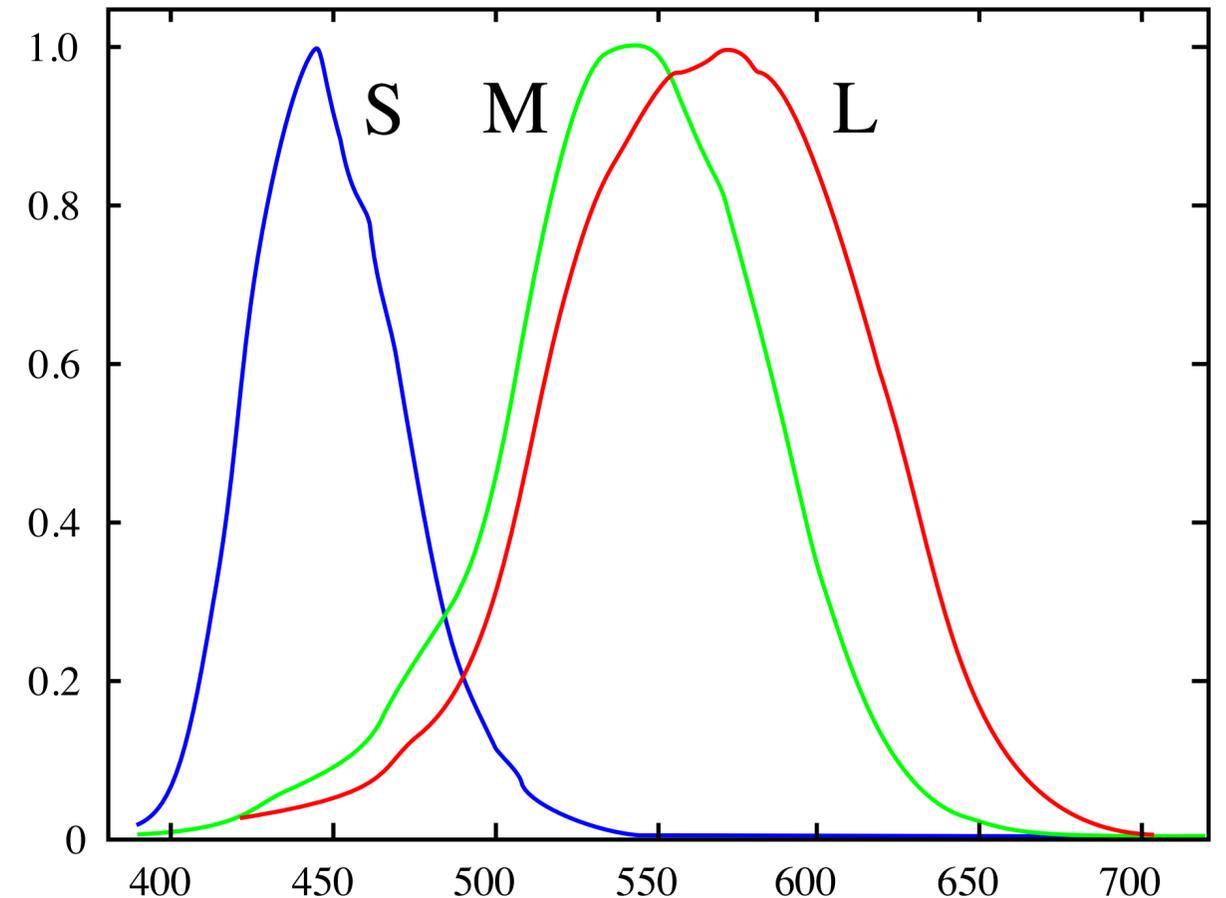
- Humans **do not** detect individual wavelengths of light
- Use **rods** and **cones** to detect light
 - rods capture intensity
 - cones capture color



[N. Cuenca]

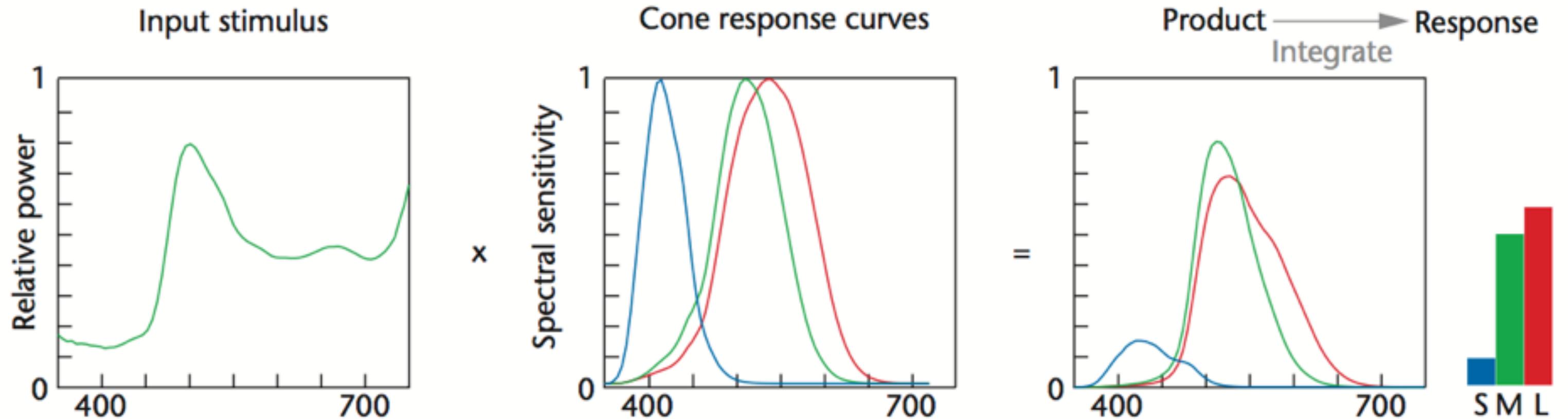
Human Color Perception

- Humans are **trichromatic**—we have three different types of cones
 - S (430nm): blue
 - M (540nm): green
 - L (570nm): "red"
- Note that the response curves **overlap**
- Spectra of visible light are "covered" by these responses
- Three numbers -> color



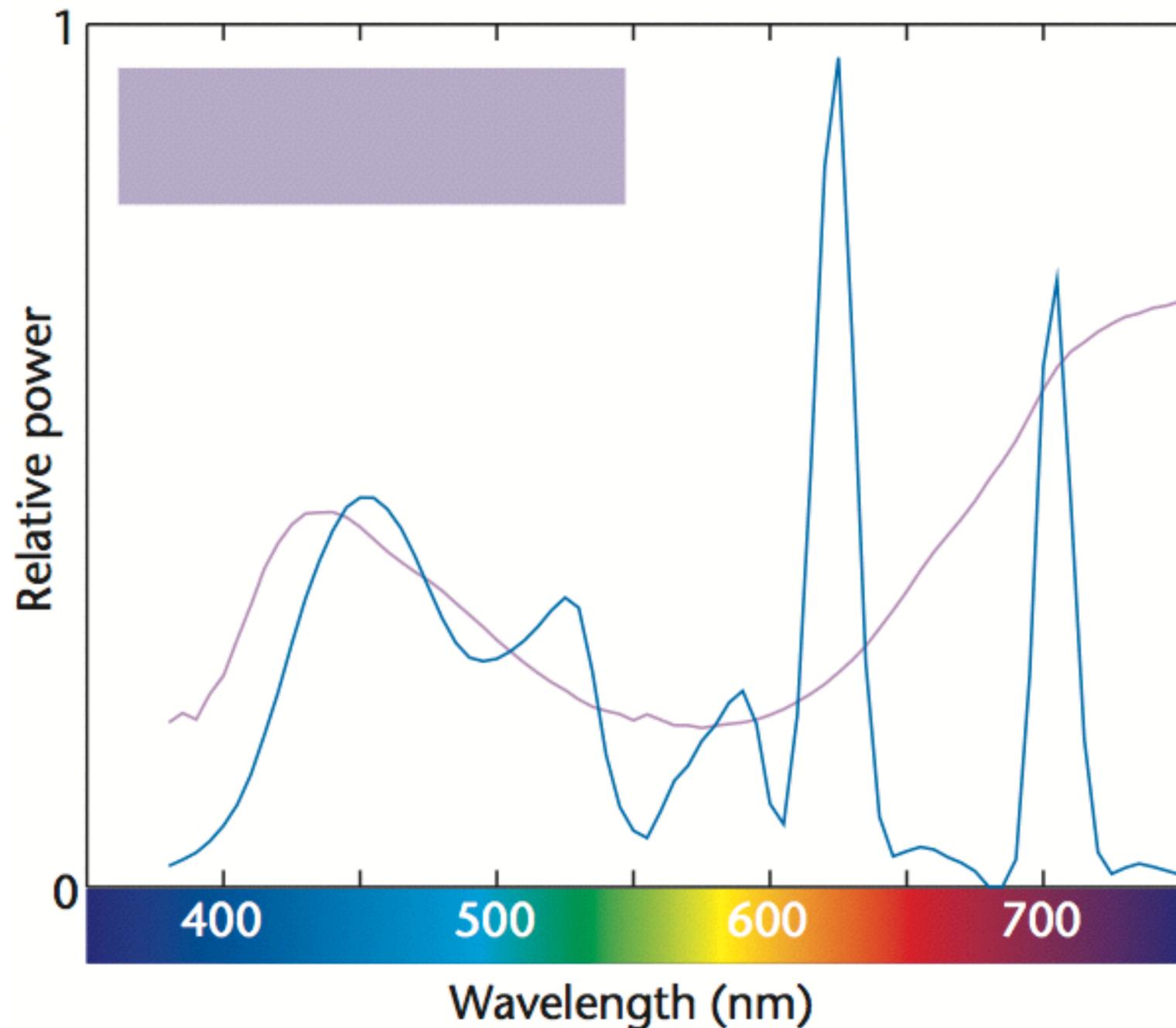
[Vanessaezekowitz at en.wikipedia]

Human Color Perception



[via M. Meyer]

Metamerism



- Same responses == same color
- Humans are not spectrometers
- Do not get the whole function
- Three responses

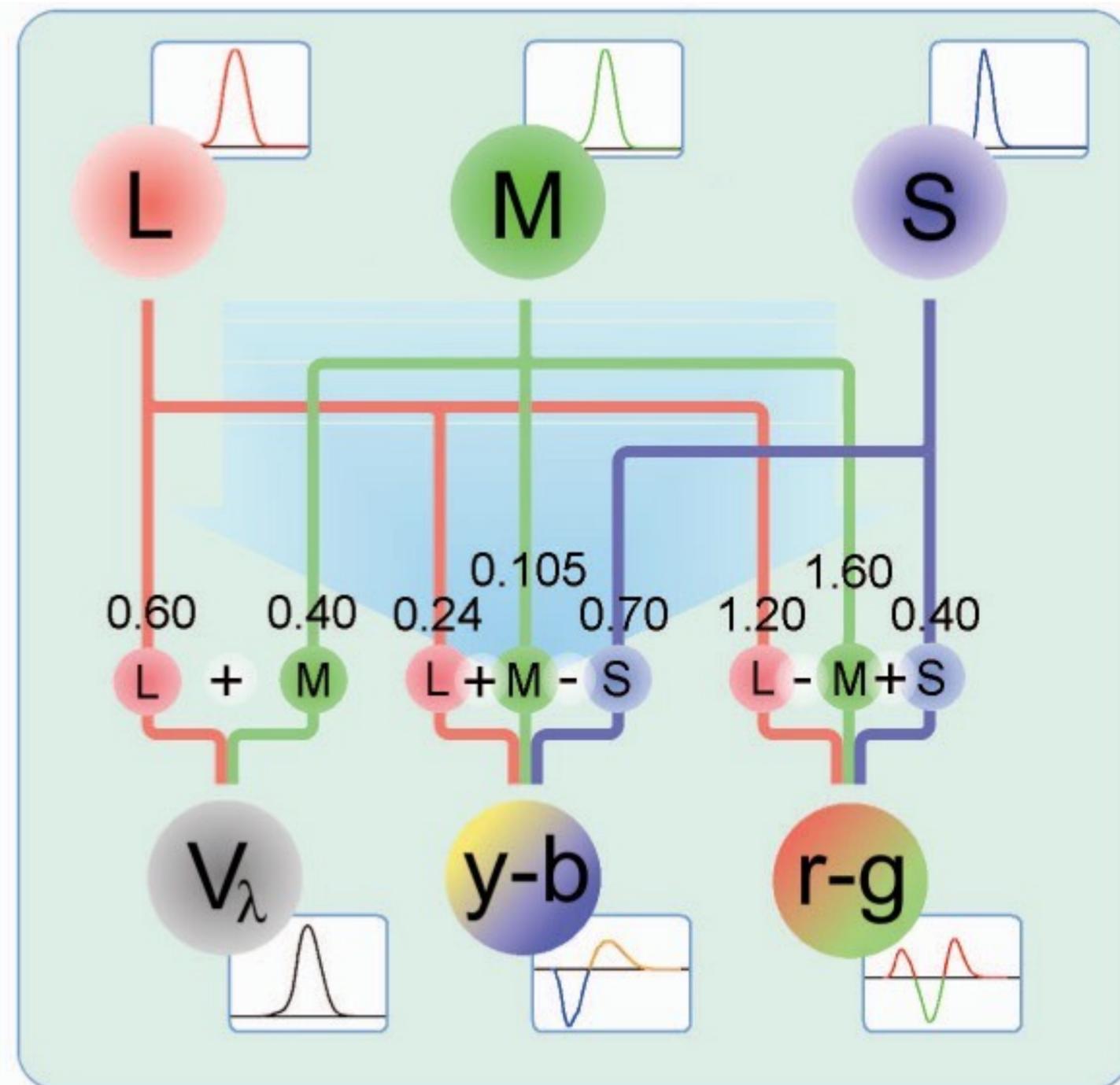


[via M. Meyer]

Color

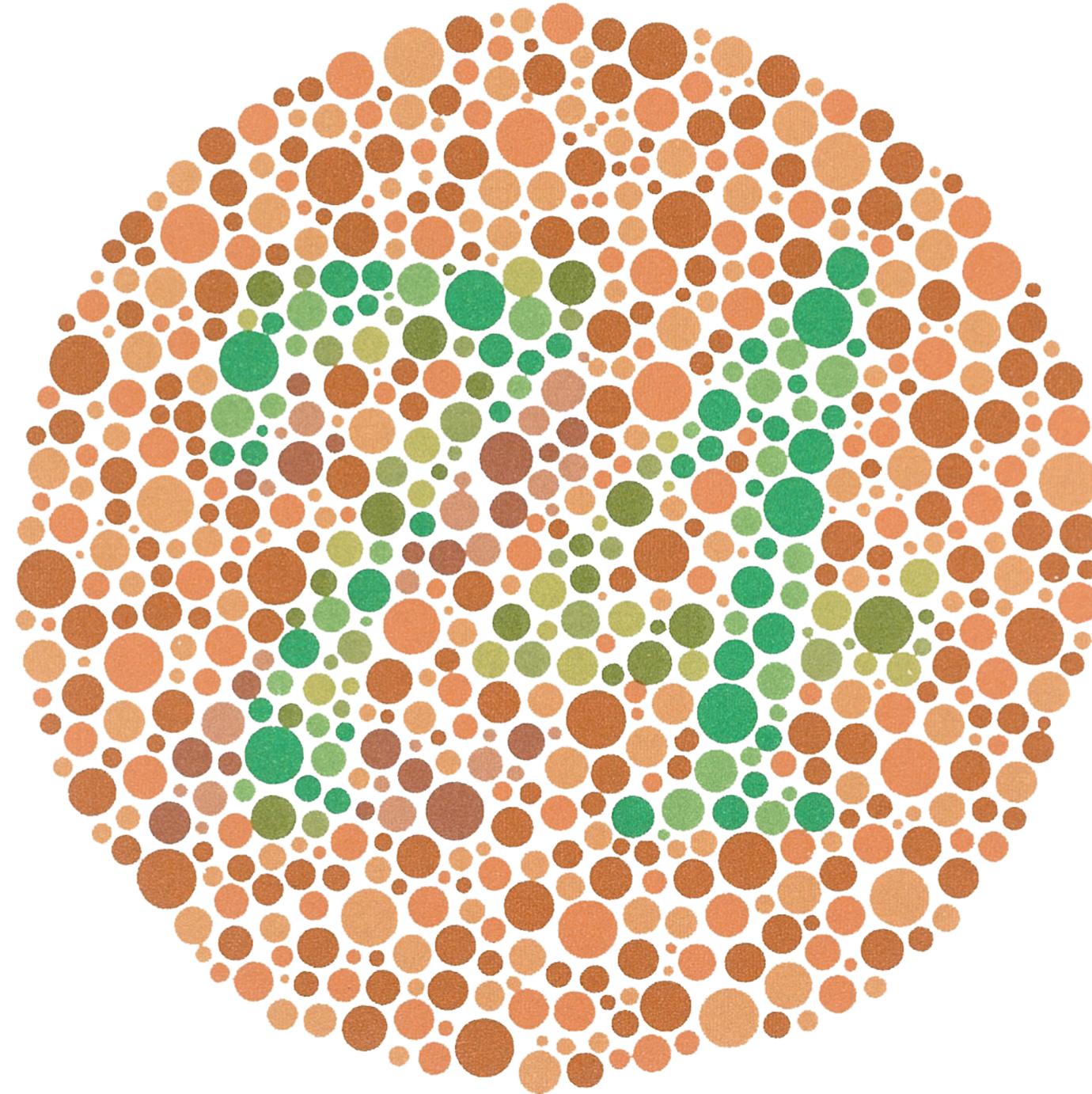
- Cones respond to different areas of the visible light spectrum
- Cover all wavelengths but certain wavelengths generate greater responses
- Color is determined by calculations based on the responses from the different cones
- Opponent Process Theory: three "opponent" channels
 - Light/Dark
 - Blue/Yellow
 - Red/Green
- Opposite colors are not perceived together

Opponent Process Theory



[Machado et. al, 2009]

Color Blindness

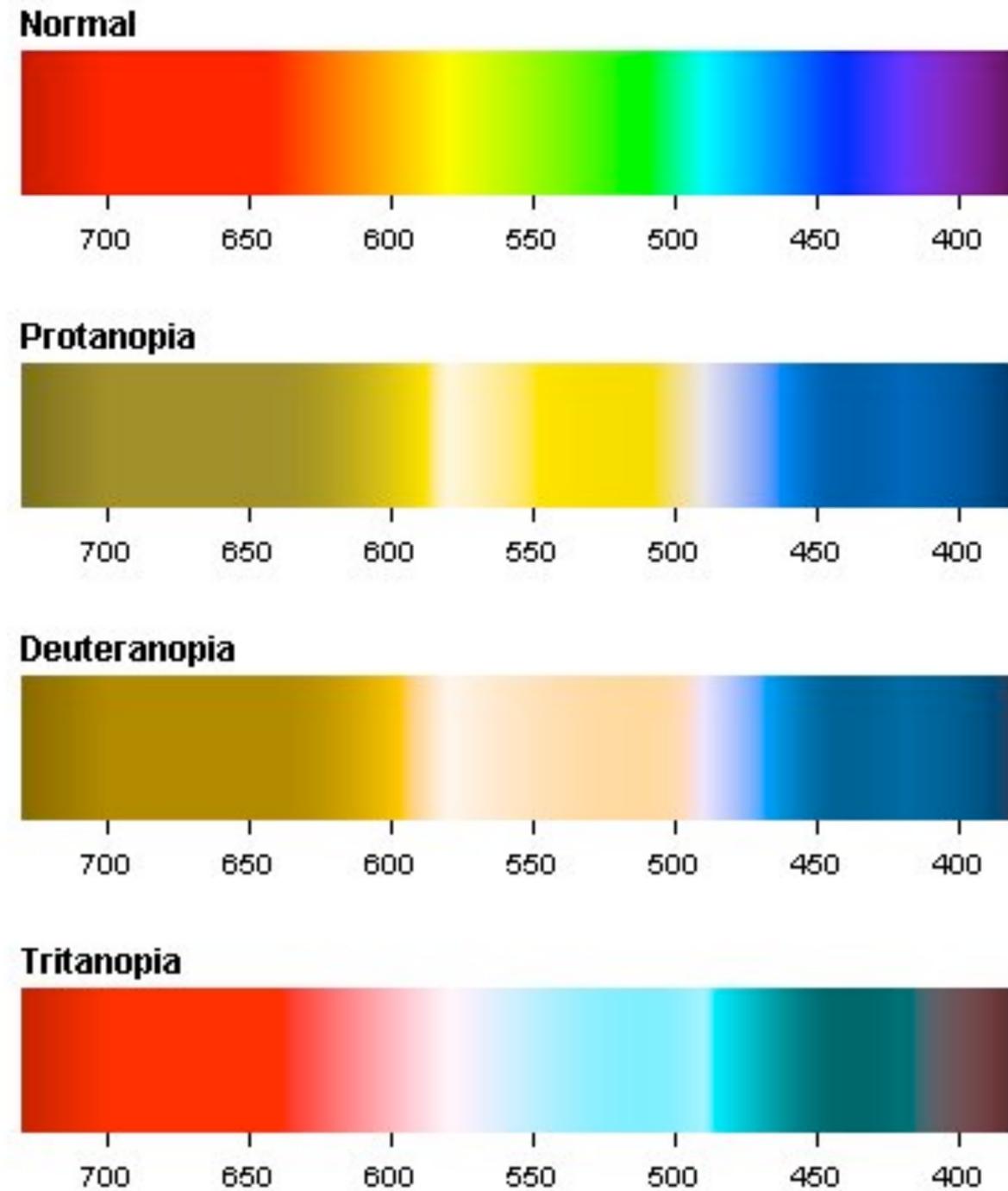


[Ishihara (Plate 9) via Wikipedia]

Color Blindness

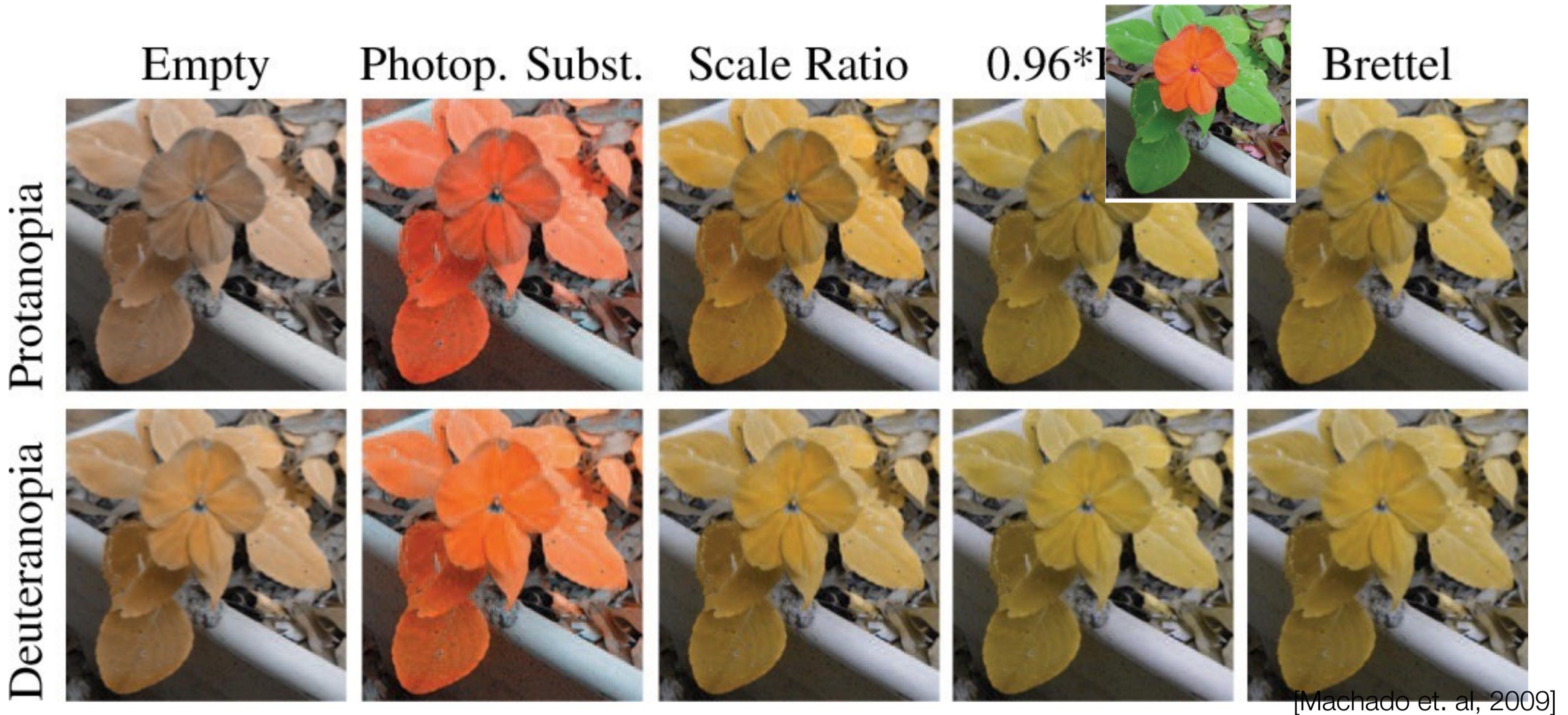
- Sex-linked: 8% of males and 0.4% of females of N. European ancestry
- Abnormal distribution of cones (e.g. missing the S, M, or L types)
- Either dichromatic (only two types of cones) or anomalous trichromatic (one type of cones has a defect)
 - Protanopia (L missing), Protanomaly (L defect)
 - Deuteranopia (M missing), Deuteranomaly (M defect) [Most Common]
 - Tritanopia (S missing), Tritanomaly (S defect) [Rare]
- Dichromacy is rarer than anomalous trichromacy
- Opponent process model explains why colors cannot be differentiated

Color Blindness



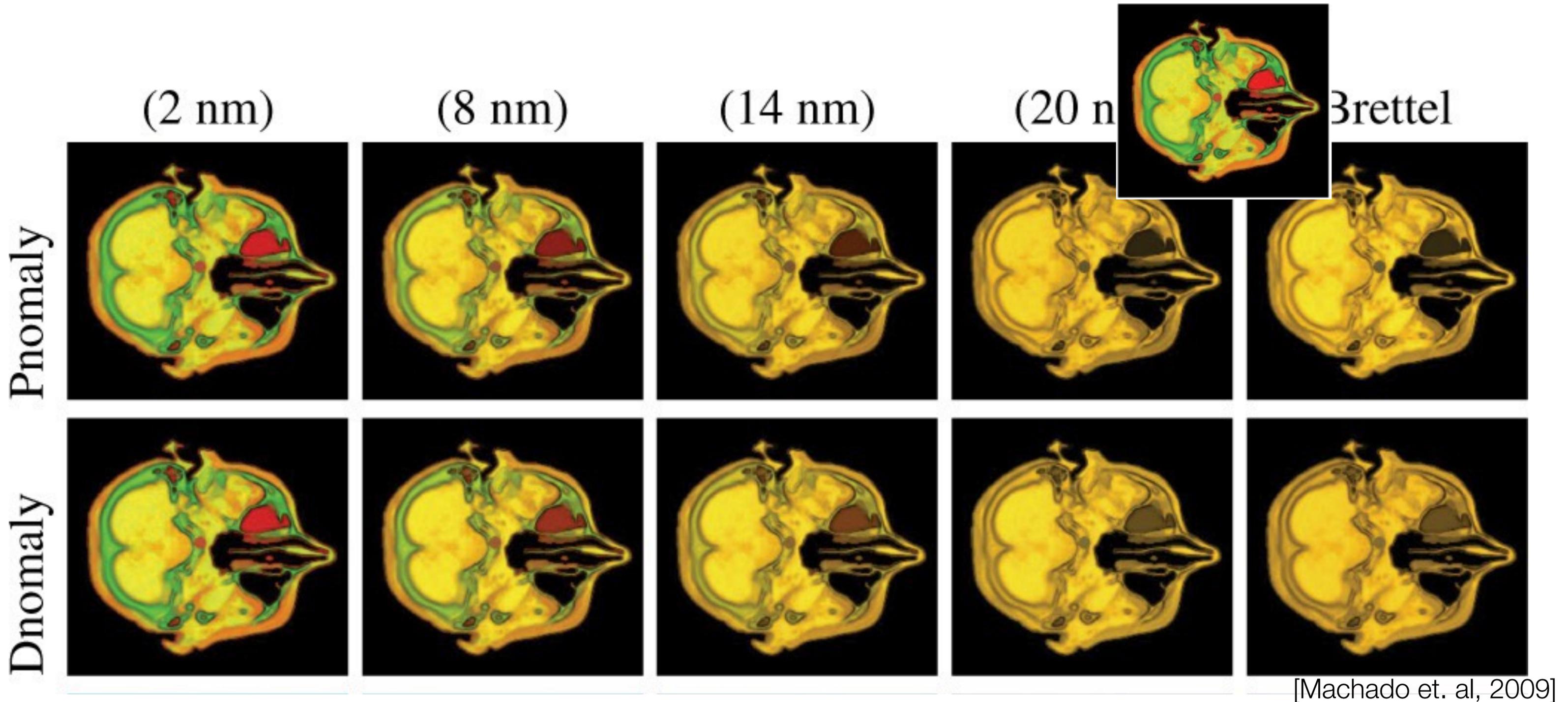
[via M. Meyer]

Simulating Color Blindness



[Machado et. al, 2009]

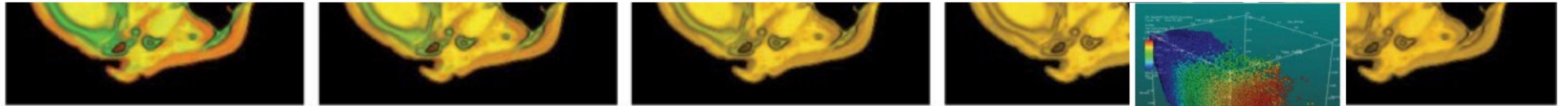
Simulating Color Blindness



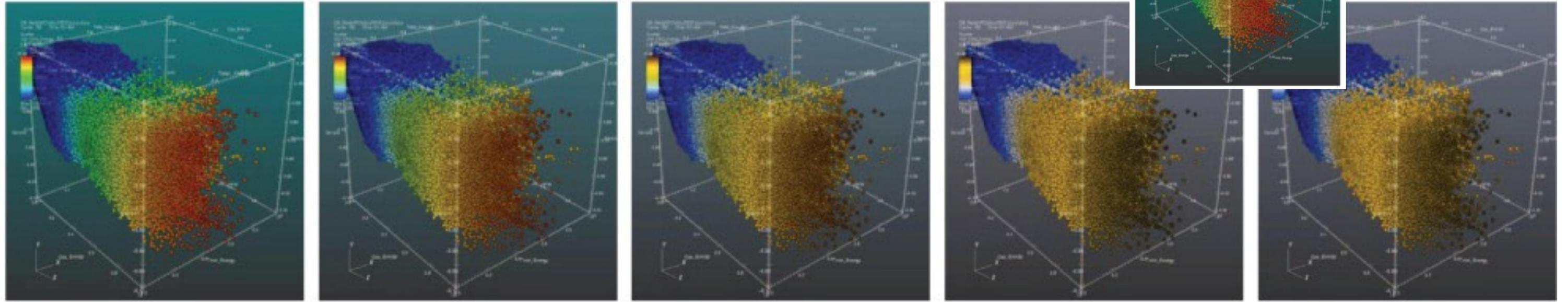
[Machado et. al, 2009]

Simulating Color Blindness

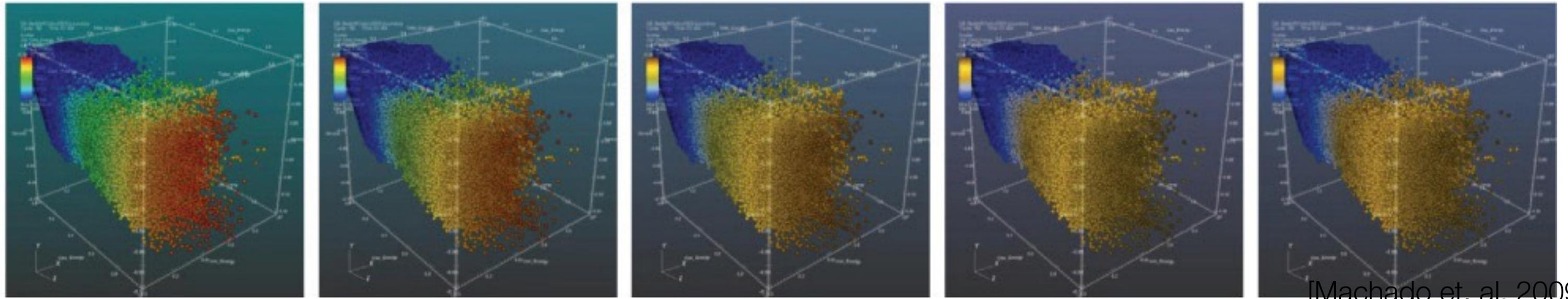
Dnoi



Pnomaly

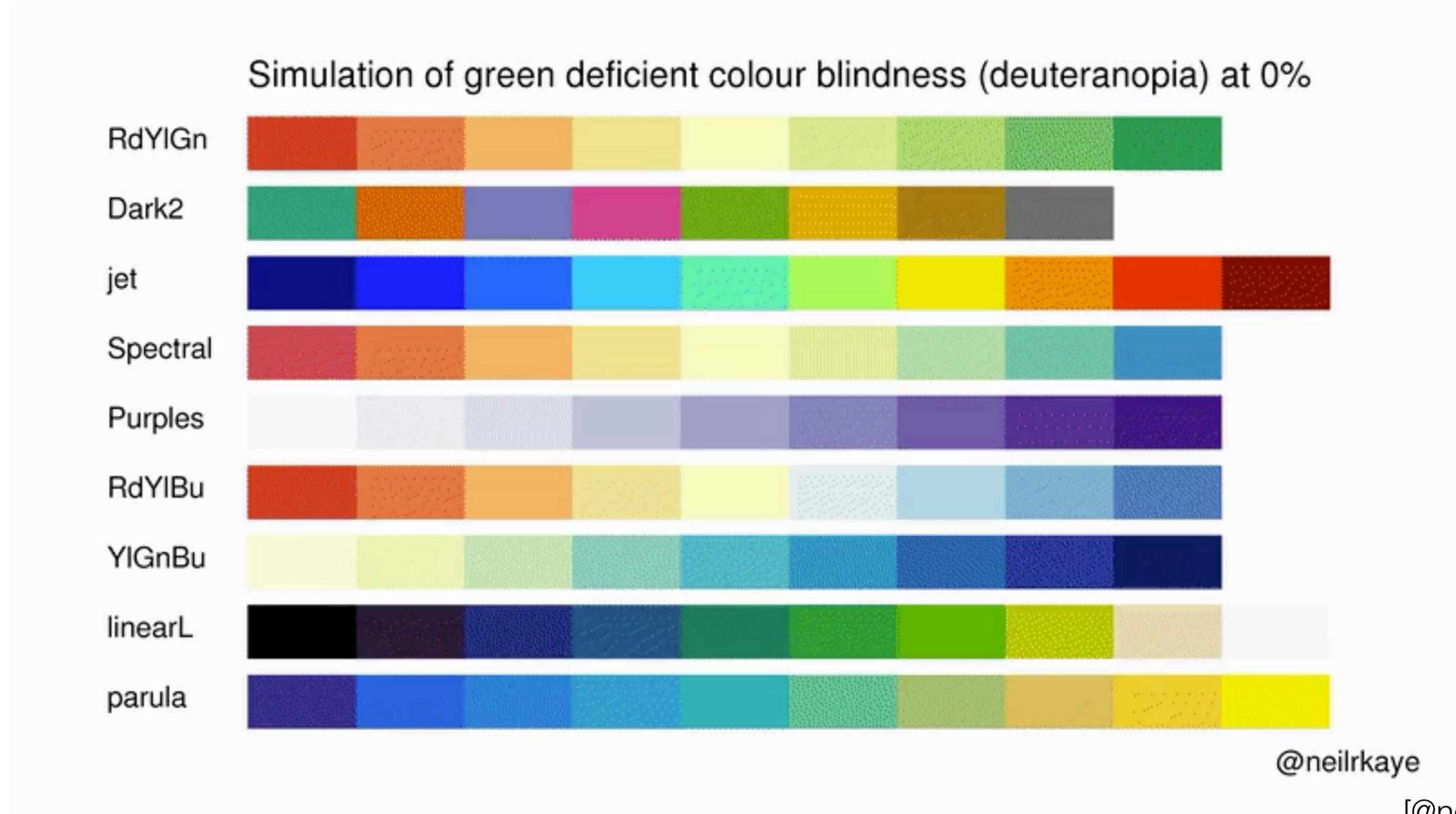


Dnomaly



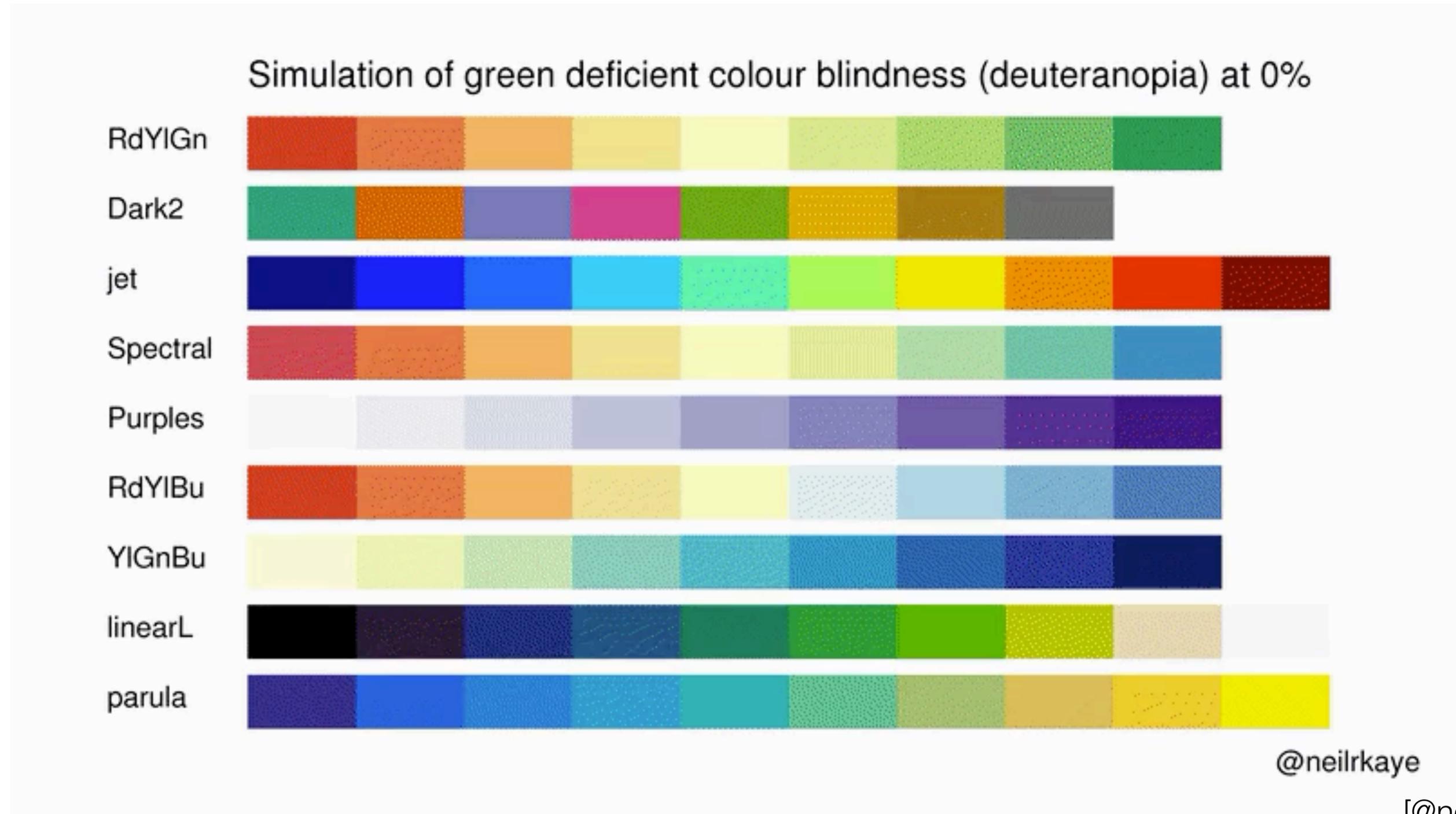
[Machado et. al, 2009]

Simulating Deuteranopia (Colormaps)



[@neilrkaye, reddit]

Simulating Deuteranopia (Colormaps)



[@neilrkaye, reddit]

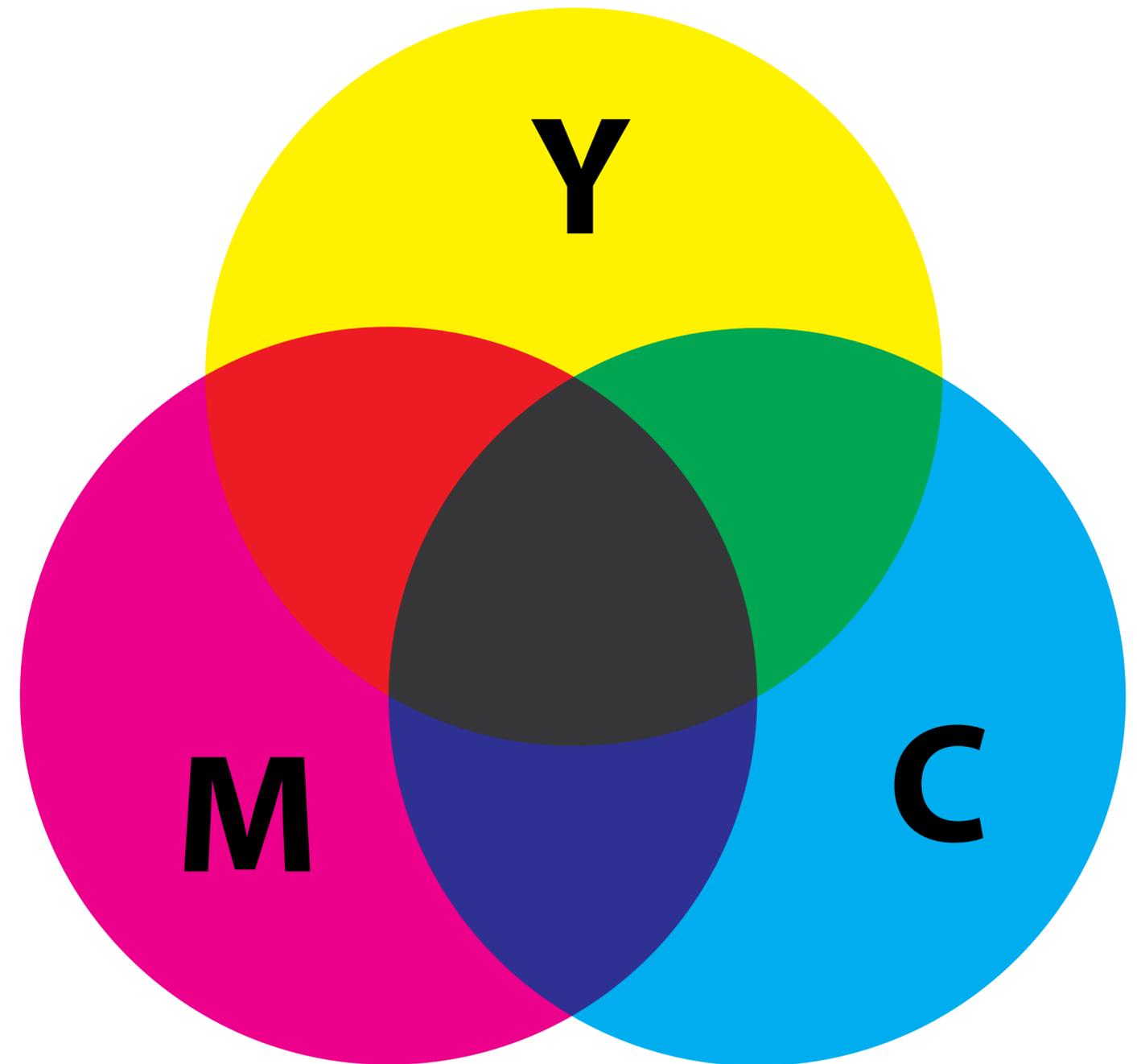
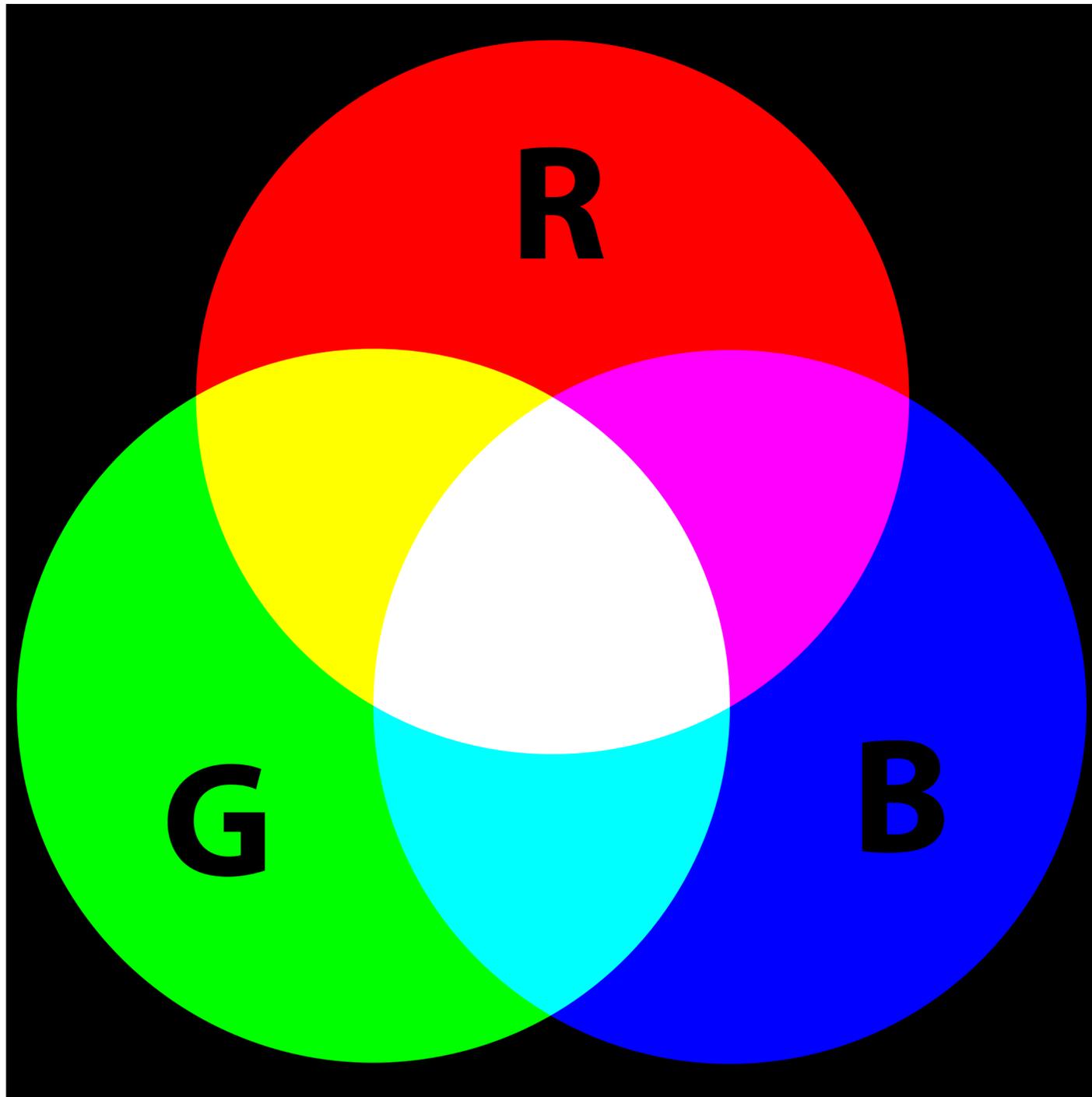
Primary Colors?

- Red, Green, and Blue
- Red, Yellow, and Blue
- Orange, Green, and Violet
- Cyan, Magenta, and Yellow

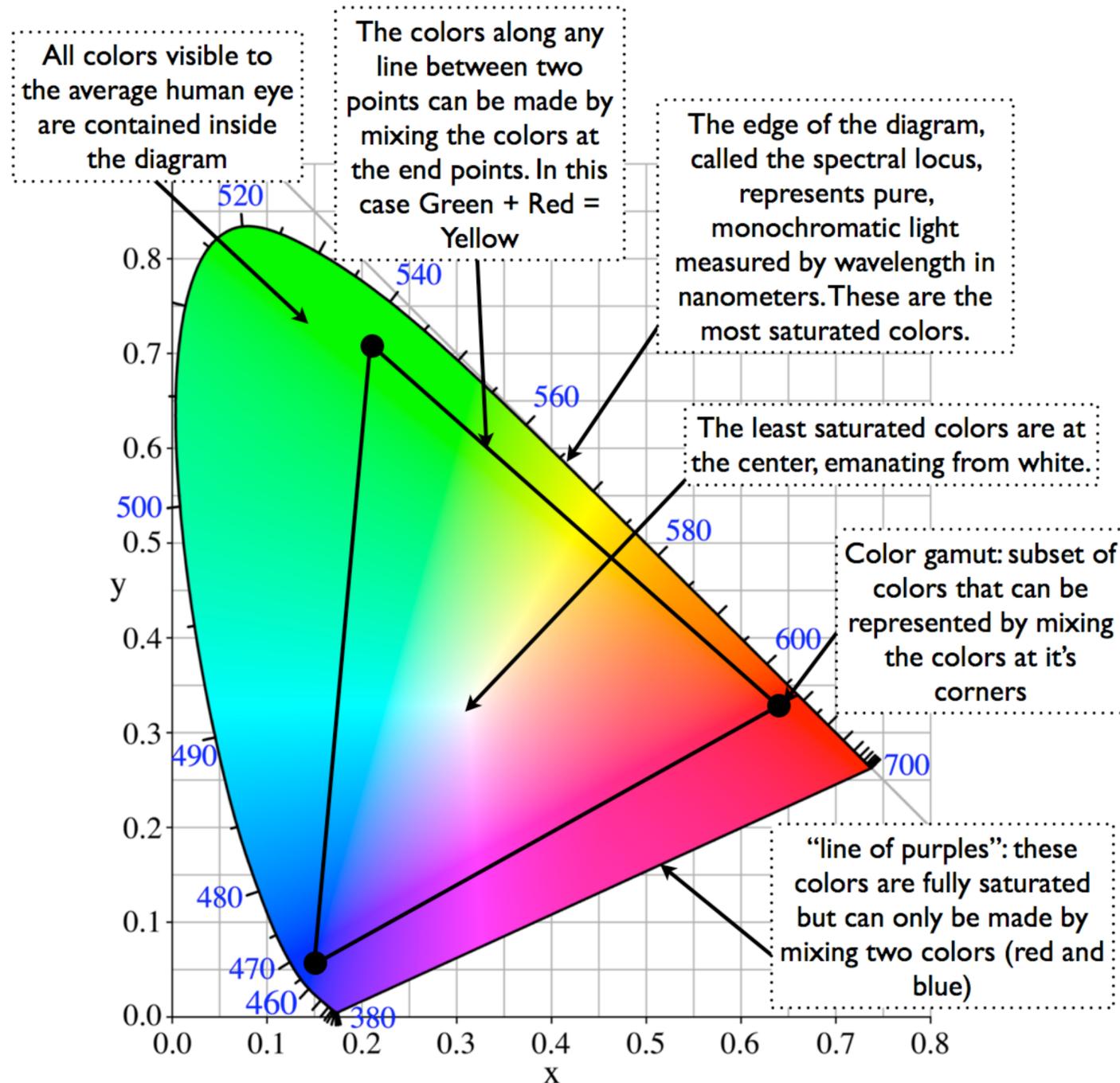
Primary Colors?

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

Color Addition and Subtraction



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 of 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 \neq the gamut of someone else's or a printer

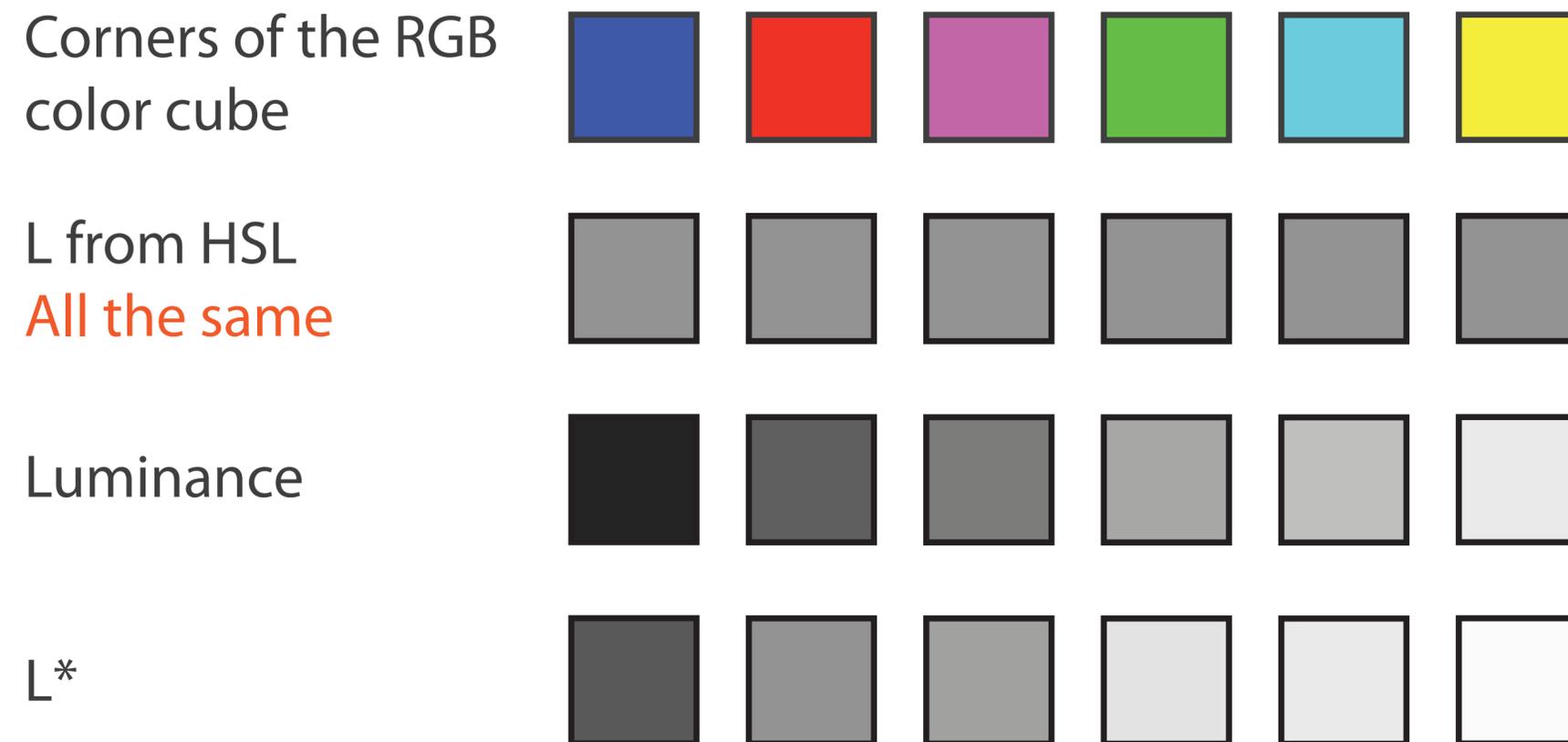
[Anatomy of a CIE Chromaticity Diagram]

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

Luminance

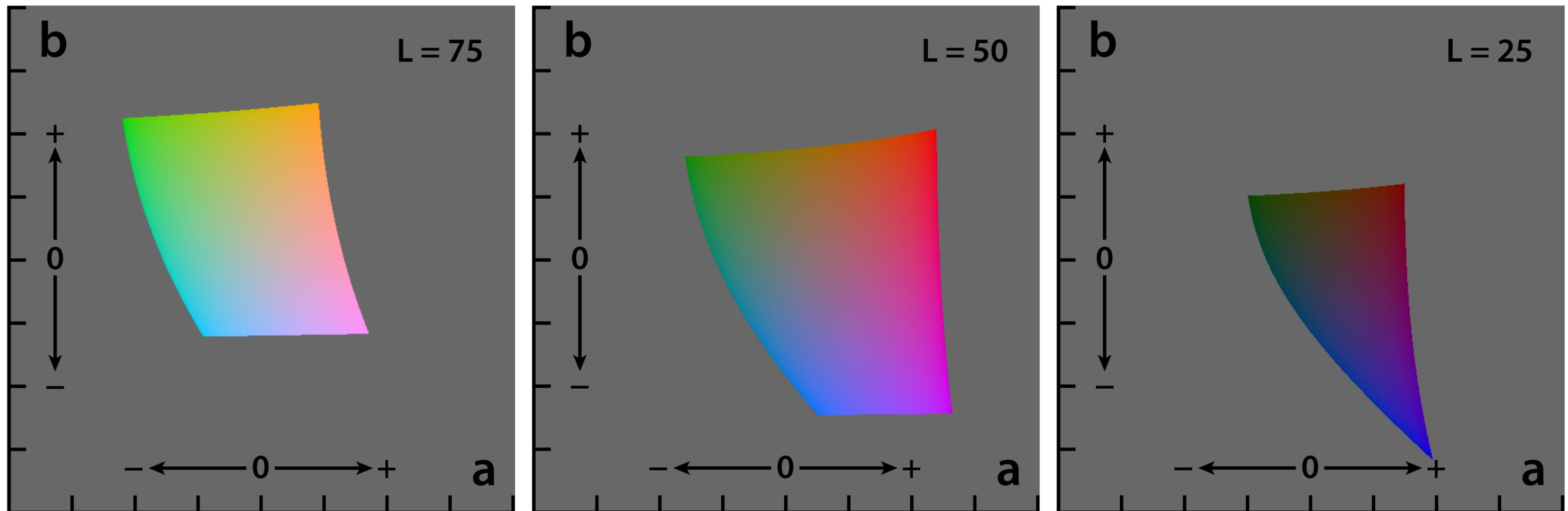
- HSL does not truly reflect the way we perceive color
- Even though colors have the same lightness, we perceive their luminance differently
- Our perception (L^*) is **nonlinear**



[Munzner (ill. Maguire), 2014 (based on Stone, 2006)]

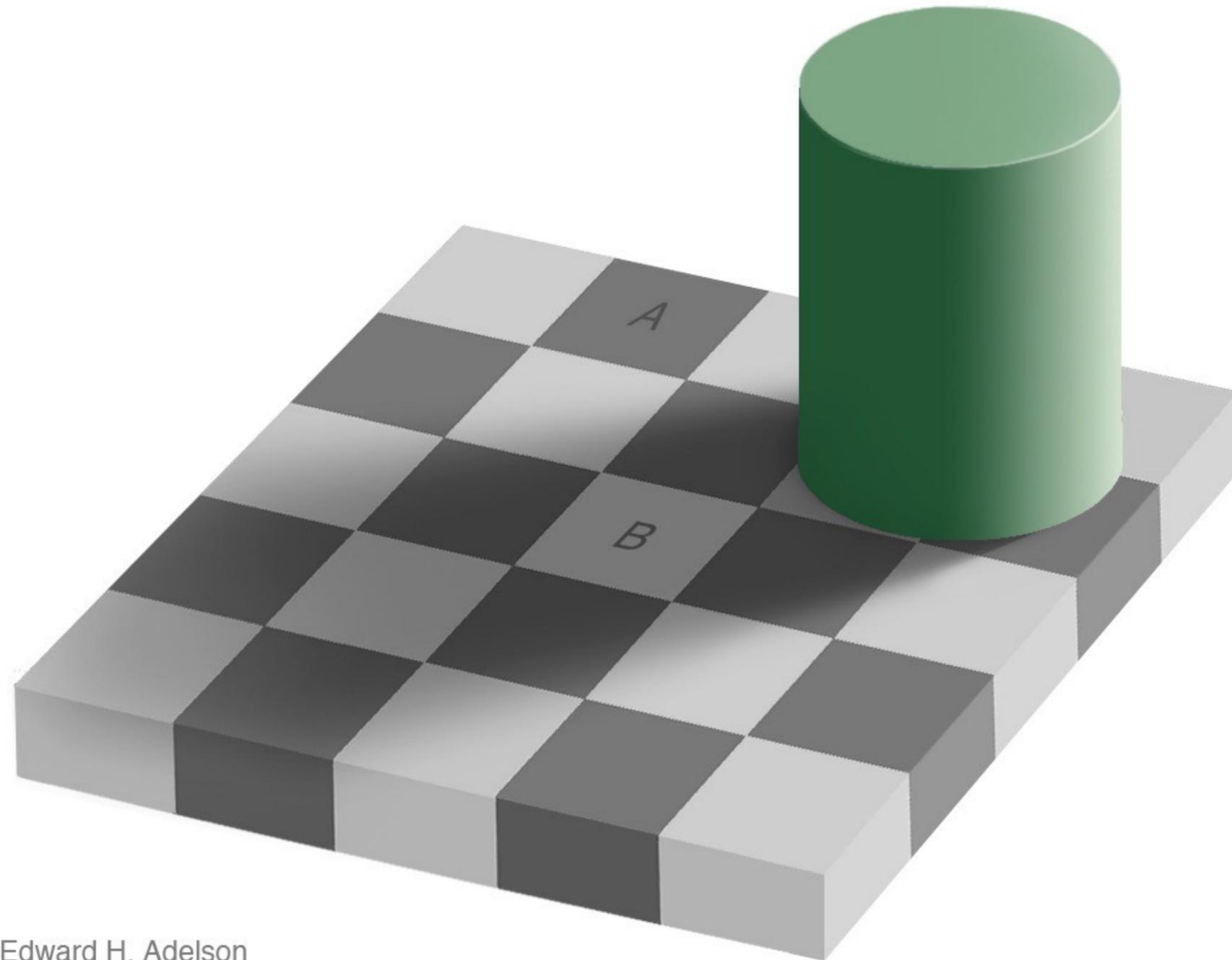
Perceptually Uniform Color Spaces

- $L^*a^*b^*$ allows perceptually accurate comparison and calculations of colors



[J. Rus, CC-BY-SA (changed to horizontal layout)]

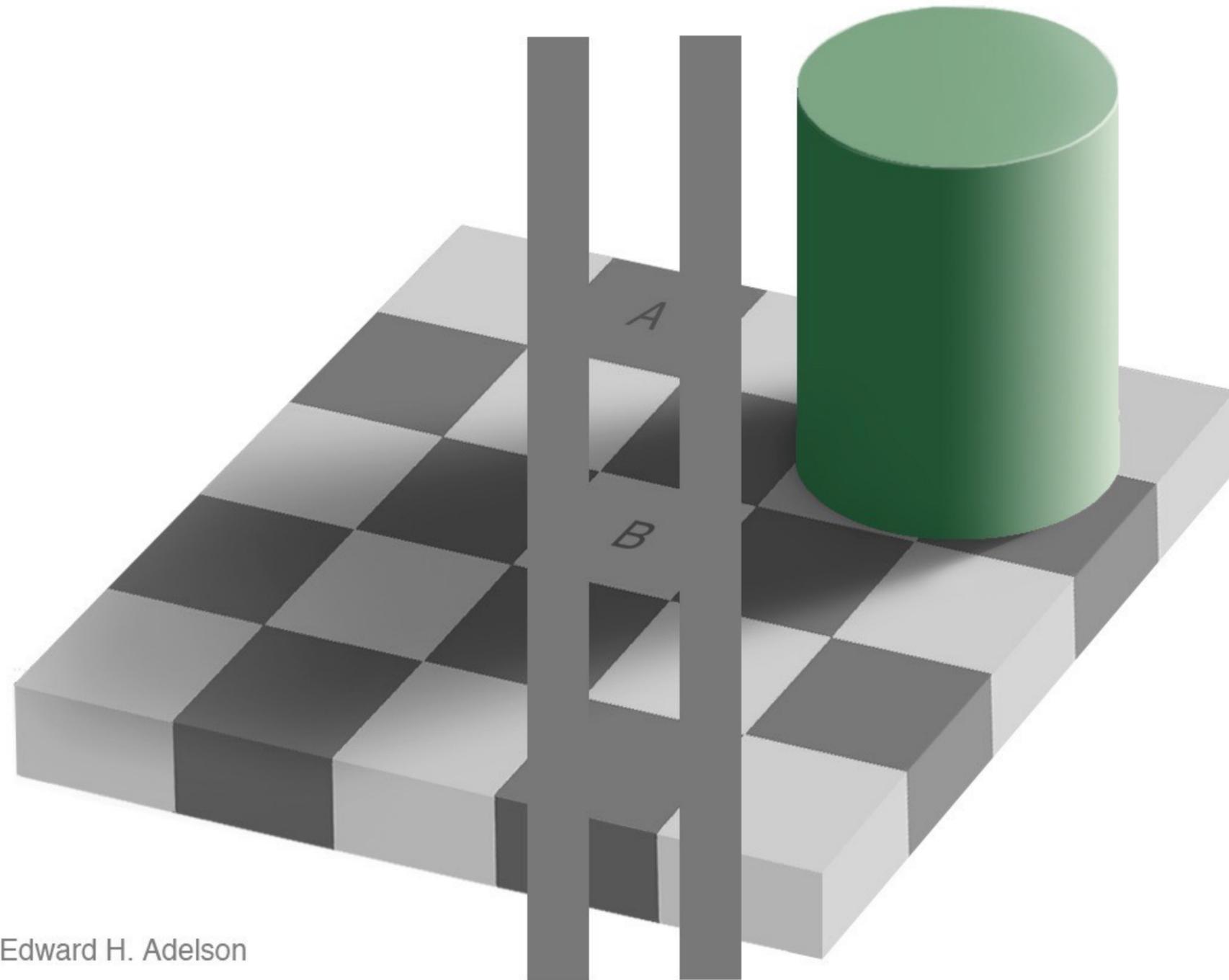
Luminance Perception (Spatial Adaption)



Edward H. Adelson

[E. H. Adelson, 1995]

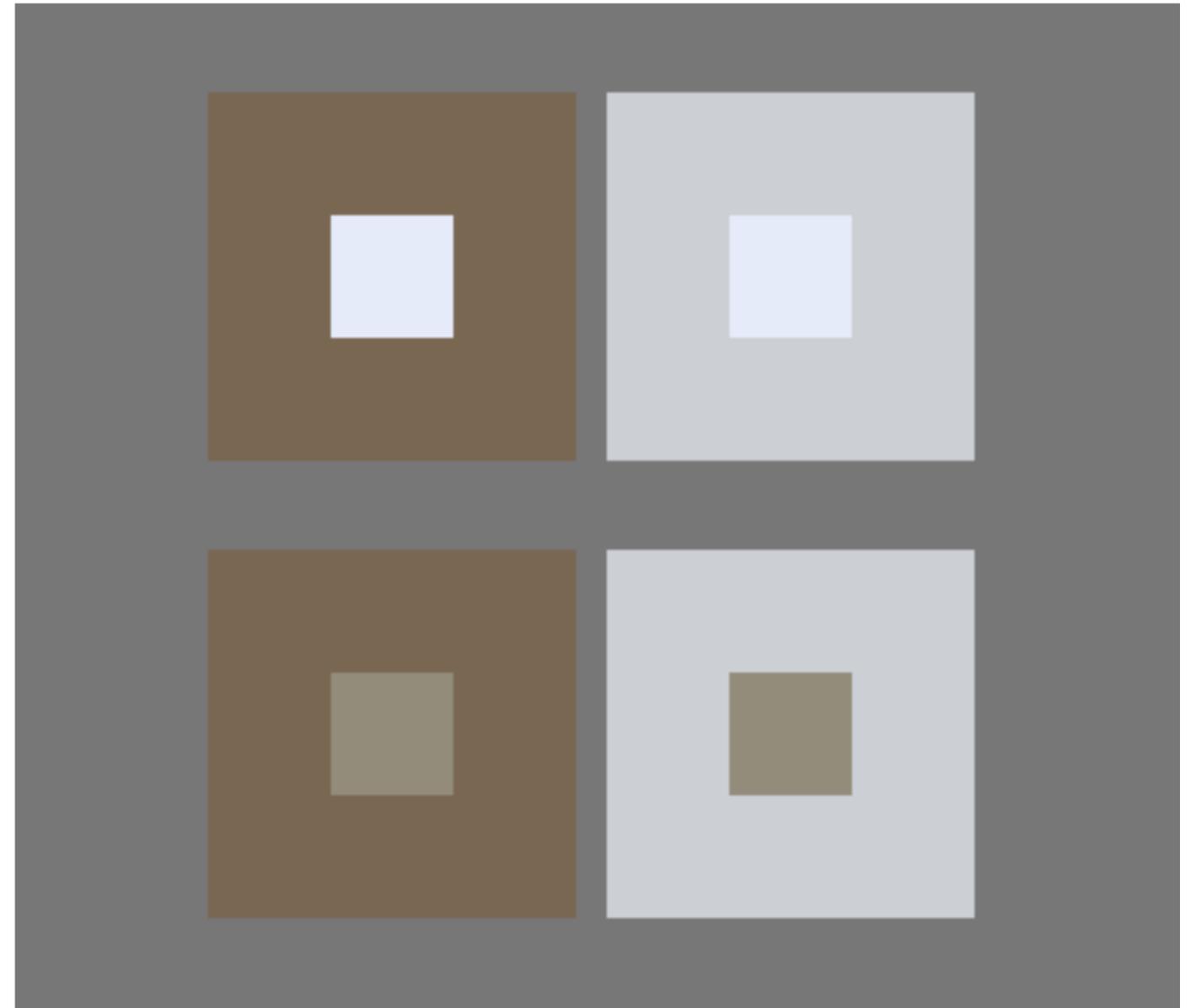
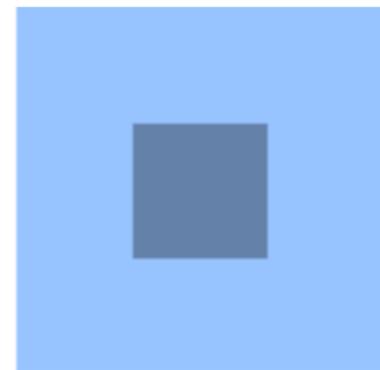
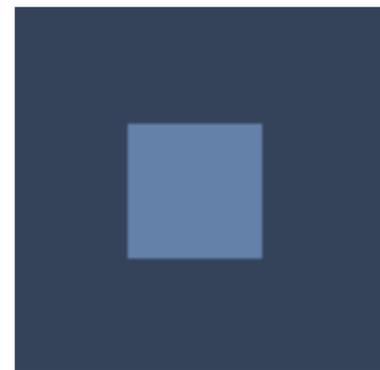
Luminance Perception (Spatial Adaption)



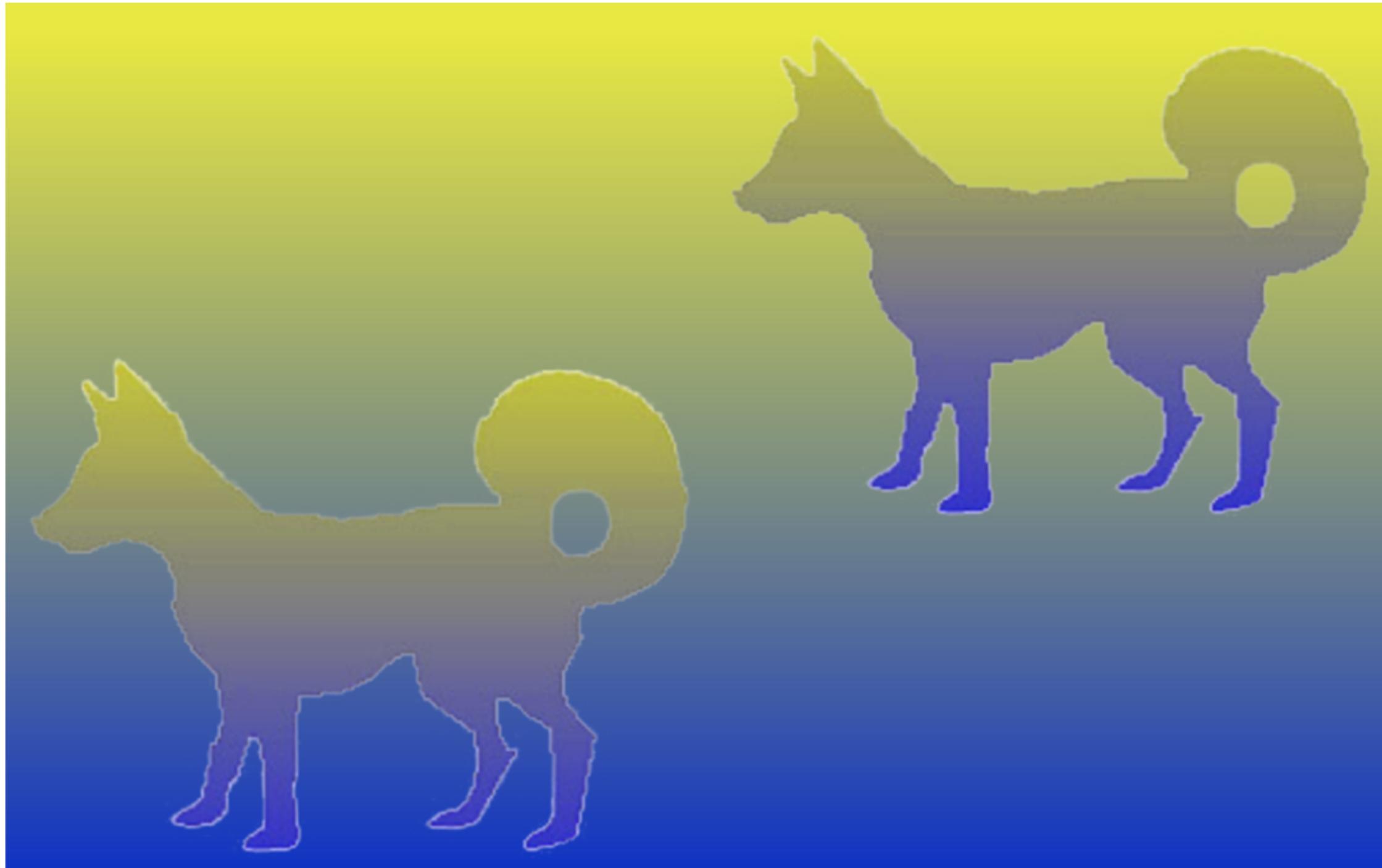
Edward H. Adelson

[E. H. Adelson, 1995]

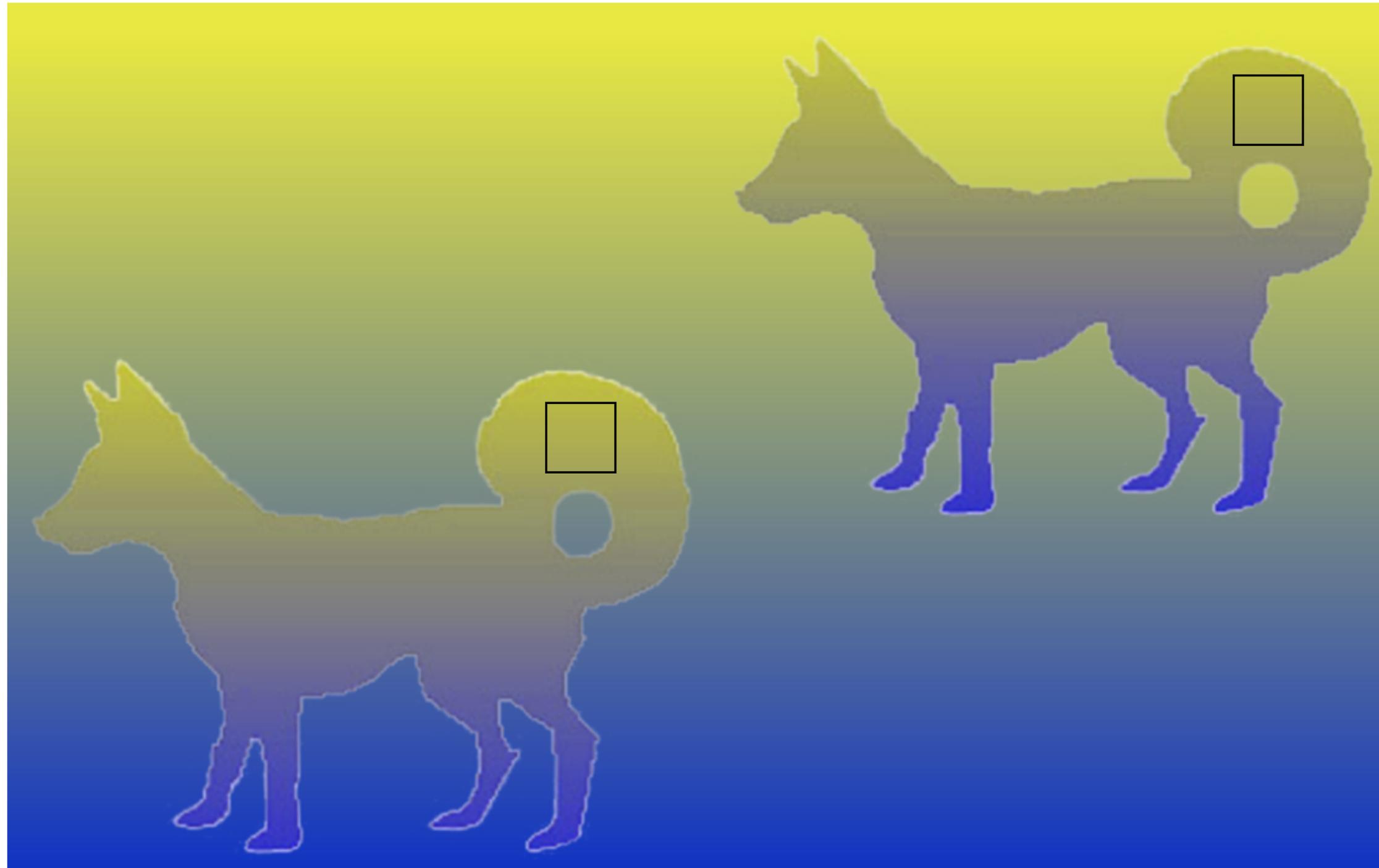
Simultaneous Contrast



Simultaneous Contrast



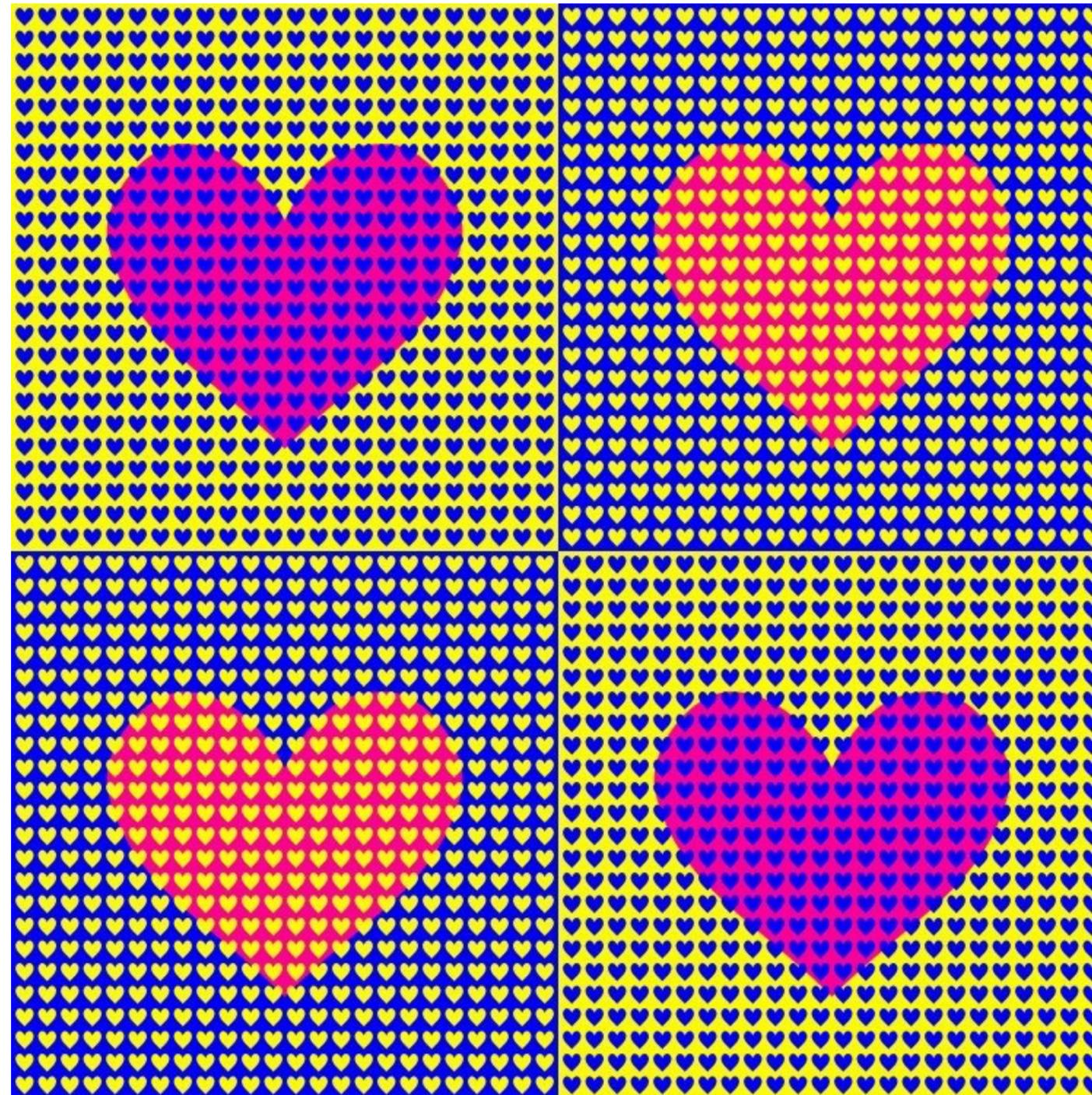
Simultaneous Contrast



Simultaneous Contrast

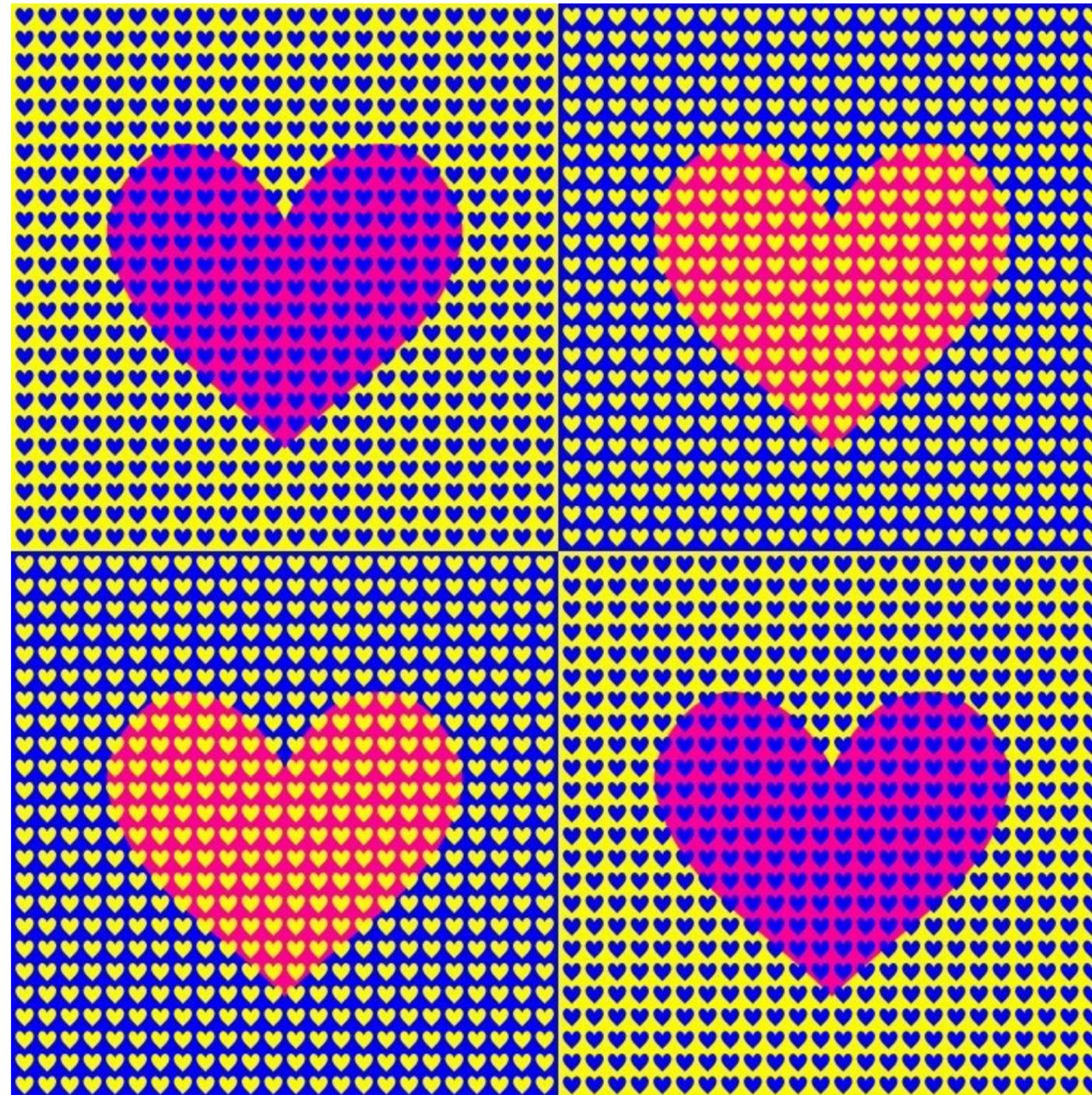


What colors?



[A. Kitaoka]

What colors?



Red, yellow, blue

Purple, orange
do not exist!

[A. Kitaoka]

What does this mean for visualization?

What does this mean for visualization?

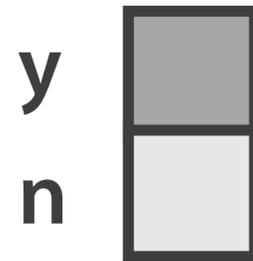
- We need to be aware of colorblindness when encoding via color
- Our brains may misinterpret color (surrounding colors matter!) even if we aren't colorblind
- Be careful! Don't assume that adding color always works the way you intended
- Use known colormaps when possible

Colormaps

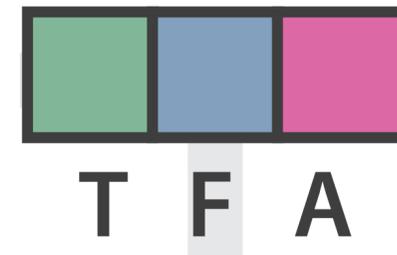
Colormap

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

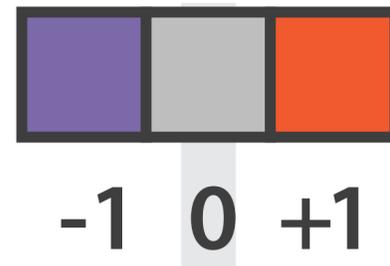
Binary



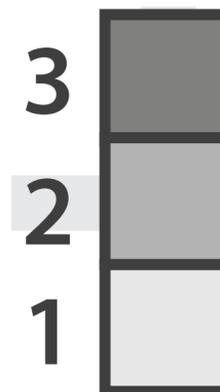
Categorical



Diverging



Sequential



[Munzner (ill. Maguire), 2014]

Categorical vs. Ordered

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

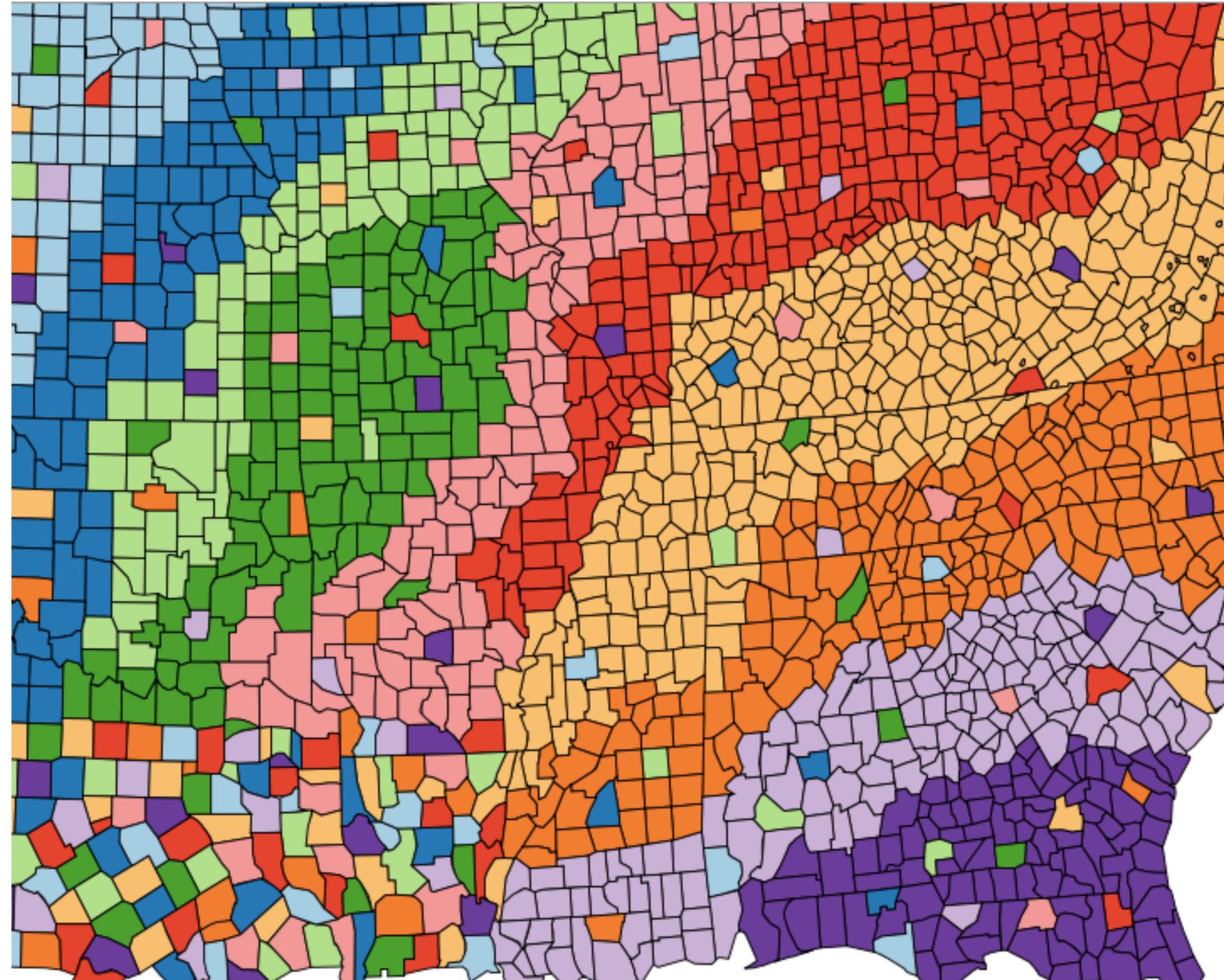


[Munzner (ill. Maguire), 2014]

Categorical Colormap Guidelines

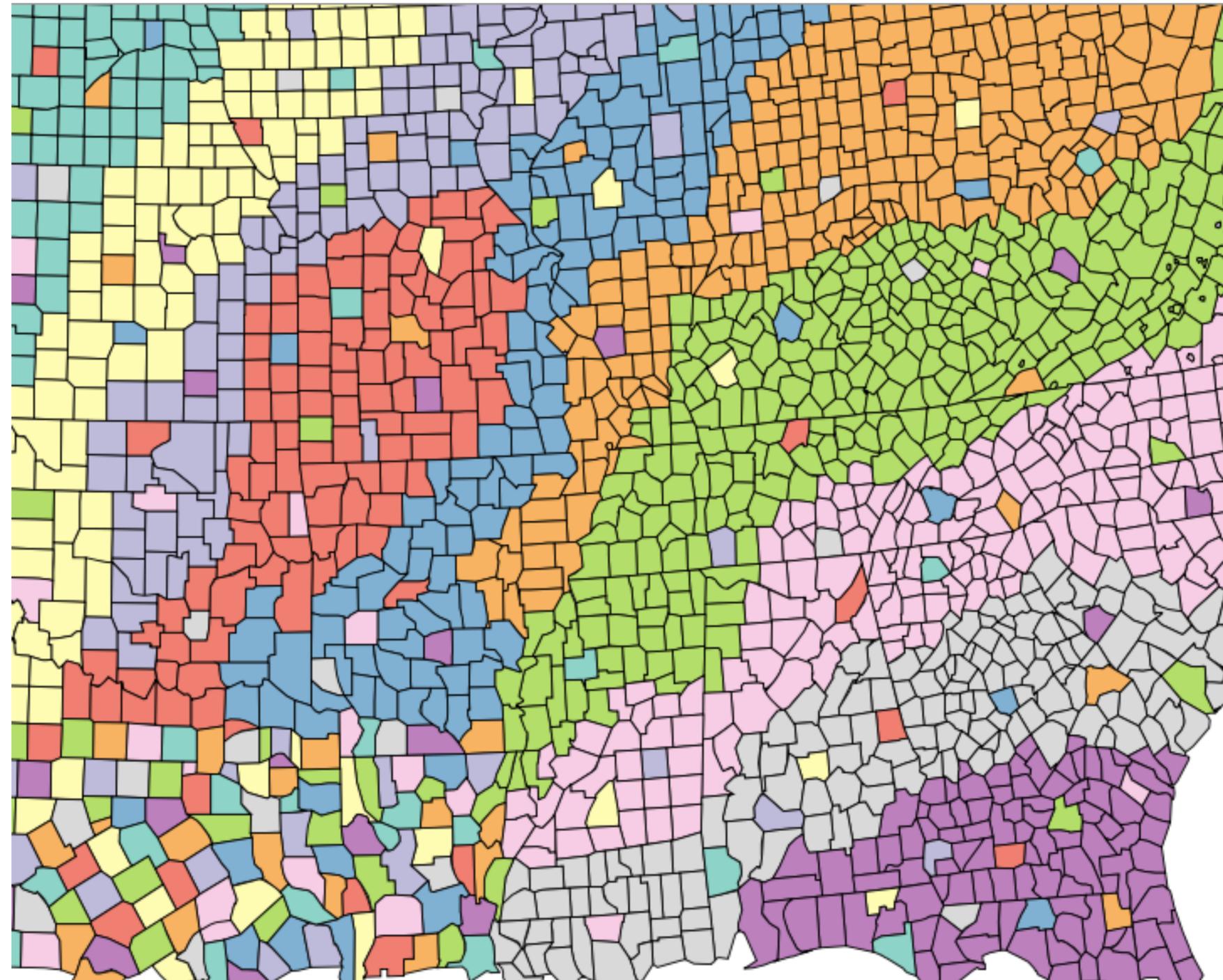
- Don't use too many colors (~12)
- Remember your background has a color, too
- Nameable colors help
- Be aware of luminance (e.g. difference between blue and yellow)
- Think about other marks you might wish to use in the visualization

Categorical Colormaps



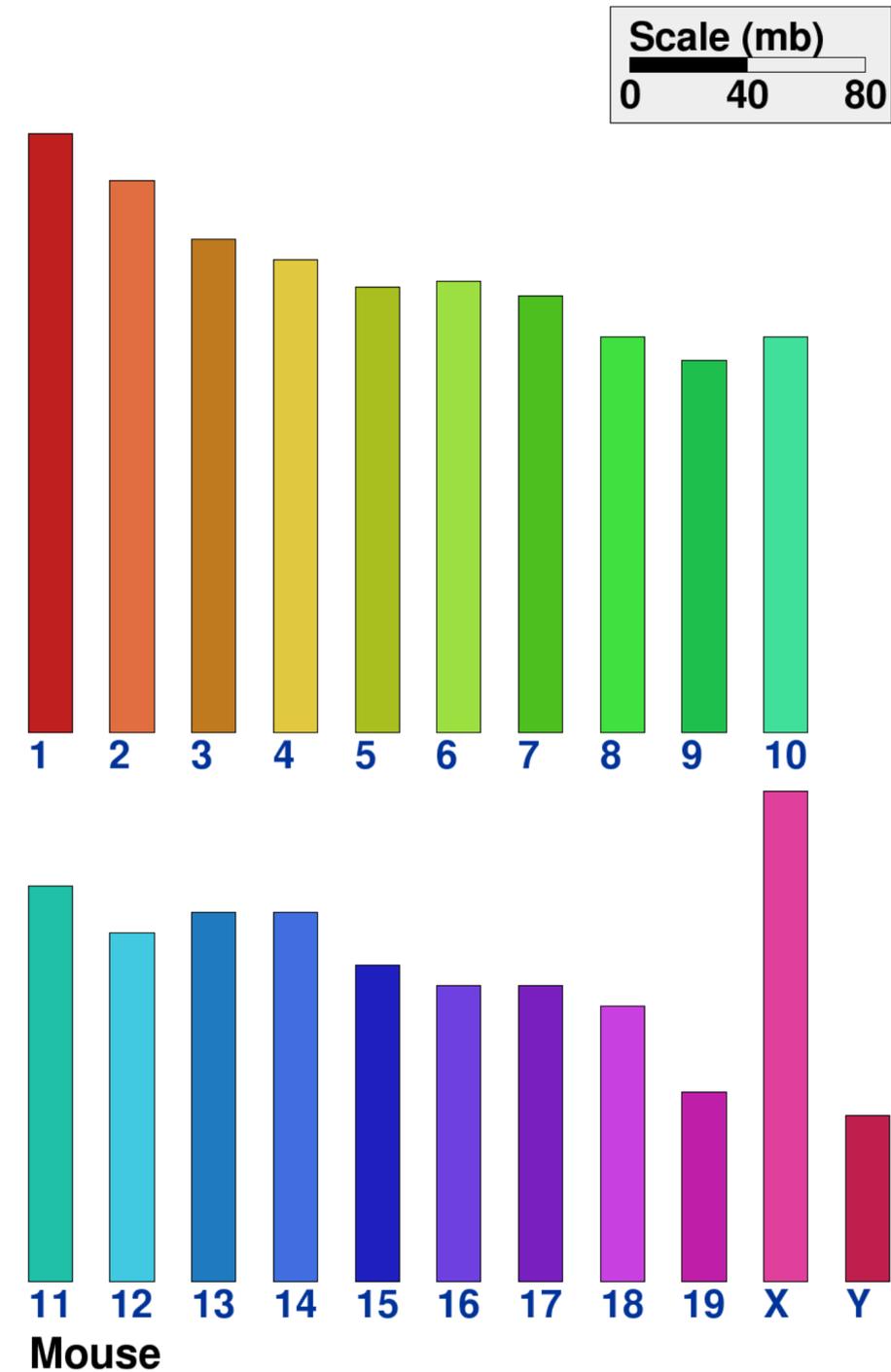
[colorbrewer2.org]

Categorical Colormaps



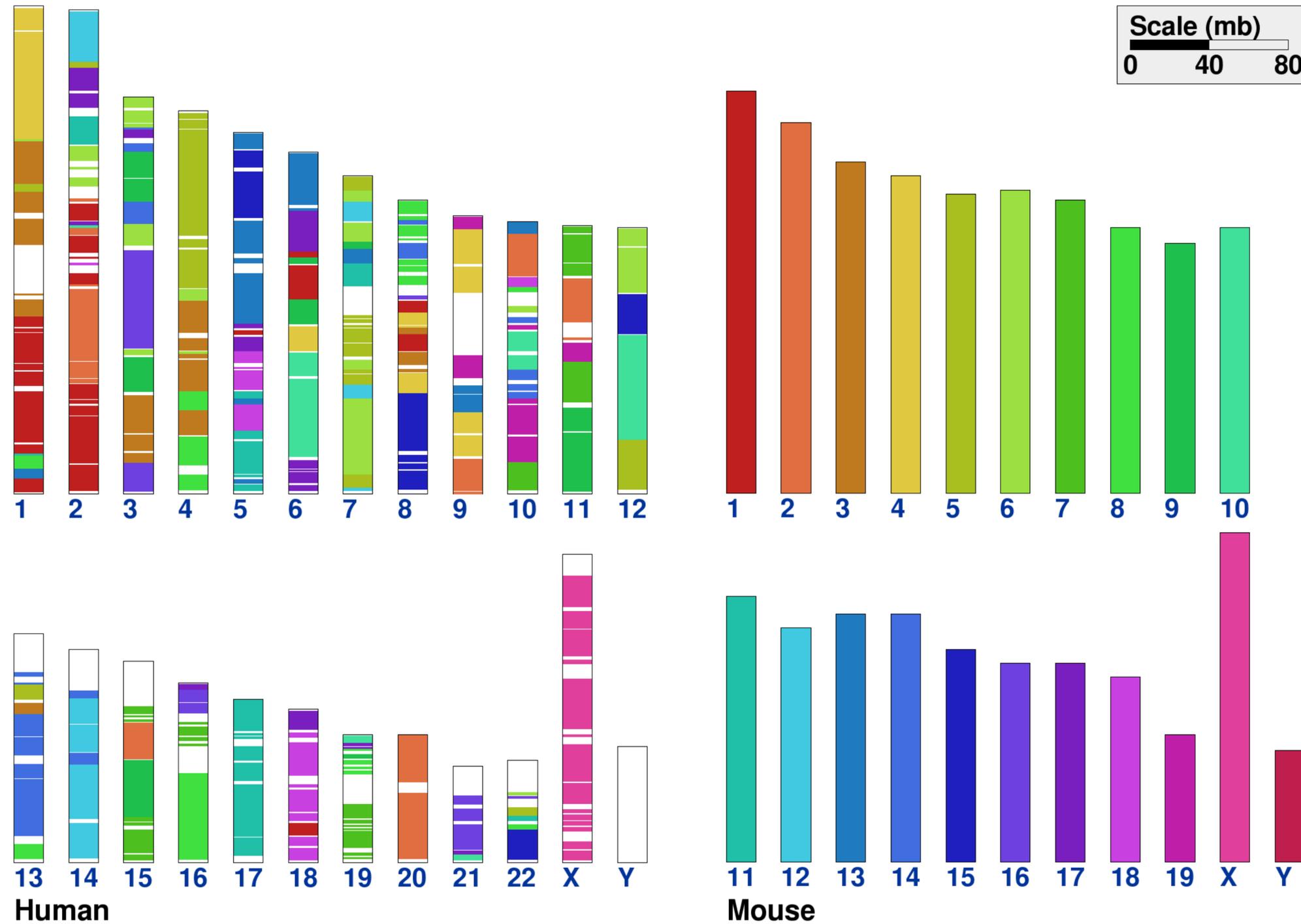
[colorbrewer2.org]

Number of distinguishable colors?



[Sinha & Meller, 2007]

Number of distinguishable colors?



[Sinha & Meller, 2007]

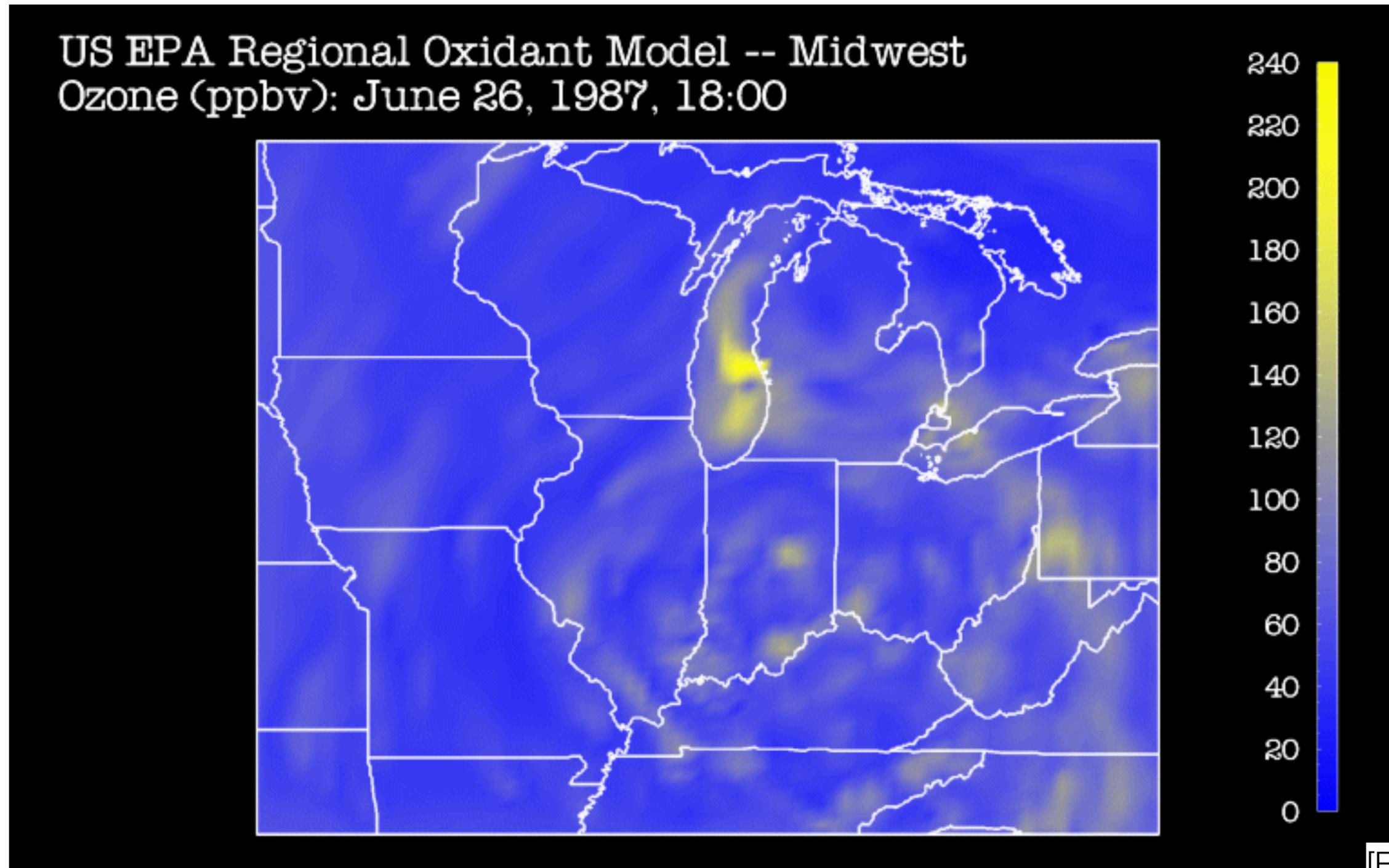
Discriminability

- 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

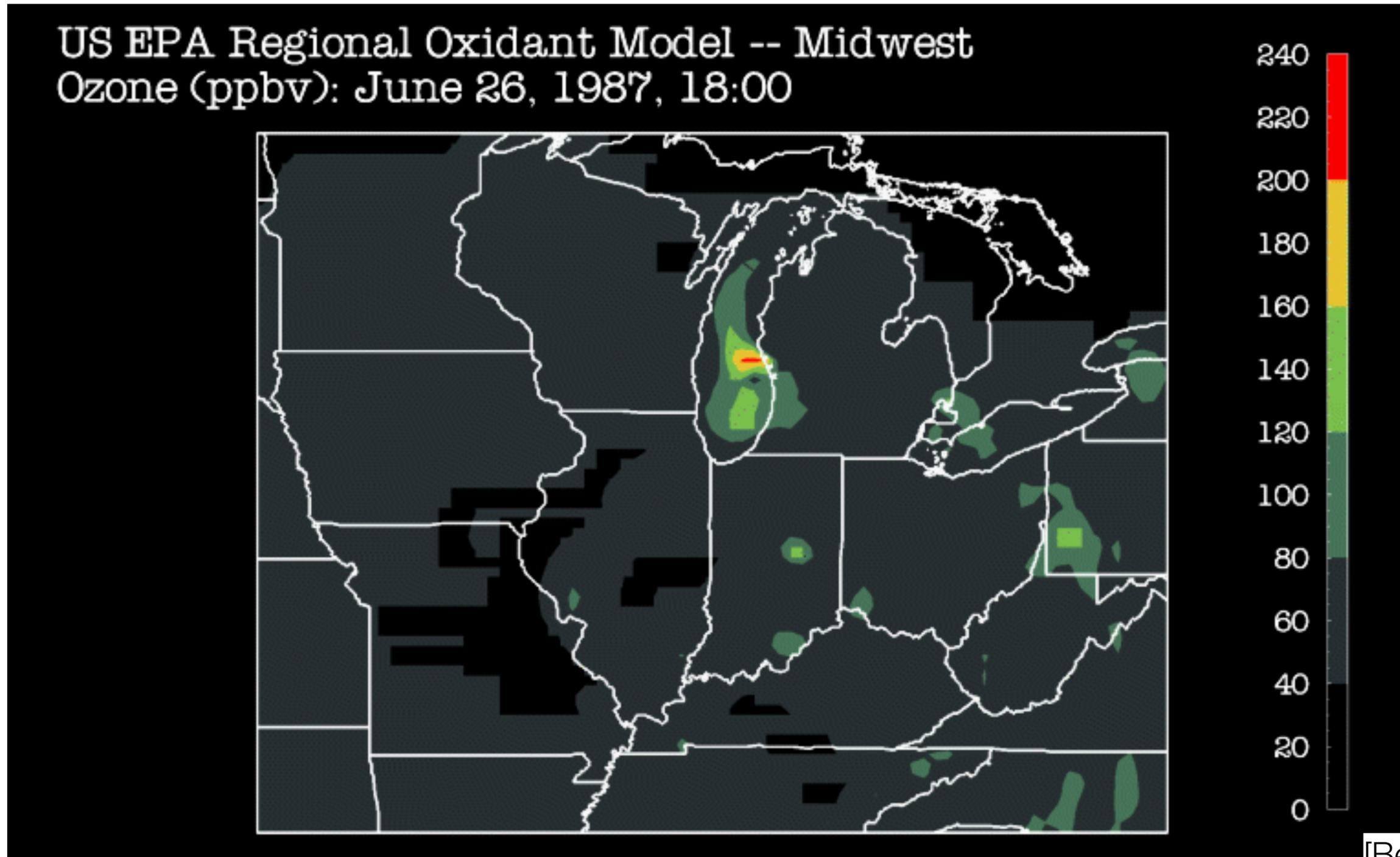
- Used for ordinal or quantitative attributes
- $[0, N]$: Sequential
- $[-N, 0, N]$: Diverging (has some meaningful midpoint)
- Can use hue, saturation, and luminance
- Remember hue is not a magnitude channel so be careful
- Can be **continuous** (smooth) or **segmented** (sharp boundaries)
 - Segmented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

Continuous Colormap



[Bergman et al., 1995]

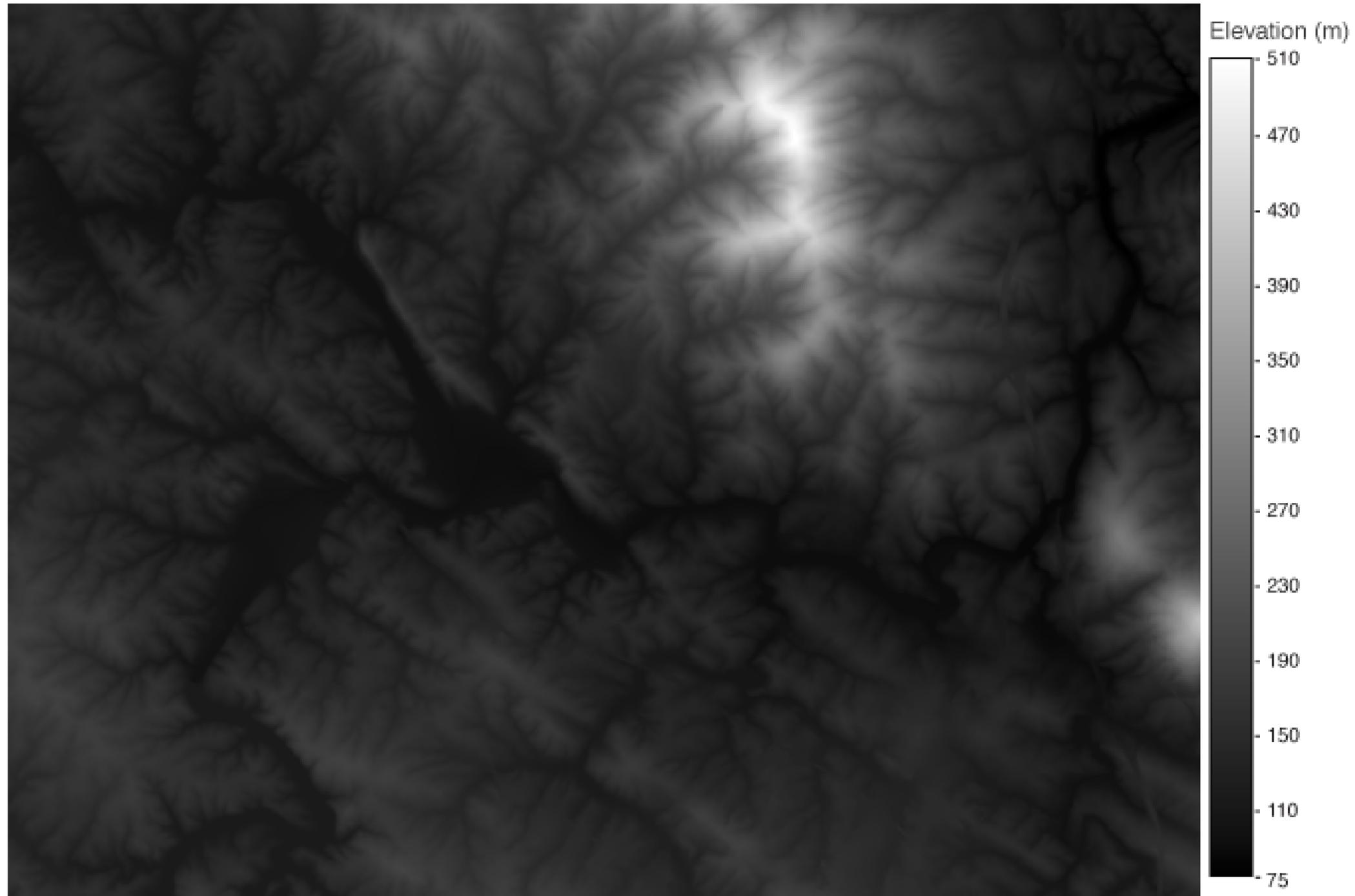
Segmented Colormap



[Bergman et al., 1995]

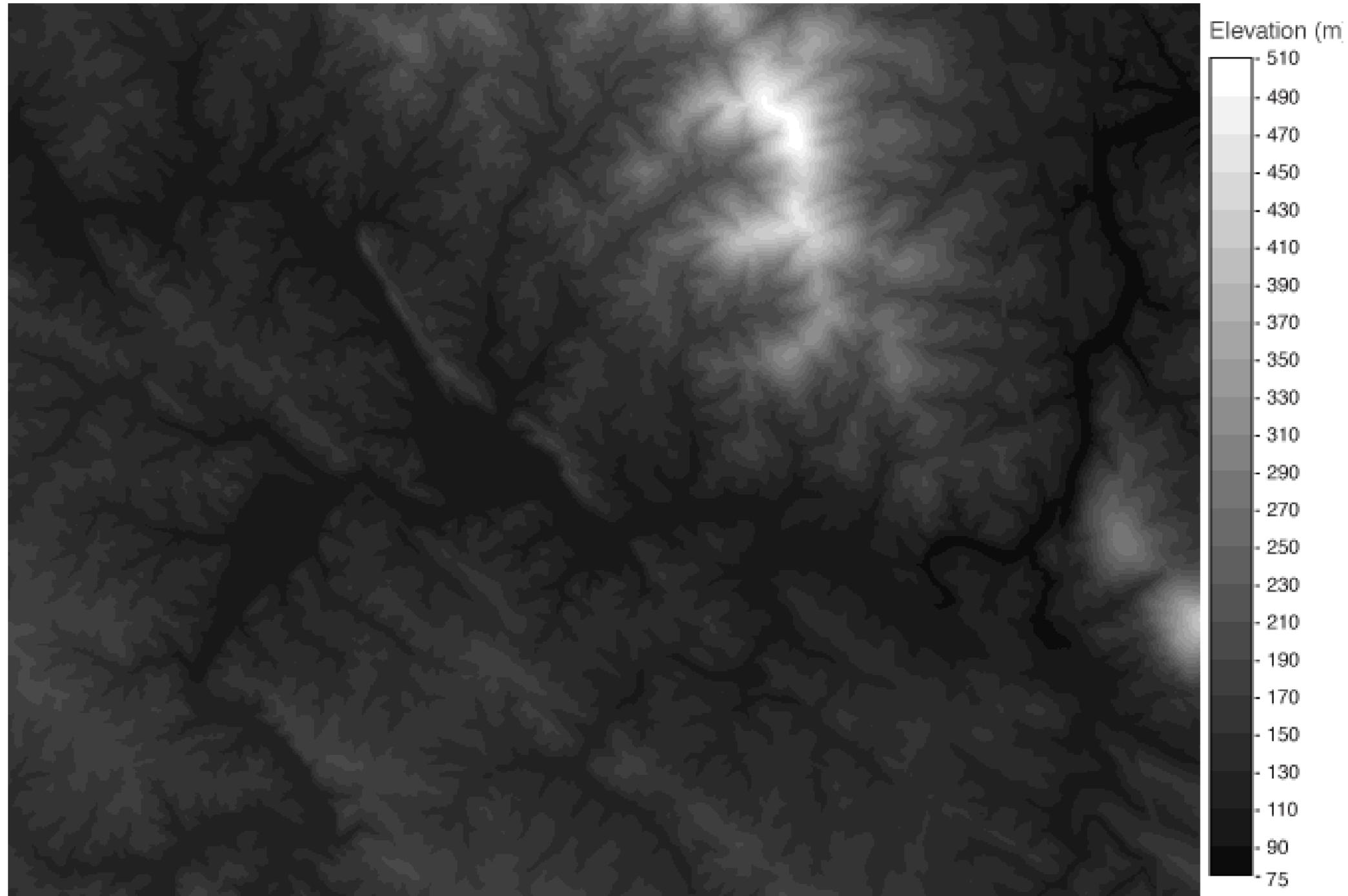
Is continuous better than segmented?

Continuous



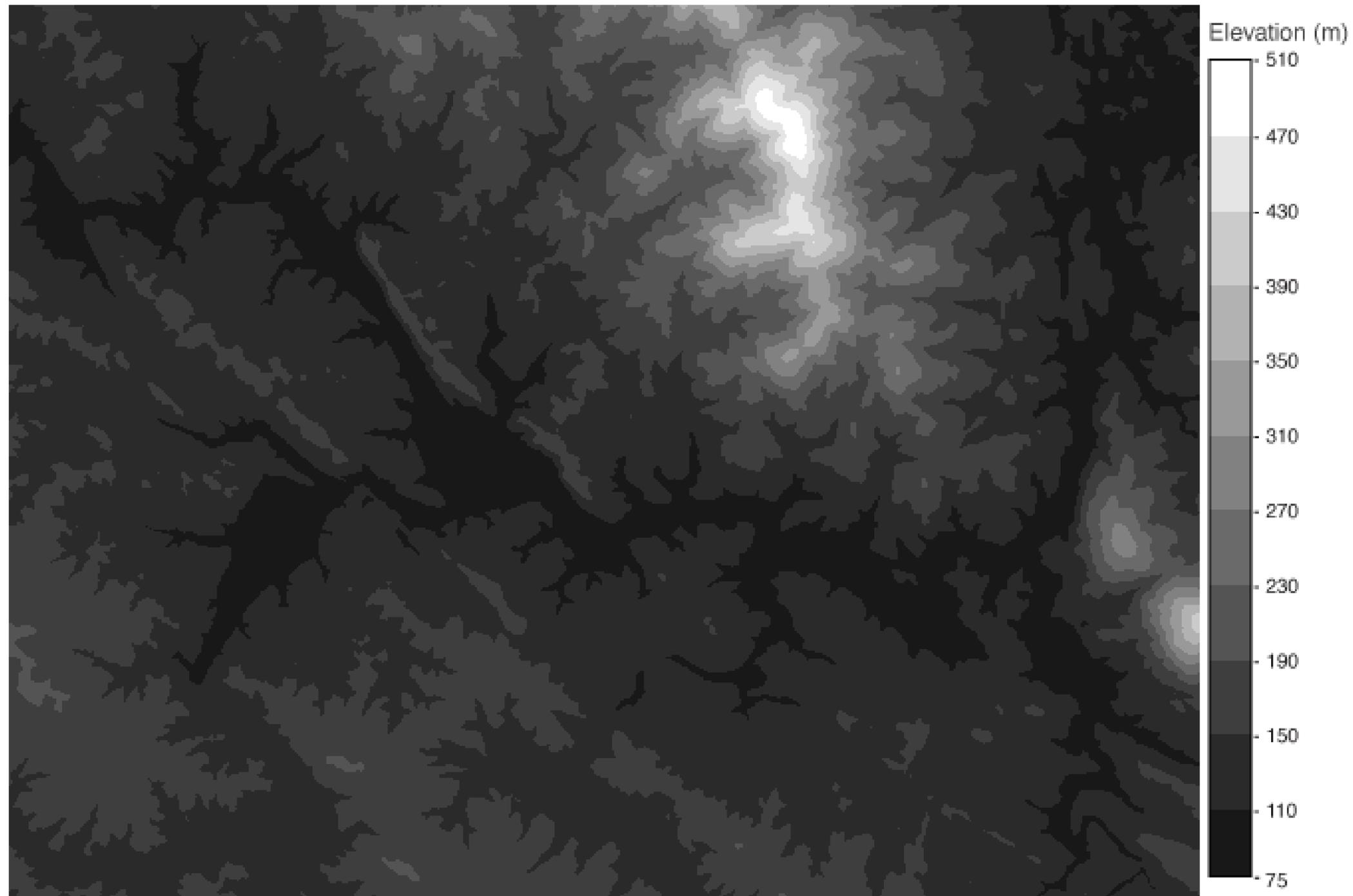
[Padilla et al., 2017]

Many Segments



[Padilla et al., 2017]

Fewer Segments



[Padilla et al., 2017]

Types of Tasks

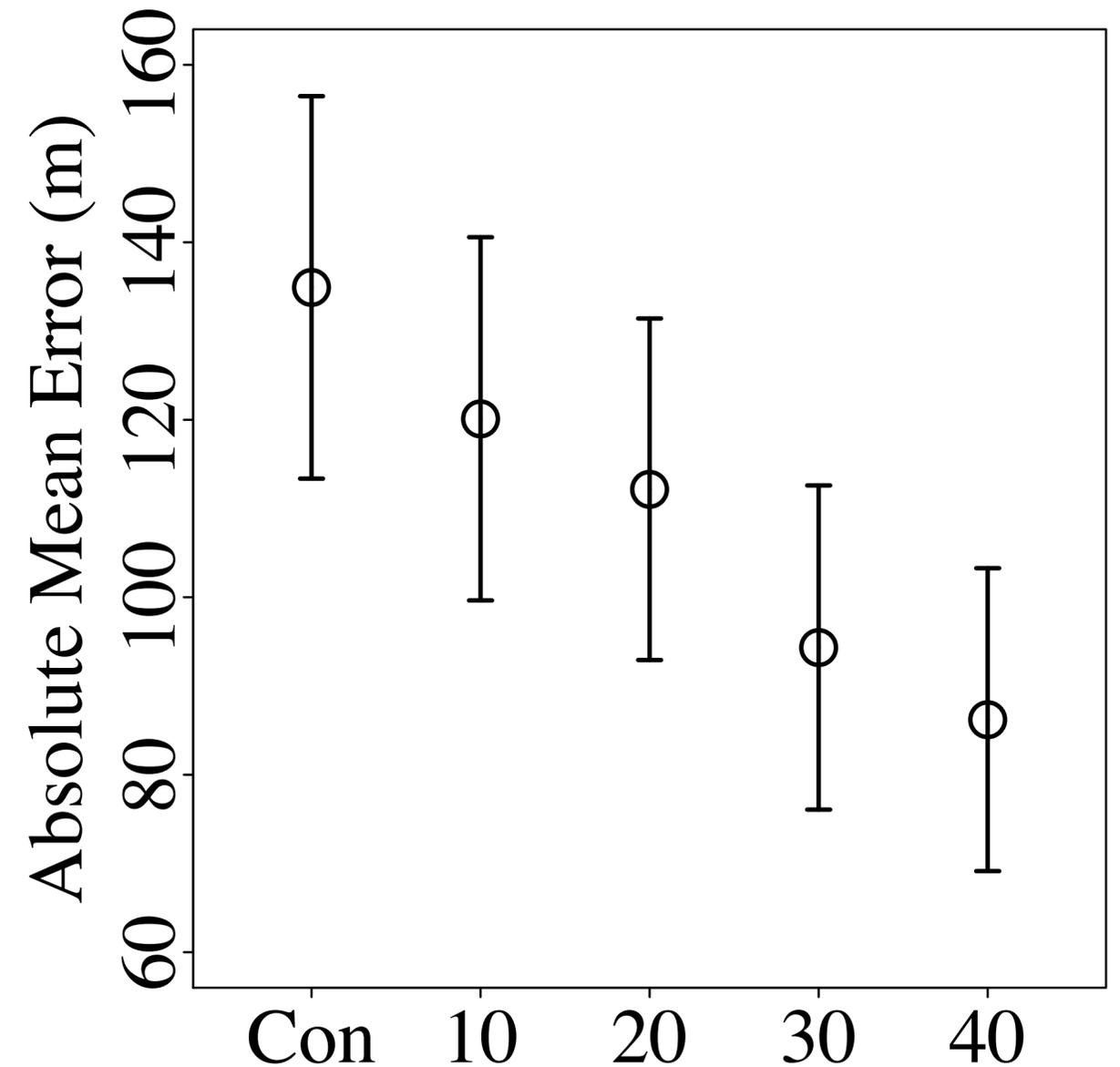
- Locate/Explore & Identify: Highest Point (Global, In Region), 275m
- Locate/Explore & Compare: Height Compare/Rank
- Explore & Identify: Steepest
- Lookup & Identify: Lookup
- Explore & Compare: Steepness Compare/Rank
- Browse & Summarize: Average Height
- Browse & Compare: Compare Average Height
- Combination: Steepest at 355m

[Padilla et al., 2017]

Results

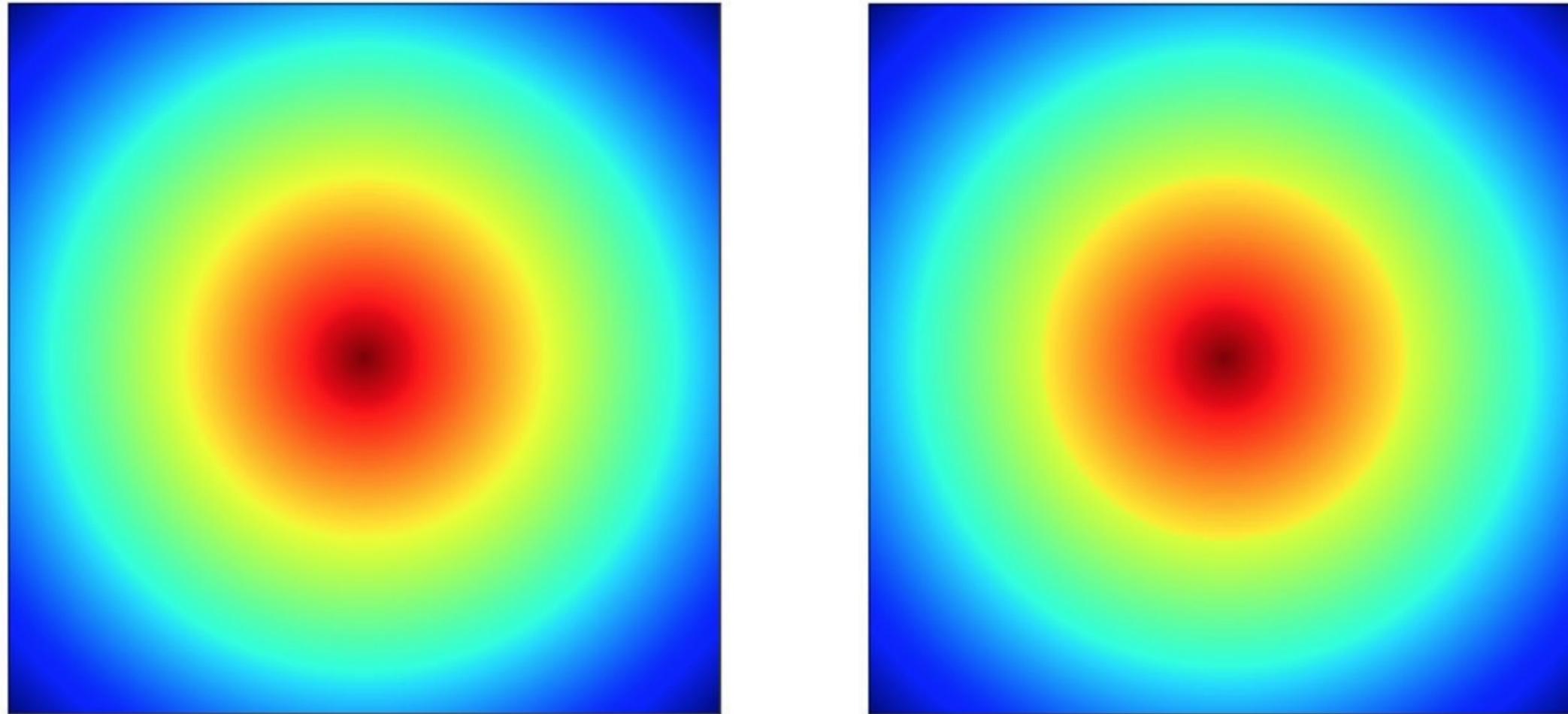
- "[C]ontrary to the expressiveness principle, no cases were found in which a continuous encoding of 2D scalar field data was advantageous for task accuracy, and for some tasks, specific binned encodings facilitated accuracy."
- "[S]upport for the counterintuitive finding that decisions with binned encoding were slower than those made with continuous encoding"
- Word of caution: single image!

Lookup Task (Lower)



[Padilla et al., 2017]

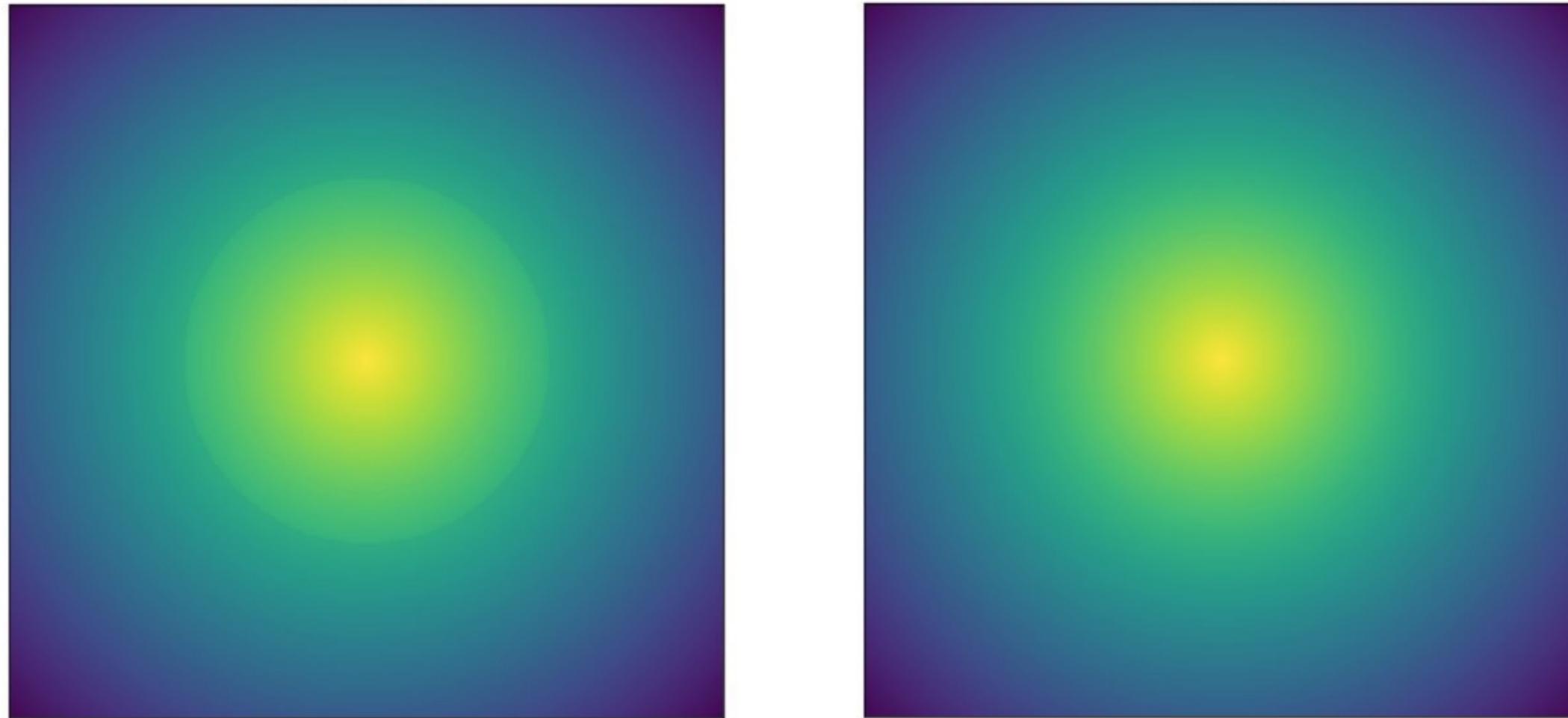
Don't Use Rainbow Colormaps



Which has a discontinuity?

[M. Bussonnier]

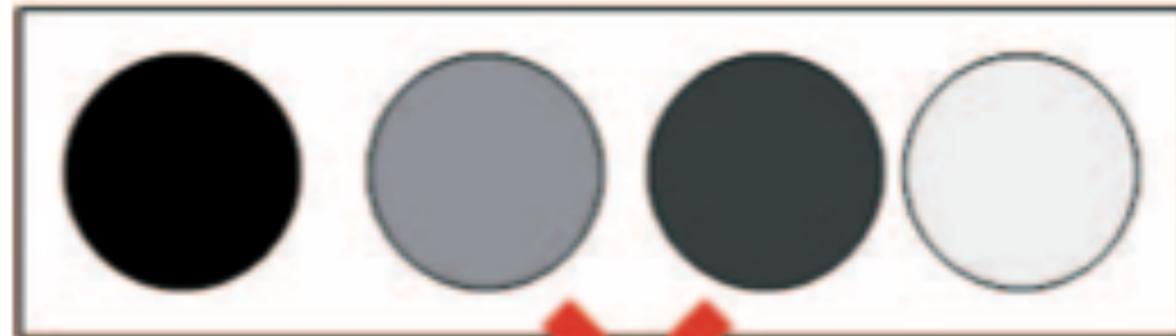
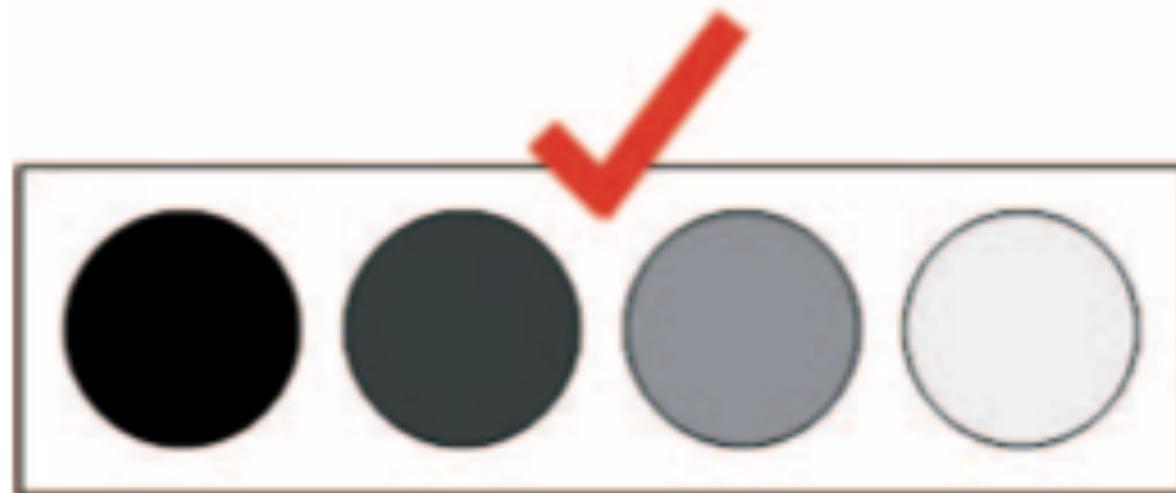
Other Colormaps Work Better



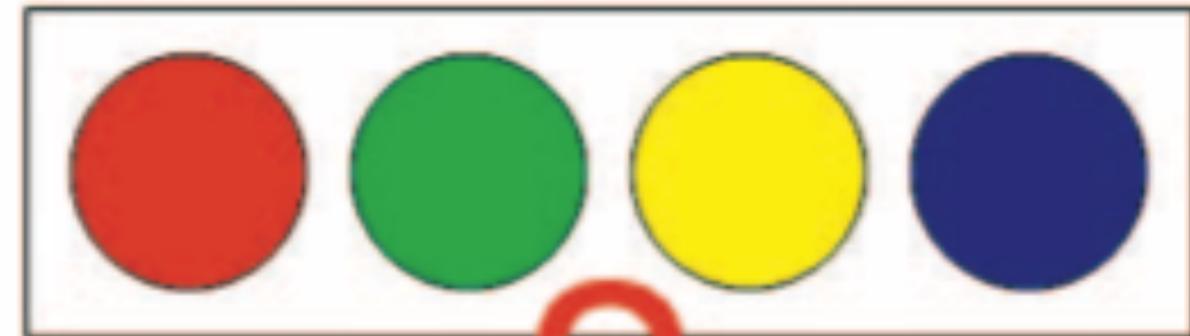
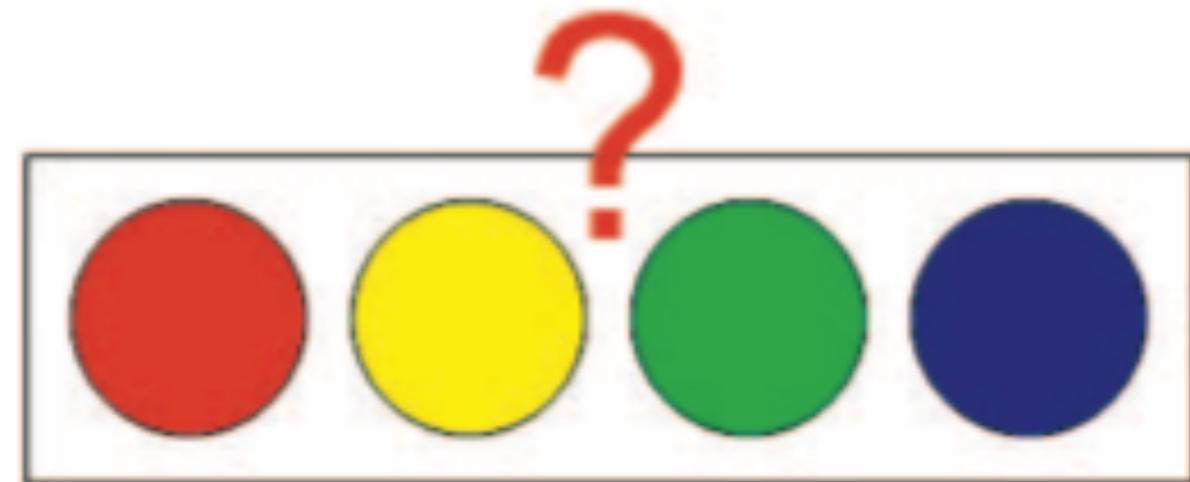
Which has a discontinuity?

[M. Bussonnier]

Ordering Color?



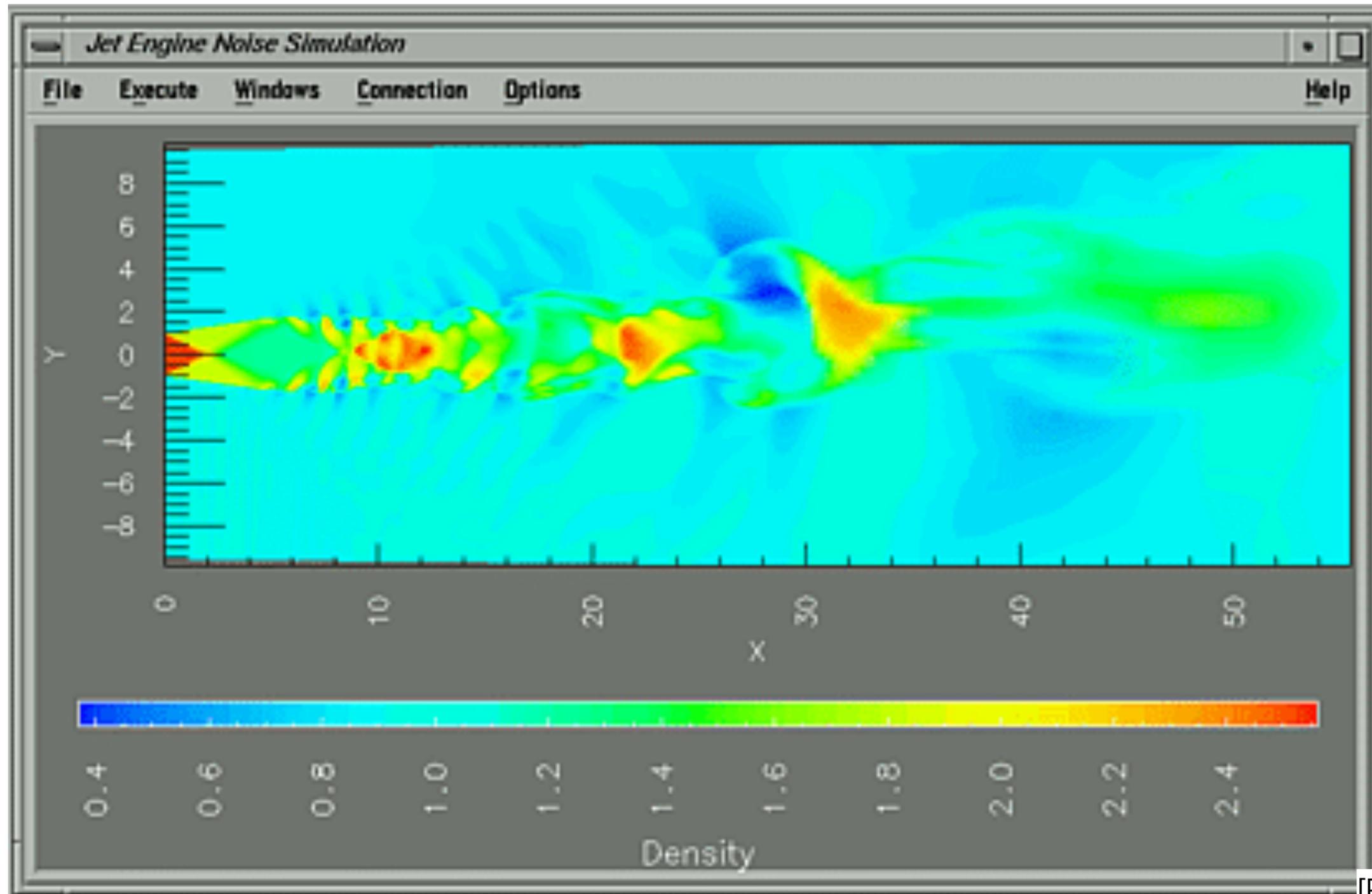
(a)



(b)

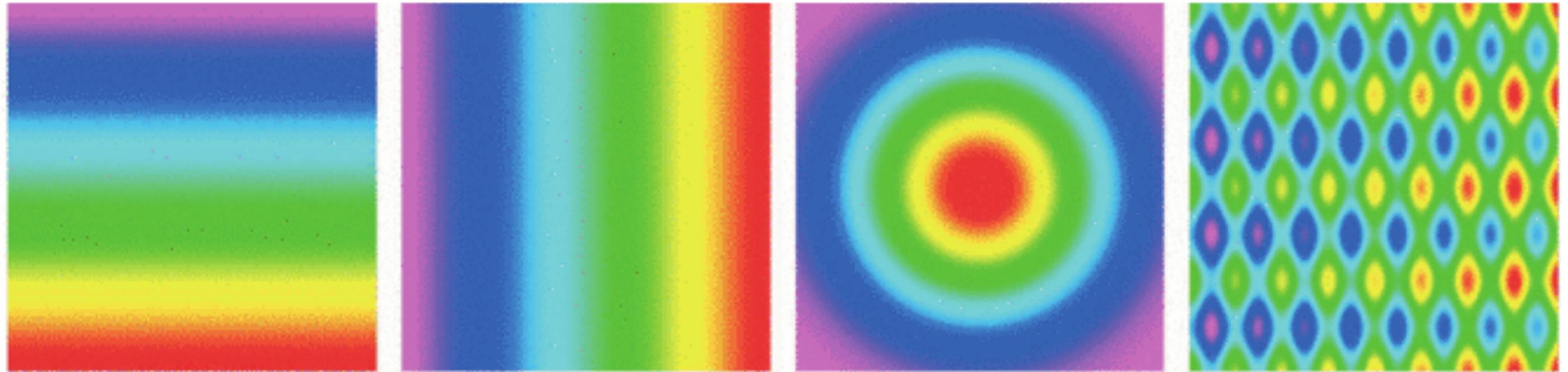
[Borland & Taylor, 2007]

Rainbow Colormap



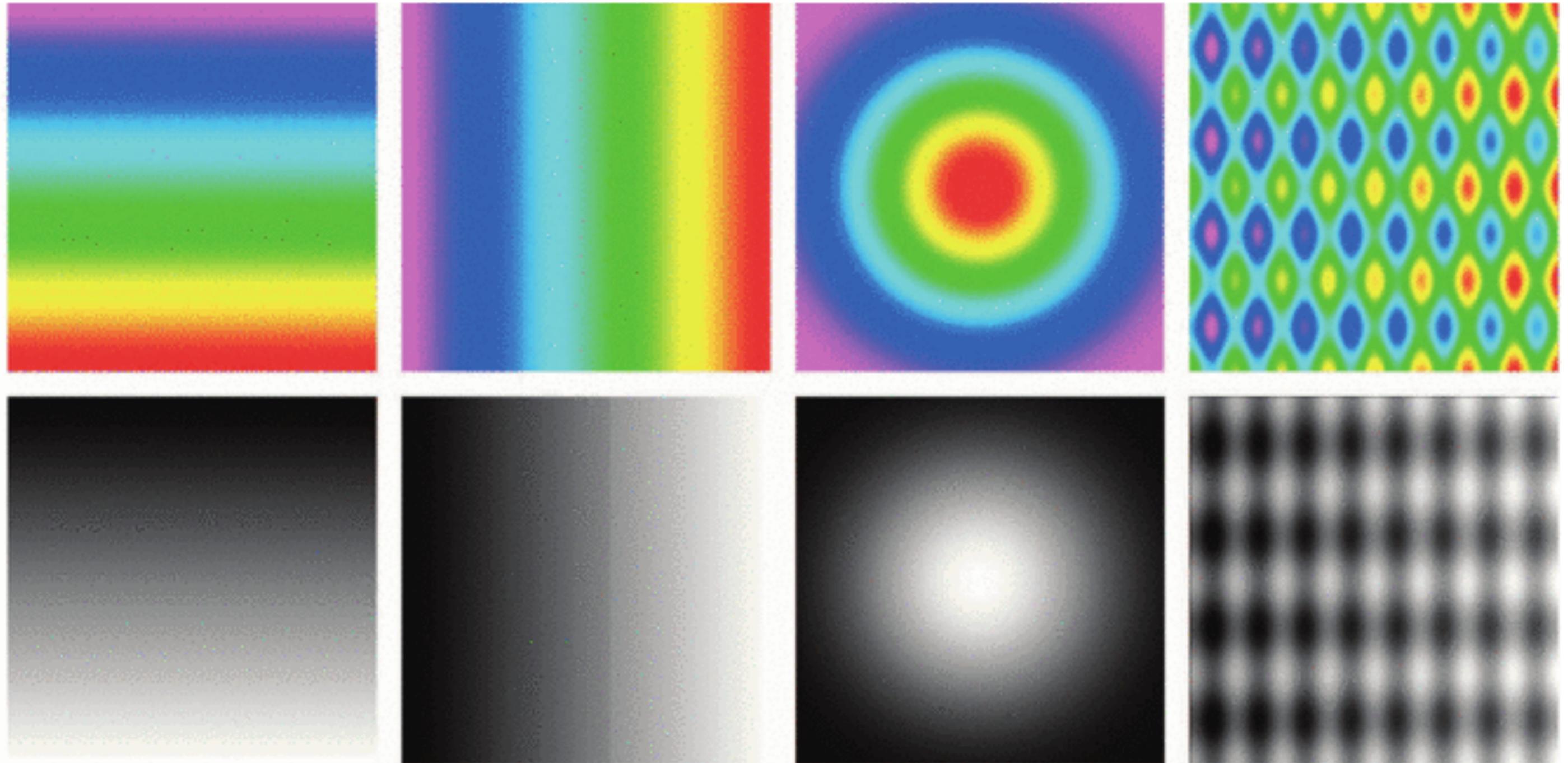
[Bergman et al., 1995]

Artifacts from Rainbow Colormaps



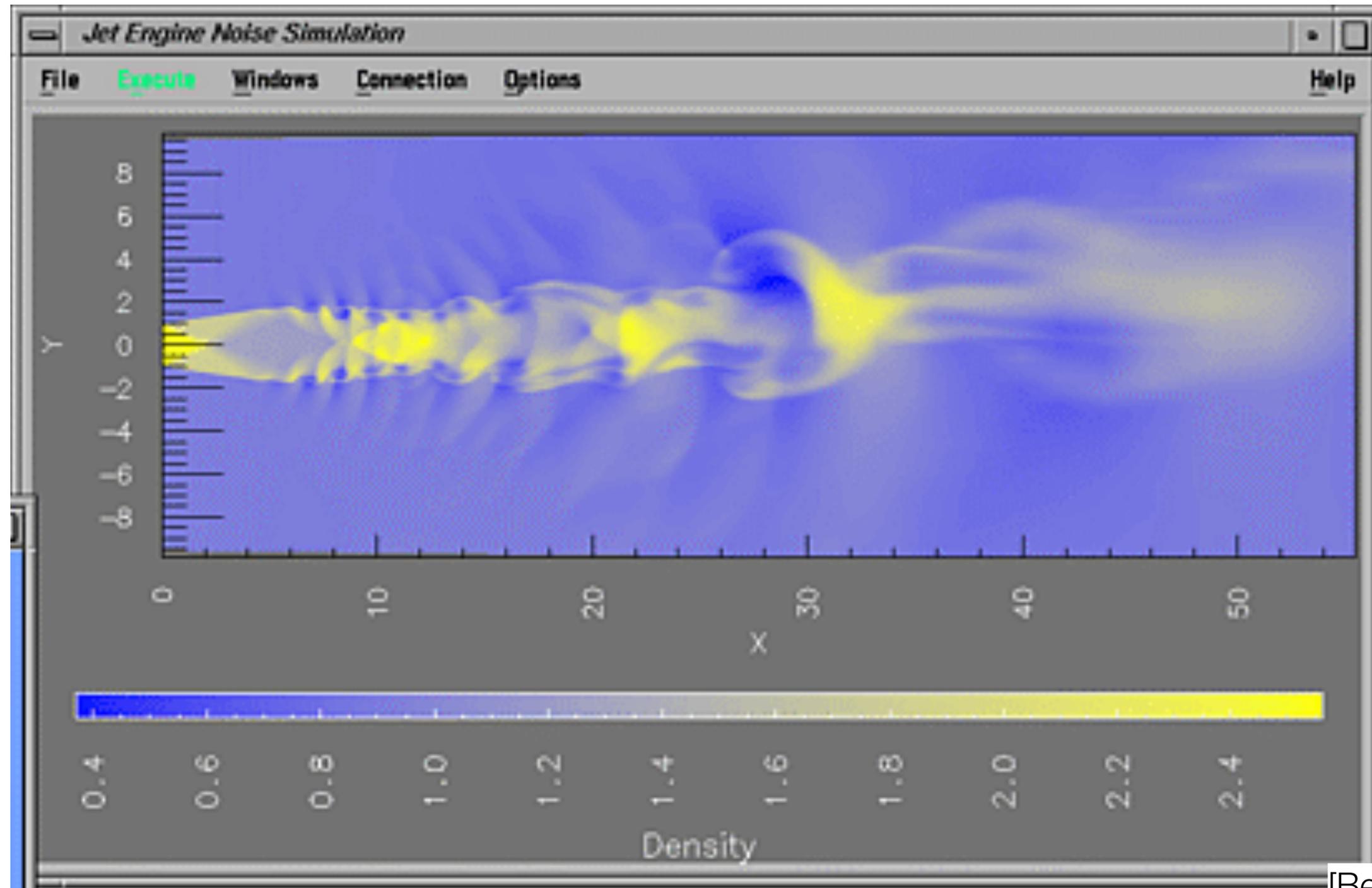
[Borland & Taylor, 2007]

Artifacts from Rainbow Colormaps



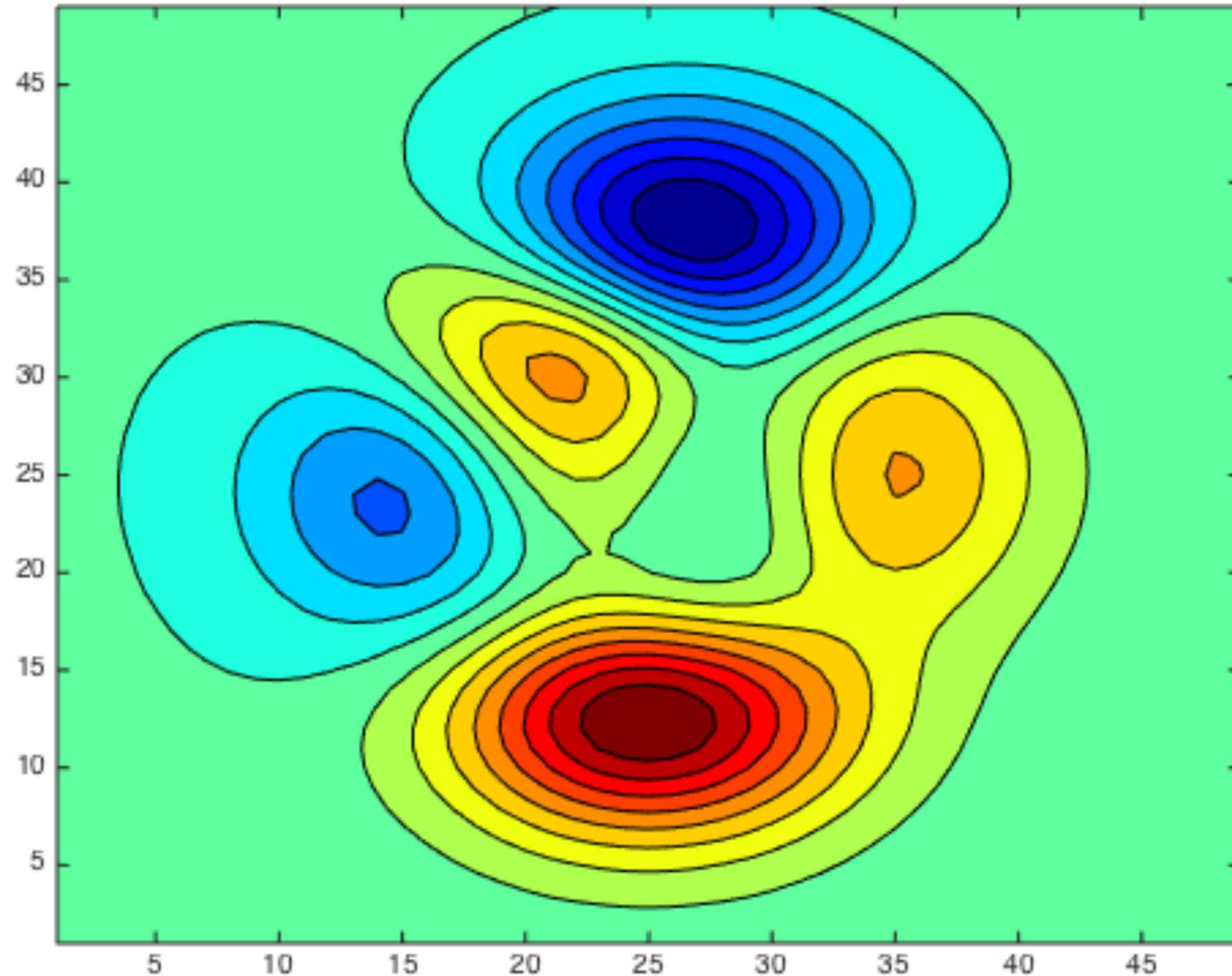
[Borland & Taylor, 2007]

Two-Hue Colormap



[Bergman et al., 1995]

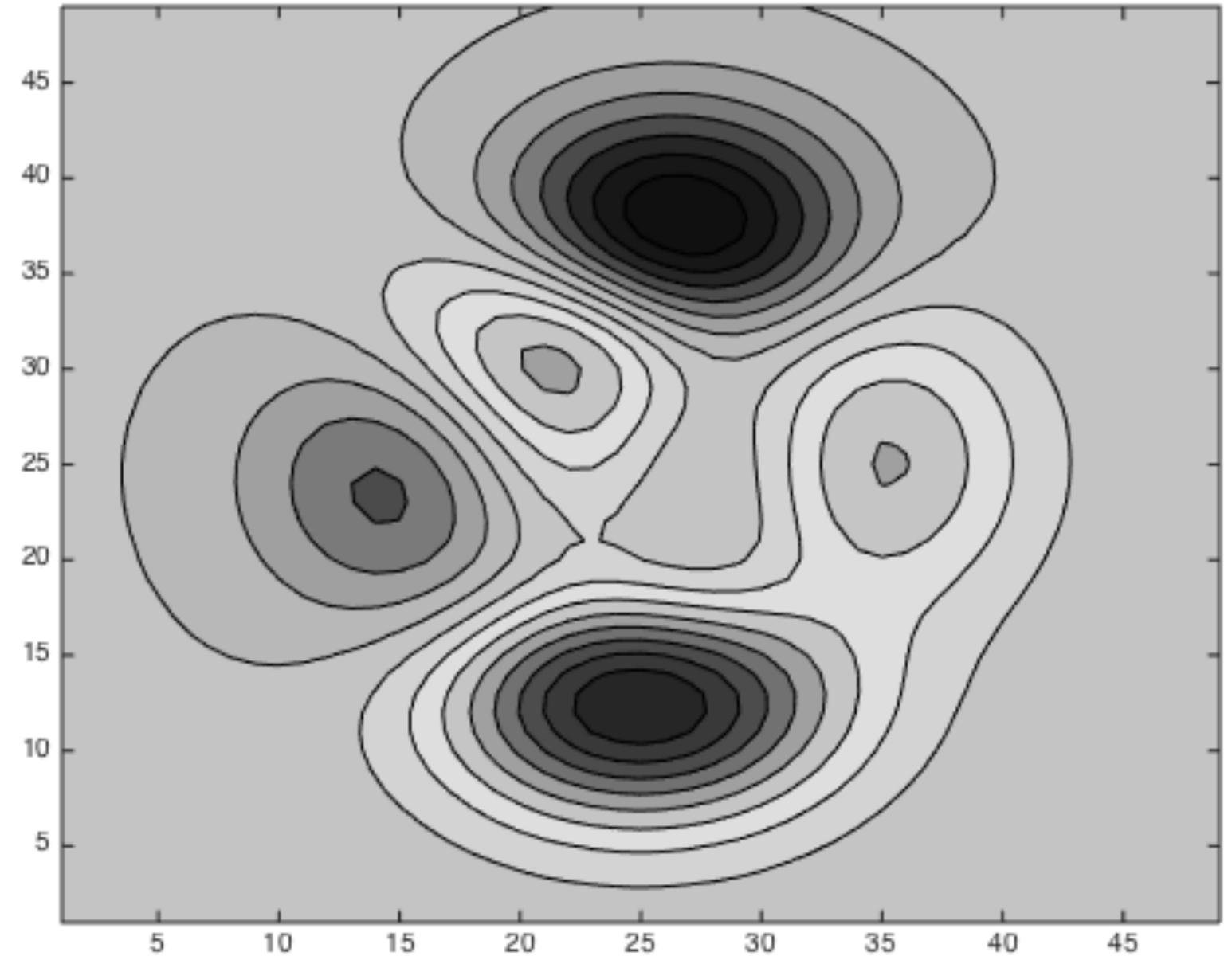
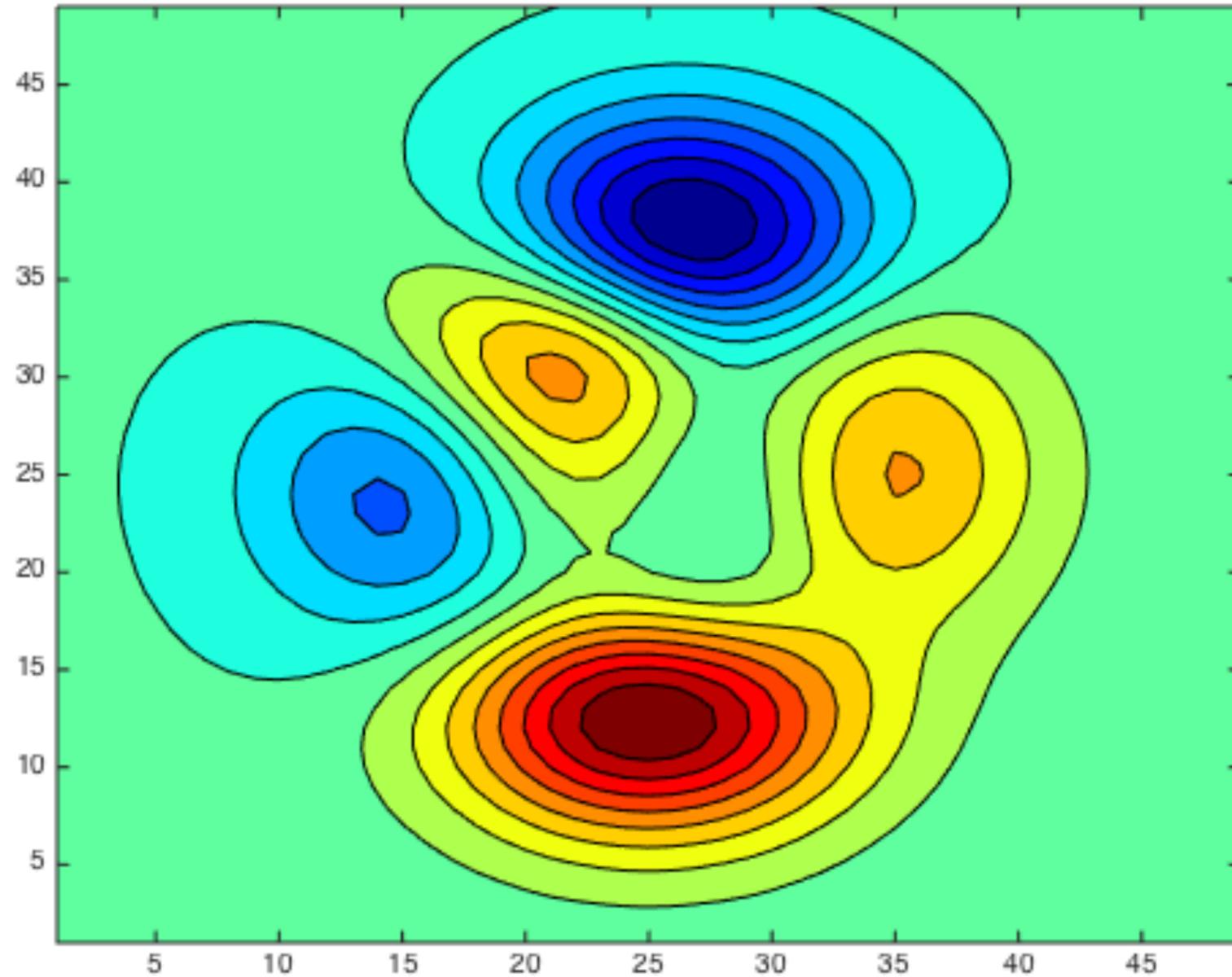
"Get It Right in Black and White" - M. Stone



jet colormap

[S. Eddins ([Matlab Blog](#)), 2014]

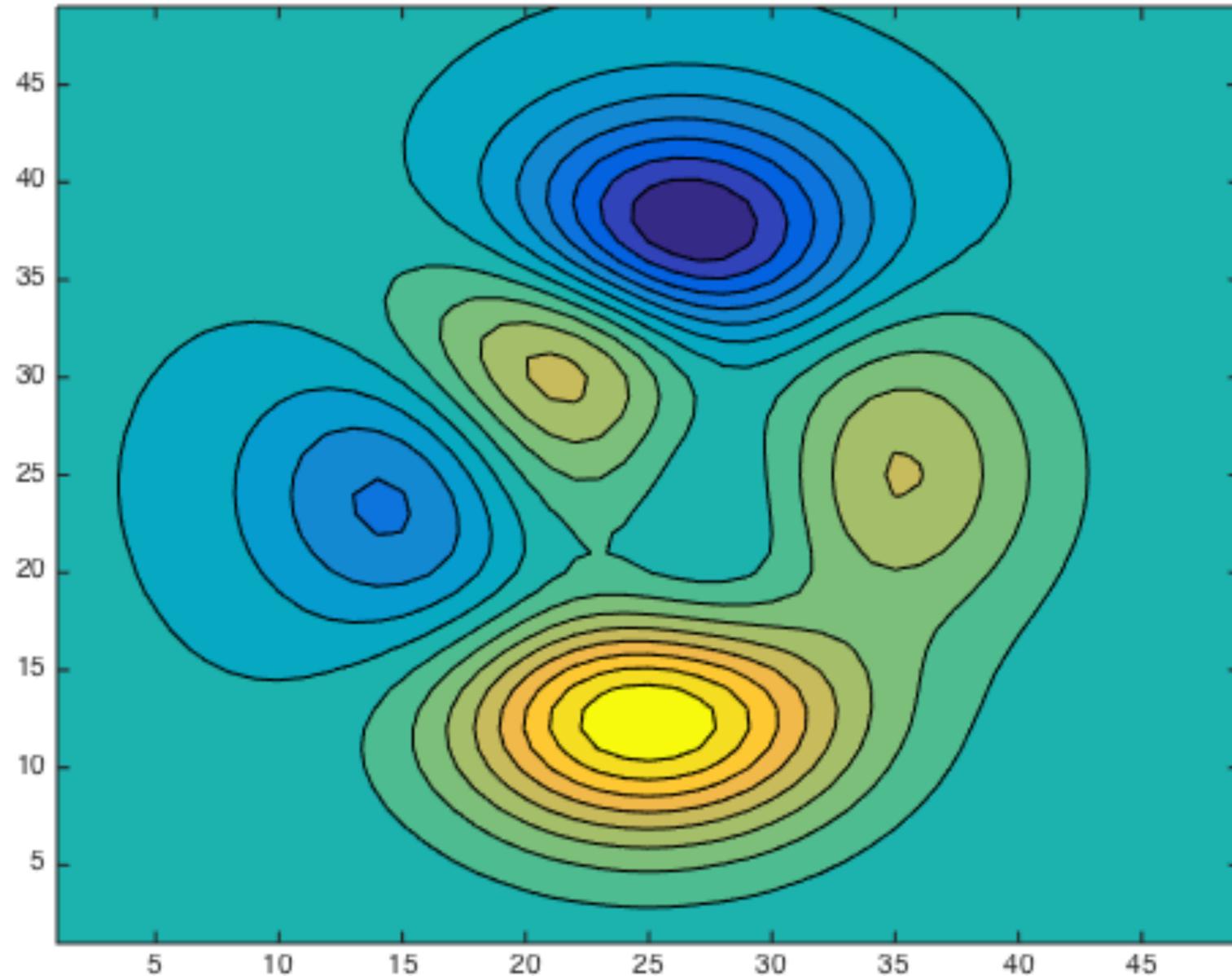
"Get It Right in Black and White" - M. Stone



jet colormap

[S. Eddins ([Matlab Blog](#)), 2014]

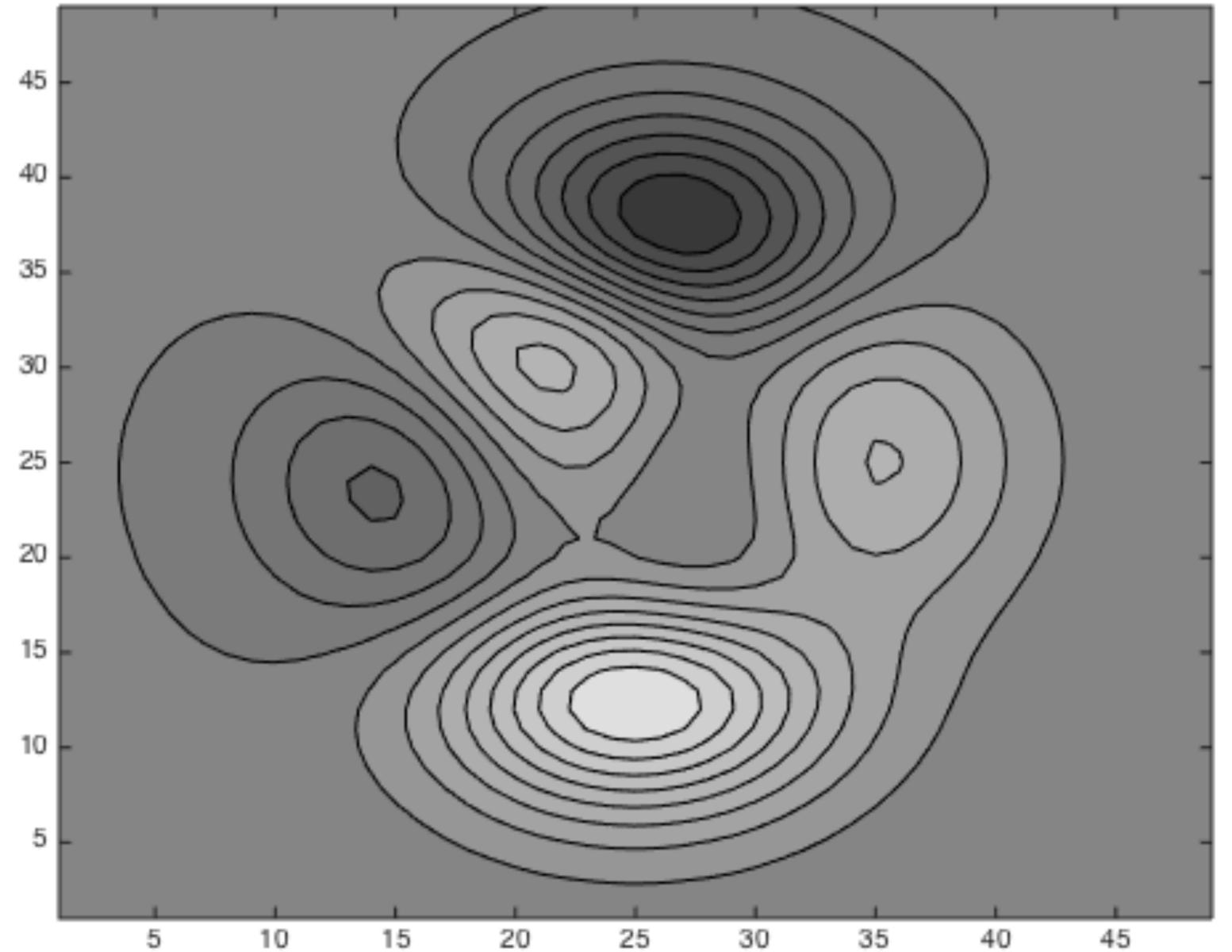
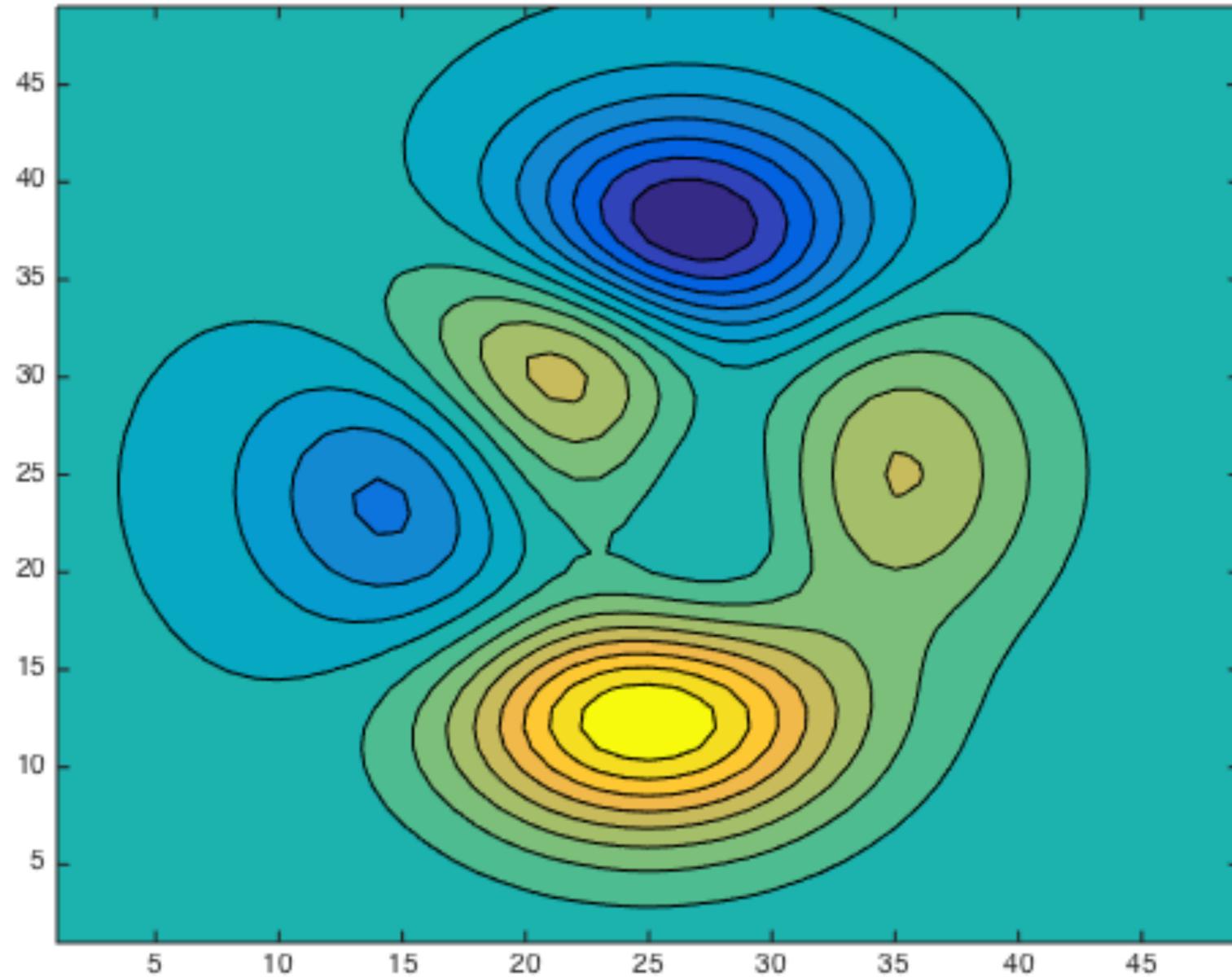
"Get It Right in Black and White" - M. Stone



parula colormap

[S. Eddins ([Matlab Blog](#)), 2014]

"Get It Right in Black and White" - M. Stone



parula colormap

[S. Eddins ([Matlab Blog](#)), 2014]

Isoluminant Rainbow Colormap



Original



Isoluminant

[Kindlmann et al., 2002]

Turbo Colormap (August 2019)

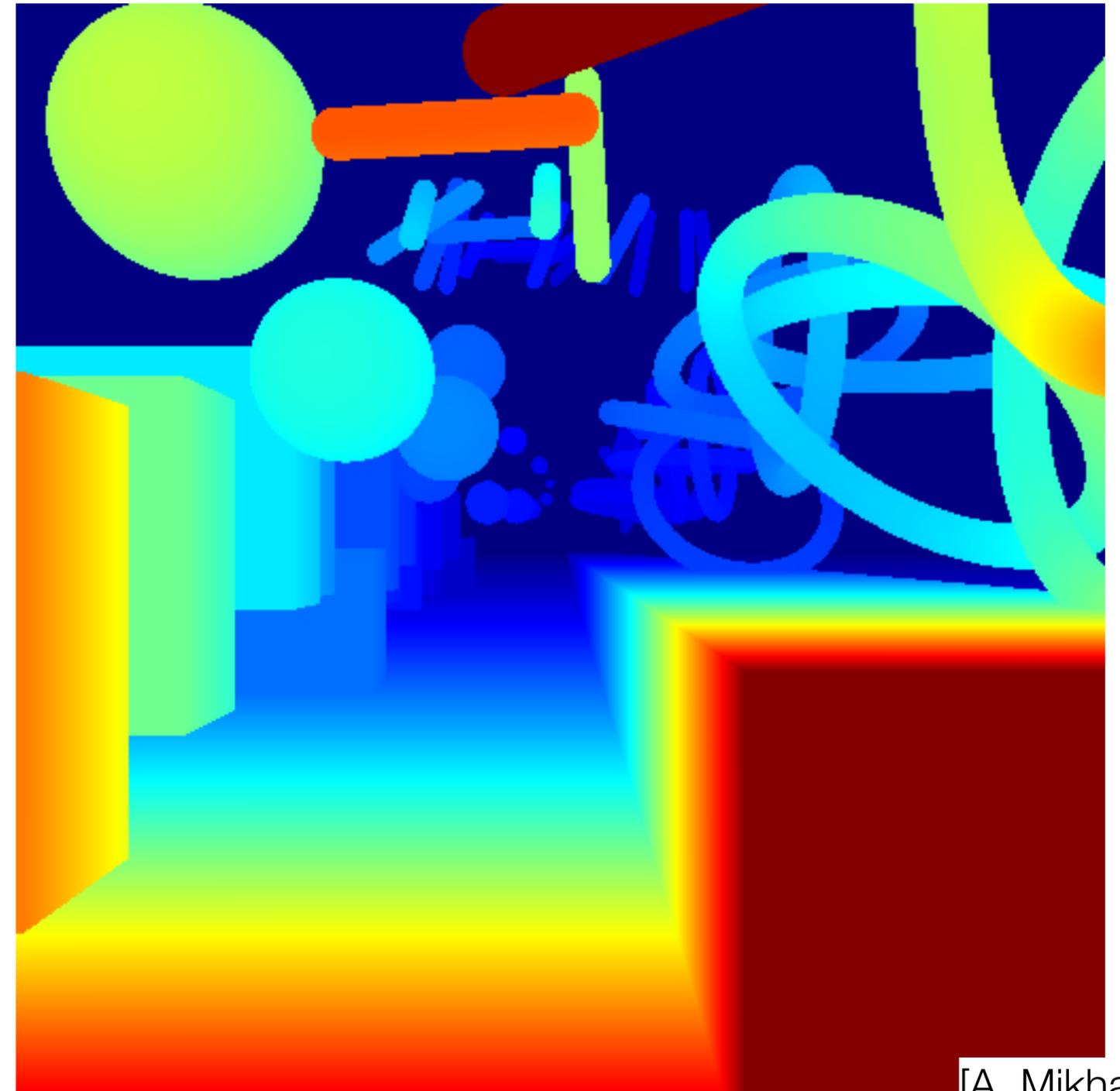
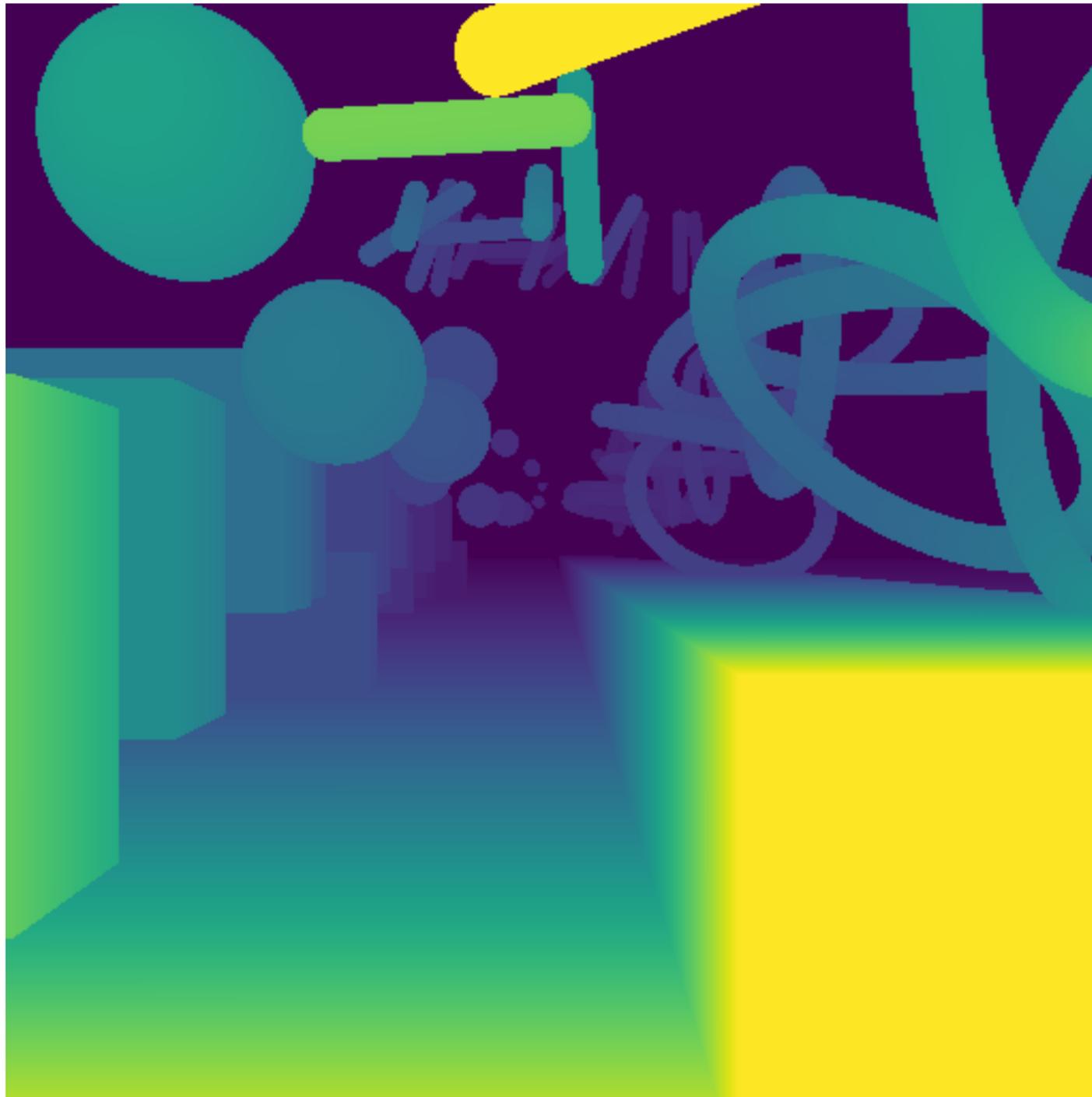


Jet



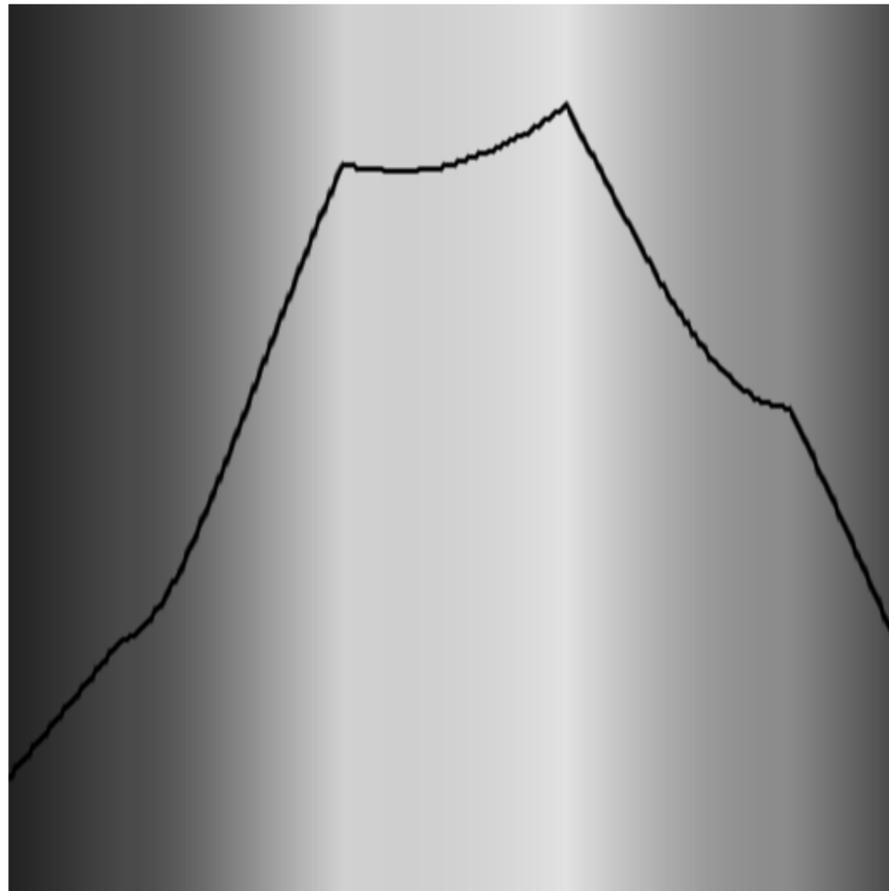
Turbo

Turbo: More Detail in Disparity Maps?

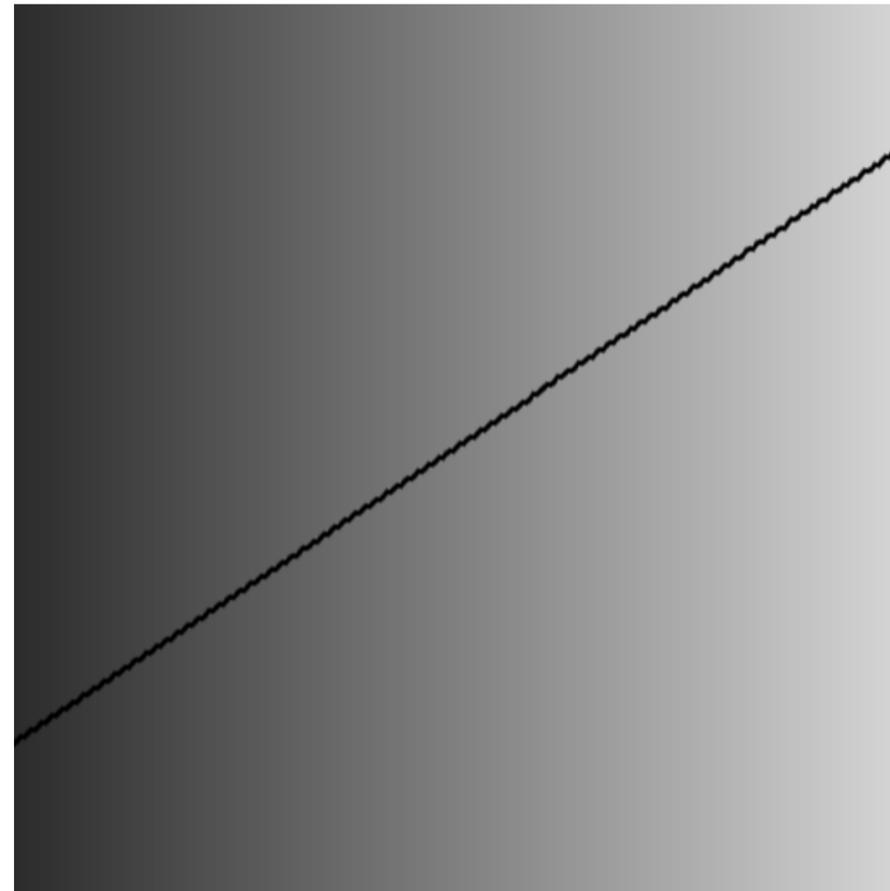


[A. Mikhailov]

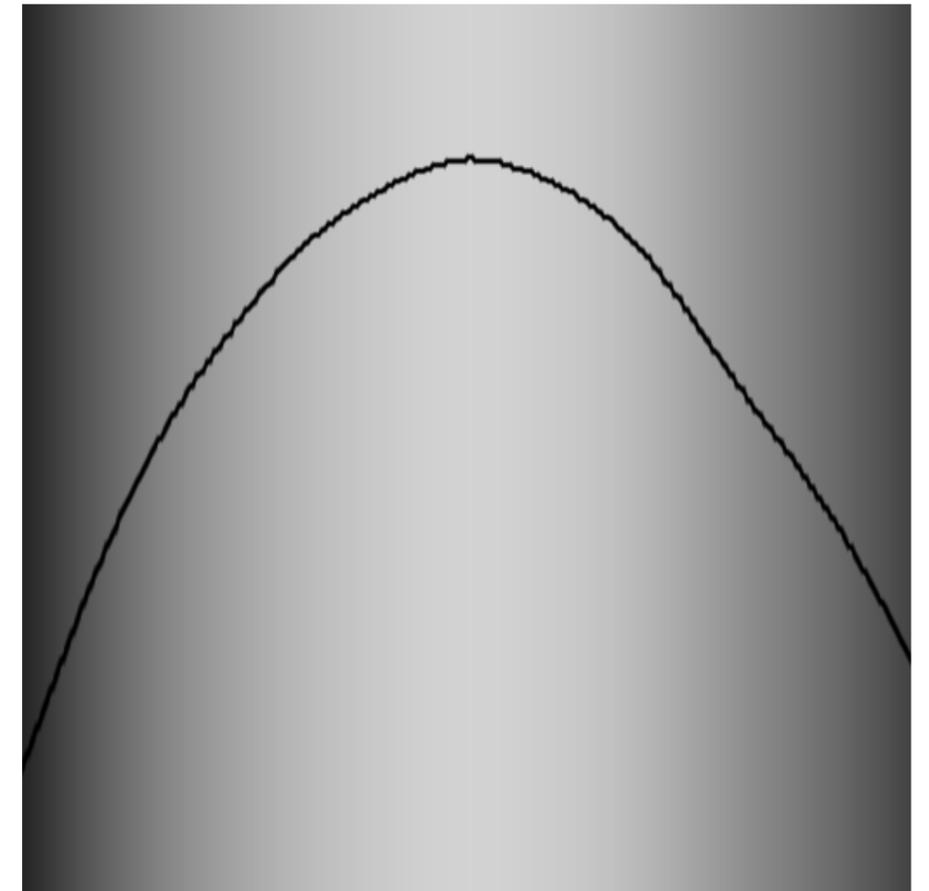
Turbo: Lightness Profiles



Jet



Viridis



Turbo

[A. Mikhailov]

Turbo Discussion

- Turbo is an improvement over jet
- Some fields (e.g. meteorology) have long used rainbow-like colormaps
- Argument is that segments are more easily located
- Turbo post claims that hue is prioritized in attention, but this seems to misinterpret the study...
- Brightness and saturation are more important than hue in attracting attention [Camgöz et al., 2004 h/t J. Stevens]