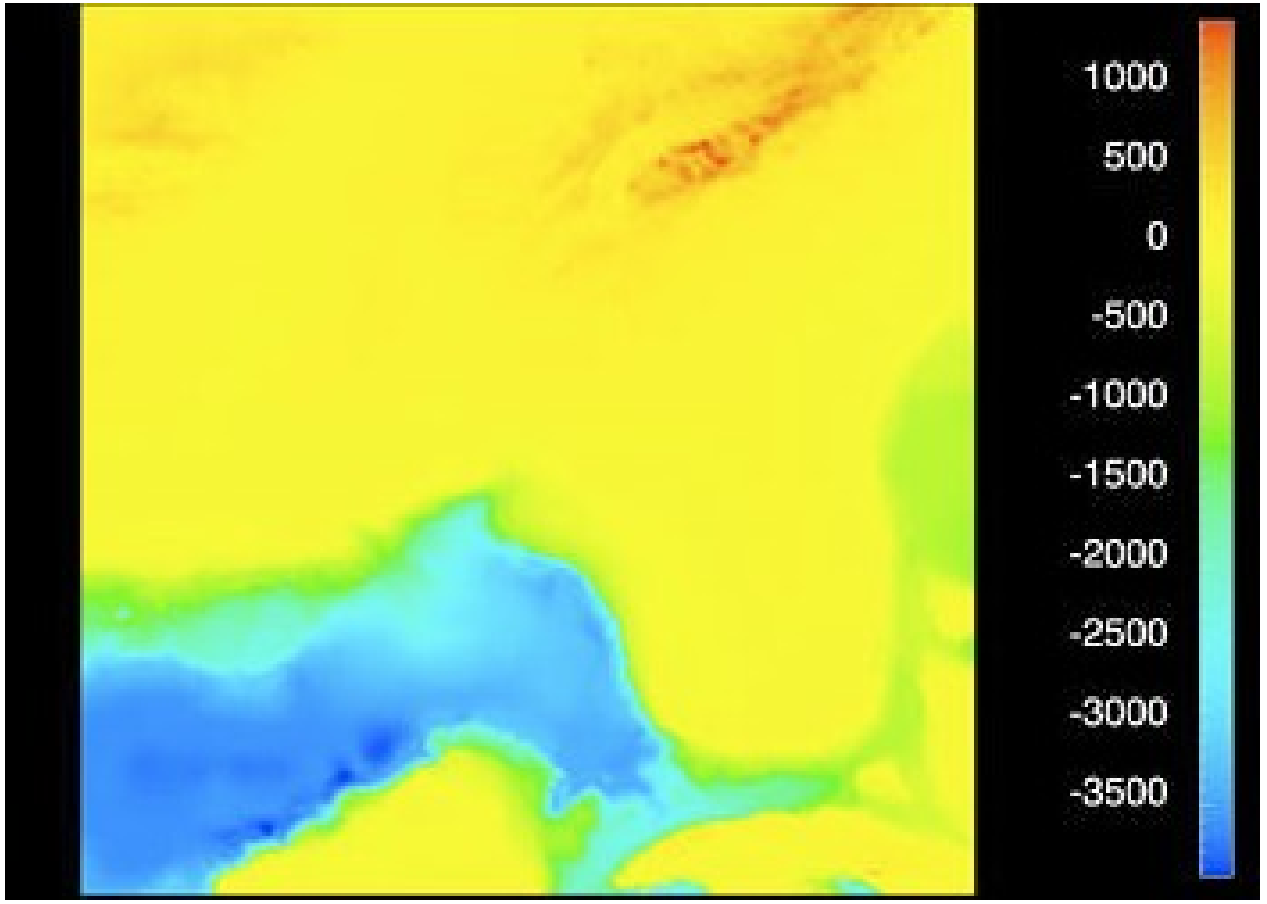
Color

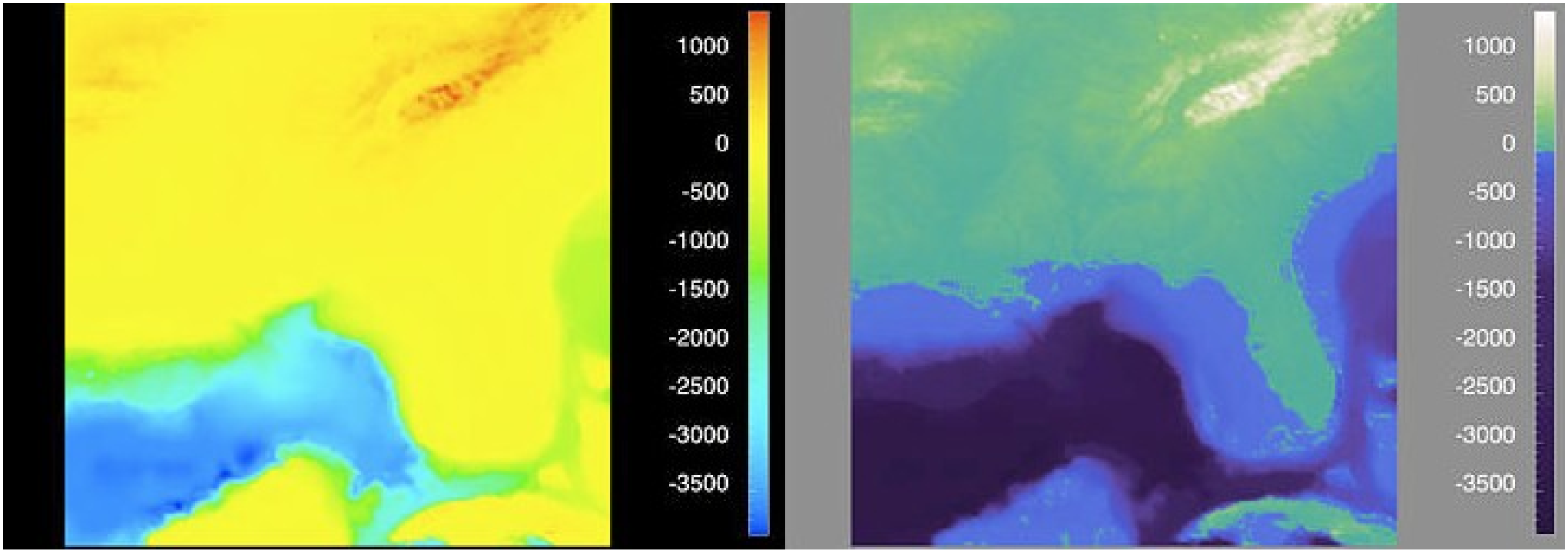
Thomas Torsney-Weir

Importance of color



Rogowitz, B.E., and L.A. Treinish. “Data Visualization: The End of the Rainbow.” IEEE Spectrum 35, no. 12 (December 1998): 52–59. https://doi.org/10.1109/6.736450.

Importance of color



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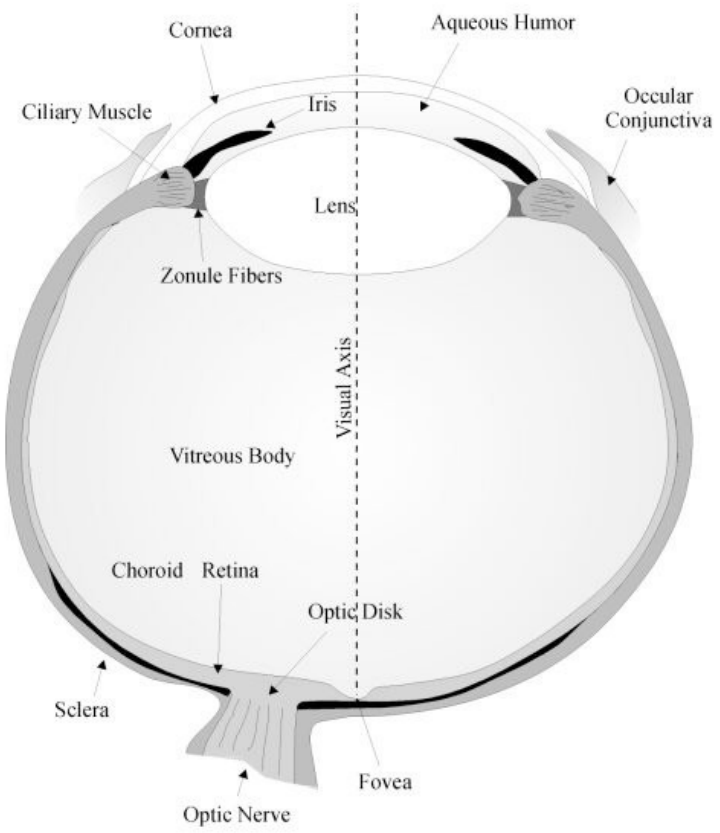
Importance of color

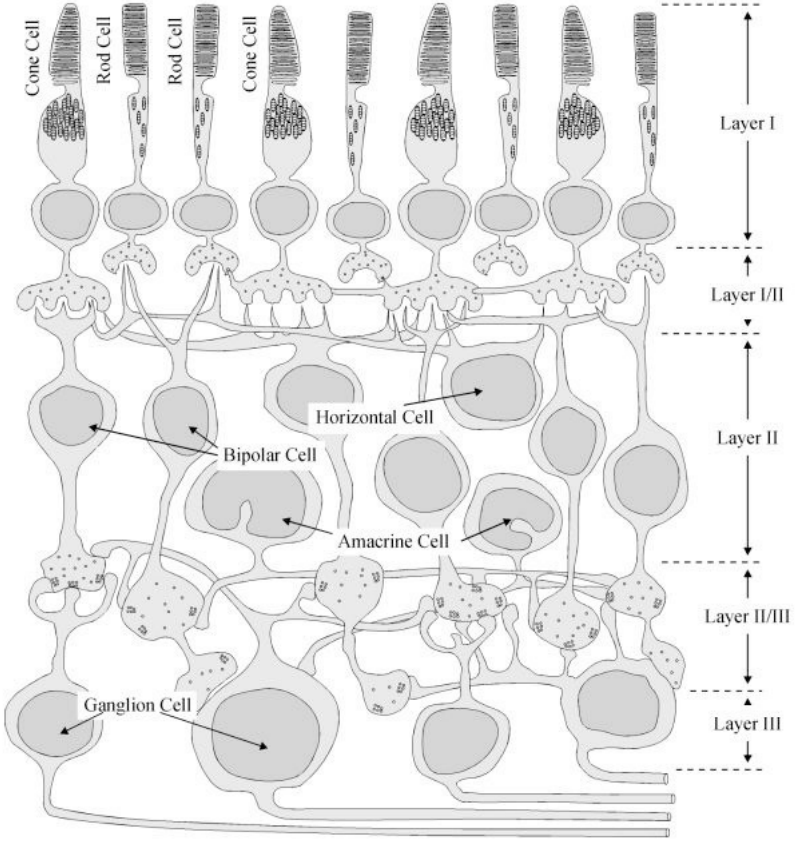
Color needs careful consideration

- Additional visual channels
- Draw attention
- Aesthetic appeal

How color works

The eye


Cornea
Aqueous Humor
Ciliary Muscle
Iris
Occular Conjunctiva
Lens
Zonule Fibers
Visual Axis
Vitreous Body
Choroid
Retina
Optic Disk
Sclera
Fovea
Optic Nerve


Cone Cell
Rod Cell
Rod Cell
Cone Cell
Layer I
Layer I/II
Horizontal Cell
Bipolar Cell
Layer II
Amacrine Cell
Layer II/III
Ganglion Cell
Layer III

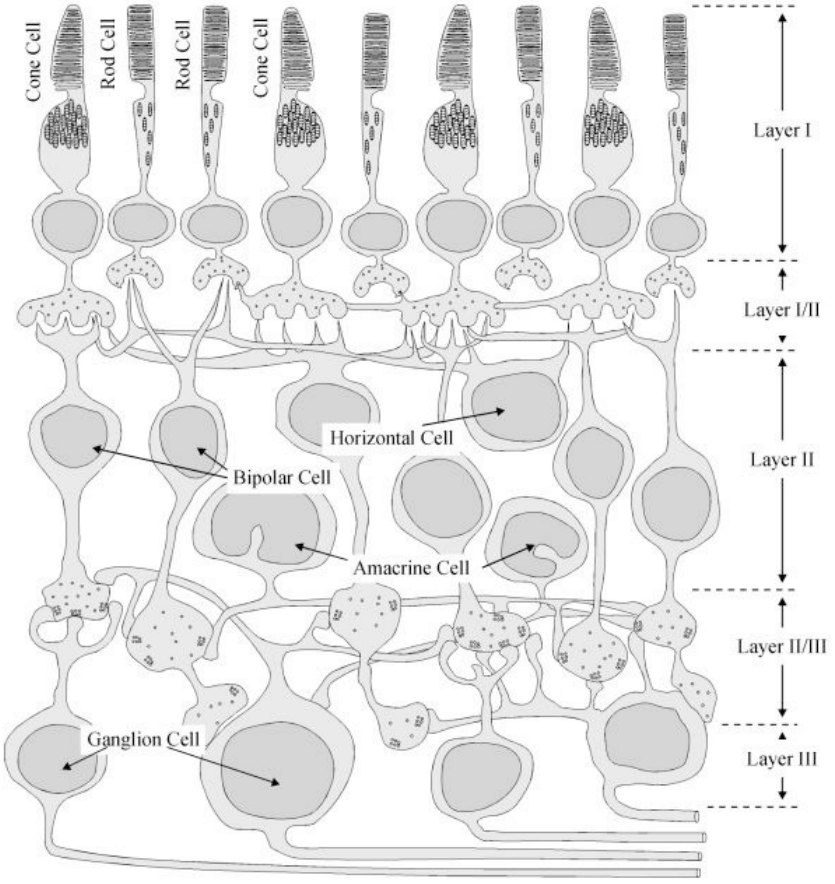
Retina detectors

Rods : monochrome sensor

- Important at low light

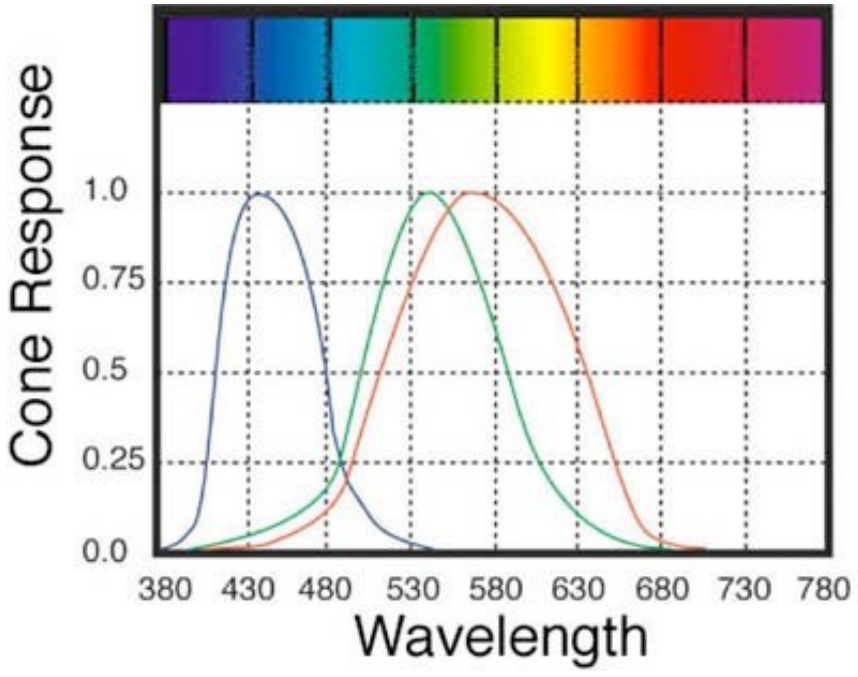
Cones : color sensors

- Lots of specialized cells --- edge detection, corners, etc
- Sensitive to contrast

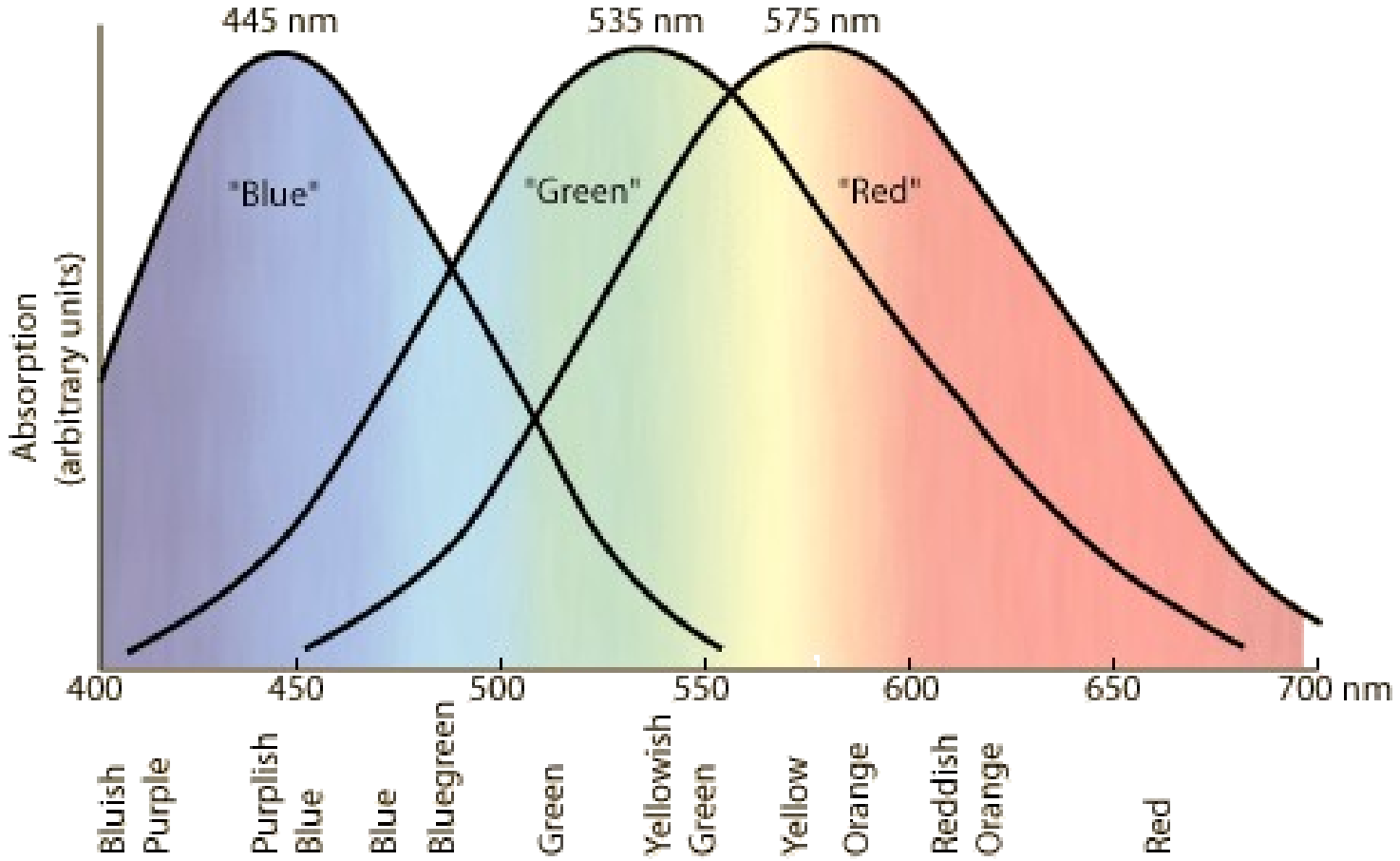


Cones

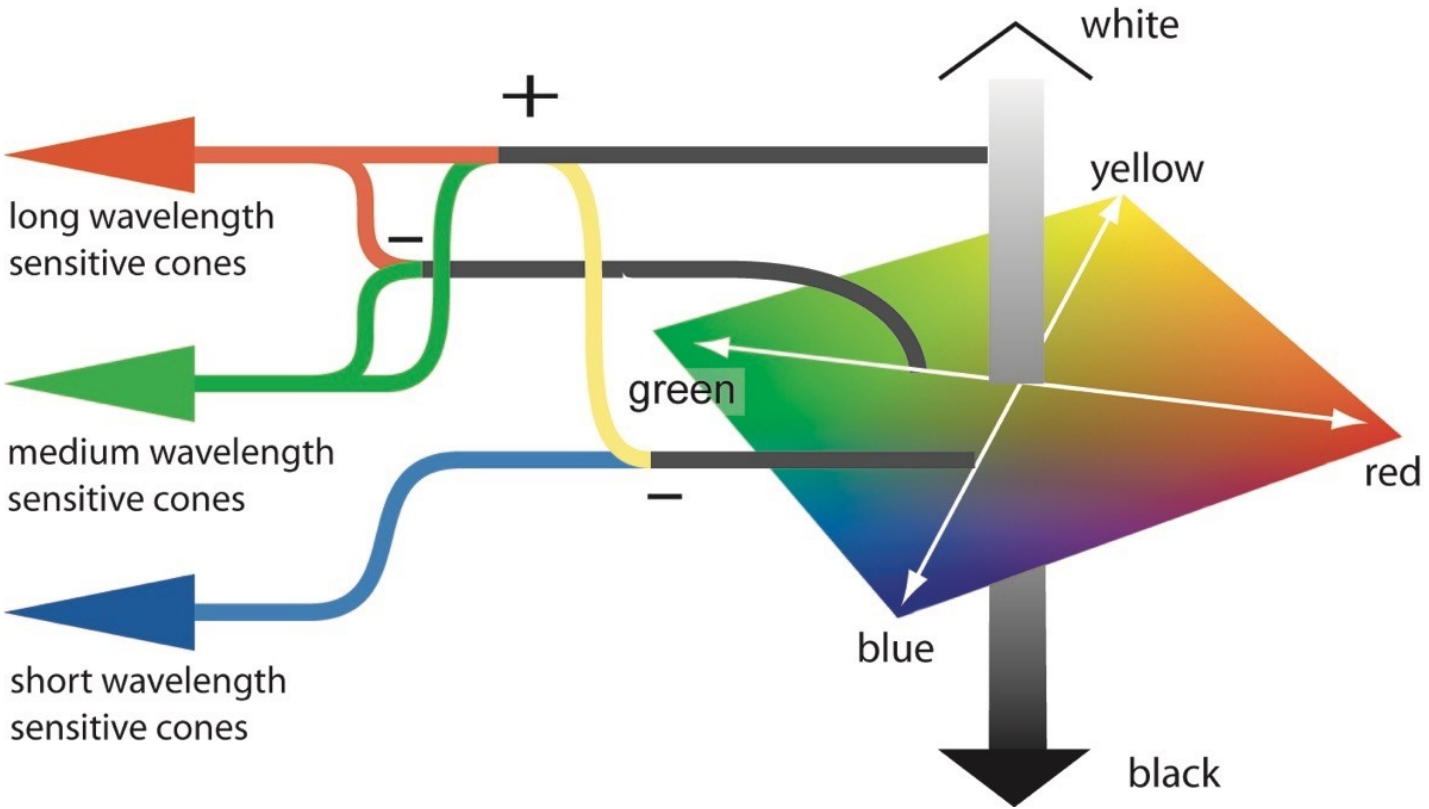
- 3 types of color sensors (S,M,L)
- Works in bright light
- Peak sensitivities located at approx. 430nm, 560nm, and 610nm for "average" observer.
- Roughly equivalent to
- blue, green, and red sensors



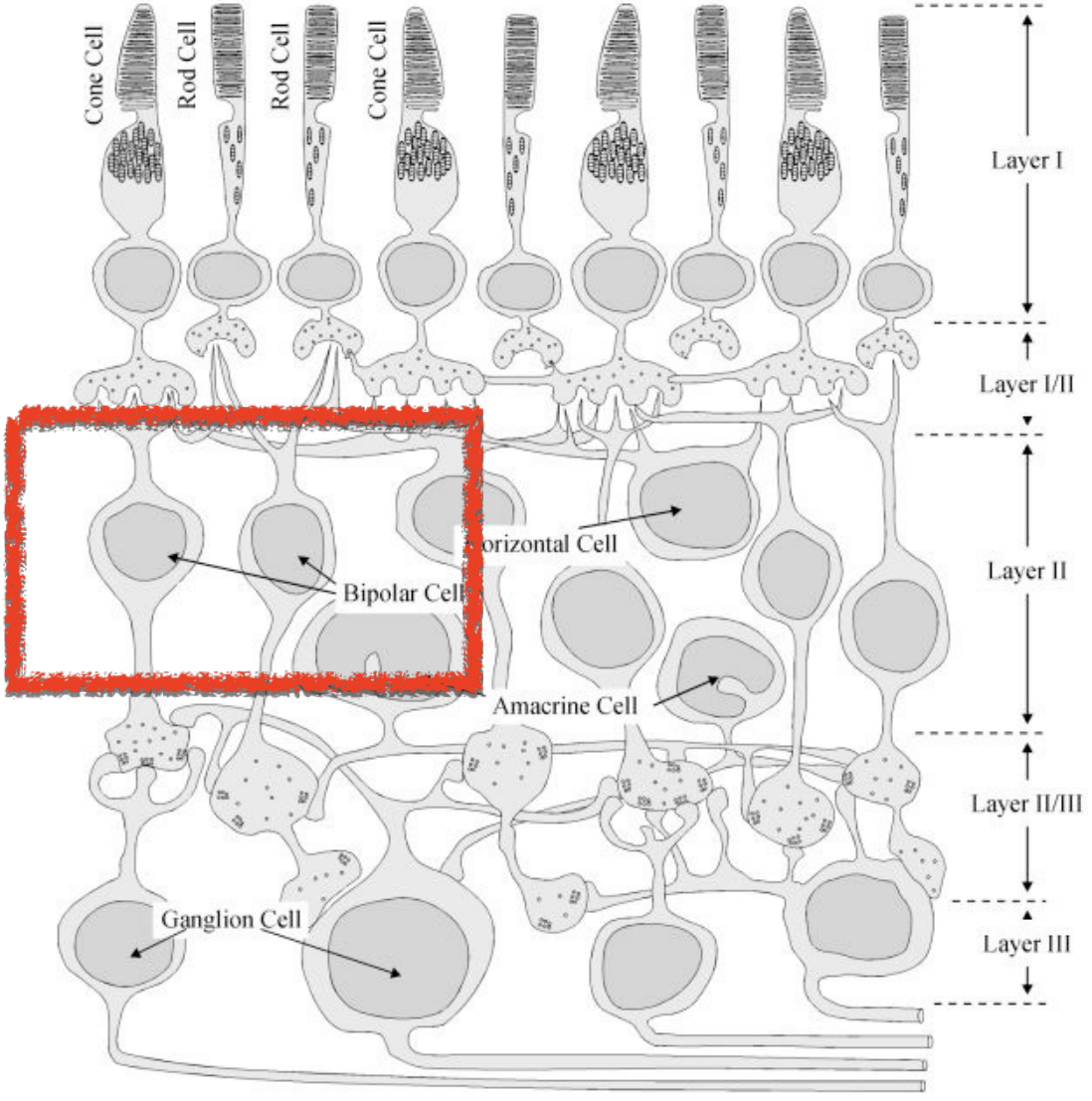
Cone response



Color opponency



Ware, Colin. *Information visualization: Perception for design* 2004.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Rod Cell
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Layer I
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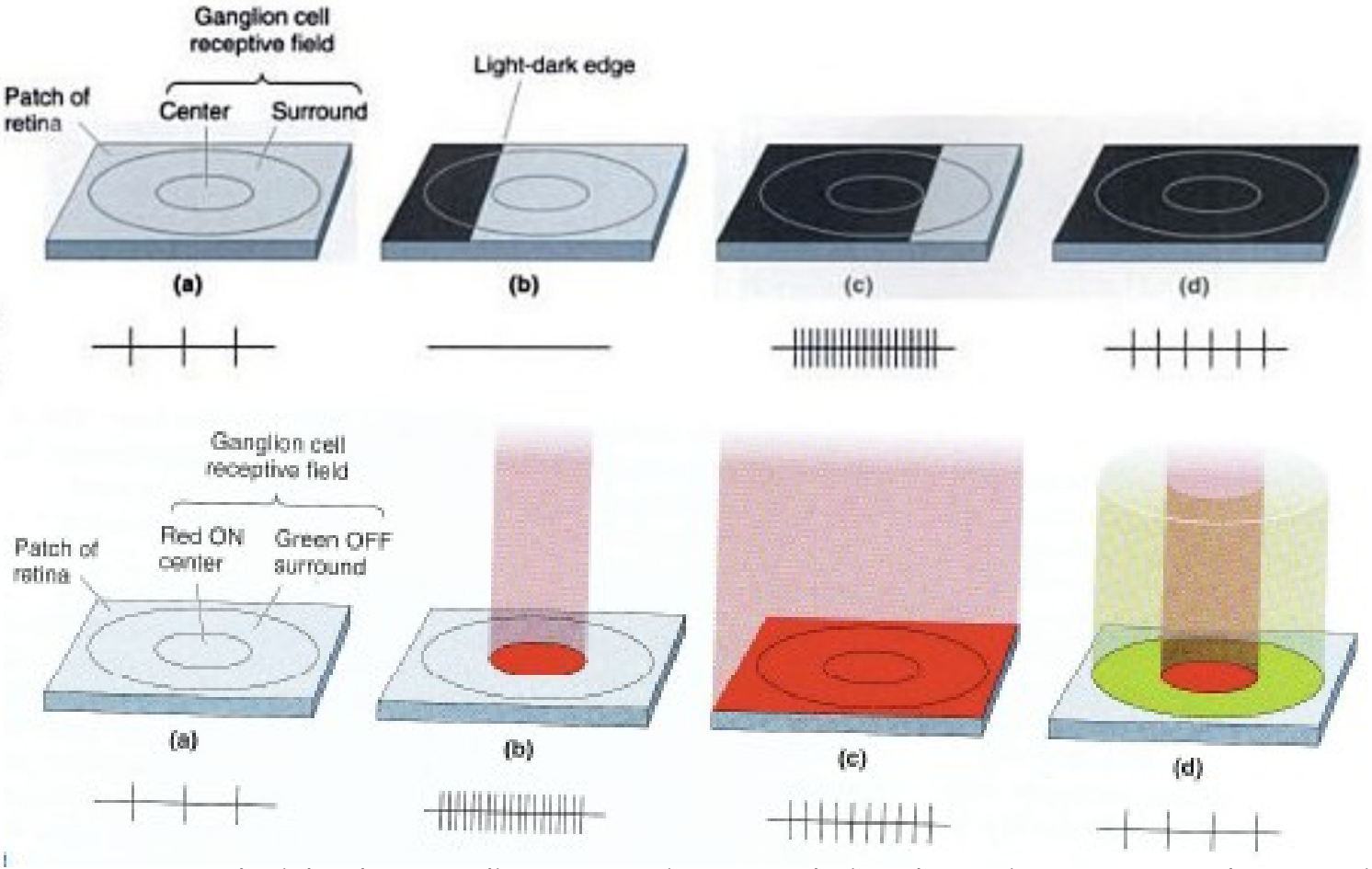
Bipolar Cell
Amacrine Cell
Ganglion Cell

Color opponent cells

B&W:

Color:



Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. Neuroscience: Exploring the Brain. Jones & Bartlett Learning, 2015.

Color models

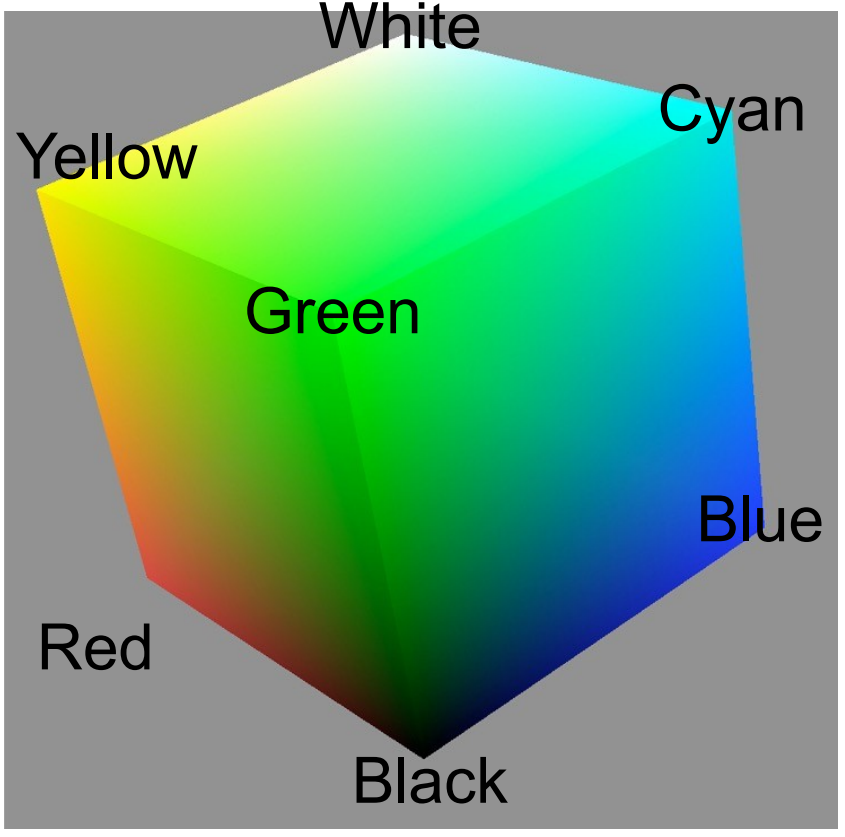
"Space" is amount of each element

- **RGB** : red, green, blue
- **HSL** : hue, saturation, lightness
- **LAB** : lightness, chroma

Saturation : "pureness" of color/distance from grey
Lightness : "brightness" of color/distance from black

RGB color space

- Additive system
- Colors that can be represented by computer monitors
- Not perceptually uniform



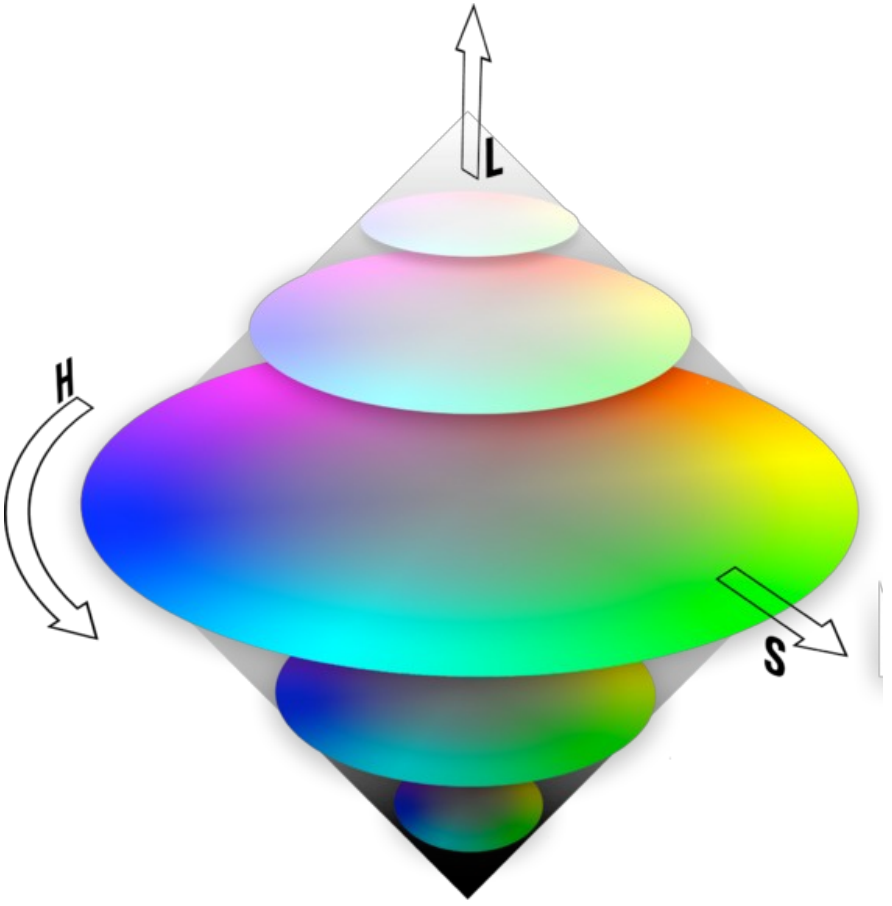
HSL color space

Hue : what people think of color

Saturation : purity, distance from grey

Lightness : from dark to light

- Not perceptually uniform

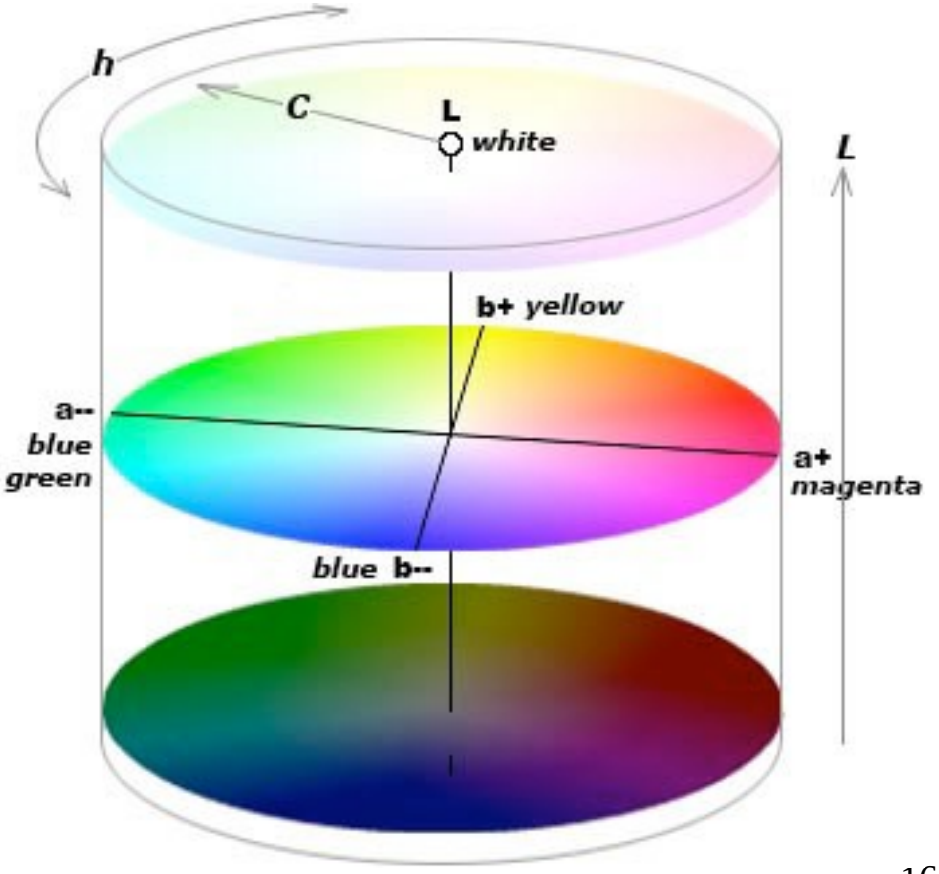


LAB color space

L : approximates human perception of lightness

a, **b** : approximate R/G and Y/B channels

- a, b called chroma
- Perceptually uniform



Applying color

Hue, luminance, saturation

Luminance

- How-much channel
- discriminability: ~2-4 bins
- contrast important

Saturation

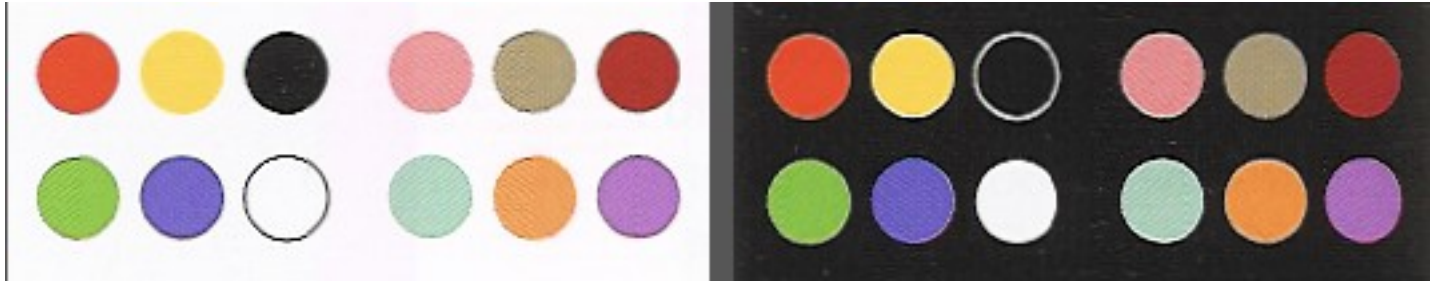
- How-much channel
- discriminability: ~3 bins

Hue

- What channel
- discriminability: ~6-12

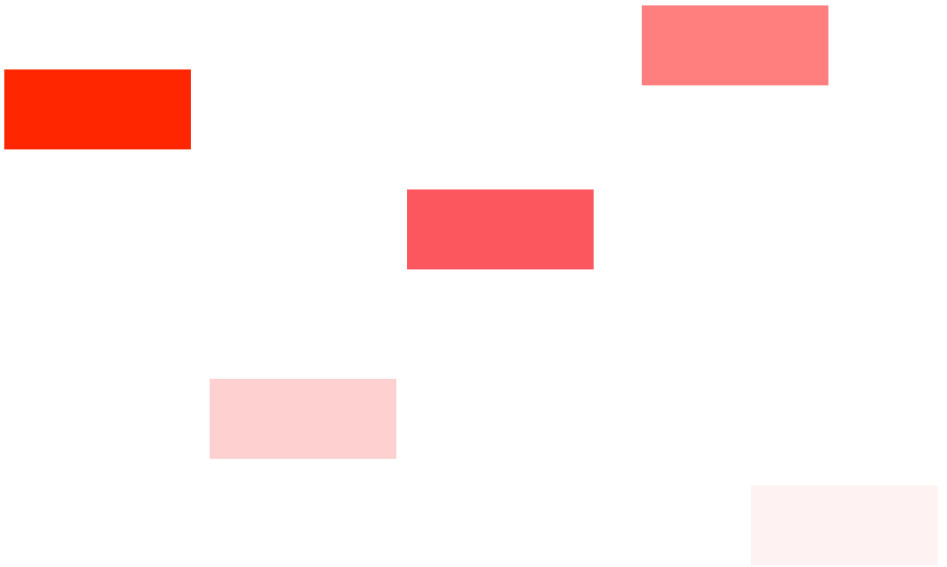
Categorical data

- Limited distinguishability (8–14)
- Best with hue
- From Ware:



Ordinal/quantitative

Order these colors



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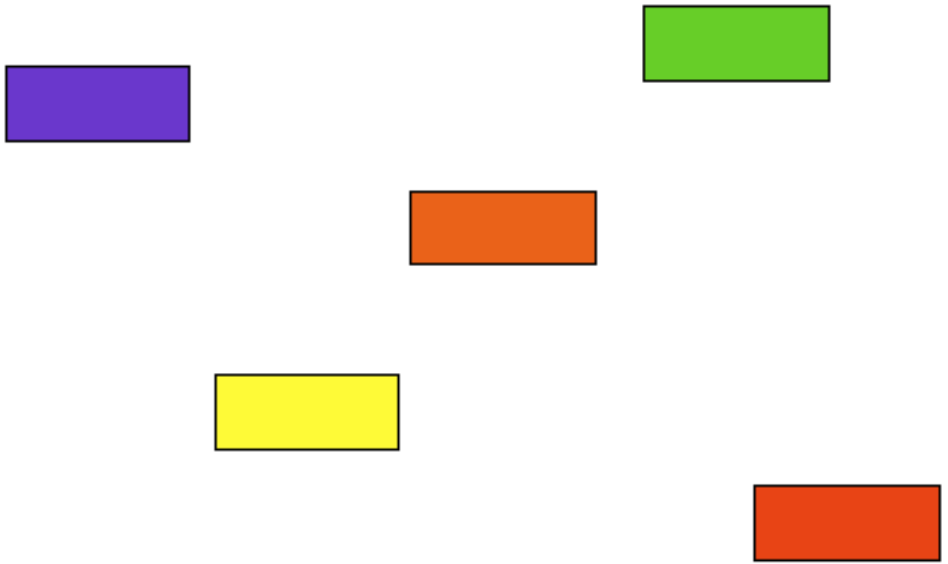
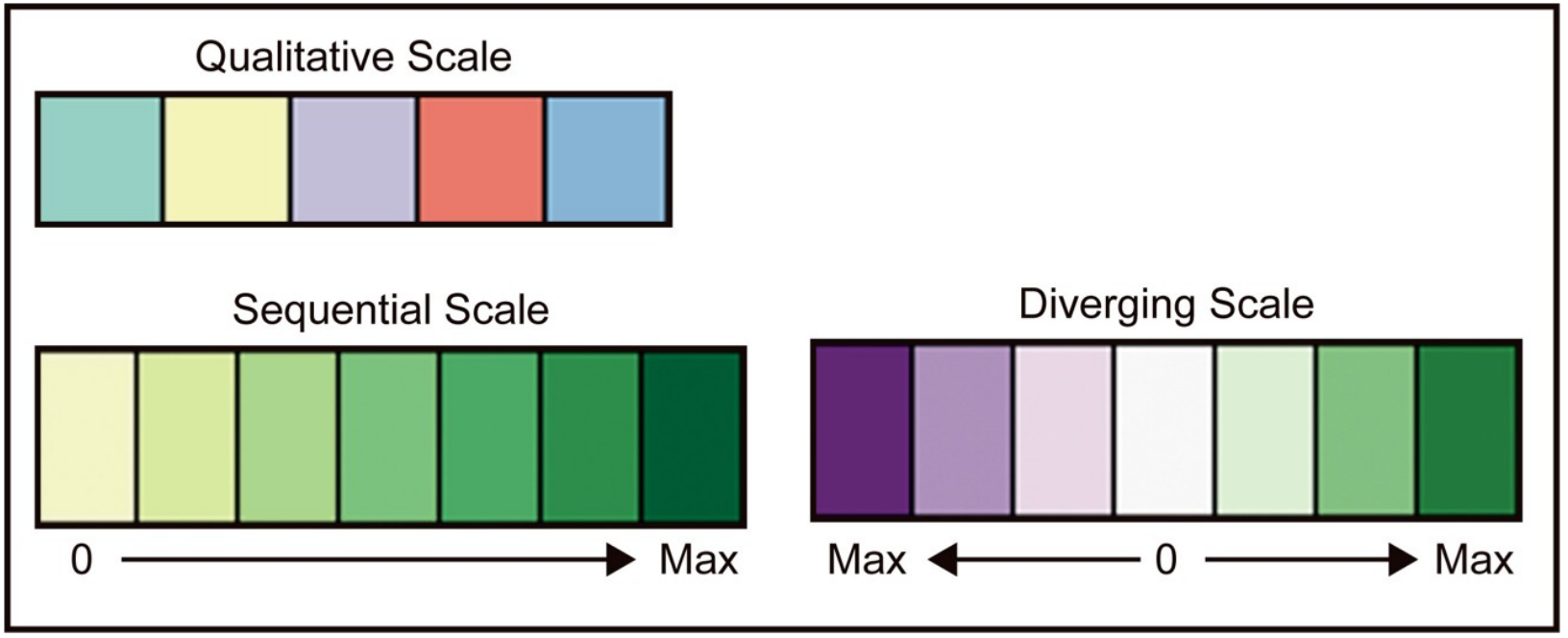


Brewer scales

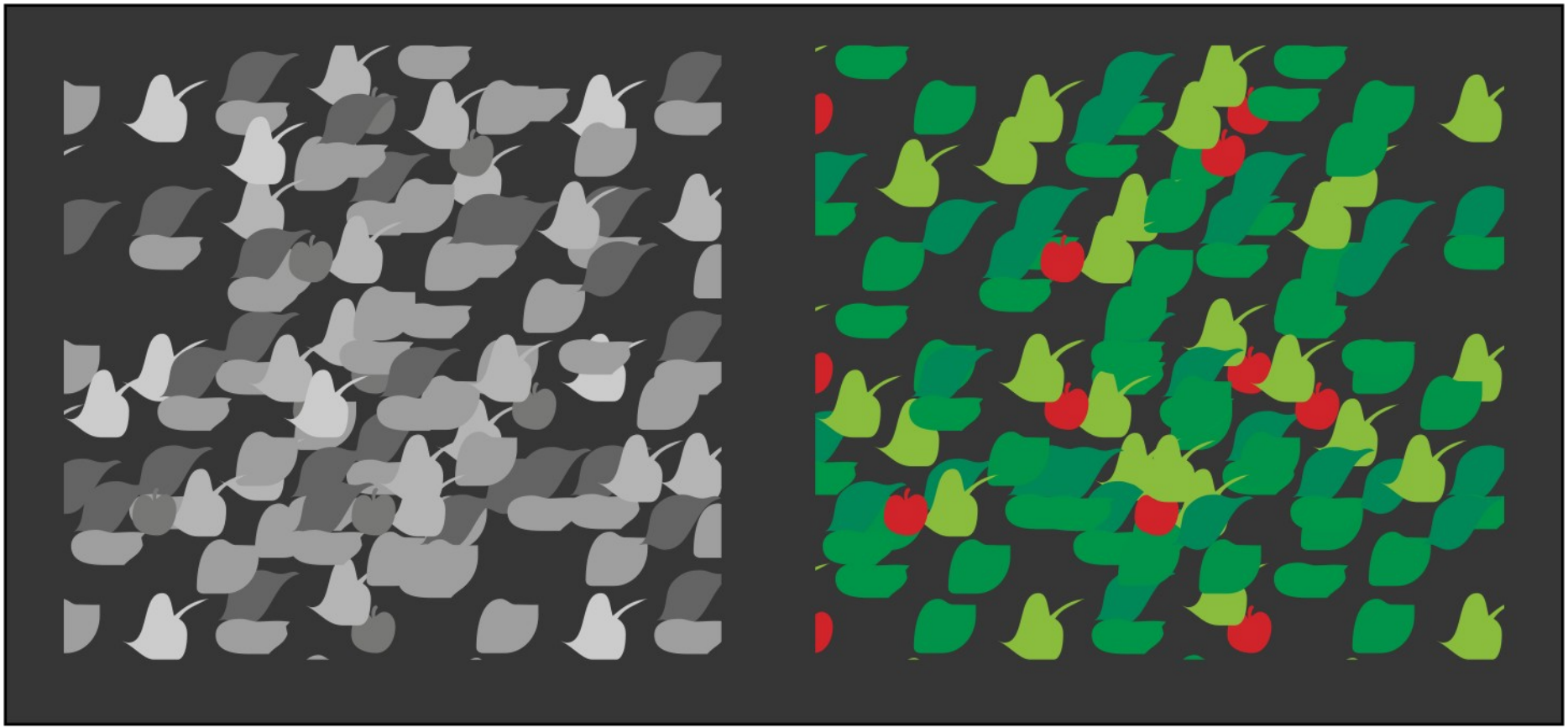
Nominal

Ordinal



Drawing attention

Highlight small items



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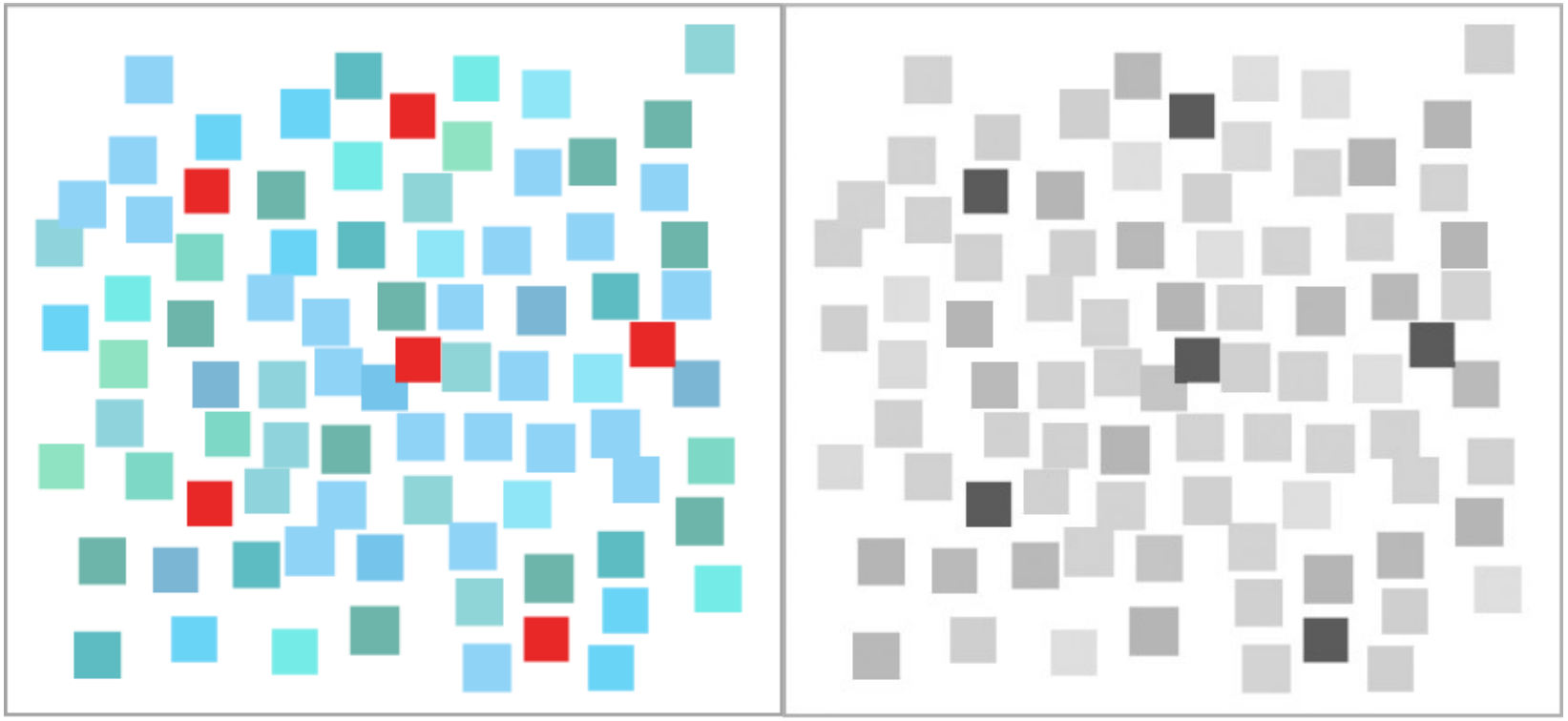
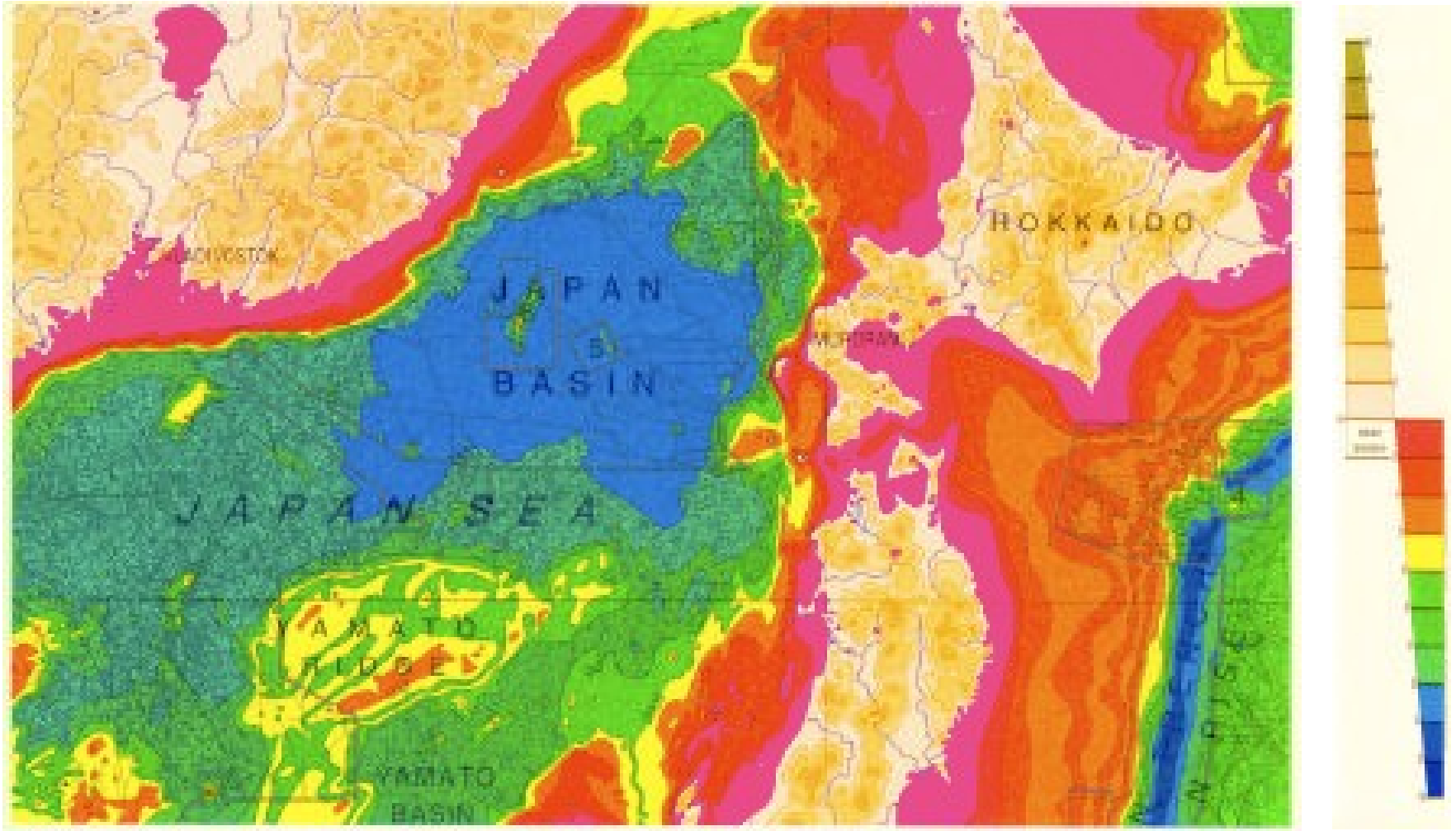


Hue and lightness

Lightness only

Need care with large areas



Need care with large areas

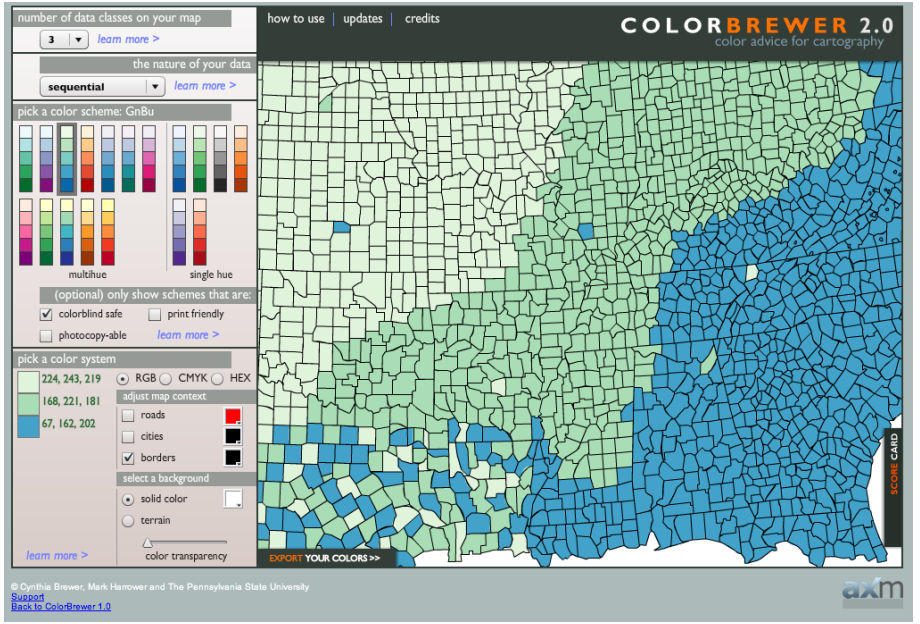
Aesthetics

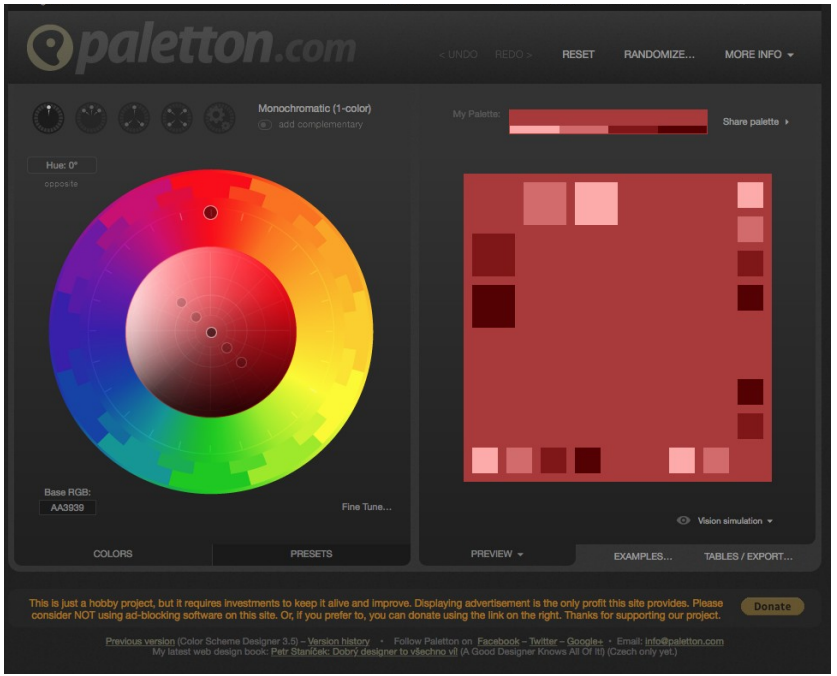
Aesthetics

- Don Norman: "Attractive things work better"
  (Norman, Don. *The design of everyday things* 1988.)
- Color influences aesthetics (Ball, Victoria K. “The Aesthetics of Color: A Review of Fifty Years of Experimentation.” Journal of Aesthetics & Art Criticism 23, no. 4 (1965): 441–52. https://doi.org/10.2307/427666.)
- Poorly designed color is confusing
  - Creates visual clutter
  - Misdirects attention

Finding good colors

- Colorbrewer
- Paletton



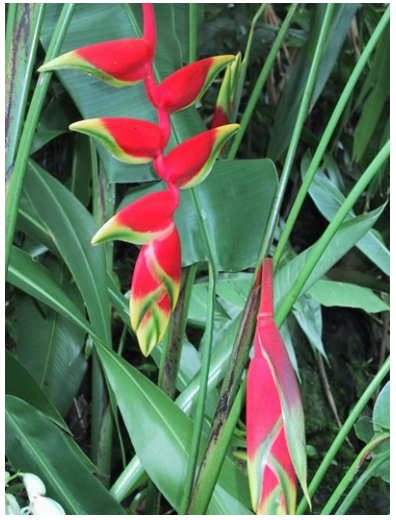


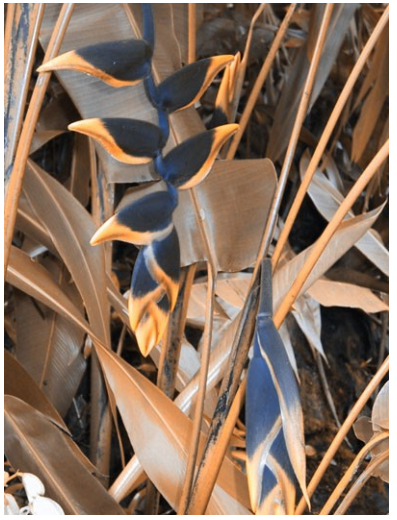
Considerations

Color blindness

- Flaw in opponent processing
  - Red-green common (deuteranope, protanope)
  - Blue-yellow possible (tritanope -- most common)
  - Luminance channel almost “normal”
- 8% of all men, 0.5% of all women
- Effect is 2D color vision model
  - Flatten color space
  - Can be simulated (Brettel et. al.)
  - http://colorfilter.wickline.org
  - http://www.colblindor.com/coblis-color-blindness-simulator/

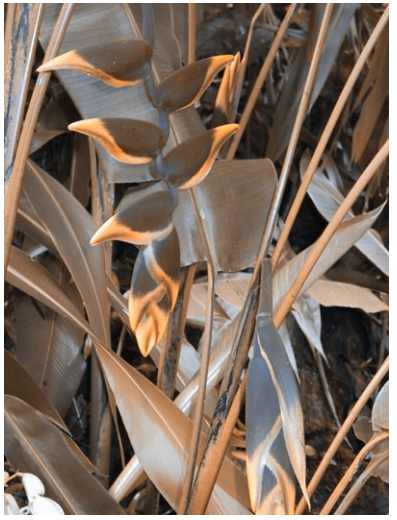
Color blindness





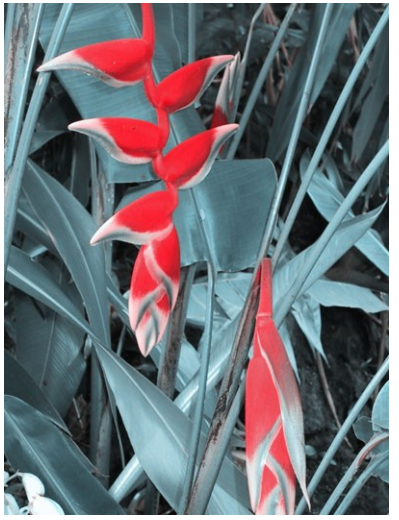
Protanope

No L cones



Deuteranope

No M cones



Tritanope

No S cones

Red / green deficiencies

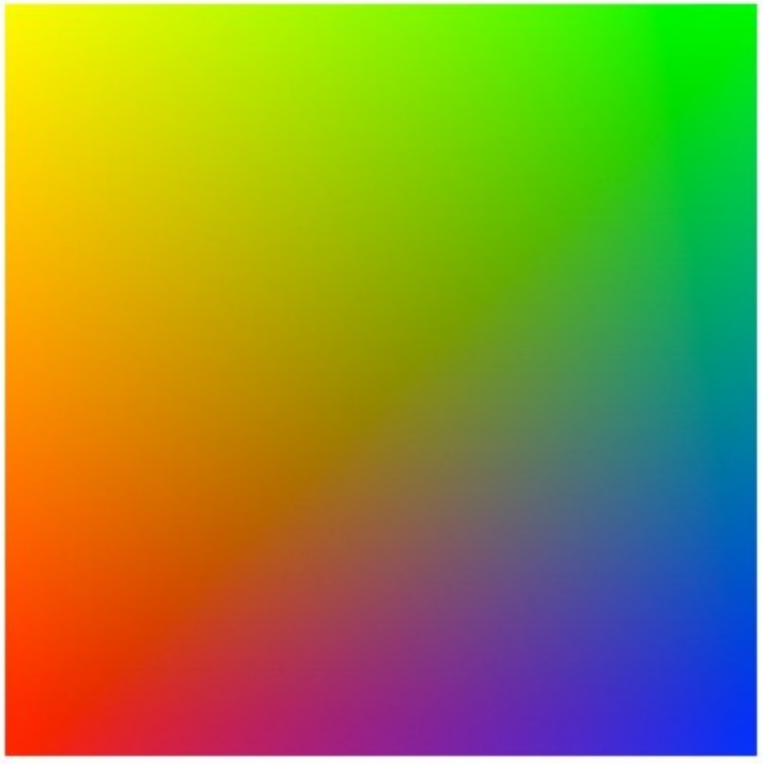
Blue / Yellow deficiency

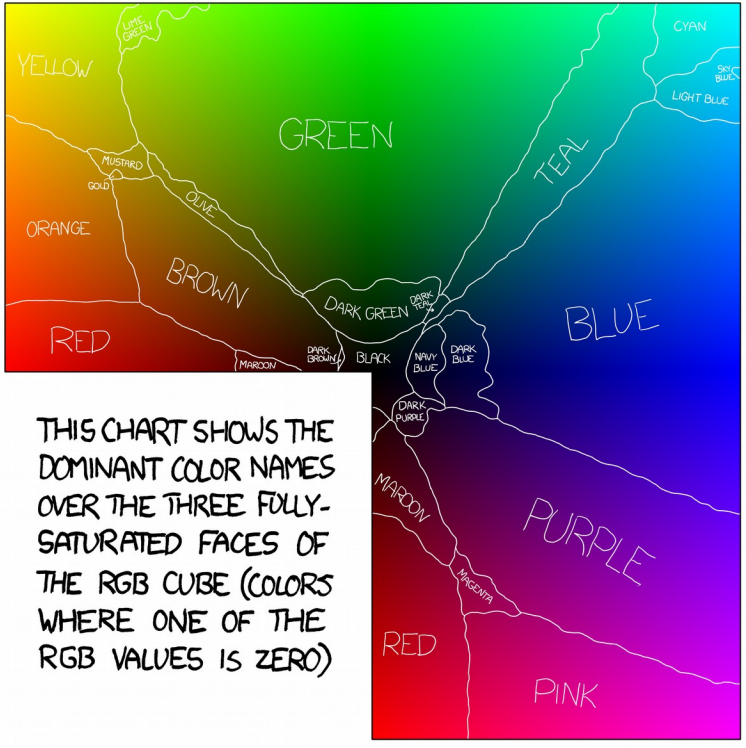
Rainbow color map

- Hue is used to show ordinal data
- Not perceptually linear: Equal steps in the continuous range are not perceived as equal steps
- Colors are a learned order
- Not good for colorblind people

Rainbow color map

Visually segmented

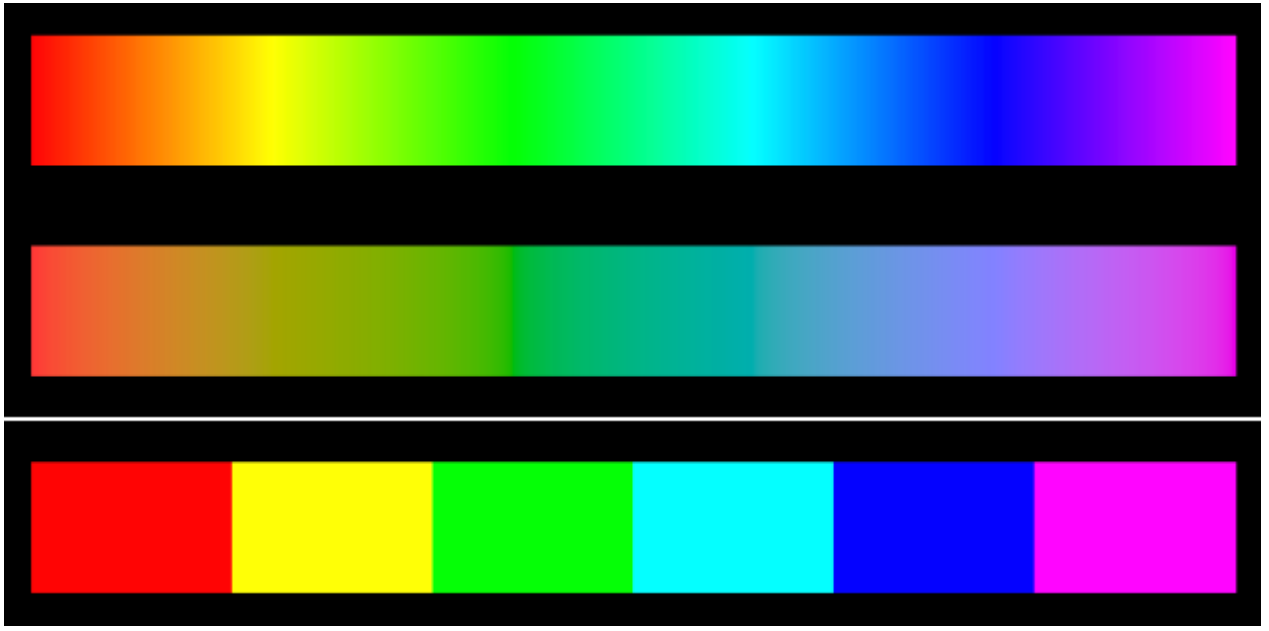




https://blog.xkcd.com/2010/05/03/color-survey-results/

Rainbow color map

- Solution — isoluminant rainbow
- Solution — discretize colormap



Conclusion

Key points

- Balance aesthetics with perceptual issues
- Hue for categories (<8!)
- Saturation for numbers
- Use colorbrewer!

Futher reading

- Harrower, Mark A., and Cynthia A. Brewer. "ColorBrewer.Org: An Online Tool for Selecting Color Schemes for Maps," The Cartographic Journal. 2003.
- Ware, Colin. *Information visualization: Perception for design* 2004.
- Borland, David, and Russell M. Taylor Ii. "Rainbow Color Map (Still) Considered Harmful," IEEE Computer Graphics and Applications. 2007.
- Ware, Colin, Terece L. Turton, Roxana Bujack, Francesca Samsel, Piyush Shrivastava, and David H. Rogers. "Measuring and Modeling the Feature Detection Threshold Functions of Colormaps," IEEE Transactions on Visualization and Computer Graphics. 2019.
- Smart, Stephen, Keke Wu, and Danielle Albers Szafir. "Color Crafting: Automating the Construction of Designer Quality Color Ramps," IEEE Transactions on Visualization and Computer Graphics. 2020.