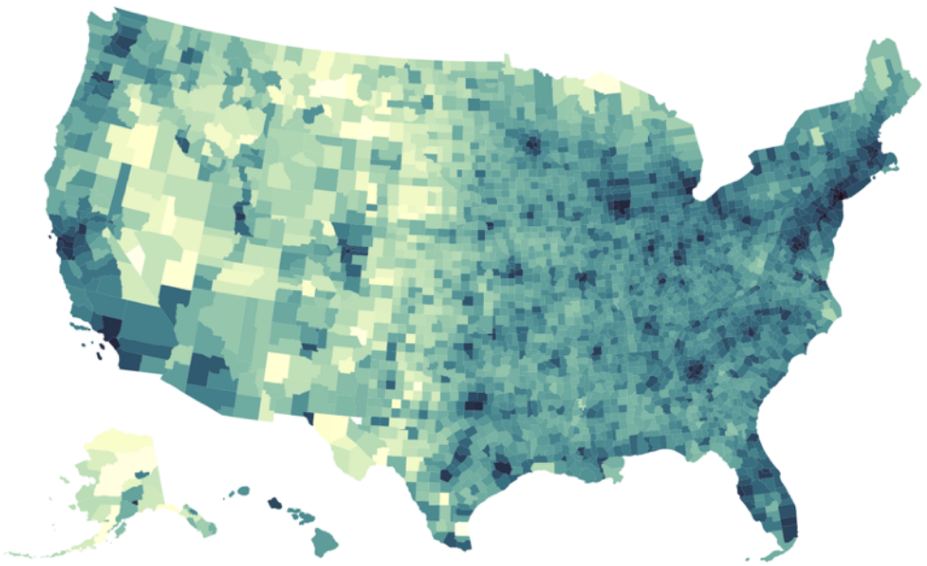
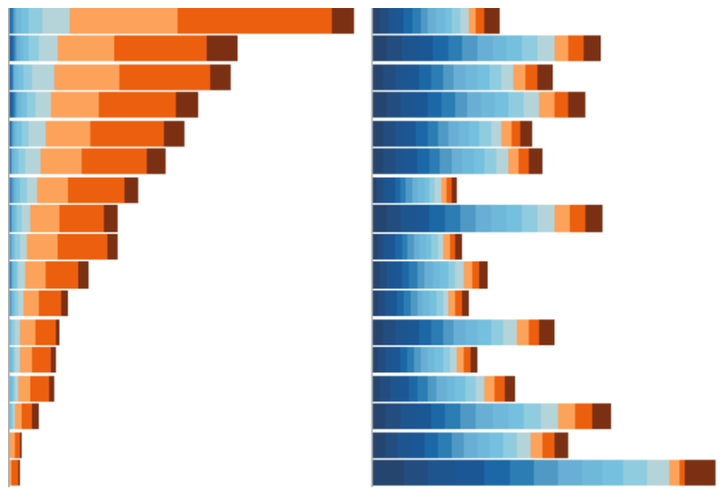
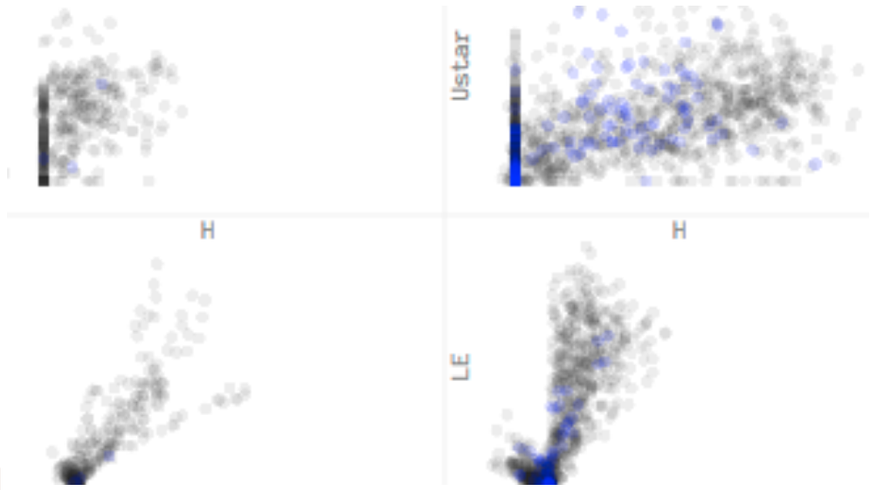
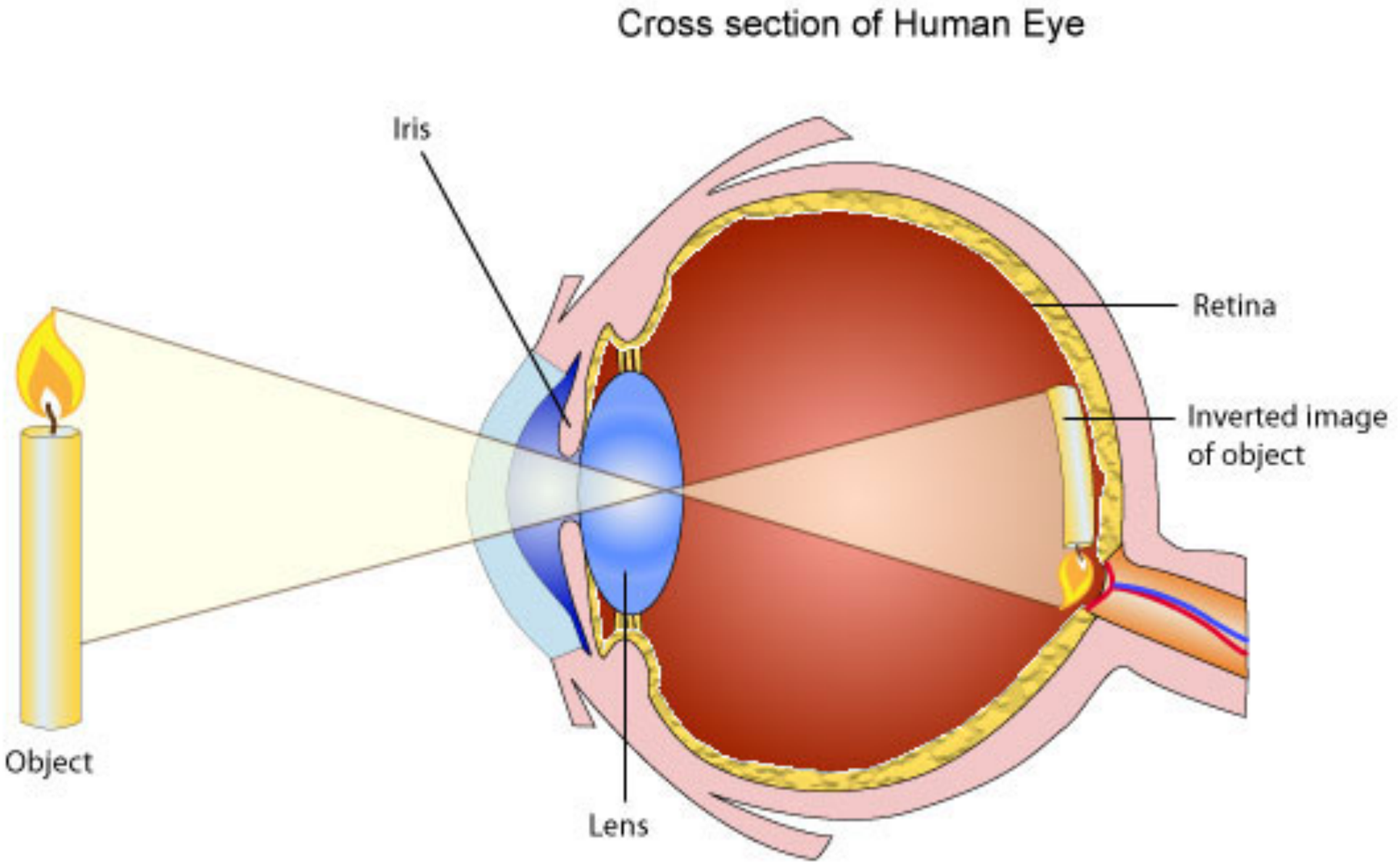




CS526 Computer Graphics II

Week 4: Color Perception

Khairi Reda | redak@uic.edu
UIC CS

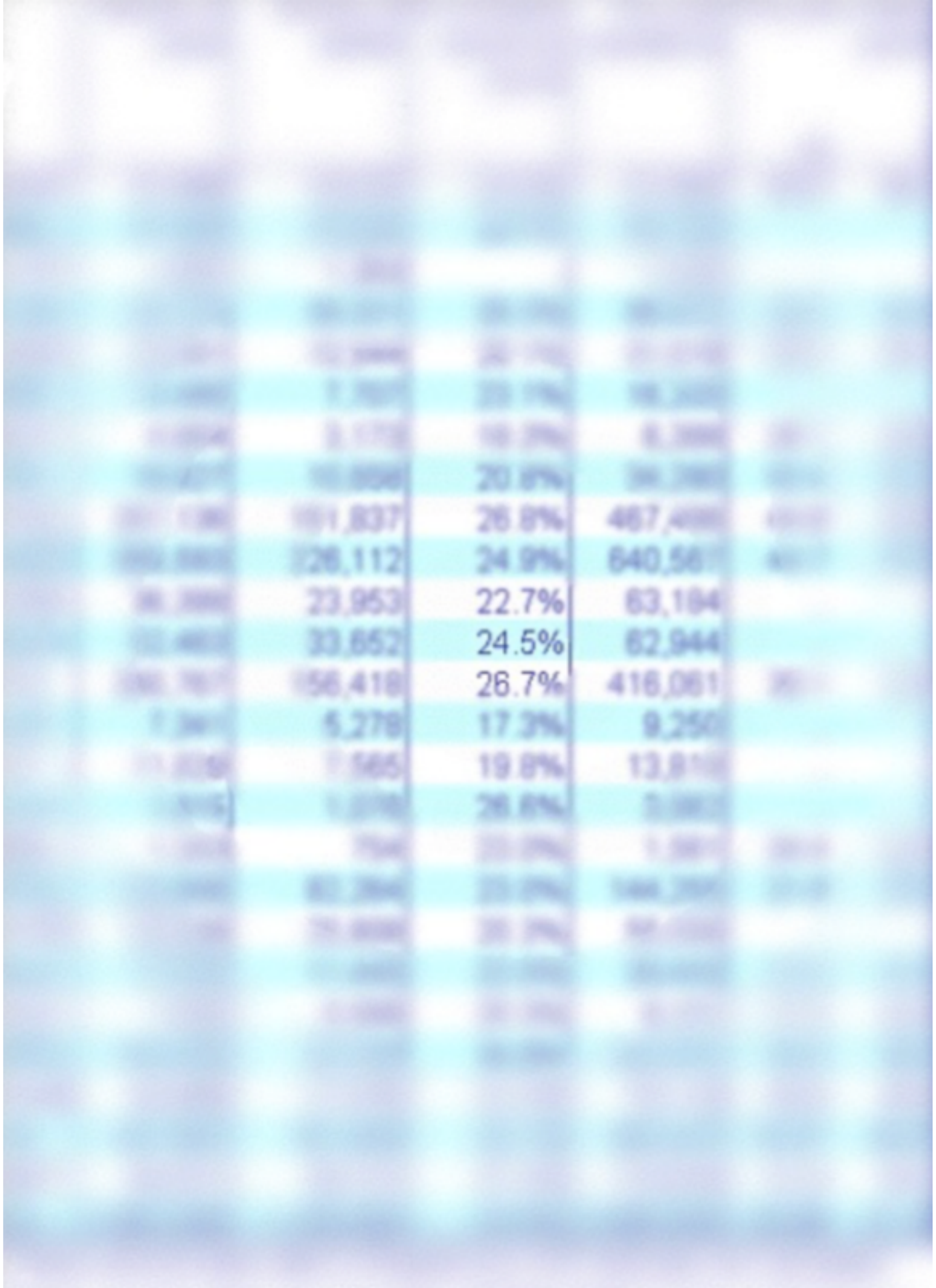
Visual perception



light

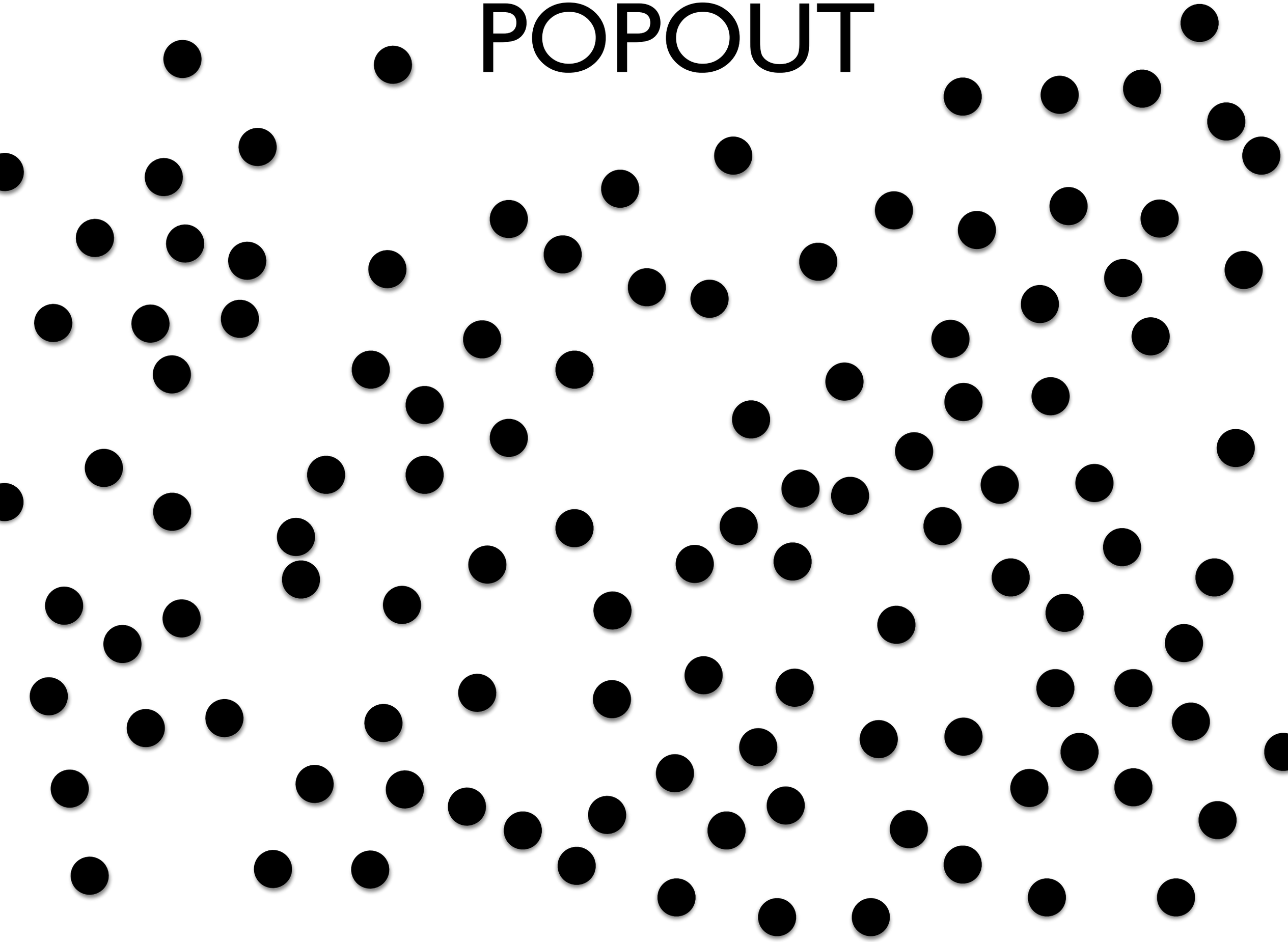
electricity

http://www.fortworthastro.com/images/eye_xsection_01.jpg



C. Ware
Visual Thinking for Design

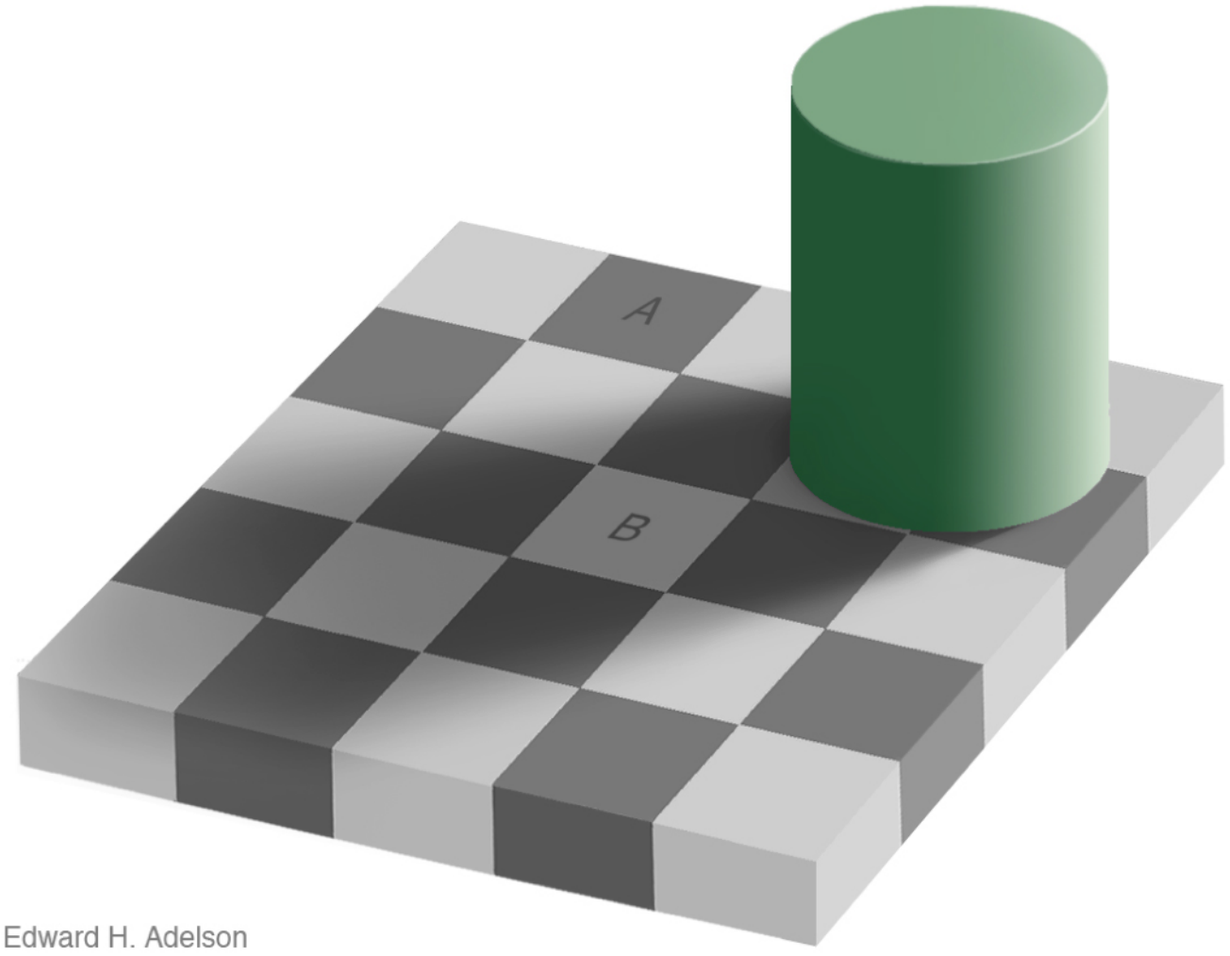
POPOUT

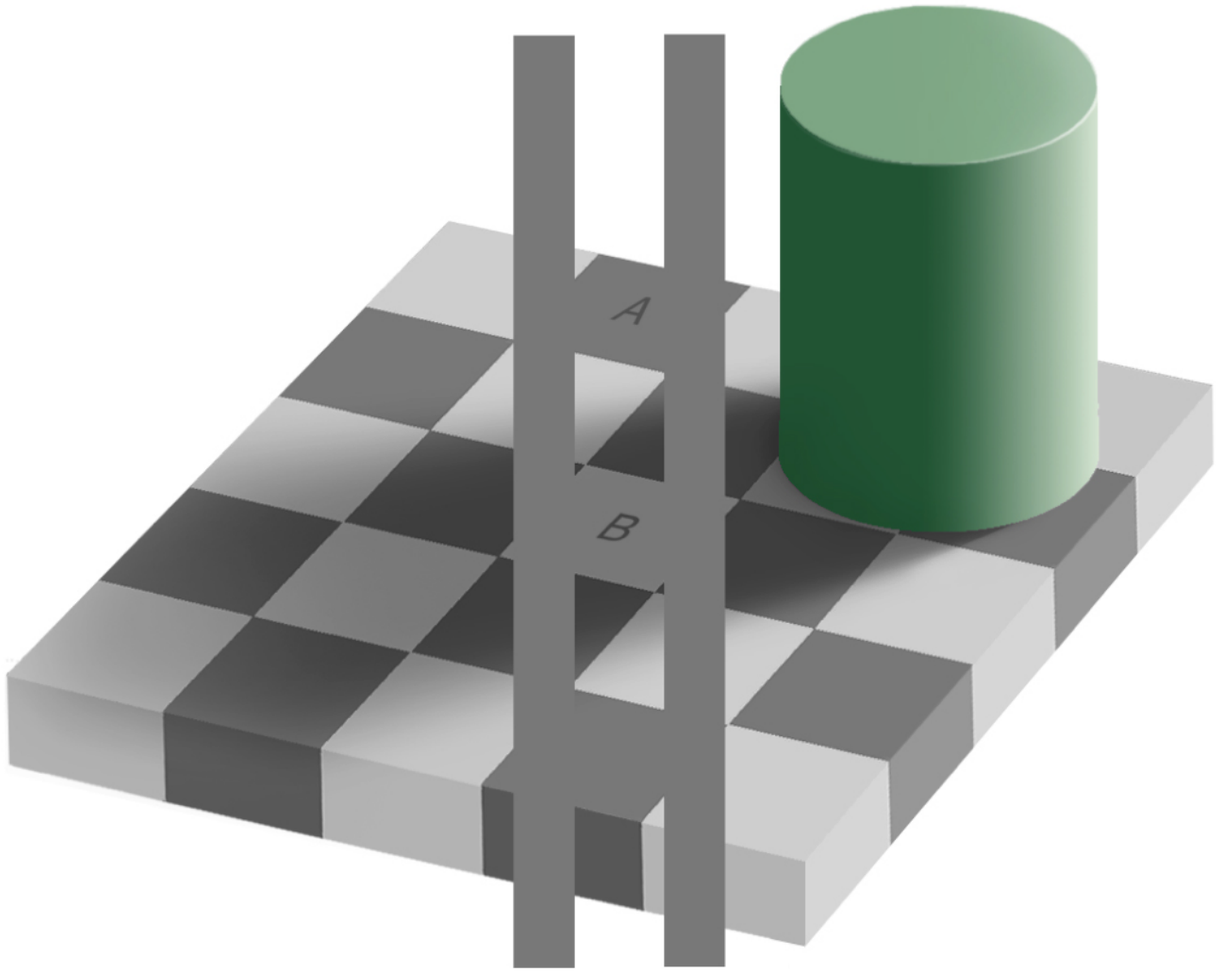


POPOUT

Visual perception is relative

Differences in contrast is relative





Edward H. Adelson

Visual perception is relative

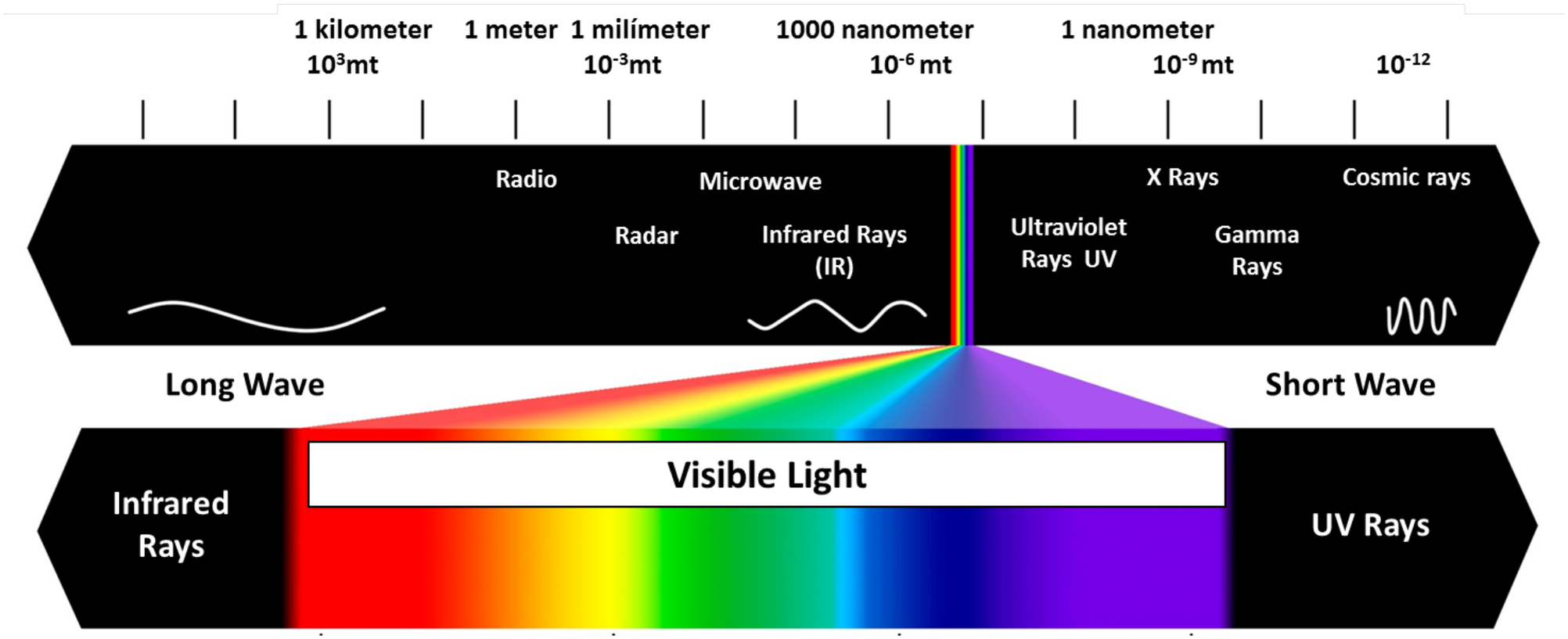
Sizes are relative (Ames room)

color

The Huffington Post

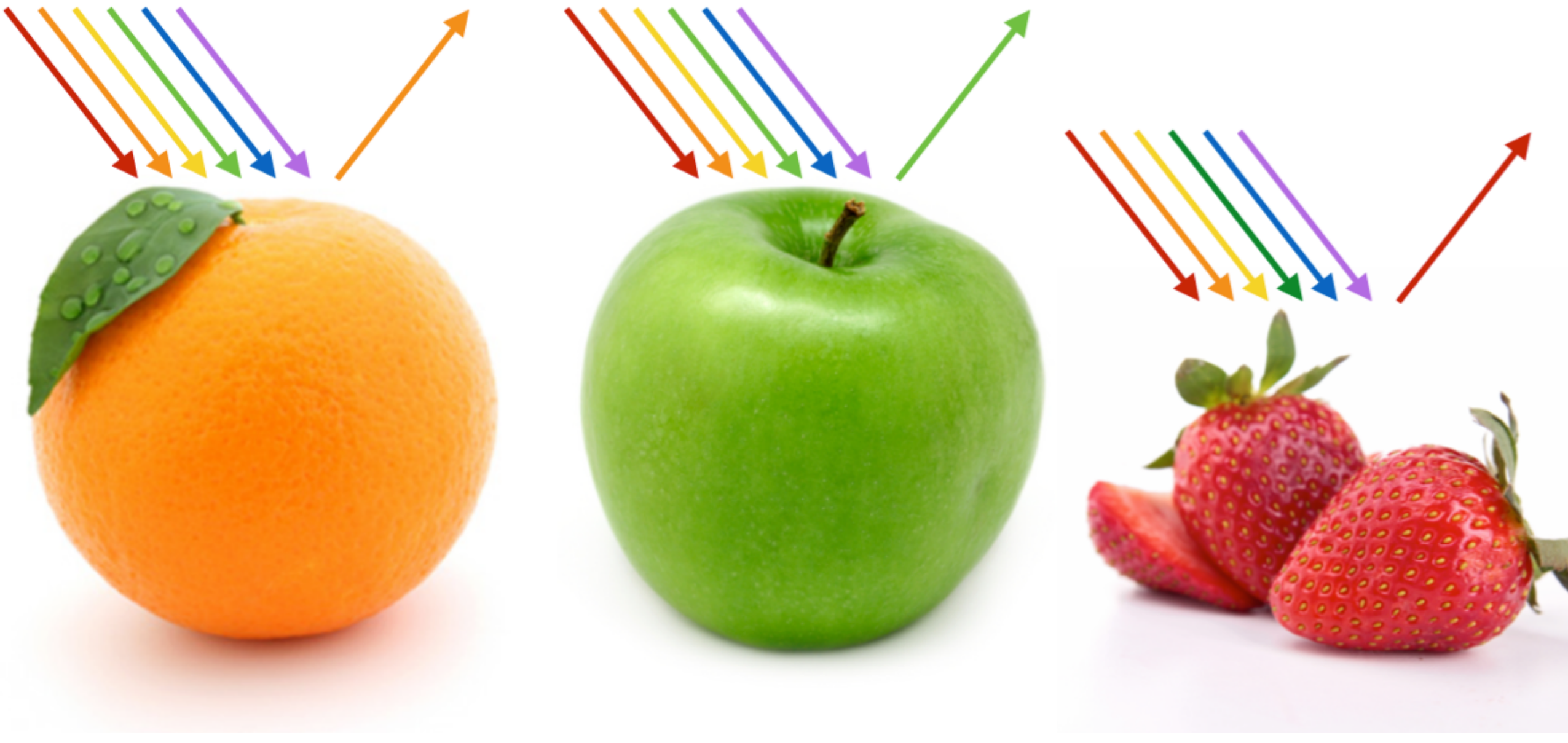
light

Electromagnetic radiation within a certain range [400nm - 700nm] of the electromagnetic spectrum



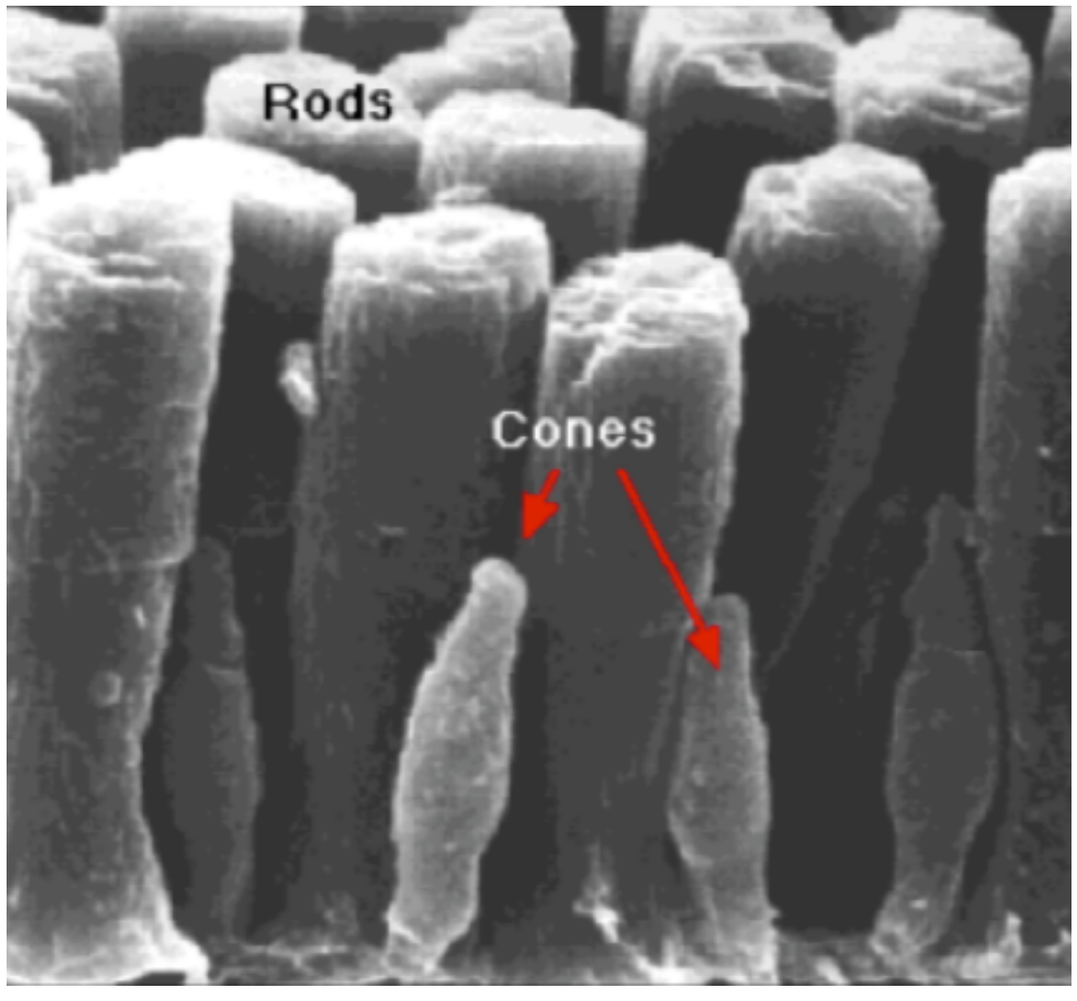
more energy

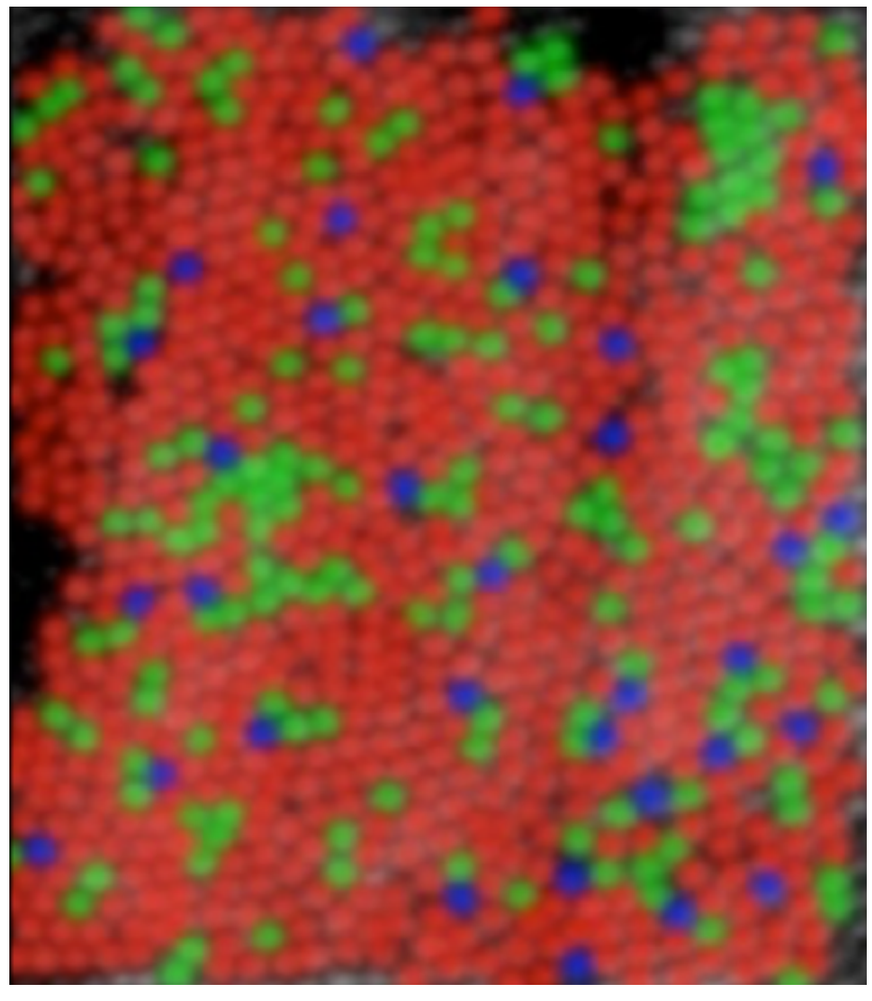
light



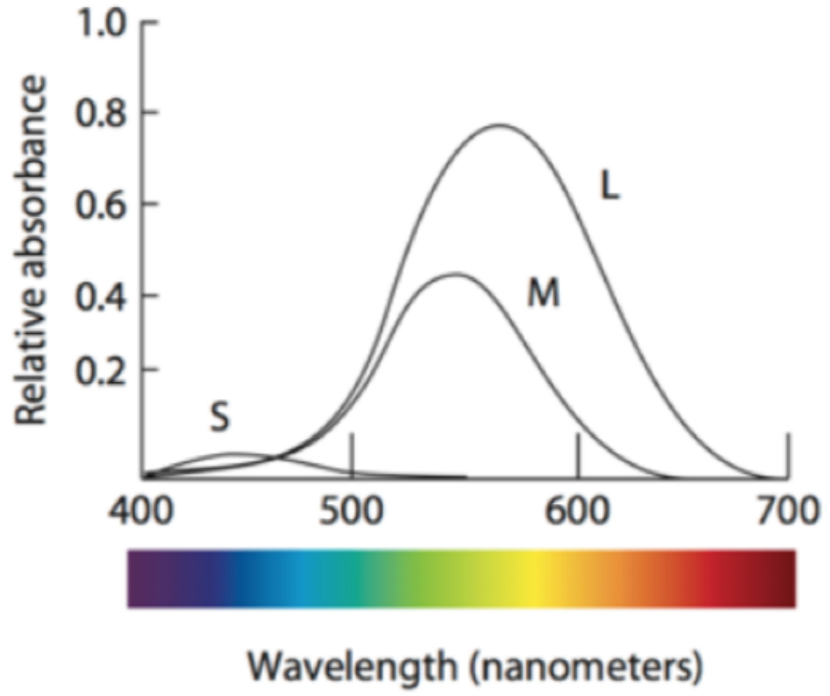
Mariah Meyer

Trichromacy





Trichromacy



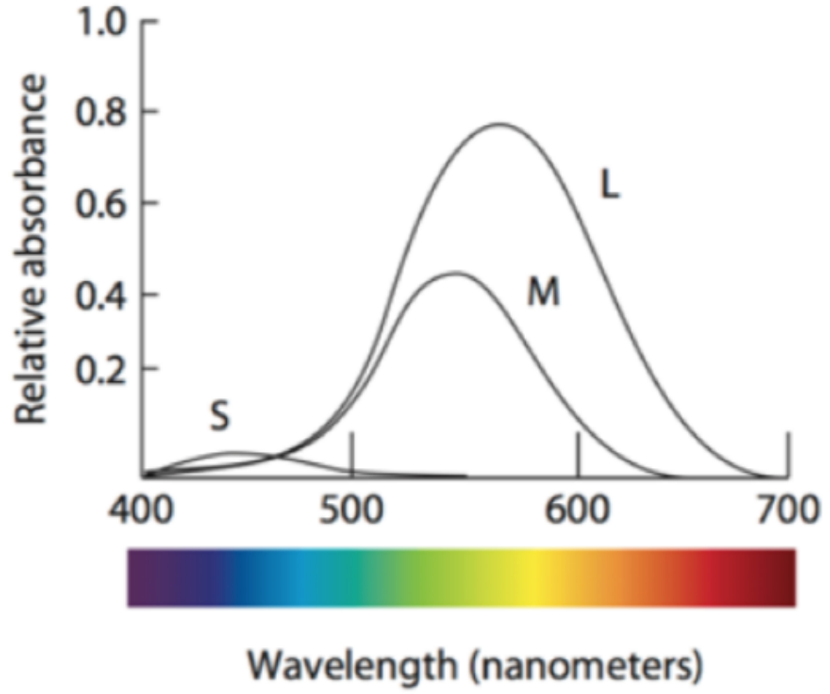
Normal human color vision is 3 dimensional

Derived from three cone types (short, medium, and long wave-length sensitivity)

Each type of cone contains a specific photosensitive pigment that reacts to a certain wavelength of light

Based on a slide by Mariah Meyer

Trichromacy



difficult to read

easy to read

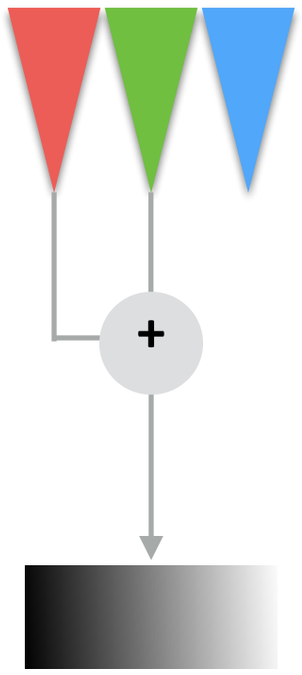
difficult to read

easy to read

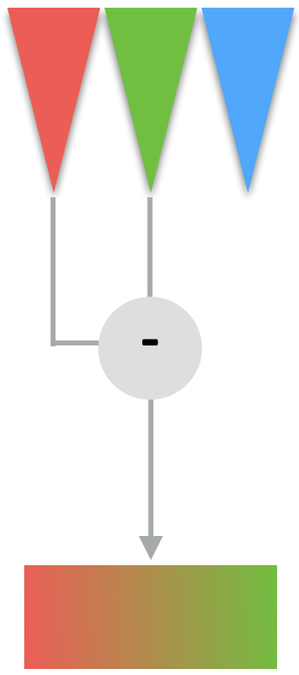
Opponent-process theory

Explains how signals are processed

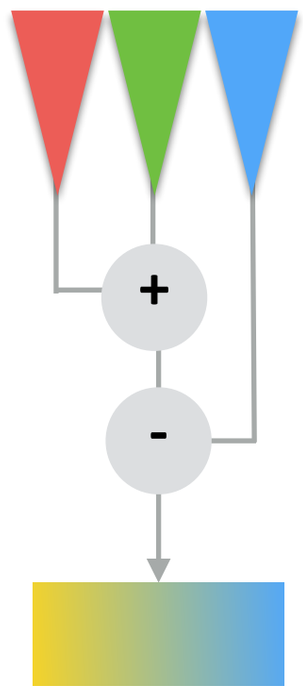
The visual perceptual system detects **differences** in the response of cones



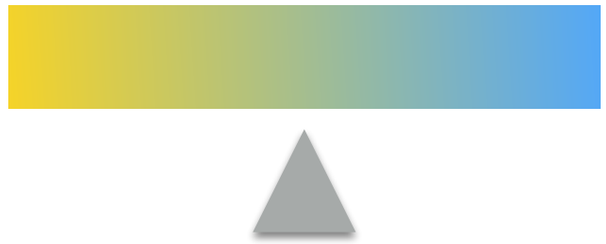
luminance

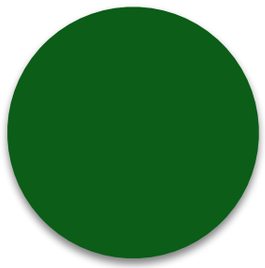


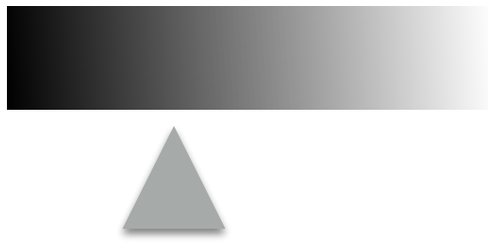
red-green opponent channel

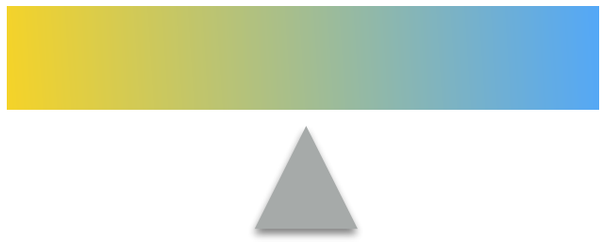


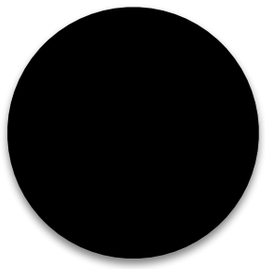
yellow-blue opponent channel

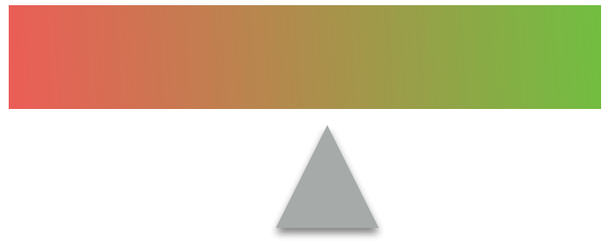


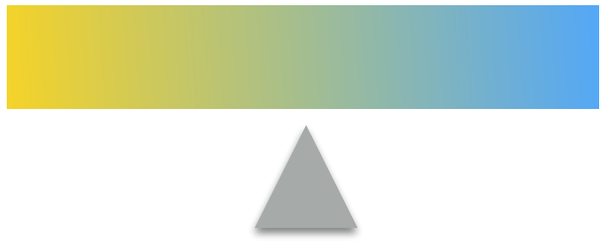








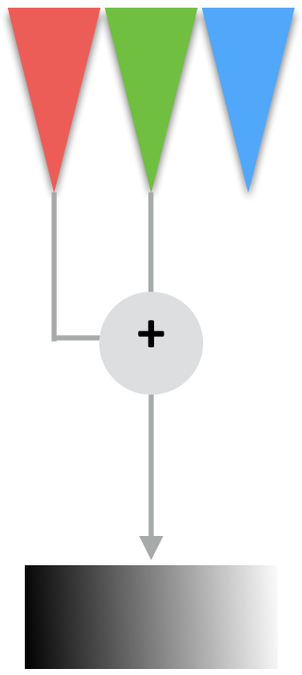




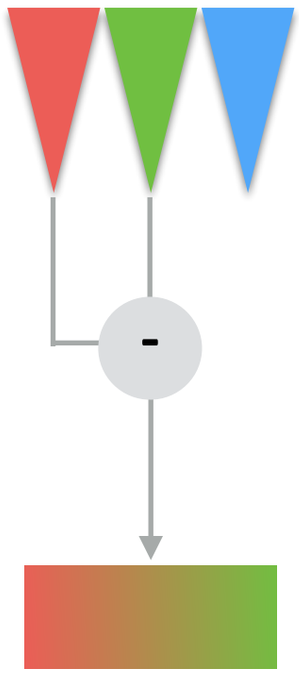
Opponent-process theory

Explains how signals are processed

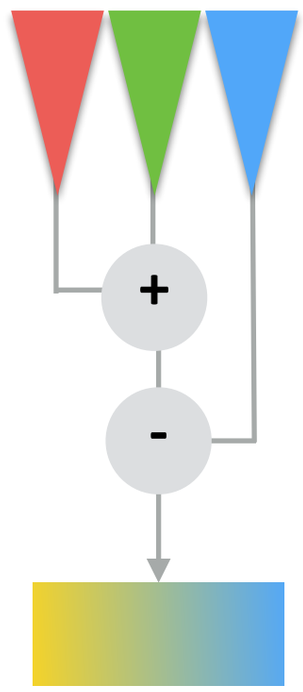
Visual perceptual system detects **differences** in the response of cones



luminance

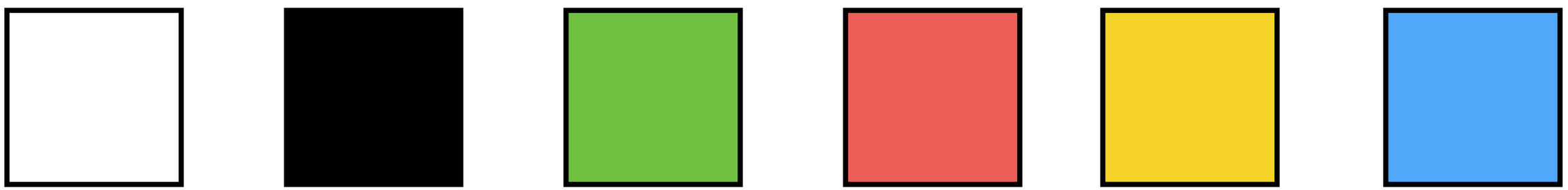


red-green opponent channel



yellow-blue opponent channel

“Important” colors

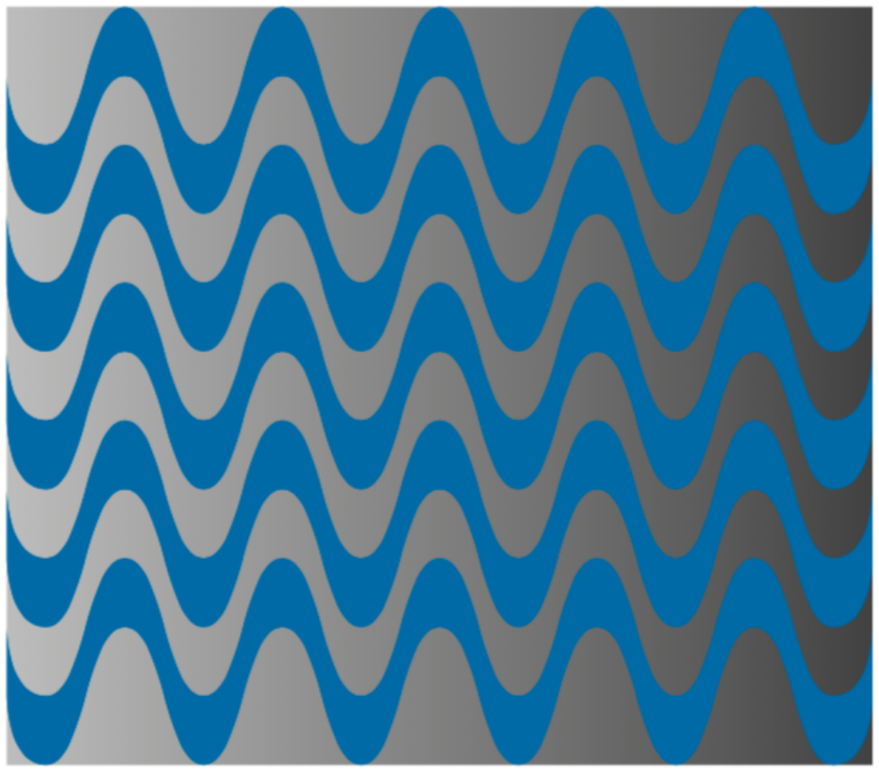


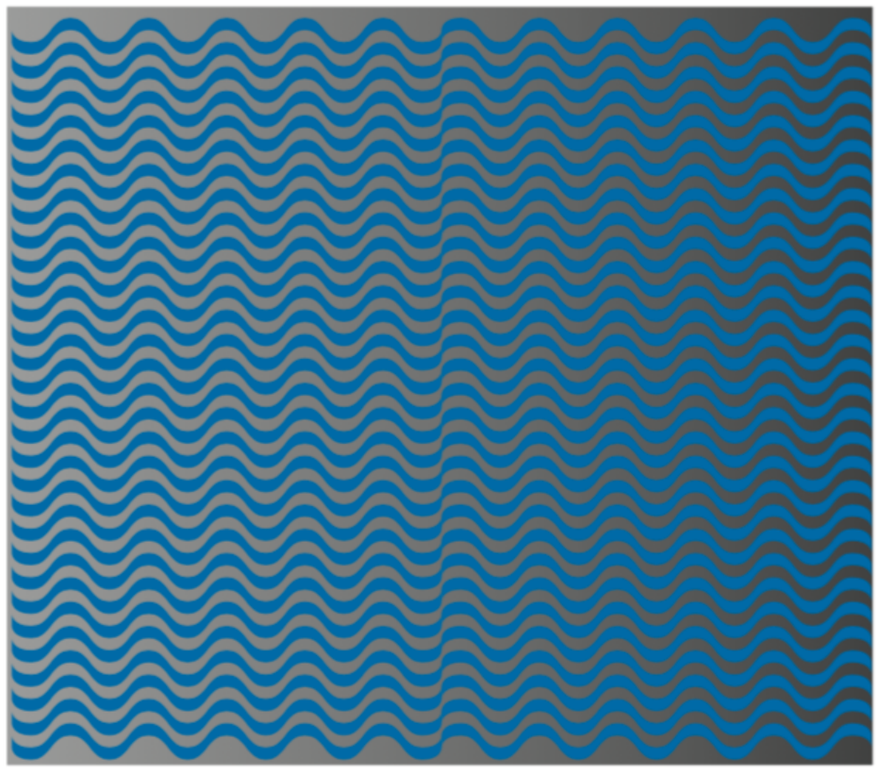
These colors have a name in virtually every human language

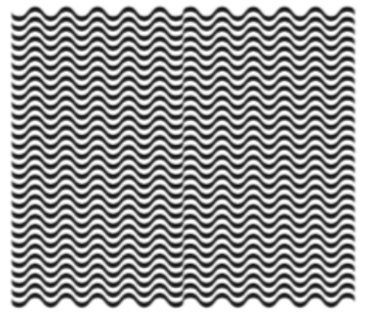
Their semantics and connotations are culture-specific

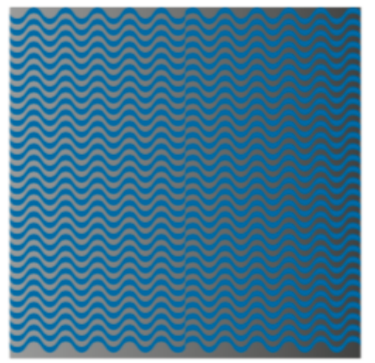
Sensitivity to spatial detail

The luminance channel has greater ability to resolve smaller detail









C. Ware, Visual Thinking for Design

Sensitivity to spatial detail

APRIL is the cruellest month, breeding
Lilacs out of the dead land, mixing
Memory and desire, stirring
Dull roots with spring rain.
Winter kept us warm, covering
Earth in forgetful snow, feeding
A little life with dried tubers.

T.S. Eliot

APRIL is the cruellest month, breeding
Lilacs out of the dead land, mixing
Memory and desire, stirring
Dull roots with spring rain.
Winter kept us warm, covering
Earth in forgetful snow, feeding
A little life with dried tubers.

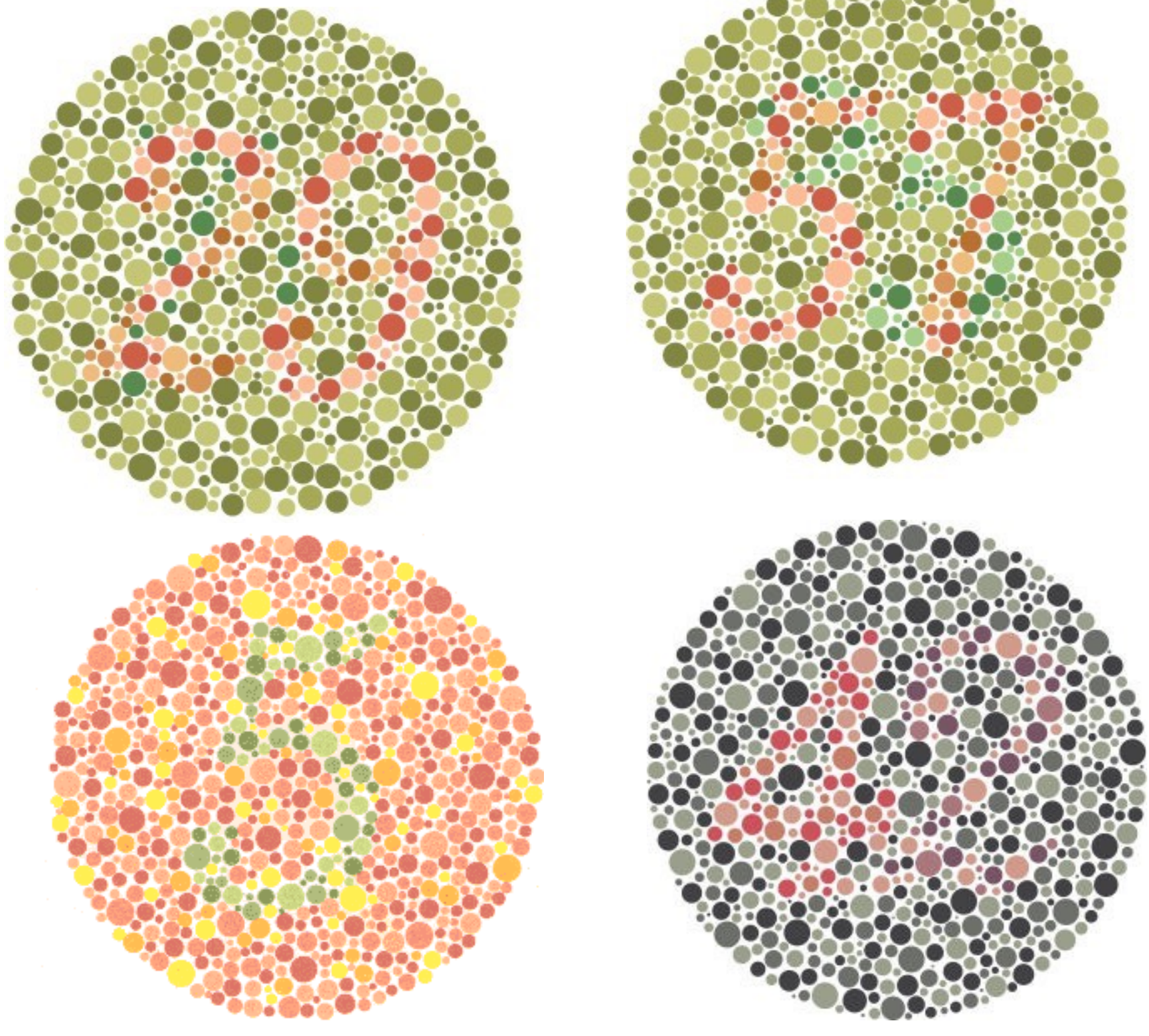
T.S. Eliot

APRIL

When text is small it is essential that there be luminance contrast with the background color. Notice how the text is hardest to read when the luminance contrast is lowest. When text is big, anything goes.

C. Ware, Visual Thinking for Design

Color deficiencies



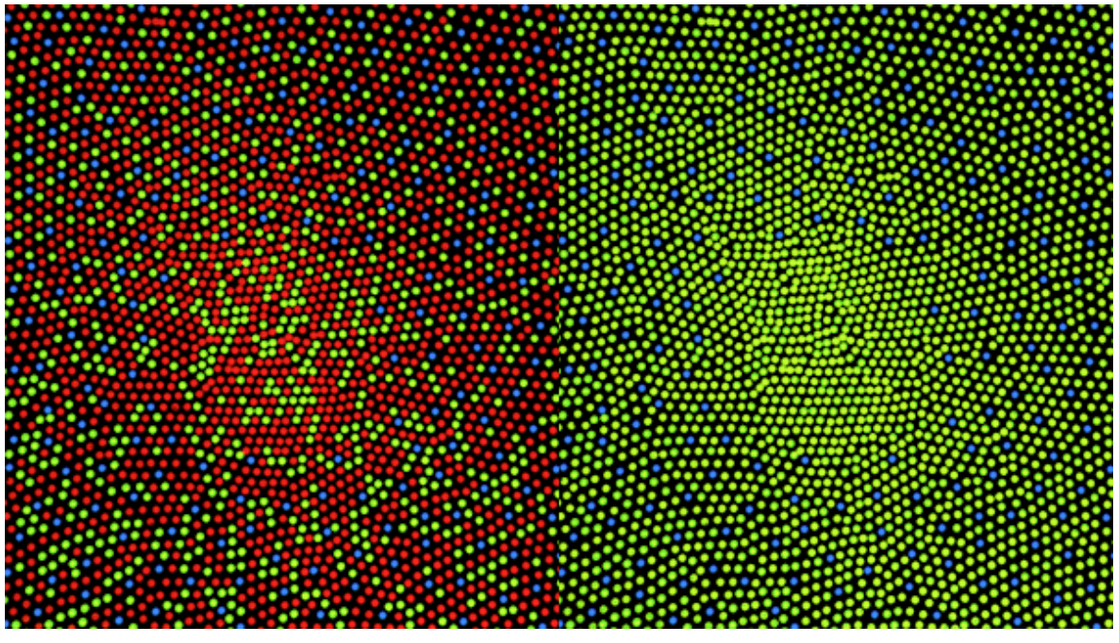
Color deficiencies

Sometimes caused by faculty cones,
sometimes by faulty pathways

red-green weakness is the most common type

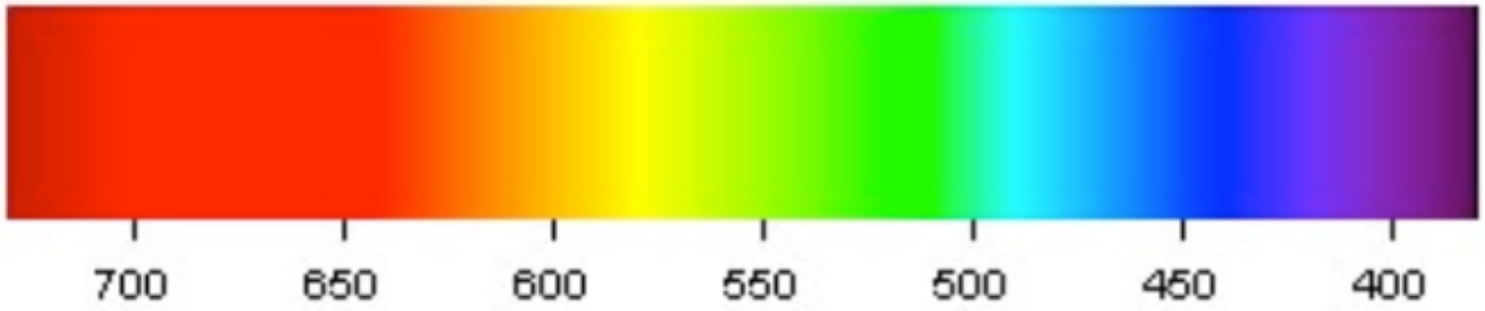
8% of (North American) males, 0.5% of female

normal retina Protanopic

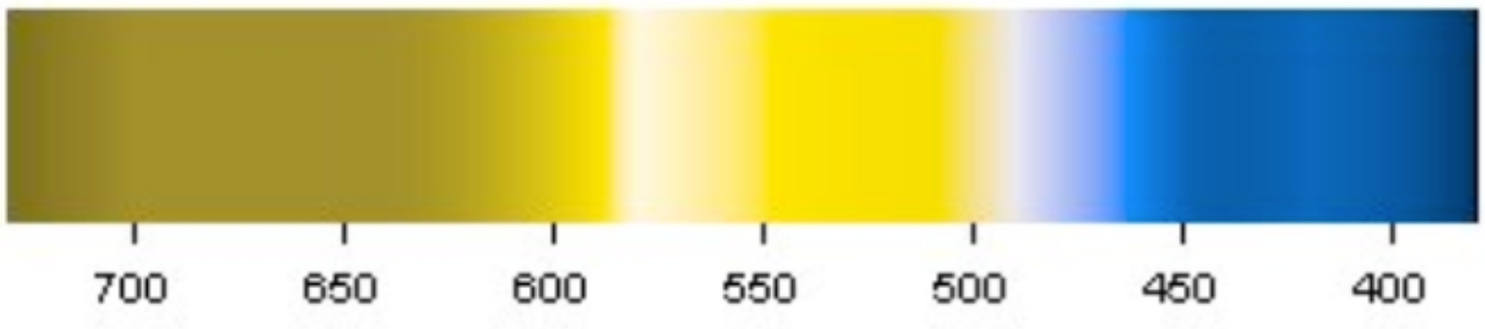


Based on a slide by Miriah Meyer

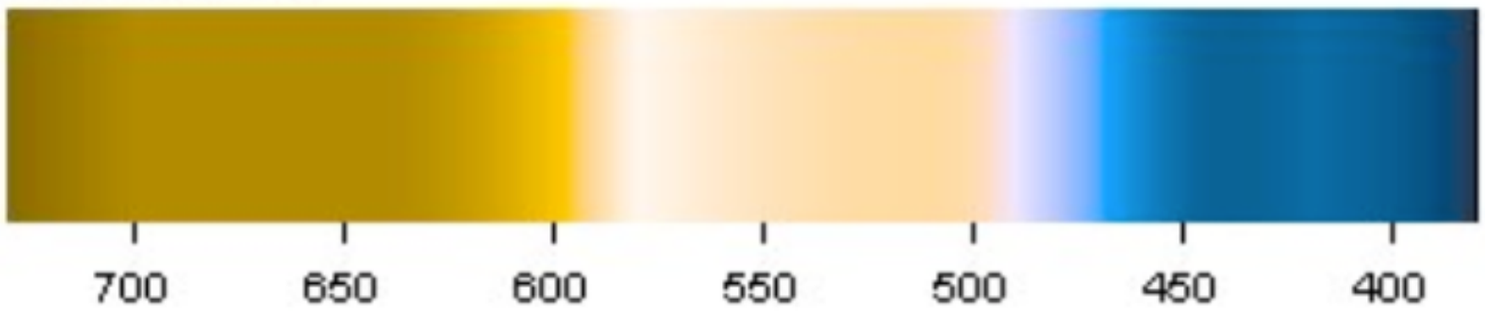
Normal



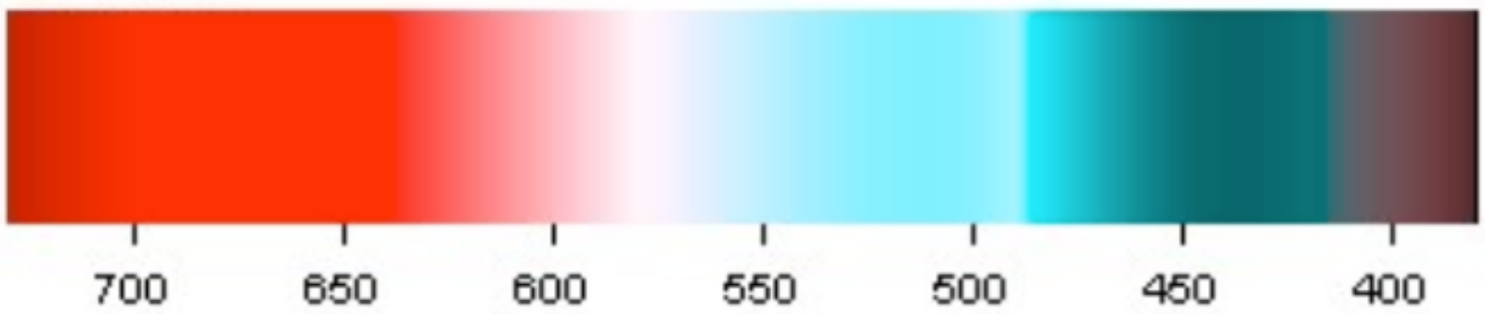
Protanopia — **lacking red cones**



Deuteranopia — **lacking green cones**



Tritanopia — **lacking blue cones**



Via Miriah Meyer

Four Ways to Slice Obama's 2013 Budget Proposal

Explore every nook and cranny of President Obama's federal budget proposal.

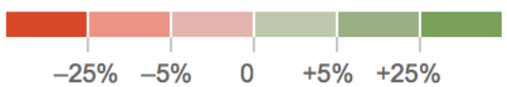
All Spending | Types of Spending | Changes | Department Totals

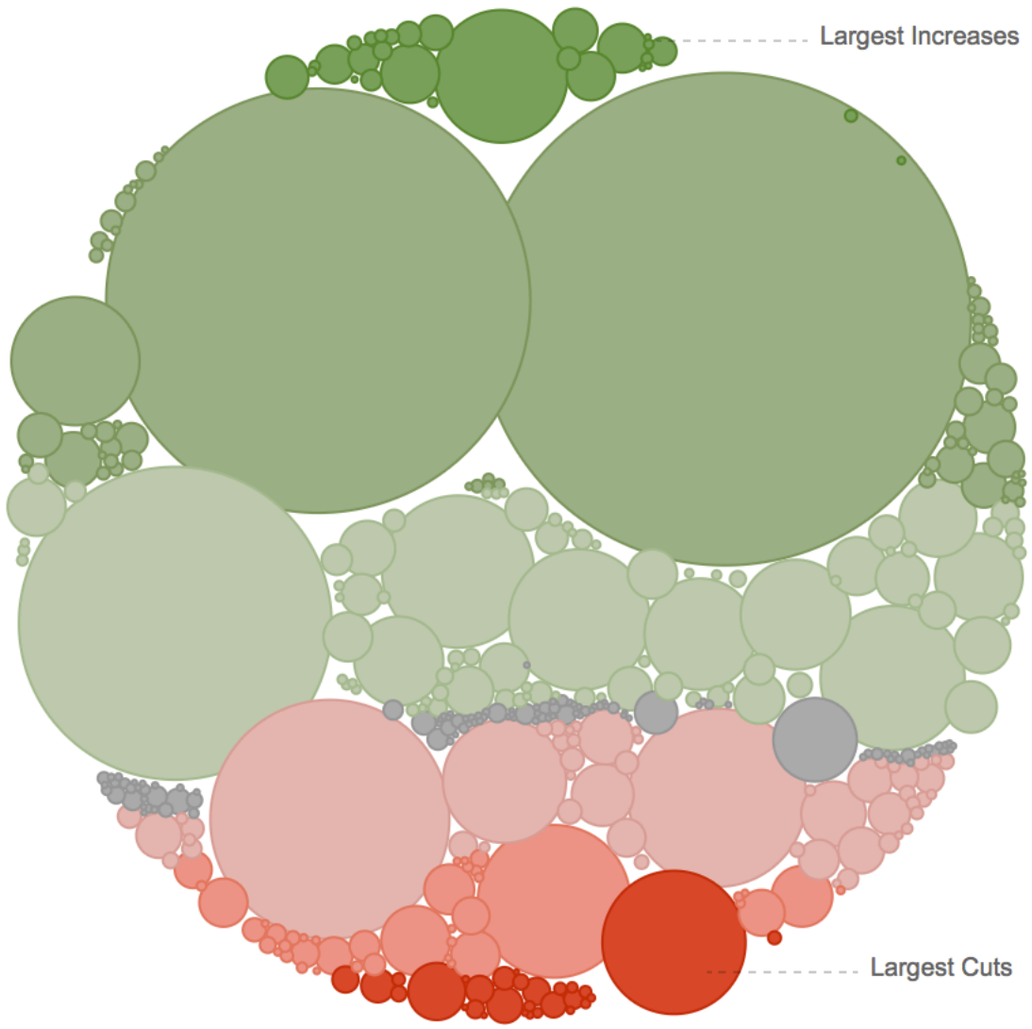
How $3.7 Trillion Is Spent

Mr. Obama's budget proposal includes $3.7 trillion in spending in 2013, and forecasts a $901 billion deficit.

Circles are sized according to the proposed spending.

Color shows amount of cut or increase from 2012.





The proposal forecasts a $901 billion deficit.

Four Ways to Slice Obama's 2013 Budget Proposal

Explore every nook and cranny of President Obama's federal budget proposal.

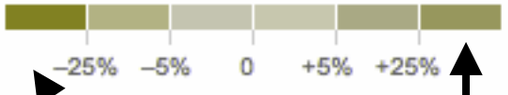
All Spending | Types of Spending | Changes | Department Totals

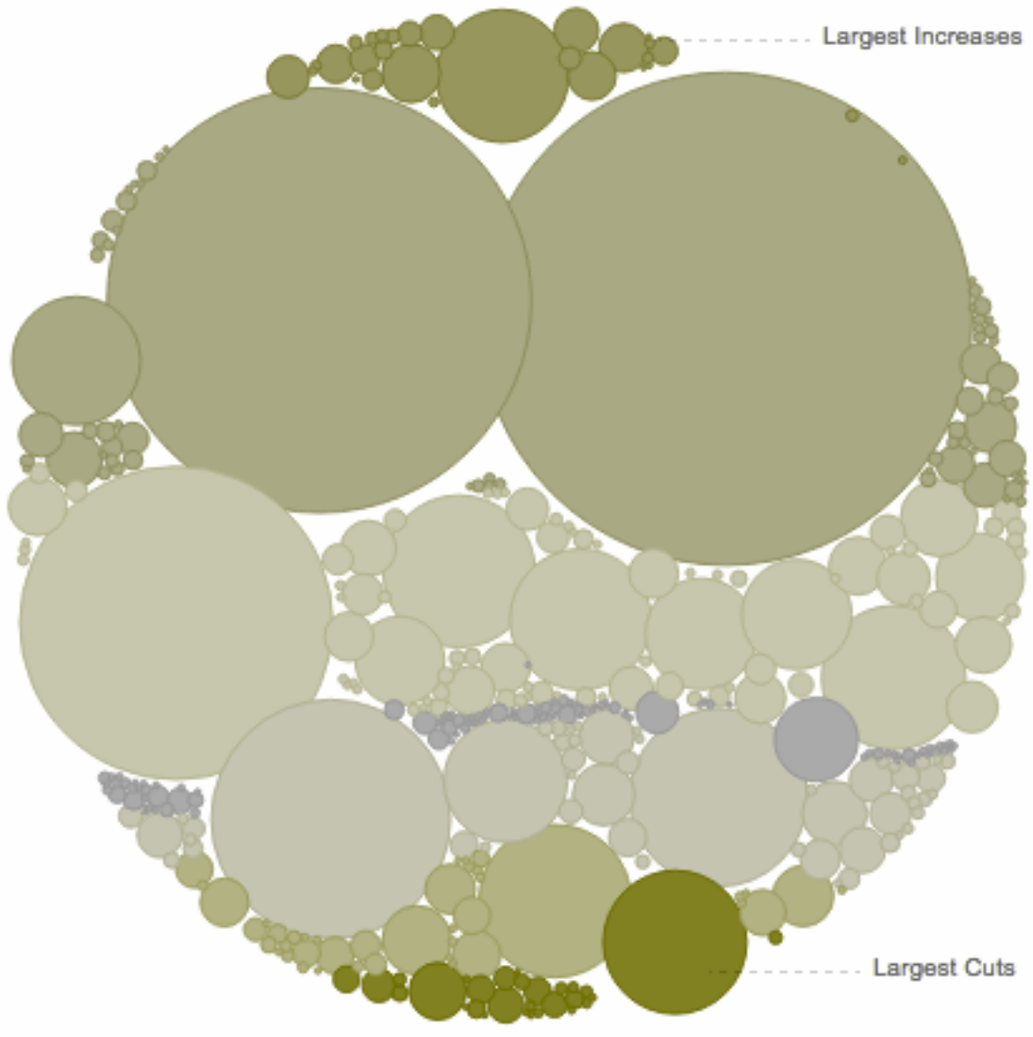
How $3.7 Trillion Is Spent

Mr. Obama's budget proposal includes $3.7 trillion in spending in 2013, and forecasts a $901 billion deficit.

Circles are sized according to the proposed spending.

Color shows amount of cut or increase from 2012.





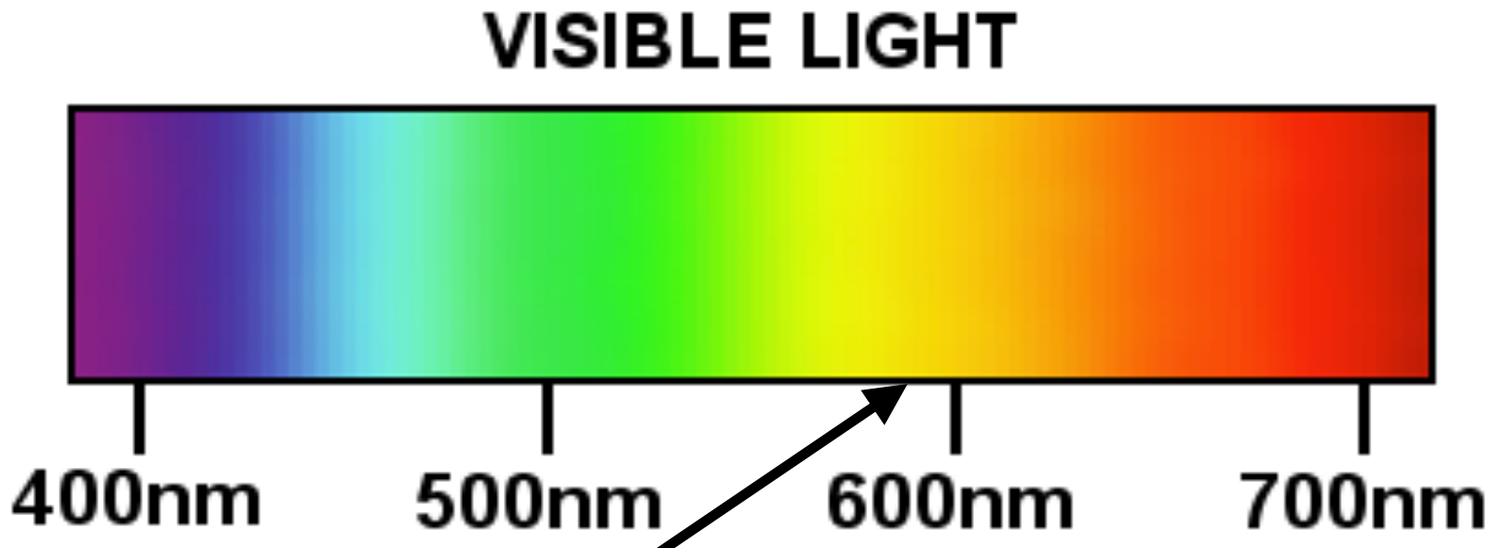
The proposal forecasts a $901 billion deficit.

difficult to distinguish for people with Deuteranopia

Color spaces

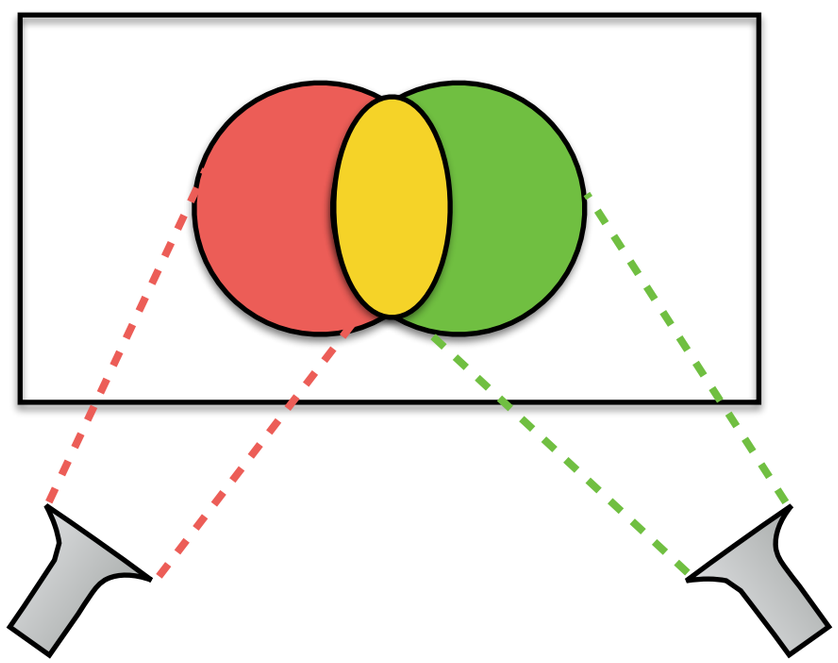
Representing color with numbers

light

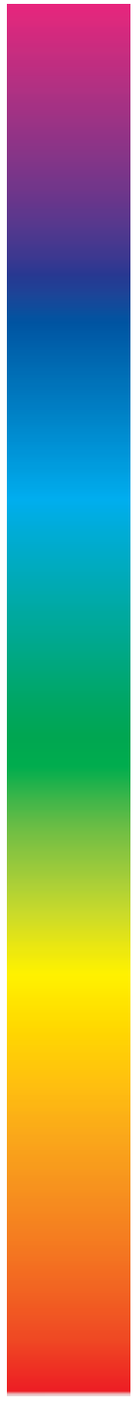


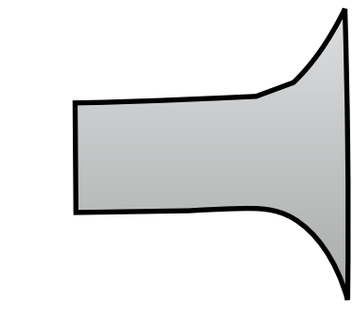
1. pure yellow: 580 nm

2. color matching yellow

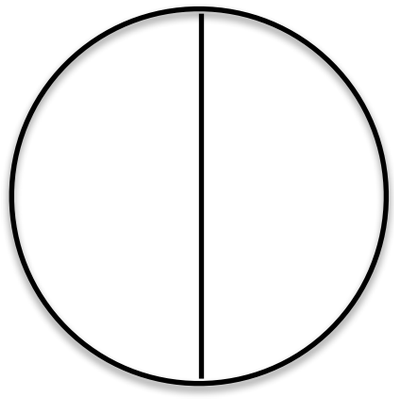


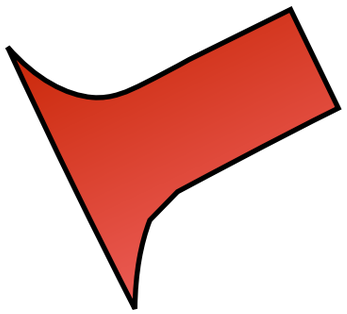
Tristimulus color matching



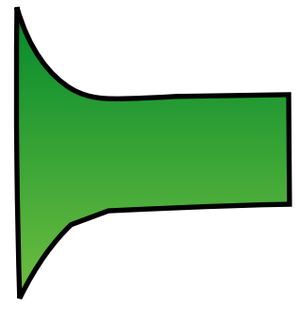


test color

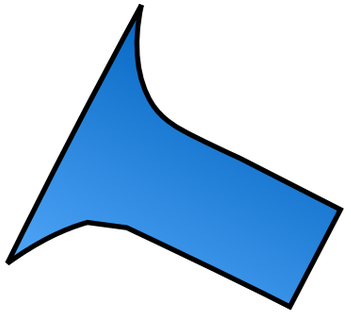




red

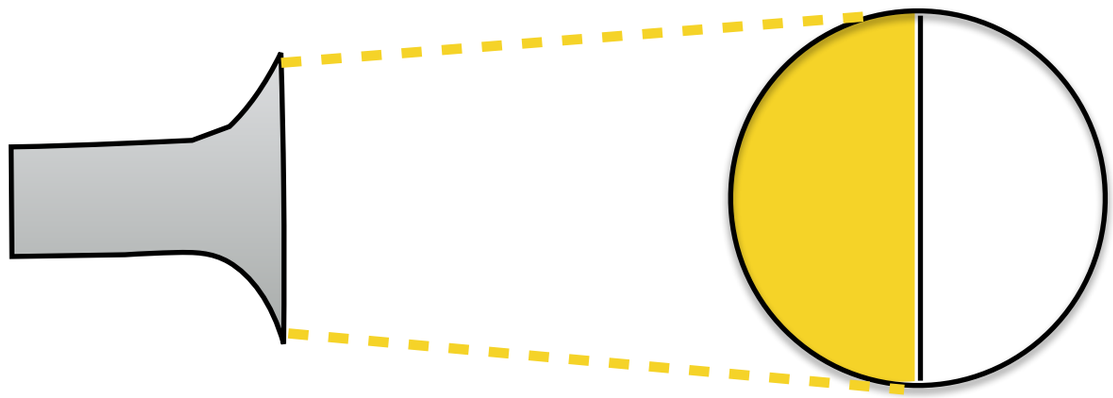


green

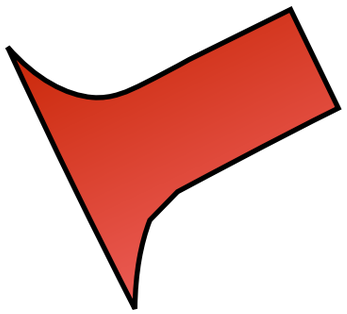


blue

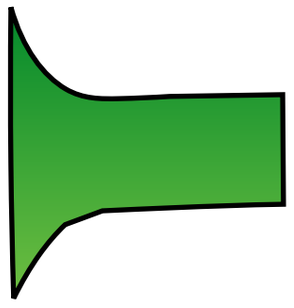
Tristimulus color matching



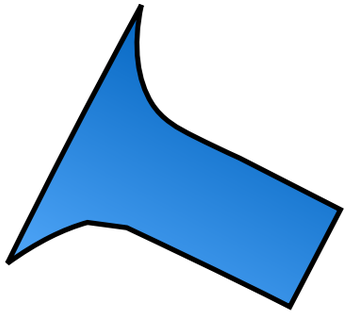
test color
580nm



red

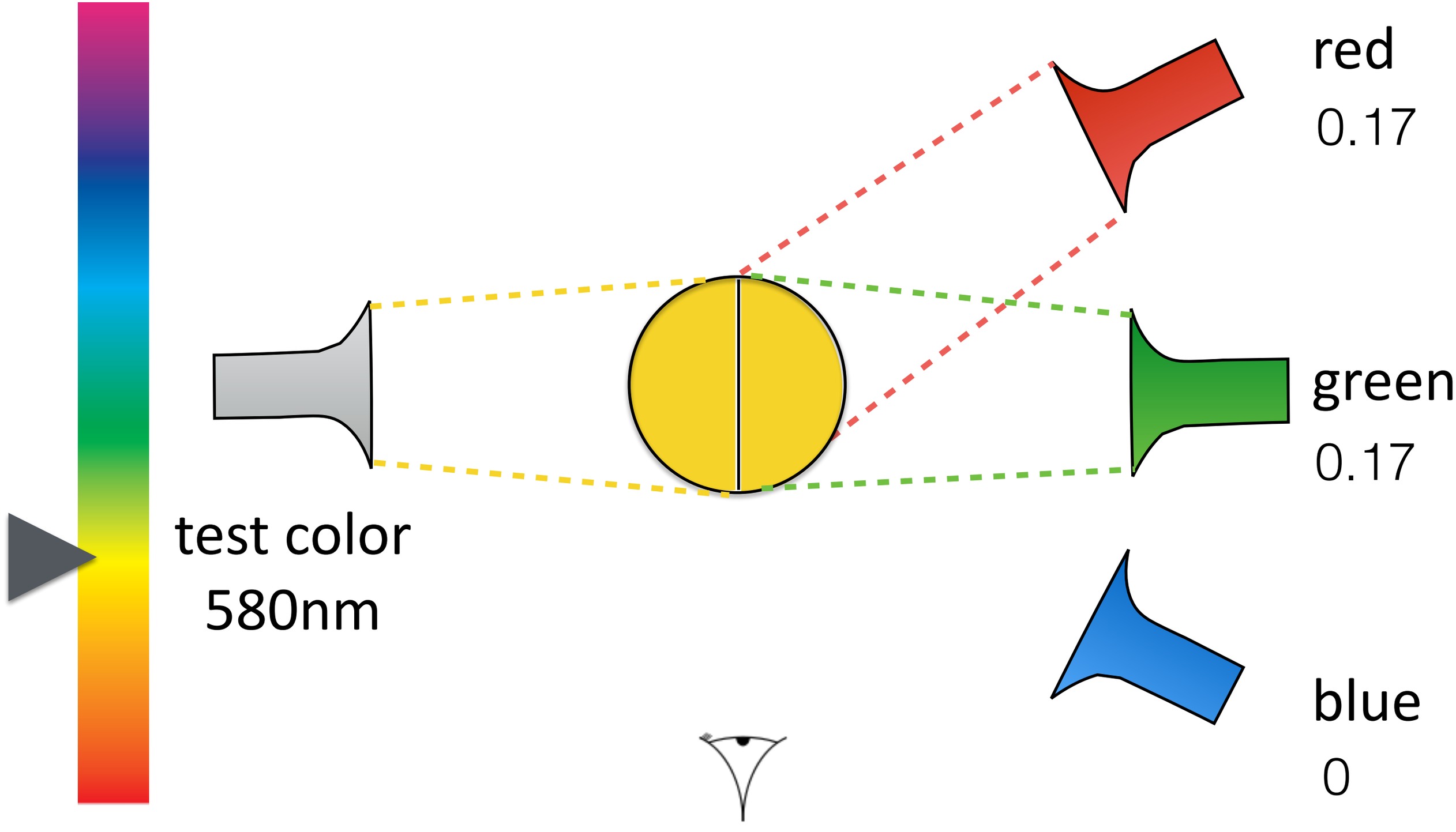


green

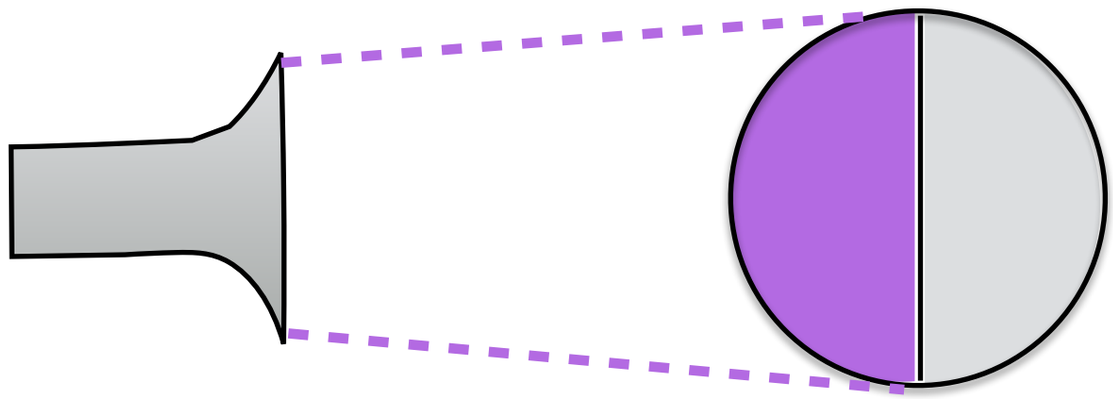


blue

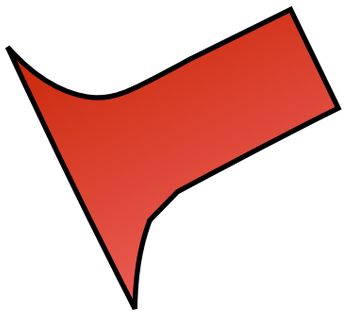
Tristimulus color matching



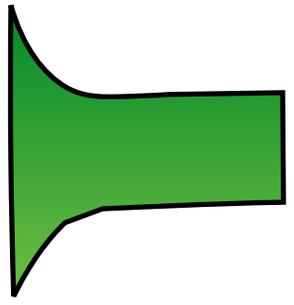
Tristimulus color matching



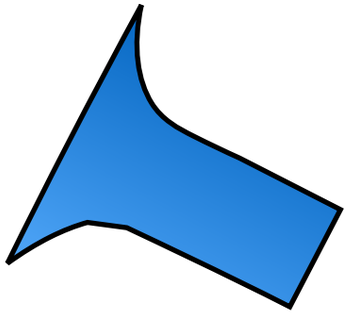
test color
580nm



red

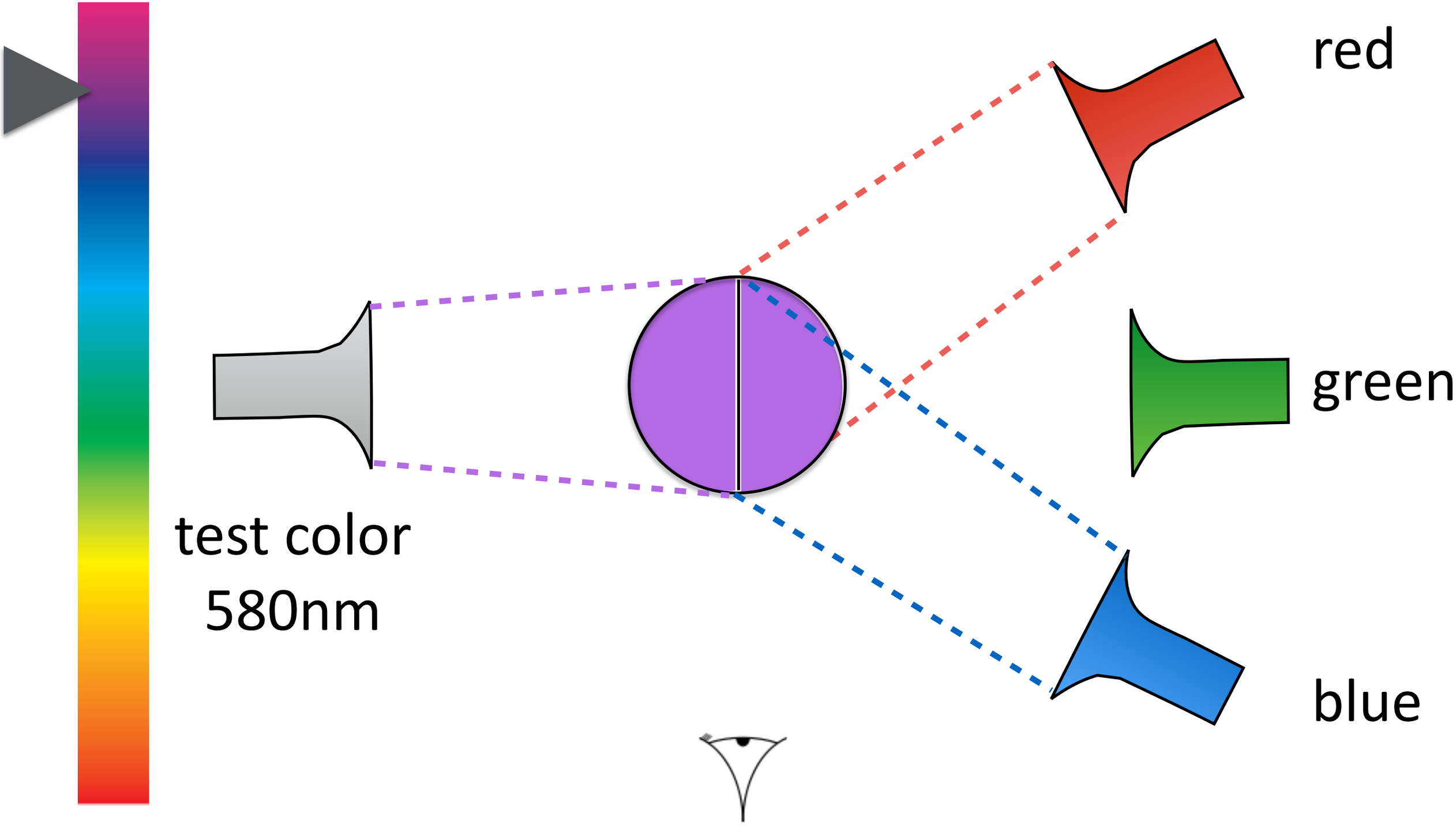


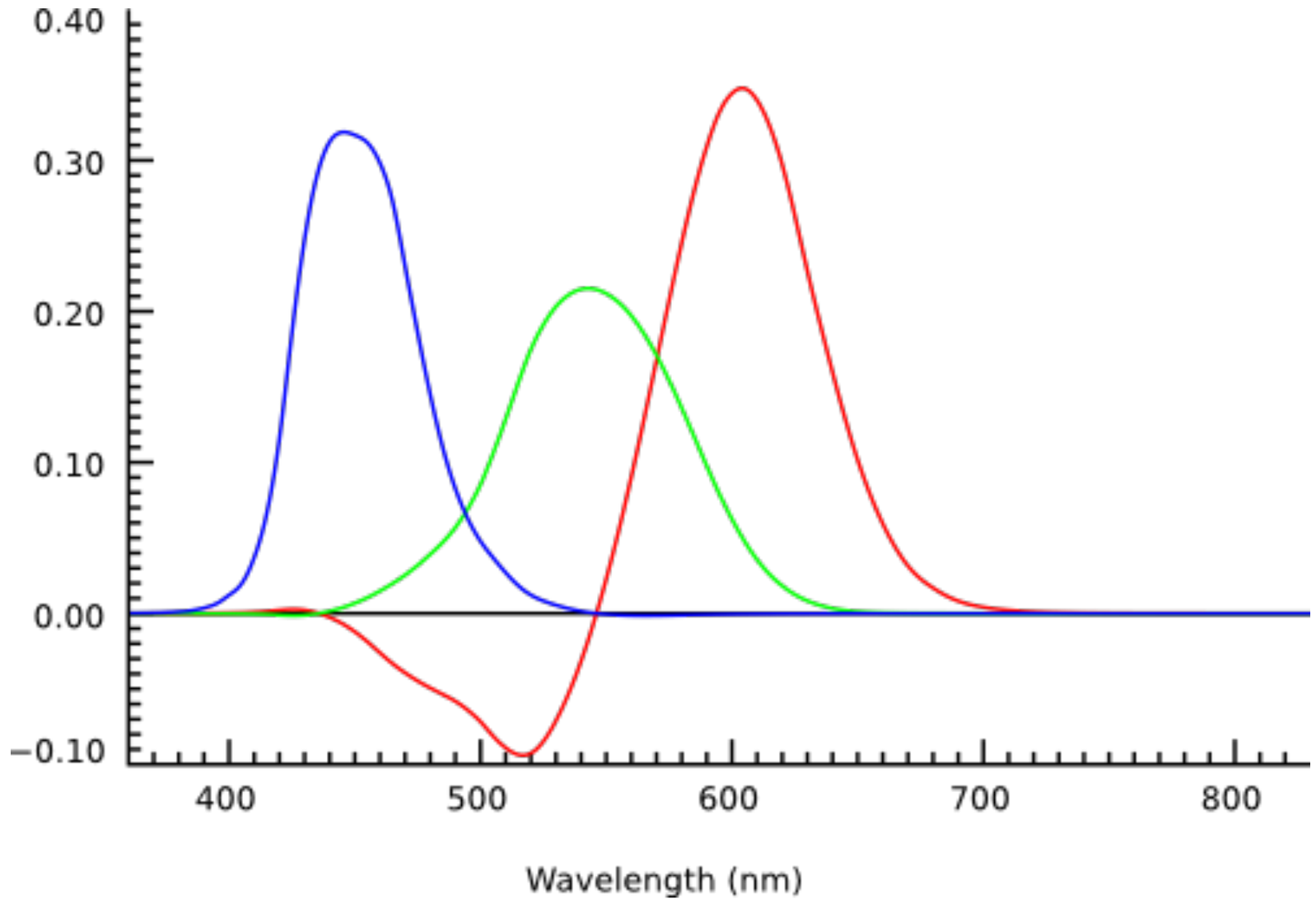
green

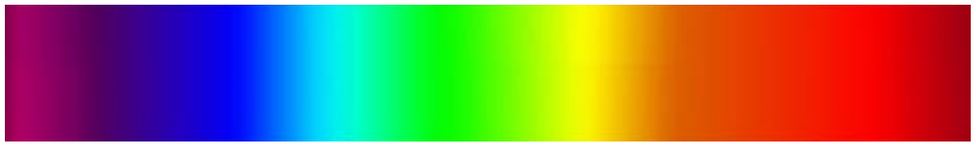


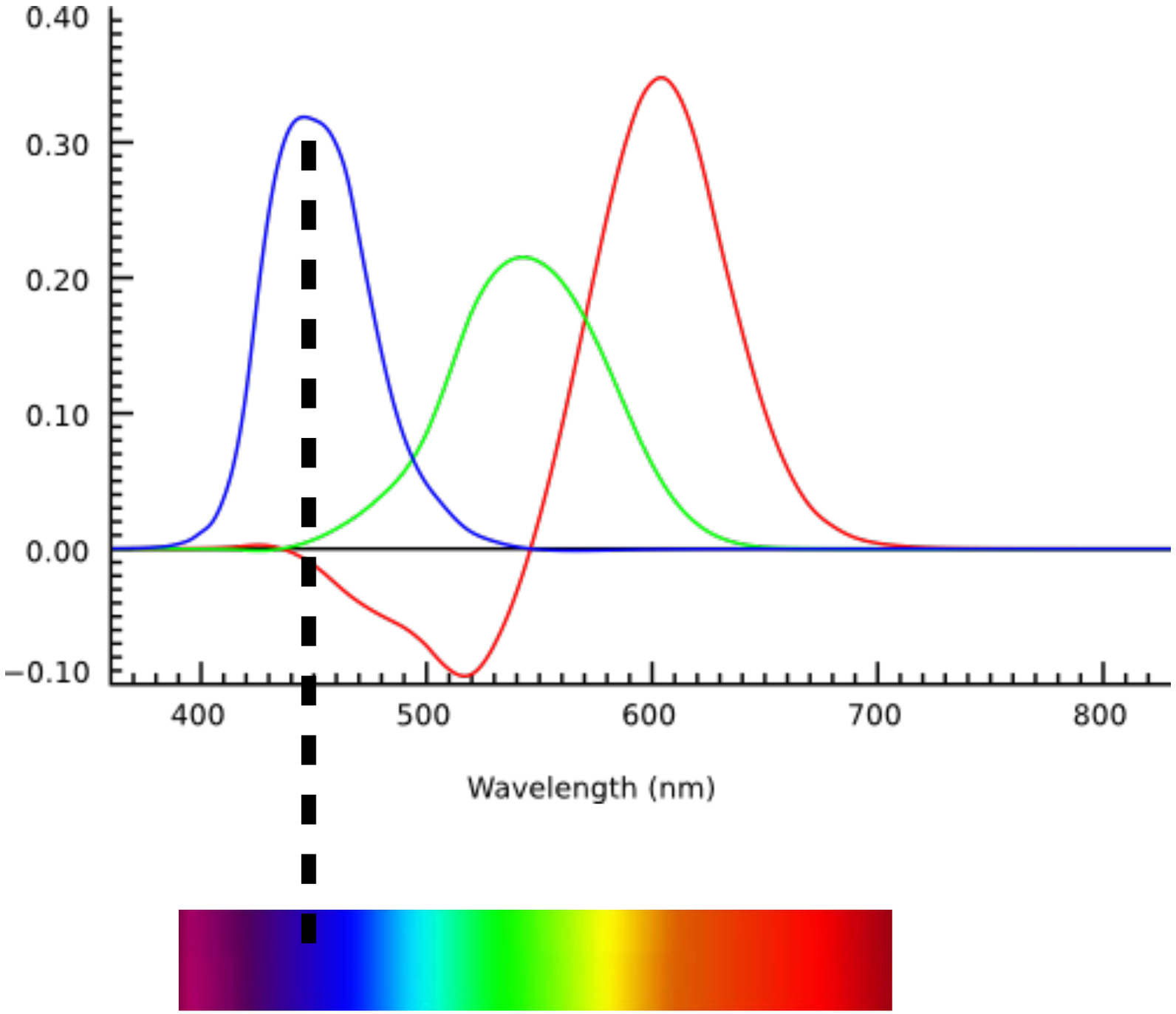
blue

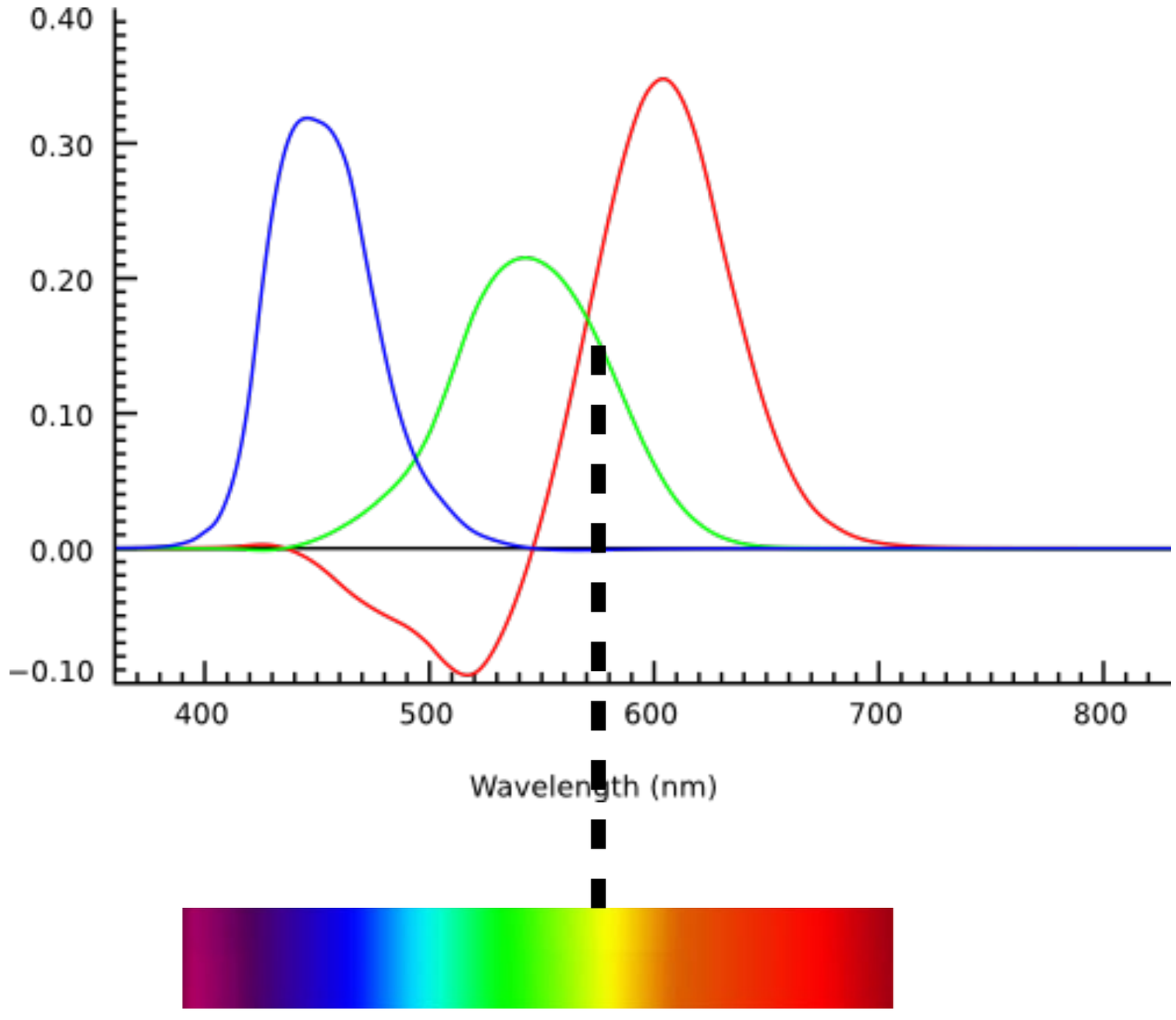
Tristimulus color matching




0.40
0.30
0.20
0.10
0.00
−0.10
400
500
600
700
800
Wavelength (nm)



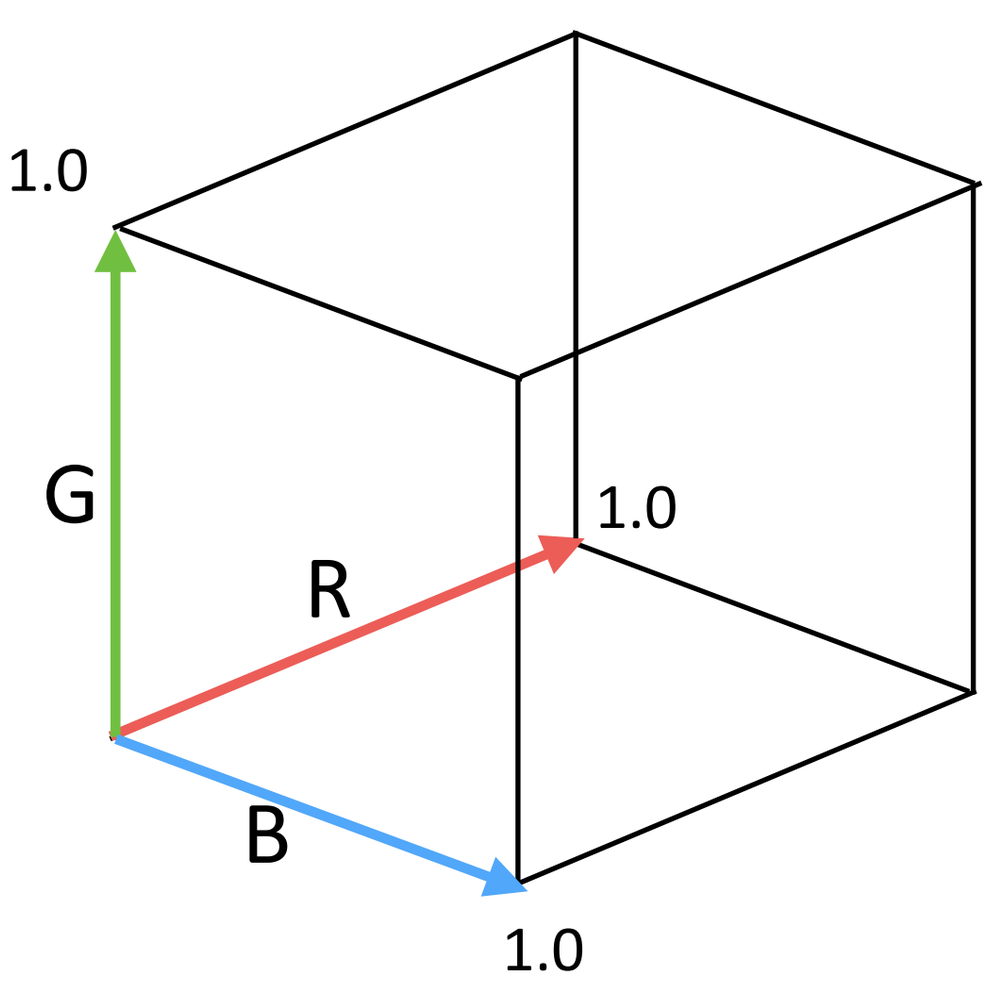

0.40
0.30
0.20
0.10
0.00
−0.10
400
500
600
700
800
Wavelength (nm)


0.40
0.30
0.20
0.10
0.00
−0.10
400
500
600
700
800
Wavelength (nm)

RGB color space

Each point within the cube is defined by a 3D vector (r, g,b) and represents a unique color

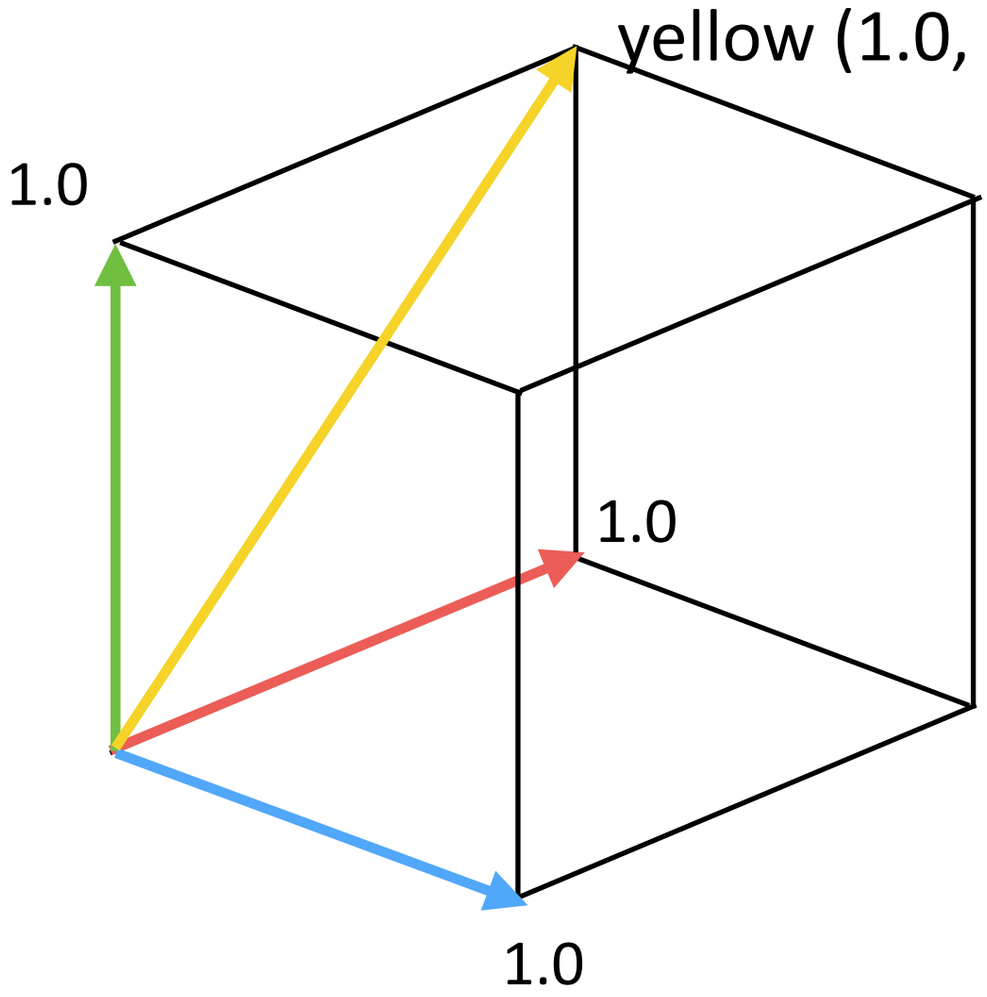
The **r, g, b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g,b) and represents a unique color

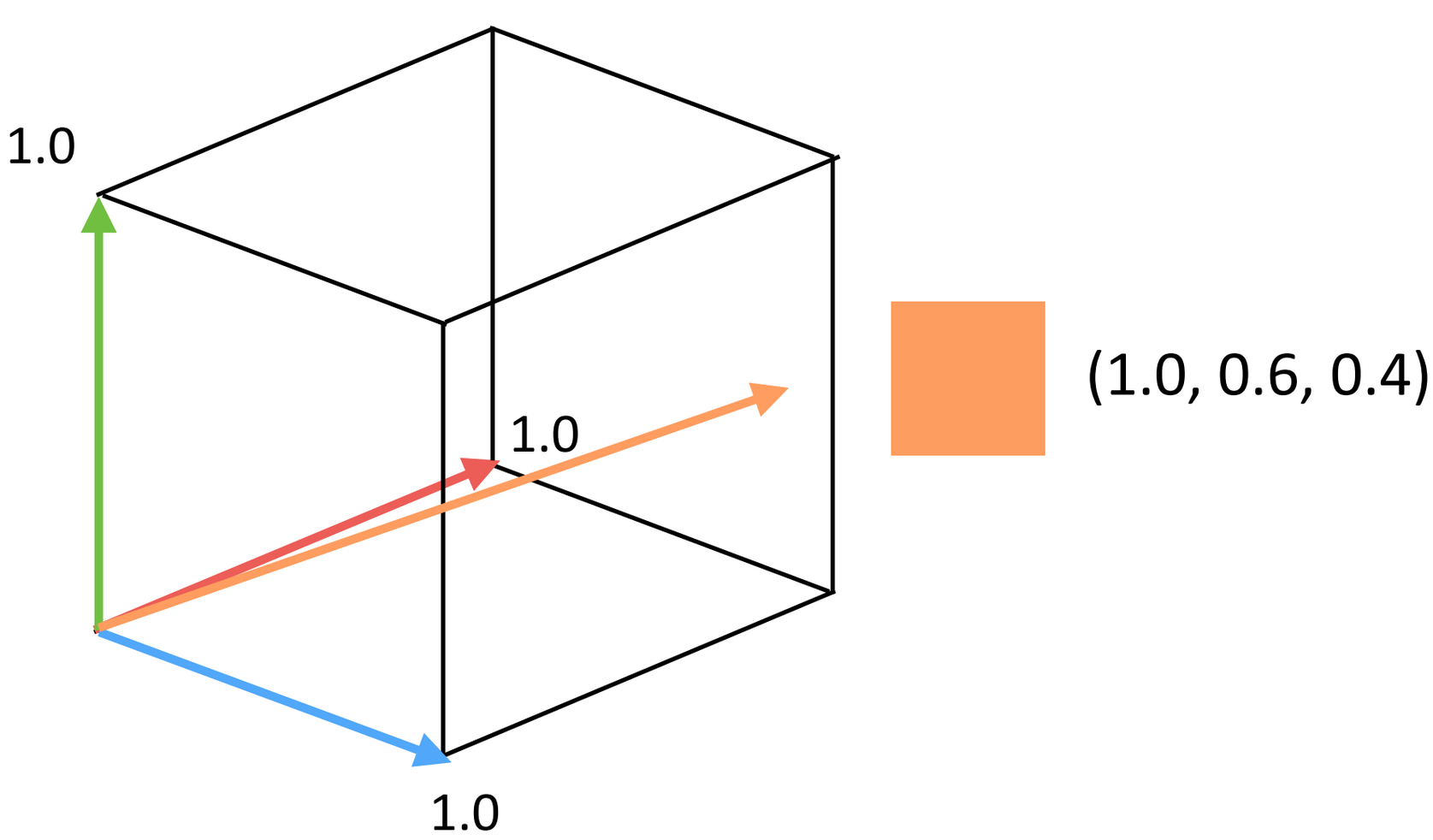
The **r, g, b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g,b) and represents a unique color

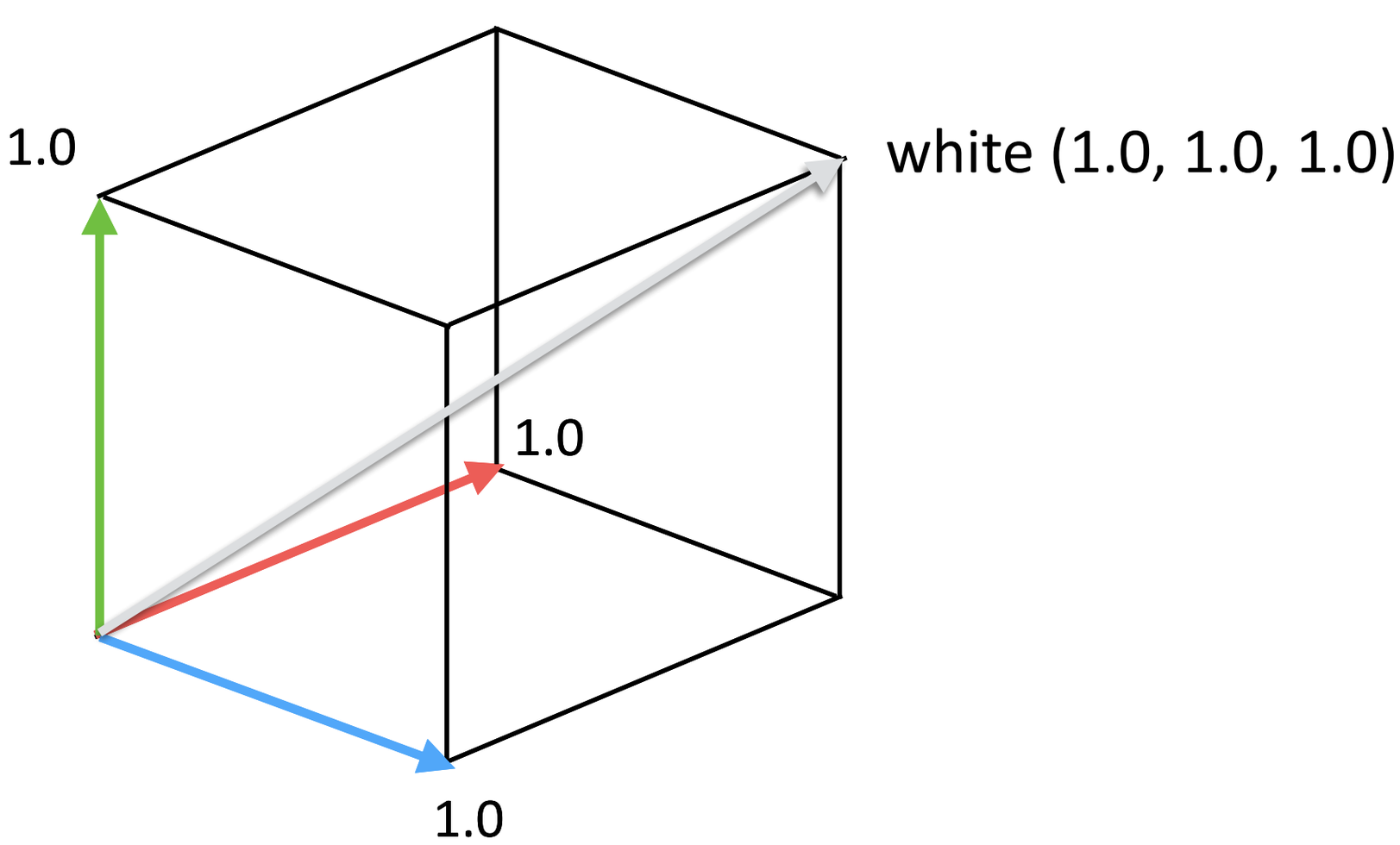
The **r, g, b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g,b) and represents a unique color

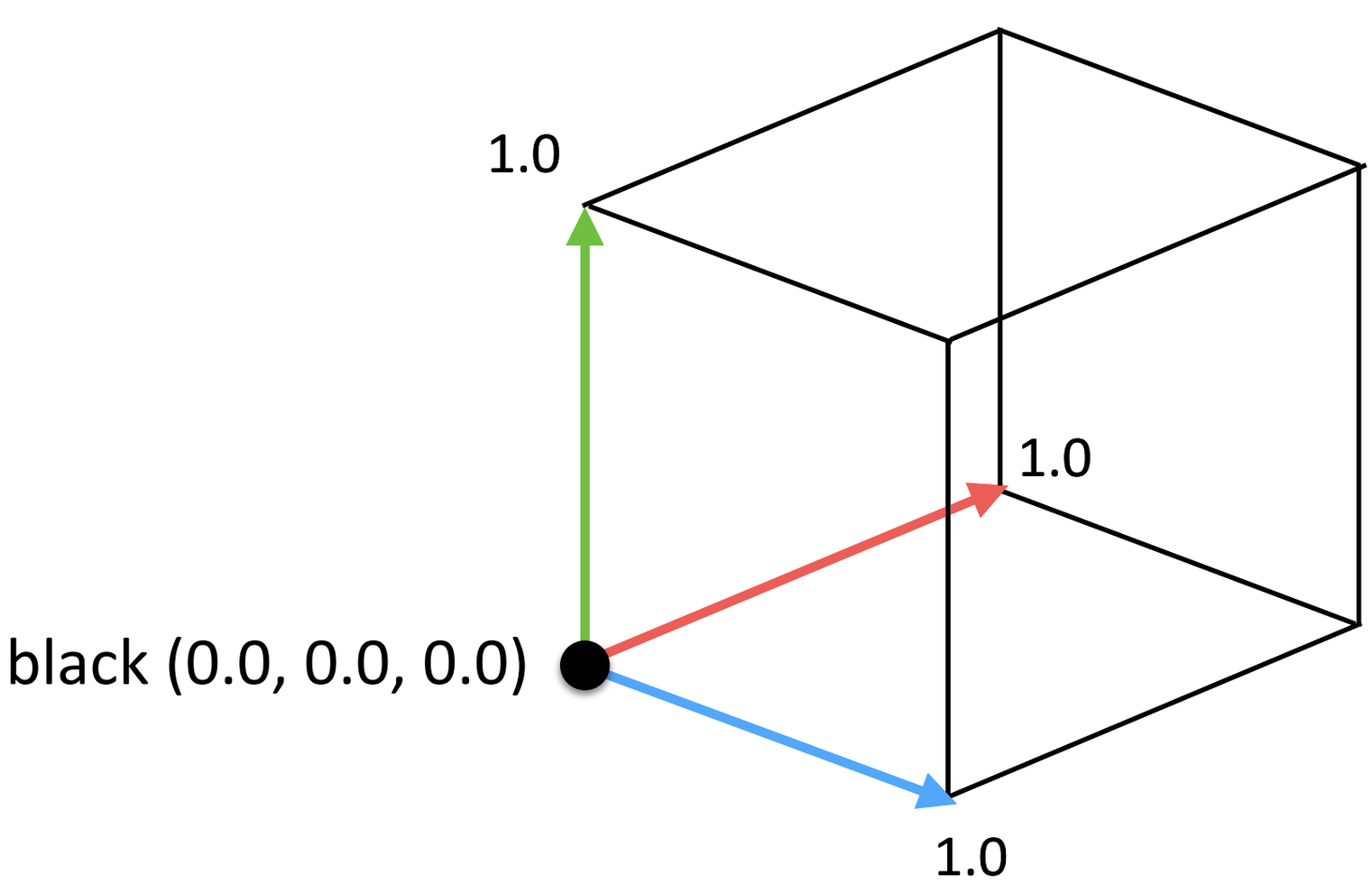
The **r, g, b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g,b) and represents a unique color

The **r, g, b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



what colors combination can be used to re-producing the visible light spectrum by mixing?

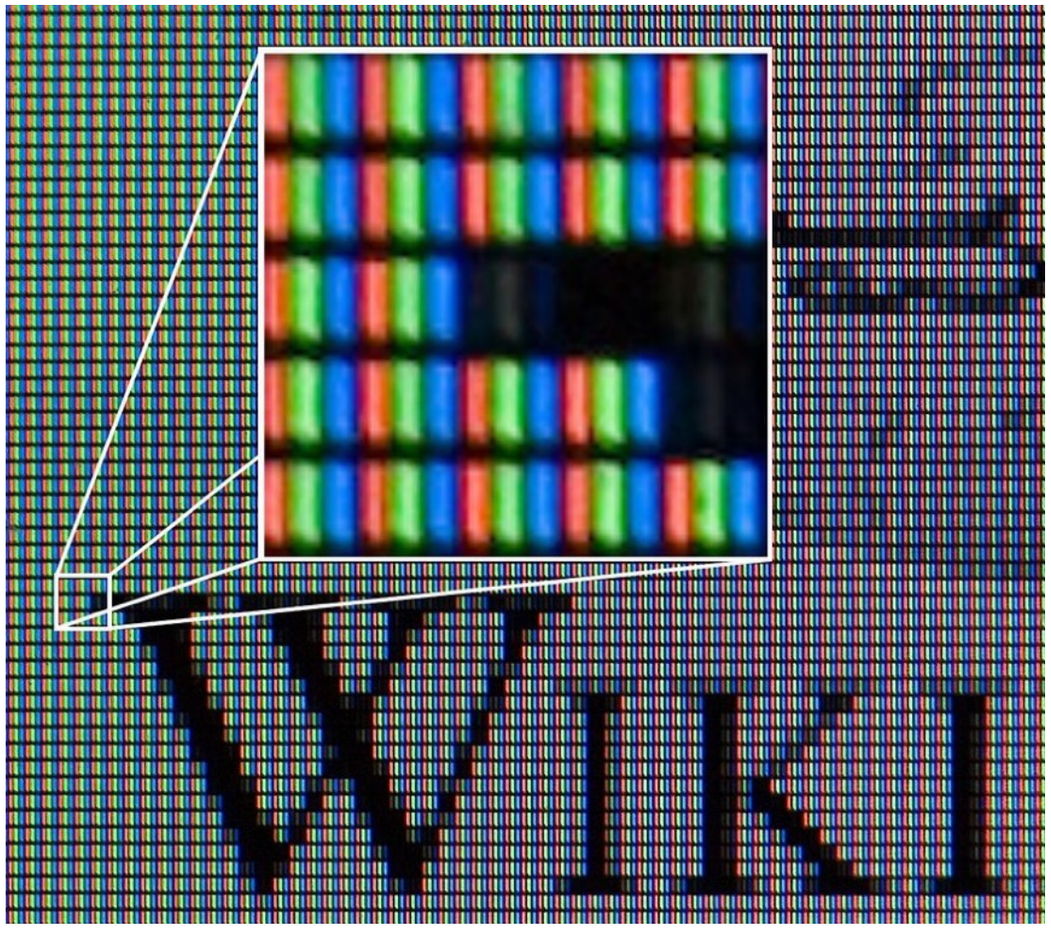
- red, yellow, blue
- red, green, blue
- orange, green, violet
- cyan, magenta, yellow
- all of the above

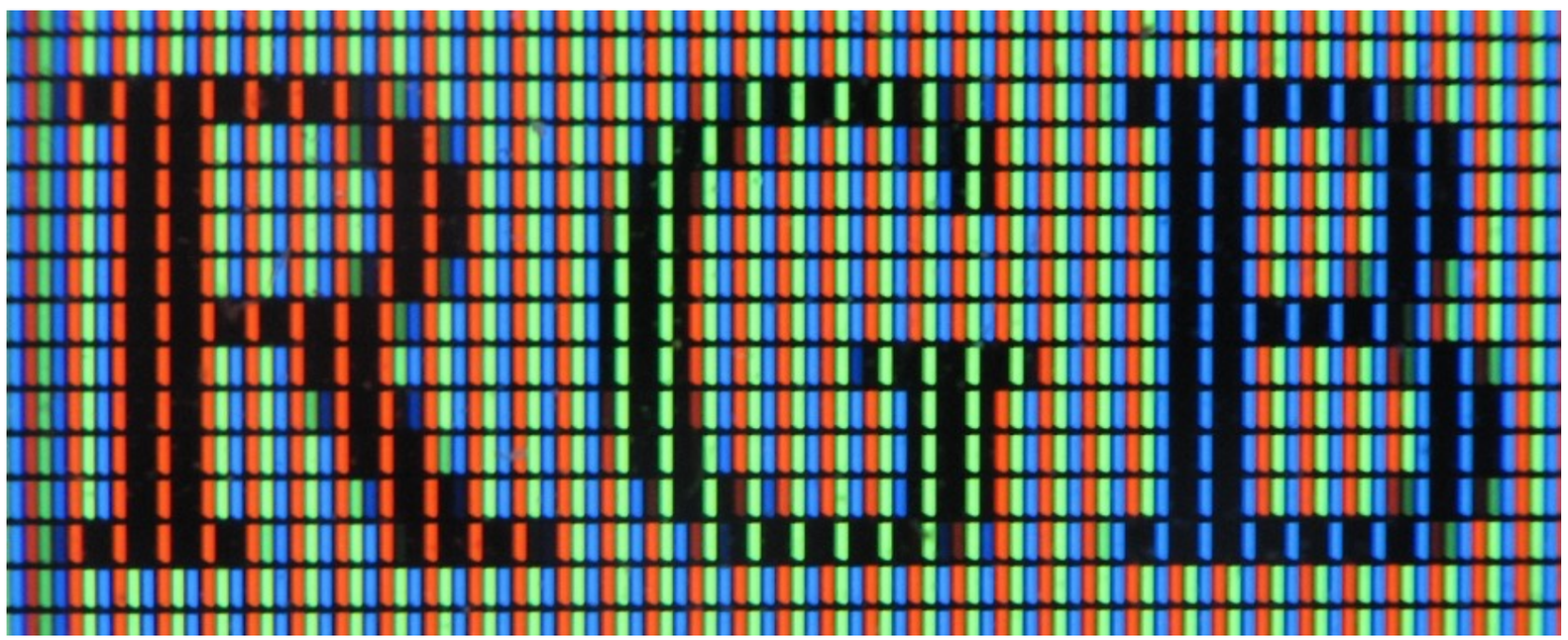
Light mixing (RGB)

Additive mixing of colored lights

Light mixing (RGB)

LCD display closeup





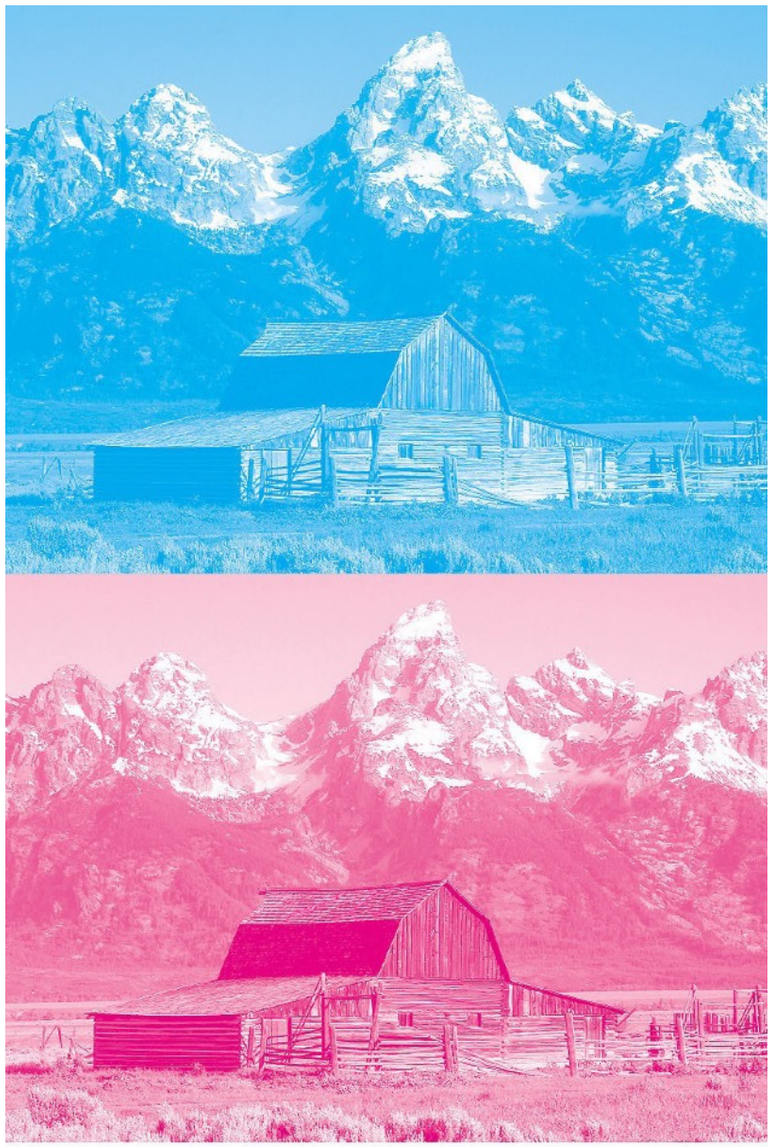
Wikipedia

Ink mixing (CMY / CMYK)

Subtractive mixing of inks printed on white paper

Color picture

CMY composite



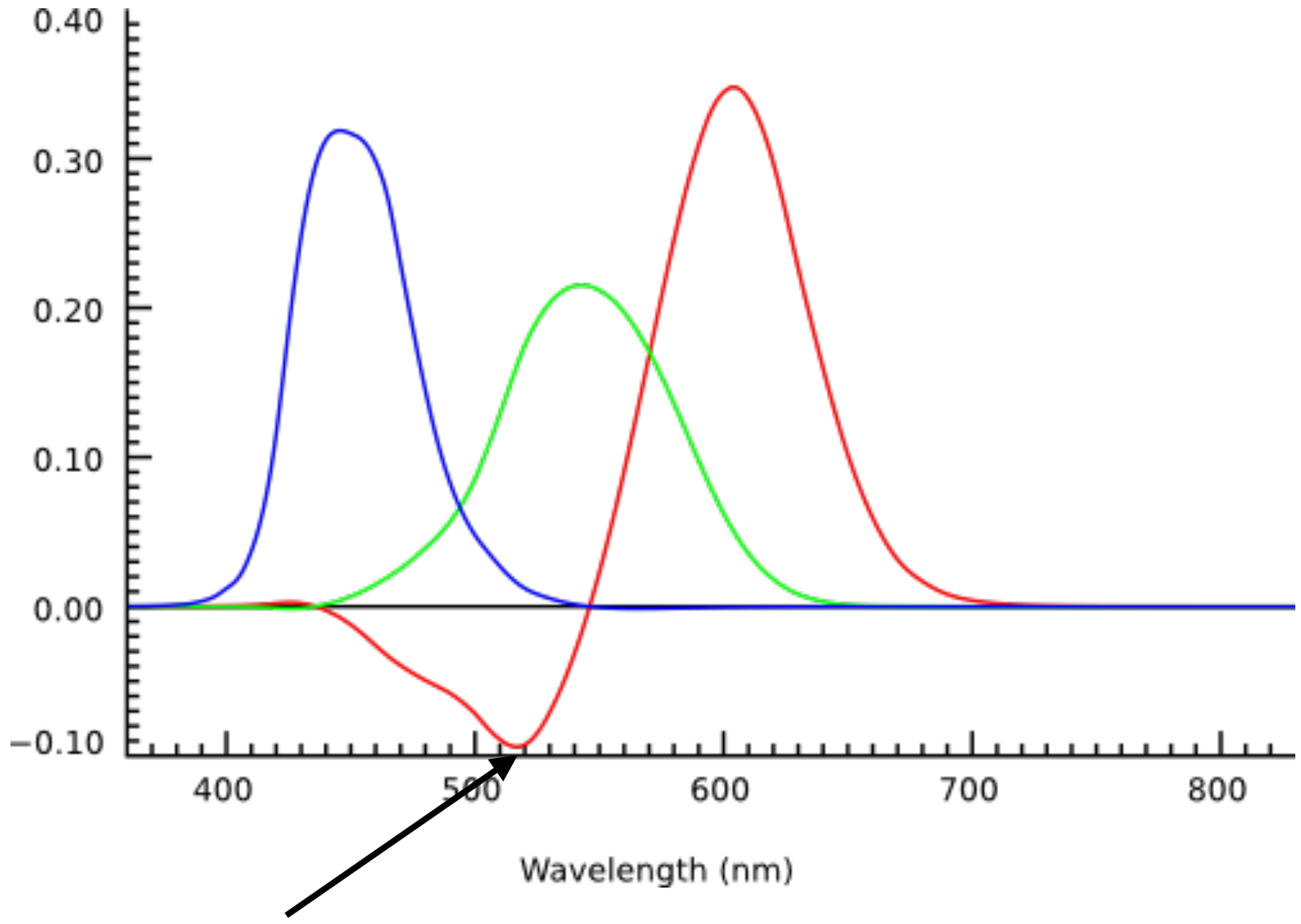
CMYK composite

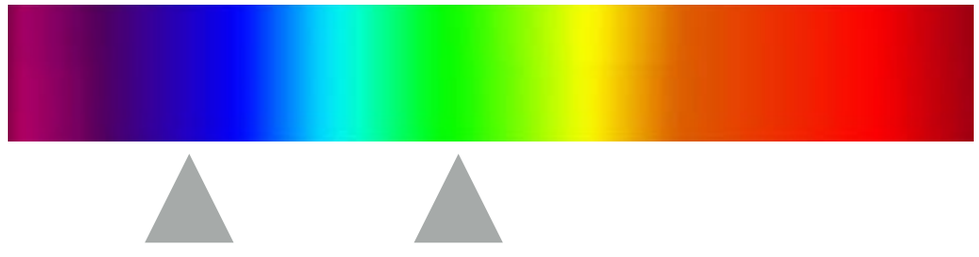
Wikipedia

what colors combination can be used to re-producing the visible light spectrum by mixing?

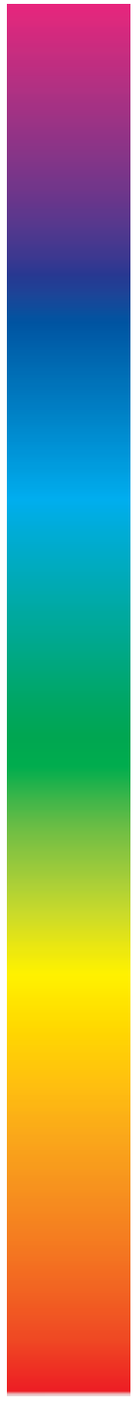
- red, yellow, blue
- red, green, blue
- orange, green, violet
- cyan, magenta, yellow
- **all of the above , almost**

Miriah Meyer

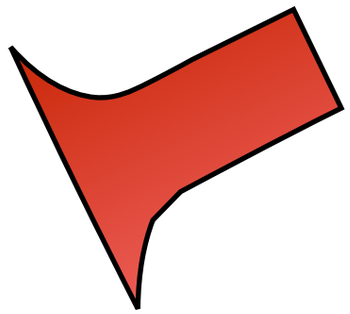

0.40
0.30
0.20
0.10
0.00
−0.10
400
500
600
700
800
Wavelength (nm)



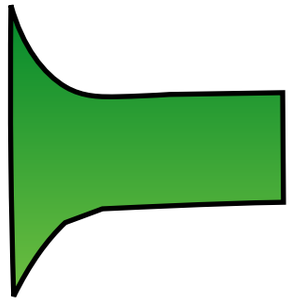
Tristimulus color matching



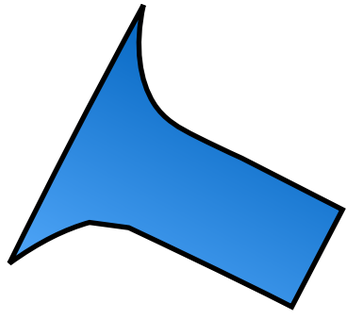
test color
500nm



red

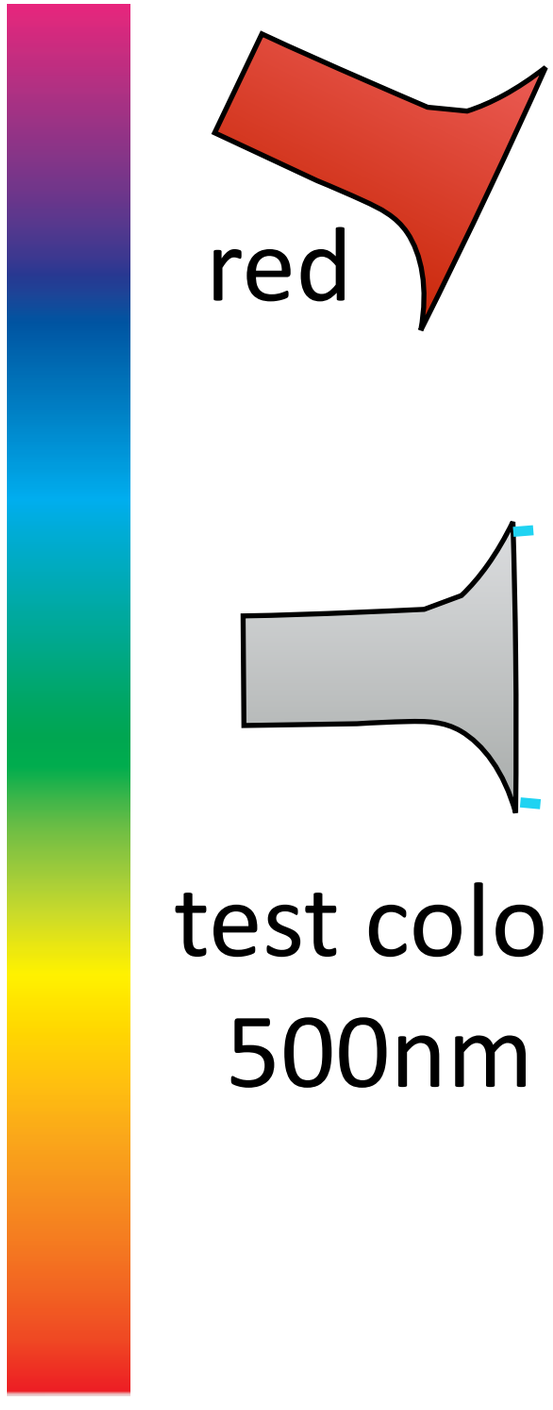


green

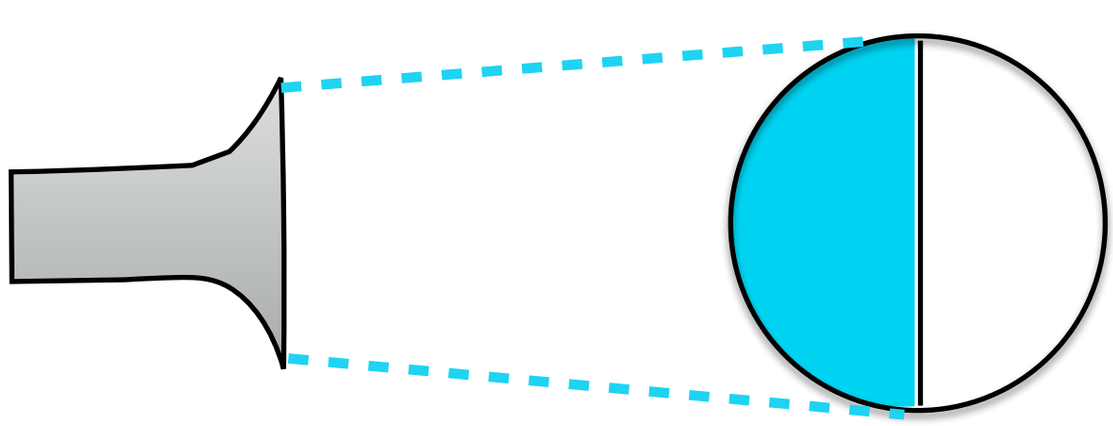


blue

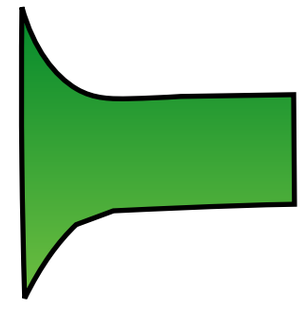
Tristimulus color matching



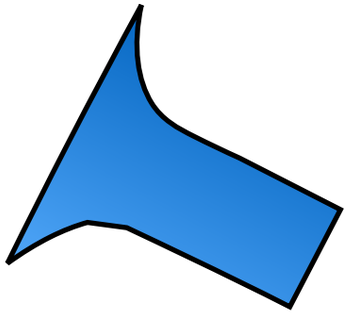
red



test color
500nm

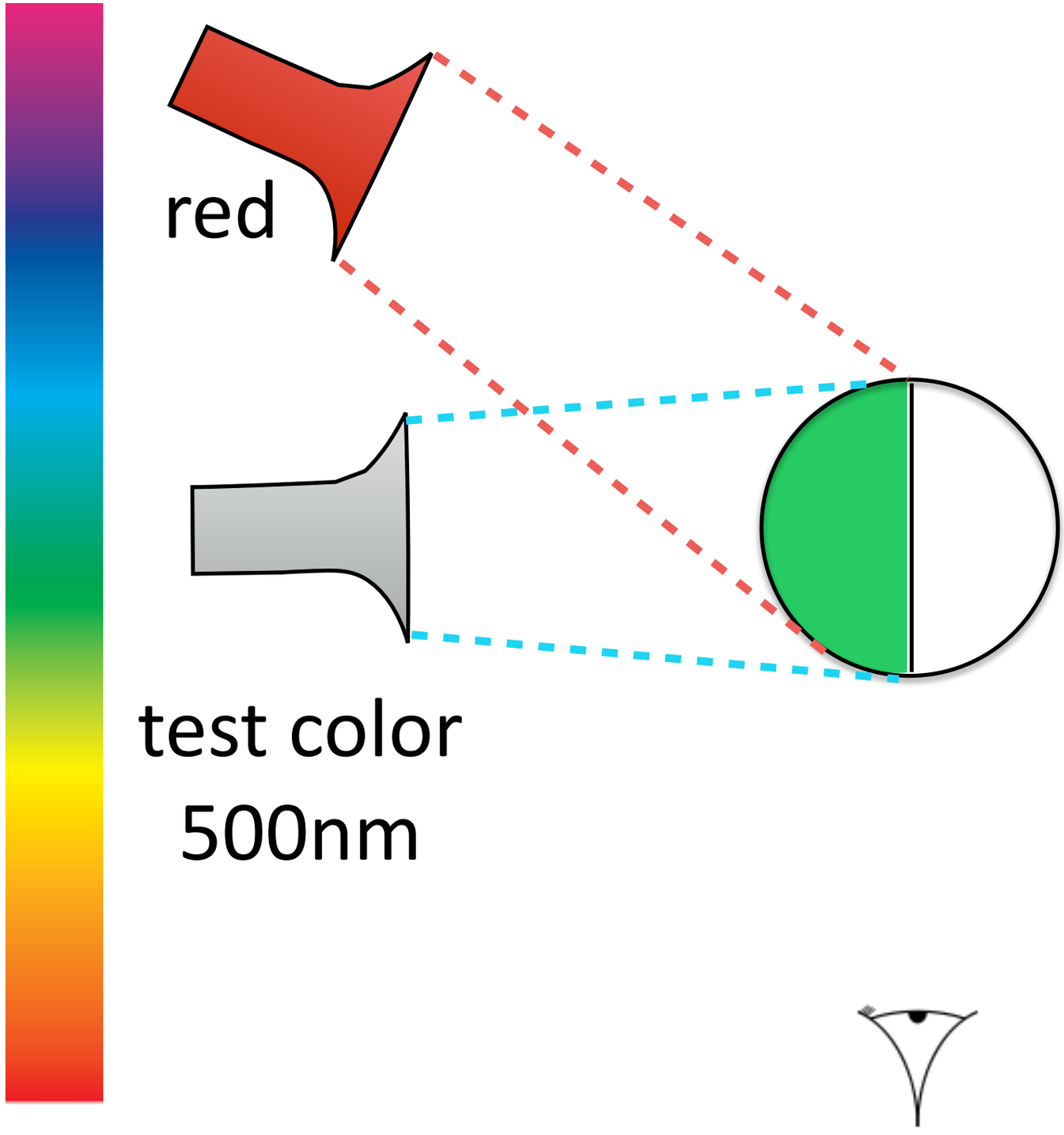


green

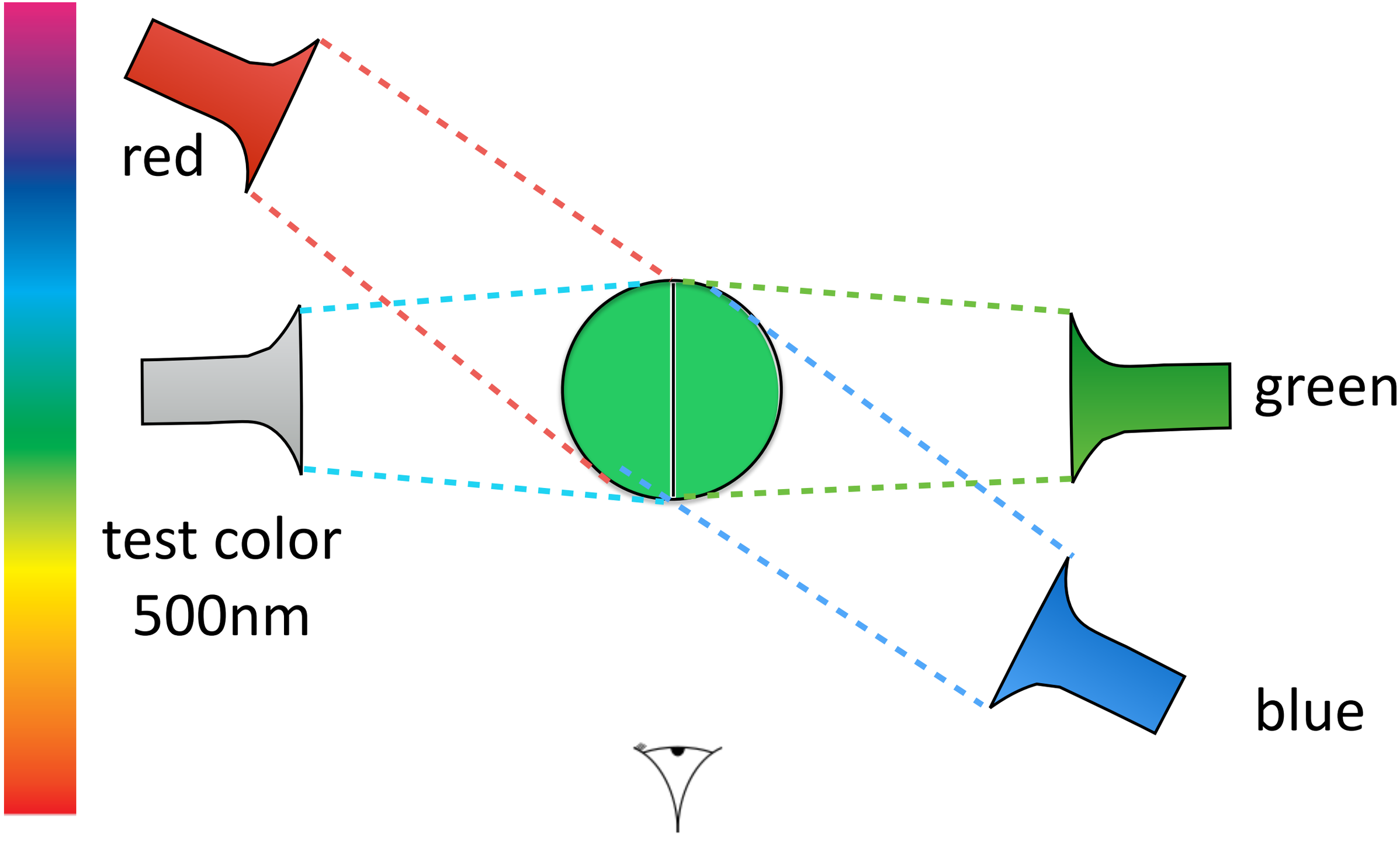


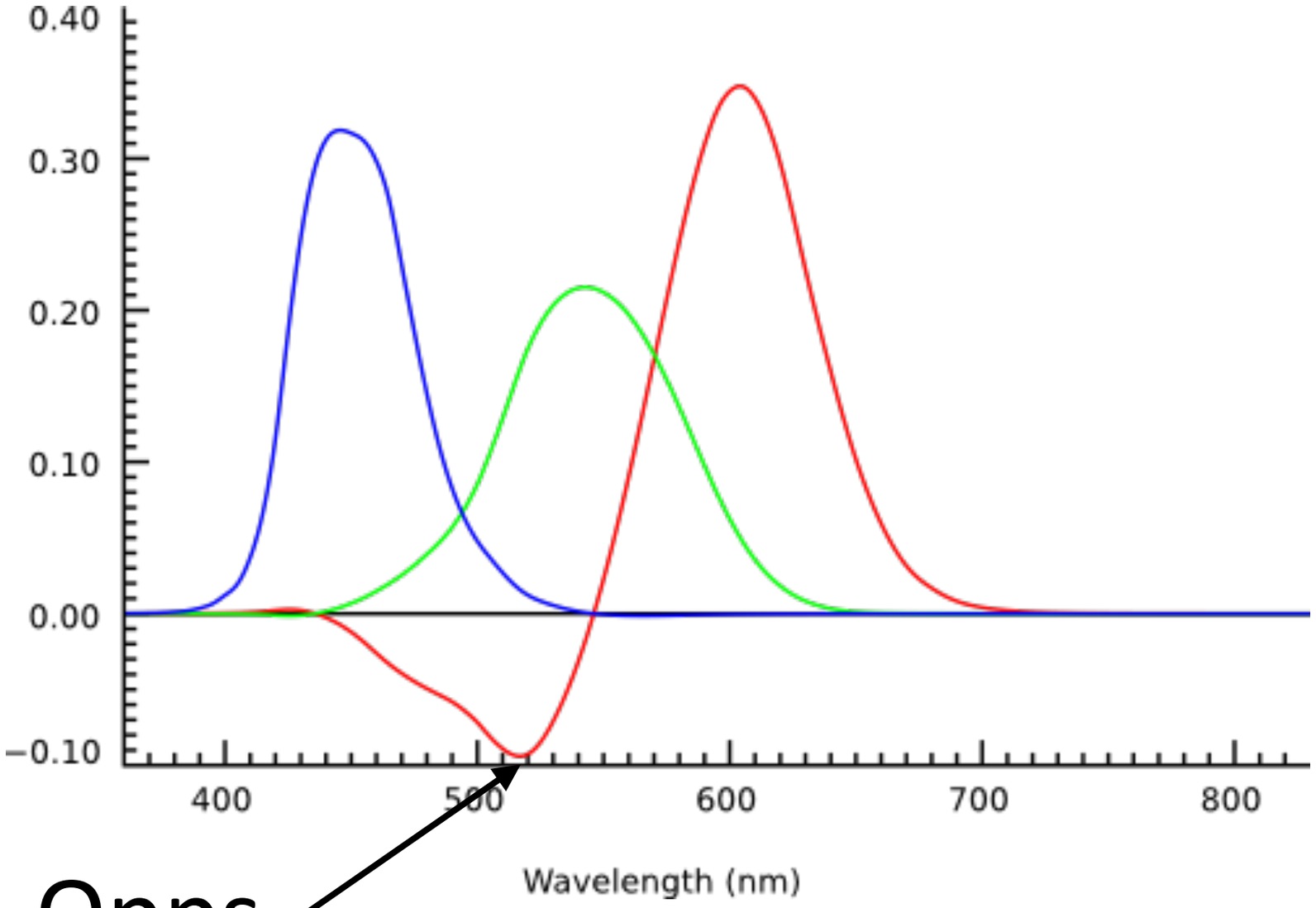
blue

Tristimulus color matching

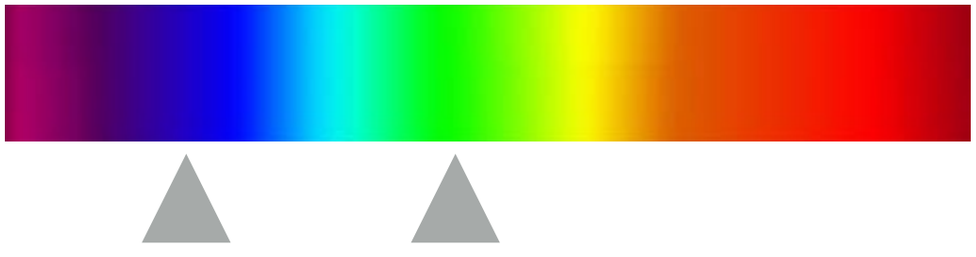


Tristimulus color matching





Opps

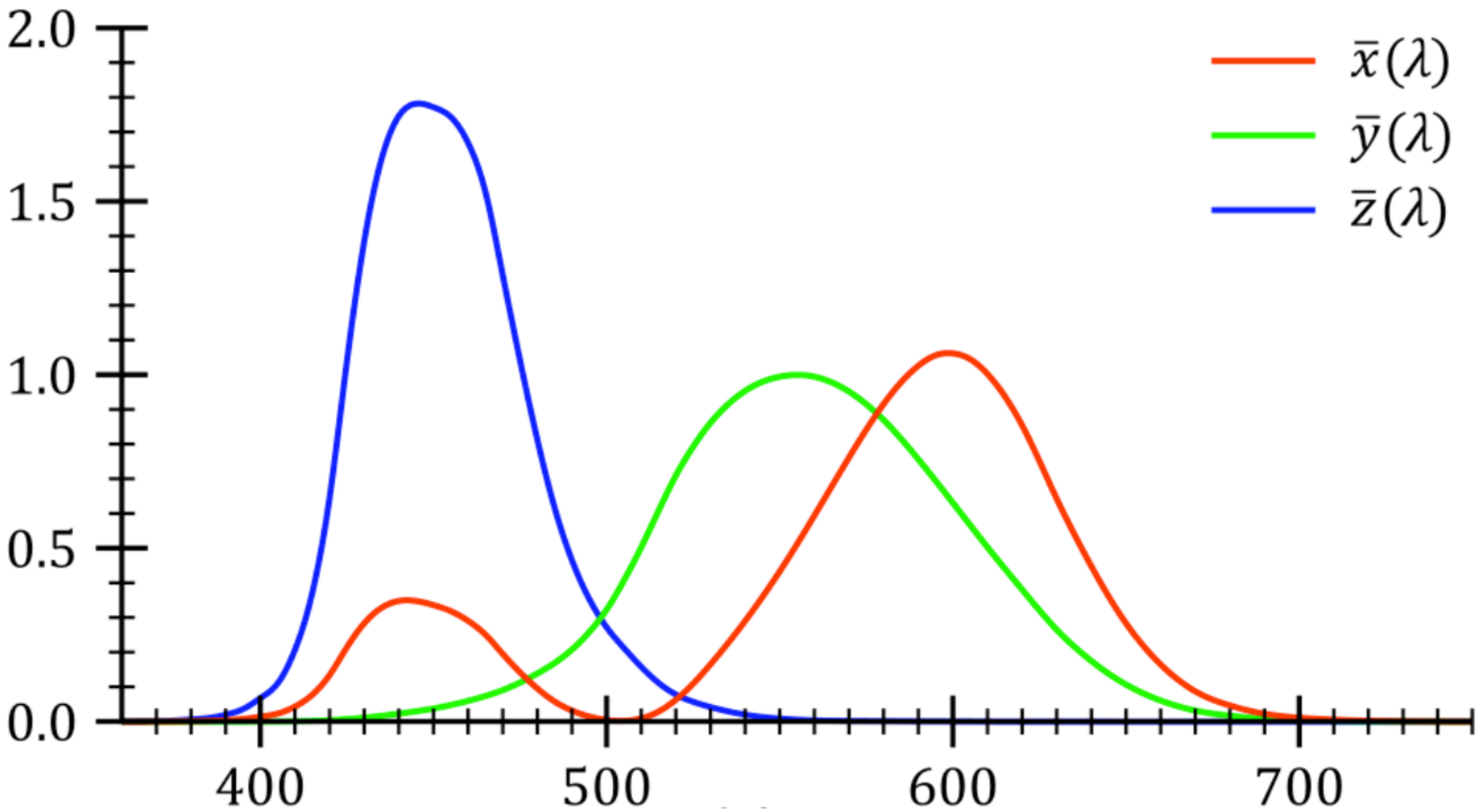


CIE color space

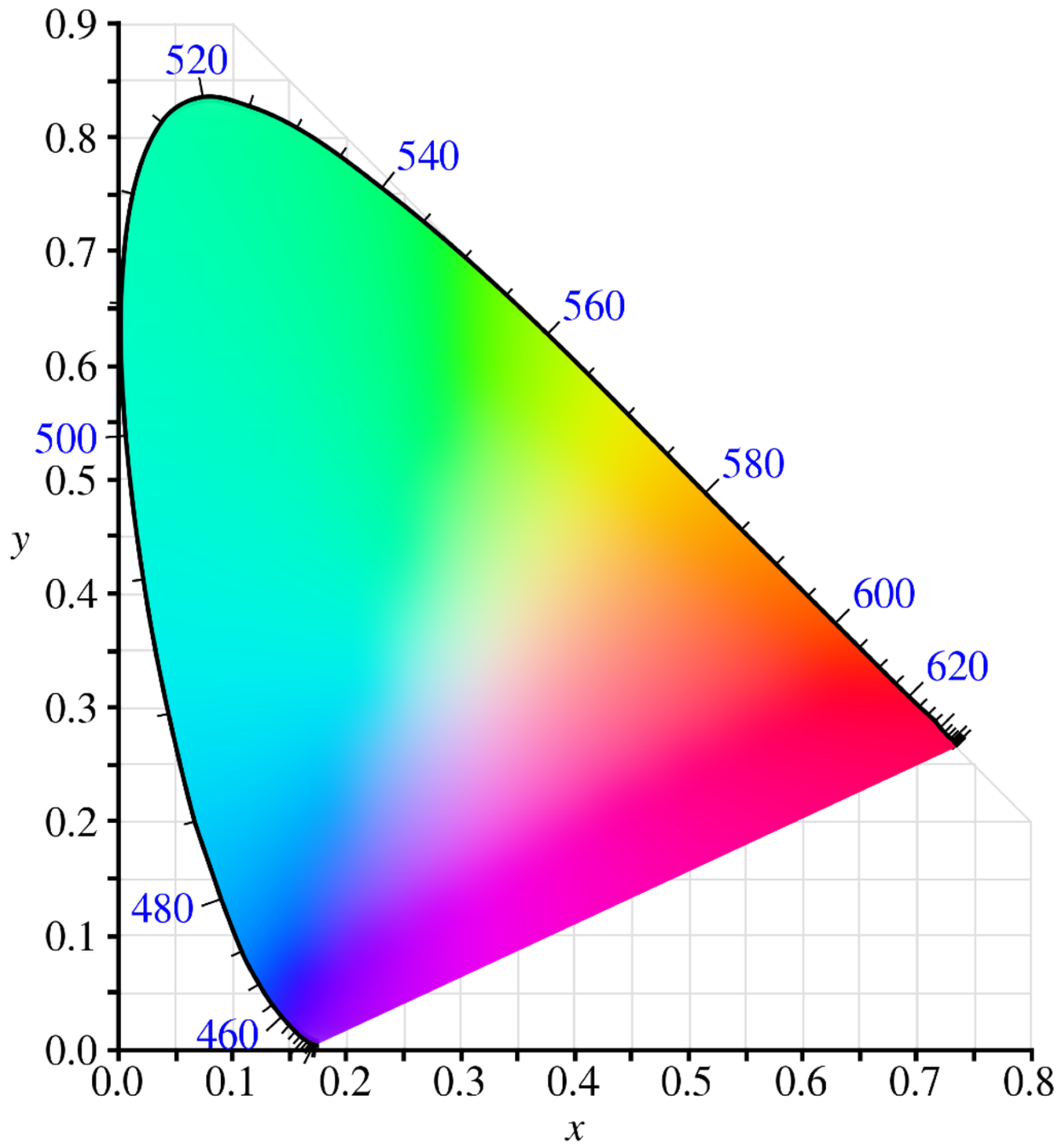
- At a meeting in of the CIE in 1931
  - Let's have imaginary primary colors!
  - Construct linear, possibly non-realizable combinations of primaries so that color matching functions are positive throughout the visible light
- **X, Y, Z** primaries
- Can be linearly transformed from RGB (and vice versa)

Based on a slide by Siddhartha Chaudhuri

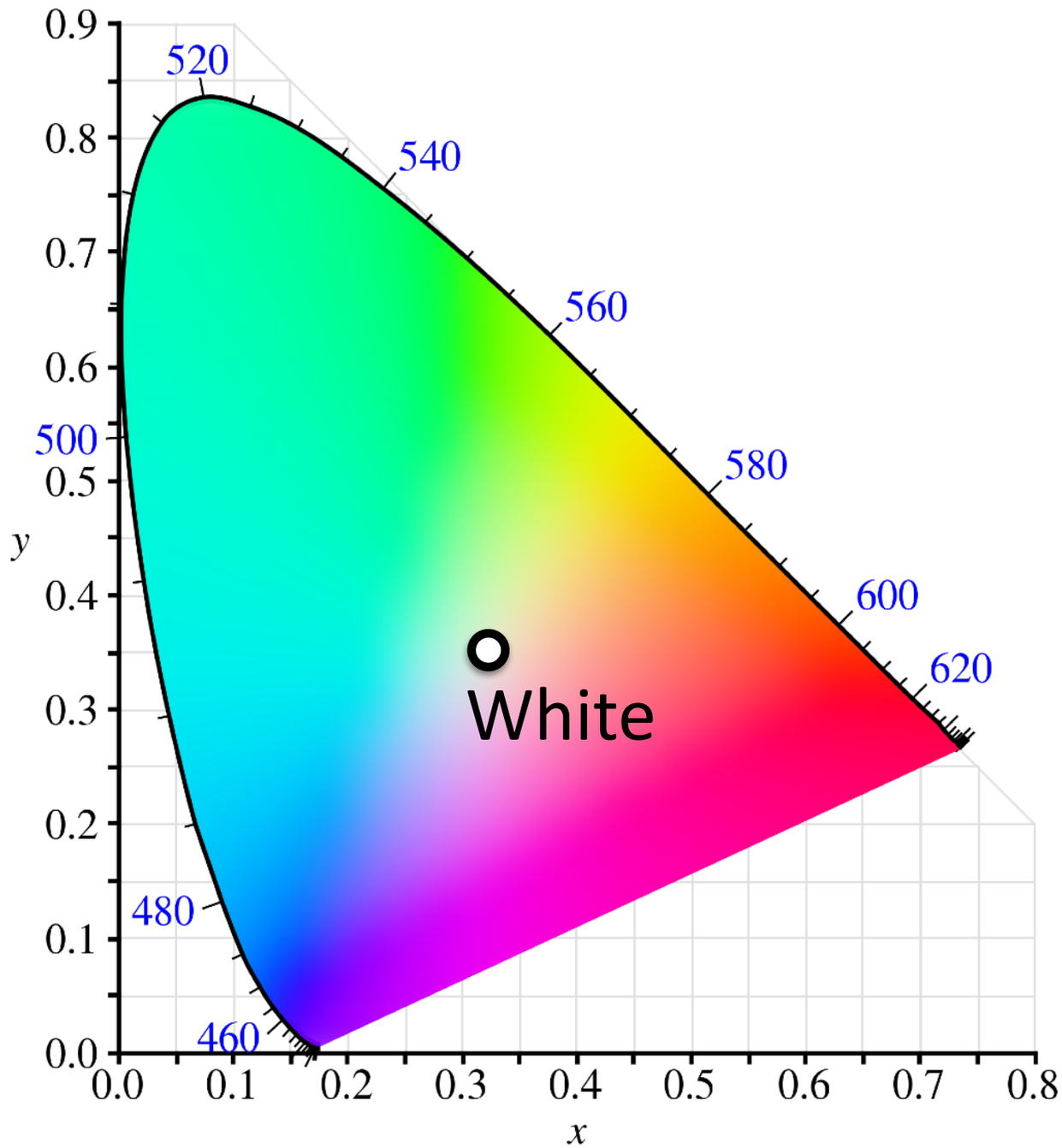
CIE color space



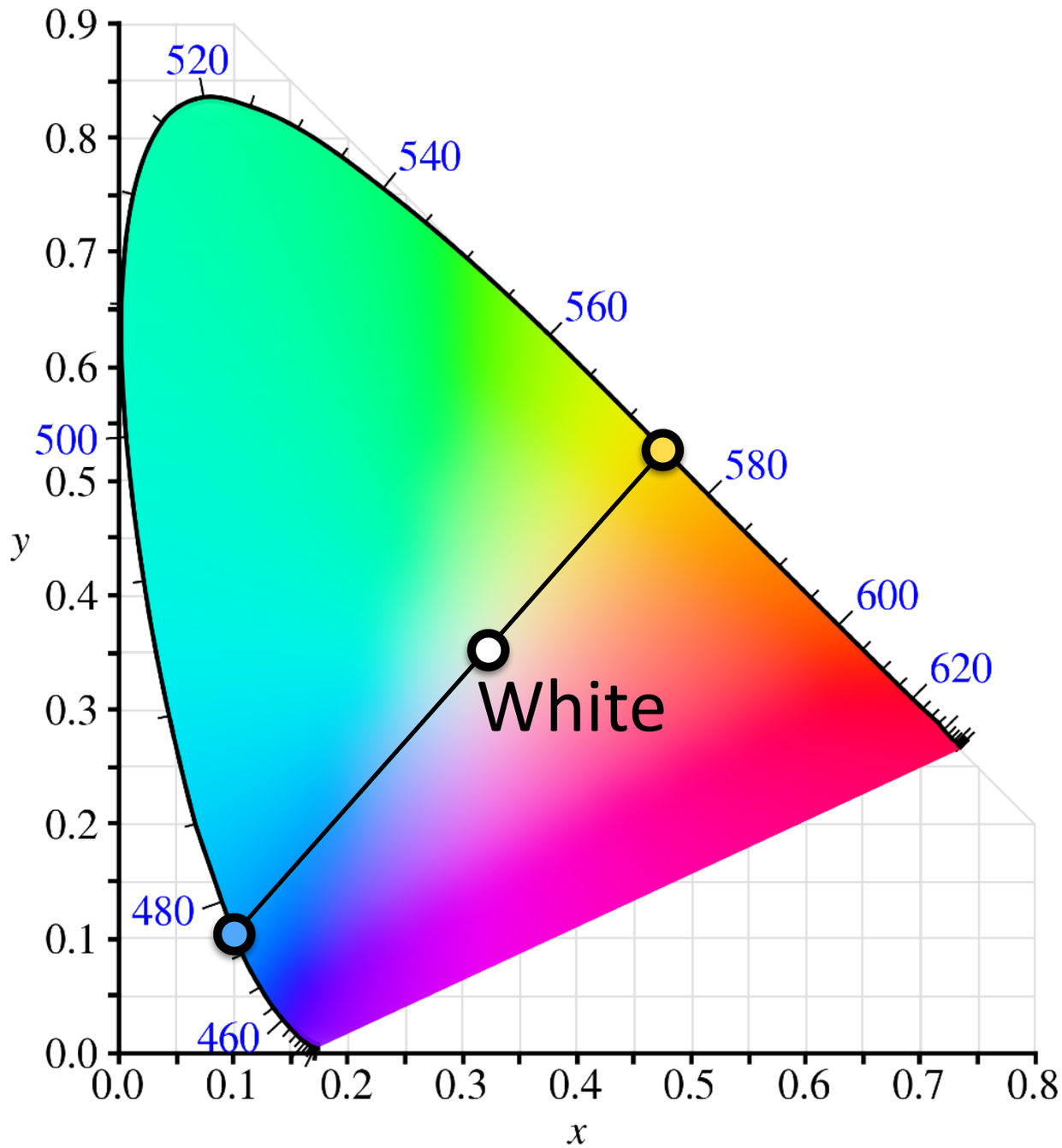
CIE chromaticity diagram



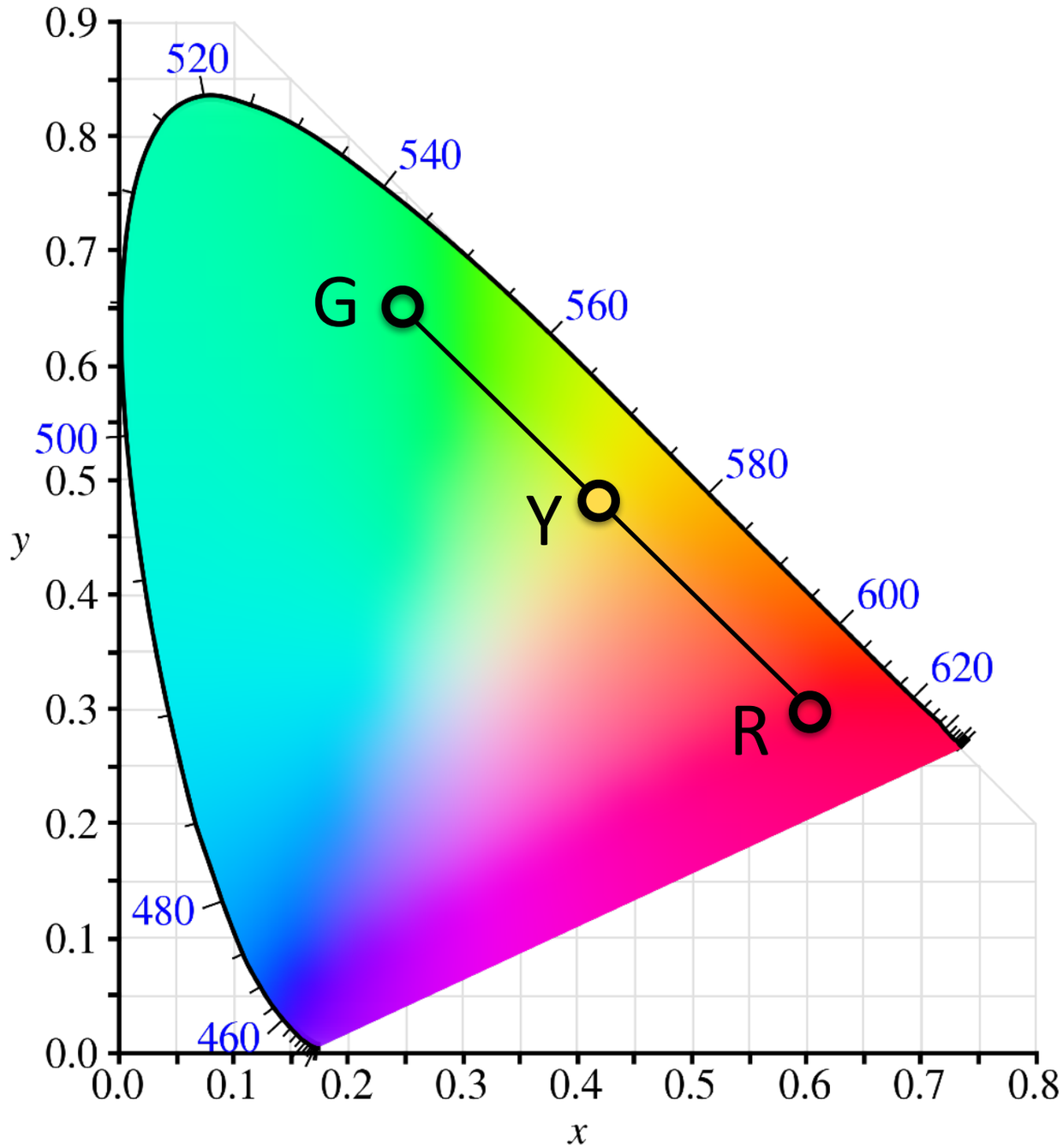
CIE chromaticity diagram



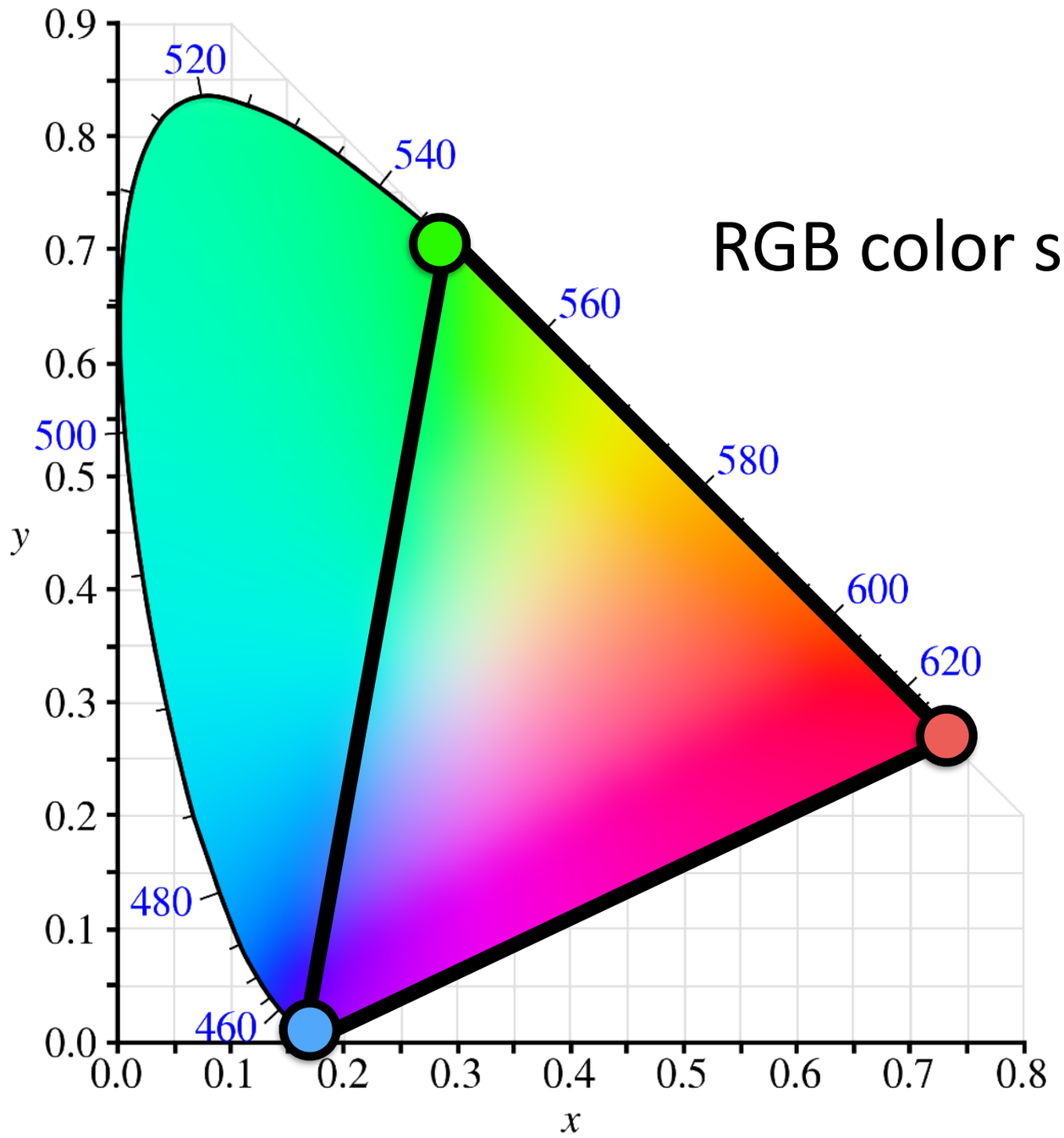
CIE chromaticity diagram



CIE chromaticity diagram



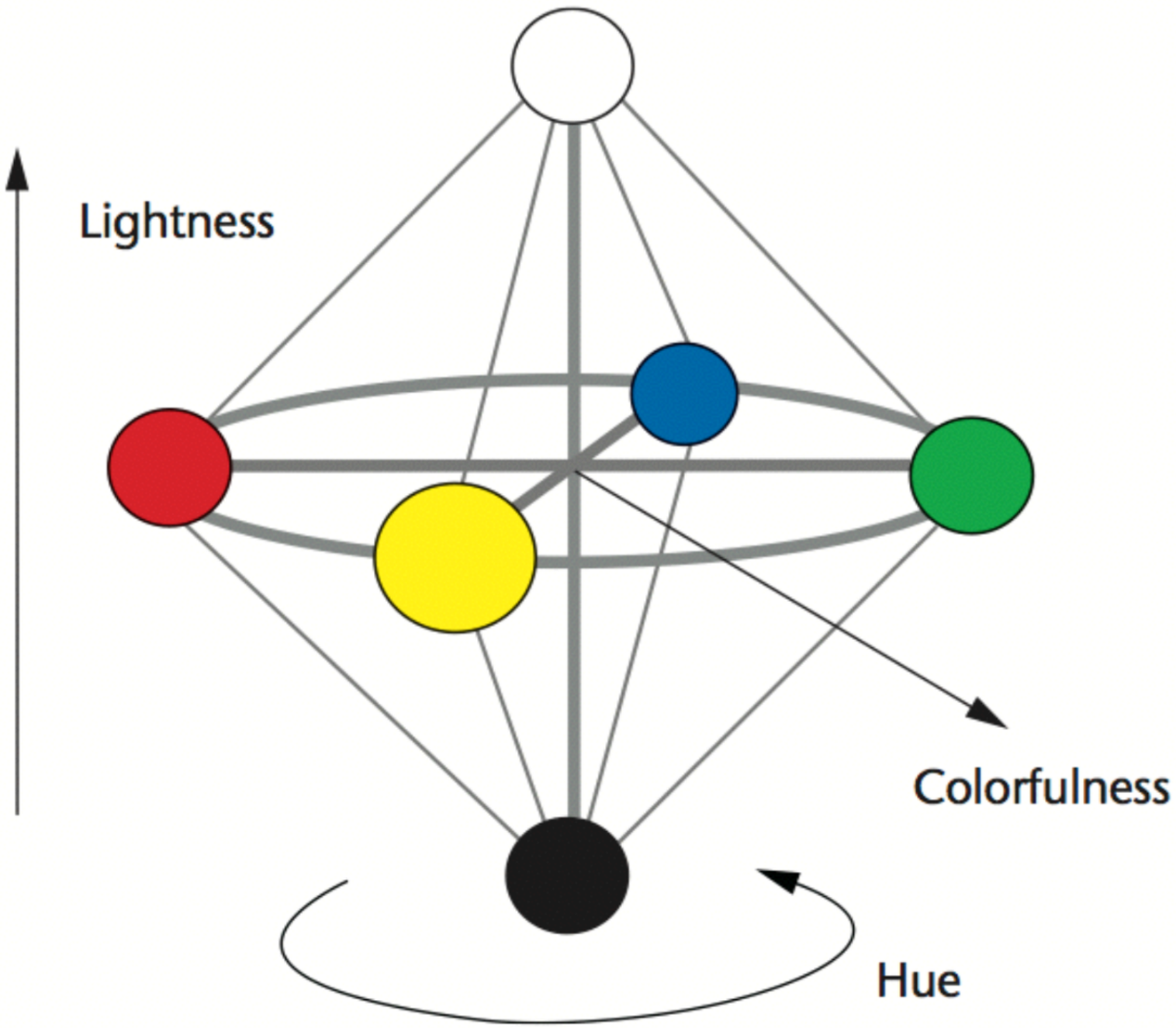
CIE chromaticity diagram



RGB color space

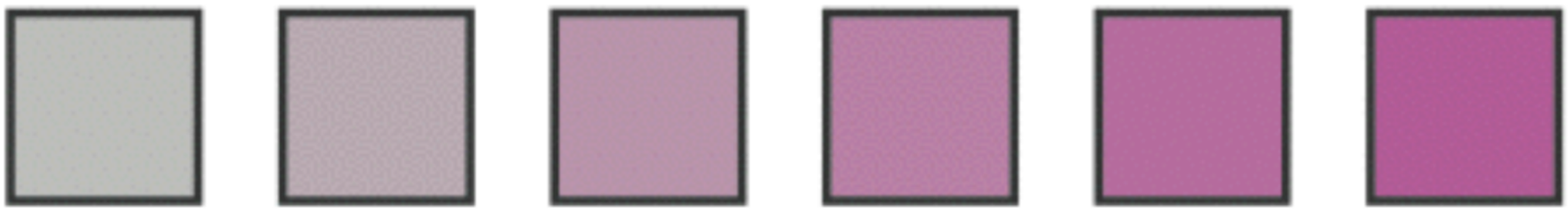
Perceptual color spaces

A change in the amount of color value should produce a proportional change in the way we see the color

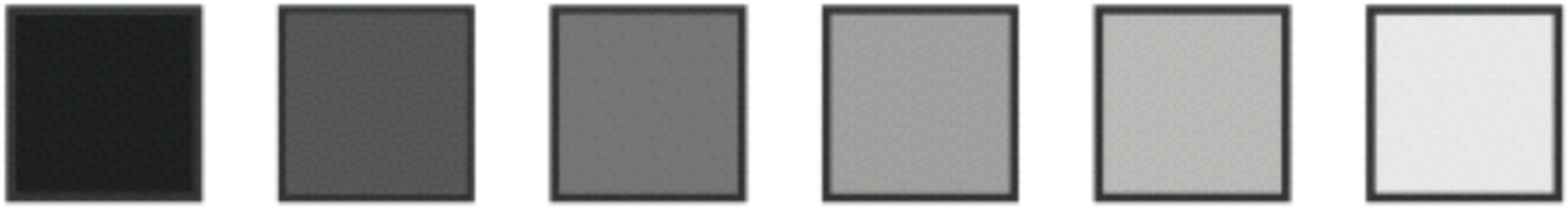


Via Miriah Meyer

hue



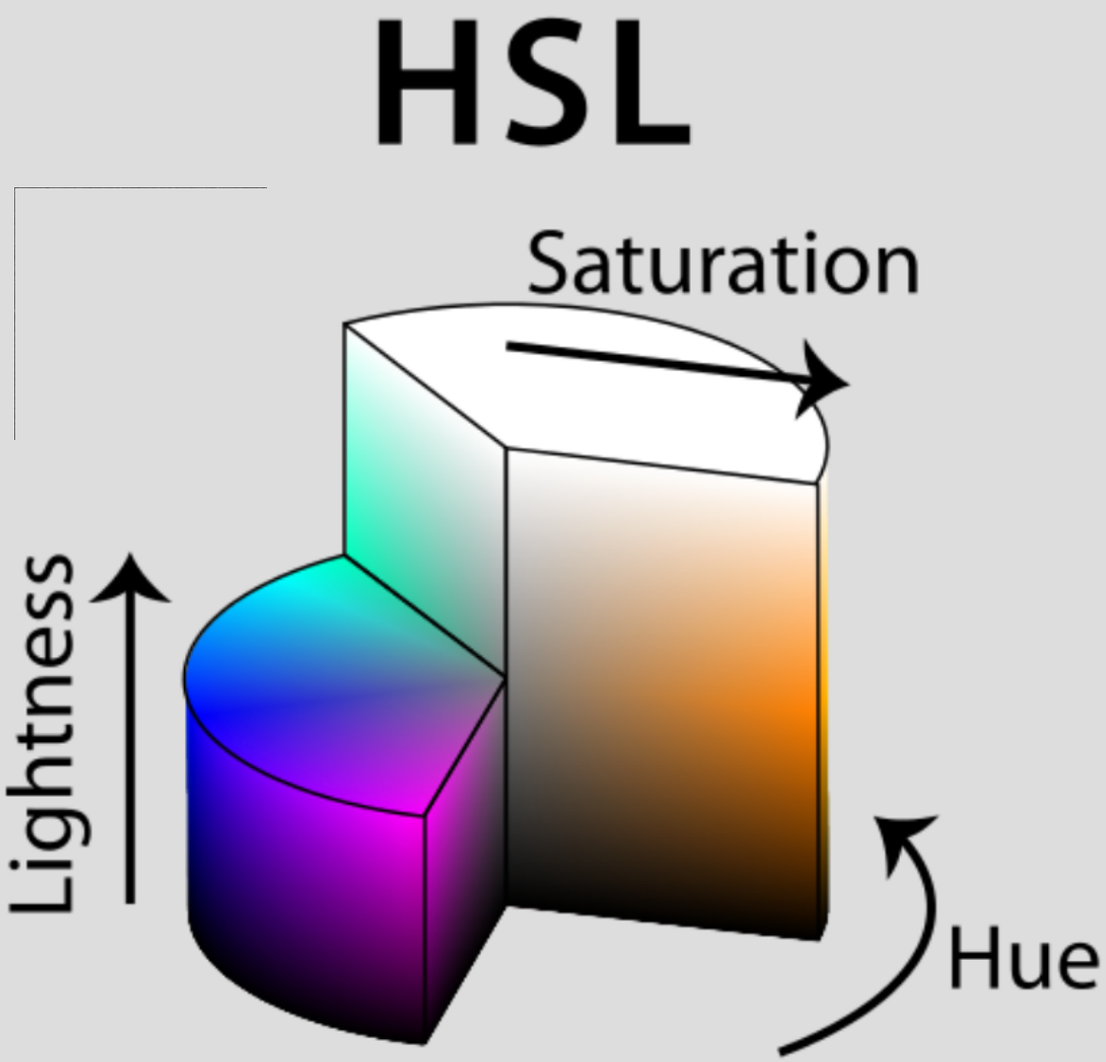
saturation



luminance

HSL

- **hue:** what people think of as color
- **saturation:** the vividness of the color
- **luminance:** amount of black mixed in

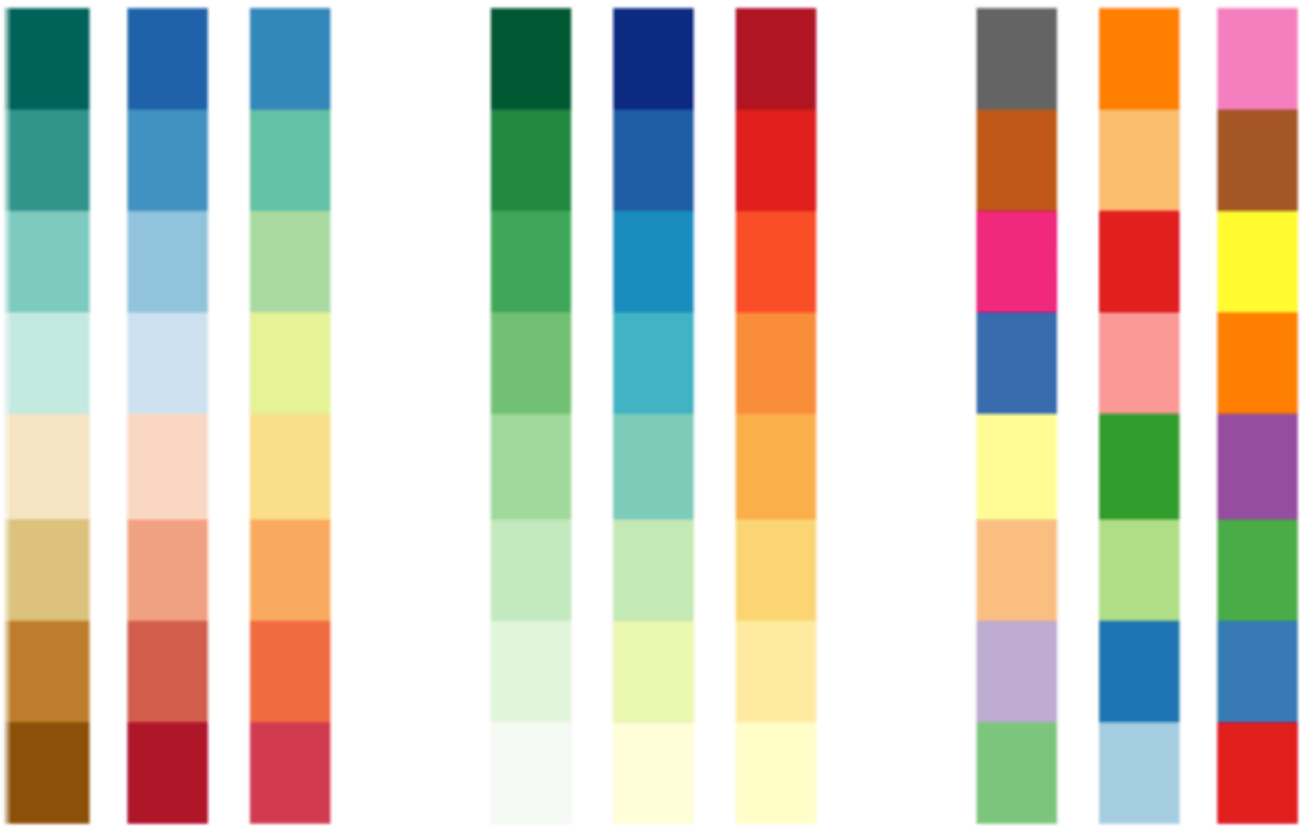


Guidelines for using color in visualization

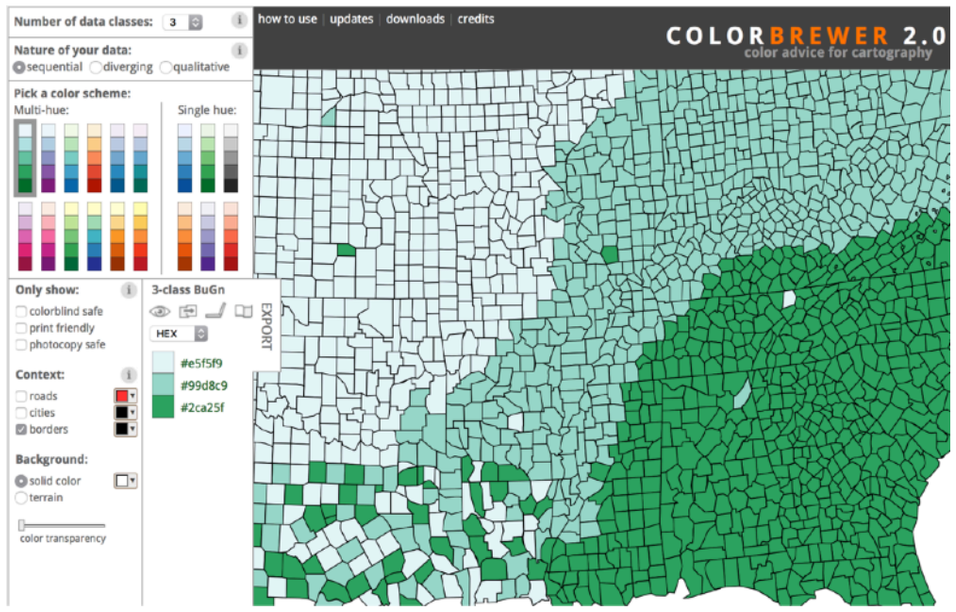
Colormap

Specifies a mapping between color and values

[0, 8] ⟶

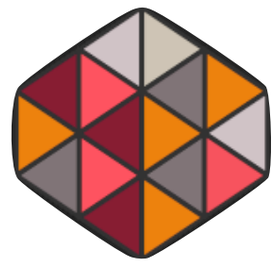


Color design tools



Color Brewer

colorbrewer2.org/



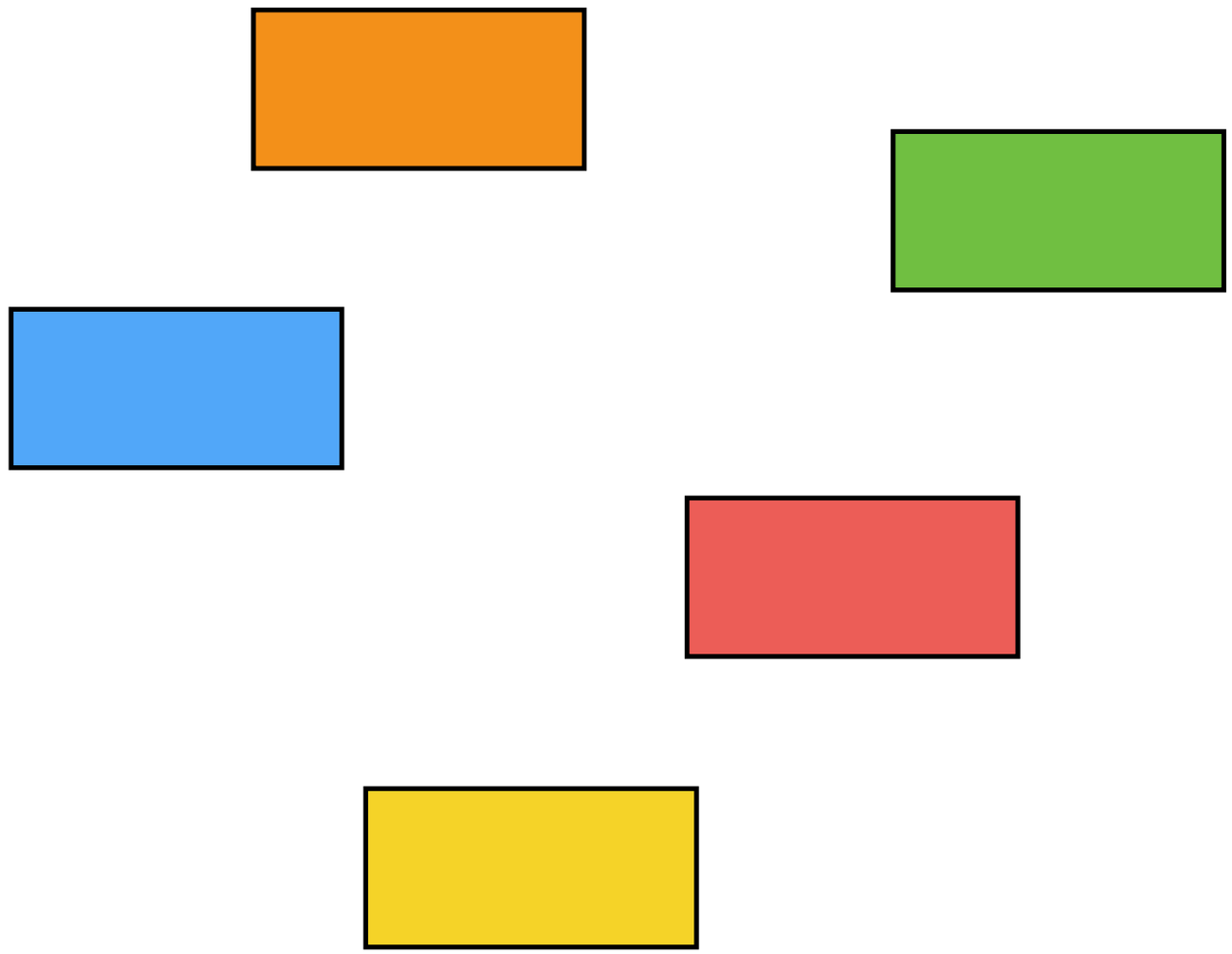
Colorgorical

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

Color Oracle

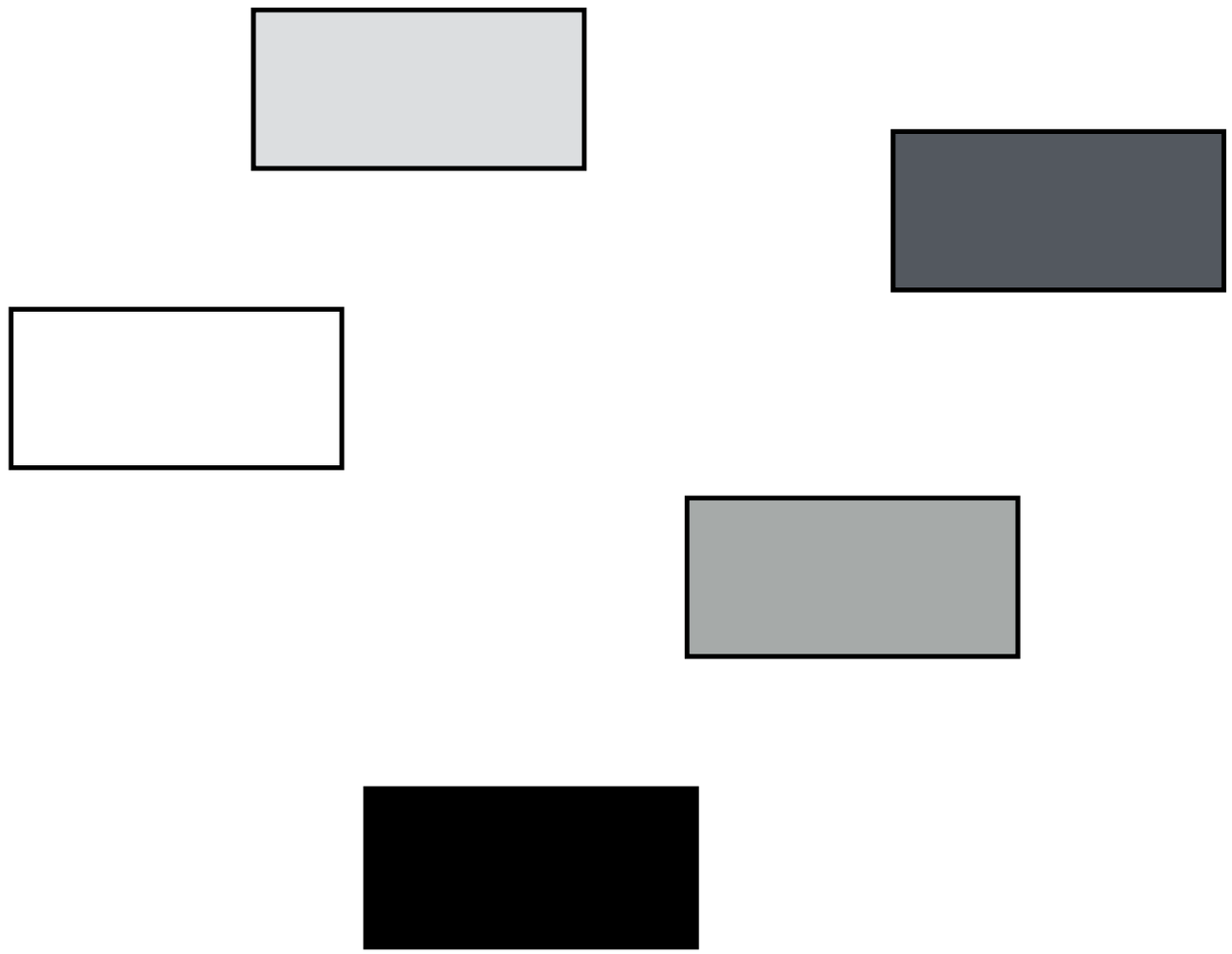
http://colororacle.org

Order these colors…



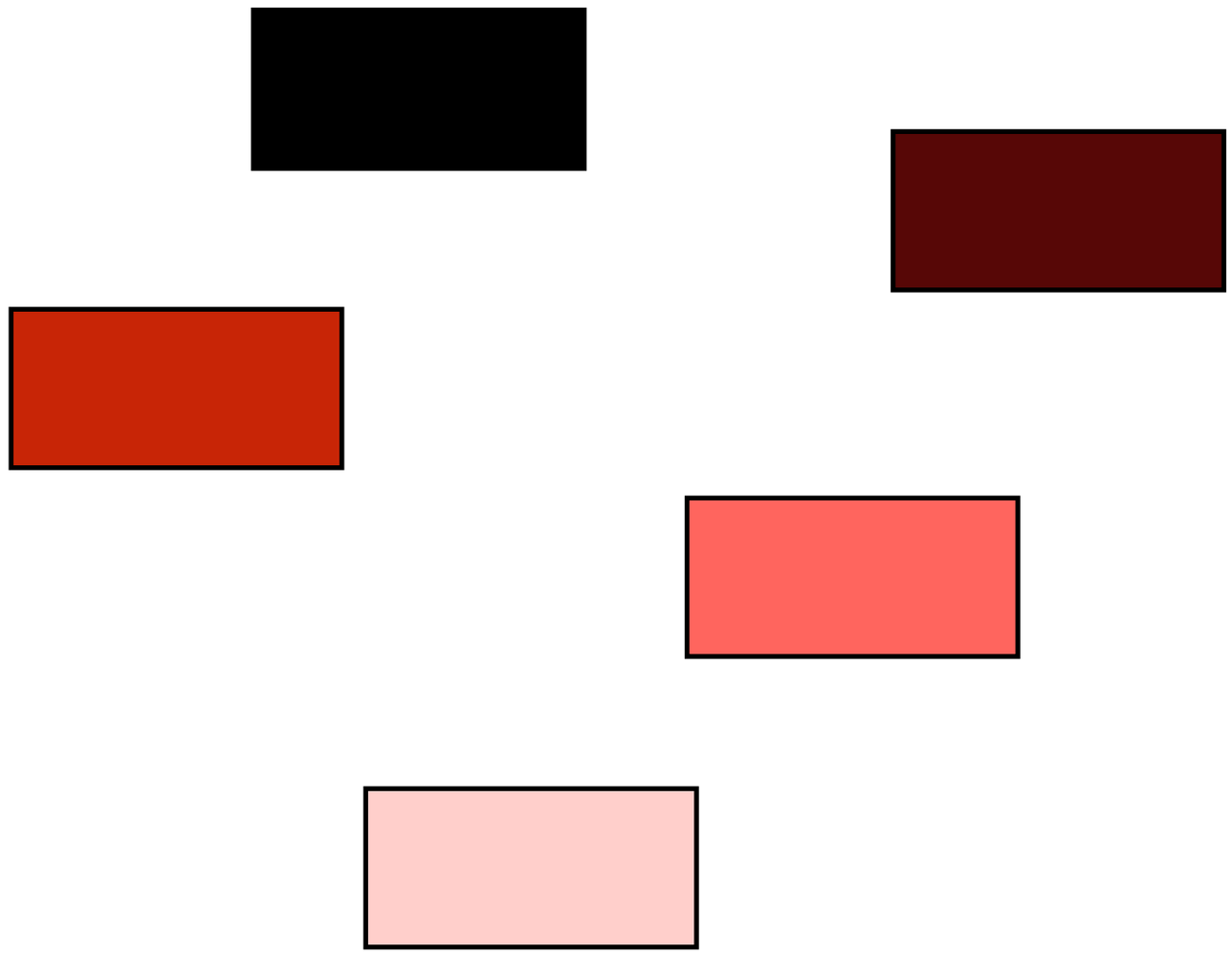
Miriah Meyer

Order these colors…



Miriah Meyer

Order these colors…



Miriah Meyer

guidelines

colormaps for ordered data should

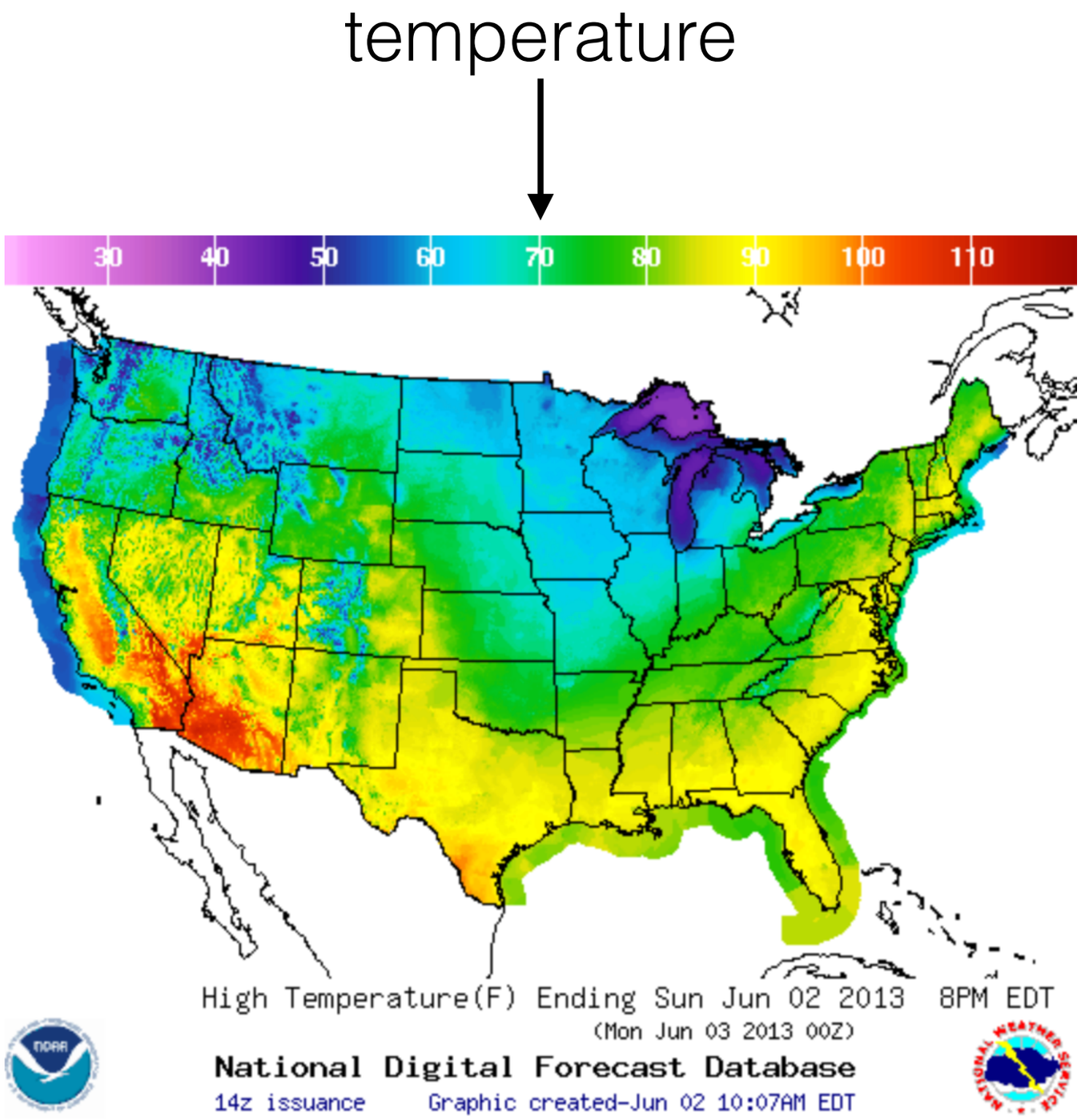
vary **monotonically in luminance**

Hue alone is good for categorical data

Categorical colors are easier to remember if they are nameable

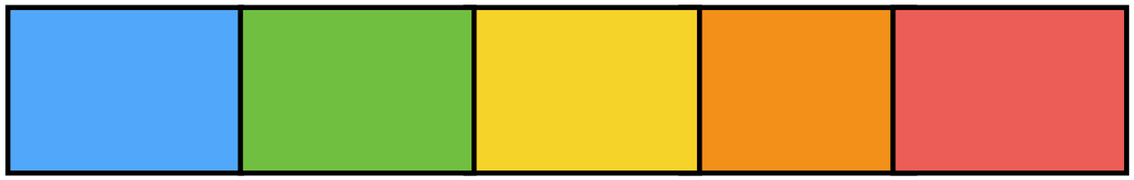
Colin Ware

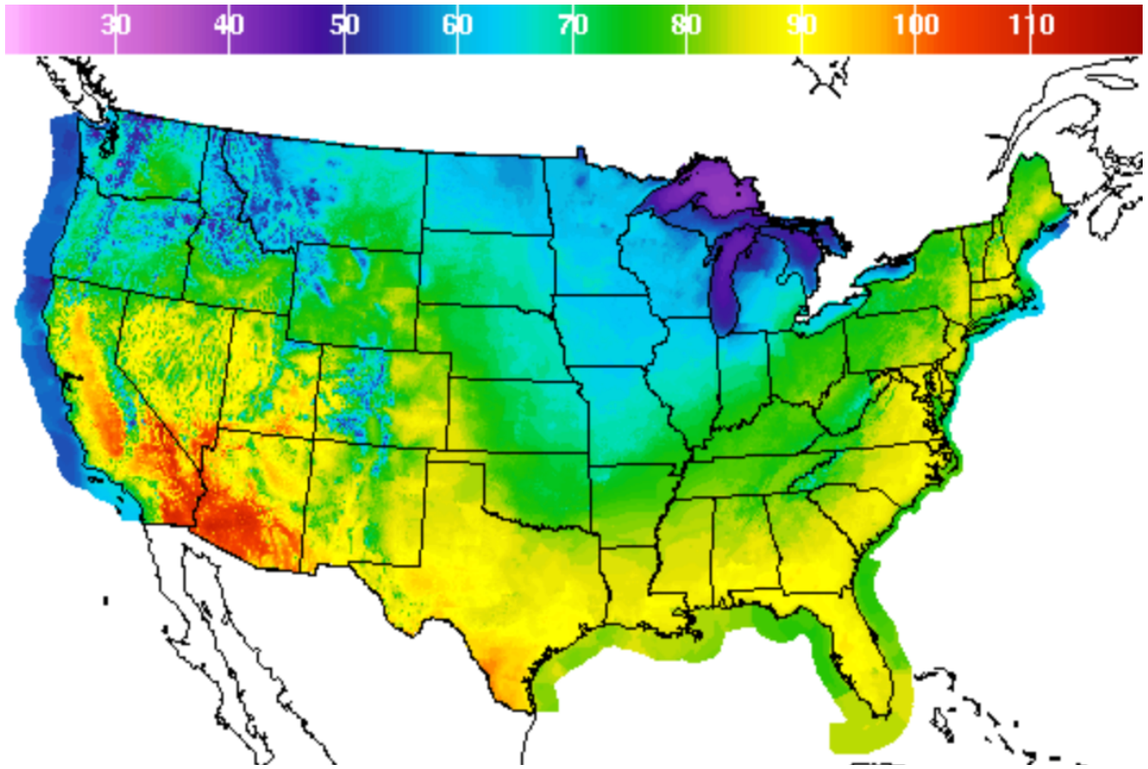
the rainbow colormap



the rainbow colormap

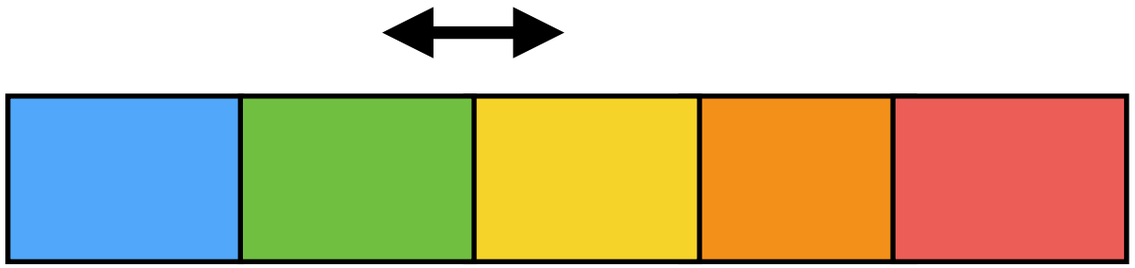
order?

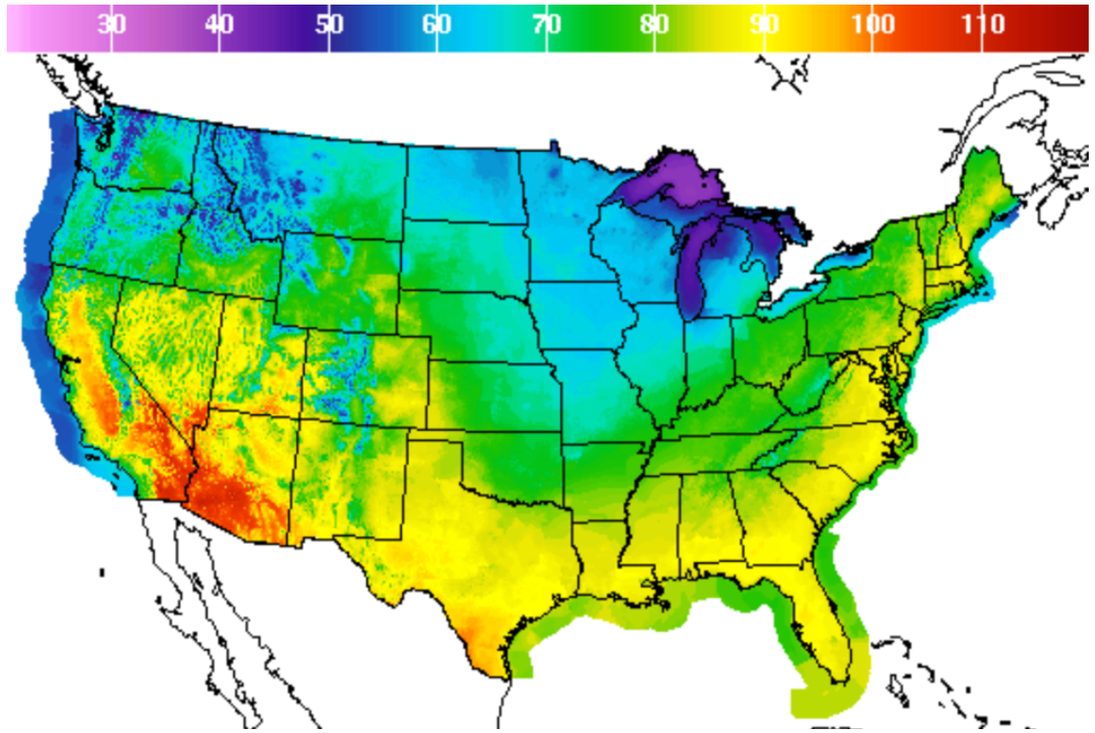




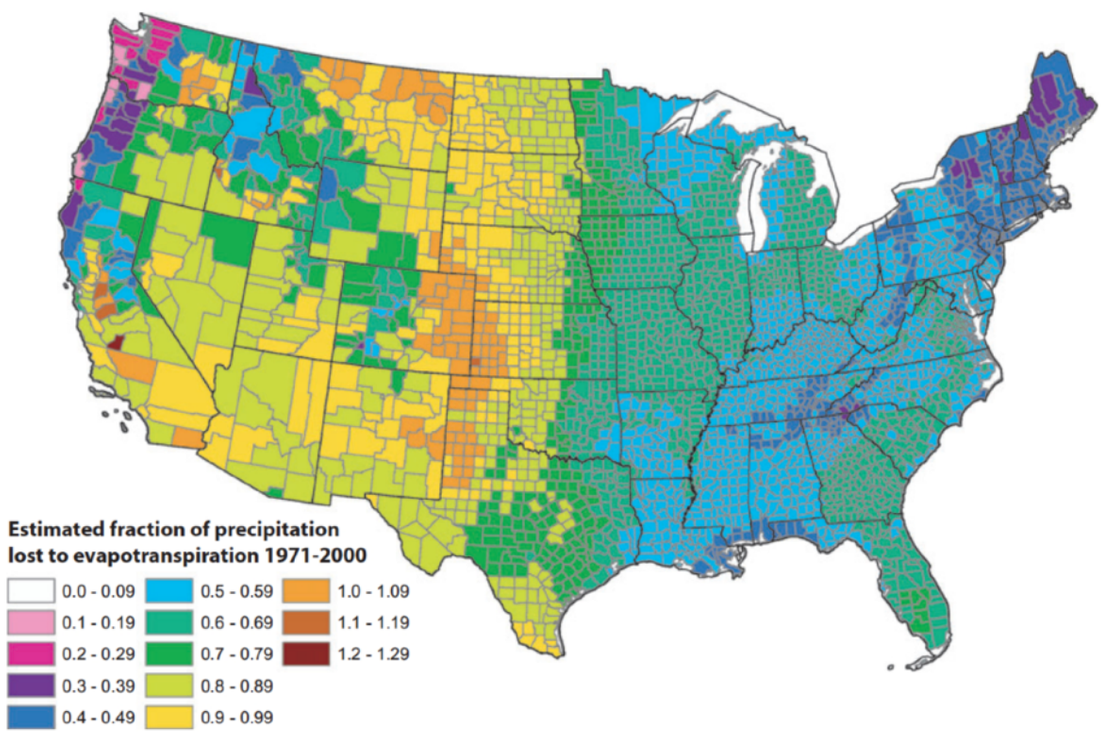
the rainbow colormap

sharp boundary



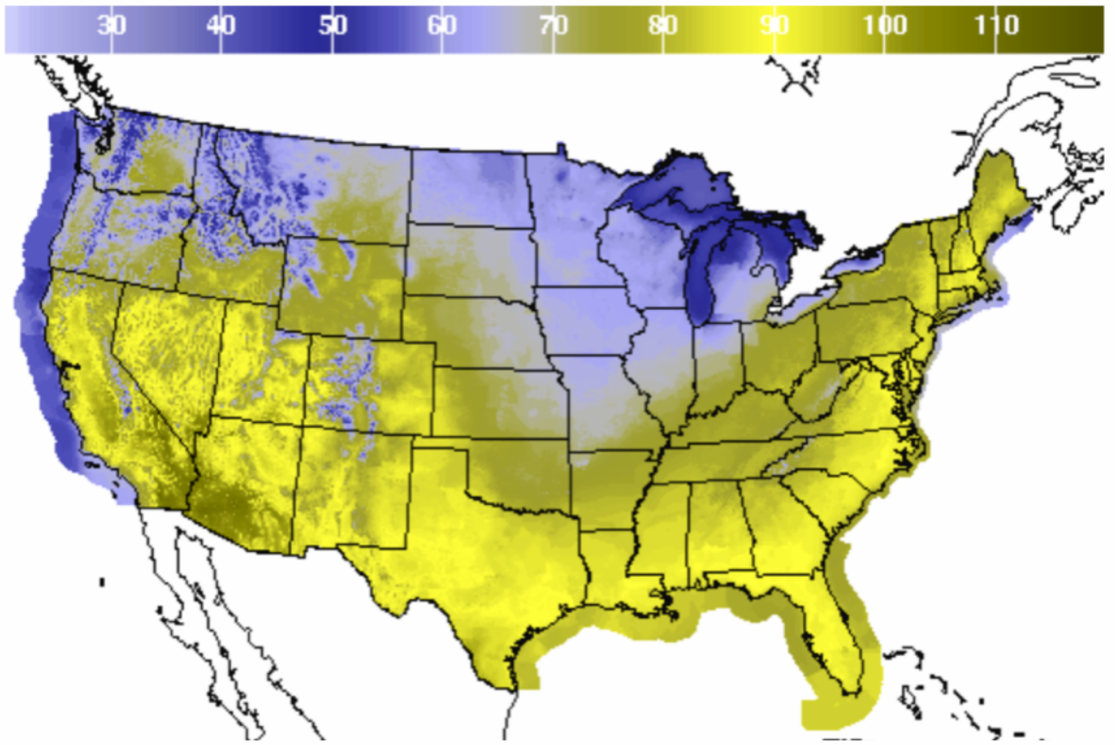


Sanford and Selnick

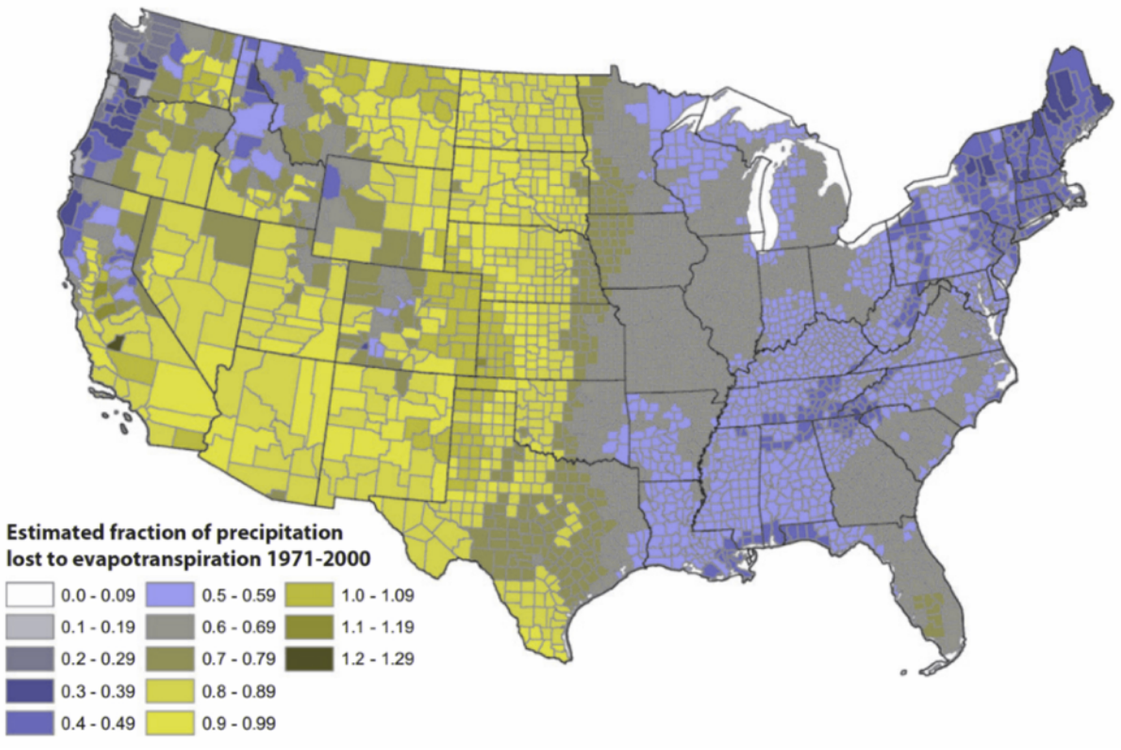


the rainbow colormap

not color blind safe

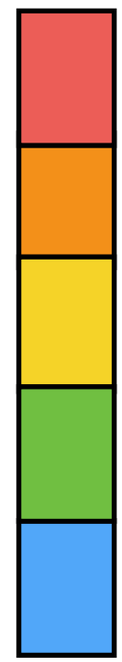


Sanford and Selnick

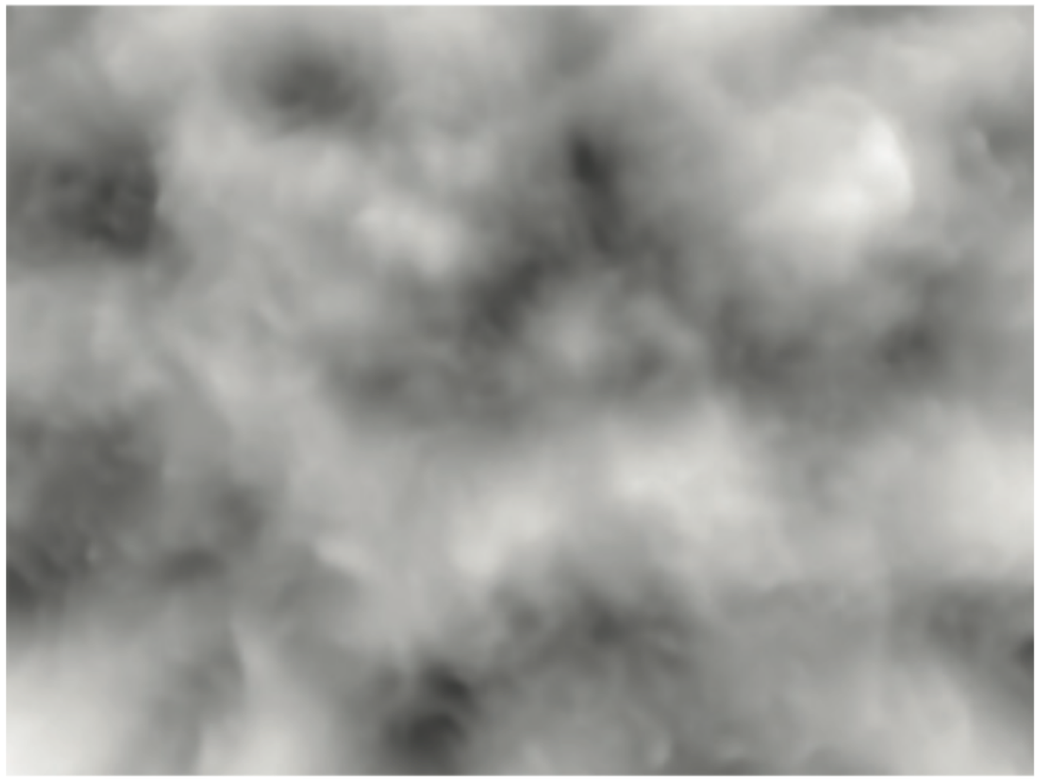


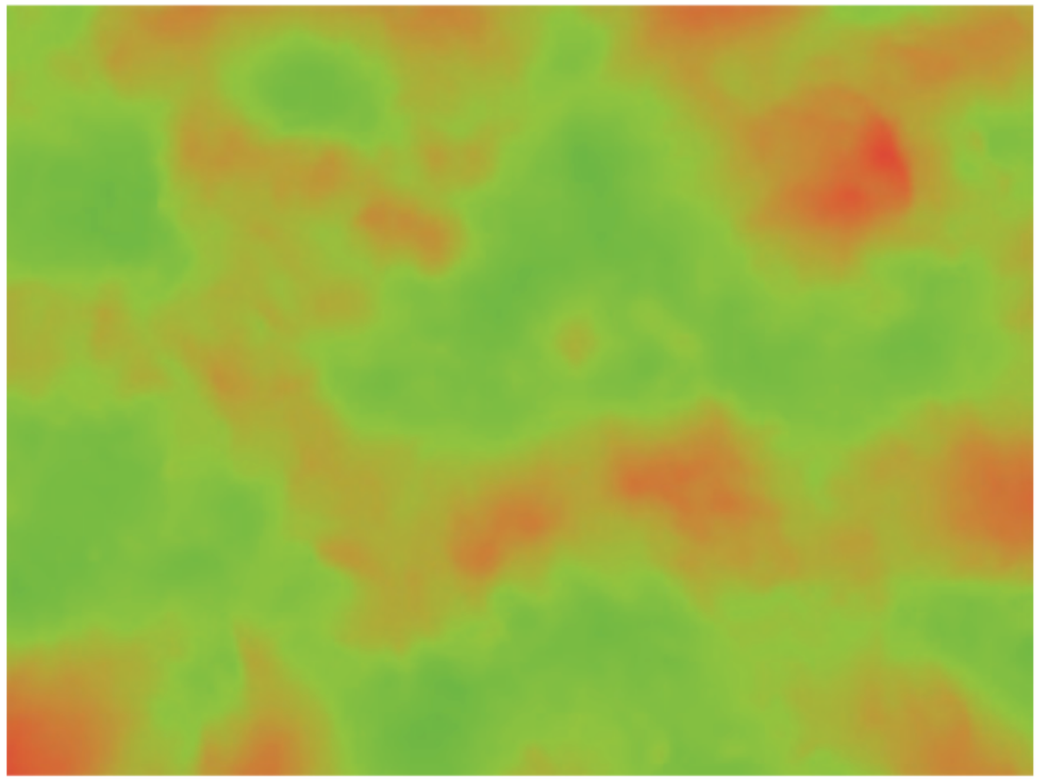
the rainbow colormap

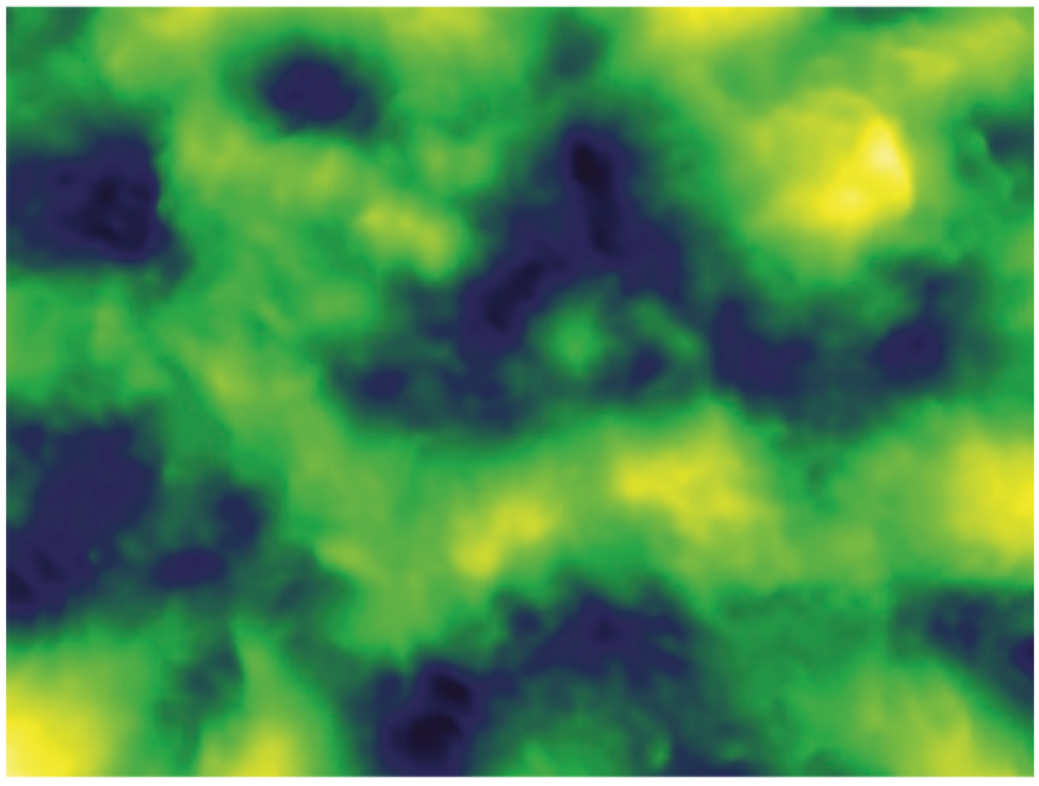
Rainbow colormaps should be avoided as a default option for **ordered data**

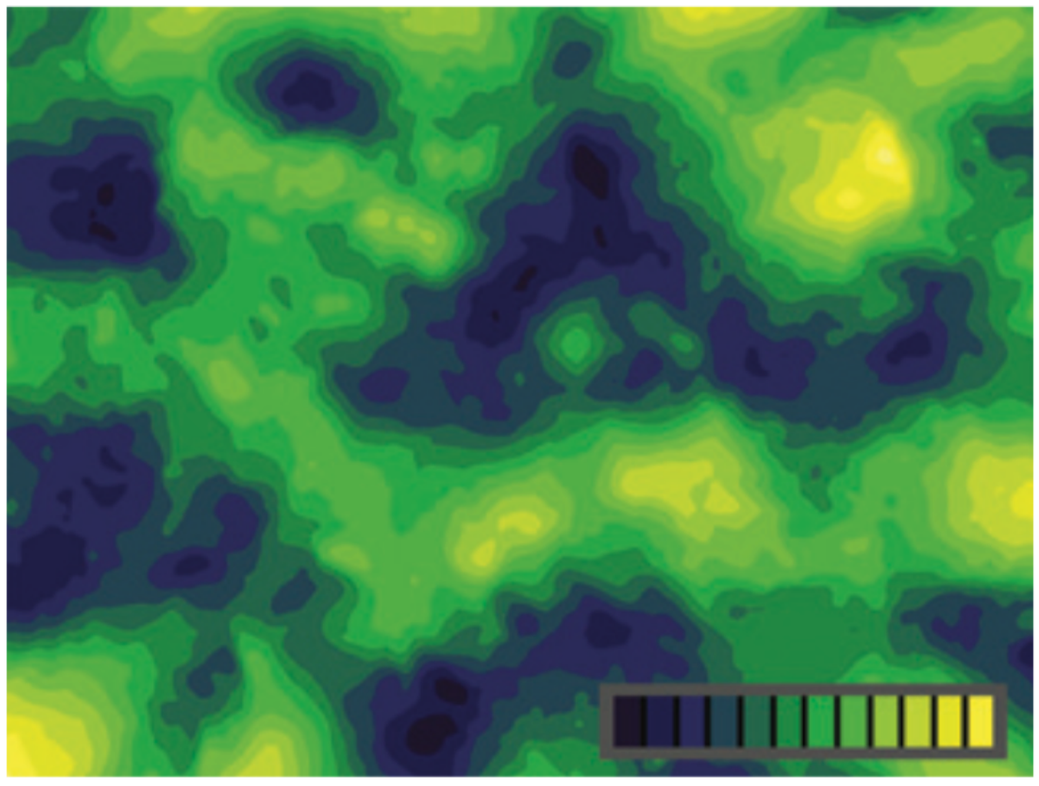


A safer, more effective option is a colormap that varies in **luminance.** Ideally **luminance and hue**.



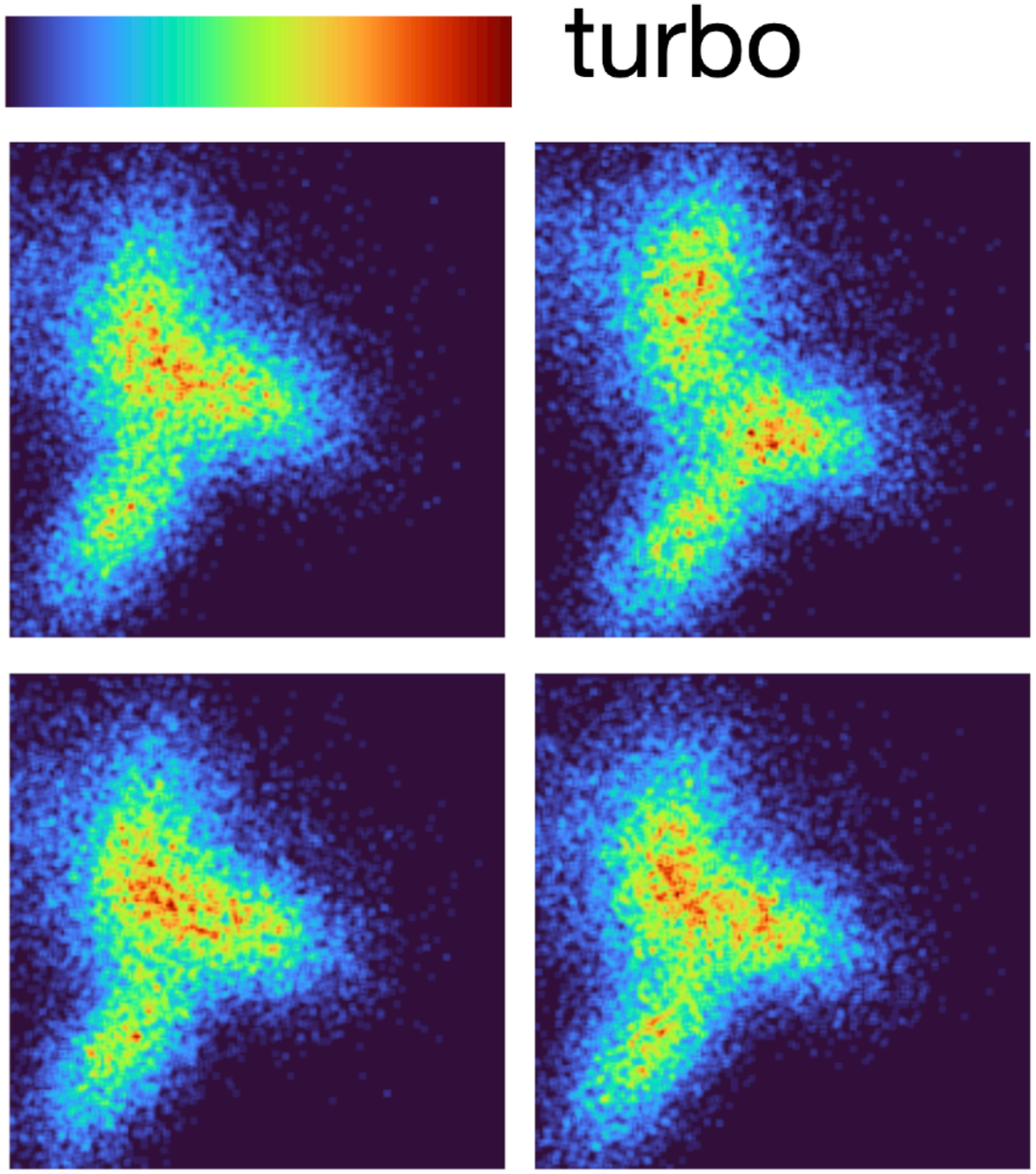




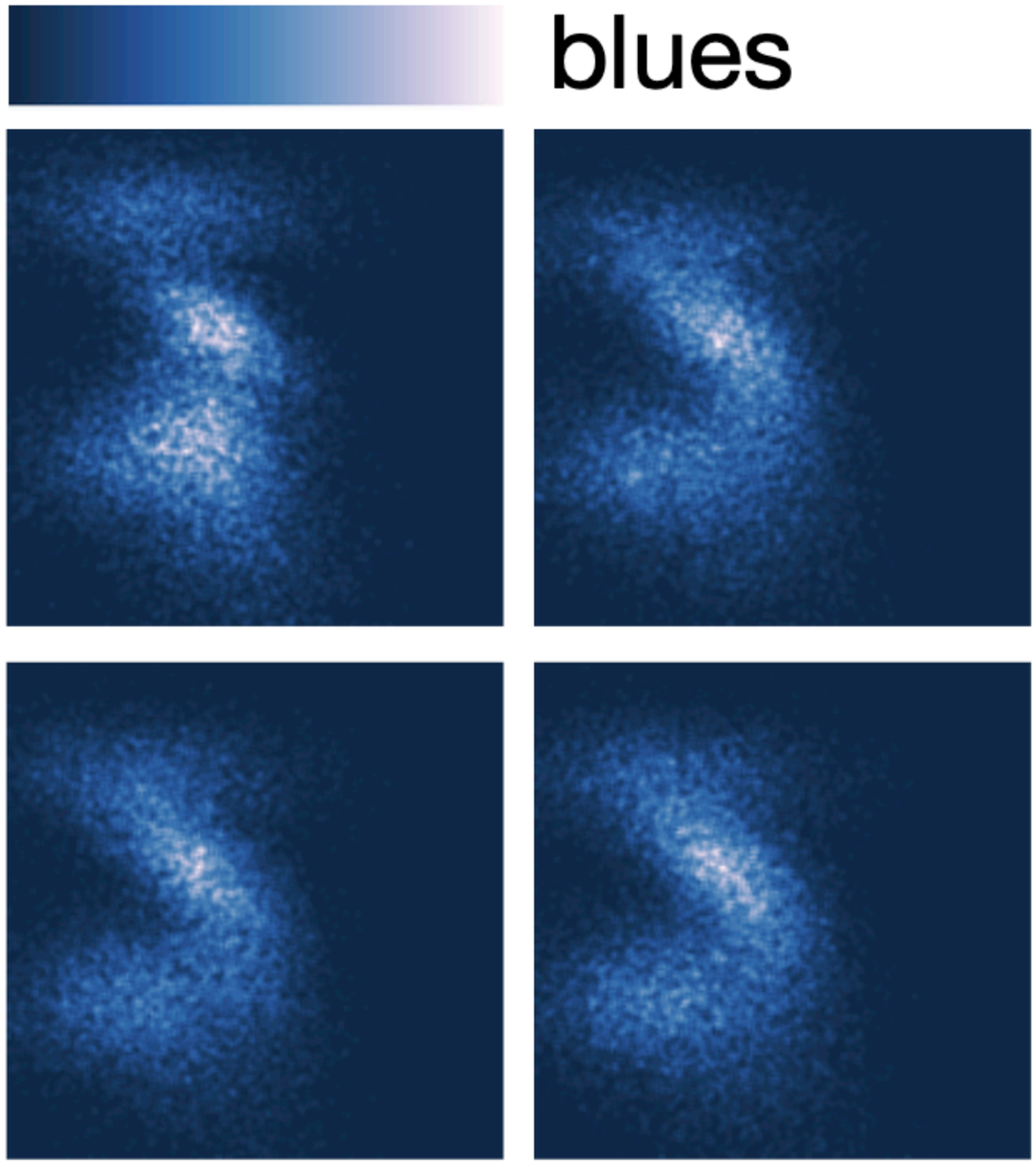


Colin Ware

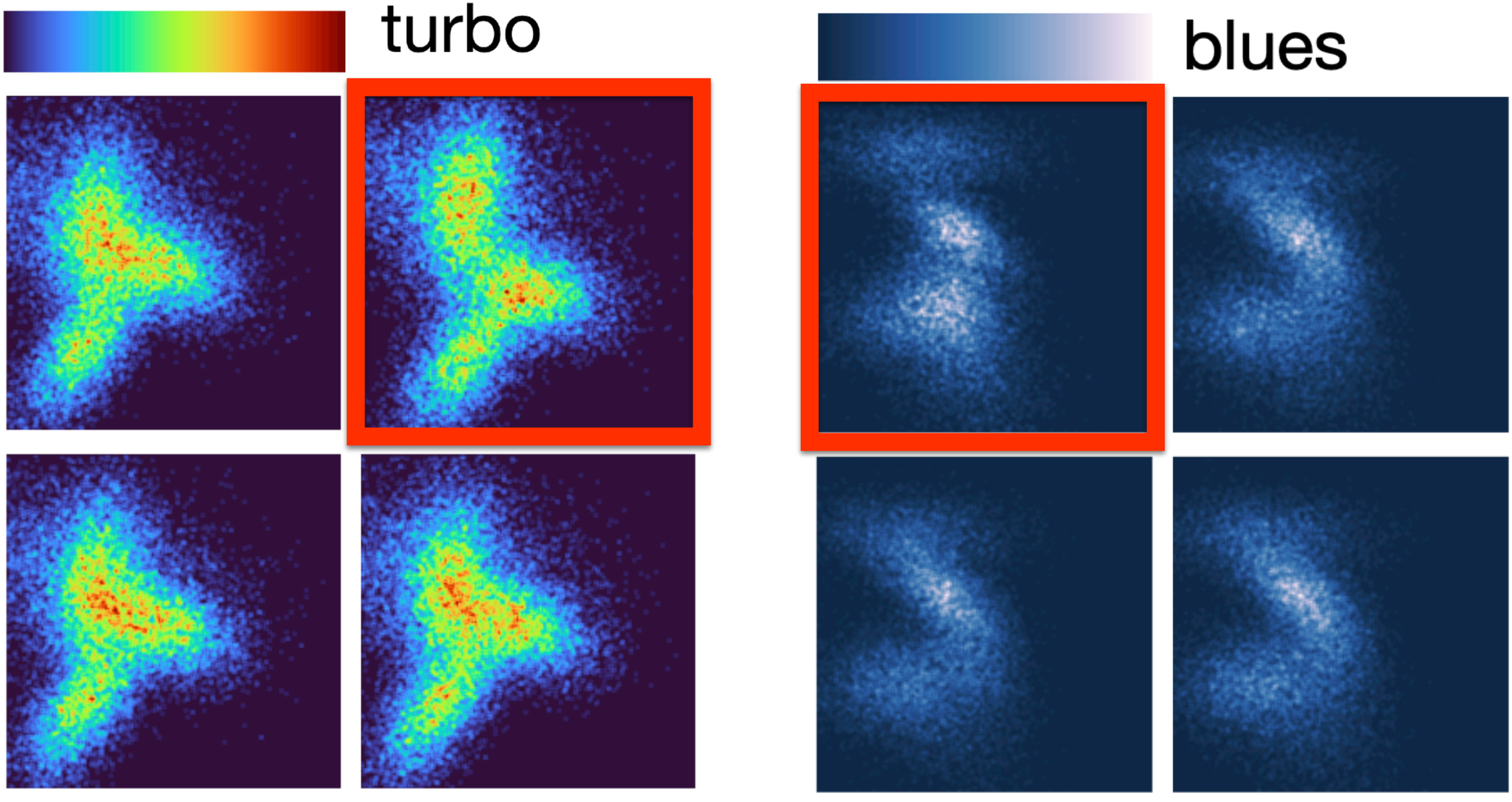
However...
Using a different kind of task



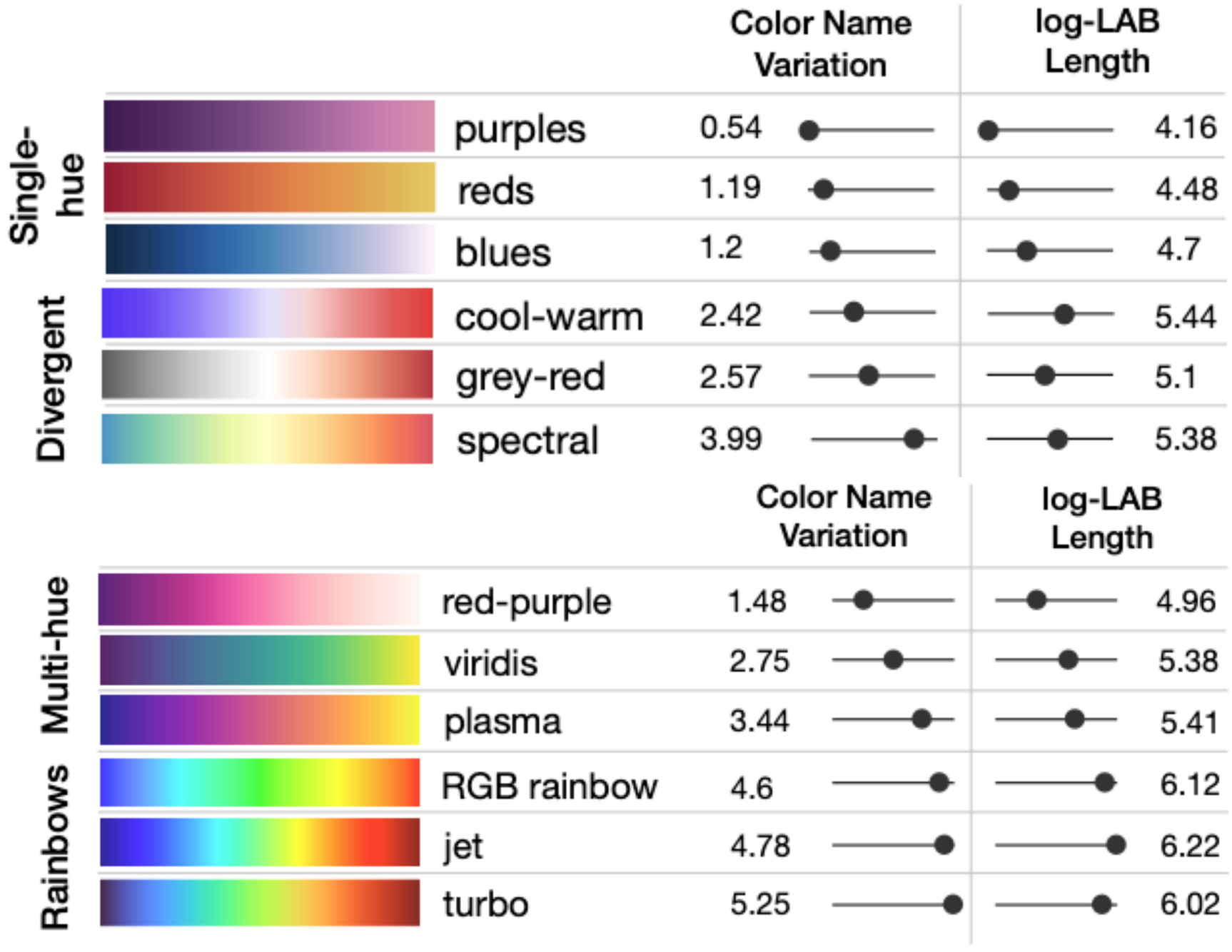
However…
Using a different kind of task



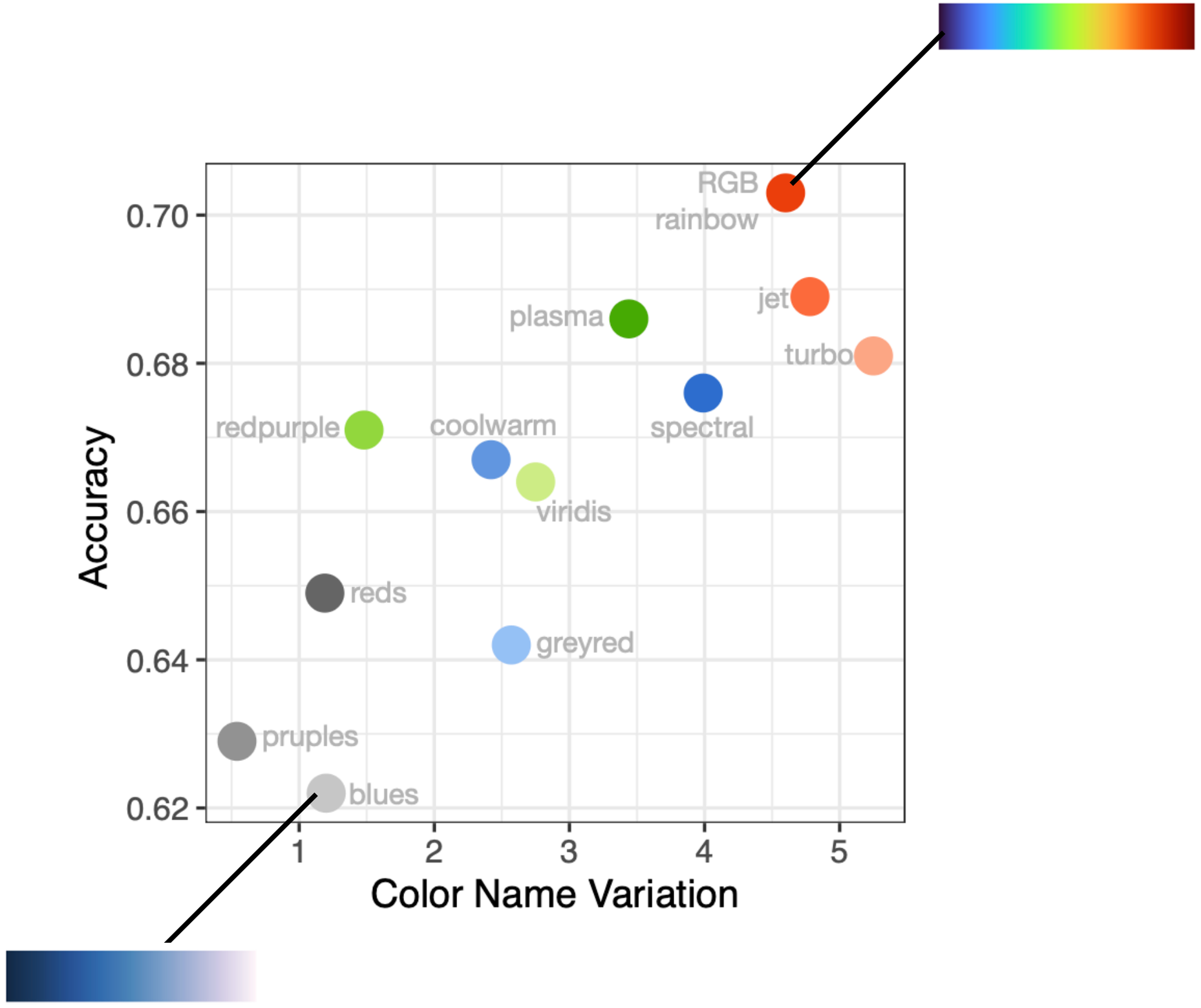
However...
Using a different kind of task



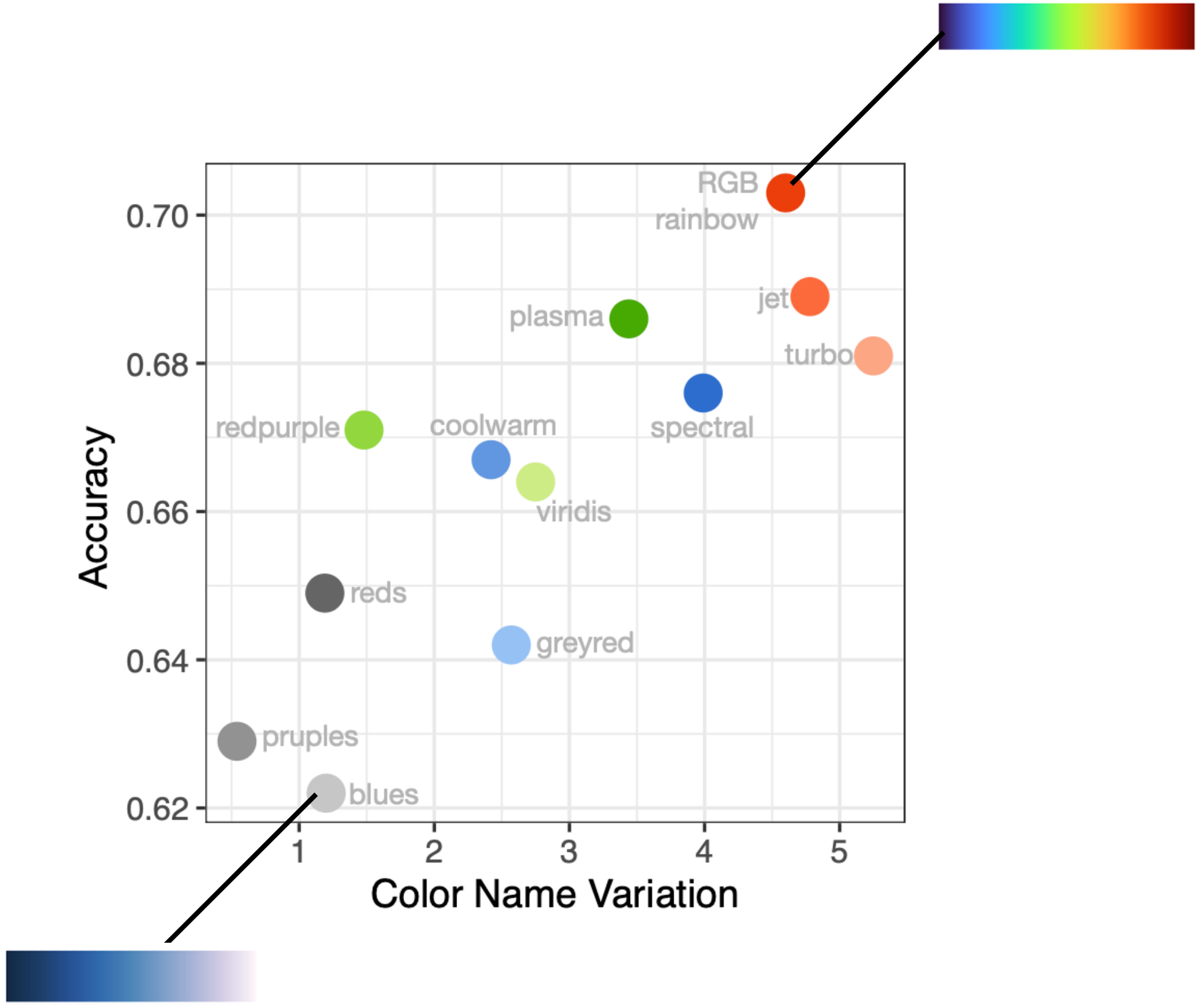
However...
Using a different kind of task



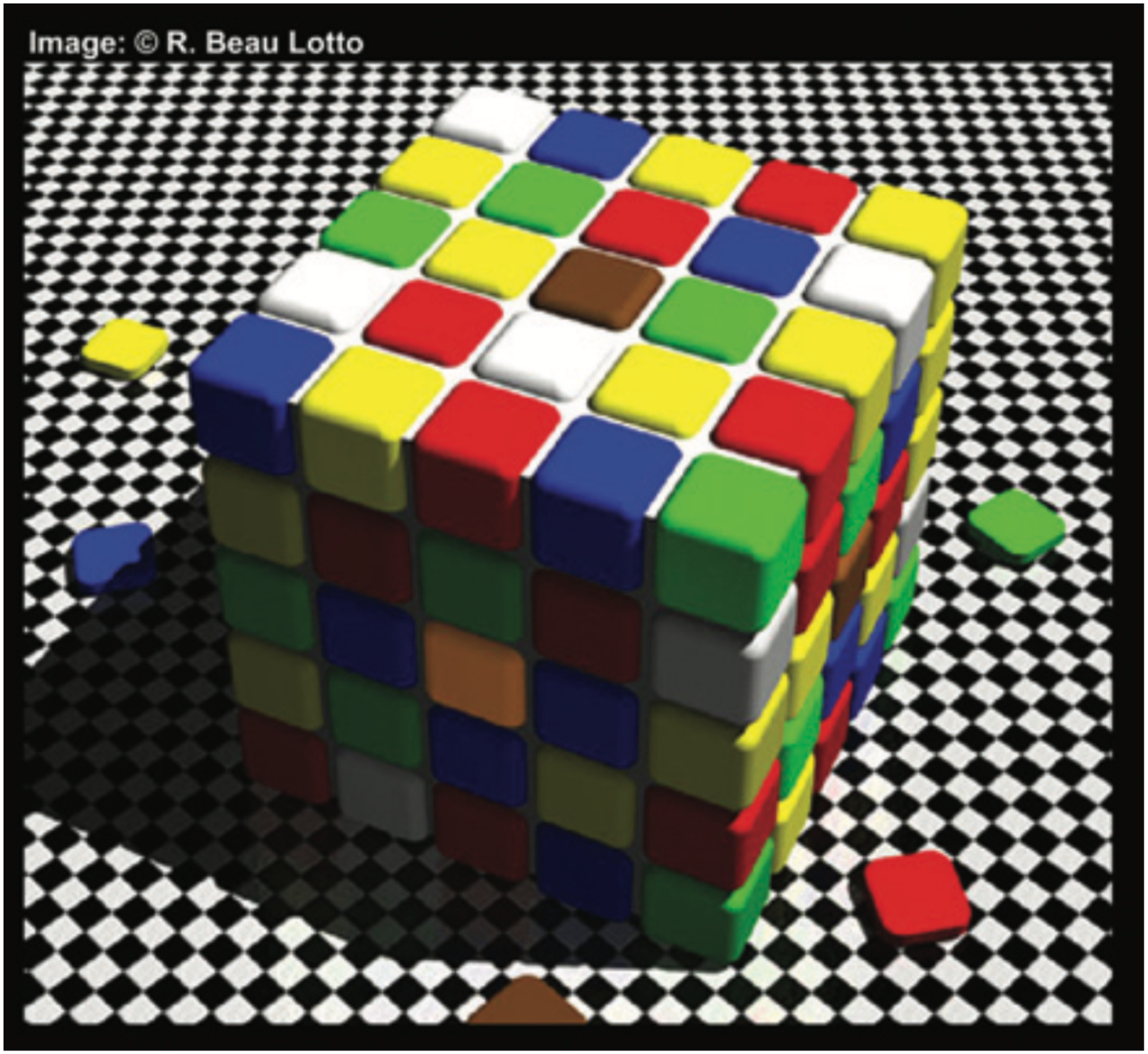
However…
Using a different kind of task



However…
Using a different kind of task



Simultaneous contrast



Via Colin Ware