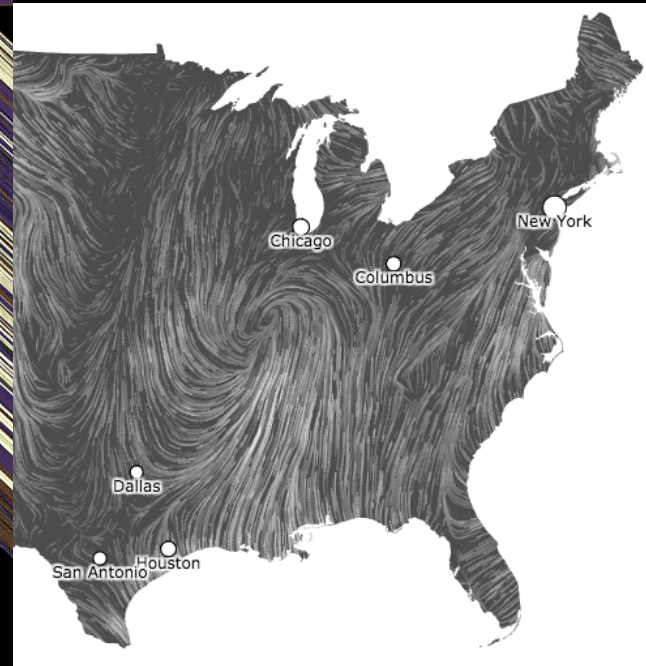
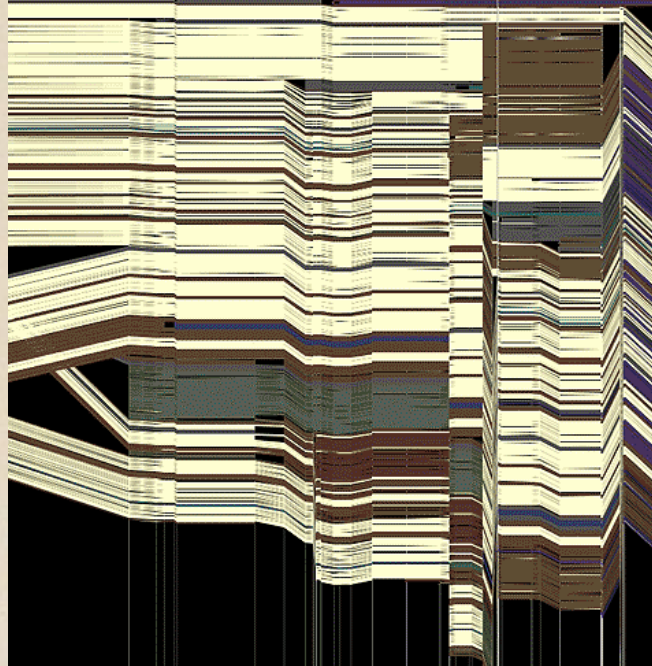
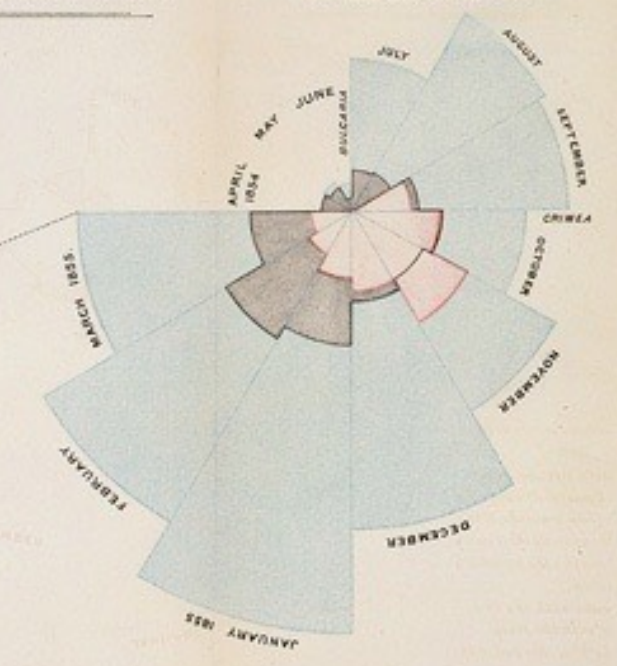


# CSE 442 - Data Visualization

# Color



Jeffrey Heer University of Washington

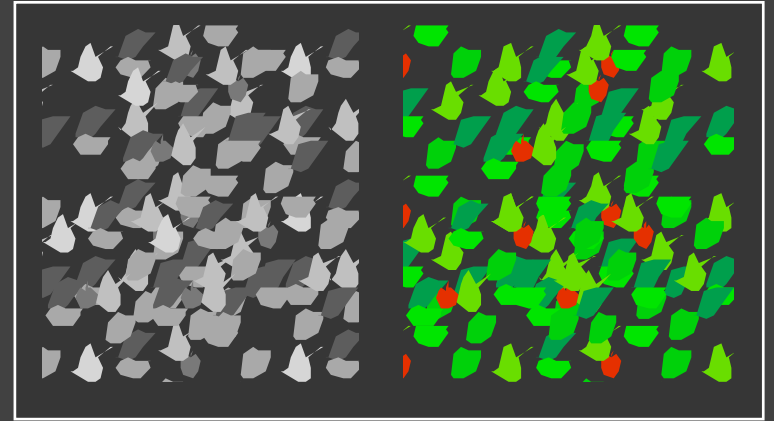
# Purpose of Color

To label

To measure

To represent and imitate

To enliven and decorate



*"Above all, do no harm."*

- Edward Tufte

# Topics

## **Perception of Color**

Light, Visual system, Mental models

## **Color in Information Visualization**

Categorical & Quantitative encoding

Guidelines for color palette design

# Perception of Color

What color is this?

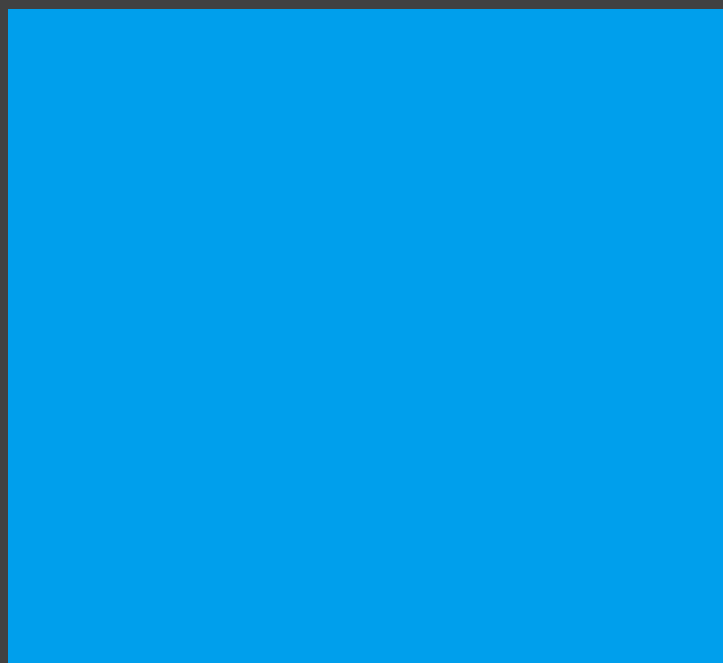


What color is this?

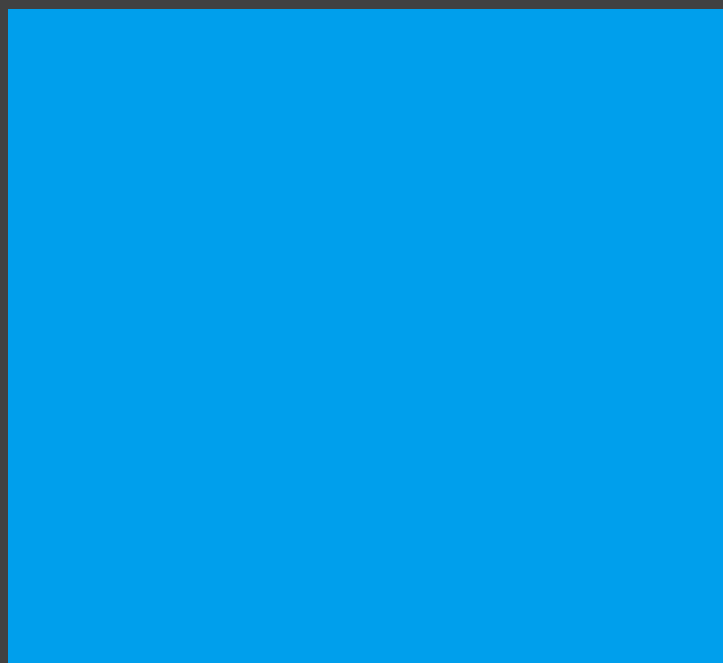


"Yellow"

What color is this?



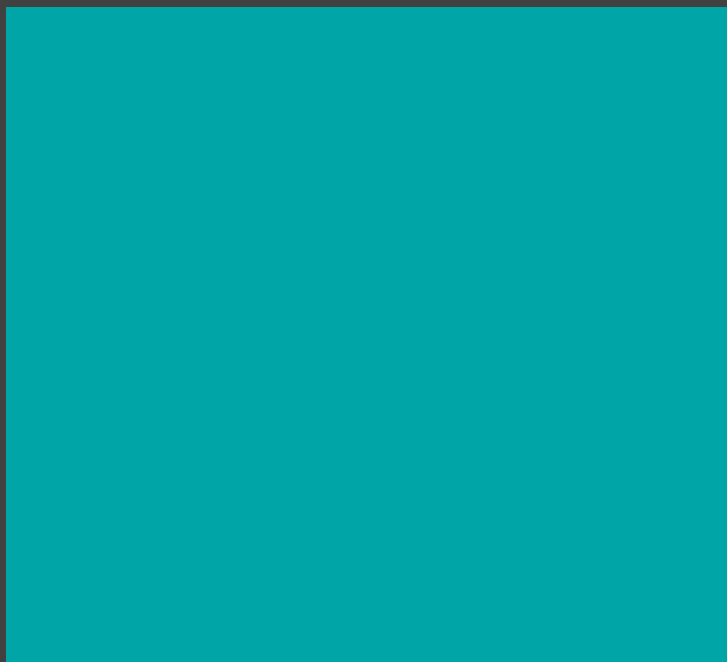
What color is this?



"Blue"



What color is this?

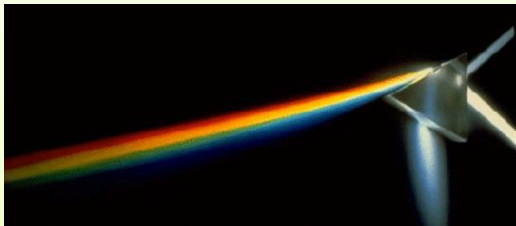


What color is this?

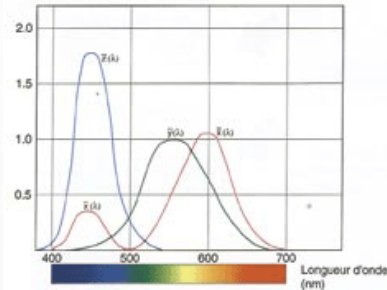


"Teal" ?

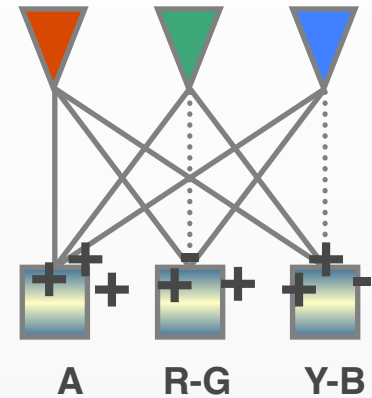
# Perception of Color



Light



Cone Response



Opponent Signals

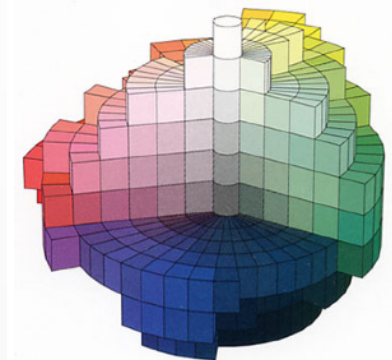
“Yellow”

Color Cognition



Mark D. Fairchild  
COLOR APPEARANCE  
MODELS

Color Appearance



Color Perception

# Physicist's View

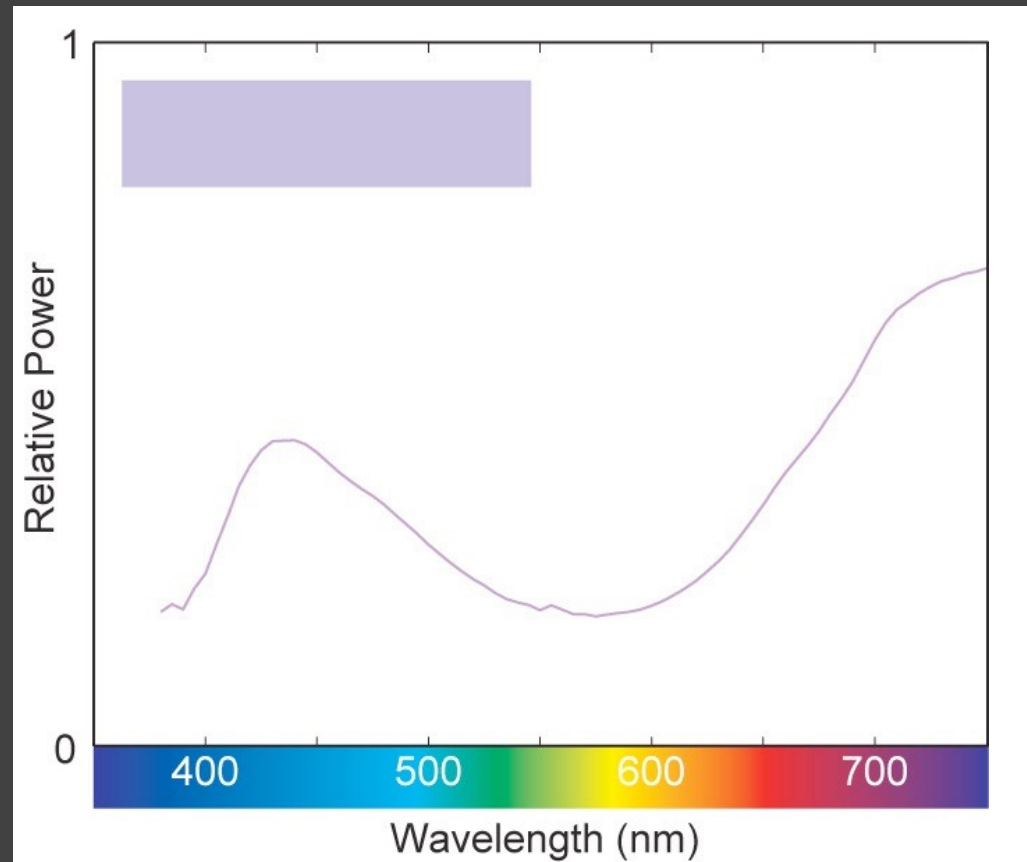
Light as electromagnetic waves

## Wavelength

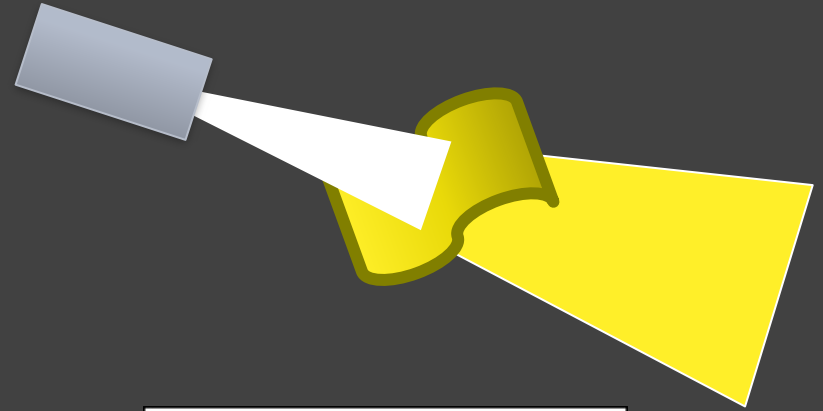
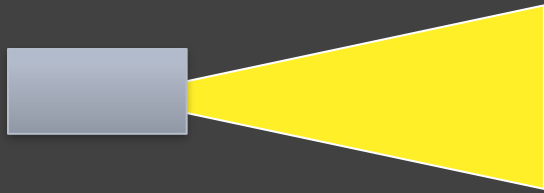
Visible spectrum is  
370-730 nm

## Power or

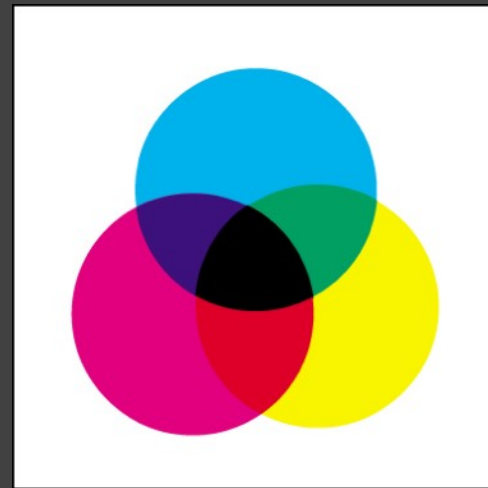
"Relative luminance"



# Emissive vs. Reflective Light



Additive  
(digital displays)

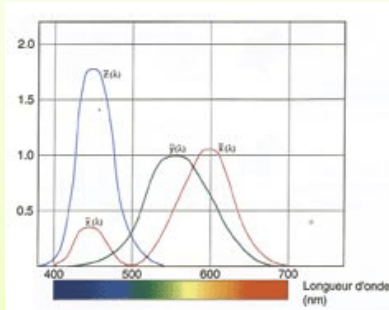


Subtractive  
(print, e-paper)

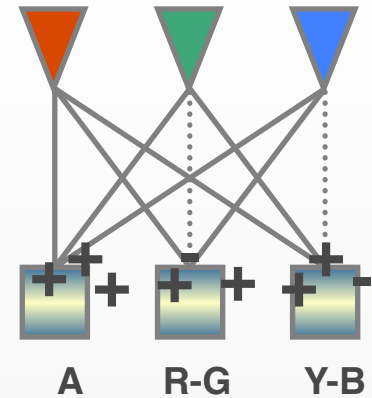
# Perception of Color



Light



Cone Response



Opponent Signals

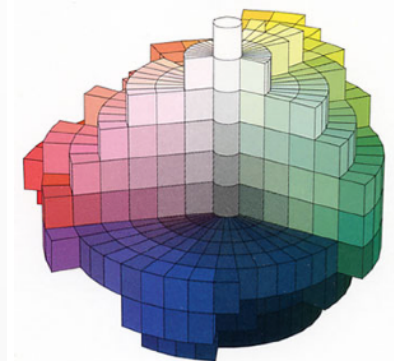
**“Yellow”**

Color Cognition



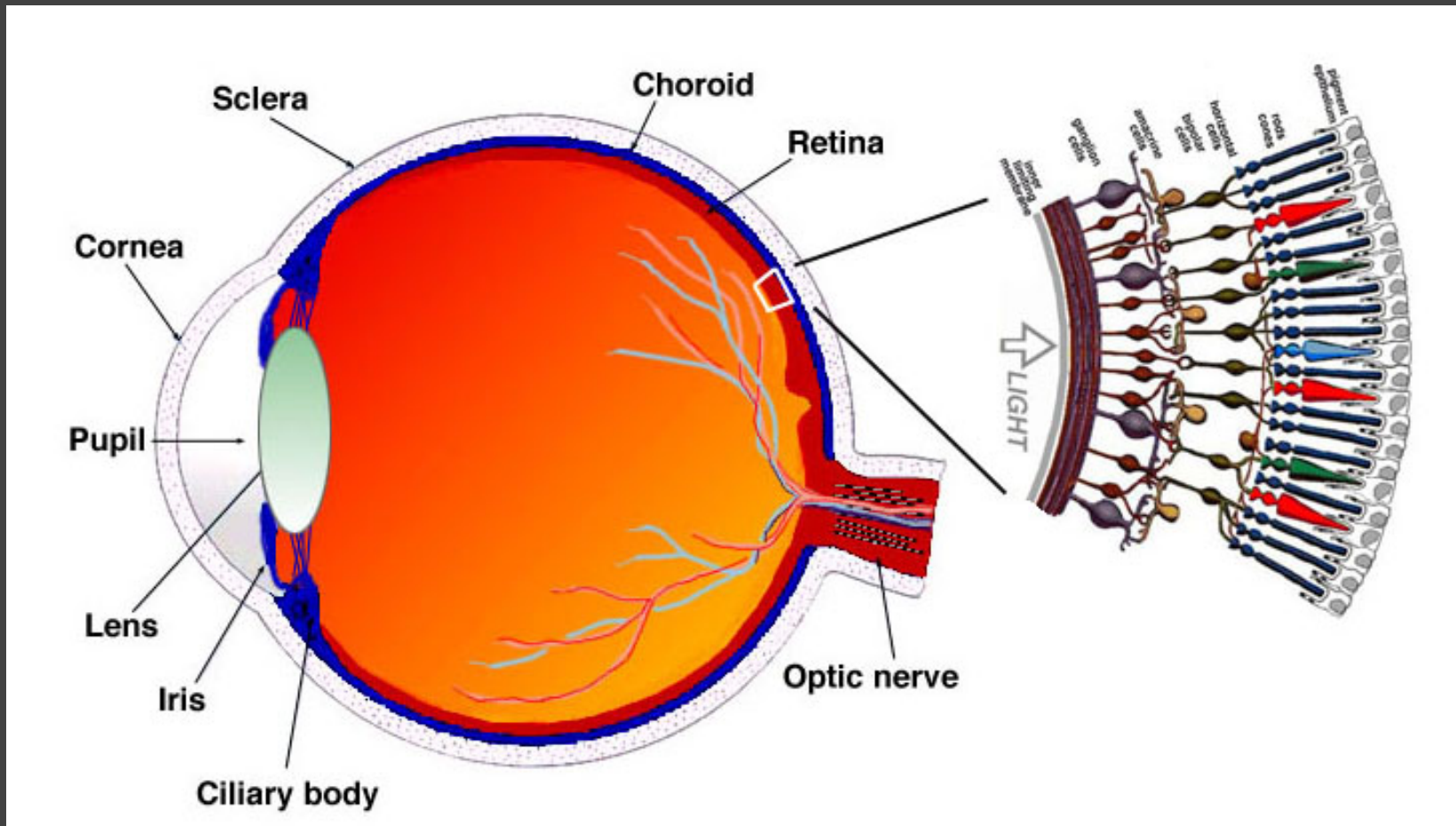
Mark D. Fairchild  
**COLOR APPEARANCE  
MODELS**

Color Appearance



Color Perception

# Retina

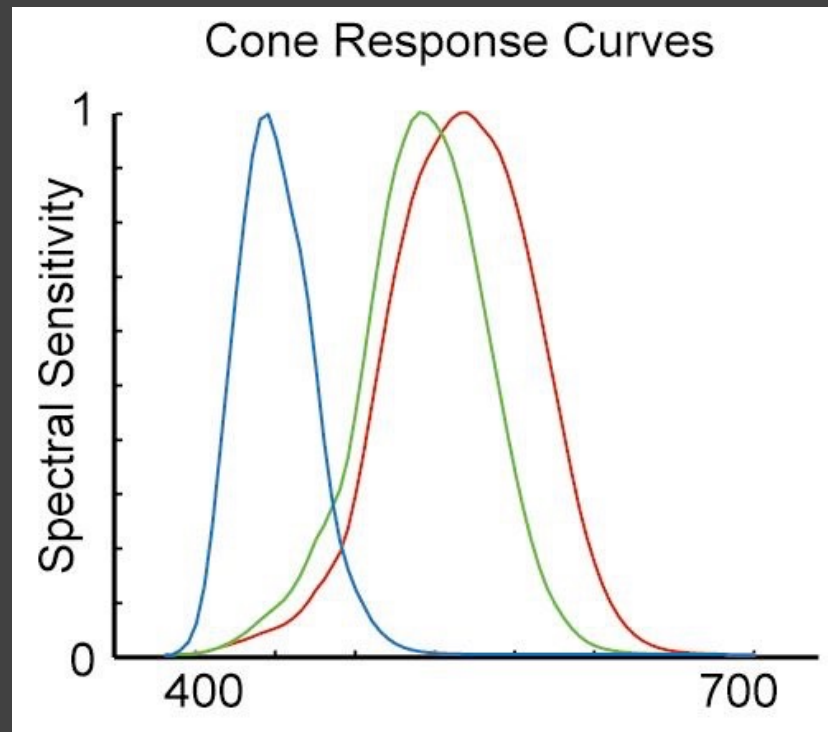


*Simple Anatomy of the Retina, Helga Kolb*

# As light enters our retina...

LMS (Long, Middle, Short) Cones

Sensitive to different wavelengths



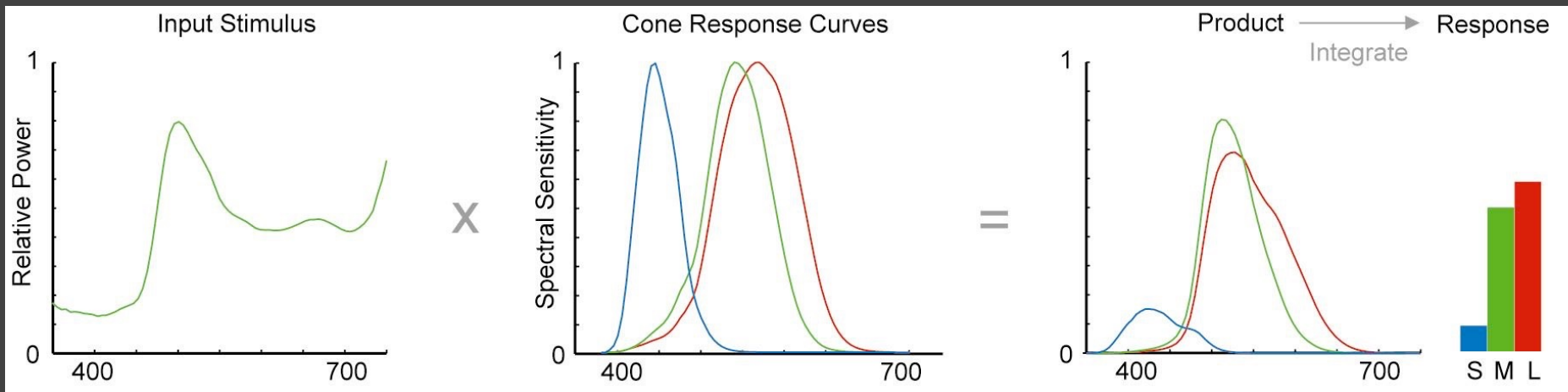


# As light enters our retina...

## LMS (Long, Middle, Short) Cones

Sensitive to different wavelengths

Integration with input stimulus



# Effects of Retina Encoding

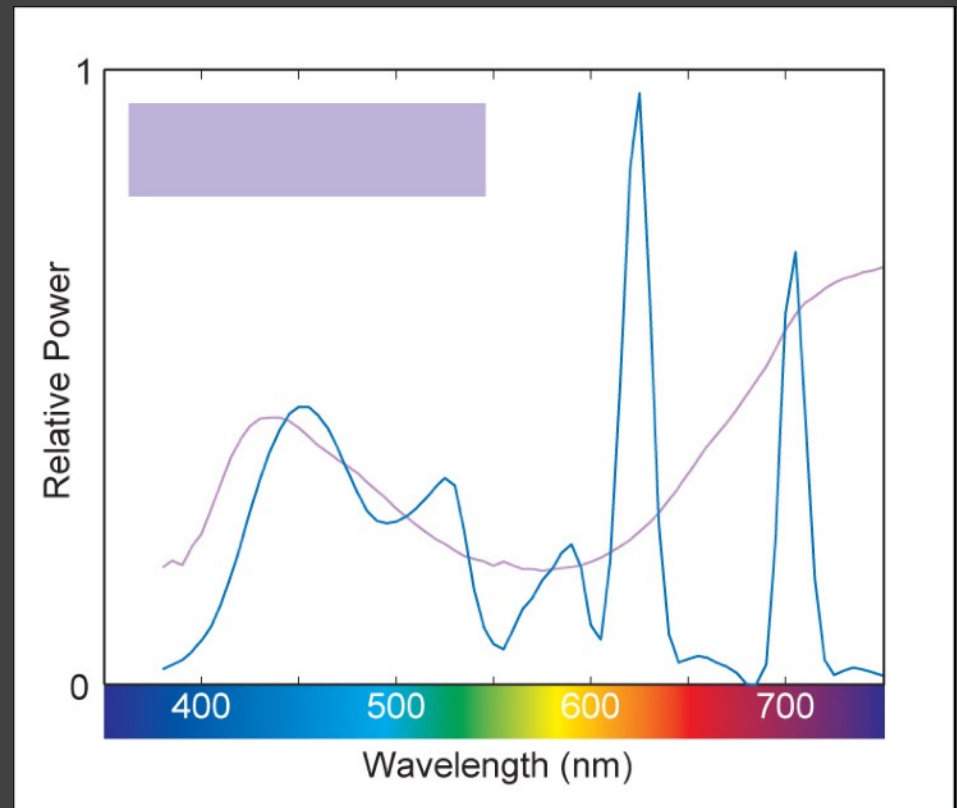
Spectra that stimulate the same LMS response are indistinguishable (a.k.a. "metamers").

## "Tri-stimulus"

Computer displays

Digital scanners

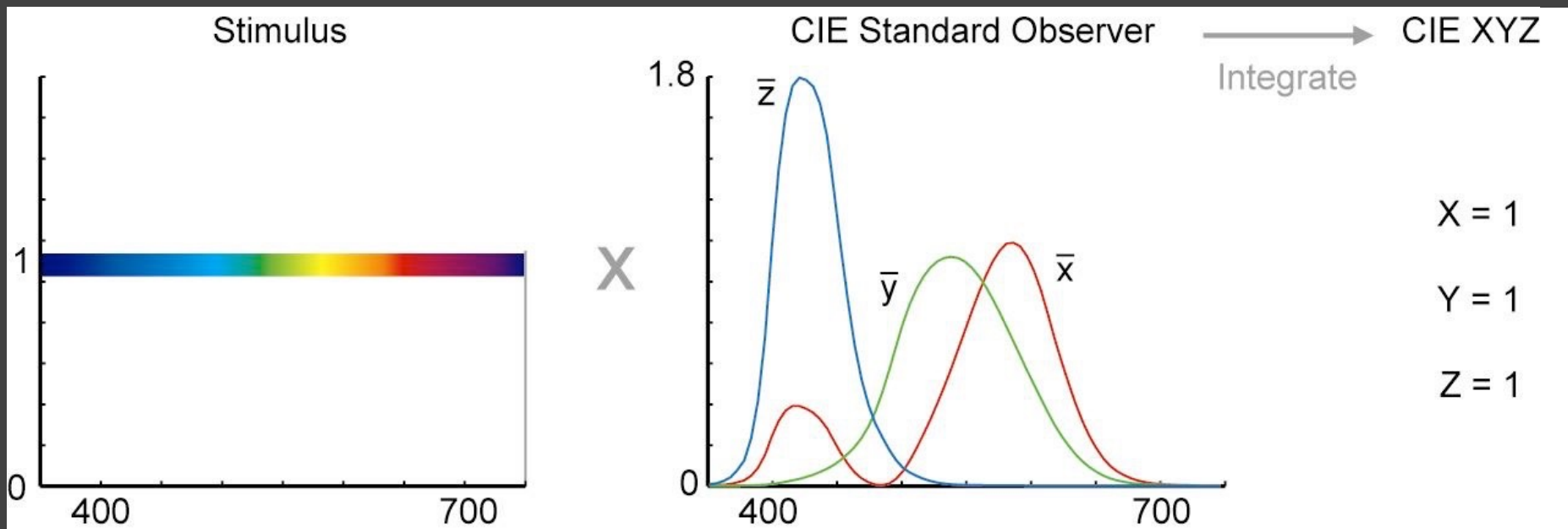
Digital cameras



# CIE XYZ Color Space

Standardized in 1931 to mathematically represent tri-stimulus response from cones on the retina.

“Standard observer” response curves



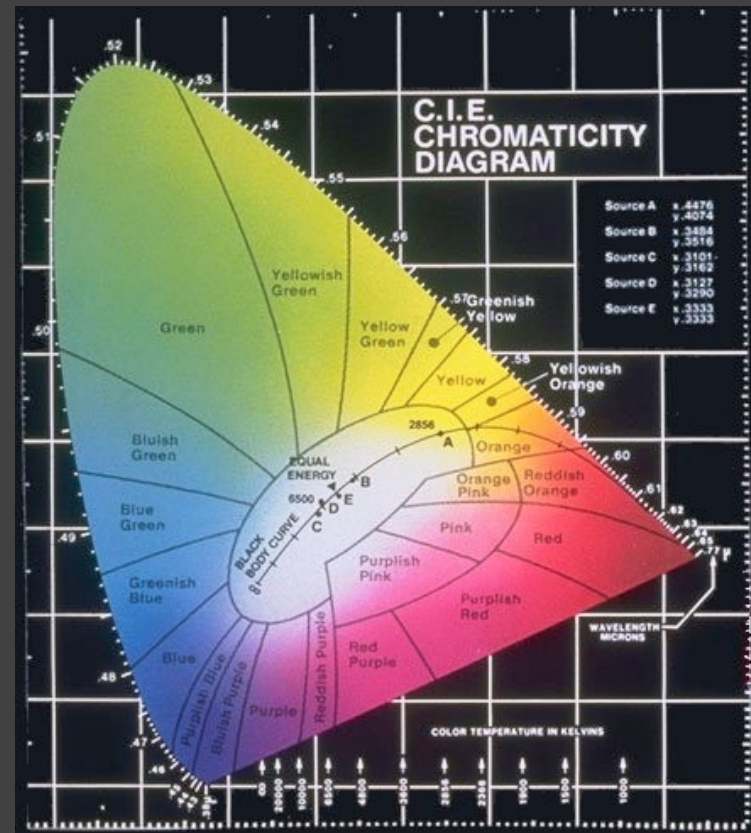
# CIE Chromaticity Diagram

Colorfulness vs. Brightness

$$x = X / (X+Y+Z)$$

$$y = Y / (X+Y+Z)$$

y



x

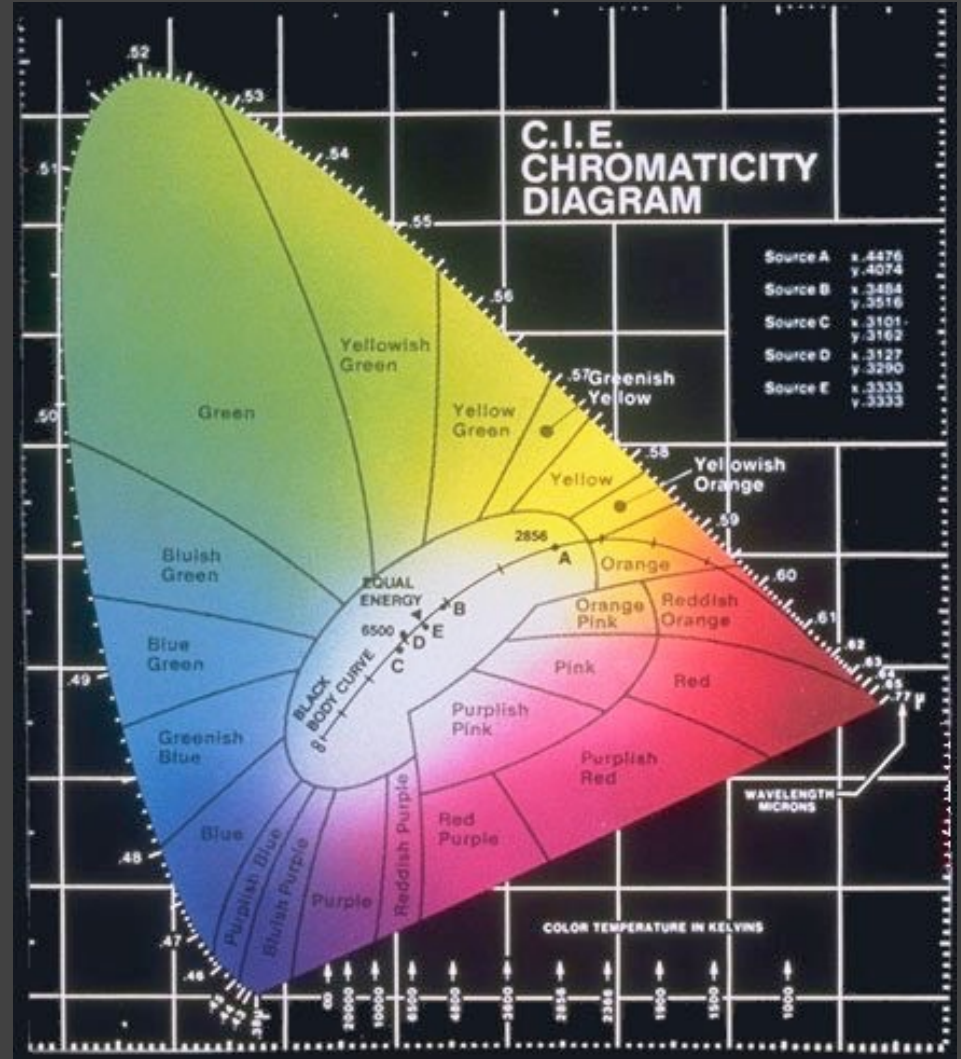


# CIE Chromaticity Diagram

Spectrum locus

Purple line

Mixture of two lights appears as a straight line.

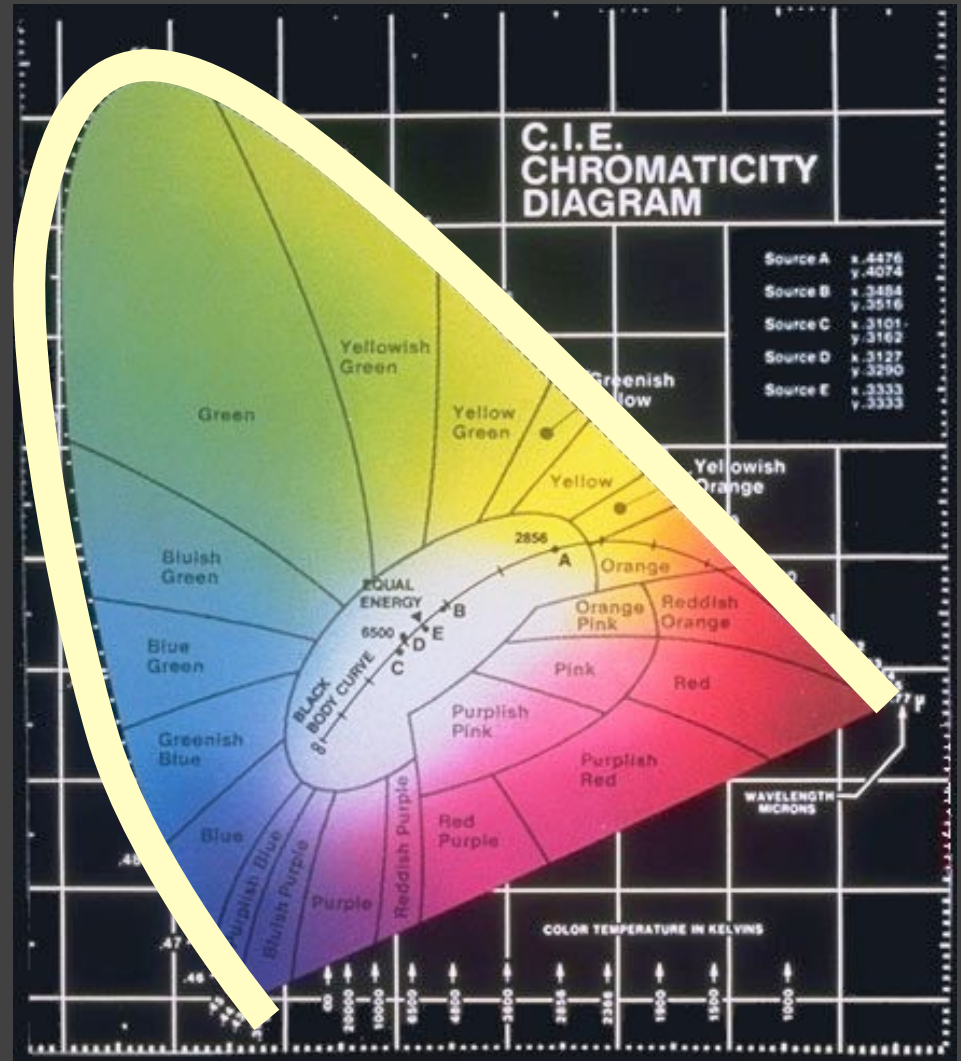


# CIE Chromaticity Diagram

Spectrum locus

Purple line

Mixture of two lights appears as a straight line.

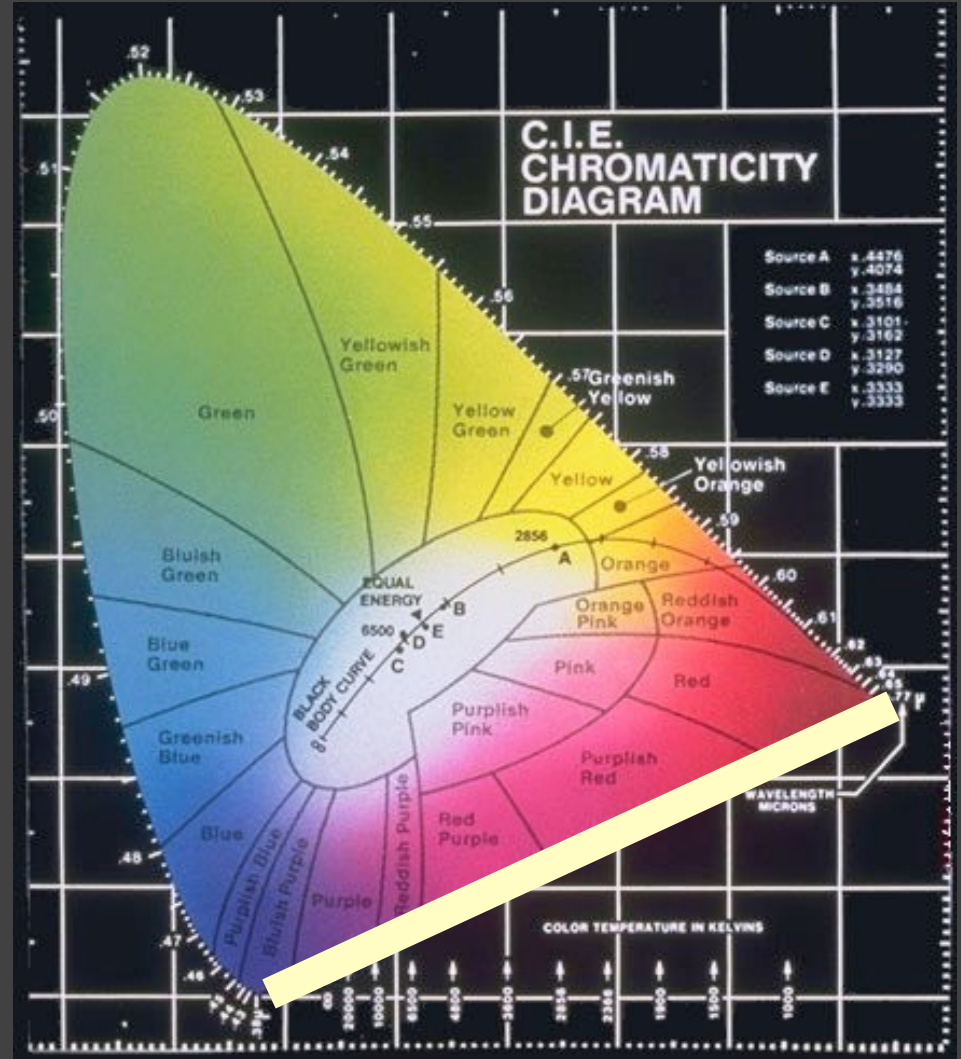


# CIE Chromaticity Diagram

Spectrum locus

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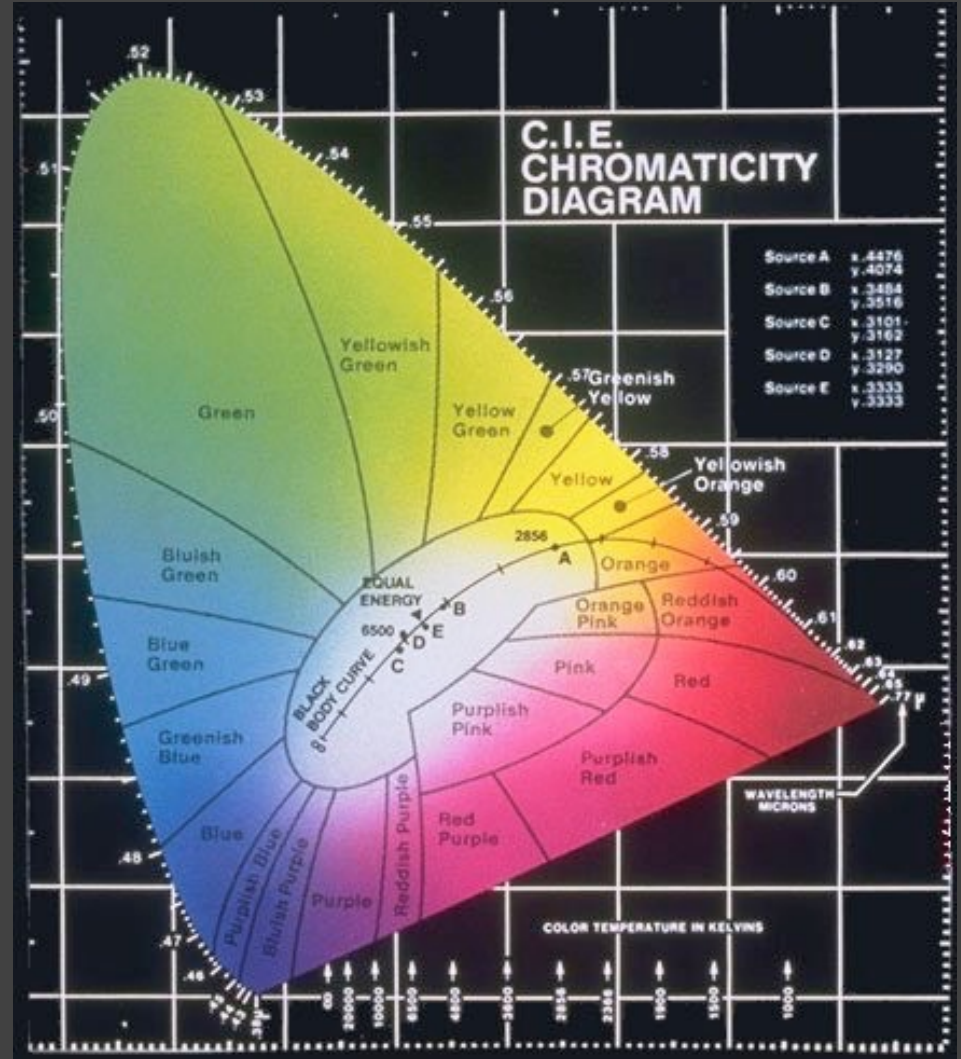


# CIE Chromaticity Diagram

Spectrum locus

Purple line

Mixture of two lights appears as a straight line.



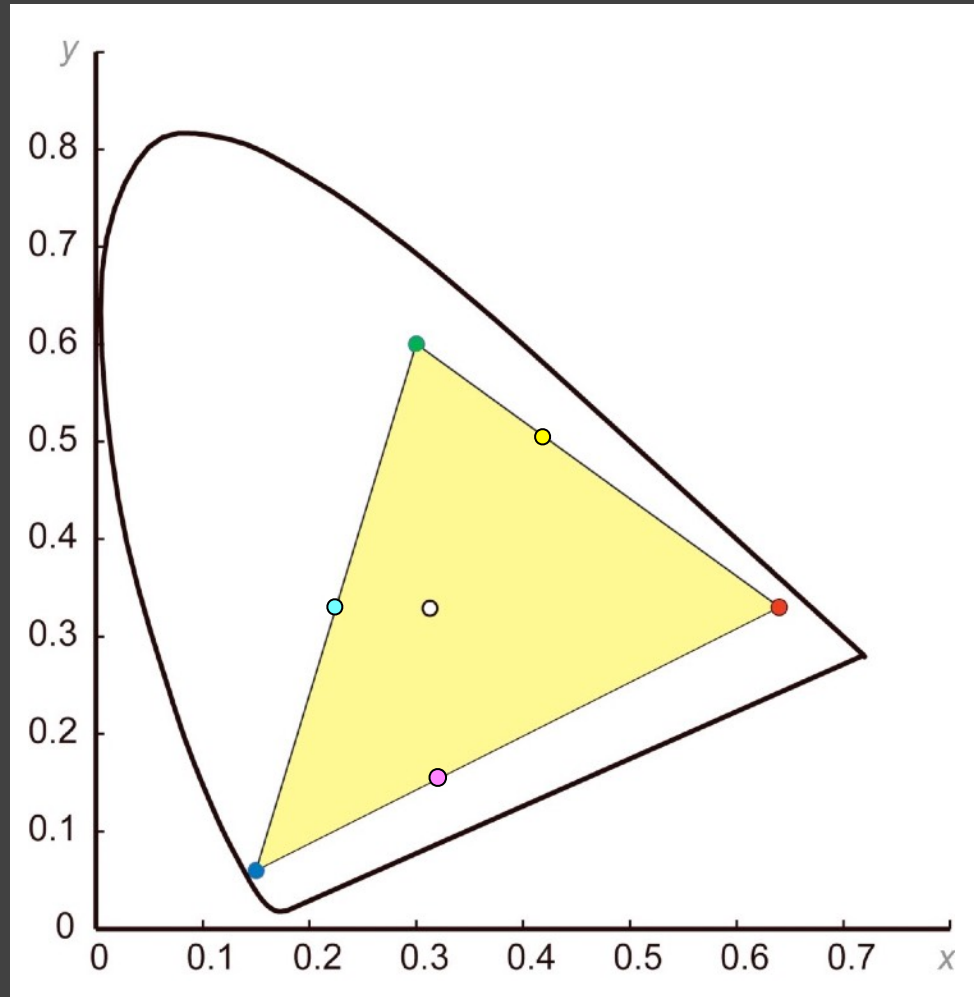


# Display Gamuts

Typically defined by:

3 Colorants

Convex region



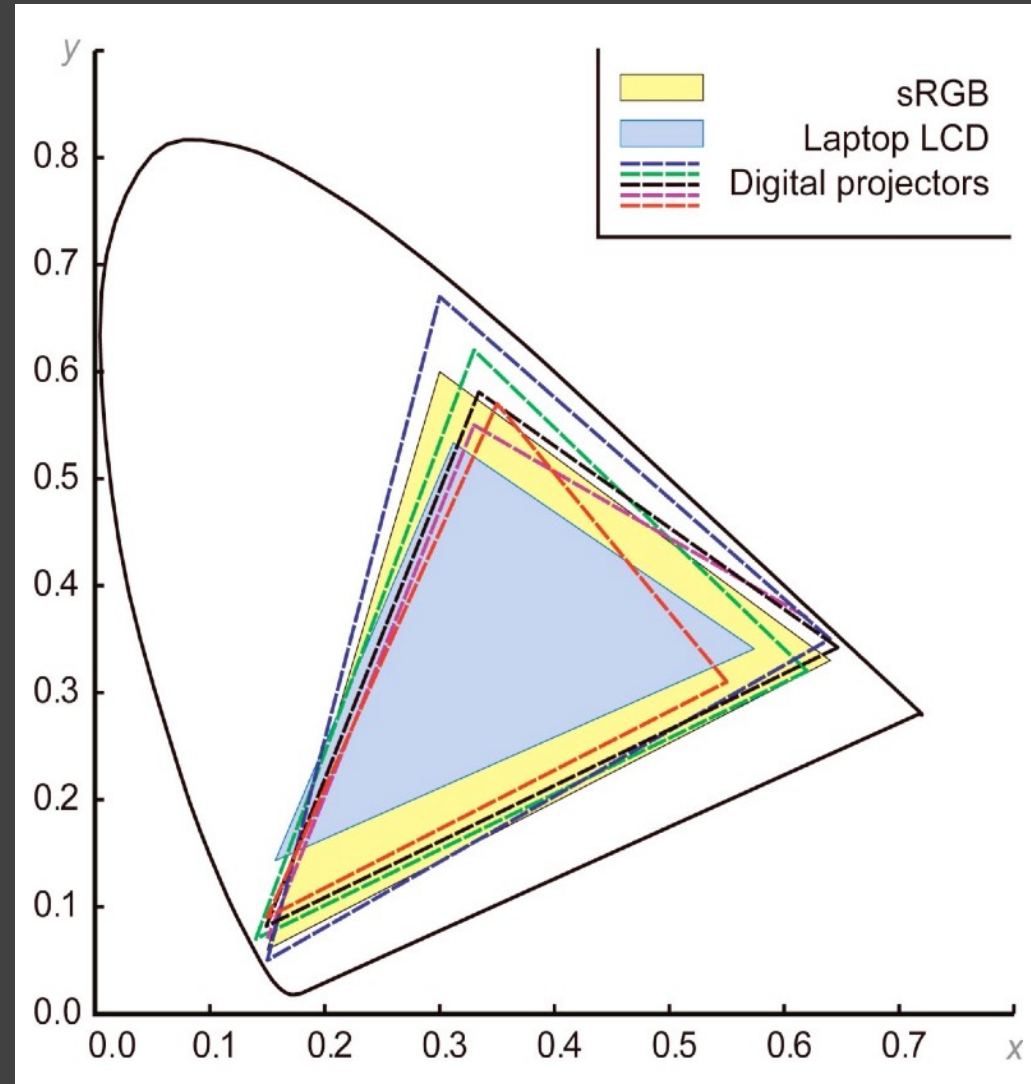
# Display Gamuts

Deviations from  
sRGB specification

*Example:*

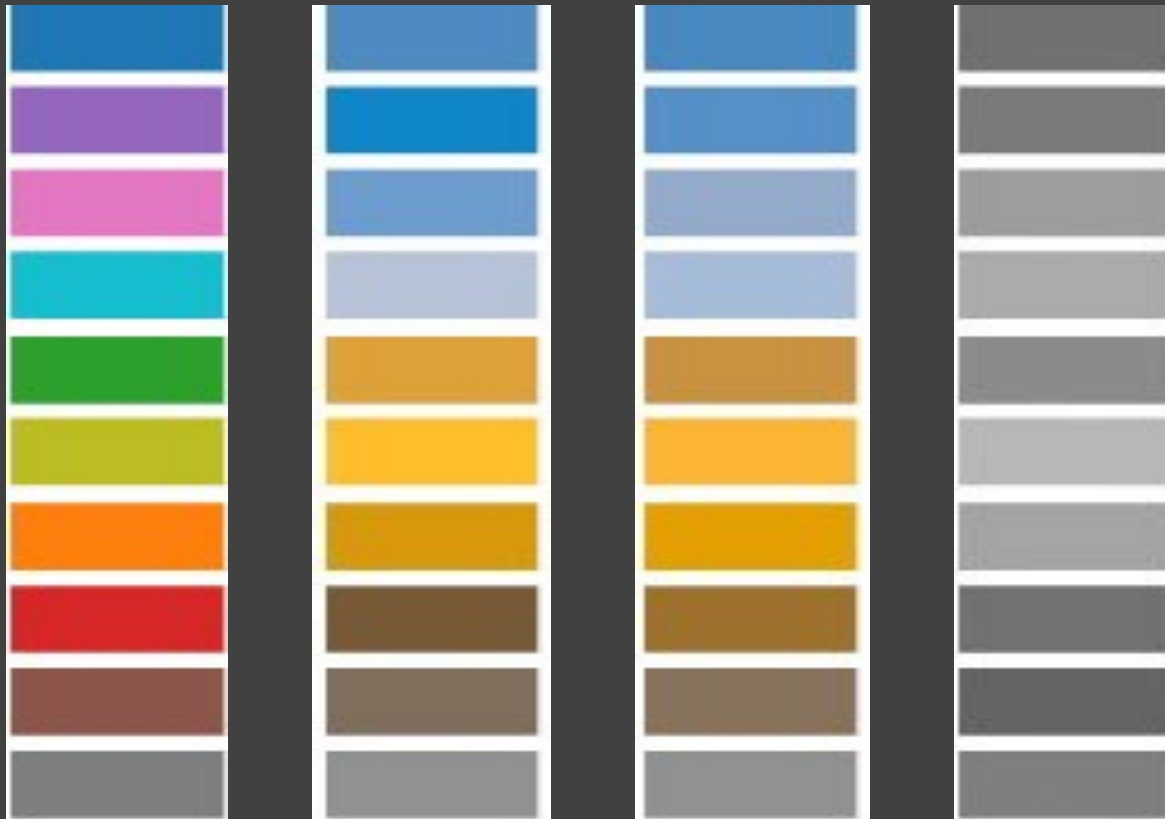
(R, G, B) coordinates  
ranging from 0-255.

Displays may  
produce different  
colors for a coord!



# Color Vision Deficiency (CVD)

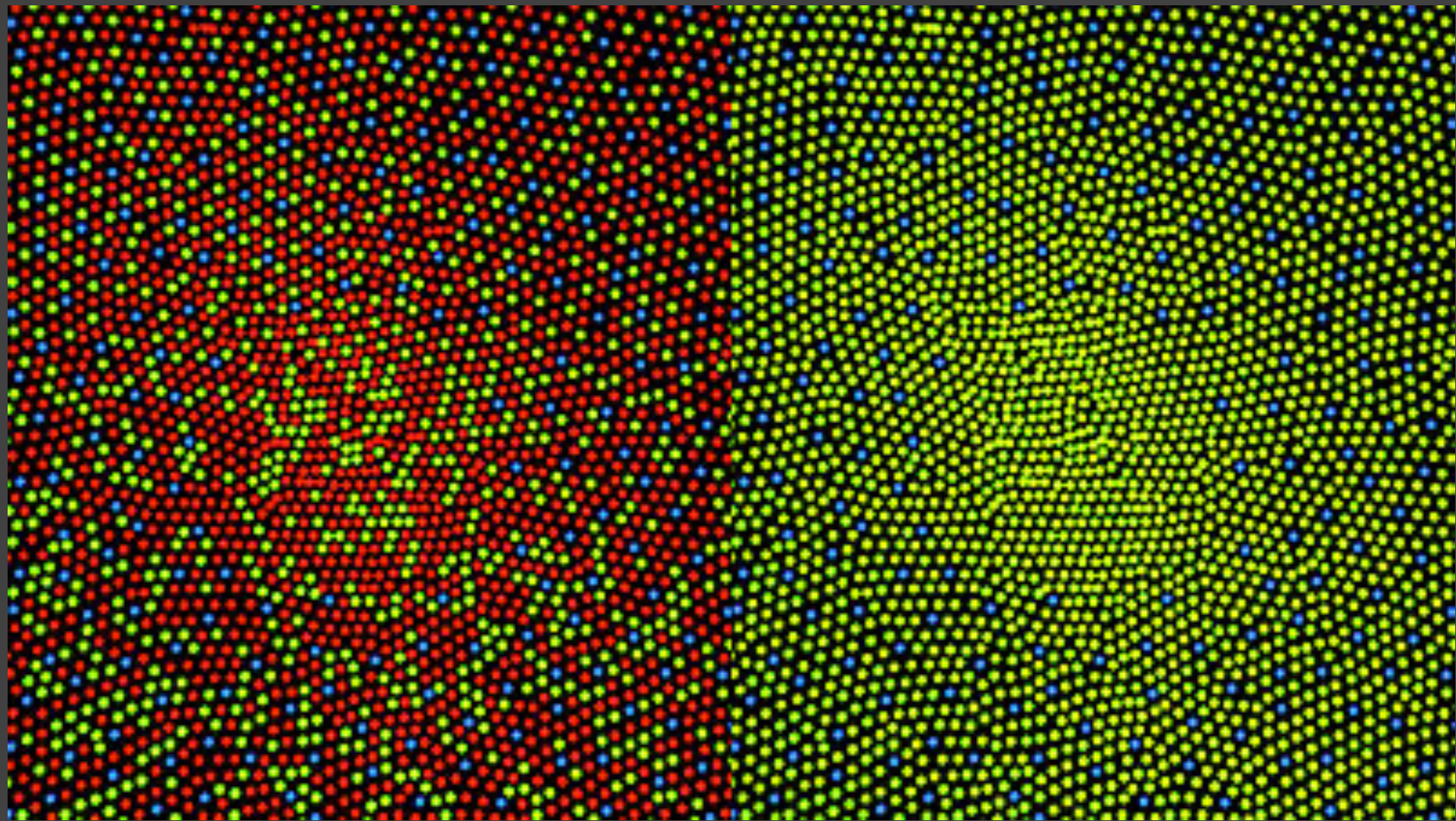
Missing one or more cones or rods in retina.



Protanope

Deuteranope

Luminance



Normal Retina

Protanopia

# Color Vision Simulators

Simulate color vision deficiencies

Browser plug-ins

Photoshop plug-ins, etc.



Deuteranope

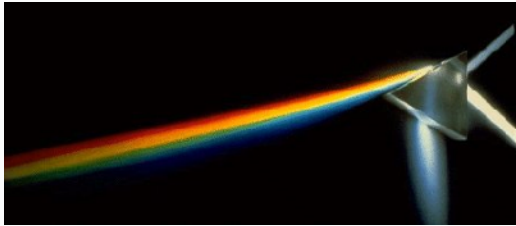


Protanope

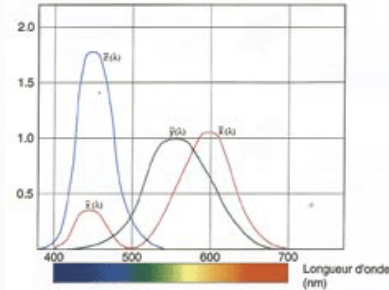


Tritanope

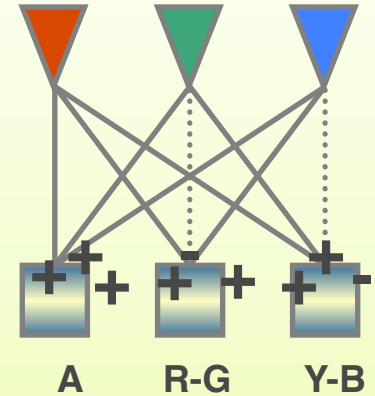
# Perception of Color



Light



Cone Response



Opponent Signals

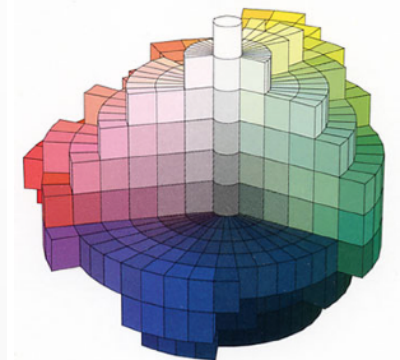
“Yellow”

Color Cognition



Mark D. Fairchild  
COLOR APPEARANCE  
MODELS

Color Appearance



Color Perception

# Primary Colors

To paint "all colors":

Leonardo da Vinci, circa 1500 described in his notebooks a list of simple colors...

**Yellow**

**Blue**

**Green**

**Red**

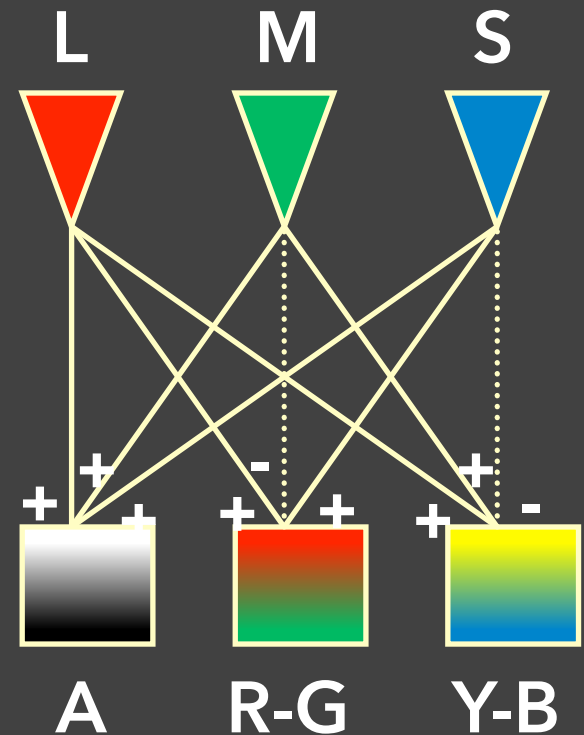
# Opponent Processing

**LMS are combined to create:**

Lightness

Red-green contrast

Yellow-blue contrast



[Fairchild]



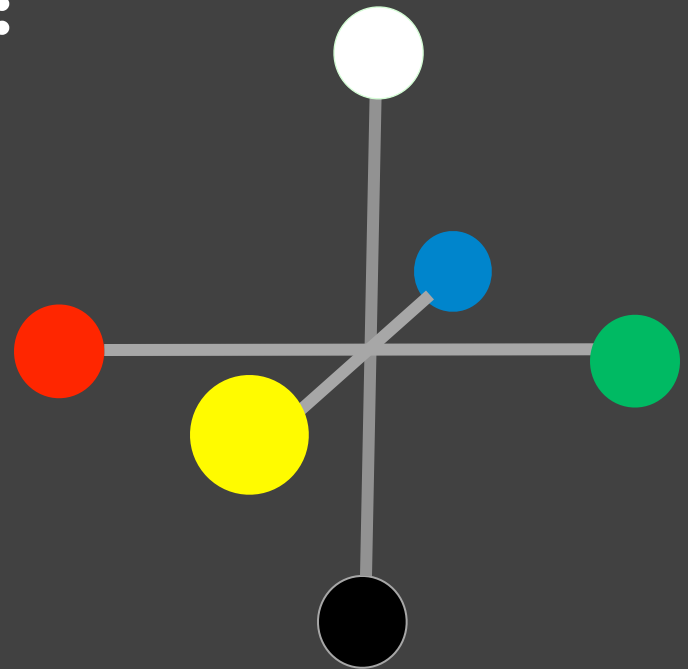
# Opponent Processing

**LMS are combined to create:**

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Red-green contrast

Yellow-blue contrast



# Opponent Processing

**LMS are combined to create:**

Lightness

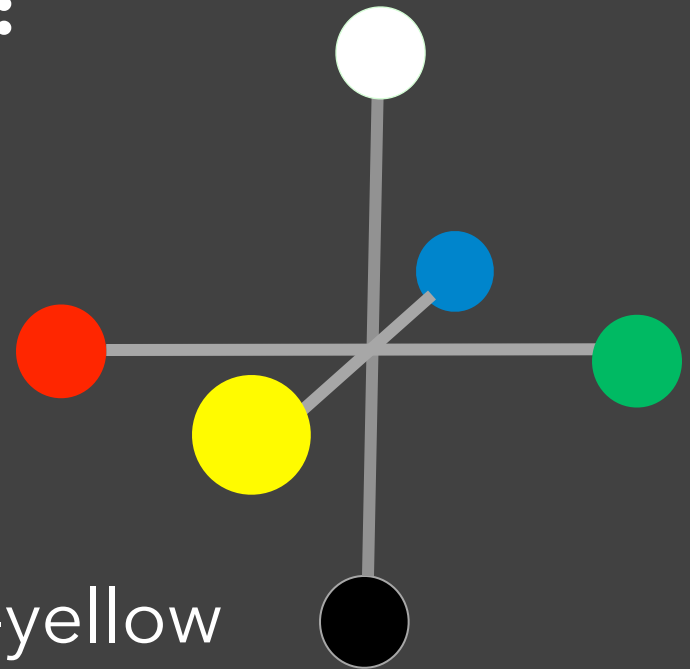
Red-green contrast

Yellow-blue contrast

**Experiments:**

No reddish-green, no blueish-yellow

Color after images



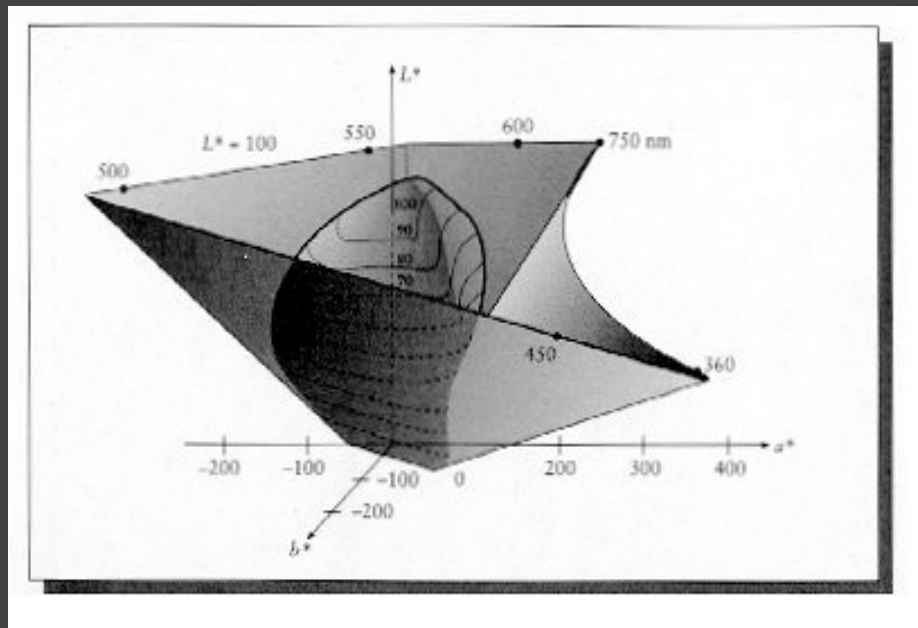
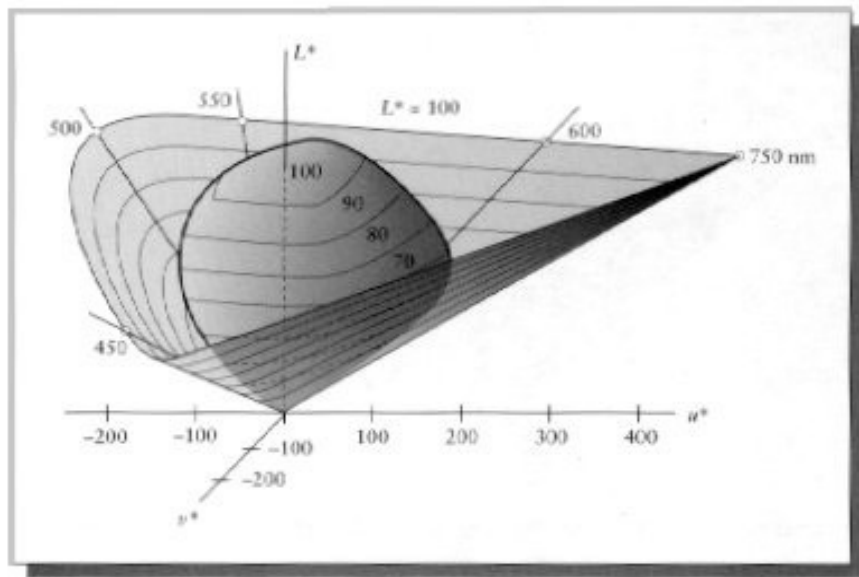




# CIE LAB and LUV Color Spaces

Standardized in 1976 to mathematically represent opponent processing theory.

Non-linear transformation of CIE XYZ



# CIE LAB Color Space

Axes correspond to opponent signals

**L\*** = Luminance

**a\*** = Red-green contrast

**b\*** = Yellow-blue contrast

Much more perceptually uniform than sRGB!

Scaling of axes to represent "color distance"

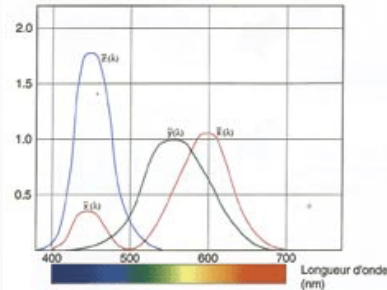
JND = Just noticeable difference (~2.3 units)

D3 + Vega include LAB color space support!

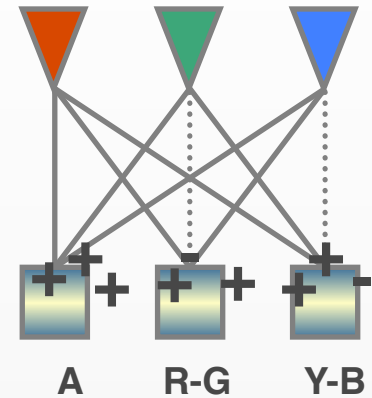
# Perception of Color



Light



Cone Response



Opponent Signals

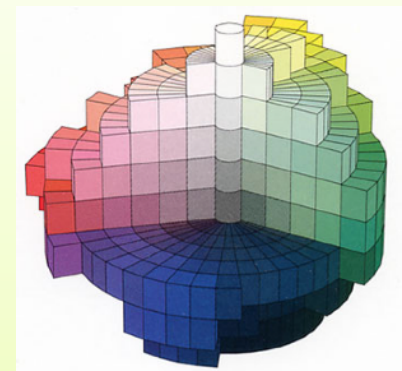
**“Yellow”**

Color Cognition



Mark D. Fairchild  
**COLOR APPEARANCE  
MODELS**

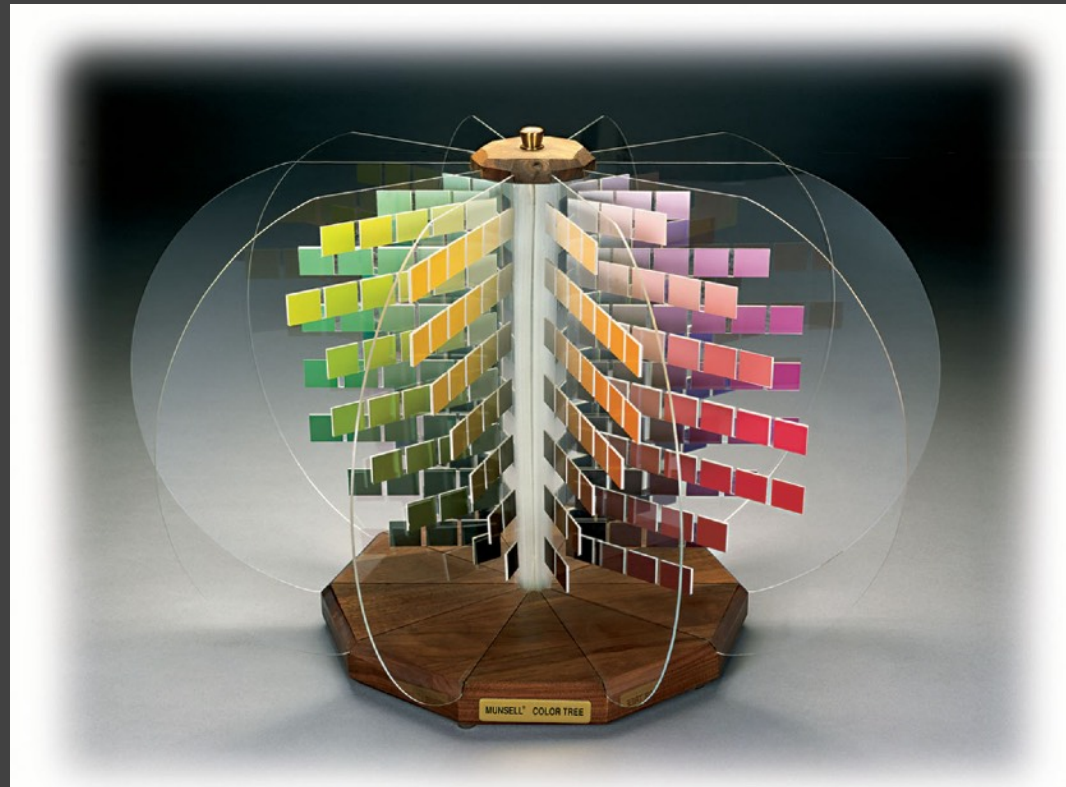
Color Appearance



Color Perception

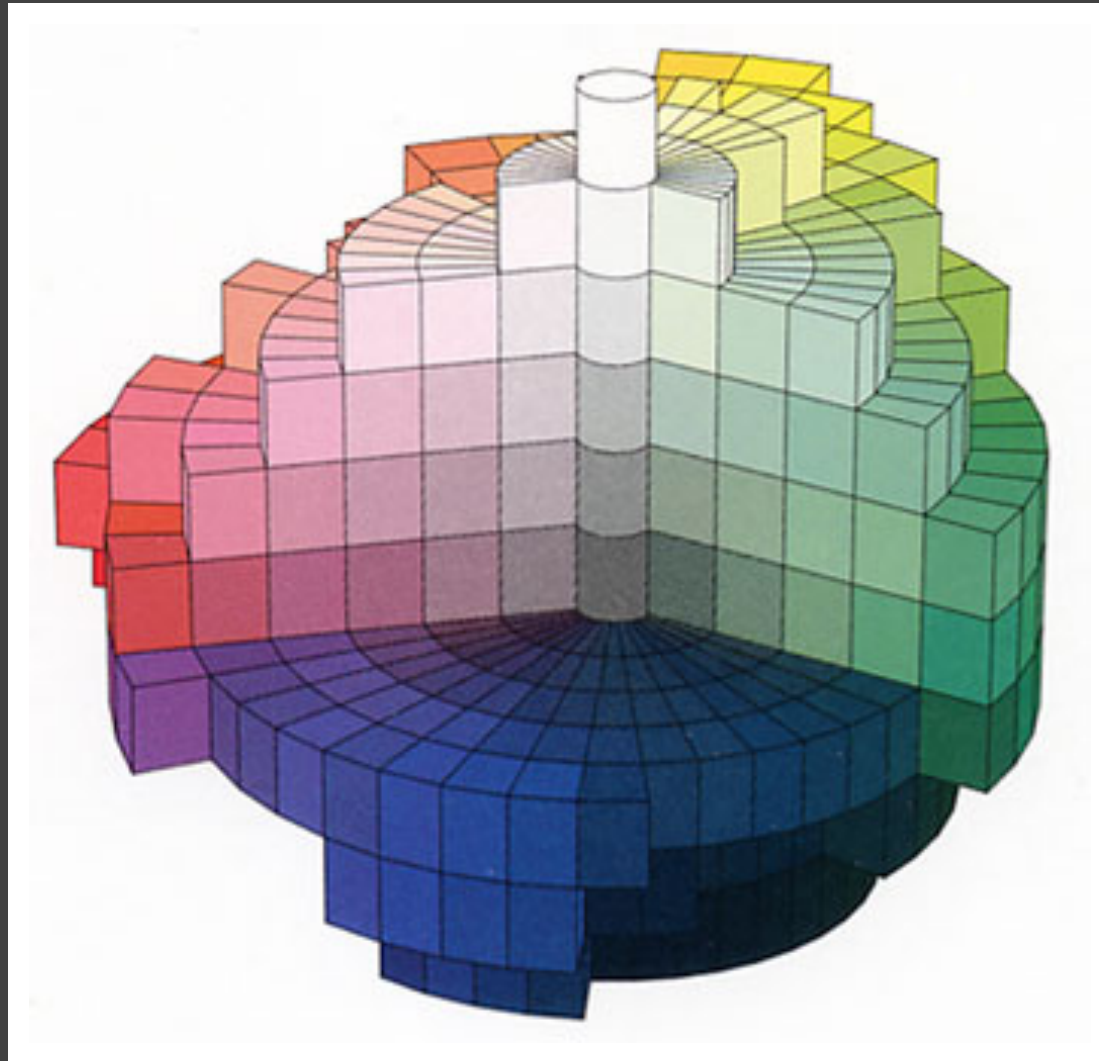
# Albert Munsell

Developed the first perceptual color system based on his experience as an artist (1905).

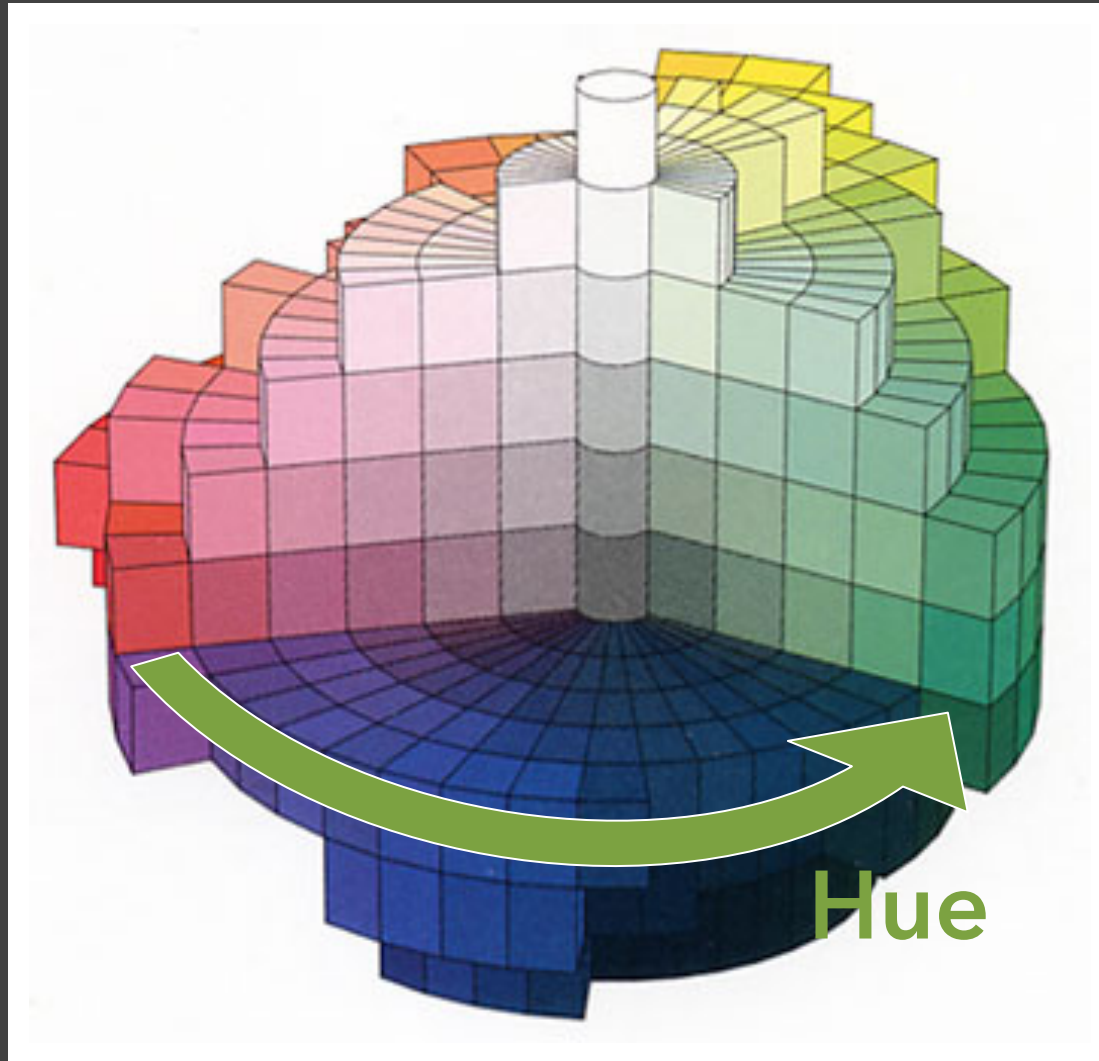




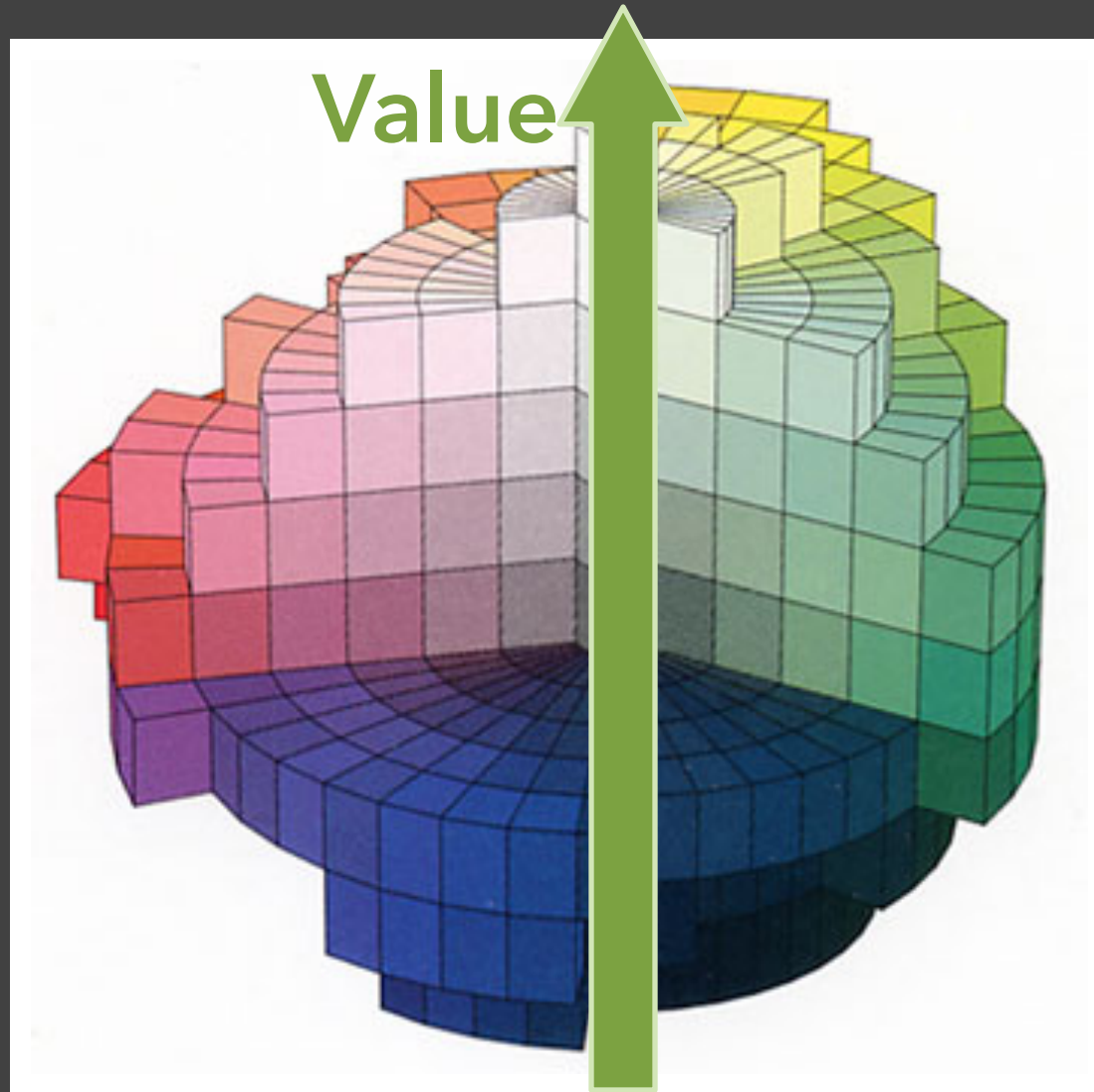
# Hue, Value, and Chroma



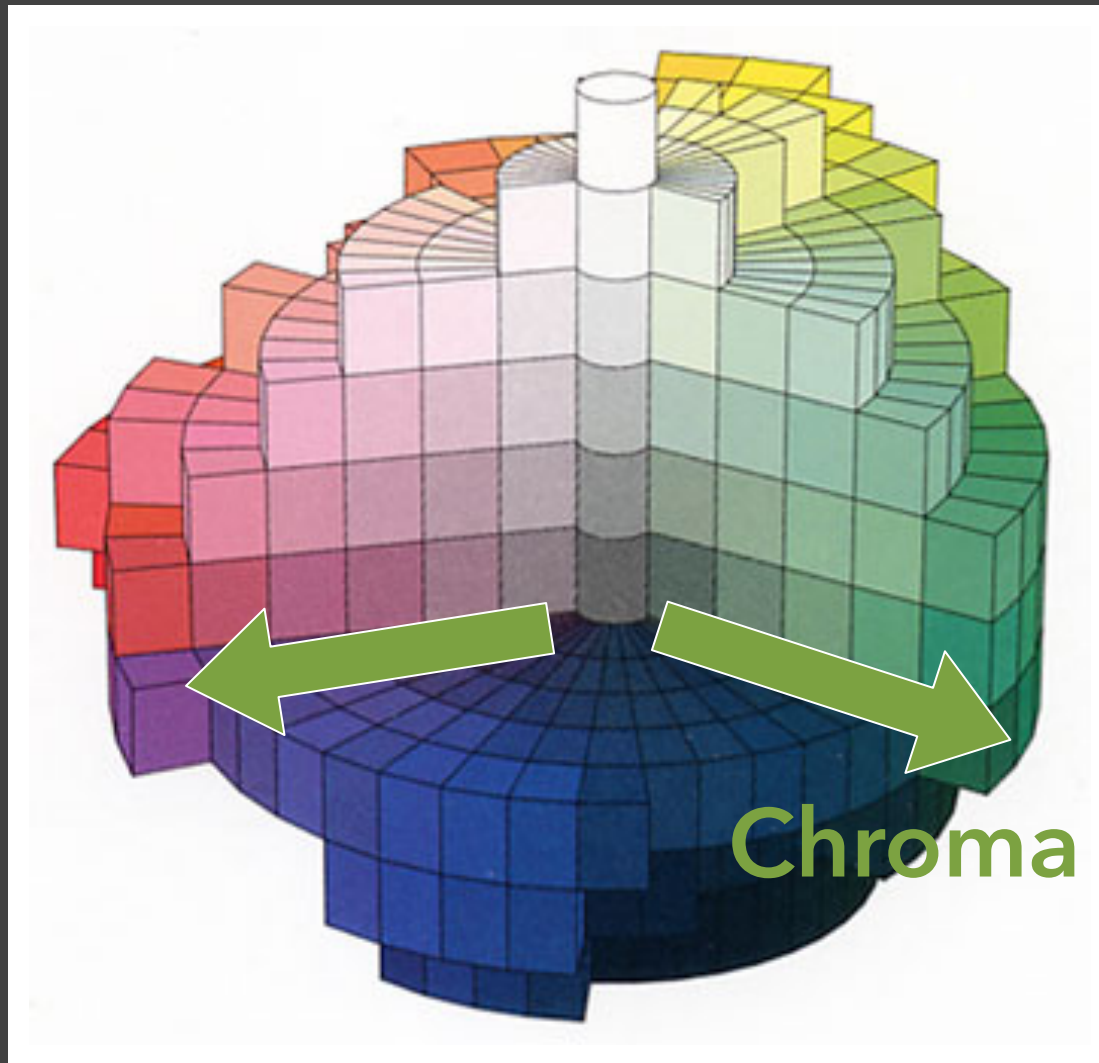
# Hue, Value and Chroma



# Hue, Value and Chroma

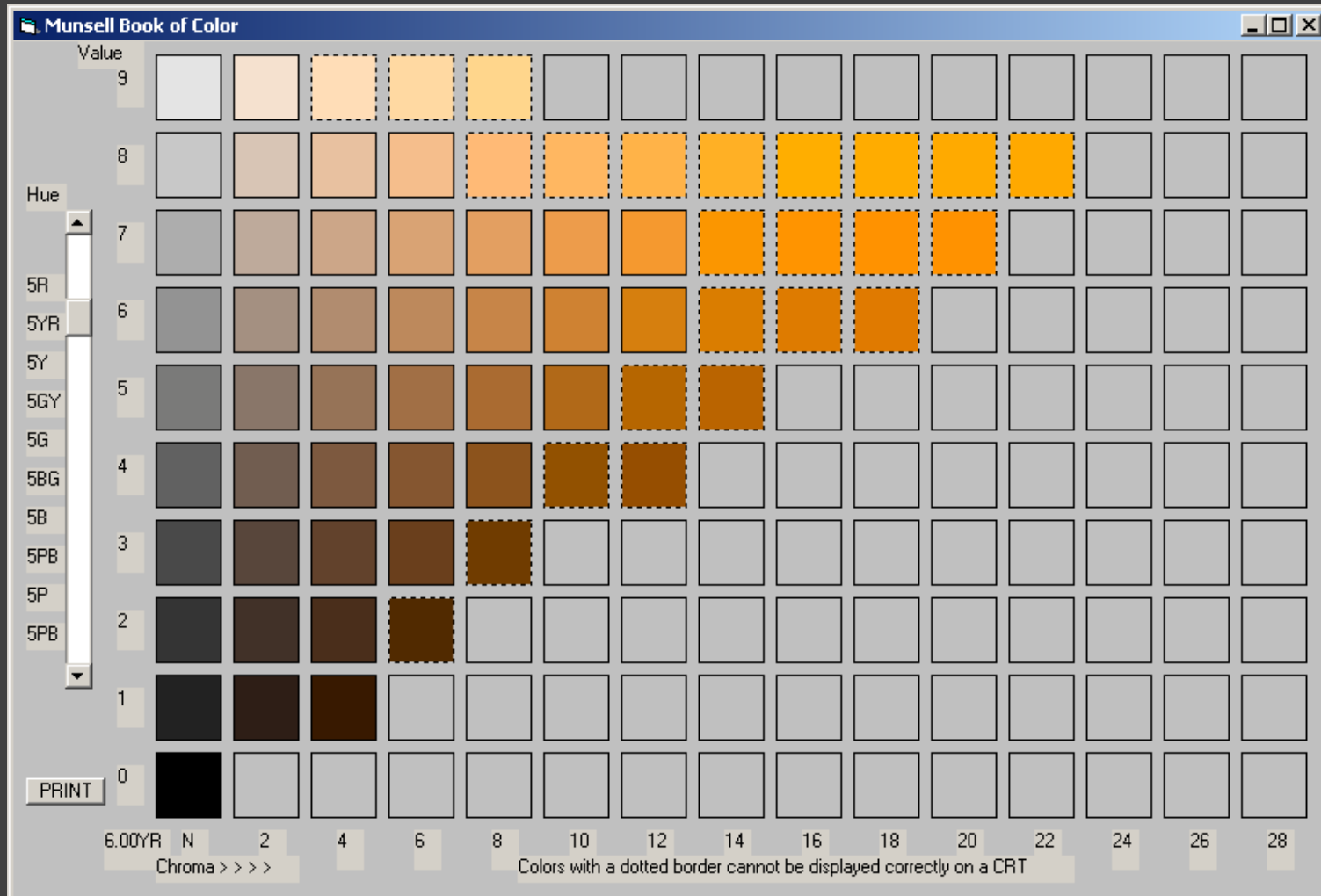


# Hue, Value and Chroma



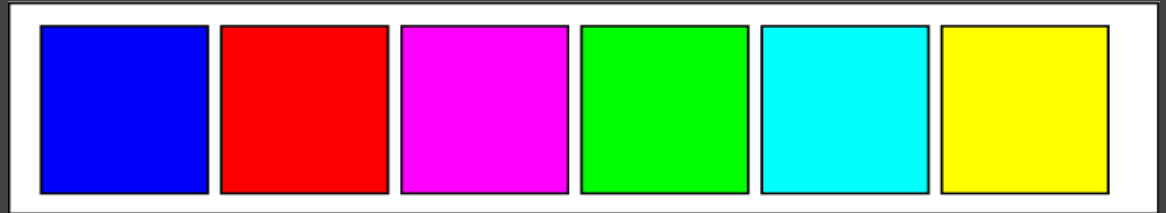


# Munsell Color System



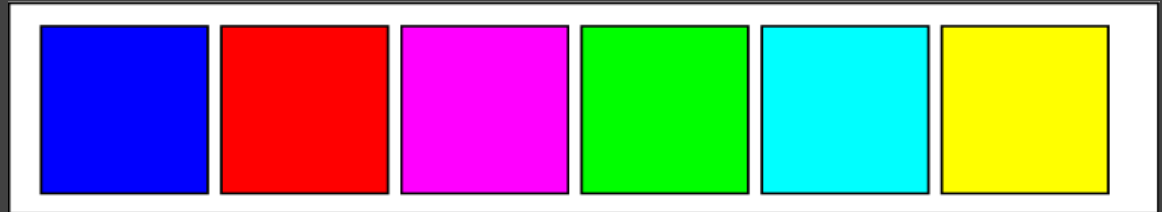
# Perceptual Brightness

Color palette



# Perceptual Brightness

Color palette



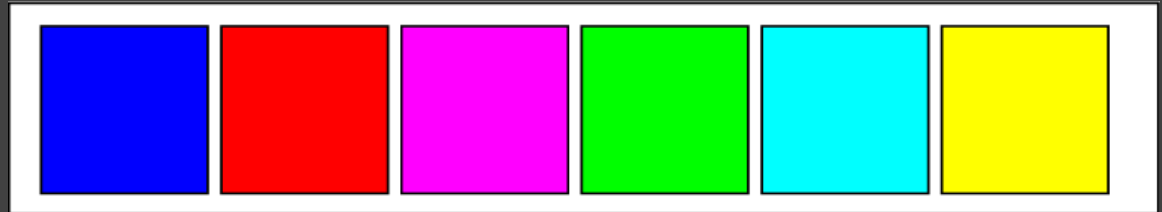
HSL Lightness  
*(Photoshop)*





# Perceptual Brightness

Color palette

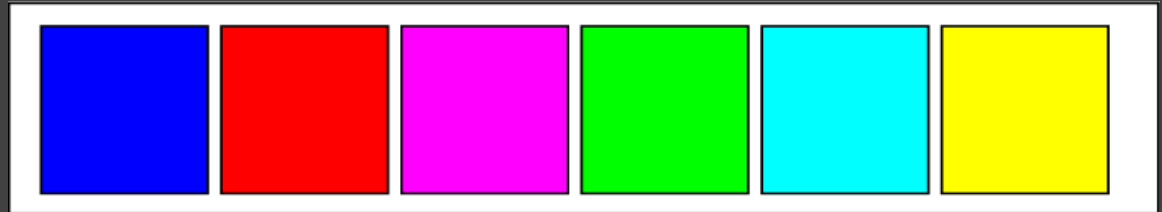


Luminance Y  
(CIE XYZ)



# Perceptual Brightness

Color palette

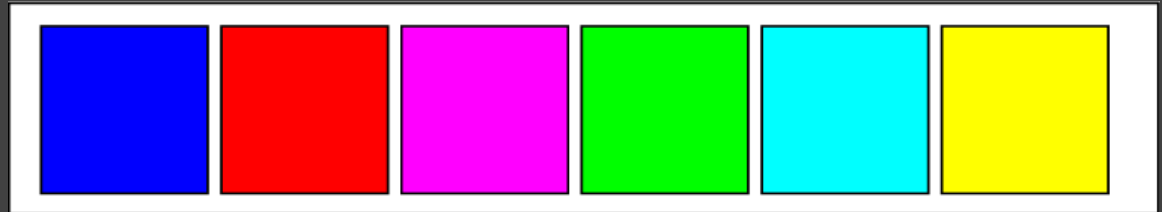


Munsell Value



# Perceptual Brightness

Color palette

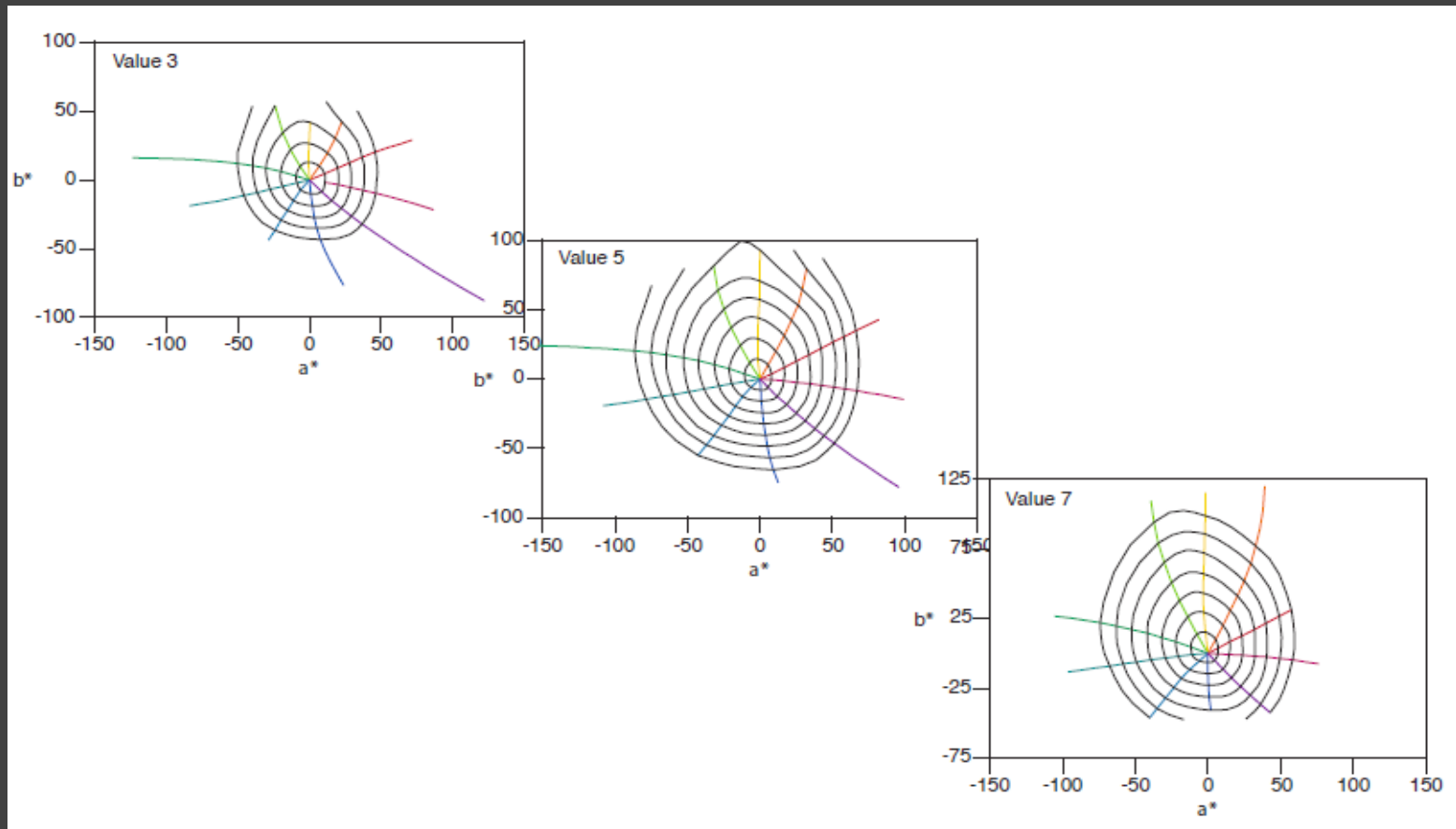


Munsell Value  
L\* (CIE LAB)



# Perceptually-Uniform Color Space

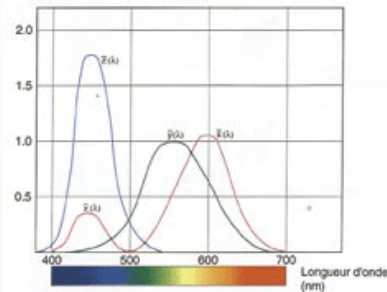
Munsell colors in CIE LAB coordinates



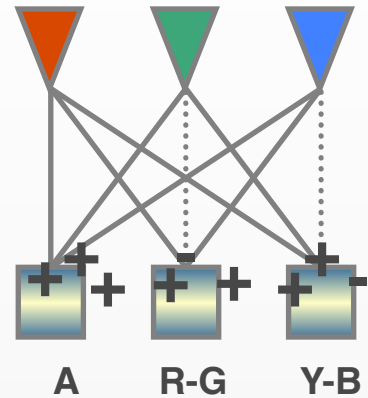
# Perception of Color



Light



Cone Response



Opponent Signals

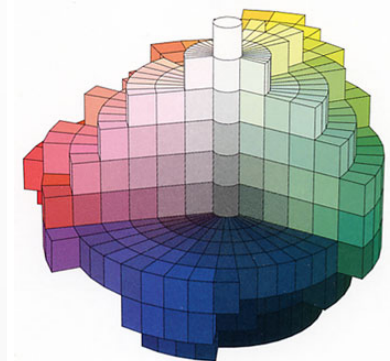
“Yellow”

Color Cognition



Mark D. Fairchild  
COLOR APPEARANCE  
MODELS

Color Appearance



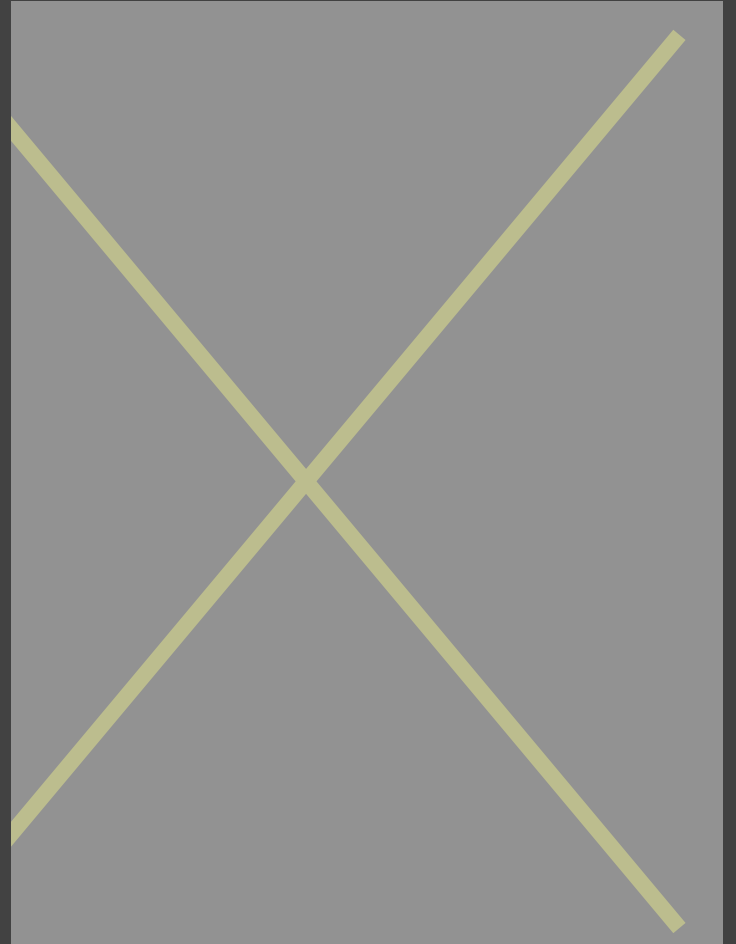
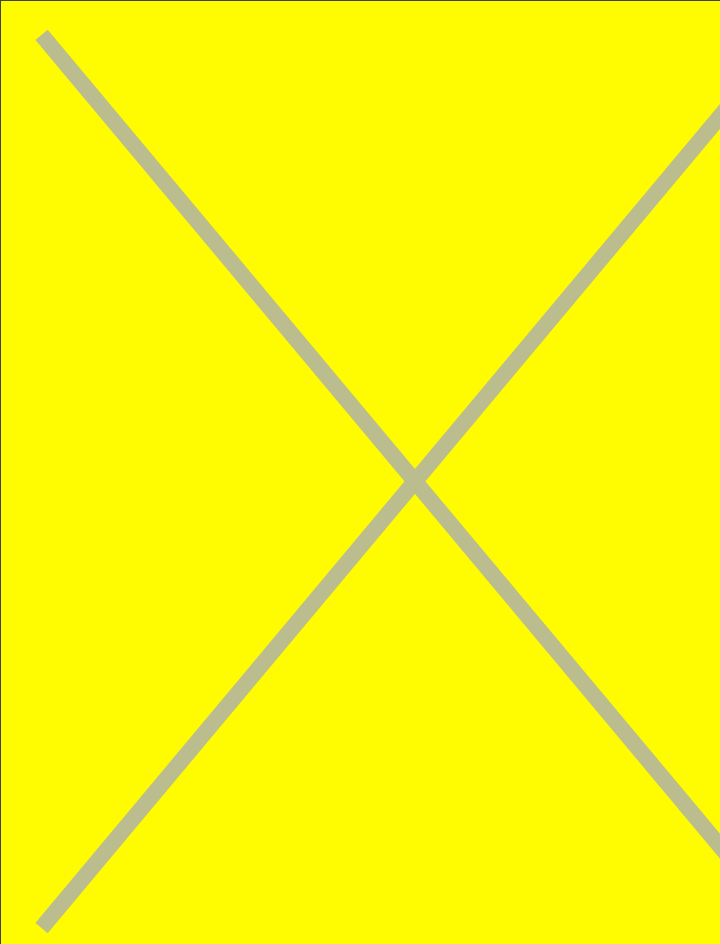
Color Perception

# Color Appearance

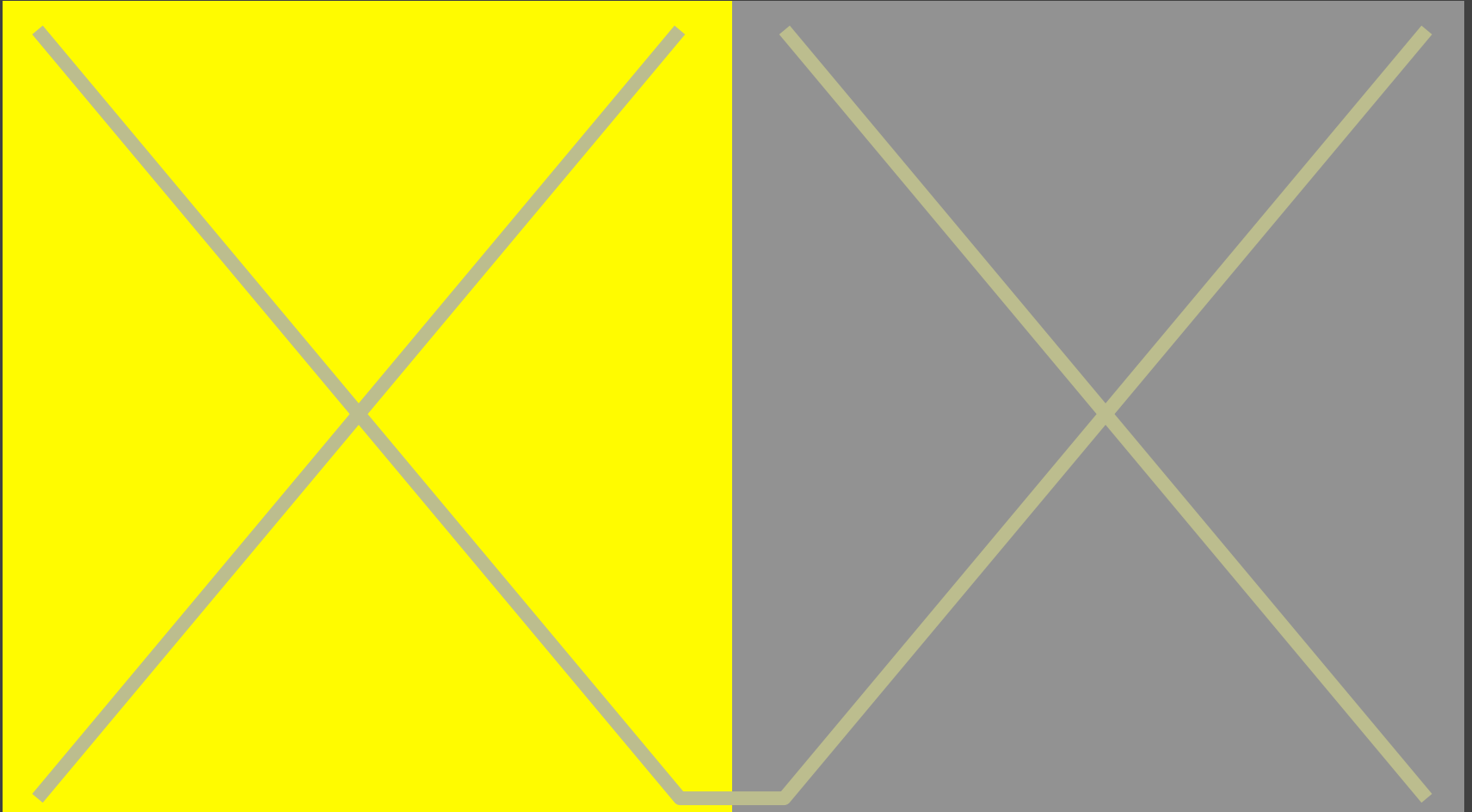
If we have a perceptually-uniform color space,  
can we predict how we perceive colors?

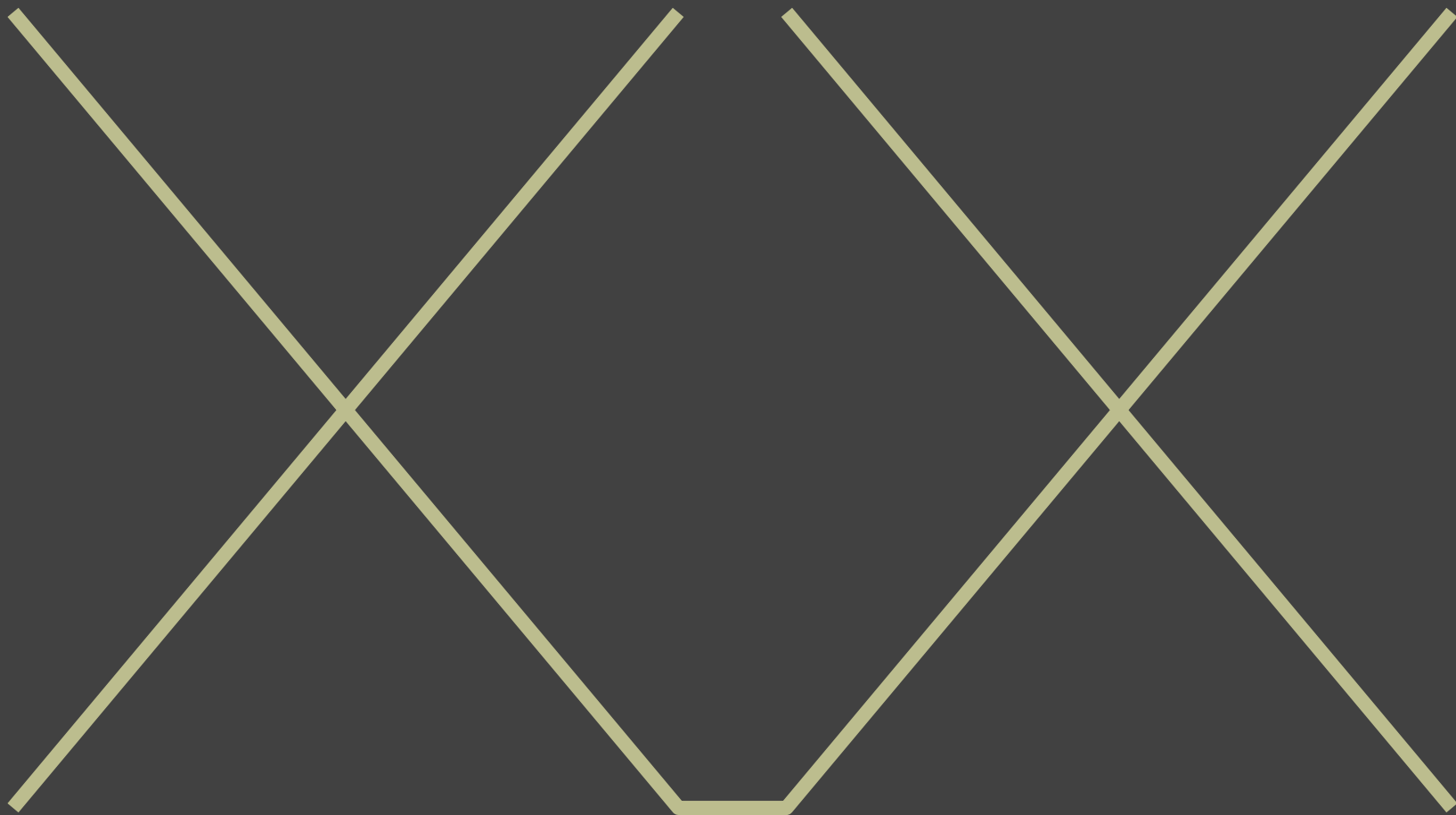
**“In order to use color effectively it is necessary to recognize that it deceives continually.”**

- Josef Albers, *Interaction of Color*

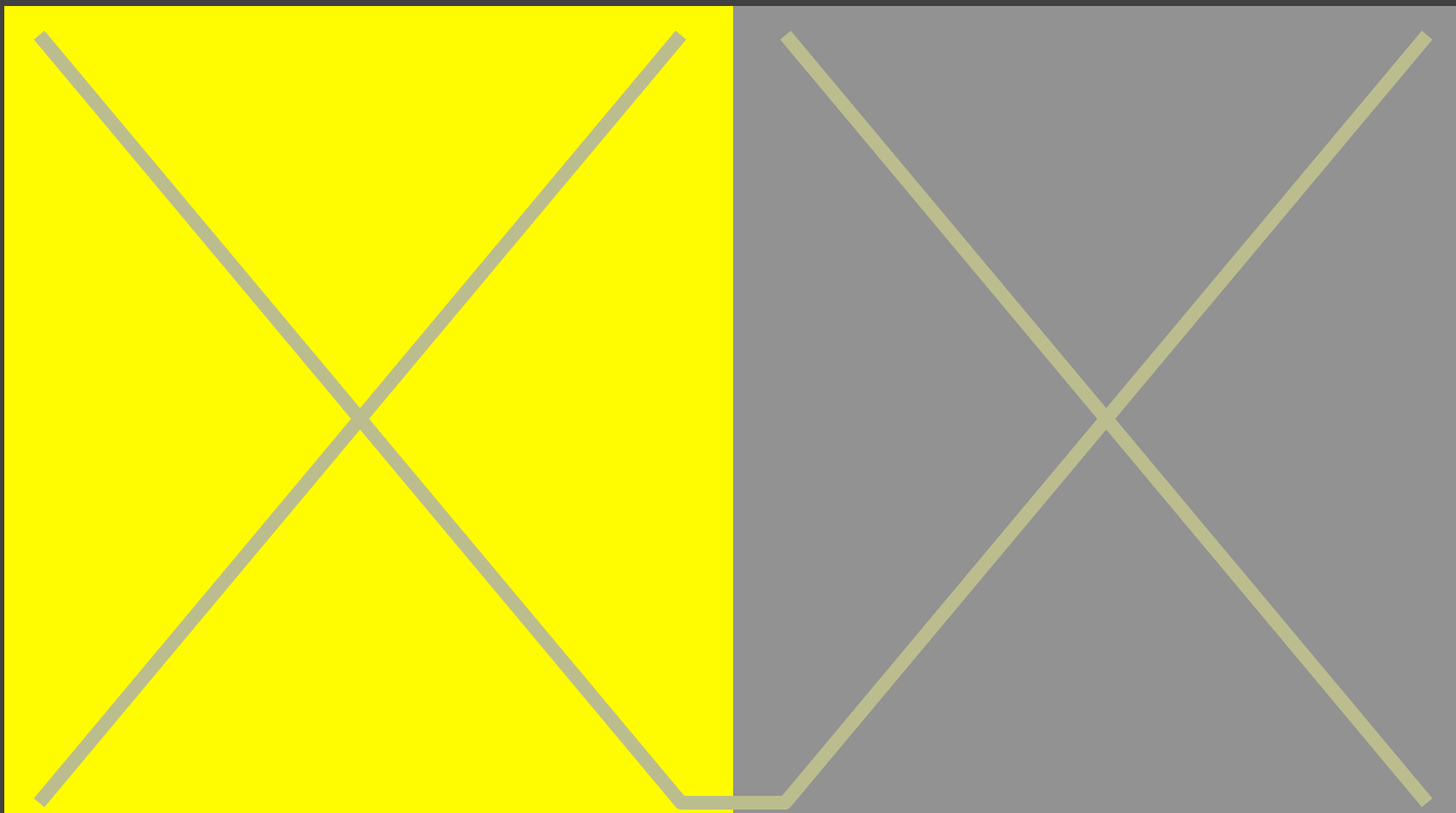








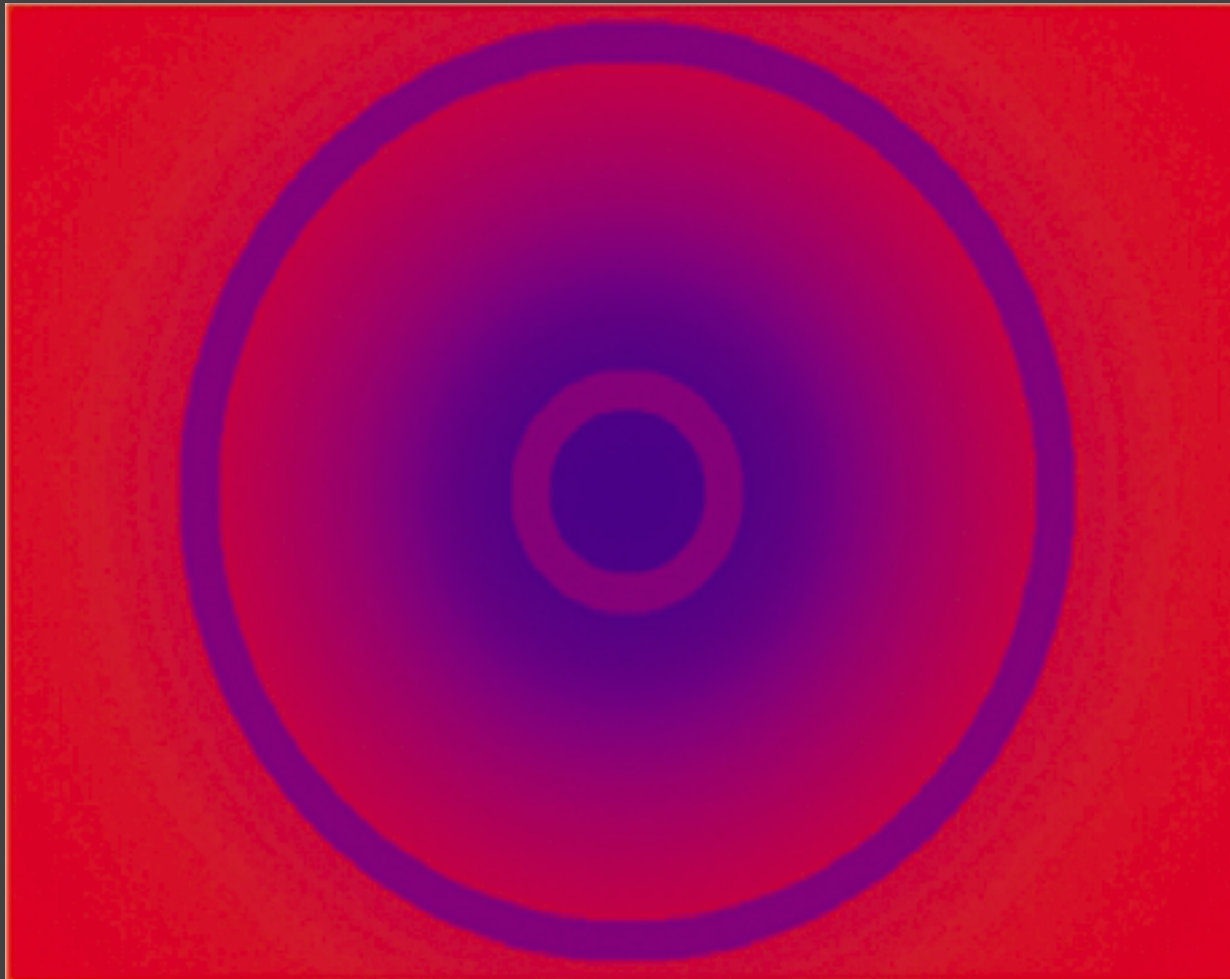
# Simultaneous Contrast



Josef Albers

# Simultaneous Contrast

Inner & outer rings are the same physical purple.



Donald  
MacLeod

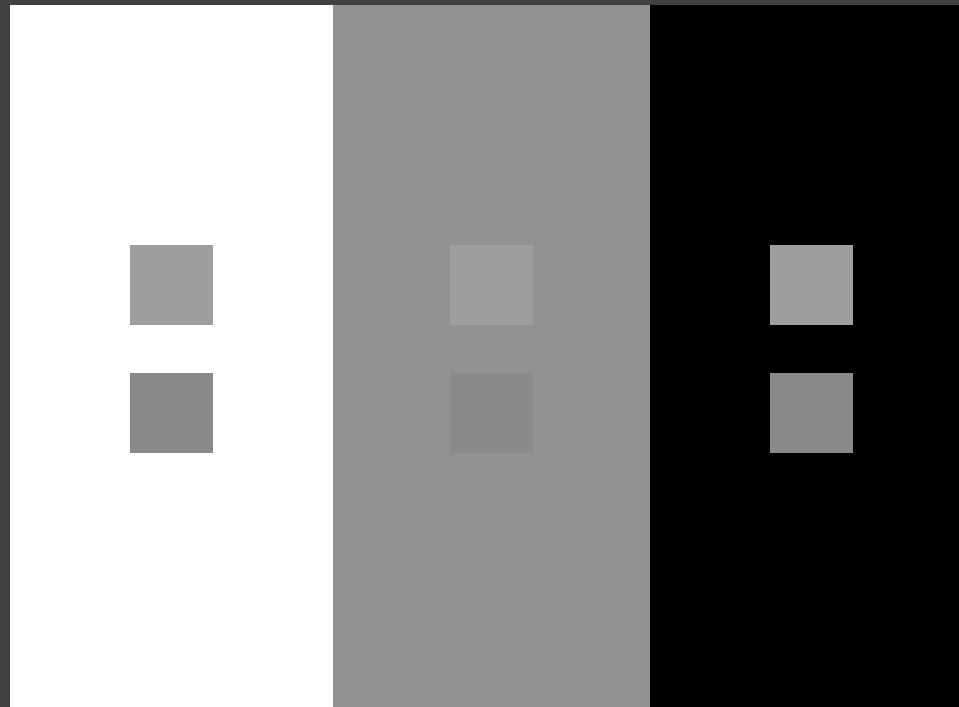
# Bezold Effect

Color appearance depends on adjacent colors



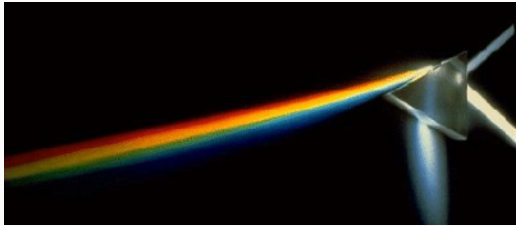
# Crispening

Perceived difference depends on background

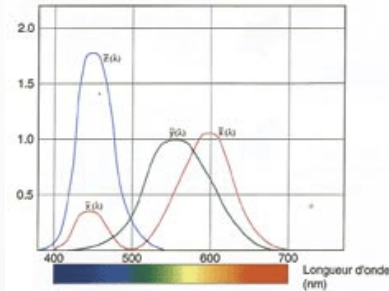


*Color Appearance Models, Fairchild*

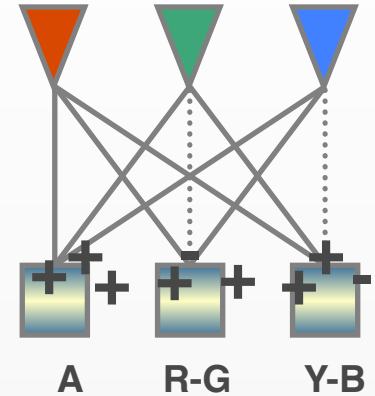
# Perception of Color



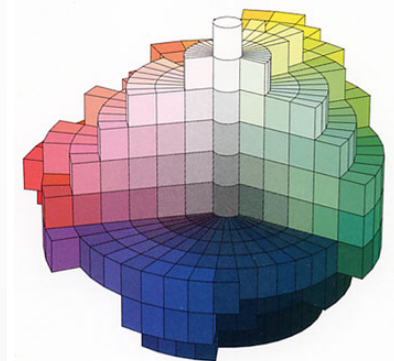
Light



Cone Response



Opponent Signals



Color Perception

**“Yellow”**

Color Cognition

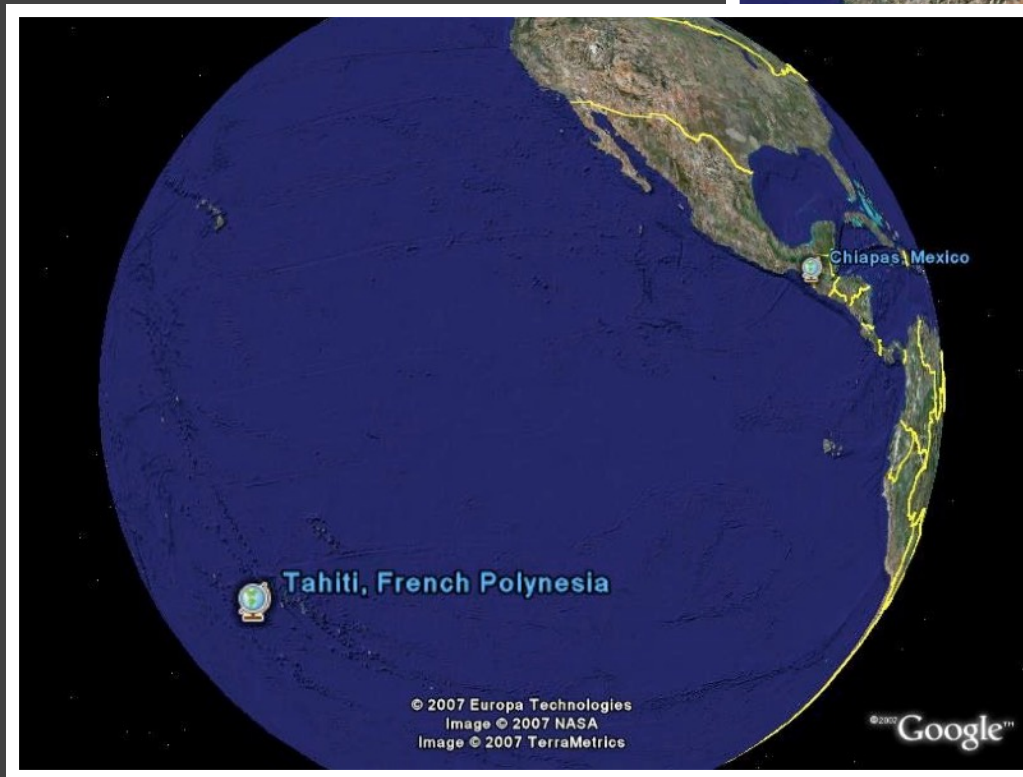


Mark D. Fairchild  
**COLOR APPEARANCE  
MODELS**

Color Appearance

# Basic Color Terms

Chance discovery by Brent Berlin and Paul Kay.





# Basic Color Terms

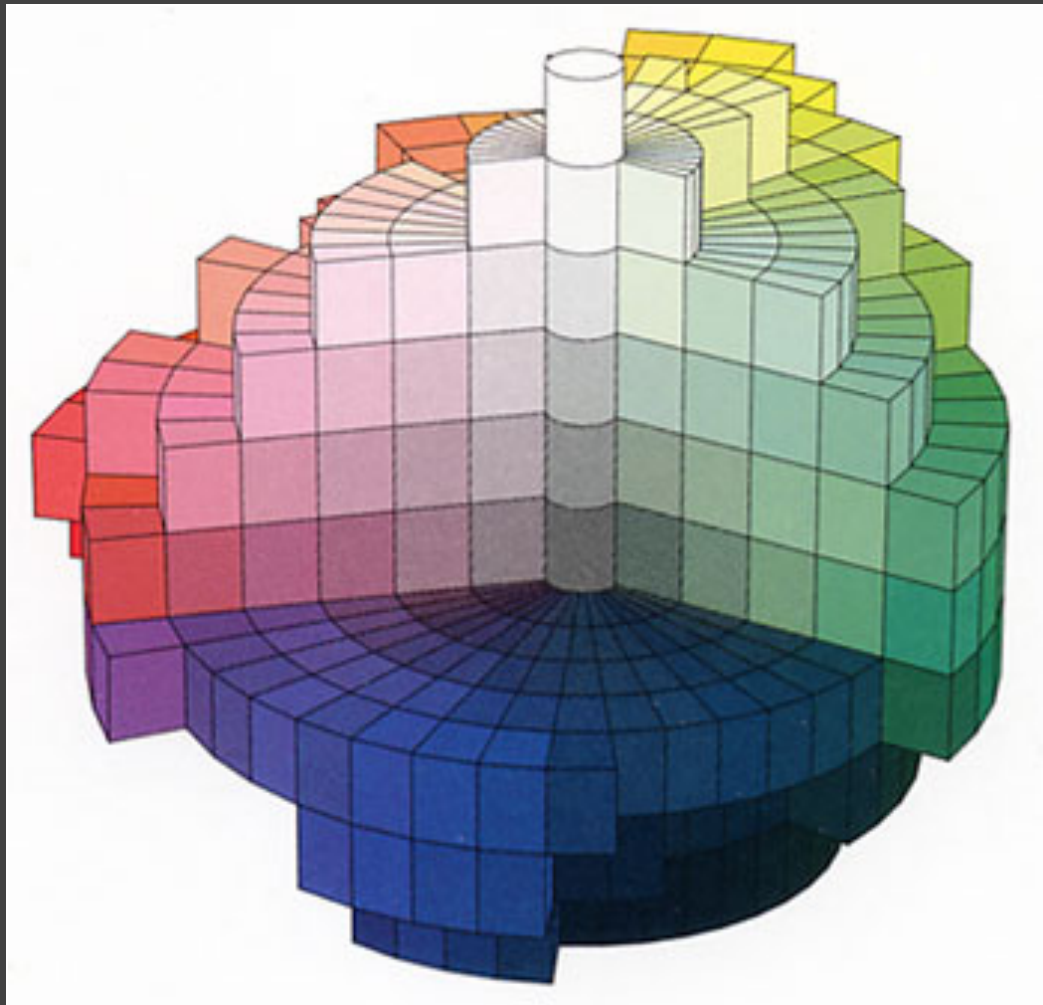
Chance discovery by Brent Berlin and Paul Kay.

Initial study in 1969

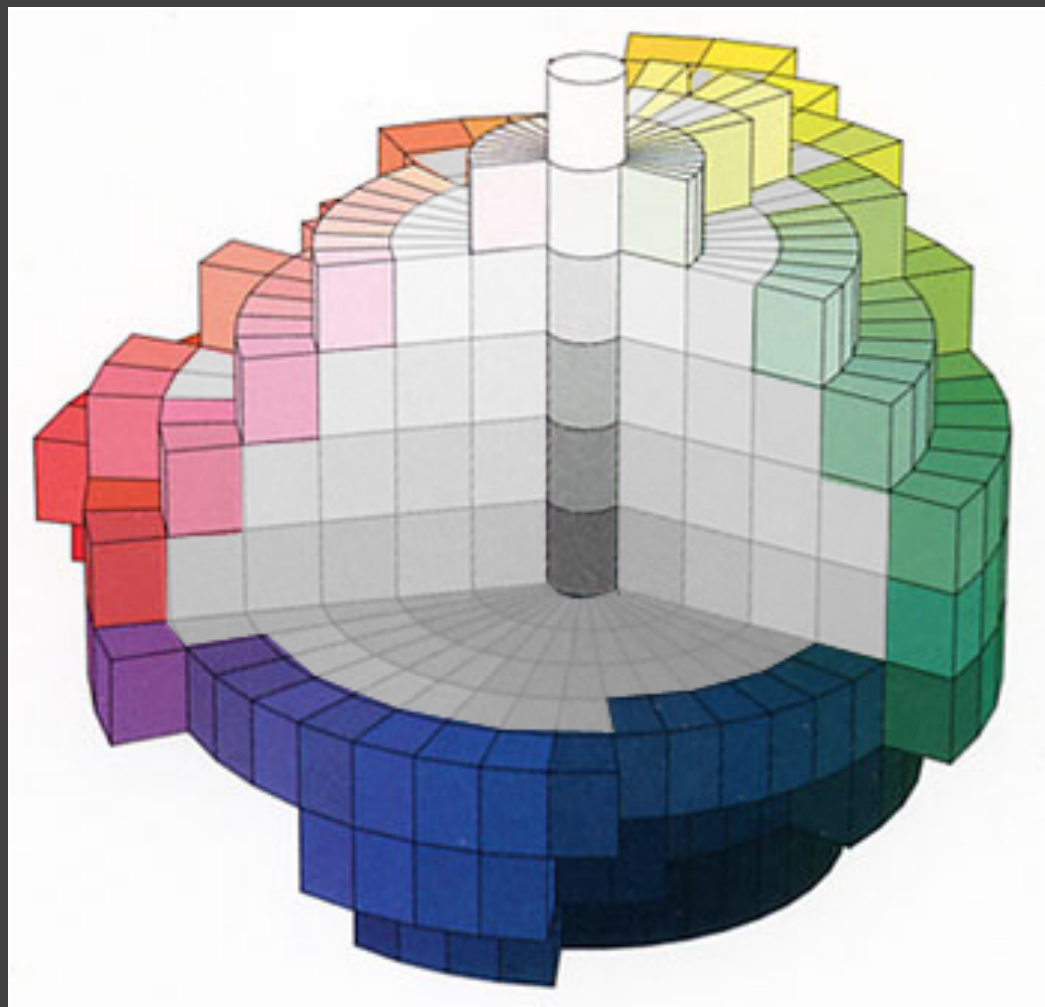
Surveyed speakers from 20 languages

Literature from 69 languages

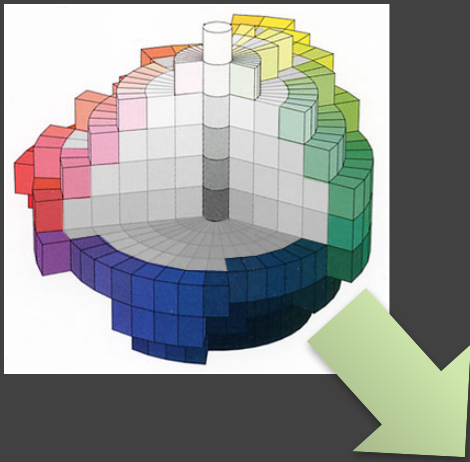
# World Color Survey



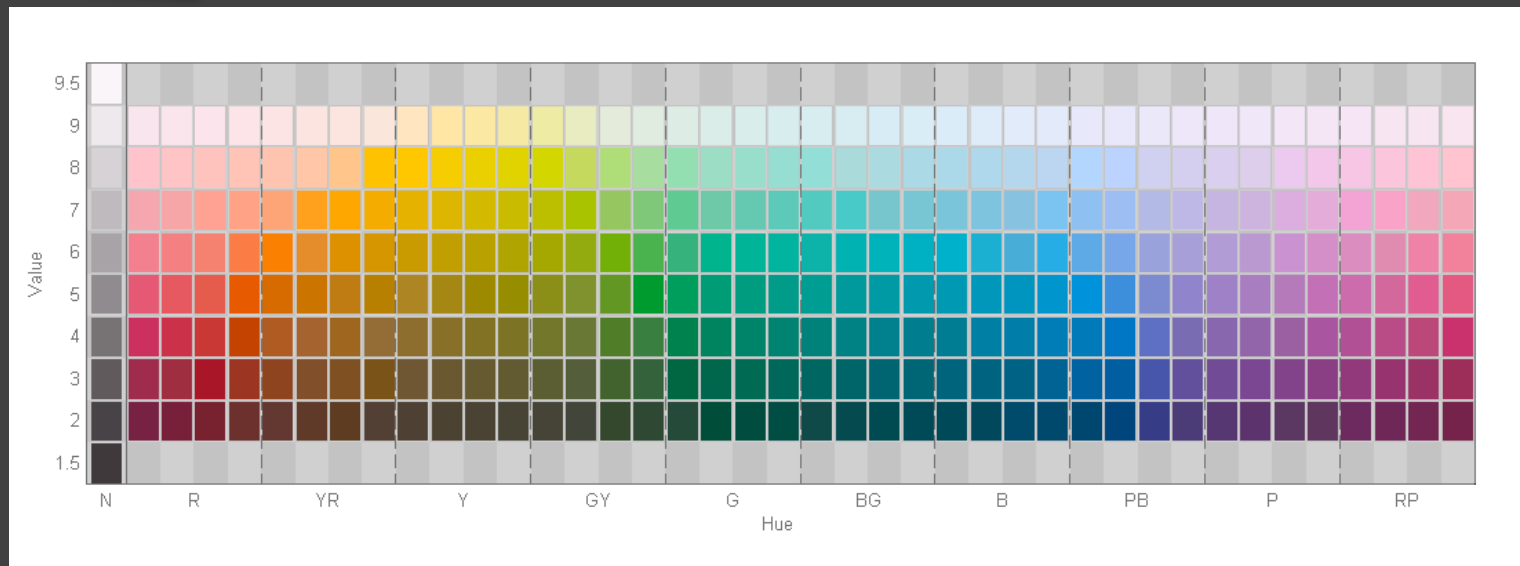
# World Color Survey



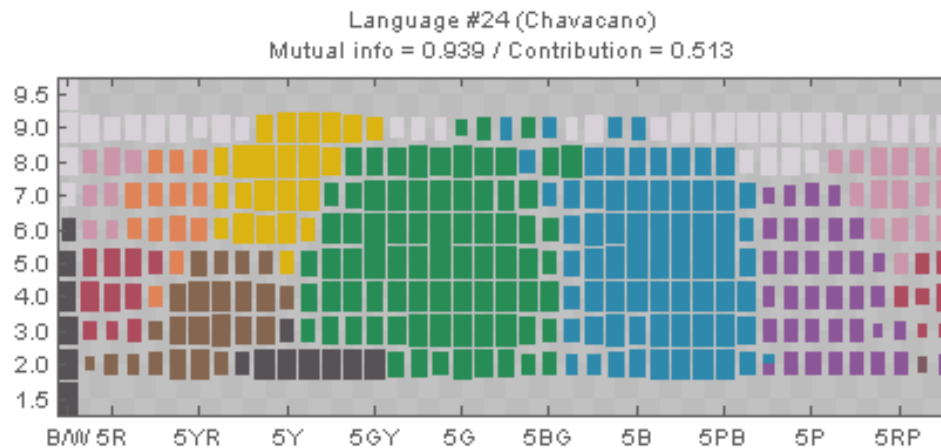
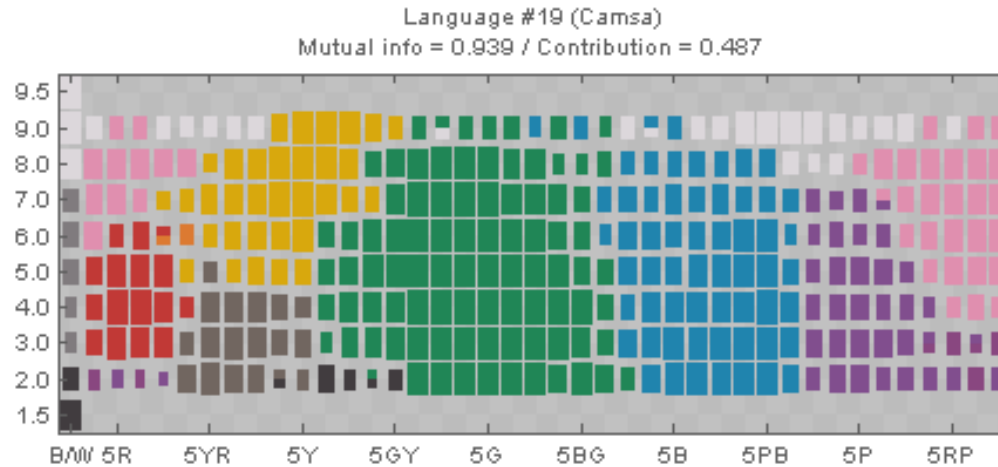
# World Color Survey



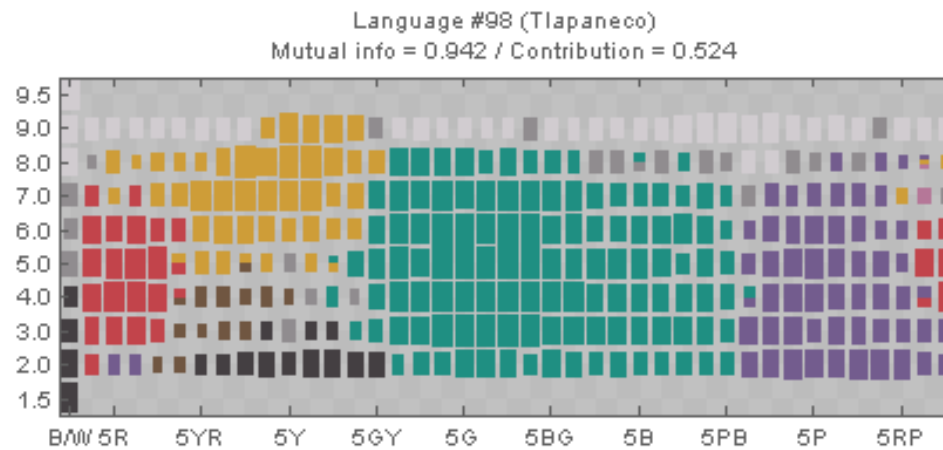
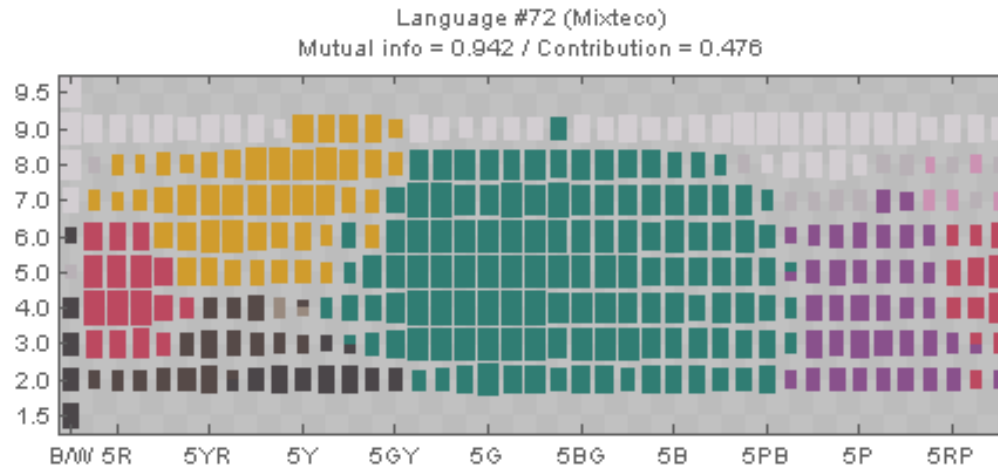
Naming information from 2,616 speakers from 110 languages on 330 Munsell color chips



# Results from WCS



# Results from WCS



# Universal (?) Basic Color Terms

Basic color terms recur across languages.



White



Red



Pink



Grey



Yellow



Brown



Black



Green



Orange



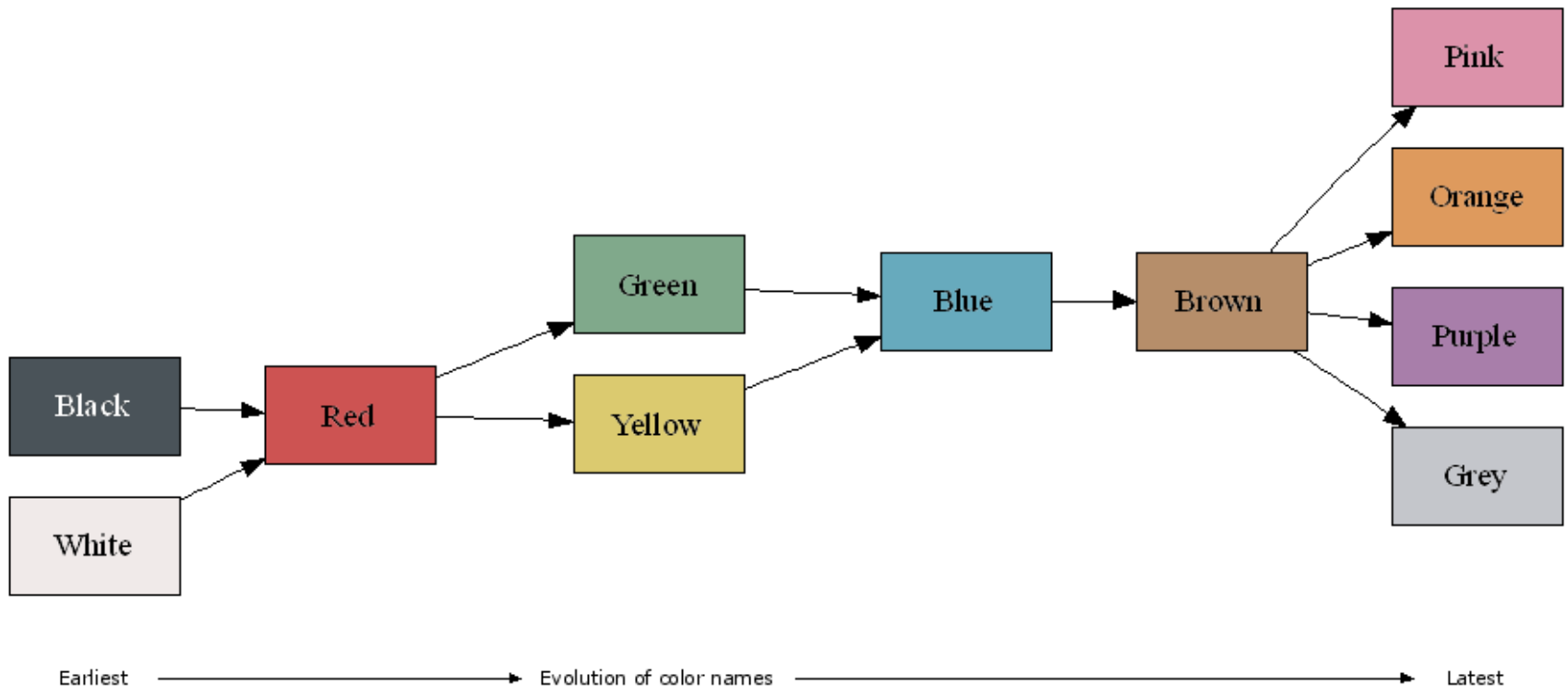
Blue



Purple

# Evolution of Basic Color Terms

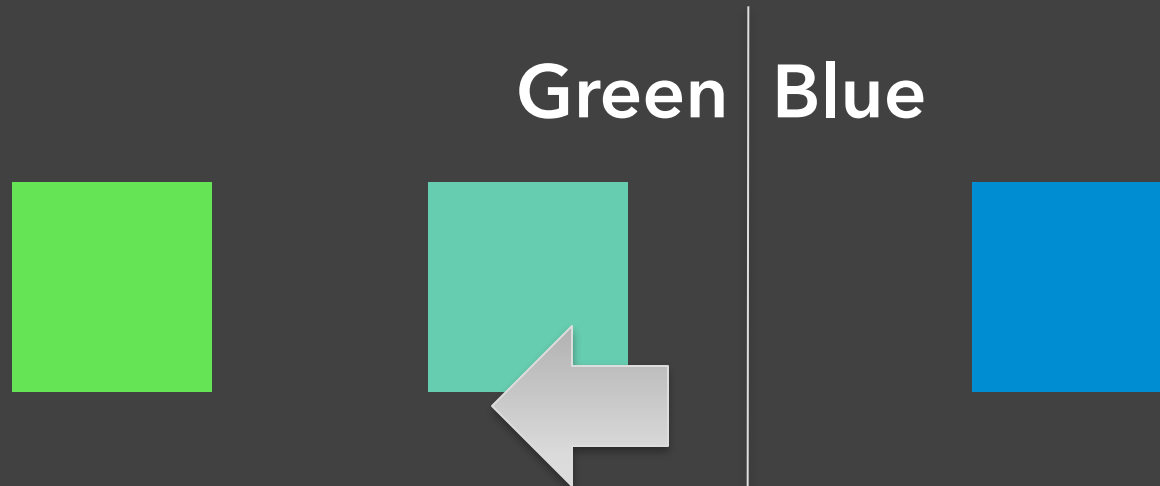
Proposed term evolution across languages.





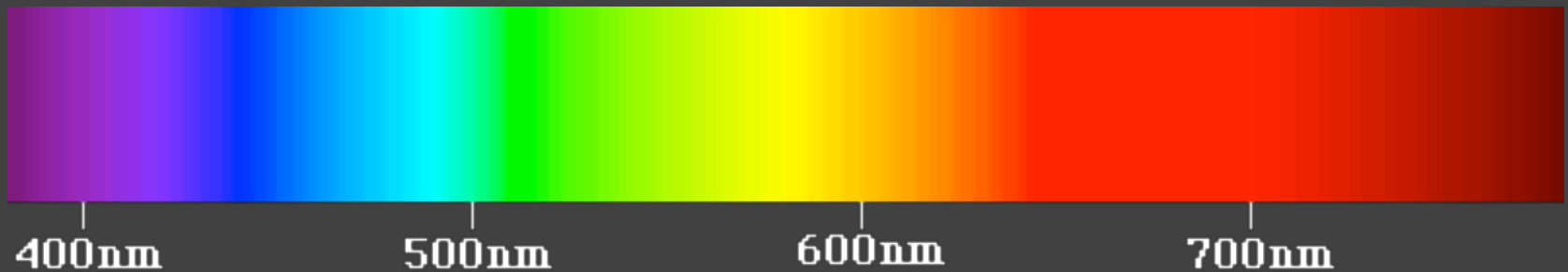
# Naming Effects Color Perception

Color name boundaries



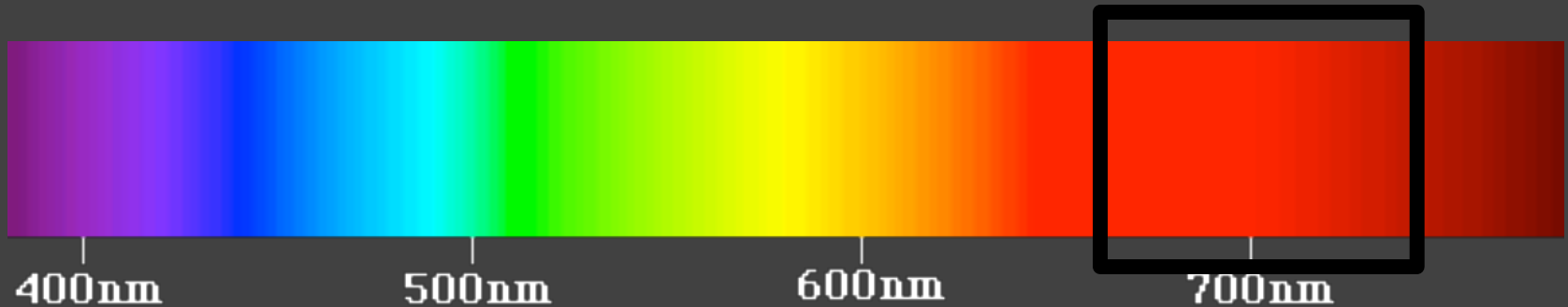
# Rainbow Color Map

We associate and group colors together, often using the name we assign to the colors.



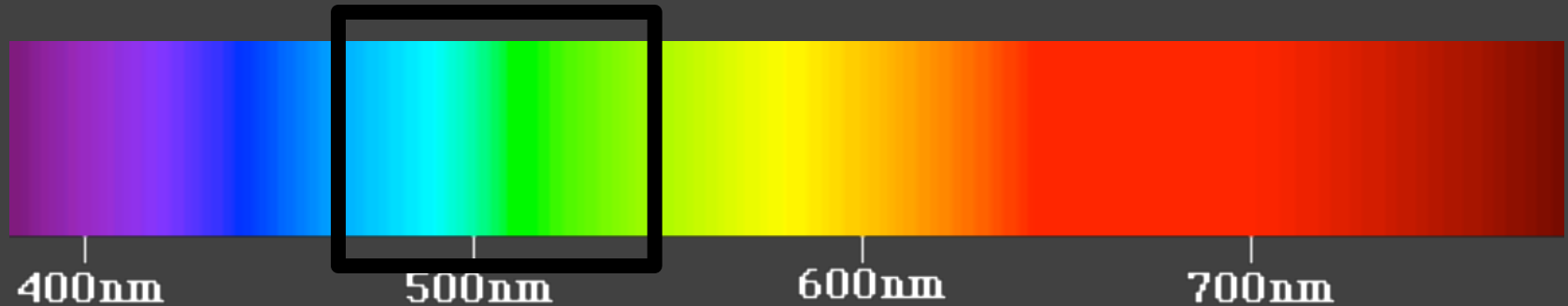
# Rainbow Color Map

We associate and group colors together, often using the name we assign to the colors.

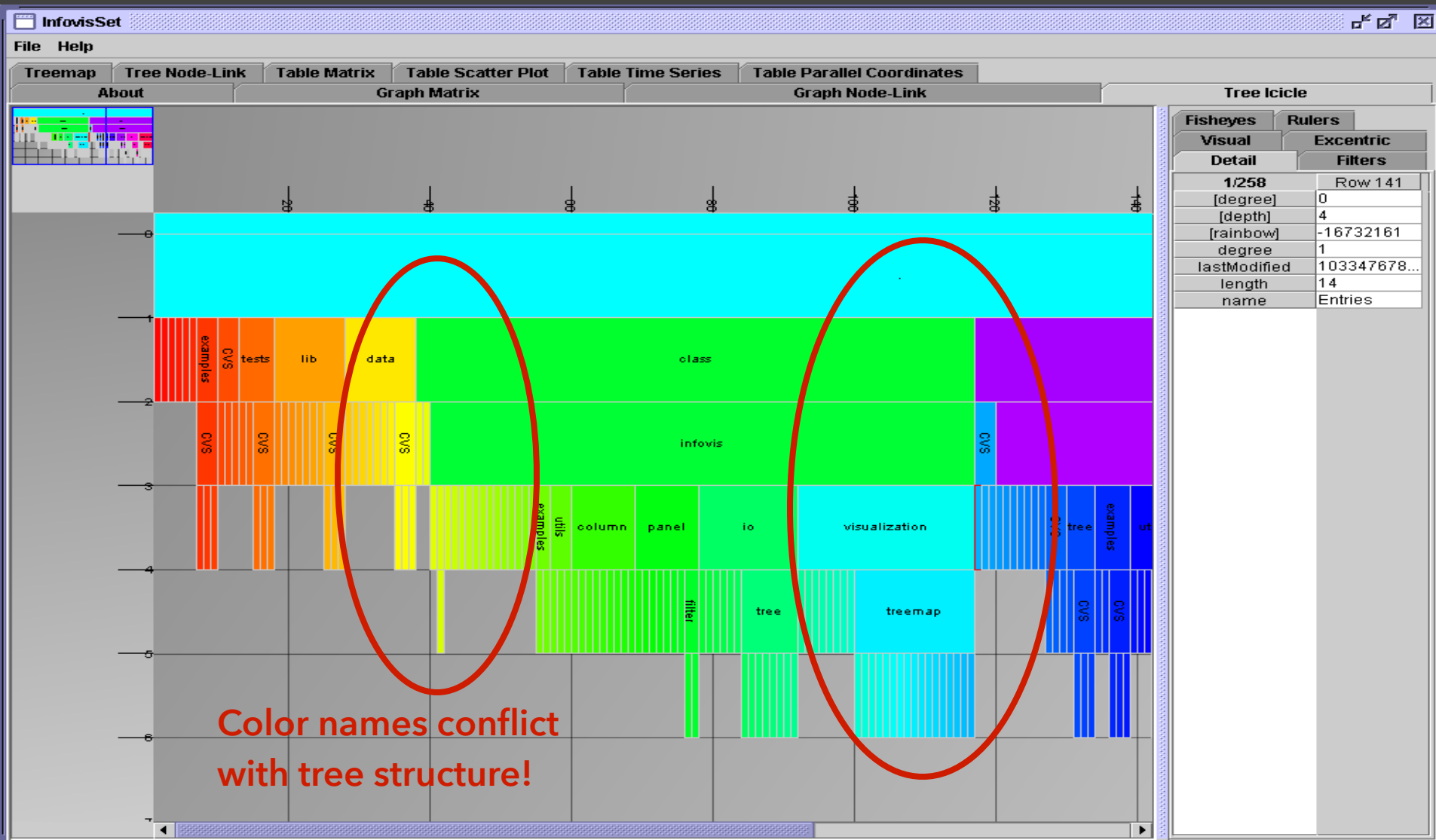


# Rainbow Color Map

We associate and group colors together, often using the name we assign to the colors.



# Icicle Tree with Rainbow Coloring



| Tree Icicle  |              |
|--------------|--------------|
| Fisheyes     | Rulers       |
| Visual       | Excentric    |
| Detail       | Filters      |
| 1/258        | Row 141      |
| [degree]     | 0            |
| [depth]      | 4            |
| [rainbow]    | -16732161    |
| degree       | 1            |
| lastModified | 103347678... |
| length       | 14           |
| name         | Entries      |

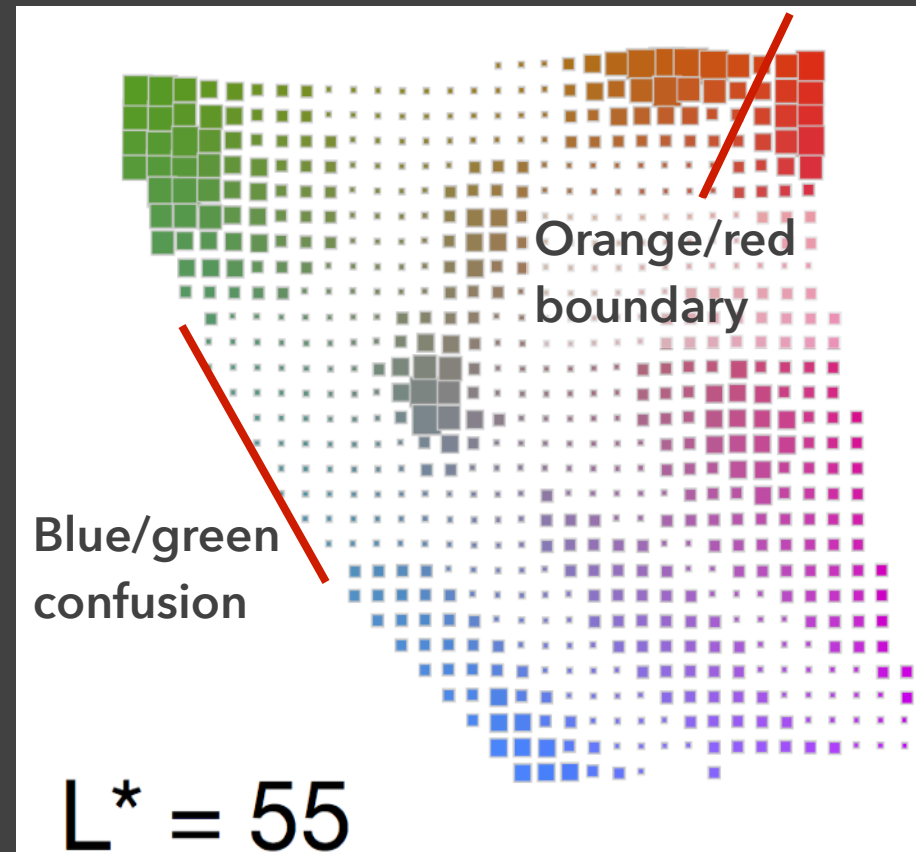
# Color Naming Models [Heer & Stone '12]

Model 3 million responses from XKCD survey

Bins in LAB space  
sized by *saliency*:

How much do people  
agree on color name?

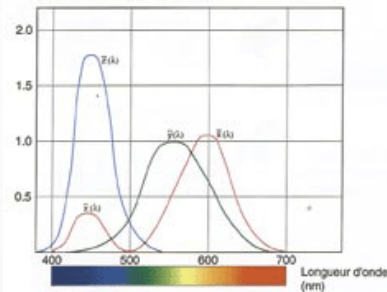
Modeled by entropy  
of  $p(\text{name} \mid \text{color})$



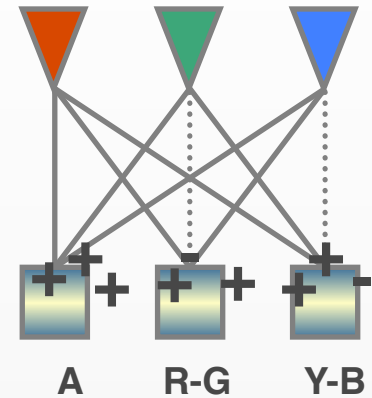
# Perception of Color



Light



Cone Response



Opponent Signals

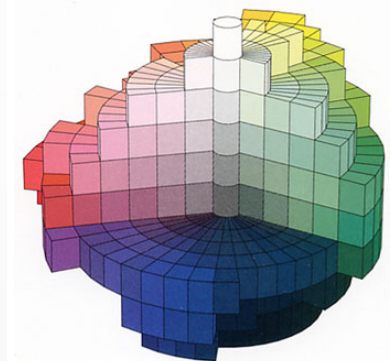
**“Yellow”**

Color Cognition



Mark D. Fairchild  
**COLOR APPEARANCE  
MODELS**

Color Appearance



Color Perception

# Designing Colormaps



# Colormap Design Considerations

Perceptually distinguishable colors

Value distance matches perceptual distance

Colors and concepts properly align

Aesthetically pleasing, intriguing

Respect color vision deficiencies

Should survive printing to black & white

Don't overwhelm people's capability!

# Discrete (Binary, Categorical)

## Symbol Legend



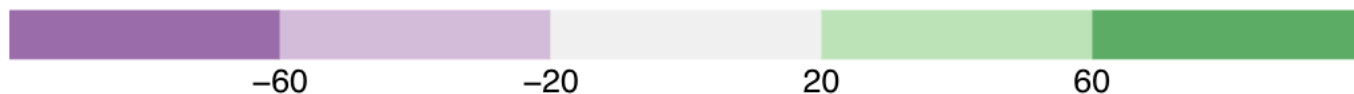
# Continuous (Sequential, Diverging, Cyclic)

## Gradient Legend



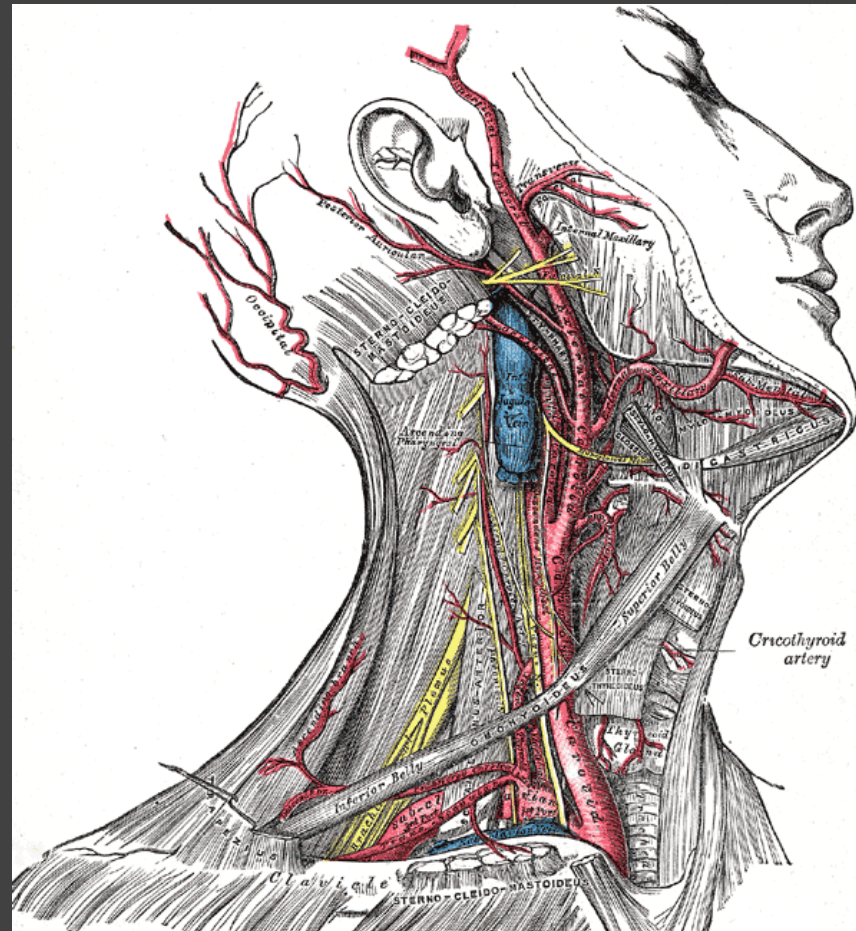
# Discretized Continuous

## Discrete Gradient



# Categorical Color

# Gray's Anatomy



Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries. (<http://www.bartleby.com/107/illus520.html>)

# Allocation of the Radio Spectrum

## UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

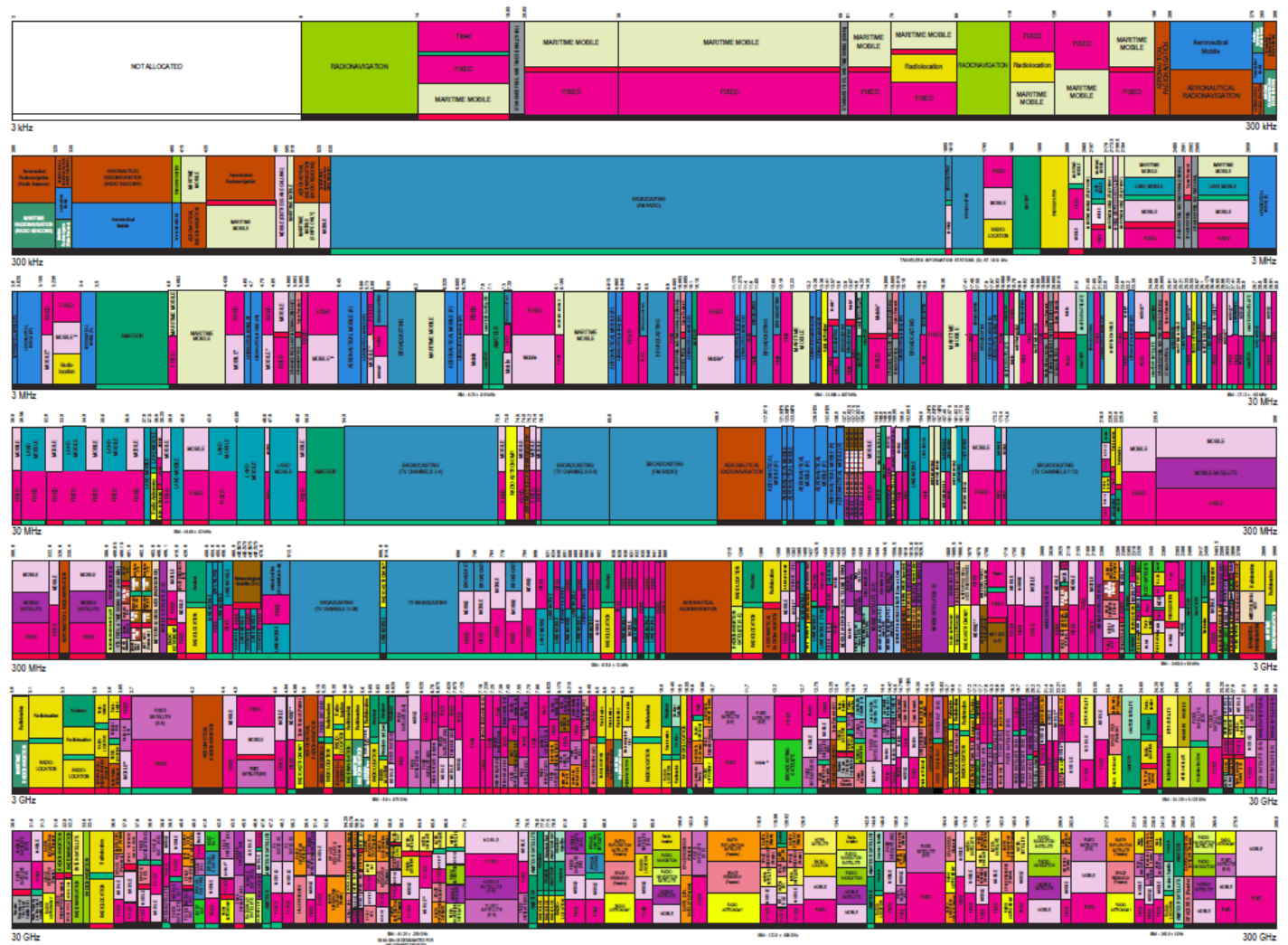
### RADIO SERVICES COLOR LEGEND

- |                               |                           |  |
|-------------------------------|---------------------------|--|
| AERONAUTICAL MOBILE           | HYPER-SATELLITE           | RADIO ASTRONOMY                              |
| AERONAUTICAL MOBILE SATELLITE | LAND MOBILE               | RADIO DETERMINATION SATELLITE                |
| AERONAUTICAL RADIO NAVIGATION | LAND MOBILE SATELLITE     | RADIO LOCATION                               |
| AMATEUR                       | MARITIME MOBILE           | RADIO LOCATION SATELLITE                     |
| AMATEUR SATELLITE             | MARITIME MOBILE SATELLITE | RADIO NAVIGATION                             |
| BROADCASTING                  | MARITIME RADIO NAVIGATION | RADIO NAVIGATION SATELLITE                   |
| BROADCASTING SATELLITE        | METEOROLOGICAL AID        | SPACE OPERATION                              |
| EARTH DEPLOYMENT SATELLITE    | METEOROLOGICAL SATELLITE  | SPACE RESEARCH                               |
| FIXED                         | MOBILE                    | STANDARD FREQUENCY AND TIME SIGNAL           |
| FIXED SATELLITE               | MOBILE SATELLITE          | STANDARD FREQUENCY AND TIME SIGNAL SATELLITE |

- ### ACTIVITY CODE
- |                          |                                  |
|--------------------------|----------------------------------|
| GOVERNMENT EXCLUSIVE     | GOVERNMENT/NON-GOVERNMENT SHARED |
| NON-GOVERNMENT EXCLUSIVE |                                  |

### ALLOCATION USE DESIGNATION


| SERVICE   | EXAMPLE | DESCRIPTION     |
|-----------|---------|-----------------|
| Primary   | F1E2    | Capital Letters |
| Secondary | F1E2    | Capital Letters |



# Alloc

# UNITED STATES FREQUENCY ALLOCATION THE RADIO SPECTRUM

## RADIO SERVICES COLOR LEGEND

|   |   |  |
|---|---|--|
|  AERONAUTICAL MOBILE           |  INTER-SATELLITE           |  RADIO ASTRONOMY                                |
|  AERONAUTICAL MOBILE SATELLITE |  LAND MOBILE               |  RADIODETERMINATION SATELLITE                   |
|  AERONAUTICAL RADIONAVIGATION  |  LAND MOBILE SATELLITE     |  RADIOLOCATION                                  |
|  AMATEUR                       |  MARITIME MOBILE           |  RADIOLOCATION SATELLITE                        |
|  AMATEUR SATELLITE             |  MARITIME MOBILE SATELLITE |  RADIONAVIGATION                                |
|  BROADCASTING                  |  MARITIME RADIONAVIGATION  |  RADIONAVIGATION SATELLITE                      |
|  BROADCASTING SATELLITE        |  METEOROLOGICAL AIDS       |  SPACE OPERATION                                |
|  EARTH EXPLORATION SATELLITE  |  METEOROLOGICAL SATELLITE |  SPACE RESEARCH                                |
|  FIXED                       |  MOBILE                  |  STANDARD FREQUENCY AND TIME SIGNAL           |
|  FIXED SATELLITE             |  MOBILE SATELLITE        |  STANDARD FREQUENCY AND TIME SIGNAL SATELLITE |

## ACTIVITY CODE

### RADIO SERVICES COLOR LEGEND

|  |  |   |
|--|--|---|
| <input type="checkbox"/> AERONAUTICAL MOBILE           | <input type="checkbox"/> INTER-SATELLITE           | <input type="checkbox"/> RADIO ASTRONOMY                              |
| <input type="checkbox"/> AERONAUTICAL MOBILE SATELLITE | <input type="checkbox"/> LAND MOBILE               | <input type="checkbox"/> RADIODETERMINATION SATELLITE                 |
| <input type="checkbox"/> AERONAUTICAL RADIONAVIGATION  | <input type="checkbox"/> LAND MOBILE SATELLITE     | <input type="checkbox"/> RADIOLOCATION                                |
| <input type="checkbox"/> AMATEUR                       | <input type="checkbox"/> MARITIME MOBILE           | <input type="checkbox"/> RADIOLOCATION SATELLITE                      |
| <input type="checkbox"/> AMATEUR SATELLITE             | <input type="checkbox"/> MARITIME MOBILE SATELLITE | <input type="checkbox"/> RADIONAVIGATION                              |
| <input type="checkbox"/> BROADCASTING                  | <input type="checkbox"/> MARITIME RADIONAVIGATION  | <input type="checkbox"/> RADIONAVIGATION SATELLITE                    |
| <input type="checkbox"/> BROADCASTING SATELLITE        | <input type="checkbox"/> METEOROLOGICAL AIDS       | <input type="checkbox"/> SPACE OPERATION                              |
| <input type="checkbox"/> EARTH EXPLORATION SATELLITE   | <input type="checkbox"/> METEOROLOGICAL SATELLITE  | <input type="checkbox"/> SPACE RESEARCH                               |
| <input type="checkbox"/> FIXED                         | <input type="checkbox"/> MOBILE                    | <input type="checkbox"/> STANDARD FREQUENCY AND TIME SIGNAL           |
| <input type="checkbox"/> FIXED SATELLITE               | <input type="checkbox"/> MOBILE SATELLITE          | <input type="checkbox"/> STANDARD FREQUENCY AND TIME SIGNAL SATELLITE |

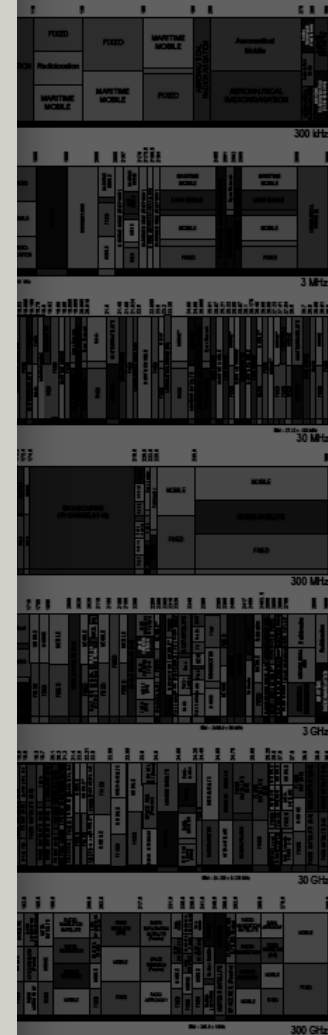
### ACTIVITY CODE

|   |   |
|---|---|
| <input type="checkbox"/> GOVERNMENT EXCLUSIVE     | <input type="checkbox"/> GOVERNMENT-GOVERNMENT SHARED |
| <input type="checkbox"/> NON-GOVERNMENT EXCLUSIVE |   |

### ALLOCATION USAGE DESIGNATION

| SERVICE   | EXAMPLE | DESCRIPTION     |
|-----------|---------|-----------------|
| Primary   | F2E2    | Coastal Station |
| Secondary | F2E2    | Coastal Station |

# rum



# Allocation of the Radio Spectrum

## UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

### RADIO SERVICES COLOR LEGEND

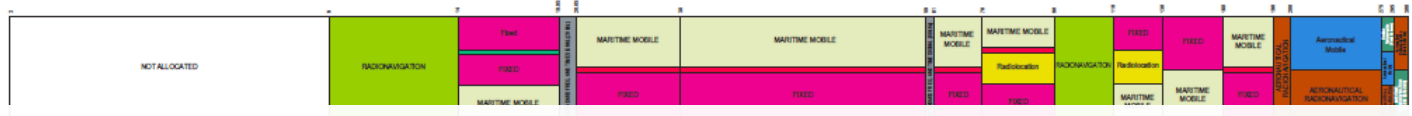
|                               |                           |  |
|-------------------------------|---------------------------|--|
| AERONAUTICAL MOBILE           | INTERSATELLITE            | RADIO ASTRONOMY                              |
| AERONAUTICAL MOBILE SATELLITE | LAND MOBILE               | RADIO DETERMINATION SATELLITE                |
| AERONAUTICAL RADIOLOCATION    | LAND MOBILE SATELLITE     | RADIO LOCATION                               |
| AMATEUR                       | MARITIME MOBILE           | RADIO LOCATION SATELLITE                     |
| AMATEUR SATELLITE             | MARITIME MOBILE SATELLITE | RADIO NAVIGATION                             |
| BROADCASTING                  | MARITIME RADIOLOCATION    | RADIO NAVIGATION SATELLITE                   |
| BROADCASTING SATELLITE        | METEOROLOGICAL AIDS       | SPACE OPERATION                              |
| EARTH EXPLORATION SATELLITE   | METEOROLOGICAL SATELLITE  | SPACE RESEARCH                               |
| FIXED                         | MOBILE                    | STANDARD FREQUENCY AND TIME SIGNAL           |
| FIXED SATELLITE               | MOBILE SATELLITE          | STANDARD FREQUENCY AND TIME SIGNAL SATELLITE |

### ACTIVITY CODE

|                          |                                  |
|--------------------------|----------------------------------|
| GOVERNMENT EXCLUSIVE     | GOVERNMENT/NON-GOVERNMENT SHARED |
| NON-GOVERNMENT EXCLUSIVE |                                  |

### ALLOCATION USAGE DESIGNATION

| SERVICE   | EXAMPLE | DESCRIPTION     |
|-----------|---------|-----------------|
| Primary   | FIXED   | Capital Letters |
| Secondary | Mobile  | Small Letters   |



## Issues:

Too many colors

Hard to remember mapping

Colors not distinctive, some are very similar

Poor grouping: similar colors, different values

Labels cause clutter

Color surround effects

Colors interactions may not look good together




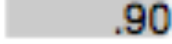
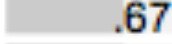





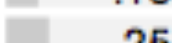

# Palette Design & Color Names

Minimize overlap and ambiguity of colors.

Color Name Distance

|             |             |             |             |             |             |             |             |             |             |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>0.00</b> | 1.00        | 1.00        | 1.00        | 0.98        | 1.00        | 1.00        | 1.00        | 1.00        | <b>0.20</b> |
| 1.00        | <b>0.00</b> | 1.00        | 0.97        | 1.00        | 1.00        | 1.00        | 1.00        | 0.96        | 1.00        |
| 1.00        | 1.00        | <b>0.00</b> | 1.00        | 1.00        | 1.00        | 1.00        | 1.00        | 0.90        | 0.99        |
| 1.00        | 0.97        | 1.00        | <b>0.00</b> | 1.00        | 0.95        | 0.99        | 1.00        | 1.00        | 1.00        |
| 0.98        | 1.00        | 1.00        | 1.00        | <b>0.00</b> | 0.96        | 0.91        | 0.97        | 1.00        | 0.99        |
| 1.00        | 1.00        | 1.00        | 0.95        | 0.96        | <b>0.00</b> | 0.97        | 0.93        | 0.98        | 1.00        |
| 1.00        | 1.00        | 1.00        | 0.99        | 0.91        | 0.97        | <b>0.00</b> | 1.00        | 1.00        | 1.00        |
| 1.00        | 1.00        | 1.00        | 1.00        | 0.97        | 0.93        | 1.00        | <b>0.00</b> | 1.00        | 1.00        |
| 1.00        | 0.96        | 0.90        | 1.00        | 1.00        | 0.98        | 1.00        | 1.00        | <b>0.00</b> | 1.00        |
| <b>0.20</b> | 1.00        | 0.99        | 1.00        | 0.99        | 1.00        | 1.00        | 1.00        | 1.00        | <b>0.00</b> |

Saliency

|   |     |
|---|-----|
|    | .47 |
|    | .90 |
|    | .67 |
|    | .66 |
|    | .47 |
|    | .37 |
|   | .58 |
|  | .67 |
|  | .18 |
|  | .25 |

Name

|               |       |
|---------------|-------|
| <b>blue</b>   | 62.9% |
| <b>orange</b> | 93.9% |
| <b>green</b>  | 79.8% |
| <b>red</b>    | 80.4% |
| <b>purple</b> | 51.4% |
| <b>brown</b>  | 54.0% |
| <b>pink</b>   | 71.7% |
| <b>grey</b>   | 79.4% |
| <b>yellow</b> | 31.2% |
| <b>blue</b>   | 25.4% |

Tableau-10

Average 0.97











.52



# Palette Design & Color Names

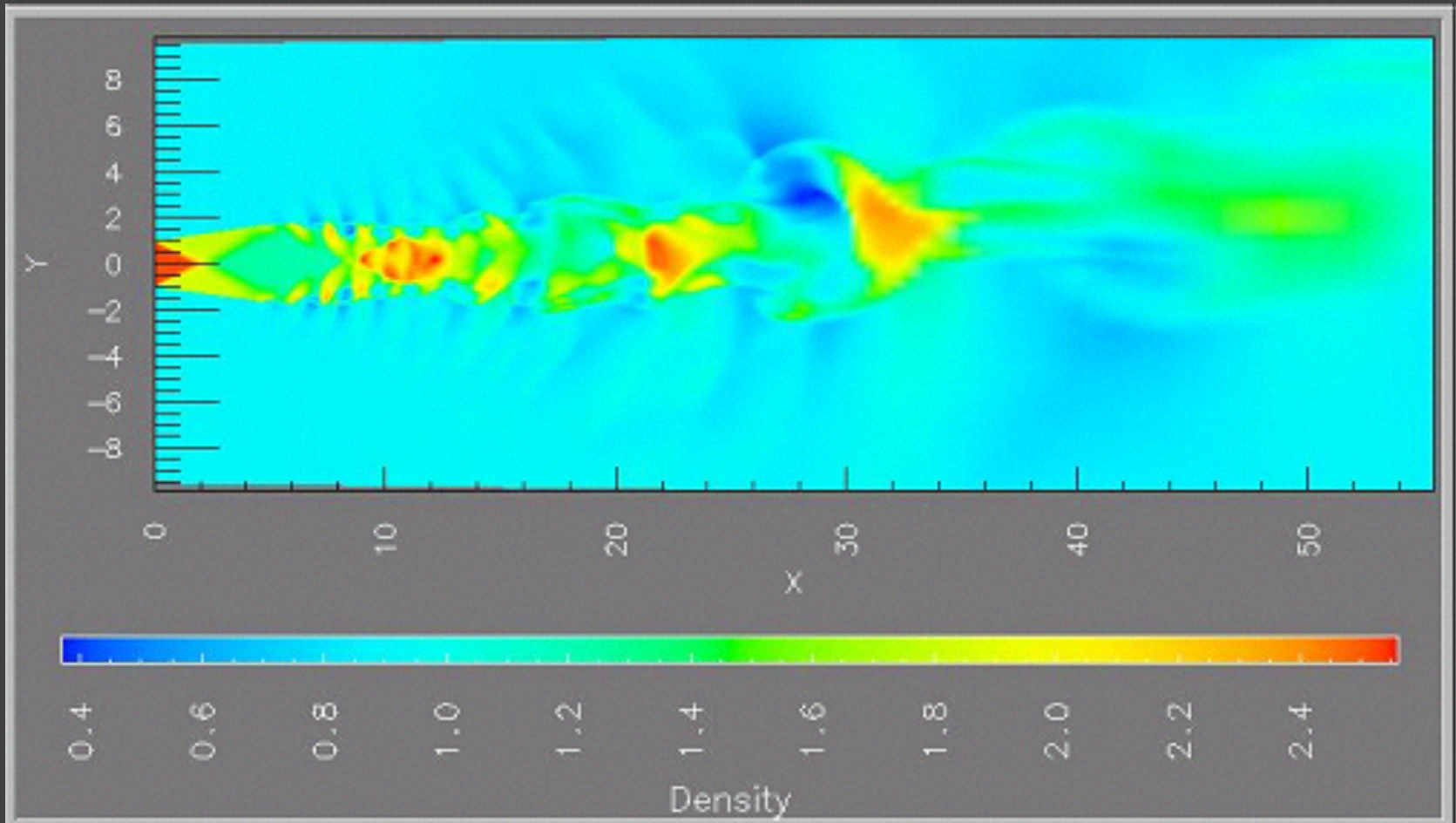
Minimize overlap and ambiguity of colors.

Color Name Distance

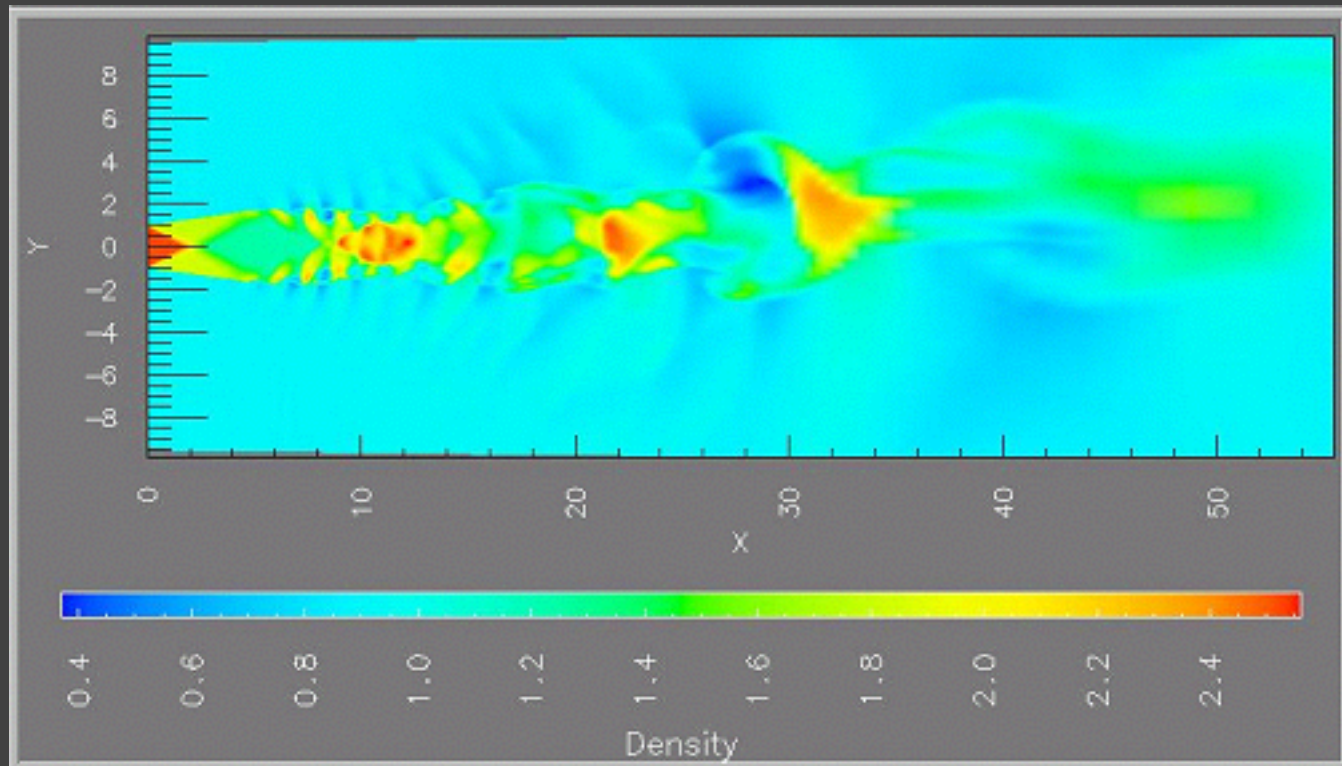
| Color Name Distance |             |             |             |             |             |             |             |             |             | Salience  | Name                |            |
|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---|---------------------|------------|
| <b>0.00</b>         | 1.00        | 1.00        | 0.89        | <b>0.07</b> | 1.00        | <b>0.35</b> | 0.99        | 1.00        | 0.89        |  .30   | <b>blue</b> 50.5%   |            |
| 1.00                | <b>0.00</b> | 0.99        | 1.00        | 1.00        | 0.92        | 1.00        | <b>0.84</b> | 0.98        | 0.99        |  .21   | <b>red</b> 27.8%    |            |
| 1.00                | 0.99        | <b>0.00</b> | 1.00        | 0.98        | 1.00        | 1.00        | 1.00        | <b>0.17</b> | 1.00        |  .34   | <b>green</b> 36.8%  |            |
| 0.89                | 1.00        | 1.00        | <b>0.00</b> | 0.98        | 1.00        | <b>0.71</b> | 0.93        | 1.00        | <b>0.32</b> |  .55   | <b>purple</b> 67.3% |            |
| <b>0.07</b>         | 1.00        | 0.98        | 0.98        | <b>0.00</b> | 1.00        | <b>0.36</b> | 1.00        | 0.97        | 0.95        |  .20   | <b>blue</b> 36.6%   |            |
| 1.00                | 0.92        | 1.00        | 1.00        | 1.00        | <b>0.00</b> | 1.00        | 0.97        | 0.99        | 1.00        |  .39   | <b>orange</b> 51.9% |            |
| <b>0.35</b>         | 1.00        | 1.00        | <b>0.71</b> | <b>0.36</b> | 1.00        | <b>0.00</b> | 0.95        | 0.92        | <b>0.42</b> |  .13   | <b>blue</b> 15.7%   |            |
| 0.99                | <b>0.84</b> | 1.00        | 0.93        | 1.00        | 0.97        | 0.95        | <b>0.00</b> | 0.98        | <b>0.85</b> |  .16 | <b>pink</b> 29.4%   |            |
| 1.00                | 0.98        | <b>0.17</b> | 1.00        | 0.97        | 0.99        | 0.92        | 0.98        | <b>0.00</b> | 0.97        |  .12 | <b>green</b> 21.7%  |            |
| 0.89                | 0.99        | 1.00        | <b>0.32</b> | 0.95        | 1.00        | <b>0.42</b> | 0.85        | 0.97        | <b>0.00</b> |  .30 | <b>purple</b> 23.9% |            |
| <b>Excel-10</b>     |             |             |             |             |             |             |             |             |             | <i>Average</i>  | <b>0.87</b>         | <b>.27</b> |

# Quantitative Color

# Rainbow Color Maps

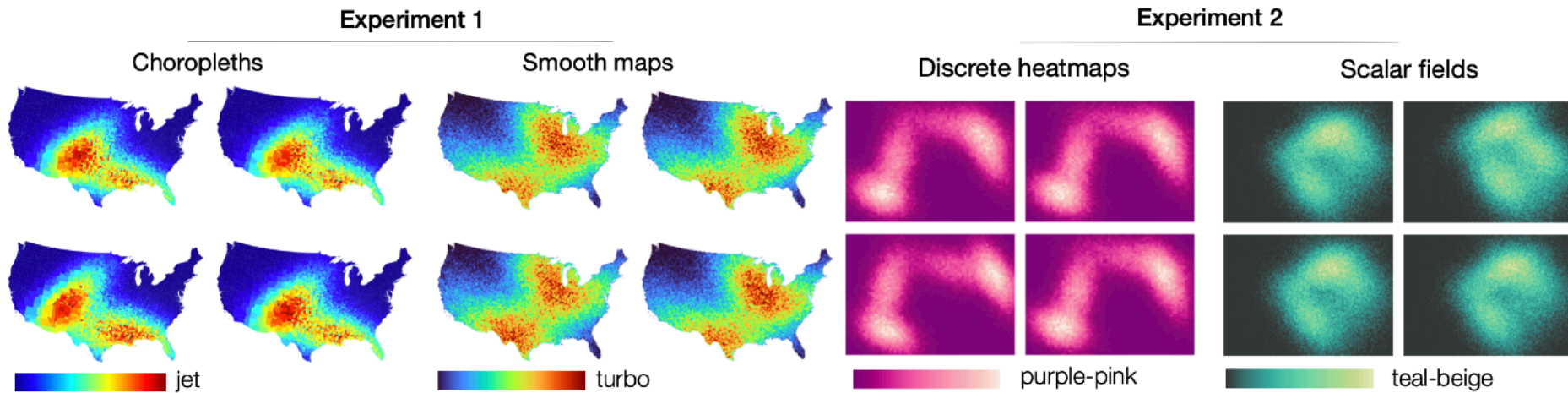


# Be wary of naïve rainbows?



1. Naive rainbows are unfriendly to color blind viewers
2. Hues are not naturally ordered
3. Some colors are less effective at high spatial frequencies
4. People segment colors into classes -> perceptual banding

# But rainbow helpful for inference?



Reda et al. '21: Color Nameability Predicts Inference Accuracy in Spatial Visualizations

Rainbow found ineffective for *value comparison* [Liu '18]...

...but color name salience found to improve performance on *inference task* of distinguishing distributions [Reda '21]

**Task matters!**

# Steps, rather than Gradients?

number of data classes on your map  
3 [learn more >](#)

the nature of your data  
sequential [learn more >](#)

pick a color scheme: BuGn

multihue single hue

(optional) only show schemes that are:  
 colorblind safe  print friendly  
 photocopy-able [learn more >](#)

pick a color system  
229, 245, 249  
153, 216, 201  
44, 162, 95

adjust map context  
 roads  cities  borders

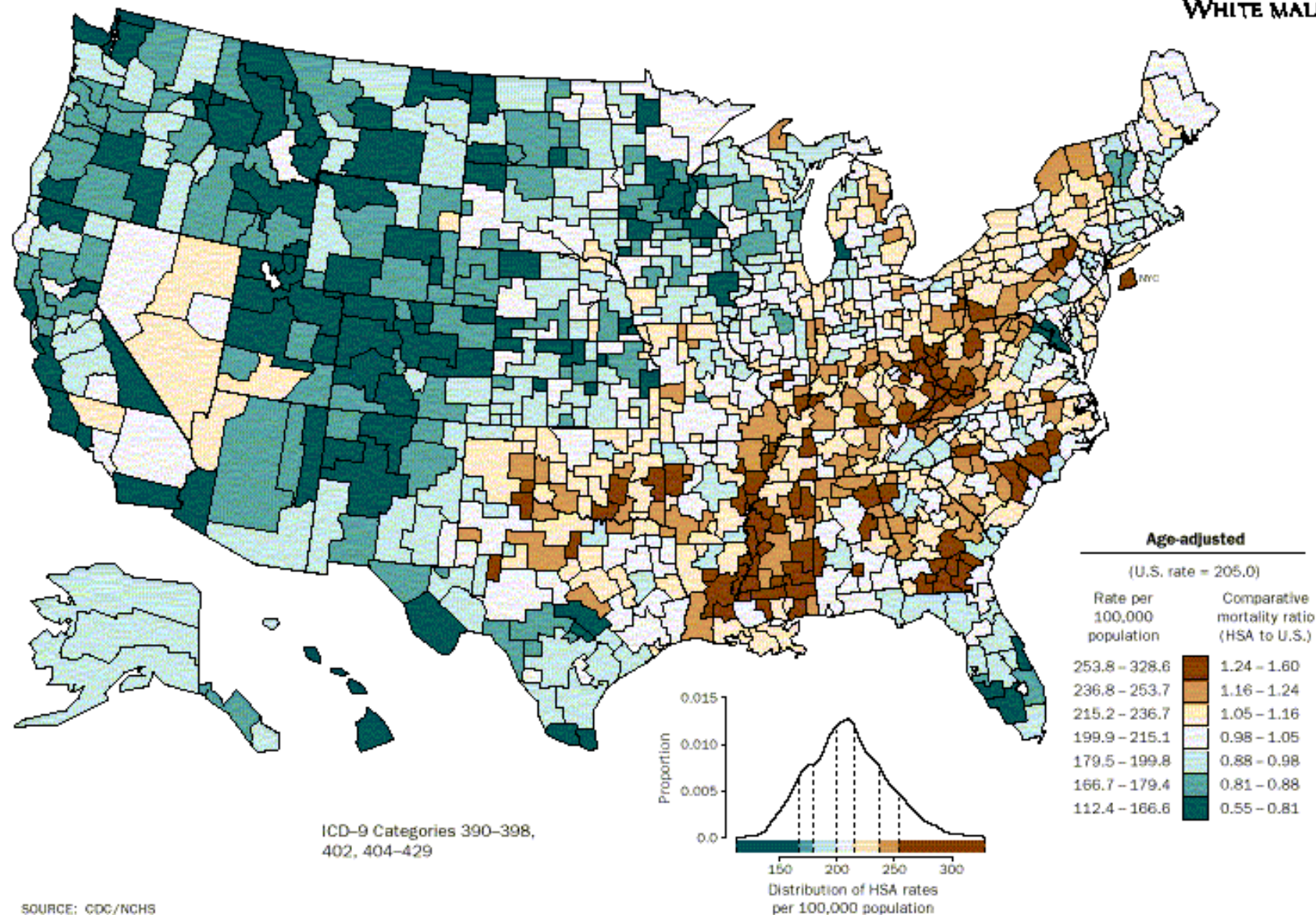
select a background  
 solid color  terrain

how to use | updates | credits

**COLORBREWER 2.0**  
color advice for cartography

SCORE CARD

## AGE-ADJUSTED DEATH RATES BY HSA, 1988-92

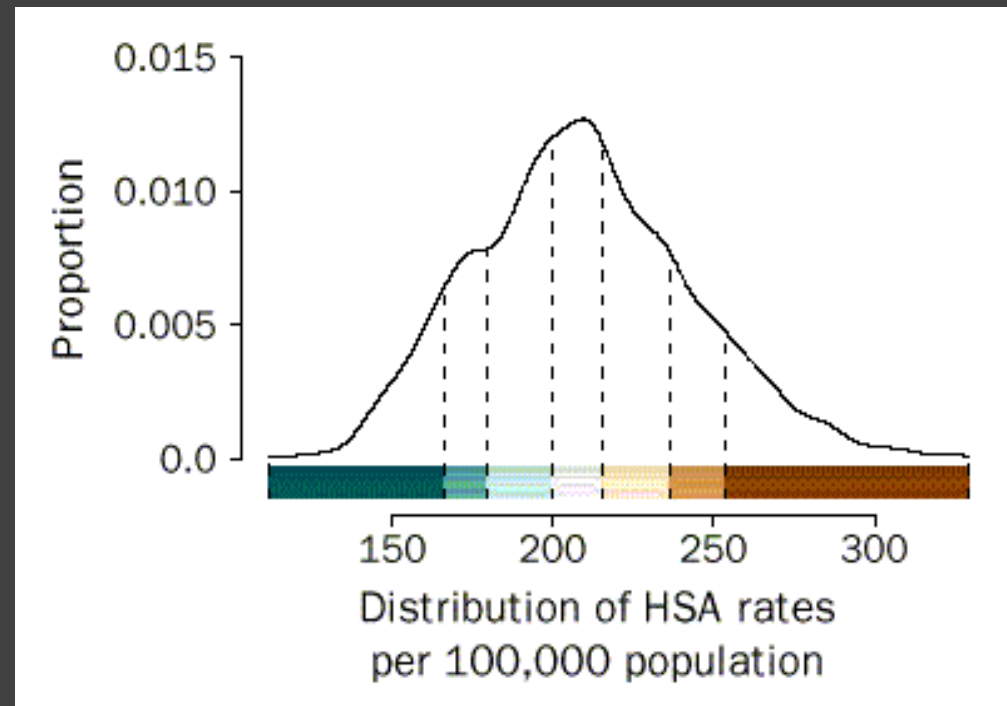
HEART DISEASE  
WHITE MALE

# Classing Quantitative Data

**Age-adjusted**

(U.S. rate = 205.0)

| Rate per 100,000 population | Comparative mortality ratio (HSA to U.S.) |
|-----------------------------|---|
| 253.8 - 328.6               | 1.24 - 1.60                               |
| 236.8 - 253.7               | 1.16 - 1.24                               |
| 215.2 - 236.7               | 1.05 - 1.16                               |
| 199.9 - 215.1               | 0.98 - 1.05                               |
| 179.5 - 199.8               | 0.88 - 0.98                               |
| 166.7 - 179.4               | 0.81 - 0.88                               |
| 112.4 - 166.6               | 0.55 - 0.81                               |



Age-adjusted mortality rates for the United States.  
Common option: break into 5 or 7 quantiles.



# Classing Quantitative Data

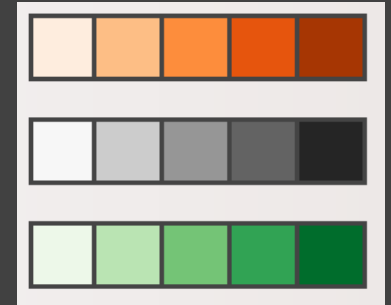
1. Equal interval (arithmetic progression)
2. Quantiles (***recommended***)
3. Standard deviations
4. Clustering (Jenks' natural breaks / 1D K-Means)
  - Minimize within group variance
  - Maximize between group variance

# Quantitative Color Encoding

## Sequential color scale

Ramp in luminance, possibly also hue

Higher value -> darker color (or vice versa)



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Useful when data has meaningful "midpoint"

Use neutral color (e.g., grey) for midpoint

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## Limit number of steps in color to 3-9

*Why?*

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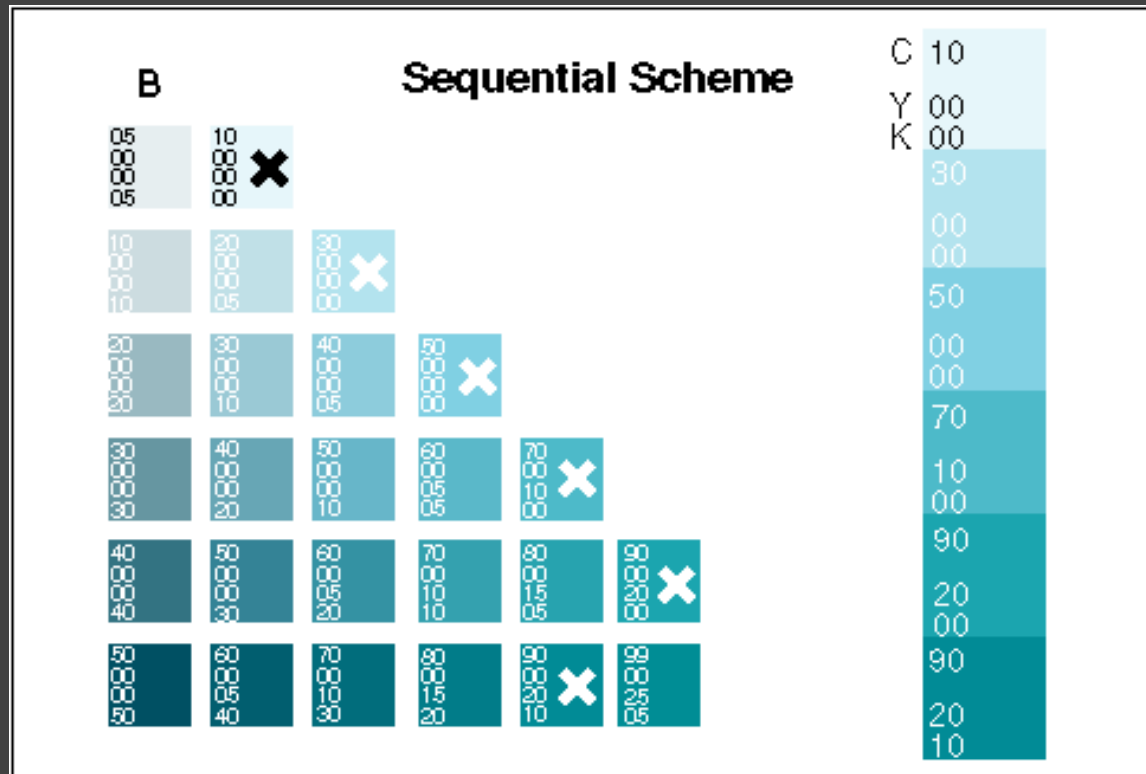


## Limit number of steps in color to 3-9

Avoid simultaneous contrast, hold mappings in memory

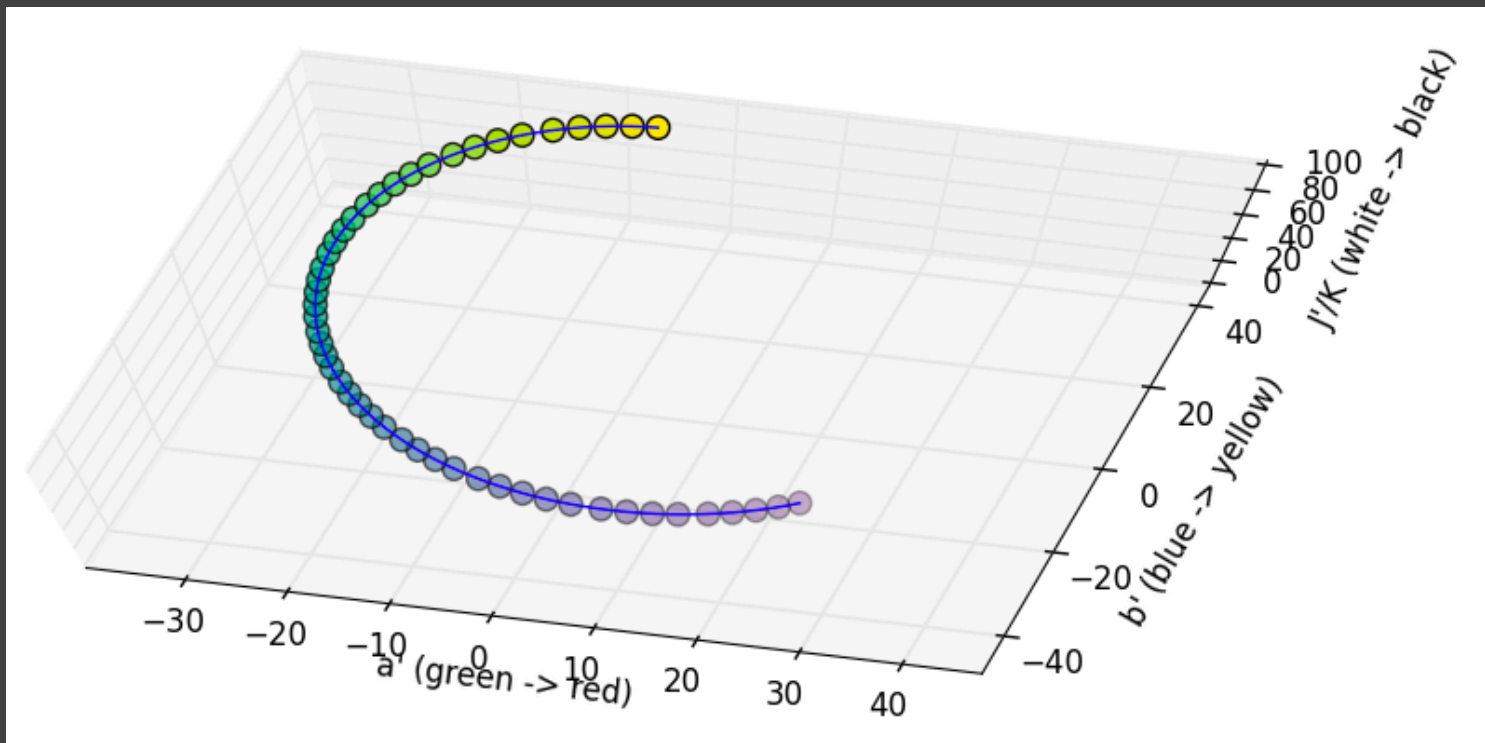
# Sequential Scales: Single-Hue

Ramp primarily in luminance, subtle hue difference

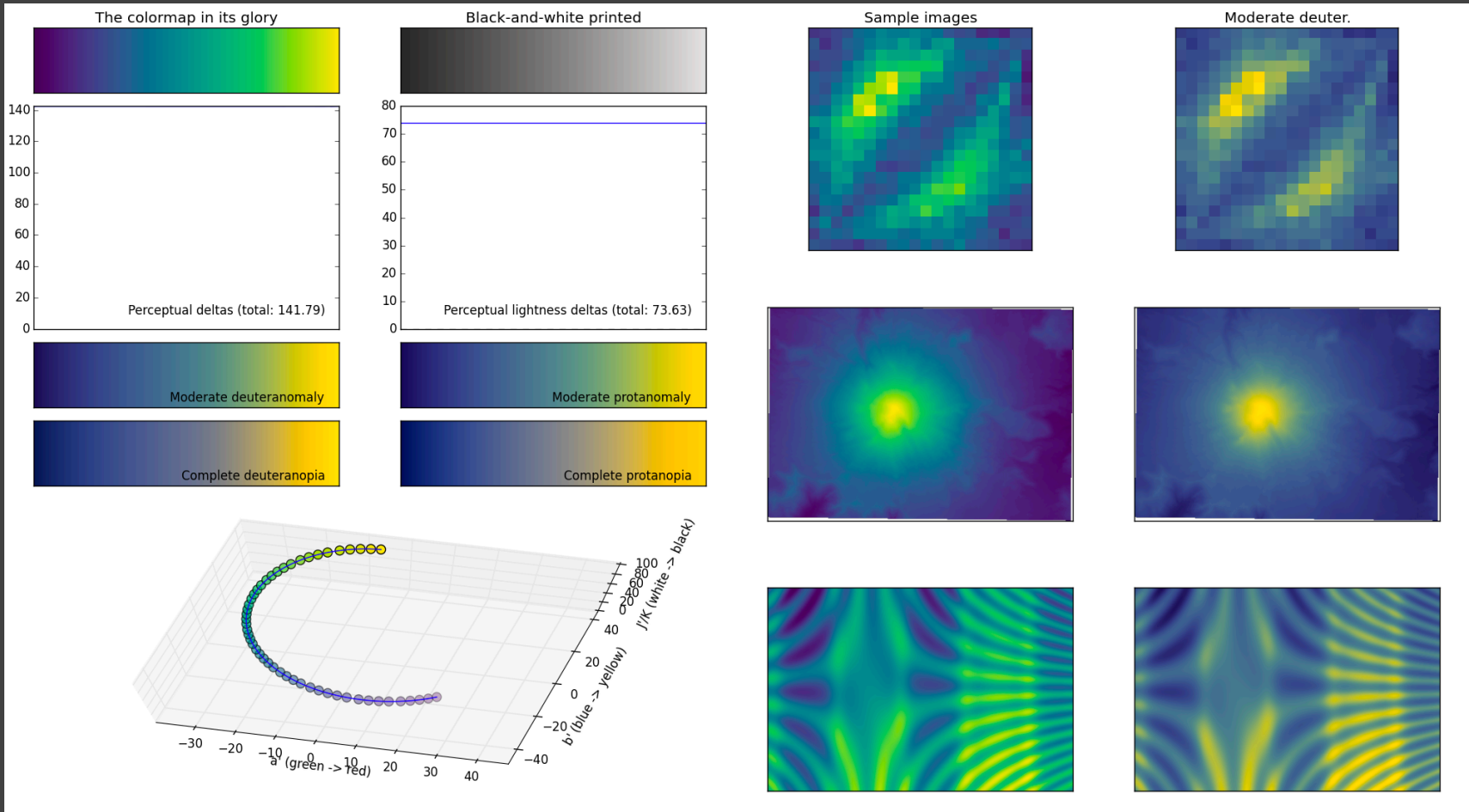


# Sequential Scales: Multi-Hue

Ramp luminance & hue in perceptual color space  
Avoid contrasts subject to color blindness!

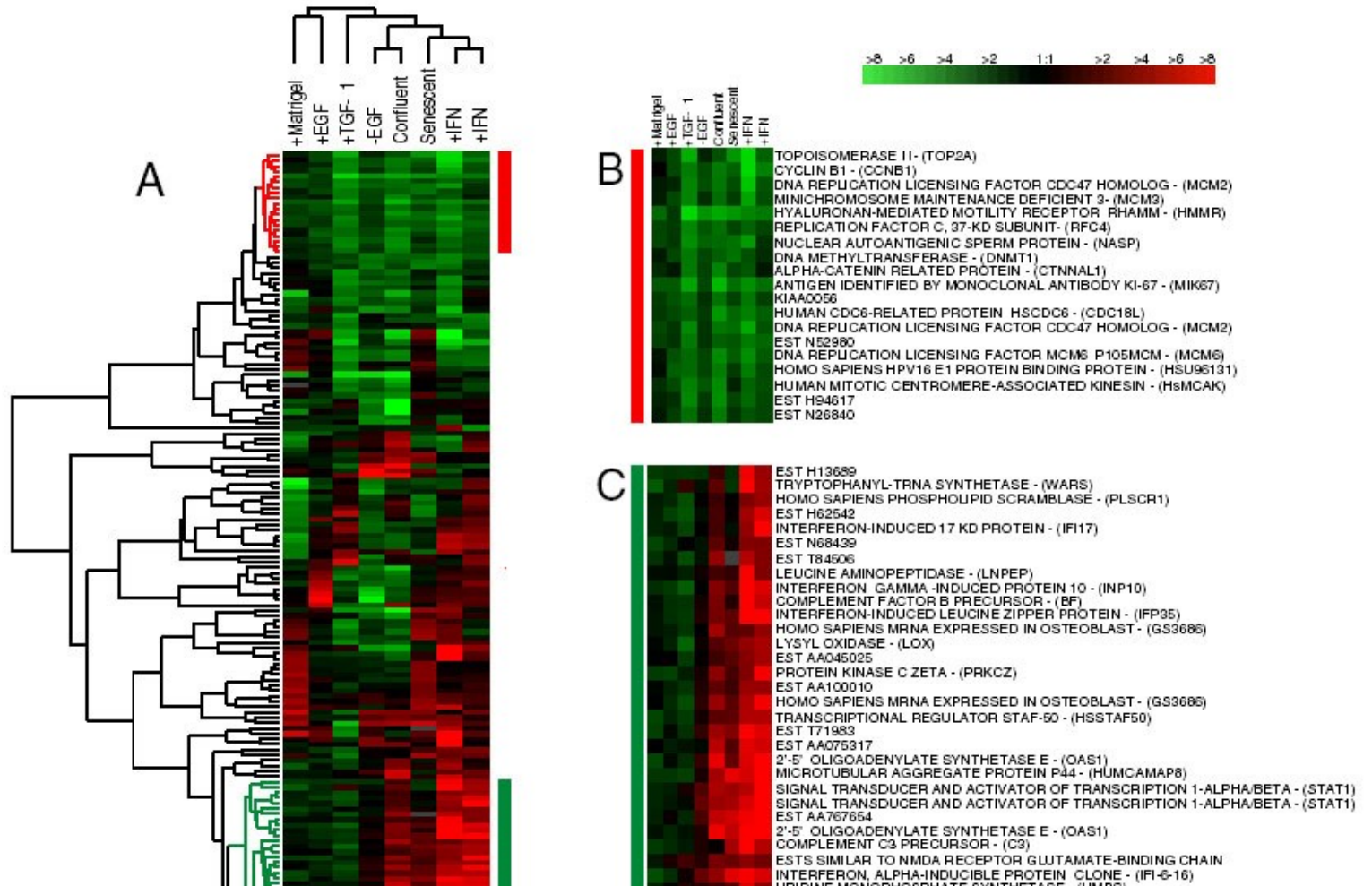


# Sequential Scales: Multi-Hue

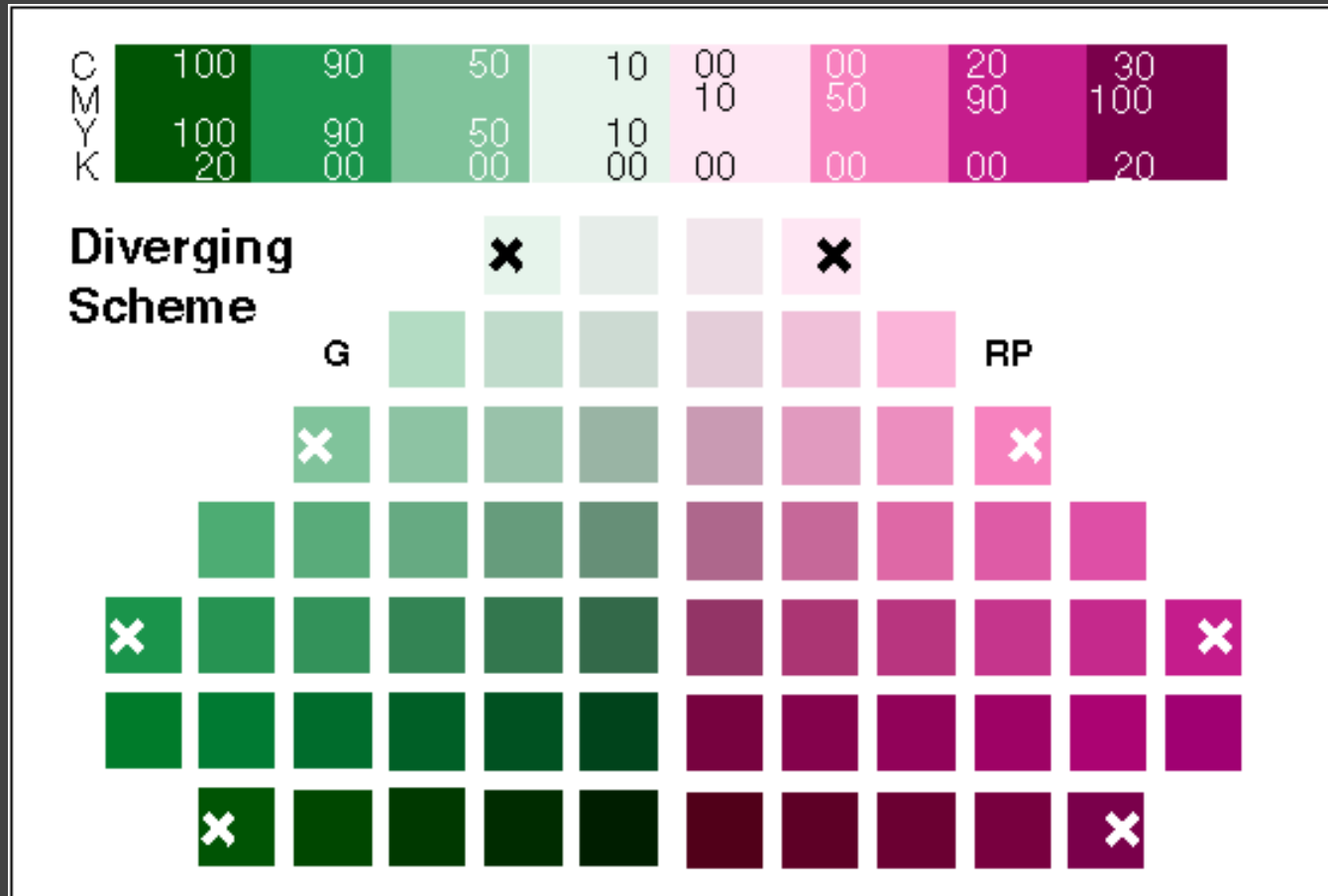




# Diverging Color Scheme



# Designing Diverging Scales



# Designing Diverging Scales

## Hue Transition

### Carefully Handle Midpoint

Choose classes of values

Low, Average, High - Average should be gray

### Critical Breakpoint

Defining value e.g., 0

Positive & negative should use different hues

**Extremes saturated, middle desaturated**

# Hints for the Colorist

Use **only a few** colors (~6 ideal)

Colors should be **distinctive** and **named**

Strive for color **harmony** (natural colors?)

Use **cultural conventions**; appreciate symbolism

Get it right in **black and white**

Respect the **color blind**

Take advantage of **perceptual color spaces**

**Color is cultural and a matter of taste!**