

# Data Visualization Principles: Color

CSC544

Acknowledgments for today's lecture:  
Tamara Munzner, Miriah Meyer, Maureen Stone

# Outlook

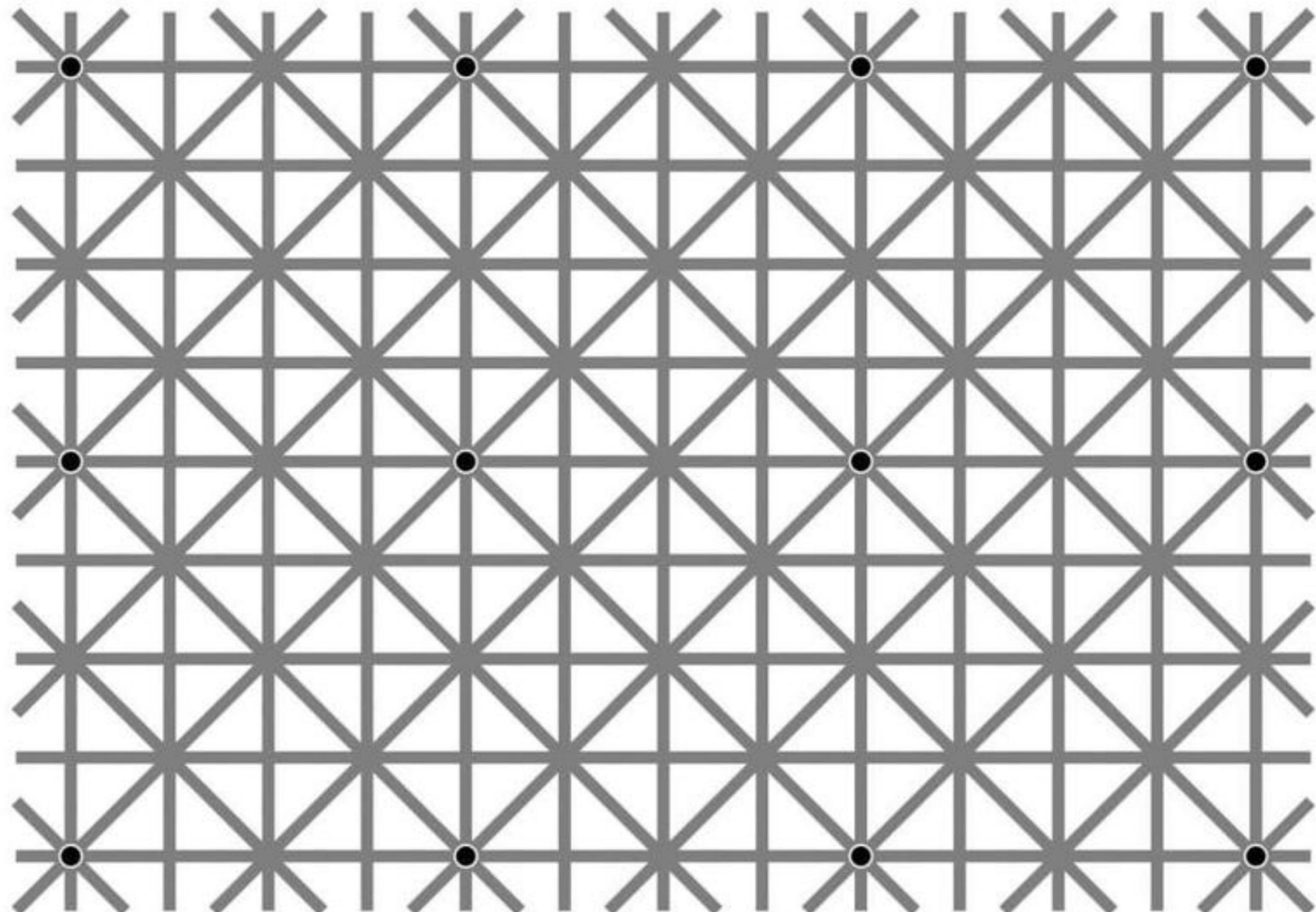
Mechanics

## Principles

Techniques

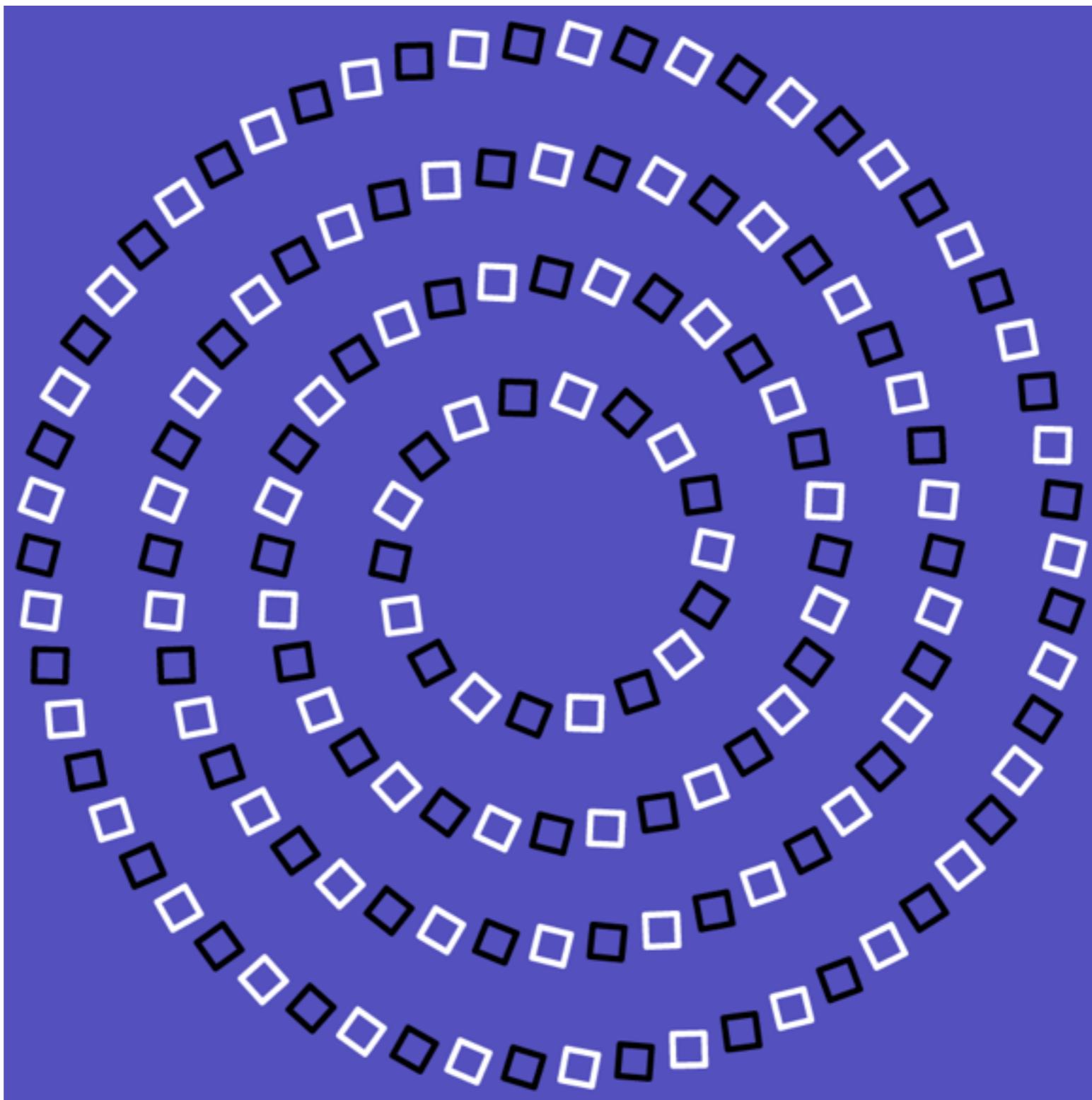
# **Why worry about principles?**

# Why worry about principles?

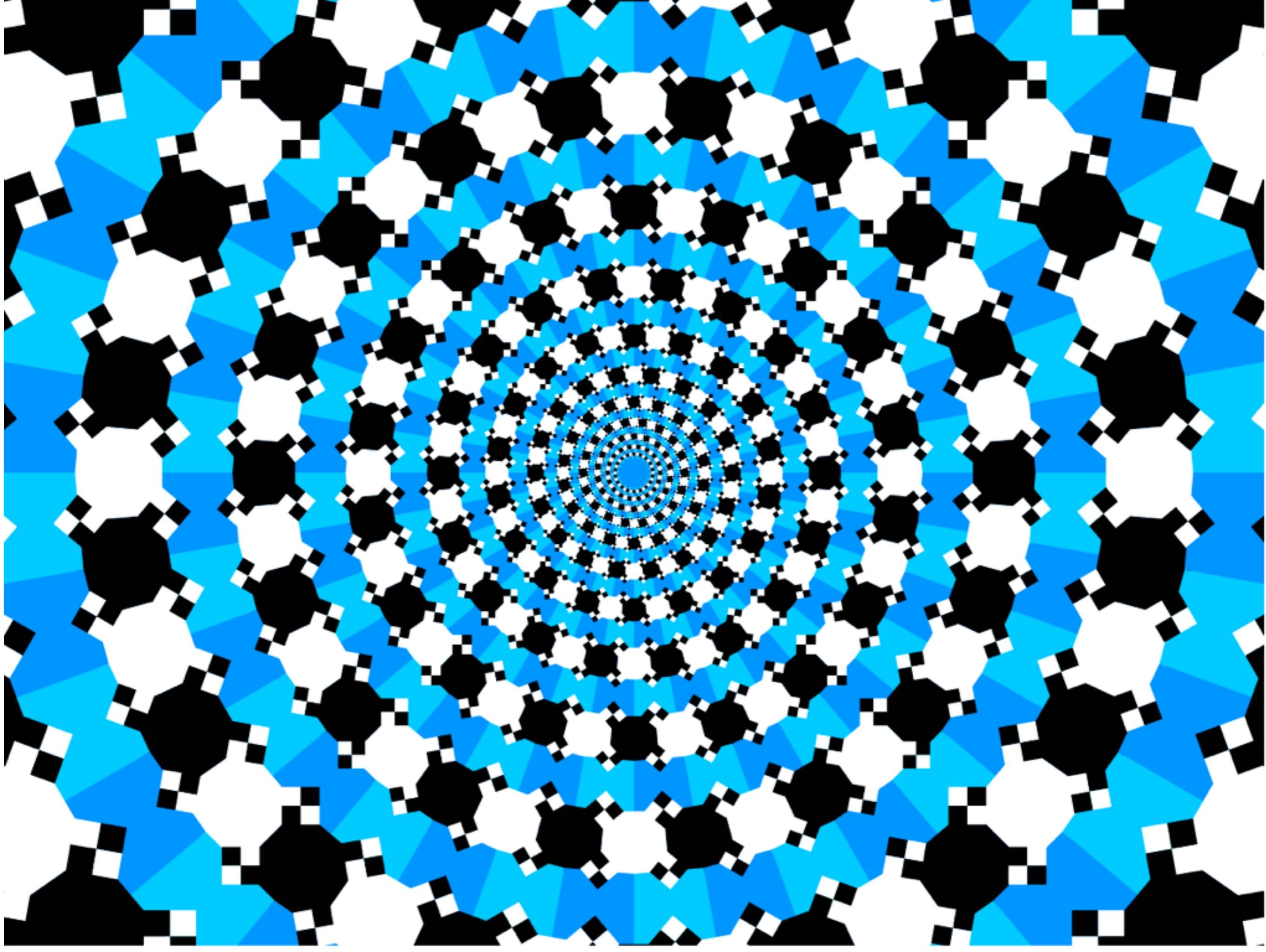


Ninio's extinction illusion

# Why worry about principles?



<https://cscheid.net/2014/12/13/not-spirals.html>

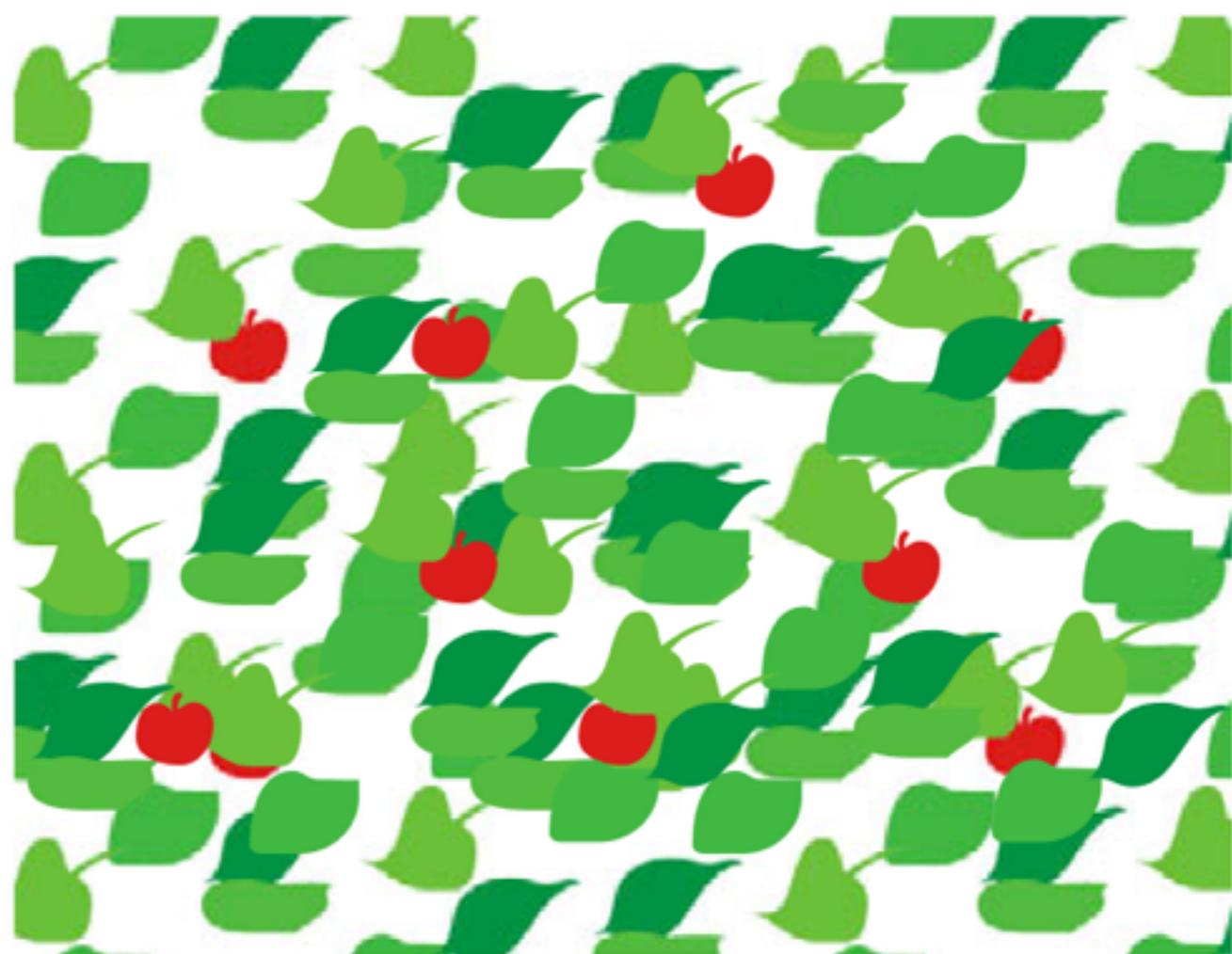


VISION IS COMPLICATED

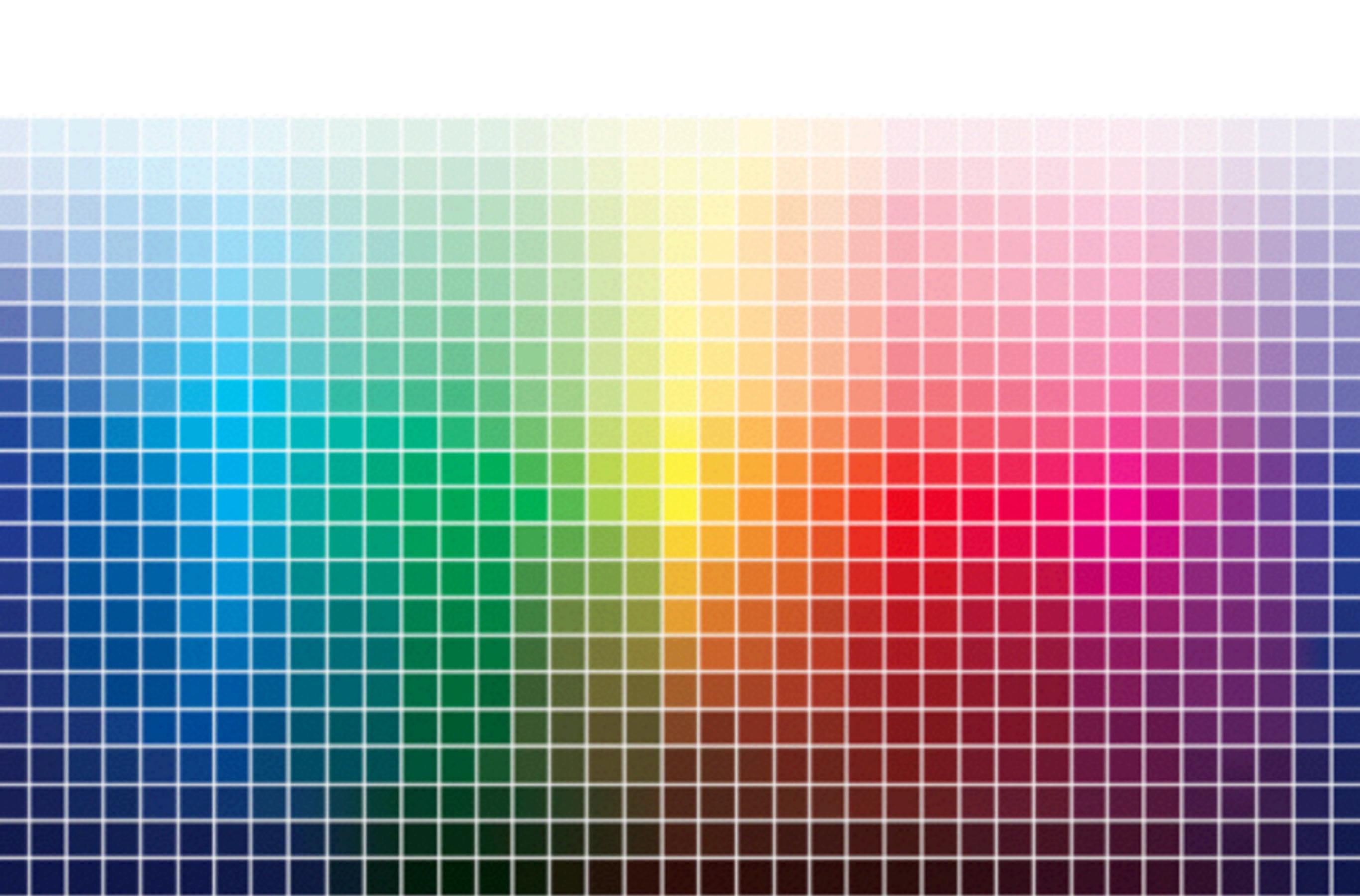
# Reading

- “Representing Colors as Three Numbers”, Stone
- Rainbow Colormap (Still) Considered Harmful, Borland and Russell.
- Face-based Luminance Matching... Kindlmann et al.
- Matplotlib colormaps
- Colorgorical: Creating discriminable and preferable color palettes for information visualization, InfoVis 2016
- Interactions between color and mark type. Modeling Color Difference for Visualization Design: best paper award, Infovis 2017

WHY COLOR?



Colin Ware, Information Visualization



LIGHT AND  
COLOR

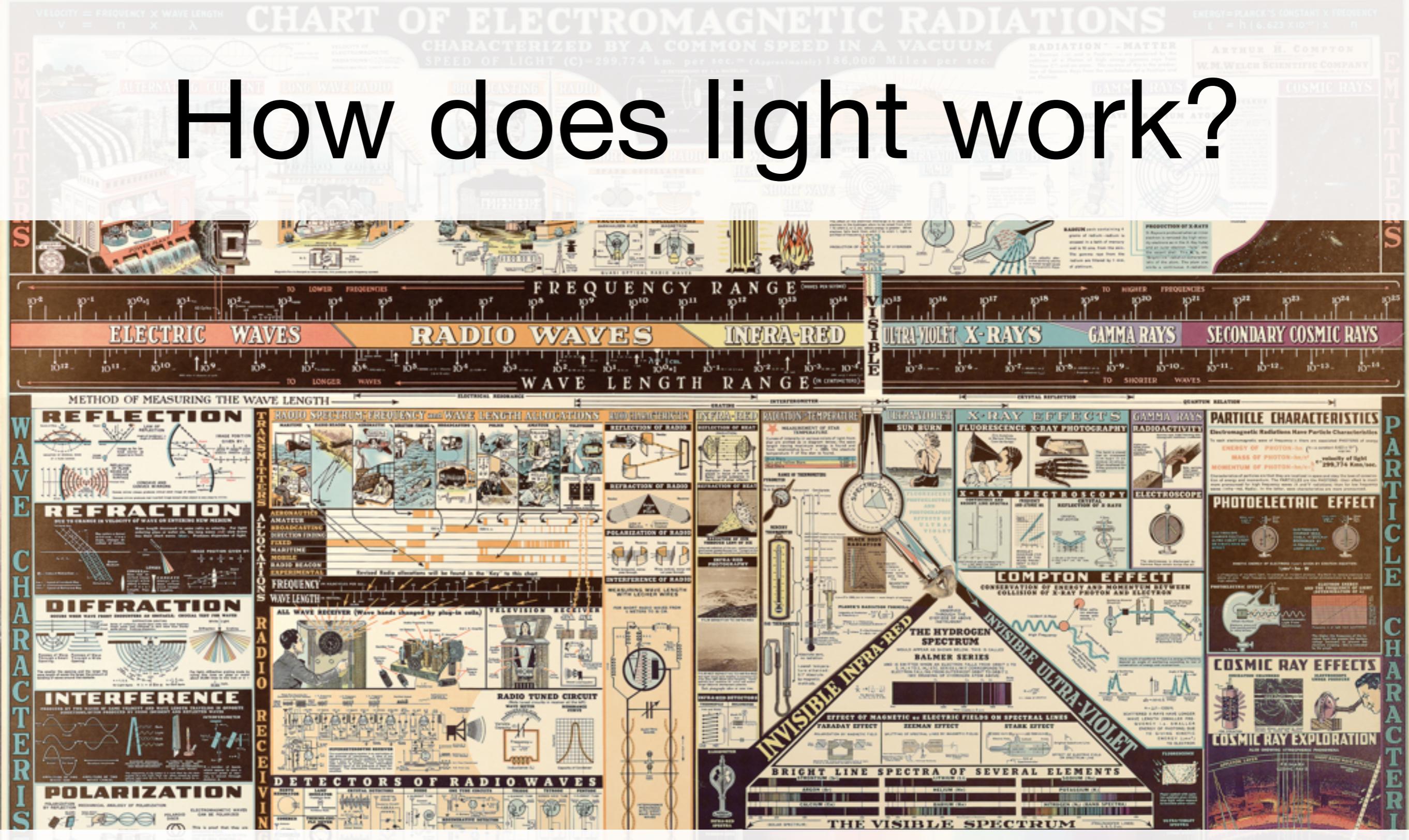
How does the yellow from your  
**laptop display** “equal” the yellow  
from the **sun**, and that from a  
**painting?**

# How does light work?

- Each photon has a “wavelength”, roughly characterizing the frequency with which it wiggles as it travels through space
- **Visible light** is the same thing as **FM radio** is the same thing as **X-rays** is the same thing as **microwaves**



# How does light work?



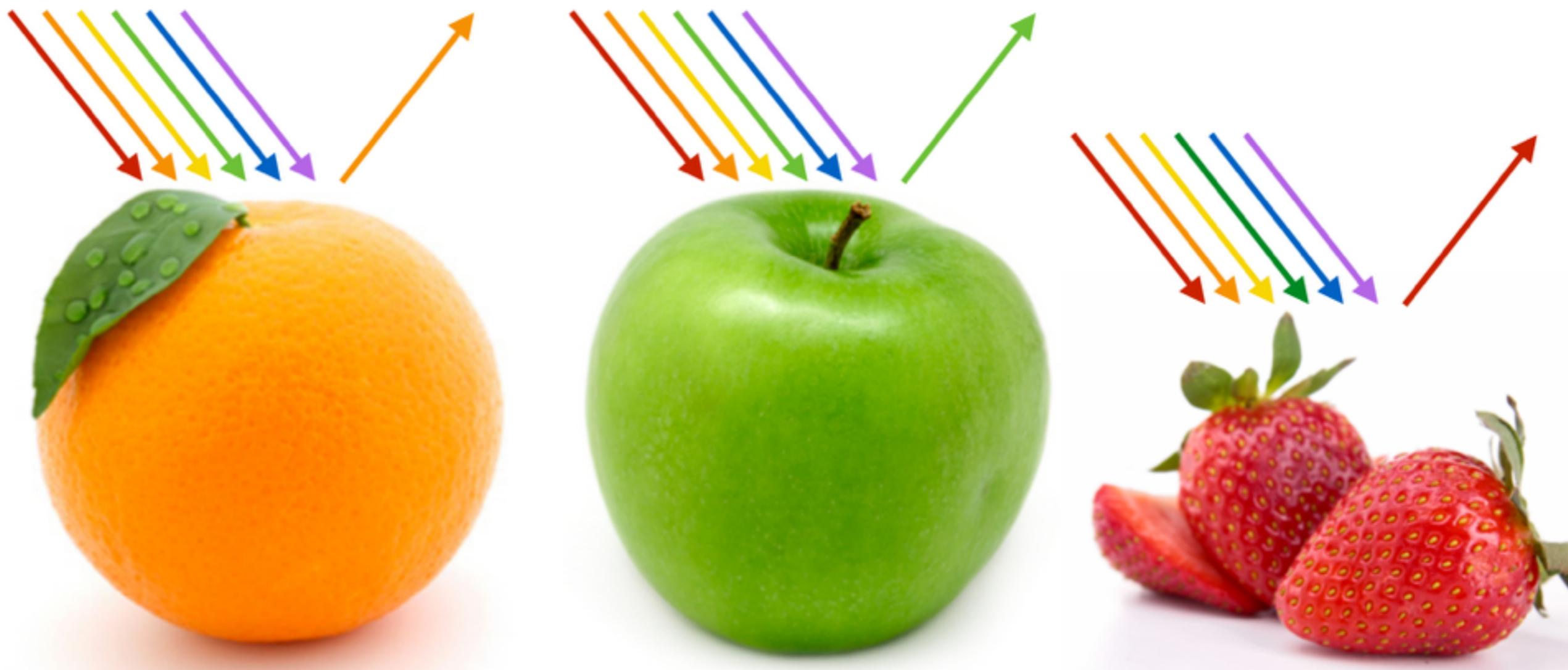
<https://www.flickr.com/photos/llnl/9403051123/>

# How does light work?

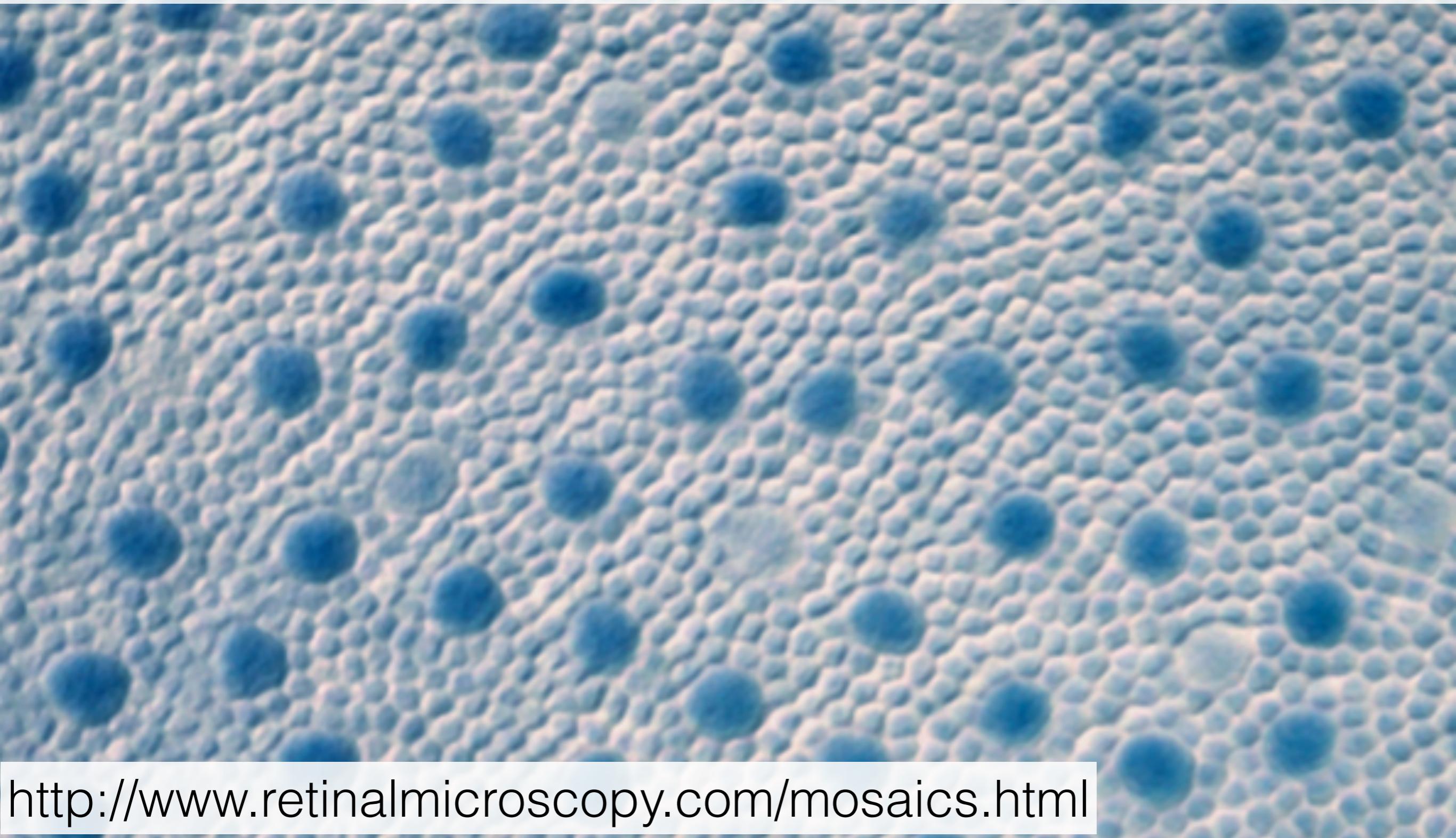
[http://www.chemistryland.com/CHM107Lab/Exp7/  
Spectroscope/Spectroscope.html](http://www.chemistryland.com/CHM107Lab/Exp7/Spectroscope/Spectroscope.html)



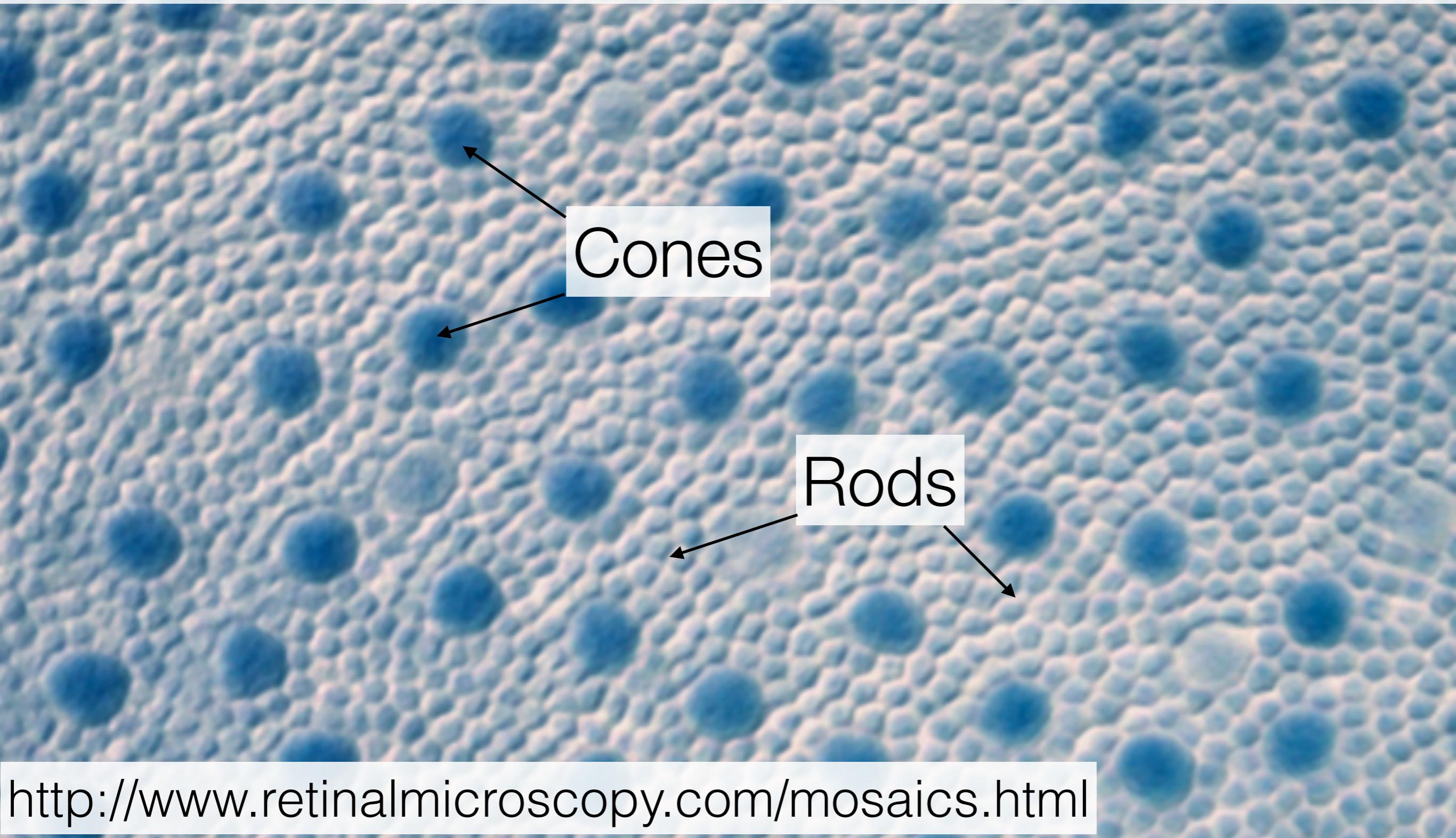
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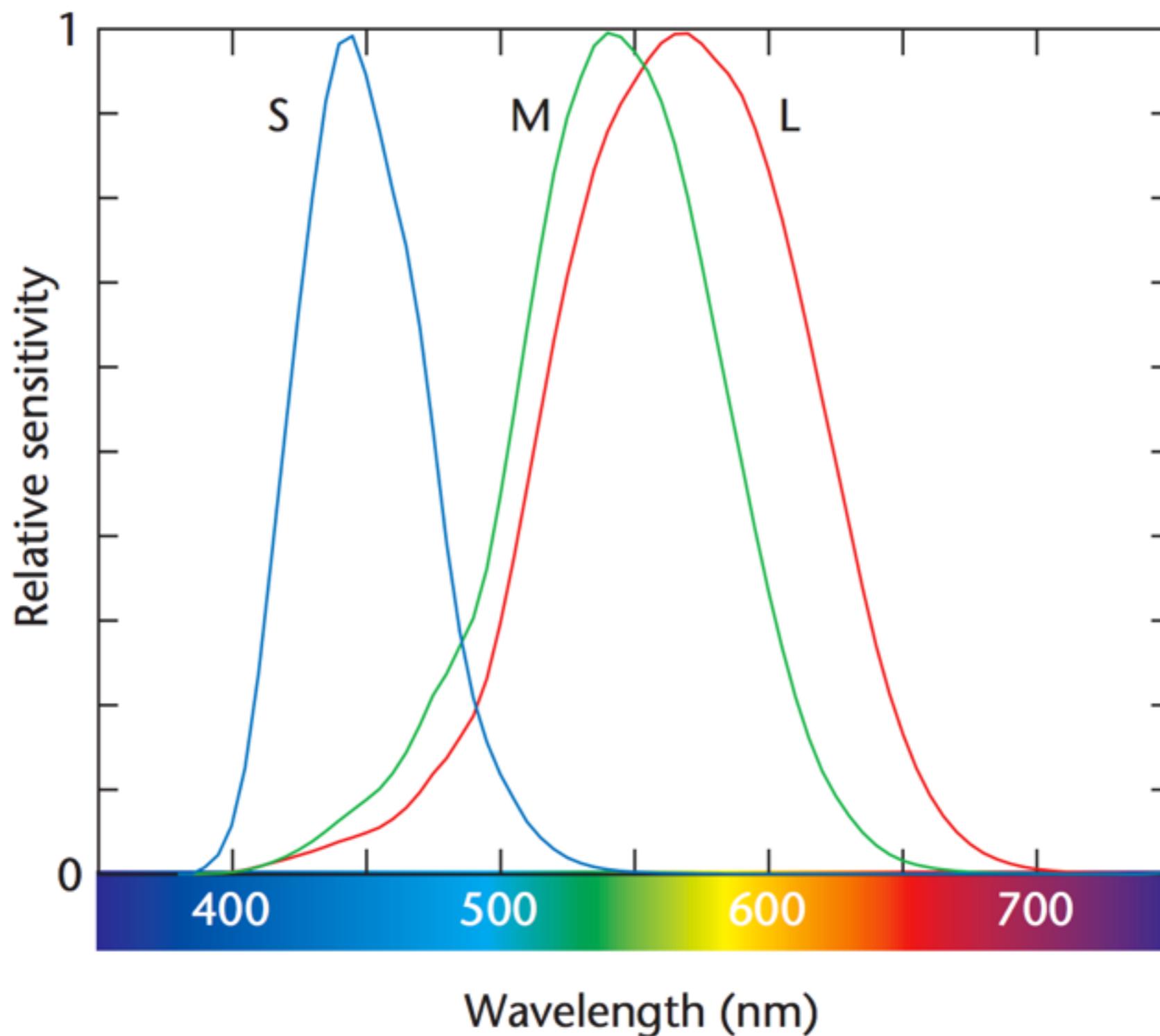
# How does your eye work?



# How does your eye work?

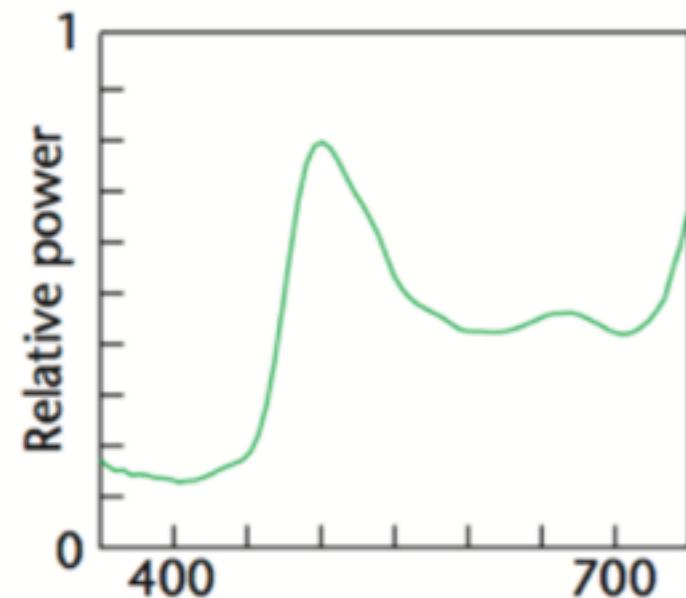


# How does your eye work?

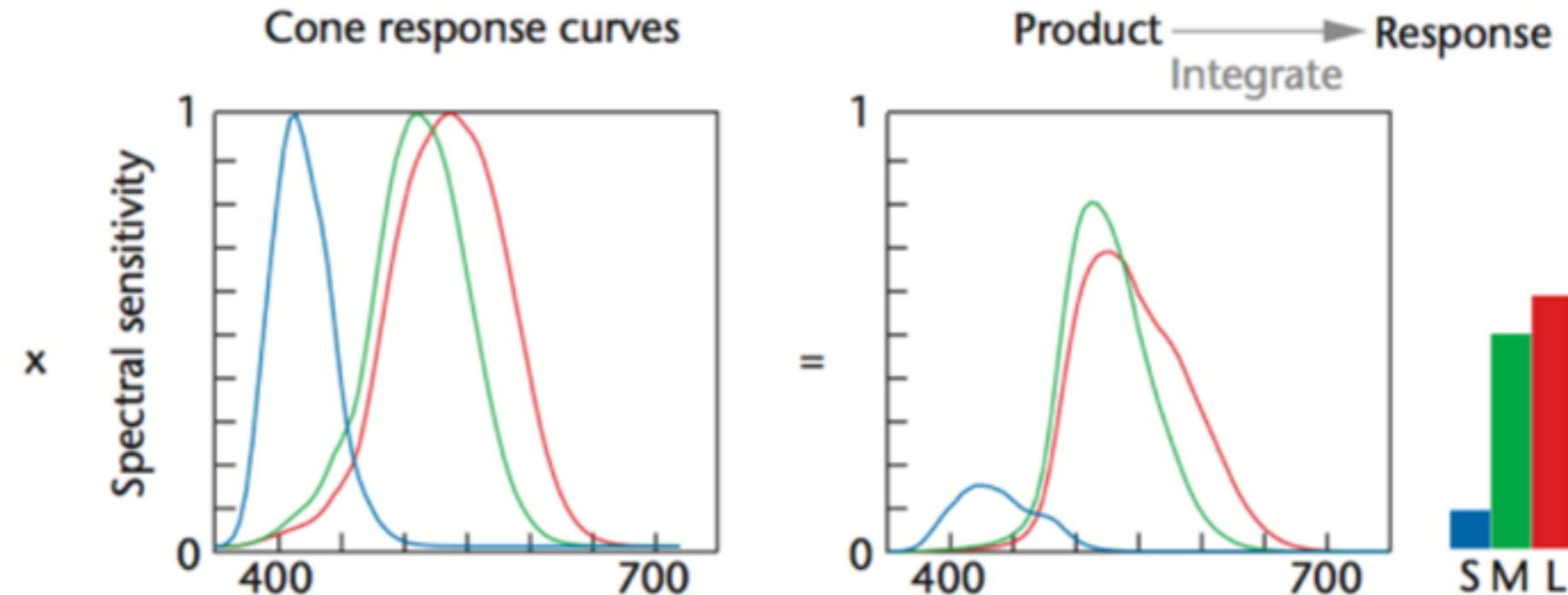


# TRICHRAMY

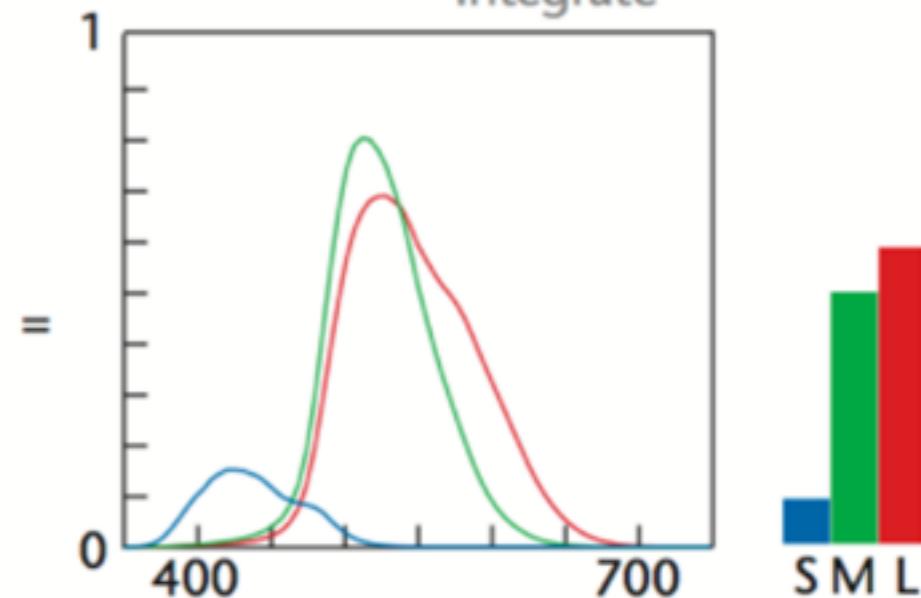
Input stimulus



Cone response curves

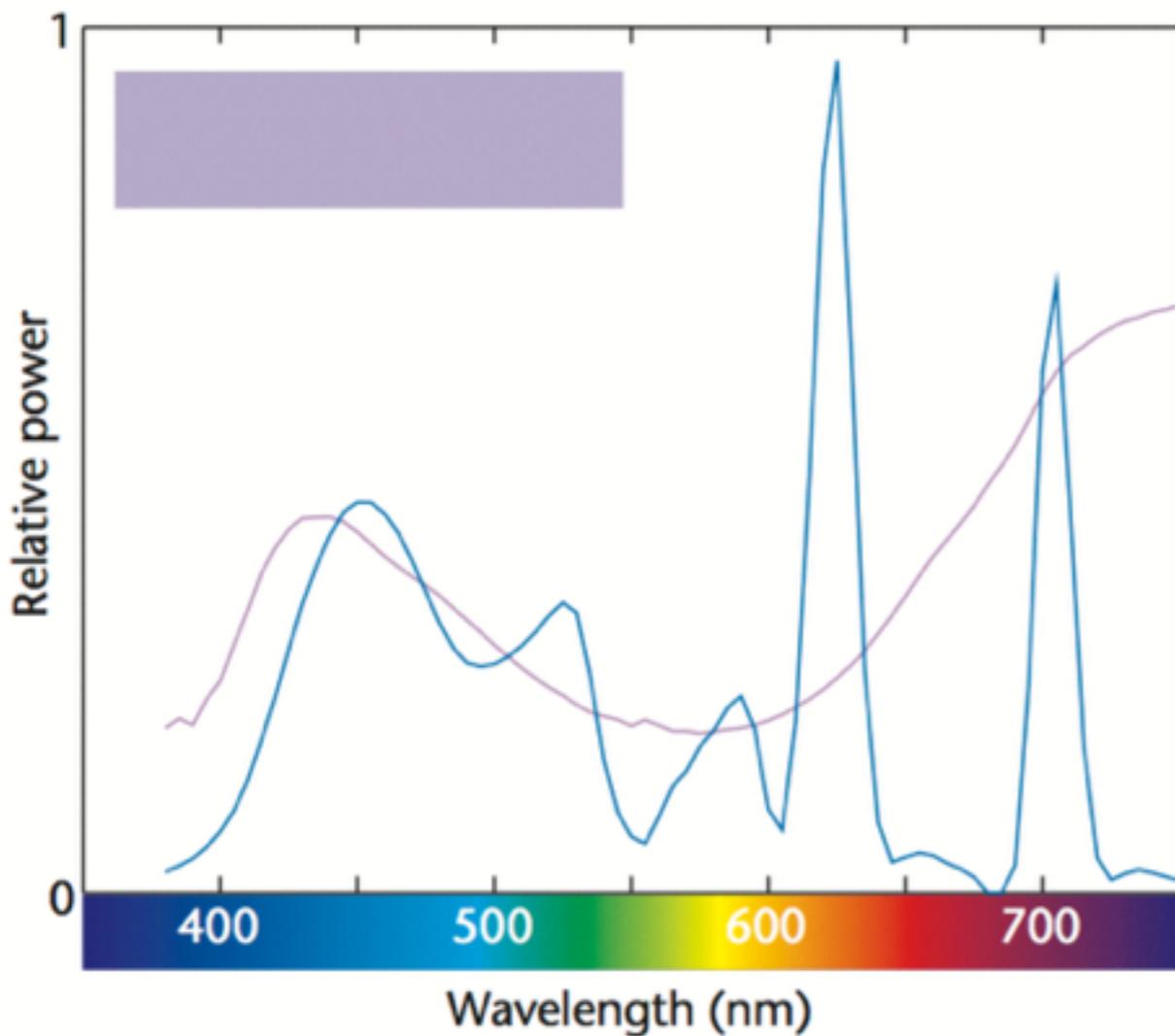


Product  $\longrightarrow$  Response  
Integrate



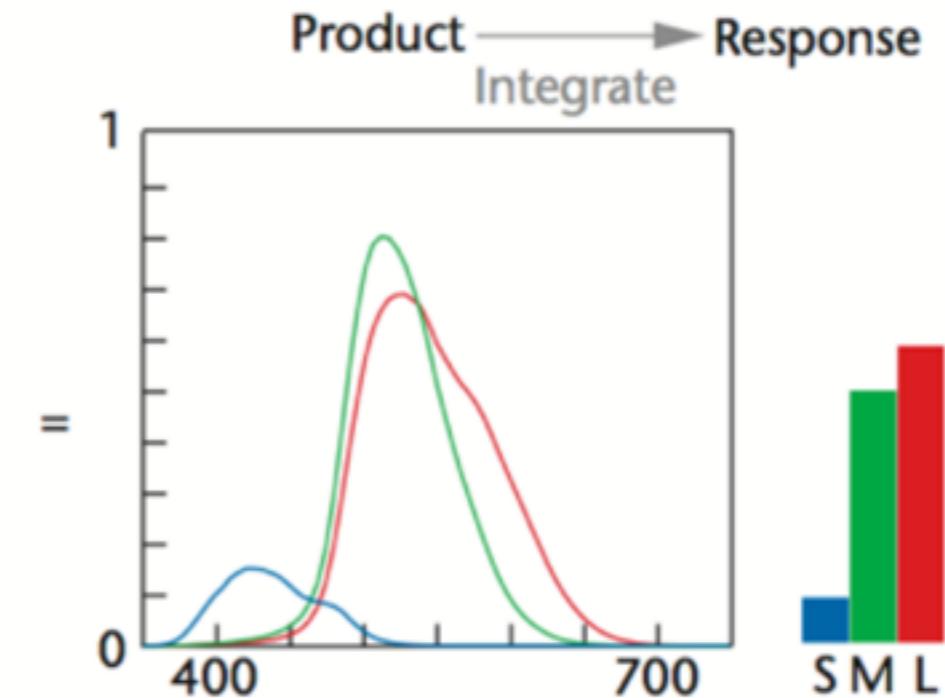
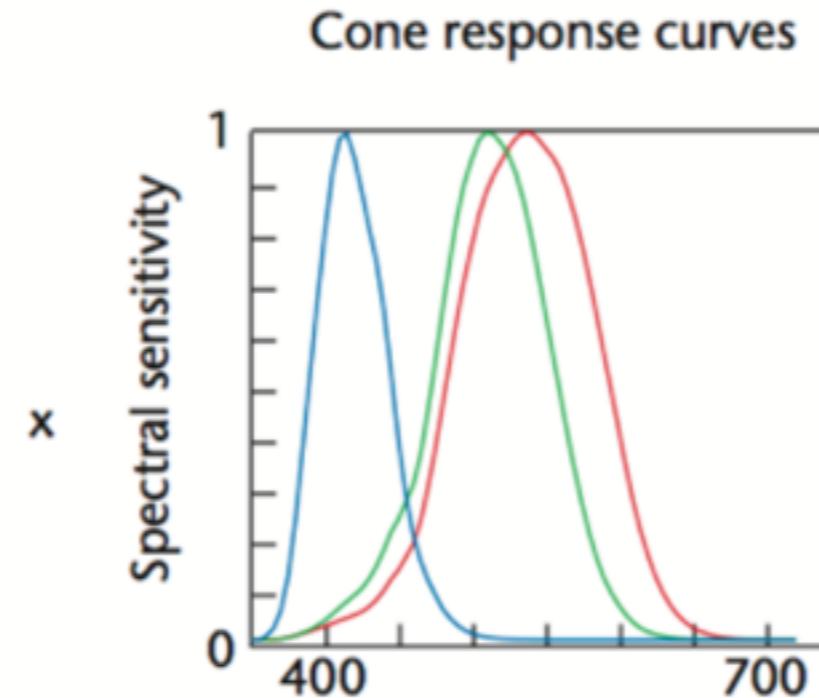
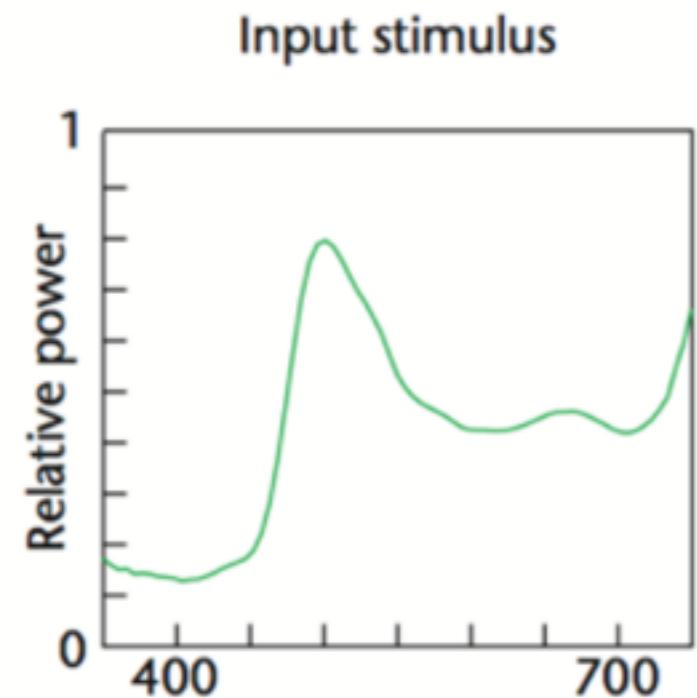
**Three numbers!**



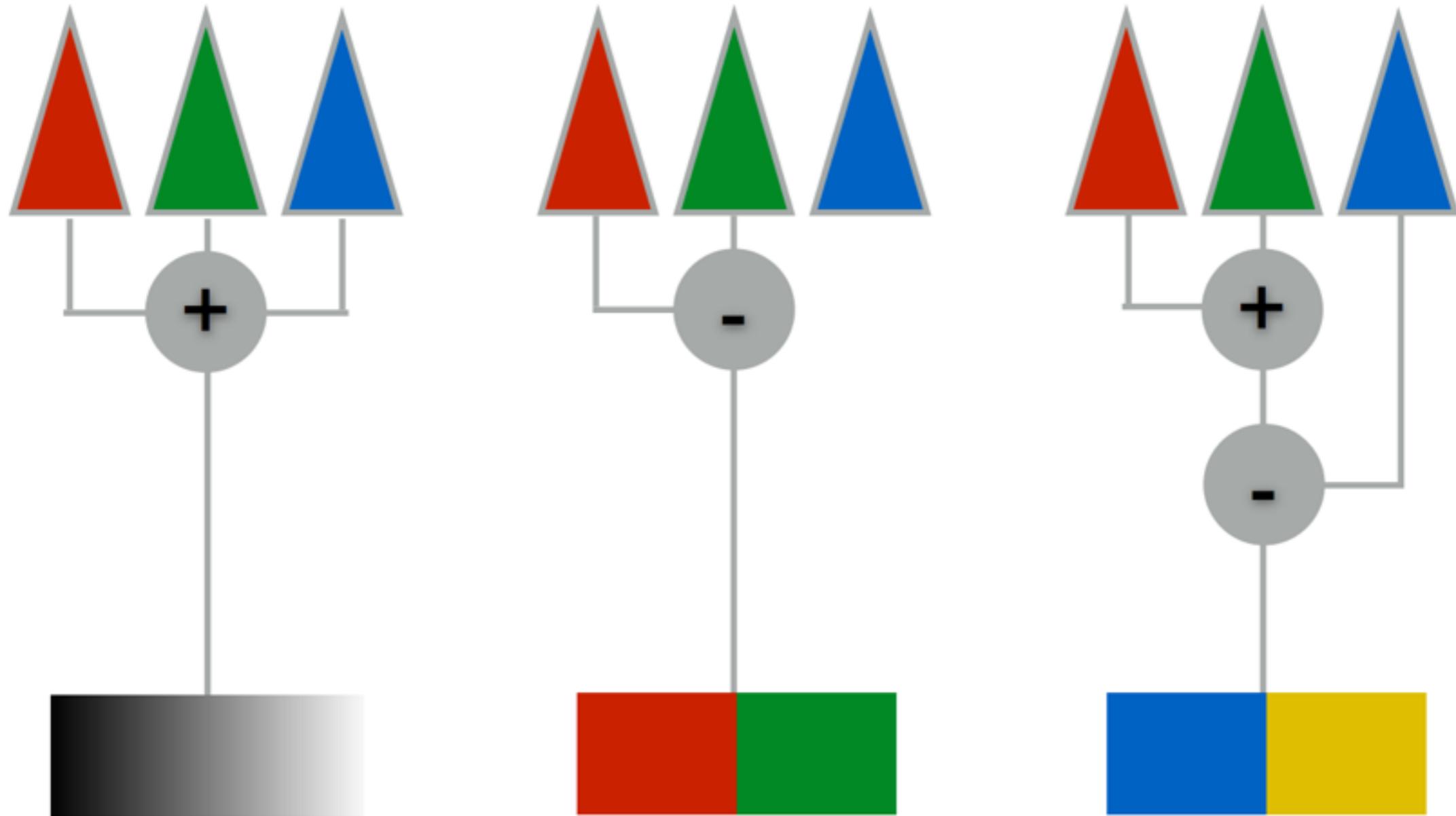


**same** three numbers,  
**same** impression

# METAMERISM

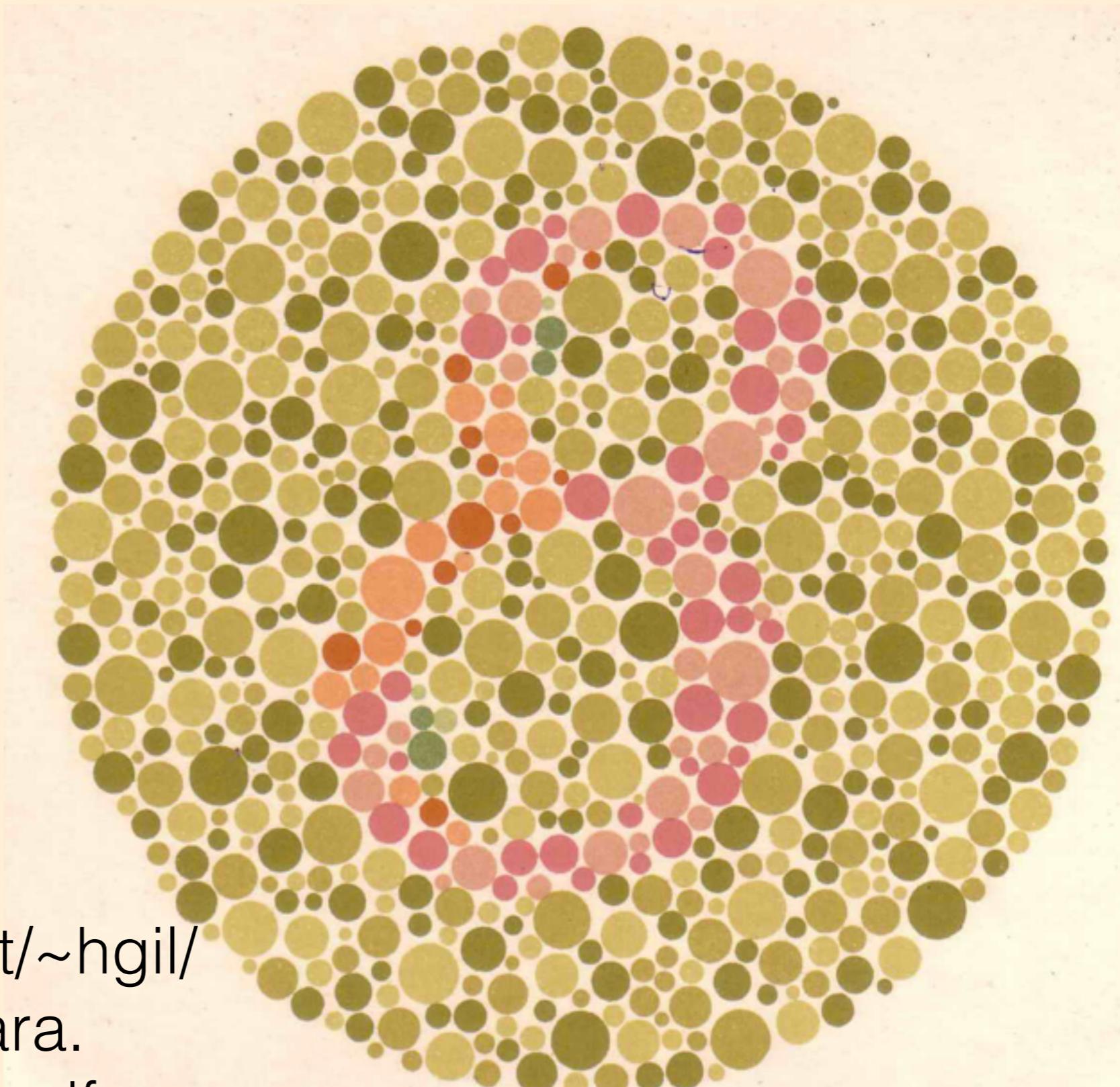


# OPPONENT PROCESS MODEL



# COLOR VISION DEFICIENCIES

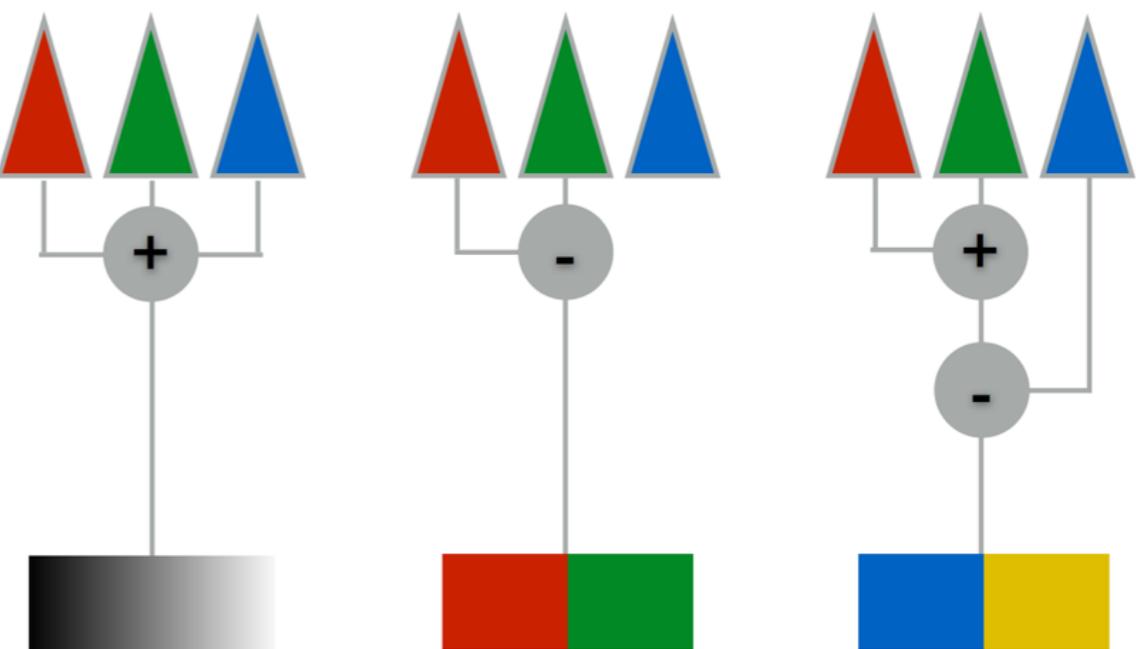
# Ishihara Plates



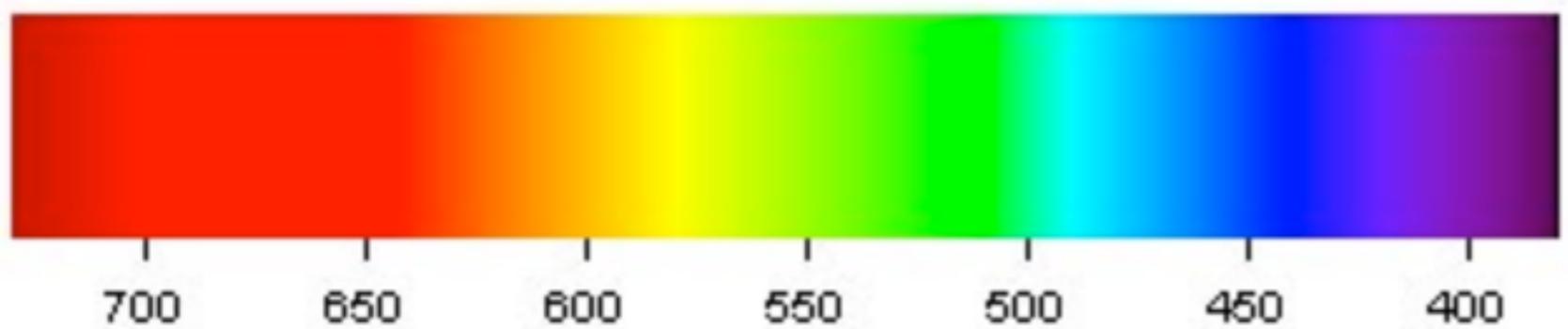
[http://www.dfisica.ubi.pt/~hgil/  
p.v.2/Ishihara/Ishihara.  
24.Plate.TEST.Book.pdf](http://www.dfisica.ubi.pt/~hgil/p.v.2/Ishihara/Ishihara.24.Plate.TEST.Book.pdf)

# What goes wrong?

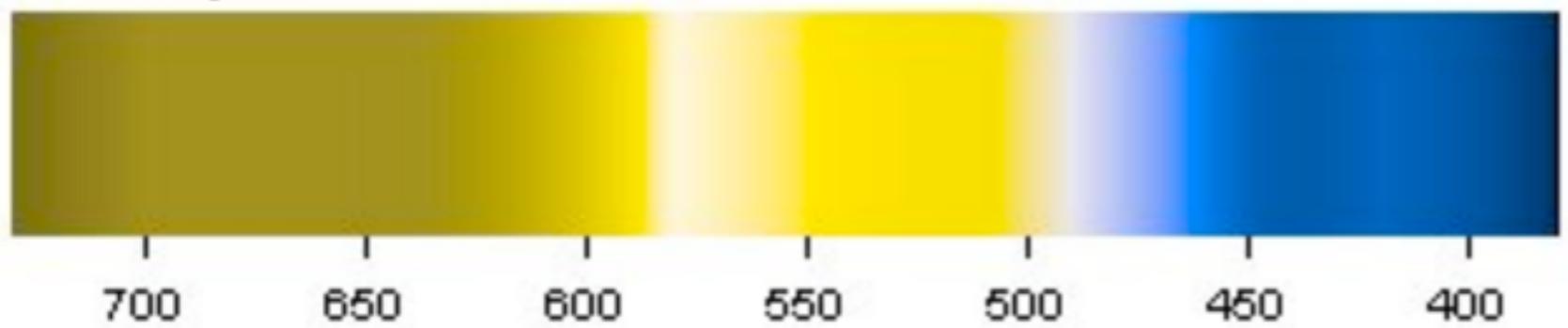
- Two broad classes of problems:
  - Only some types of cones present in the eye (rare)
    - red-green dichromacy, blue-yellow dichromacy
  - Two types of cones with abnormally close response curves
    - relatively common for red-green



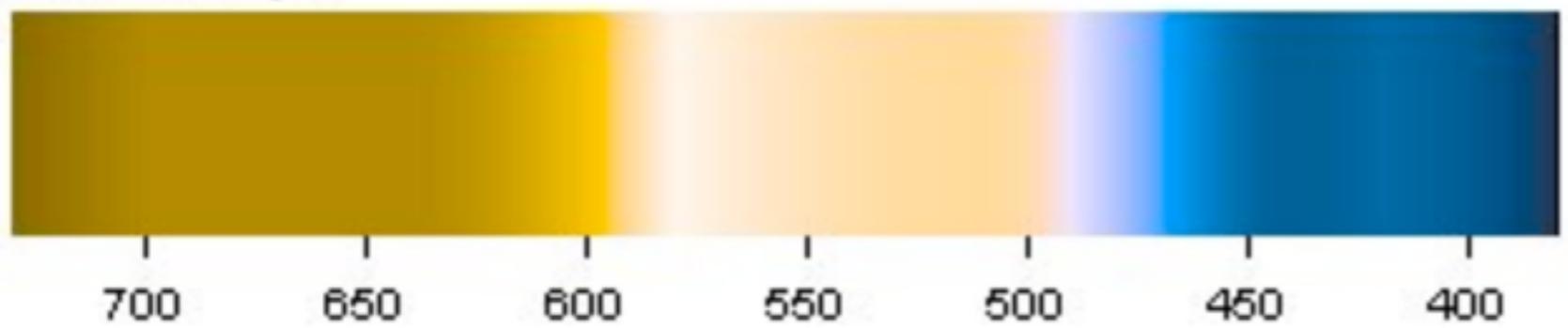
## Normal



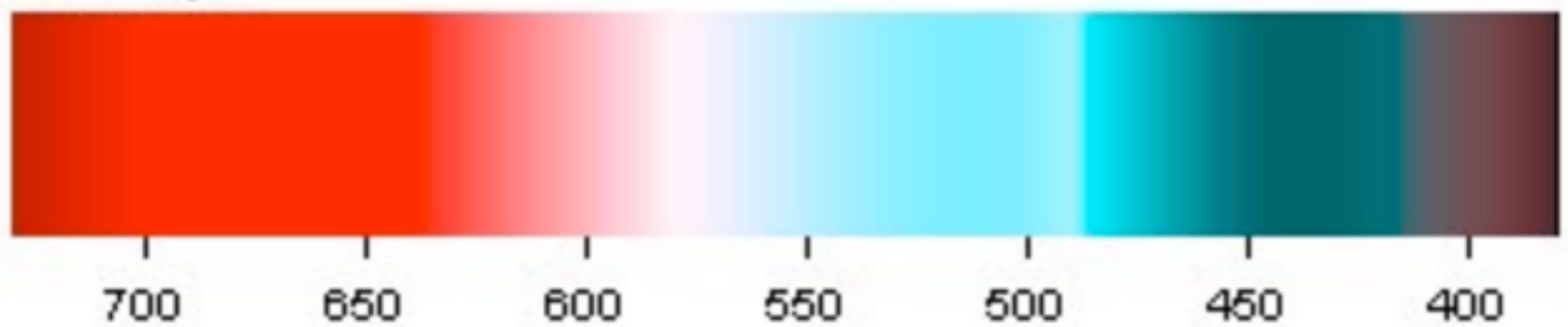
## Protanopia



## Deuteranopia



## Tritanopia



WHAT ARE THE  
PRIMARY COLORS?

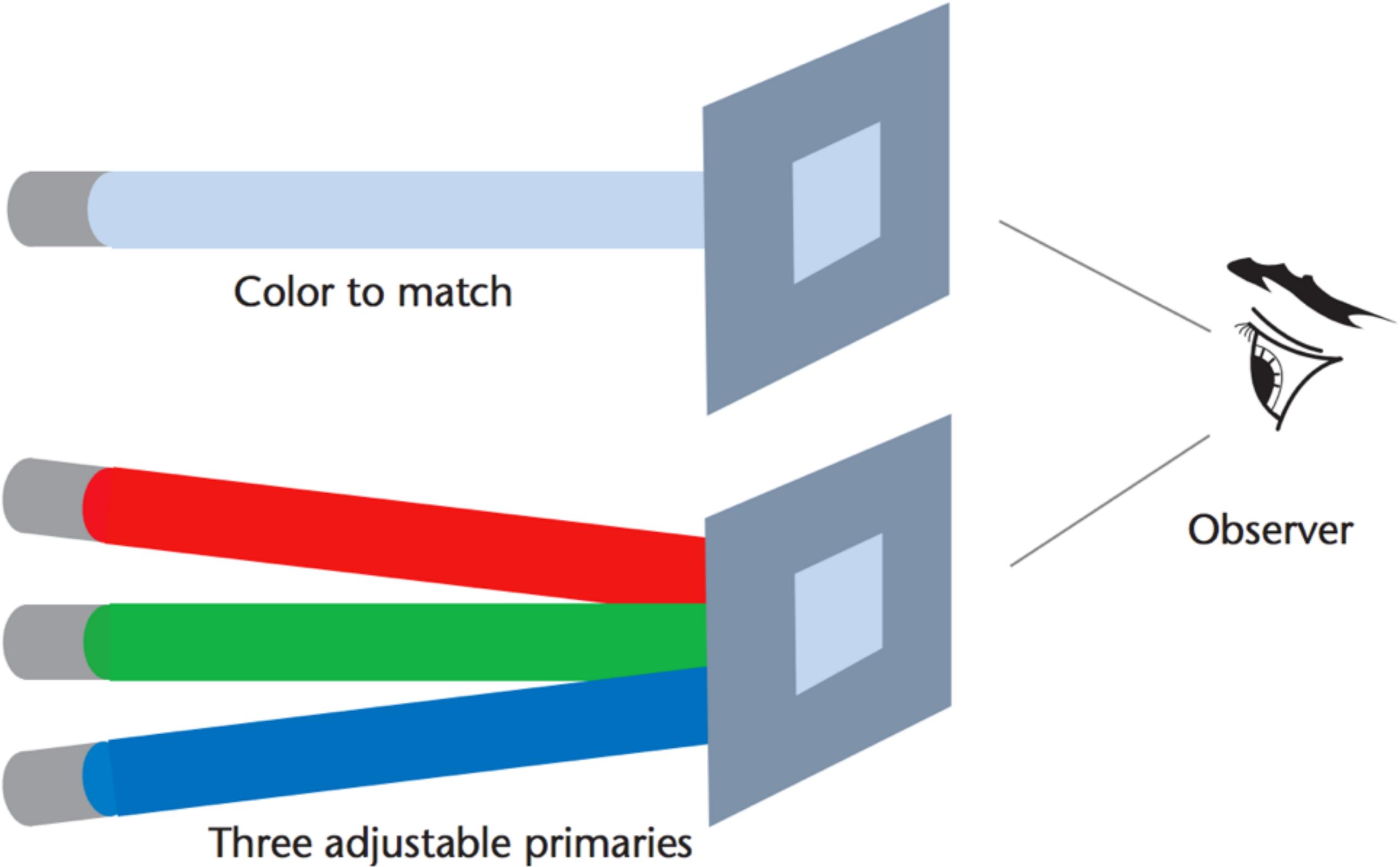
# WHAT ARE THE PRIMARY COLORS?

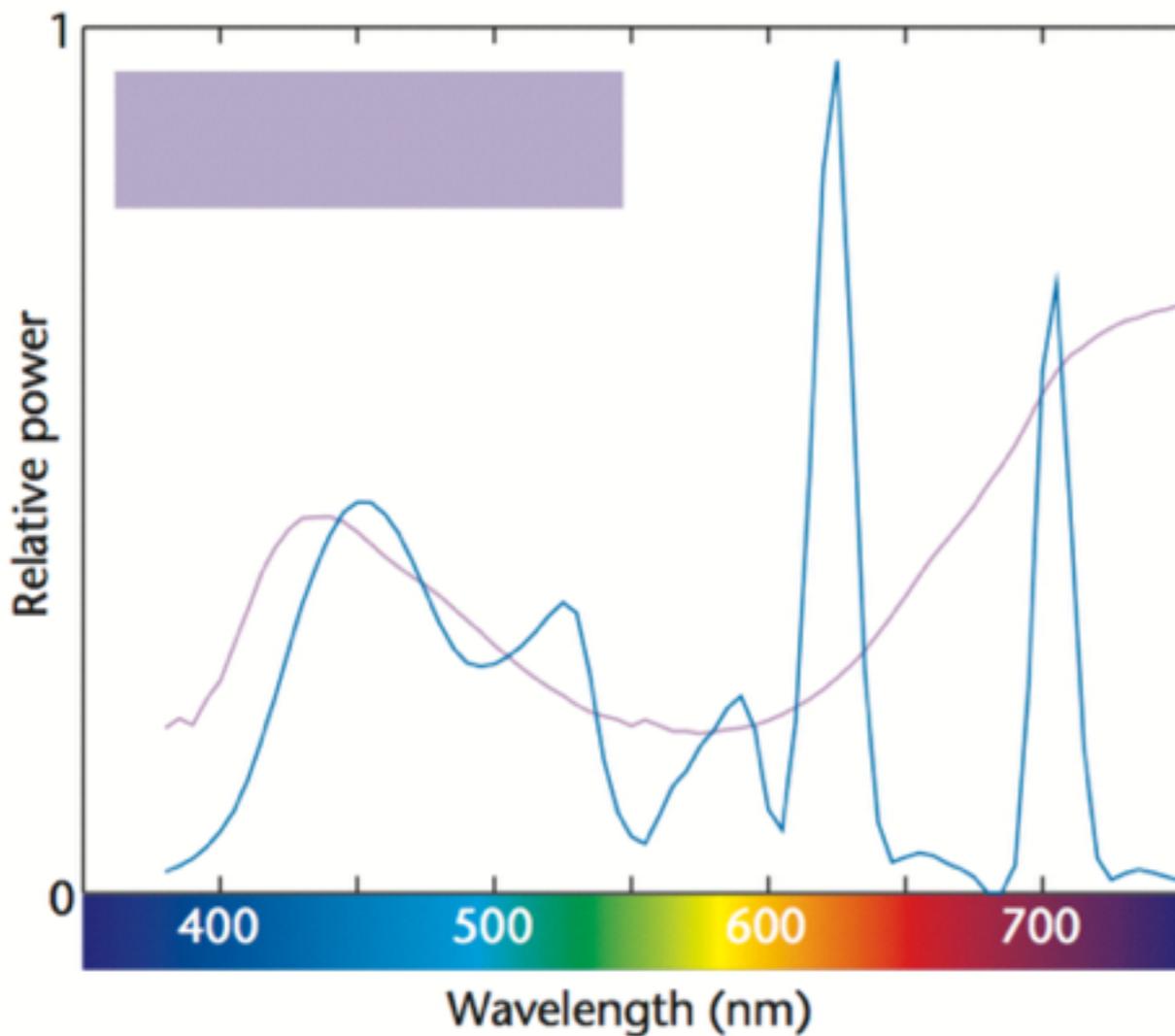
1. red, green, blue
2. red, yellow, blue
3. orange, green, violet
4. cyan, magenta, yellow

# WHAT ARE THE PRIMARY COLORS?

1. red, green, blue
2. red, yellow, blue
3. orange, green, violet
4. cyan, magenta, yellow
5. **all of the above**

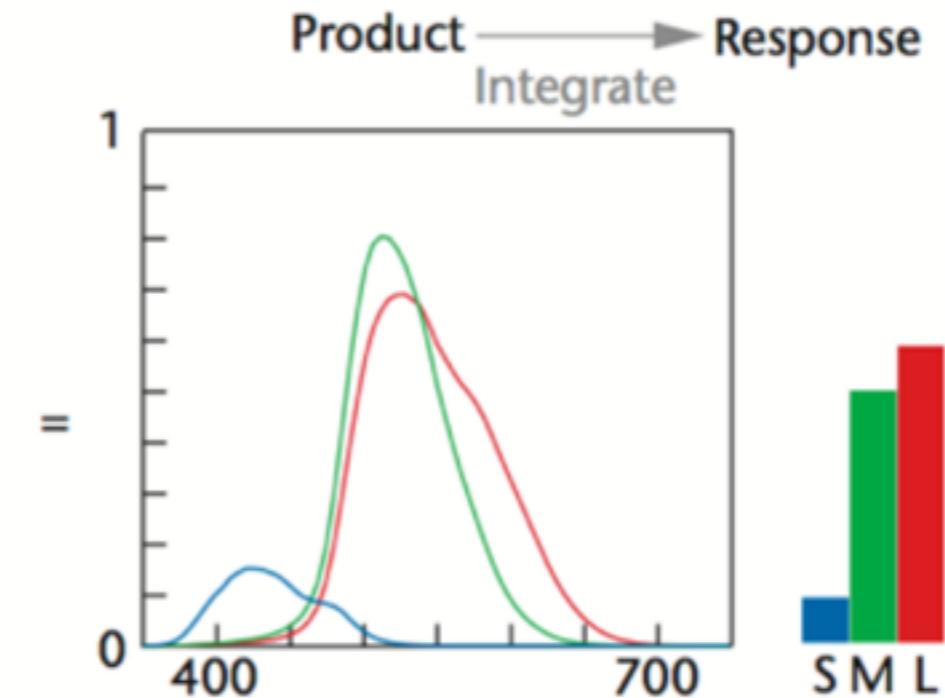
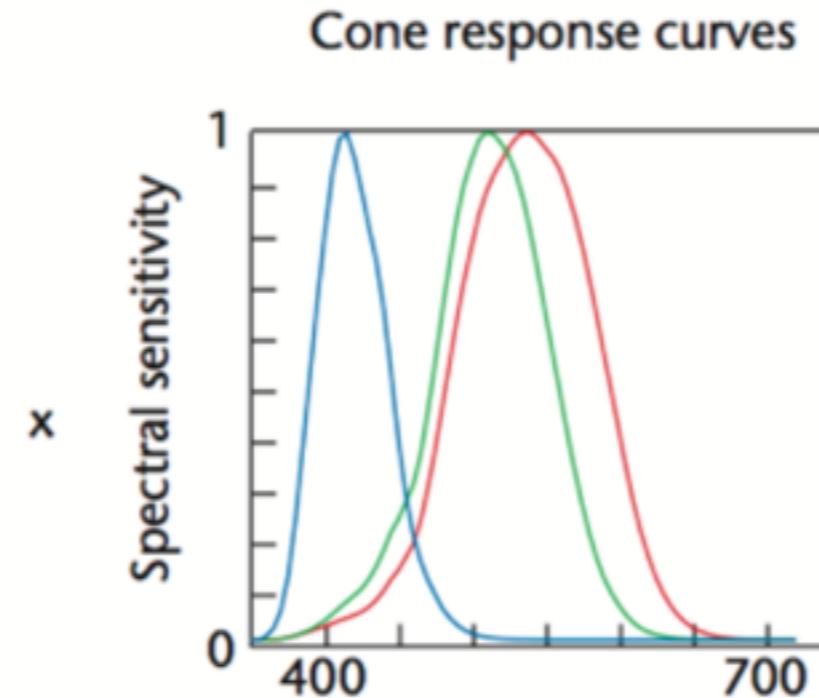
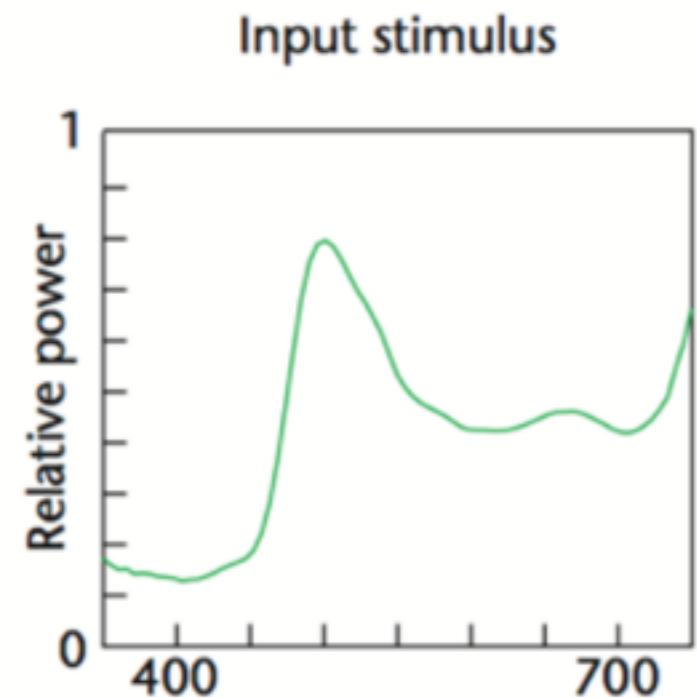
Any three “independent”  
ways of combining color  
works (!)

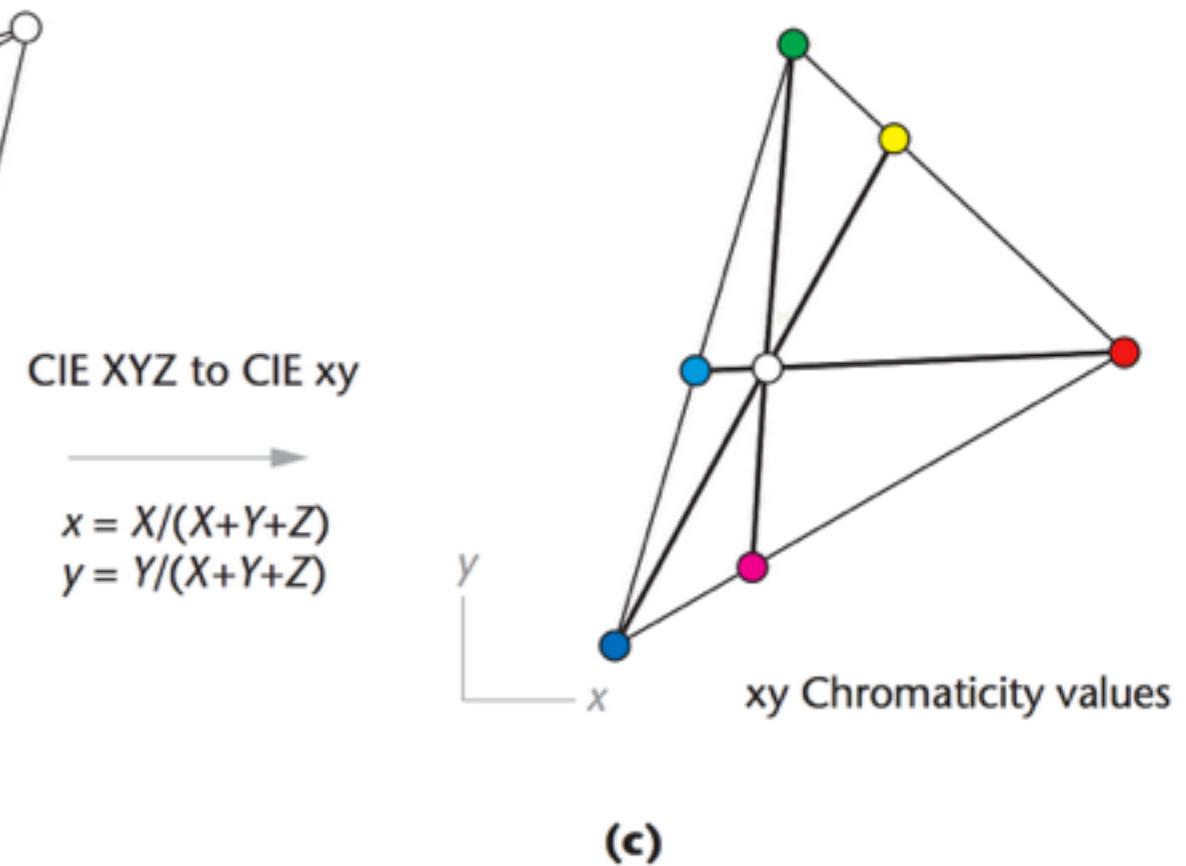
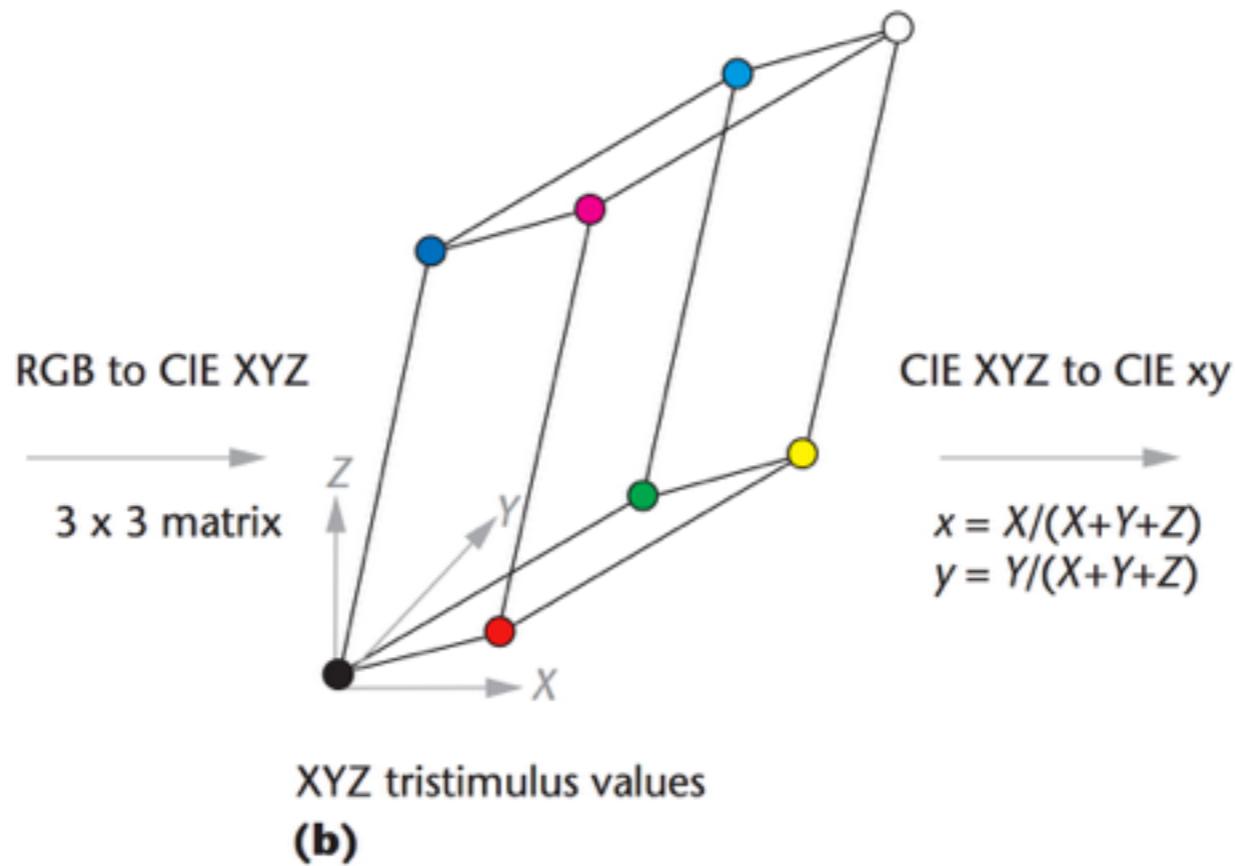
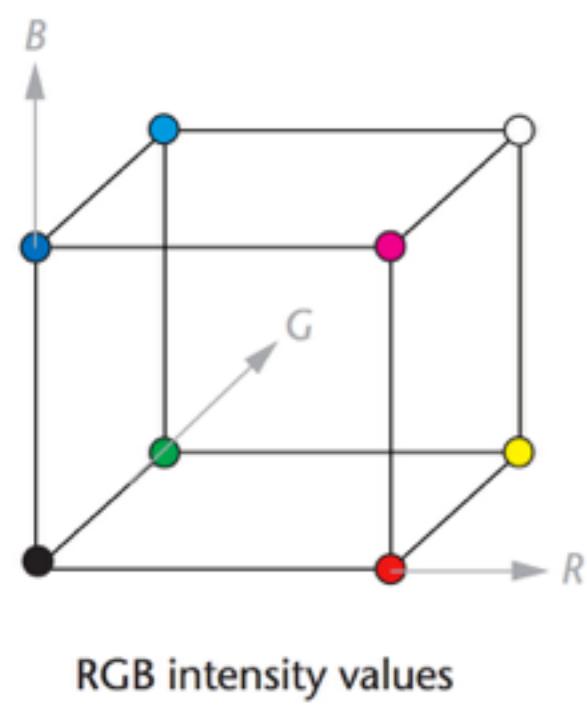


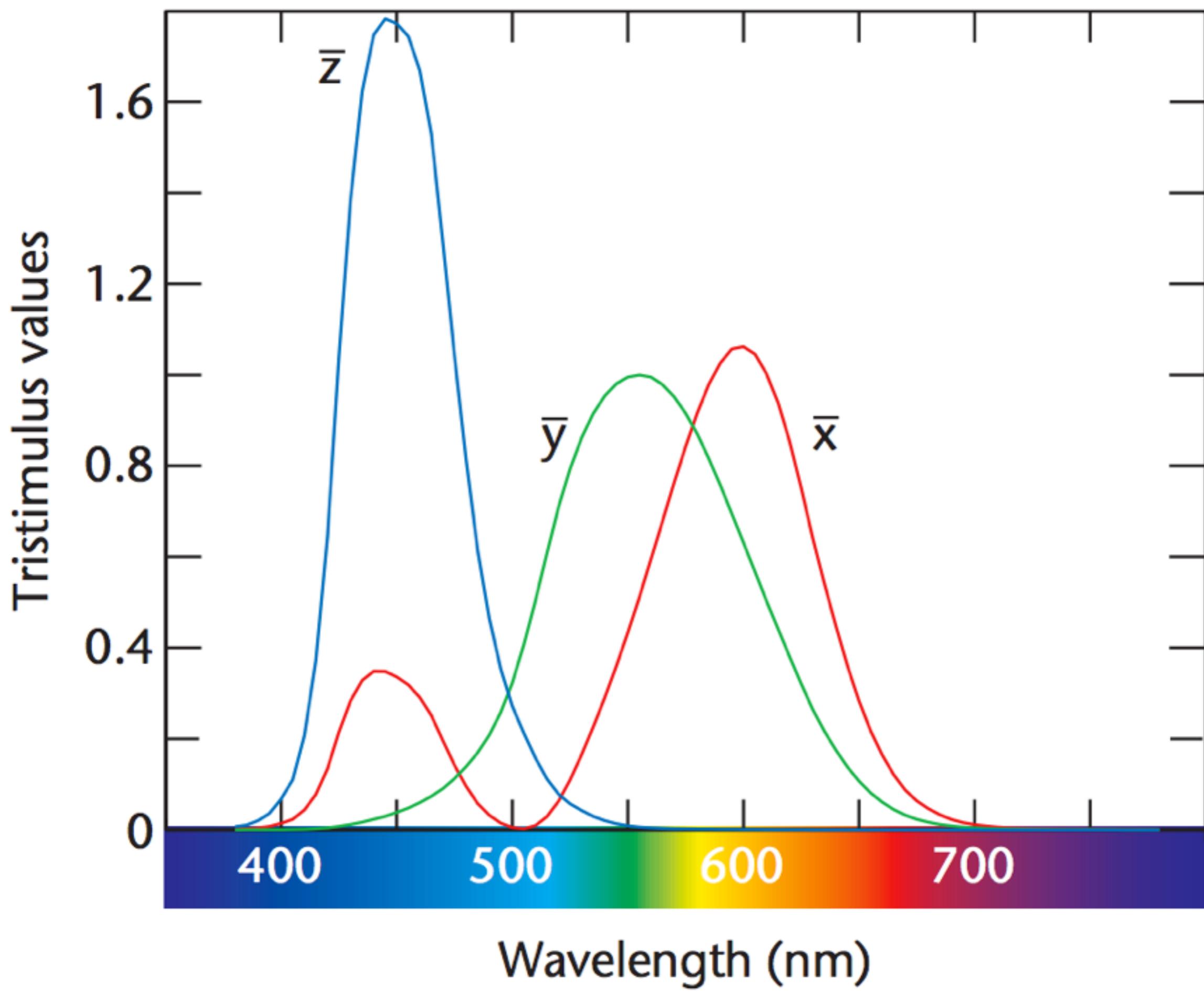


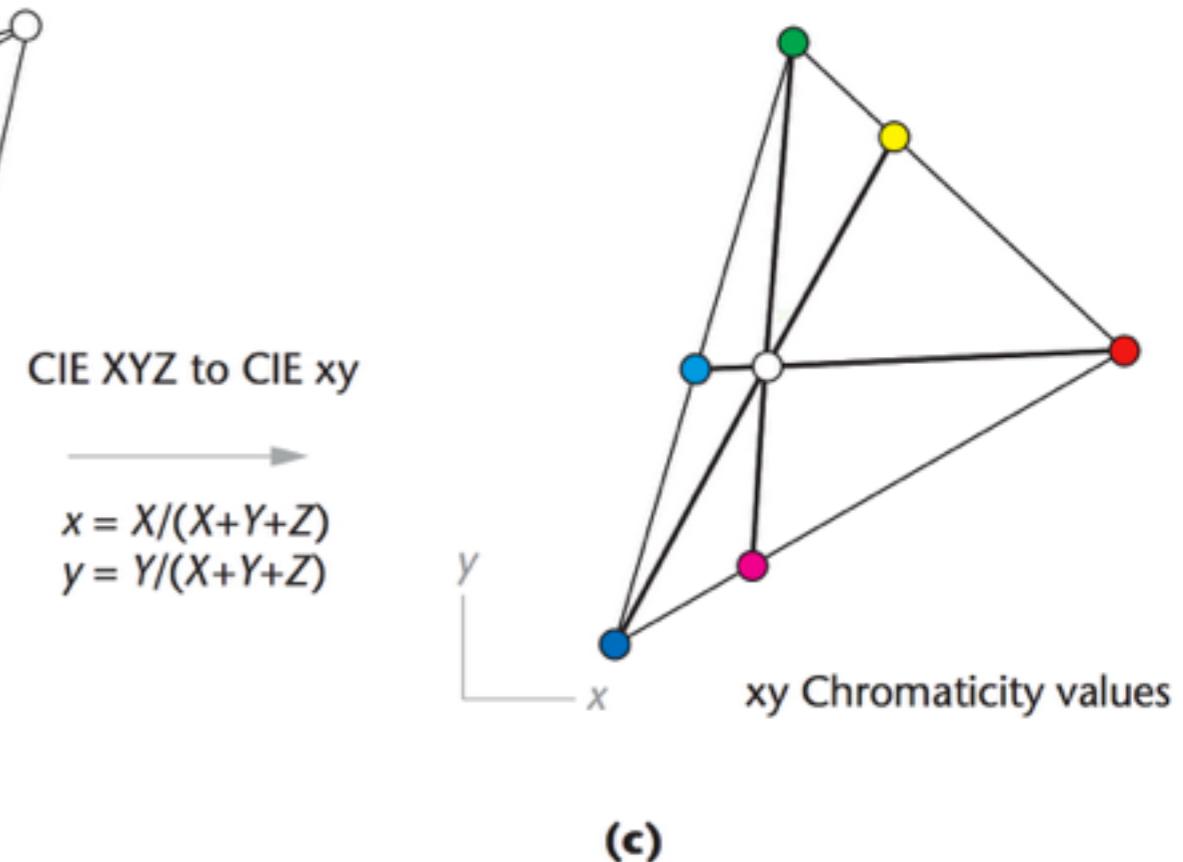
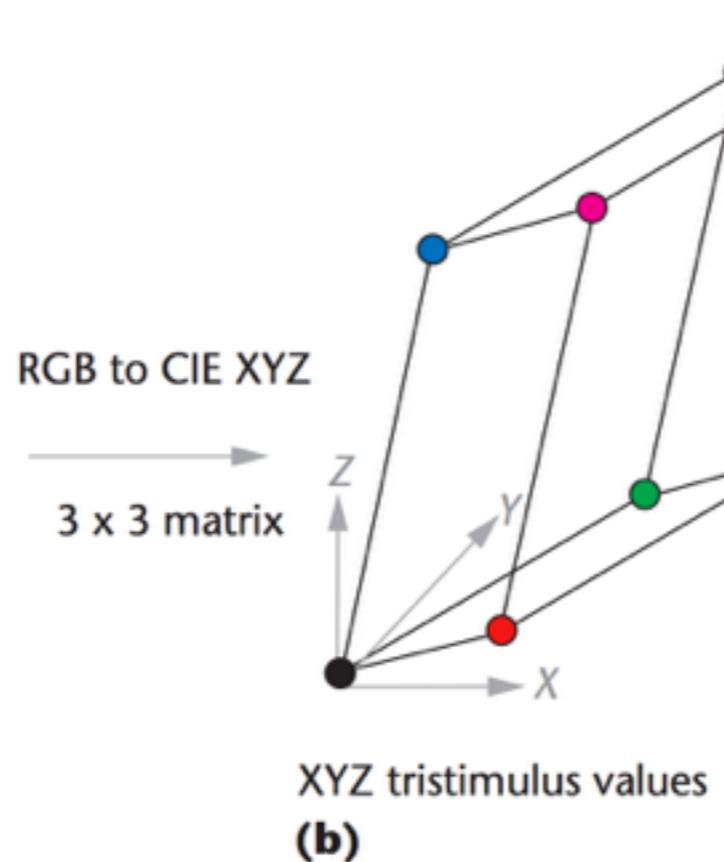
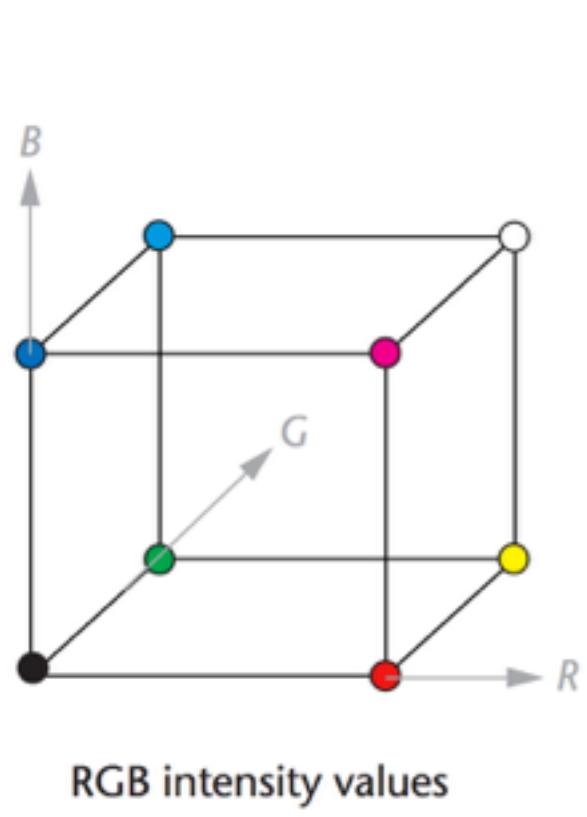
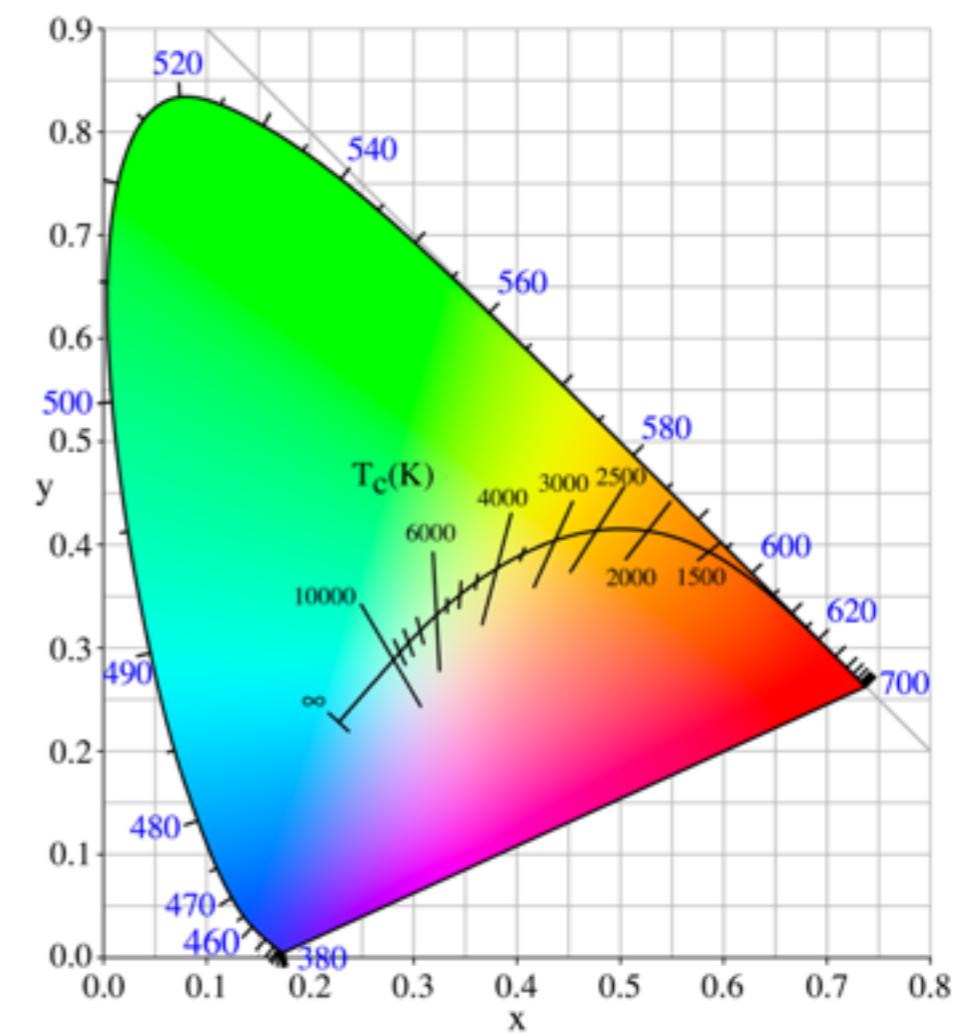
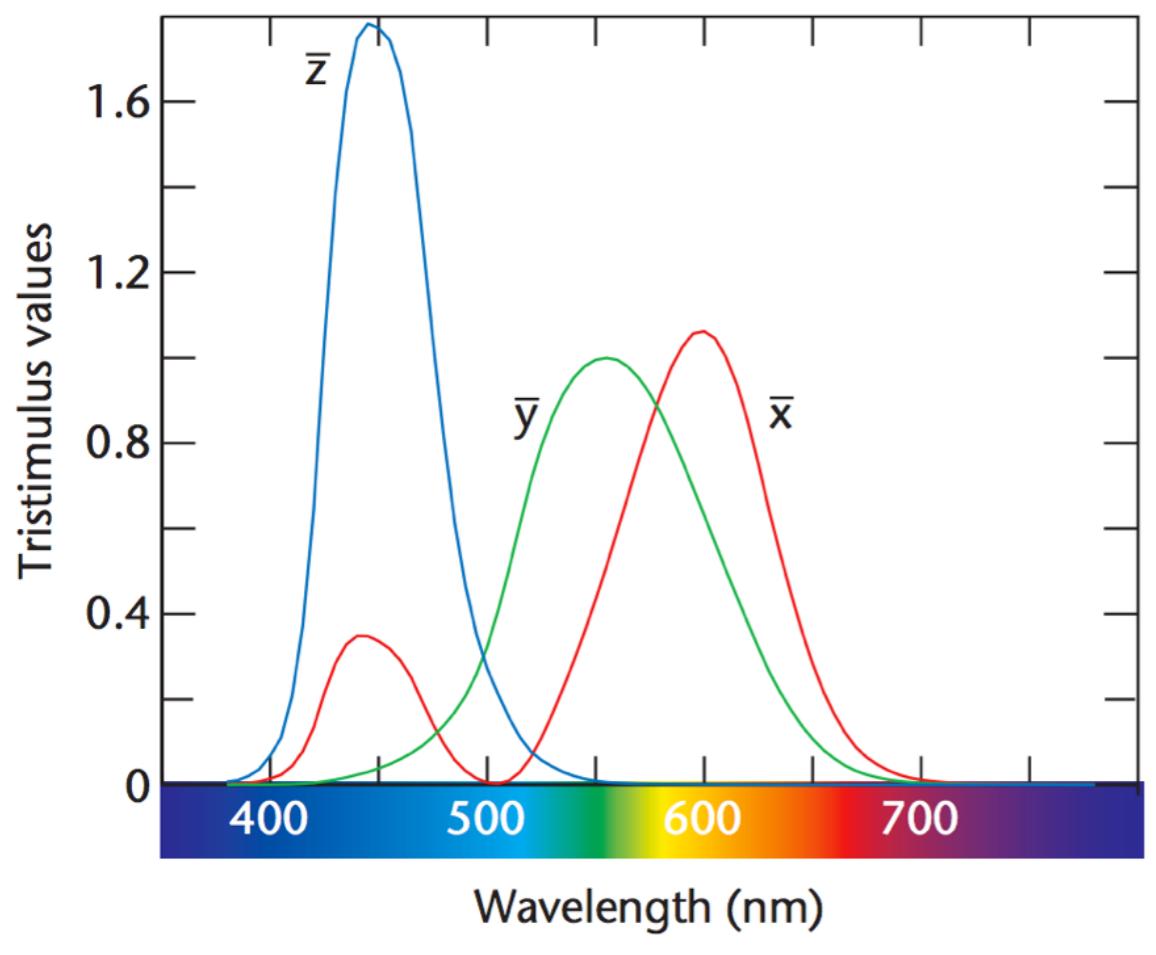
**same** three numbers,  
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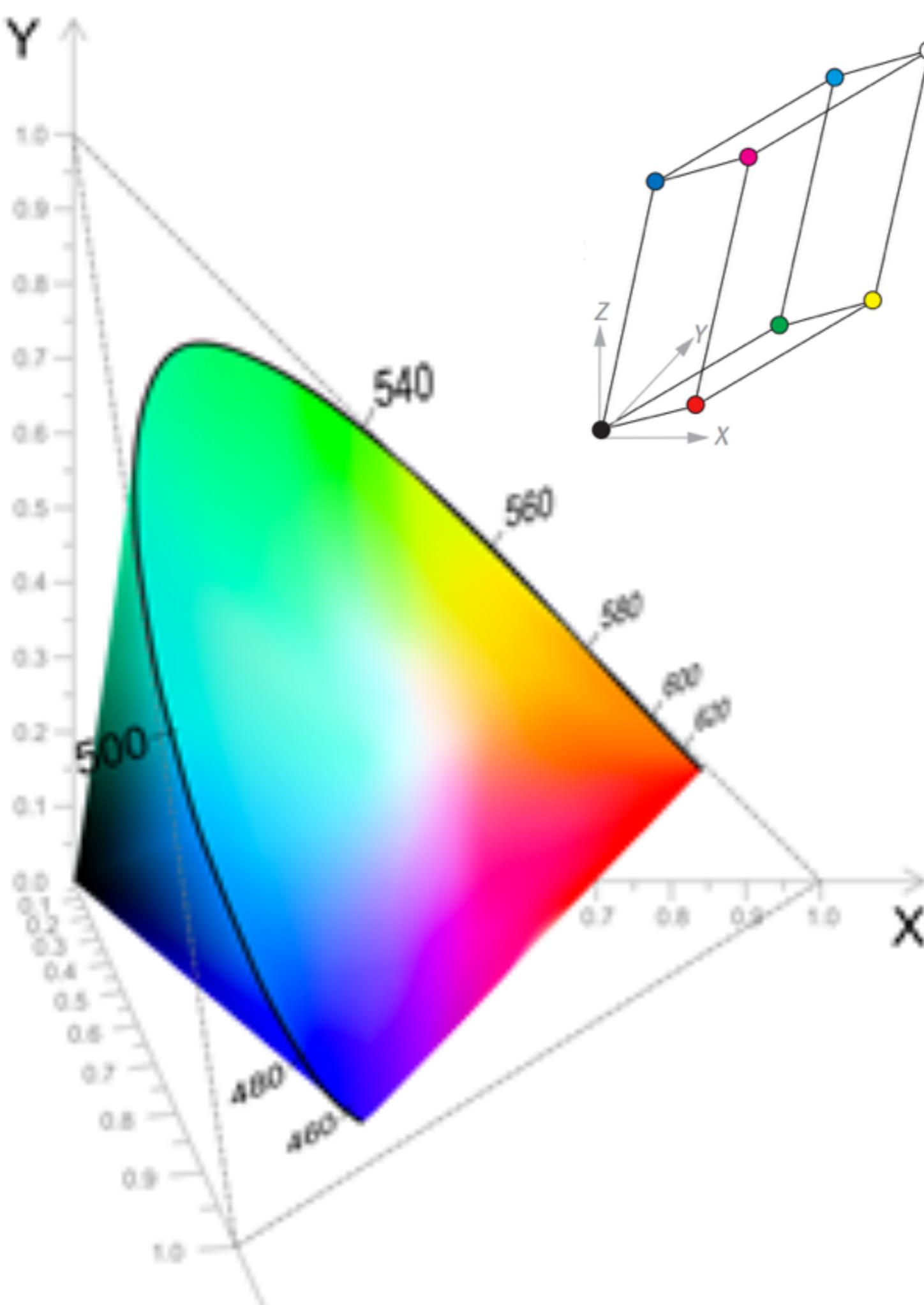
# METAMERISM







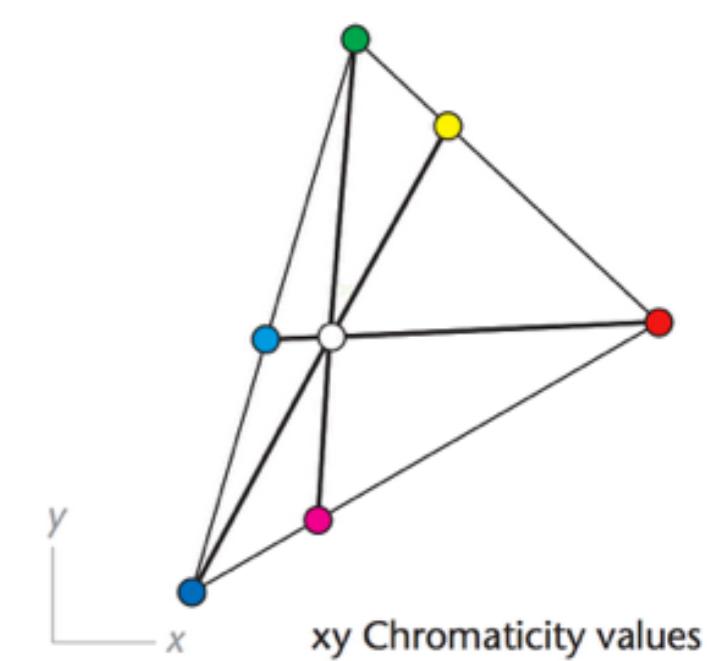




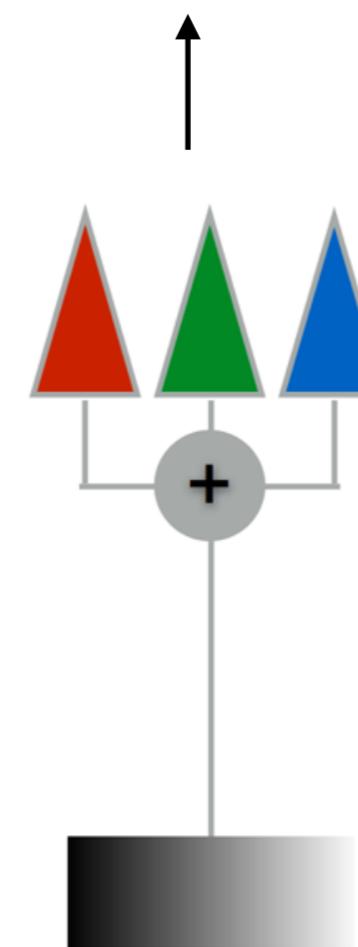
CIE XYZ to CIE xy

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

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

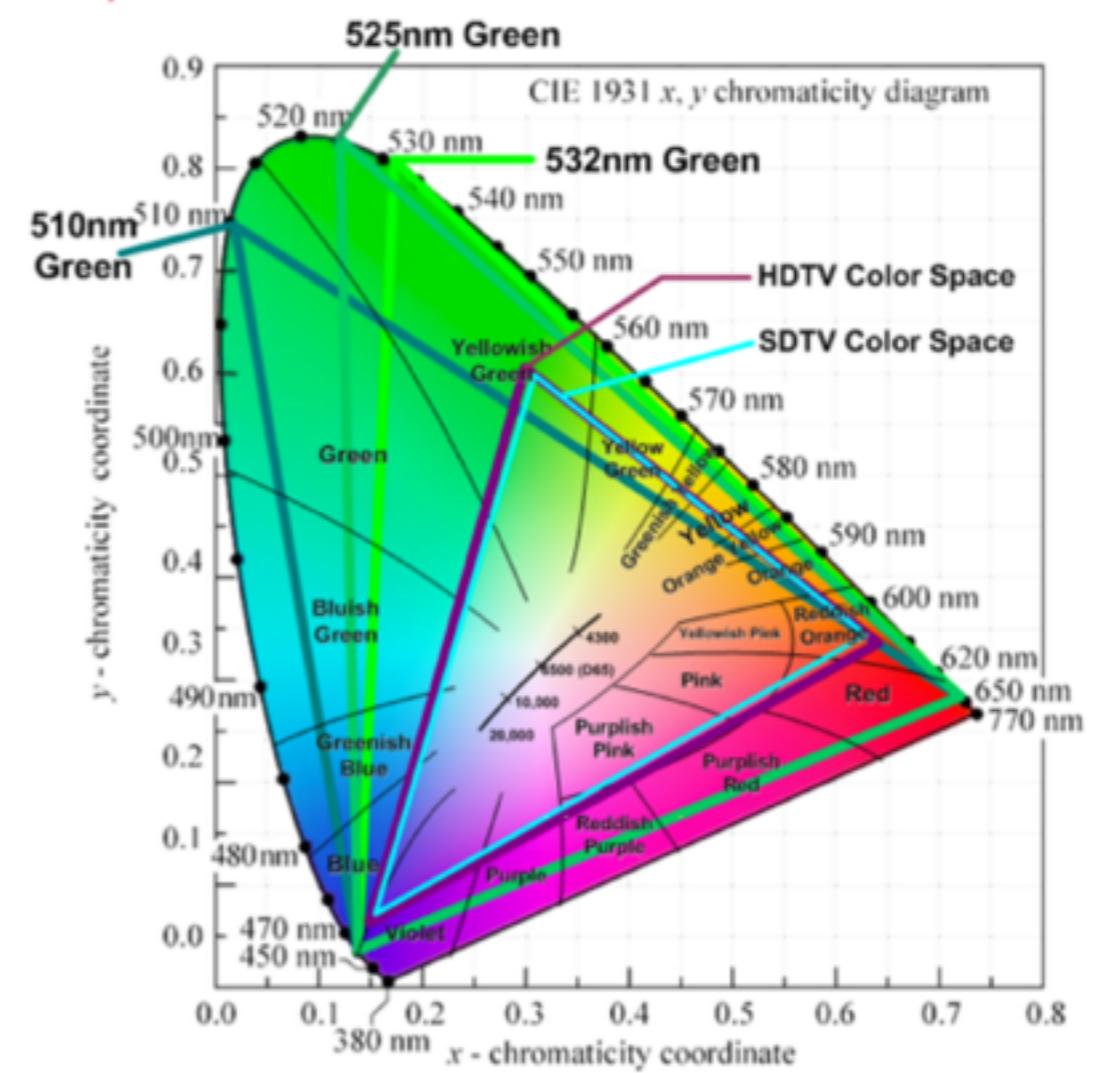
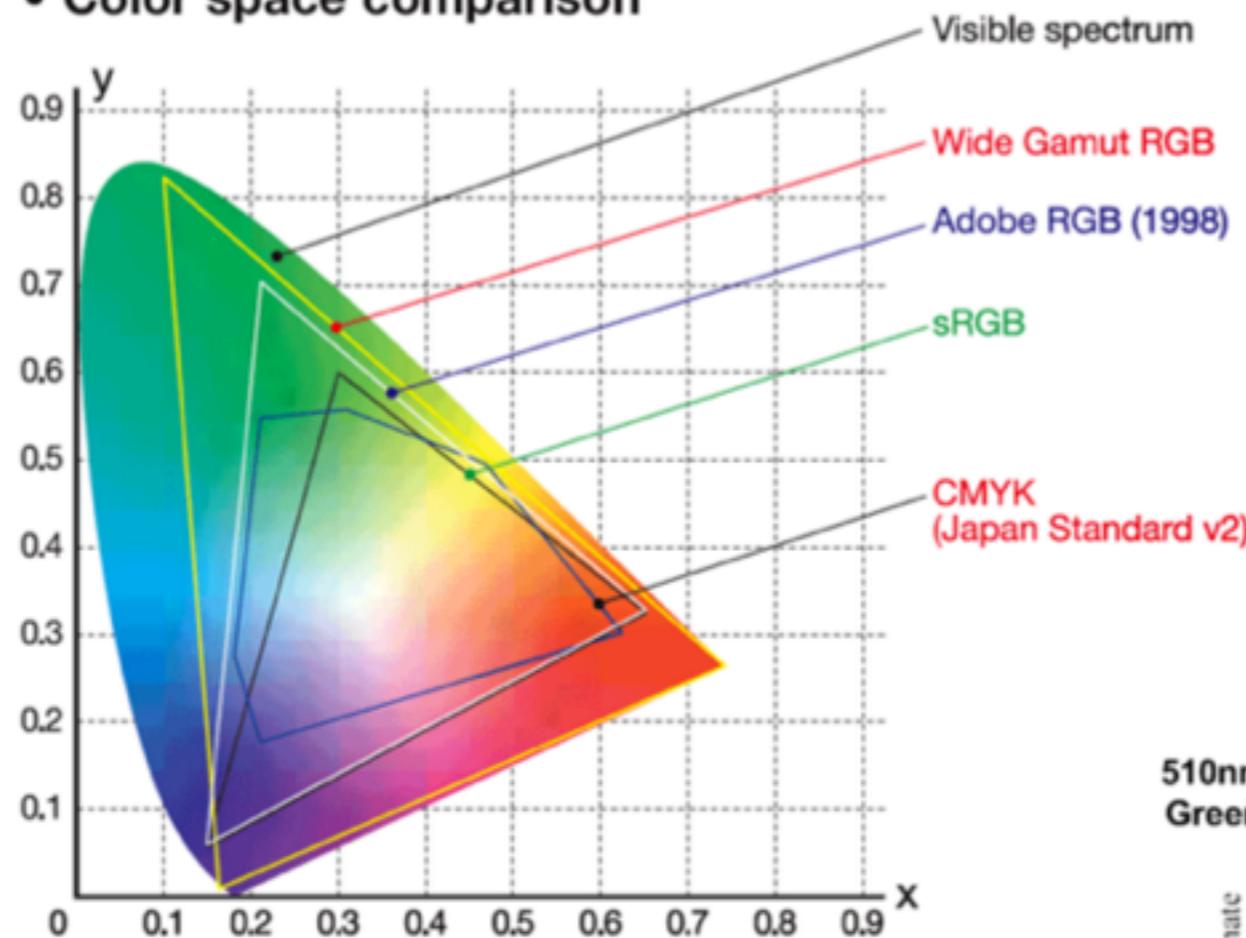


Dividing by  
“luminance”



# COLOR GAMUTS

- Color space comparison

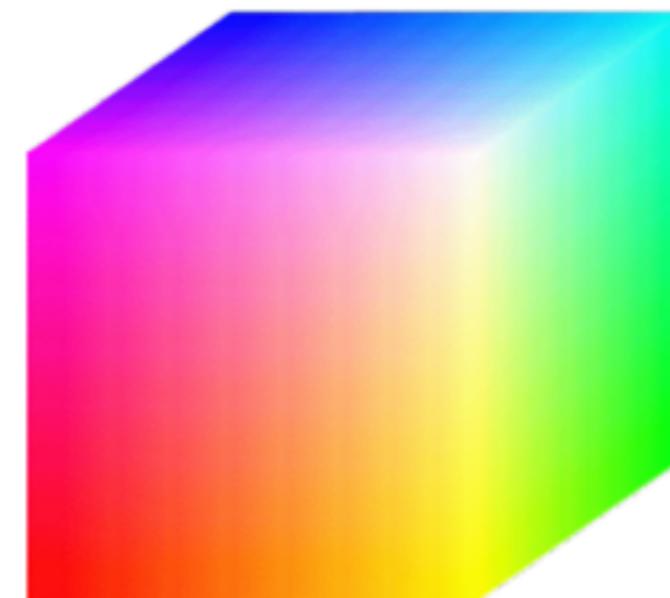
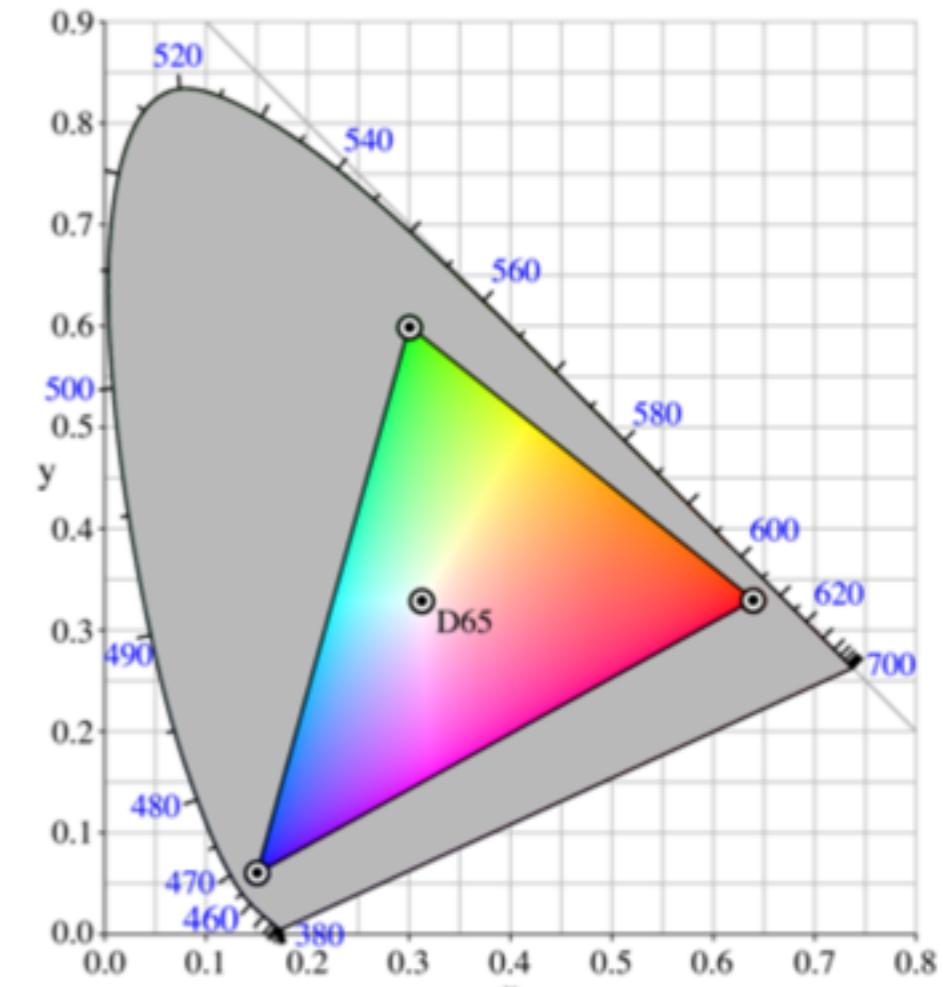
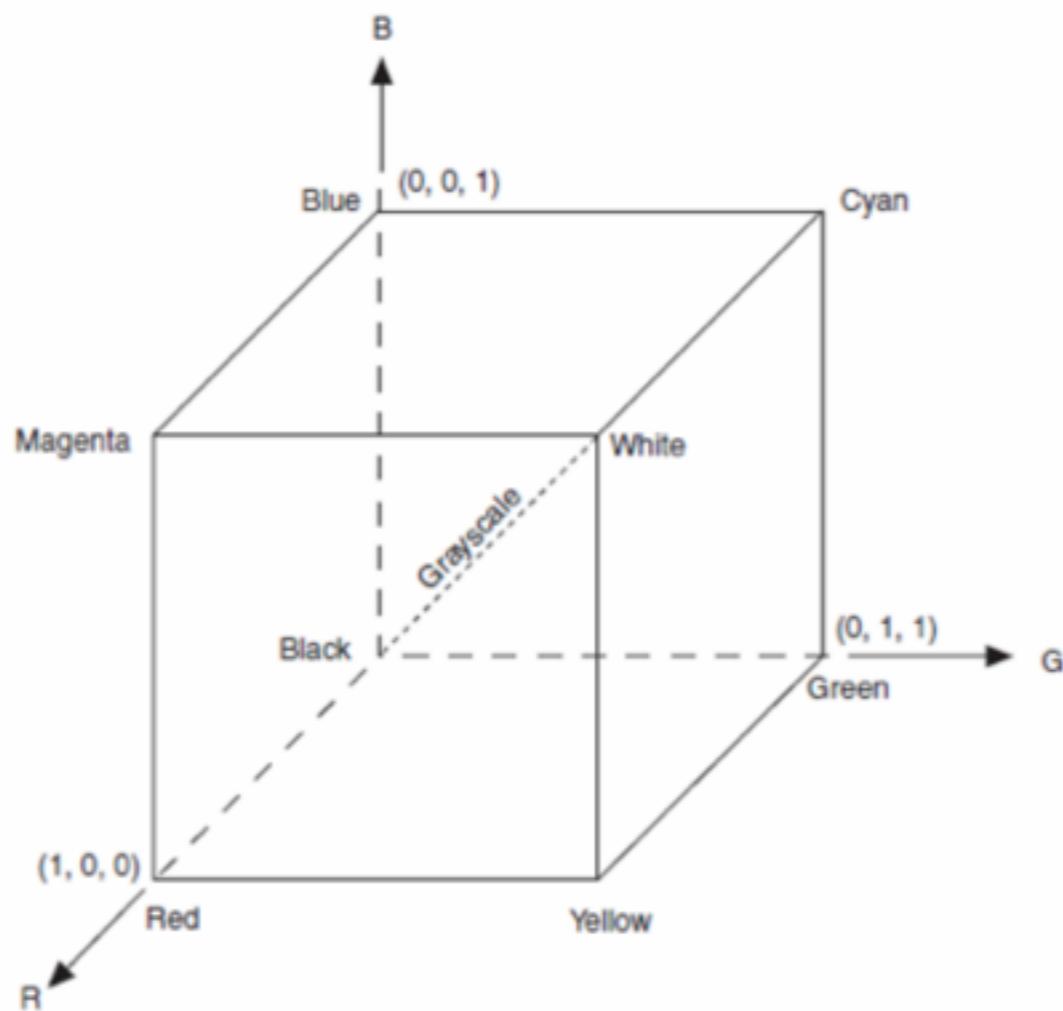


# COLOR SPACES

DEVICE DEPENDENT

# RGB

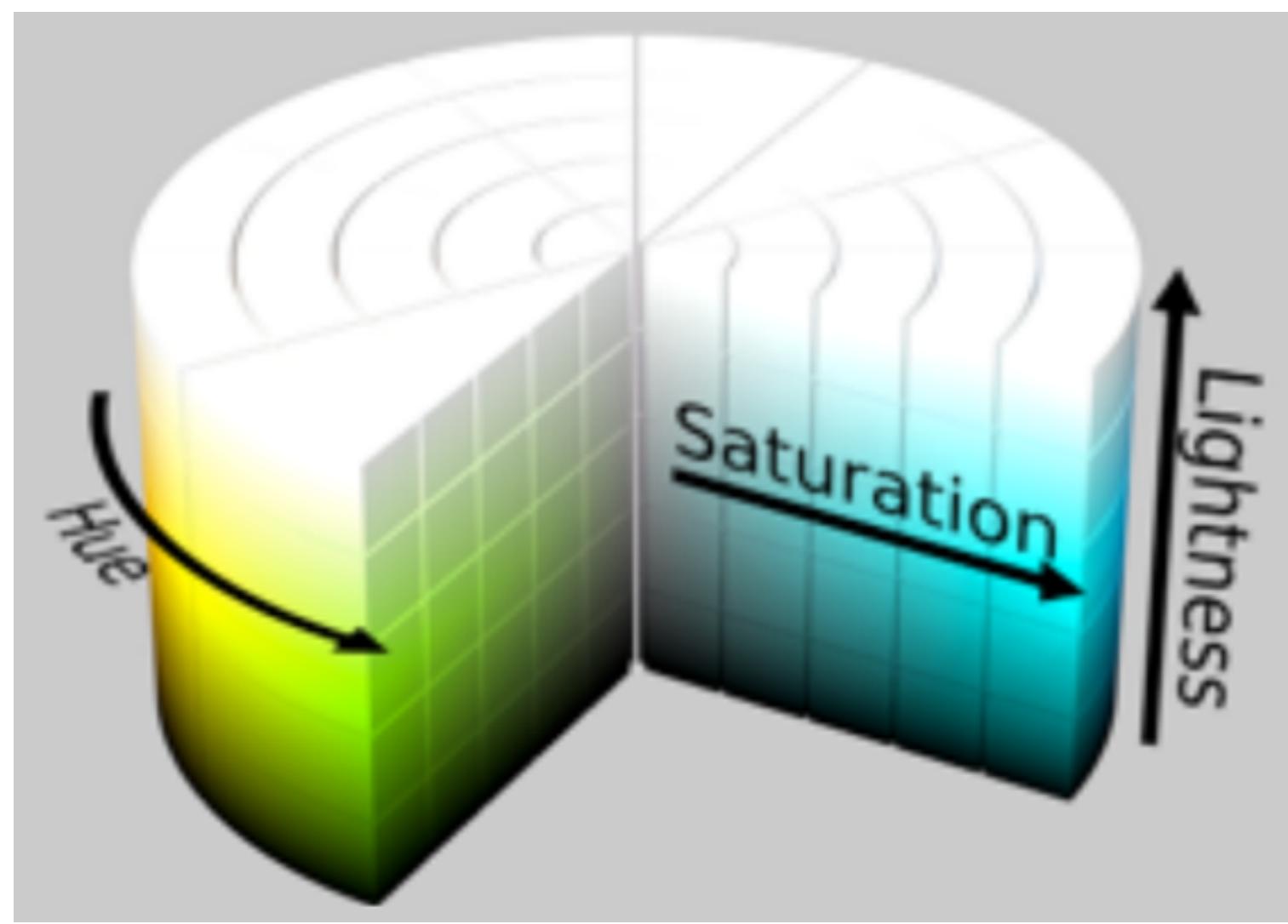
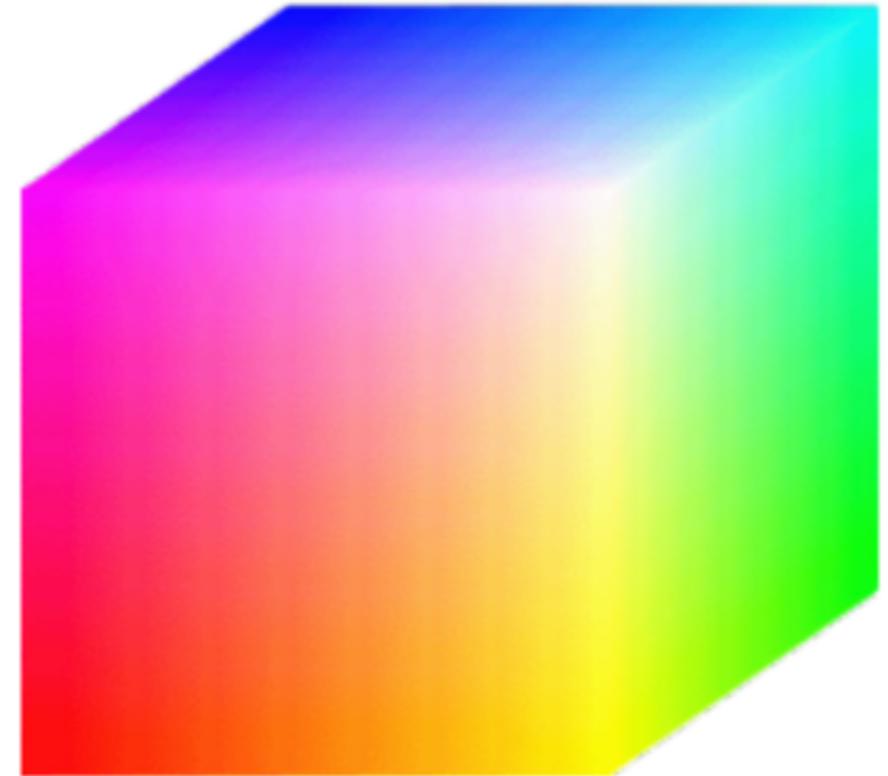
- Device-centric
- What programs want,  
**not** what humans want



D65: midday sun in Western Europe

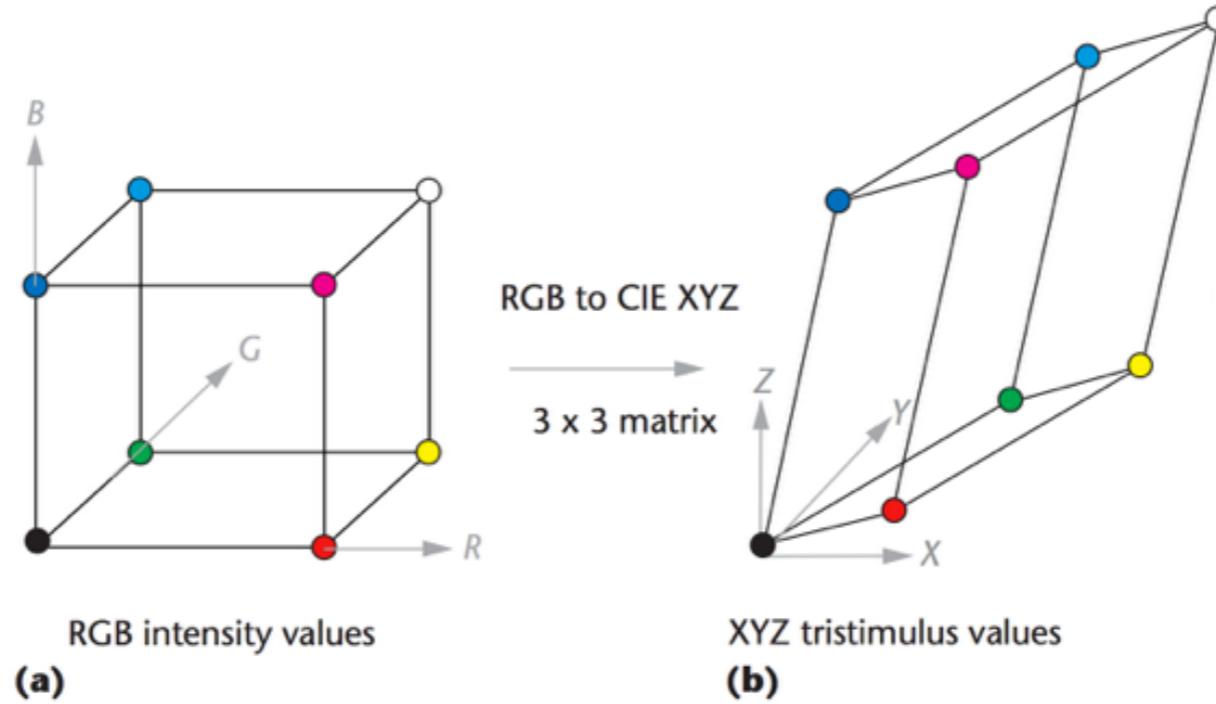
# HSL

- Still device-centric



# DEVICE INDEPENDENT

# XYZ Color Space



- “Optically linear”
- Designed so that all visible colors have positive coordinates, and Y is “luminance”

# CIE Lab Color Space

- “Perceptually uniform”
  - Euclidean distance roughly corresponds to perceptual distance (**very useful!**)
- L is “luminance”, a and b are opponent colors

$$L^* = 116f(Y/Y_n) - 16$$

$$a^* = 500 [f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200 [f(Y/Y_n) - f(Z/Z_n)]$$

where

$$f(t) = \begin{cases} t^{1/3} & \text{if } t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{4}{29} & \text{otherwise} \end{cases}$$

# Polar Lab (or HCL)

- “Perceptually uniform”, like Lab
- Transform ab to polar coordinates: radius is Chroma, Angle is Hue
- Conversion to/from RGB is complicated, but distances in HCL make sense, **and** it makes sense for humans
  - Like HSL, but good. All else being equal, try HCL first

# Demos

[http://cscheid.net/static/20120216/hsv frame.html](http://cscheid.net/static/20120216/hsv_frame.html)

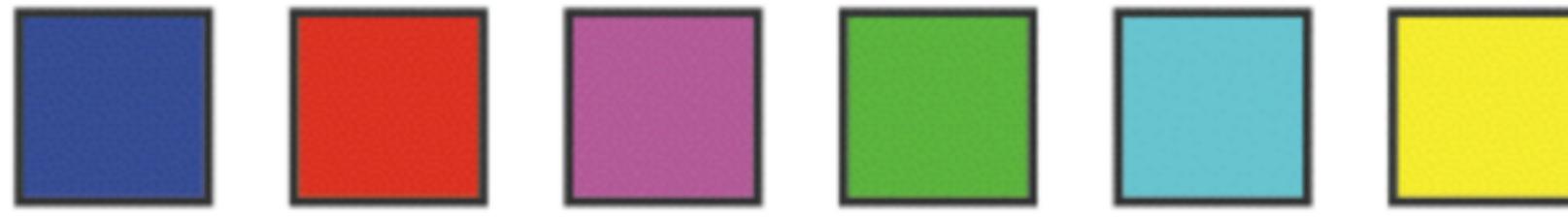
[http://cscheid.net/static/20120216/xyz frame.html](http://cscheid.net/static/20120216/xyz_frame.html)

[http://cscheid.net/static/20120216/luv frame.html](http://cscheid.net/static/20120216/luv_frame.html)

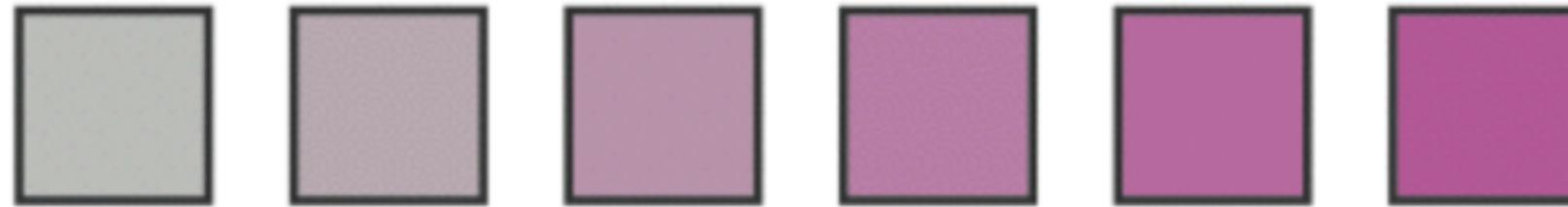
[http://cscheid.net/static/20120216/hcl frame.html](http://cscheid.net/static/20120216/hcl_frame.html)

[https://cscheid.net/courses/fal16/cs444/lectures/lecture8/  
colors.html](https://cscheid.net/courses/fal16/cs444/lectures/lecture8/colors.html)

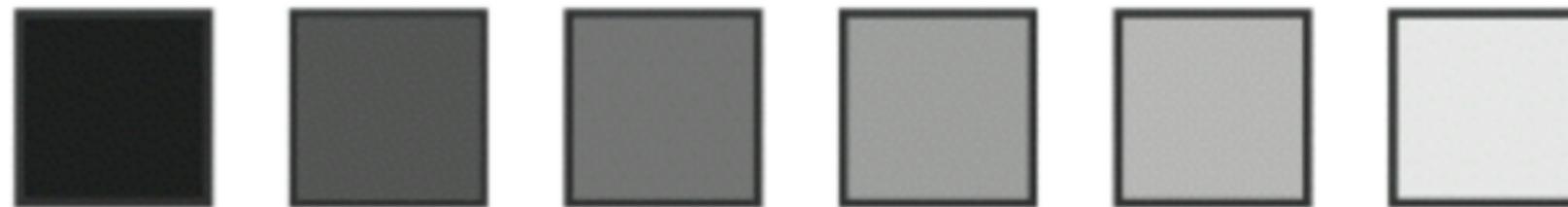
# Let's use consistent names in class



Hue



Saturation



Luminance