

Data Visualization Principles: Color

CSC444

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

Outlook

Mechanics

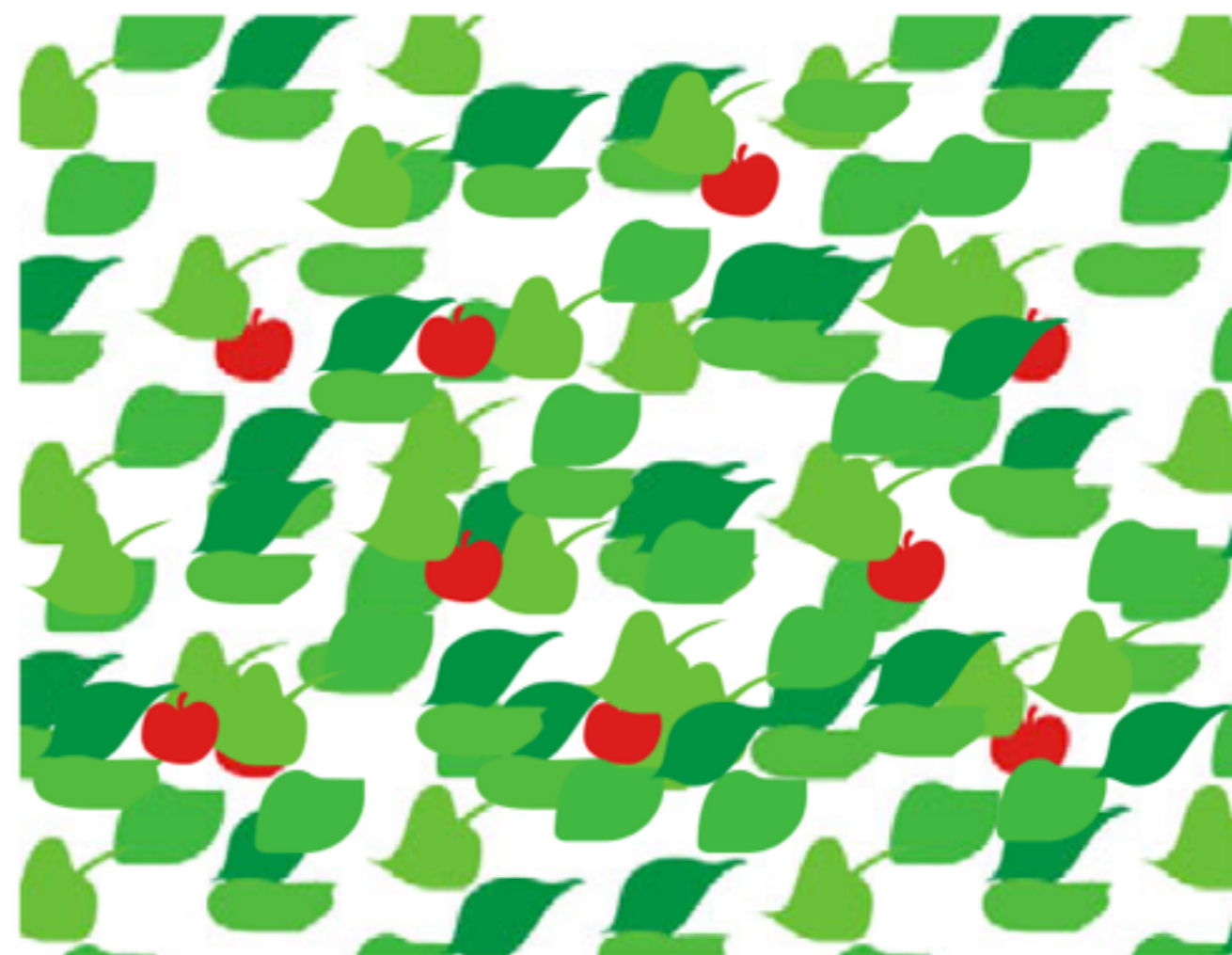
Principles

Techniques

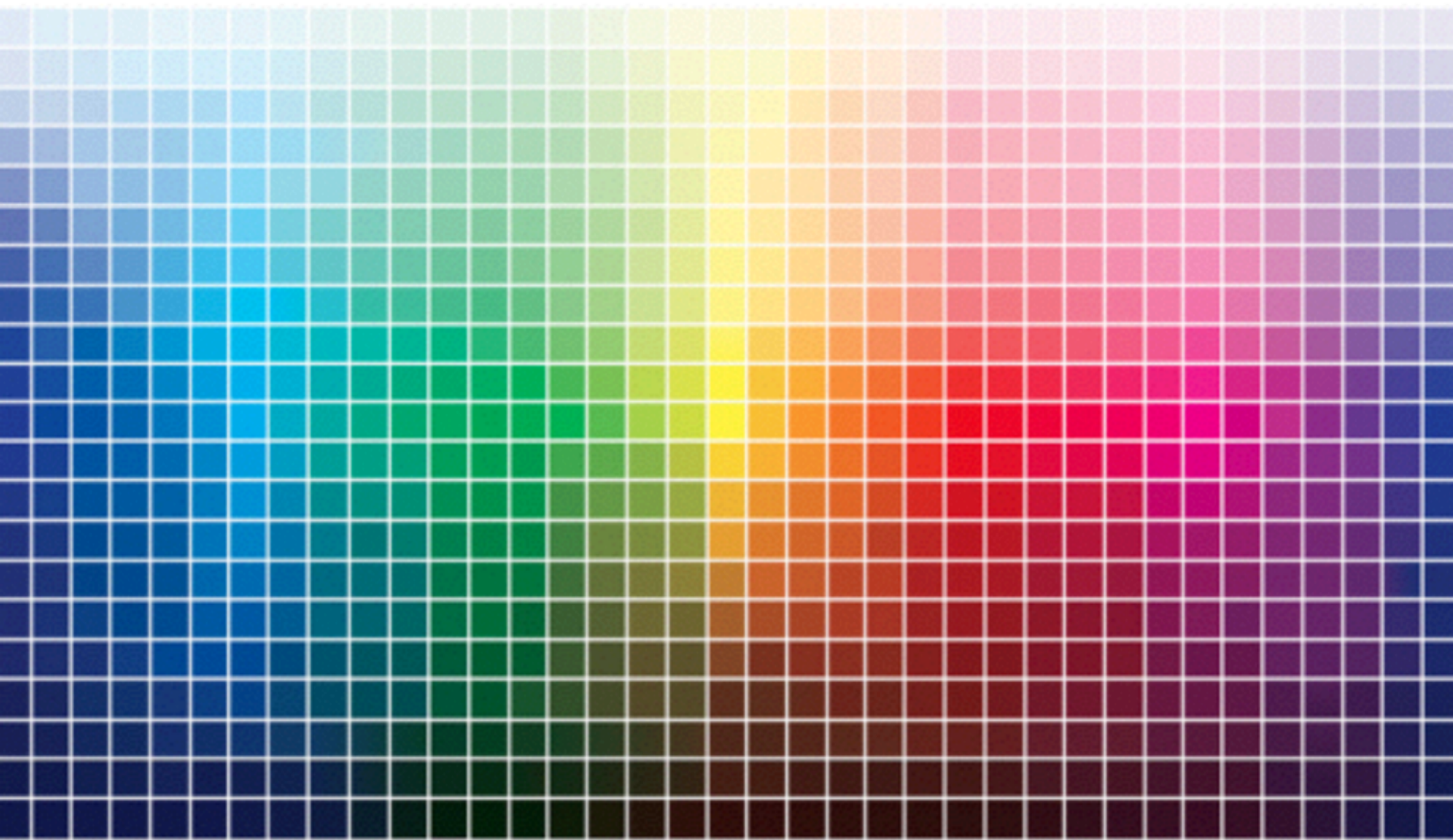
Reading

- “Representing Colors as Three Numbers”, Stone
- Rainbow Colormap (Still) Considered Harmful, Borland and Russell.
- CSC544:
 - Face-based Luminance Matching... Kindlmann et al.

WHY COLOR?



Colin Ware, Information Visualization



LIGHT AND COLOR

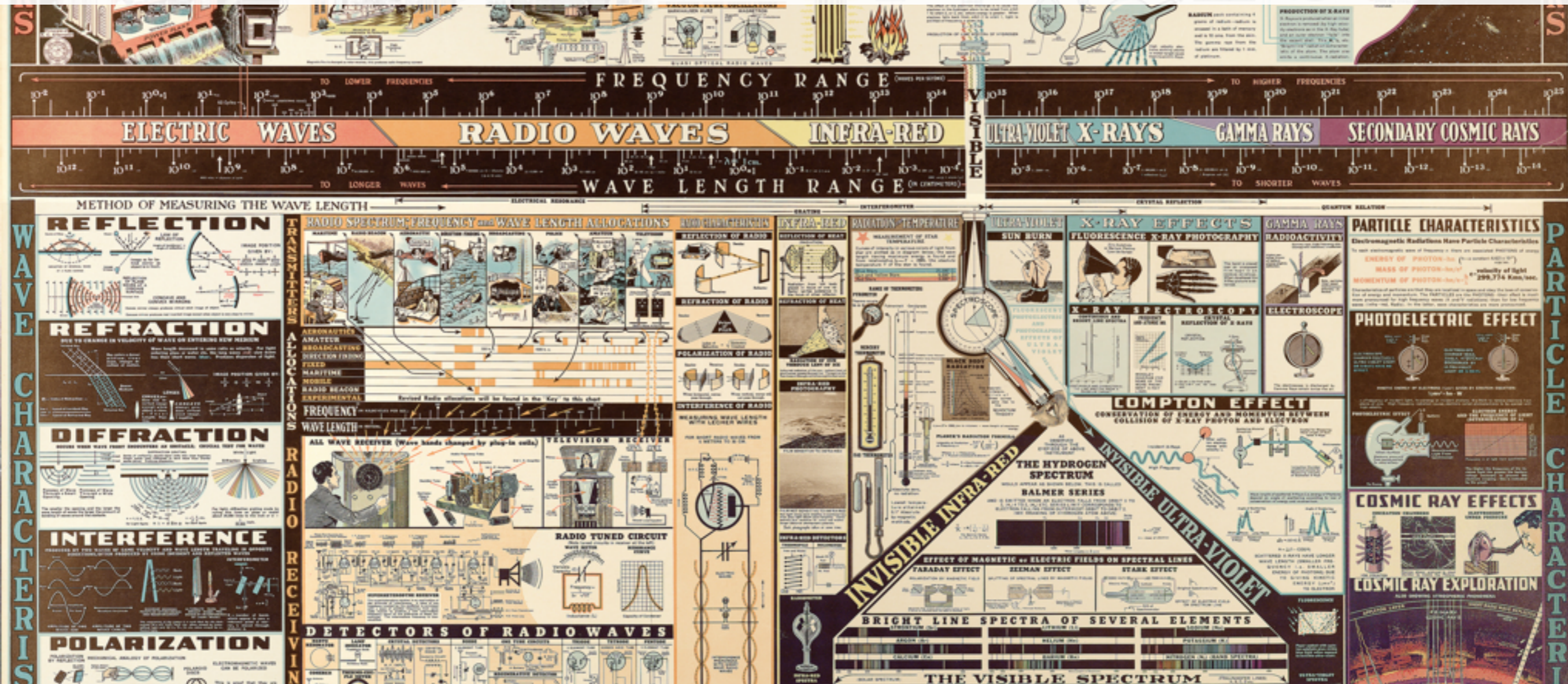
How does the yellow from your **laptop display** “equal” the yellow from the **sun**, and that from a **painting**?

How does light work?

- Each photon has a “wavelength”, roughly the frequency in 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?



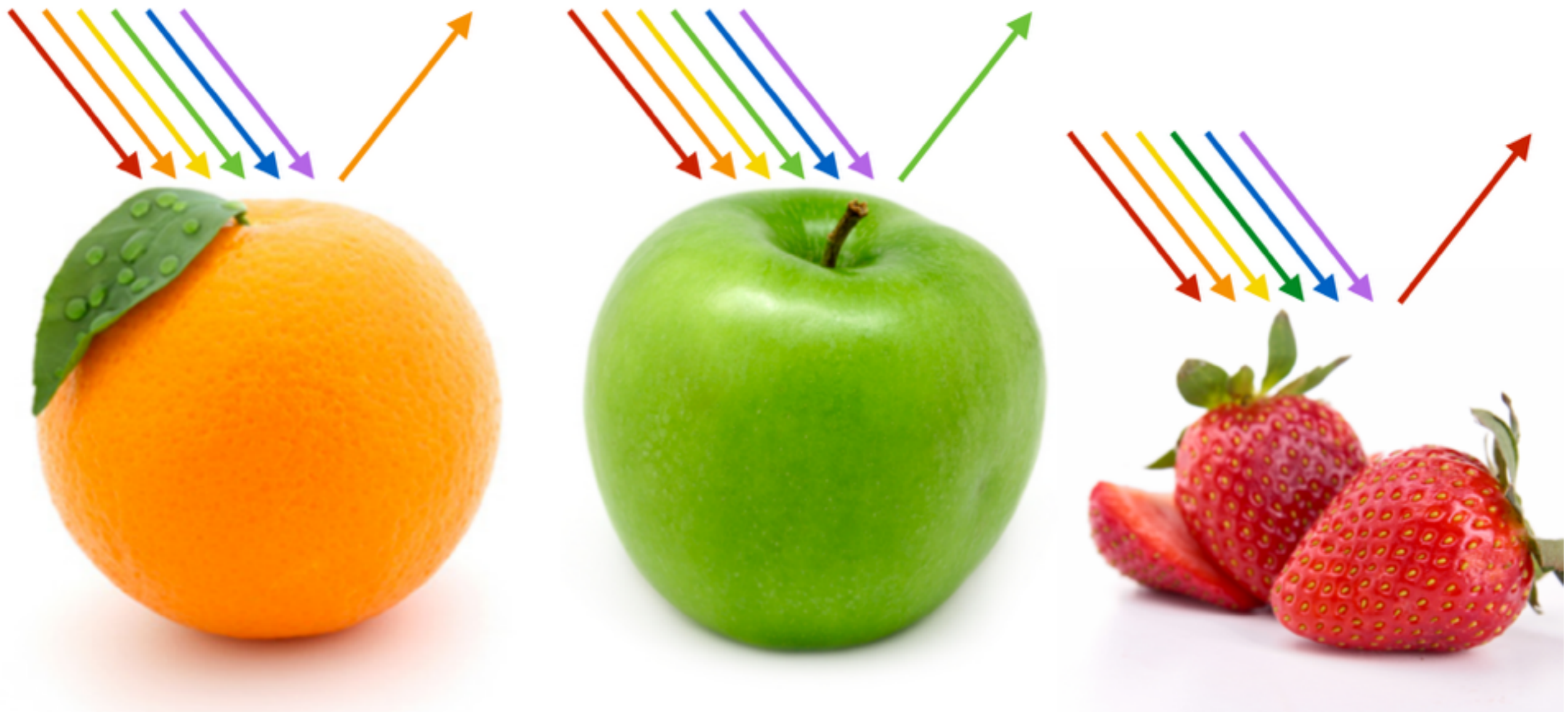
<https://www.flickr.com/photos/llnl/9403051123/>

How does light work?

<http://www.chemistryland.com/CHM107Lab/Exp7/Spectroscope/Spectroscope.html>

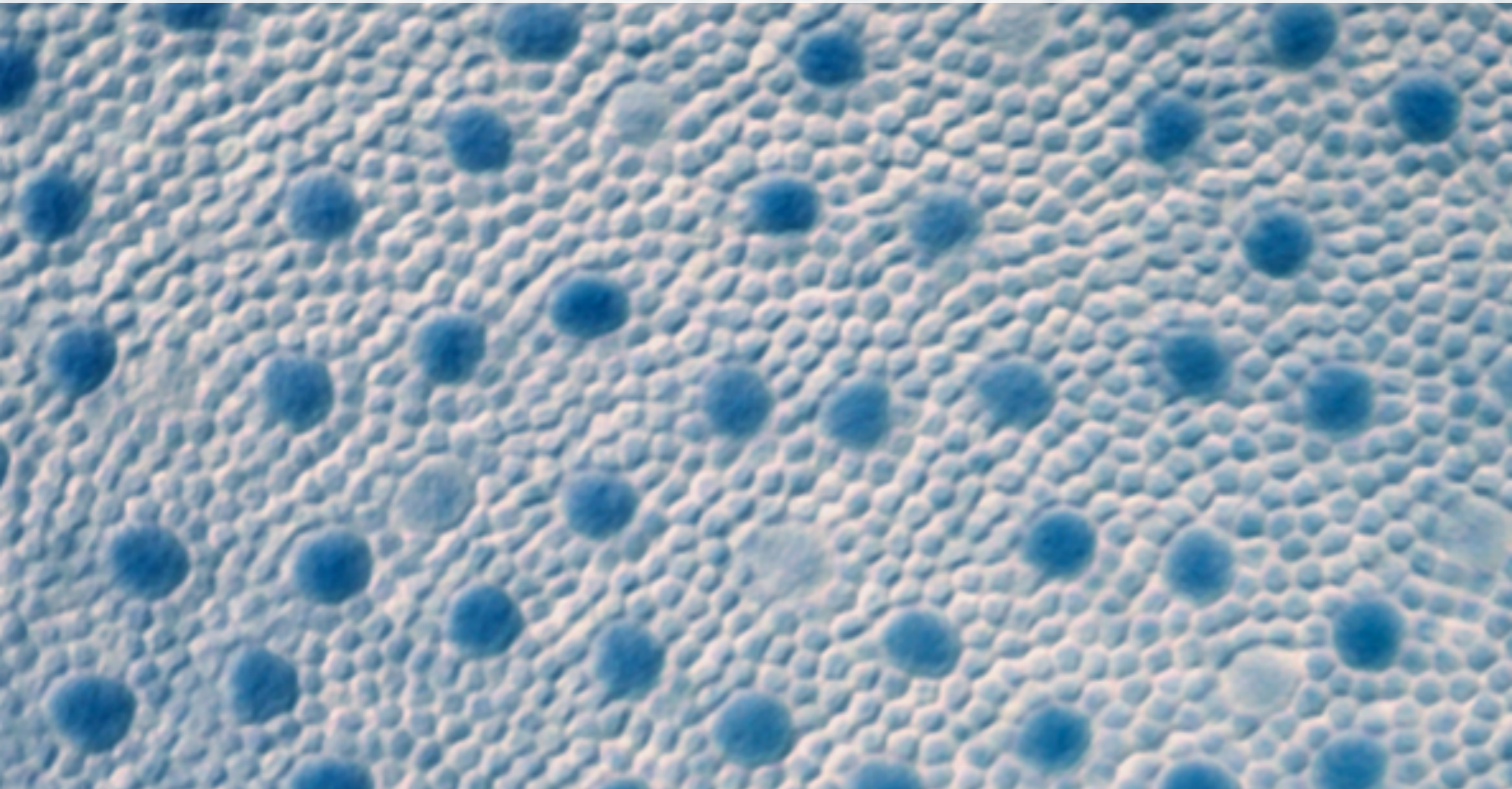


How does light work?



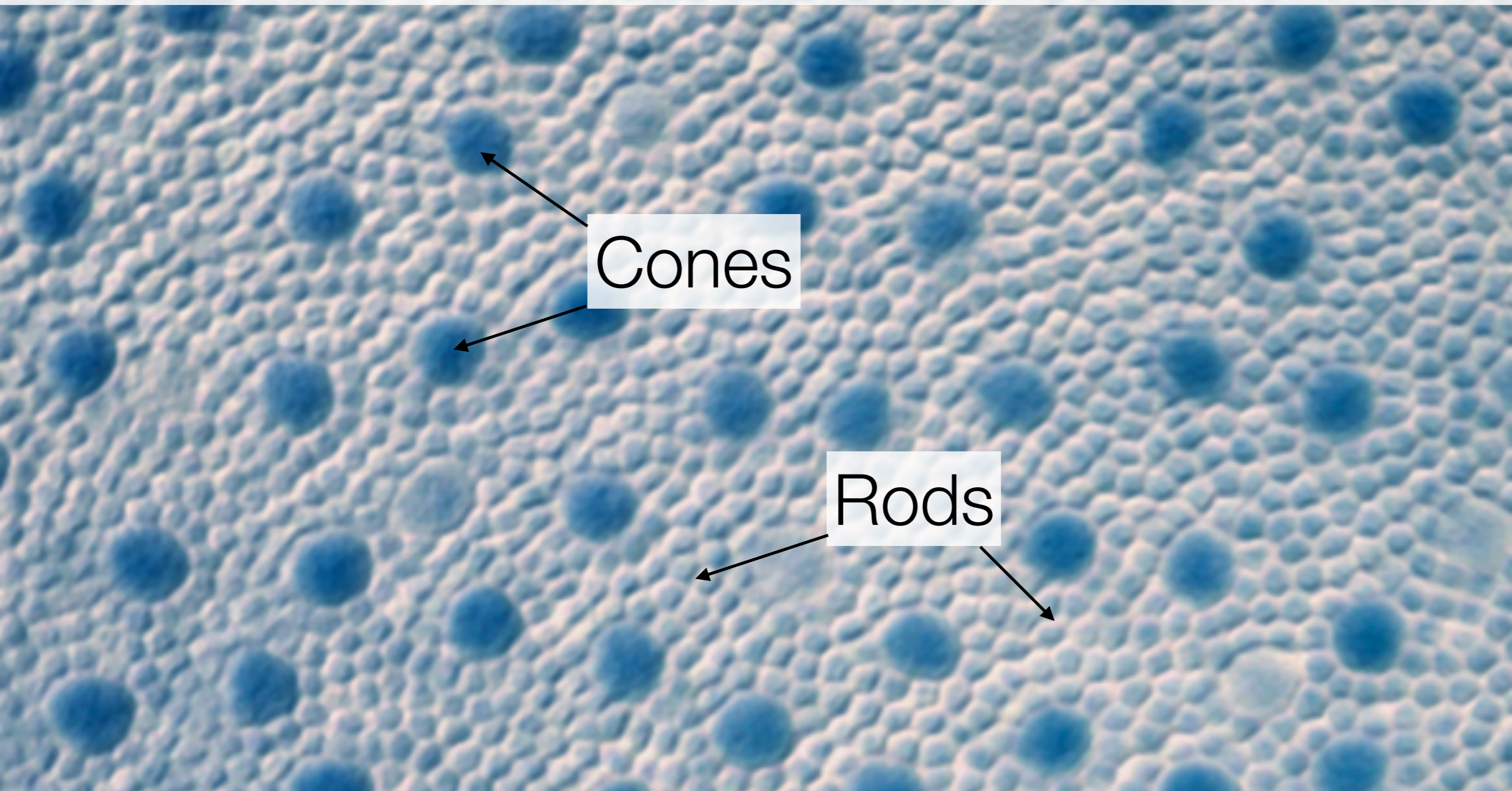
Wavelength (nm)

How does your eye work?

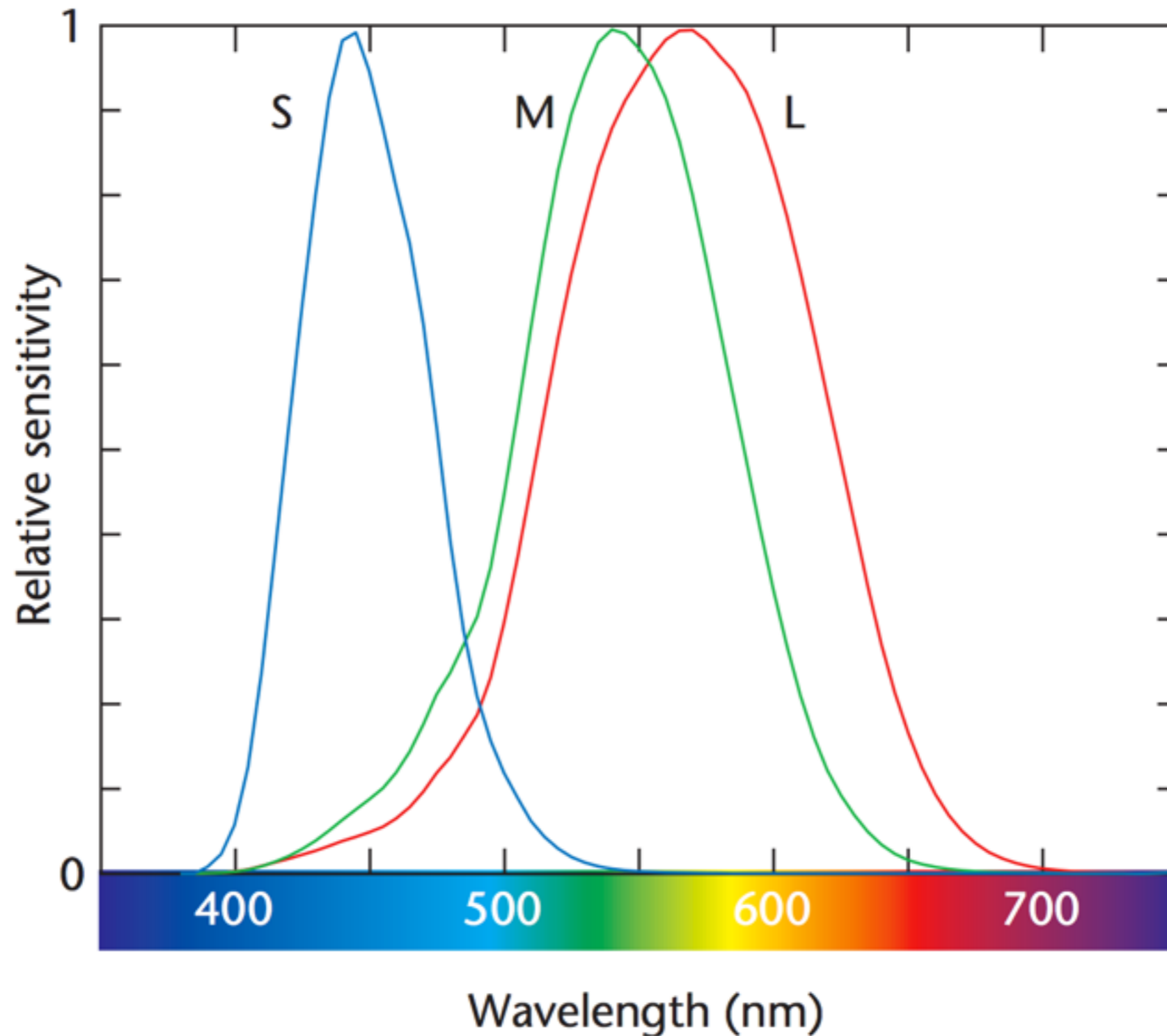


<http://www.retinalmicroscopy.com/mosaics.html>

How does your eye work?

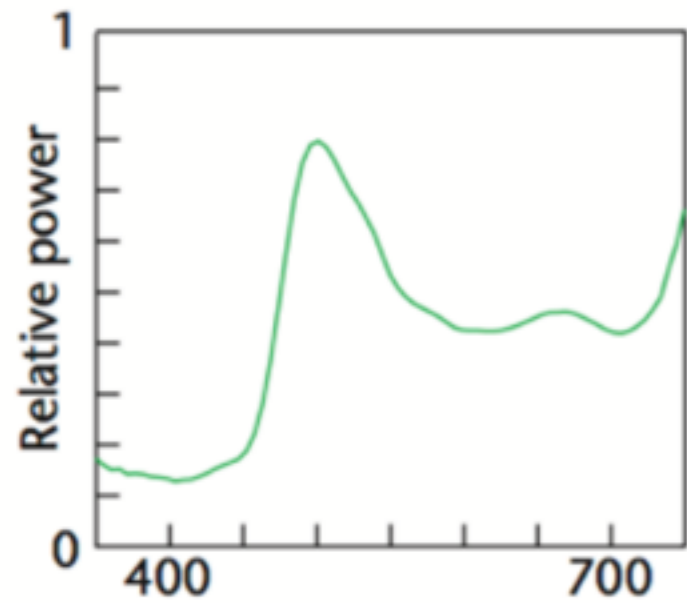


How does your eye work?

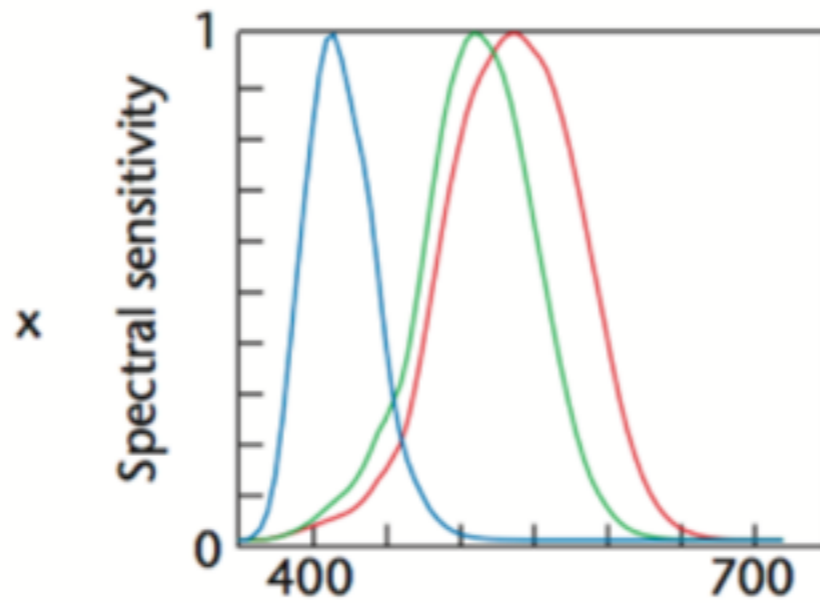


TRICHRROMACY

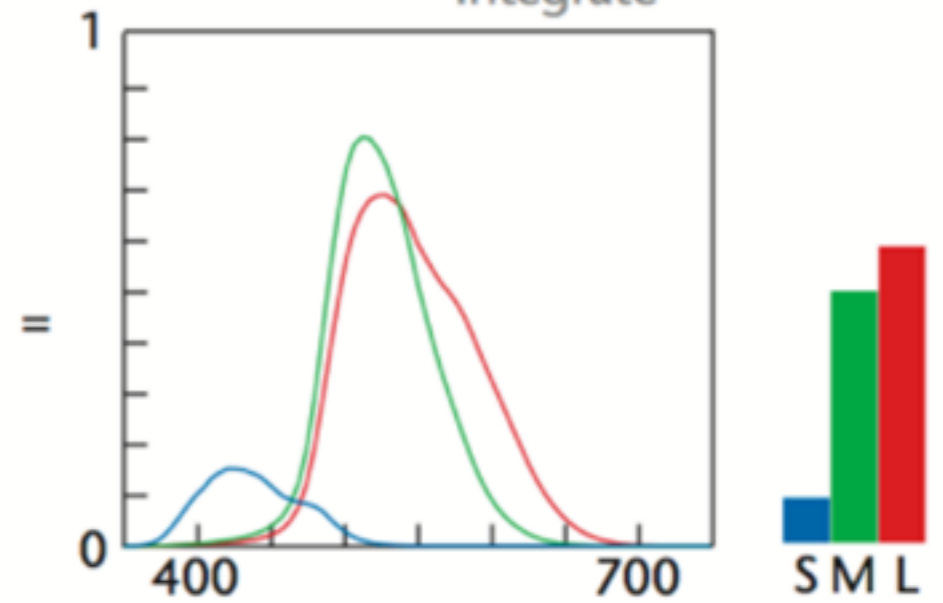
Input stimulus



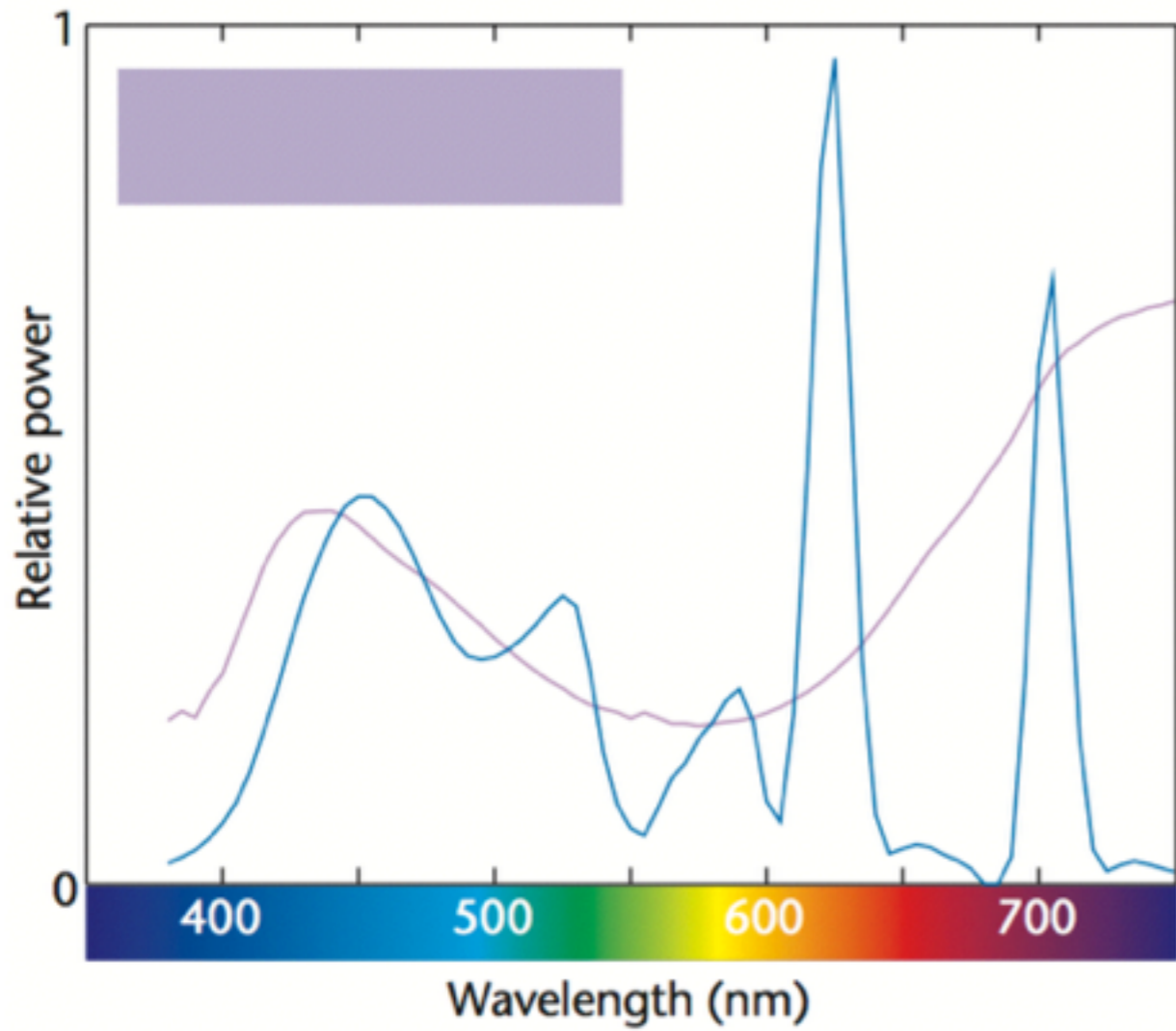
Cone response curves



Product \longrightarrow Response
Integrate



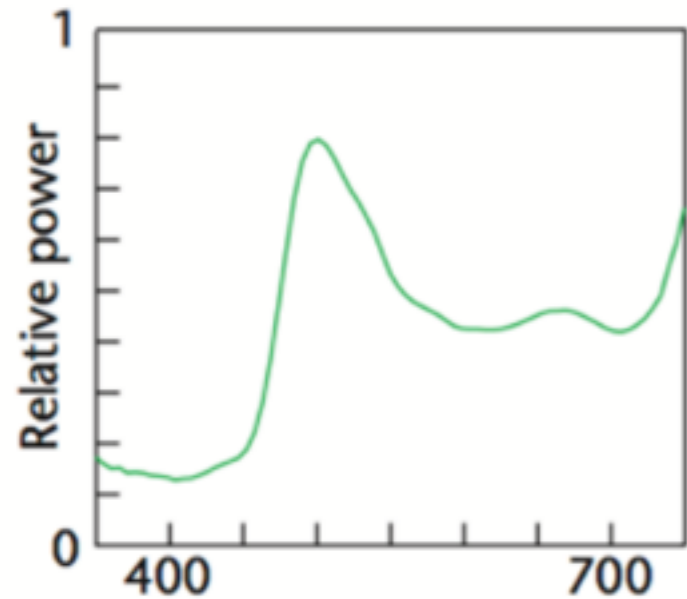
Three numbers!



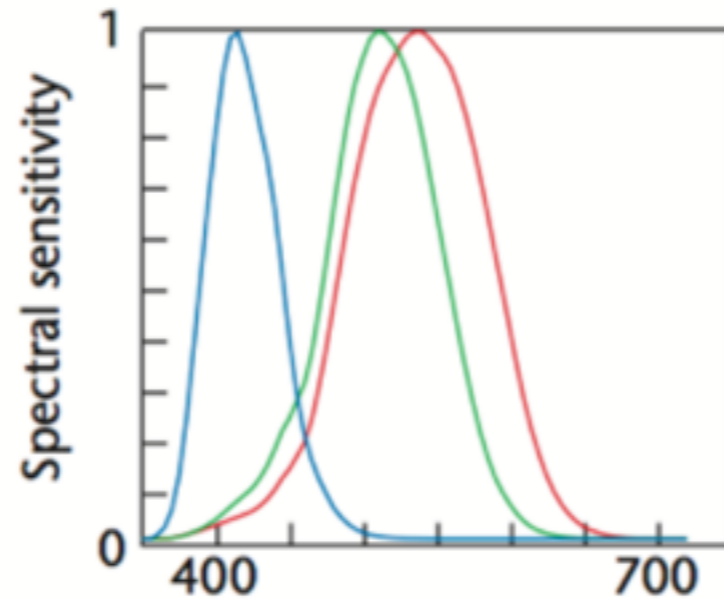
same three numbers,
same impression

METAMERISM

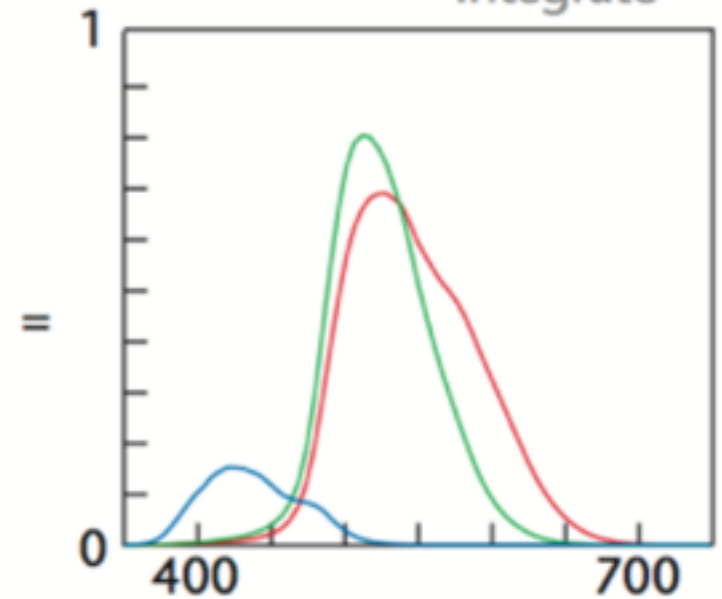
Input stimulus



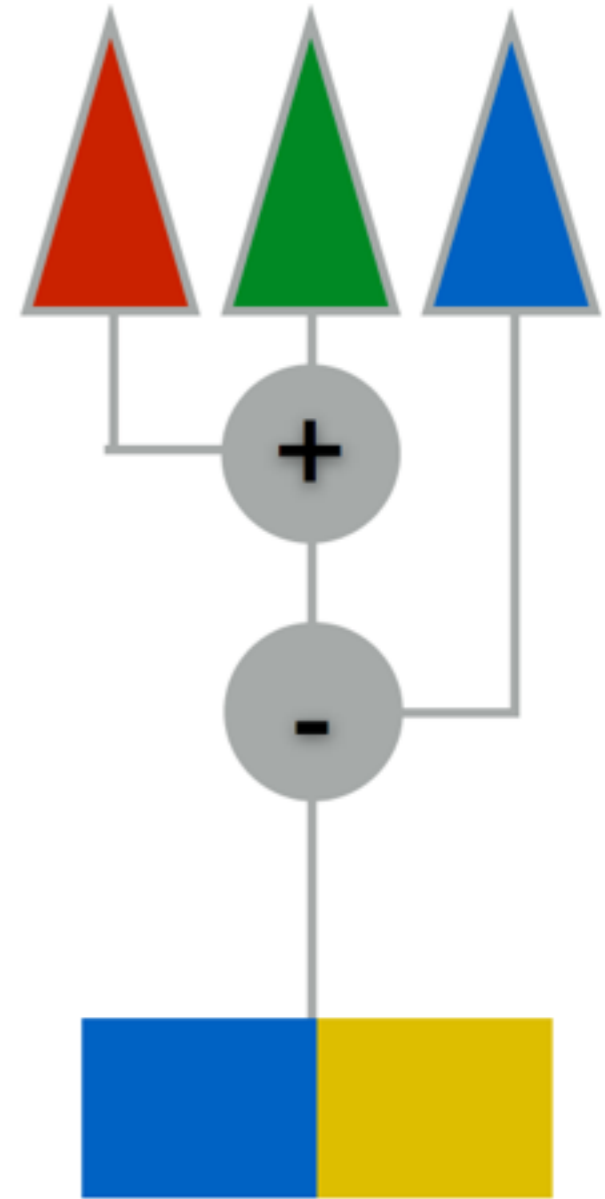
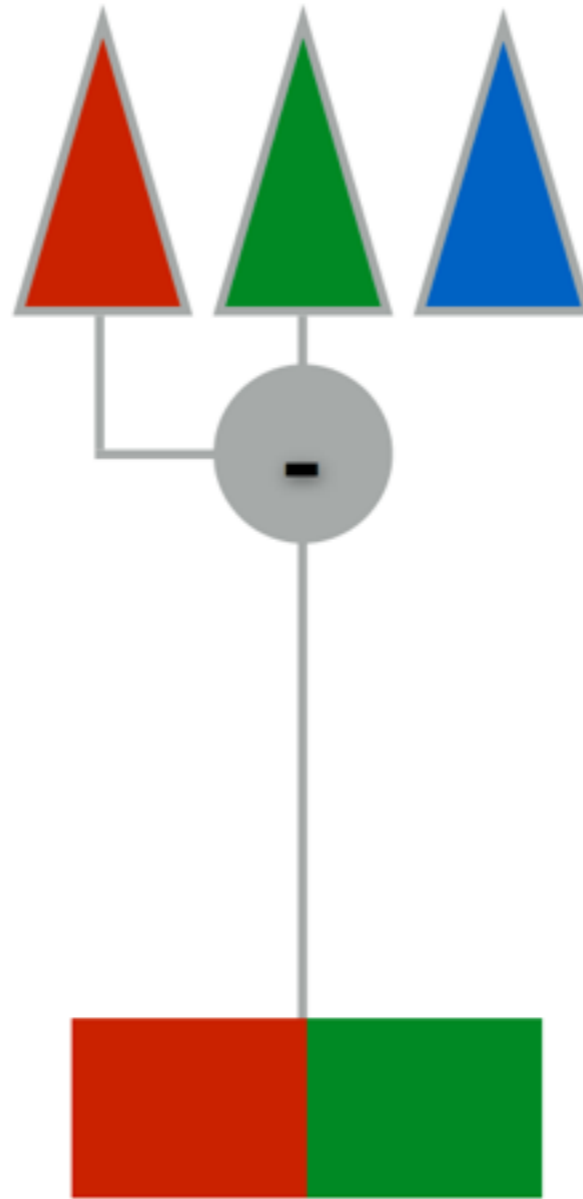
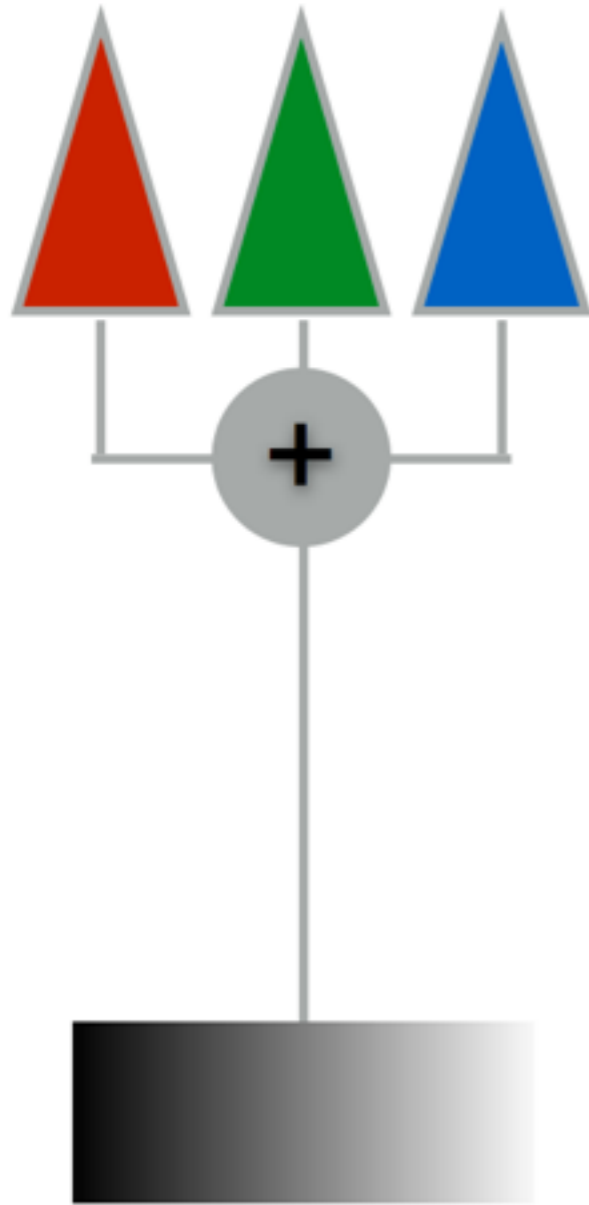
Cone response curves



Product \longrightarrow Response
Integrate

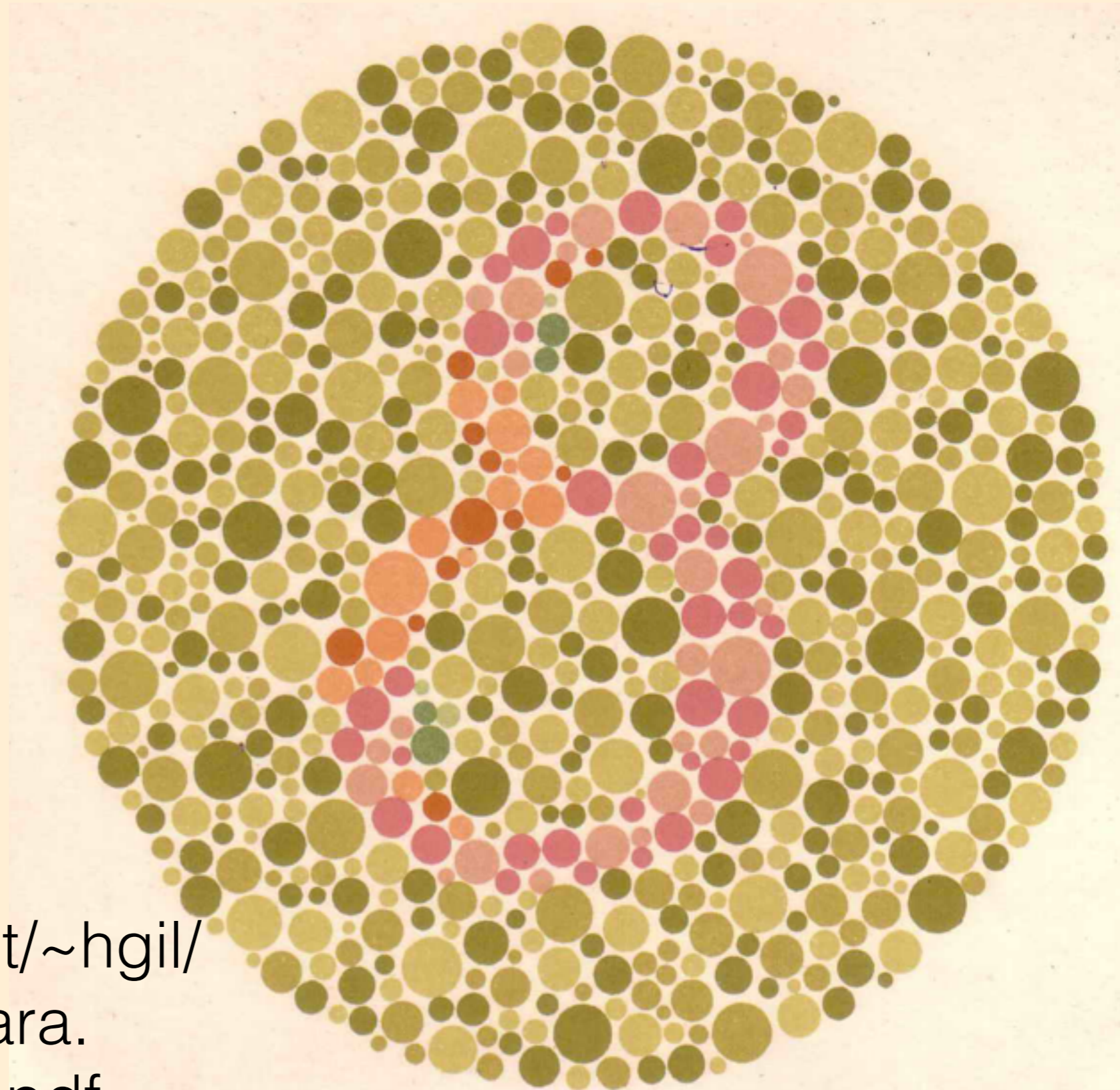


OPPONENT PROCESS MODEL



COLOR VISION DEFICIENCIES

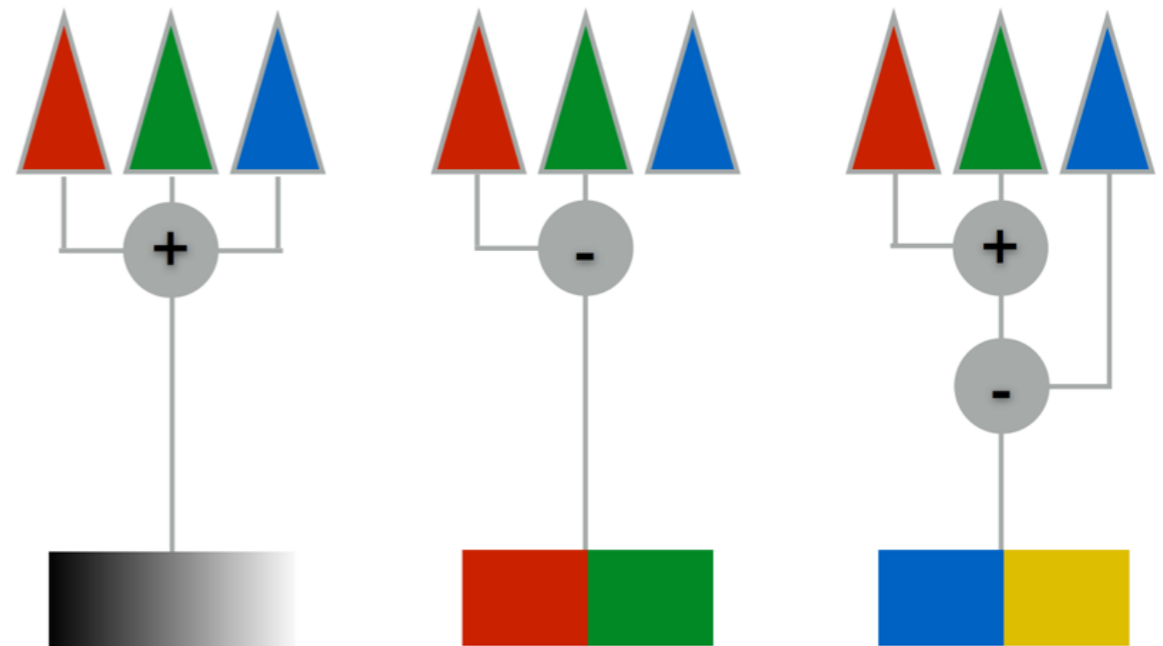
Ishihara Plates



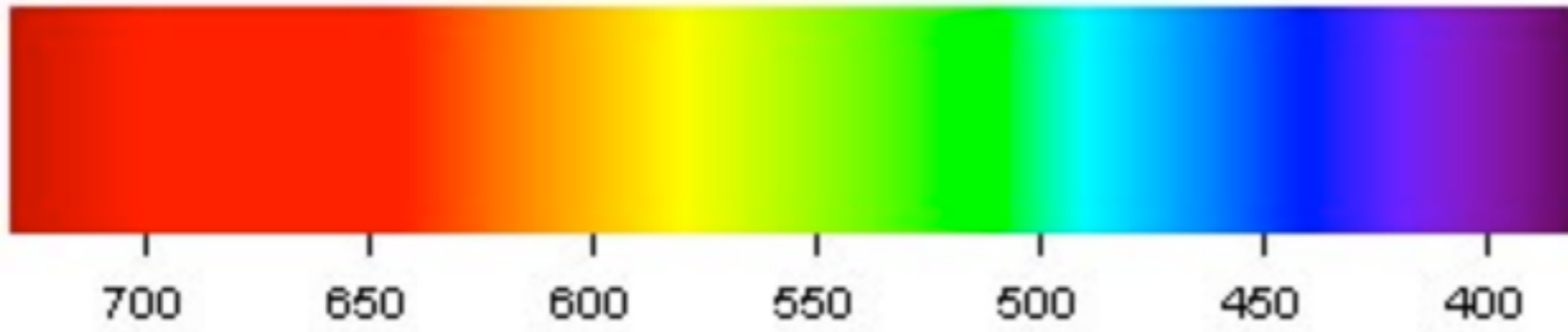
<http://www.dfisica.ubi.pt/~hgil/p.v.2/Ishihara/Ishihara.24.Plate.TEST.Book.pdf>

What goes wrong?

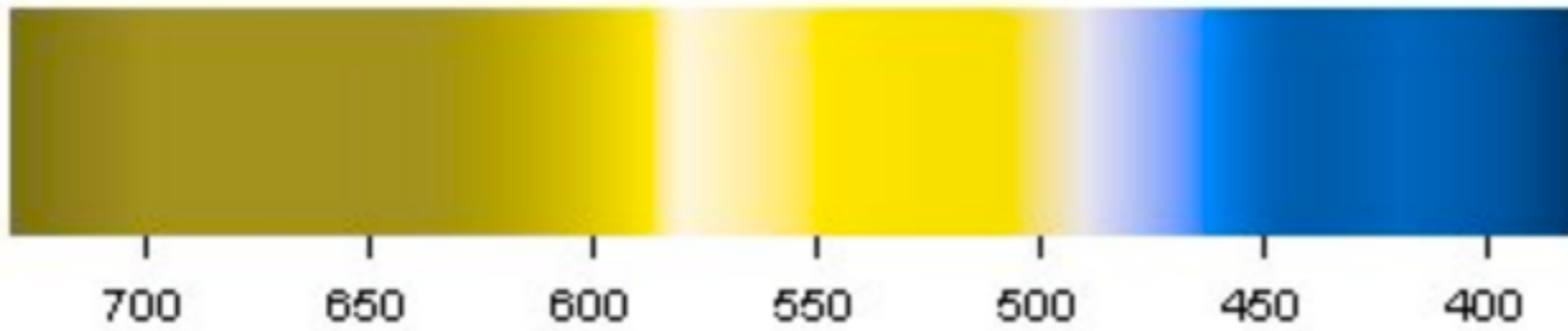
- Only some types of cones present in the eye
- red-green dichromacy, blue-yellow dichromacy (rare)



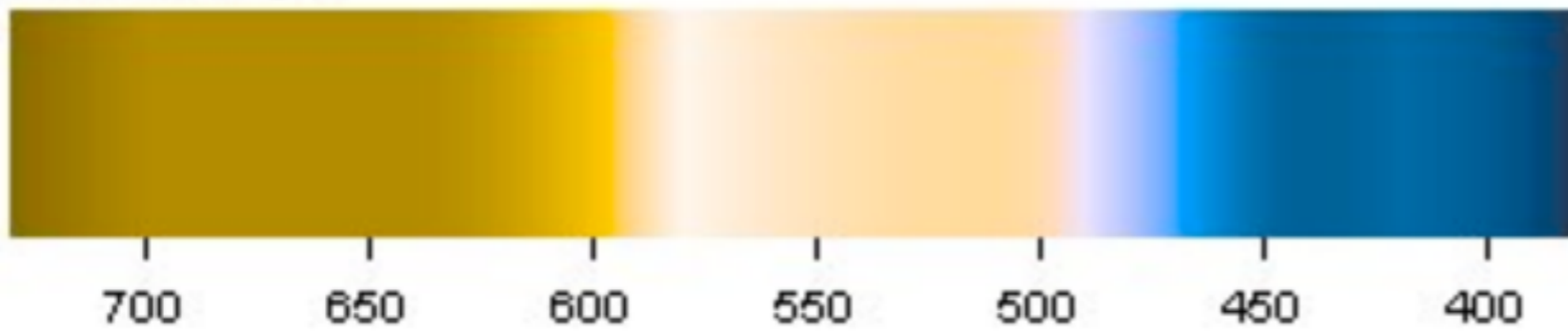
Normal



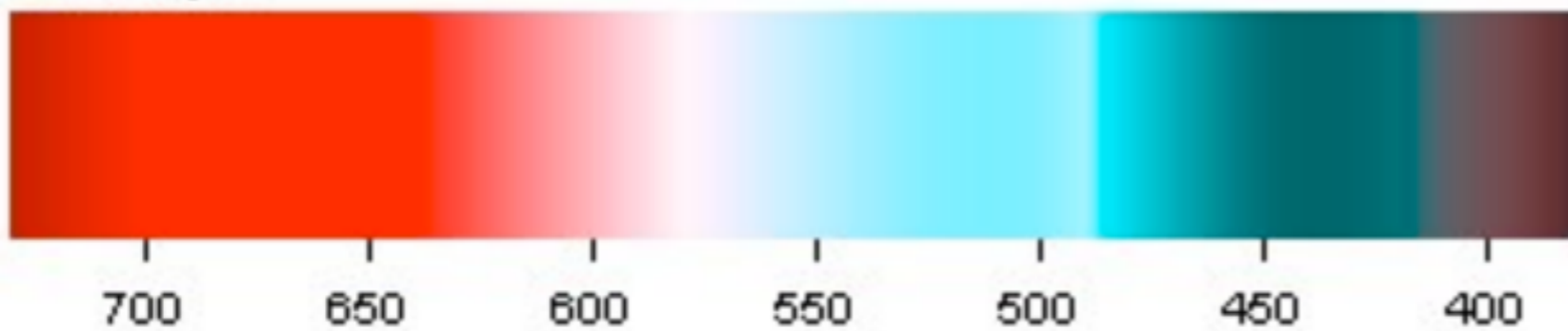
Protanopia



Deuteranopia



Tritanopia



WHAT ARE THE
PRIMARY COLORS?

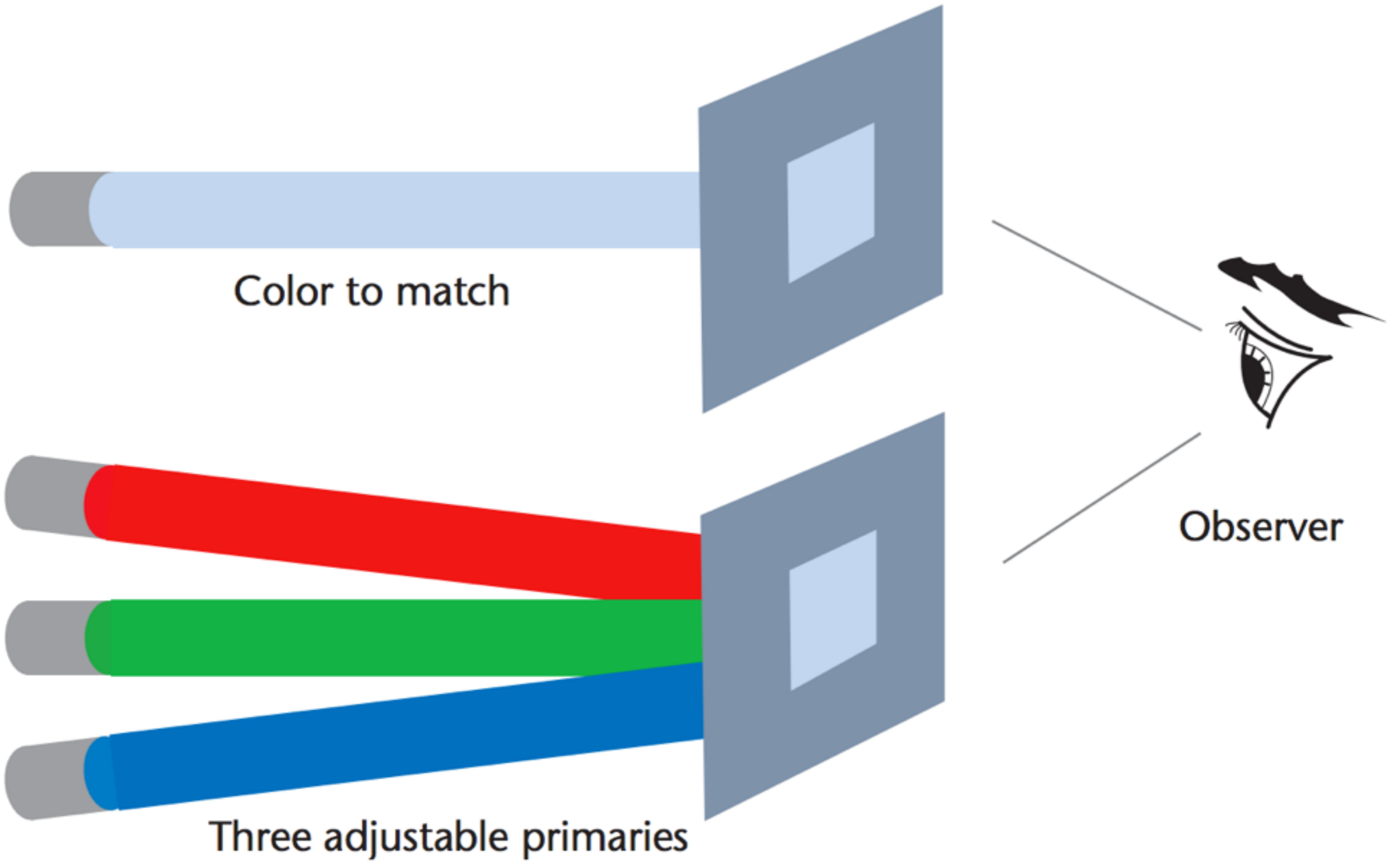
WHAT ARE THE PRIMARY COLORS?

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**

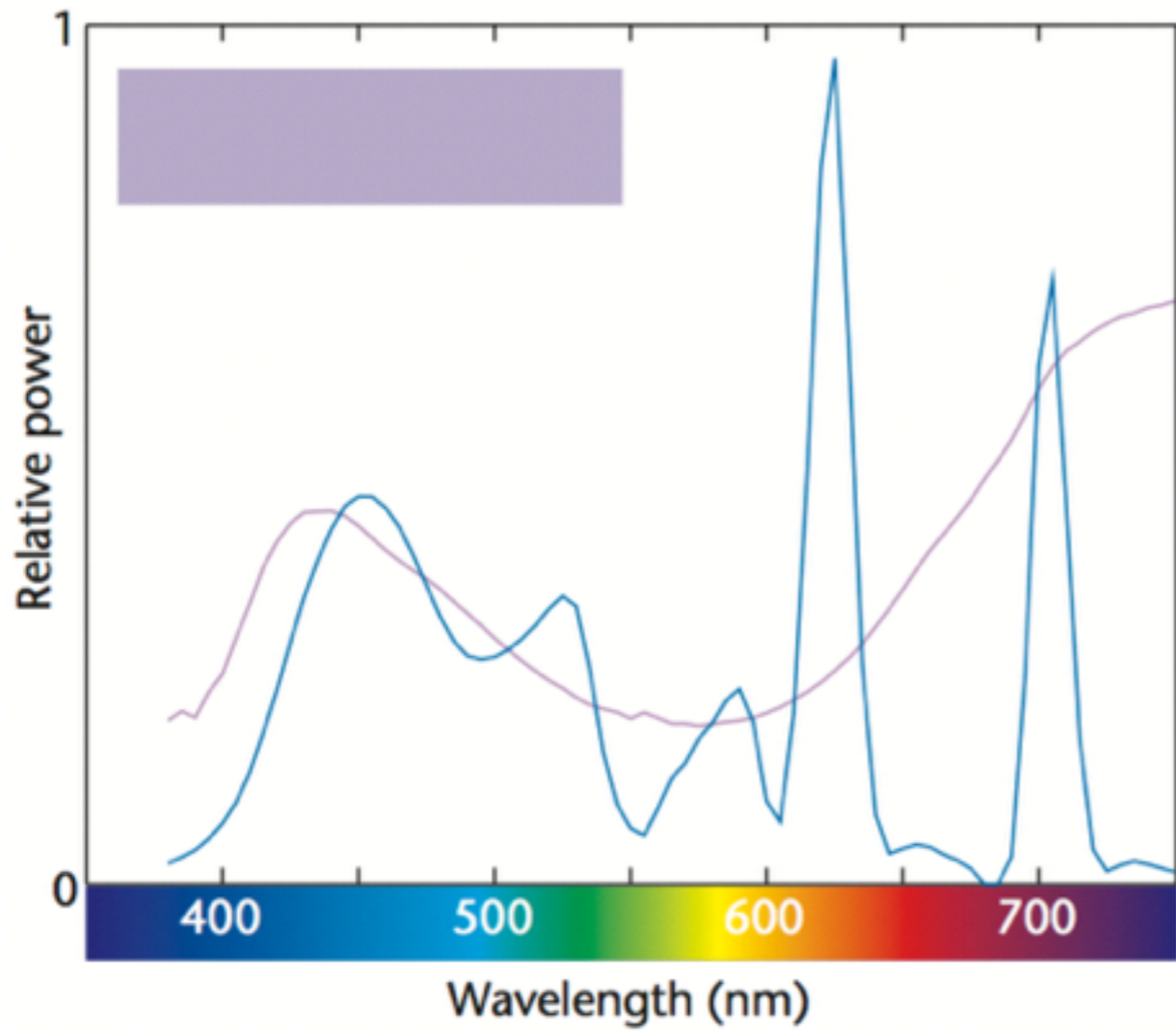
Any three “independent”
ways of combining color
works (!)



Color to match

Three adjustable primaries

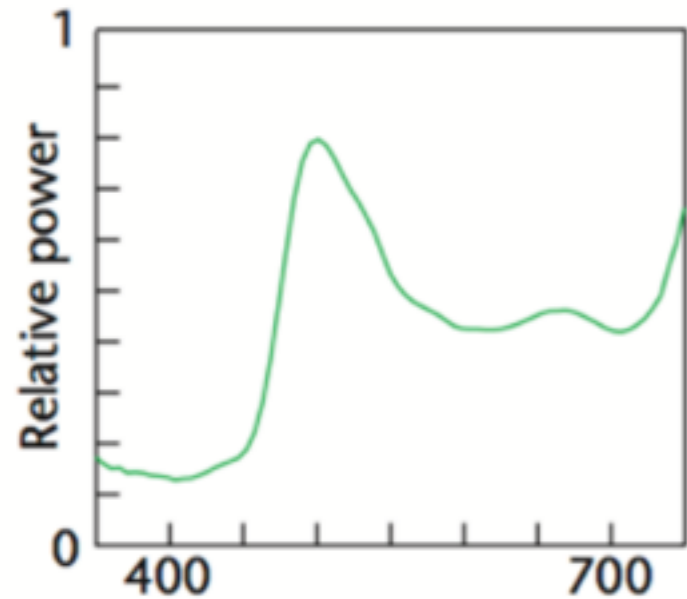
Observer



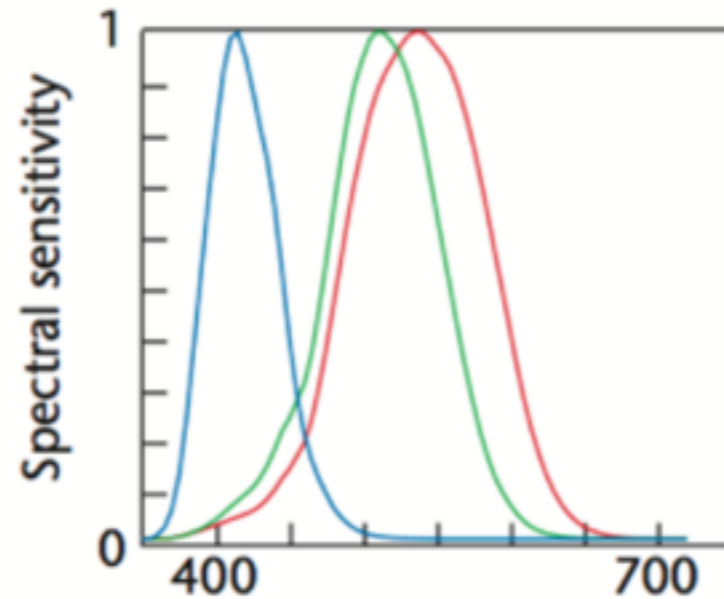
same three numbers,
same impression

METAMERISM

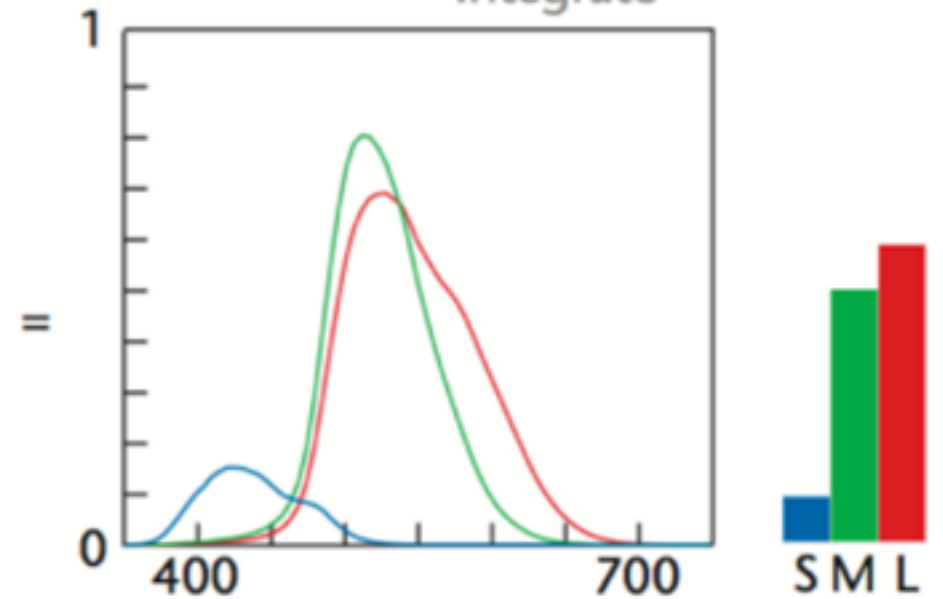
Input stimulus

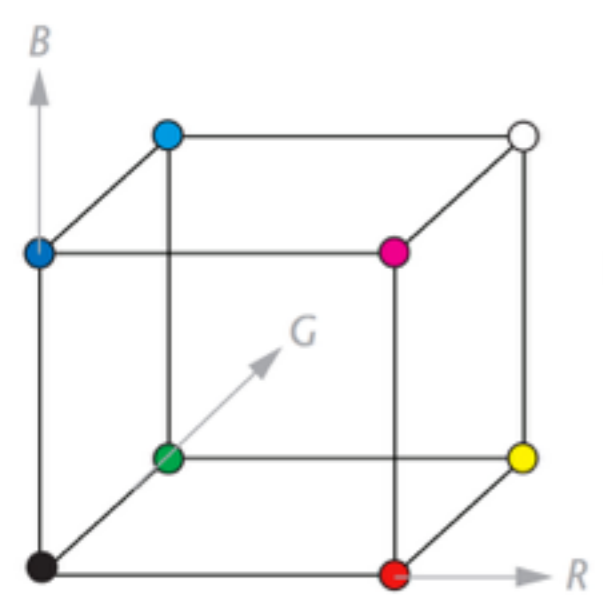


Cone response curves



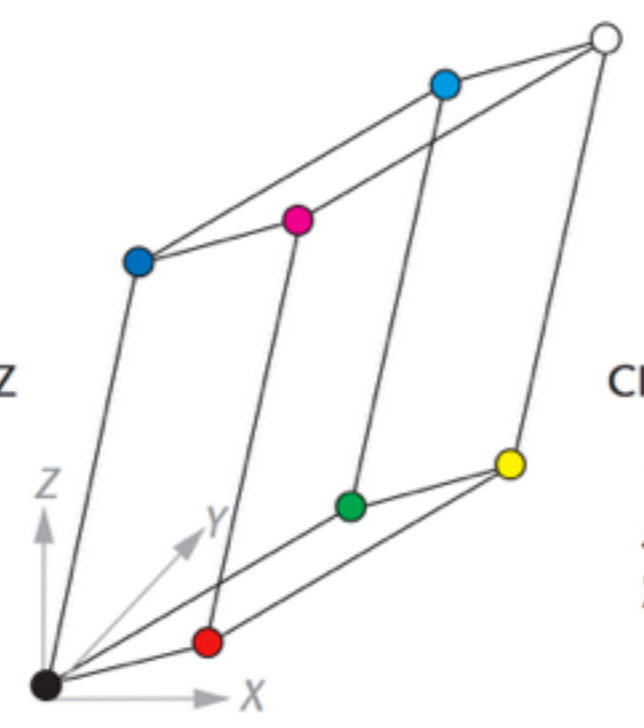
Product \longrightarrow Response
Integrate





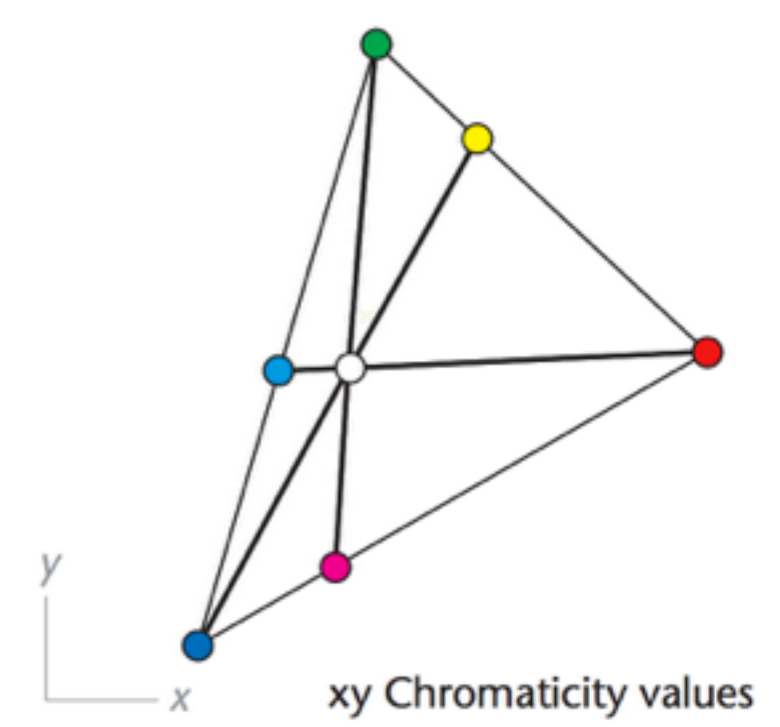
RGB intensity values
(a)

RGB to CIE XYZ
3 x 3 matrix

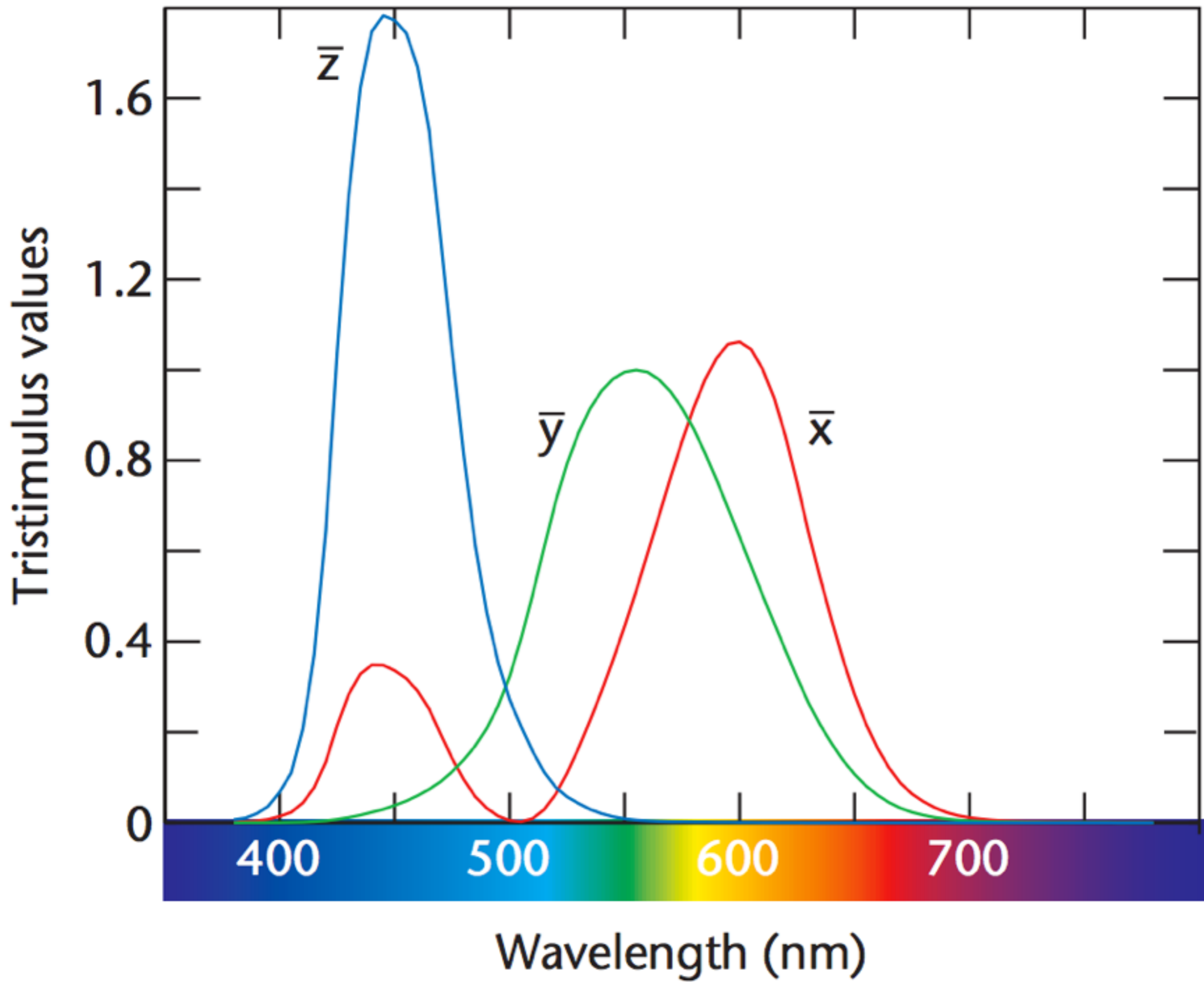


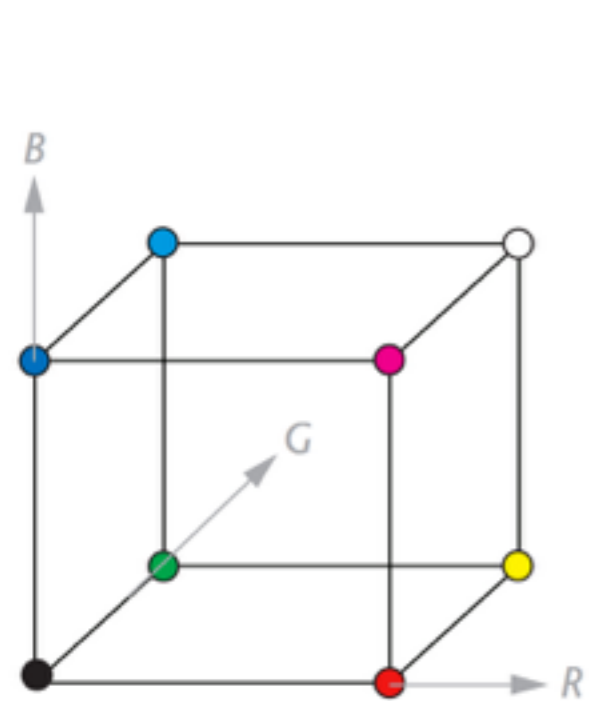
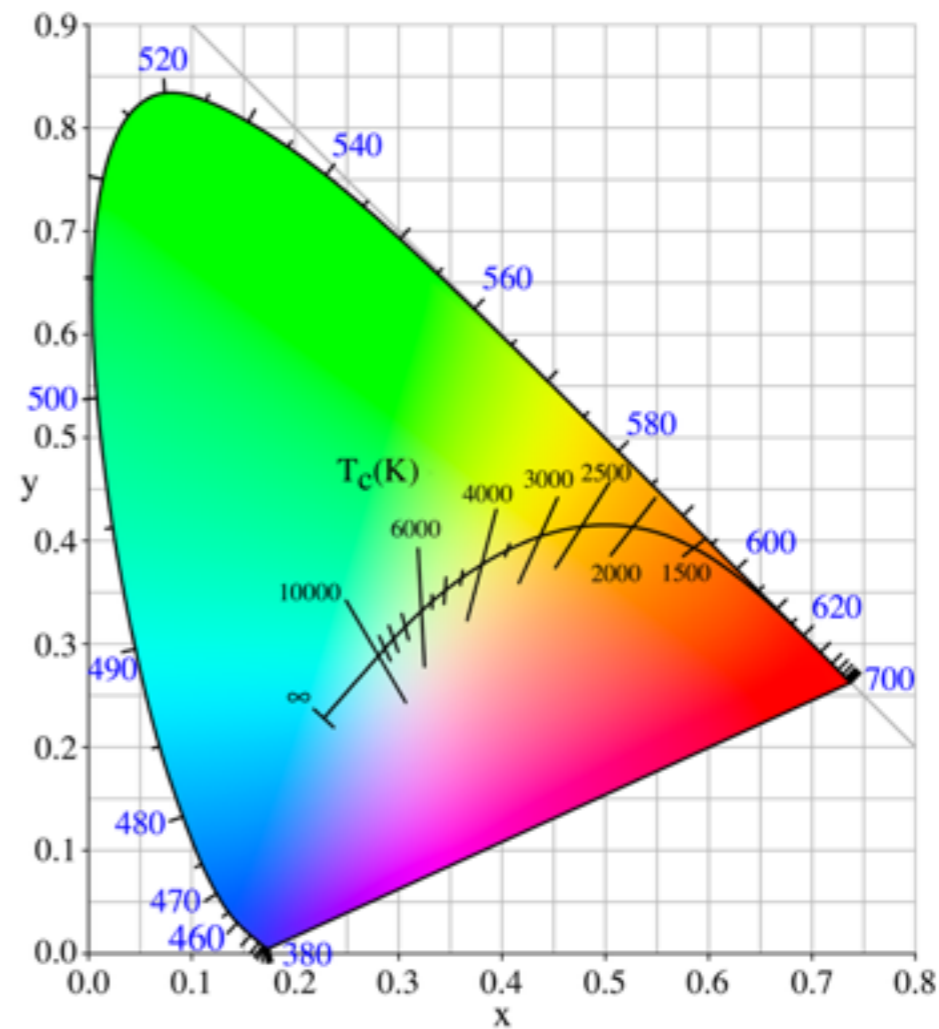
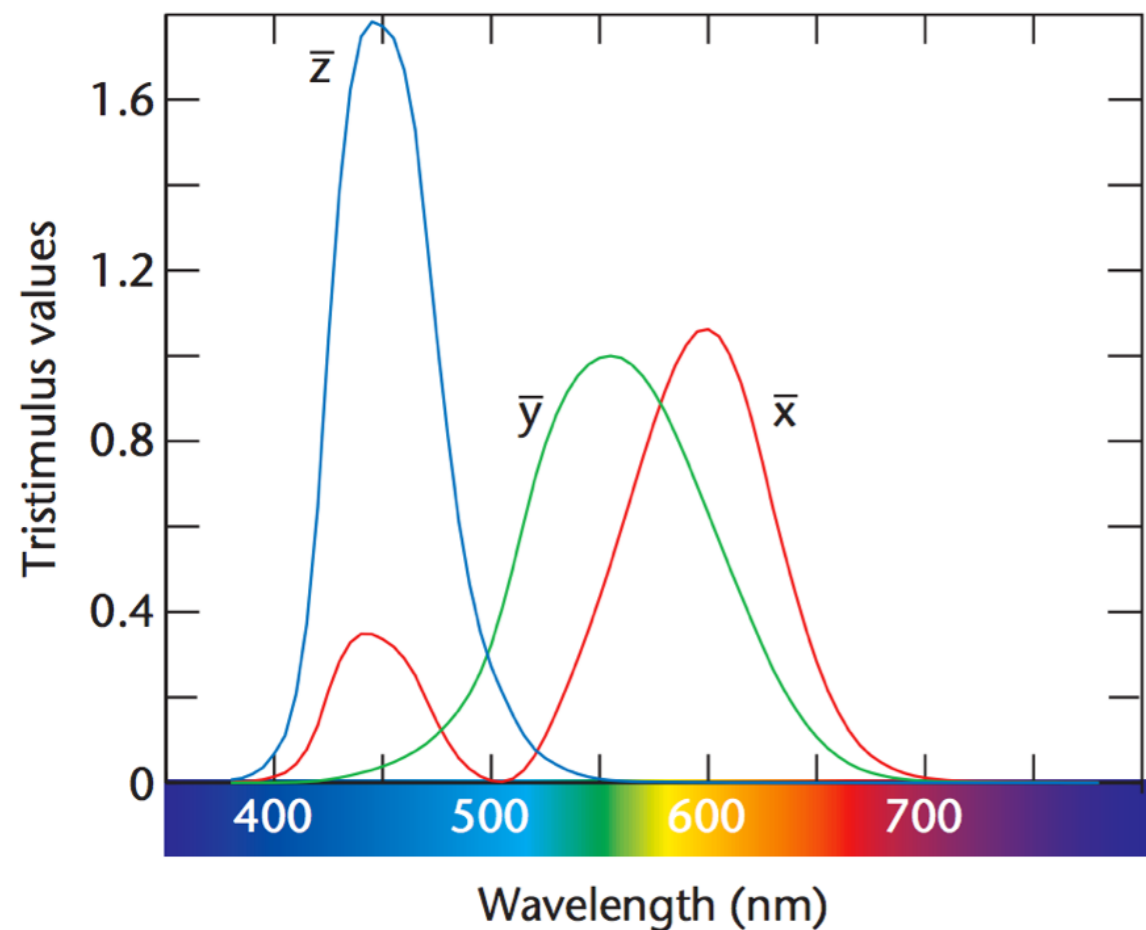
XYZ tristimulus values
(b)

CIE XYZ to CIE xy
 $x = X/(X+Y+Z)$
 $y = Y/(X+Y+Z)$



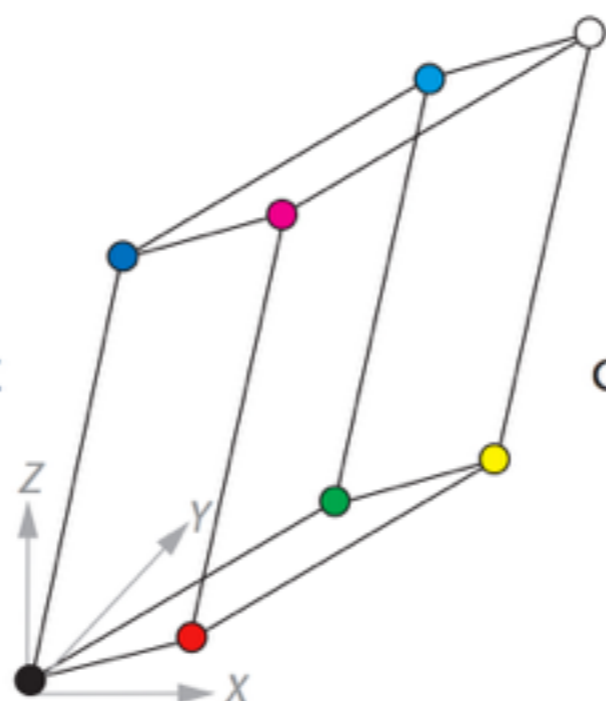
xy Chromaticity values
(c)





RGB to CIE XYZ

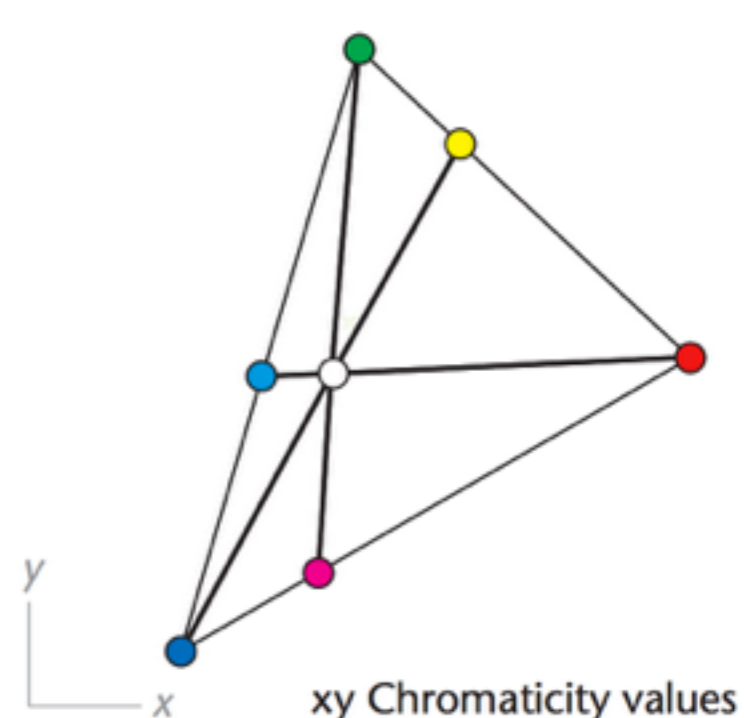
3 x 3 matrix



CIE XYZ to CIE xy

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

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



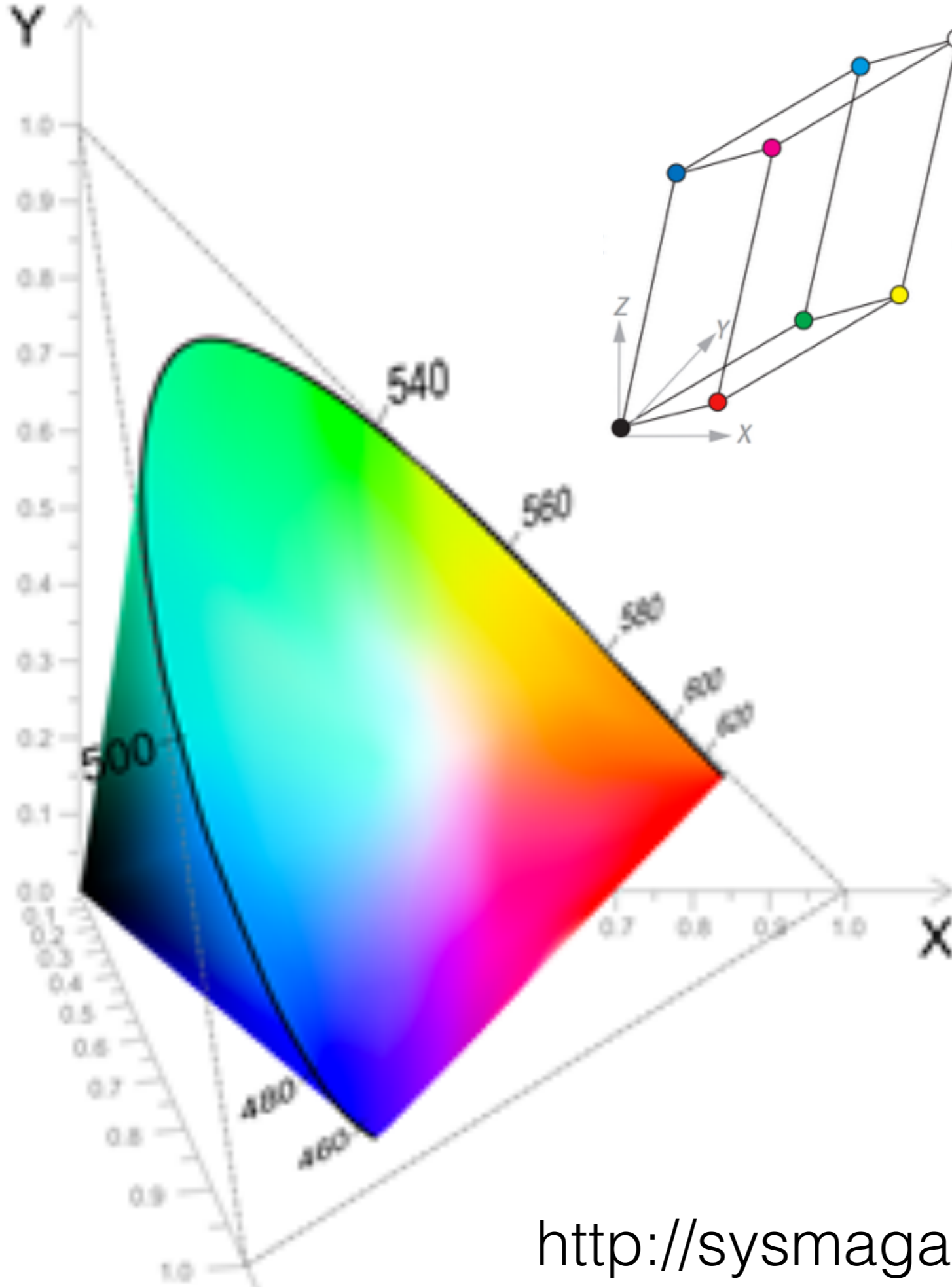
RGB intensity values

(a)

XYZ tristimulus values

(b)

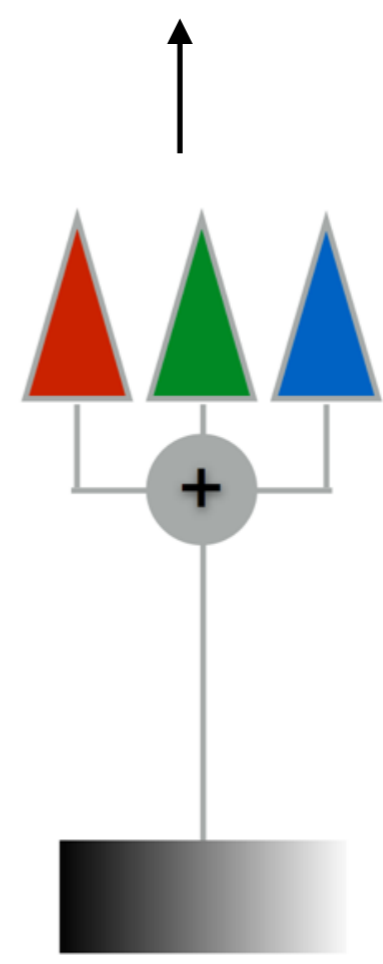
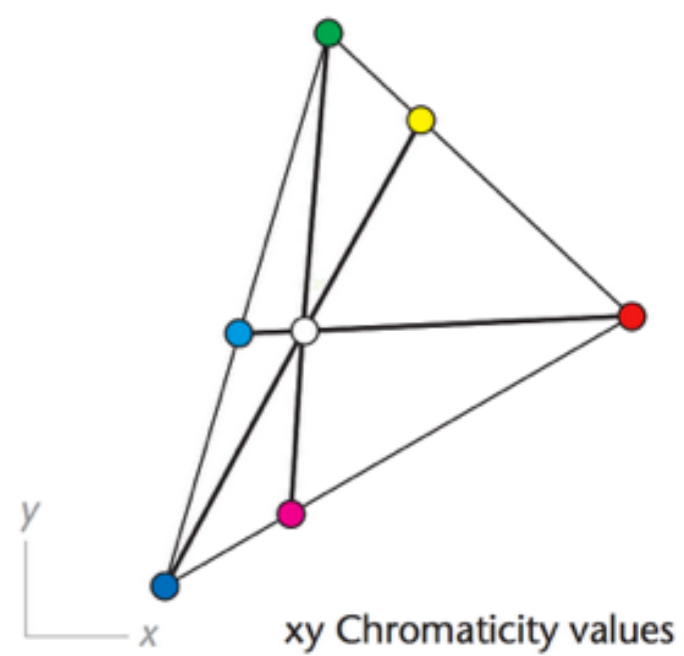
(c)



CIE XYZ to CIE xy

$$x = \frac{X}{X+Y+Z}$$

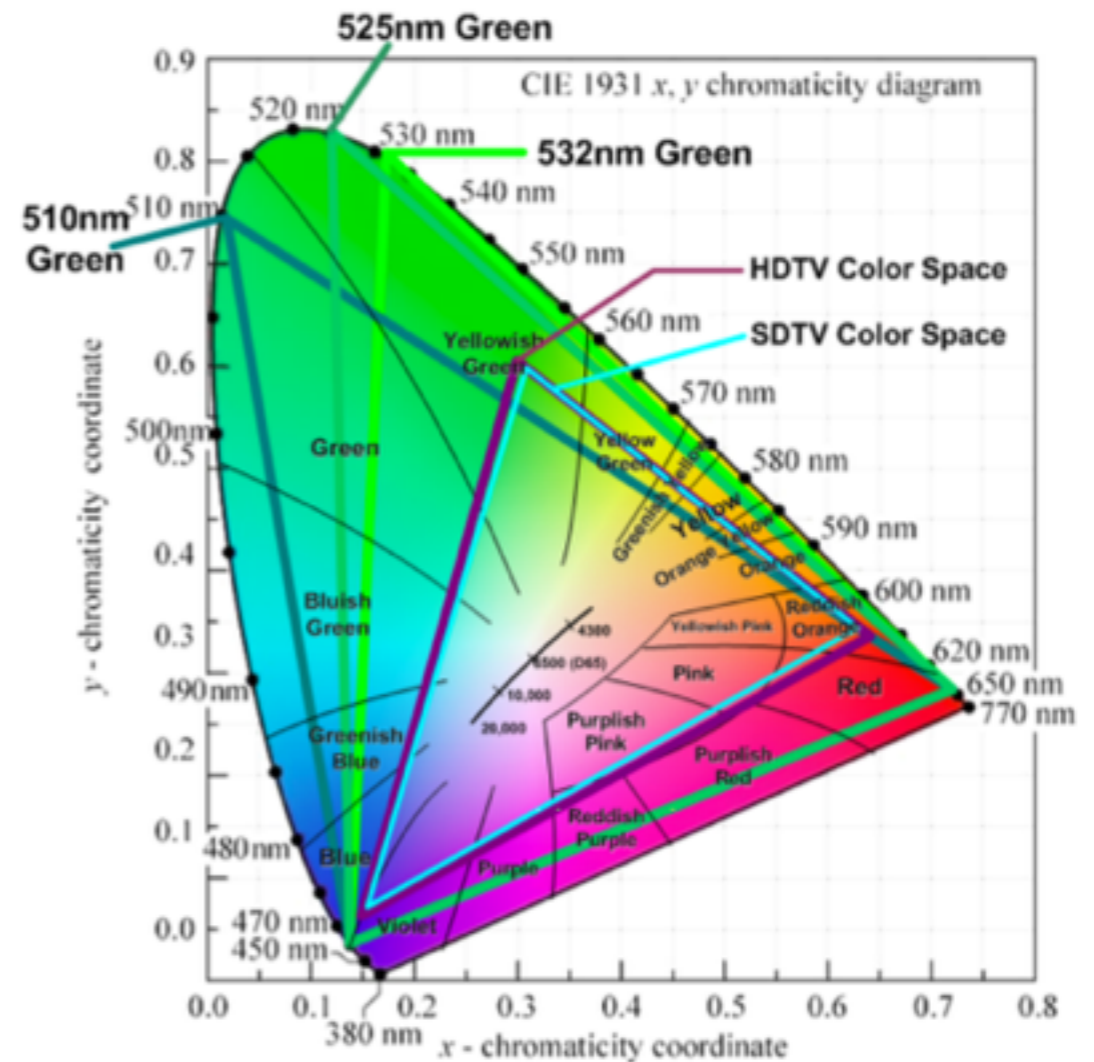
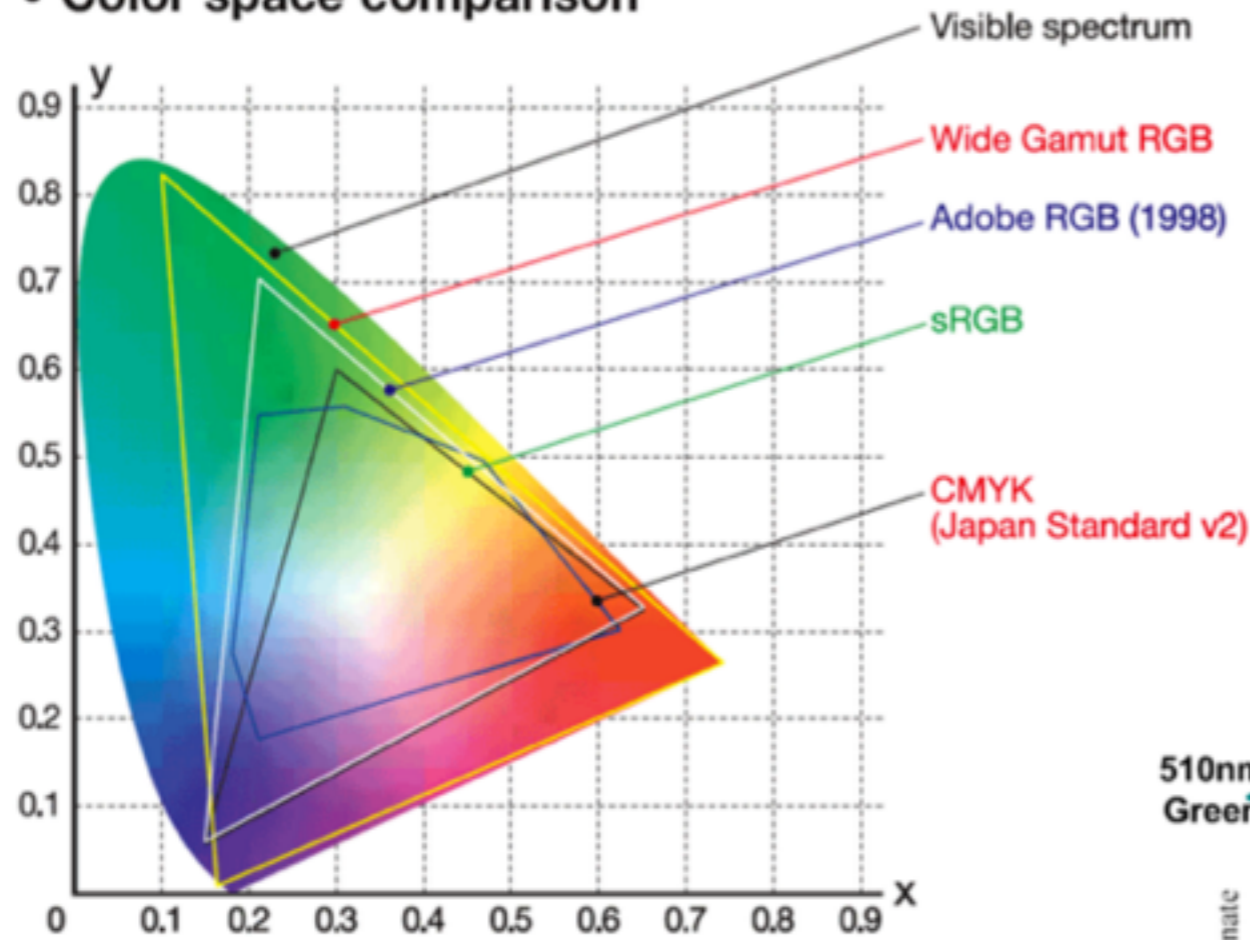
$$y = \frac{Y}{X+Y+Z}$$



Dividing by
"luminance"

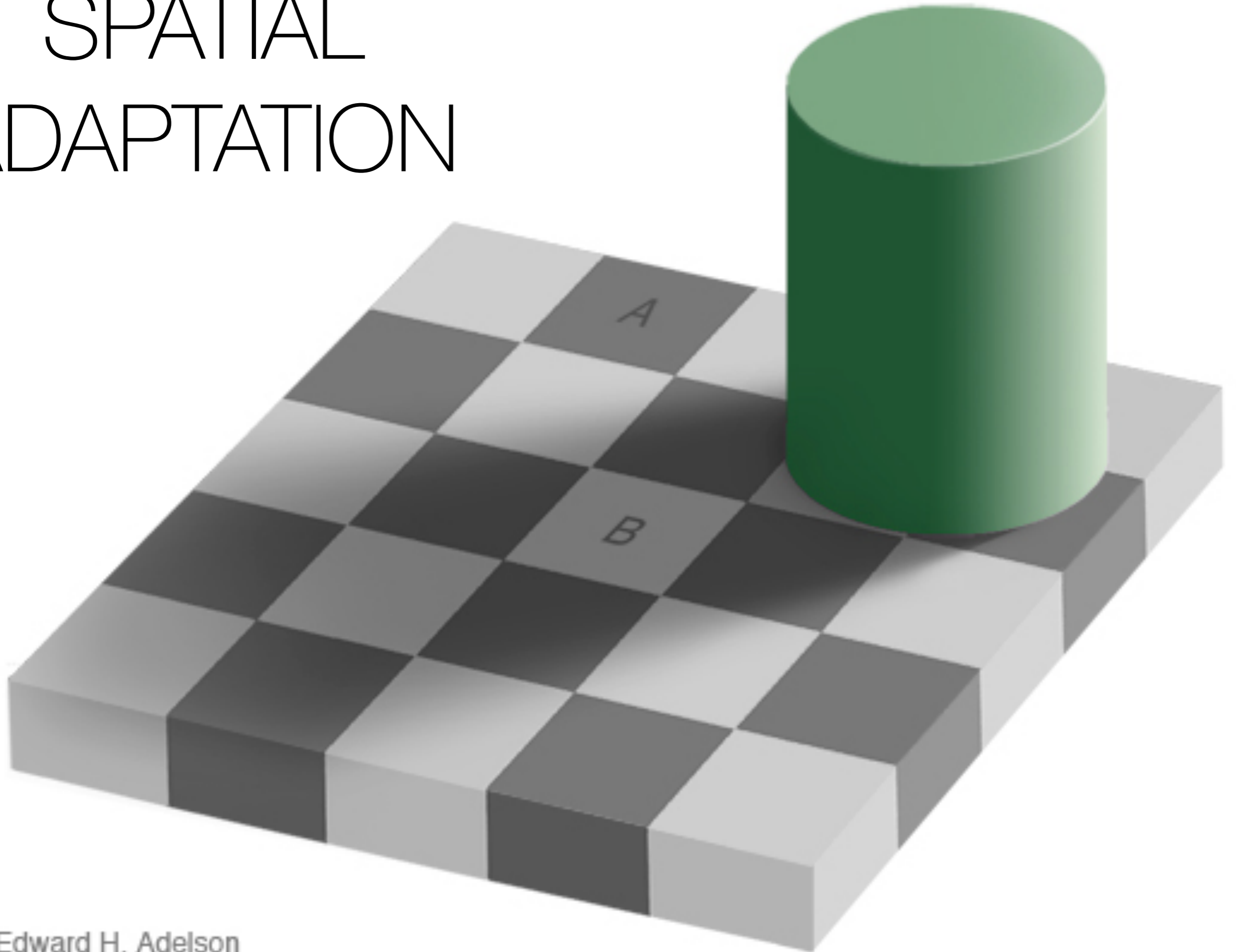
COLOR GAMUTS

• Color space comparison



CONSTANCY AND ADAPTATION

SPATIAL ADAPTATION



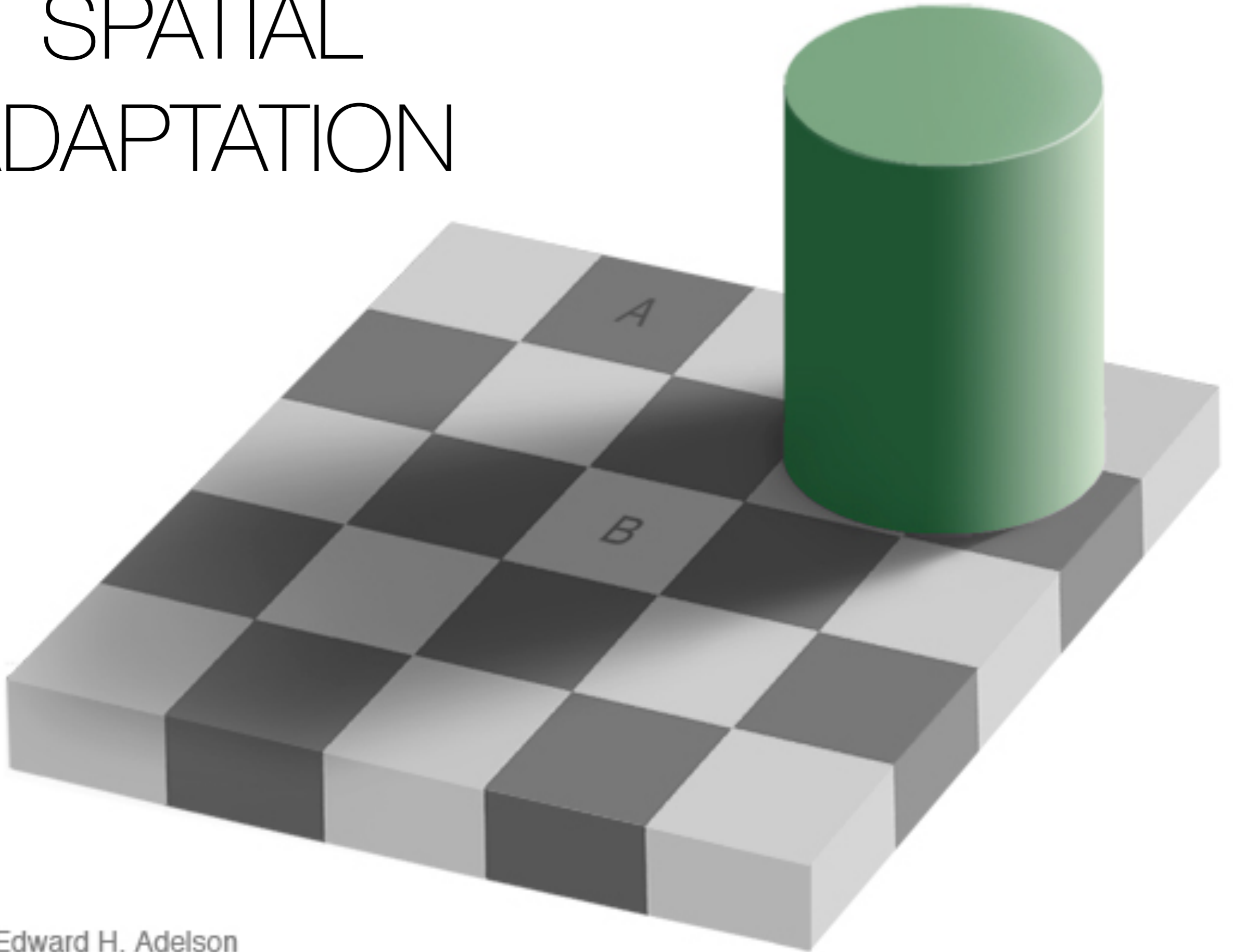
SPATIAL ADAPTATION



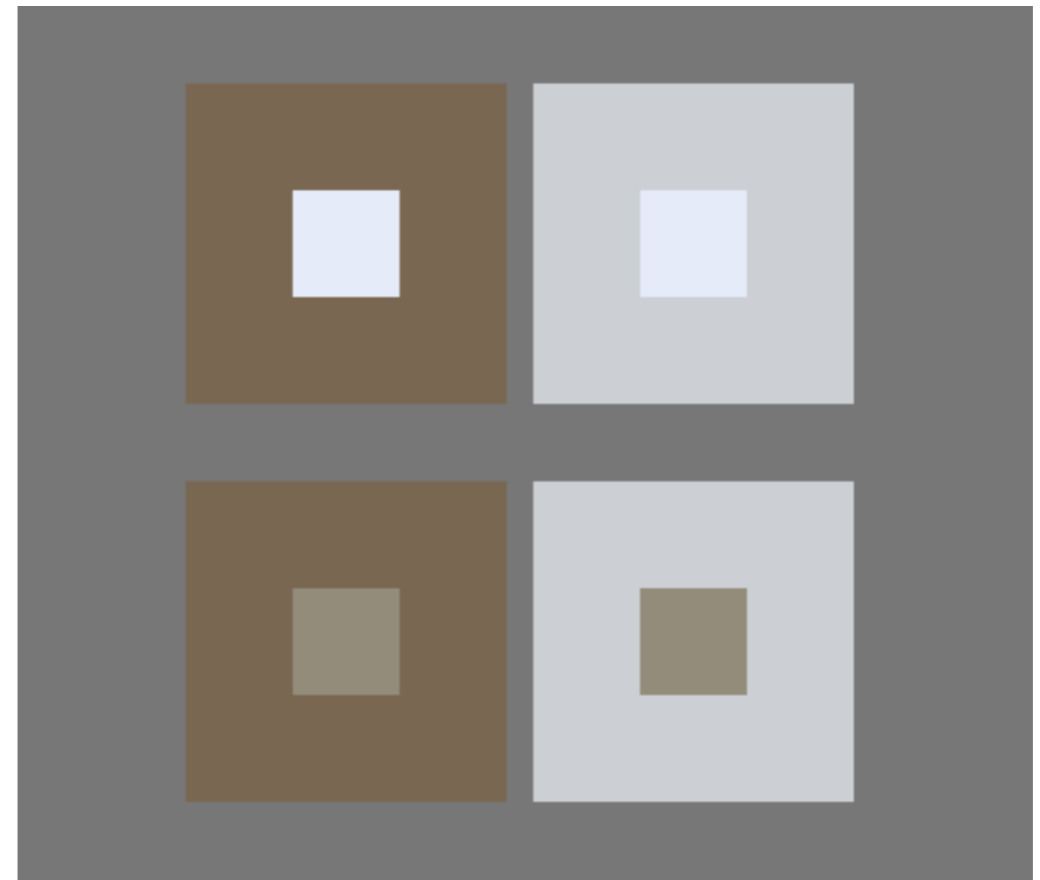
SPATIAL ADAPTATION



SPATIAL ADAPTATION



SIMULTANEOUS CONTRAST







TEMPORAL ADAPTATION

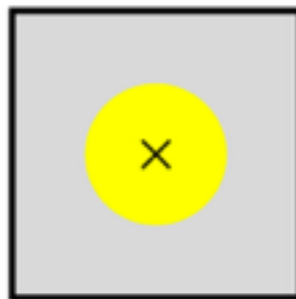
<http://www.moillusions.com/black-and-white-in-colour-again.html/13191556xteeocm7>

Impossible Colors (!)

<http://upload.wikimedia.org/wikipedia/commons/5/56/Chimerical-color-demo.svg>
Chimerical-color-demo.svg

CHIMERICAL COLOR DEMO TEMPLATES

Fatigue template
(stare at "x")



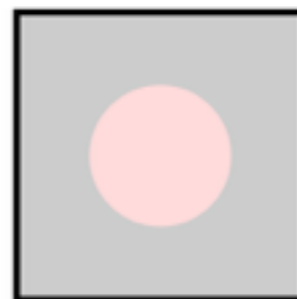
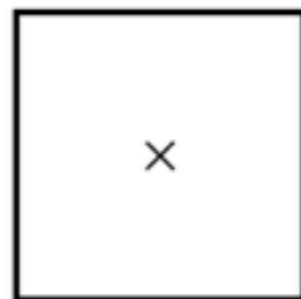
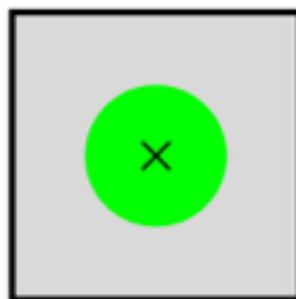
Target field
(glance at "x")



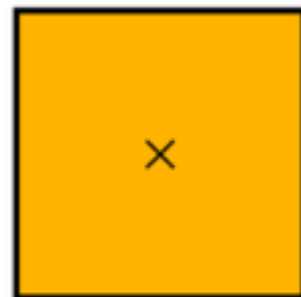
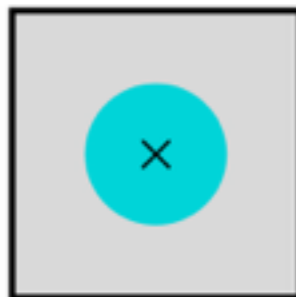
Approximate
Rendering



STYGIAN BLUE
(simultaneously deep
blue and black)



SELF-LUMINOUS RED
(simultaneously red and
brighter than white)



HYPERBOLIC ORANGE
(more than 100%
color saturation)