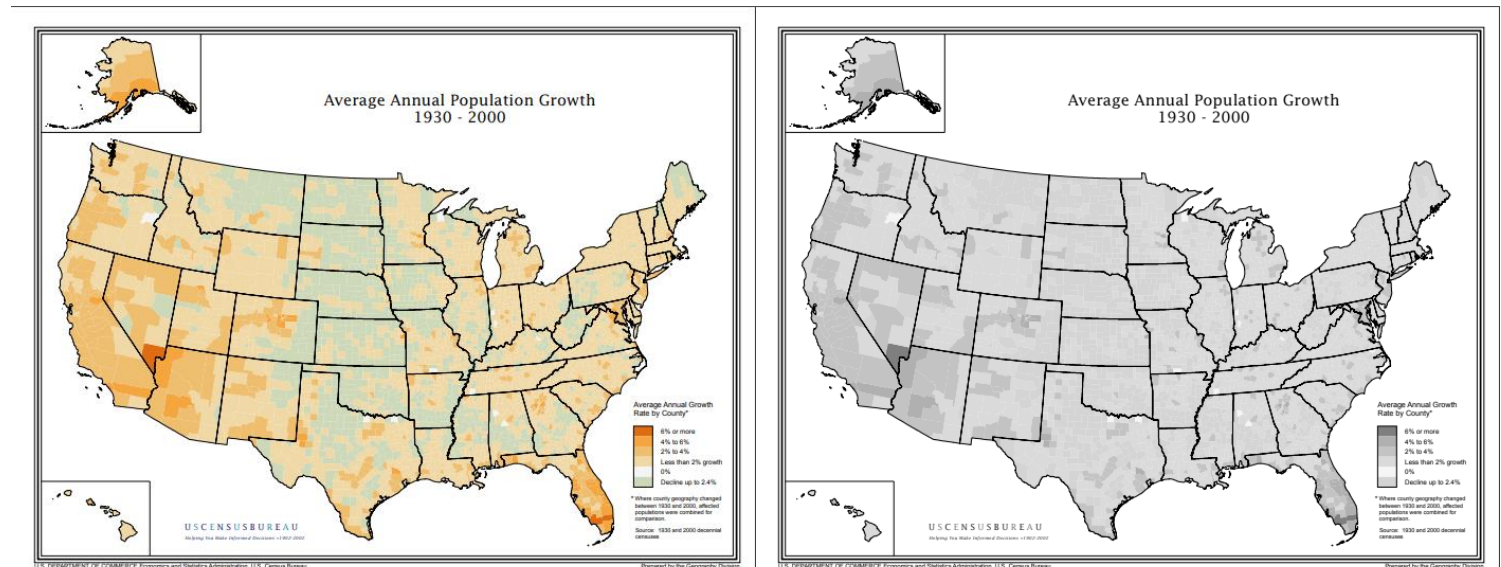


Geog183: Cartographic Design and Geovisualization Spring Quarter 2020

## Lecture 7: Color and its use

# Color

- Most powerful element in map symbolization
- Invokes unconscious, perceptual and cognitive responses
- Both input (eye) and output (video) concern in cartography
- Color rendering methods use additive and subtractive color
- Color models
  - Hardware
    - RGB
    - CMYK
  - User-oriented
    - HSV
    - Munsell
    - HVC

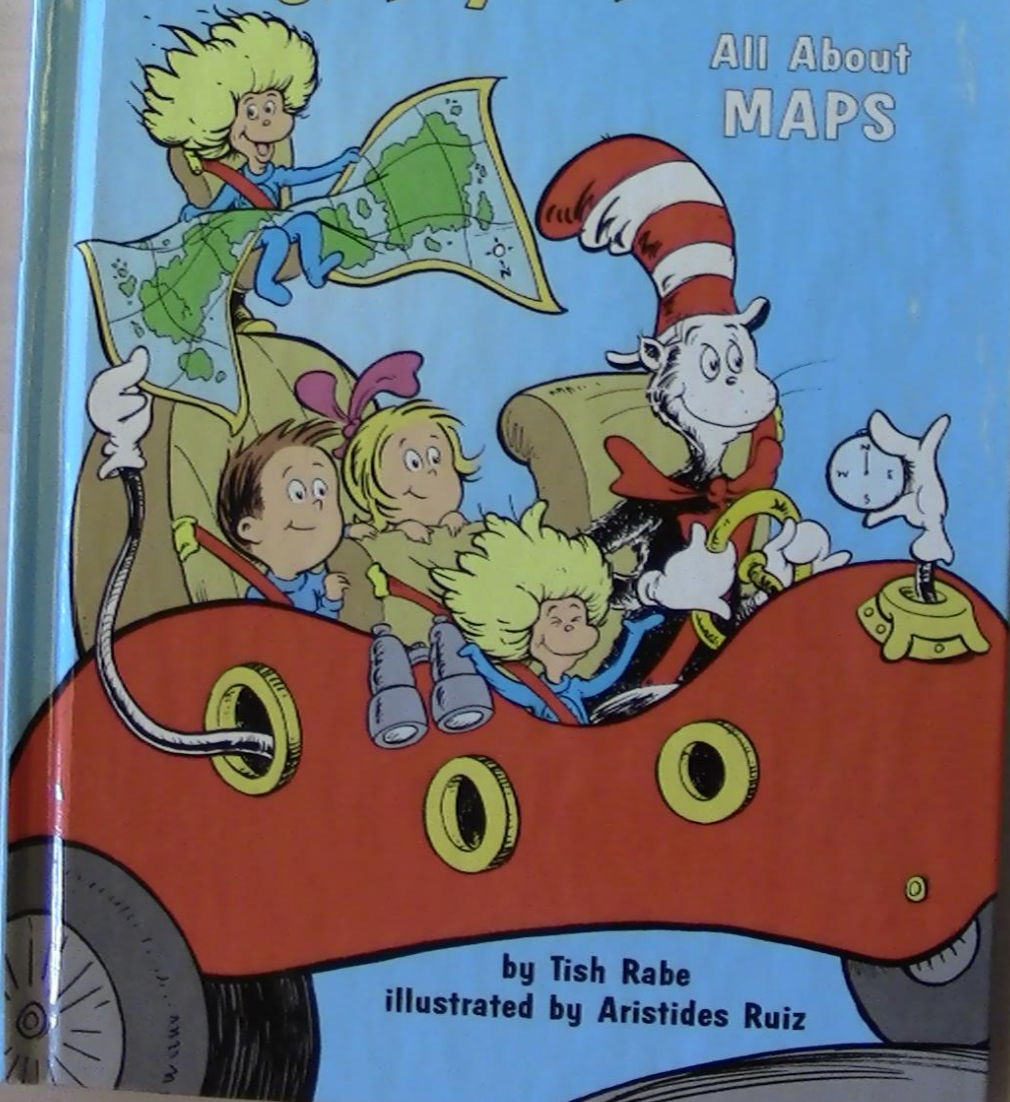




# There's a Map on My Lap!



## All About MAPS



by Tish Rabe  
illustrated by Aristides Ruiz

Some maps use colors  
to tell you a lot.

I used blue where it's cold  
and red where it's hot.

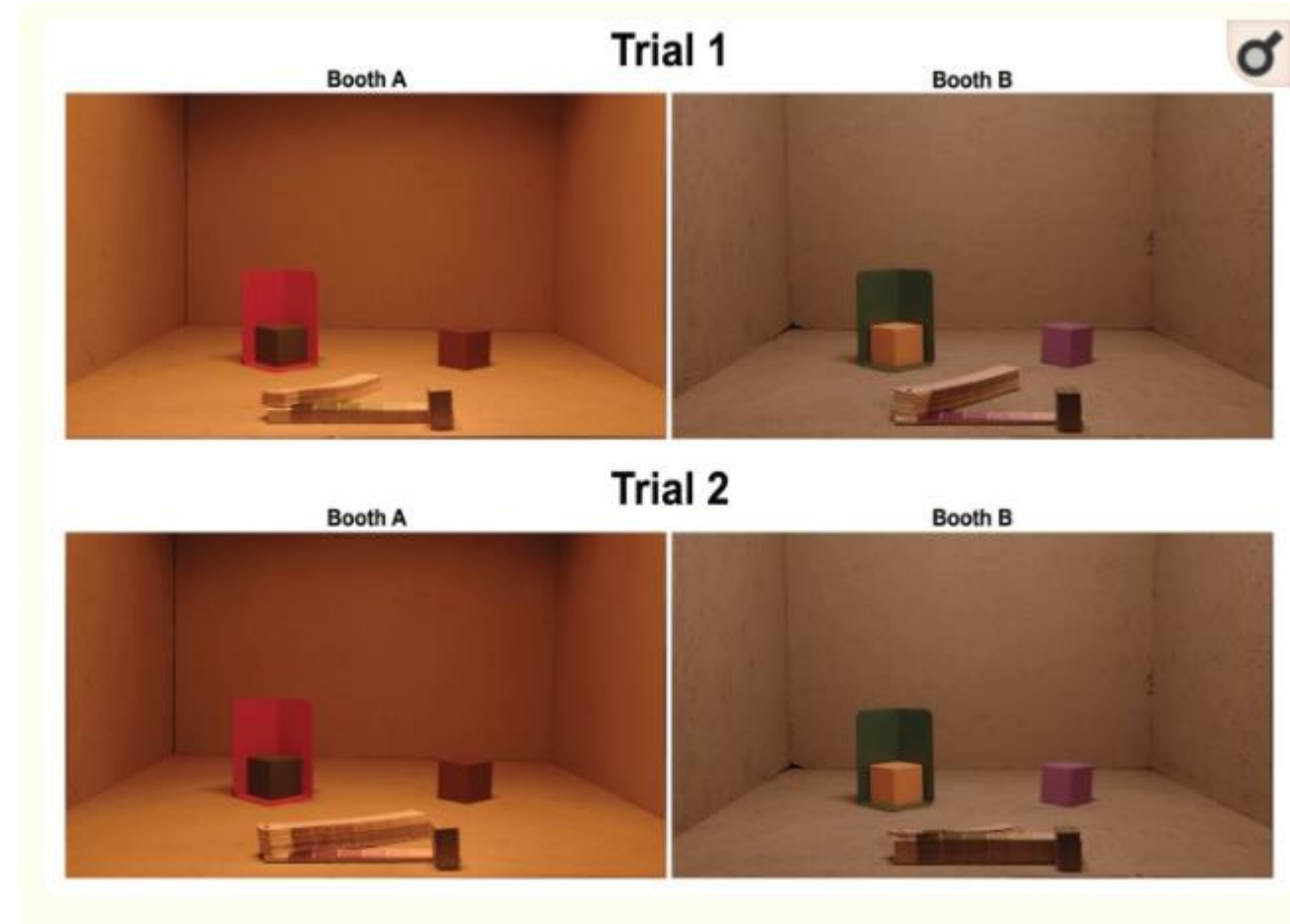
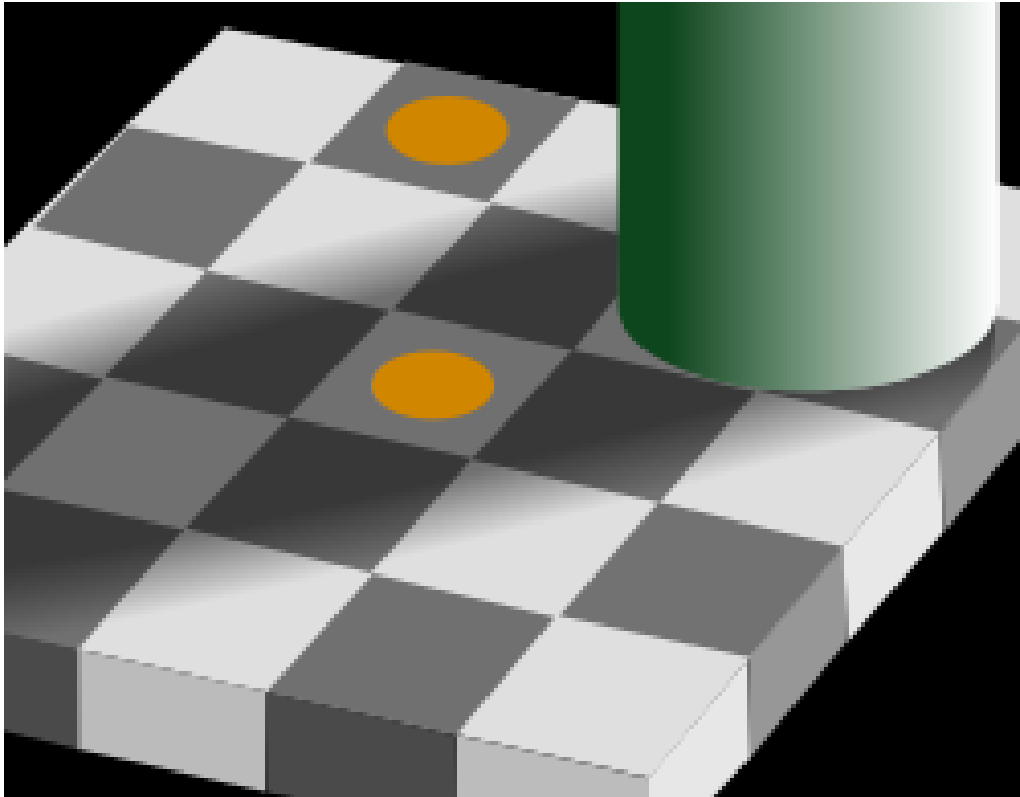




# Color context



# Context and illumination



Allred, Sarah R., and Maria Olkkonen. "The Effect of Background and Illumination on Color Identification of Real, 3D Objects." *Frontiers in Psychology* 4 (2013): 821. *PMC*. Web. 25 Apr. 2018.

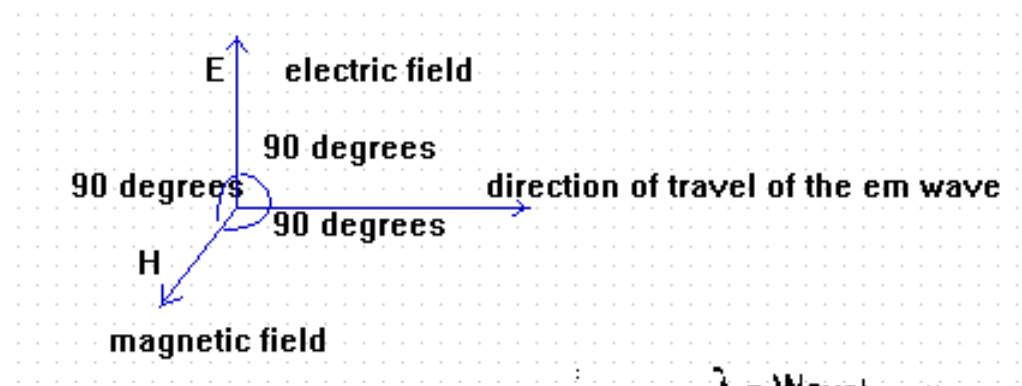
Not just a good idea, it's the law

- $c = 299\,792\,458\text{ m/s}$
- $c = 670\,444\,951\text{ miles per hour}$
- Eye can process up to
  - Movies run at 24 FPS
  - TV runs at 30 FPS = 33 milliseconds/frame
  - Using 50 FPS, light can travel 5,995,849m between frames
- Effect on light is motion blur at high velocities

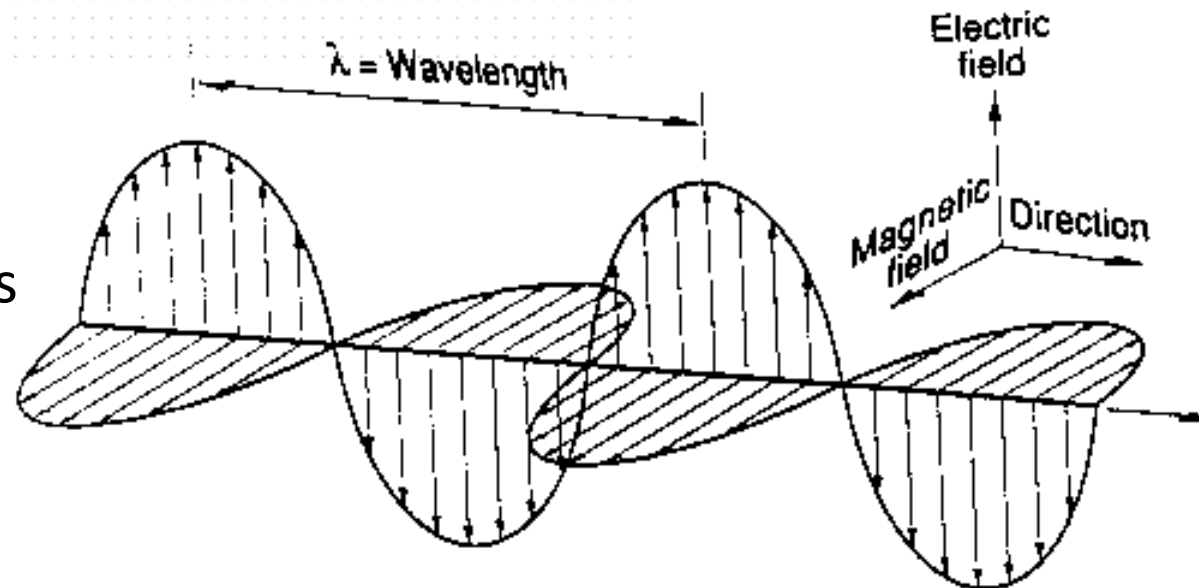




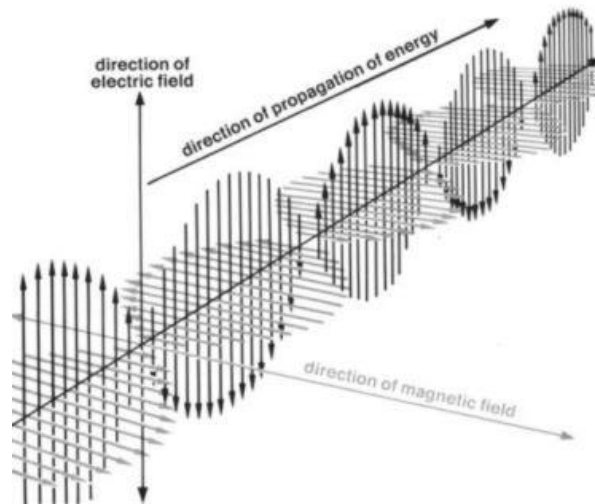
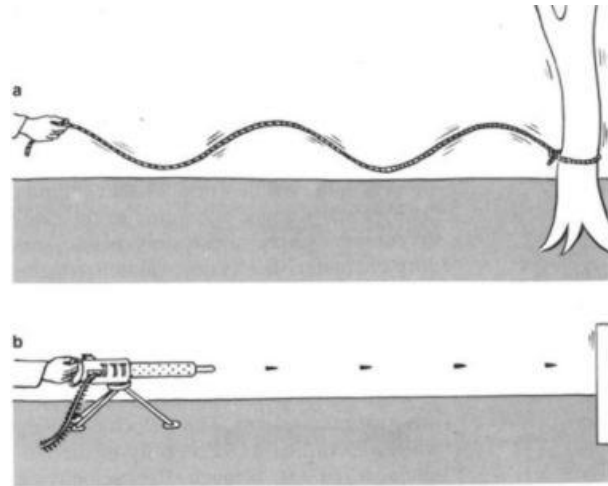
# Wave theory of EMR: Polarization



Dual Orthogonal  
Fluctuating fields

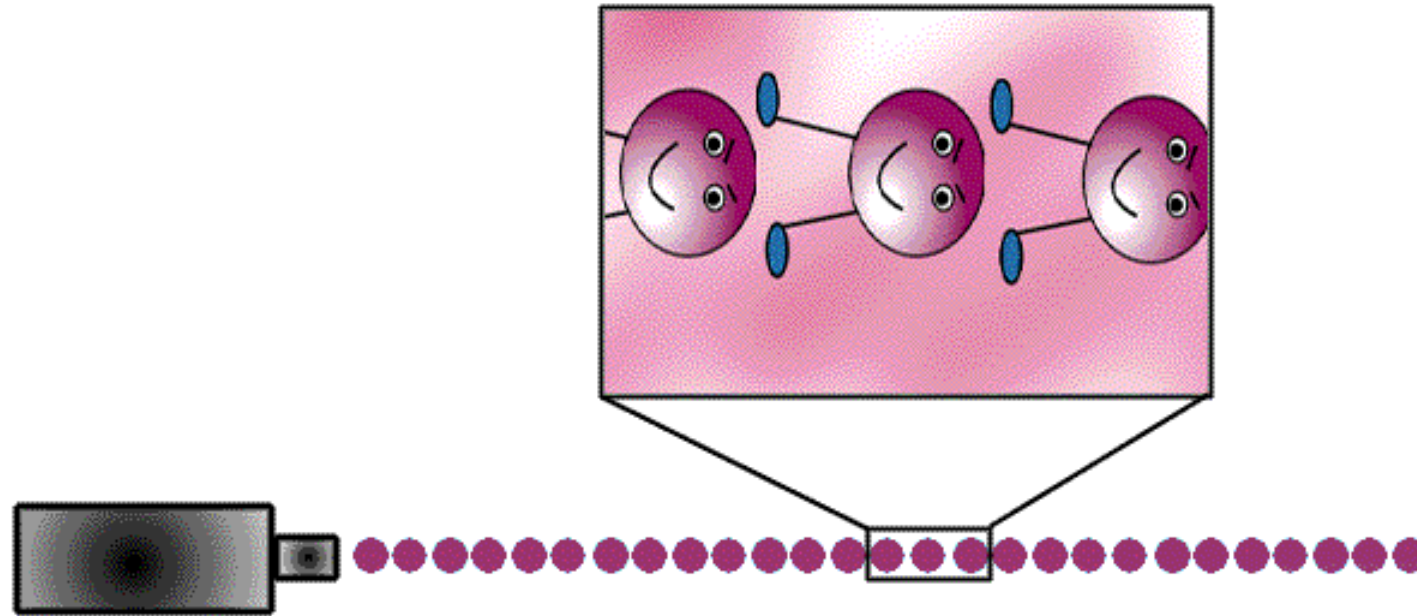


# EMR Theory: A Duality



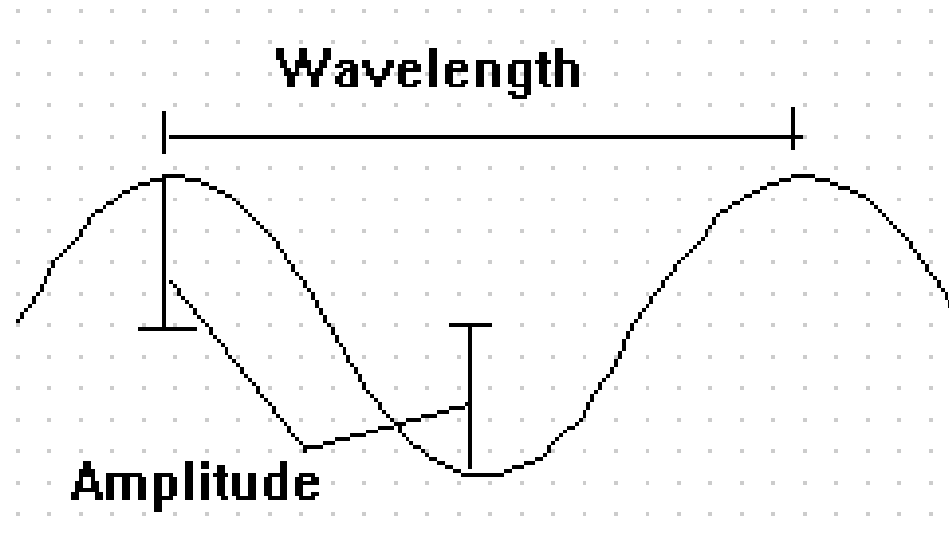


# Particle Theory of EMR Photons



# EMR has a wavelength

- Wavelength ( $\lambda$ ) =  $c / \nu$
- Frequency ( $f$ ) =  $1/\lambda$
- Amplitude (A)

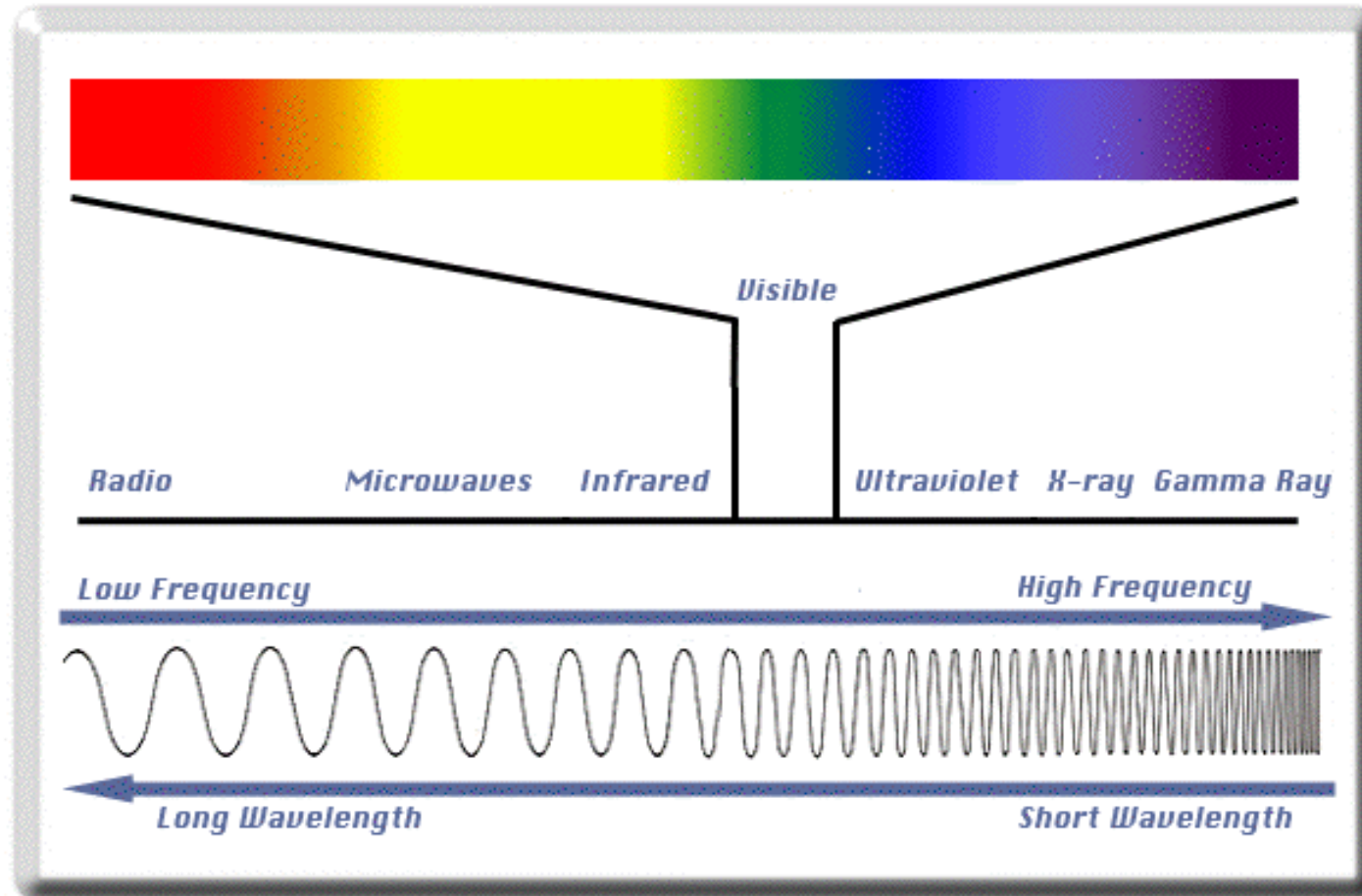


# Intensity of EMR = Brightness

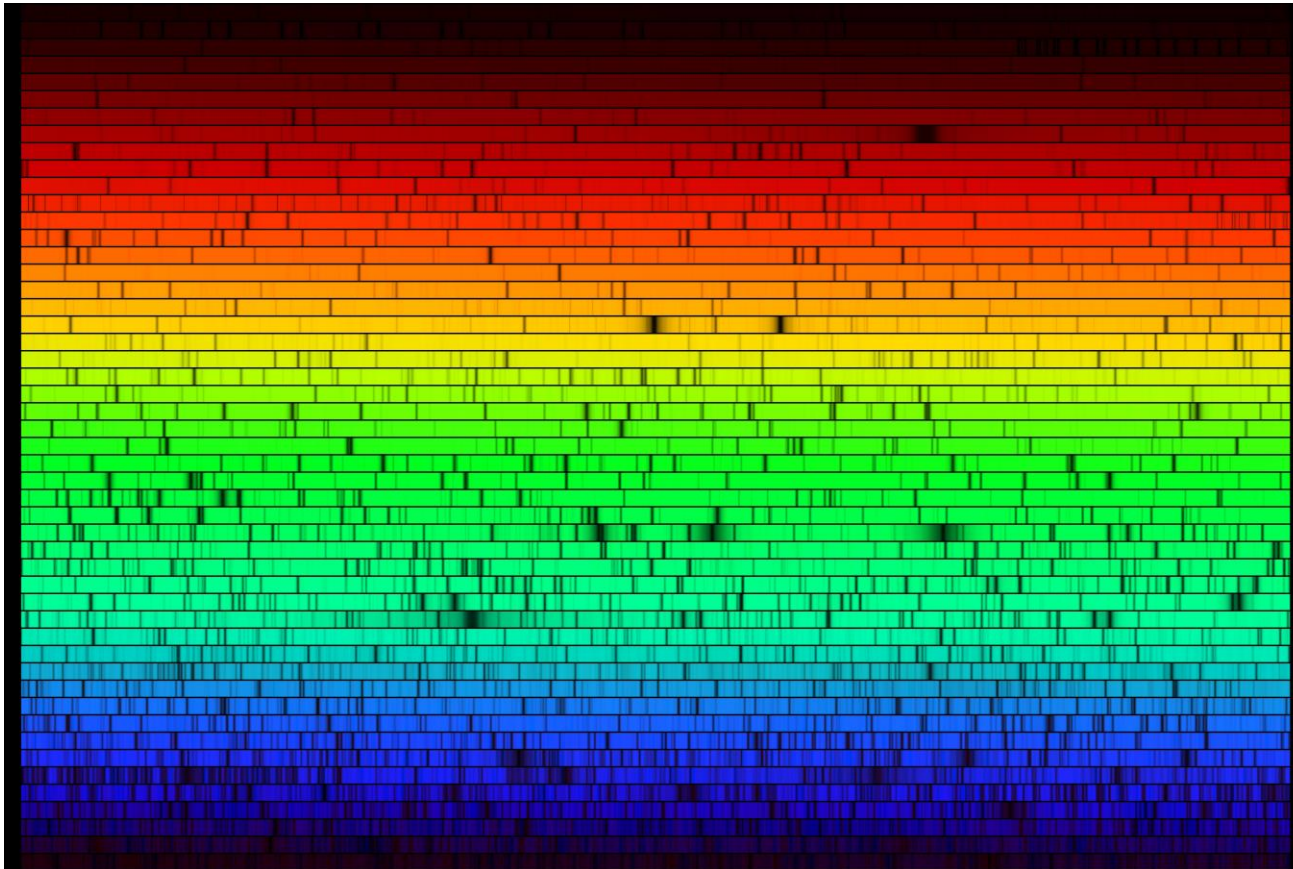
- Energy content =  $E = f(\# \text{ photons})$
- $E = hc / \lambda$   
Planck's constant (h)
- $6.626 \times 10^{-34}$  Joules/second
- Basic energy equation
- E.g. UV and visible light on skin
- UV shorter  $\lambda$



# Electromagnetic spectrum



# “Pure” sunlight: absorption features



‘Solar Flux Atlas from 296 to 1300 nm’ by Robert L. Kurucz, Ingemar Furenlid, James Brault, and Larry Testerman: National Solar Observatory Atlas No. 1, June 1984.

# Light interactions

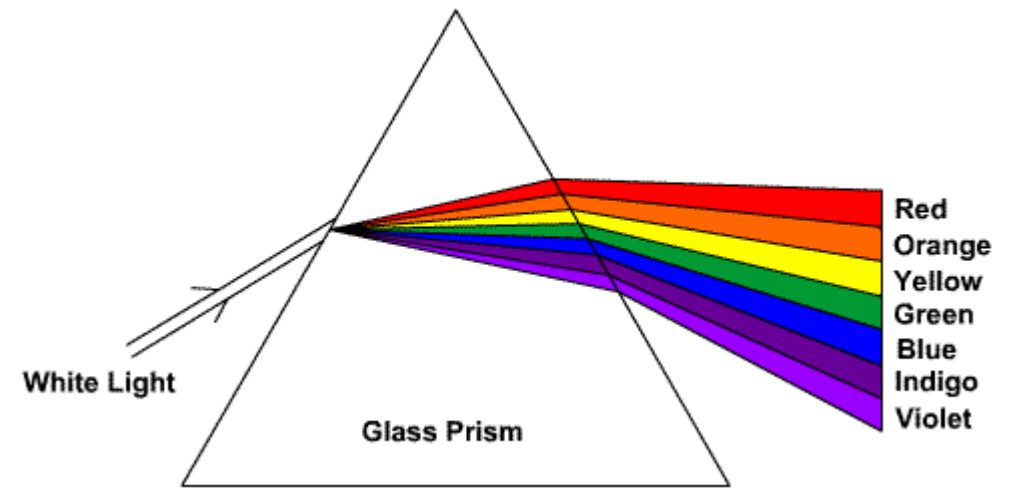
- Shadowing (depth)
- Reflection
- Refraction
- Scattering
- Absorption
- Re-emission



Direct Flash

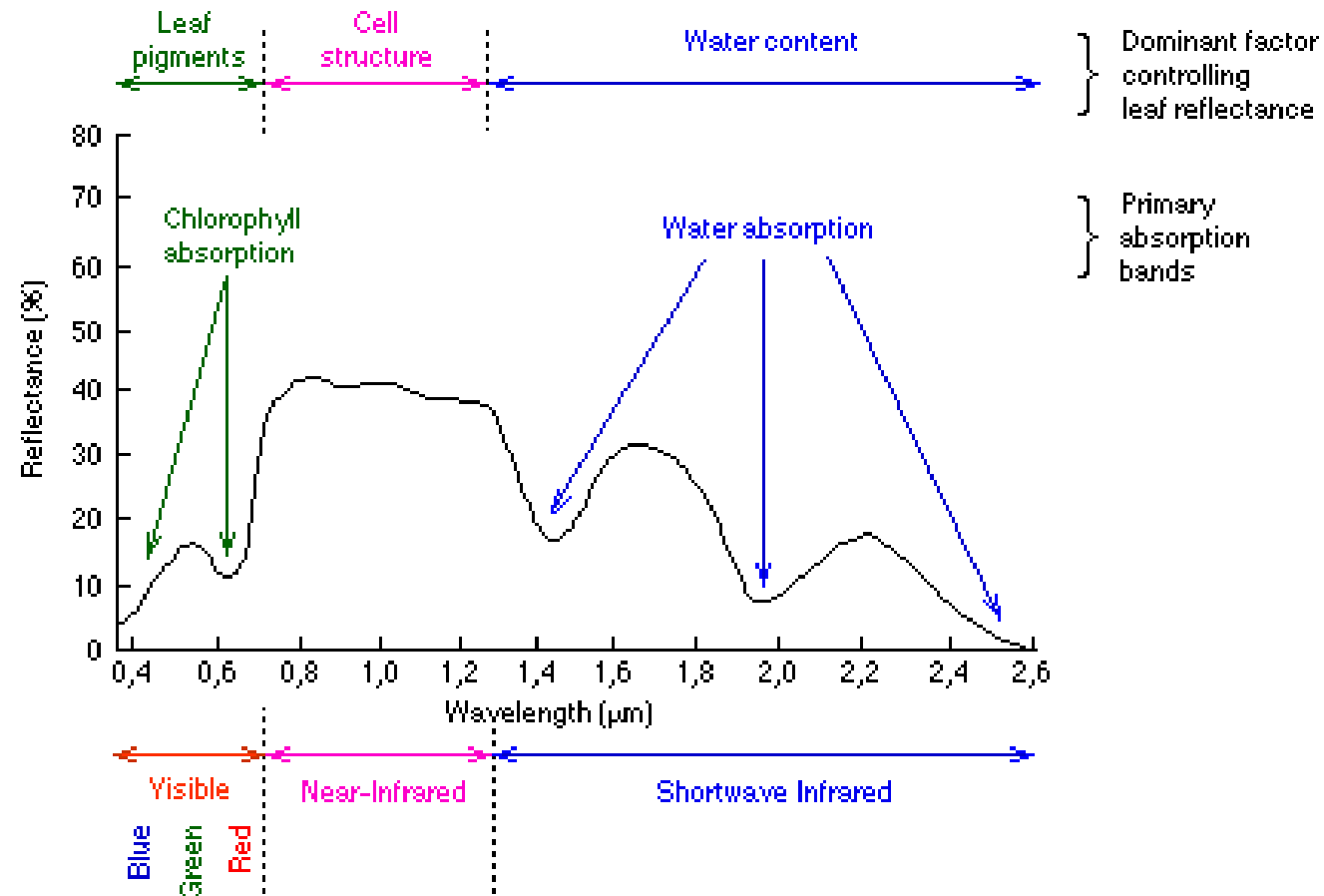


Bounced Flash

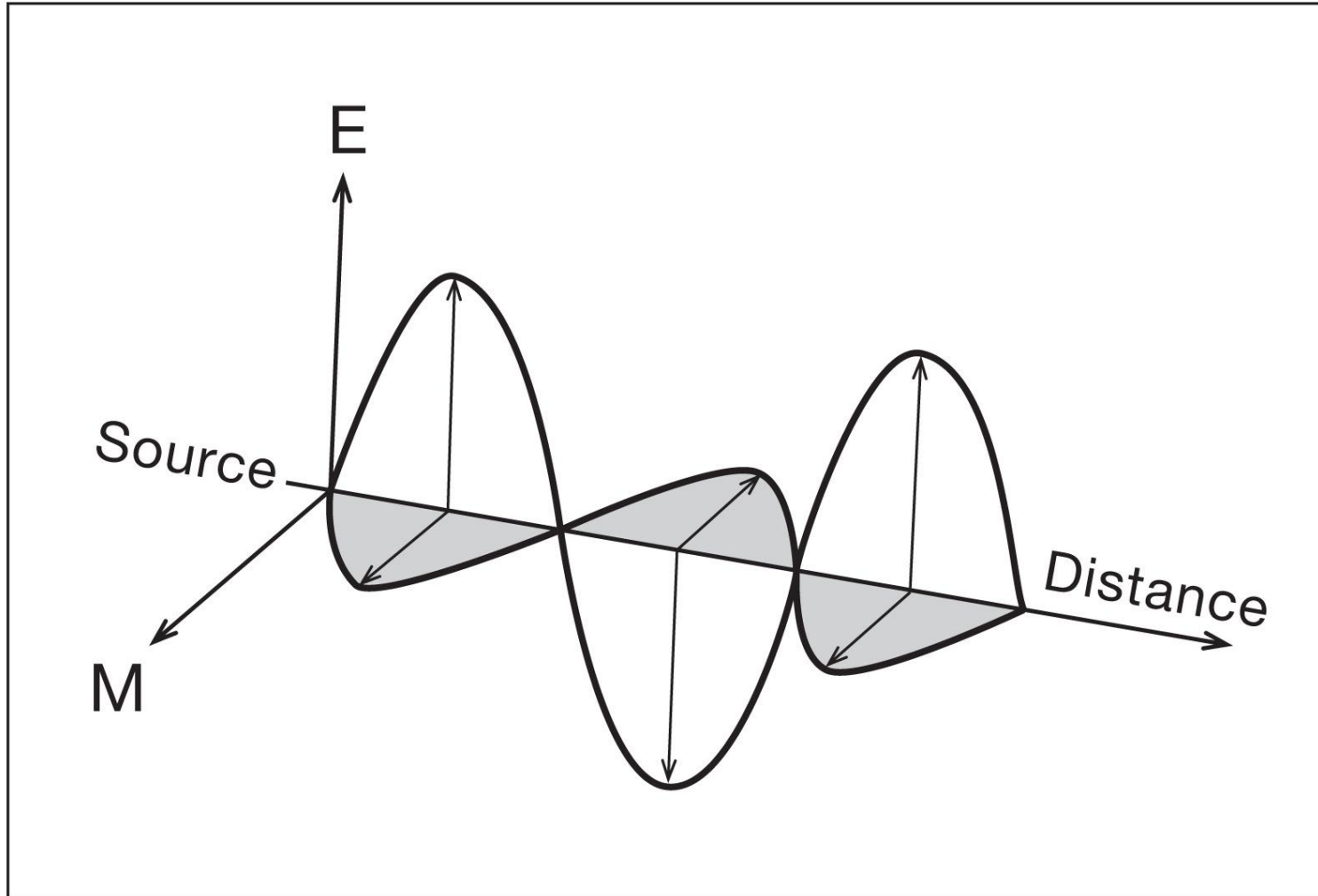




# Spectrum and Absorption



# Light: Electrical and magnetic dimensions (Polarization)



# Rods and cones

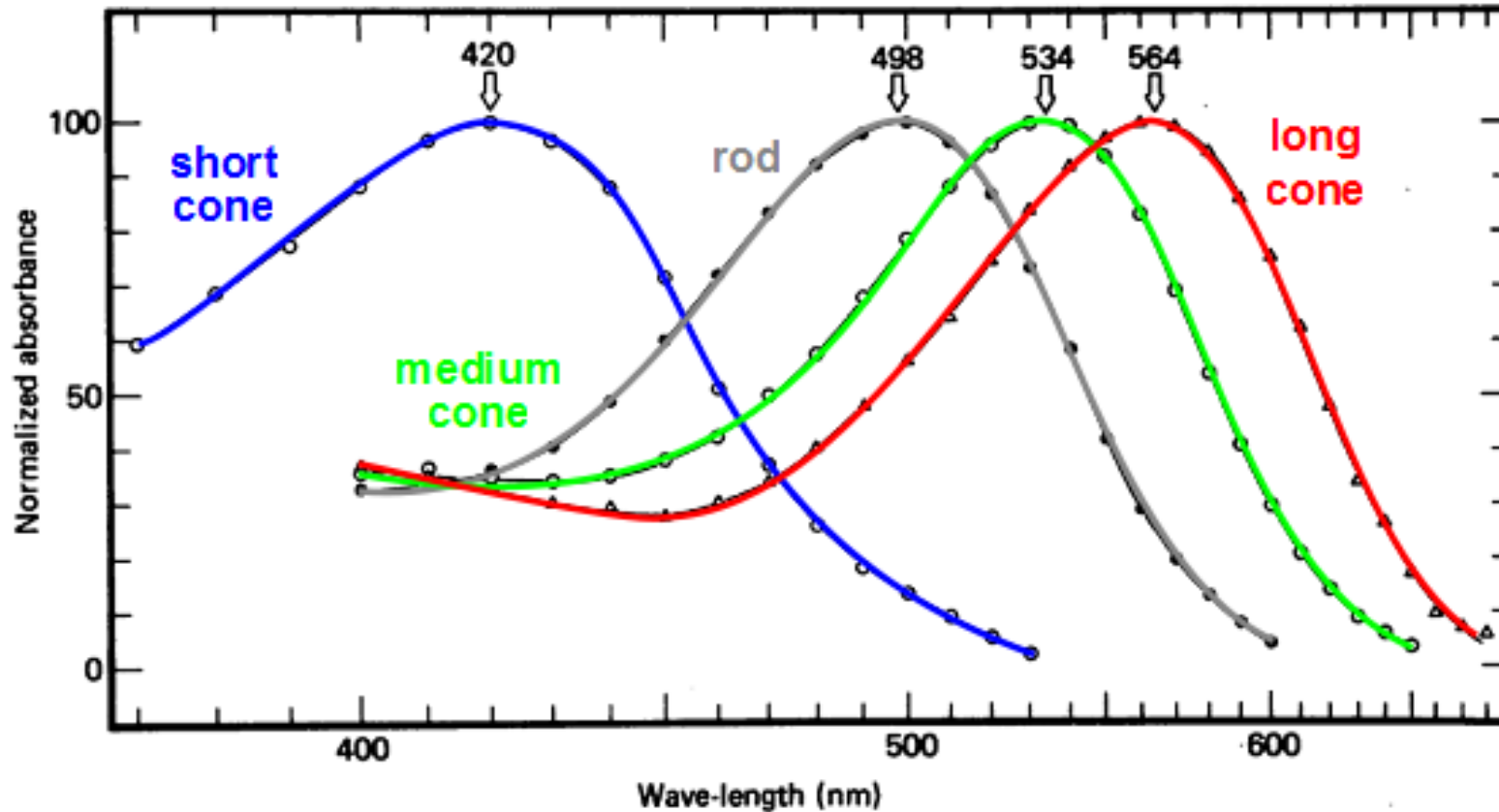


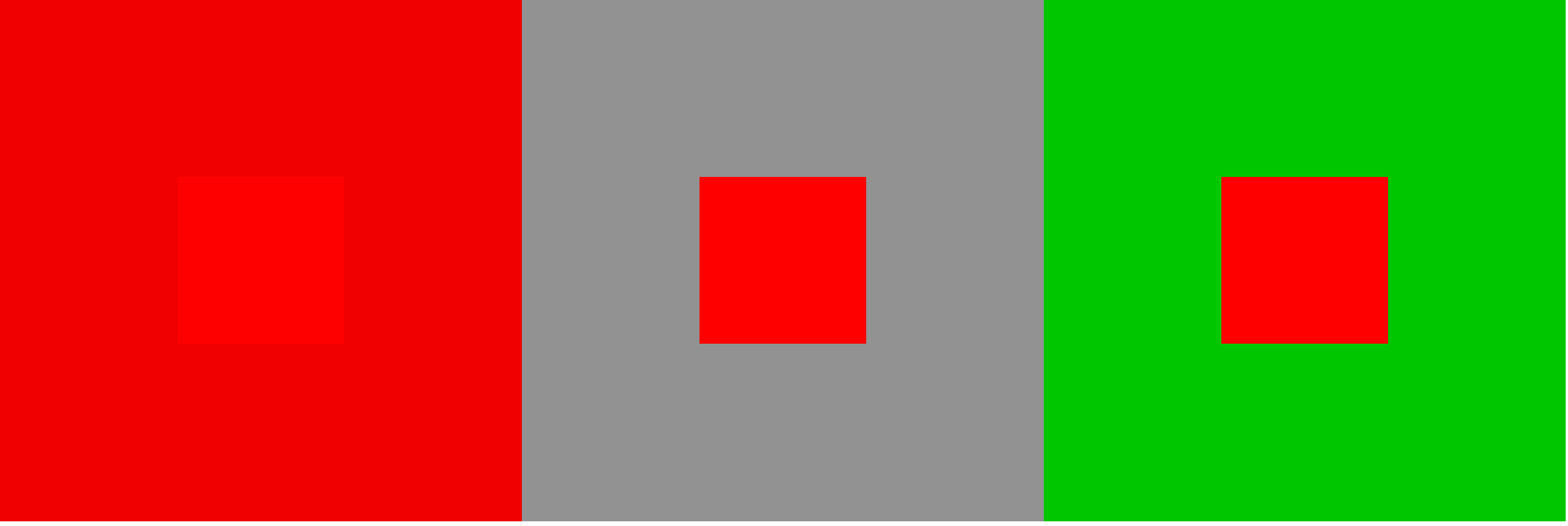
Fig. 2. The mean absorbance spectra of outer segments of the four classes of human photoreceptors. Curves labelled as follows: '498', mean of eleven rods; '420', mean of three blue-sensitive cones; '534', mean of eleven green-sensitive cones; '564', mean of nineteen red-sensitive cones.



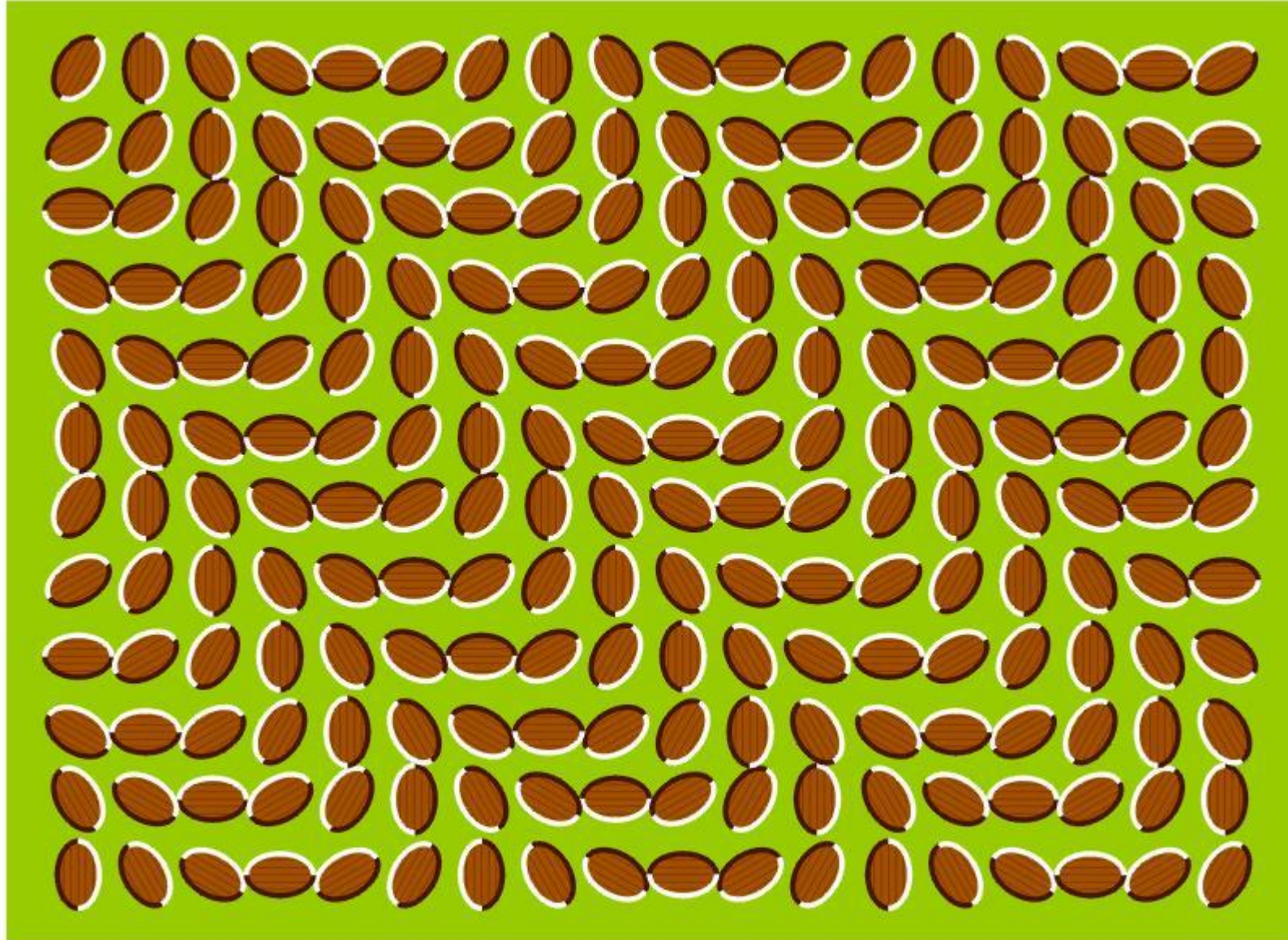
# Theories of color perception

- Trichromatic theory
  - RGB cones
- Opponent-process theory
  - Light-dark and two color scales, red-green and blue-yellow
- Both theories have value
- Nerves fire at a constant rate
- Above standard is excitation, below is inhibition

# Simultaneous contrast



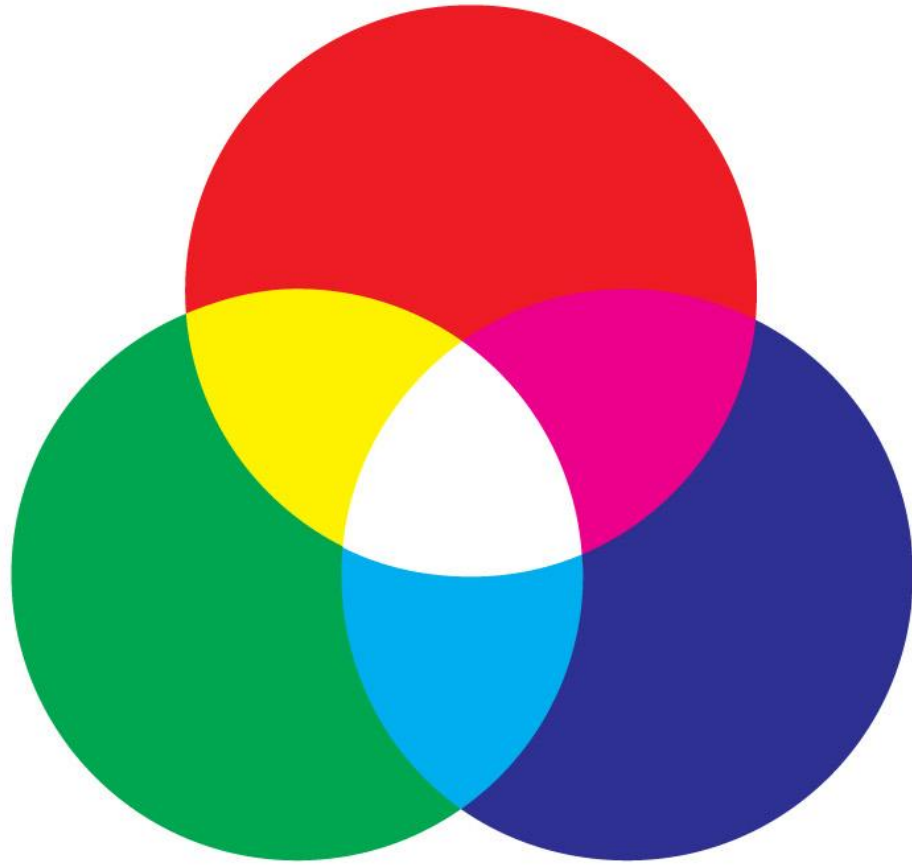
# Almond illusion



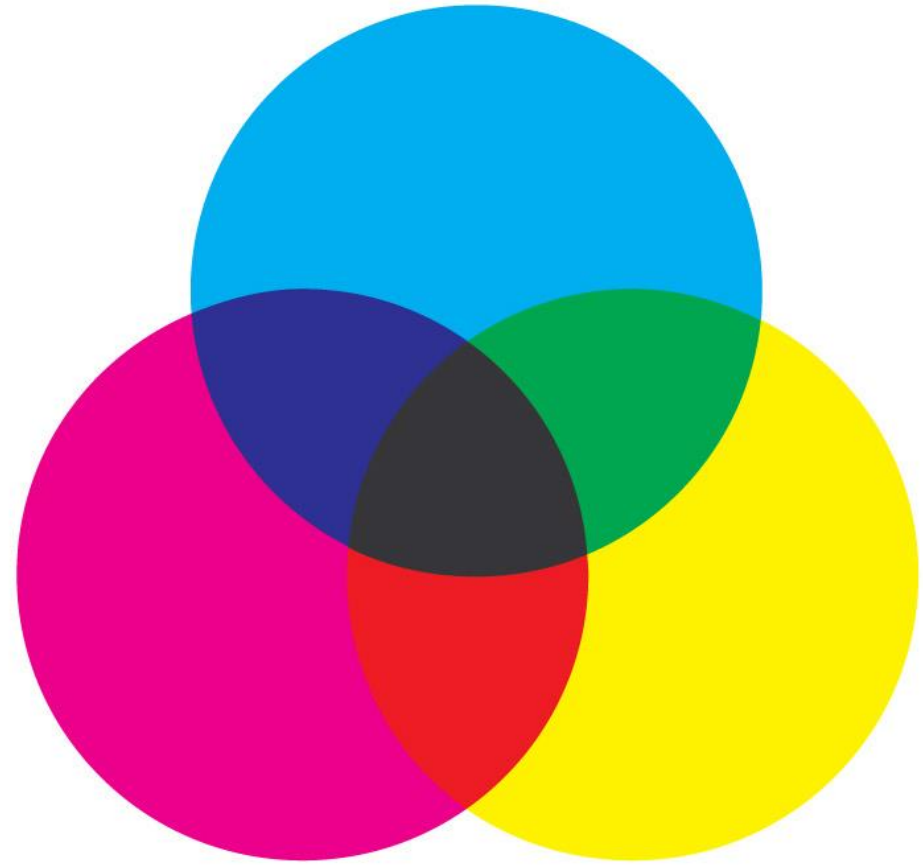


# Rendering color

- Depends on medium, but one major contrast
- Subtractive color
  - Assumes background color is white, uses filtering pigments to add to surface to create color
  - Add little color, unsaturated and light
  - Add full color, saturated and darker
  - Non-primary colors are blends of MCY
- Additive color
  - Assumes background is black
  - Adds illumination to achieve color
  - More color more saturated, more light brighter
  - Non-primary colors are blends of RGB



Additive Colors

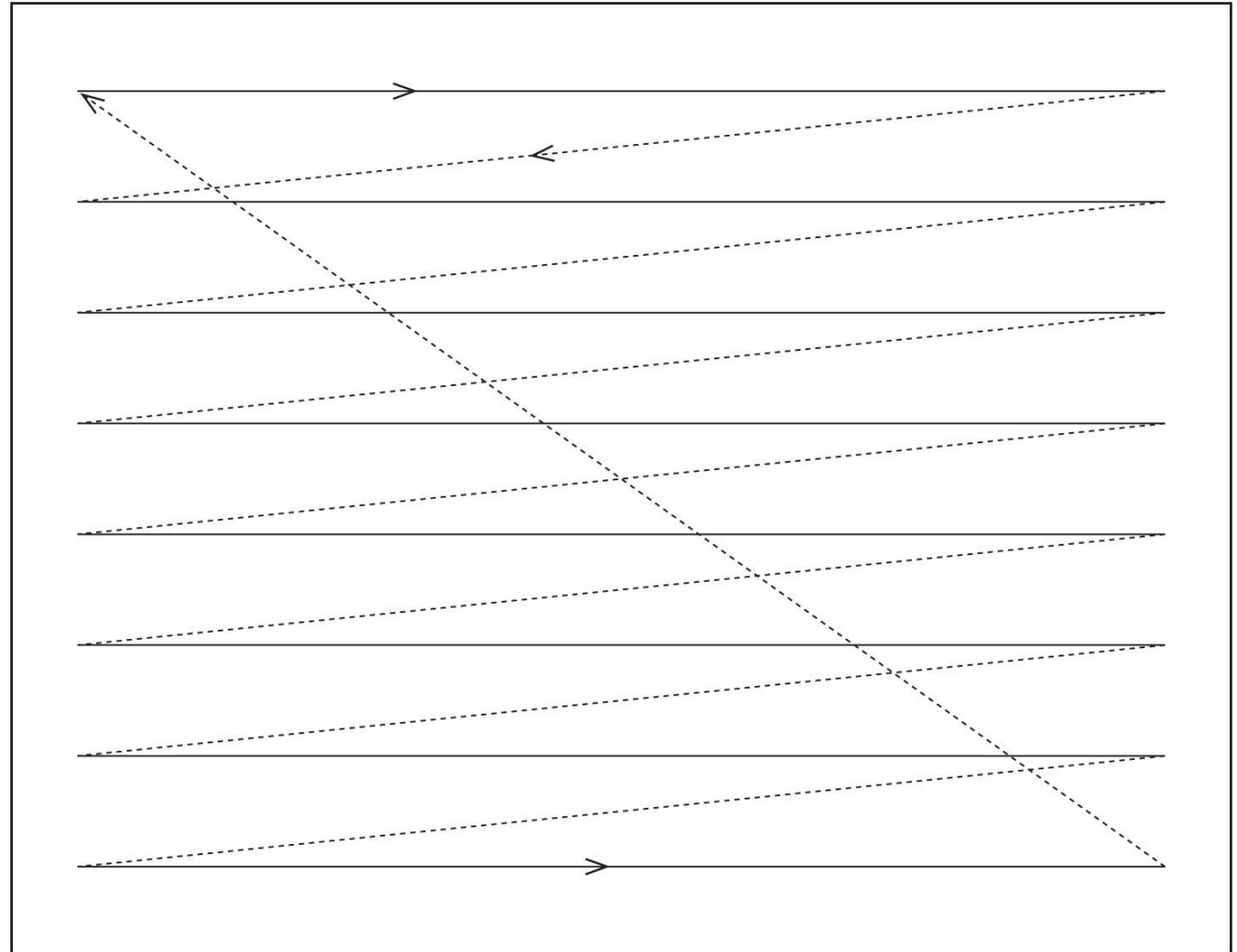


Subtractive Colors

# Offset color lithographic printing

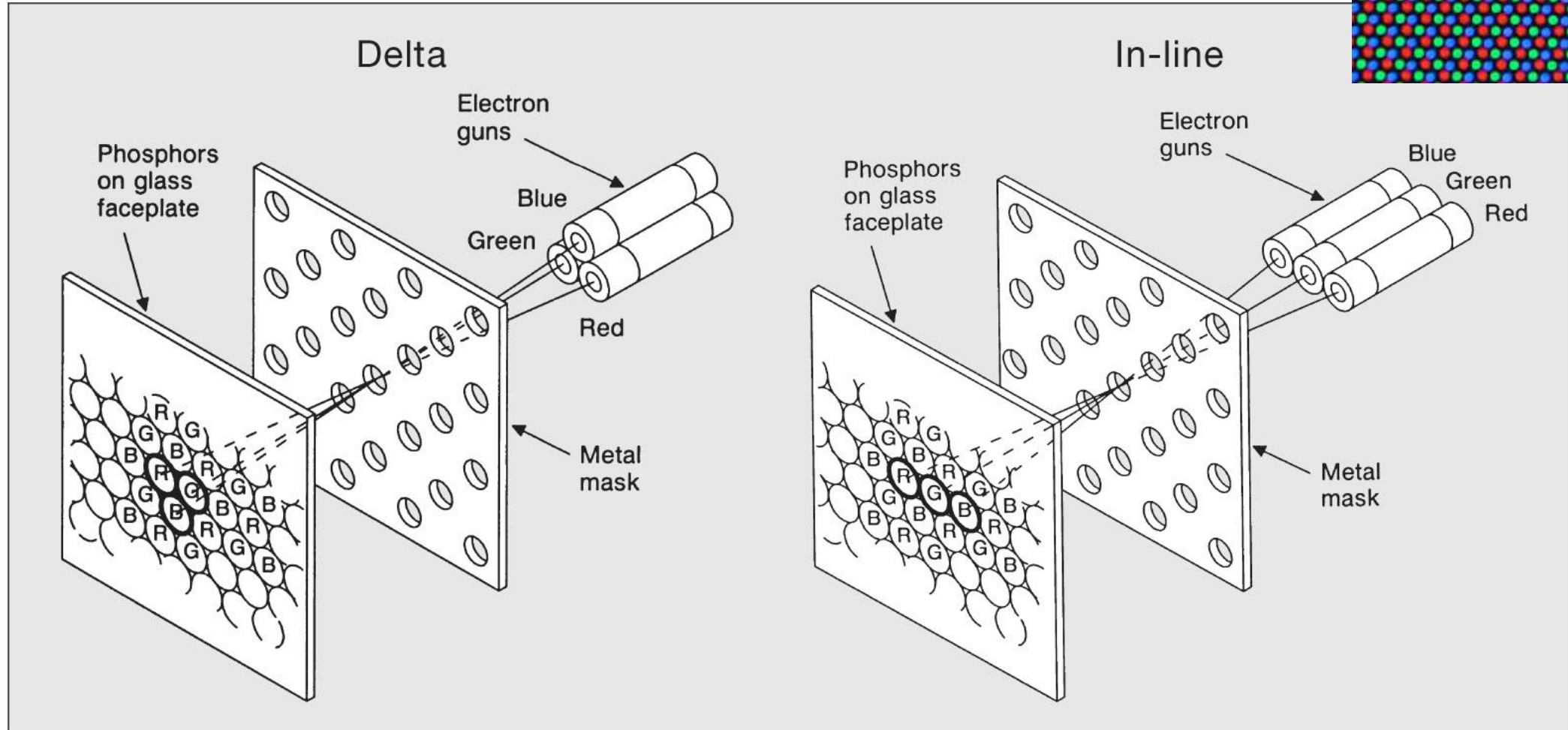
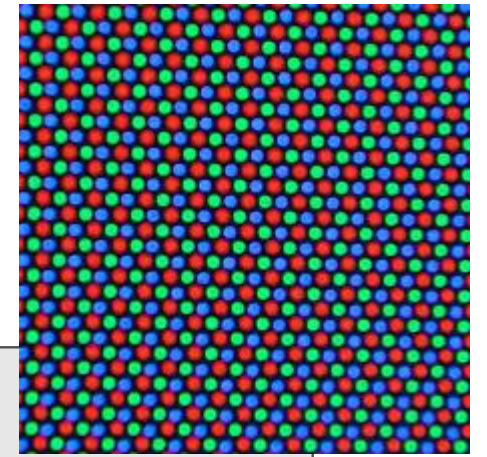


# Raster graphics





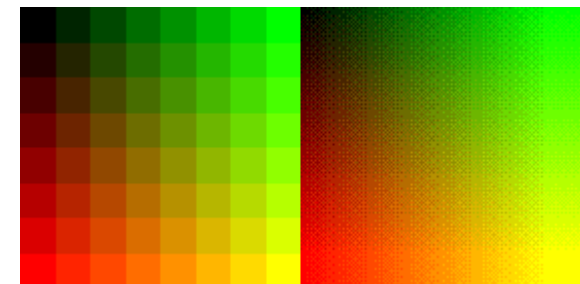
# Raster imaging technologies



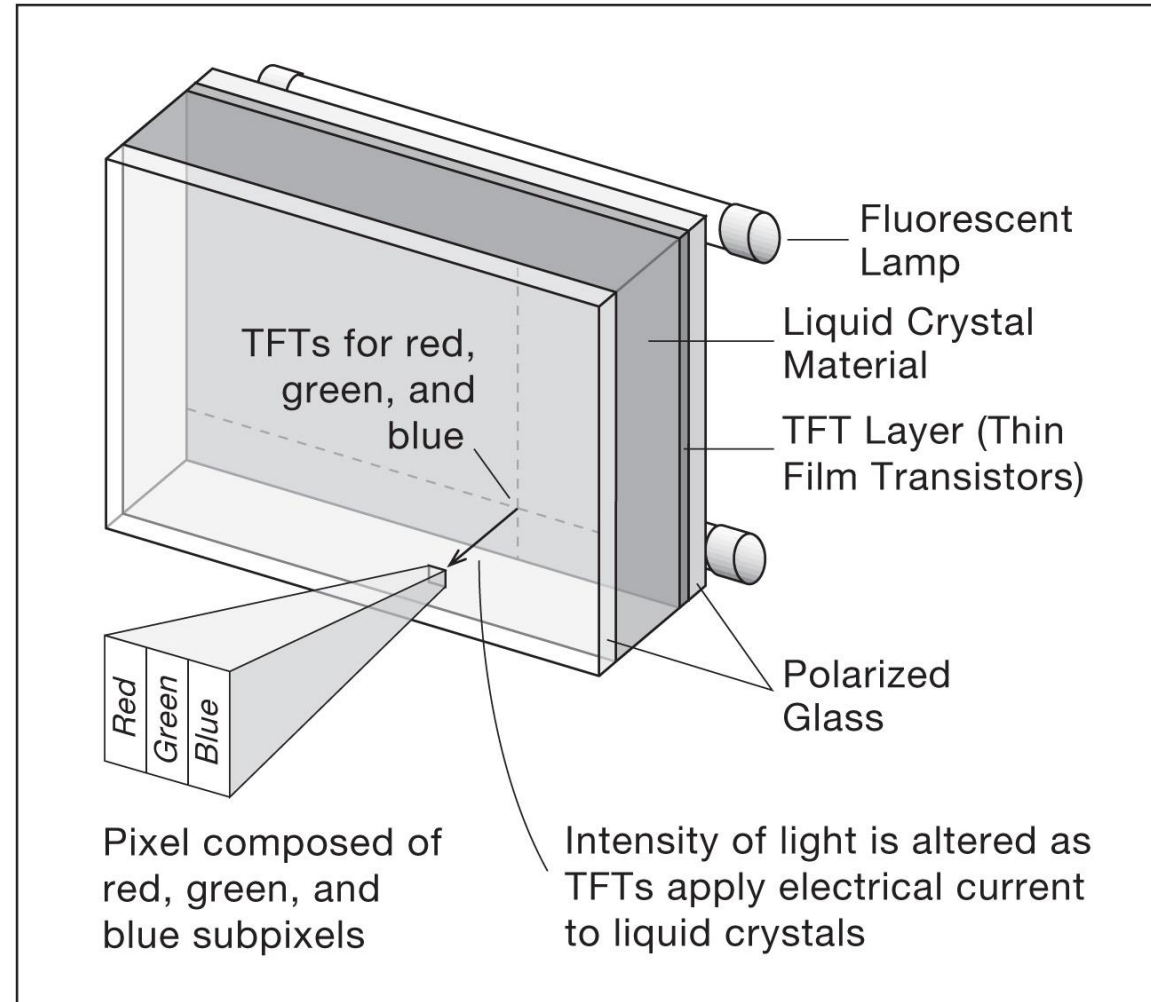
# Display details

- Pixelization
- Aliasing and anti-aliasing
- Dithering
- Frame buffers and the refresh rate
- Movement periodicity

<https://www.youtube.com/watch?v=smDpCsVVgPA>



# Liquid Crystal Display



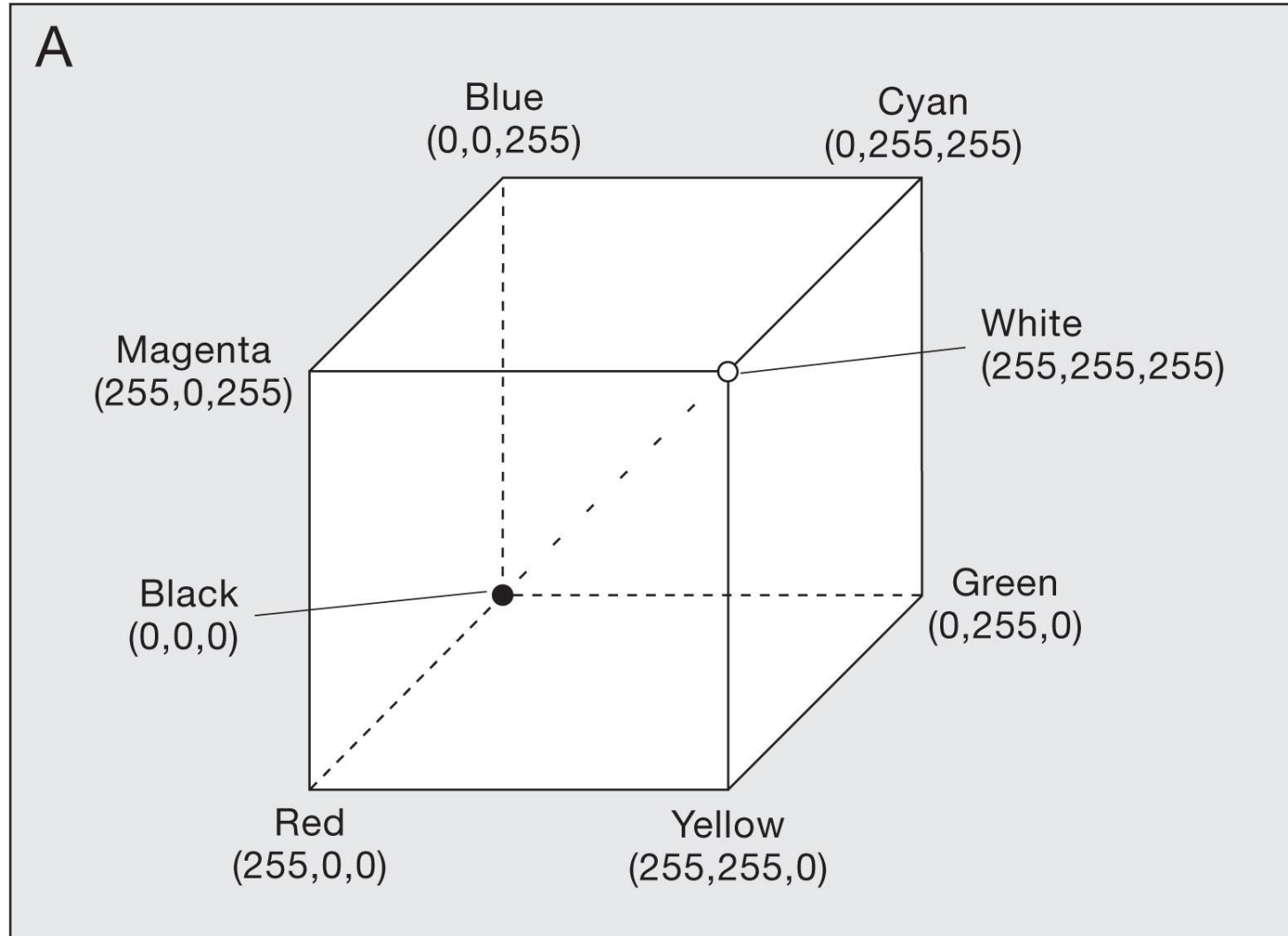
# Light Emitting Diodes

- LED panels: conventional (using discrete LEDs) and surface-mounted device (SMD) panels
- A cluster of red, green, and blue diodes is driven together to form a full-color pixel, usually square
- Pixels are spaced evenly apart and are measured from center to center for absolute pixel resolution
- Largest LED display in the world is over 500 meters long in Suzhou, China
- Largest LED television in the world is the Center Hung Video Display at Cowboys Stadium, which is 49 m × 22 m
- LED TVs using SMD pixels of red, green, and blue diodes mounted in a single package, which is then mounted on the driver PC board
- Individual diodes are smaller than a pinhead and are set very close together
- Reduces maximum viewing distance by 25% from the discrete diode screen at the same resolution





# Color models: Cube

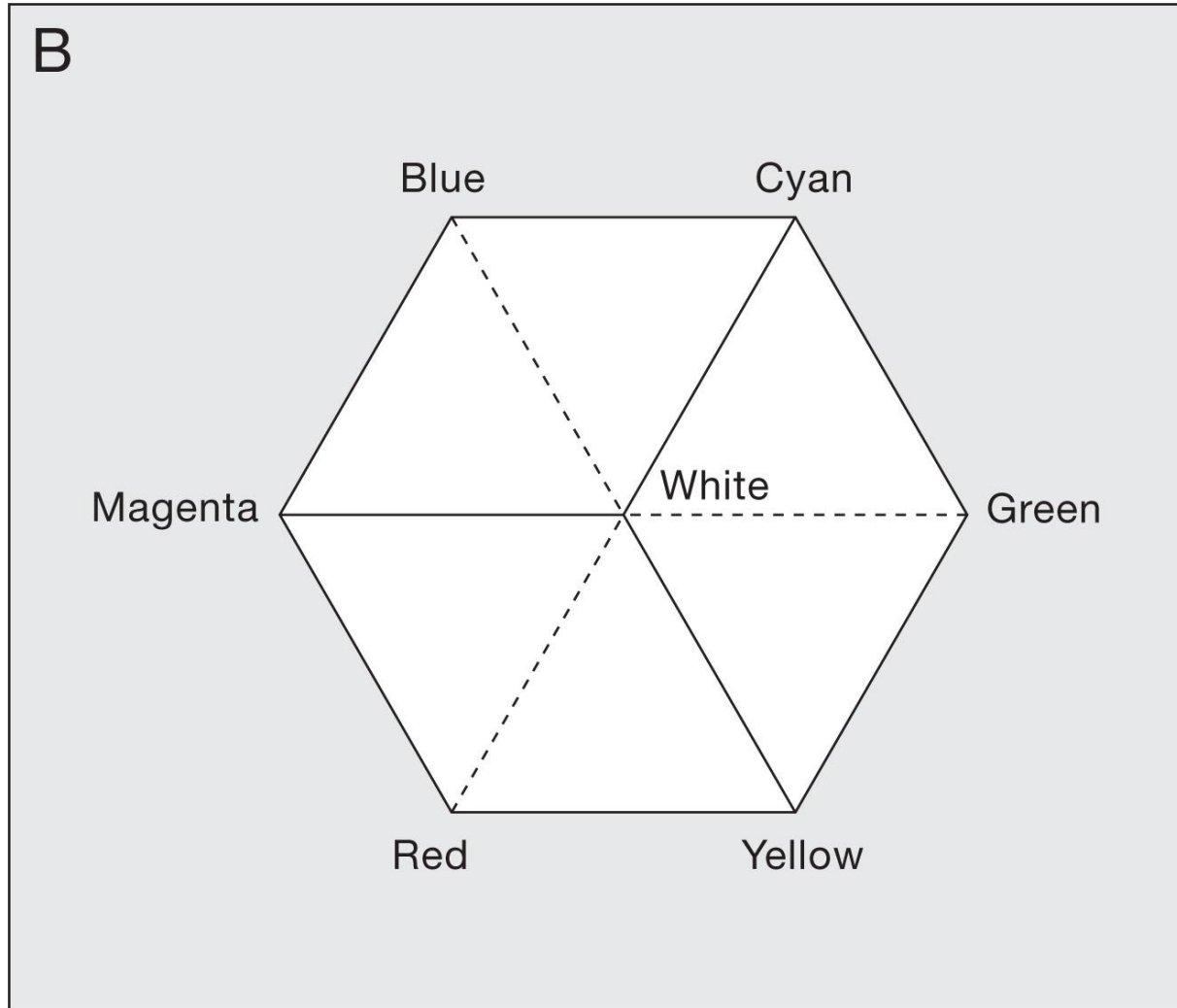


# Color production and reproduction

- Requires measurement
- Based on standards
- Names are subjective
- Applies to foveal zone only
- Requires color MODEL



# Color models: Wheel (Hue and Saturation)





# CMYK: Subtractive primaries Cyan, magenta, yellow, black



CYAN



MAGENTA



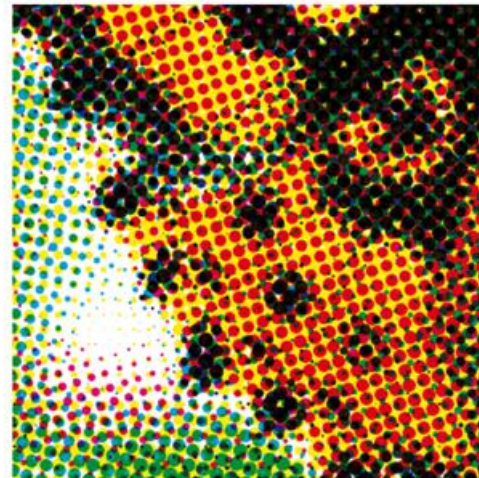
YELLOW



BLACK



FINAL CMYK



DETAIL VIEW

CMYK Color Code according to the Commission for the Geological Map of the World (CGMW), Paris, France

Phanerozoic (40/0/5/0)	Cenozoic (5/0/90/0)	Quaternary (0/5/10/0)	Holocene (0/5/5/0)			
		Pleistocene (0/5/30/0)	Upper (0/5/15/0)	'Ionian' (0/5/20/0)		
			Calabrian (0/5/25/0)	Gelasian (0/5/35/0)		
			Piacenzian (0/0/25/0)	Zanclean (0/0/30/0)		
		Miocene (0/0/100/0)	Neogene (0/10/90/0)	Messinian (0/0/55/0)	Tortonian (0/0/60/0)	Serravallian (0/0/65/0)
				Langhian (0/0/70/0)	Burdigalian (0/0/75/0)	Aquitanian (0/0/80/0)
	Chattian (0/10/30/0)			Rupelian (0/15/35/0)	Priabonian (0/20/30/0)	
	Oligocene (0/25/45/0)		Bartonian (0/25/35/0)	Lutetian (0/30/40/0)	Ypresian (0/35/45/0)	Thanetian (0/25/50/0)
			Selandian (0/25/55/0)	Danian (0/30/55/0)	Maastrichtian (5/0/45/0)	Campanian (10/0/50/0)
			Santonian (15/0/55/0)	Coniacian (20/0/60/0)	Turonian (25/0/65/0)	Cenomanian (30/0/70/0)
	Paleocene (0/35/55/0)	Upper (35/0/75/0)	Albian (20/0/40/0)	Aptian (25/0/45/0)	Barremian 30/0/50/0)	
			Hauterivian (35/0/55/0)	Valanginian (40/0/60/0)	Berriasian (45/0/65/0)	
			Lower (45/0/70/0)			

Phanerozoic (40/0/5/0)	Mesozoic (60/0/100/0)	Jurassic (80/0/5/0)	Upper (30/0/0/0)	Tithonian (15/0/0/0)	Kimmeridgian (20/0/0/0)	Oxfordian (25/0/0/0)	Callovian (25/0/5/0)	Bathonian (30/0/5/0)	Bajocian (35/0/5/0)	Aalenian (40/0/5/0)	Toarcian (40/5/0/0)	Pienbachiian (50/5/0/0)	Sinemurian (60/5/0/0)	Hettangian (70/5/0/0)	Rhaetian (10/25/0/0)	Norian (15/30/0/0)	Carnian (20/35/0/0)			
			Lower (75/5/0/0)	Triassic (50/80/0/0)	Upper (25/40/0/0)	Ladinian (25/45/0/0)	Anisian (25/50/0/0)	Olenekian (30/65/0/0)	Induan (35/70/0/0)	Changhsingian (0/25/20/0)	Wuchiapingian (0/30/25/0)	Capitanian (0/40/35/0)	Wordian (0/45/40/0)	Roadian (0/50/45/0)	Kungurian (10/45/40/0)	Artinskian (10/50/45/0)	Sakmarian (10/55/50/0)	Asselian (10/60/55/0)	Gzhelian (20/10/15/0)	
				Permian (5/75/75/0)	Lopingian (0/35/30/0)	Guadalupian (0/55/50/0)	Cisuralian (5/65/60/0)	Upper (25/10/20/0)	Middle (35/10/20/0)	Lower (45/0/20/0)	Upper (30/15/55/0)	Middle (40/15/55/0)	Lower (60/15/55/0)	Tournaisian (45/15/55/0)						

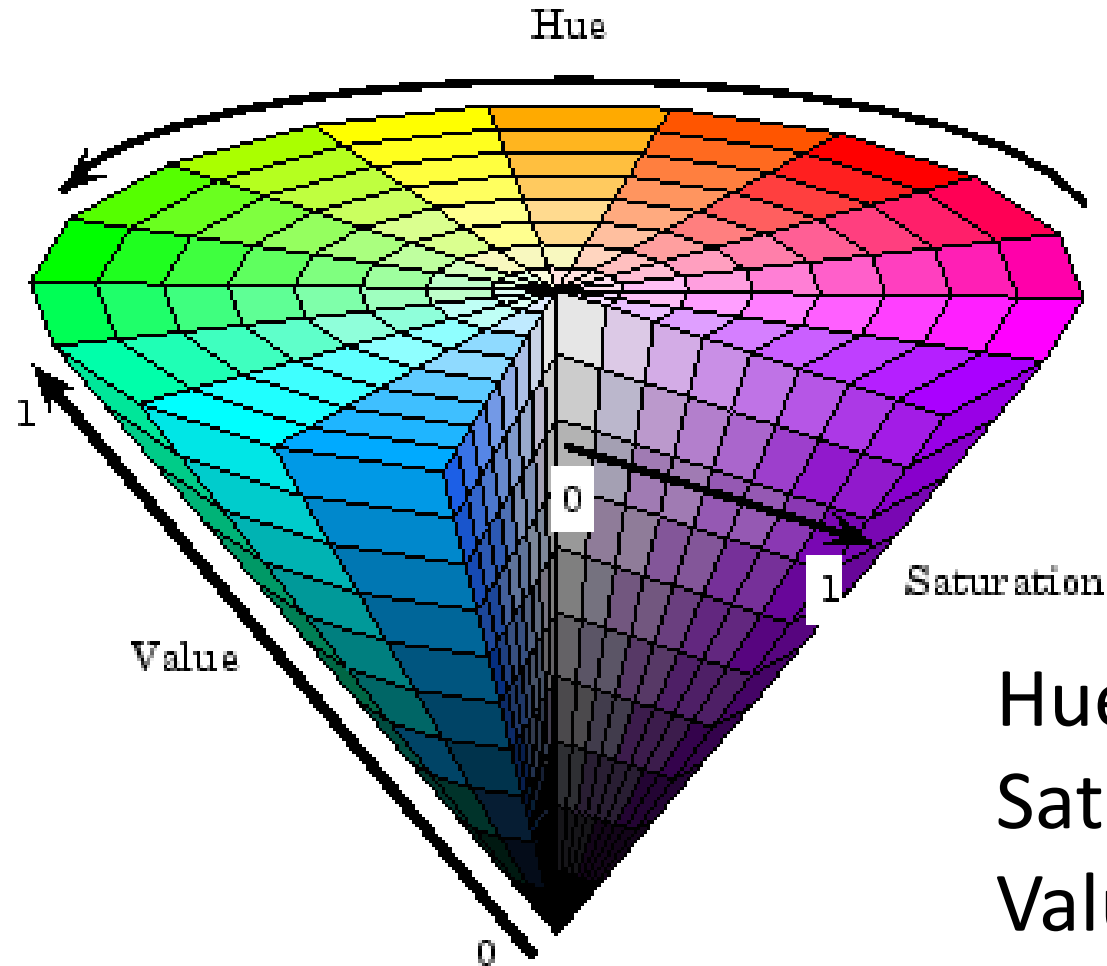
Phanerozoic (40/0/5/0)	Paleozoic (40/10/40/0)	Devonian (20/40/75/0)	Upper (5/10/35/0)	Famennian (5/5/20/0)	Frasnian (5/5/30/0)	Givetian (5/10/45/0)	Eifelian (5/15/50/0)	Pragian (10/15/50/0)	Emasian (10/20/55/0)	Moscovian (30/10/20/0)	Artinskian (10/50/45/0)	Sakmarian (10/55/50/0)	Asselian (10/60/55/0)	Gzhelian (20/10/15/0)	Kasimovian (25/10/15/0)	Moscovian (30/10/20/0)	Bashkirian (40/10/20/0)	Serpukhovian (25/15/55/0)	Visian (35/15/55/0)	Tournaisian (45/15/55/0)									
			Lower (10/30/65/0)	Pridoli (10/0/10/0)	Ludlow (25/0/15/0)	Gorstian (20/0/10/0)	Homerian (20/0/15/0)	Shinarumpian (25/0/20/0)	Telychian (25/0/15/0)	Aeronian (30/0/20/0)	Rhuddanian (35/0/25/0)	Himantian (35/0/30/0)	Katian (40/0/35/0)	Sandbian (45/0/40/0)	Dapingian (60/0/40/0)	Floian (75/0/45/0)	Tremadocian (80/0/50/0)	Stage 10 (10/0/20/0)	Jiangshanian (15/0/25/0)	Paibian (20/0/30/0)	Guzhangian (20/5/30/0)	Drumian (25/5/35/0)	Stage 5 (30/5/40/0)	Stage 4 (30/10/40/0)	Stage 3 (35/10/45/0)	Stage 2 (35/15/45/0)	Furongian (30/0/40/0)	Terreneuvian (45/15/65/0)	Fortunian (40/15/55/0)
				Middle (70/0/50/0)	Wenlock (30/0/20/0)	Sheinwoodian (25/0/20/0)	Aeronian (30/0/20/0)	Rhuddanian (35/0/25/0)	Himantian (35/0/30/0)	Katian (40/0/35/0)	Sandbian (45/0/40/0)	Dapingian (60/0/40/0)	Floian (75/0/45/0)	Tremadocian (80/0/50/0)	Stage 10 (10/0/20/0)	Jiangshanian (15/0/25/0)	Paibian (20/0/30/0)	Guzhangian (20/5/30/0)	Drumian (25/5/35/0)	Stage 5 (30/5/40/0)	Stage 4 (30/10/40/0)	Stage 3 (35/10/45/0)	Stage 2 (35/15/45/0)	Furongian (30/0/40/0)	Terreneuvian (45/15/65/0)	Fortunian (40/15/55/0)			

Color composition by J.M. Pellé (BRGM, France)

Phanerozoic (40/0/5/0)	Proterozoic (0/60/35/0)	Neoproterozoic (0/30/70/0)	Ediacaran (0/15/55/0)	Cryogenian (0/20/60/0)	Tonian (0/25/65/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)
			Mesoproterozoic (0/30/55/0)	Neoproterozoic (0/30/70/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)	
				Paleoproterozoic (0/75/30/0)	Neoproterozoic (0/30/70/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)
		Archean (0/100/0/0)			Neoproterozoic (0/30/70/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)
			Hadean (30/100/0/0)		Neoproterozoic (0/30/70/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)
				Archean (0/100/0/0)	Neoproterozoic (0/30/70/0)	Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)
	Hadean (30/100/0/0)	Neoproterozoic (0/30/70/0)			Stenian (0/15/35/0)	Ectasian (0/20/40/0)	Calymnian (0/25/45/0)	Orosirian (0/60/15/0)	Rhyacian (0/65/20/0)	Siderian (0/70/25/0)	

The CMYK color code is an additive model with percentages of Cyan, Magenta, Yellow and Black. For example: the CMYK color for Devonian (20/40/75/0) is a mixture of 20% Cyan, 40% Magenta, 75% Yellow and 0% Black. The CMYK values are the primary reference system for designating the official colors for these geological units.

HSV color model: Perceptual, but not all equal value



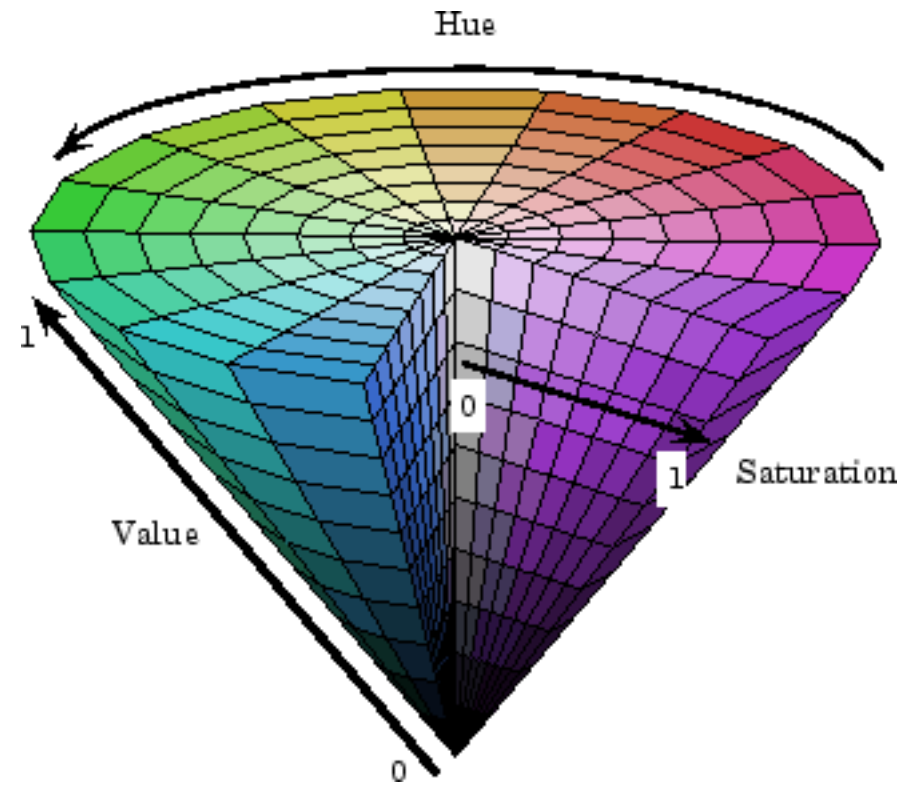
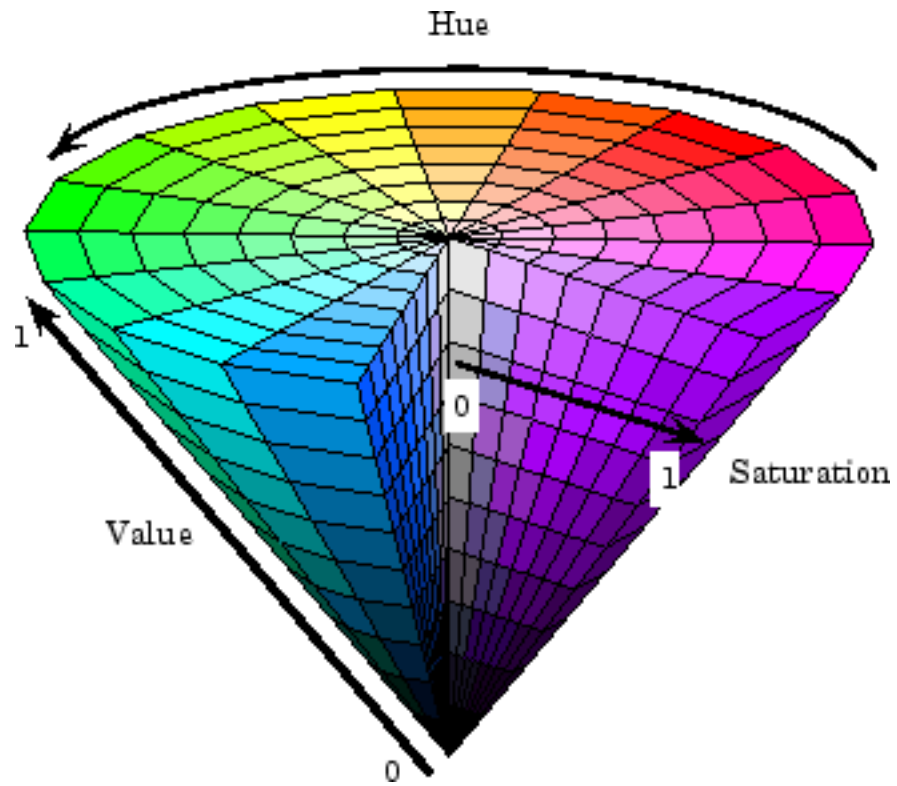
Hue: Wavelength

Saturation: Amount of pigment

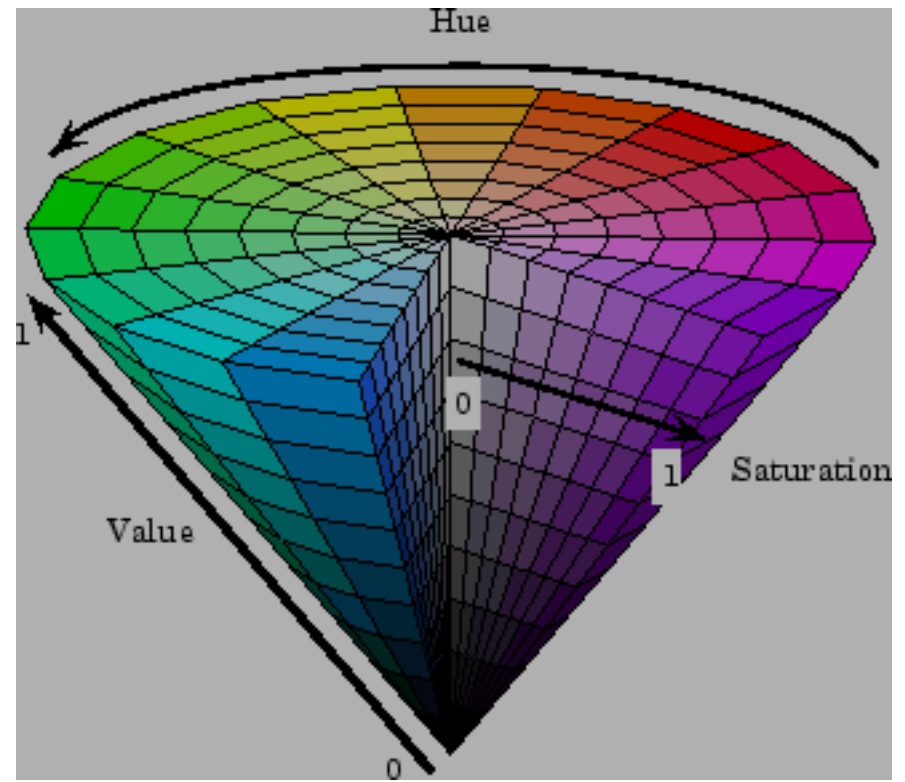
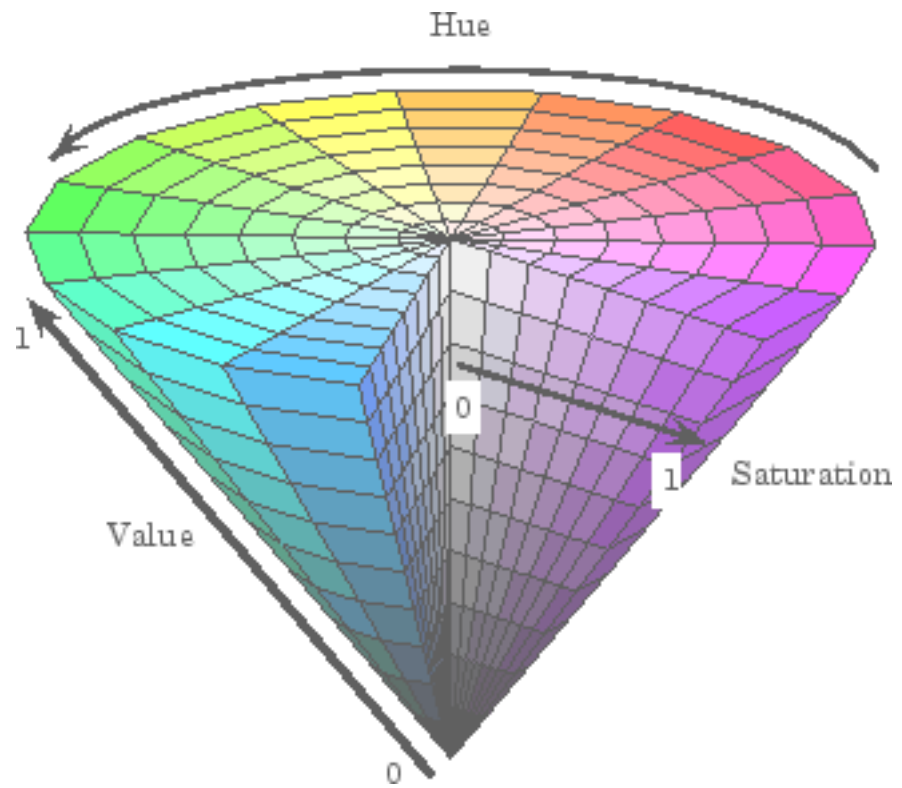
Value: Intensity or brightness

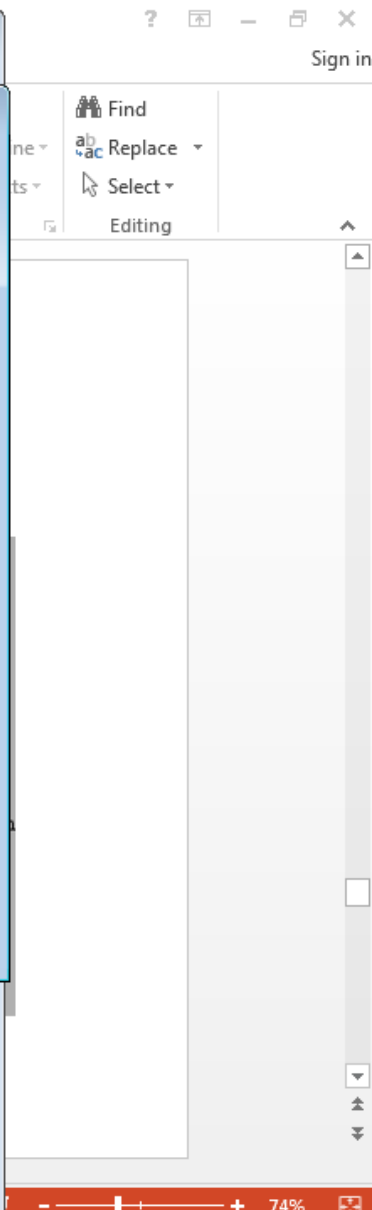
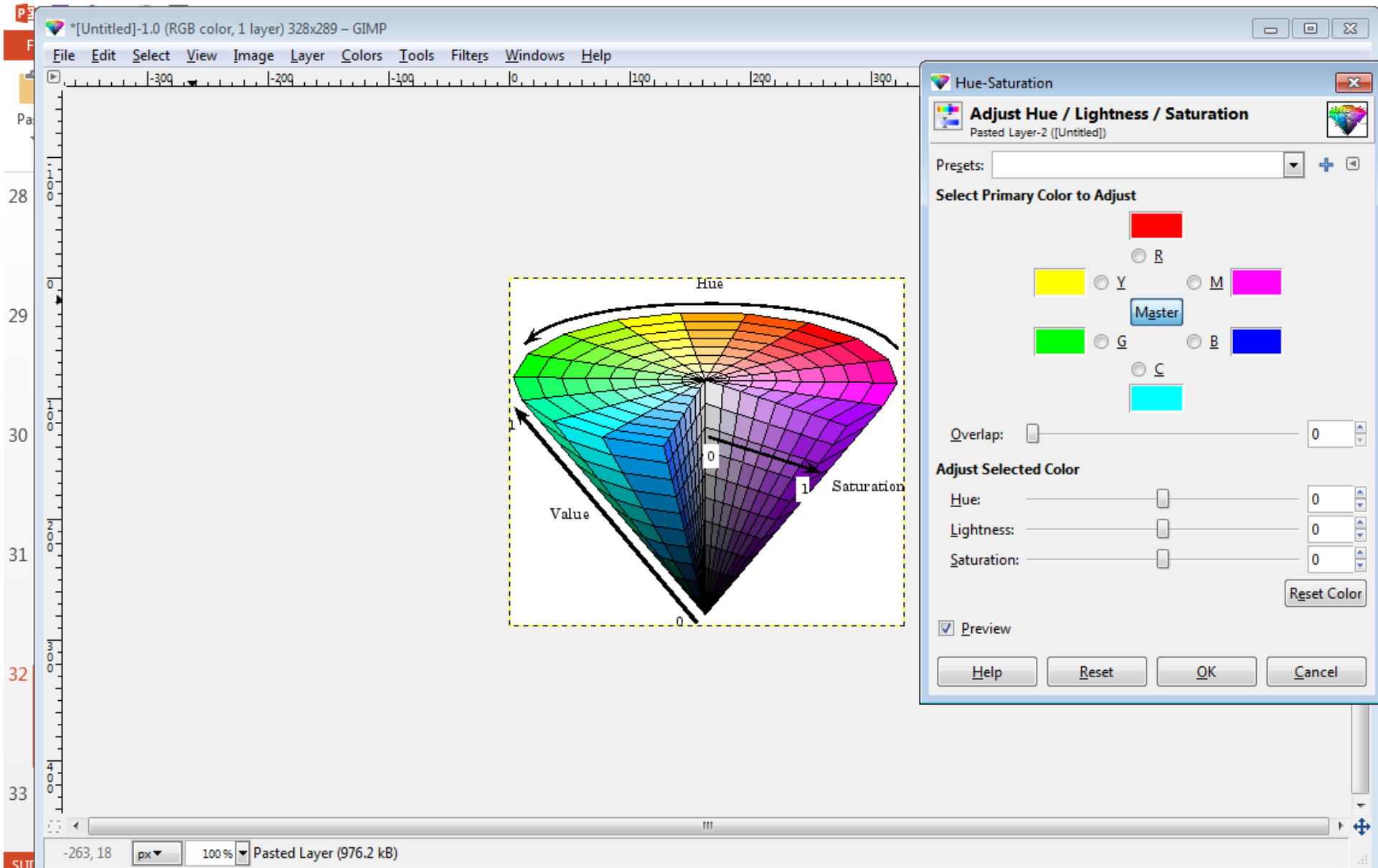


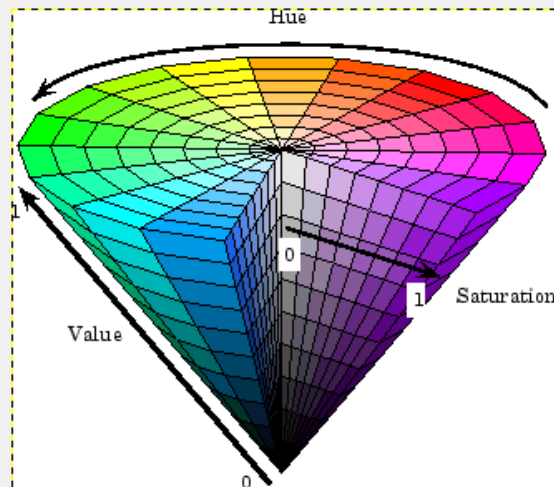
# Saturation



# Intensity







Brightness-Contrast

**Adjust Brightness and Contrast**  
Pasted Layer-2 ([Untitled])

Pregets: [dropdown] + -

Brightness: [slider] 0

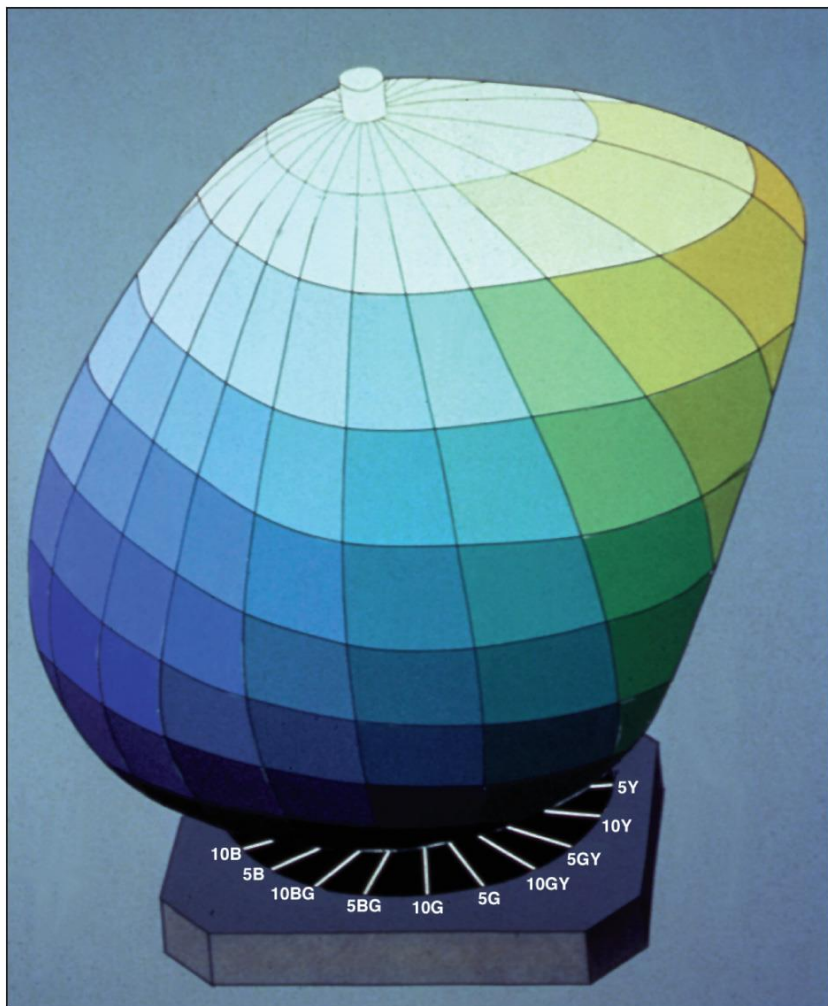
Contrast: [slider] 0

Edit these Settings as Levels

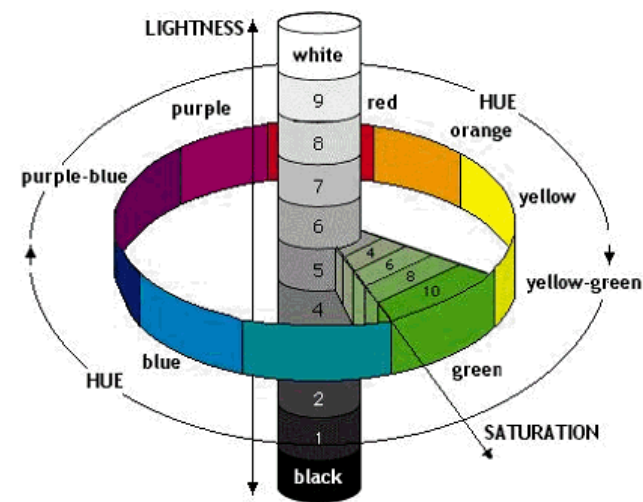
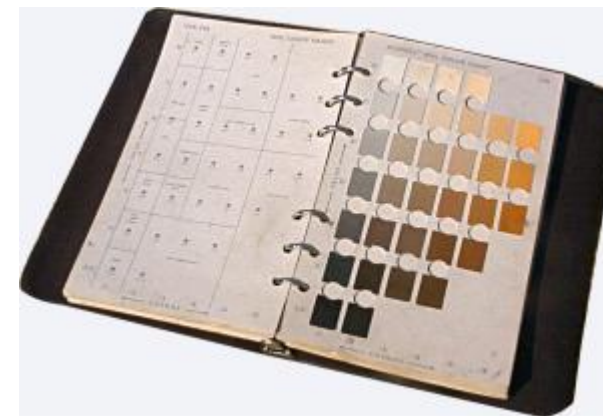
Preview

Help Reset OK Cancel

# Munsell color model

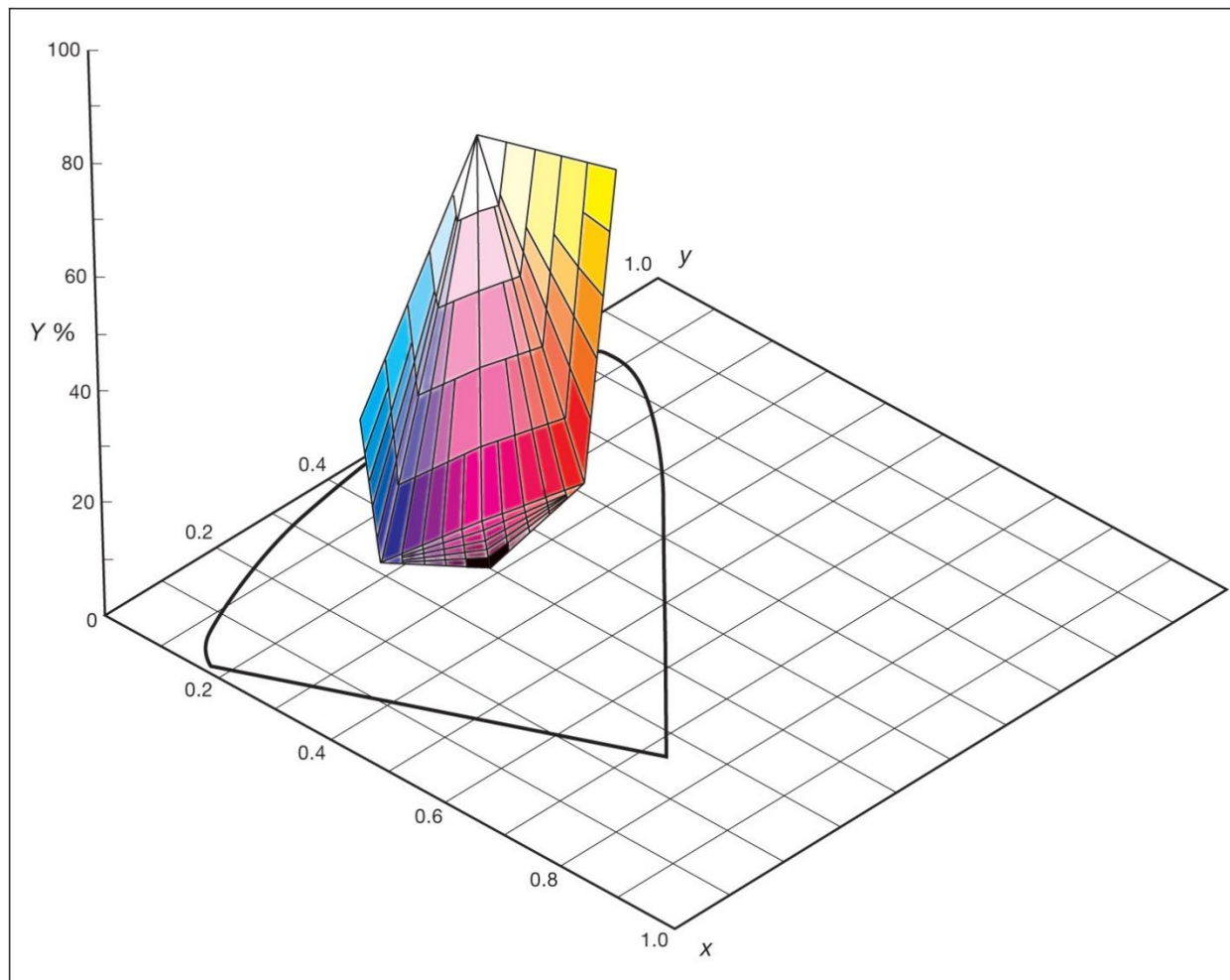


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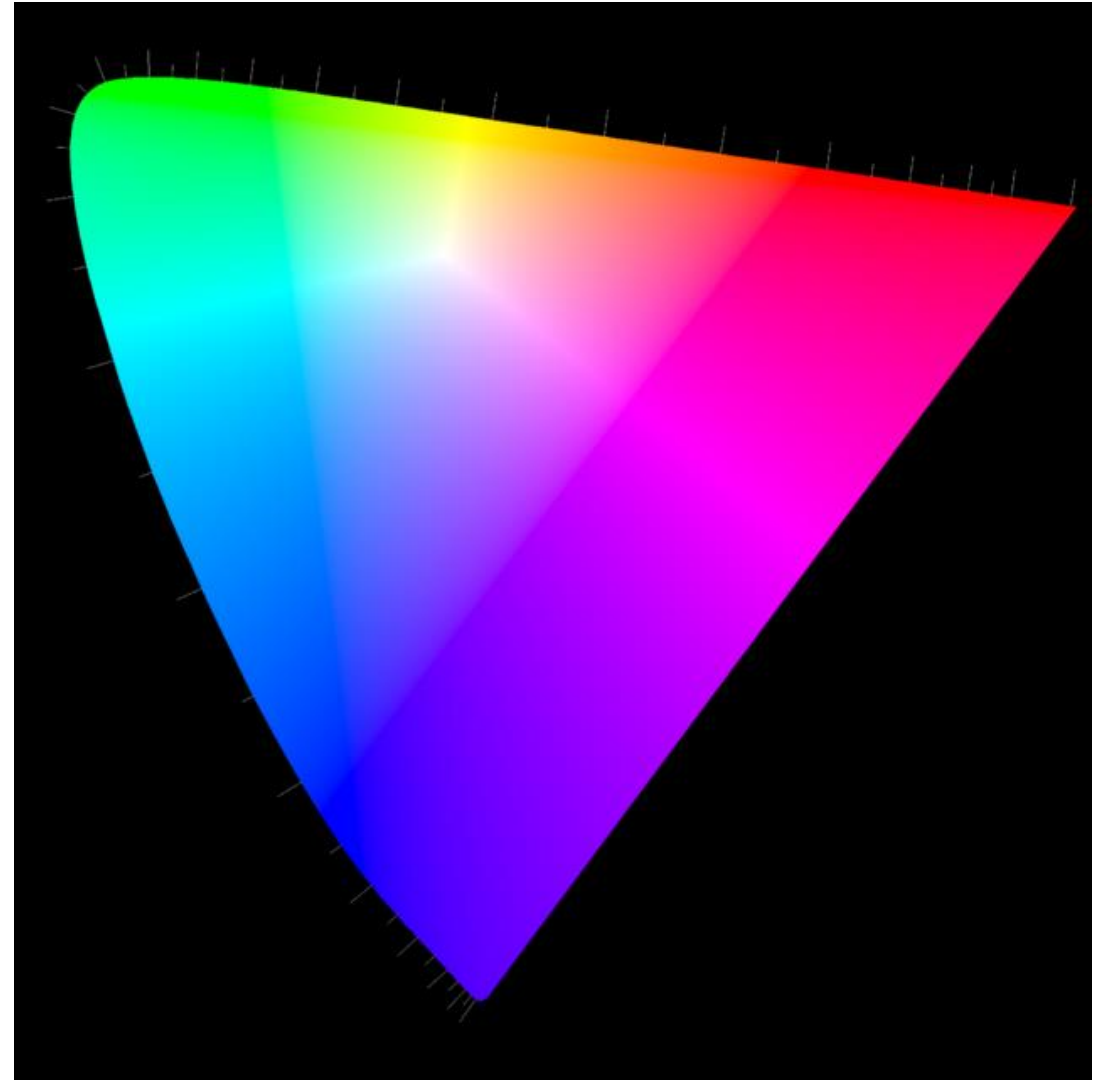
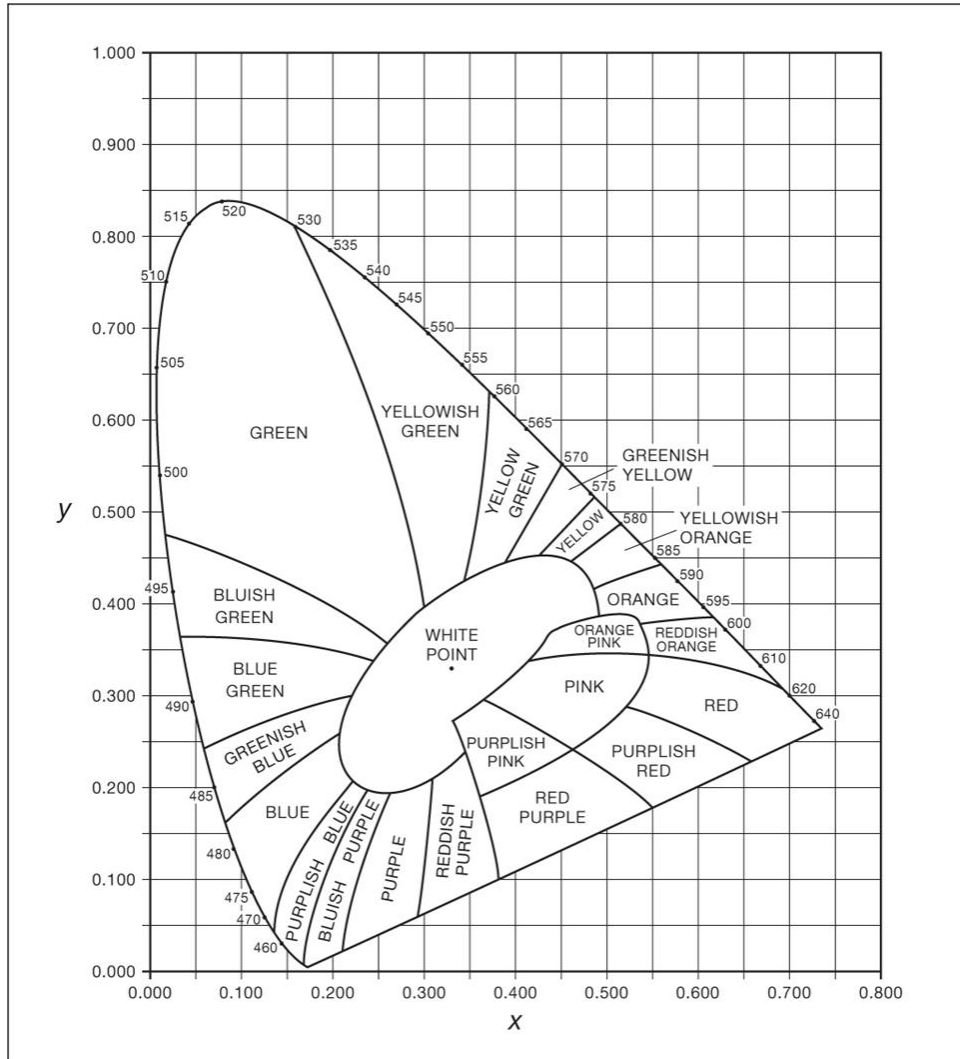
# Munsell layers



# CIE color model

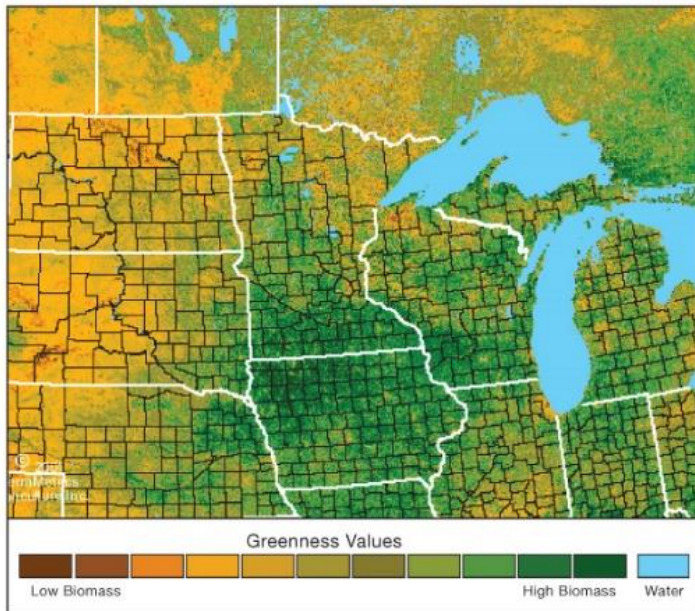
- Commission Internationale de l'Éclairage
- Objective way to specify color
- Based on three numbers  $Yxy$
- Two dimensional space for range of hue and saturation
- Central white-point (or equal energy)
- Uses RGB theory, color combinations and human subjects for color repetition
- Attempt to rectify perceptual difference in luminescence as a function of hue

# CIE color spaces

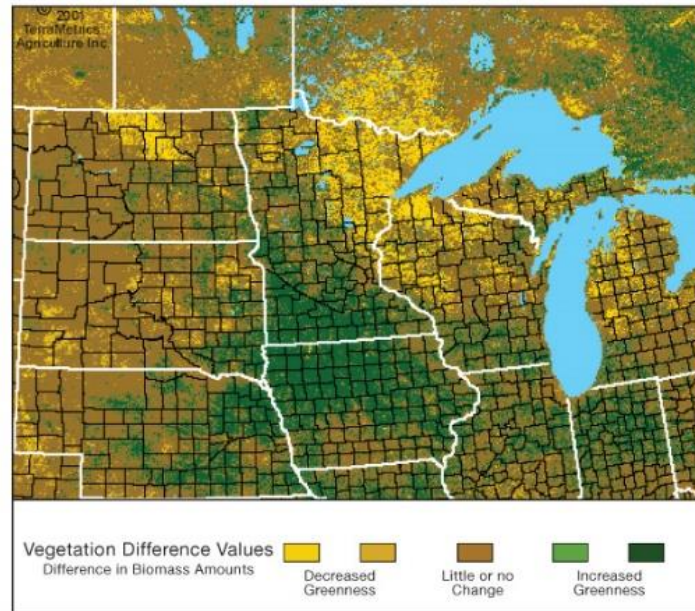




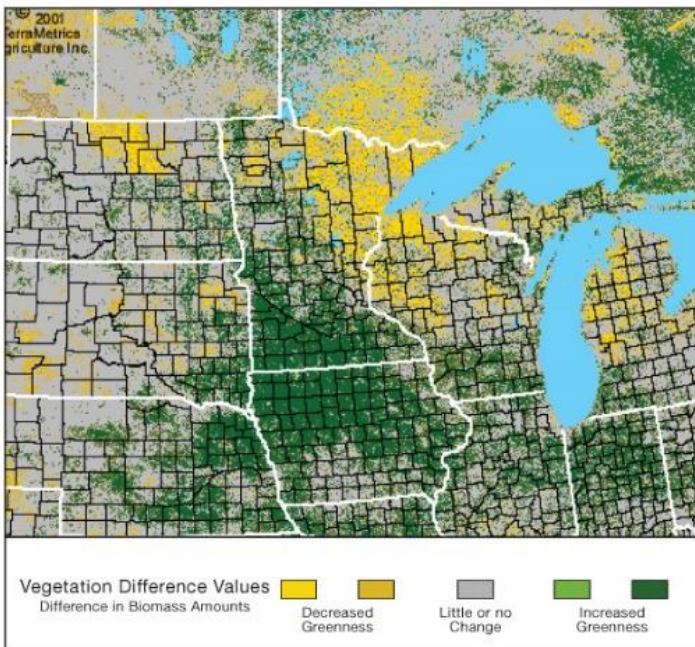
A



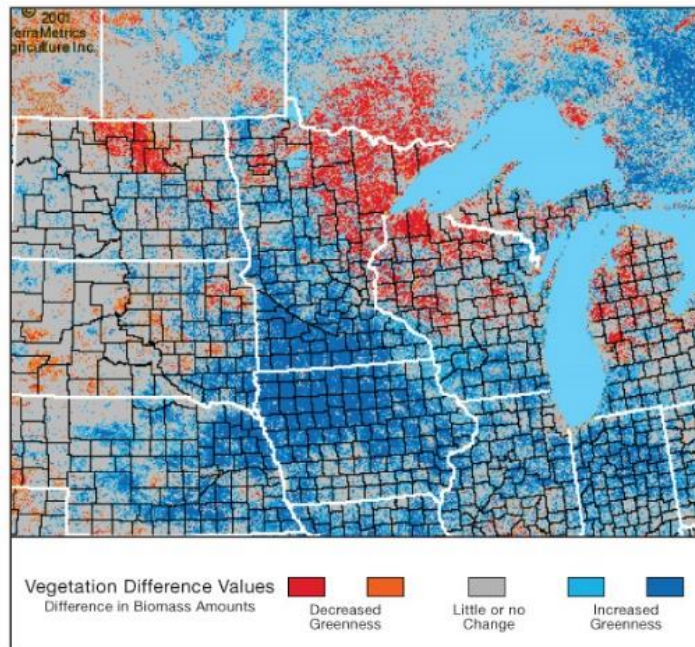
B



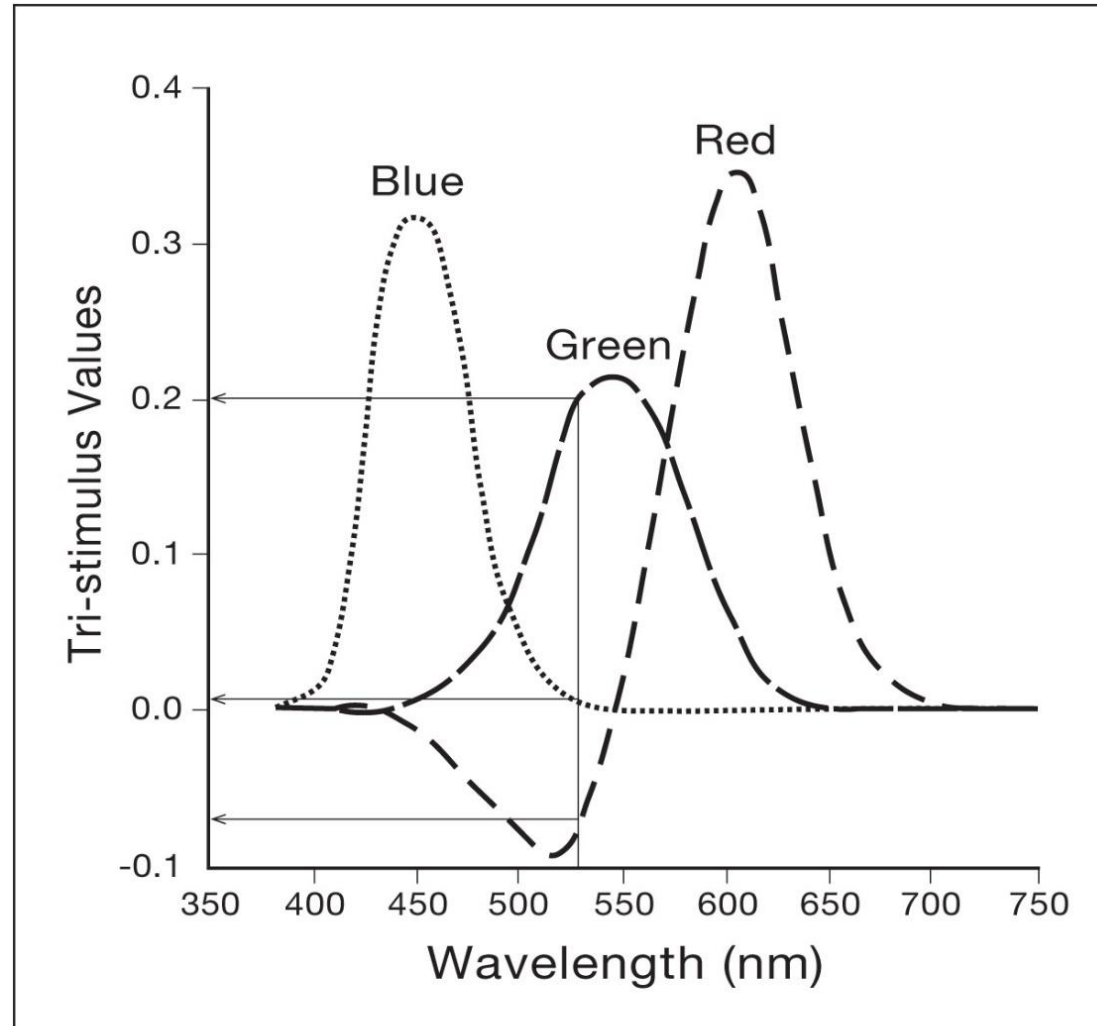
C



D



# CIE stimulus adjustment





Number of data classes: 3

Nature of your data: sequential (selected) diverging qualitative

Pick a color scheme:

Multi-hue: [Color swatches]

Single hue: [Color swatches]

Only show:

- colorblind safe
- print friendly
- photocopy safe

Context:

- roads
- cities
- borders

Background:

- solid color
- terrain

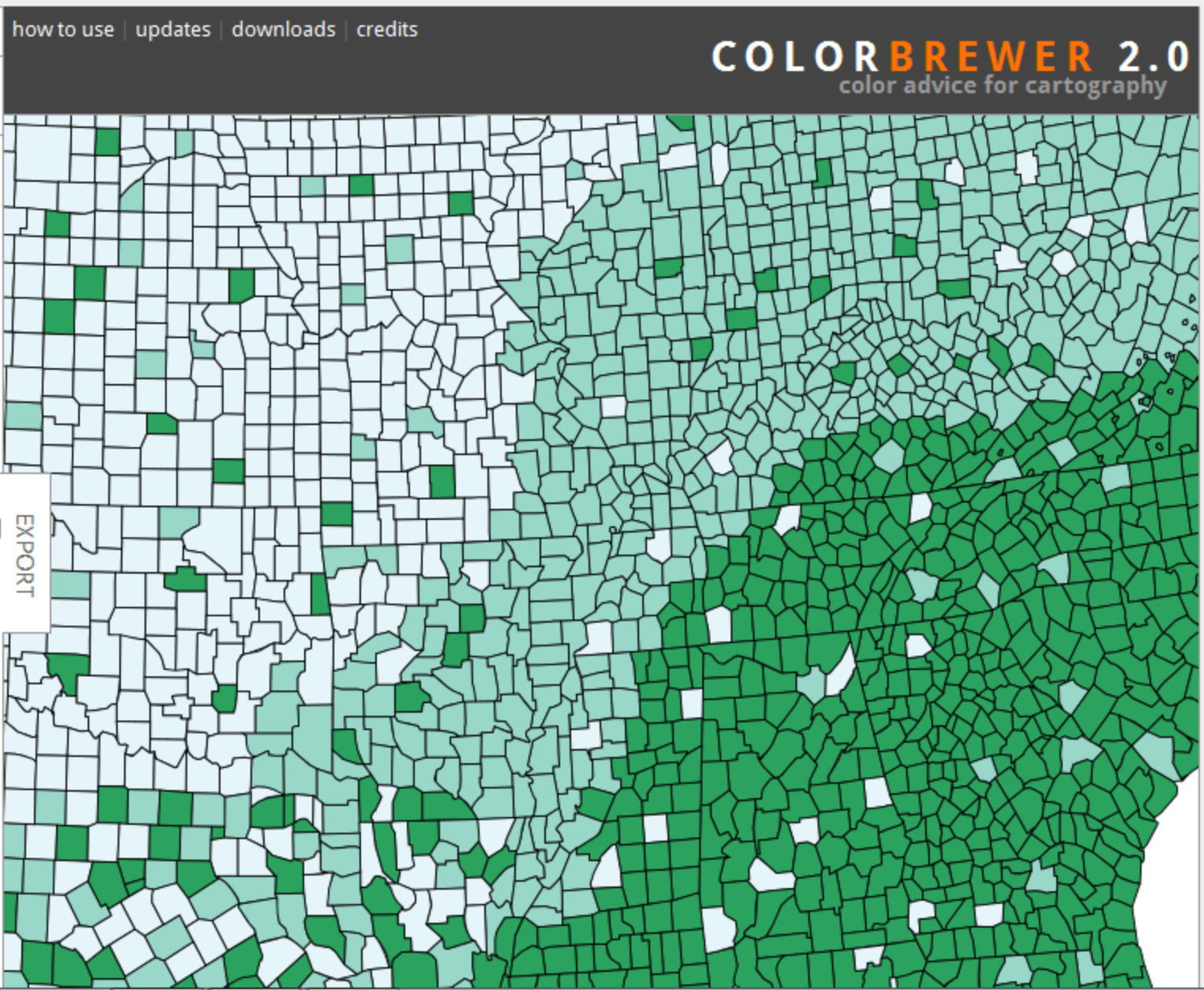
color transparency [Slider]

3-class BuGn

EXPORT

HEX

- #e5f5f9
- #99d8c9
- #2ca25f



# Diverging

ColorBrewer: Color Advice for ...

colorbrewer2.org

Number of data classes: 3

Nature of your data:  
 sequential  diverging  qualitative

Pick a color scheme:

Only show:  
 colorblind safe  
 print friendly  
 photocopy safe

Context:  
 roads  
 cities  
 borders

Background:  
 solid color  
 terrain

color transparency

how to use | updates | downloads | credits

**COLORBREWER 2.0**  
color advice for cartography

3-class BrBG

EXPORT

CMYK

15,25,55,0  
0,0,0,5  
65,5,23,0

# Qualitative

The screenshot displays the ColorBrewer 2.0 web application interface. The browser address bar shows the URL `colorbrewer2.org`. The page title is "ColorBrewer: Color Advice for ...". The interface includes a search bar, navigation icons, and a list of most visited sites.

The main content area features a map of a region with a qualitative color scheme applied. The map is divided into numerous small, irregular polygons, each colored according to the selected scheme. The colors used are green, purple, and orange.

The left sidebar contains several control panels:

- Number of data classes:** Set to 3.
- Nature of your data:** Radio buttons for sequential, diverging, and qualitative (selected).
- Pick a color scheme:** A grid of 12 color scheme thumbnails.
- Only show:** Checkboxes for colorblind safe, print friendly, and photocopy safe.
- Context:** Checkboxes for roads, cities, and borders (checked).
- Background:** Radio buttons for solid color (selected) and terrain.
- color transparency:** A slider control.

The right sidebar displays the selected color scheme, "3-class Accent", with a legend showing three classes and their corresponding RGB values:

Color	RGB
Green	127,201,127
Purple	190,174,212
Orange	253,192,134

The bottom of the screen shows the Windows taskbar with various application icons and the system tray displaying the time as 3:38 PM on 1/22/2015.

# Summary

- Color is complex and powerful
- Light behaves as both a wave and particles
- Light interacts with all aspects of map viewing
- Colors can be additive or subtractive
- Color models allow color specification and control
- Covered RGB, CMYK, HSV, Munsell and CIE
- Colorbrewer recommends color sequences for sequential, diverging and qualitative color sets
- Don't forget: Hue suggests class, saturation and intensity suggest value