COLOR FOR IMAGE PROCESSING

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Courtesy to K. Ikeuchi, T. Darrell for inspiration and some pictures found in their teaching presentations.

COLOR IN SEVERAL DOMAINS

- Physics.
- Human vision, physiology.
- Psychophysics, perception.
- Computer vision.
- Painting, photography, movies.

COLOR IN COMPUTER VISION

- Color in image formation, reflection physics.
- Color for segmentation.

LIGHT AND COLOR

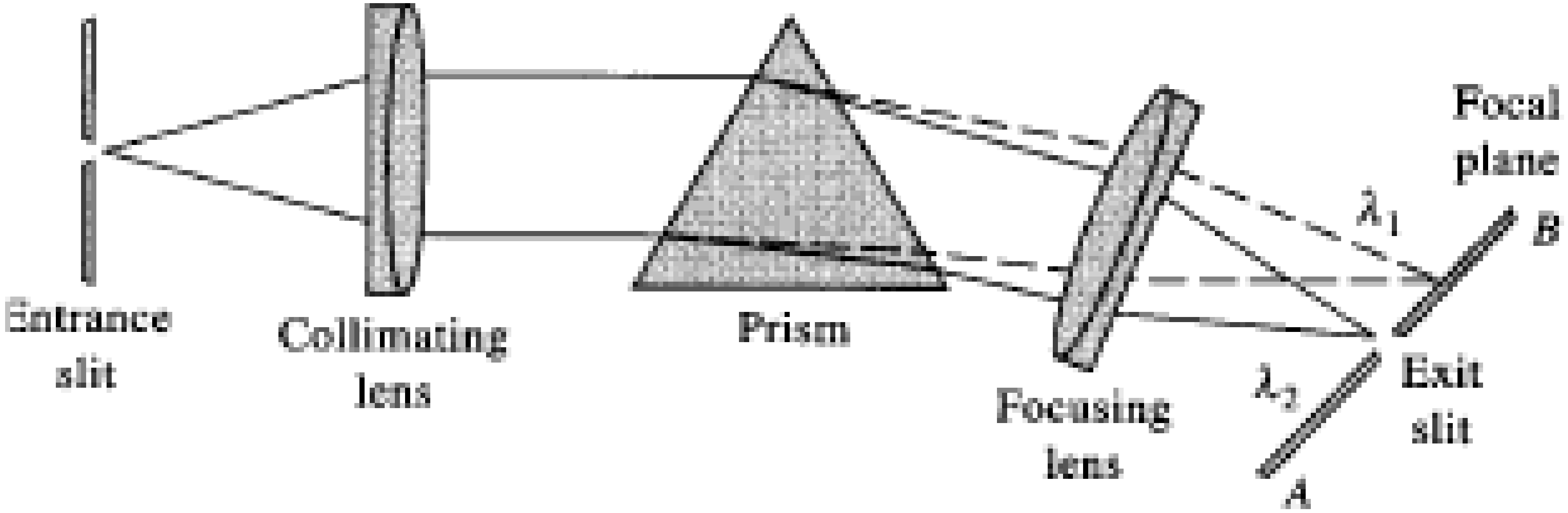
- Light = electromagnetic radiation.
- Spectrum visible to humans $\langle 400\text{nm}, 700\text{nm}\rangle$.
- Sensors do not have direct access to color, i.e., wavelength λ. Exception: spectrometer.
- Response of i-th sensor

$$s_i = \int\limits_{\lambda_1}^{\lambda_2} s(\lambda) r_i \, d\lambda \,, \quad \text{where}$$

r_i is spectral density of i-th sensor,

$s(\lambda)$ is spectral density of light.

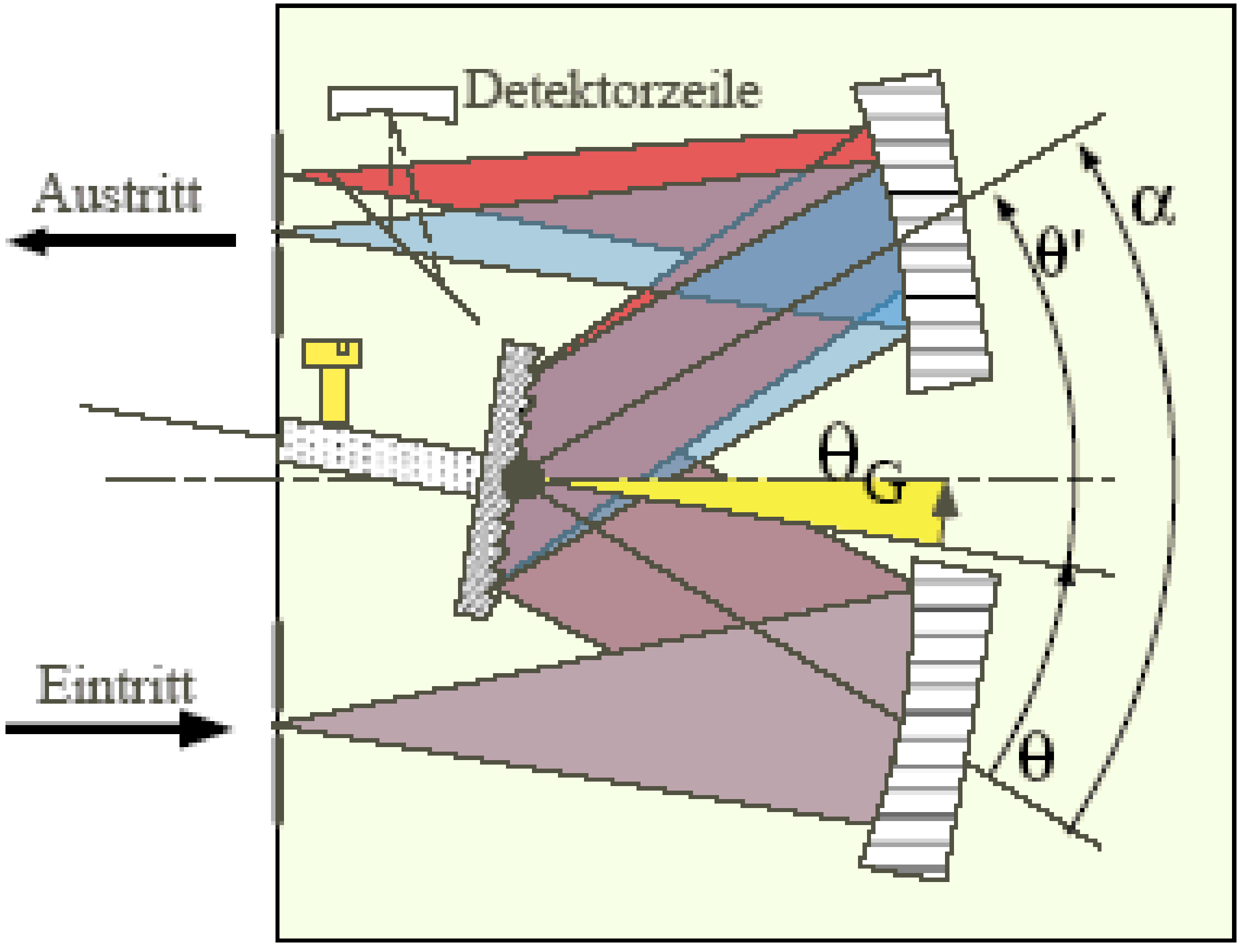
BUNSEN PRISM MONOCHROMATOR



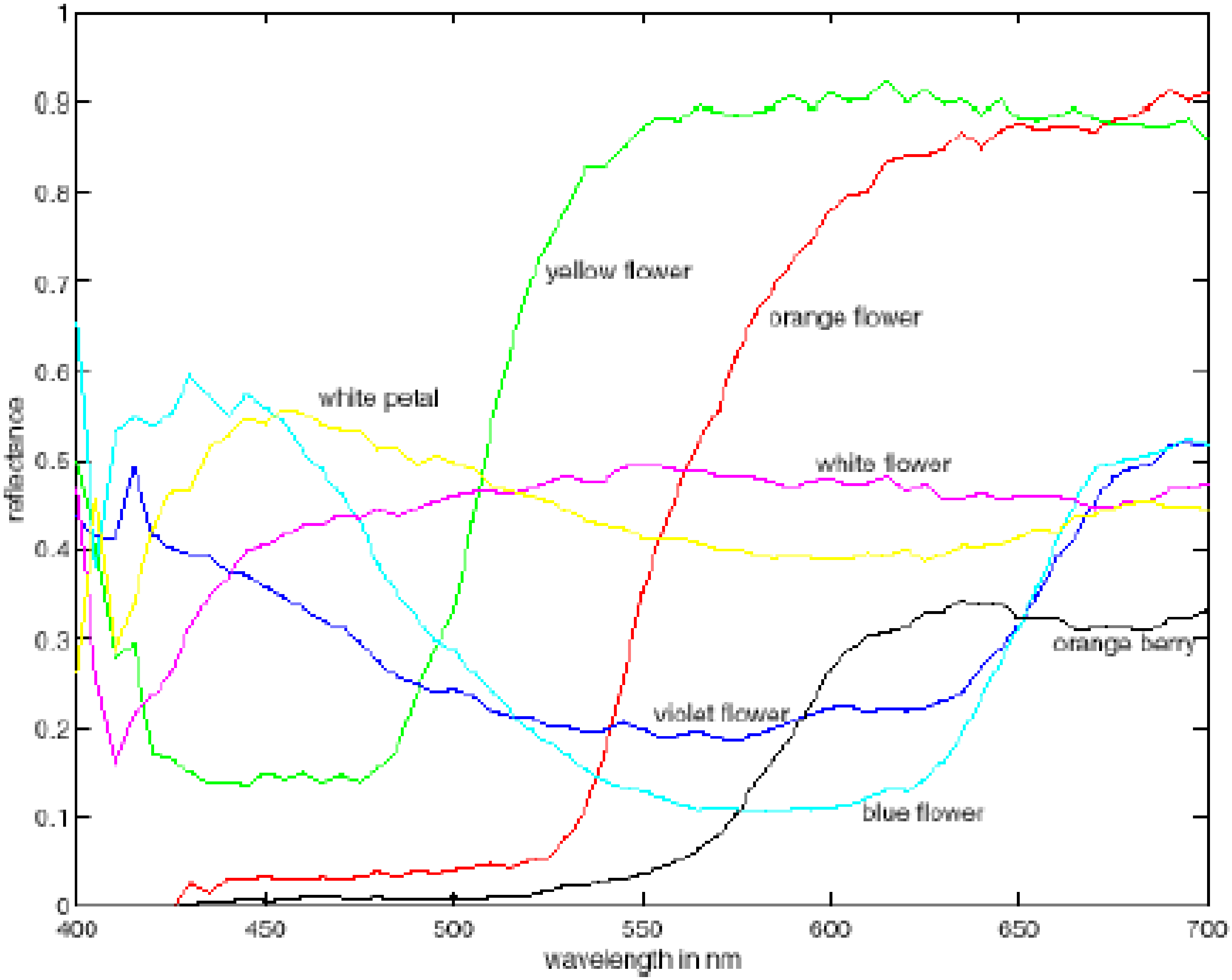
DIFFRACTION (GRATING) MONOCHROMATOR

Czerny-Turner-Monochromator

$$\lambda = \sin(\theta_G) * \text{const.}$$



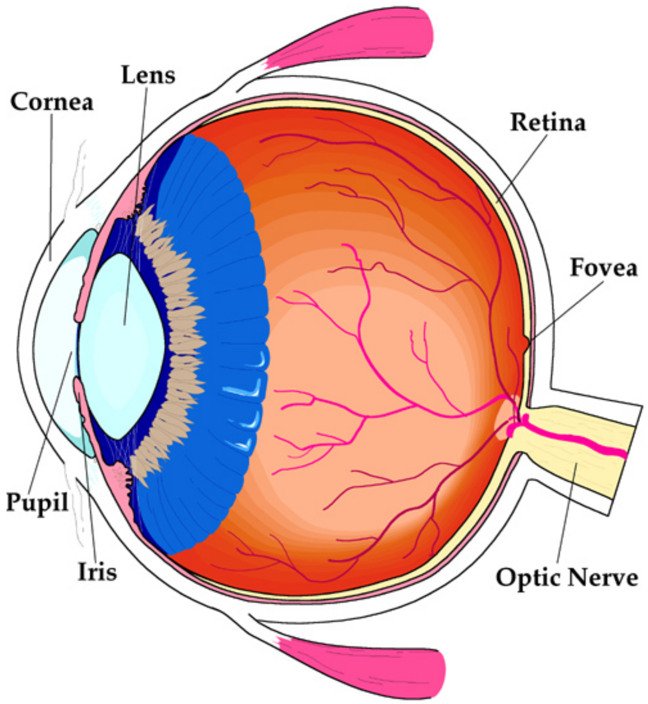
SPECTRAL REFLECTANCE OF FLOWERS



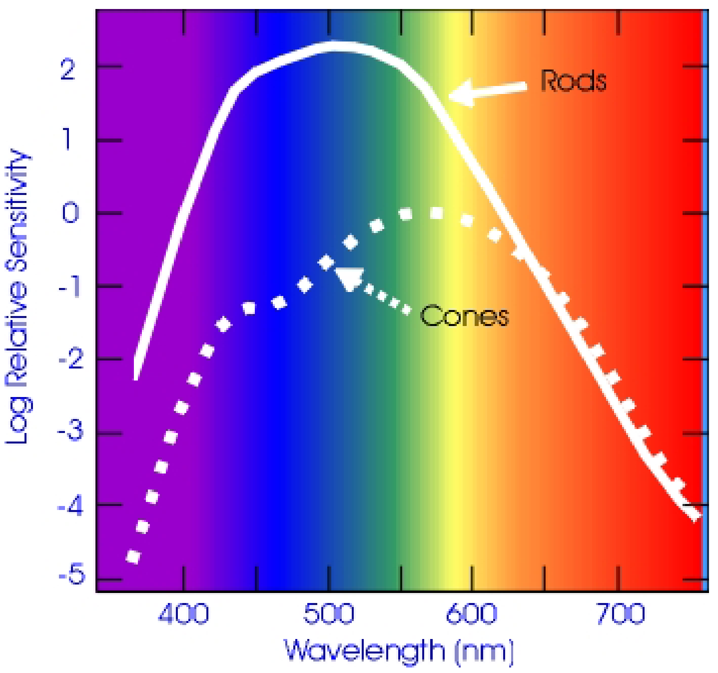
Spectral albedoes for several different leaves, with color names attached. Notice that different colours typically have different spectral albedo, but that different spectral albedoes may result in the same perceived color (compare the two whites). Spectral albedoes are typically quite smooth functions. Measurements by E.Koivisto.

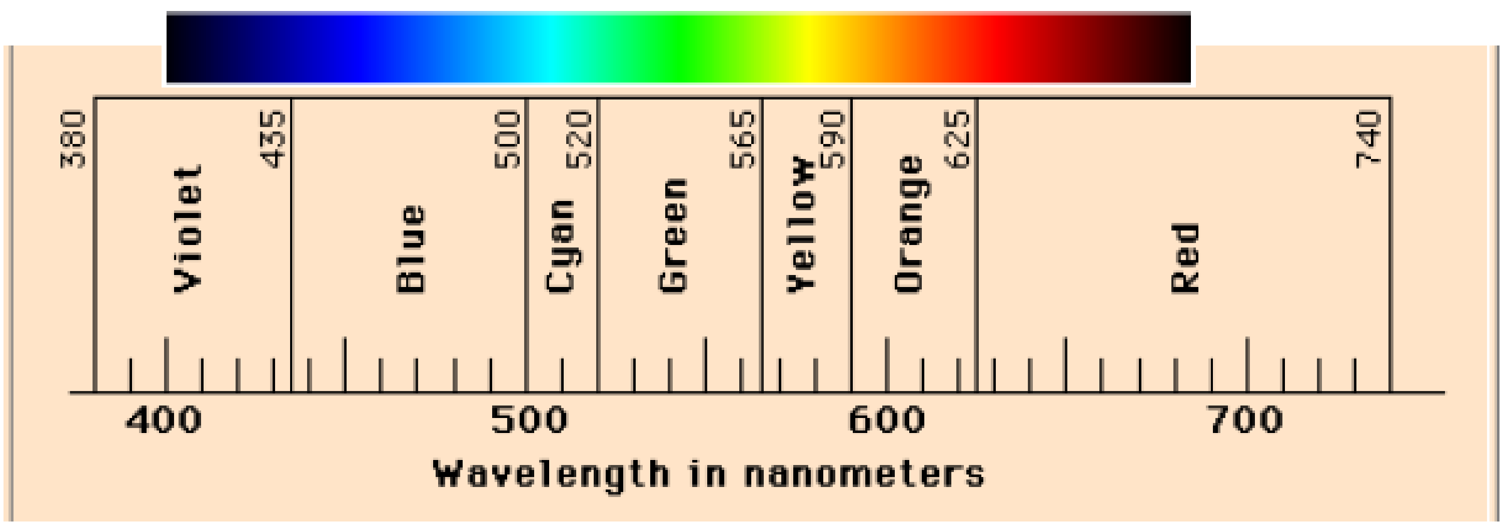
Forsyth, 2002

VISIBLE SPECTRUM



- Retina – 4 types of receptors.
- R, G, B cones, color vision.
- Rods, monochromatic vision with higher sensitivity.





RADIOMETRY FOR COLOR

- All definitions are now "per unit wavelength".
- All units are now per unit wavelength.
- All terms are now "spectral".
- Radiance becomes spectral radiance [watts per square meter per steradian per unit wavelength].
- Irradiance becomes spectral irradiance [watts per square meter per unit wavelength].

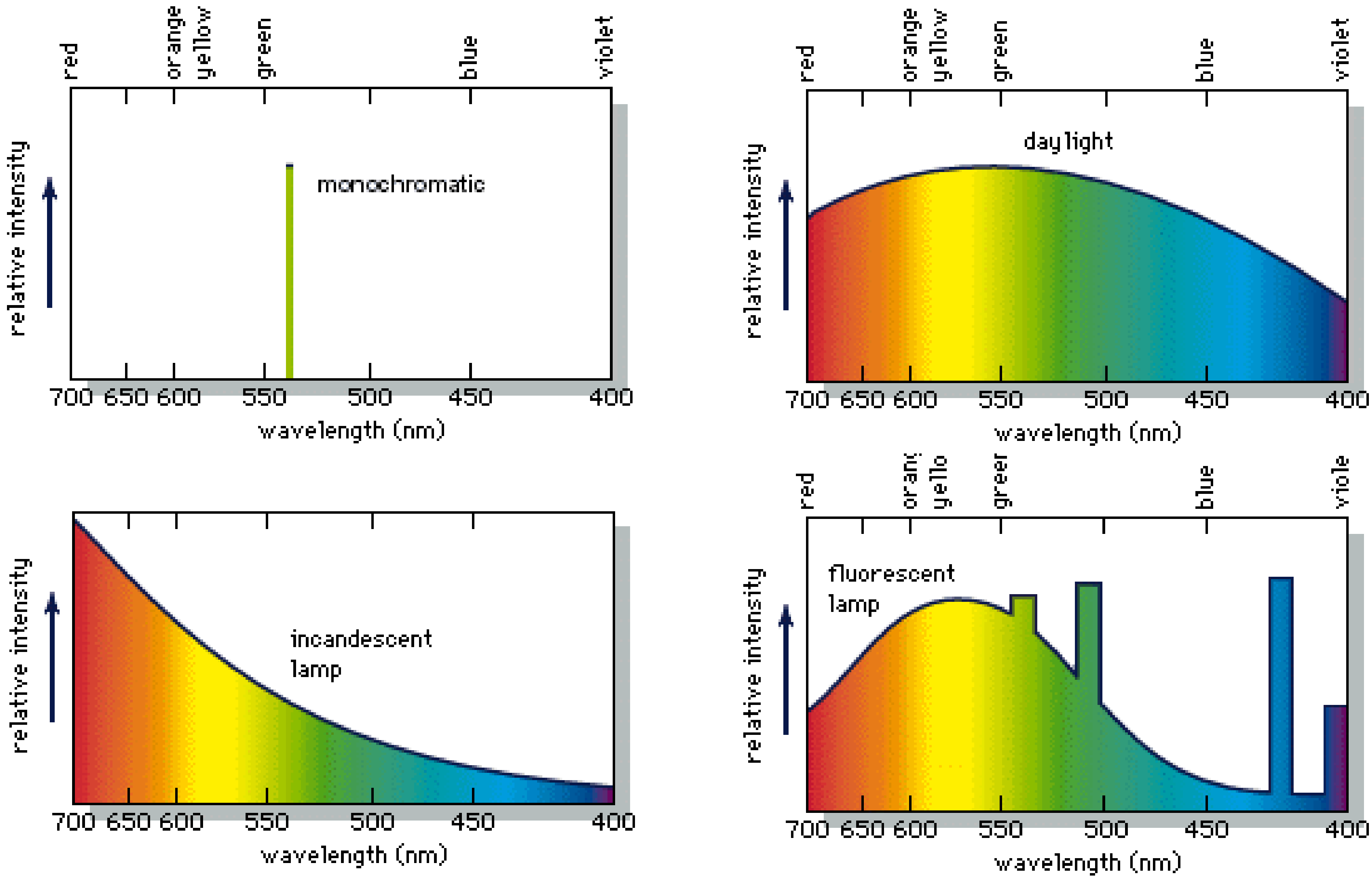
RADIOMETRY FOR COLOR 2

- Dependence on wavelength λ is introduced into BRDF.
- L becomes spectral radiance.
- E becomes spectral irradiance.

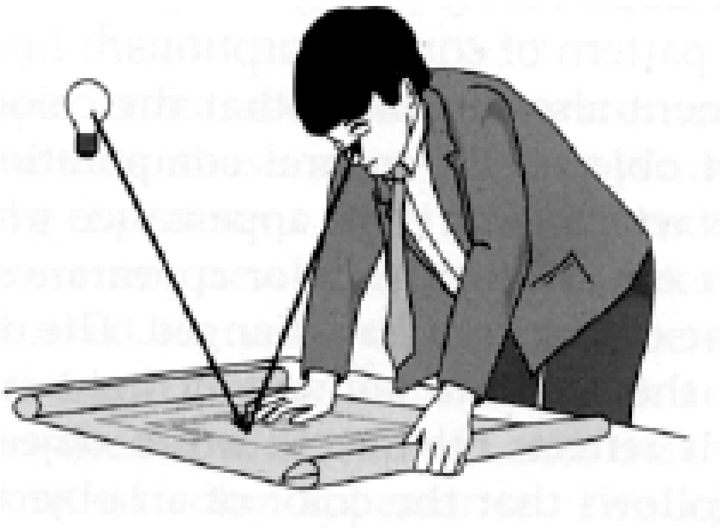
$$BRDF = f(\Theta_i, \Phi_i, \Theta_e, \Phi_e, \lambda) = \frac{L(\Theta_i, \Phi_i, \lambda)}{E(\Theta_e, \Phi_e, \lambda)}$$

In computer vision, simplified models are often used which use relative measures instead of absolute absolute measures.

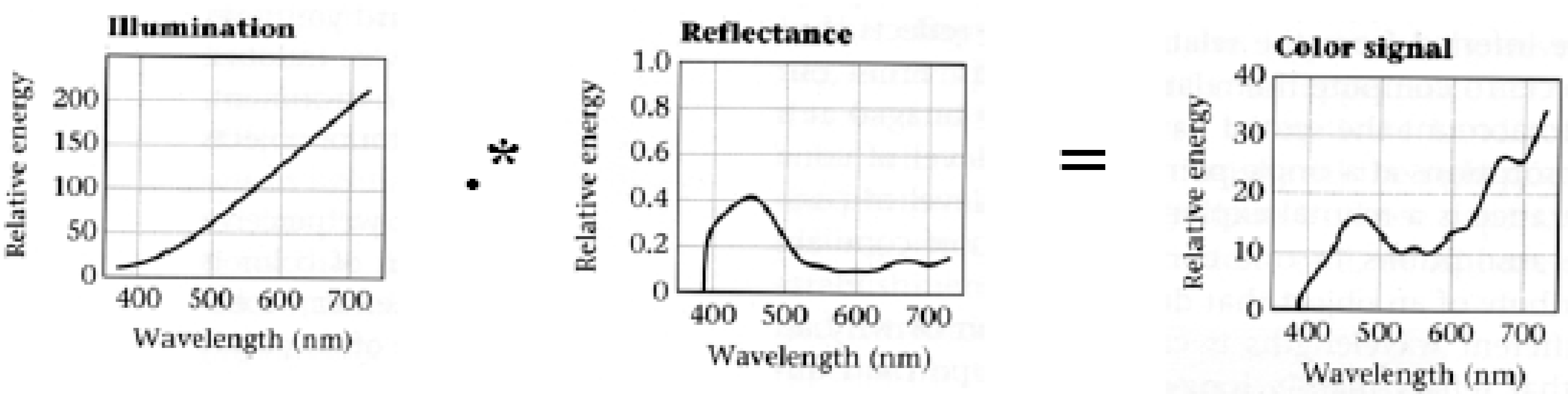
ILLUMINATION SPECTRUM



RELATIVE REFLECTANCE

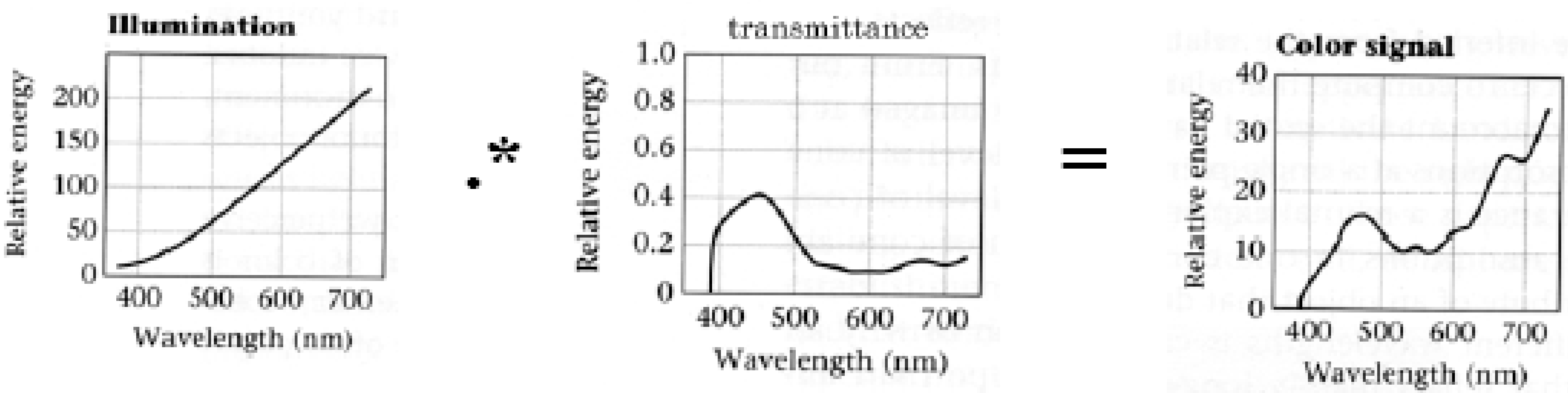


Often are more interested in relative spectral composition than in overall intensity, so the spectral BRDF computation simplifies a wavelength-by-wavelength multiplication of relative energies.



Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

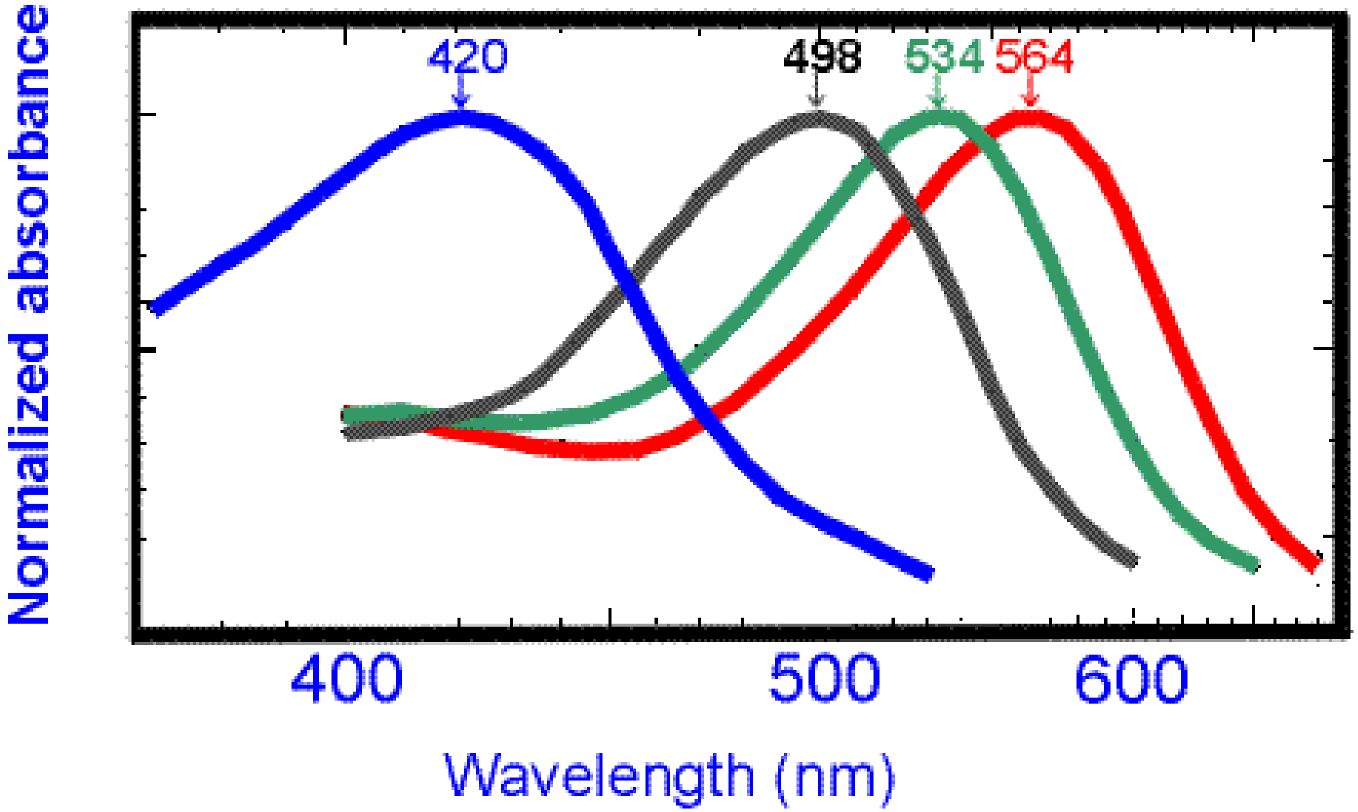
RELATIVE TRANSMITTANCE



Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

HUMANS AND TRICHROMACY

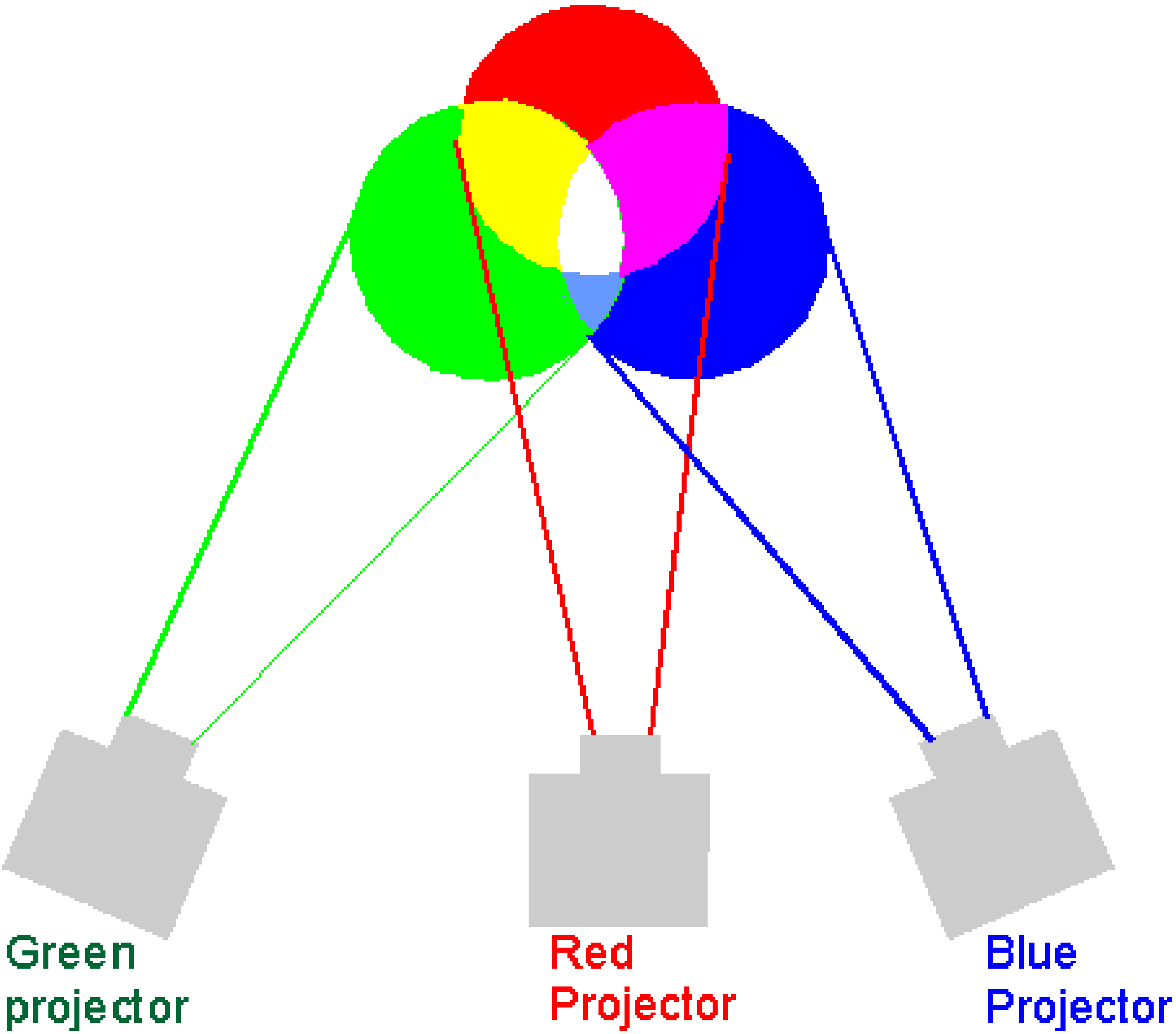
The eye reduces all the wavelengths at a given ‘pixel’ to just the total amount of red, green, and blue.



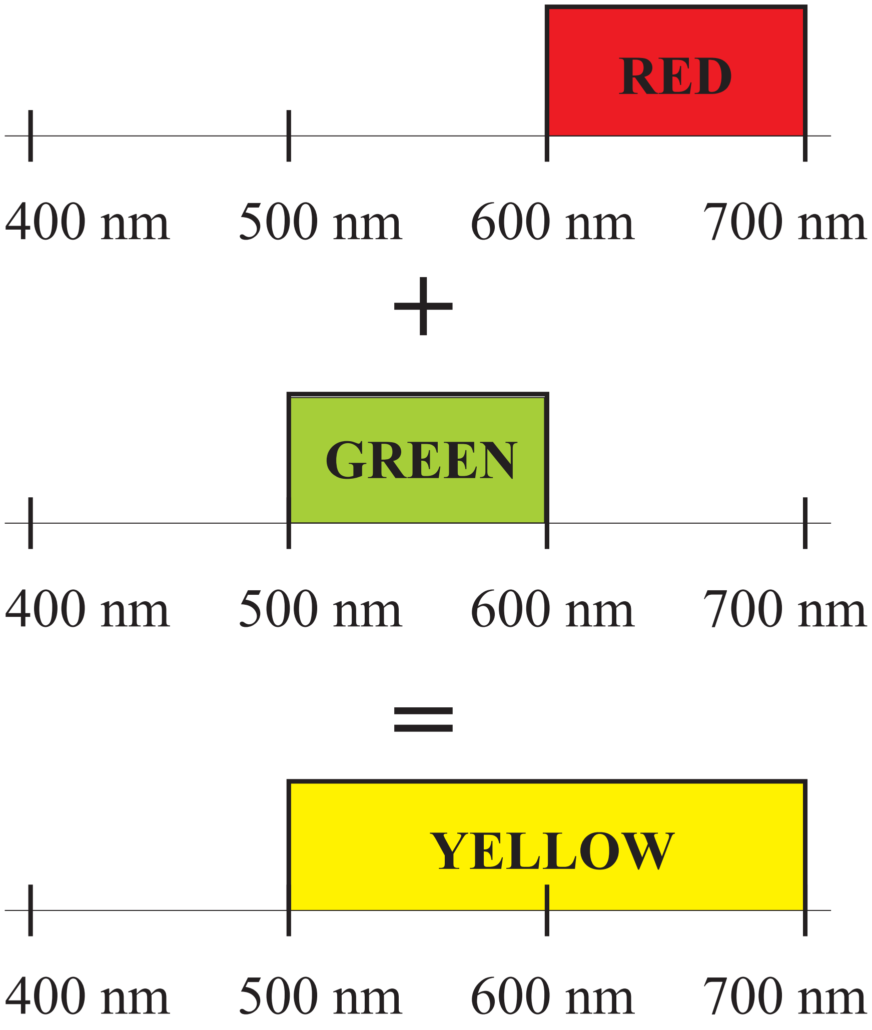
After Bowmaker & Dartnall, 1980

RGB COMPONENTS OF A COLOR IMAGE

MIXTURE OF COLORS

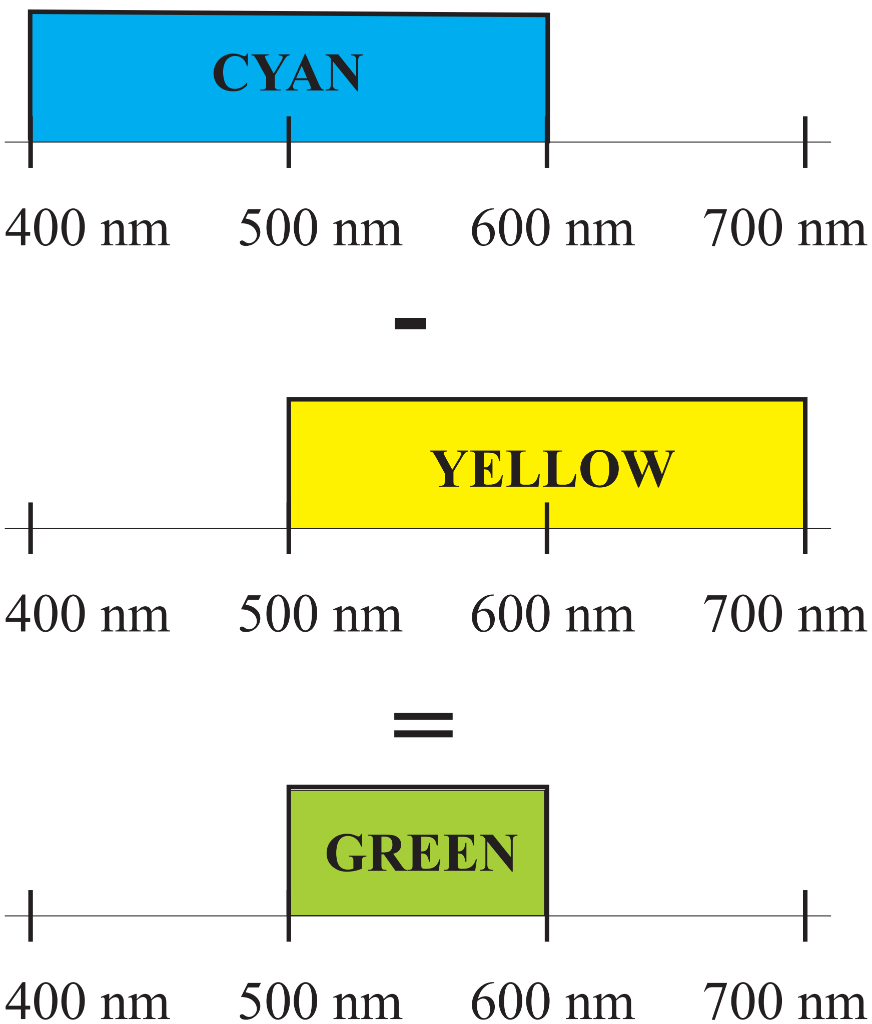


ADDITIVE COLOR MIXING



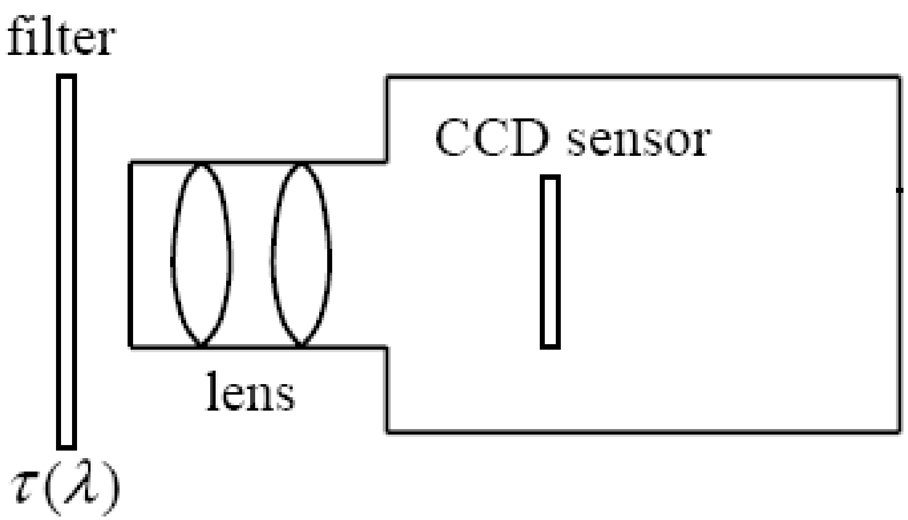
- Red plus green makes yellow.
- Additive mixing model holds for CRT phosphors, multiple projectors aimed at a screen, Polachromeslide film, human eye cones.

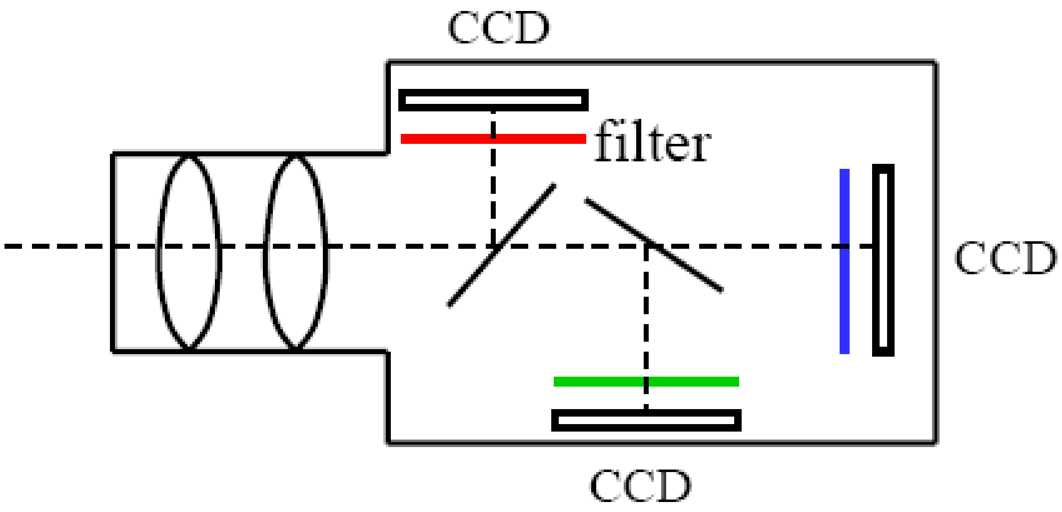
SUBTRACTIVE COLOR MIXING



- Applies when colors mix by multiplying the color spectra.
- Cyan (called blue in crayons) minus (actually multiply) yellow makes green.
- Subtractive mixing model holds for most photographic films, paint, crayons, printing, cascaded optical filters.

COLOR CAMERAS

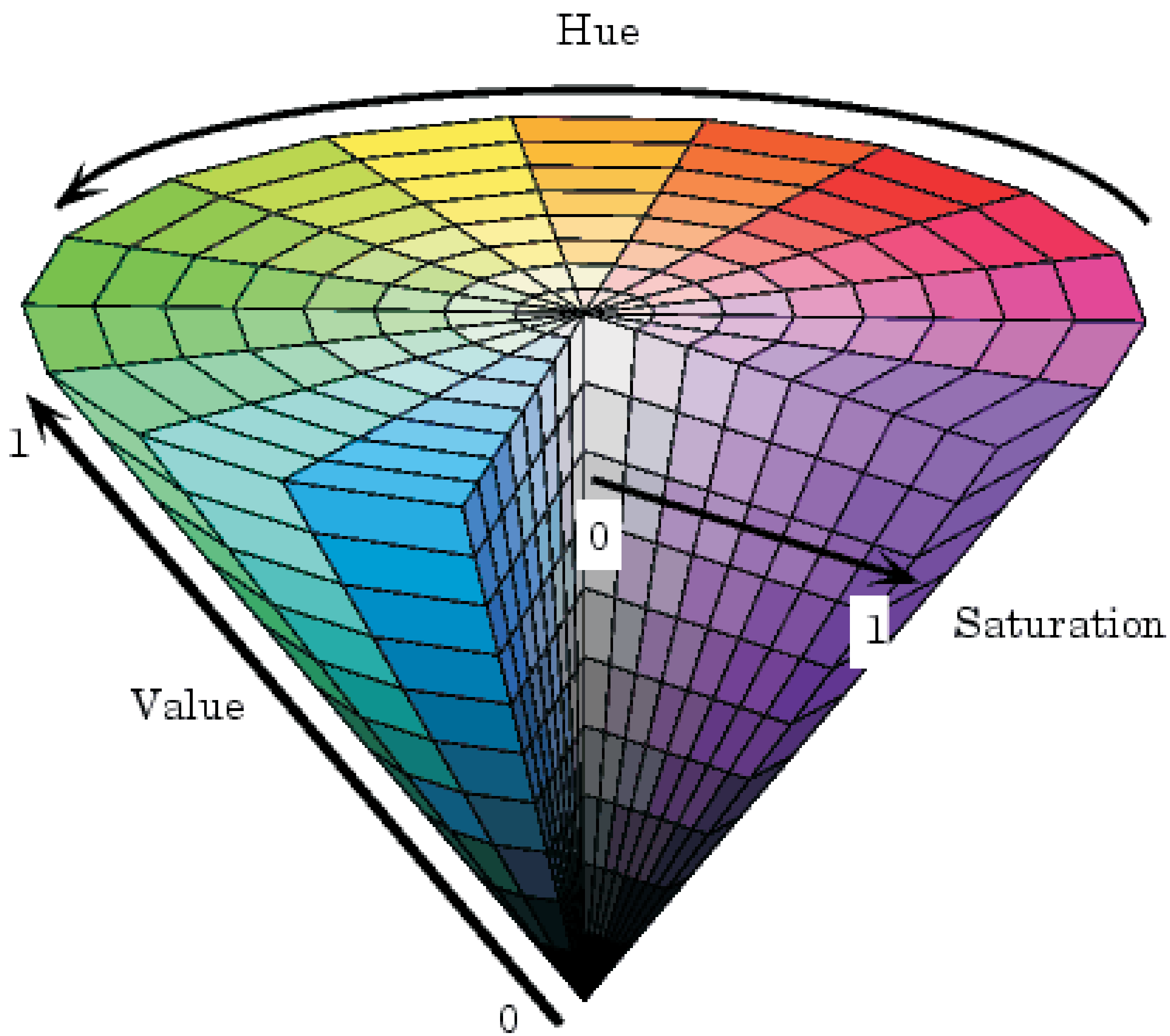




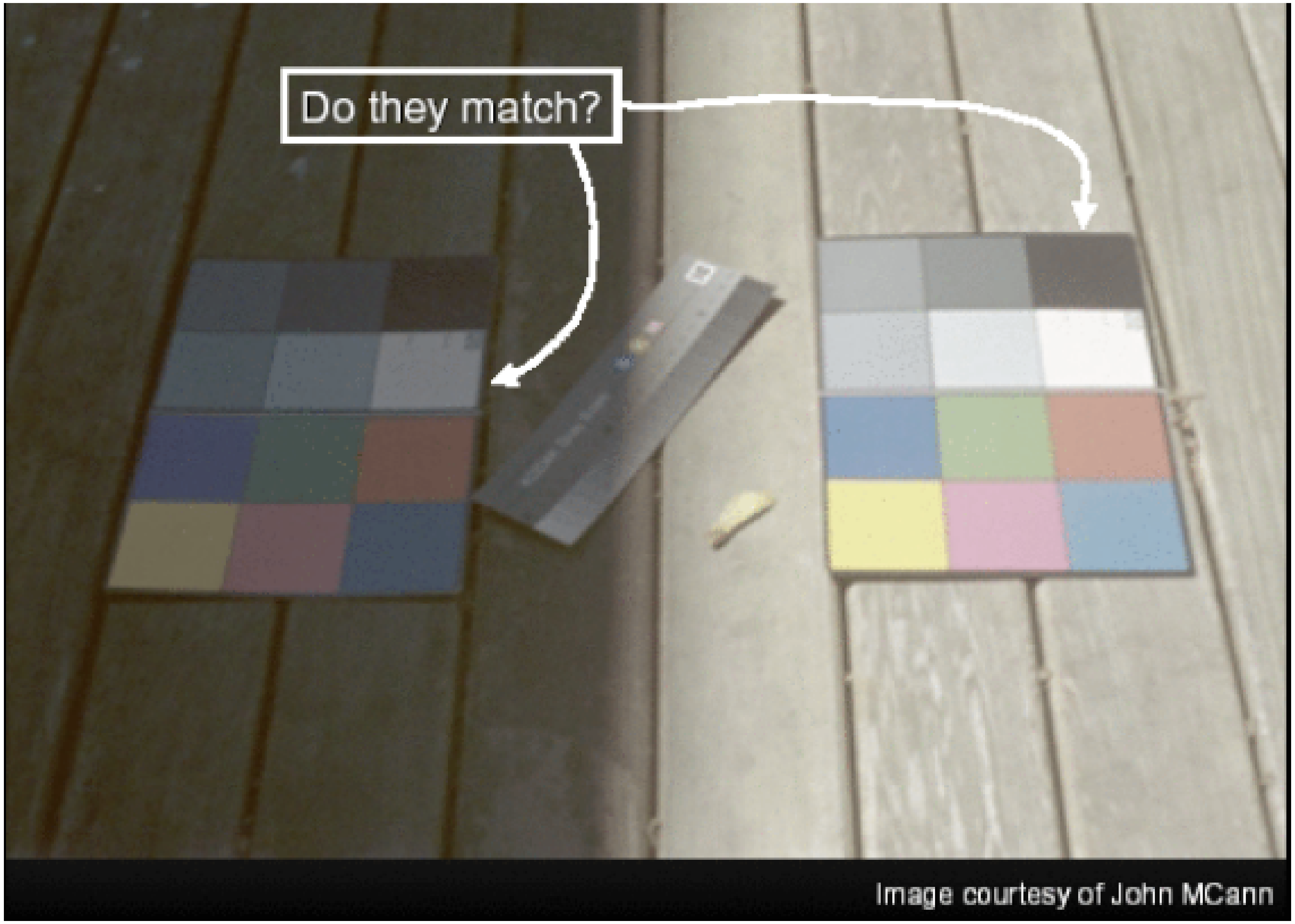
1 chip camera + filter

3 chip camera

HUE, SATURATION, VALUE COLOR SPACE

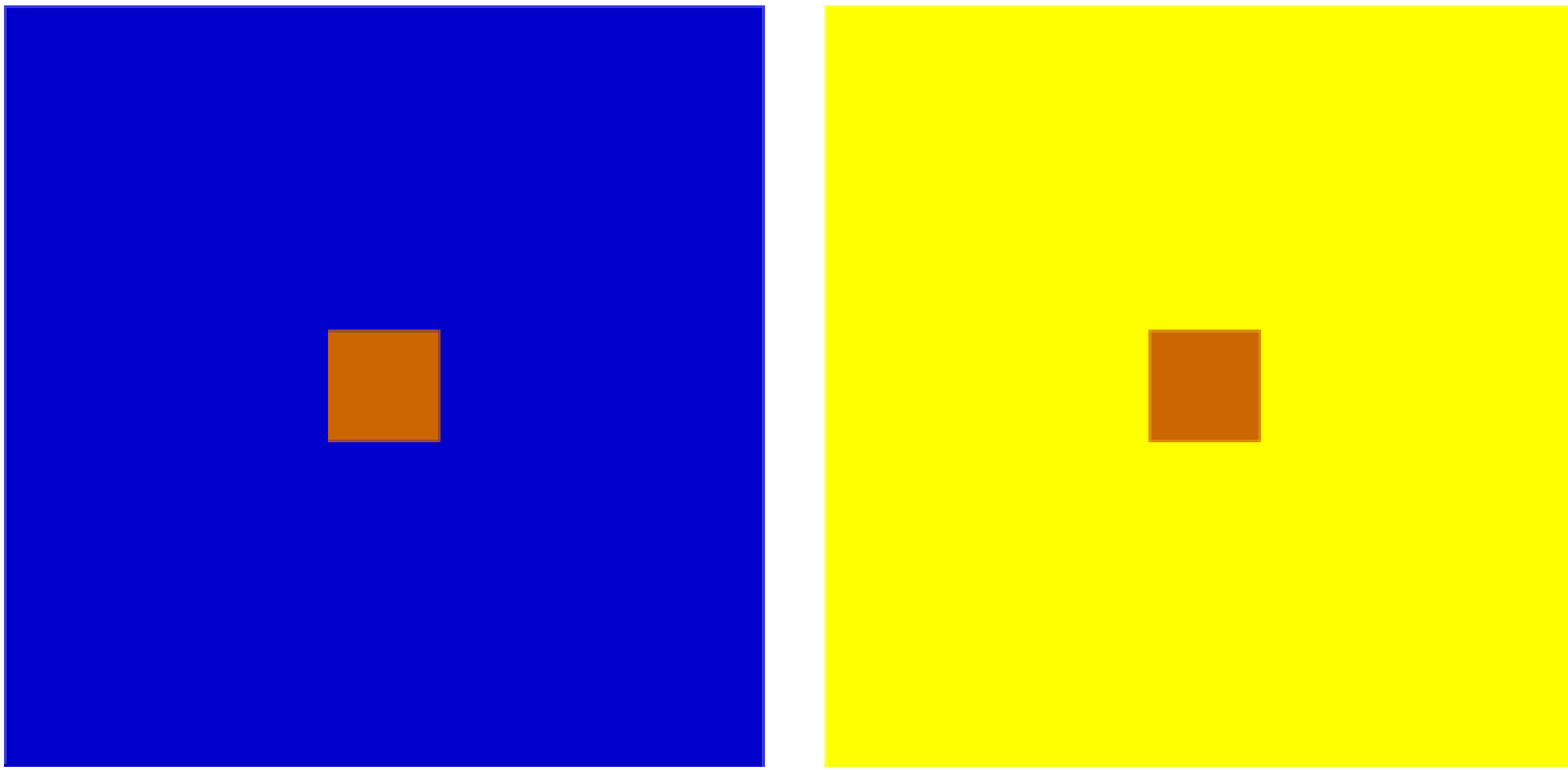


COLOR CONSTANCY, MOTIVATION

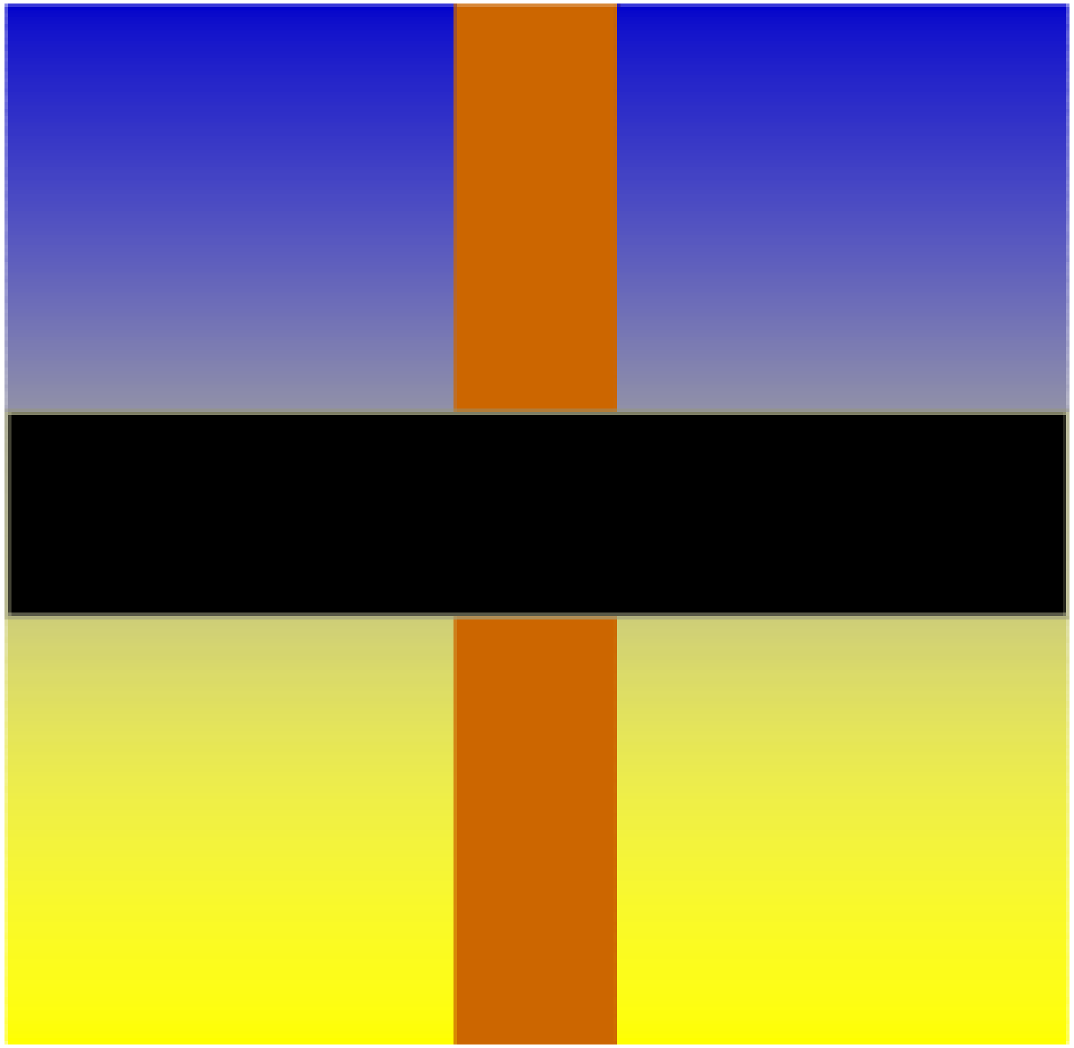


Colorimetry versus color perception.

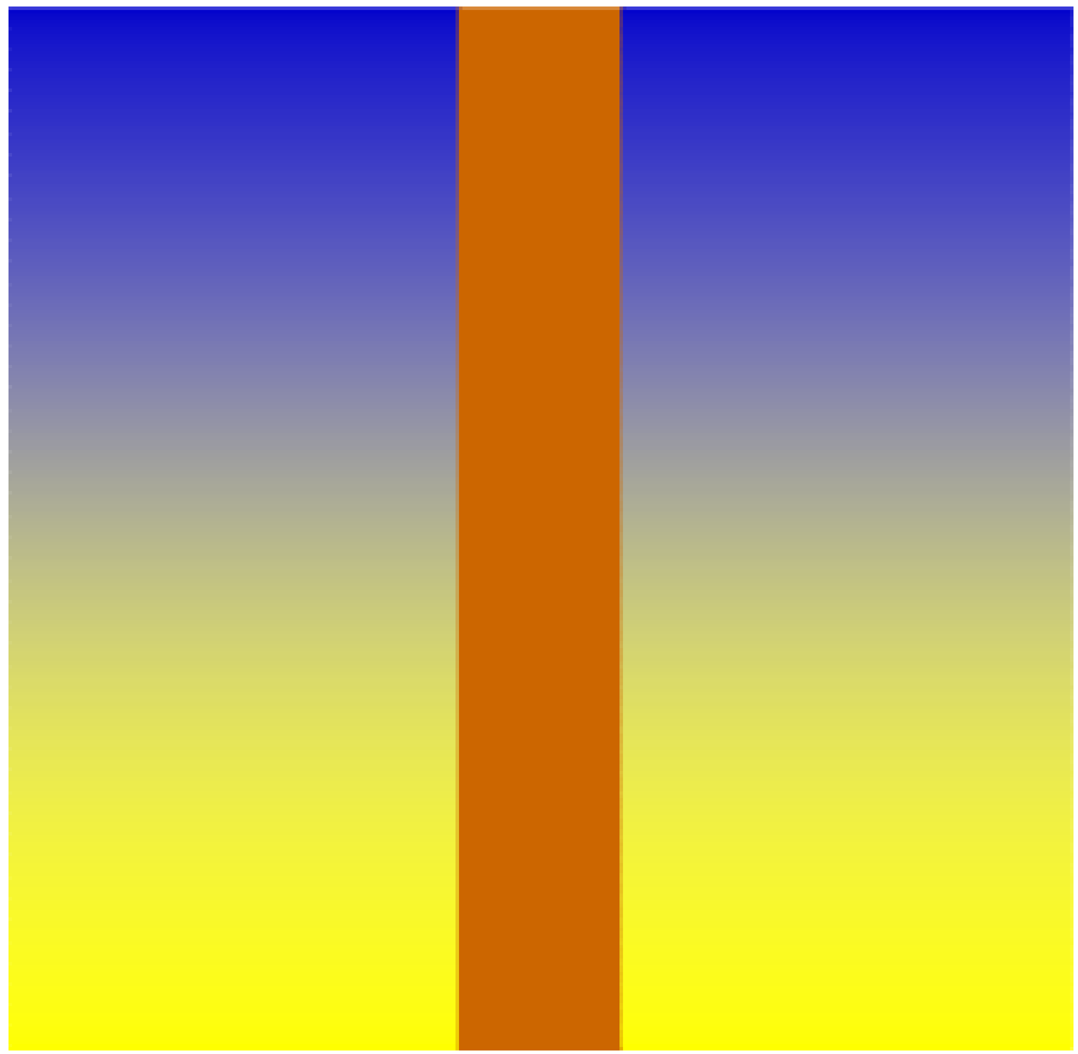
FAILURES IN COLOR CONSTANCY



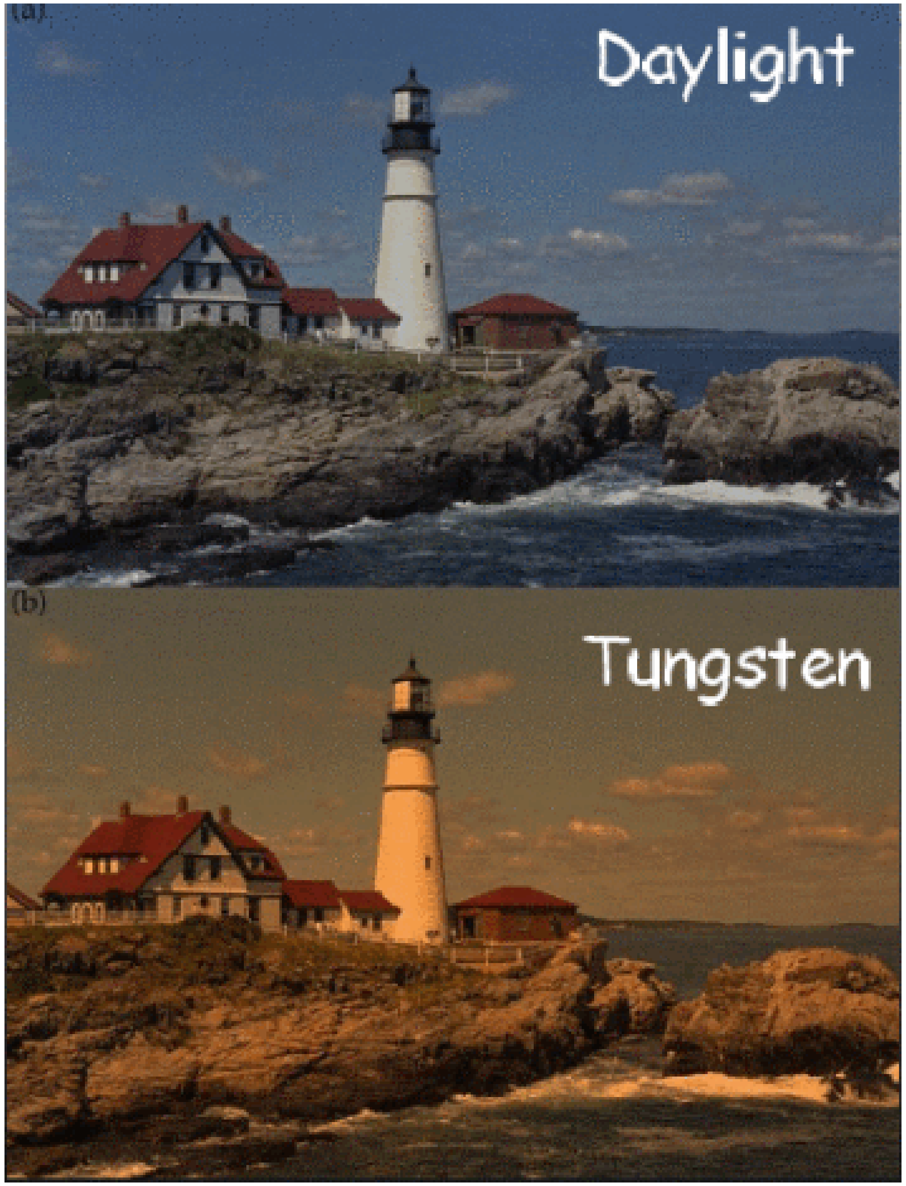
FAILURES IN COLOR CONSTANCY (2)



FAILURES IN COLOR CONSTANCY (3)



INFLUENCE OF ILLUMINATION



INFLUENCE OF ILLUMINATION (2)

INFLUENCE OF OUTLINE

Bezold effect