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 \(=\) 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 \(\lambda\). Exception: spectrometer.

Response of \(i\)-th sensor

\[
s_i = \int_{\lambda_1}^{\lambda_2} s(\lambda) r_i \, d\lambda ,
\]

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

\[ \lambda = \sin(\theta_G) \times \text{const.} \]
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 $\lambda$ 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 measures.
ILLUMINATION SPECTRUM

- Monochromatic intensity
- Daylight spectrum
- Incandescent lamp spectrum
- Fluorescent lamp spectrum

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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 TRICHRROMACY

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

Green projector

Red Projector

Blue Projector
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
Colorimetry versus color perception.
FAILURES IN COLOR CONSTANCY
FAILURES IN COLOR CONSTANCY (2)
FAILURES IN COLOR CONSTANCY (3)
INFLUENCE OF ILLUMINATION

(a) Daylight

(b) Tungsten
INFLUENCE OF ILLUMINATION (2)
INFLUENCE OF OUTLINE

Bezold effect