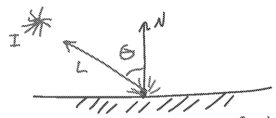
Surface reflectance

* Relate light source intensity to reflected light intensity
* Lambertian surface → Diffuse reflection

$\cos\theta = N \cdot L$

$N \cdot L < 0 \Rightarrow$ surface not visible



surface albedo $\in [0,1]$ (reflection coefficient)

$$I_{ref} = I \cdot \rho \cdot \cos\theta = I \cdot \rho \cdot (N \cdot L)$$

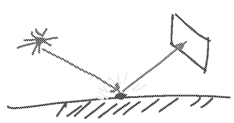
I_{ref}: intensity of reflection

I: intensity of source

Radiosity model

* Relate light in the scene (surface radiance) to light in the image (image irradiance)

$L(p)$ = power of light per unit area reflected from surface (surface radiance)



$E(p)$ = power of light per unit area received at the image (image irradiance)

Fundamental equation of radiometric image formation

$$E(p) = L(p)\, \frac{\pi}{4} \left(\frac{d}{f}\right)^2 (\cos\alpha)^4$$

$E(p)$: light at image

$L(p)$: light at surface

d: diameter of lens

f: focal length

α: angle between principal axis and surface normal

$d \uparrow \Rightarrow E(p) \uparrow$

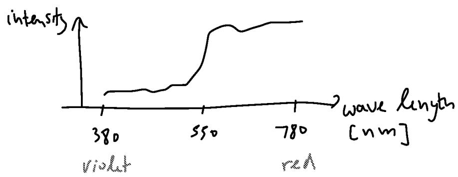
$f \uparrow \Rightarrow E(p) \downarrow$

$\alpha \uparrow \Rightarrow E(p) \downarrow$

Color

* visible light: 380 – 780 nm
  - ↑ higher frequency (380)
  - ↑ lower frequency (780)

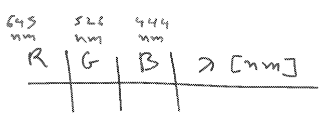
* e.g. Brown banana

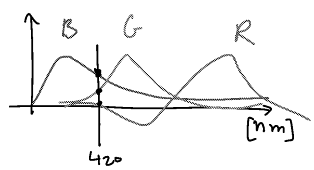


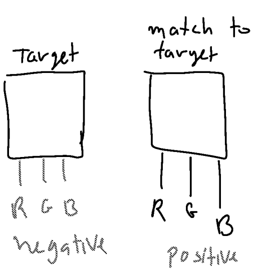
* Human vision: R, G, B receptors

CIE tables

* Map wavelength to RGB intensities



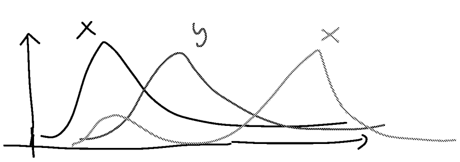




negative values are added to target to help match

Hypothetical light source

use X, Y, Z instead of R, G, B so that negative weights are not necessary.



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.177 & 0.813 & 0.011 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

TABLE 3.4 Color Coordinate Systems

Color coordinate system	Description
1. *C.I.E. spectral primary system: R, G, B*	Monochromatic primary sources P_1, red = 700 nm, P_2, green = 546.1 nm, P_3, blue = 435.8 nm. Reference white has flat spectrum and $R = G = B = 1$. See Figs. 3.13 and 3.14 for spectral matching curves and chromaticity diagram.
2. *C.I.E. X, Y, Z system* Y = luminance	$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$
3. *C.I.E. uniform chromaticity scale (UCS) system: u, v, Y*	$u = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3}$
u, v = chromaticities	$v = \frac{6Y}{X + 15Y + 3Z} = \frac{6y}{-2x + 12y + 3}$
Y = luminance	$U = \frac{2X}{3}, V = Y, W = \frac{-X + 3Y + Z}{2}$
U, V, W = tristimulus values corresponding to u, v, w	
4. U^*, V^*, W^* system (modified UCS system)	$U^* = 13W^*(u - u_0)$ $V^* = 13W^*(v - v_0)$ $W^* = 25(100Y)^{1/3} - 17, 1 \le 100Y \le 100$
Y = luminance [0.01, 1]	u_0, v_0 = chromaticities of reference white W^* = contrast or brightness
5. S, θ, W^* system: S = saturation θ = hue W^* = brightness	$S = [(U^*)^2 + (V^*)^2]^{1/2} = 13W^*[(u - u_0)^2 + (v - v_0)^2]^{1/2}$ $\theta = \tan^{-1}\left(\frac{V^*}{U^*}\right) = \tan^{-1}[(v - v_0)/(u - u_0)], 0 \le \theta \le 2\pi$
6. *NTSC receiver primary system* R_N, G_N, B_N	Linear transformation of X, Y, Z. Is based on television phosphor primaries. Reference white is illuminant C for which $R_N = G_N = B_N = 1$. $\begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix} = \begin{bmatrix} 1.910 & -0.533 & -0.288 \\ -0.985 & 2.000 & -0.028 \\ 0.058 & -0.118 & 0.896 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$
7. *NTSC transmission system:* Y = luminance I, Q = chrominances	$Y = 0.299R_N + 0.587G_N + 0.114B_N$ $I = 0.596R_N - 0.274G_N - 0.322B_N$ $Q = 0.211R_N - 0.523G_N + 0.312B_N$
8. L^*, a^*, b^* *system:*	$L^* = 25\left(\frac{100Y}{Y_0}\right)^{1/3} - 16, 1 \le 100Y \le 100$
L^* = brightness	$a^* = 500\left[\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right]$
a^* = red-green content	$b^* = 200\left[\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right]$
b^* = yellow-blue content	X_0, Y_0, Z_0 = tristimulus values of the reference white

CIE - LAB

*Euclidean distance in RGB space does not correspond to human perception.

whereas Euclidean distance in LAB space does correspond to perception.

$RGB \rightarrow L^* a^* b^* \rightarrow$ compare colors

$|c_1 - R| < |c_2 - R|$

$\Downarrow$

c_1 is more similar to R (e.g. skin color)

Quantization