Illumination

Total light decomposition

Light = reflected + transmitted + absorbed

Reflected light

Reflected light = ambient + diffuse + specular

\[ I = I_a + I_d + I_s \]
Illumination - Examples

ambient

ambient + diffuse

ambient + diffuse + specular
(and a checkerboard)
Ambient Reflection

- Uniform background light
- $I_a = k_a I_A$
  - $I_A$: ambient light
  - $k_a$: material’s ambient reflection coefficient
- Models general level of brightness in the scene
- Accounts for light effects that are difficult to compute (secondary diffuse reflections, etc)
- Constant for all surfaces of a particular object and the directions it is viewed at
Diffuse Reflection

- Models dullness, roughness of a surface
- Equal light scattering in all directions
- For example, chalk is a diffuse reflector

\[ L = \frac{\text{Light} - P}{|\text{Light} - P|} = \frac{(\text{Light}_x - P_x)}{|L'|}, \frac{(\text{Light}_y - P_y)}{|L'|}, \frac{(\text{Light}_z - P_z)}{|L'|} \]

\[ |L'| = \sqrt{(\text{Light}_x - P_x)^2 + (\text{Light}_y - P_y)^2 + (\text{Light}_z - P_z)^2} \]

Dot product:

\[ \mathbf{N} \cdot \mathbf{L} = (N_x L_x + N_y L_y + N_z L_z) \]

Lambertian cosine law:

\[ I_d = k_d I_L \cos \phi = k_d I_L \mathbf{N} \cdot \mathbf{L} \]

- \( I_L \): intensity of light source
- \( \mathbf{N} \): surface normal vector
- \( \mathbf{L} \): light vector (unit length)
- \( \phi \): angle of light incidence
- \( k_d \): diffuse reflection coefficient (material constant)

Note: \( I_d = 0 \) for \( \mathbf{N} \cdot \mathbf{L} < 0 \)
Specular Reflection - Fundamentals

- Models reflections on shiny surfaces (polished metal, chrome, plastics, etc.)
- Ideal specular reflector (perfect mirror) reflects light only along reflection vector $R$
- Non-ideal reflectors reflect light in a lobe centered about $R$
  - $\cos(\alpha)$ models this lobe effect
  - the width of the lobe is modeled by Phong exponent $n_s$, it scales $\cos(\alpha)$

**Phong specular reflection model:**

$$I_s = k_s \ I_L \ \cos^{n_s} \ \alpha = k_s \ I_L \ (E \cdot R)^{n_s}$$

- $I_L$: intensity of lightsource
- $L$: light vector
- $R$: reflection vector $= 2 \ N \ (N \cdot L) - L$
- $E$: eye vector $= (\text{Eye-P}) / ||\text{Eye-P}||$
- $\alpha$: angle between $E$ and $R$
- $n_s$: Phong exponent
- $k_s$: specular reflection coefficient

- $n_s = \infty$ (perfect mirror)
- $n_s$ large (100) (shiny surface)
- $n_s$ small (8) (dull surface)
Specular and Diffuse Reflection - Varying the Coefficients

diffuse coefficient $k_d$

Phong exponent $n_s$
Specular Reflection - Using the Half Vector

• Sometimes the half vector $H$ is used instead of $R$ in specular lighting calculation
• Both alternatives have similar effects

Phong specular reflection model:

$$I_s = k_s \ I_L \ \cos^{ns} \ \beta = k_s \ I_L \ (H \cdot N)^{ns}$$

$I_L$: intensity of lightsource
$L$: light vector
$H$: half vector $= (L + E) / |L + E|$
$R$: reflection vector
$E$: eye vector
Total Reflected Light

- Total reflected light (for a white object):
  \[ I = k_a I_A + k_d I_L N \cdot L + k_s I_L (H \cdot N)^{ns} \]

- Multiple lightsources:
  \[ I = k_a I_A + \sum (k_d I_i N \cdot L_i + k_s I_i (H_i \cdot N)^{ns}) \]

- Usually, \( I \) is a color vector of (R=red, G=green, B=blue)
- Object has a color vector \( C_{obj} = (R_{obj}, G_{obj}, B_{obj}) \)
- Object reflects \( I \), modulated by \( C_{obj} \)
- Color \( C \) reflected by object:
  \[ C = C_{obj} (k_a I_A + \sum (k_d I_i N \cdot L_i)) + \sum (k_s I_i (H_i \cdot N)^{ns}) \]

- In many applications, the specular color is not modulated by object color
  - specular highlight has the color of the lightsource

- Note: (R, G, B) cannot be larger than 1.0 (later scaled to [0, 255] for display)
  - either set a maximum for each individual term or clamp final colors to 1.0