CSE 681
Illumination and Phong Shading
What is Light?

- Physics tells us …
  - “We don’t see objects, we see light reflected off of objects”
  - “Light is a particle and a wave”

- The frequency of light
What is Color?

- Our visual system perceives the visible spectrum as color
Primary Colors

- A color is a summation of primary colors
  \[ C(\lambda) = r(\lambda) + g(\lambda)G + b(\lambda)B \]
Definitions

- **Illumination**
  - Transport of luminous flux
  - One or more light sources where light hits a surface either directly or indirectly

- **Shading**
  - The process of assigning a color to a pixel

- **Illumination Models**
  - Approximations to light transport
  - Goal: Physically correct models
Illumination

- **Light Sources** *(Emitters)*
  - Positional, directional, area

- **Surfaces** *(Reflectors)*
  - Light source energy is cumulative *(additive)*
  - Absorb and emit light
  - Position and orientation
  - Smooth vs. Micro –structure *(roughness)*
General Problem

Robert Cook (Siggraph 1984)

“The intensity of reflected light at a point on a surface is an integral over the hemisphere above the surface of an illumination function $L$ and a reflectance function $f$.”

\[
L_o(p,\omega_o) = \int f(p,\omega_i,\omega_o) L_i(p,\omega_i) |\cos \theta_i| \, d\omega_i
\]
Local vs. Global Illumination

- Global
  - Illuminate a point on a surface taking into account other surfaces
  - Shadows, reflection, refraction, radiosity

- Local
  - Illuminate a point on a surface assuming it is the only point in the scene
Phong Illumination Model

- **Ambient**
  - Gross (very cheap) approximation to indirect light hitting a surface after reflecting off of other surfaces
  - Absorbs this light and reflects surface color

- **Diffuse**
  - Light reflected off a surface *equally in all directions* after being absorbed by the surface (subsurface scattering) and then re-emitted
  - Reflects surface color

- **Specular**
  - Light reflected immediately off the surface
  - Light is not absorbed
  - Reflects light color
The Phong Illumination Model

- Sum these three components:
  
  \[ \text{Illumination} = \text{ambient} + \text{diffuse reflection} + \text{specular reflection} \]
 Ambient (Global Illumination)

- Radiosity
  - Calculate the propagation of light through the scene as it reflects off all surfaces
  - We see the reflection of all this indirect illumination
  - Computationally intensive to do correctly

- Ambient
  - A gross approximation to radiosity
  - Use a constant to represent the amount of indirect light
  - Yeah, it’s a hack! But global illumination is tough!

\[ I_{\text{ambient}} = k_a I_a \]
Lambert’s Cosine Law

- Diffuse reflection is proportional to the amount of light that hits the surface per unit area
Lambert’s Cosine Law

- Projected Area = \( \cos(\theta) = (\mathbf{N} \cdot \mathbf{L}) \)
- Use \( \max((\mathbf{N} \cdot \mathbf{L}), 0) \) * color_{\text{object}}
Specular (Local Illumination)

- Light reflected at a mirror reflection angle
Specular Reflection

- The reflection of the light source on the object
- Shiny/Glossy surfaces
  - Not a perfect mirror

Show up as Specular Highlights, i.e., bright spots
Specular

- Cosine falloff about mirror reflection vector
- View-dependent
Reflectance Ray

\[(L \cdot N) N\]

\[S = (L \cdot N)N - L\]

\[R = (L \cdot N)N + (L \cdot N)N - L\]

\[R = 2(N \cdot L)N - L\]
Cosine Falloff

- The angle between the ideal reflection direction \( \mathbf{R} \) and the view direction \( \mathbf{V} \) is \( \alpha \)

\[
\cos(\alpha) = \mathbf{V} \cdot \mathbf{R} = \mathbf{L} \cdot \mathbf{V}_R
\]
Material Property

- \( \cos(\alpha))^q = (V \cdot R)^q \),
- Power \( q \) = size of the lobe
  = how fast the specular component falls
  = glossiness of the surface
Specular Reflection Coefficient
Alternative Specular Calculation

- Half-way vector $H$ bisects the angle between $V$ and $L$
  - Compare $H$ to $N$
  - Cheaper to compute than $R$

\[ H = \frac{V + L}{|V + L|} \]

May use: $(H \cdot N)^q \times \text{Color}_{\text{light}}$
Blinn-Torrance Variation

- Use halfway vector $\mathbf{H}$ between $\mathbf{V}$ and $\mathbf{L}$
A Comparison

- Is the variation a good approximation?
- Difficult to distinguish visually – used in OpenGL!

Phong

Blinn-Torrance
Phone Illumination (Single Light)

- Terms
  - $K_d =$ diffuse coefficient, $K_s =$ specular coefficient
  - Let $K_a = K_d$, assume ambient term is diffusely reflected
  - $I =$ light intensity

- Compute for each wavelength (r, g, b)

$$C = (K_d I_a + N \cdot L * K_d * I_d) * \text{color}_{\text{object}} + (V \cdot R)^q * K_s * I_s * (1,1,1)$$

white light source
Multiple Light Sources

- Simply add together the contribution from each light source equally.

- Add in the effects of a light source iff the “face is a FRONT FACE” with respect to the light.
  - The sign of $N \cdot L$

- $\delta_i = 0$ if light is behind face
  - $= 1$ if light is in front of face

$$C = \sum_i \delta_i \left[ K_d \cdot I_d \cdot c_{obj} + (N \cdot L_i \cdot K_d \cdot I_d) \cdot c_{obj} + (V \cdot R)^q \cdot K_s \cdot I_s \cdot c_i \right]$$
Ambient/Diffuse/Specular

- Just ambient light:

- Diffuse + Specular and change Ambient

- Left: Sphere with just diffuse reflection
- Right: Sphere with just specular reflection
Ambient Only

- Cheap global illumination
Ambient + Diffuse
Ambient + Diffuse + Specular
Phong Illumination