Lighting and Shading

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Why we need shading

- Suppose we build a model of a red sphere
- We get something like

\[ \text{Red sphere} \]

- But we want

\[ \text{Shaded sphere} \]
Why does a real sphere look like this?
Why does a real sphere look like this?

- facing light
- shadow
Shading - material properties

- shiny
- matte

Image source: [1]
Shading - viewing location

What if I move?

Image source: [1]
Shading - surface orientation

well lit

poorly lit
Based on physics
- conservation of energy

Surfaces can
- absorb light
- emit light
- reflect light
- transmit light
Ideaialized light sources

- Ambient point light
- Spotlight
- Directional light
Ambient light

- Achieve uniform light level
- No shadows
- Same light level everywhere
Point light

- Light emitted from a point \( p \)
- Uniform in all directions
- Falls off with distance: \( \ell(x) = \frac{1}{\|x - p\|^2} L \)
Point light - limitations

- rapid falloff
- no light
- sharp shadow
Soft shadows
Spotlight

- Light emitted from a point $p$
- Emitted in a cone
- Brightest in middle of cone
- Falls off with distance
\[
\ell(x) = \frac{\cos^e \phi}{\|x - p\|^2} L
\]
Spotlight - exploring $e$

$-\theta \quad \theta$

$e = 1$

$e = 20$

$e = 60$
Directional light

- Light source at infinity
- Rays come in parallel
- No falloff
- Characterized by direction
Lambertian reflection model

Image source: [1]
Lambertian reflection model

Light Incident

Intensity

\[ I = \frac{L}{L'} \]

Energy

\[ E = L' \omega a \]

\[ E = L' \omega h \]
Lambertian reflection model

\[ \begin{align*}
\text{Intensity:} & \quad L \quad L' \quad I = RL' \\
\text{Energy:} & \quad E = Lwa \quad E = L'wh \quad RE
\end{align*} \]
Lambertian reflection model

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Light</th>
<th>Incident</th>
<th>Reflected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>$L$</td>
<td>$L'$</td>
<td>$I = RL'$</td>
</tr>
<tr>
<td></td>
<td>$E = Lwa$</td>
<td>$E = L'wh$</td>
<td>$RE$</td>
</tr>
</tbody>
</table>

$I = LR\frac{a}{h}$
Lambertian reflection model

\[ I = LR \frac{a}{h} \]
Lambertian reflection model

\( I = LR \frac{a}{h} = LR \cos \theta \)
Lambertian reflection model

\[ I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l} \]
Lambertian reflection model

\[ I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l} \]

Avoid bug: \( I = LR \max(\mathbf{n} \cdot \mathbf{l}, 0) \)
Ambient reflection

\[ I = LR \max(n \cdot l, 0) \]

Surfaces facing away from the light will be totally black.
All surfaces get the same amount of ambient light

\[ I = L_a R_a + L_d R_d \max(n \cdot l, 0) \]
Phong reflection model

Image source: [1]
Phong reflection model

- Efficient
- Reasonably realistic
- 3 components
- 4 vectors

Ambient + Diffuse + Specular = Phong
Phong reflection model

\[ I = I_a + I_d + I_s \]
\[ = R_a L_a + R_d L_d \max(n \cdot l, 0) + R_s L_s \max(\cos \phi, 0)^\alpha \]
Ambient reflection

\[ I_a = R_a L_a \quad 0 \leq R_a \leq 1 \]
Diffuse reflection

Ambient + Diffuse + Specular = Phong
Diffuse reflection

\[ I_d = R_d L_d \max(n \cdot l, 0) \]
Specular reflection

Ambient + Diffuse + Specular = Phong

Ideal reflector
\[ \theta_i = \theta_r \]

\( r \) is the mirror reflection direction
Specular reflection

Ambient + Diffuse + Specular = Phong

specular reflection is strongest in reflection direction
Specular reflection drops off with increasing $\phi$. 

$I_s = R_s L_s \max(\cos \phi, 0)^\alpha$
Phong reflection model

\[ I = I_a + I_d + I_s \]

\[ = R_a L_a + R_d L_d \max(n \cdot l, 0) + R_s L_s \max(v \cdot r, 0)^\alpha \]