Direct Illumination

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Ray Casting

```cpp
Image RayCast( Camera camera , Scene scene , int width , int height )
{
    Image image( width , height );
    for( int i=0 ; i<width ; i++ ) for( int j=0 ; j<height ; j++ )
    {
        Ray ray = ConstructRayThroughPixel( camera , i , j );
        Intersection hit = FindIntersection( ray , scene );
        image[i][j] = GetColor( scene , ray , hit );
    }
    return image;
}
```
Ray Casting

Image RayCast( Camera camera , Scene scene , int width , int height )
{
    Image image( width , height );
    for( int i=0 ; i<width ; i++ ) for( int j=0 ; j<height ; j++ )
    {
        Ray ray = ConstructRayThroughPixel( camera , i , j );
        Intersection hit = FindIntersection( ray , scene );
        image[i][j] = GetColor( scene , ray , hit );
    }
    return image;
}
Illumination

• How do we compute radiance for a sample ray?

\[ \text{image}[i][j] = \text{GetColor}( \text{scene}, \text{ray}, \text{hit} ); \]
Goal

- Must derive models for ...
  - Emission at light sources
  - Direct light at surface point
  - Scattering between surfaces

- Desirable features …
  - Concise
  - Efficient to compute
  - Convincing
Overview

• Direct Illumination
  ◦ Emission at a light source
  ◦ Direct light at surface point

• Global illumination
  ◦ Shadows
  ◦ Inter-object reflections
  ◦ Transmissions

Intersection Testing
Overview

• Direct Illumination
  ◦ Emission at light sources
  ◦ Direct light at surface points

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  ◦ Shadows
  ◦ Inter-object reflections
  ◦ Transmissions

Lambertian Shading
Overview

• Direct Illumination
  ◦ Emission at light sources
  ◦ Direct light at surface points

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  ◦ Shadows
  ◦ Inter-object reflections
  ◦ Transmissions

Phong Shading
Overview

• Direct Illumination
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  ◦ Transmissions
Overview

• Direct Illumination
  ◦ Emission at light sources
  ◦ Direct light at surface points

• Global illumination
  ◦ Shadows
  ◦ Inter-object reflections
  ◦ Transmissions

Reflections
Overview

• Direct Illumination
  ◦ Emission at light sources
  ◦ Direct light at surface points

• Global illumination
  ◦ Shadows
  ◦ Inter-object reflections
  ◦ Transmissions
Overview

• Direct Illumination
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  ◦ Transmissions
Modeling Light Sources

- $I_L(q, d, \lambda)$ describes the intensity of energy ($I$):
  - arriving at $q$,
  - from direction $d$,
  - with wavelength $\lambda$
Empirical Models

• Ideally measure irradiant energy for “all” situations
  ◦ Too much storage
  ◦ Difficult in practice

\[ (q_x, q_y, q_z) \]
Simplified Light Source Models

- Simple mathematical models:
  - Point light
  - Directional light
  - Spot light
Point Light Source

- Models omni-directional point source
  - intensity $I$, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - factors $(k_c, k_l, k_q)$ for attenuation with distance ($\delta$)

\[
\delta = \|(p_x, p_y, p_z) - (q_x, q_y, q_z)\|
\]

\[
I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}
\]

The light hitting a surface point $q$ comes in from direction $q - p$. 
Directional Light Source

• Models point light source at infinity
  ◦ intensity $I$, (typically a three-channel value)
  ◦ direction $\vec{d} = (d_x, d_y, d_z)$

No attenuation with distance

$$k_c = 1, k_l = k_q = 0$$

The light hitting a surface point $p$ comes in from direction $d$. 
Spot Light Source

• Models point light source
  ◦ intensity $I$, (typically a three-channel value)
  ◦ position $p = (p_x, p_y, p_z)$,
  ◦ attenuation $(k_c, k_l, k_q)$

$$I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}$$
Spot Light Source

- Models point light source with direction
  - intensity $I$, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation $(k_c, k_l, k_q)$
  - direction $\vec{d} = (d_x, d_y, d_z)$
  - cut-off and drop-off $(\gamma, \alpha)$

$$I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}$$

How can we modify the intensity of a point light to decrease as $\gamma$ increases?
Spot Light Source

- Models point light source with direction and fall-off
  - intensity $I$, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation $(k_c, k_l, k_q)$
  - direction $\vec{d} = (d_x, d_y, d_z)$
  - cut-off and drop-off $(\gamma, \alpha)$

\[ I_L(q) = \begin{cases} 
  \frac{I \cdot \langle \vec{d}, \vec{v} \rangle^\alpha}{k_c + k_l \cdot \delta + k_q \cdot \delta^2} & \text{if } \langle \vec{d}, \vec{v} \rangle > \cos \gamma \\
  0 & \text{otherwise}
\end{cases} \]
Spot Light Source

- Models point light source with direction and fall-off
  - intensity $I$, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation $(k_c, k_l, k_q)$
  - direction $\vec{d} = (d_x, d_y, d_z)$
  - cut-off and drop-off $(\gamma, \alpha)$

The light hitting a surface point $q$ comes in from direction $q - p$.
Assumes that $\vec{d}$ and $\vec{v}$ are unit vectors!

$$I_L(q) = \begin{cases} 
I \cdot \langle \hat{d}, \hat{v} \rangle^\alpha \\
\frac{k_c + k_l \cdot \delta + k_q \cdot \delta^2}{k_c + k_l \cdot \delta + k_q \cdot \delta^2} \\
0
\end{cases} \text{ if } \langle \hat{d}, \hat{v} \rangle > \cos \gamma$$
otherwise
Overview

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  ◦ Inter-object reflections
Modeling Surface Reflectance

- $R_S(p, \overrightarrow{d^{in}}, \lambda^{in}, \overrightarrow{d^{out}}, \lambda^{out})$ describes the fraction of incident energy ($R$) at the surface ($S$),
  - arriving at point $p$
  - from direction $\overrightarrow{d^{in}}$,
  - with incoming wavelength $\lambda^{in}$,
  - with outgoing wavelength $\lambda^{out}$,
  - leaving in direction $\overrightarrow{d^{out}}$
Empirical Models

• Ideally measure radiant energy for all combinations of incident angles, all surface positions, and all combinations of incoming and outgoing wavelengths
  - Too much storage
  - Difficult in practice
Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”

Based on model proposed by Phong
Simple Reflectance Model

• Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”
Diffuse Reflection

• Assume surface reflection is viewer independent, i.e. the surface reflects equally in all directions
  ◦ Examples: chalk, clay
Diffuse Reflection

- How much light is reflected?
  - Only depends on angle of incident light
  - aka “Lambertian”
Diffuse Reflection

• How much light is reflected?
  ◦ Only depends on angle of incident light
    \[ dL = dA \cdot \cos \theta \]
Diffuse Reflection

Lambertian model:

- cosine law: \( \cos \theta = \langle \vec{N}, \vec{L} \rangle \), with \( \vec{N} \) and \( \vec{L} \) unit vectors
- \( K_D \) is surface property
- \( I_L \) is incoming light

\[
I_D = K_D \cdot \langle \vec{N}, \vec{L} \rangle \cdot I_L
\]
Diffuse Reflection

• Light/surface properties have RGB components!
  ◦ Need to run calculation below on EACH color channel
  ◦ This holds true for all lighting calculations

\[
I_D^C = K_D^C \cdot \langle \hat{N}, \hat{L} \rangle \cdot I_L^C, \quad C \in \{R, G, B\}
\]
Diffuse Reflection

- Assume surface reflects equally in all directions
  - Examples: chalk, clay
Simple Reflectance Model

• Simple analytic model:
  ◦ diffuse reflection +
  ◦ specular reflection +
  ◦ emission +
  ◦ “ambient”
Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: metals, shiny apples
Specular Reflection

How much light is seen?

Depends on how well the:
  ◦ reflected direction, and
  ◦ direction to the viewer

line up.

\[ \mathbf{V} \quad \mathbf{R} \quad \mathbf{L} \quad \mathbf{N} \quad \theta \quad \theta \]
Specular Reflection

Phong Model:

- \( \cos(\alpha) = \langle \vec{V}, \vec{R} \rangle \) describes how aligned the reflected and view directions are
- \( n \) describes the specularity of the surface
  - \( n = 0 \): the surface is Lambertian
  - \( n \to \infty \): the surface is a mirror

This is a physically-motivated hack!

\[ I_S = K_S \cdot \langle \vec{V}, \vec{R} \rangle^n \cdot I_L \]
Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: metals, shiny apples
Simple Reflectance Model

• Simple analytic model:
  ◦ diffuse reflection +
  ◦ specular reflection +
  ◦ emission +
  ◦ “ambient”
Emission

Represents light emanating uniformly from a surface that cannot be described by the three light sources

\[ \text{Emission} \neq 0 \]
Emission

\[ I_E = I_E \]

Emission \( \neq 0 \)
Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”
Ambient Term

• Represents reflection from all indirect illumination

This is a hack (avoids complexity of global illumination)!
Ambient Term

- Represents reflection from all indirect illumination

\[ I_A = K_A \cdot I_L^A \]

Typically \( K_A = K_D \) describe the “color” of the surface.
**Simple Reflectance Model**

- **Simple analytic model:**
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”

  ![Diagram showing light positions and dependencies]

  - Light position dependent
  - Light + viewer position dependent
Simple Reflectance Model

• Simple analytic model:
  ○ diffuse reflection +
  ○ specular reflection +
  ○ emission +
  ○ “ambient”

- Light position dependent
- Light + viewer position dependent
Surface Illumination Calculation

- Single light source:

\[
I = I_E + K_A \cdot I_L^A + \left( K_D \cdot \langle \vec{N}, \vec{L} \rangle + K_S \cdot \langle \vec{V}, \vec{R} \rangle^n \right) \cdot I_L
\]
Surface Illumination Calculation

• Multiple light source:

\[ I = I_E + \sum_L \left[ K_A \cdot I_L^A + \left( K_D \cdot \langle \vec{N}, \vec{L} \rangle + K_S \cdot \langle \vec{V}, \vec{R}^n \rangle \right) \cdot I_L \right] \]