Acceleration and Illumination

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HB Ch. 14.1, 14.2
FvDFH 16.1, 16.2
Ray Casting

Image RayCast(Camera camera, Scene scene, int width, int height) {
    Image image = new 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

```java
Image RayCast(Camera camera, Scene scene, int width, int height) {
    Image image = new Image(width, height);
    for (int i = 0; i < width; i++) {
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            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 on surface points
  ○ Scattering at surfaces
  ○ Reception at the camera

• Desirable features …
  ○ Concise
  ○ Efficient to compute
  ○ “Accurate”
Overview

• Direct Illumination
  ◦ Emission at a light source
  ◦ Reflection off the surface

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

• Direct Illumination
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Lambertian Shading
Overview

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Overview

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Shadow Computation
Overview

• Direct Illumination
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Overview

• Direct Illumination
  - Emission at light sources
  - Reflection off the surface

• Global illumination
  - Shadows
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Overview

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Modeling Light Sources

- $I_L(x, y, z, \theta, \phi, \lambda)$
  - describes the intensity of energy ($I$),
  - leaving a light source ($L$),
  - at a particular angle ($\theta, \phi$)
  - arriving at a location ($x, y, z$),
  - with a particular wavelength ($\lambda$)
Empirical Models

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

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

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

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

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

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

No attenuation with distance

$k_c = 1, k_l = k_q = 0$

$I_L = I$

The light hitting a surface point $q$ comes in from direction $\vec{d}$. 
Spot Light Source

- Models point light source with direction
  - intensity $I$,
  - 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 $(\gamma, \alpha)$

How can we modify point light to decrease as $\gamma$ increases?

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

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

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

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

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

• Global illumination
  ◦ Shadows
  ◦ Transmissions
  ◦ Inter-object reflections
Modeling Surface Reflectance

- \( R_S(\theta, \phi, \lambda, \gamma, \psi) \)
  - describes the fraction of incident energy (\( R \)),
  - at the surface (\( S \)),
  - arriving from direction (\( \theta, \phi \)),
  - with wavelength (\( \lambda \)),
  - leaving in direction (\( \gamma, \psi \)),
Empirical Models

• Ideally measure radiant energy for “all” combinations of incident angles
  ◦ 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”

Based on model proposed by Phong
Diffuse Reflection

• Assume surface reflects equally in all directions
  ◦ Examples: chalk, clay
Diffuse Reflection

• How much light is reflected?
  ◦ Depends on angle of incident light
  ◦ aka “Lambertian”
Diffuse Reflection

• How much light is reflected?
  ◦ Depends on angle of incident light

\[ dL = dA \cdot \cos \theta \]
Diffuse Reflection

• Lambertian model
  ◦ cosine law: \( \cos \theta = \langle \vec{N}, \vec{L} \rangle \)
  ◦ \( K_D \) is surface property
  ◦ \( I_L \) is incoming light

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

• Note that lights and surface properties have R, G, and B components!
  ○ So amount of red light reflected is not necessarily equal to amount of green light, etc.
  ○ You will need to run calculation below on EACH color channel
  ○ This holds true for all lighting calculations

\[ I_{D}^{\text{Red}} = K_{D}^{\text{Red}} \cdot \langle \vec{N}, \vec{L} \rangle \cdot I_{L}^{\text{Red}} \]
Diffuse Reflection

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

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  - diffuse reflection +
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  - 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.
Specular Reflection

• Phong Model
  ◦ $\cos^n \alpha$

This is a physically-motivated hack!

$\mathbf{I}_S = K_S \cdot \langle \mathbf{V}, \mathbf{R} \rangle^n \cdot I_L$
Specular Reflection

• Reflection is strongest near mirror angle
  ◦ Examples: metals, shiny apples
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  - “ambient”
Emission

Represents light emanating directly 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 of all indirect illumination

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

- Represents reflection of all indirect illumination

\[ I_A = K_A \cdot I_L^A \]
Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - "ambient"

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:

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

- Multiple light source:

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