Direct Illumination

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CS 4810: Graphics

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Recall: 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;
}
Recall: 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++) {
        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;
}
```

With Illumination

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Illumination

- How do we compute radiance for a sample ray?

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

• Must derive models for ...
  o Emission at light sources
  o Direct light on surface points
  o Scattering at surfaces
  o Reception at the camera

• Desirable features …
  o Concise
  o Efficient to compute
  o “Accurate”
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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Lambertian Shading
Overview

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Phong Shading
Overview

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Refractive Bouncing
Overview

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Modeling Light Sources

- $I_L(x,y,z,\theta,\phi,\lambda)$...
  - describes the intensity of energy,
  - leaving a light source, ...
  - arriving at location $(x,y,z)$, ...
  - from direction $(\theta,\phi)$, ...
  - with 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 ($I_0$),
  - Position ($px, py, pz$),
  - Factors ($k_c, k_l, k_q$) for attenuation with distance ($d$)

$$I_L = \frac{I_0}{k_c + k_l d + k_q d^2}$$
**Directional Light Source**

- Models point light source at infinity
  - **Intensity** \( I_0 \),
  - **Direction** \( (dx, dy, dz) \)

\[ I_L = I_0 \]

No attenuation with distance
Spot Light Source

- Models point light source with direction
  - Intensity ($I_0$),
  - Position ($px, py, pz$),
  - Attenuation ($k_c, k_l, k_q$)
  - Direction ($dx, dy, dz$)
  - Cut-off and drop-off ($\gamma, \alpha$)

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

$$I_L = \frac{I_0}{k_c + k_1d + k_qd^2}$$
Spot Light Source

- Models point light source with direction
  - Intensity \( (I_0) \),
  - Position \( (px, py, pz) \),
  - Attenuation \( (k_c, k_l, k_q) \)
  - Direction \( (dx, dy, dz) \)
  - Cut-off and drop-off \( (\gamma, \alpha) \)

\[
I_L = \begin{cases} 
  \frac{I_0 \langle D, L \rangle^\alpha}{k_c + k_l d + k_q d^2} & \text{if } \langle D, L \rangle < \cos(\gamma) \\
  0 & \text{otherwise}
\end{cases}
\]
Overview

• Direct Illumination
  - Emission at light sources
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• Global illumination
  - Shadows
  - Transmissions
  - Inter-object reflections
Modeling Surface Reflectance

- $R_s(\theta, \phi, \lambda, \gamma, \psi)$ ...
  - describes the fraction of incident energy, 
  - arriving from direction $(\theta, \phi)$, ...
  - with wavelength $\lambda$, ...
  - leaving in direction $(\gamma, \psi)$, ...

\[ \text{Surface} \]
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?
  o Depends on angle of incident light

Think of a flashlight!
Diffuse Reflection

- How much light is reflected?
  - Depends on angle of incident light

\[ dL = dA \cos \theta \]

Think of a flashlight!
Diffuse Reflection

- Lambertian model
  - Cosine law (dot product)
  - $K_D$ is surface property
  - $I_L$ is incoming light

\[ I_D = K_D(N \cdot L)I_L \]
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

\[ I_{D\_Red} = K_{D\_RED} (N \cdot L) I_{L\_RED} \]
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: non-metallic “shiny” surfaces
Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: non-metallic shiny surfaces
Specular Reflection

How much light is seen?

Depends on:
- angle of incident light
- angle to viewer
Specular Reflection

• Phong Model

\[ \omega \cos(\alpha)^n \]

This is a physically-motivated hack!

\[ I_S = K_S (V \cdot R)^n I_L \]
Specular Reflection

• Reflection is strongest near mirror angle
  o Examples: non-metallic shiny surfaces
Simple Reflectance Model

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

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

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

\[ I = I_E \]

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

\[ I_A = K_A I_{AL} \]
Simple Reflectance Model

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

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

- Single light source:

\[
I = I_E + K_A I_{AL} + K_D (N \cdot L) I_L + K_S (V \cdot R)^n I_L
\]
Surface Illumination Calculation

- Multiple light sources:

\[ I = I_E + K_A I_{AL} + \sum_i \left( K_D (N \cdot L_i) I_i + K_S (V \cdot R_i)^n I_i \right) \]
Next Lecture

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

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