Direct Illumination

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CS 4810: Graphics

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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;
}
```
Recall: Ray Casting

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Image RayCast(Camera camera, Scene scene, int width, int height) {
    Image image = new Image(width, height);
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            Ray ray = ConstructRayThroughPixel(camera, i, j);
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            image[i][j] = GetColor(scene, ray, hit);
        }
    }
    return image;
}
```

With Illumination
Illumination

- How do we compute radiance for a sample ray?

\[
\text{image}[i][j] = \text{GetColor(}\text{scene, ray, hit})
\]
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
  o Emission at light sources
  o Direct light at surface points

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

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Lambertian Shading
Overview

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Phong Shading
Overview

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Shadow Computation
Overview

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Reflective Bouncing
Overview

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Modeling Light Sources

- $I_L(x,y,z,\theta,\phi,\lambda)$ ...
  - describes the intensity of energy, originating from 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
  o Too much storage
  o 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 \((dx, dy, dz)\)

No attenuation with distance

\[ I_L = I_0 \]
Spot Light Source

• Models point light source with direction
  o intensity ($I_0$),
  o position ($px$, $py$, $pz$),
  o attenuation ($k_c$, $k_l$, $k_q$)
  o direction ($dx$, $dy$, $dz$)
  o cut-off and drop-off ($\gamma$, $\alpha$)

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

$$I_L = \frac{I_0}{k_c + k_l d + k_q d^2}$$
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
  - 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,
  - arriving from direction $(\theta, \phi)$, ...
  - with wavelength $\lambda$, ...
  - leaving in direction $(\gamma, \psi)$, ...

![Diagram showing incident and reflected light](image)
Empirical Models

- Ideally measure radiant energy for “all” combinations of incident angles
  - Too much storage
  - Difficult in practice
Gonioreflectometry
Goniorelectometry

[Image of goniorelectometry setup]

[Matusik et al. 2003]
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?
  o Depends on angle of incident light
  o aka “Lambertian”
Diffuse Reflection

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

Think of a flashlight!
Diffuse Reflection

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

\[ dL = dA \cos \Theta \]
Diffuse Reflection

- Lambertian model
  - ocosine law (dot product)
  - $oK_D$ is surface property
  - $oI_L$ is incoming light

(If the dot product is less than zero, then $I_D$ is zero)

$$I_D = K_D (N \cdot L) I_L$$
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"

Surface
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

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

N: Normal
L: Light direction
R: Reflected light direction
V: View direction
Specular Reflection

- Phong Model
  \[ o \cos(\alpha)^n \]

This is a physically-motivated hack!

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

(Again, if dot product is negative, then \( I_S \) should be set to zero)
Specular Reflection

- Reflection is strongest near mirror angle
  - 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:

\[ \text{odiffuse reflection} + \text{ospecular reflection} + \text{oemission} + \text{“ambient”} \]
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:

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

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

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