Illumination Models

Local Illumination

Example

Local Illumination in the projective rendering pipeline

1. Only models light arriving directly from light source
2. Interreflections and shadows
   - Added through tricks, multiple rendering passes

Types of Models

1. Simple, non-physical reflection models (Phong, Blinn)
2. Physically-based reflection models
   - BRDFs: Bidirectional Reflection Distribution Functions

Light Sources

Types of light sources

1. Directional/parallel lights
   - E.g. Sun
   - Homogeneous vector
2. (Homogeneous) point lights
   - Same intensity in all directions
3. Spot lights
   - Limited set of directions:
     * Point + direction + cutoff angle
Local Illumination

Commonly used model (simple, non-physical)

Combine diffuse, specular, ambient
- E.g. OpenGL / graphics hardware:
\[ I_{\text{out}}(x) = k_a \cdot I_a + k_d \cdot (l \cdot n) \cdot I_{\text{diff}} + k_s \cdot (h \cdot n)^\gamma \cdot I_{\text{spec}} \]

Materials

Ambient Light
- Incoming light component that is identical everywhere in the scene
- No direction
- Hack for replacing true global illumination (light bouncing off from other objects)
\[ I_{\text{in}}(x) = k_a \cdot I_a \]

Diffuse component: Lambert’s Law

Johann Friedrich Lambert (1783):
- Power per unit area arriving at some object point \( x \) also depends on the angle of the surface to the light direction
  - \( dA \): differential surface area surrounding \( x \)
  - \( l \): light direction (unit length!)
\[ I_{\text{in}}(x) = \cos(\angle(n, l)) \cdot I_{\text{in}}(x) = (n \cdot l) \cdot I_{\text{in}}(x) \]

Diffuse Component: a more detailed look
- Independent of viewing direction

Materials

Specular/Glossy
- Light is mostly reflected into the directions around the mirror direction \( r_l \) of \( l \)

\[ f_s(l \rightarrow r_l) \]

\[ n \]

\[ l \]

\[ r_l \]
**Materials**

**Specular/Glossy**
- Computing reflection direction $r_l$ of $I$
  - $n$ and $I$ are unit length!

$$r_l = 2(n \cdot l) \cdot n - l$$

**Phong Model (Phong Bui-Tuong, 1975)**
- Use cosine power as heuristic

$$I_{\text{spec}}(x) = k_s \cdot (v \cdot r_l)^n \cdot I_n(x)$$

**Blinn-Phong model (Jim Blinn, 1977)**
- Variation with better physical interpretation
  - $h$: halfway vector; $n$: shininess

$$I_{\text{diff}}(x) = k_d \cdot (h \cdot n)^n \cdot I_n(x); \text{with } h = (l + v) / 2$$

**Commonly used model (simple, non-physical)**
- Combine diffuse, specular, ambient
  - E.g. OpenGL / graphics hardware:

$$I_{\text{out}}(x) = k_a \cdot I_a + k_d \cdot (l \cdot n) \cdot I_{\text{diff}} + k_s \cdot (h \cdot n)^n \cdot I_{\text{spec}}$$
Lighting in OpenGL

- **Light source**: amount of RGB light emitted
  - value represents percentage of full intensity, e.g., (1.0,0.5,0.5)
  - every light source emits ambient, diffuse, and specular light
- **Materials**: amount of RGB light reflected
  - value represents percentage reflected e.g., (0.0,1.0,0.5)

```gl
glLightfv(GL_LIGHT0, GL_AMBIENT, amb_light_rgba);
glLightfv(GL_LIGHT0, GL_DIFFUSE, dif_light_rgba);
glLightfv(GL_LIGHT0, GL_SPECULAR, spec_light_rgba);
glLightfv(GL_LIGHT0, GL_POSITION, position);
glEnable(GL_LIGHT0);
```

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Flat Shading

**Example:**

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Gouraud Shading

**Example:**

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Materials

**Summary**
- Very simple reflection models
- Fast (dot products & exponentiation)
- No physical justification
- Not very good for modeling real world

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Light Sources

**Quadratic falloff**
- Brightness of objects depends on power per unit area that hits the object
- The power per unit area for a point or spot light decreases quadratically with distance

![Quadratic falloff diagram](Image)
Light Sources

**Non-quadratic falloff:**
- Many systems allow for other falloffs
- Allows for faking of the effect of area light sources
- OpenGL / graphics hardware:
  - $I_o$: intensity of light source
  - $x$: object point
  - $r$: distance of light from $x$

\[ I_{in}(x) = \frac{1}{ar^2 + br + c} \cdot I_0 \]

Materials

**Bi-directional Reflectance Distribution Function (BRDF):**
- Describes fraction of light reflected for all combinations of incoming (light) and outgoing (viewing) directions
- Color channels (R, G, B) are treated separately
  - Actually: wavelengths (see later in course)

\[ f_r(l \rightarrow v) \cdot (n \cdot l) \cdot I_{in}(x) \]

Materials

**Polar plot of BRDF**
- Fix incoming light direction $l$
- Plot $f_r(l \rightarrow v)$ for all viewing directions $v$
- Works for 2D and 3D plots
- Example: 2D polar plot for diffuse BRDF

Light Sources

**Area lights:**
- light sources with a finite area
- more realistic model of many light sources
- Not available with projective rendering pipeline, (i.e., not available with OpenGL)

Gouraud Shading

**Mach Bands:**
- Eye enhances discontinuity in first derivative
- Very disturbing, especially for highlights