Local Illumination

CMSC 435/634
Illumination

- Global and Local Illumination
Illumination

- Effect of light on objects
- Mostly look just at intensity
  - Apply to each color channel independently
- Good for most objects
  - Not fluorescent
  - Not phosphorescent
Local Illumination

- Light sources shining directly on object
Global Illumination

- Lights from objects shining on other objects
- Ambient Illumination
  - Approximate global illumination as constant color
  - Typically 0.1% of direct illumination
 Bidirectional Reflectance Distribution Function

How much light reflects from $L_i$ to $L_o$
Physically Plausible BRDF

- Positive
- Reciprocity
  - Same light from $L_i$ to $L_o$ as from $L_o$ to $L_i$
- Conservation of Energy
  - Don’t reflect more energy than comes in
Plotting BRDFs

- Polar plot of reflectance strength
  - For one view direction, showing light directions
  - For one light direction, showing view directions

- Reciprocity – same if you swap view and light
Rendering Equation

Integral of all Incoming Light

\[ L_o(\hat{v}) = \int_{\Omega(\hat{n})} f_r(\hat{v} \leftarrow \hat{l}) L_i(\hat{l}) \hat{n} \cdot \hat{l} \, d\omega(\hat{l}) \]

Parts of this equation:

- \( L_o(\hat{v}) \): outgoing light in direction \( \hat{v} \)
- \( \Omega(\hat{n}) \): hemisphere above \( \hat{n} \)
- \( f_r(\hat{v} \leftarrow \hat{l}) \): BRDF from \( \hat{l} \) to \( \hat{v} \)
- \( L_i(\hat{l}) \): incoming light from direction \( \hat{l} \)
- \( \int_{\Omega(\hat{n})} \ldots \hat{n} \cdot \hat{l} \, d\omega(\hat{l}) \): integration over hemisphere
- \( \hat{n} \cdot \hat{l} \, d\omega(\hat{l}) \): projection of differential solid angle onto surface
Rendering Equation for Point Lights

Sum for Each Light

\[ L_o(\hat{v}) = \sum_i f_r(\hat{v} \leftarrow \hat{l}_i) L_i \hat{n} \cdot \hat{l}_i \]

Parts of this equation:

- \( L_o(\hat{v}) \): outgoing light in direction \( \hat{v} \)
- \( f_r(\hat{v} \leftarrow \hat{l}) \): BRDF from \( \hat{l} \) to \( \hat{v} \)
- \( L_i \): incoming light intensity for light \( i \)
- \( \hat{l}_i \): incoming light direction for light \( i \)
Results

- Integrating full environment
- Light at one point, black elsewhere
Important directions

\( \hat{n} \)  
Surface normal

\( \hat{v} \)  
Vector from surface toward viewer

\( \hat{l} \)  
Vector from surface toward light

\( \hat{R}_v = 2\hat{n}(\hat{n} \cdot \hat{v}) - \hat{v} \)  
Mirror reflection direction for view

\( \hat{R}_l = 2\hat{n}(\hat{n} \cdot \hat{l}) - \hat{l} \)  
Mirror reflection direction for light

\( \hat{h} = \frac{\hat{v} + \hat{l}}{|\hat{v} + \hat{l}|} \)  
Normal direction that would reflect \( \hat{v} \) to \( \hat{l} \)

\( \hat{T}_v = \left( \eta \hat{n} \cdot \hat{v} - \sqrt{1 - \eta^2(\hat{n} \cdot \hat{v})^2} \right) \hat{n} - \eta \hat{v} \)  
Refraction (transmission) direction for \( \hat{v} \)
Decomposing BRDFs

- Decompose BRDF into convenient parts
- Typical breakdown:
  - Diffuse (view independent)
  - Specular (view dependent near reflection)
  - Others less common, often ignored (e.g. retro reflection)

\[
L_o(\hat{v}) = \sum_i \left( f_d(\hat{v} \leftarrow \hat{l}_i) + f_s(\hat{v} \leftarrow \hat{l}_i) \right) L_i \hat{n} \cdot \hat{l}_i
\]

\[
L_o(\hat{v}) = \sum_i f_d(\hat{v} \leftarrow \hat{l}_i) L_i \hat{n} \cdot \hat{l}_i + \sum_i f_s(\hat{v} \leftarrow \hat{l}_i) L_i \hat{n} \cdot \hat{l}_i
\]
Diffuse

- Also called Lambertian or Matte
- BRDF constant
- Total reflectance: \( \sum_i Kd \hat{n} \cdot \hat{i} L_i \)
Phong

- Strongest where $\hat{R}_l$ lines up with $\hat{v}$ or $\hat{R}_v$ lines up with $\hat{l}$
- BRDF: $\frac{(\hat{R}_l \cdot \hat{v})^e}{\hat{n} \cdot \hat{l}} = \frac{(\hat{R}_v \cdot \hat{l})^e}{\hat{n} \cdot \hat{l}}$
  - Size of peak determined by exponent
- Total reflectance: $\sum_i Ks (\hat{R}_v \cdot \hat{l}_i)^e L_i$
- Non-physical
  - Too much energy; division by $\hat{n} \cdot \hat{l}$ breaks reciprocity
Blinn-Phong

- Alternate formulation, similar behavior
- Strongest where $\hat{h}$ lines up with $\hat{n}$
- BRDF: $\frac{(\hat{n} \cdot \hat{h})^e}{\hat{n} \cdot \hat{l}}$
- Total reflectance: $\sum_i K_s (\hat{n} \cdot \hat{h}_i)^e L_i$
- Still non-physical
Cook-Torrance

- Imagine random V-shaped mirrored *microfacets*
- Probability facet has normal $\hat{h}$ (distribution term)
  - Beckmann Distribution = Gaussian distribution of slope
- Proportion of light or view blocked (geometry term)
  - Blocked light = *shadowing*
  - Blocked view = *masking*
- Fresnel term
Cook-Torrance

- **BRDF:** \( \frac{D(\hat{n}, \hat{h}) G(\hat{n}, \hat{v}, \hat{l}) F(\hat{v}, \hat{l})}{\pi \hat{n} \cdot \hat{v} \cdot \hat{n} \cdot \hat{l}} \),

- Total reflectance: \( \sum_i K_s \frac{D(\hat{n}, \hat{h}_i) G(\hat{n}, \hat{v}, \hat{l}_i) F(\hat{v}, \hat{l}_i)}{\pi \hat{n} \cdot \hat{v}} L_i \)

- **Is** physically-plausible

- Differs from Blinn-Phong primarily at glancing reflection
Illumination

Interpolation
When to Compute

- **Flat Shading** = Compute per-polygon
- **Gouraud Shading** = Compute per-vertex & interpolate
  - Lose sharp highlights
  - Subject to *Mach banding*
- **Phong Shading** = Interpolate normals & compute per-pixel
Phong Shading

- Phong shading can refer to lighting model or interpolation
- To save confusion:
  - *Phong lighting*
  - *Phong interpolation*