Local Illumination

CMSC 435/634

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

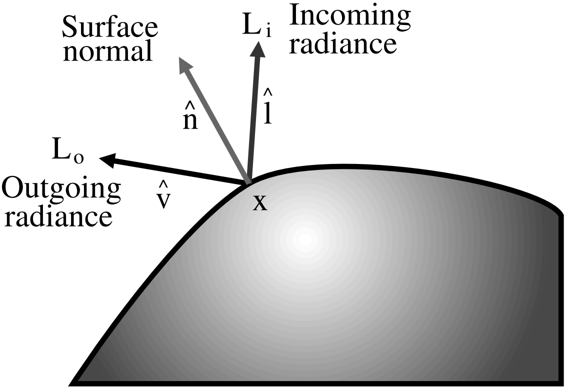
Global Illumination

- Lights from objects shining on other objects
- Ambient Illumination
  - Approximate global illumination as constant color
  - Typically ~1% of direct illumination

BRDF

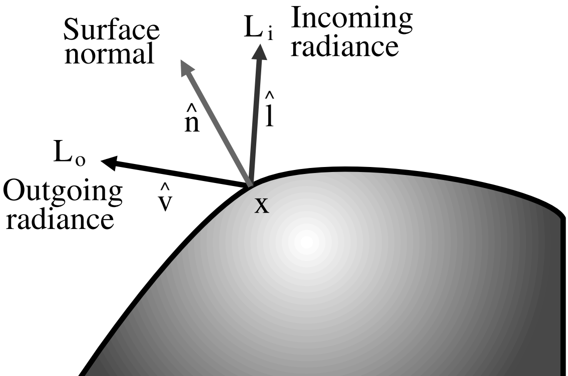
Bidirectional Reflectance Distribution Function

How much light reflects from L_i to L_o



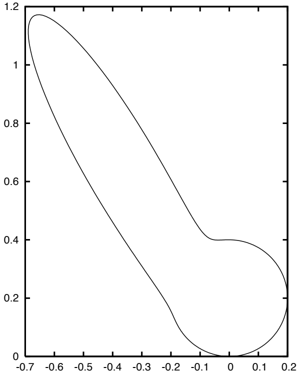
Physically Plausible BRDF

- 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

$$L_o(\hat{v}) = \int_{\Omega(\hat{n})} f_r(\hat{v} \leftarrow \hat{l})\, L_i(\hat{l})\, \hat{n} \bullet \hat{l}\, d\omega(\hat{l})$$

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 $\hat{l}$
$\int_{\Omega(\hat{n})} \ldots \hat{n} \bullet \hat{l}\, d\omega(\hat{l})$	integration over hemisphere
$\hat{n} \bullet \hat{l}\, d\omega(\hat{l})$	projection of differential solid angle onto surface

Rendering Equation for Point Lights

Sum for Each Light

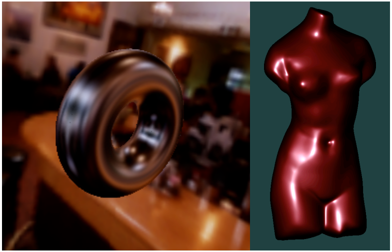
$$L_o(\hat{v}) = \sum_i f_r(\hat{v} \leftarrow \hat{l}_i)\, L_i\, \hat{n} \bullet \hat{l}_i$$

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
$\hat{R}_v = 2\hat{n}(\hat{n} \bullet \hat{v}) - \hat{v}$	Mirror reflection direction for view
$\hat{R}_l = 2\hat{n}(\hat{n} \bullet \hat{l}) - \hat{l}$	Mirror reflection direction for light
$\hat{h} = \frac{\hat{v}+\hat{l}}{\lvert\hat{v}+\hat{l}\rvert}$	Normal direction that would reflect $\hat{v}$ to $\hat{l}$
$\hat{T}_v = \left(\eta\, \hat{n} \bullet \hat{v} - \sqrt{1 - \eta^2(\hat{n} \bullet \hat{v})^2}\right) \hat{n} - \eta\, \hat{v}$	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)

$$L_o(\hat{v}) = \sum_i \left(f_d(\hat{v} \leftarrow \hat{l}_i) + f_s(\hat{v} \leftarrow \hat{l}_i) \right) L_i \, \hat{n} \bullet \hat{l}_i$$

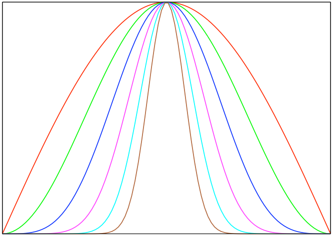
$$L_o(\hat{v}) = \sum_i f_d(\hat{v} \leftarrow \hat{l}_i) \, L_i \, \hat{n} \bullet \hat{l}_i + \sum_i f_s(\hat{v} \leftarrow \hat{l}_i) \, L_i \, \hat{n} \bullet \hat{l}_i$$

Diffuse

- Also called Lambertian or Matte
- BRDF constant
- Total reflectance: $\sum_i Kd\, \hat{n} \bullet \hat{l}_i\, L_i$

Phong

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



Blinn-Phong

- Alternate formulation, similar behavior
- Strongest where $\hat{h}$ lines up with $\hat{n}$
- BRDF: $\frac{(\hat{n} \bullet \hat{h})^e}{\hat{n} \bullet \hat{l}}$
- Total reflectance: $\sum_i Ks \, (\hat{n} \bullet \hat{h}_i)^e \, L_i$
- 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: $\frac{D(\hat{n},\hat{h})\,G(\hat{n},\hat{v},\hat{l})\,F(\hat{v},\hat{l})}{\pi\;\hat{n}\bullet\hat{v}\;\hat{n}\bullet\hat{l}}$,
- Total reflectance: $\sum_i Ks\,\frac{D(\hat{n},\hat{h}_i)\,G(\hat{n},\hat{v},\hat{l}_i)\,F(\hat{v},\hat{l}_i)}{\pi\;\hat{n}\bullet\hat{v}}\,L_i$
- Is physically-plausible
- Differs from Blinn-Phong primarily at glancing reflection

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

Gouraud

Phong

Phong Shading

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