CSCI 420 Computer Graphics
Lecture 9

Lighting and Shading

Light Sources
Phong Illumination Model
Normal Vectors
[Angel Ch. 6.1-6.4]

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Outline

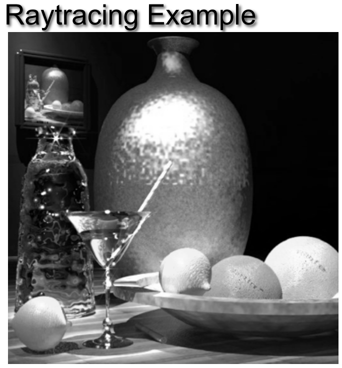
- Global and Local Illumination
- Normal Vectors
- Light Sources
- Phong Illumination Model

Global Illumination

- Ray tracing
- Radiosity
- Photon Mapping
- Follow light rays through a scene
- Accurate, but expensive (off-line)

Tobias R. Metoc

Raytracing Example



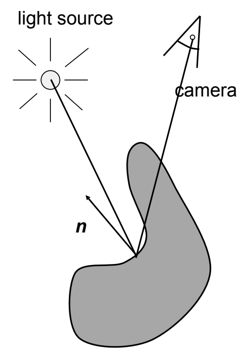
Martin Moeck,
Siemens Lighting

Radiosity Example

Restaurant Interior. Guillermo Leal, Evolucion Visual

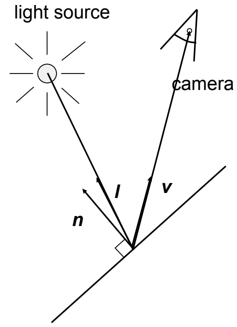
Local Illumination

- Approximate model
- Local interaction between light, surface, viewer
- Phong model (this lecture): fast, supported in OpenGL
- GPU shaders
- Pixar Renderman (offline)



Local Illumination

- Approximate model
- Local interaction between light, surface, viewer
- Color determined only based on surface normal, relative camera position and relative light position
- What effects does this ignore?



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Normal Vectors

- Must calculate and specify the normal vector
  - Even in OpenGL!
- Two examples: plane and sphere

Normals of a Plane, Method I

- Method I: given by ax + by + cz + d = 0
- Let p_0 be a known point on the plane
- Let p be an arbitrary point on the plane
- Recall: $u \cdot v = 0$ if and only if u orthogonal to v
- $n \cdot (p - p_0) = n \cdot p - n \cdot p_0 = 0$
- Consequently $n_0 = [a \;\; b \;\; c]^T$
- Normalize to $n = n_0/|n_0|$

Normals of a Plane, Method II

- Method II: plane given by p_0, p_1, p_2
- Points must not be collinear
- Recall: u x v orthogonal to u and v
- $n_0 = (p_1 - p_0) \times (p_2 - p_0)$
- Order of cross product determines orientation
- Normalize to $n = n_0/|n_0|$

Normals of Sphere

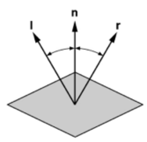
- Implicit Equation $f(x, y, z) = x^2 + y^2 + z^2 - 1 = 0$
- Vector form: $f(p) = p \cdot p - 1 = 0$
- Normal given by gradient vector

$$n_0 = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \\ \frac{\partial f}{\partial z} \end{bmatrix} = \begin{bmatrix} 2x \\ 2y \\ 2z \end{bmatrix} = 2p$$

- Normalize $n_0/|n_0| = 2p/2 = p$

Reflected Vector

- Perfect reflection: angle of incident equals angle of reflection
- Also: ***l***, ***n***, and ***r*** lie in the same plane
- Assume |***l***| = |***n***| = 1, guarantee |***r***| = 1



$\boldsymbol{l} \cdot \boldsymbol{n} = \cos(\theta) = \boldsymbol{n} \cdot \boldsymbol{r}$

$\boldsymbol{r} = \alpha\, \boldsymbol{l} + \beta\, \boldsymbol{n}$

Solution: $\alpha = -1$ and $\beta = 2\,(\boldsymbol{l} \cdot \boldsymbol{n})$

$\boldsymbol{r} = 2\,(\boldsymbol{l} \cdot \boldsymbol{n})\, \boldsymbol{n} - \boldsymbol{l}$

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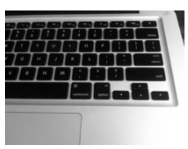
Light Sources and Material Properties

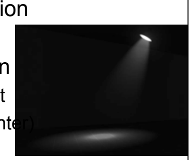
- Appearance depends on
  - Light sources, their locations and properties
  - Material (surface) properties:



  - Viewer position

Types of Light Sources

- Ambient light: no identifiable source or direction
- Point source: given only by point
- Distant light: given only by direction
- Spotlight: from source in direction
  - Cut-off angle defines a cone of light
  - Attenuation function (brighter in center)



Point Source

- Given by a point p_0
- Light emitted equally in all directions
- Intensity decreases with square of distance

$$I \propto \frac{1}{|p - p_0|^2}$$

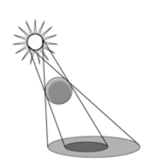
Limitations of Point Sources

- Shading and shadows inaccurate
- Example: penumbra (partial "soft" shadow)
- Similar problems with highlights
- Compensate with attenuation

$$\frac{1}{a + bq + cq^2}$$

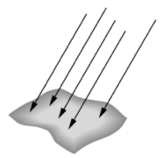
q = distance $|p - p_0|$
a, b, c constants

- Softens lighting
- Better with ray tracing
- Better with radiosity



Distant Light Source

- Given by a direction vector
- Simplifies some calculations
- In OpenGL:
  - Point source $[x\ \ y\ \ z\ \ 1]^T$
  - Distant source $[x\ \ y\ \ z\ \ 0]^T$



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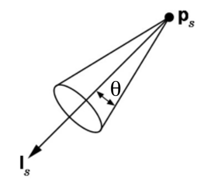
Spotlight

- Most complex light source in OpenGL
- Light still emanates from point
- Cut-off by cone determined by angle θ



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Global Ambient Light

- Independent of light source
- Lights entire scene
- Computationally inexpensive
- Simply add $[G_R\ G_G\ G_B]$ to every pixel on every object
- Not very interesting on its own.
  A cheap hack to make the scene brighter.

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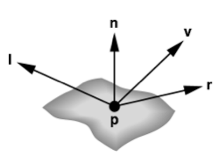
Phong Illumination Model

- Calculate color for arbitrary point on surface
- Compromise between realism and efficiency
- Local computation (no visibility calculations)
- Basic inputs are material properties and **l**, **n**, **v**:

l = unit vector to light source
n = surface normal
v = unit vector to viewer
r = reflection of **l** at **p**
(determined by **l** and **n**)



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Phong Illumination Overview

1. Start with global ambient light $[G_R\ G_G\ G_B]$
2. Add contributions from each light source
3. Clamp the final result to [0, 1]

- Calculate each color channel (R,G,B) **separately**
- Light source contributions decomposed into
  - Ambient reflection
  - Diffuse reflection
  - Specular reflection
- Based on ambient, diffuse, and specular lighting and material properties

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Ambient Reflection

$I_a = k_a L_a$

- Intensity of ambient light is uniform at every point
- Ambient reflection coefficient k_a, $0 \le k_a \le 1$
- May be different for every surface and r,g,b
- Determines reflected fraction of ambient light
- L_a = ambient component of light source
  (can be set to different value for each light source)
- Note: L_a is not a physically meaningful quantity

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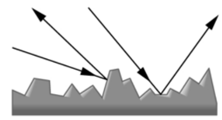
Diffuse Reflection

- Diffuse reflector scatters light
- Assume equally all direction
- Called Lambertian surface
- Diffuse reflection coefficient k_d, $0 \le k_d \le 1$
- Angle of incoming light is important



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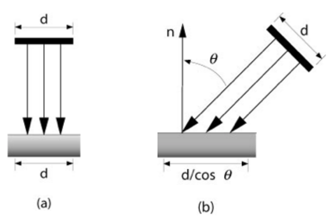
Lambert's Law

Intensity depends on angle of incoming light.



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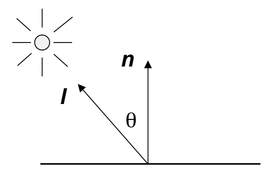
Diffuse Light Intensity Depends On Angle Of Incoming Light

- Recall
  - ***l*** = unit vector to light
  - ***n*** = unit surface normal
  - θ = angle to normal
- $\cos\theta = \boldsymbol{l} \cdot \boldsymbol{n}$



- $I_d = k_d L_d (\boldsymbol{l} \cdot \boldsymbol{n})$
- With attenuation:

$$I_d = \frac{k_d L_d}{a + bq + cq^2}(l \cdot n)$$

q = distance to light source,
L_d = diffuse component of light

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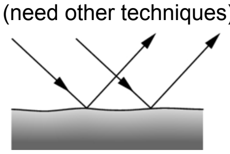
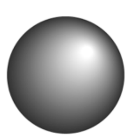
Specular Reflection

- Specular reflection coefficient k_s, $0 \le k_s \le 1$
- Shiny surfaces have high specular coefficient
- Used to model specular highlights
- Does not give mirror effect
  (need other techniques)



specular reflection



specular highlights

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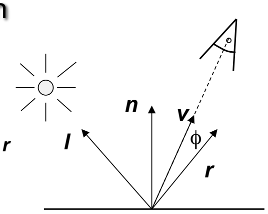
Specular Reflection

- Recall
  - ***v*** = unit vector to camera
  - ***r*** = unit reflected vector
  - ϕ = angle between ***v*** and ***r***
- $\cos\phi = \boldsymbol{v} \cdot \boldsymbol{r}$



- $I_s = k_s L_s (\cos\phi)^{\alpha}$
- L_s is specular component of light
- α is shininess coefficient
- Can add distance term as well

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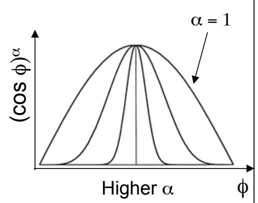
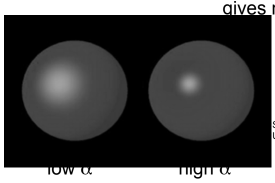
Shininess Coefficient

- $I_s = k_s L_s (\cos \phi)^\alpha$
- α is the shininess coefficient



Higher α gives narrower curves



Source: Univ. of Calgary

low α high α

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Summary of Phong Model

- Light components for each color:
  - Ambient (L_a), diffuse (L_d), specular (L_s)
- Material coefficients for each color:
  - Ambient (k_a), diffuse (k_d), specular (k_s)
- Distance q for surface point from light source

$$I = \frac{1}{a + bq + cq^2}(k_d L_d (l \cdot n) + k_s L_s (r \cdot v)^\alpha) + k_a L_a$$

l = unit vector to light ***r*** = ***l*** reflected about ***n***
n = surface normal ***v*** = vector to viewer

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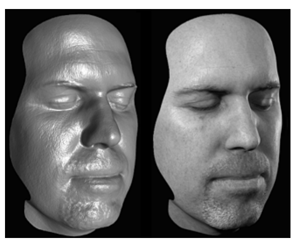
BRDF

- Bidirectional Reflection Distribution Function
- Must measure for real materials
- Isotropic vs. anisotropic
- Mathematically complex
- Programmable pixel shading



Lighting properties of a human face were captured and face re-rendered; Institute for Creative Technologies

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