Reflectance

CS510 Lecture #02

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Photorealistic Images:

As a first level approximation, photorealistic images can be generated by:

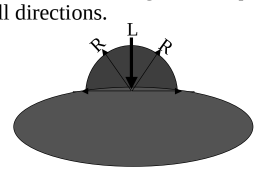
- An illumination model
- A surface & reflectance model
- A sensor model (discussed last lecture)

Last lecture, we started to trace this path backwards, by looking at sensors

Today we continue to work backwards from reflectance to illumination...

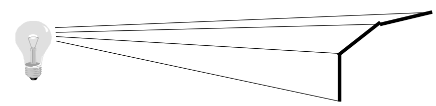
Lambertion Reflection

- Consider a directional light source an a *Lambertian* Surface.
- *Lambertian* surface reflects light with equal intensity in all directions.

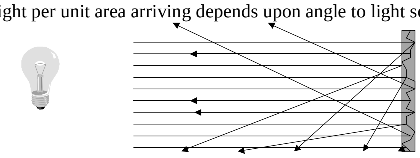


- This does ***not*** mean all surfaces appear equally bright ...

Lambertian (II)



Light per unit area arriving depends upon angle to light source.

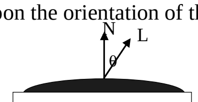


Light leaves in all directions, reflected off micro surfaces.

Lambertian (III)

- Illumination/area drops when tilted from light.
- Therefore, *I* depends upon the orientation of the surface:

$$I_{l_i,\text{diff}} = k_d I_{l_i} \cos(\theta)$$



where l_i is the i_{th} light source, and k_d is a constant determining the percent of reflected light

$$I_{l_i,\text{diff}} = k_d I_{l\,i} (N \bullet L)$$

- Using unit length vectors for N and L yields.

Lambertian (color)

- Lambertian reflectance is "deep" reflection
  - Light is inter-reflected off miniscule facets
  - Color of the reflected light is therefore strongly effected by the color of the surface
- If the color of the incident light is represented by a vector $I_{l_i} = \left[R_{l_i}, G_{l_i}, B_{l_i}\right]$
- Then the color of the reflected light is computed by replacing the Lambertian constant k_d with a matrix: $K = \begin{bmatrix} k_{r,r} & k_{r,g} & k_{r,b} \\ k_{g,r} & k_{g,g} & k_{g,b} \\ k_{b,r} & k_{b,g} & k_{b,b} \end{bmatrix}$

Lambertian (N)

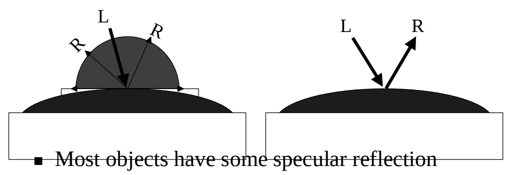
- Note that the off-diagonals are non-zero because standard red, green and blue filters overlap (fig 15-6 of H&B)
- The color Lambertian reflectance equation is therefore:

$$I_{l_i,\text{diff}} = K \cdot I_{l_i}(N \bullet L)$$

- However, we will usually cheat and assume that off-diagonal terms are zero (e.g. in the assignment)

Specular Reflection

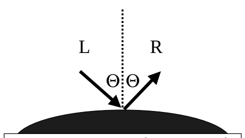
- Most surfaces do not act as *Lambertian* reflectors.
- Consider two extremes, *Lambertian* surface and a Mirror.



- Most objects have some specular reflection component
  - The mirror is an extreme, all energy reflects about an angle ...

Pure Specular Reflection

- In pure specular reflection:
  - The angle of incidence equals the angle of reflectance
  - The color of the reflected light is the color of the illuminant



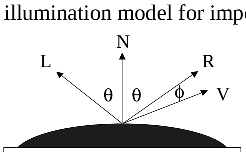
$$I_{l_i,spec} = k_s I_{l_i}(\theta_i = \theta_r)$$

"Real" Specular Reflection

- Only mirrors exhibit pure specular reflection
- Most objects have "impure" specular reflections:
  - They have both Lambertian and Specular components
  - The angle of incidence does not have to be *exactly* the angle of reflection

Phong Illumination

- Phong illumination model for imperfect reflectors.



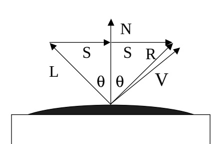
$$I_{S_i} = k_s I_{l_i} \cos(\phi)^n$$

Note that k_s is a scalar even for color illuminants, and that $\cos(\phi) = RV$

Phong (II)

- When the viewing vector V is not equal to the reflection vector R, R is not readily available.
- Therefore, use the congruent triangles to remove it.

$$R = N\cos(\theta) + S$$
$$S = N\cos(\theta) - L$$
$$R = 2N\cos(\theta) - L$$
$$= 2N(N\cdot L) - L$$



$$R\,V = (2N(N\cdot L) - L)\cdot V$$

Hybrid Reflectance

- Most objects are characterized by a combination of Lambertian and Specular reflection
- In intensity, reflectance is:

$$I_{observed,l_i} = k_d I_{l_i}(N \cdot L) + k_s I_{l_i}(R \cdot V)^n$$

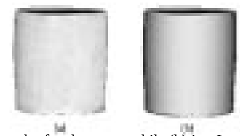
$$I_{observed,l_i} = k_d I_{l_i}(N \cdot L) + k_s I_{l_i}((2N(N \cdot L) - L) \cdot V)^n$$

- In color, reflectance is:

$$I_{observed,l_i} = K I_{l_i}(N \cdot L) + k_s I_{l_i}((2N(N \cdot L) - L) \cdot V)^n$$

Real-world Reflectance

- Does hybrid reflectance describe real-worl objects?
  - Yes, for shiny objects (seemingly)
  - Yes, for perfectly matte objects (but these are rare)
  - No, for surface materials in the middle



(a) is a photograph of a clay mug, while (b) is a Lambertian rendering
from Oren & Nayar, "Generalization of the Lambertian Model and Implications for Machine Vision," IJCV, 14(3):227-251, 1995.

Surface-specific Models

- The problem is that Lambertian assumes a perfectly random micro-surface, while real surfaces may have dominant orientations, larger facets, etc.
- Nayar (and Koeenderink) are developing more complex surface models, and building tables of surface constant values for common surface types
- Such tables already exist for Phong constants

Bi-directional Reflectance Functions

- BDRF's are an empirical mapping from lighting angle (θ_i) and (θ_r) to a scalar k
  - Take surface into laboratory, sample all lighting and viewing directions

$$I_{observed,l_i} = I_{l_i} BDRF(L \cdot N, V \cdot N)$$

  - In color, BDRF(θ_I, θ_r) returns a matrix…

(from Oren & Nayar, as before)

BDRF's