Illumination Models

Things to Model

Light sources
- What color, intensity, lines through space

Reflection of light off surfaces
- How much light reflected in each direction
    - How are color and intensity changed

Real Lights

Real lights are complicated
- Sun light, iridescent bulbs, fluorescent bulbs
- Different spectra in different directions
    - probably time-varying as well, but we don't perceive much of that

Simpler Light Models

- **Point lights**
- **Directional lights**
- **Spot (Warn) lights**
- **Area lights (not really so simple)**

Real Reflection

Again, pretty complicated
- May be described by bidirection reflectance distribution function (BRDF)
- BRDF is 5D function
    - 2D for incoming light direction
    - 2D for outgoing light direction
    - 1D for wavelength of light

Simpler Reflection Models

Phong illumination

Cook and Torrance illumination

Life on a Surface

L: direction to light
N: normal vector
R: reflection of light about normal
V: direction to viewer (i.e. reflection direction of interest)

Point Light

point light

Specified by:

- **position (x,y,z)**
- **intensity (r,g,b)**

Radiates equal intensity in all directions

$$L = P_{light} - P_{surface}$$

Directional Light

point light at infinity

Point light at infinity

Specified by:

- **direction (x,y,z)**
- **intensity (r,g,b)**

All light rays are parallel

L = -direction

Spot (Warn) Light

reflector

point light

Specular reflection of point light source

Specified by:

- **position of reflector**
- **position of point light (or direction to point light)**
- **intensity of point light**
- **falloff exponent**

$$I_{warn} = I_{point}\cos^p\gamma = I_{point}(V'.R')^p = I_{point}(-L.L')^p$$

Warn Light (cont.)

Also possible to truncate region of effect

- **flaps**
- **cone (used in OpenGL spotlight)**

Warn Light Profile and Examples

From Foley, vanDam, Feiner, and Hughes, **Computer Graphics: Principles and Practice, 2nd edition, page 732, 733**

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Phong Illumination

Empirically divides reflection into 3 components

- **Ambient**
- **Diffuse (Lambertian)**
- **Specular**

Ambient Light

Independent of location of viewer, location of light, and curvature of surface

$$I = I_a k_a$$

- I_a **is intensity of ambient light**
- k_a **is ambient coefficient of surface**

Note: this is a total hack, of course

Diffuse Reflection

Component of reflection due to even scattering of light by uniform, rough surfaces

Depends on direction of light and surface normal

$$I_d = I_p(L.N)$$

- I_p **is intensity of point light**

Important Note

When we write:

$$(N.L)$$

we often really **mean:**

$$max(N.L , 0)$$

- **The latter computes 1-sided lighting**
- **For 2-sided lighting, use:**

$$abs(N.L)$$

Diffuse Reflection Examples

Fig. 16.3 Spheres shaded using a diffuse-reflection model (Eq. 16.4). For all spheres, I_p = 1.0. From left to right, k_d = 0.4, 0.55, 0.7, 0.85, 1.0. (By David Kurlander, Columbia University.)
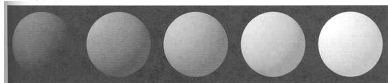

Fig. 16.4 Spheres shaded using ambient and diffuse reflection (Eq. 16.5). For all spheres, $I_a = I_p$ = 1.0, k_d = 0.4. From left to right, k_a = 0.0, 0.15, 0.30, 0.45, 0.60. (By David Kurlander, Columbia University.)

From Foley, vanDam, Feiner, and Hughes, **Computer Graphics: Principles and Practice, 2nd edition, page 725**

Specular Reflection

Component of reflection due to mirror-like reflection off shiny surface

Depends on perfect reflection direction, viewer direction, and surface normal

$$I_s = I_p(R.V)^n$$

- **n is specular exponent, determining falloff rate**
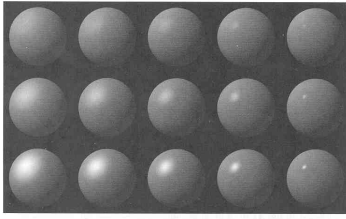
Phong Illumination Example

Fig. 16.10 Spheres shaded using Phong's illumination model (Eq. 16.14) and different values of k_s and n. For all spheres, $I_a = I_p = 1.0$, $k_a = 0.1$, $k_d = 0.45$. From left to right, $n = 3.0, 5.0, 10.0, 27.0, 200.0$. From top to bottom, $k_s = 0.1, 0.25, 0.5$. (By David Kurlander, Columbia University.)

From Foley, vanDam, Feiner, and Hughes, **Computer Graphics: Principles and Practice, 2nd edition, page 730**

Illumination with Color

Surface reflection coefficients and light intensity may vary by wavelength

For RGB color

- **Light intensity specified for R, G, and B**
- **Surface reflection coefficients also for R, G, B**
- **Compute reflected color for R, G, and B**

Cook and Torrance Illumination

**Replace specular component with more physically accurate model**

$$\rho_s = F_\lambda DG/\pi[(N.V)(N.L)]$$

- **F_λ is Fresnel term, which accounts for change of highlight color with respect to angle of incidence**
- **D is microfacet distribution term, for more accurate measurement specular reflection off tiny microfacets**
- **G is geometry term, which models self-shadowing effects**

Phong vs. Cook/Torrance Example
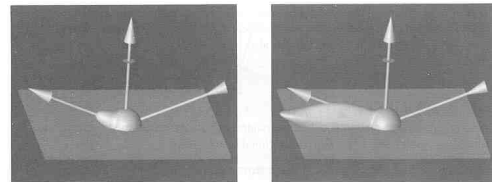
(a) Phong model   (b) Torrance-Sparrow model

Fig. 16.44 Comparison of Phong and Torrance–Sparrow illumination models for light at a 70° angle of incidence. (By J. Blinn [BLIN77a], courtesy of the University of Utah.)

From Foley, vanDam, Feiner, and Hughes, **Computer Graphics: Principles and Practice, 2nd edition, page 768**