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

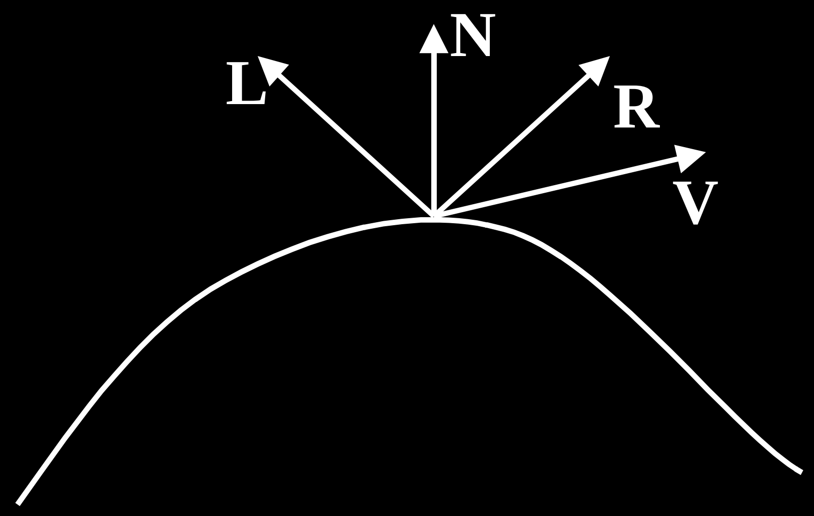
Simpler Reflection Models

Phong illumination

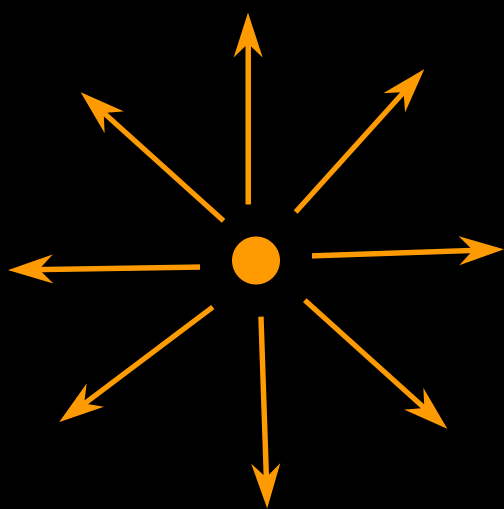
Cook and Torrance illumination

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:

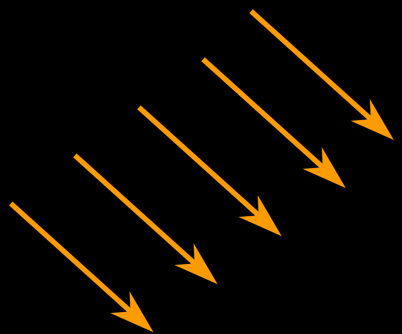
- **position (x,y,z)**
- **intensity (r,g,b)**

Radiates equal intensity in all directions

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

Directional Light

- point light at infinity



Point light at infinity

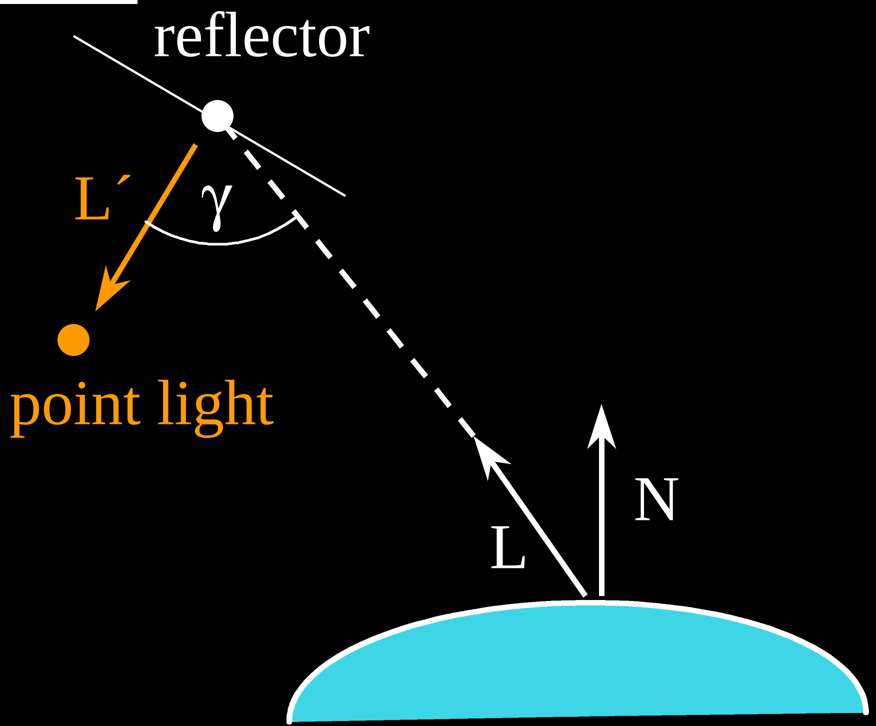
Specified by:

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

All light rays are parallel

L = -direction

Spot (Warn) Light



Specular reflection of point light source

Specified by:

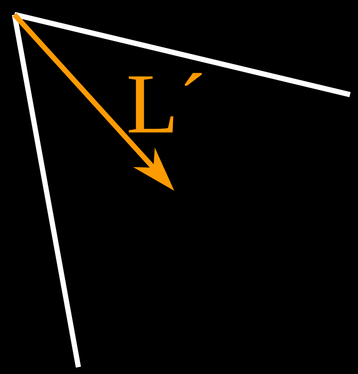
- **position of reflector**
- **position of point light (or direction to point light)**
- **intensity of point light**
- **falloff exponent**

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

Warn Light (cont.)

Also possible to truncate region of effect

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



Warn Light Profile and Examples

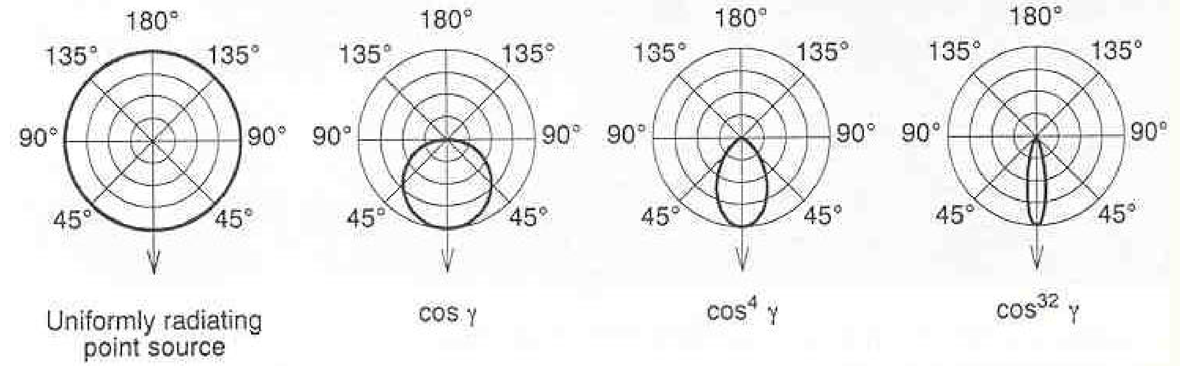


Fig. 16.14 Intensity distributions for uniformly radiating point source and Warn light source with different values of *p*.

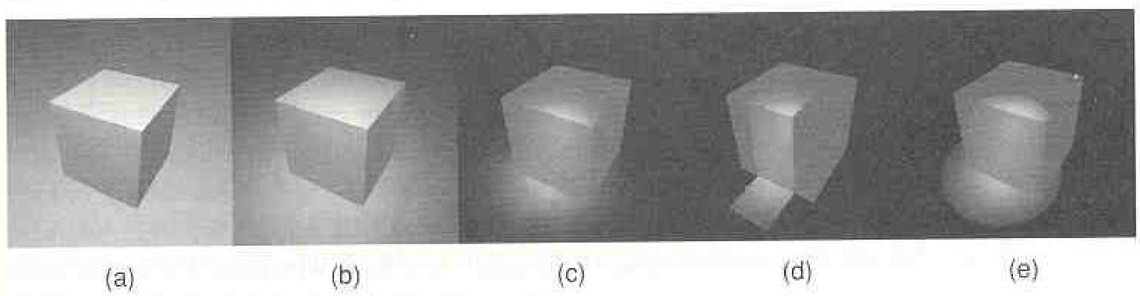


Fig. 16.15 Cube and plane illuminated using Warn lighting controls. (a) Uniformly radiating point source (or $p = 0$). (b) $p = 4$. (c) $p = 32$. (d) Flaps. (e) Cone with $\delta = 18°$. (By David Kurlander, Columbia University.)

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

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

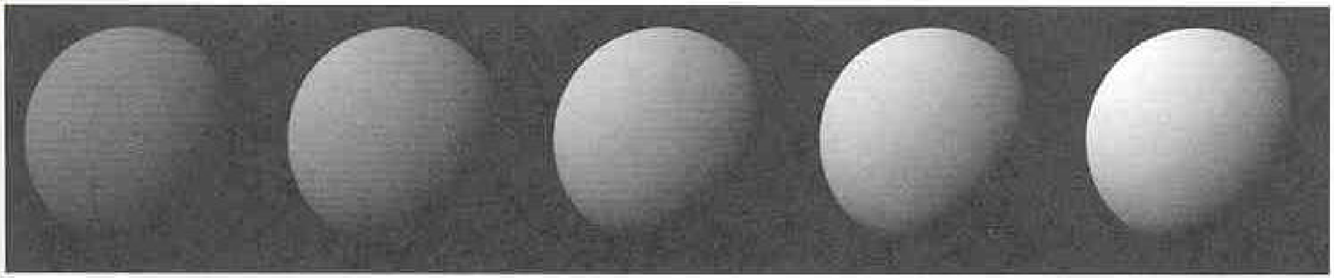


Fig. 16.3 Spheres shaded using a diffuse-reflection model (Eq. 16.4). For all spheres, $I_p = 1.0$. From left to right, $k_d = 0.4, 0.55, 0.7, 0.85, 1.0$. (By David Kurlander, Columbia University.)

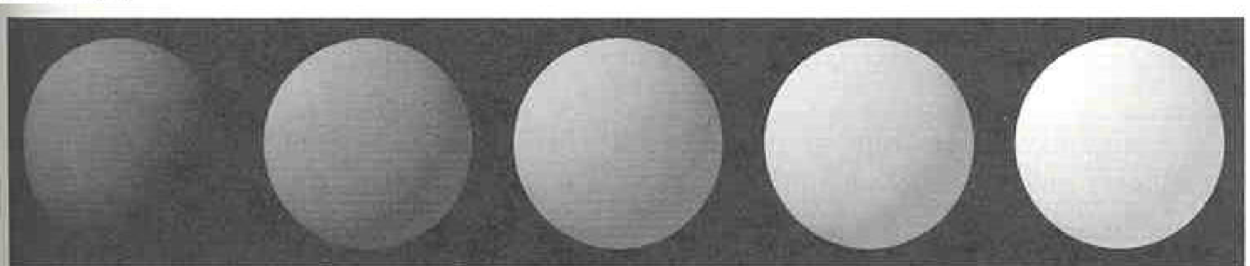


Fig. 16.4 Spheres shaded using ambient and diffuse reflection (Eq. 16.5). For all spheres, $I_a = I_p = 1.0$, $k_d = 0.4$. From left to right, $k_a = 0.0, 0.15, 0.30, 0.45, 0.60$. (By David Kurlander, Columbia University.)

***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

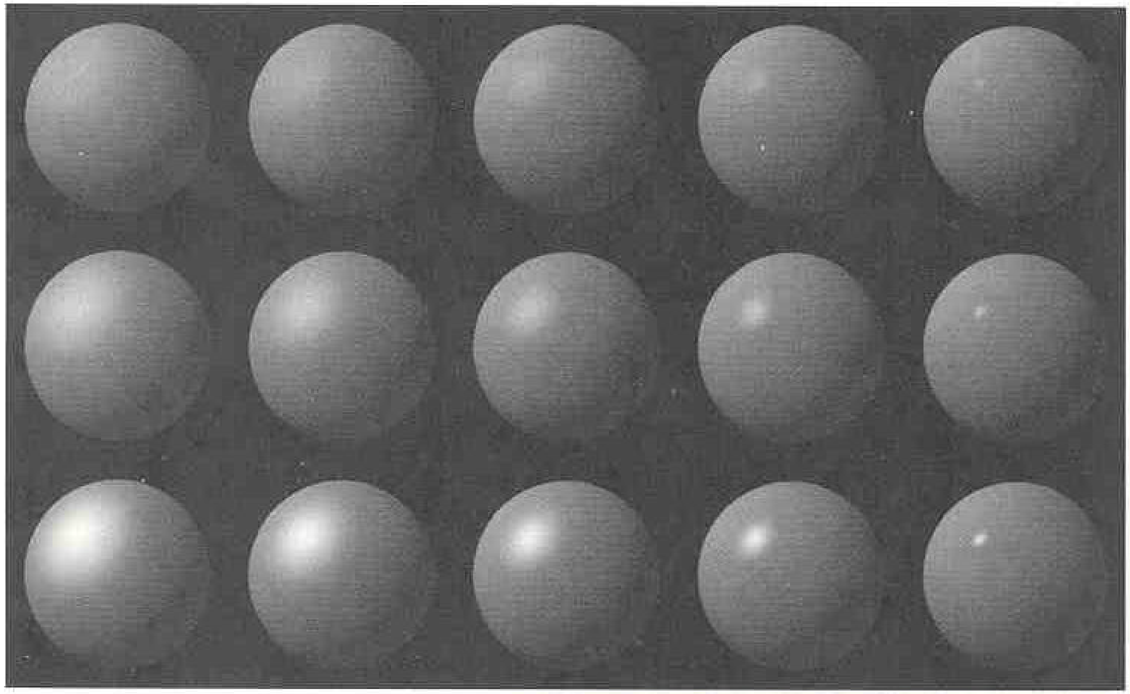


Fig. 16.10 Spheres shaded using Phong's illumination model (Eq. 16.14) and different values of k_s and n. For all spheres, $I_a = I_p = 1.0$, $k_a = 0.1$, $k_d = 0.45$. From left to right, n = 3.0, 5.0, 10.0, 27.0, 200.0. From top to bottom, k_s = 0.1, 0.25, 0.5. (By David Kurlander, Columbia University.)

***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

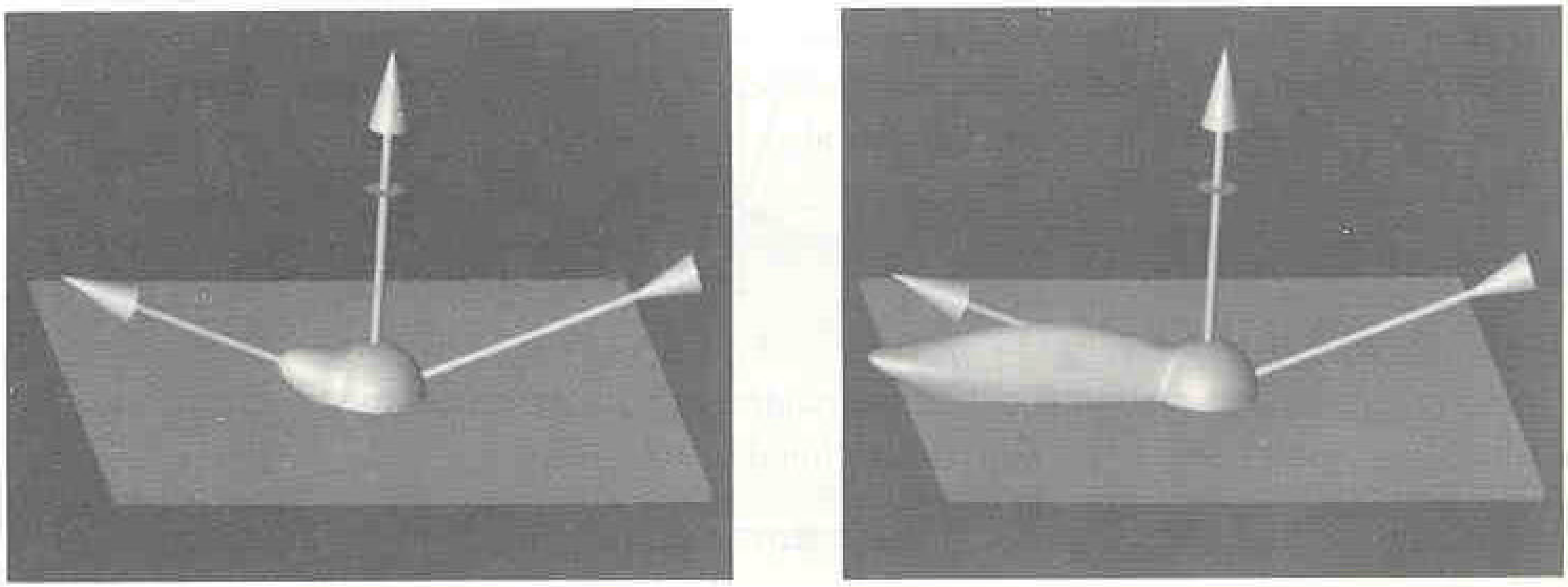
Cook and Torrance Illumination

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**