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

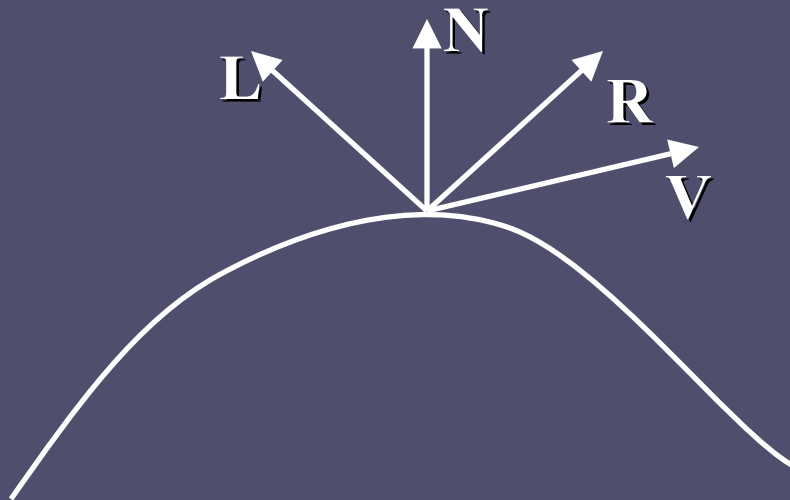Phong illumination

Cook and Torrance illumination

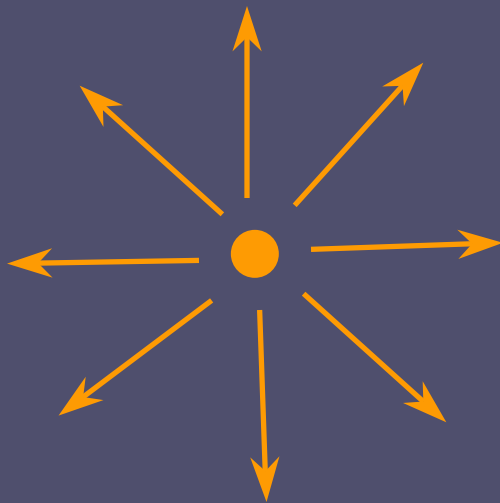# Life on a Surface

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

Specified by:

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

Radiates equal intensity in all directions

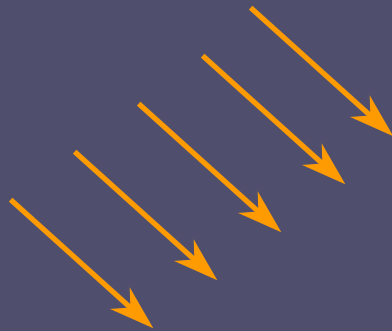$$L = P_{light} - P_{surface}$$

point light

Directional Light

- point light at infinity

Point light at infinity

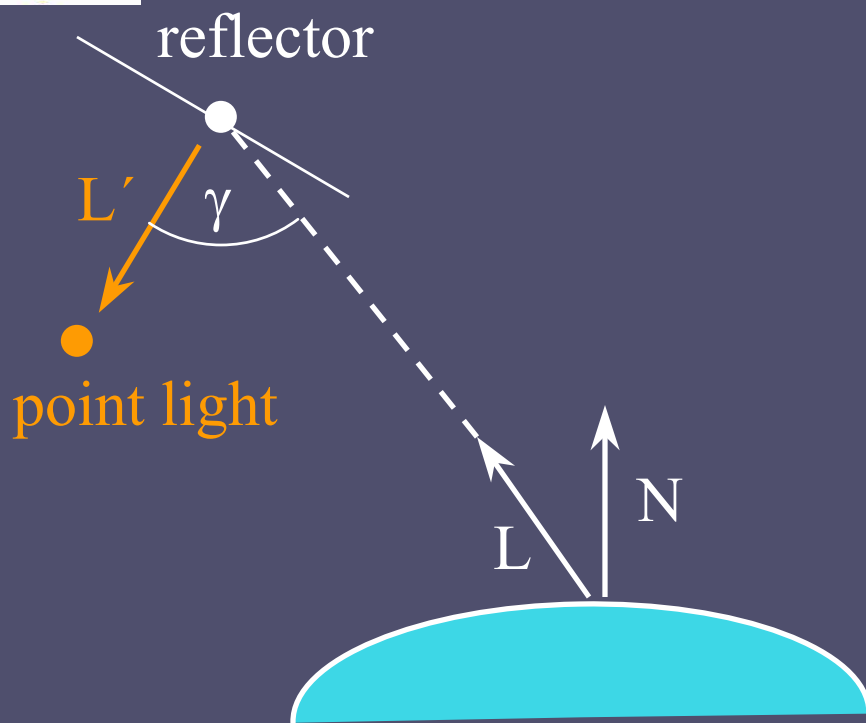**Specified by:**

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

All light rays are parallel

L = -direction

Spot (Warn) Light

reflector

L´ γ

point light

L   N

Specular reflection of point light source

Specified by:

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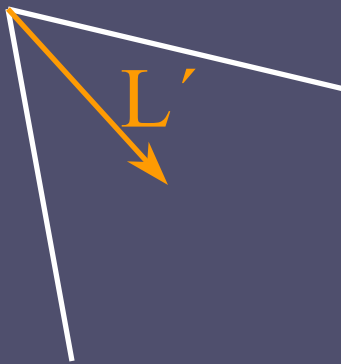- **intensity of point light**
- **falloff exponent**

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

Warn Light (cont.)

Also possible to truncate region of effect

- flaps

- cone (used in OpenGL spotlight)
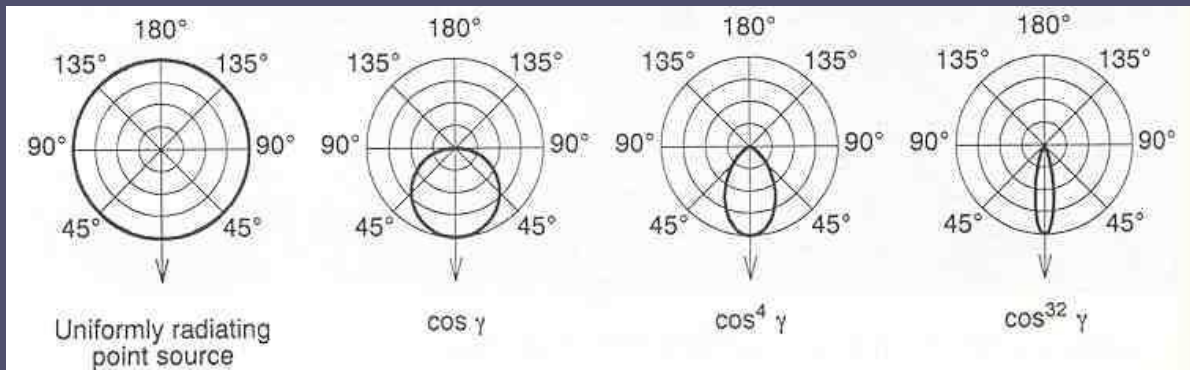
$L´$

Warn Light Profile and Examples

Fig. 16.14 Intensity distributions for uniformly radiating point source and Warn light source with different values of *p*.
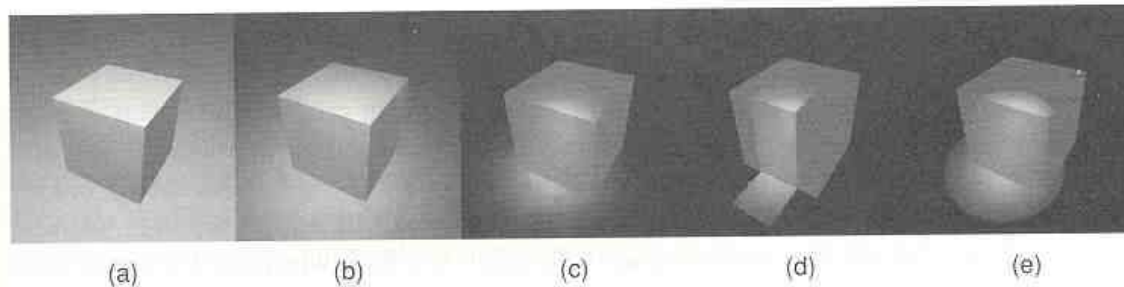
Fig. 16.15 Cube and plane illuminated using Warn lighting controls. (a) Uniformly radiating point source (or *p* = 0). (b) *p* = 4. (c) *p* = 32. (d) Flaps. (e) Cone with δ = 18°. (By David Kurlander, Columbia University.)

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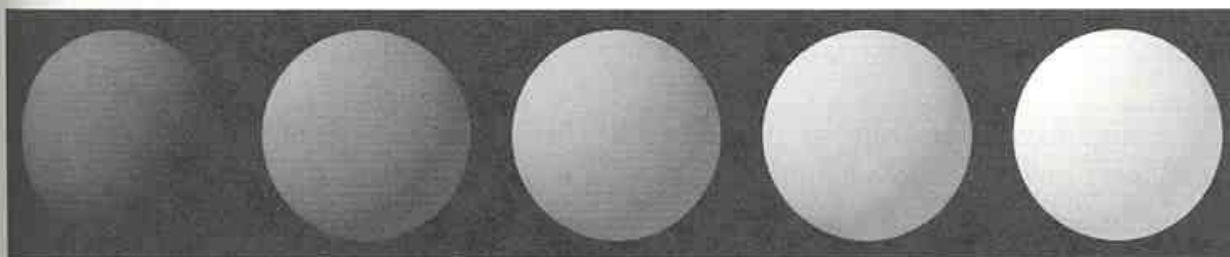
Fig. 16.4 Spheres shaded using ambient and diffuse reflection (Eq. 16.5). For all spheres, $I_a = I_p$ = 1.0, k_d = 0.4. From left to right, k_a = 0.0, 0.15, 0.30, 0.45, 0.60. (By David Kurlander, Columbia University.)

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
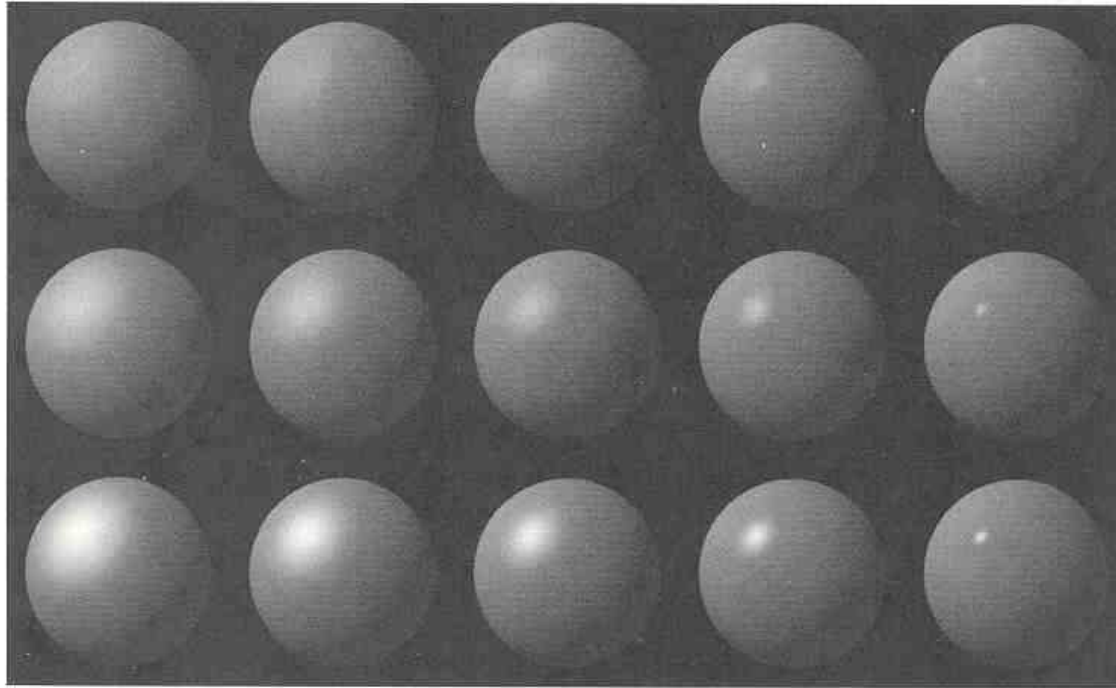
Phong Illumination Example

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**
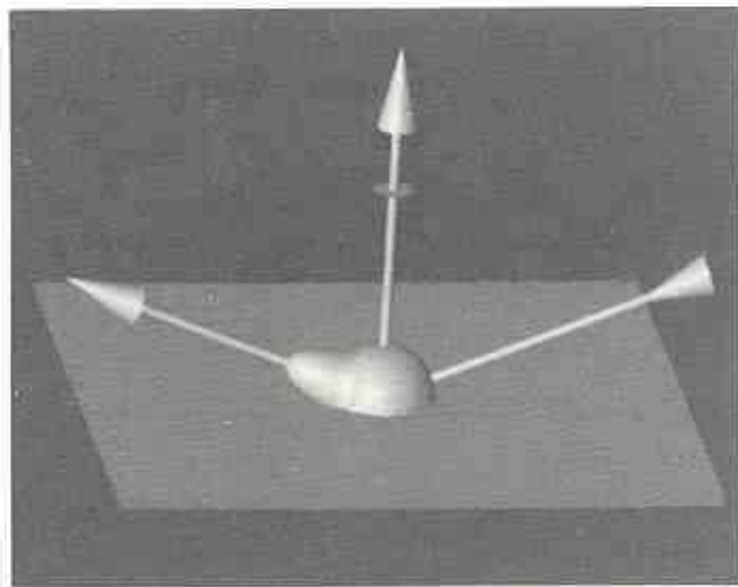
Cook and Torrance Illumination

Replace specular component with more physically accurate model
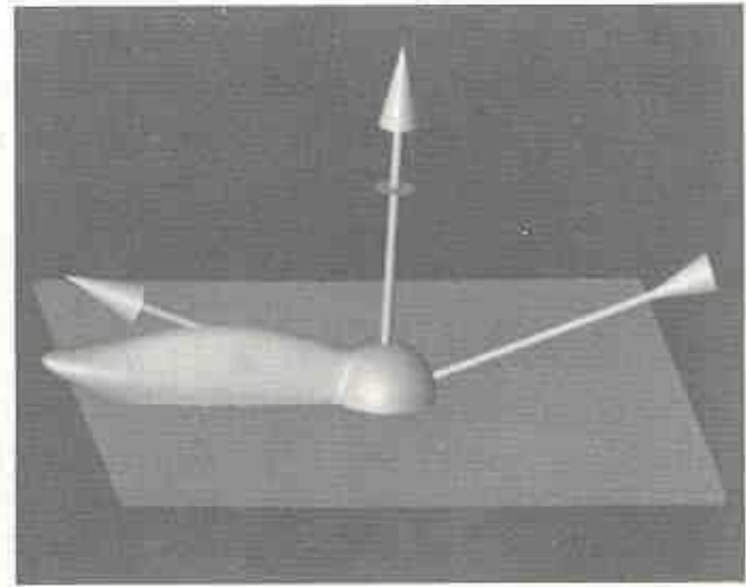
$$\rho_s = F_\lambda DG / \pi [(N.V)(N.L)]$$

- 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**