Illumination

CSU44052 Computer Graphics

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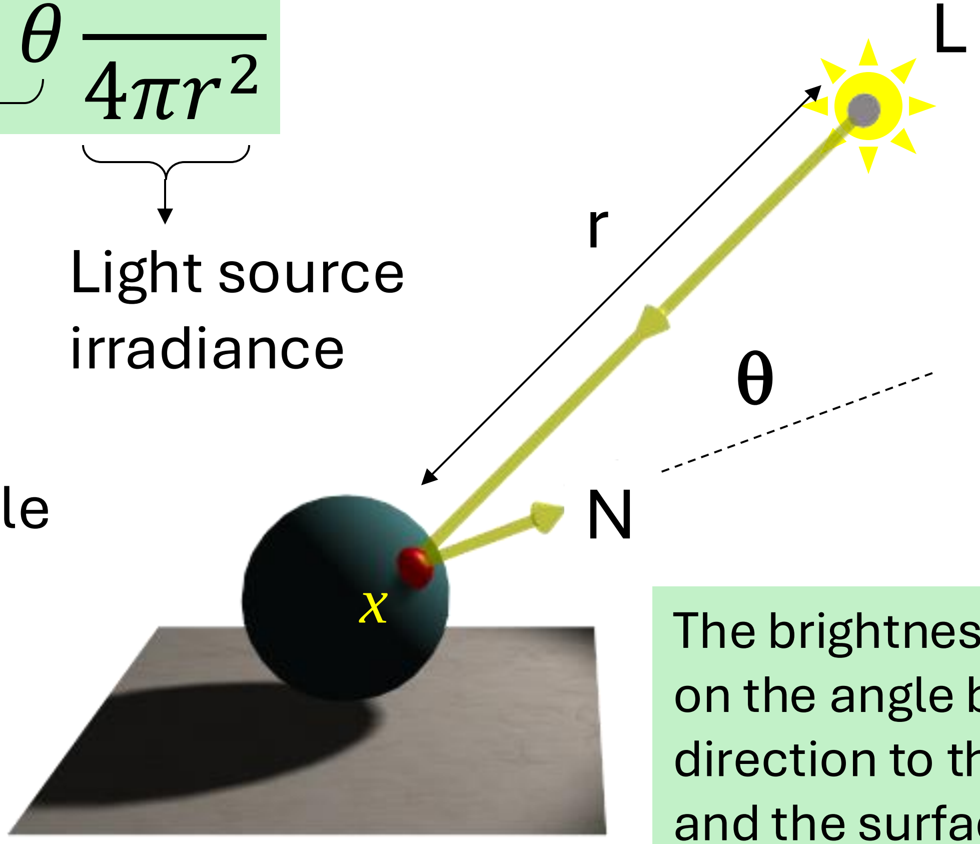
Lambertian Illumination Model

The contribution from a single source is given by:

$$\underbrace{L(x,\cdot)}_{\text{Reflected radiance}} = \underbrace{\frac{\rho_d}{\pi}}_{\text{BRDF}} \underbrace{\cos\theta}_{\text{cosine rule}} \underbrace{\frac{\Phi}{4\pi r^2}}_{\text{Light source irradiance}}$$

outgoing direction (can be any)



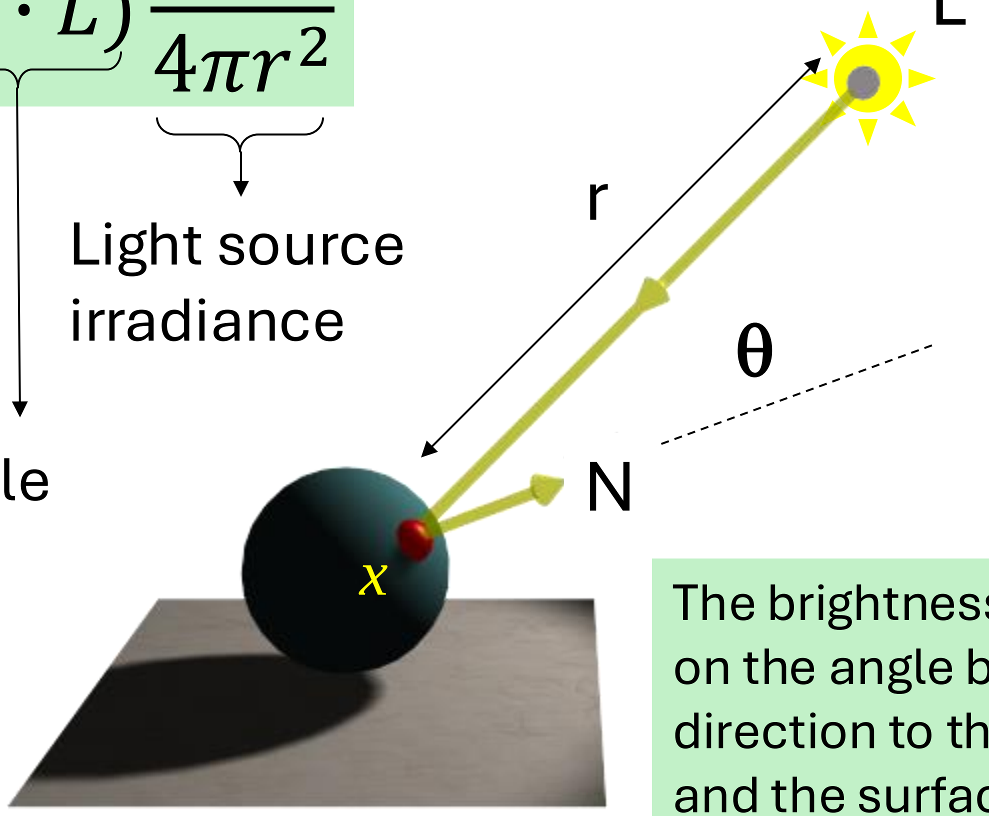
The brightness depends only on the angle between the direction to the light source and the surface normal

Lambertian Illumination Model

The contribution from a single source is given by:

$$\underbrace{L(x,\cdot)}_{\text{Reflected radiance}} = \underbrace{\frac{\rho_d}{\pi}}_{\text{BRDF}} \underbrace{(N \cdot L)}_{\text{cosine rule}} \underbrace{\frac{\Phi}{4\pi r^2}}_{\text{Light source irradiance}}$$

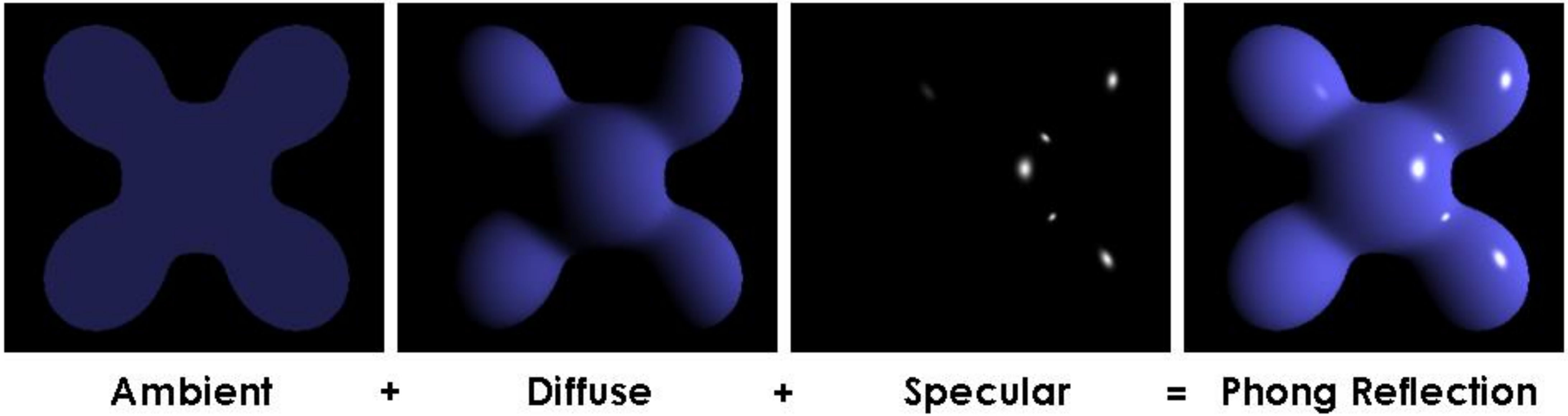
outgoing direction (can be any)



The brightness depends only on the angle between the direction to the light source and the surface normal

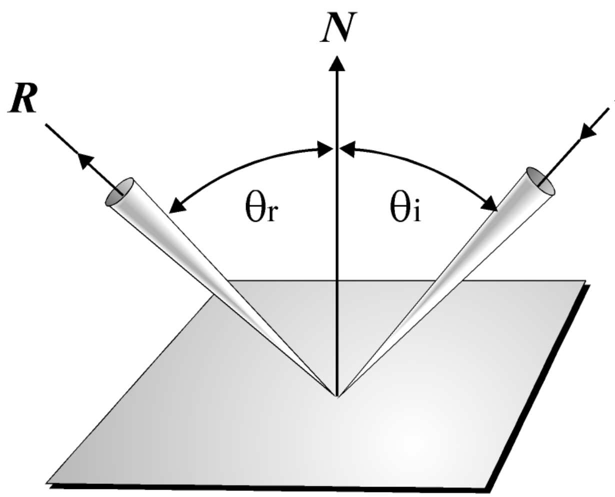
Phong Illumination Model

- The Phong illumination model includes
  - Lambertian model for diffuse reflection
  - Cosine lobe for specular reflection
  - Ambient term to approximate all other light

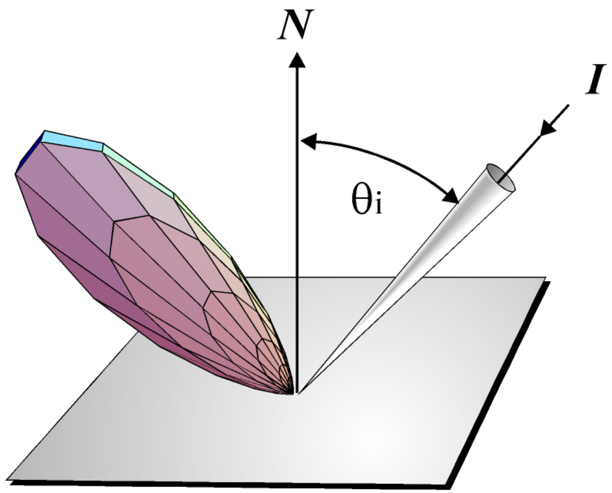


Specular Surfaces

- *Specular* surfaces exhibit a high degree of *coherence* in their reflectance, i.e. the reflected radiance depends very heavily on the outgoing direction.
  - An *ideal specular* surface is *optically smooth* (smooth even at resolutions comparable to the wavelength of light).
  - Most specular surfaces (rough specular) reflect energy in a tight distribution (or *lobe*) centered on the *optical reflection direction*:



Ideal Specular



Rough Specular

Modeling Reflections

- To simulate reflection we should examine surfaces in the reflected direction to determine incoming flux

  $\Rightarrow$*global illumination*

- A local illumination approximation considers only reflections of light sources.

- The Phong model is an *empirical* (based on observation) local model of shiny surfaces (tend to appear like plastic).

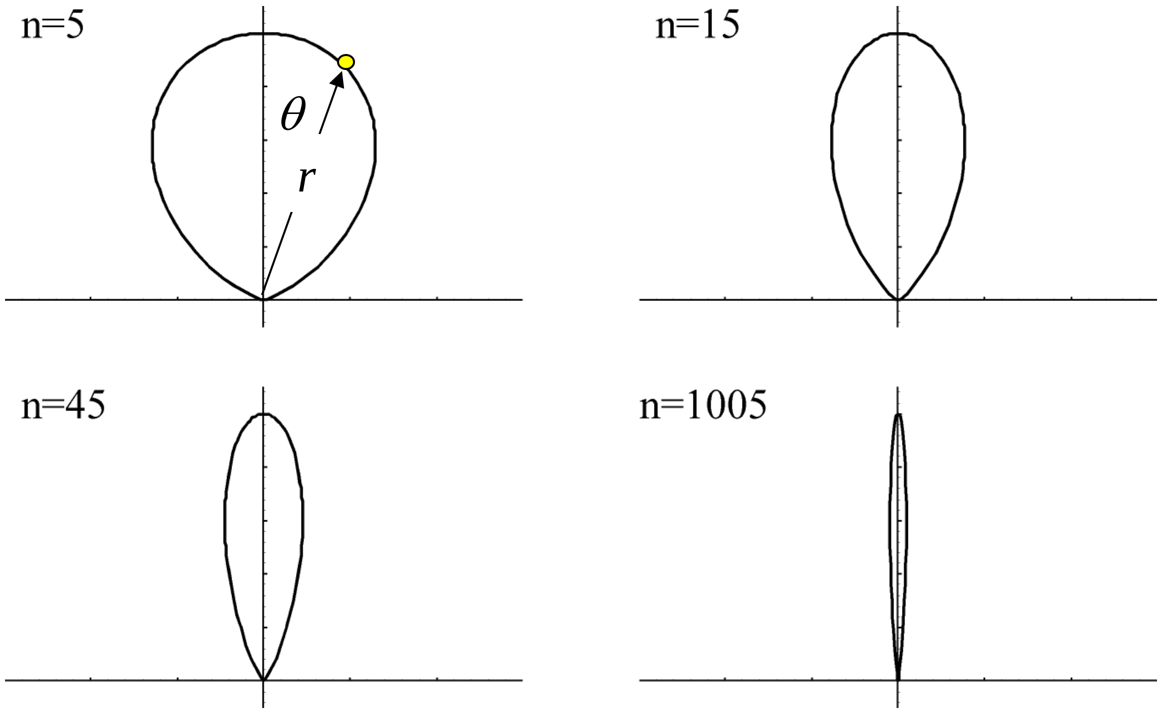
- It is assumed that the BRDF of such surfaces may be approximated by a *spherical cosine function* raised to a power (known as the *Phong exponent*).

The Cos^n Function

The cosine function gives us a lobe shape, that:

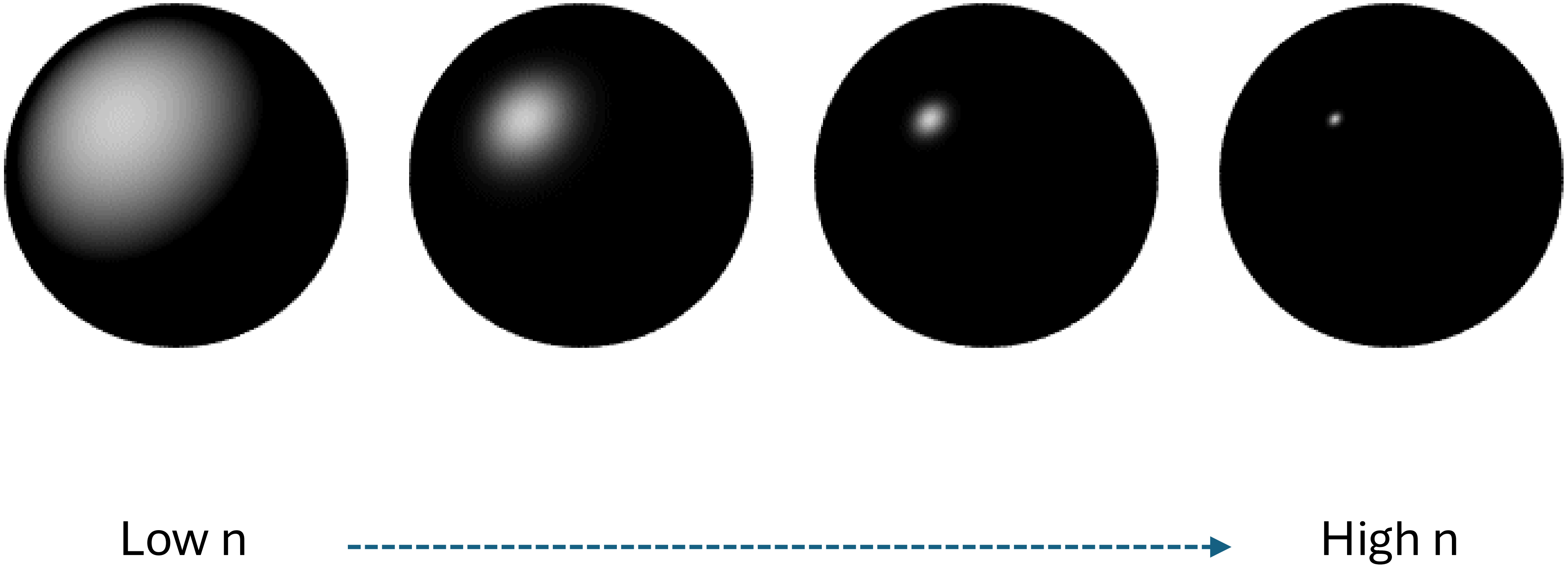
- approximates the distribution of energy about a reflected direction
- is controlled by the shininess parameter $\boldsymbol{n}$ -> the *Phong exponent*.

$$r = \cos^n \theta$$

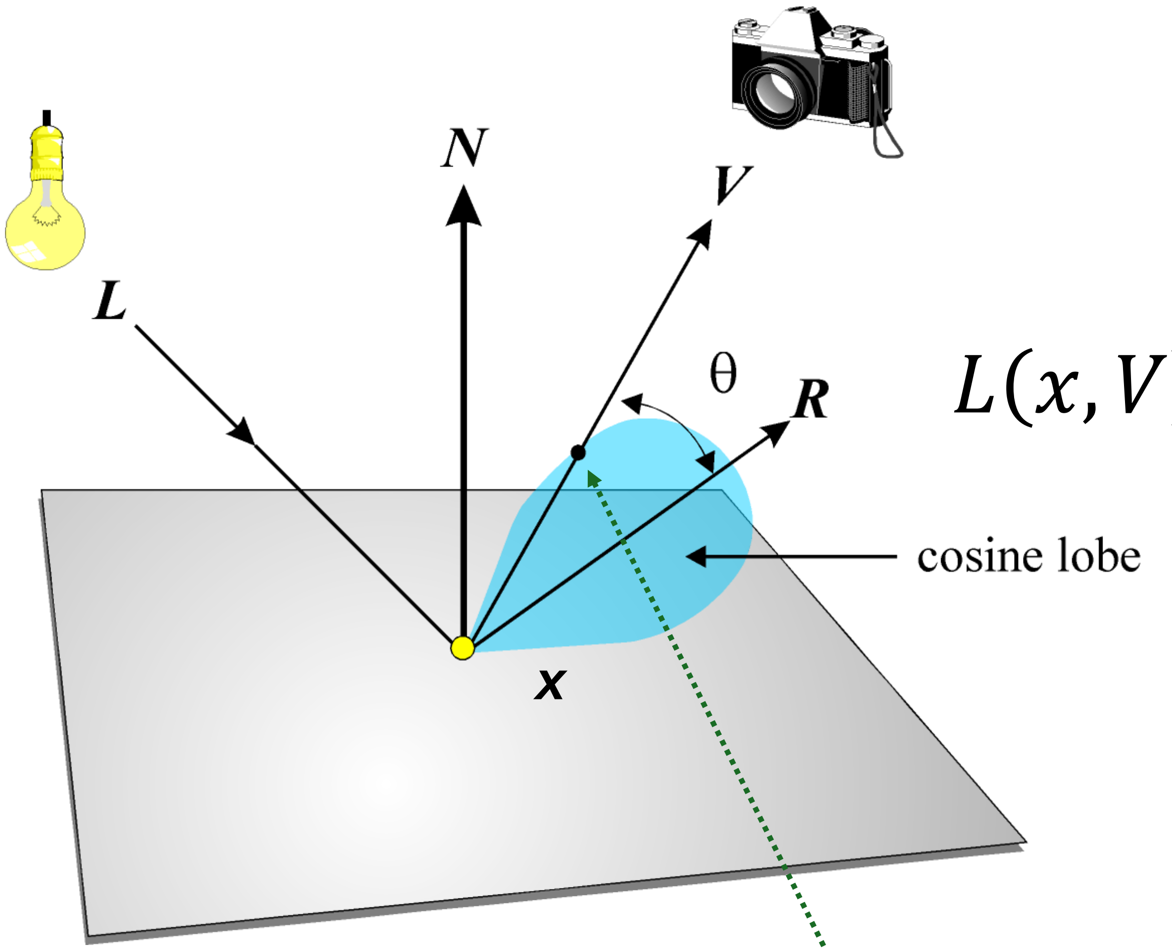


In the limit ($n \to \infty$) the function becomes a single spike (i.e. ideal specular).

The Cos^n Function



The Phong Reflection



specular reflectivity

light source irradiance

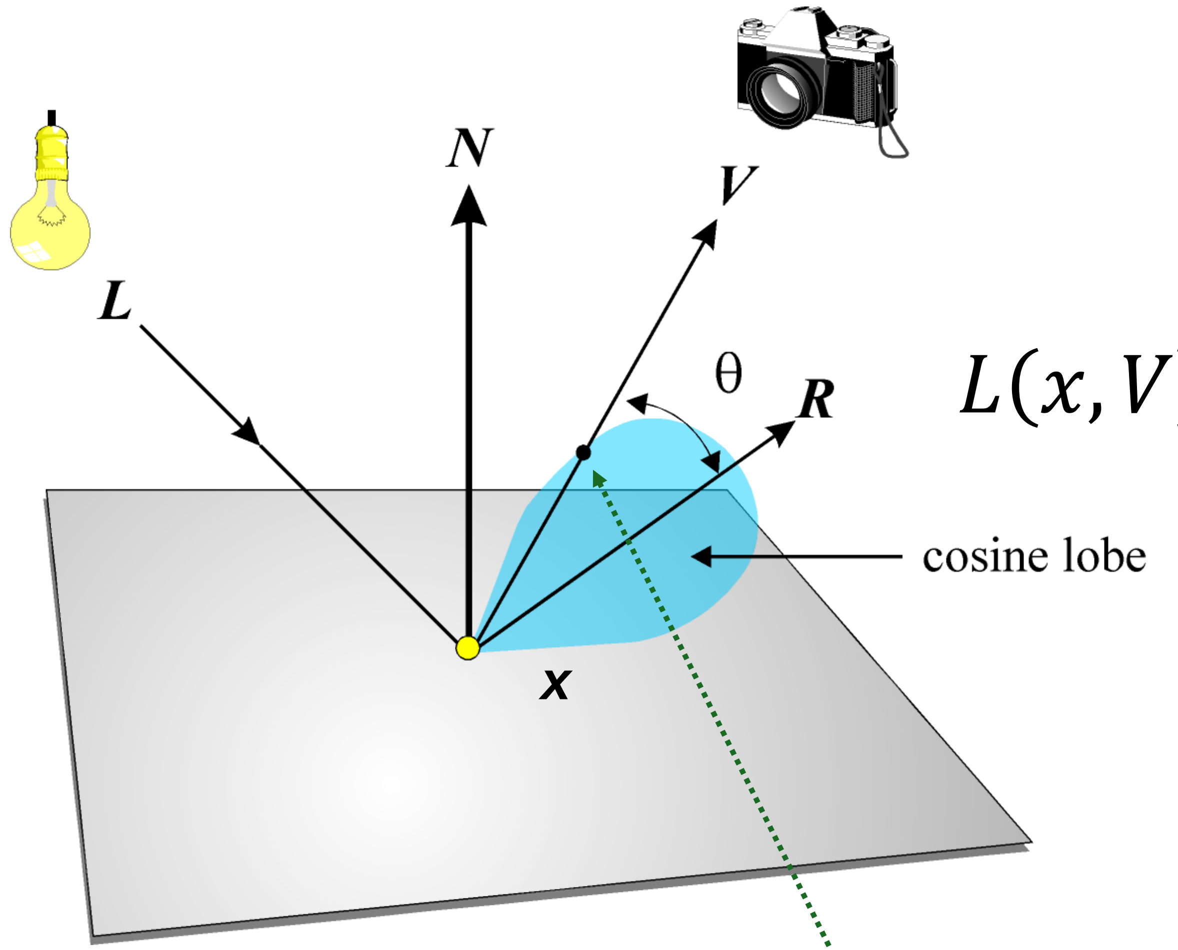
$$L(x,V) = \frac{n+2}{2\pi}\rho_s \cos^{n}\theta \, \frac{\Phi}{4\pi r^2}$$

Normalization term

cosine lobe

Radiance of reflected light given by the $\cos^n$ function

The Phong Reflection



specular reflectivity

light source irradiance

$$L(x,V) = \boxed{\frac{n+2}{2\pi}} \rho_s (V \cdot R)^n \frac{\Phi}{4\pi r^2}$$

Normalization term

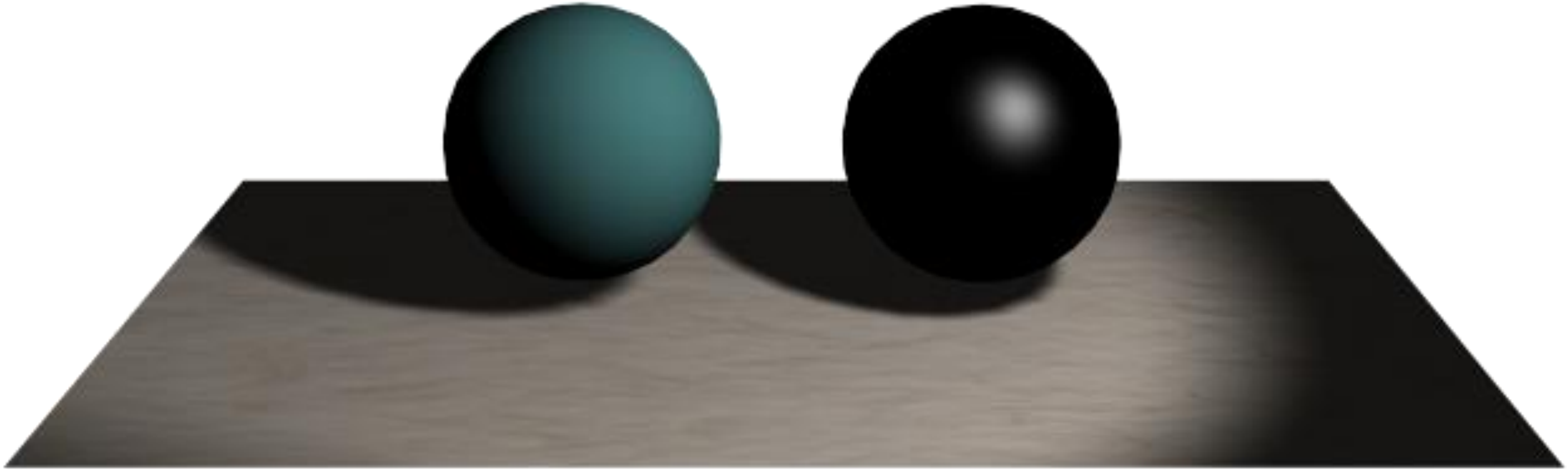
cosine lobe

Radiance of reflected light given by the $\cos^n$ function

Lambertian vs. Phong

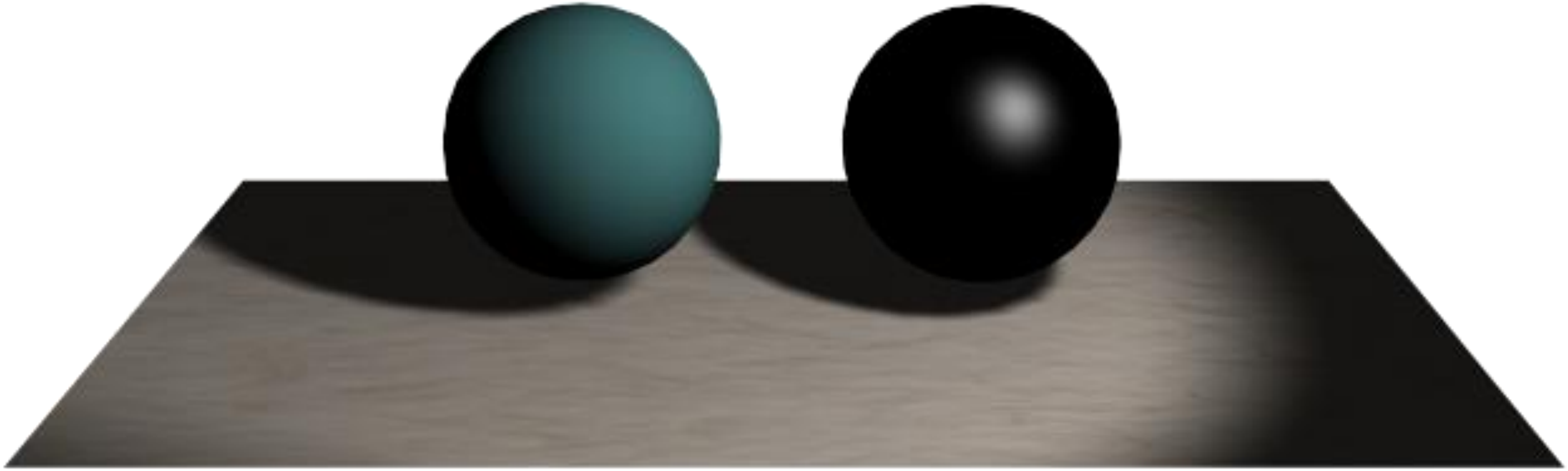
Lambertian
Surface

Phong Illuminated
Specular Surface



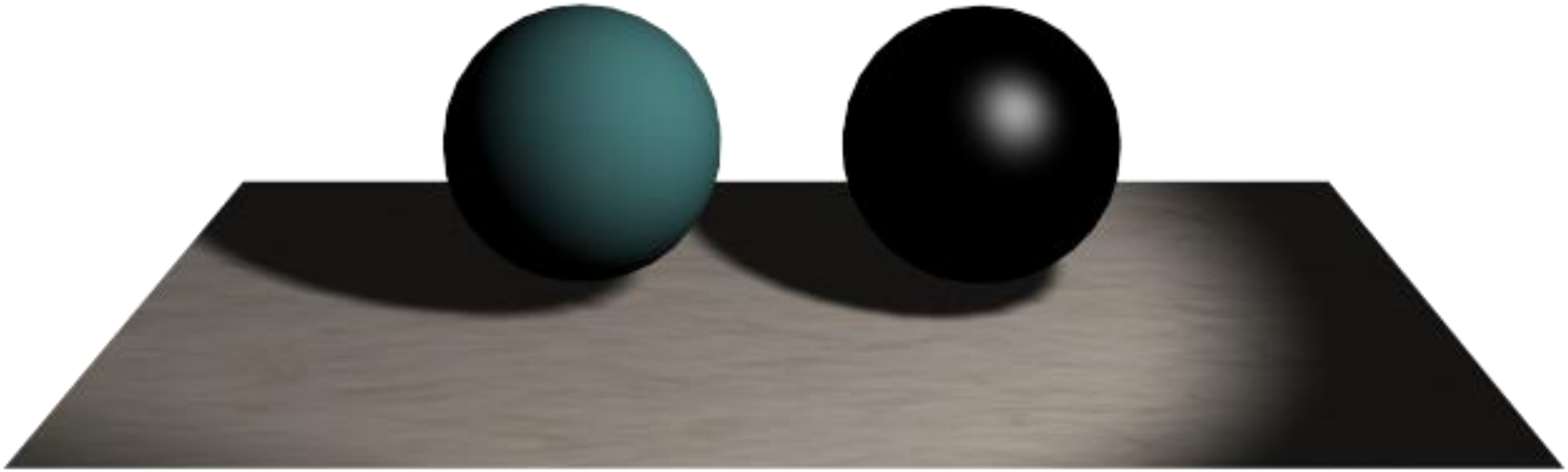
Lambertian vs. Phong

- Lambertian surfaces exhibit surface reflection <u>independent</u> of orientation and distance from viewer but not of the light source, leading to a matte appearance.



Lambertian vs. Phong

- Specular surfaces exhibit surface reflection, dependent on orientation and distance of both viewer and light source, leading to glossy appearance with highlights.



Ambient Illumination

- Local illumination account for light scattered from the light sources only.
- Light may be scattered from all surfaces in the scene. We can miss a lot of light.
- Ambient illumination is a coarse approximation to this missing flux.
- The ambient term is a constant everywhere in the scene.
- The ambient term is sometimes estimated from the total powers and geometries of the light sources.

light source irradiance

$$L(x,\cdot) = \rho_a E$$

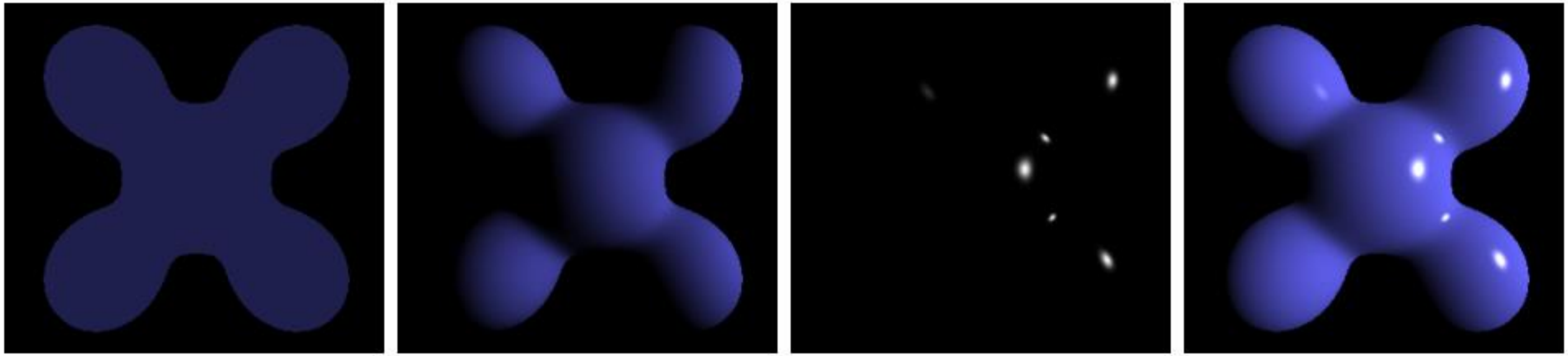
ambient reflectivity

$$L(x,\cdot) = \rho_a \frac{\Phi}{4\pi r^2}$$

Phong Illumination Model

- An object must therefore have material data associated with it to define how diffuse, specular (and shiny) or ambient it is.

$$\text{Surface Data} = \begin{cases} \rho_a = \text{ambient reflectance} \\ \rho_d = \text{diffuse reflectance} \\ \rho_s = \text{specular reflectance} \\ n = \text{phong exponent} \end{cases}$$



Phong Illumination Model

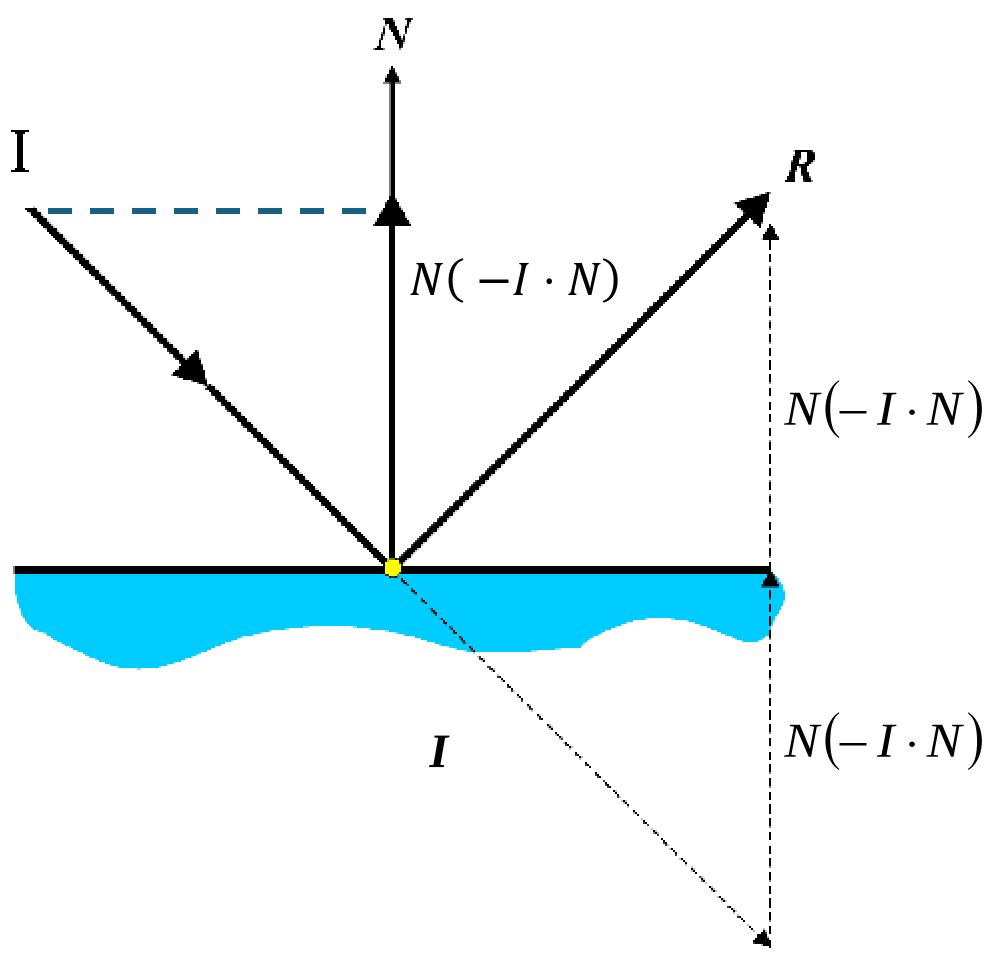
Ambient term + Diffuse term + Specular term

$$L(x,V) \ = L_a(x) + \ L_d(x) + L_s(x,V)$$

$$= \frac{\Phi}{4\pi r^2}[\rho_a + \rho_d(N \cdot L) + \rho_s(V \cdot R)^n]$$

- Ambient term not affected by light *L* or viewing angle *V*
- Diffuse term affected by light but not by viewing angle
- Specular term affected by viewing angle but not light
- For multiple light sources we compute illumination from each light and sum over their contributions.

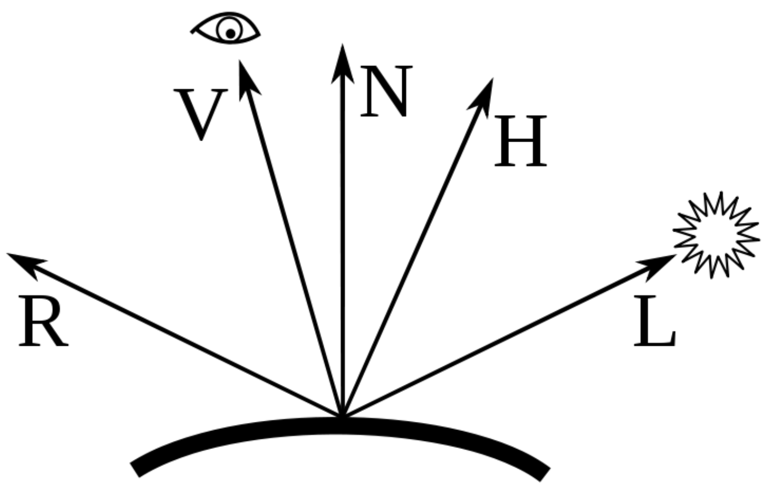
Determining the Reflected Vector



$$R = I + 2N(-I \cdot N)$$
$$= I - 2N(I \cdot N)$$

(-I . N) is the length of *I* projected onto *N*

Blinn-Phong



- Problem with computing the perfect reflection direction, R:
  - Normal N is different for every point on the surface, so must recompute R for every polygon – this is slow
- Jim Blinn proposed to use the *half vector H* in place of *R*:

$$H = \frac{V + L}{|V + L|}$$

- The specular term is:

$$(N \cdot H)^n$$

Half vector H is a vector with a direction half-way between the eye vector V and the light vector L

Blinn-Phong vs. Phong

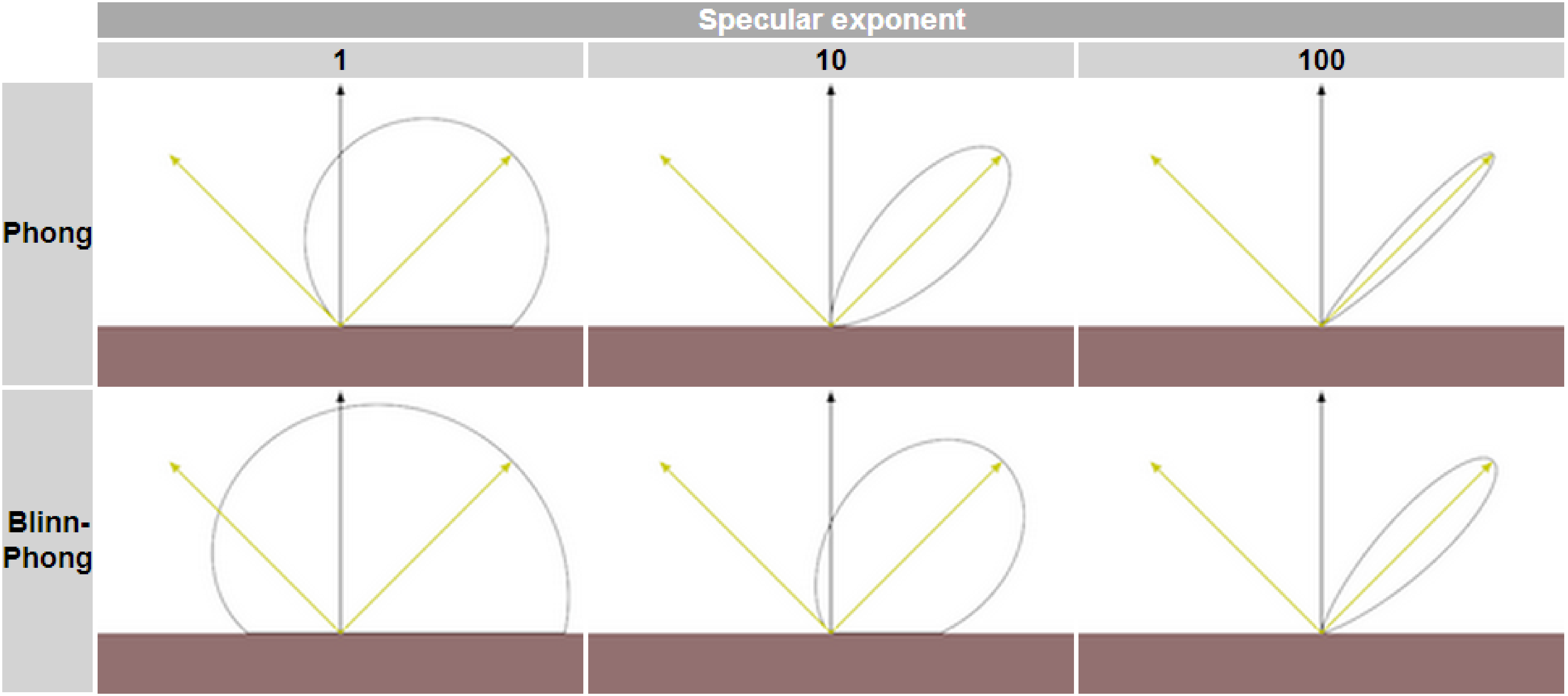
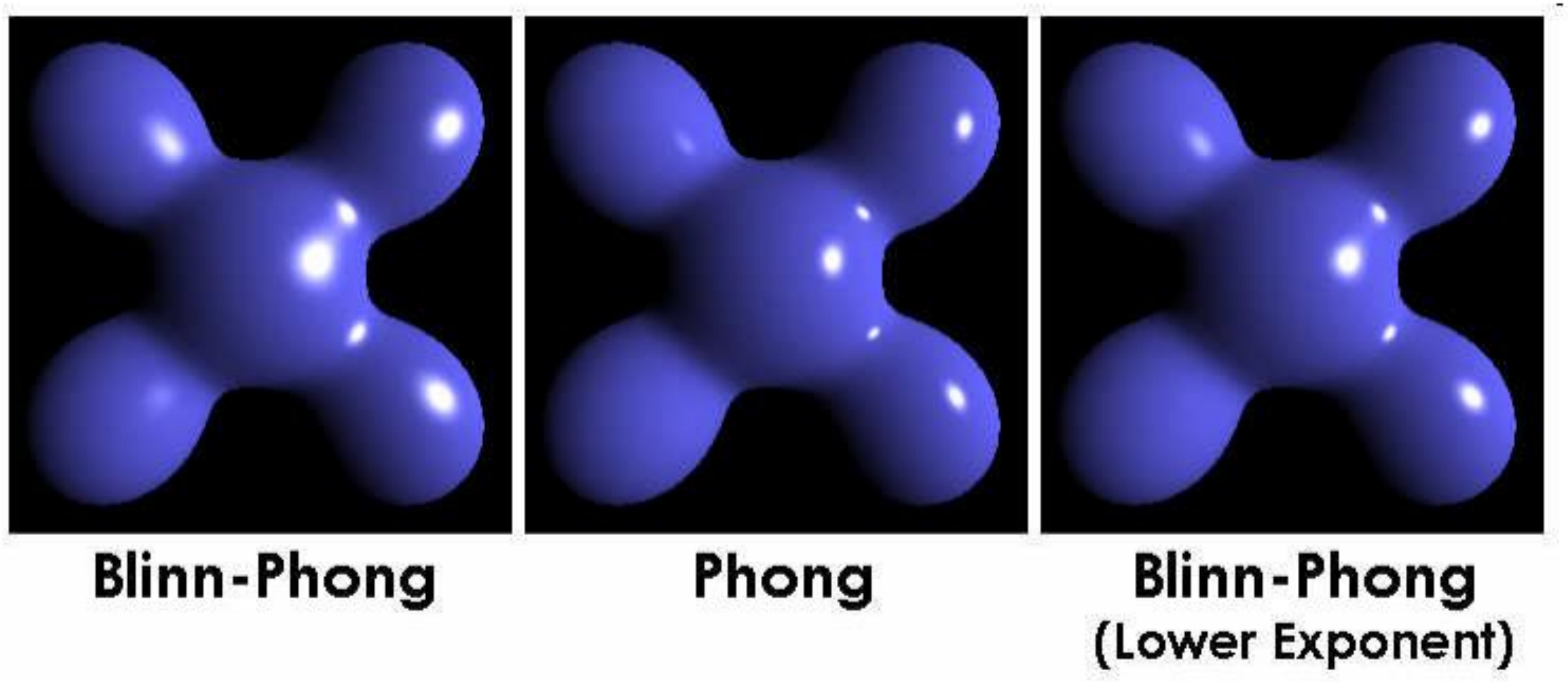


Figure 5: Phong vs Blinn-Phong With Varying Shininess Values.

Both the Phong and Blinn-Phong reflectance functions cause a highlight to appear around the direction of reflection. Blinn-Phong is cheaper to calculate, but appears more spread out at the same shininess.

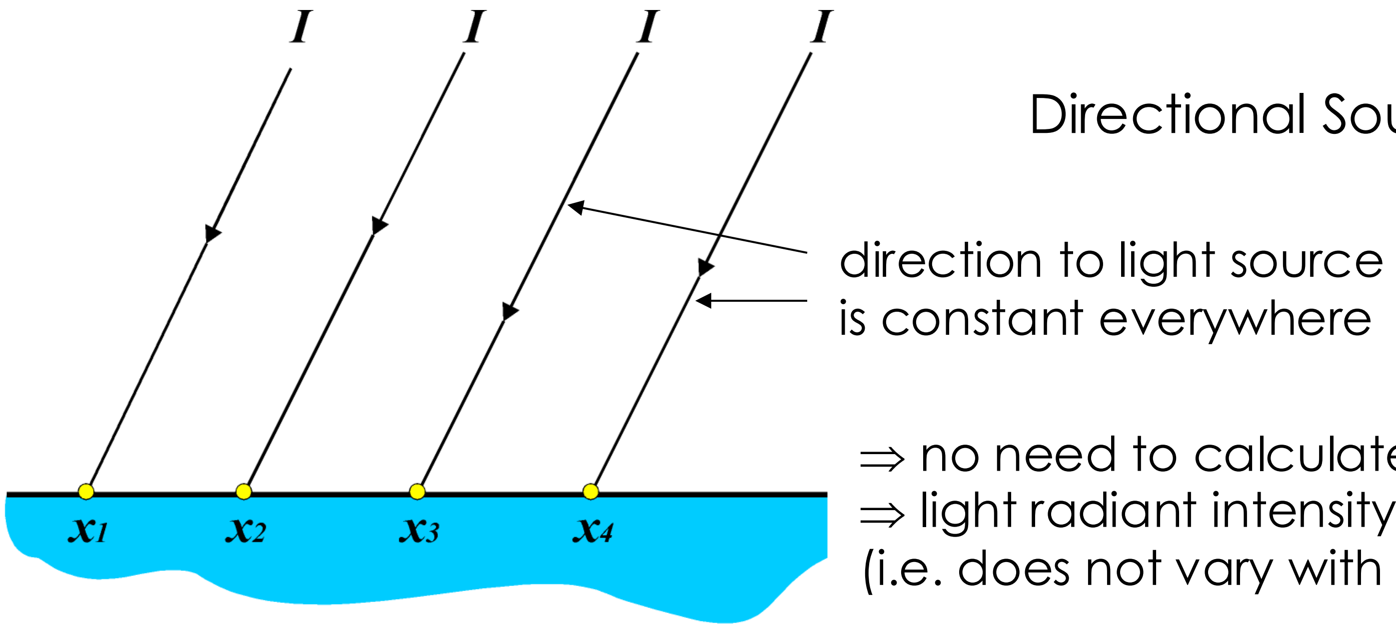
Approximating Phong

- Change the exponent so that the Blinn-Phong model matches Phong



Directional Light

- We can extend the functionality of the illumination model by admitting a number of other light source types:
- Directional light: the source is assumed to be at infinity and therefore is represented by a direction rather than a position.

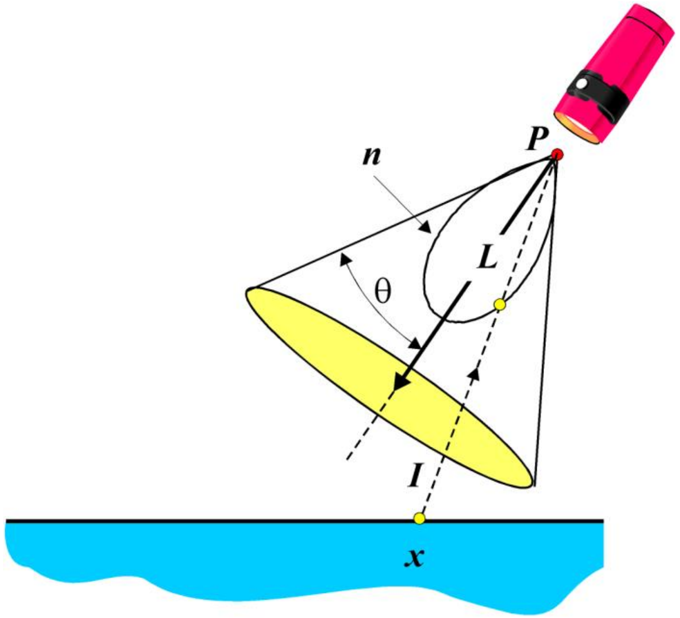


Directional Source

$\Rightarrow$ no need to calculate I for each x_i
$\Rightarrow$ light radiant intensity is constant
(i.e. does not vary with distance)

Spot Light

- Spot light can admit illumination only within a restricted solid angle. Originally proposed by Warn (1983),
- Defined by a *position*, a *direction*, a *cutoff angle* and an *exponent*.



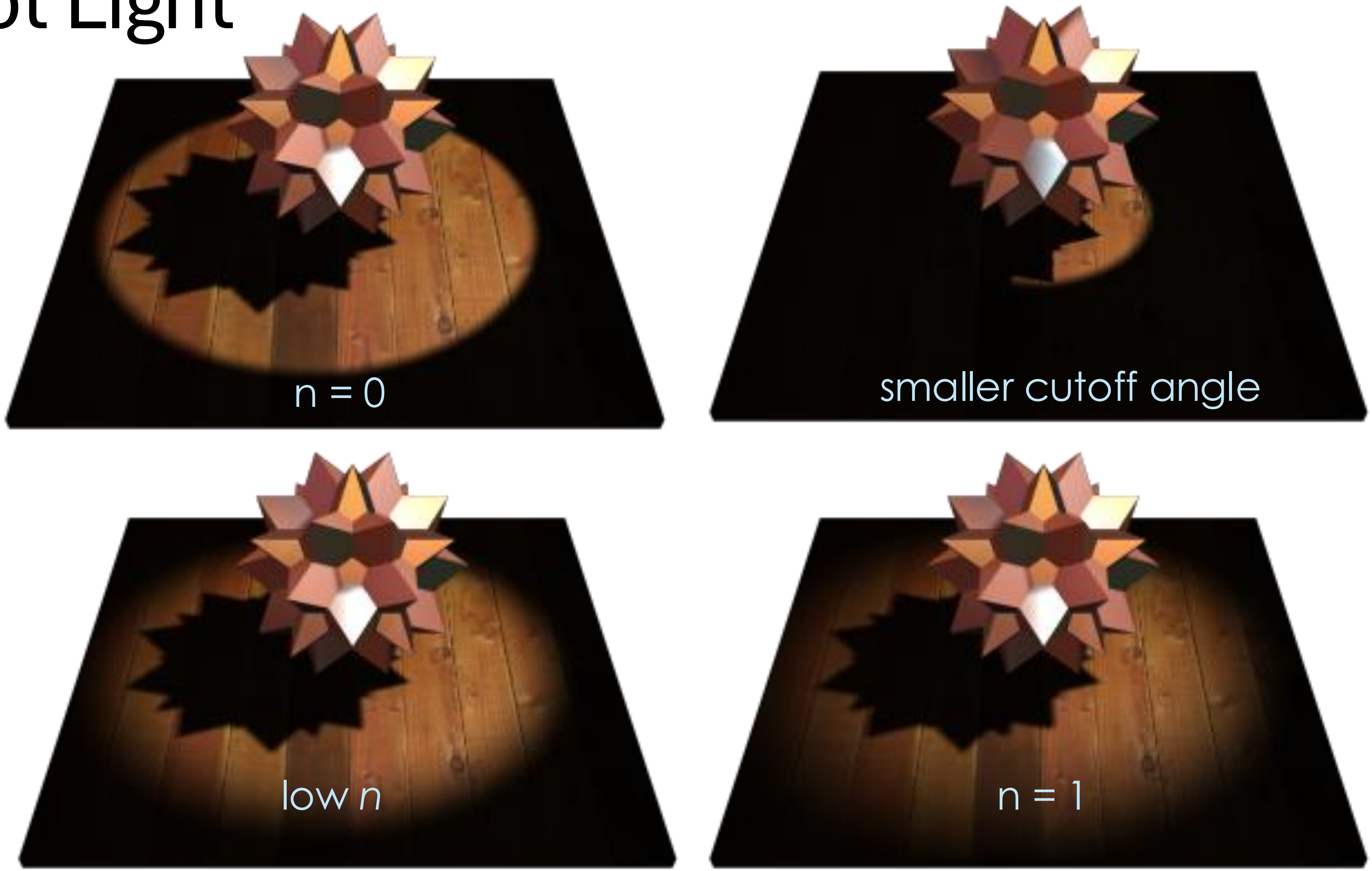
$$d = |P - x| \quad I = \frac{P - x}{d}$$

$$\text{if } \cos^{-1}(-I \cdot L) < \theta \text{ then}$$

$$E = \frac{\Phi}{4\pi d^2}\left[\frac{-I.L}{\cos\theta}\right]^n$$

spotlight attentuation

Spot Light



Incorporating Colour

$$L_r(x,V) = EC_{amb}\rho_a + EC_{diff}\,\rho_d\,(N \cdot L) + EC_{spec}\,C_{light}\,\rho_s(V \cdot R)^n$$

- For flexibility, the ambient, diffuse and specular reflections are scaled independently by colour vectors.

- The model is applied using colour vectors yielding the final colour vector to assign to a pixel.

- Note: only the specular term is scaled by the light's colour.

Further Reading

- Ambient occlusion
  https://en.wikipedia.org/wiki/Ambient_occlusion
- Screen-space ambient occlusion
  https://learnopengl.com/Advanced-Lighting/SSAO