CS130 : Computer Graphics

Lighting and Shading

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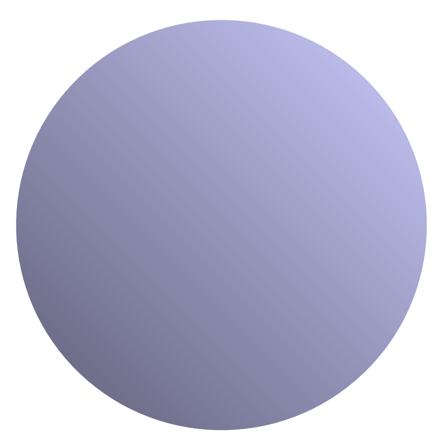
Why we need shading

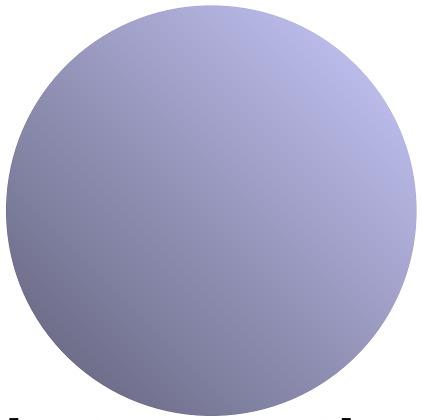
- Suppose we build a model of a sphere using many polygons and color each the same color. We get something like

- But we want



Shading

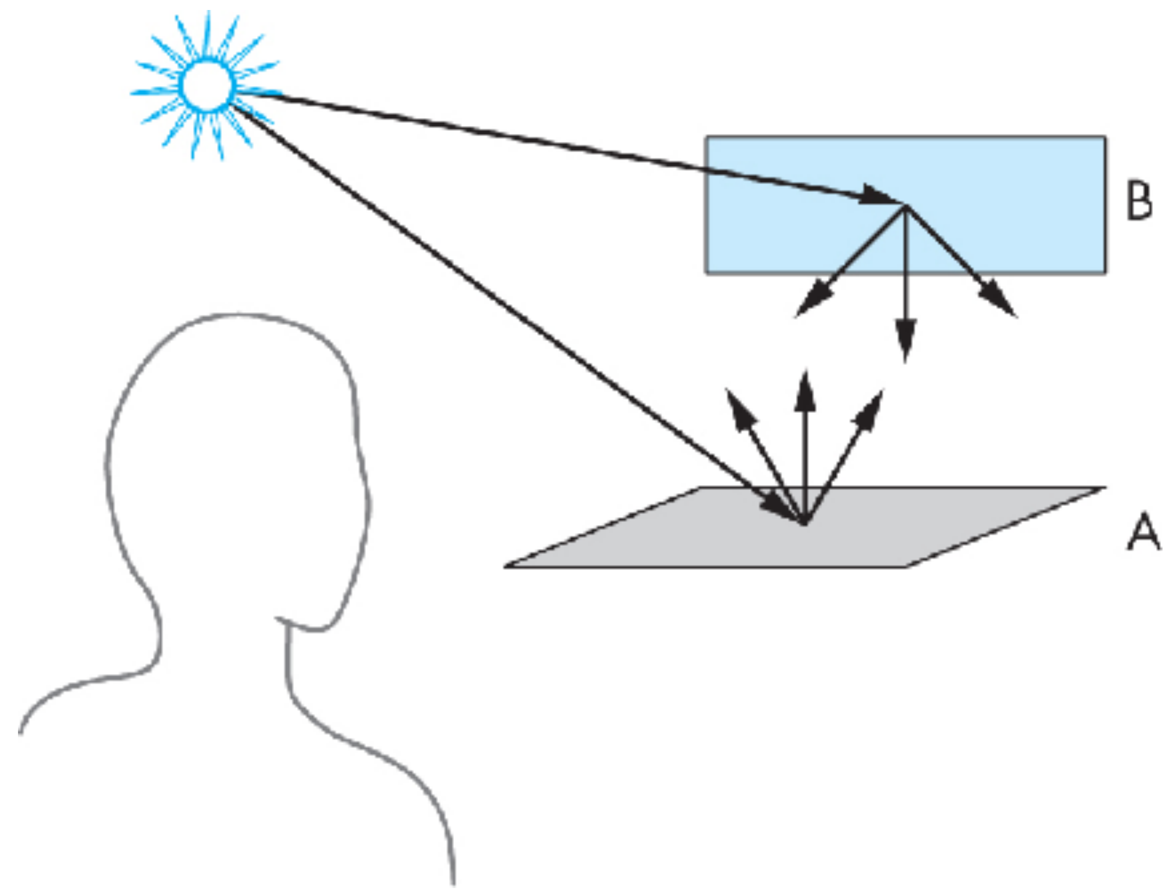
- Why does the image of a real sphere look like



- Light-material interactions cause each point to have a different color or shade
- Need to consider
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation (normal)

General rendering

- The most general approach is based on physics - using principles such as conservation of energy
- a surface either **emits** light (e.g., light bulb) or **reflects** light from other illumination sources, or both
- light interaction with materials is **recursive**
- the **rendering equation** is an integral equation describing the limit of this recursive process

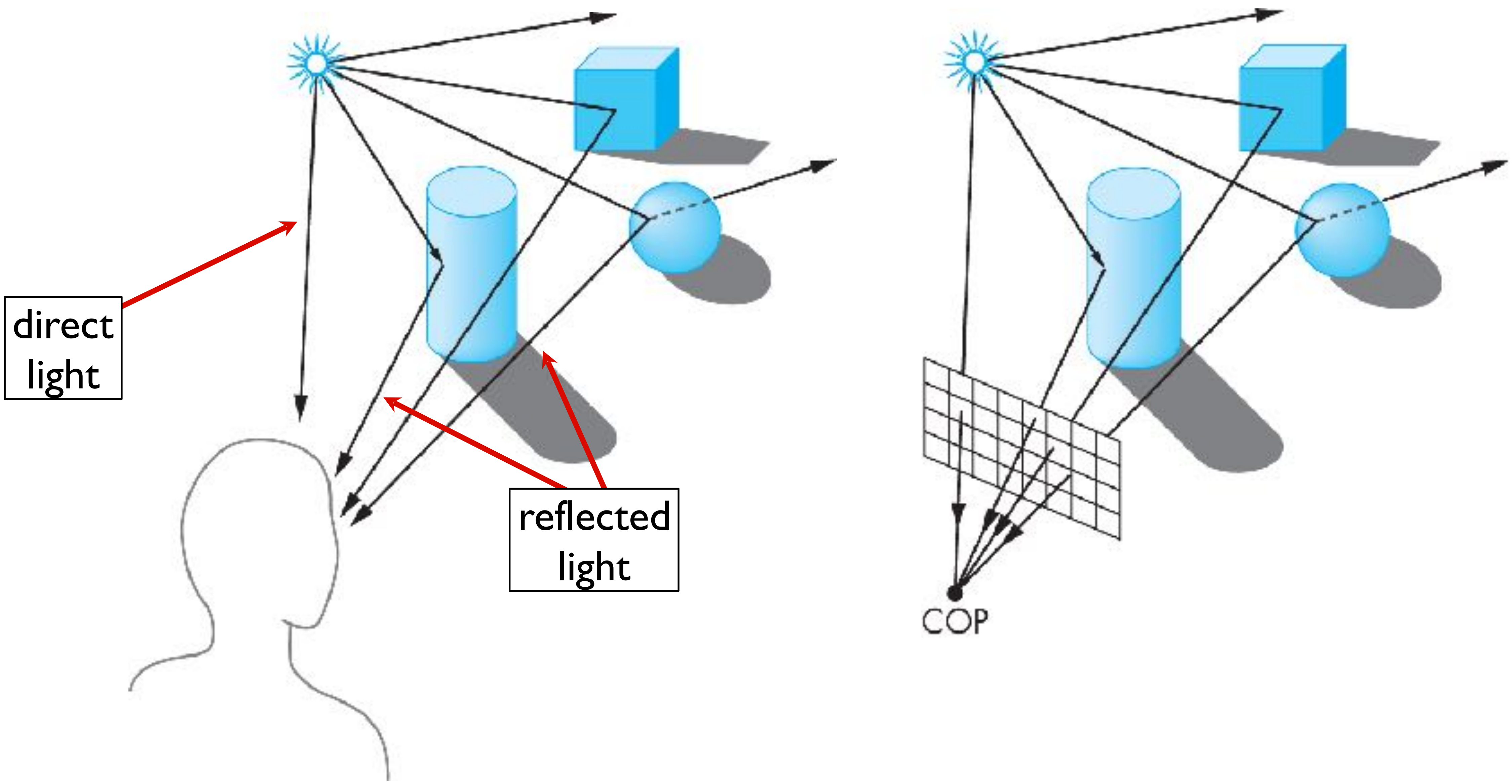


[Angel and Shreiner]

Fast local shading models

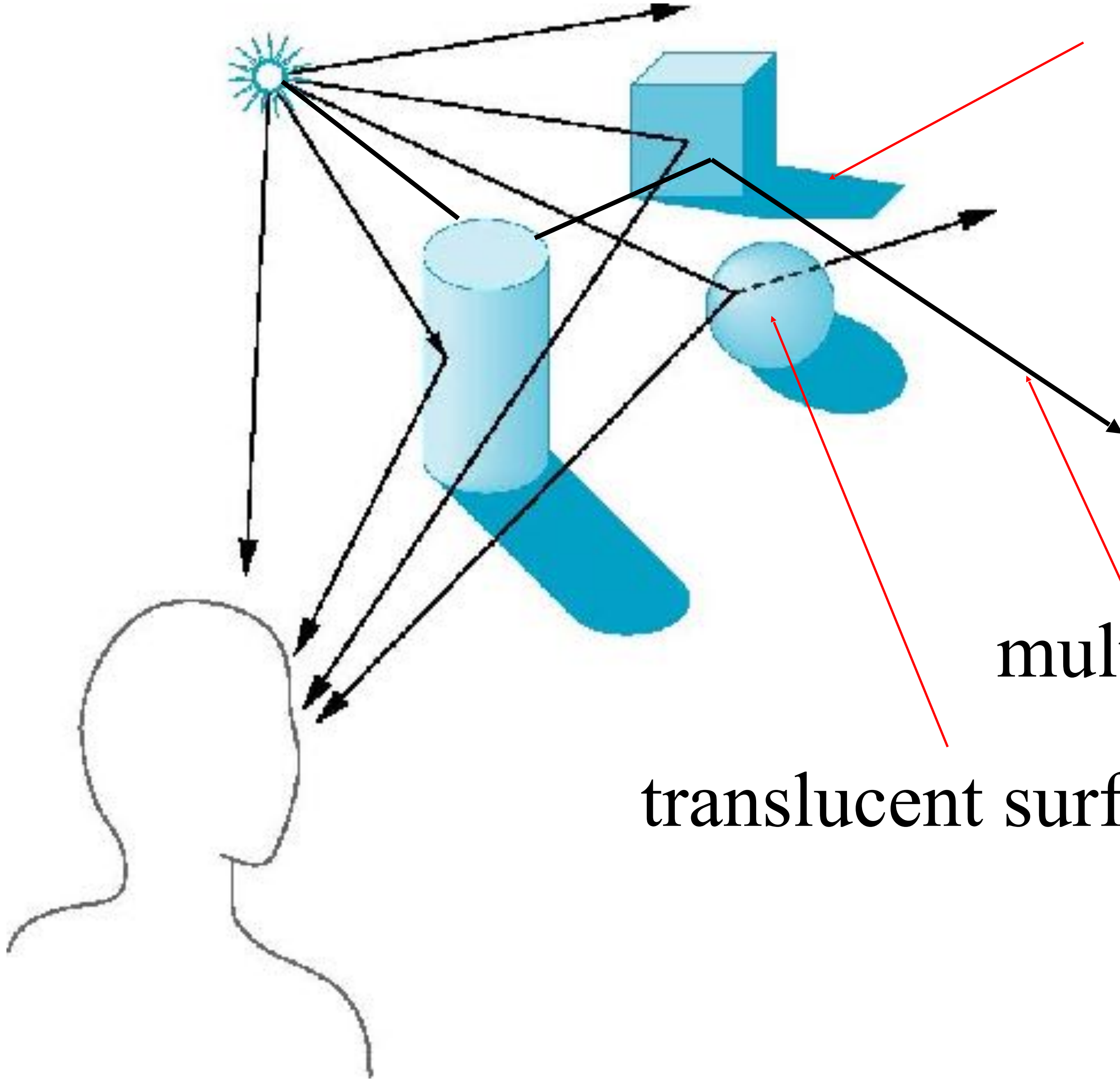
- the rendering equation can't be solved analytically
- numerical methods aren't fast enough for real-time
- for our fast graphics rendering pipeline, we'll use a **local** model where shade at a point is independent of other surfaces
- use **Phong reflection model**
  - shading based on local light-material interactions

Local shading model



[Angel and Shreiner]

Global Effects

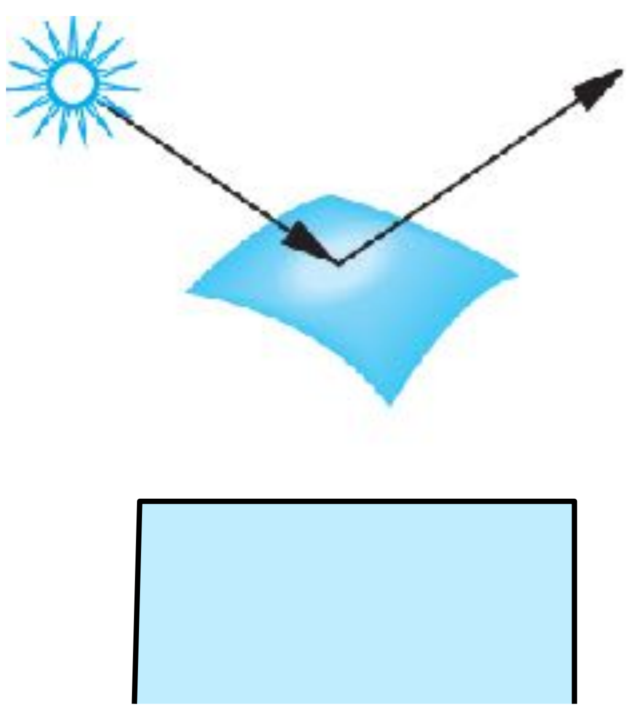


[Angel and Shreiner]

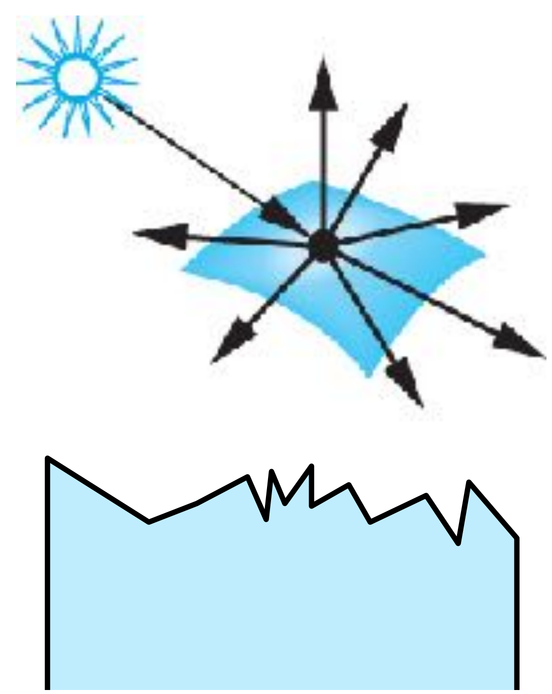
Light-material interactions

at a surface, light is absorbed, reflected, or transmitted

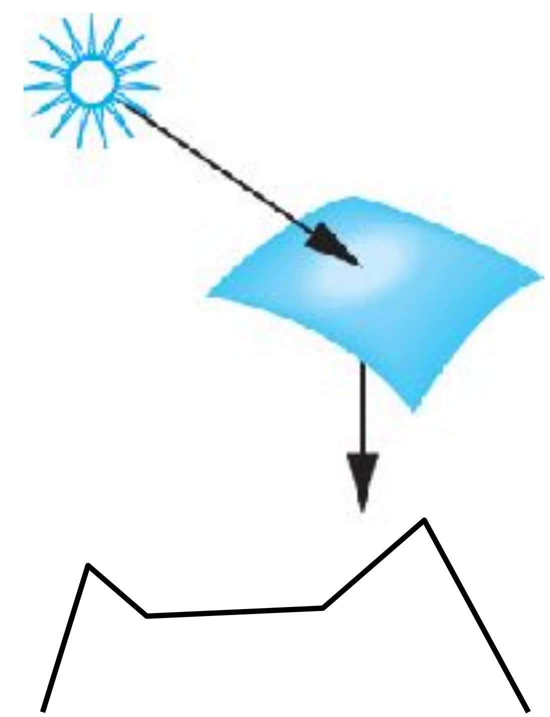
specular



diffuse



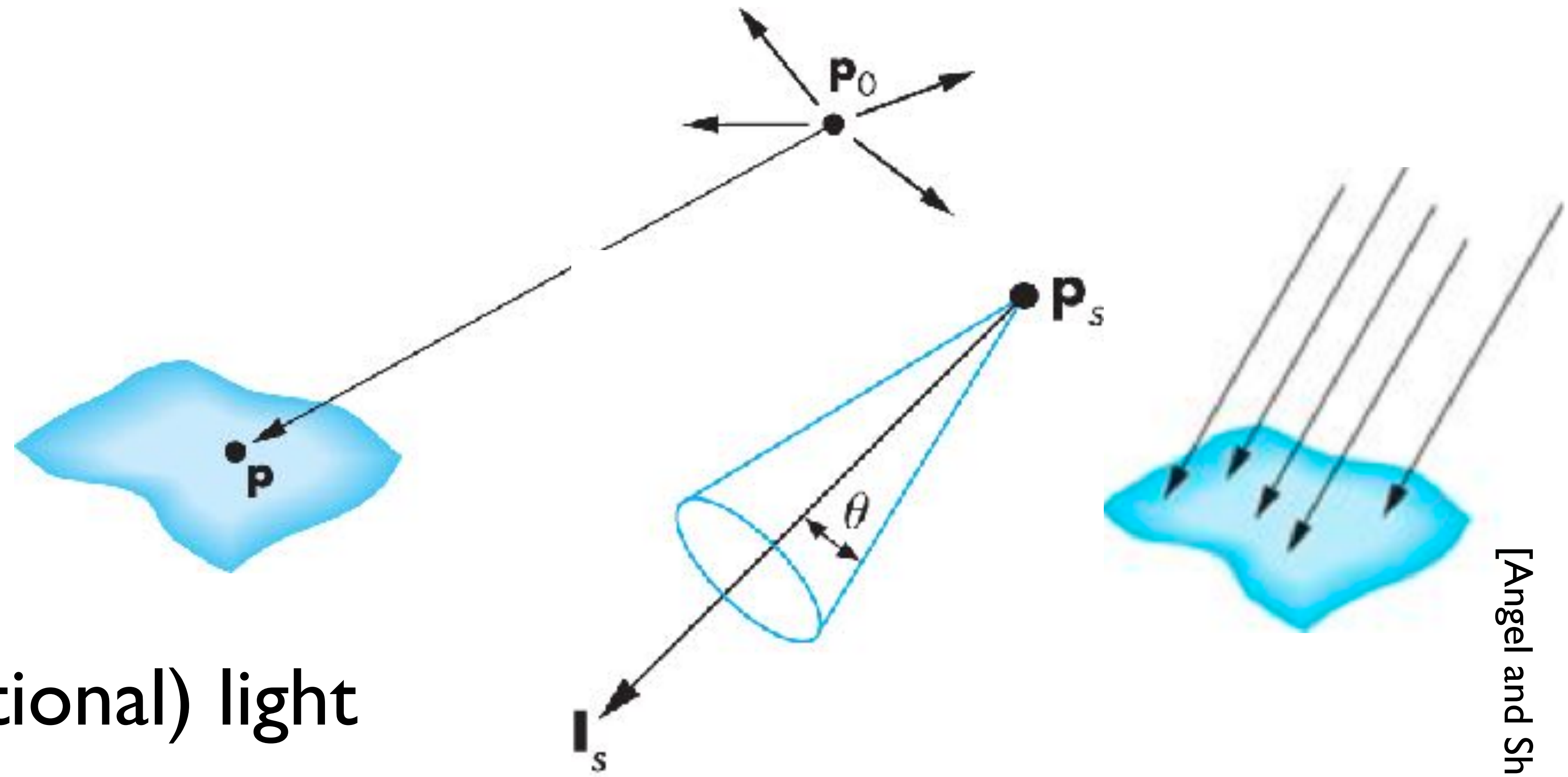
translucent



[Angel and Shreiner]

Idealized light sources

- Ambient light
- Point light
- Spotlight
- distant (directional) light



[Angel and Shreiner]

luminance: $\mathbf{L} = \begin{bmatrix} L_r \\ L_g \\ L_b \end{bmatrix}$

Ambient light source

- achieve a uniform light level
- no black shadows
- ambient light intensity at each point in the scene

$$\mathbf{L}_a = \begin{bmatrix} L_{ar} \\ L_{ag} \\ L_{ab} \end{bmatrix}$$

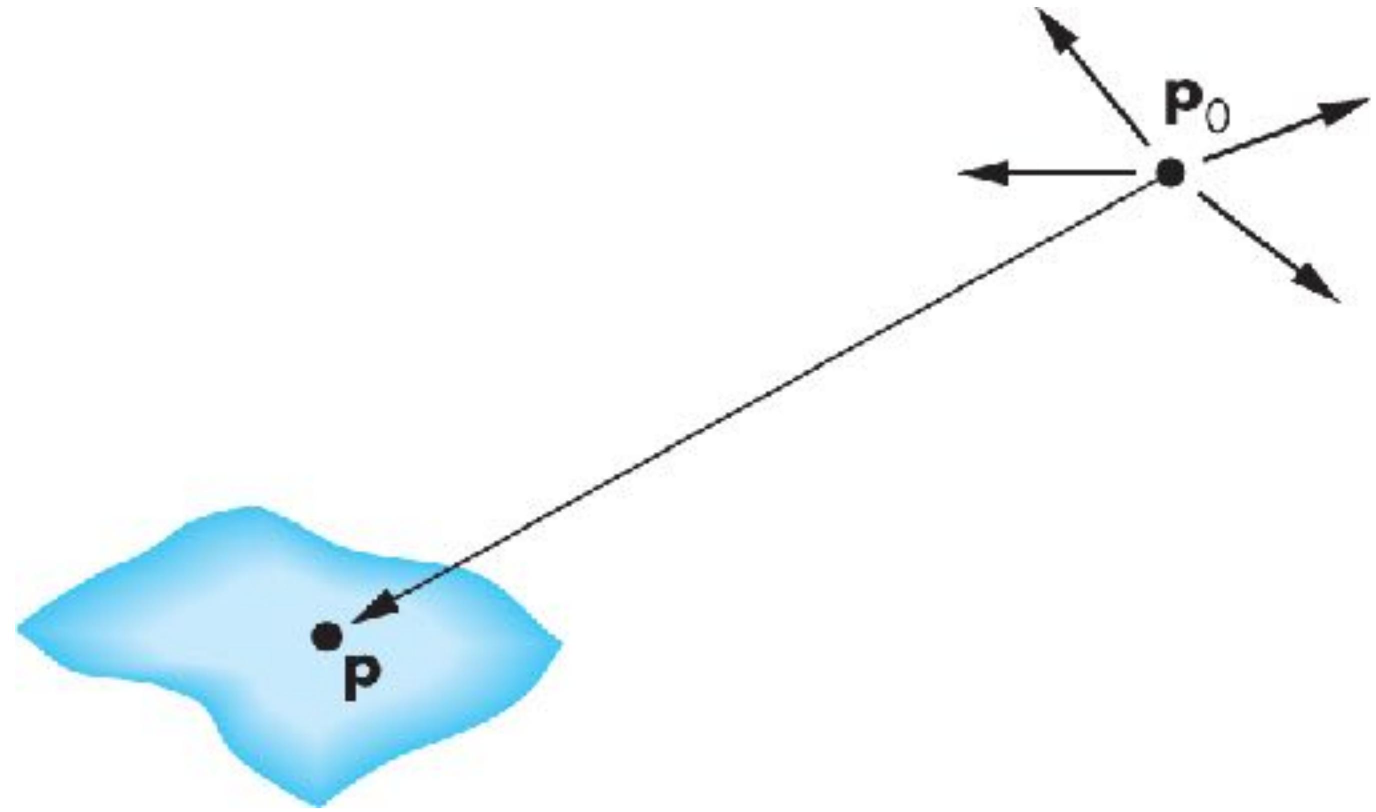
$$L_a$$

ambient light is the same everywhere
but different surfaces will **reflect** it differently

Point light source

$$\mathbf{L}(\mathbf{p}_0) = \begin{bmatrix} L_r(\mathbf{p}_0) \\ L_g(\mathbf{p}_0) \\ L_b(\mathbf{p}_0) \end{bmatrix}$$

$$L(\mathbf{p}_0)$$



[Angel and Shreiner]

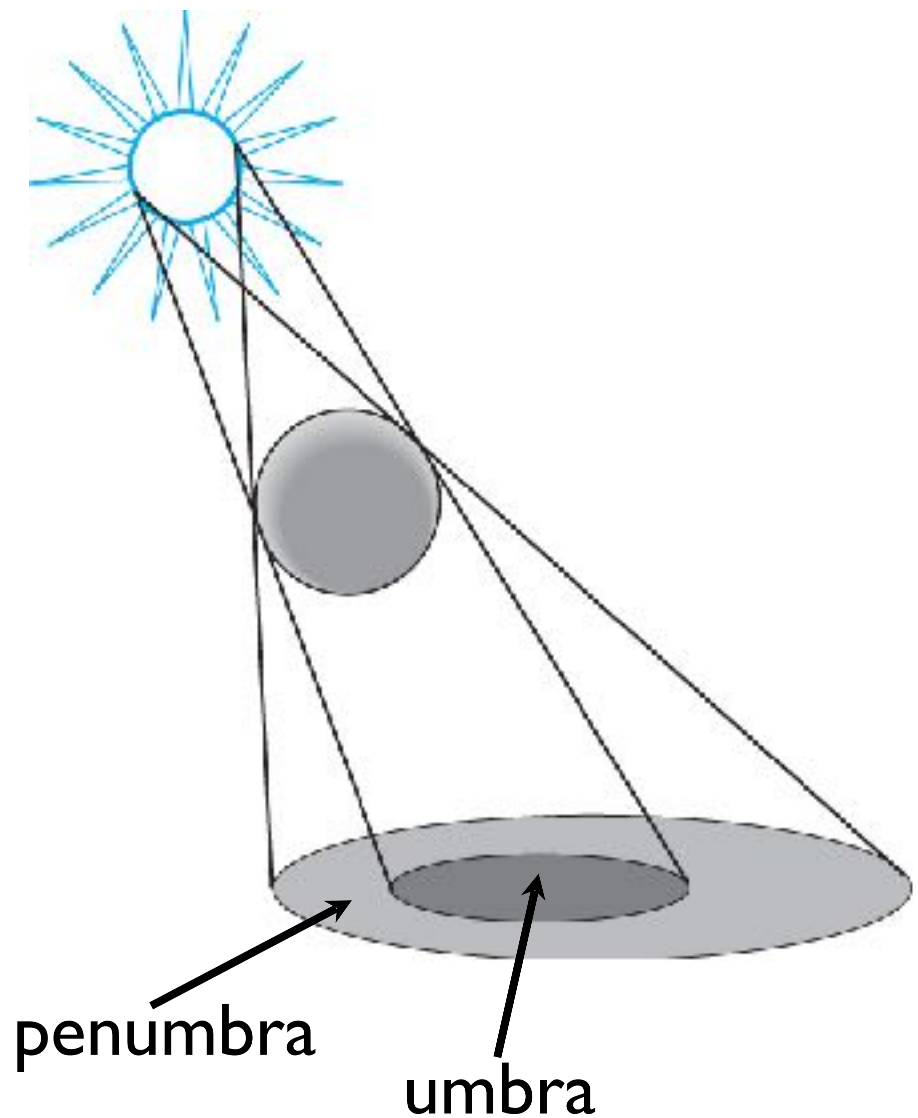
illumination intensity at **p**:

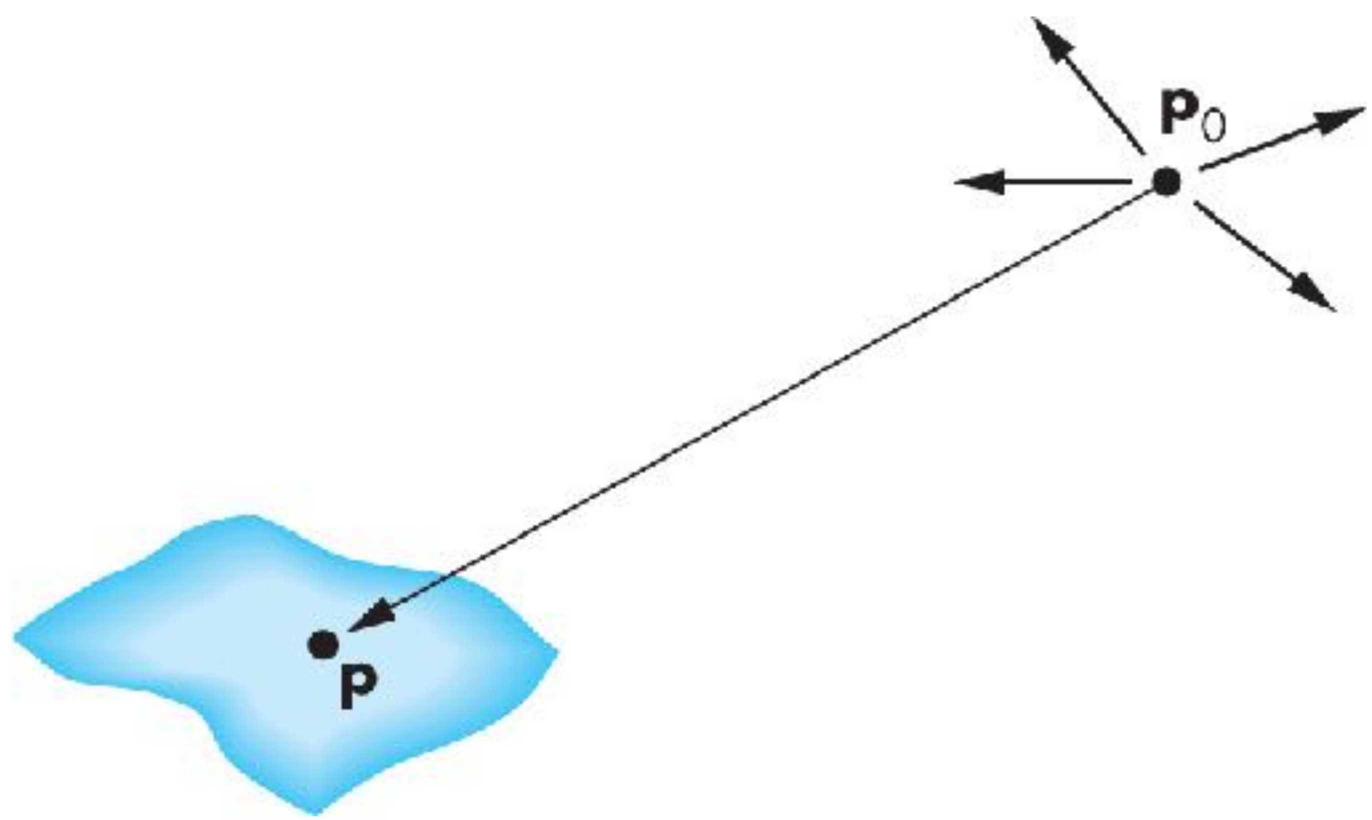
$$l(\mathbf{p}, \mathbf{p}_0) = \frac{1}{|\mathbf{p} - \mathbf{p}_0|^2} \mathbf{L}(\mathbf{p}_0)$$

Point light source

Most real-world scenes have large light sources

Point light sources alone not realistic - add ambient light to mitigate high contrast

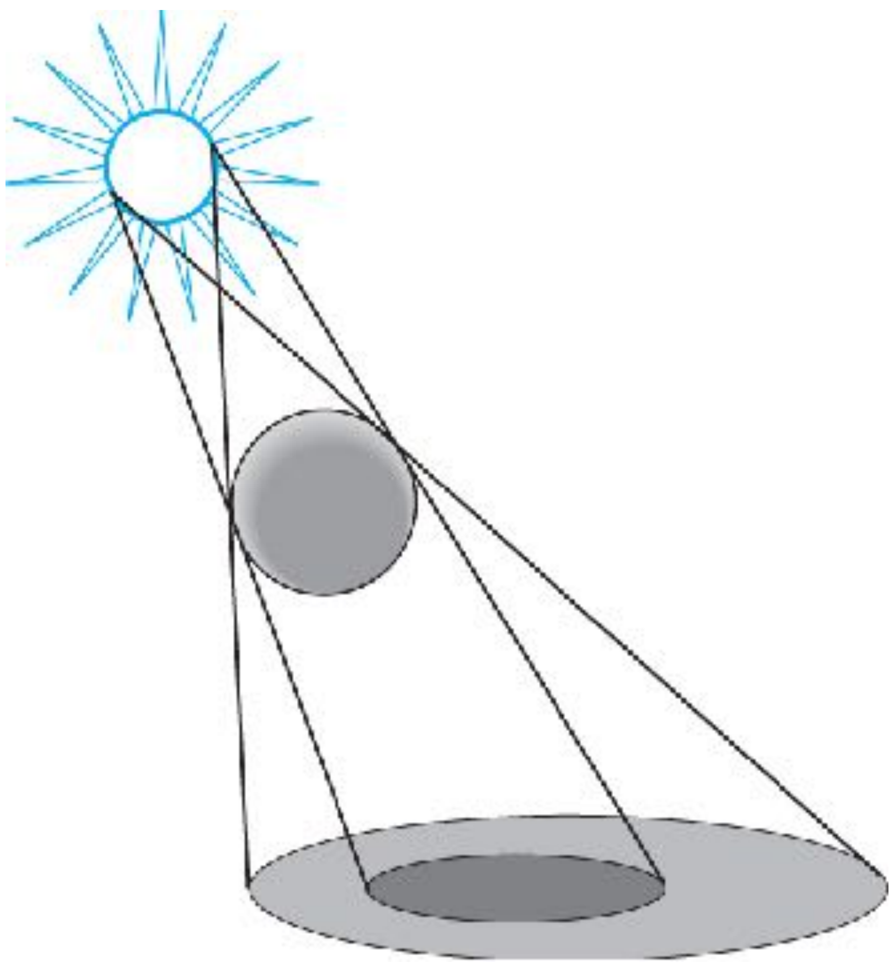




[Angel and Shreiner]

Point light source

Most real-world scenes have large light sources



Point light sources alone not realistic
- drop off intensity more slowly

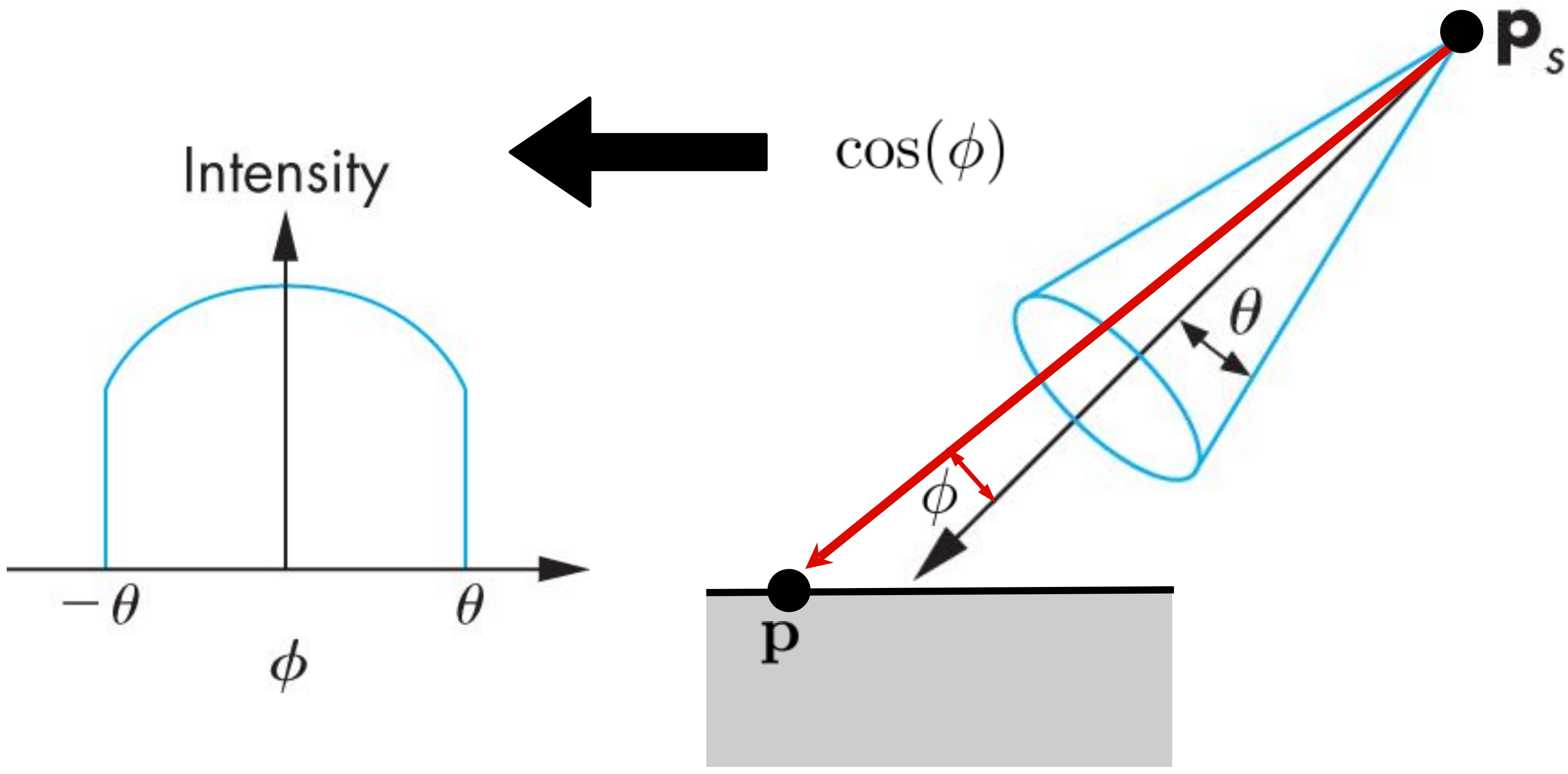
$$l(\mathbf{p}, \mathbf{p}_0) = \frac{1}{d^2}\mathbf{L}(\mathbf{p}_0)$$

$$\Downarrow$$

$$l(\mathbf{p}, \mathbf{p}_0) = \frac{1}{a + bd + cd^2}\mathbf{L}(\mathbf{p}_0)$$

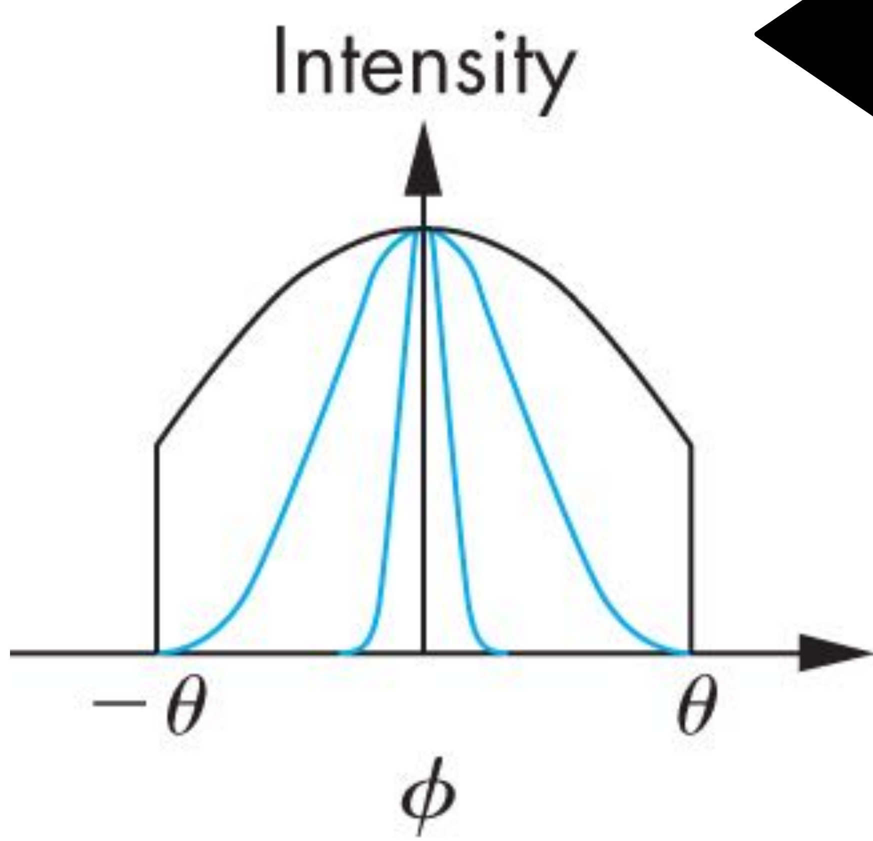
[Angel and Shreiner]

Spotlights

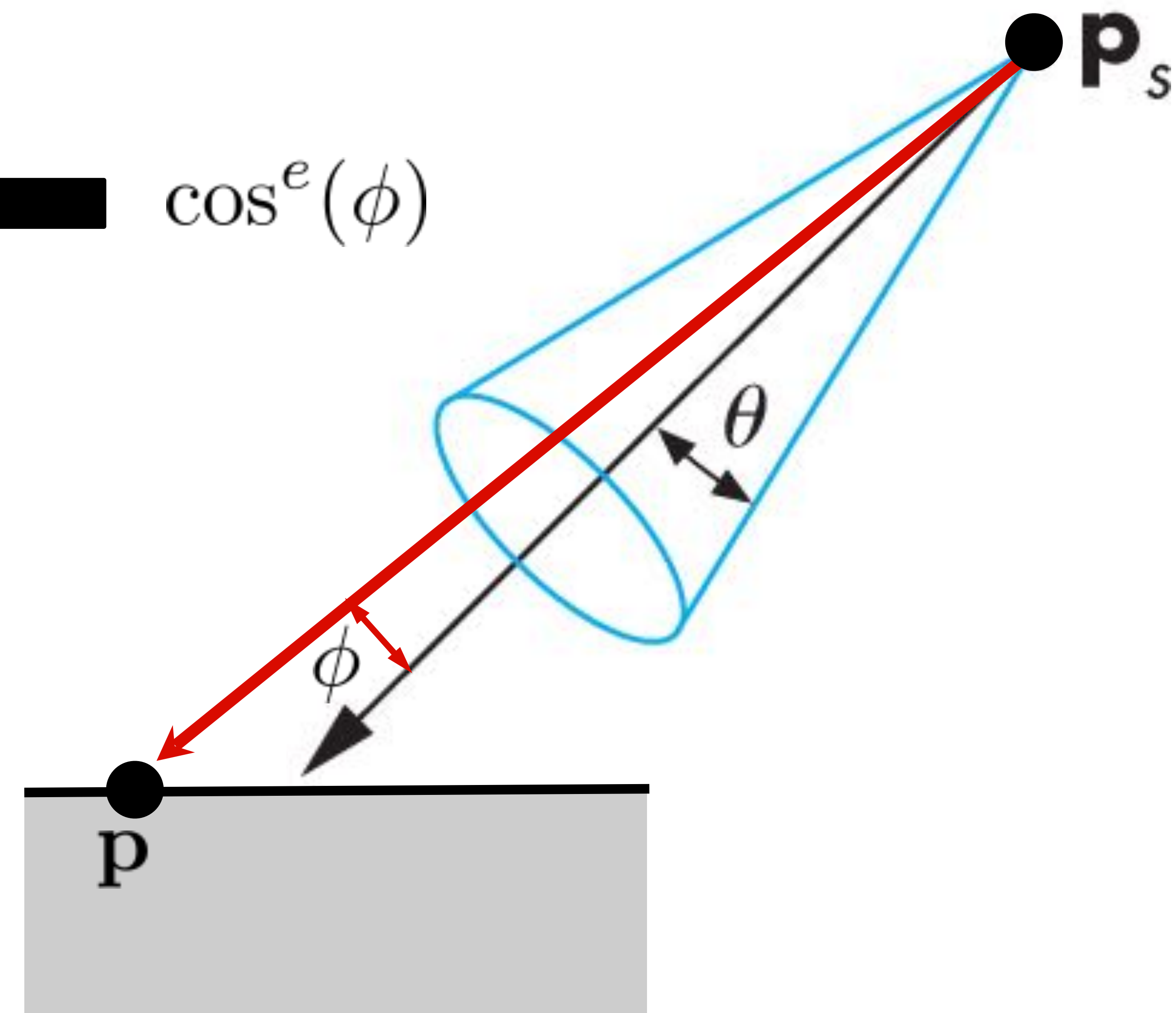


[Angel and Shreiner]

Spotlights



$\cos^e(\phi)$

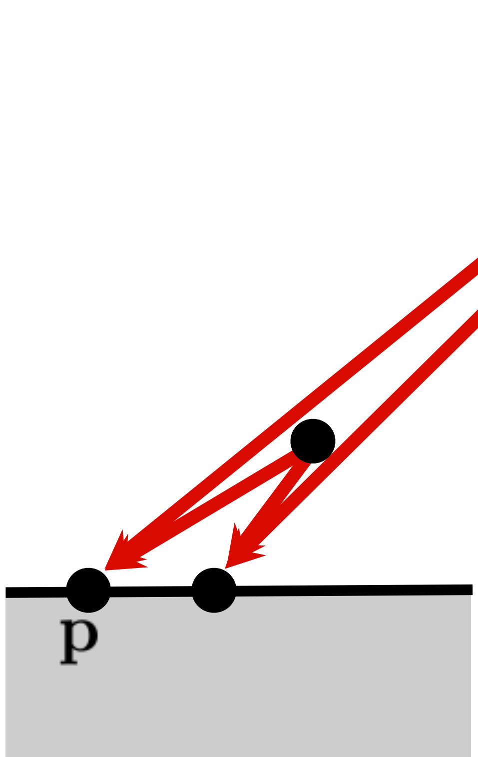


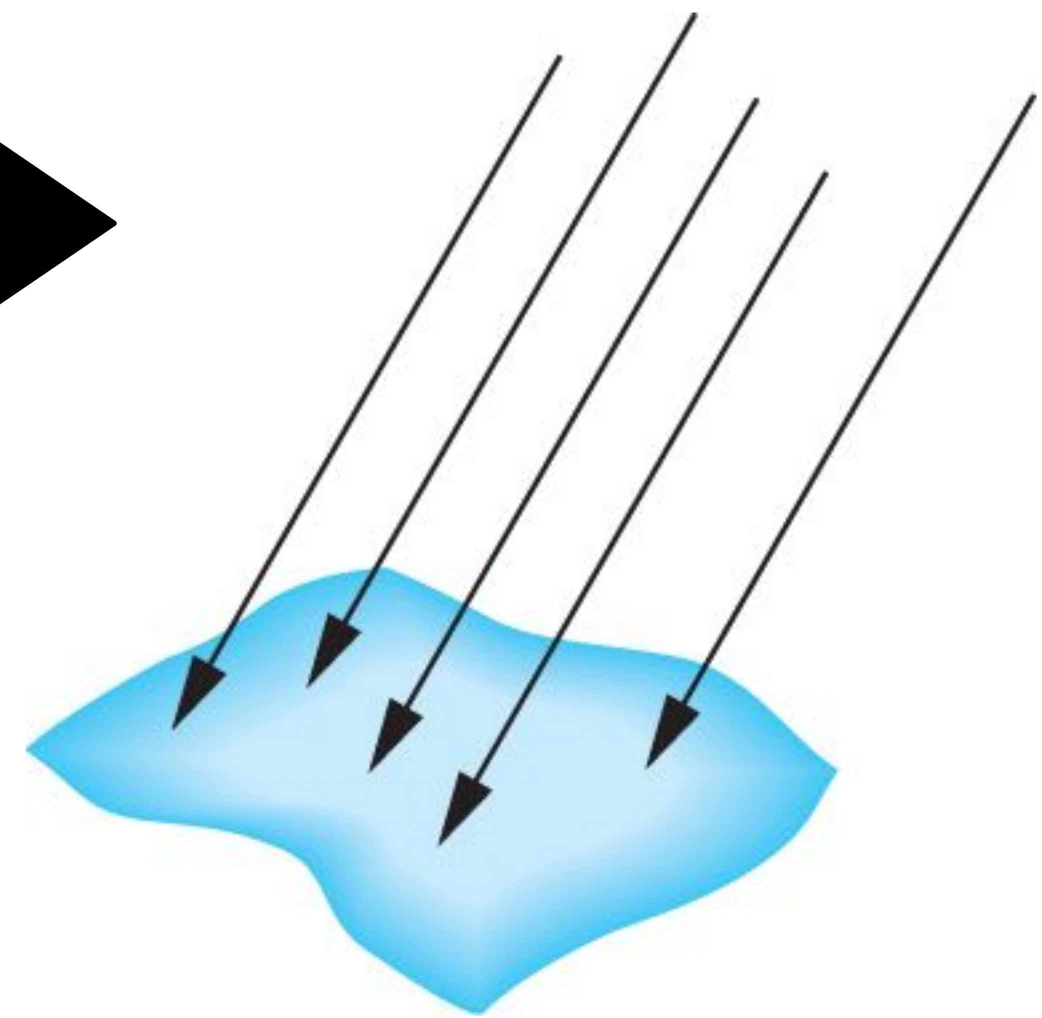
$$\cos^e(\phi)\ l(\mathbf{p}, \mathbf{p}_s)$$

[Angel and Shreiner]

Distant light source

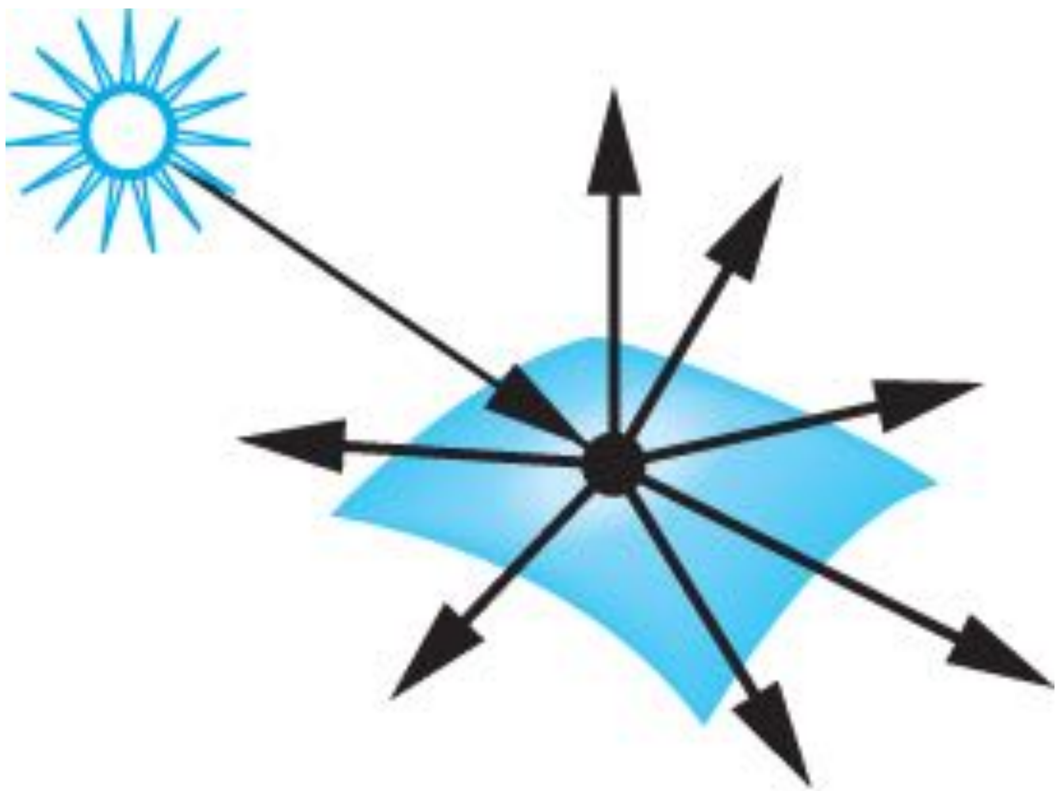
characterized by direction

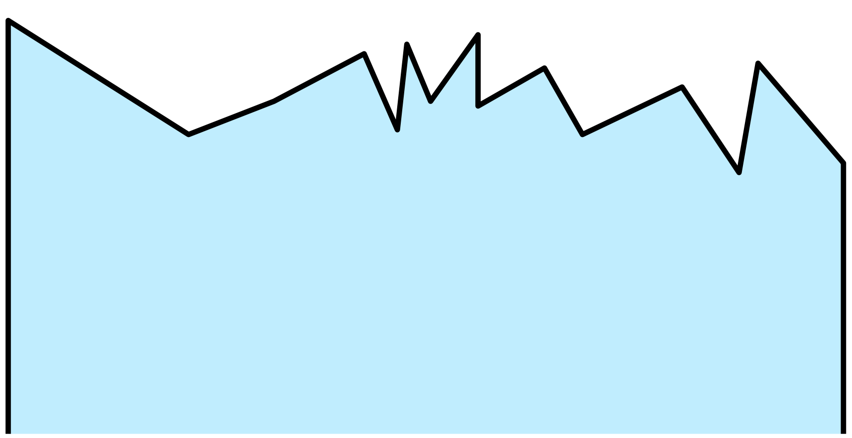




[Angel and Shreiner]

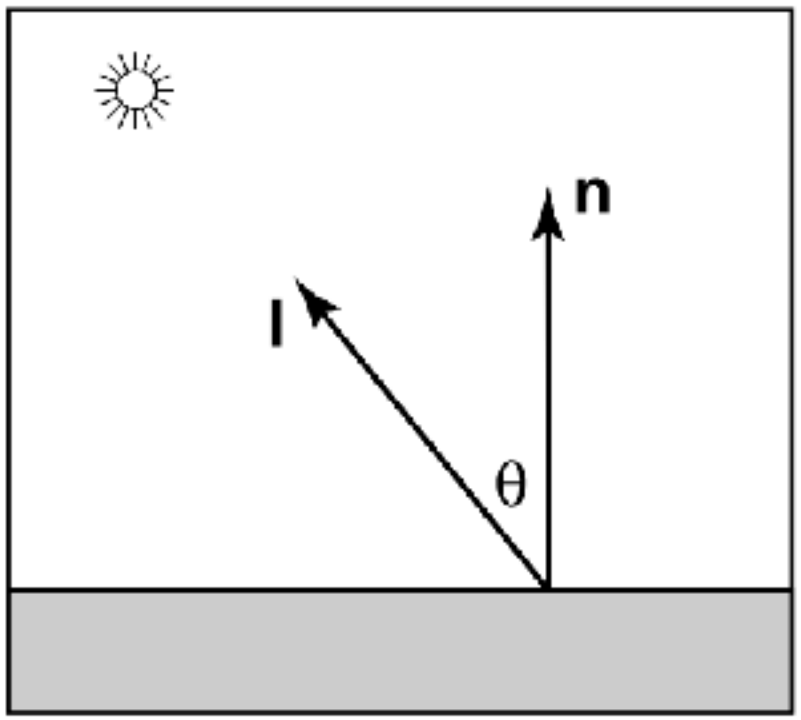
Lambertian Reflection Model





http://www.andreafisherpottery.com/cgi-bin/artistlnk.cgi?Jody_Folwell

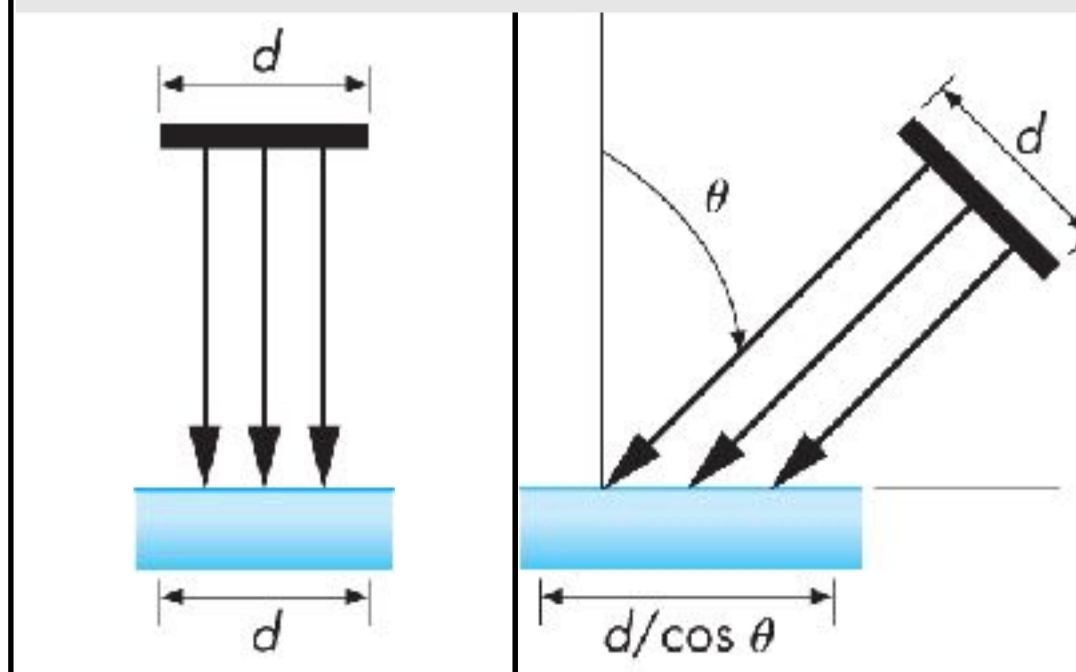
Lambertian Reflection Model



$$I \propto \cos\theta$$

color intensity

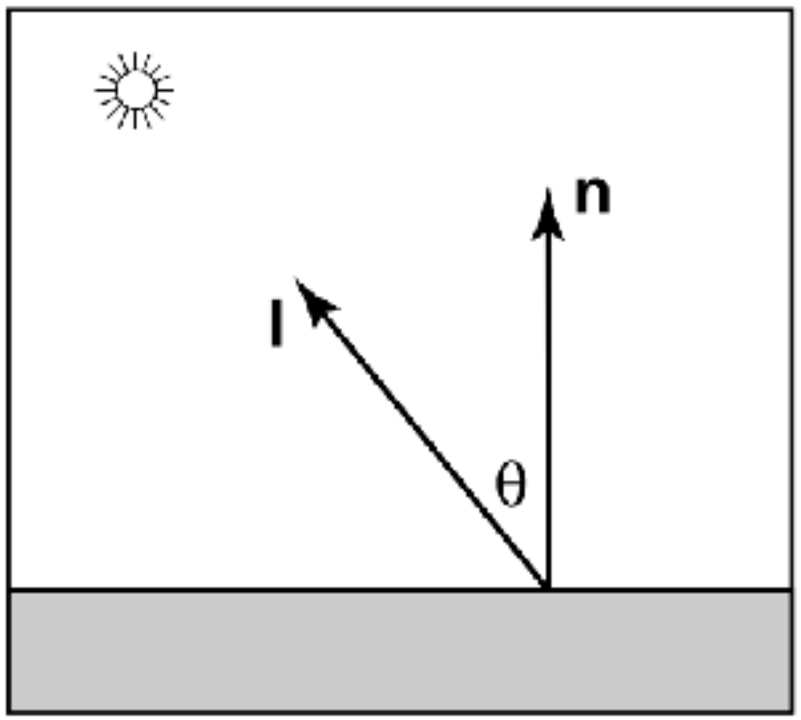
Lambert's cosine law

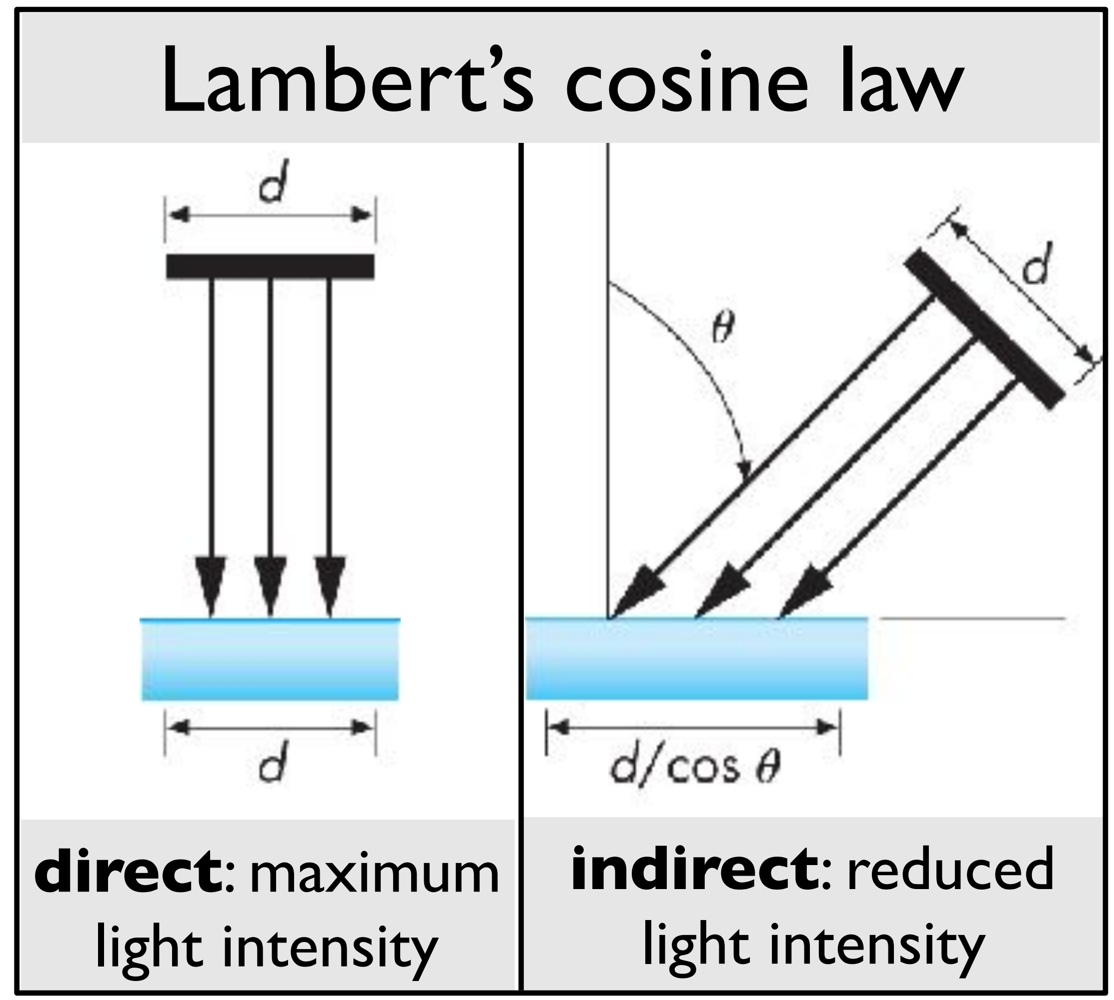


direct: maximum light intensity

indirect: reduced light intensity

Lambertian Reflection Model

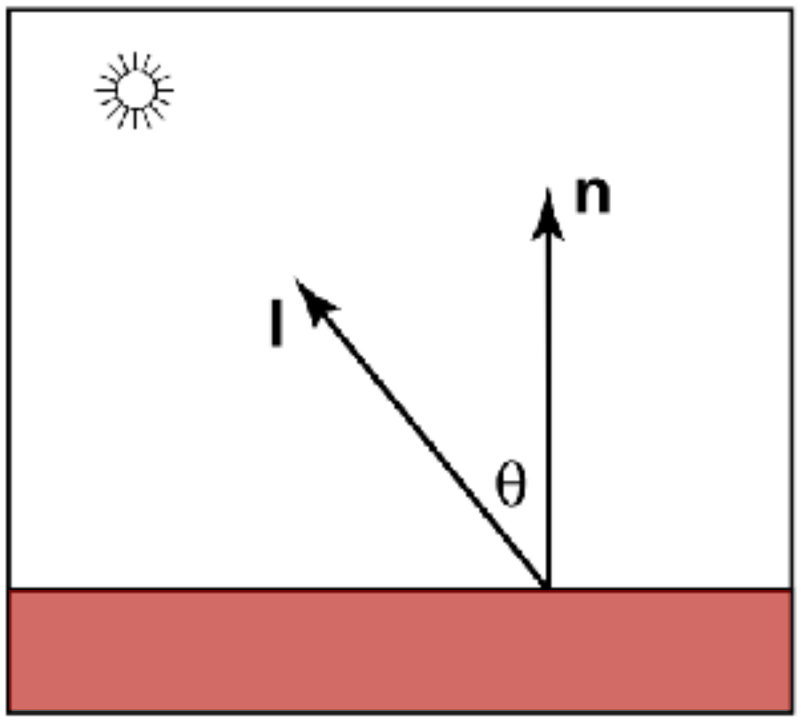




$$I \propto \mathbf{n} \cdot \mathbf{l}$$

color intensity

Lambertian Reflection Model

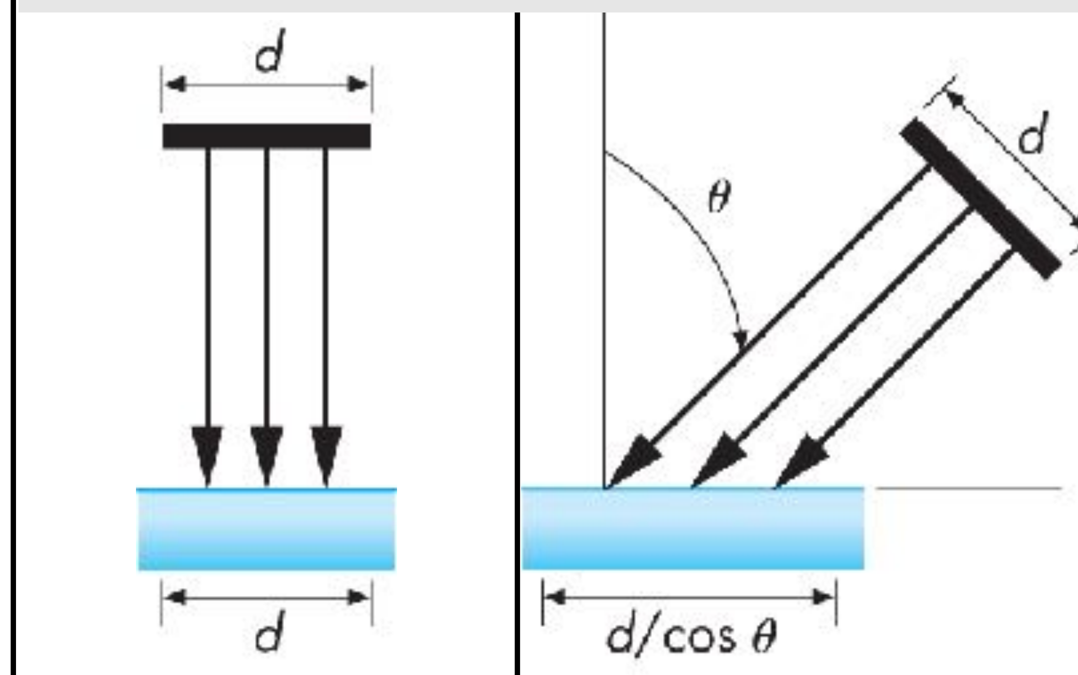


$$I \propto R\mathbf{n}\cdot\mathbf{l}$$

color intensity

reflectance

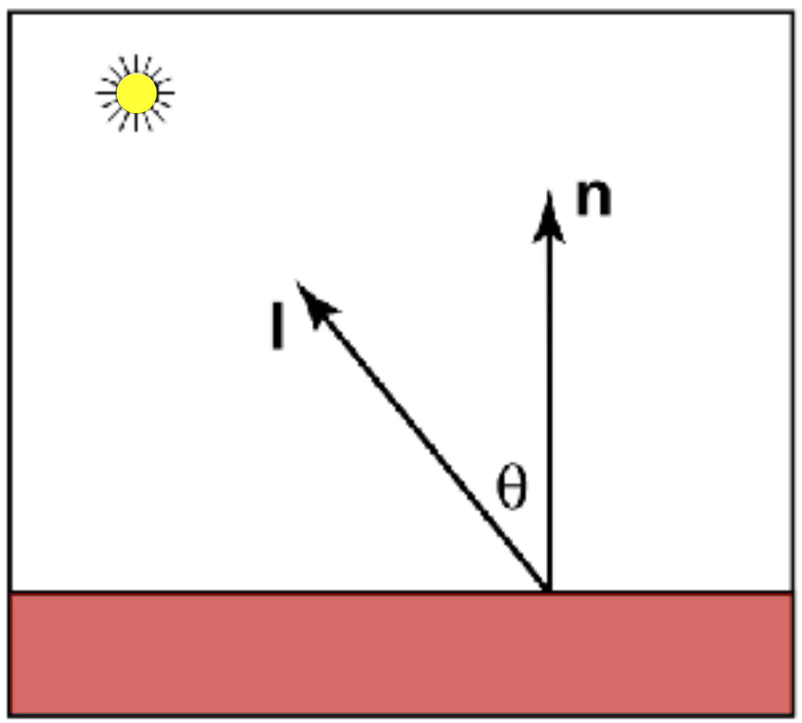
Lambert's cosine law



direct: maximum light intensity

indirect: reduced light intensity

Lambertian Reflection Model

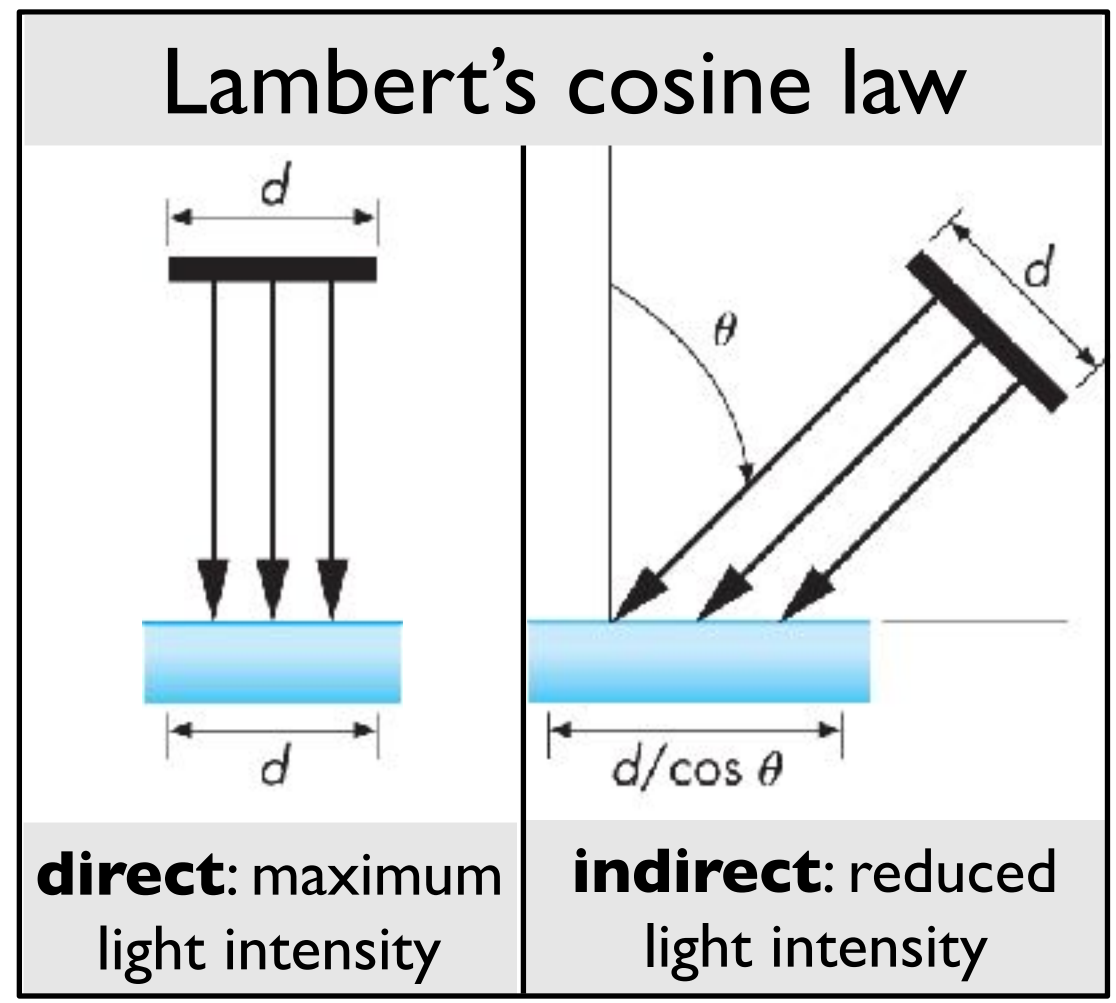


illumination

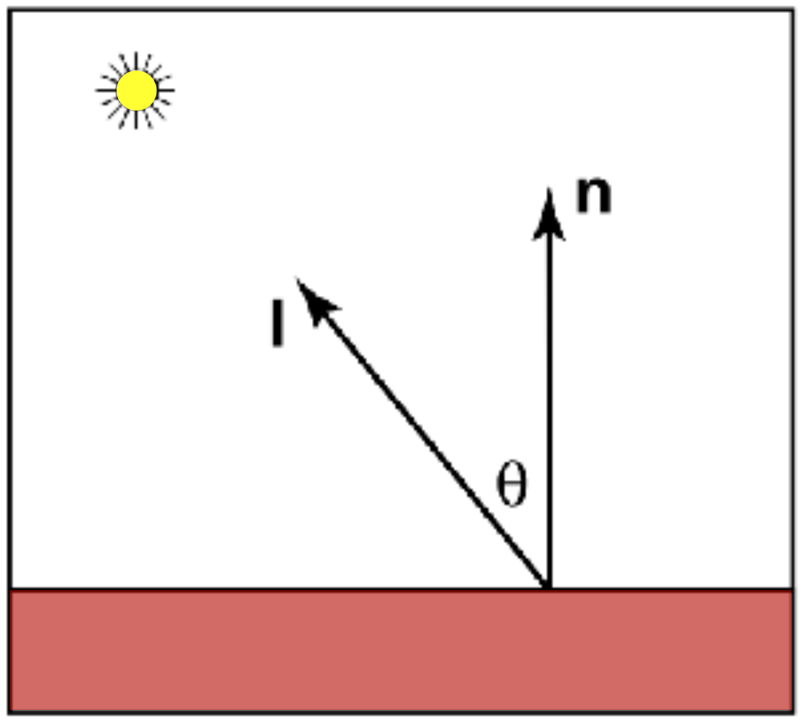
$$I = LR\mathbf{n} \cdot \mathbf{l}$$

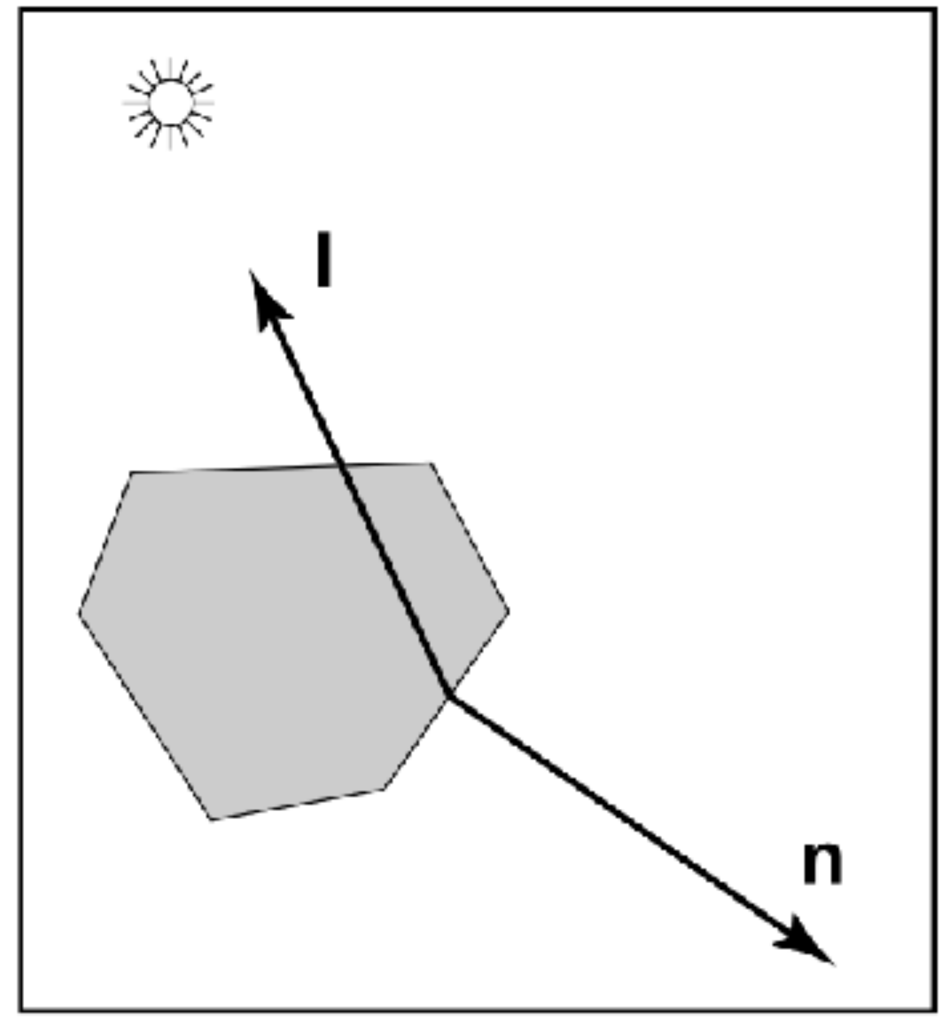
color intensity

reflectance



Lambertian Reflection Model

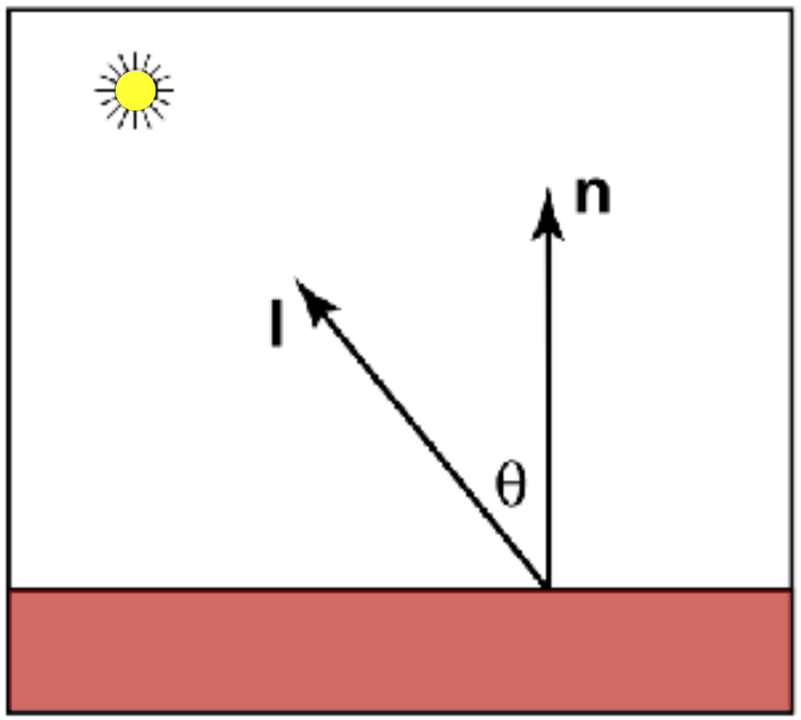




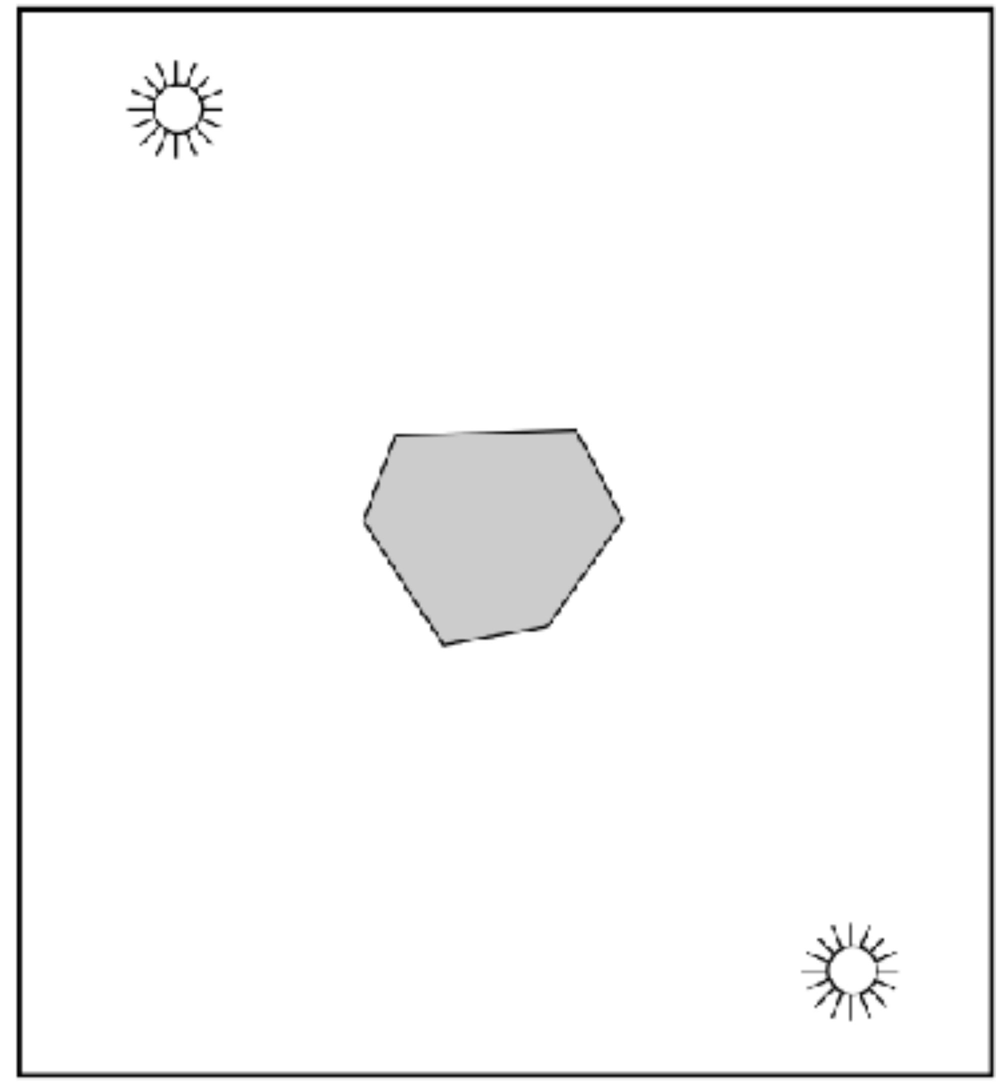
$$I = LR\max(0, \mathbf{n} \cdot \mathbf{l})$$

face points away from the light

Lambertian Reflection Model



$$I = LR|\mathbf{n} \cdot \mathbf{l}|$$

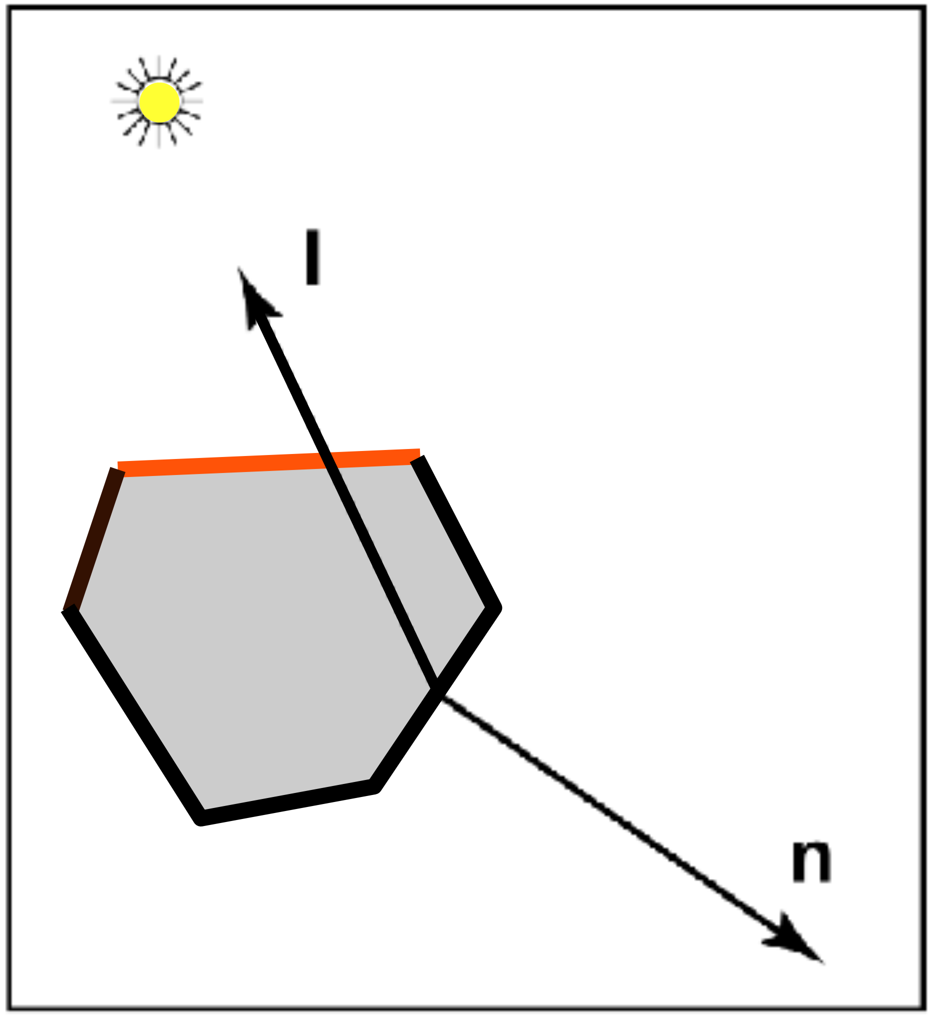


two-sided lighting

Adding Ambient Reflection

$$I = LR\max(0, \mathbf{n} \cdot \mathbf{l})$$

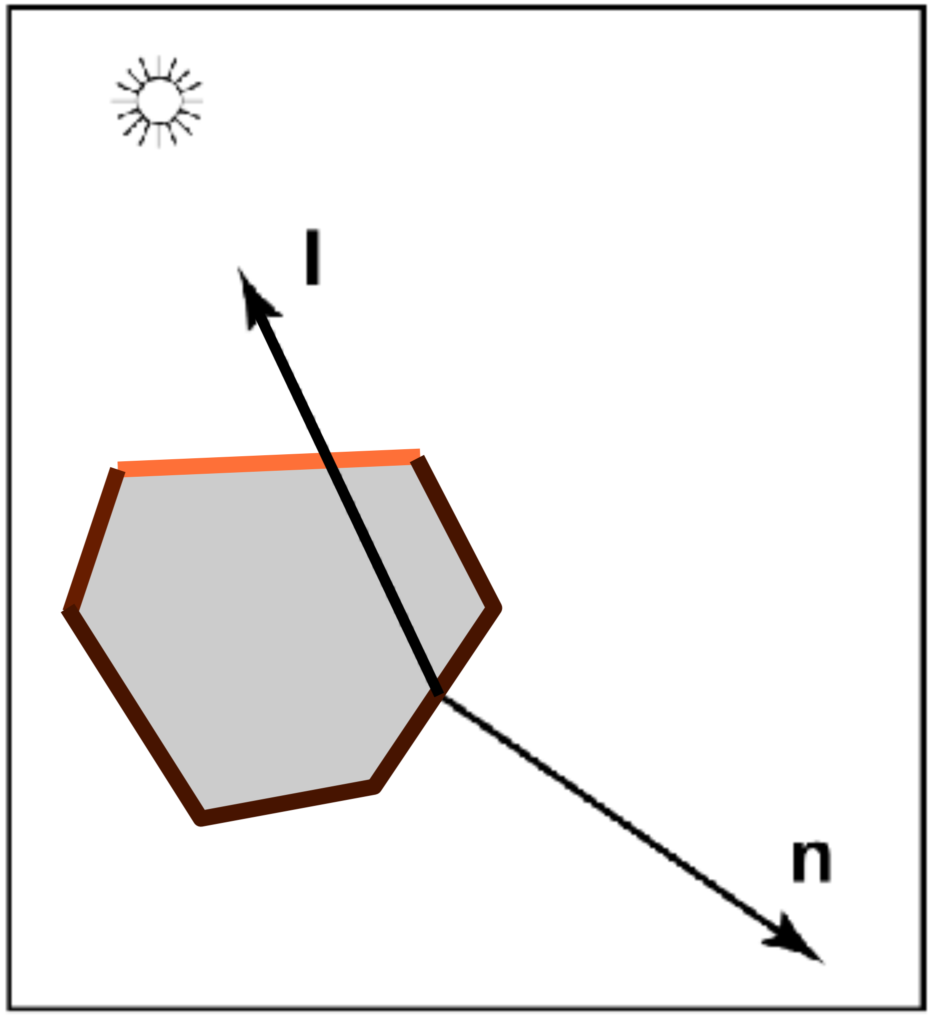
Surfaces facing away from the light will be totally **black**



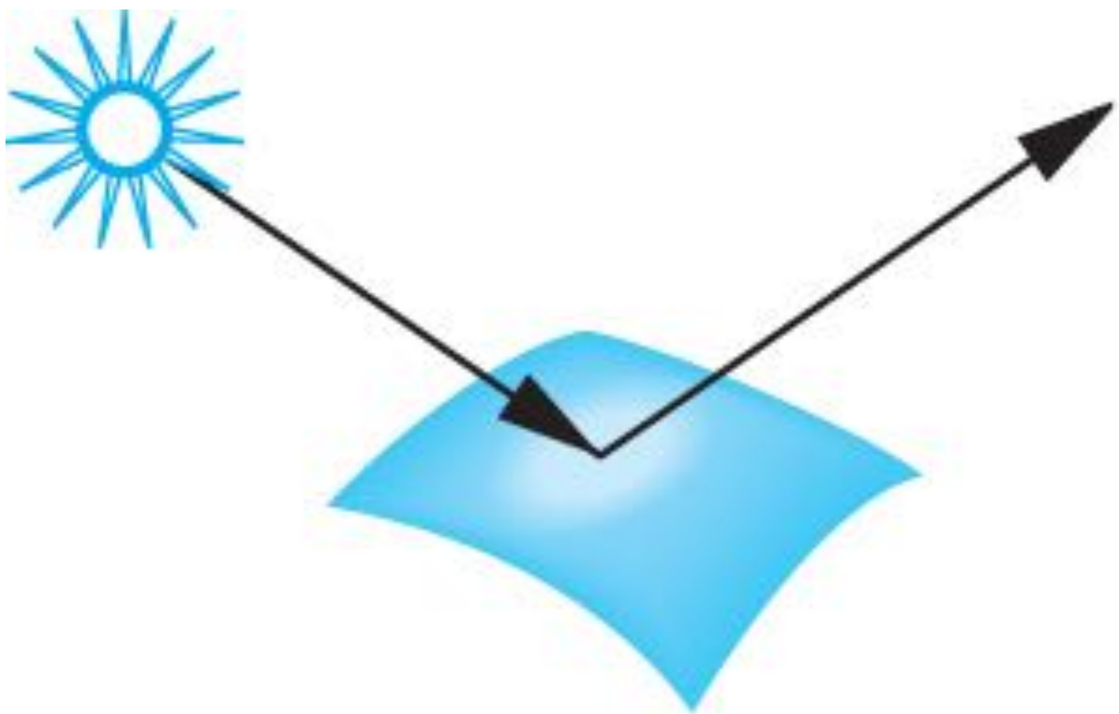
Ambient+Lambertian Reflection

$$I = L_a R_a + L_d R_d \max(0, \mathbf{n} \cdot \mathbf{l})$$

All surfaces get same amount of ambient light



Phong Reflection Model



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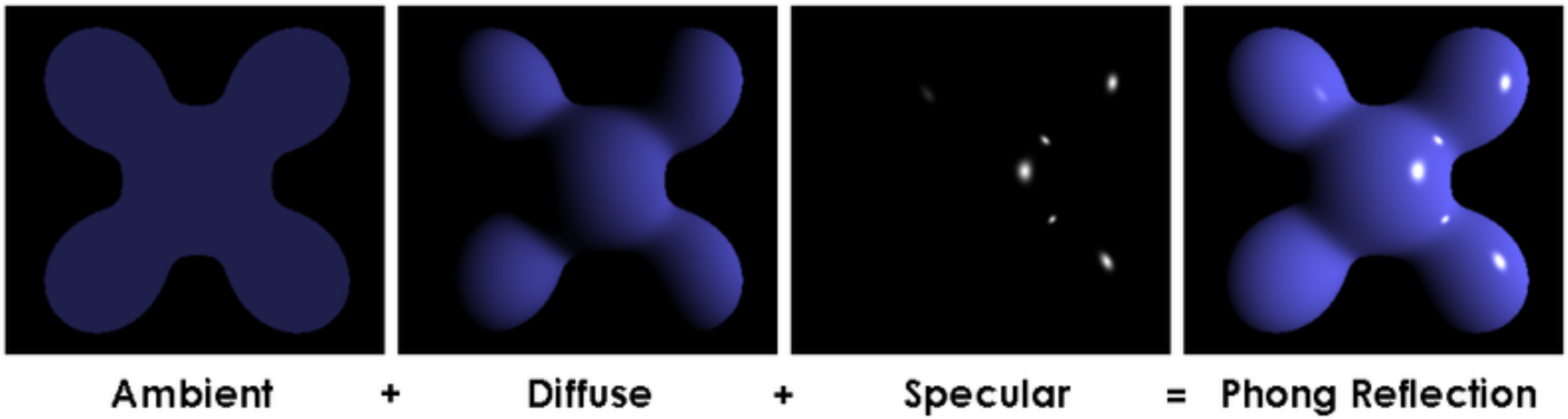
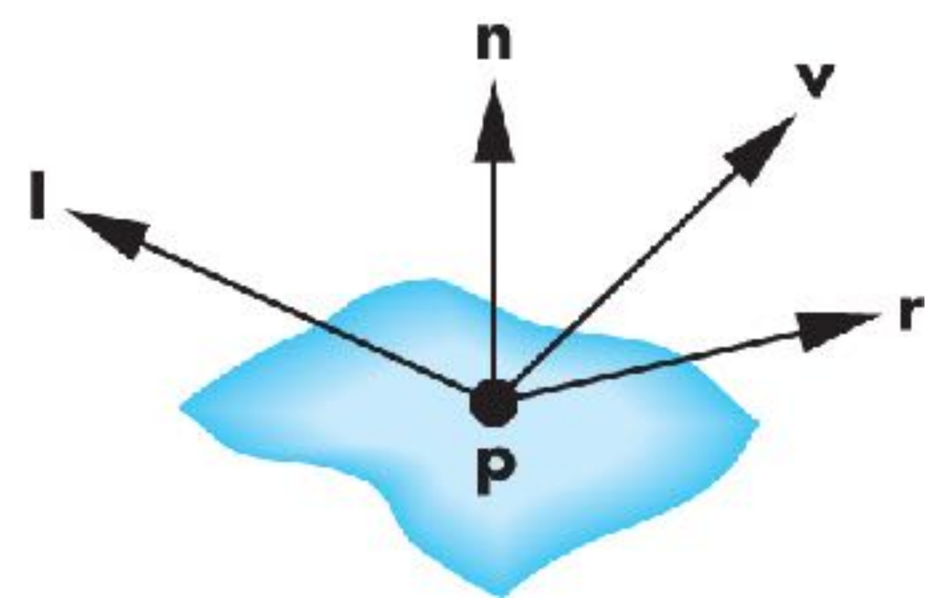
Phong Reflection Model

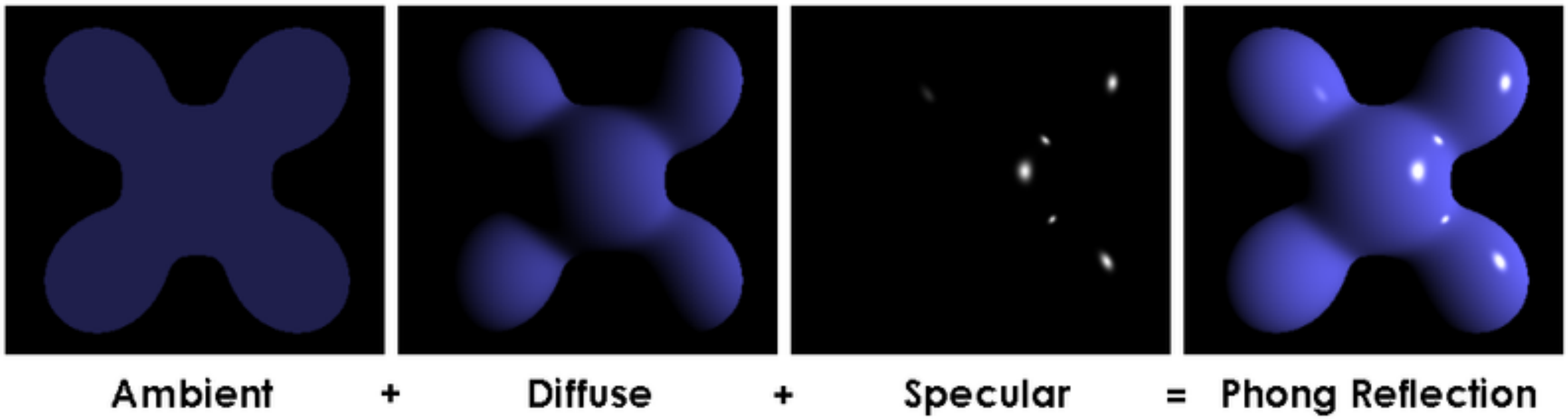


[Brad Smith, Wikimedia Commons]

- efficient, reasonably realistic
- 3 components
- 4 vectors



Phong Reflection Model



[Brad Smith, Wikimedia Commons]

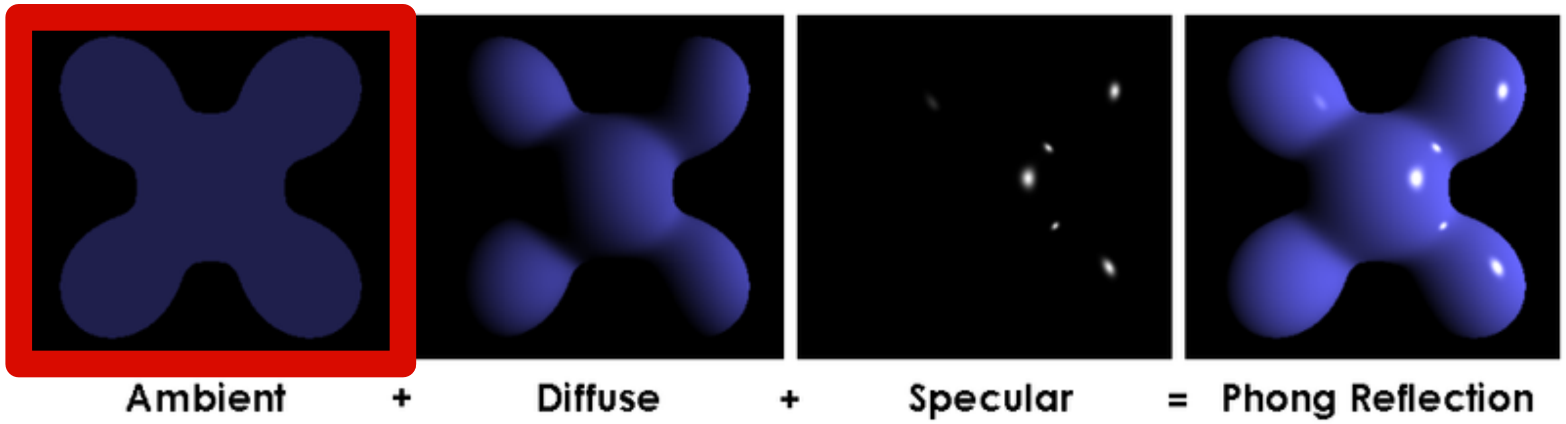
$$
\begin{aligned}
I &= I_a + I_d + I_s \\
&= R_a L_a + R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n}) + R_s L_s \max(0, \cos\phi)^\alpha
\end{aligned}
$$

color intensity

reflectance

illumination

Ambient reflection

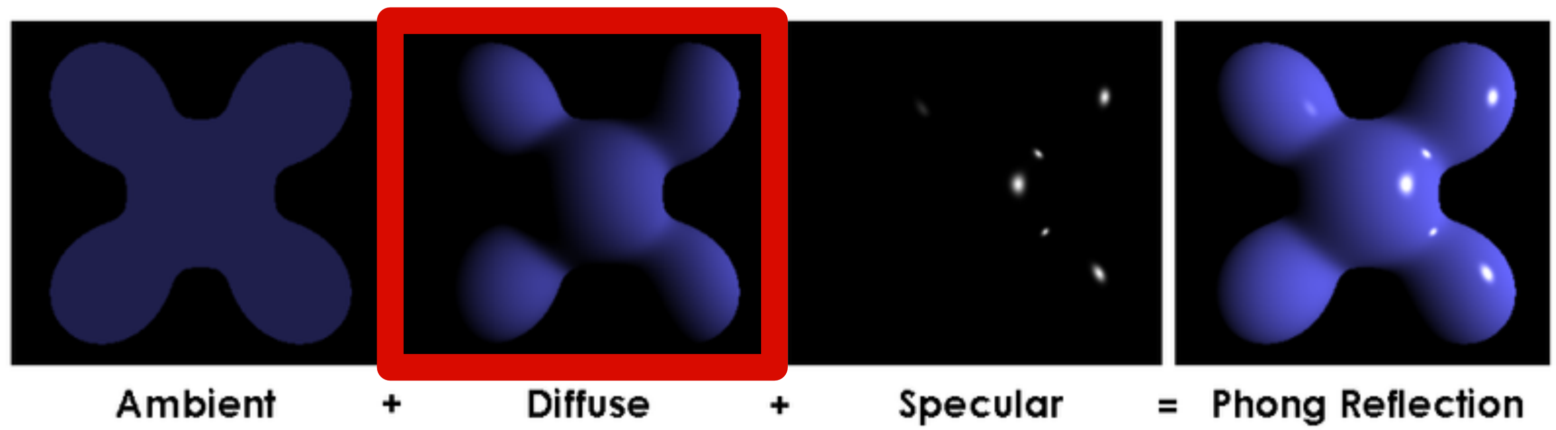


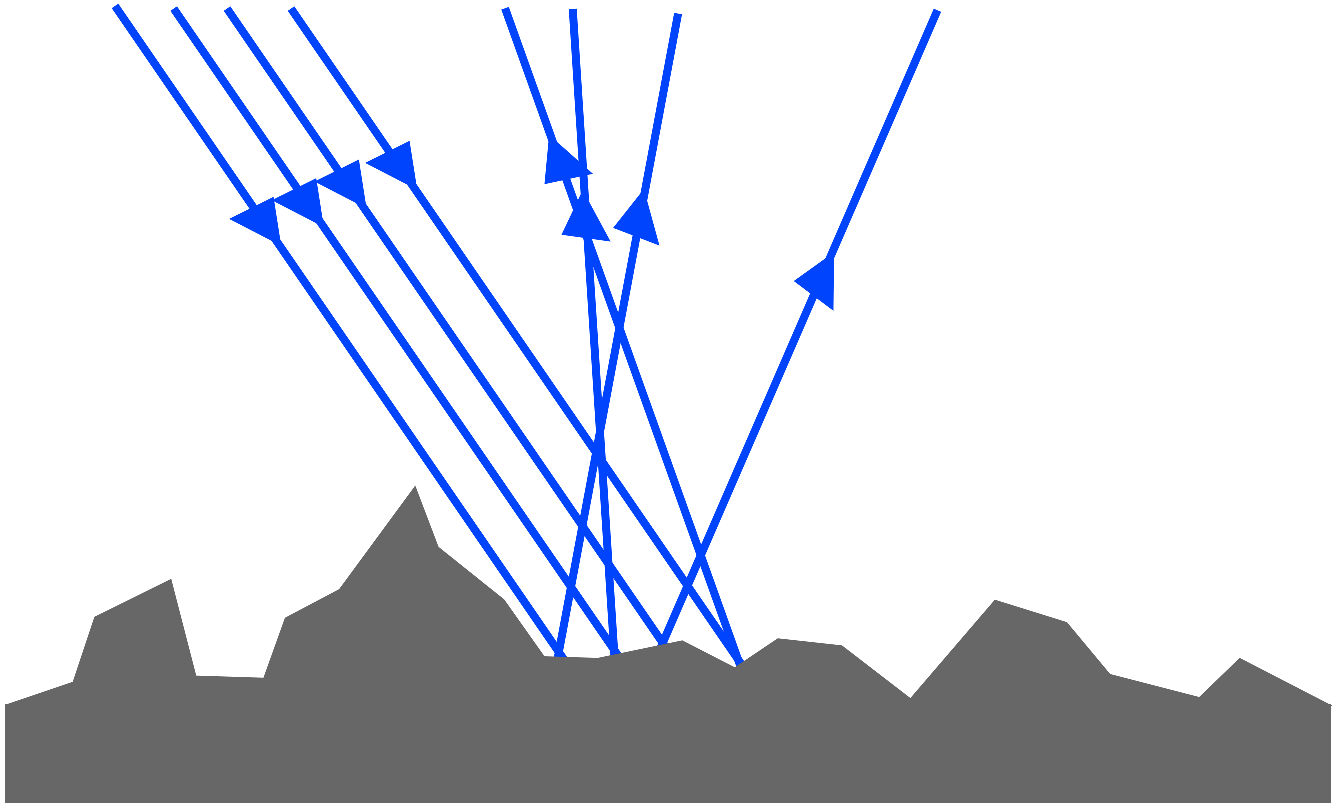
different ambient coefficients for different colors

$$I_a = R_a L_a, \qquad 0 \leq R_a \leq 1$$

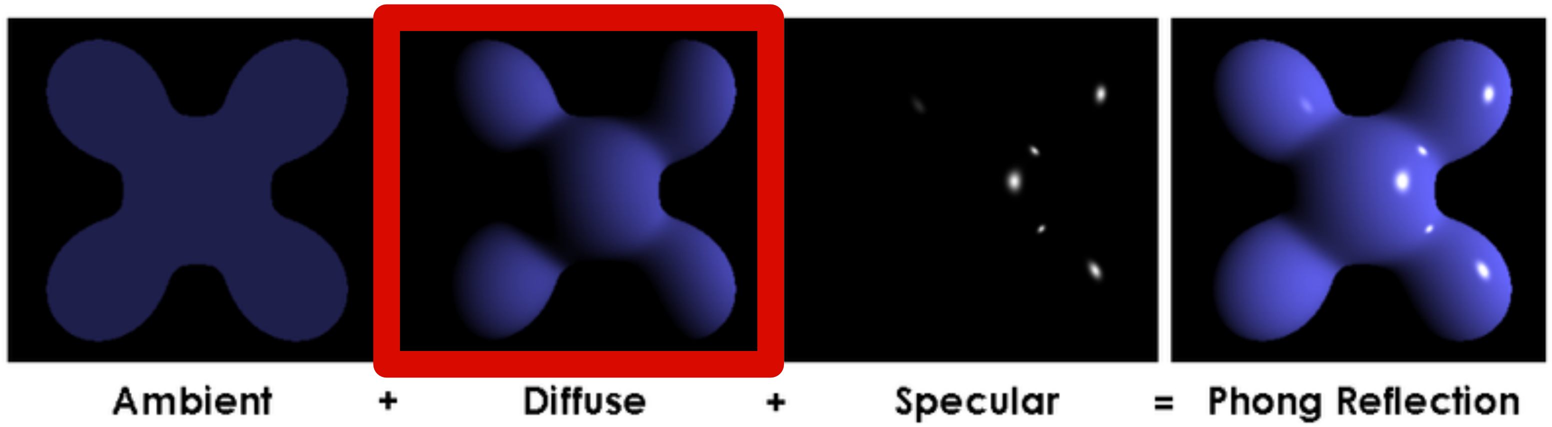
ambient reflection coefficient

Diffuse reflection





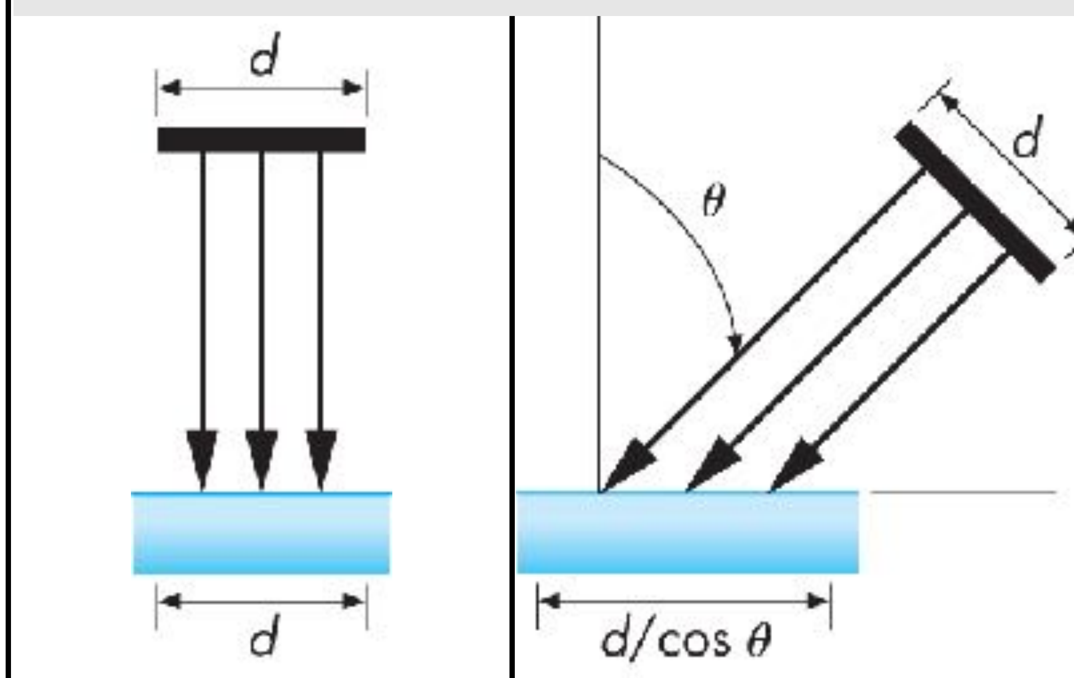
Diffuse reflection



$$I_d = R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n})$$

diffuse reflection coefficient

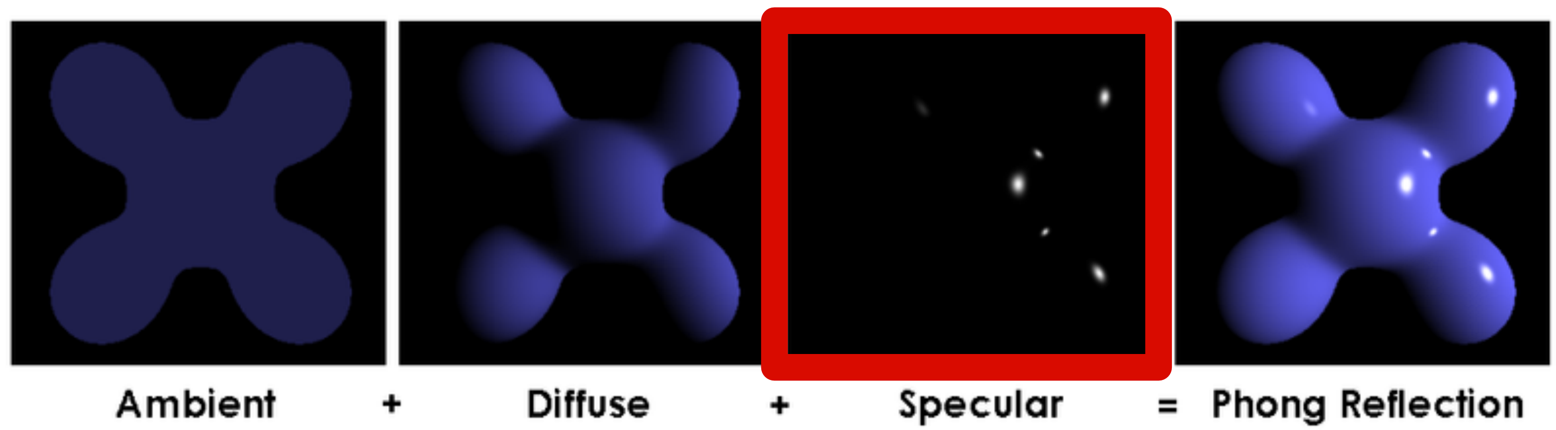
Lambert's cosine law

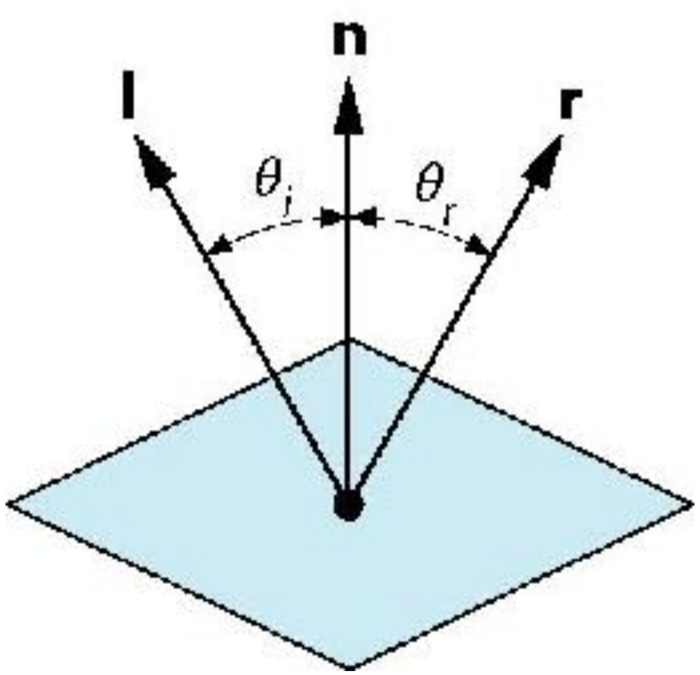


direct: maximum light intensity

indirect: reduced light intensity

Specular reflection





Ideal reflector

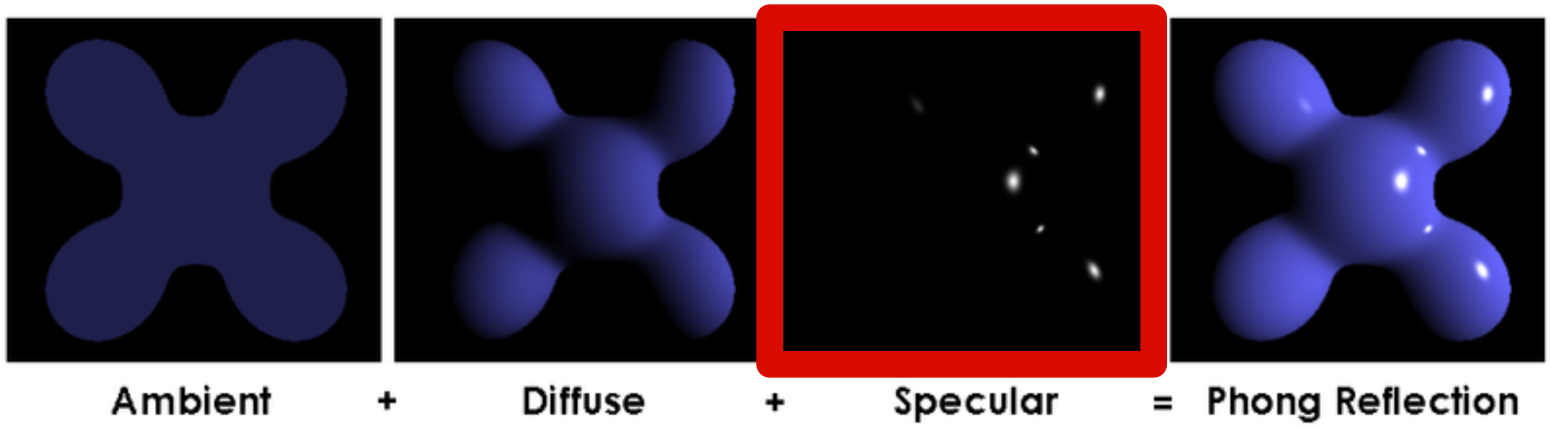
$$\theta_i = \theta_r$$

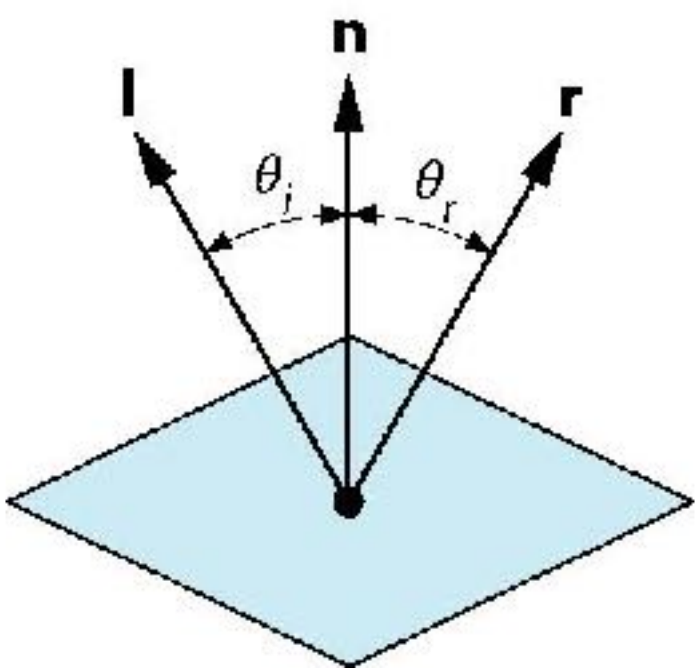
angle of incidence

angle of reflection

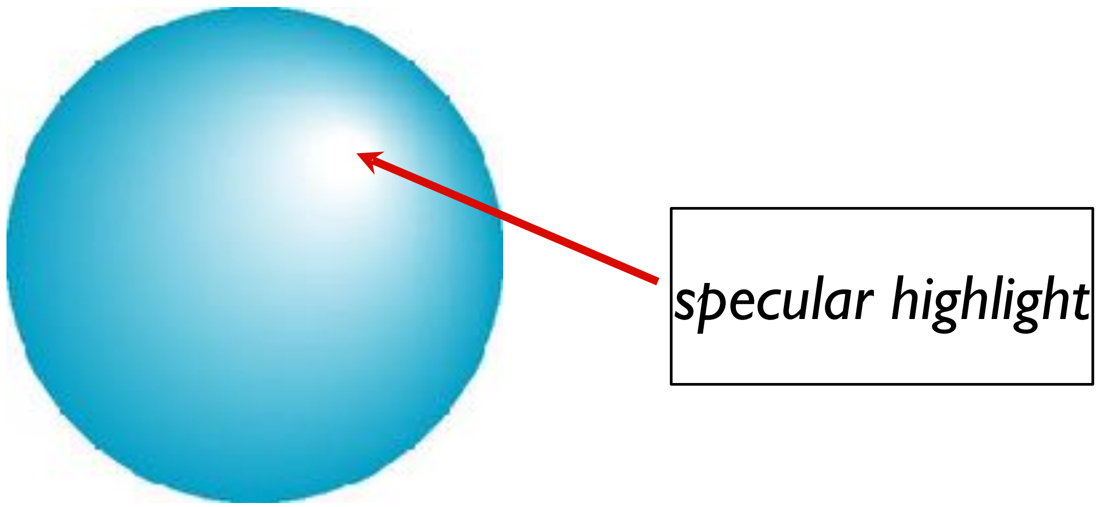
r is the mirror reflection direction

Specular reflection



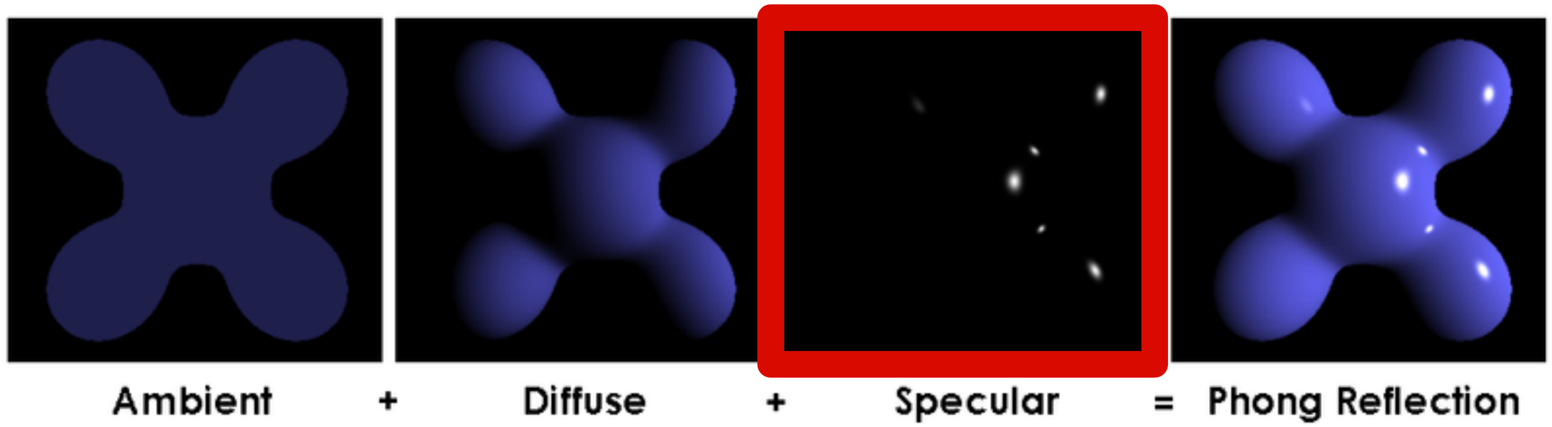


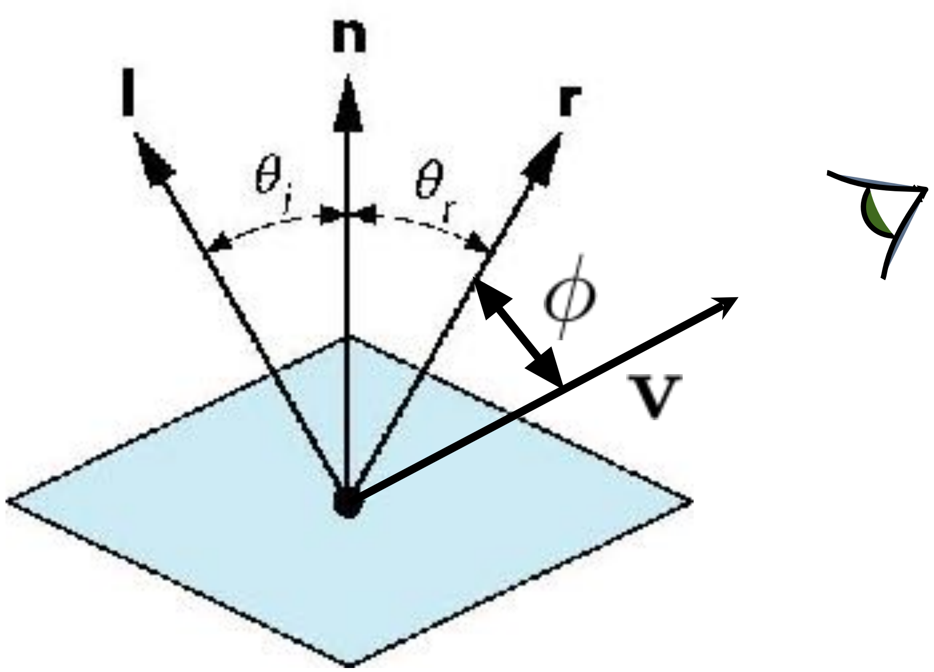
Specular surface



specular reflection is strongest in mirror reflection direction

Specular reflection





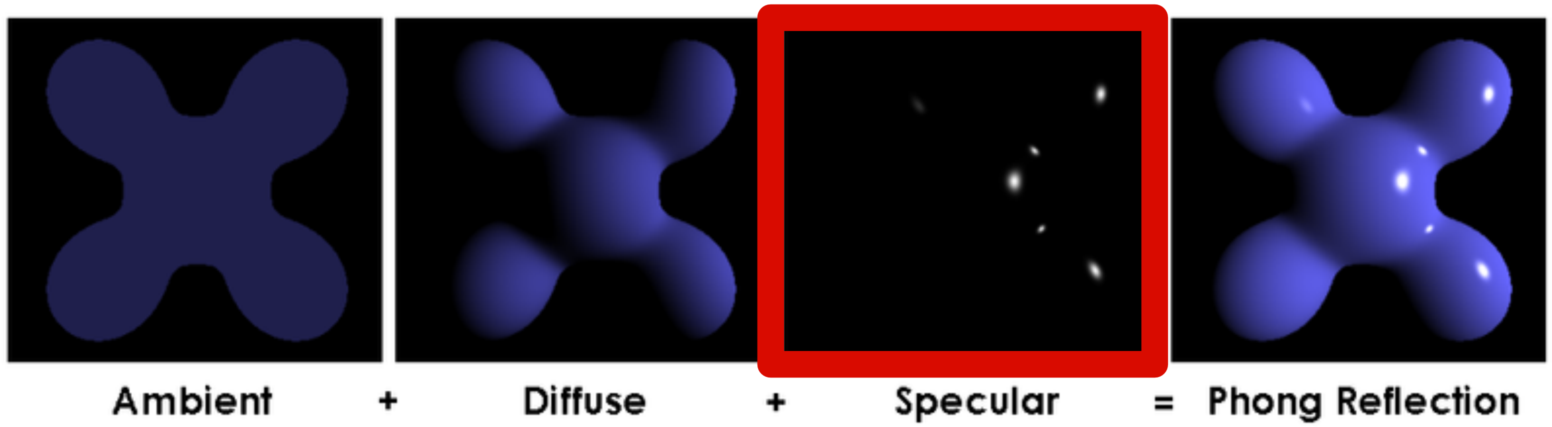
$$I_s = R_s L_s \cos^{\alpha} \phi$$

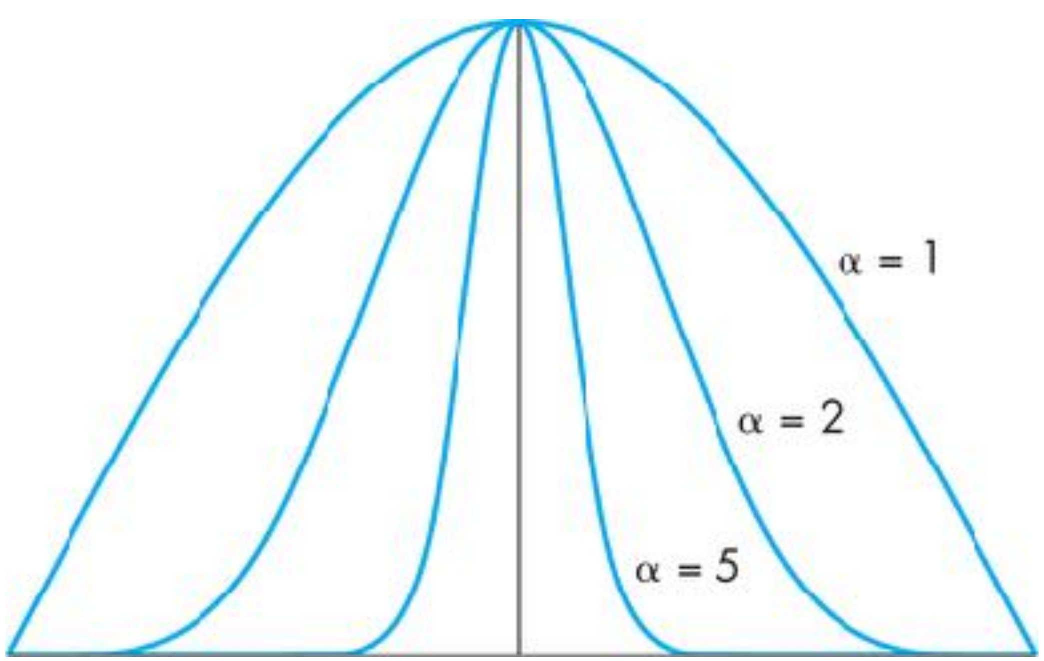
specular reflection coefficient

Phong exponent

specular reflection drops off with increasing angle ϕ

Specular reflection





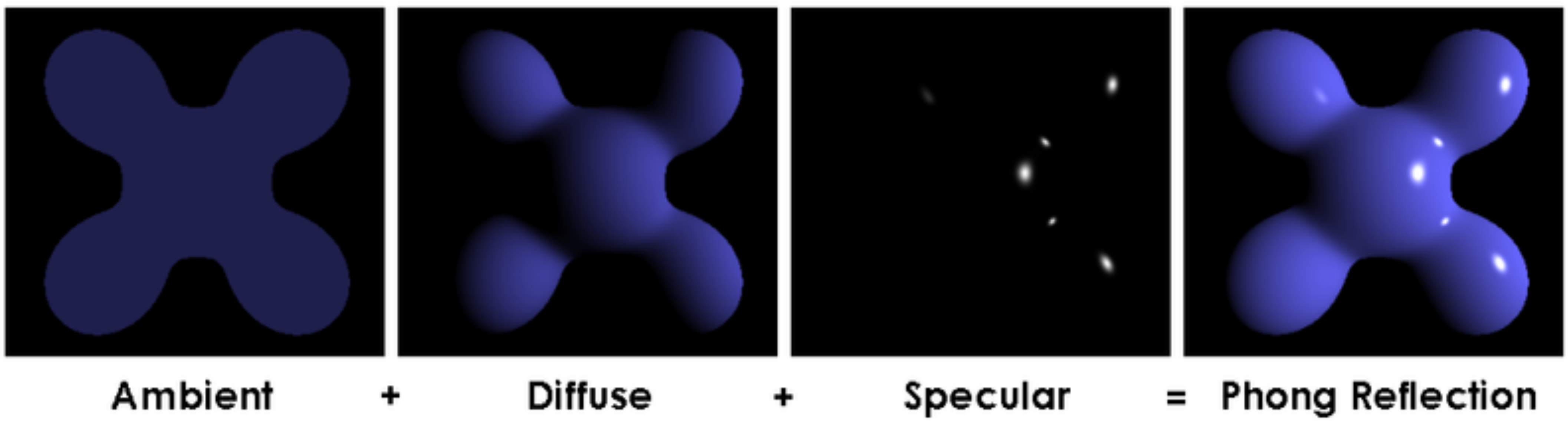
$$I_s = R_s L_s \max(0, \cos\phi)^{\alpha}$$

Phong exponent

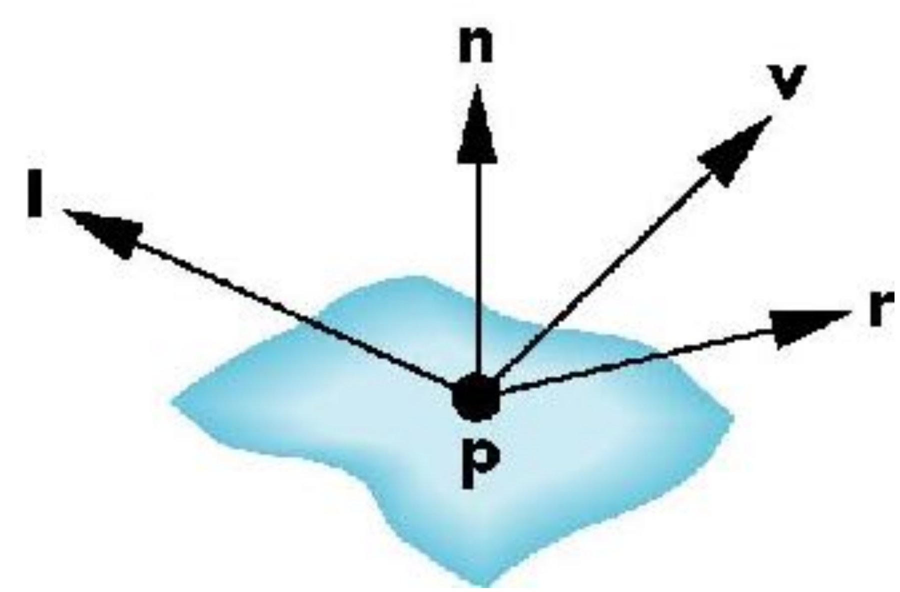
$\alpha = 5..10$ plastic

$\alpha = 100..200$ metal

Phong Reflection Model



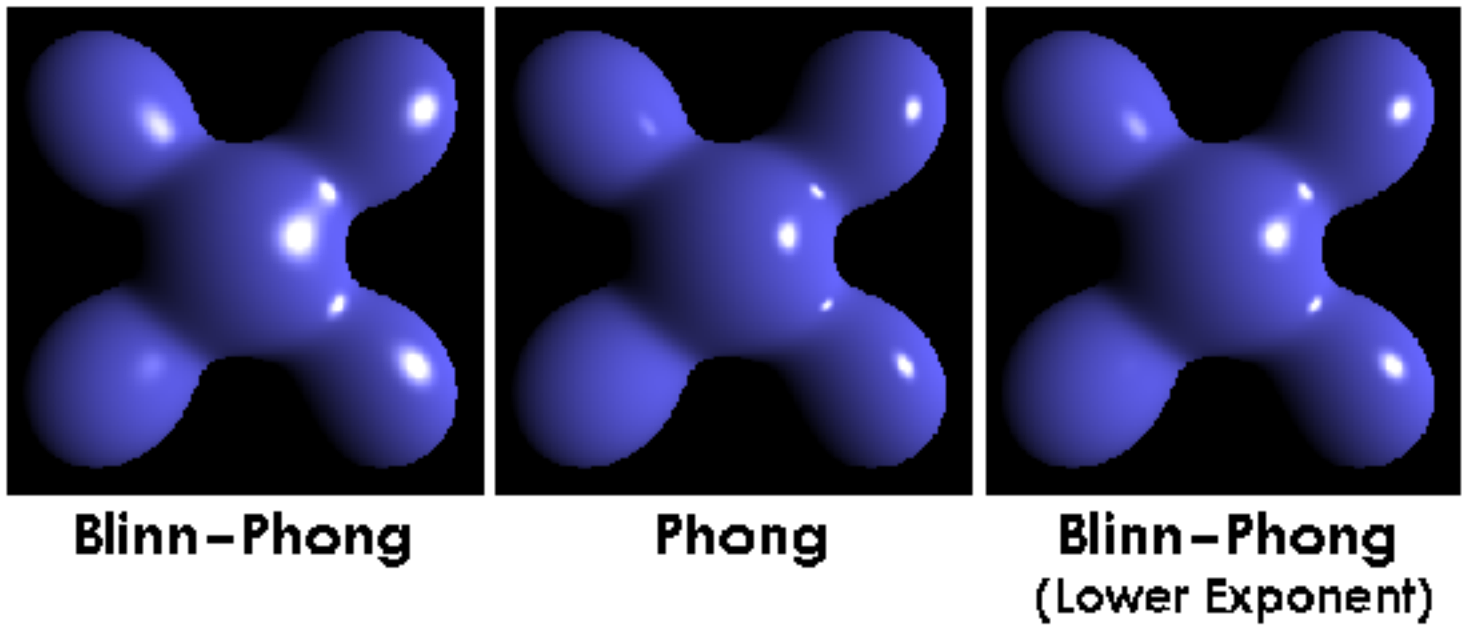
[Brad Smith, Wikimedia Commons]



$$
\begin{aligned}
I &= I_a + I_d + I_s \\
&= R_a L_a + R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n}) + R_s L_s \max(0, \mathbf{v} \cdot \mathbf{r})^{\alpha}
\end{aligned}
$$

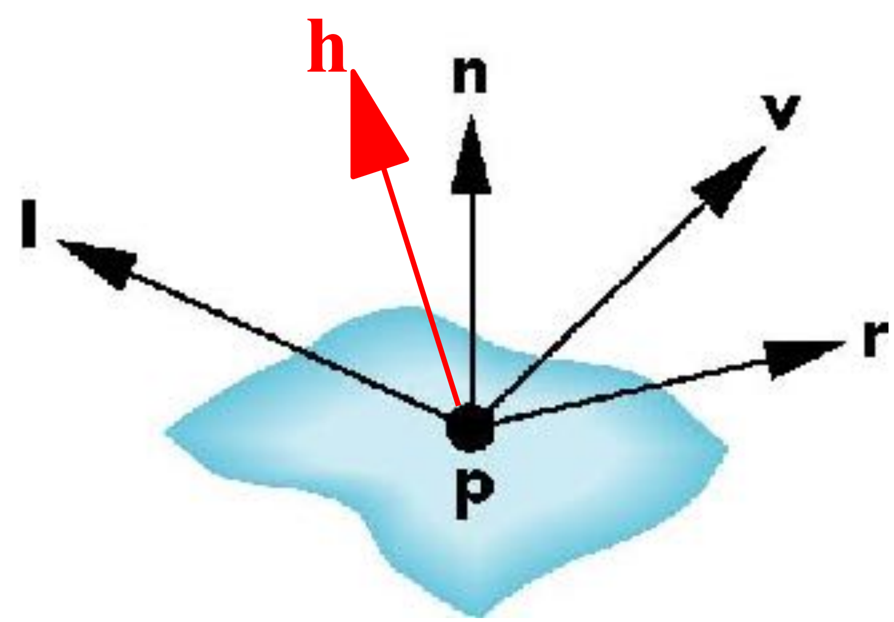
Ambient Diffuse Specular

Alternative: Blinn-Phong Model



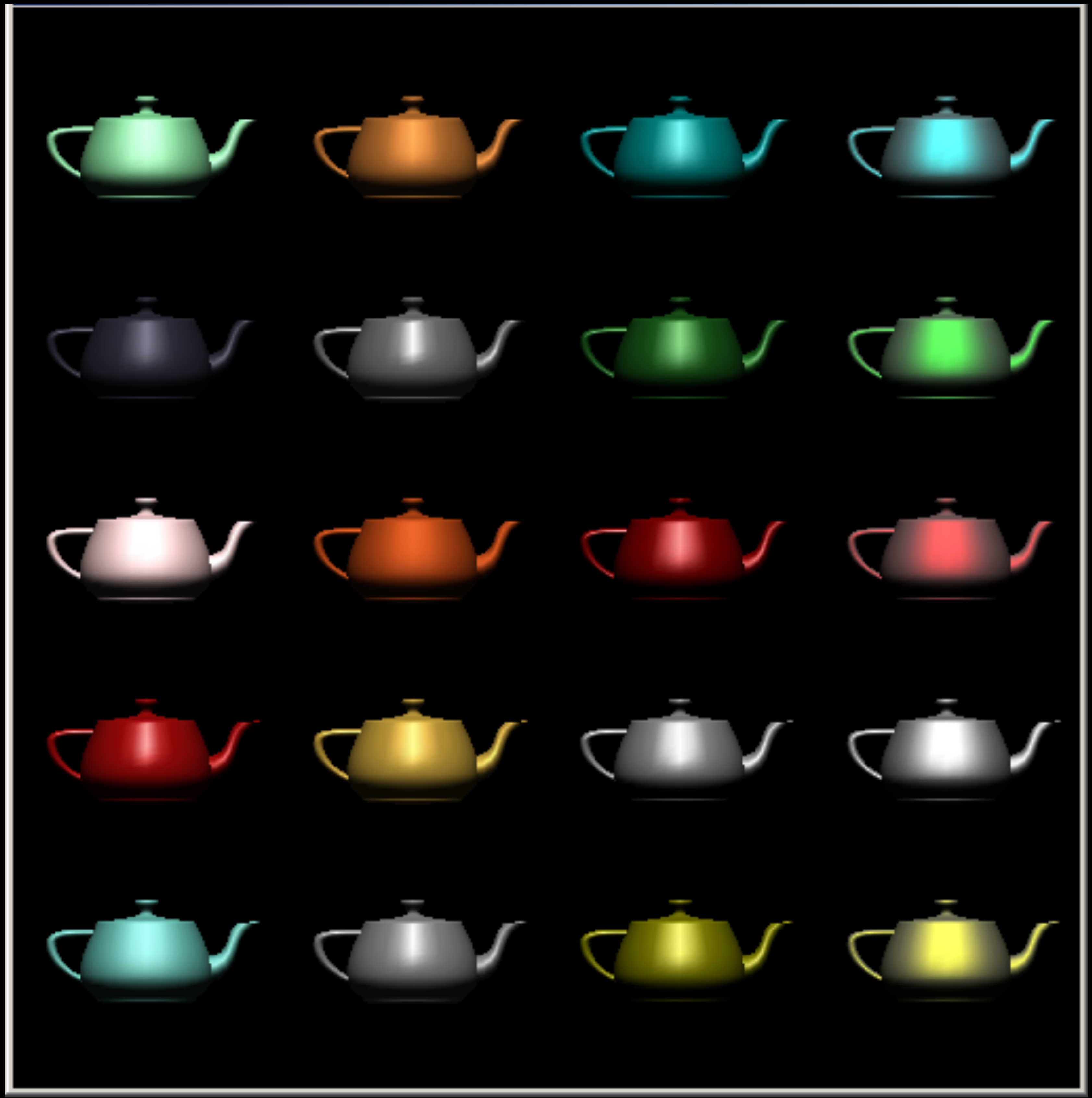
[Brad Smith, Wikimedia Commons]

halfway vector $\mathbf{h} = \dfrac{\mathbf{l} + \mathbf{v}}{|\mathbf{l} + \mathbf{v}|}$



$$
\begin{aligned}
I &= I_a + I_d + I_s \\
&= R_a L_a + R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n}) + R_s L_s \max(0, \mathbf{h} \cdot \mathbf{n})^\alpha
\end{aligned}
$$

Ambient Diffuse Specular



α

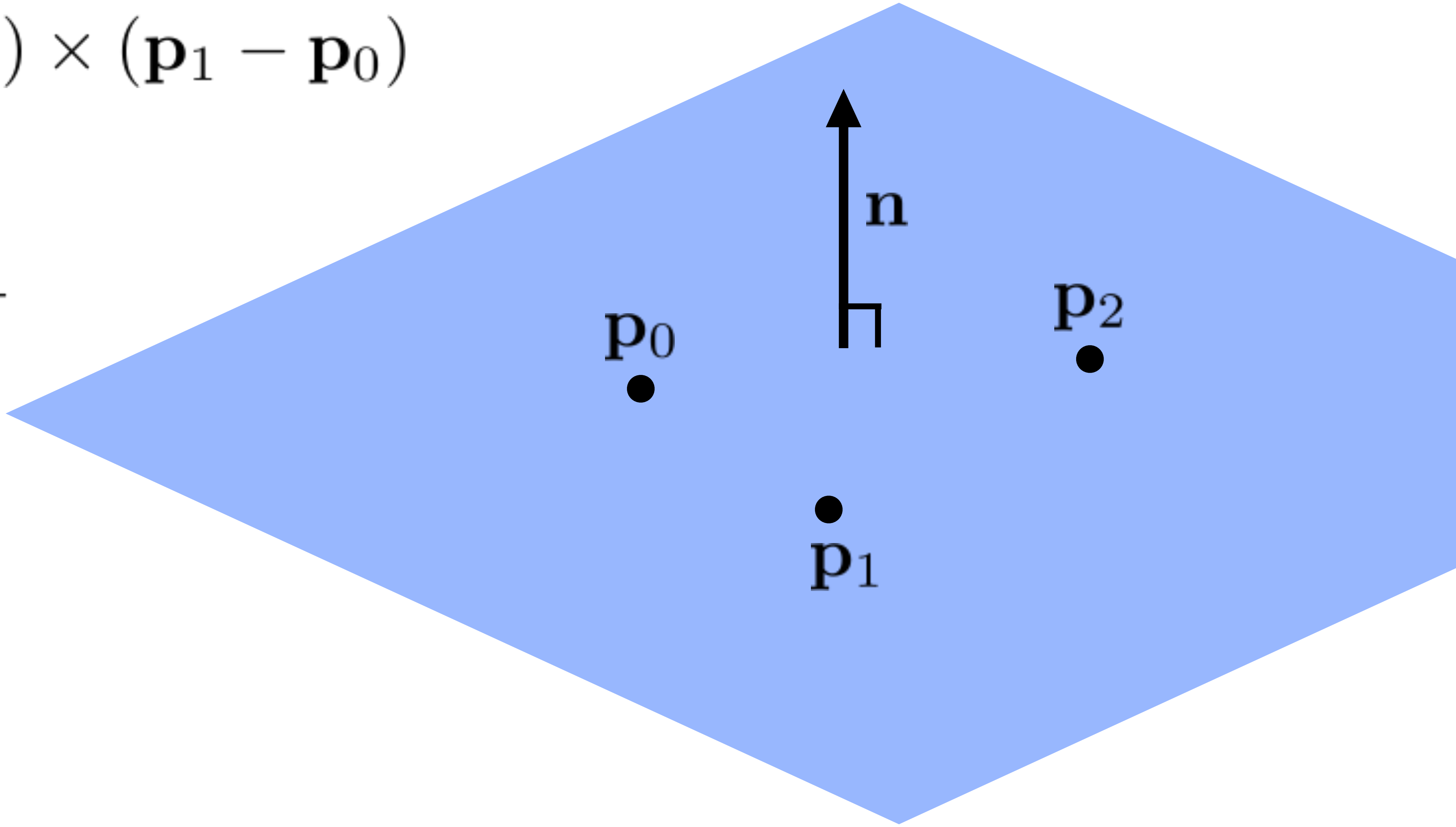
10: eggshell
100: shiny
1000: glossy
10000: mirror-like

Computing Normal Vectors

Plane Normals

$$\mathbf{v} = (\mathbf{p}_2 - \mathbf{p}_0) \times (\mathbf{p}_1 - \mathbf{p}_0)$$

$$\mathbf{n} = \frac{\mathbf{v}}{||\mathbf{v}||}$$



Implicit function normals

$$f(\mathbf{p}) = 0$$

$$\nabla f(\mathbf{p})$$

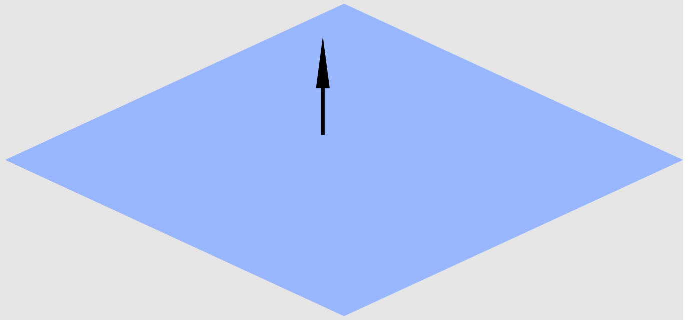
$$\nabla f = \begin{pmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \\ \frac{\partial f}{\partial z} \end{pmatrix}$$

sphere

$$\mathbf{p} \cdot \mathbf{p} - r^2 = 0$$

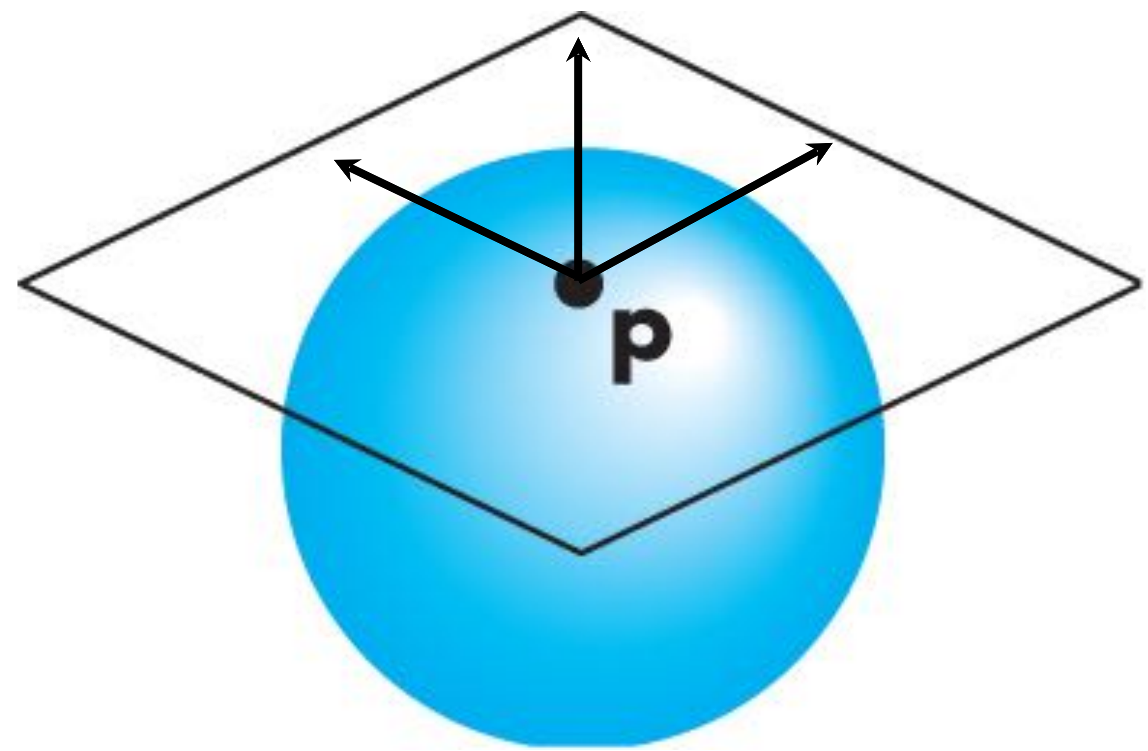
plane

$$\mathbf{n} \cdot (\mathbf{p} - \mathbf{p}_0) = 0$$



Parametric form

$$\mathbf{p}(u,v) = \begin{pmatrix} x(u,v) \\ y(u,v) \\ z(u,v) \end{pmatrix}$$



tangent vectors $\dfrac{\partial \mathbf{p}}{\partial u} \quad \dfrac{\partial \mathbf{p}}{\partial v}$

normal $\dfrac{\frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v}}{||\frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v}||}$