CS130 : Computer Graphics

Lecture 13: Lighting and Shading (cont.)

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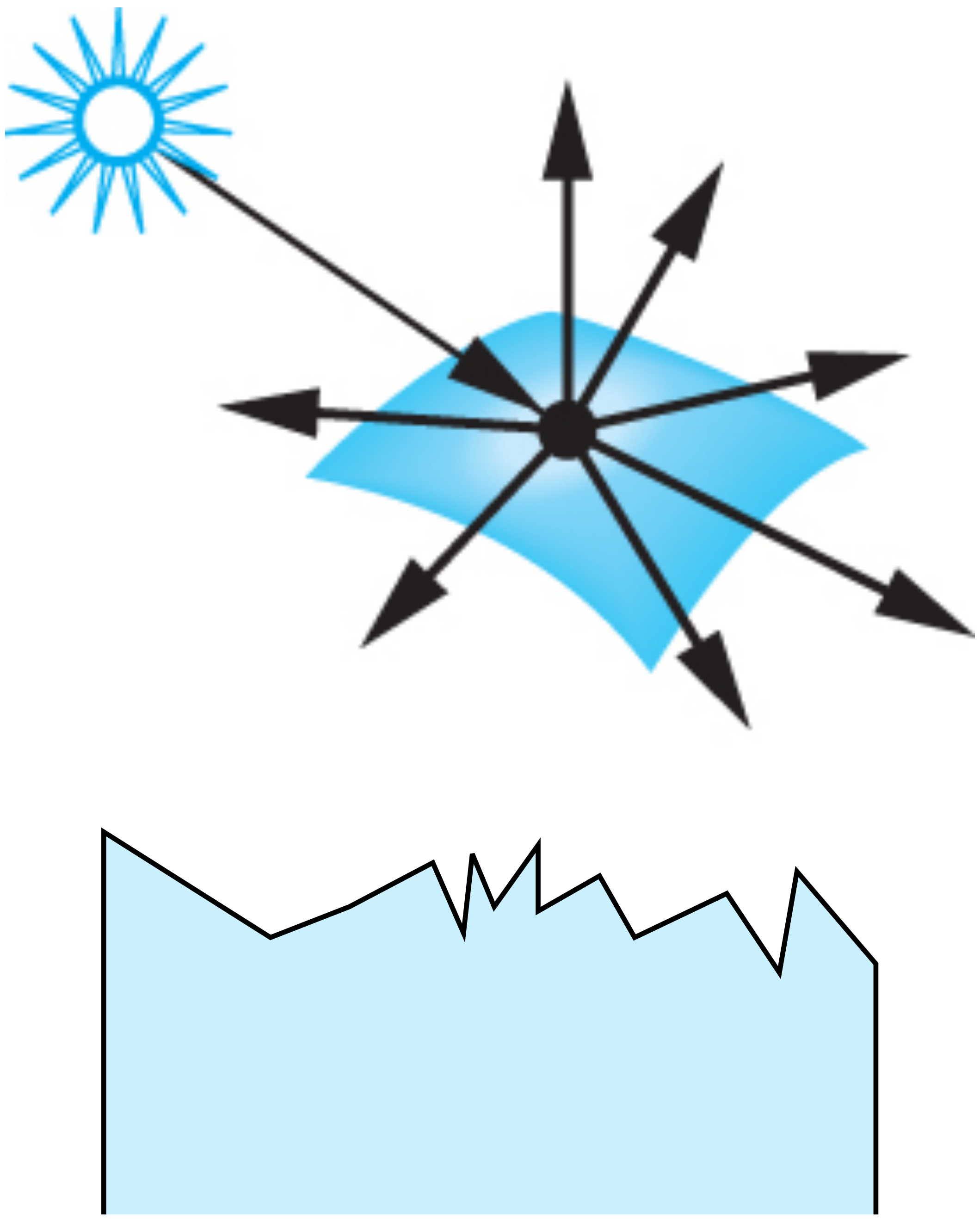
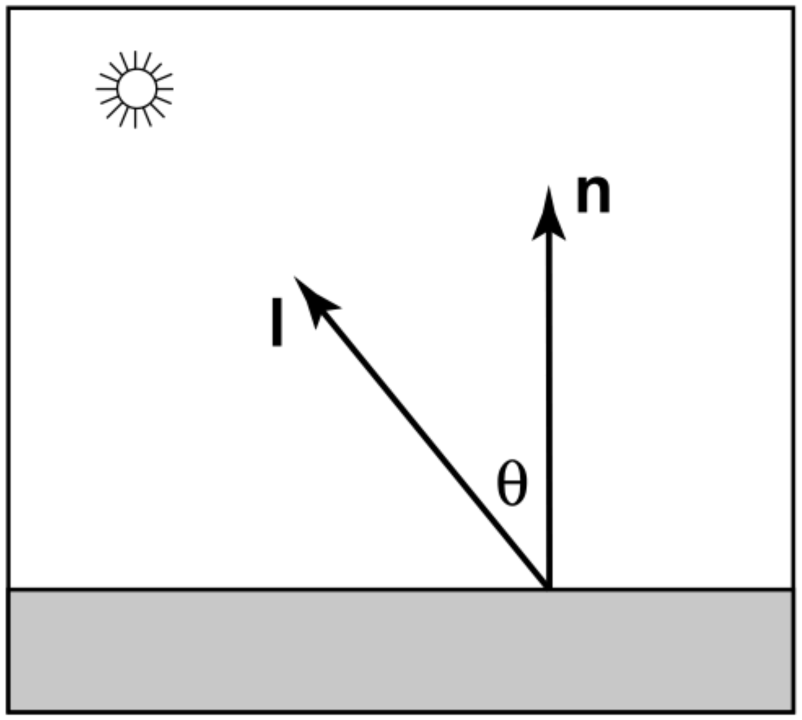
Lambertian Reflection Model

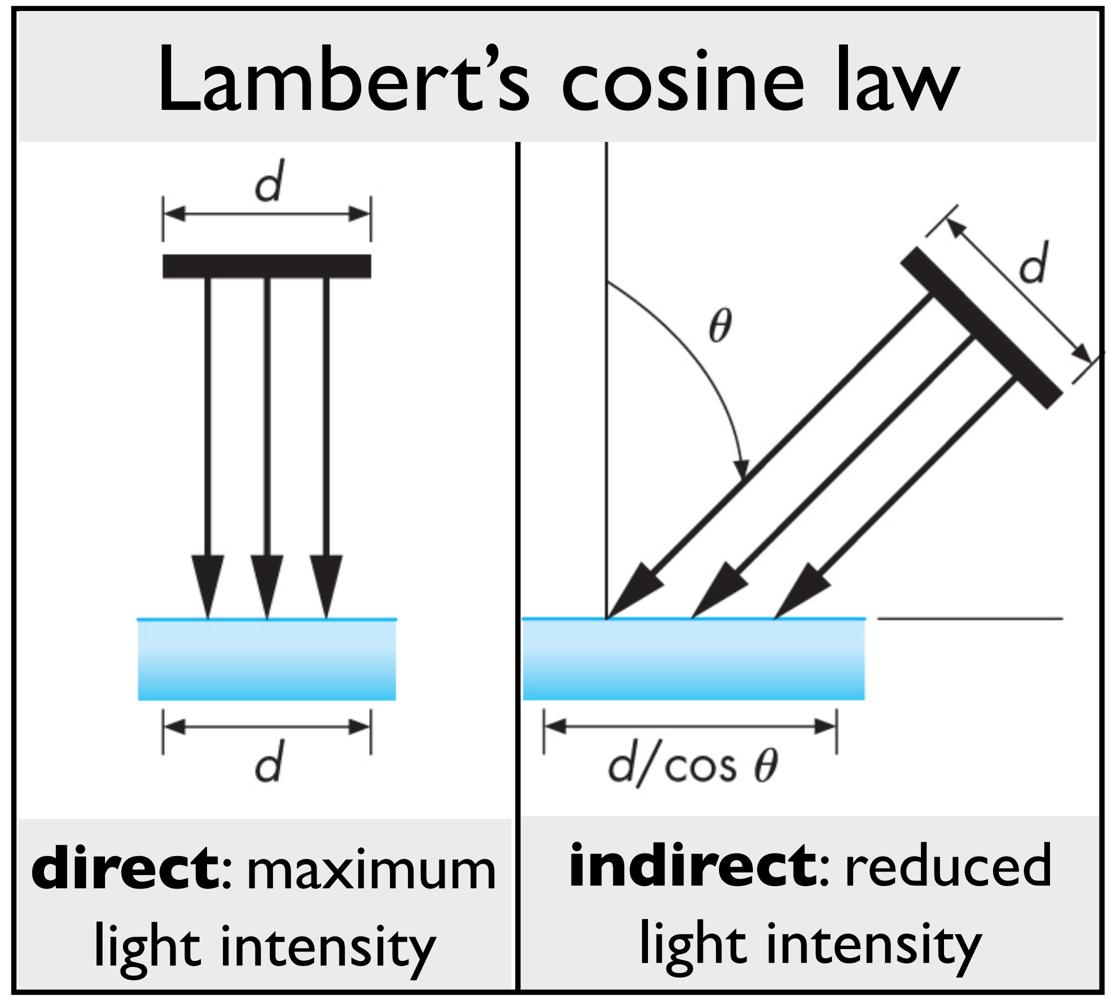


http://www.andreafisherpottery.com/cgi-bin/artistlnk.cgi?Jody_Folwell

The **Lambertian reflection model** is good for **diffuse** surfaces (those with a rough surface). The bottom part of the vase could be rendered with the Lambertian reflection model, since it is matte in appearance. The top part of the vase is reflective and has specular highlights.

Lambertian Reflection Model



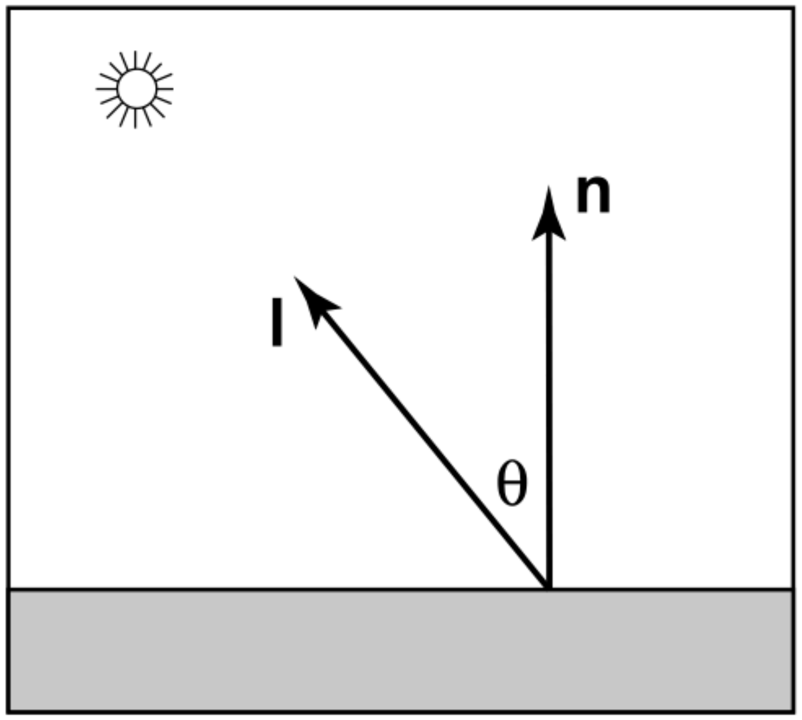


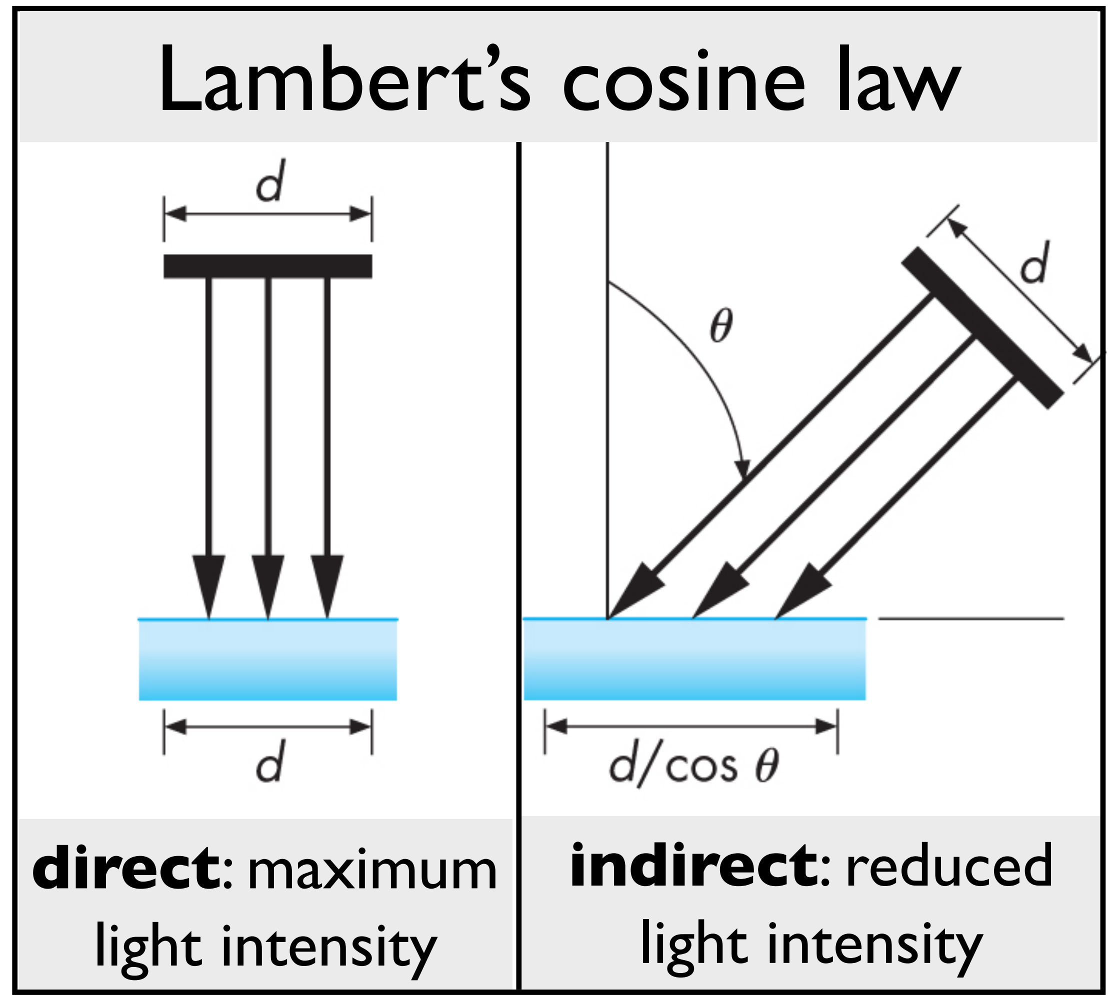
$$I \propto \cos\theta$$

color intensity

Lambert's cosine law says that the color intensity should be proportional to the cosine of the angle between l and n. The light with length d has a certain amount of light energy associated with it. If the light is tilted relative to the surface, the same amount of light energy shines on **more** surface area. Therefore, the intensity of the light is less per unit surface area.

Lambertian Reflection Model

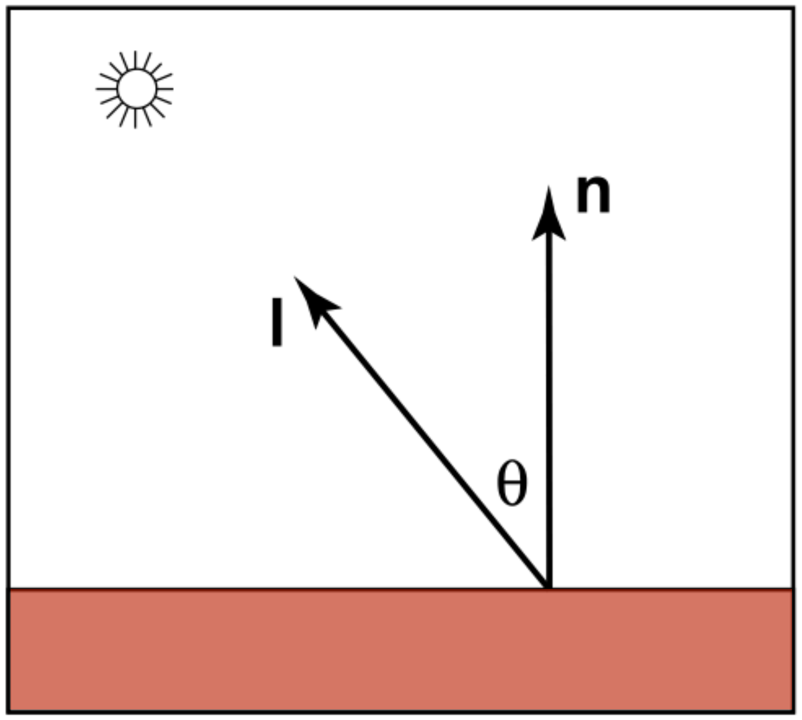


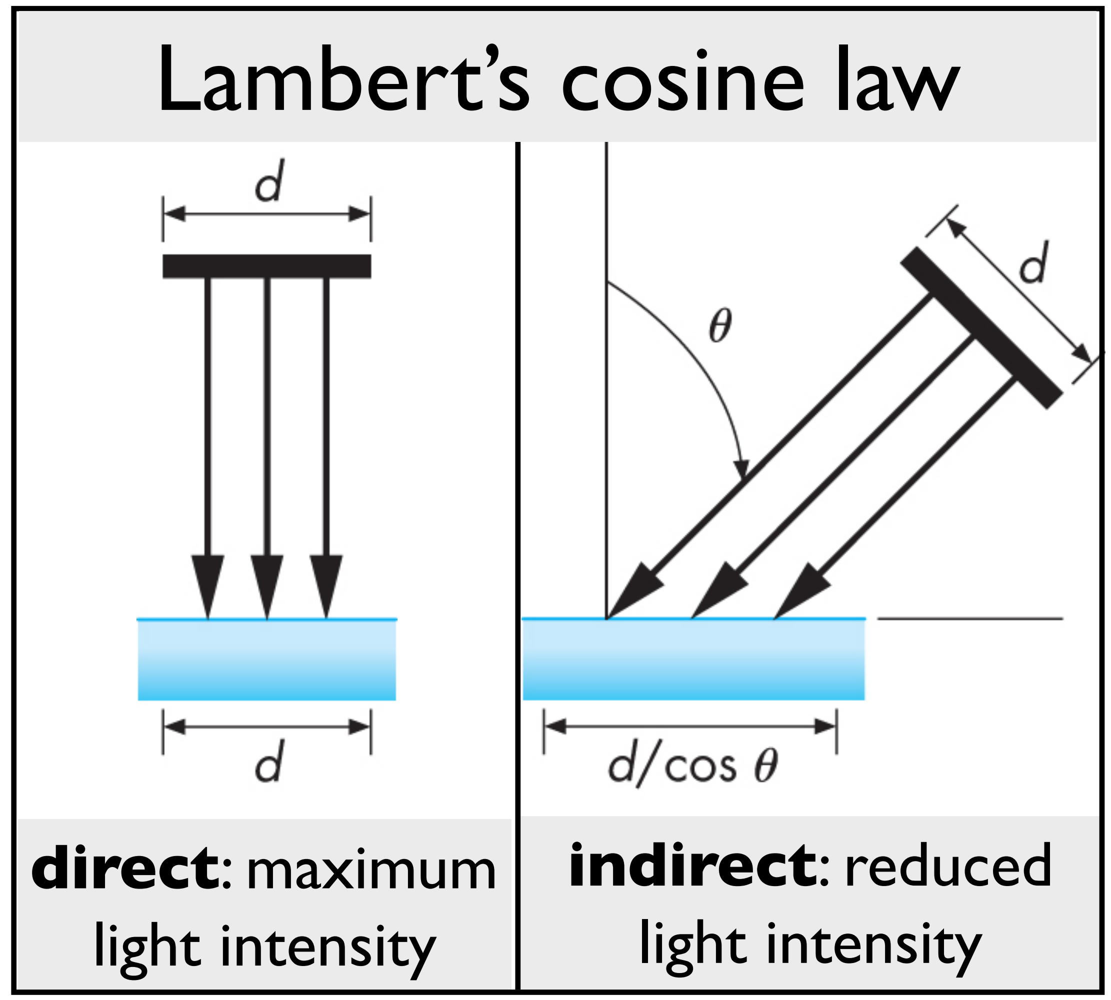


$$I \propto \mathbf{n} \cdot \mathbf{l}$$

cos theta = **n . l**

Lambertian Reflection Model





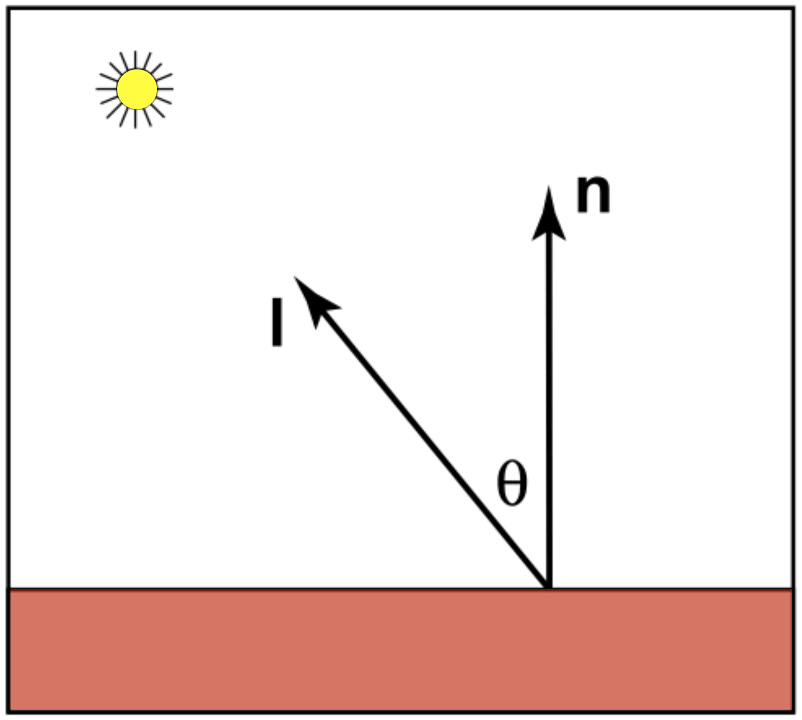
$$I \propto R\mathbf{n} \cdot \mathbf{l}$$

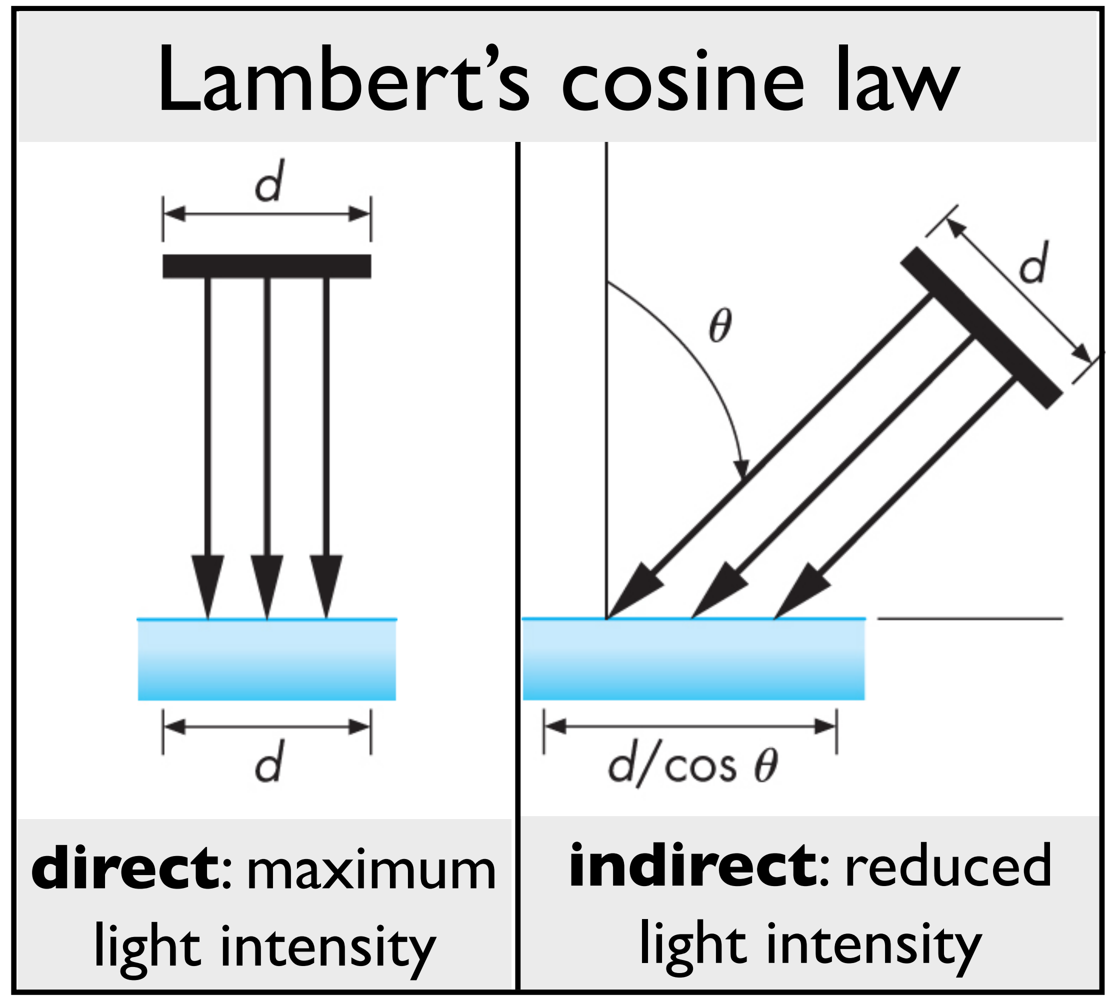
color intensity

reflectance

the color intensity is also going to be proportional to the reflectance of the object in that color channel

Lambertian Reflection Model





illumination

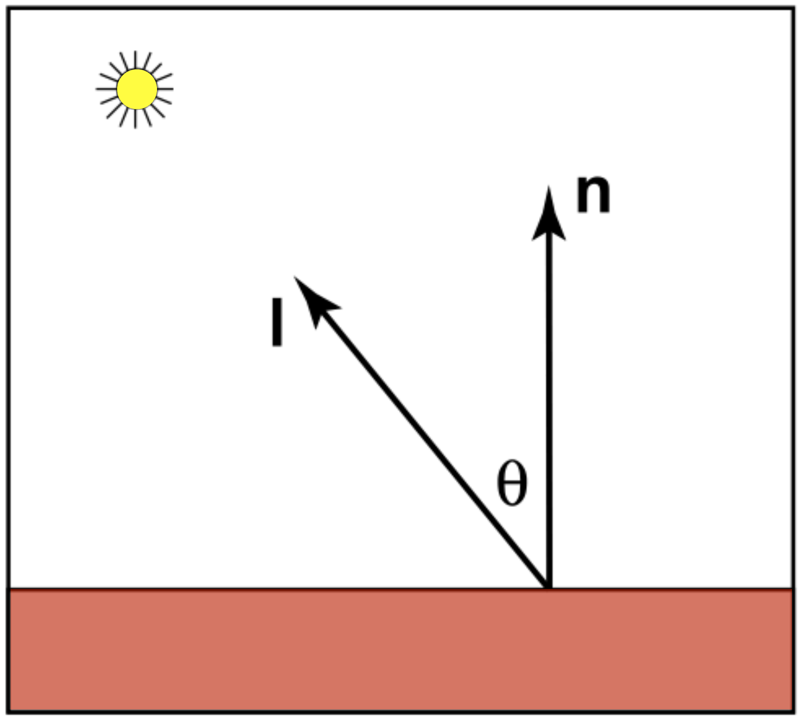
$$I = LR\mathbf{n}\cdot\mathbf{l}$$

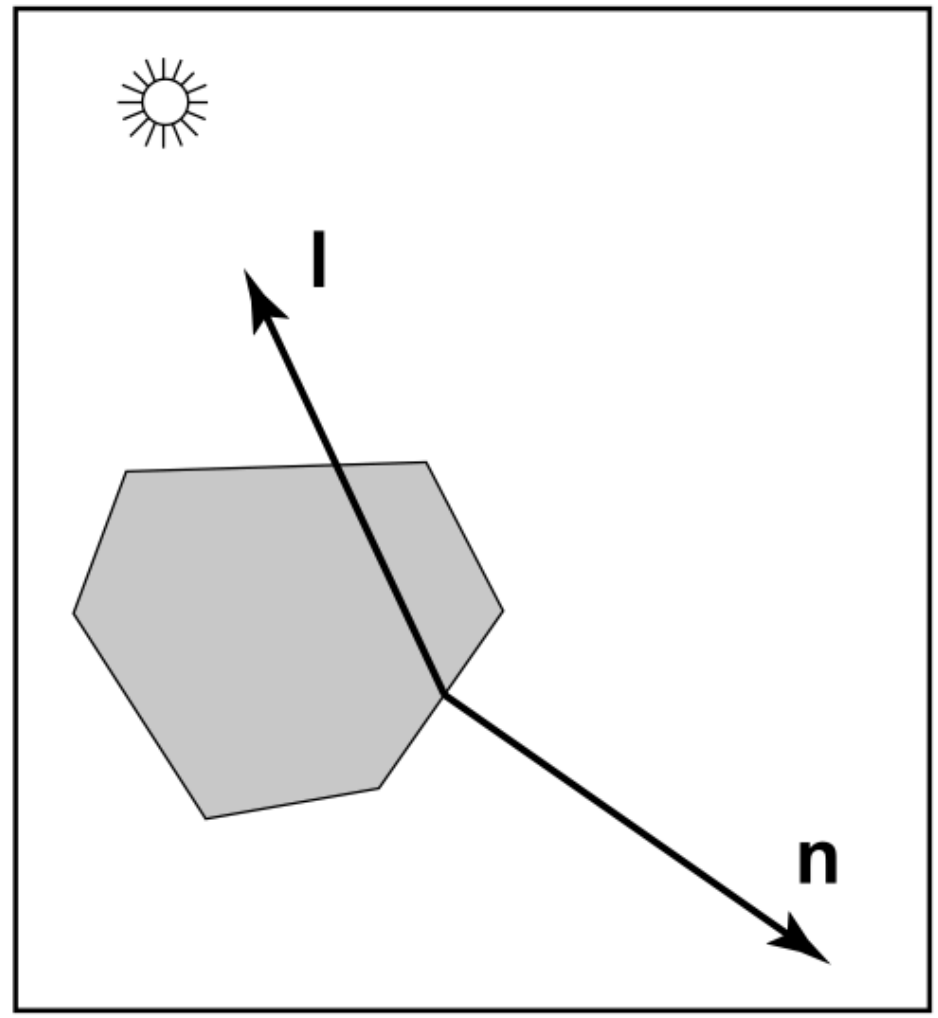
color intensity

reflectance

and it will be proportional to the light intensity

Lambertian Reflection Model

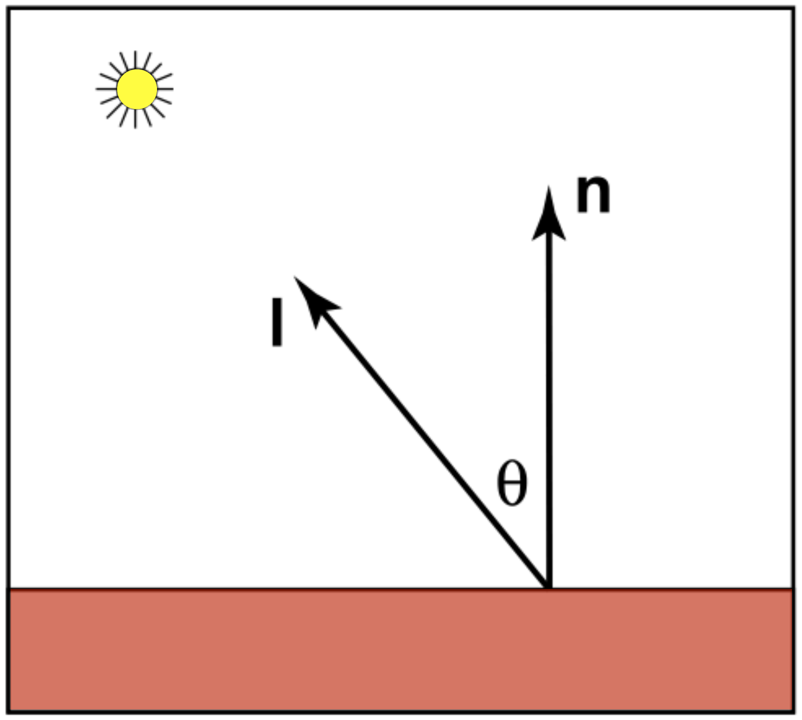




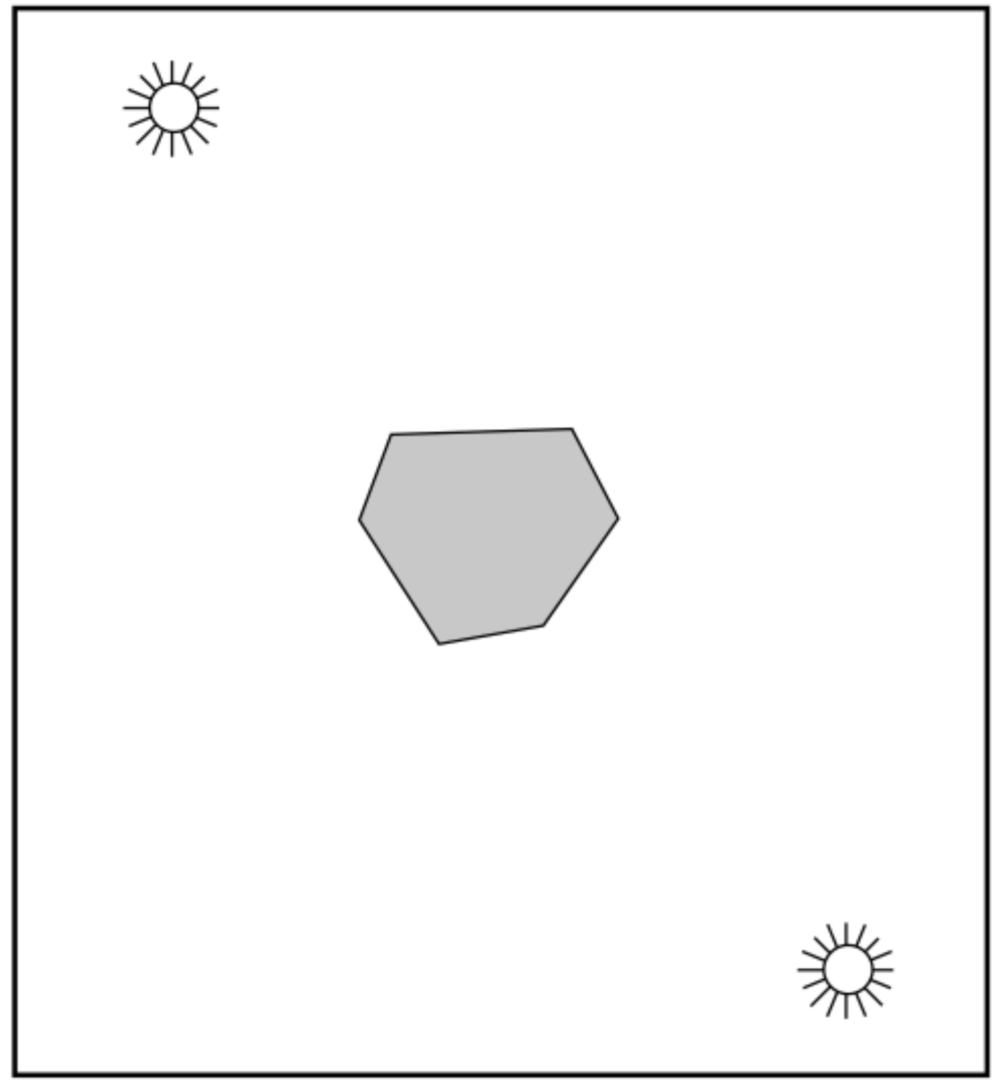
$$I = LR\max(0, \mathbf{n} \cdot \mathbf{l})$$

the cosine is negative if the angle is more than 90 degrees. In this case, the face points away from the light. If we don't modify the formula we'll get a negative intensity. We can put in the max to ensure that if the face points away, it won't be lit by the light.

Lambertian Reflection Model



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



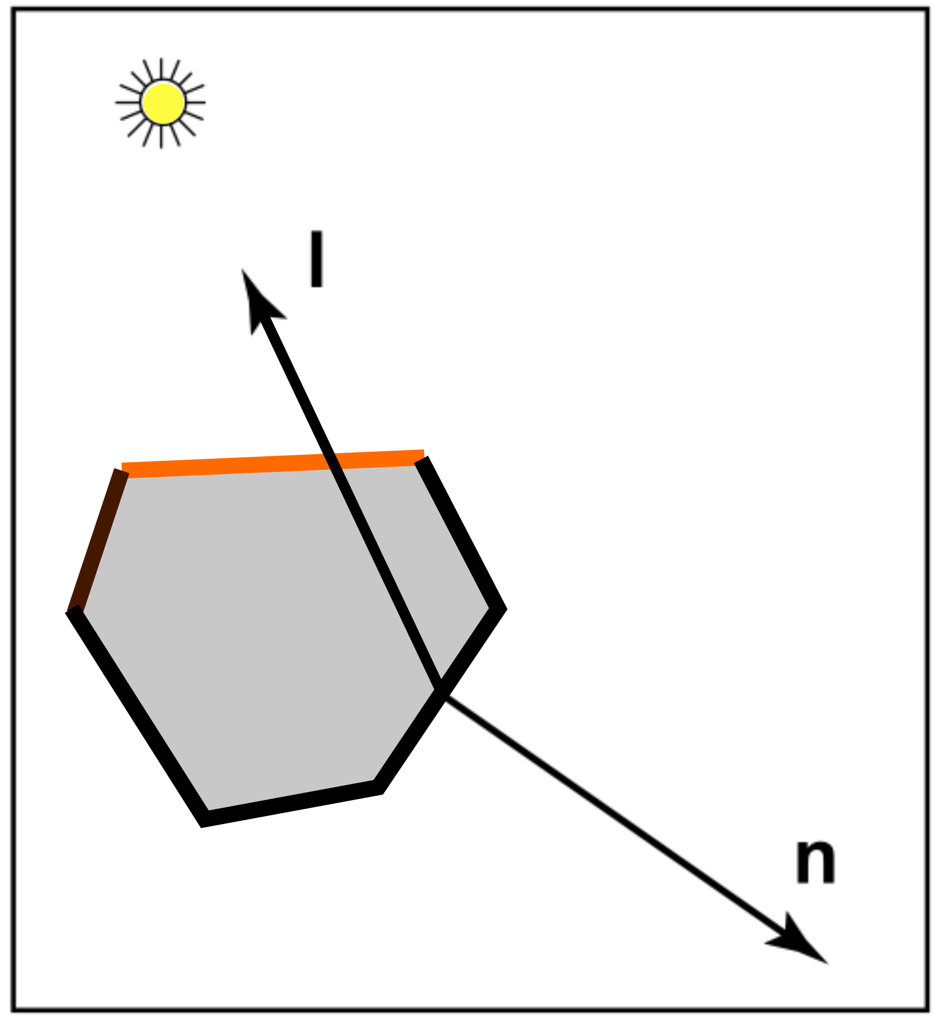
two-sided lighting

An alternative is to take the absolute value. This is equivalent to having another light on the other side of the object exactly opposite the first.

Ambient Reflection

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

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

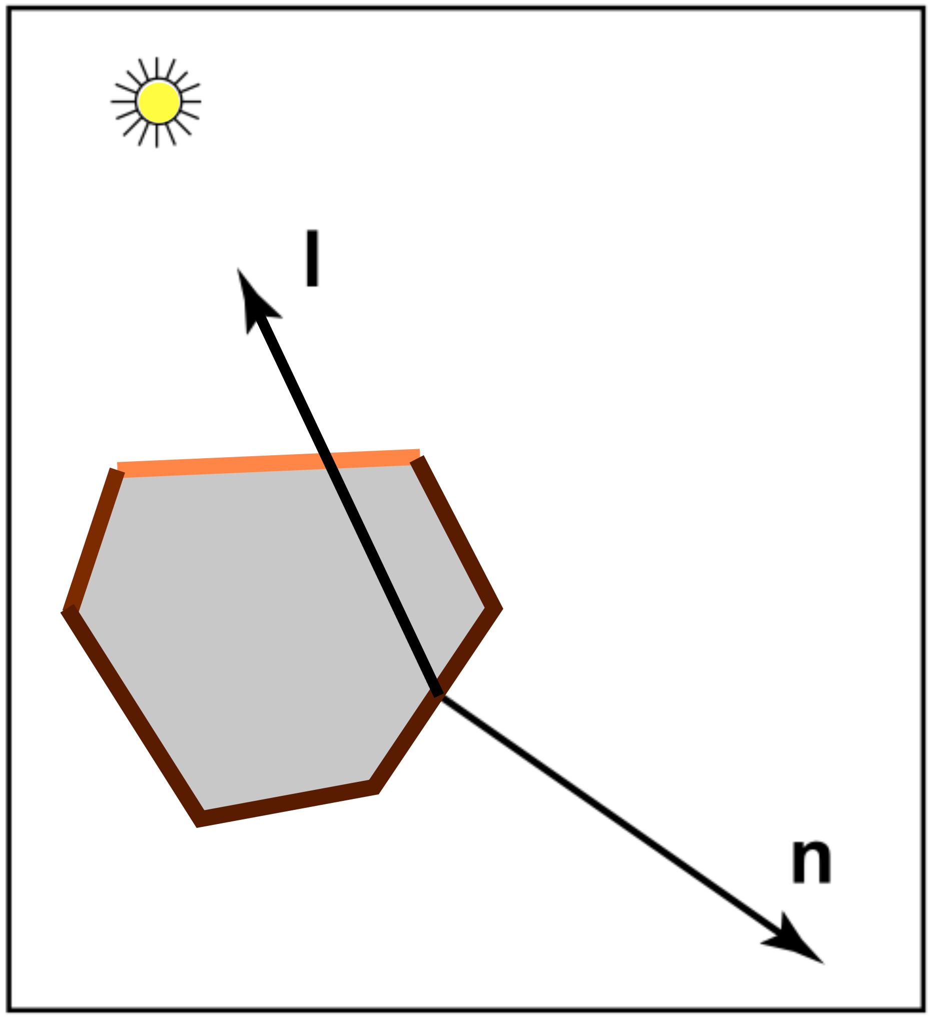


Problem: surfaces facing away from the light will be totally black.

Ambient Reflection

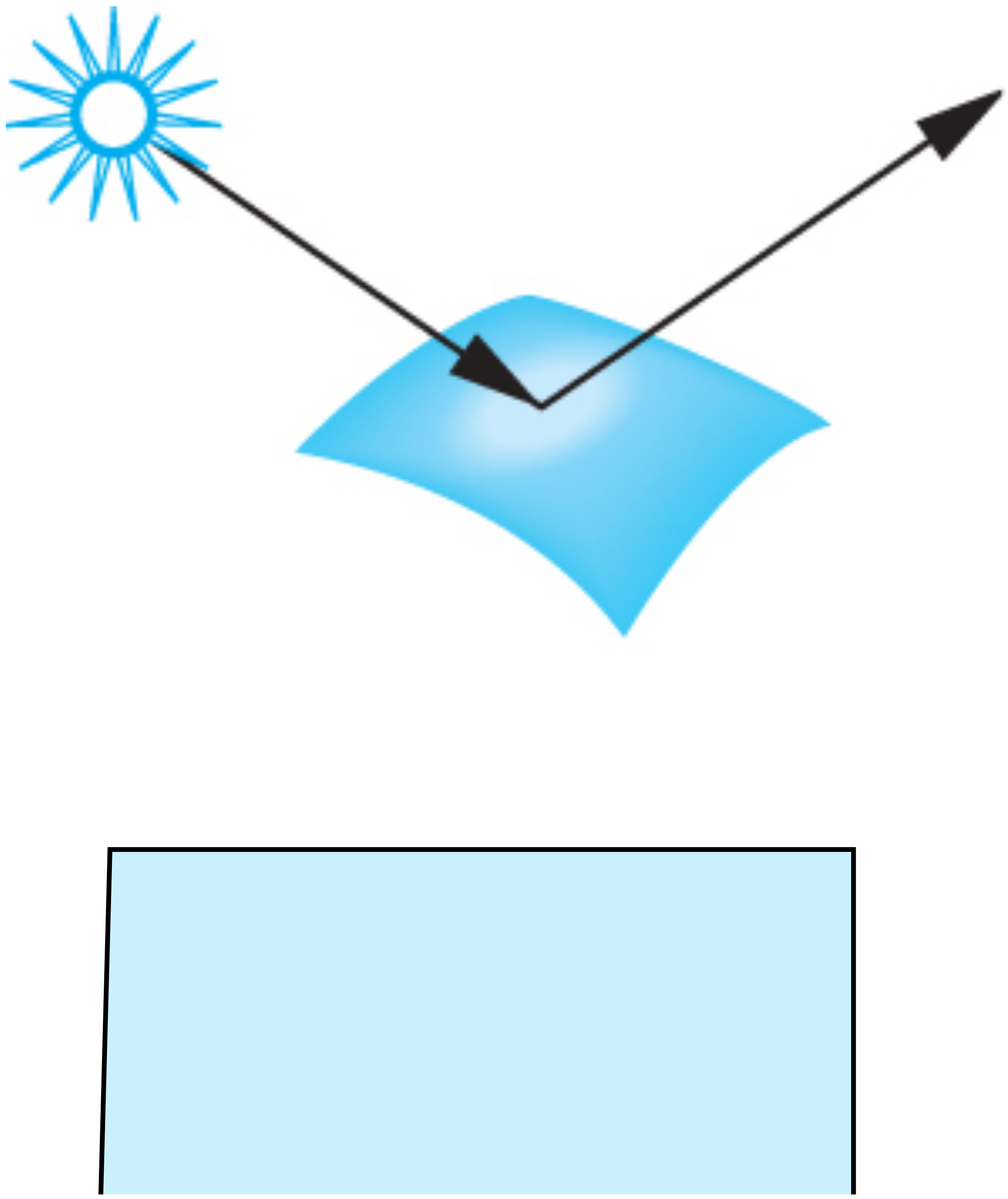
$$I = L_a R_a + L_d R_d \max(0, \mathbf{n} \cdot \mathbf{l})$$

All surfaces get same amount of ambient light



Problem: surfaces facing away from the light will be totally black – ambient light mitigates this by adding some light everywhere

Phong Reflection Model



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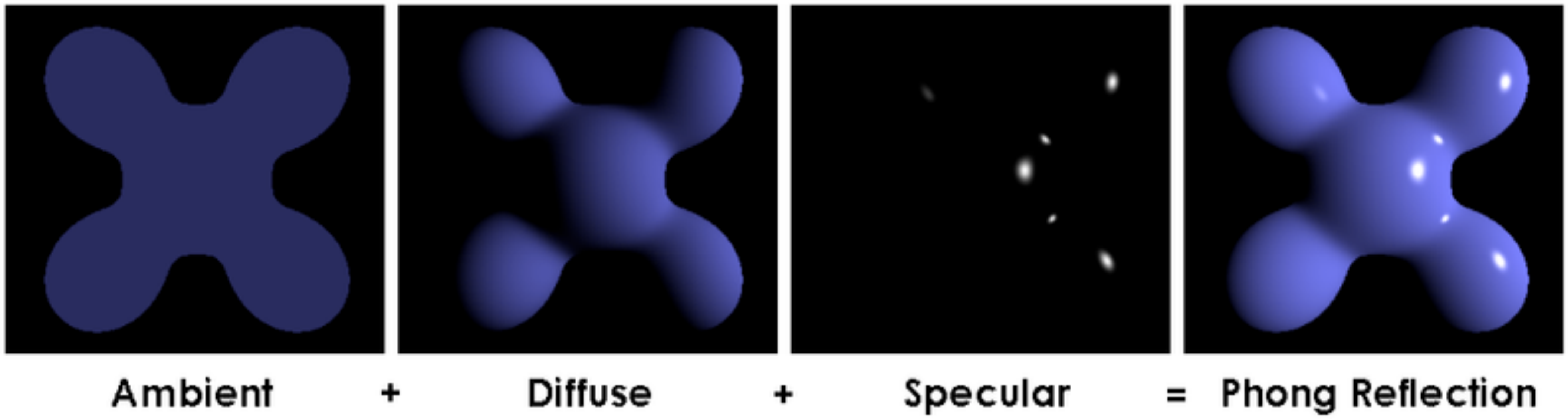
The **Phong reflection model** combines the Ambient and Lambertian reflections with a **specular** reflection to capture highlights such as the white highlight seen on the shiny part of the vase

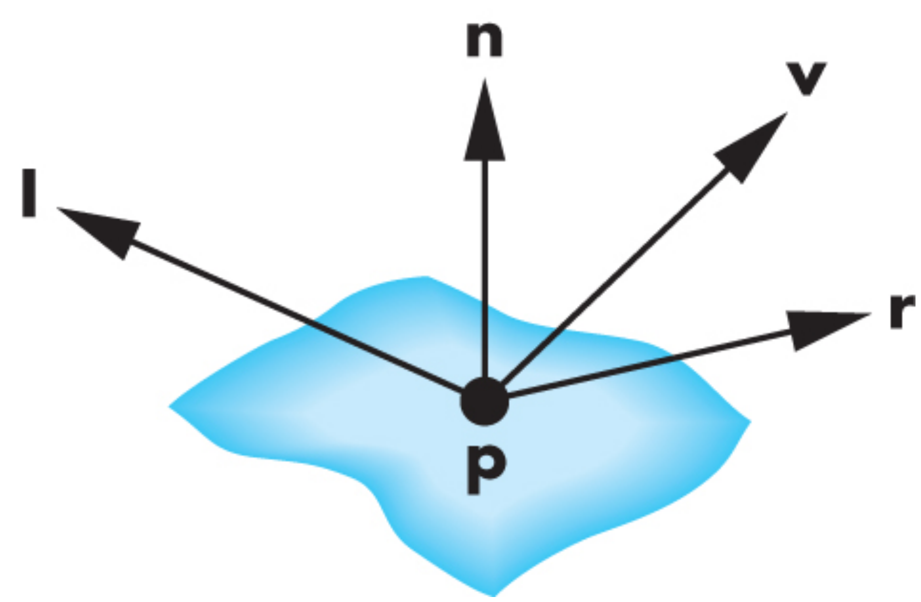
The highlight is a reflection of the light and it is the color of the light.

Phong Reflection Model



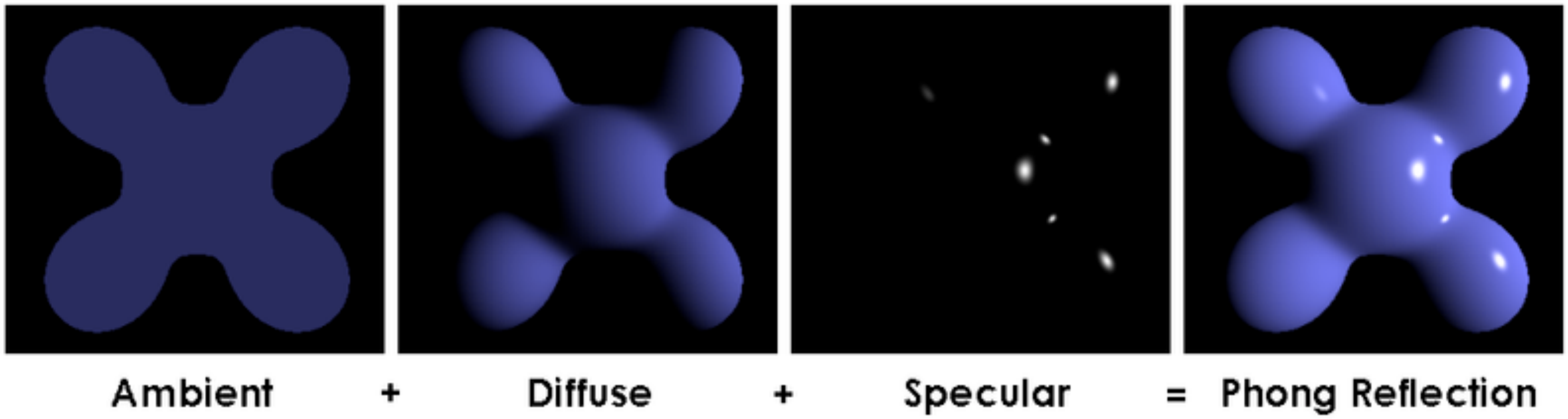
[Brad Smith, Wikimedia Commons]

- efficient, reasonably realistic
- 3 components
- 4 vectors



- **l** to light source
- **n** surface normal
- **v** to viewer
- **r** perfect reflector (function of **n** and **l**)

Phong Reflection Model



[Brad Smith, Wikimedia Commons]

$$I = I_a + I_d + I_s = L_a R_a + L_d R_d + L_s R_s$$

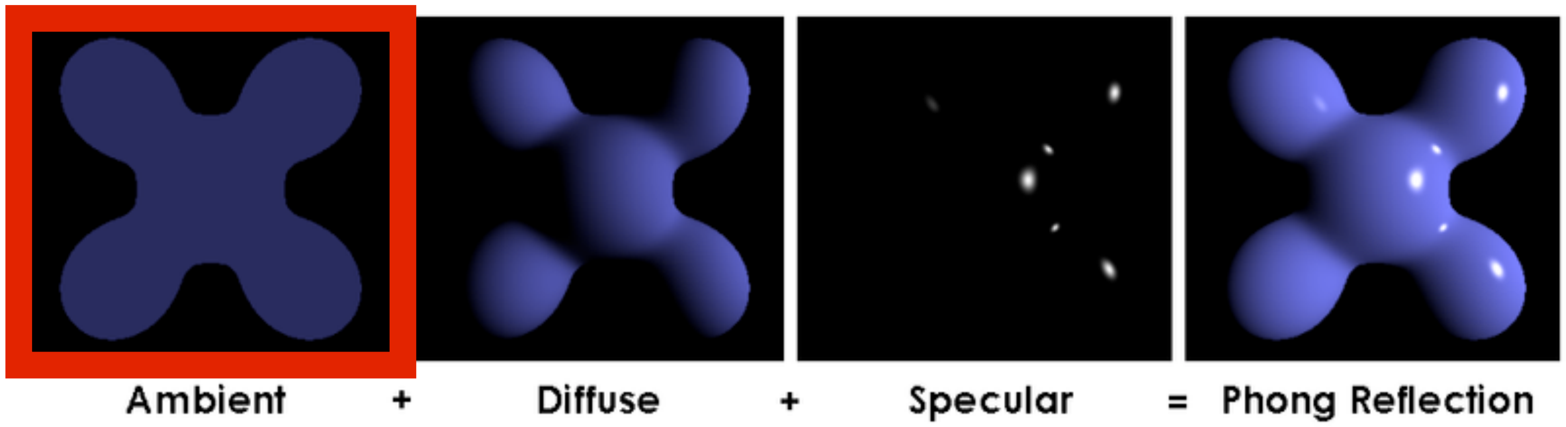
color intensity

illumination

reflectance

This formula will be applied for each of the three color channels independently.

Ambient reflection



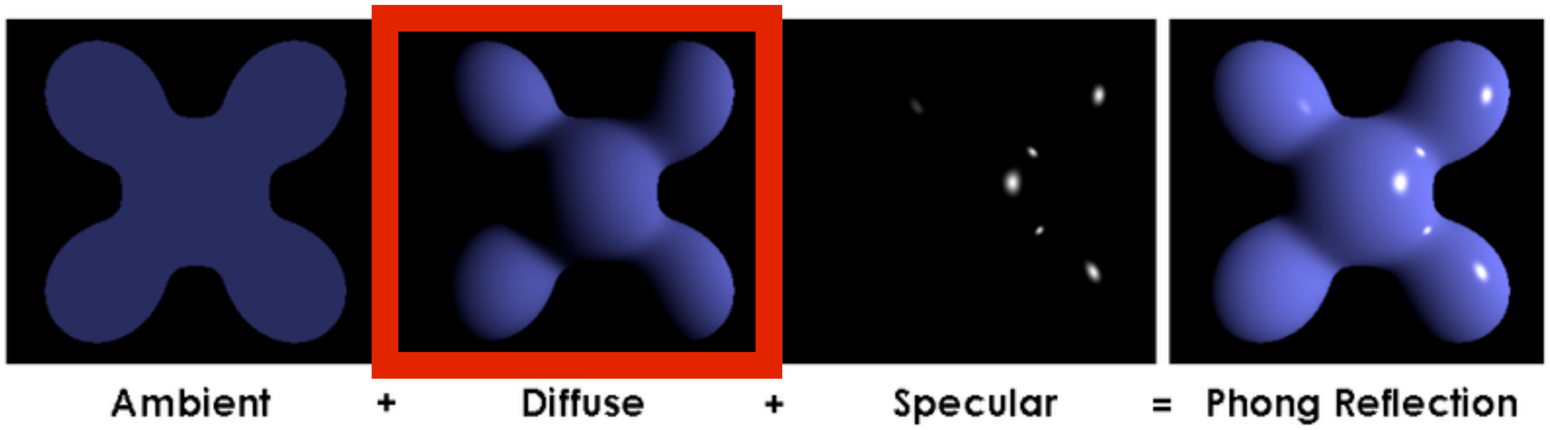
different ambient coefficients for different colors

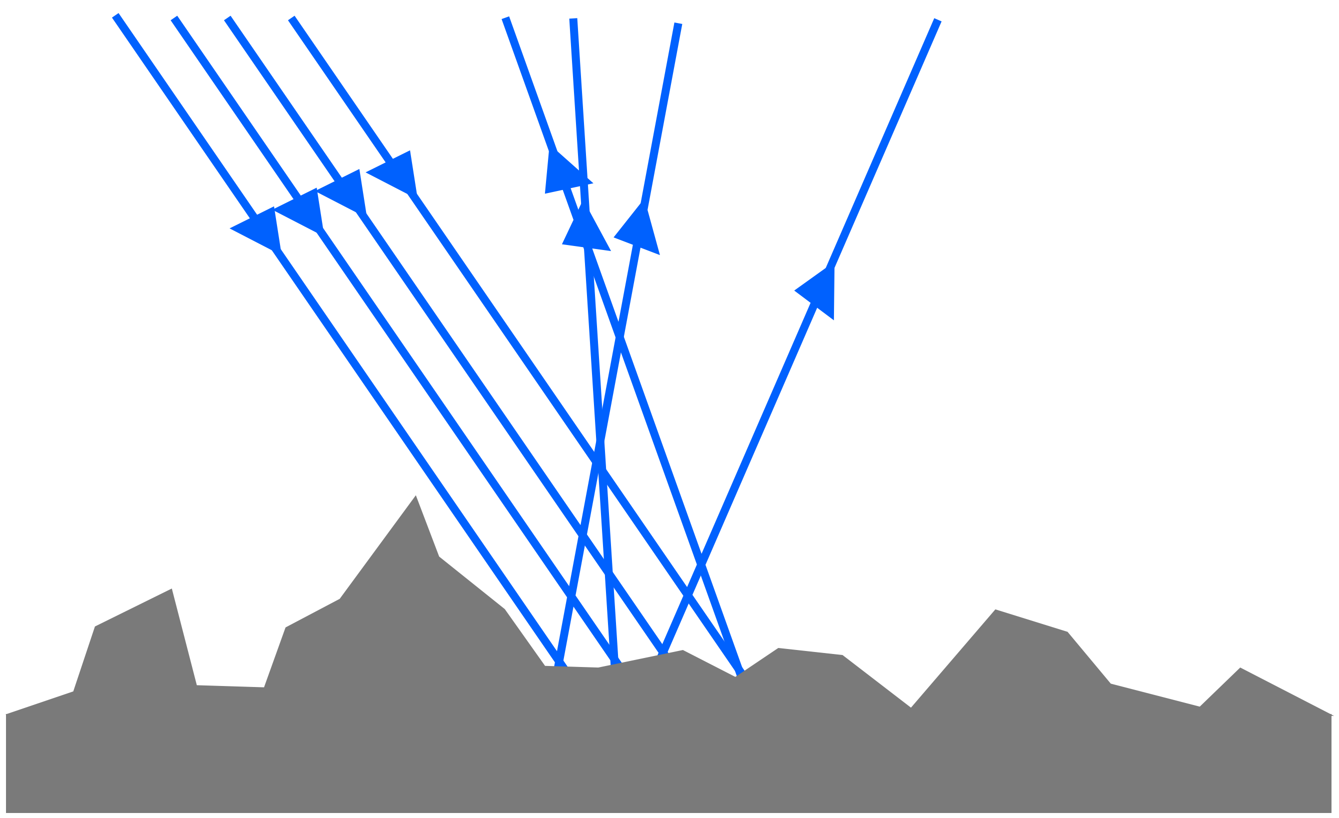
$$I_a = R_a L_a, \qquad 0 \leq R_a \leq 1$$

ambient reflection coefficient

e.g., white light shining on the object will be reflected differently in red, green, blue channels
e.g., more red and blue reflection here

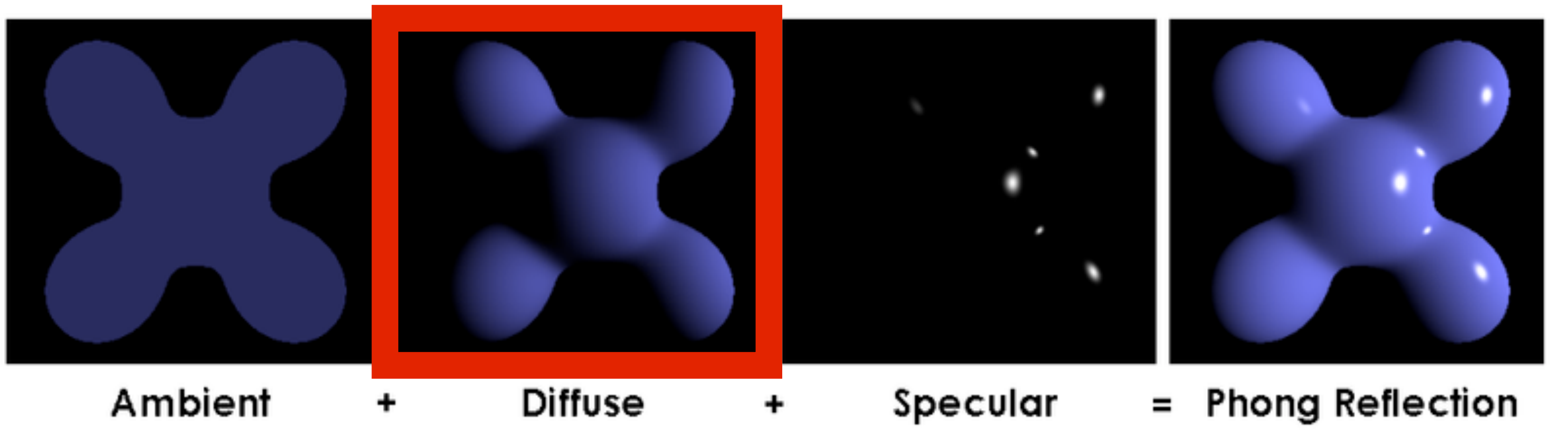
Diffuse reflection





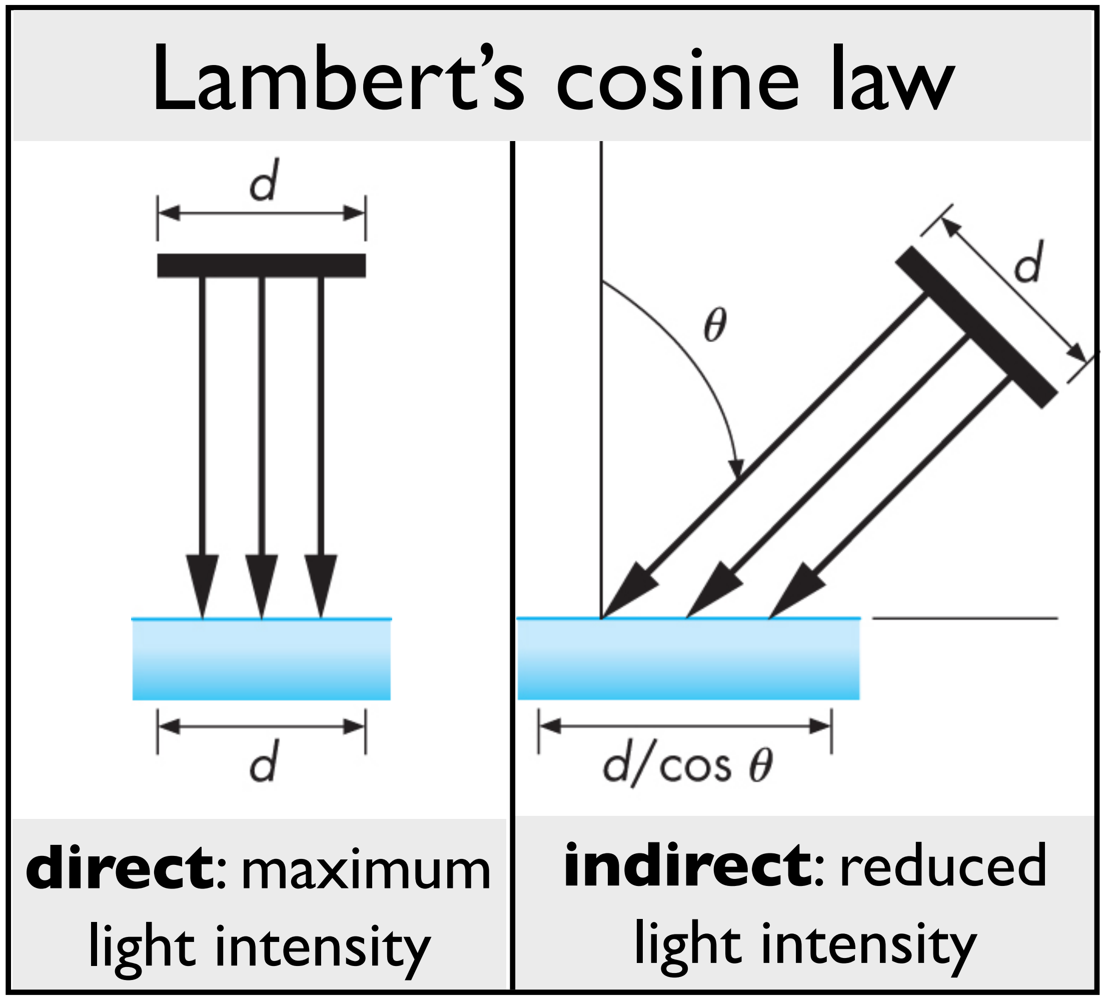
e.g., paper, unfinished wood, unpolished stone
The diffuse component of the Phong reflectance model is the same as the Lambertian reflectance model

Diffuse reflection



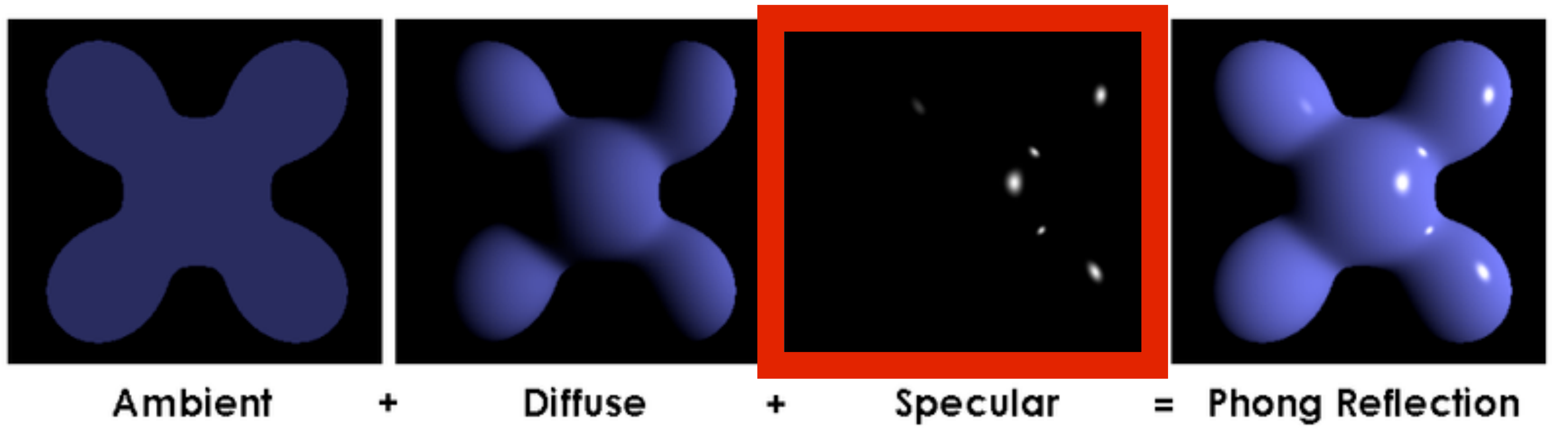
$$I_d = R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n})$$

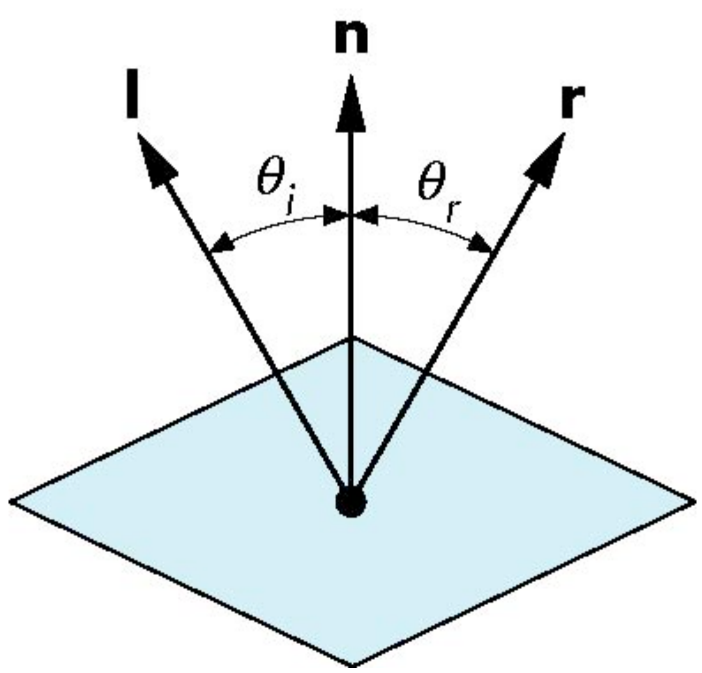
diffuse reflection coefficient



- the light is reduced by cos of angle
  - this is because same amount of light is spread over larger area when light comes in at an angle

Specular reflection





Ideal reflector

$$\theta_i = \theta_r$$

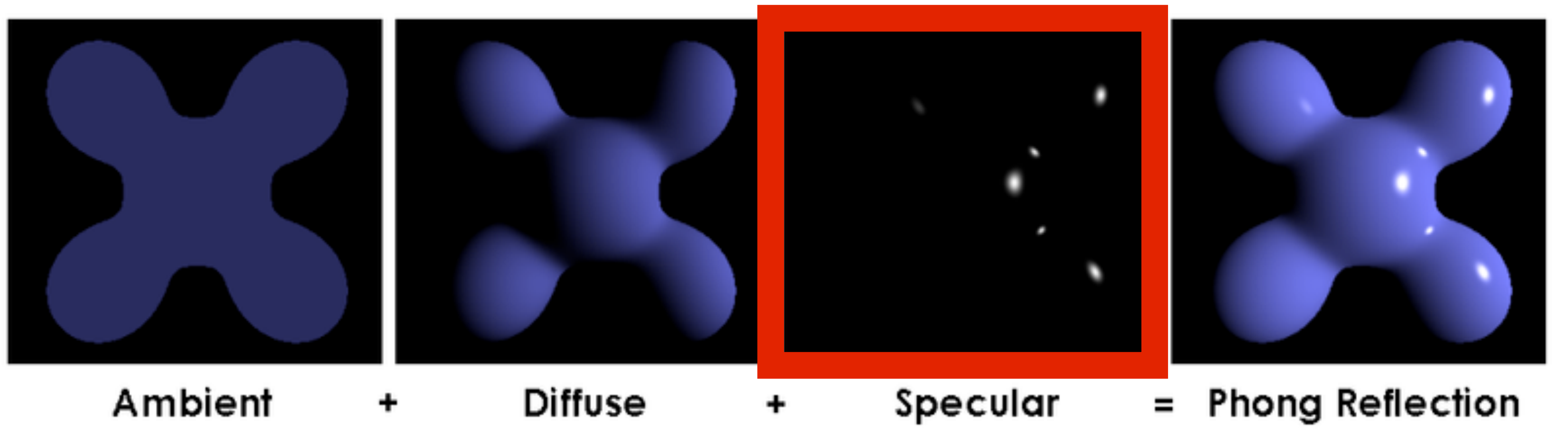
angle of incidence

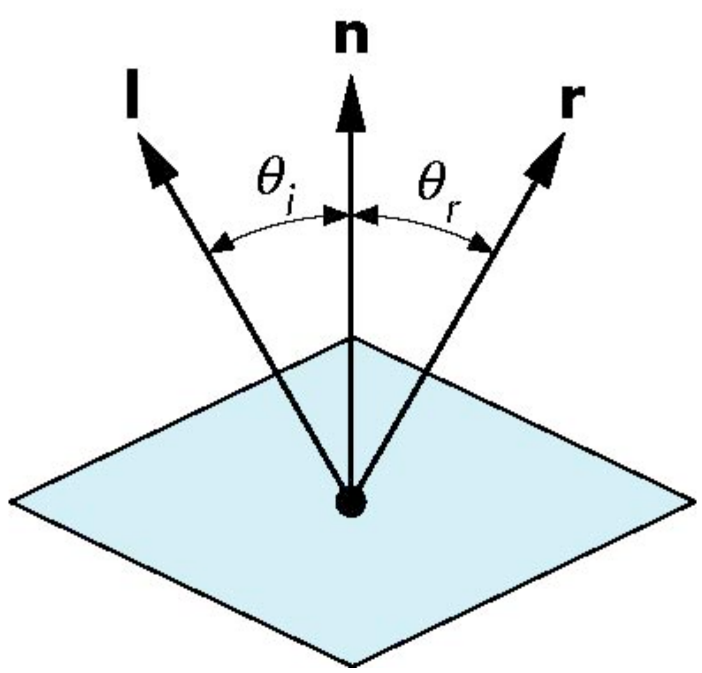
angle of reflection

r is the mirror reflection direction

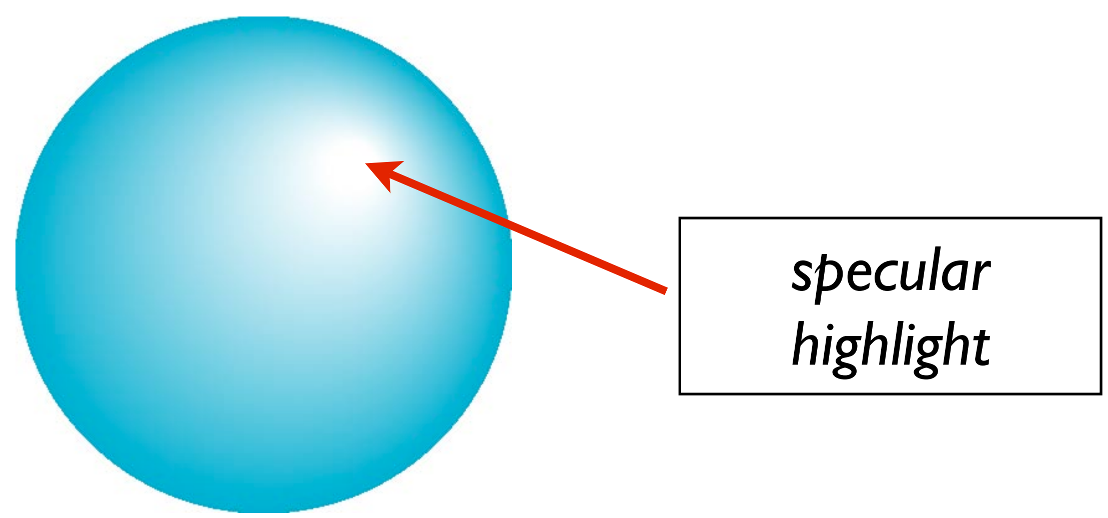
The new thing in the Phong reflection model is the specular component

Specular reflection





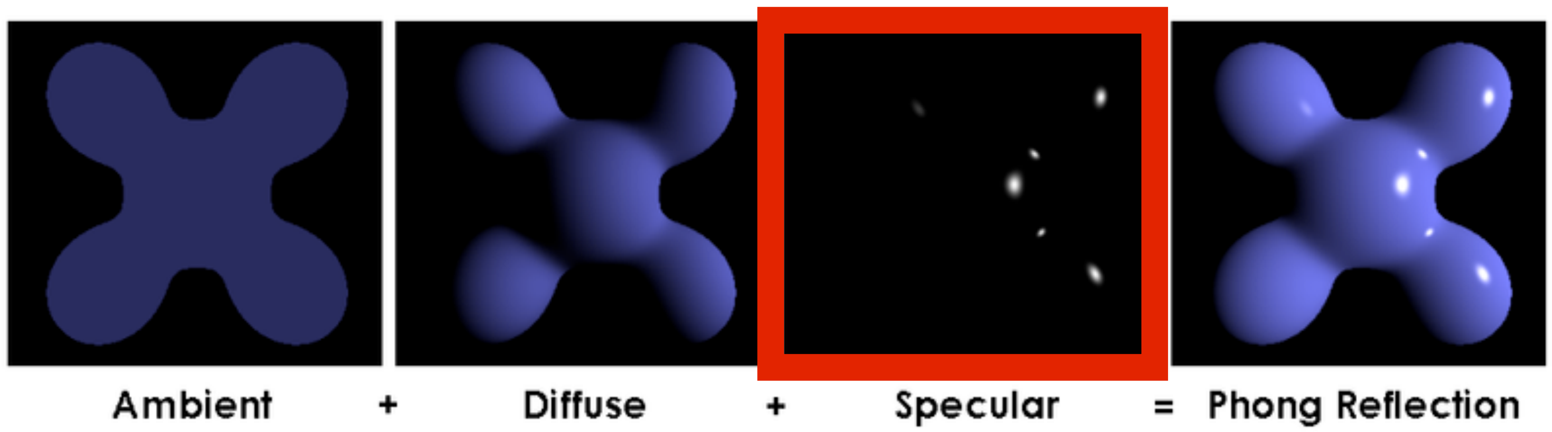
Specular surface

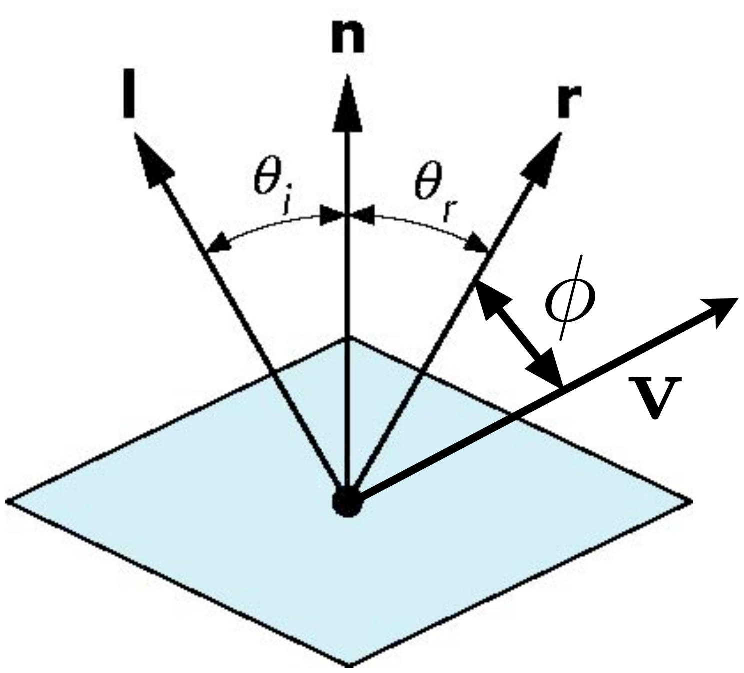


specular reflection is strongest in mirror reflection direction

area of specular highlight depends on how smooth the surface is

Specular reflection





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

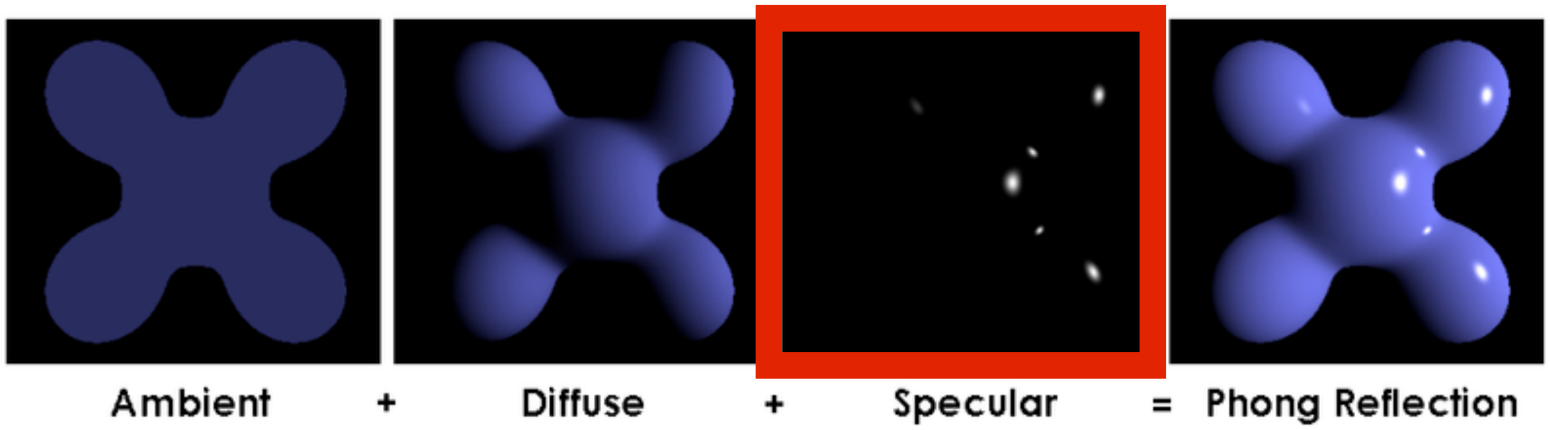
specular reflection coefficient

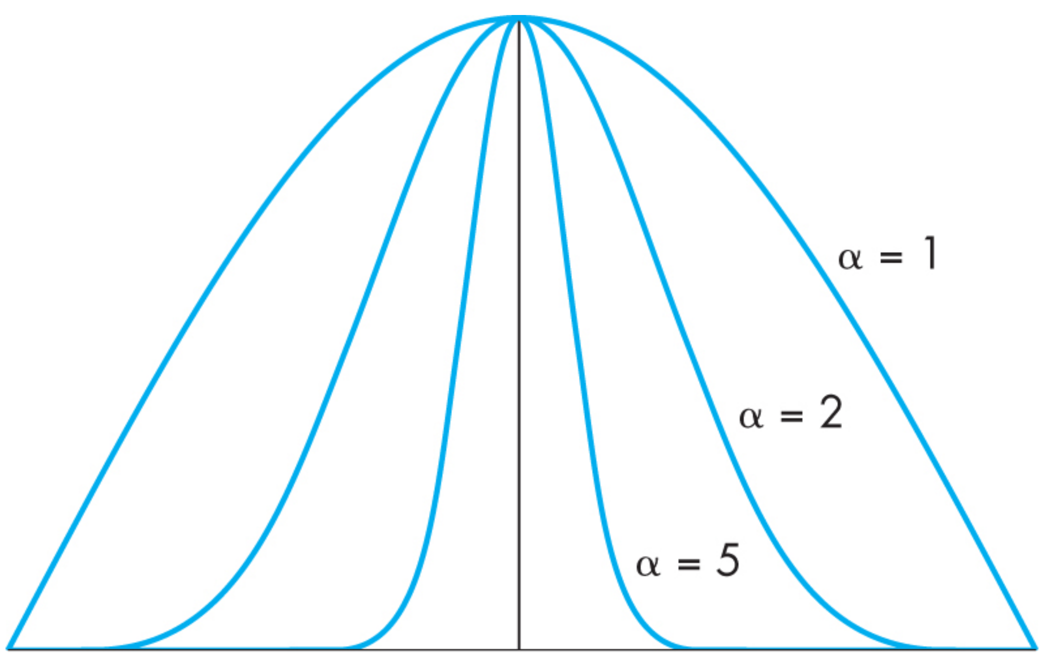
Phong exponent

specular reflection drops off with increasing angle ϕ

Phong proposed this model

Specular reflection





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

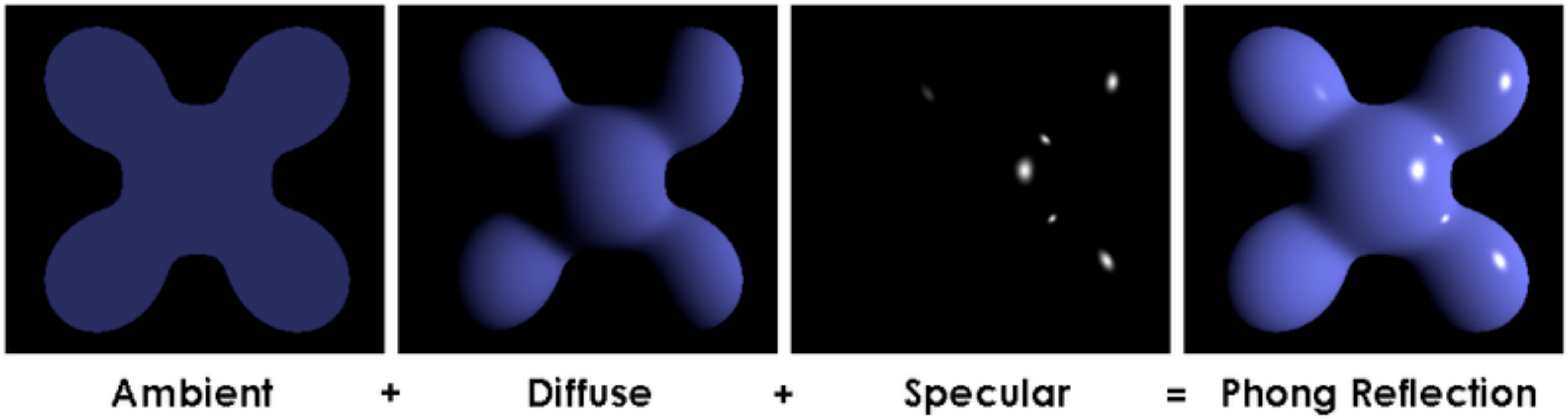
Phong exponent

$\alpha = 5..10$ **plastic**

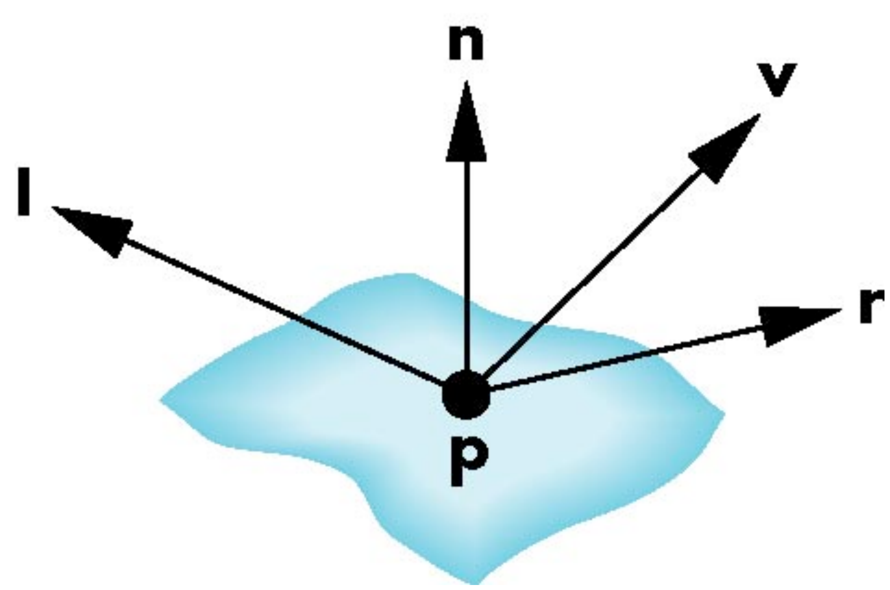
$\alpha = 100..200$ **metal**

Phong proposed this model
clamp to 0 -- avoid negative values
the fuzzy highlight was too big without an exponent

Phong Reflection Model



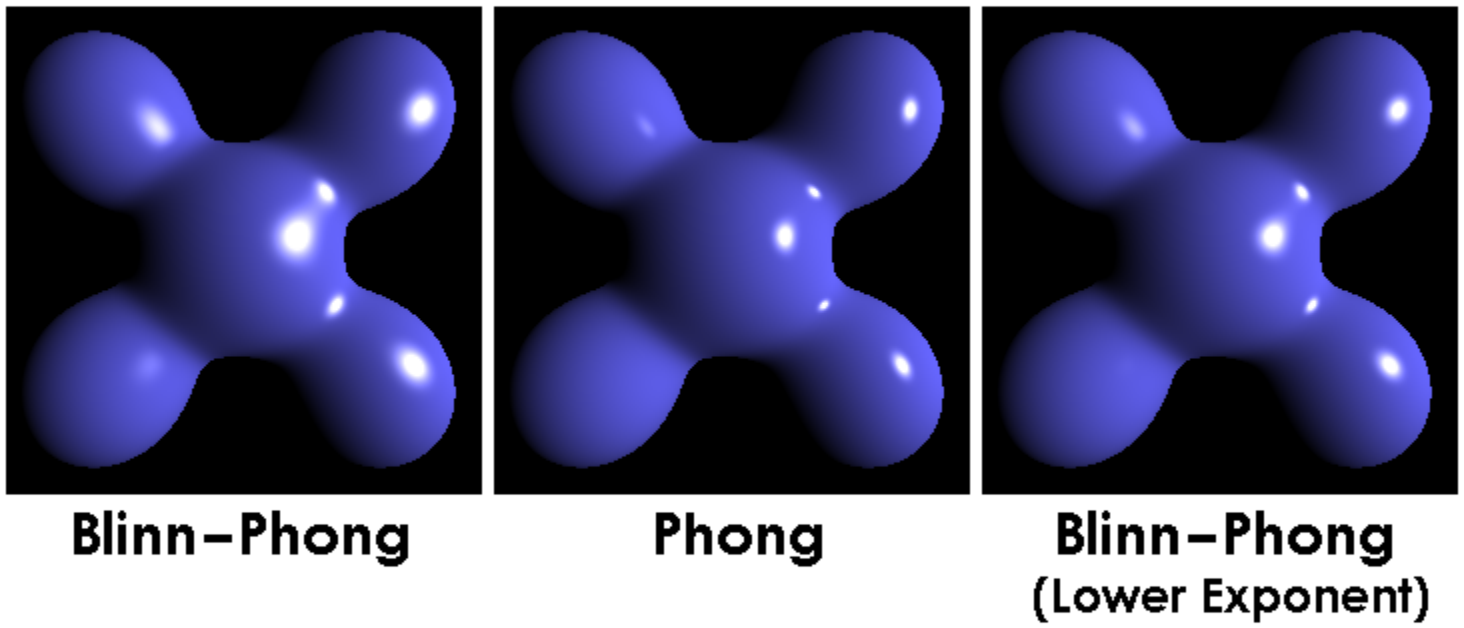
[Brad Smith, Wikimedia Commons]



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

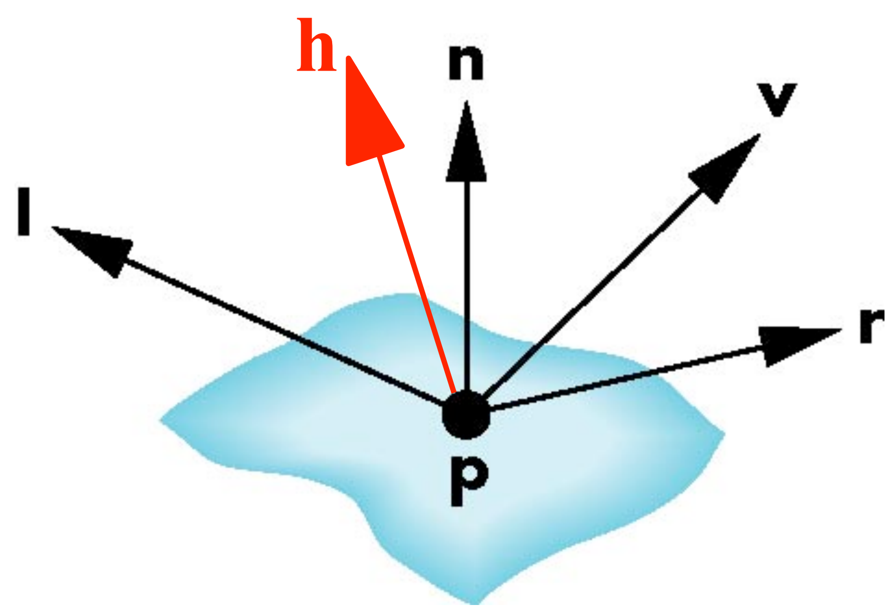
Ambient Diffuse Specular

Alternative: Blinn-Phong Model



[Brad Smith, Wikimedia Commons]

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



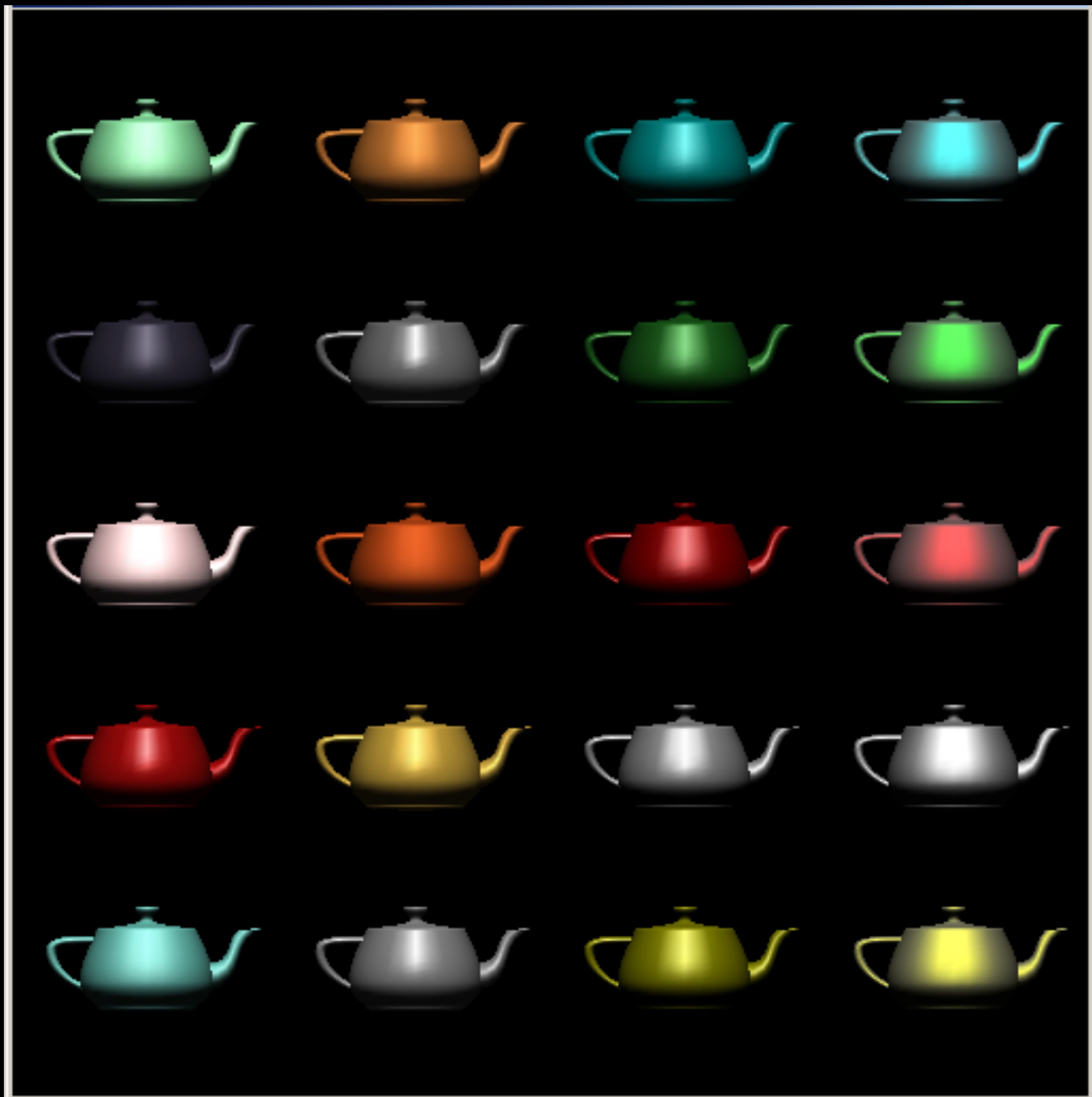
$$
\begin{aligned}
I &= I_a + I_d + I_s \\
&= \underbrace{R_a L_a}_{\text{Ambient}} + \underbrace{R_d L_d \max(0, \mathbf{l} \cdot \mathbf{n})}_{\text{Diffuse}} + \underbrace{R_s L_s \max(0, \mathbf{h} \cdot \mathbf{n})^{\alpha}}_{\text{Specular}}
\end{aligned}
$$

replace **v.r** with **h.n**

this way we don't have to recompute **r**, which depends on **n**

h does not depend on **n**

saves a lot especially for directional lights and constant viewing direction



α

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