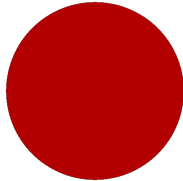


Lighting and Shading

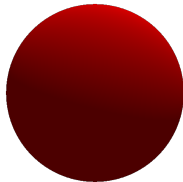
University of California Riverside

Why we need shading

- Suppose we build a model of a red sphere
- We get something like

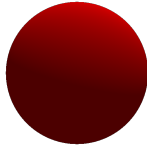


- But we want



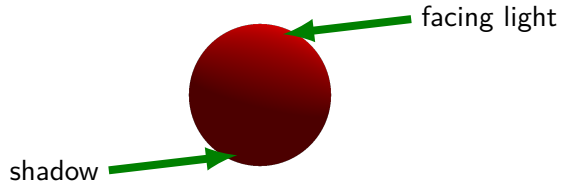
Shading

- Why does a real sphere look like this?

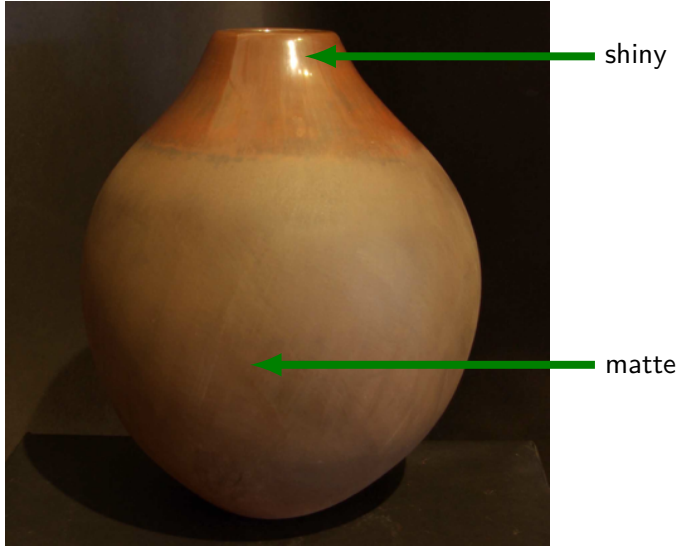


Shading - lighting

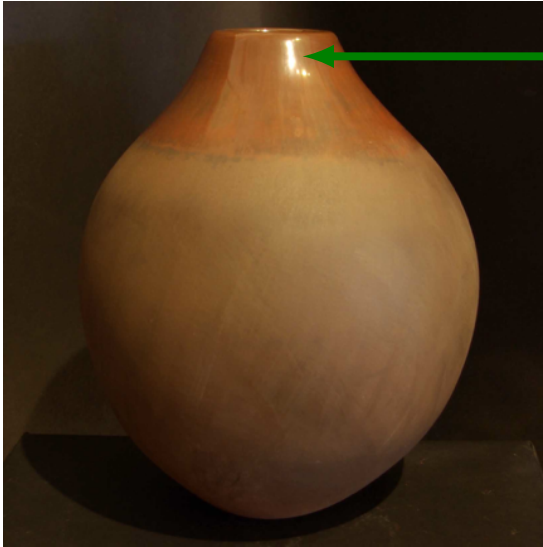
- Why does a real sphere look like this?



Shading - material properties

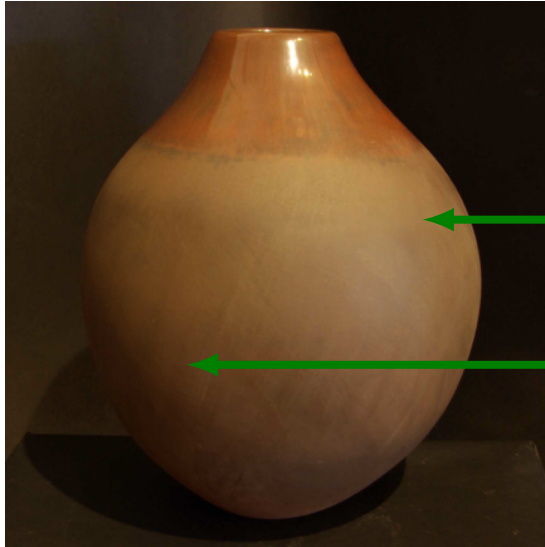


Shading - viewing location



What if I move?

Shading - surface orientation

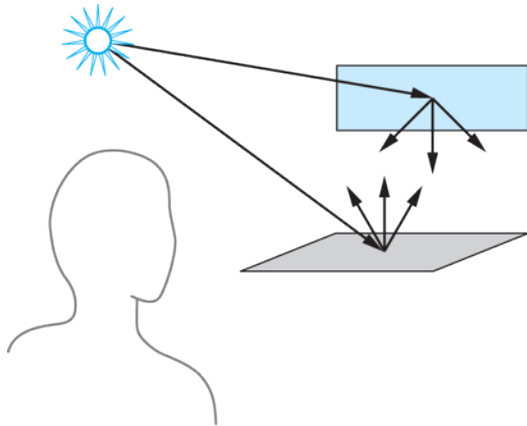


well lit

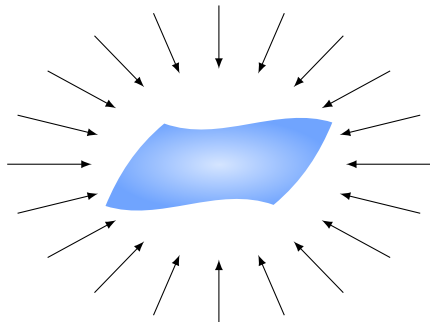
poorly lit

General rendering

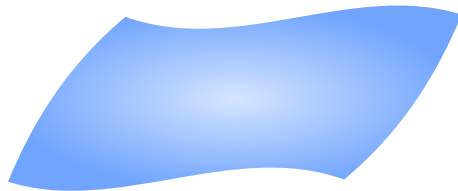
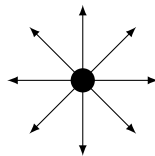
- Based on physics
 - conservation of energy
- Surfaces can
 - absorb light
 - emit light
 - reflect light
 - transmit light



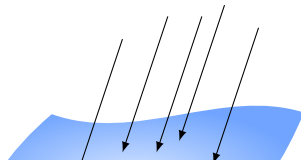
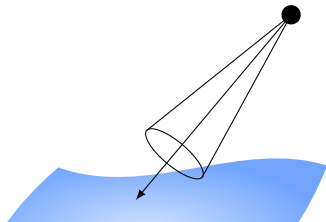
Idealized light sources



ambient

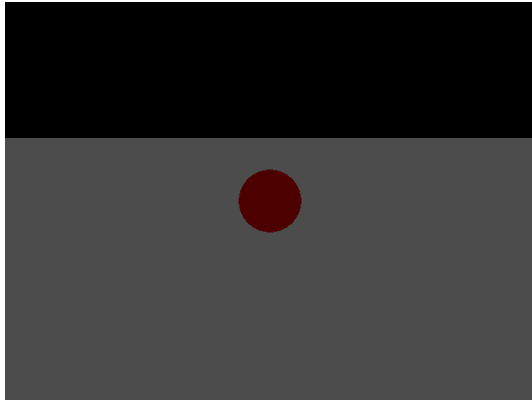
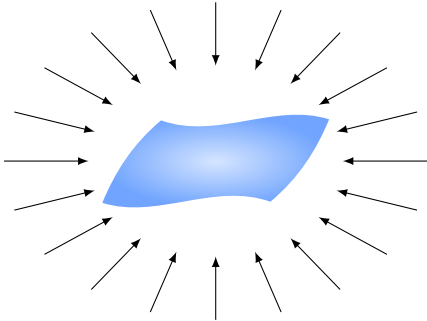


point light



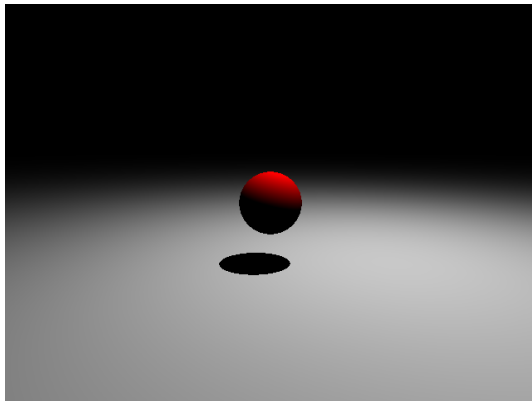
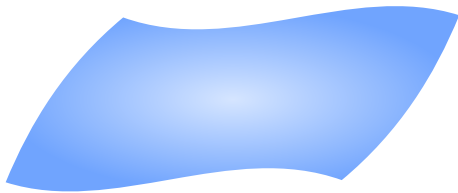
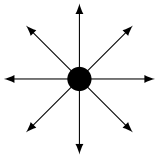
Ambient light

- Achieve uniform light level
- No shadows
- Same light level everywhere

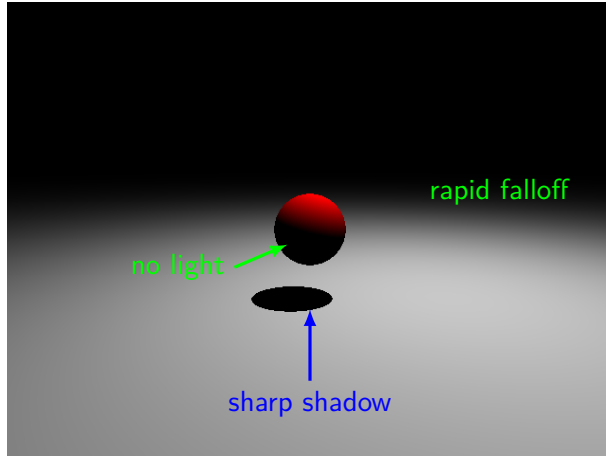


Point light

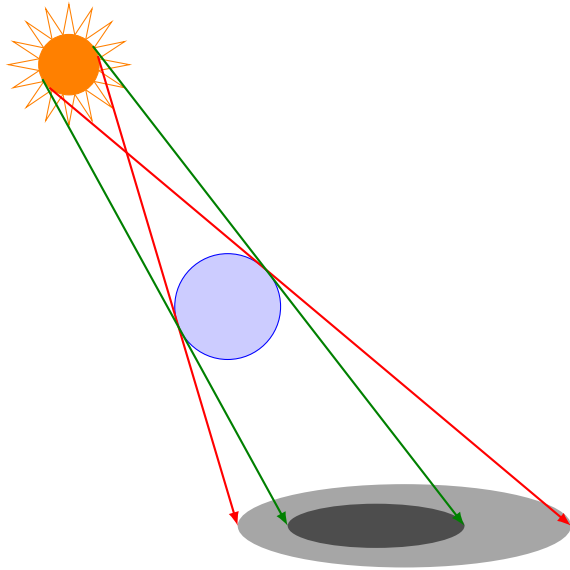
- Light emitted from a point \mathbf{p}
- Uniform in all directions
- Falls off with distance: $\ell(\mathbf{x}) = \frac{1}{\|\mathbf{x} - \mathbf{p}\|^2} L$



Point light - limitations

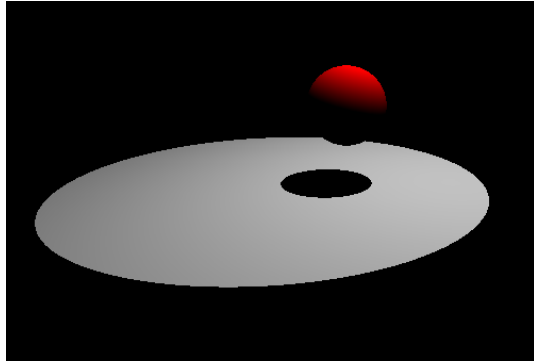
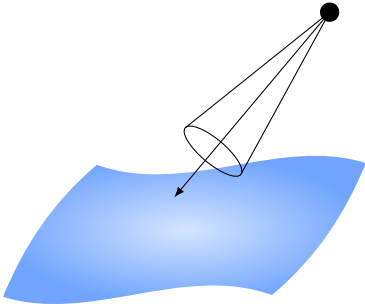


Soft shadows



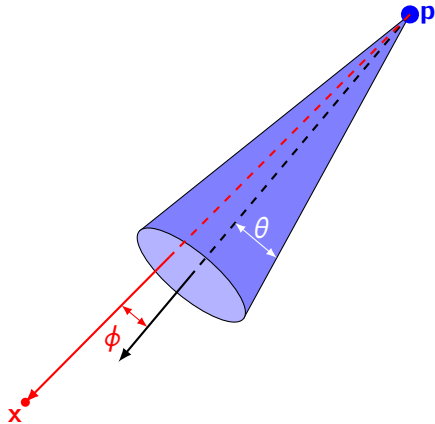
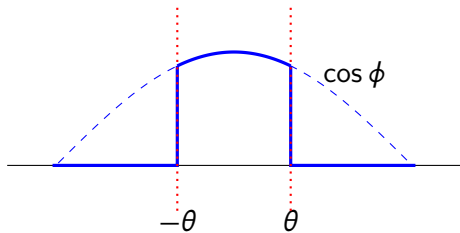
Spotlight

- Light emitted from a point \mathbf{p}
- Emitted in a cone
- Brightest in middle of cone
- Falls off with distance

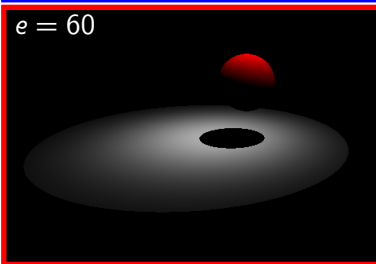
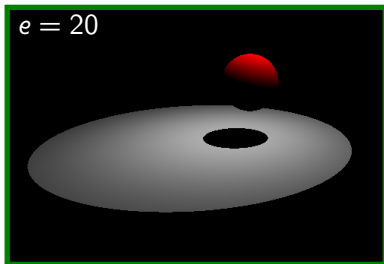
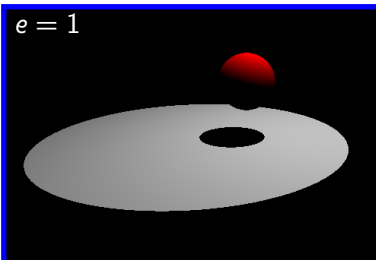
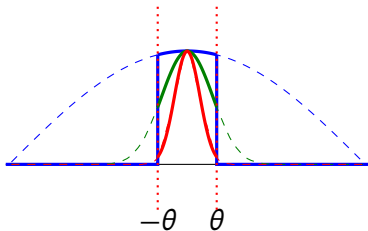


Spotlight

$$\ell(\mathbf{x}) = \frac{\cos^e \phi}{\|\mathbf{x} - \mathbf{p}\|^2} L$$

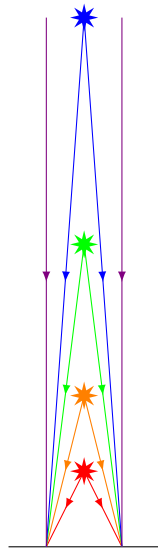
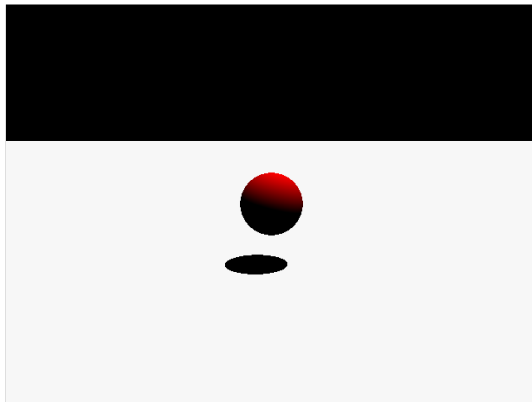
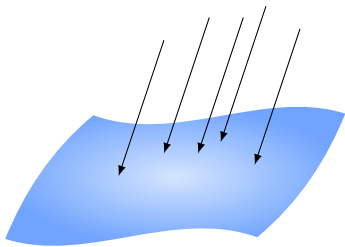


Spotlight - exploring e



Directional light

- Light source at infinity
- Rays come in parallel
- No falloff
- Characterized by direction



Lambertian reflection model

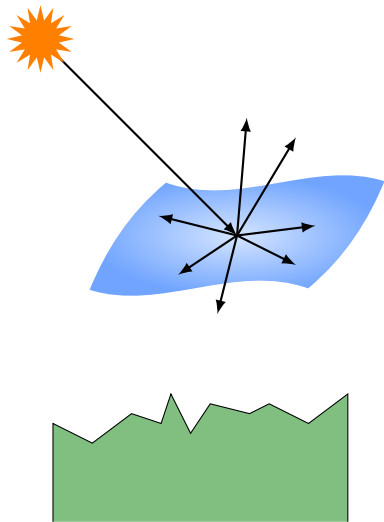
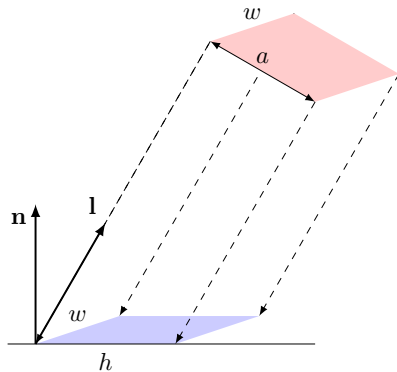
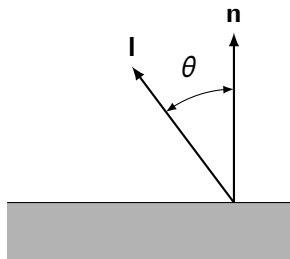


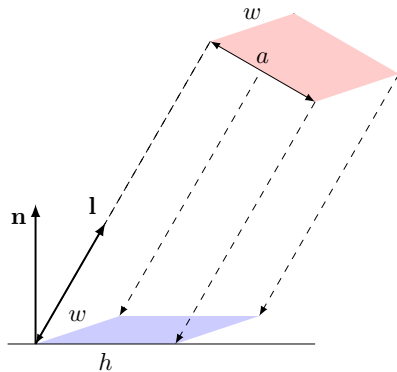
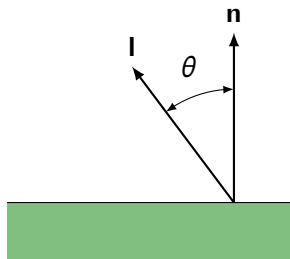
Image source: https://www.eyesofthepot.com/santa-clara/jody_folwell

Lambertian reflection model



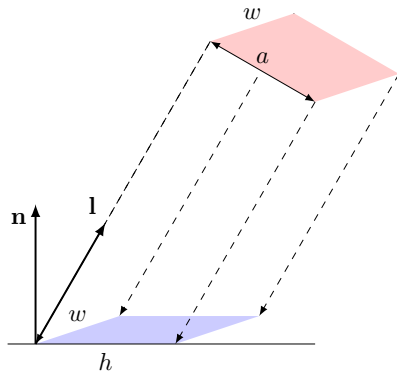
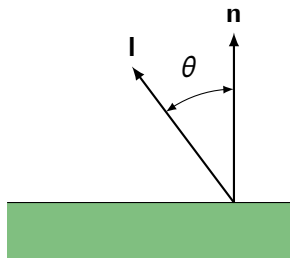
	Light	Incident
Intensity	L	L'
Energy	$E = Lwa$	$E = L'wh$

Lambertian reflection model



	Light	Incident	Reflected
Intensity	L	L'	$I = RL'$
Energy	$E = Lwa$	$E = L'wh$	RE

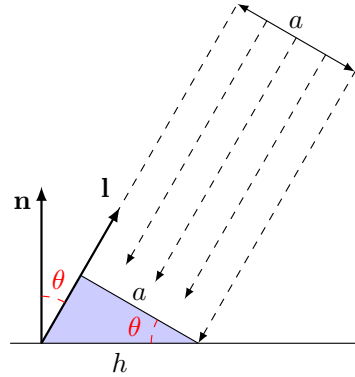
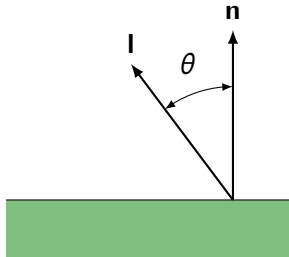
Lambertian reflection model



	Light	Incident	Reflected
Intensity	L	L'	$I = RL'$
Energy	$E = Lwa$	$E = L'wh$	RE

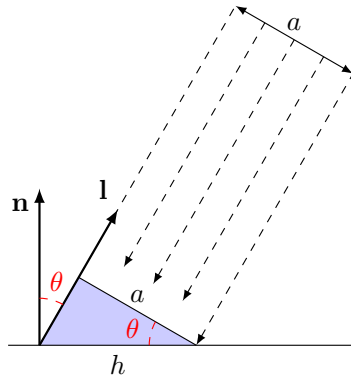
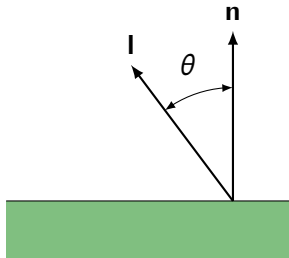
$$I = LR \frac{a}{h}$$

Lambertian reflection model



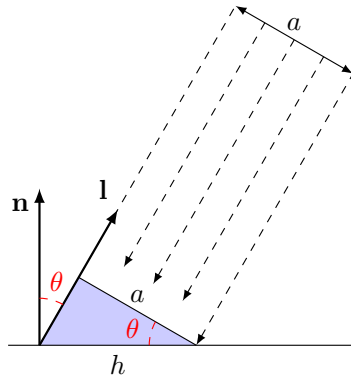
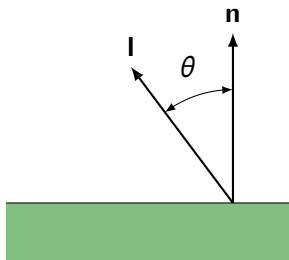
$$I = LR \frac{a}{h}$$

Lambertian reflection model



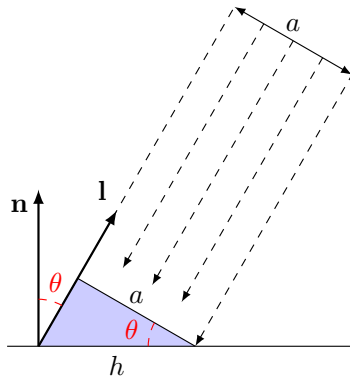
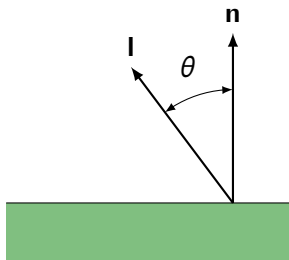
$$I = LR \frac{a}{h} = LR \cos \theta$$

Lambertian reflection model



$$I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l}$$

Lambertian reflection model



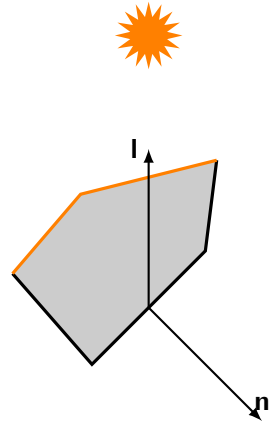
$$I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l}$$

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

Ambient reflection

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

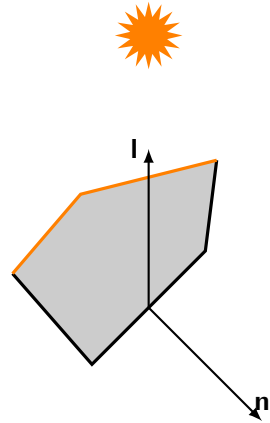
Surfaces facing away from the light will be totally **black**



Ambient reflection

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

All surfaces get the same amount of ambient light



Phong reflection model

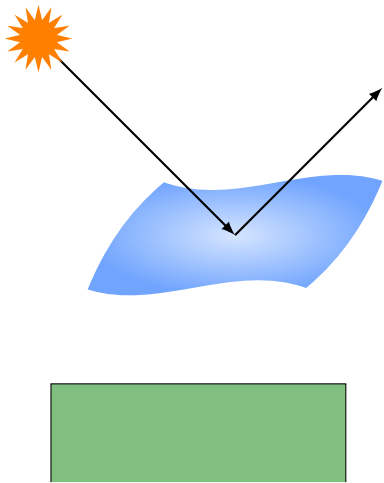
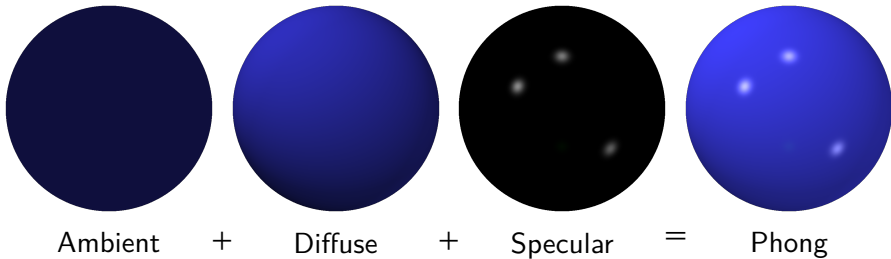
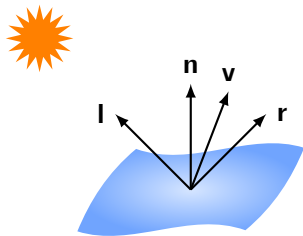


Image source: https://www.eyesofthepot.com/santa-clara/jody_folwell

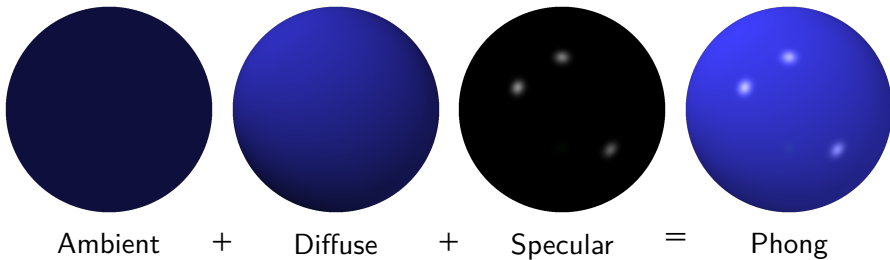
Phong reflection model



- Efficient
- Reasonably realistic
- 3 components
- 4 vectors

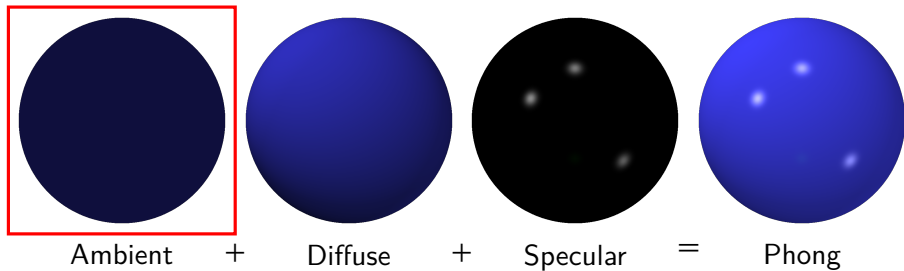


Phong reflection model



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

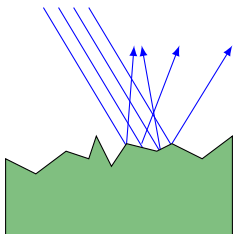
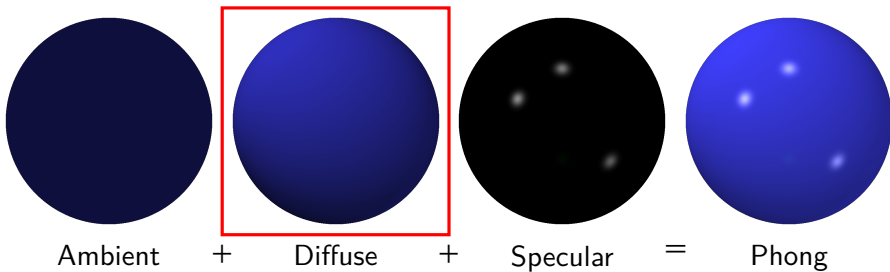
Ambient reflection



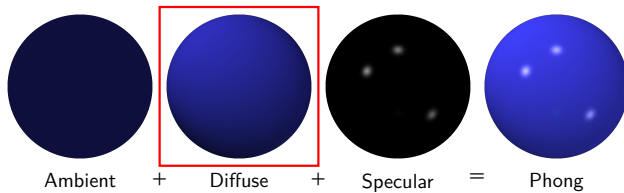
$$I_a = R_a L_a$$

$$0 \leq R_a \leq 1$$

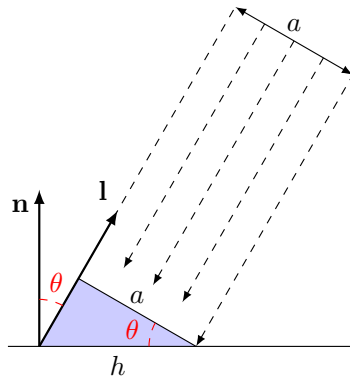
Diffuse reflection



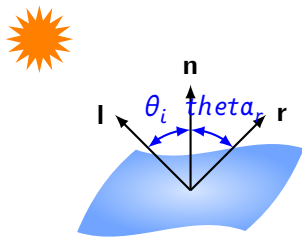
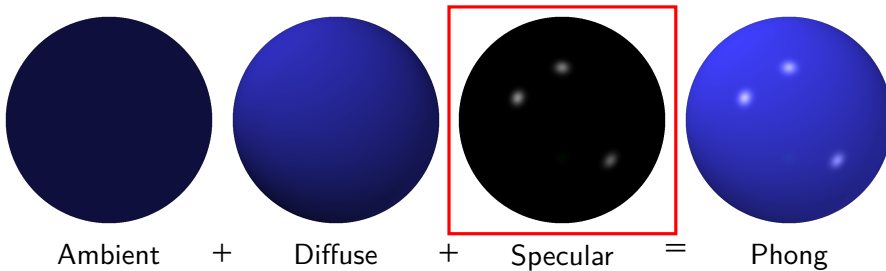
Diffuse reflection



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



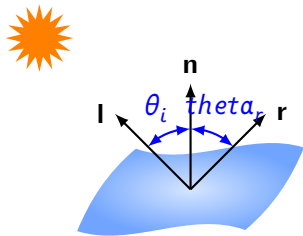
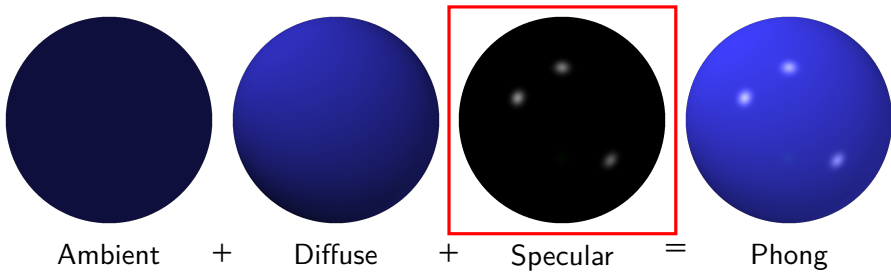
Specular reflection



Ideal reflector
 $\theta_i = \theta_r$

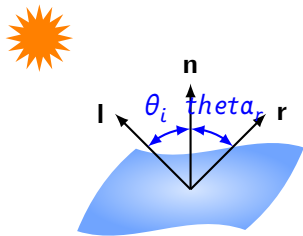
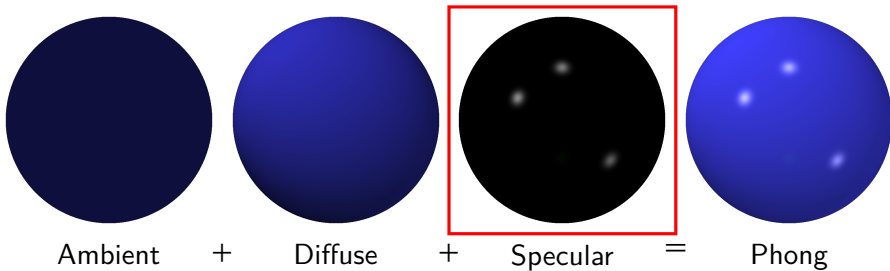
r is the mirror reflection direction

Specular reflection



specular reflection is strongest in reflection direction

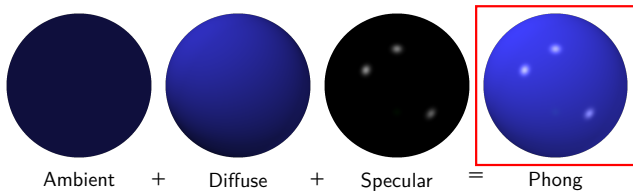
Specular reflection



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

specular reflection drops off with increasing ϕ

Phong reflection model



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

