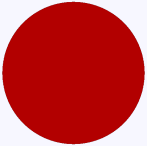
Lighting and Shading

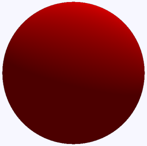
University of California Riverside

Why we need shading

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

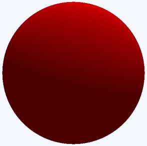


- But we want



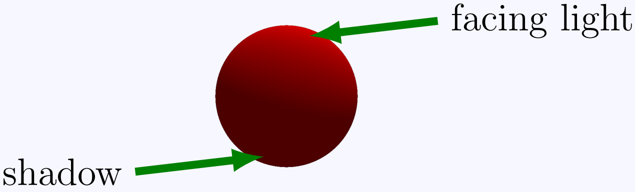
Shading

- Why does a real sphere look like this?

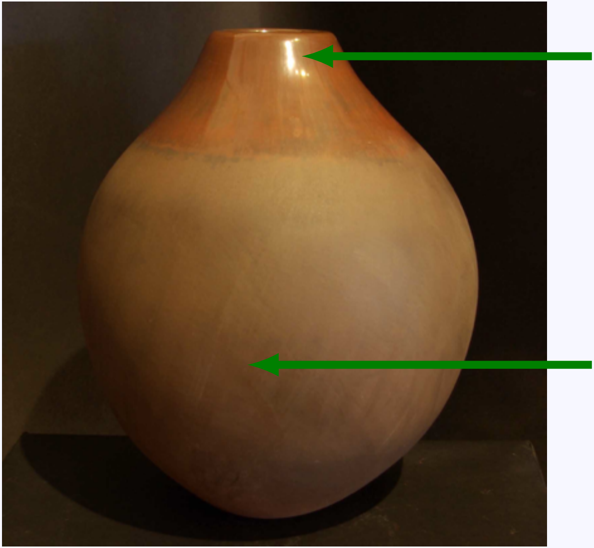


Shading - lighting

- Why does a real sphere look like this?



Shading - material properties

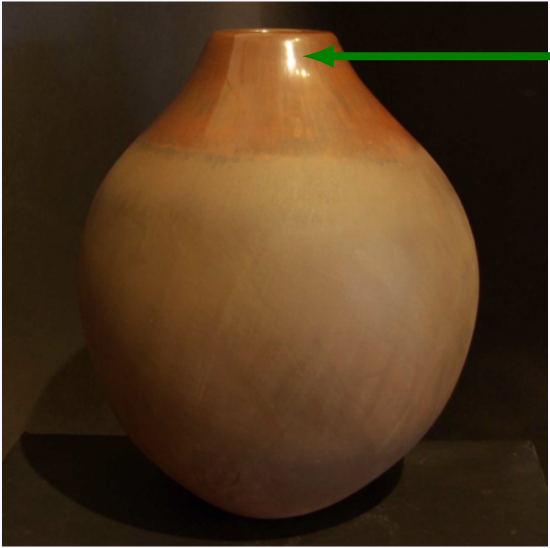


shiny

matte

Image source: [1]

Shading - viewing location



What if I move?

Image source: [1]

Shading - surface orientation

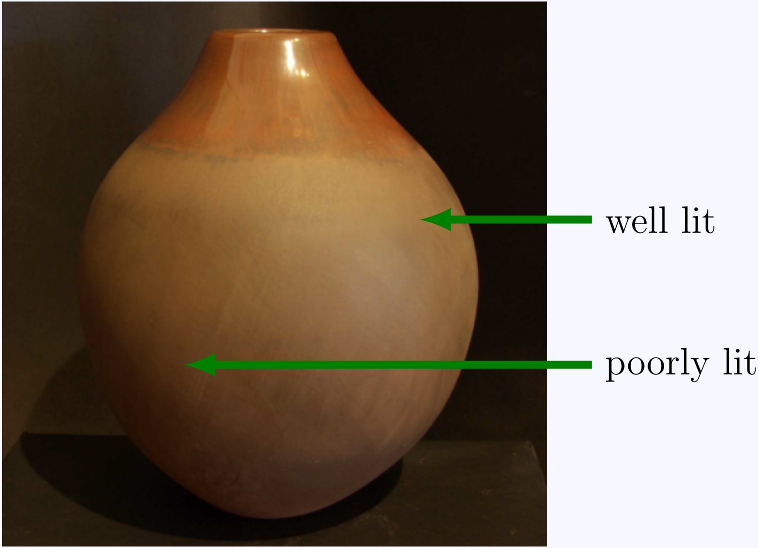
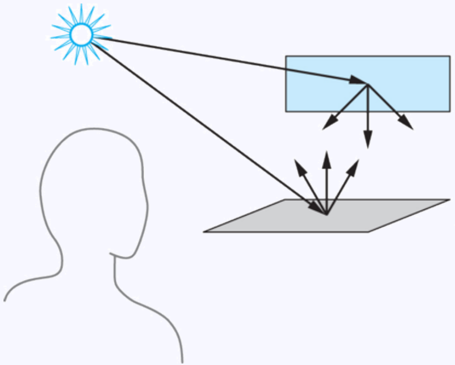


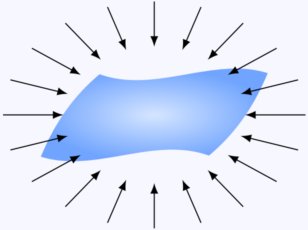
Image source: [1]

General rendering

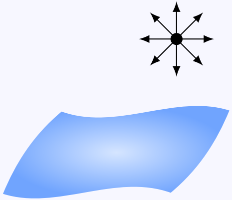
- Based on physics
  - conservation of energy
- Surfaces can
  - absorb light
  - emit light
  - reflect light
  - transmit light



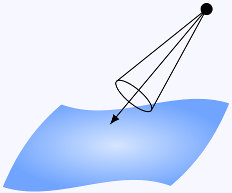
Idealized light sources



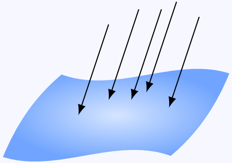
ambient



point light



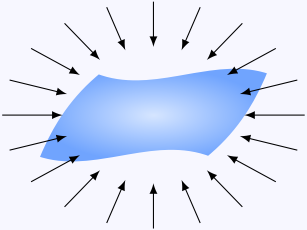
spotlight



directional light

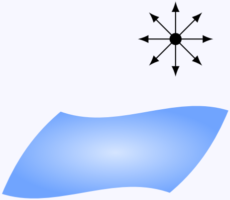
Ambient light

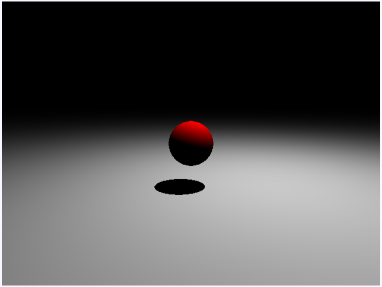
- Achieve uniform light level
- No shadows
- Same light level everywhere



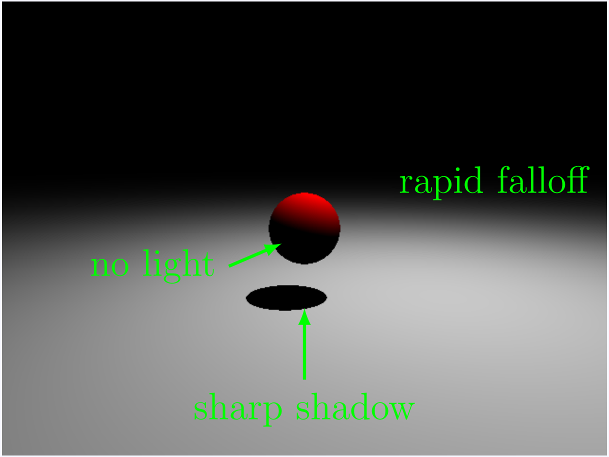
Point light

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

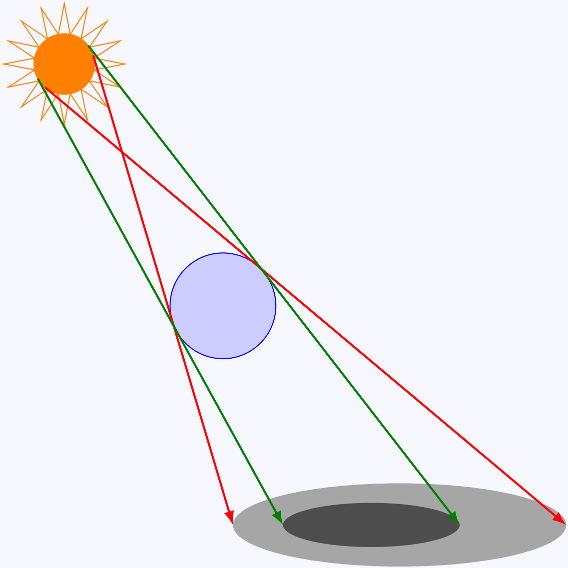




Point light - limitations

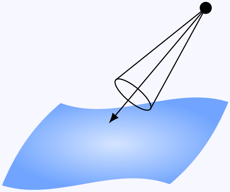


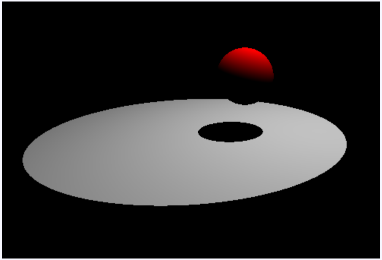
Soft shadows



Spotlight

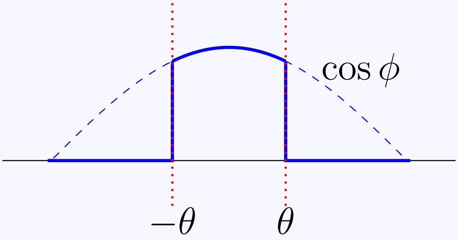
- Light emitted from a point $\mathbf{p}$
- Emitted in a cone
- Brightest in middle of cone
- Falls off with distance

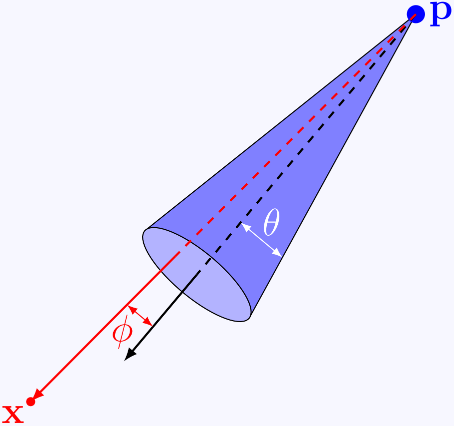




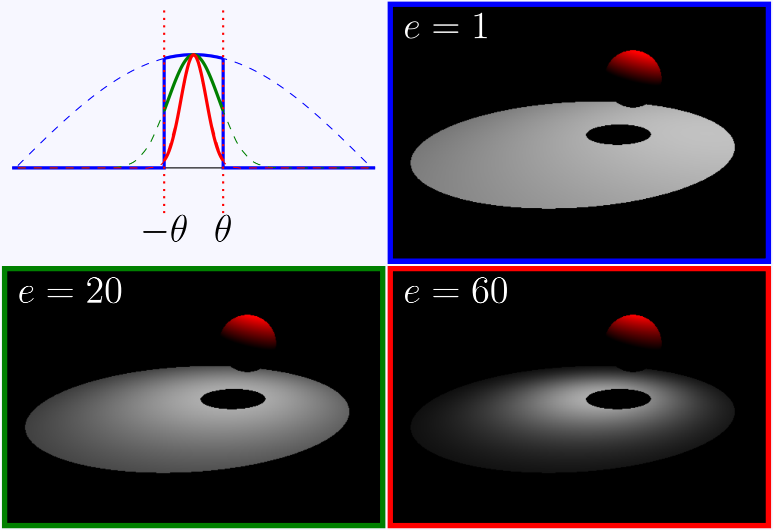
Spotlight

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



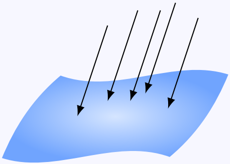


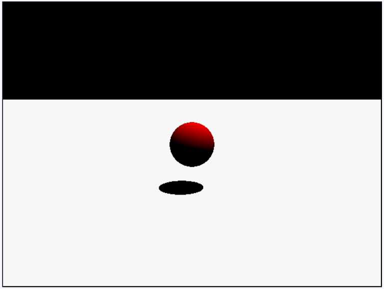
Spotlight - exploring e

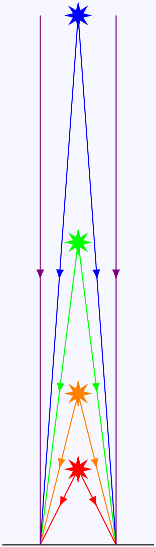


Directional light

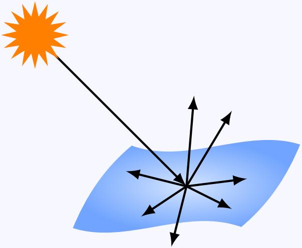
- Light source at infinity
- Rays come in parallel
- No falloff
- Characterized by direction







Lambertian reflection model



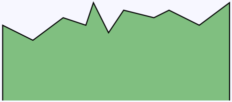
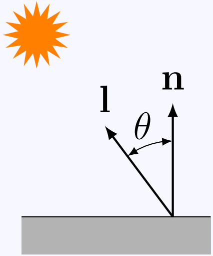
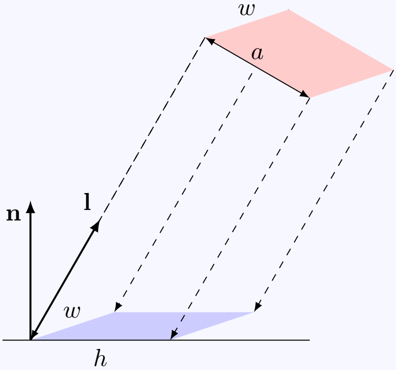


Image source: [1]

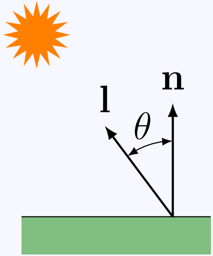
Lambertian reflection model

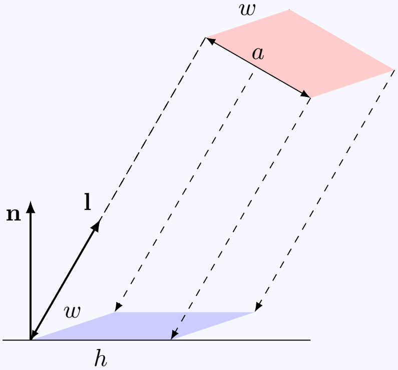




	Light	Incident
Intensity	L	L'
Energy	$E = L\color{red}{wa}$	$E = L'\color{blue}{wh}$

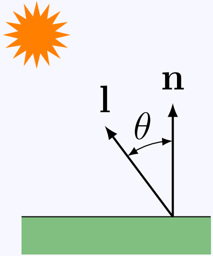
Lambertian reflection model

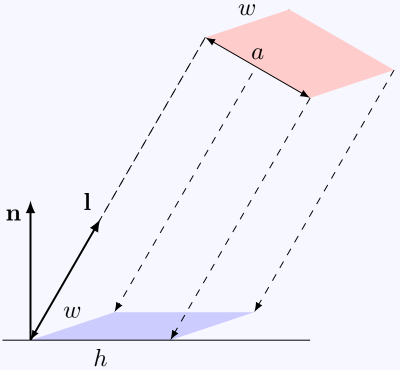




	Light	Incident	Reflected
Intensity	L	L'	$I = RL'$
Energy	$E = Lwa$	$E = L'wh$	RE

Lambertian reflection model

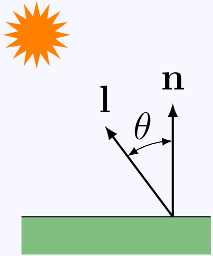


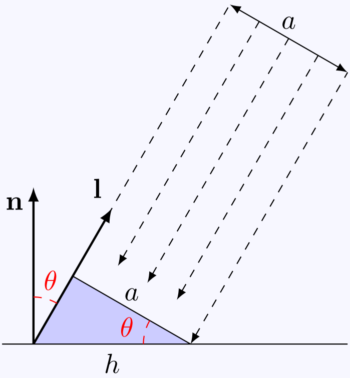


	Light	Incident	Reflected
Intensity	L	L'	$I = RL'$
Energy	$E = Lwa$	$E = L'wh$	RE

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

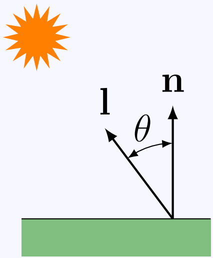
Lambertian reflection model

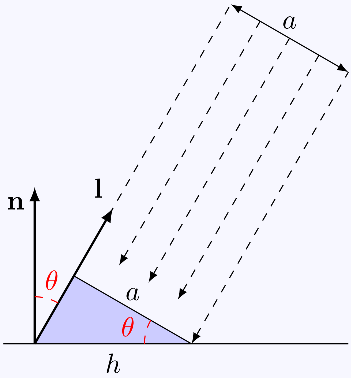




$$I = LR\frac{a}{h}$$

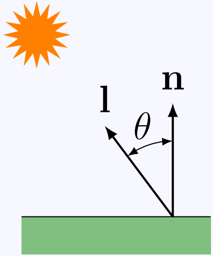
Lambertian reflection model

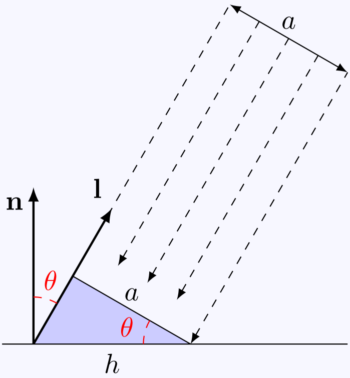




$$I = LR\frac{a}{h} = LR\cos\theta$$

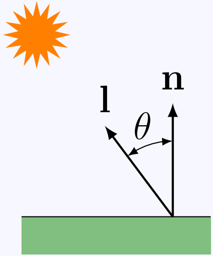
Lambertian reflection model

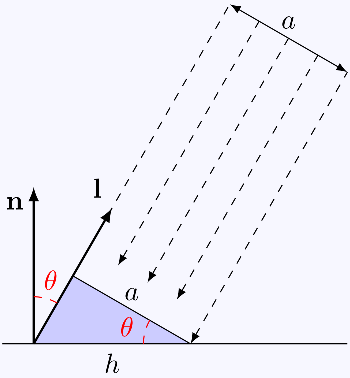




$$I = LR\frac{a}{h} = LR\cos\theta = LR\,\mathbf{n}\cdot\mathbf{l}$$

Lambertian reflection model





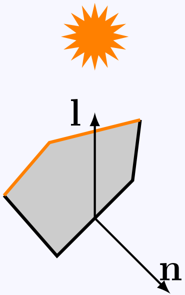
$$I = \color{orange}{L}\color{green}{R}\color{red}{\frac{a}{h}} = \color{orange}{L}\color{green}{R}\color{red}{\cos\theta} = \color{orange}{L}\color{green}{R}\color{red}{\mathbf{n}\cdot\mathbf{l}}$$

Avoid bug: $I = \color{orange}{L}\color{green}{R}\color{black}{\max(}\color{red}{\mathbf{n}\cdot\mathbf{l}}\color{black}{, 0)}$

Ambient reflection

$$I = {\color{orange}L}{\color{green}R}\max(\mathbf{n}\cdot\mathbf{l}, 0)$$

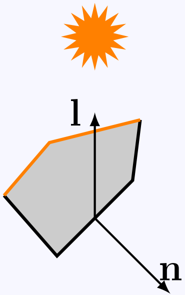
Surfaces facing away from the light will be totally **black**



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

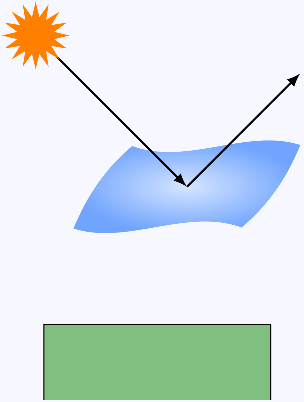
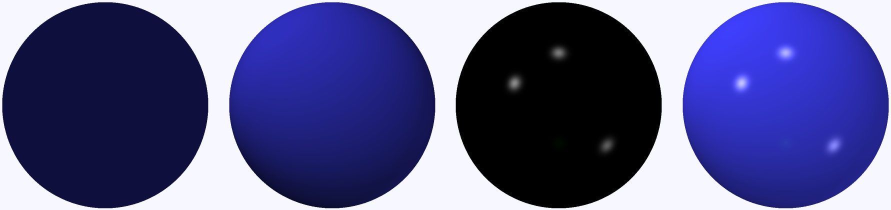


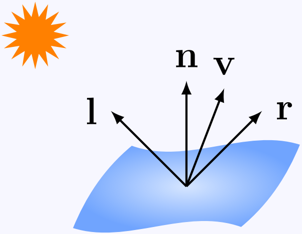
Image source: [1]

Phong reflection model

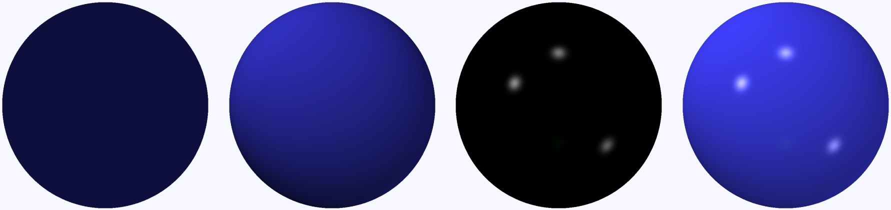


Ambient + Diffuse + Specular = Phong

- Efficient
- Reasonably realistic
- 3 components
- 4 vectors



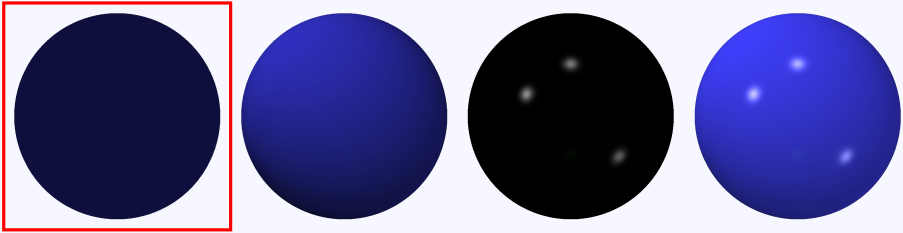
Phong reflection model



Ambient + Diffuse + Specular = Phong

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

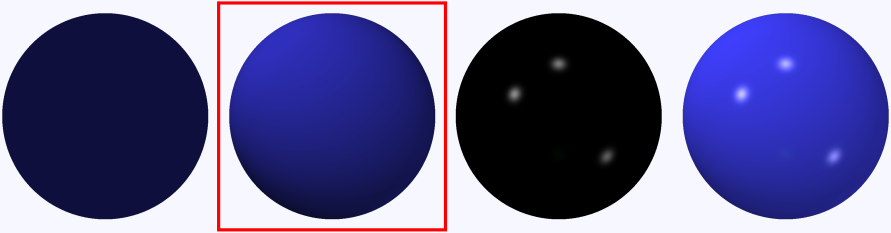
Ambient reflection



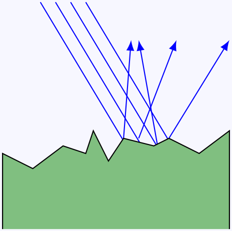
Ambient + Diffuse + Specular = Phong

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

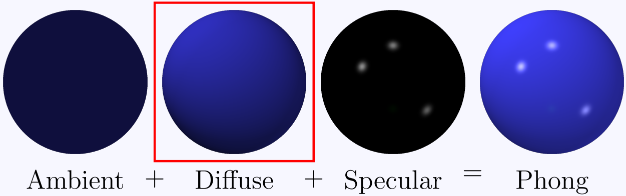
Diffuse reflection



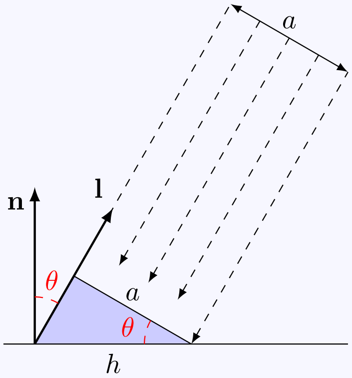
Ambient + Diffuse + Specular = Phong



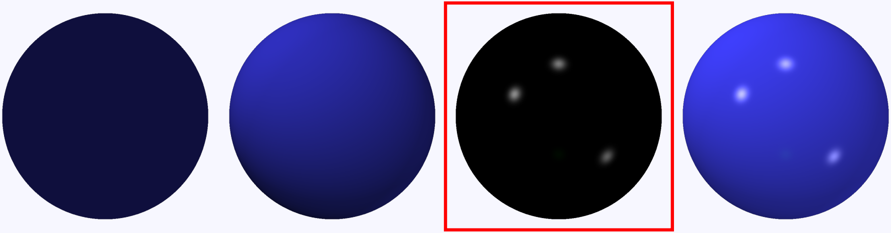
Diffuse reflection



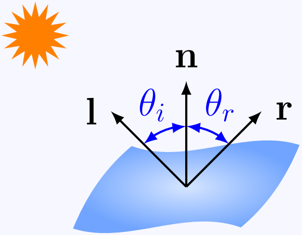
$$I_d = R_d L_d \max(\mathbf{n} \cdot \mathbf{l}, 0)$$



Specular reflection



Ambient + Diffuse + Specular = Phong

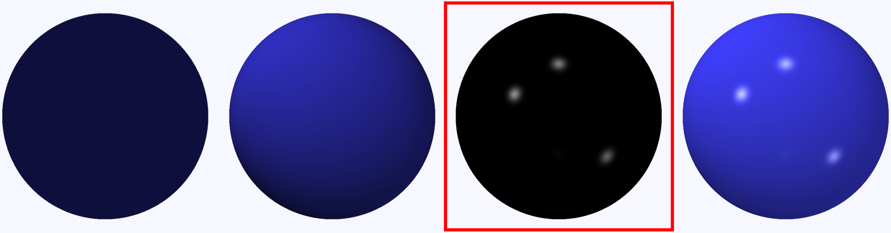


Ideal reflector

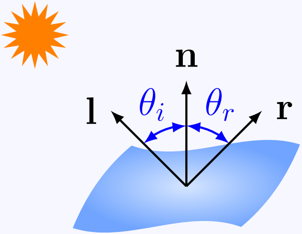
$$\theta_i = \theta_r$$

$\mathbf{r}$ is the mirror reflection direction

Specular reflection

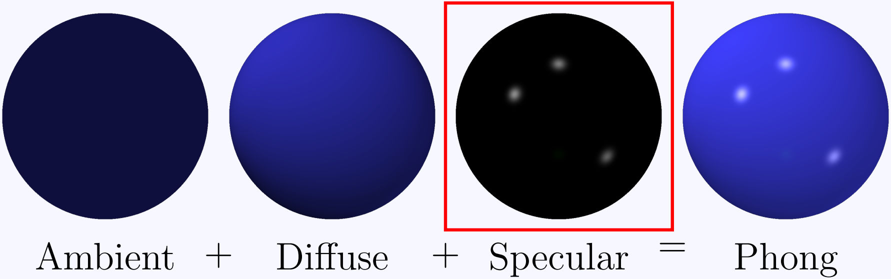


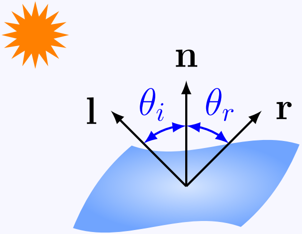
Ambient + Diffuse + Specular = Phong



specular reflection is strongest in reflection direction

Specular reflection

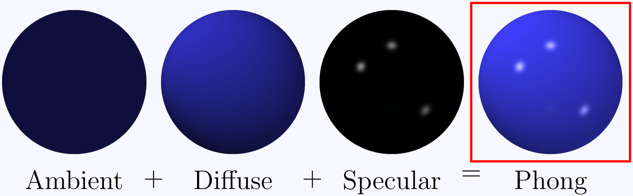




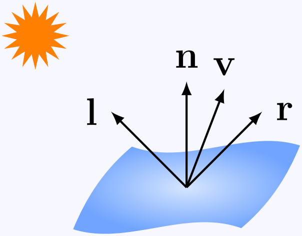
$$I_s = R_s L_s \max(\cos\phi, 0)^\alpha$$

specular reflection drops off with increasing ϕ

Phong reflection model



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



Attribution

[1] Andrea Fisher Fine Pottery. jody-folwell-jar05big.jpg.
https://www.eyesofthepot.com/santa-clara/jody_folwell.