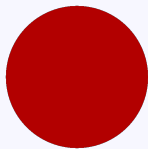


# Lighting and Shading

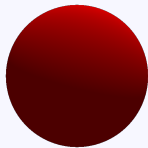
University of California Riverside

# Why we need shading

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

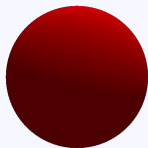


- But we want



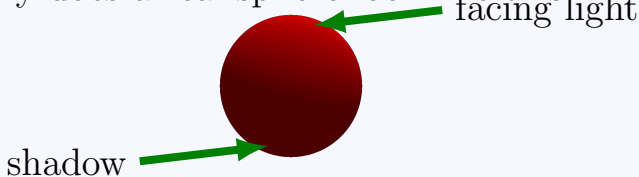
# Shading

- Why does a real sphere look like this?

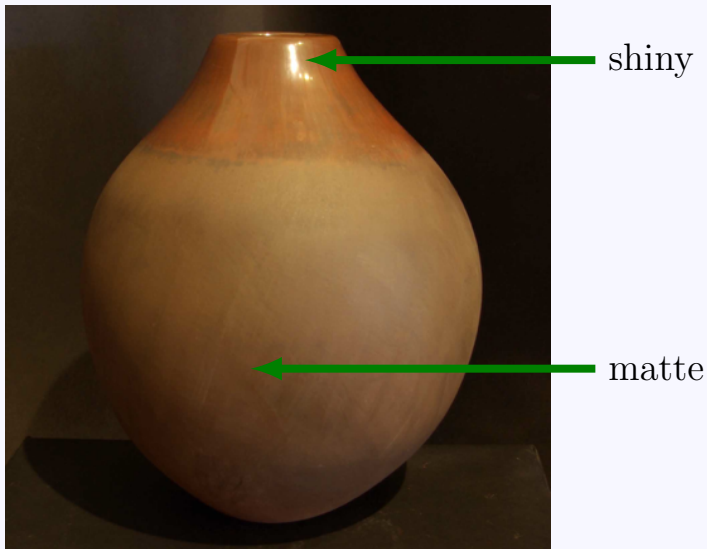


# Shading - lighting

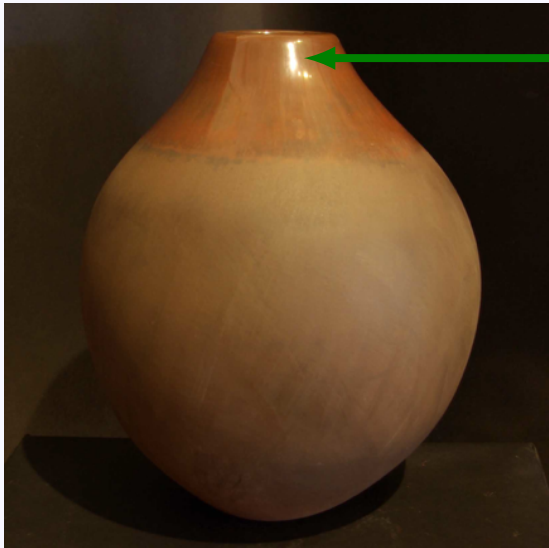
- Why does a real sphere look like this?



# Shading - material properties

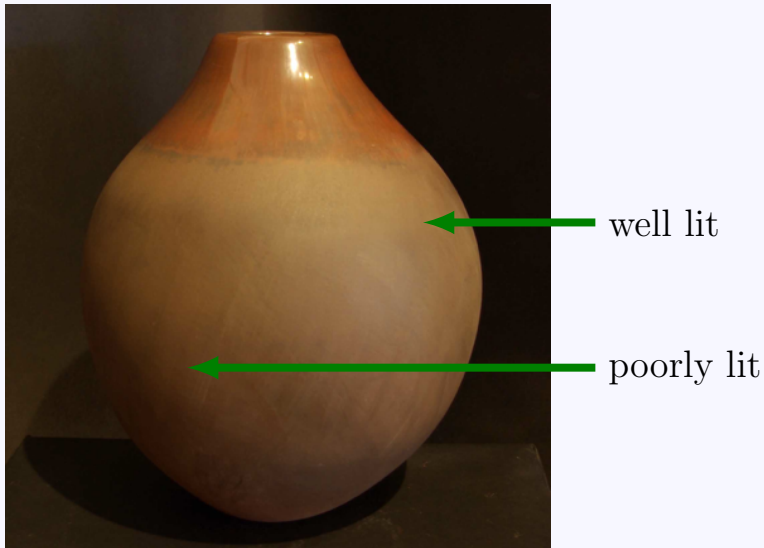


# Shading - viewing location



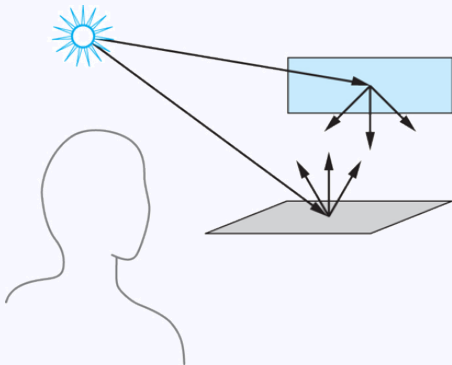
What if I move?

# Shading - surface orientation



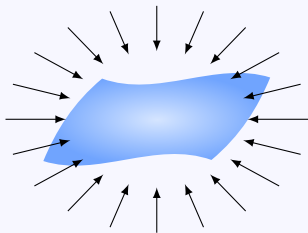
# General rendering

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

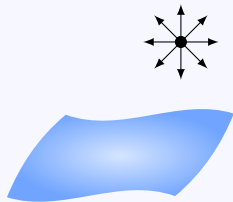




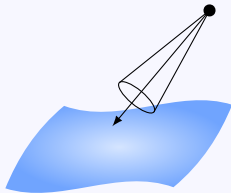
# Idealized light sources



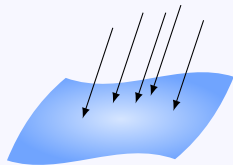
ambient



point light



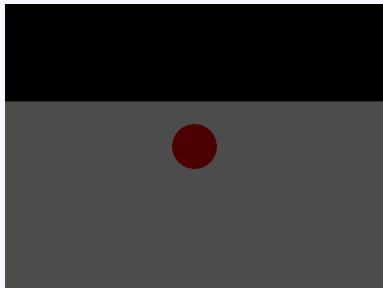
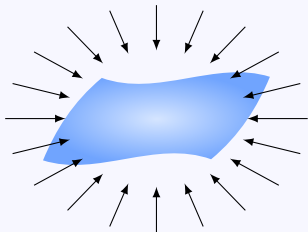
spotlight



directional light

# Ambient light

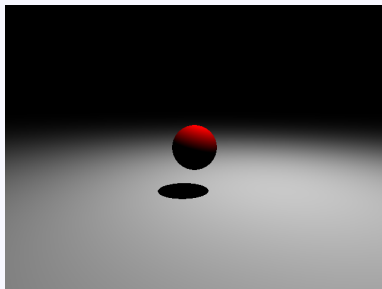
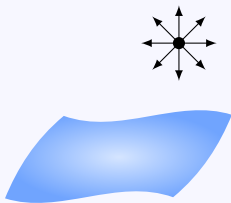
- Achieve uniform light level
- No shadows
- Same light level everywhere



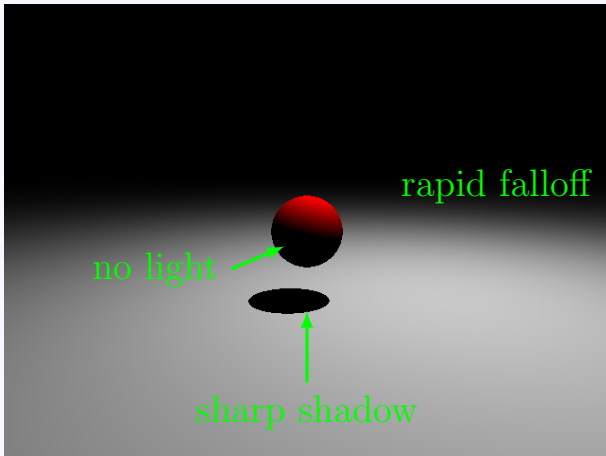
# Point light

- Light emitted from a point  $\mathbf{p}$
- Uniform in all directions

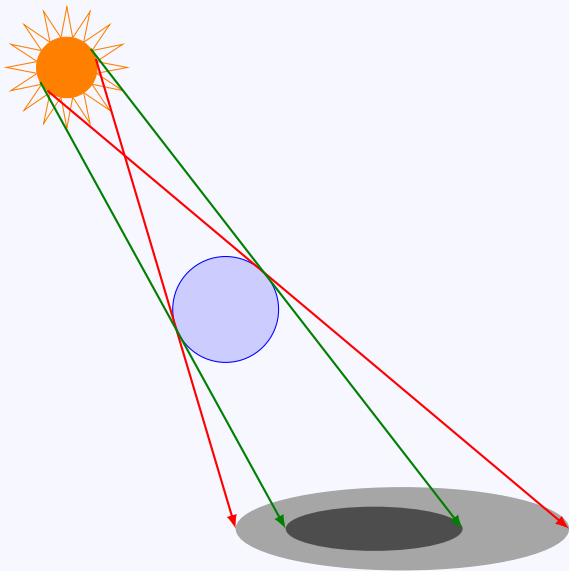
- Falls off with distance:  $\ell(\mathbf{x}) = \frac{1}{\|\mathbf{x} - \mathbf{p}\|^2} L$



# Point light - limitations

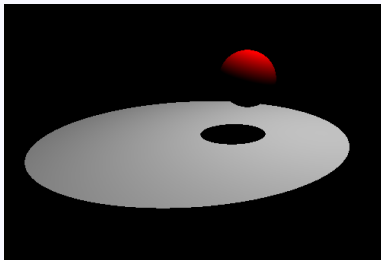
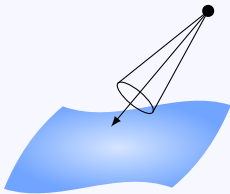


# Soft shadows



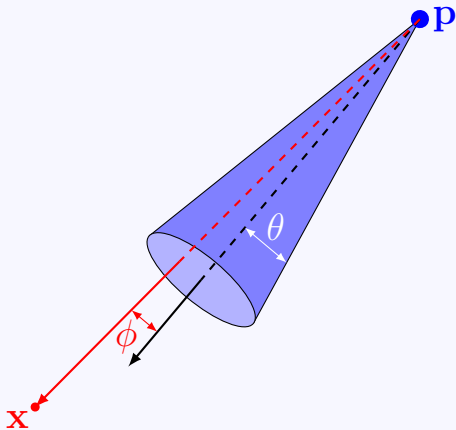
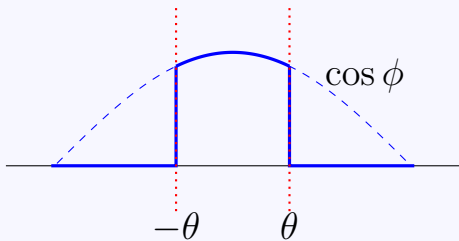
# Spotlight

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

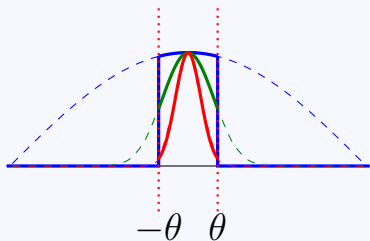


# Spotlight

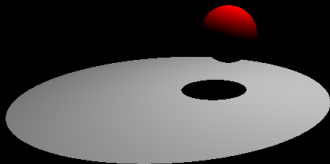
$$l(\mathbf{x}) = \frac{\cos^e \phi}{\|\mathbf{x} - \mathbf{p}\|^2} L$$



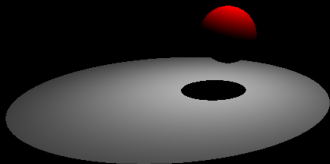
# Spotlight - exploring $e$



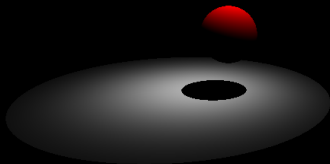
$e = 1$



$e = 20$



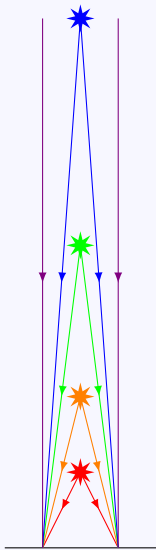
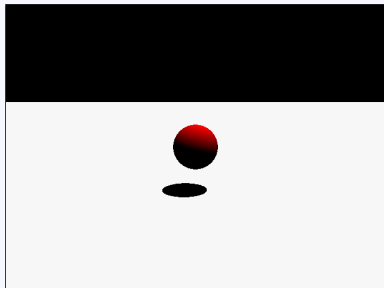
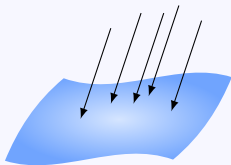
$e = 60$



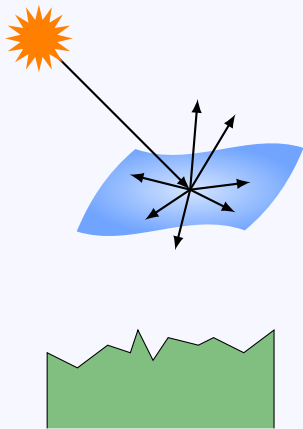


# Directional light

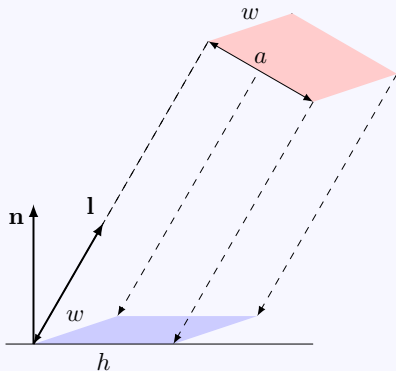
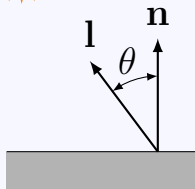
- Light source at infinity
- Rays come in parallel
- No falloff
- Characterized by direction



# Lambertian reflection model



# Lambertian reflection model

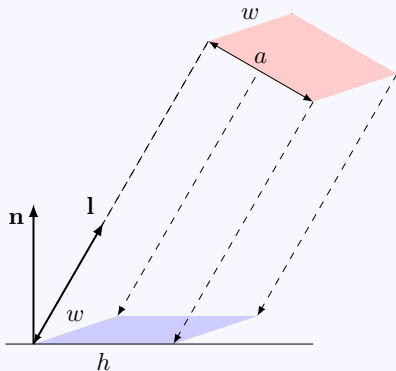
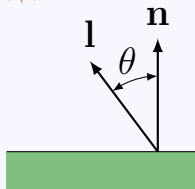


	Light	Incident
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Intensity	$L$	$L'$
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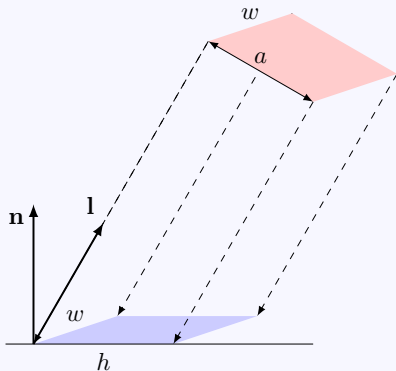
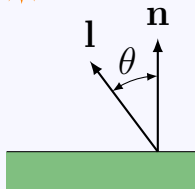
Energy	$E = Lwa$	$E = L'wh$
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# Lambertian reflection model



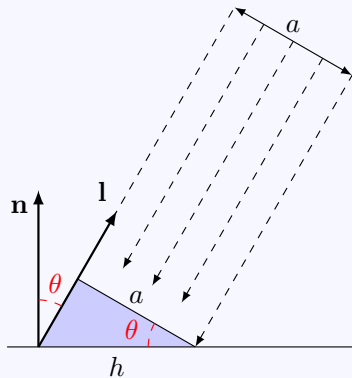
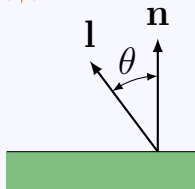
	Light	Incident	Reflected
Intensity	$L$	$L'$	$I = RL'$
Energy	$E = Lwa$	$E = L'wh$	$RE$

# Lambertian reflection model



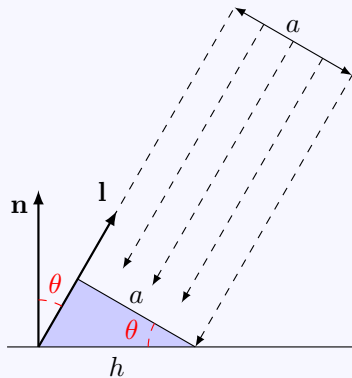
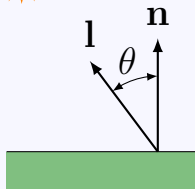
	Light	Incident	Reflected	$I = LR \frac{a}{h}$
Intensity	$L$	$L'$	$I = RL'$	
Energy	$E = Lwa$	$E = L'wh$	$RE$	

# Lambertian reflection model



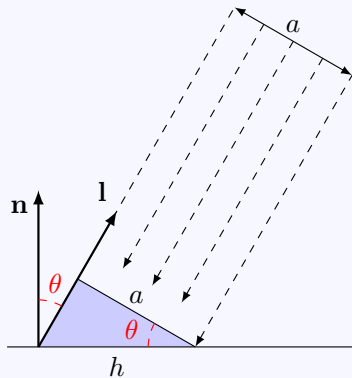
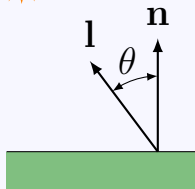
$$I = LR \frac{a}{h}$$

# Lambertian reflection model



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

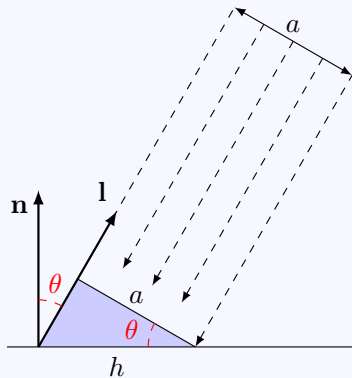
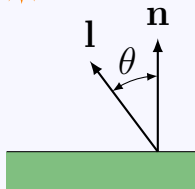
# Lambertian reflection model



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



# Lambertian reflection model



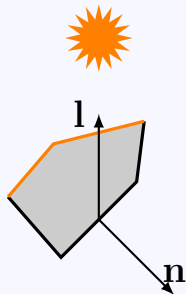
$$I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l}$$

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

# Ambient reflection

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

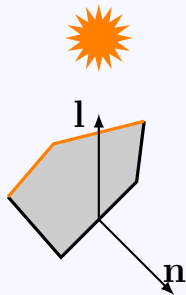
Surfaces facing away from the light will be totally **black**



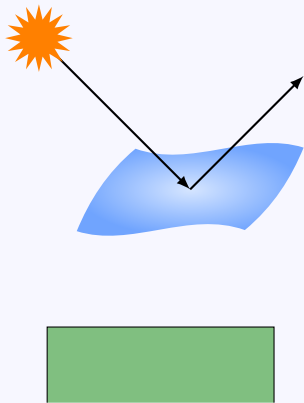
# Ambient reflection

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

All surfaces get the same amount of ambient light



# Phong reflection model

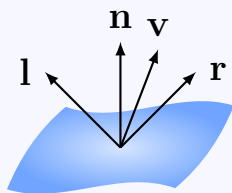


# Phong reflection model

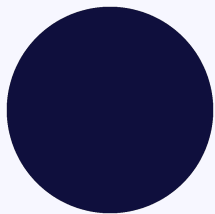


Ambient + Diffuse + Specular = Phong

- Efficient
- Reasonably realistic
- 3 components
- 4 vectors



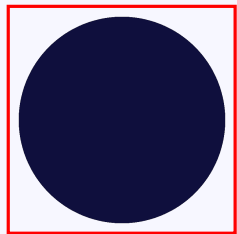
# Phong reflection model



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

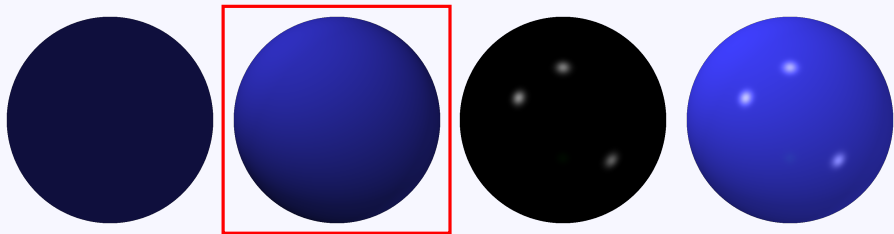


Ambient + Diffuse + Specular = Phong

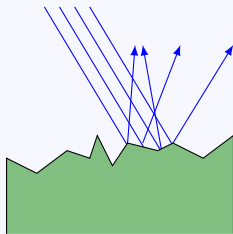
$$I_a = R_a L_a$$

$$0 \leq R_a \leq 1$$

# Diffuse reflection

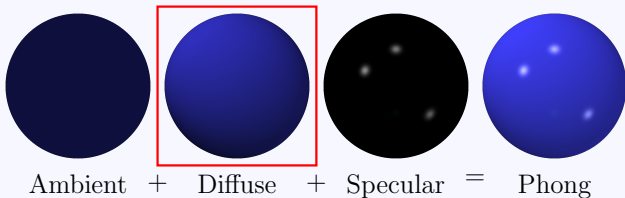


Ambient + Diffuse + Specular = Phong

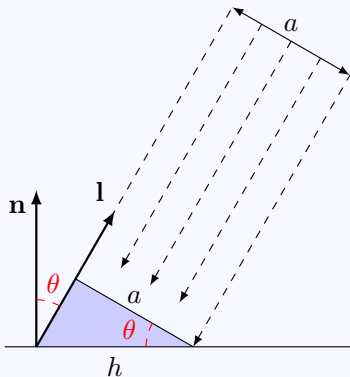




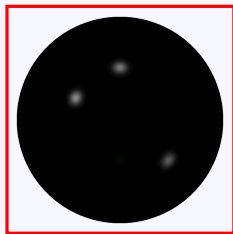
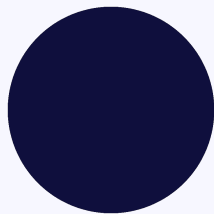
# Diffuse reflection



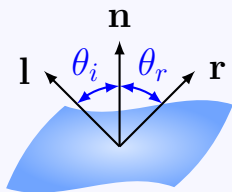
$$I_d = R_d L_d \max(\mathbf{n} \cdot \mathbf{l}, 0)$$



# Specular reflection



Ambient + Diffuse + Specular = Phong

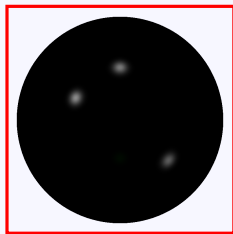
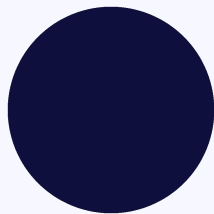


Ideal reflector

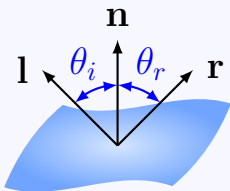
$$\theta_i = \theta_r$$

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

# Specular reflection

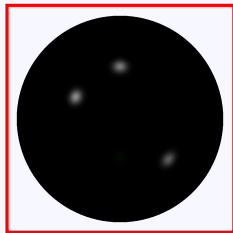
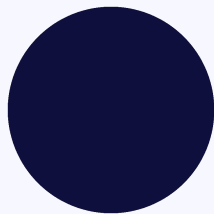


Ambient + Diffuse + Specular = Phong

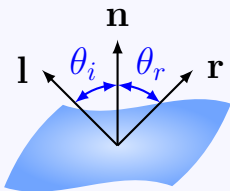


specular reflection is strongest in reflection direction

# Specular reflection



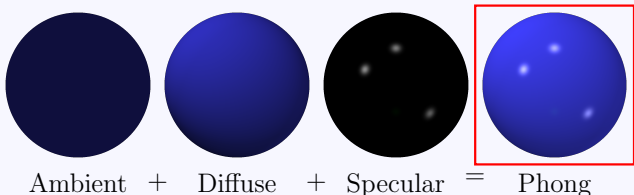
Ambient + Diffuse + Specular = Phong



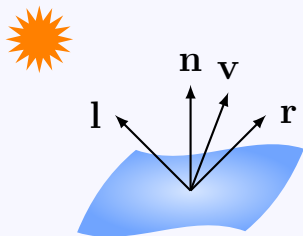
$$I_s = R_s L_s \max(\cos \phi, 0)^\alpha$$

specular reflection drops off with increasing  $\phi$

# Phong reflection model



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



# Attribution

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