

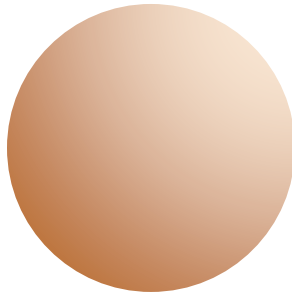
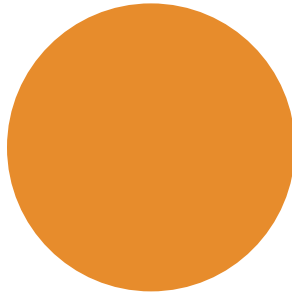
Lighting

10TH WEEK, 2022



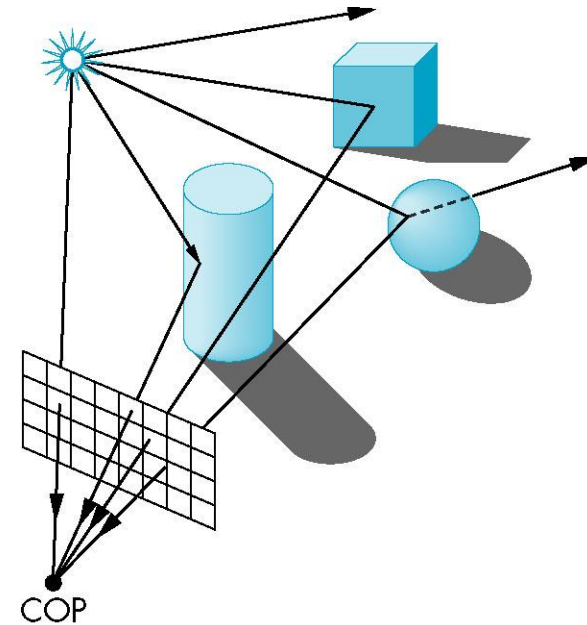
Why We Need Shading

- Suppose we build a model of a sphere using many polygons and color it with `glColor`
- We get something like
- But we want



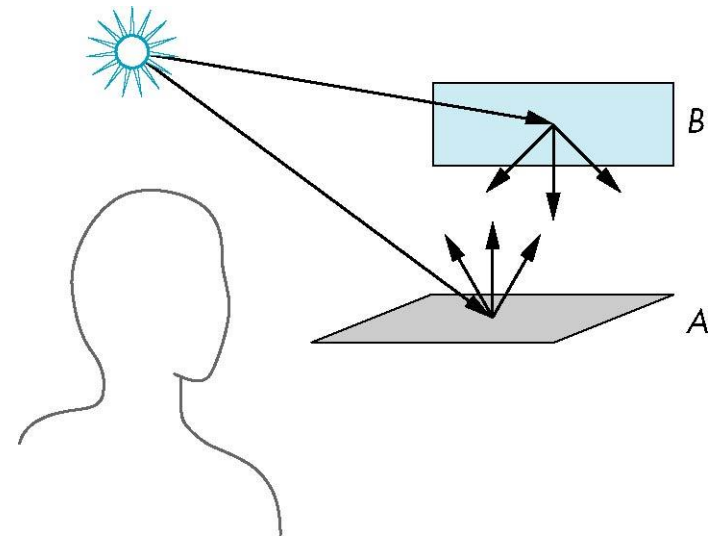
Shading

- Determining a _____ for each filled _____
- _____ - _____ interactions cause each point to have a different color or shade
- Need to consider
 - Light sources
 - Material properties
 - Location of viewer
 - Surface orientation



Scattering of Light

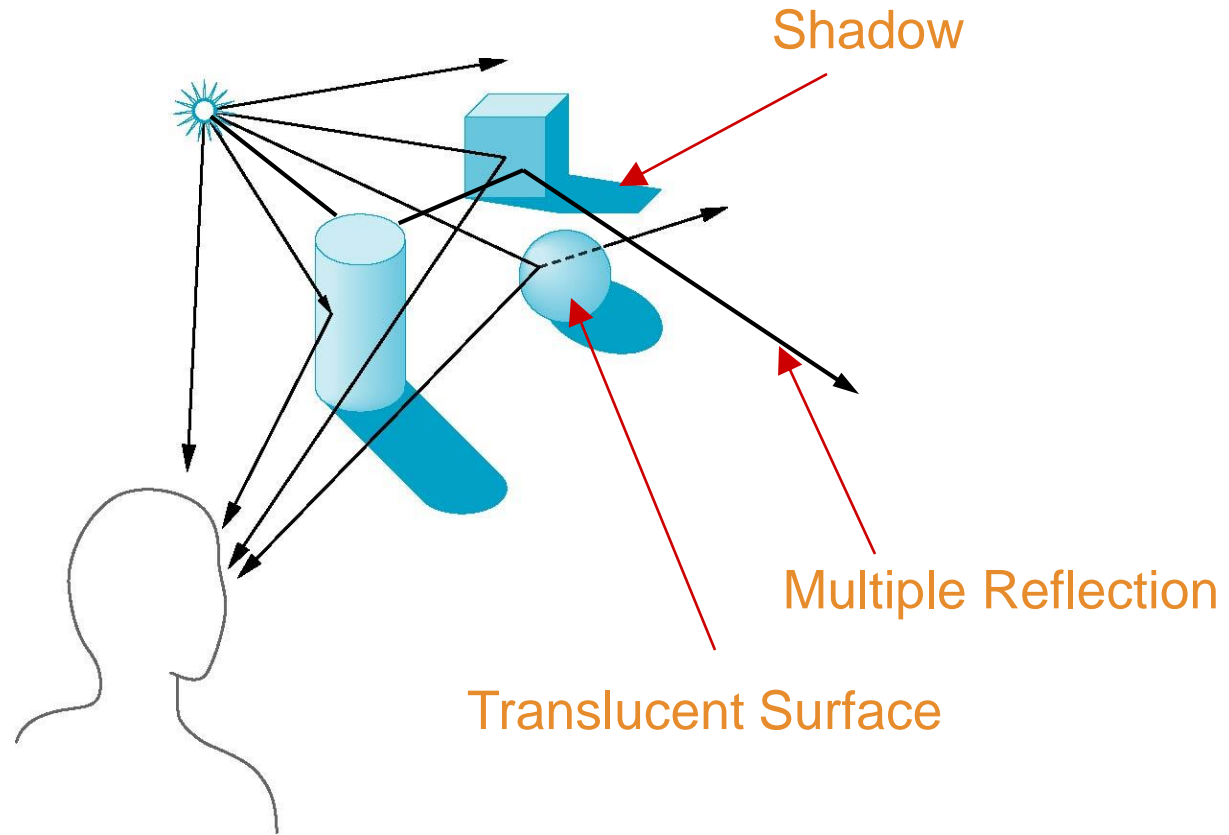
- Light strikes A
 - Some scattered
 - Some absorbed
- Some of scattered light strikes B
 - Some scattered
 - Some absorbed
- Some of this scattered light strikes A and so on



Rendering Equation

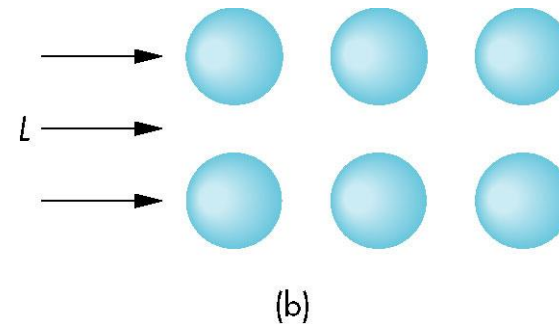
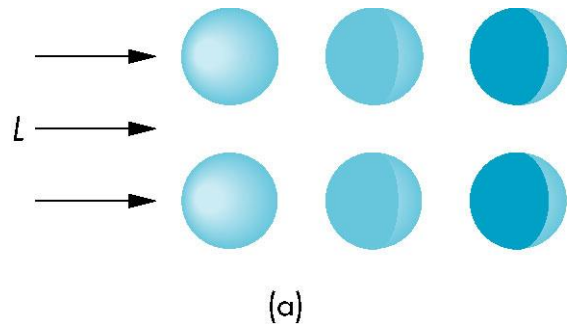
- The infinite scattering and absorption of light can be described by the *rendering equation*
 - Cannot be solved in general
 - _____ is a special case for perfectly reflecting surfaces
- Rendering equation is global and includes
 - _____s
 - Multiple scattering from object to object

Global Effects



Local vs. Global Rendering

- Correct shading requires a global calculation involving all objects and light sources
 - Incompatible with pipeline model which shades each polygon independently (→ _____ rendering)
- In computer graphics, especially real time graphics, we are happy if things “look right”
 - Many techniques exist for approximating global effects



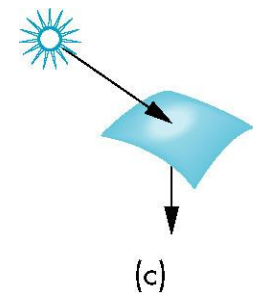
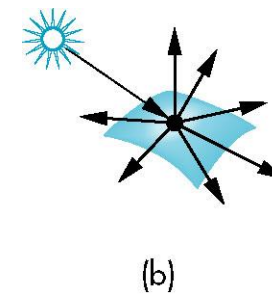
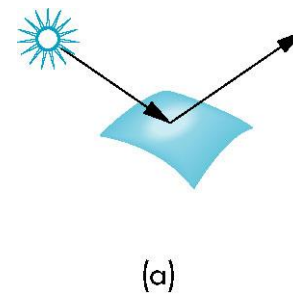
Light-Material Interaction

- Light that strikes an object is partially absorbed and partially scattered (reflected) 45%
- The amount ed determines the color and brightness of the object
 - Ex) red surface under white light
- The reflected light is scattered in a manner that depends on the smoothness and orientation of the surface

Surface Types

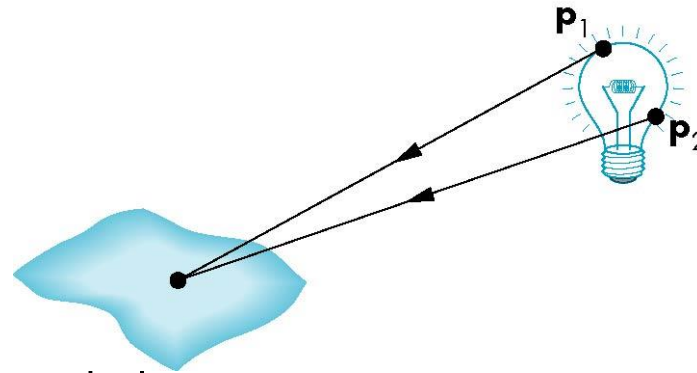
- The smoother a surface, the more reflected light is concentrated in the direction a perfect mirror
 - A very rough surface scatters light in all directions
- _____ surfaces – mirror
 - Scattering reflected light in a narrow range of angle
- _____ surfaces – chalk, clay
 - Scattering reflected light all directions
- _____ surfaces – glass, water
 - Refraction

구경



Light Sources

- General light sources are difficult to work with because we must integrate light coming from all points on the surface



- Simple mathematical models:
 - _____ light
 - Distant light (_____ light)
 - _____ light

Point Light Sources

- Emitting light equally in all directions
 - \mathbf{p}_0 : the location of a point light source

$$\mathbf{I}(\mathbf{p}_0) = \begin{bmatrix} I_r(\mathbf{p}_0) \\ I_g(\mathbf{p}_0) \\ I_b(\mathbf{p}_0) \end{bmatrix}$$

100%

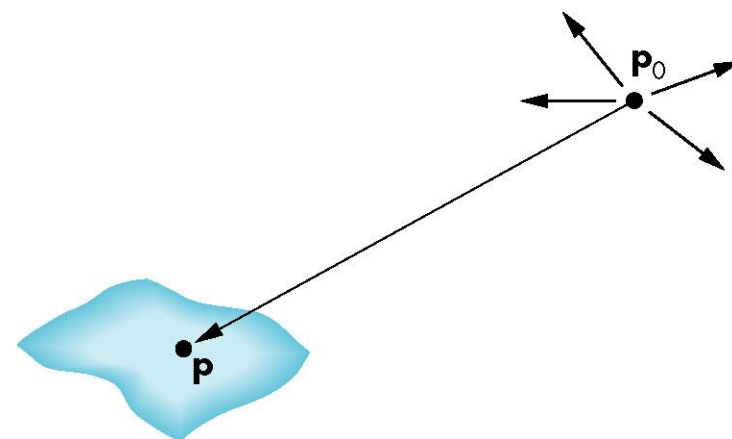

감소해능상

- Proportional to the inverse square distance

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

$$\mathbf{I}(\mathbf{p}, \mathbf{p}_0) = \frac{1}{k_c + k_l d + k_q d^2} \mathbf{I}(\mathbf{p}_0)$$

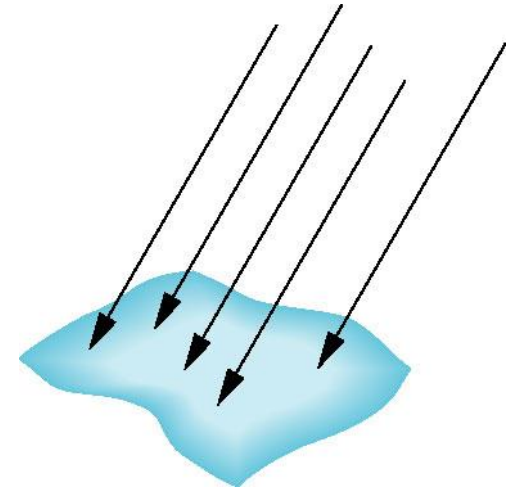
I : 강도 intensity



Directional Light Sources

- Parallel direction of lights
 - Infinite distance away from the surface
 - Location \rightarrow direction

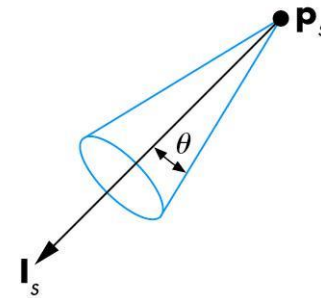
$$\mathbf{p}_0 = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad \rightarrow \quad \mathbf{p}_0 = \begin{bmatrix} x \\ y \\ z \\ 0 \end{bmatrix}$$



Spotlight Sources

- Characterized by a narrow range of angle through which light is emitted

- \mathbf{p}_s : apex of a cone
- \mathbf{l}_s : direction of pointing
- θ : angle to determine width



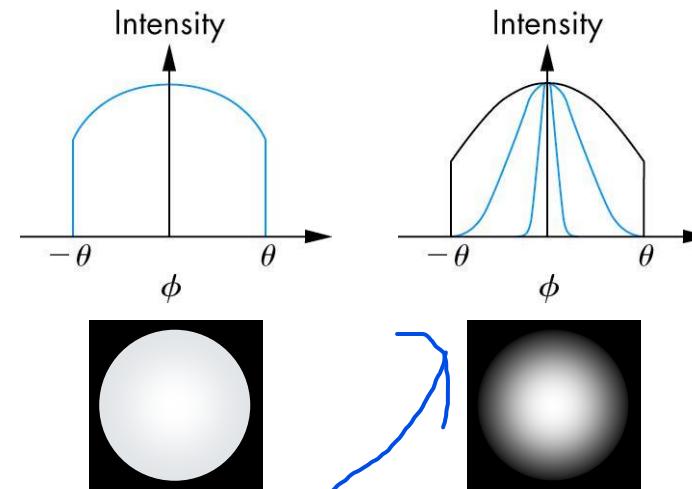
- Distribution of light

- Concentrating in the center

$$\cos \phi = \mathbf{s} \cdot \mathbf{l}_s$$

- Light intensity drop off

$$\cos^e \phi = (\mathbf{s} \cdot \mathbf{l}_s)^e$$



Phong 반사모델

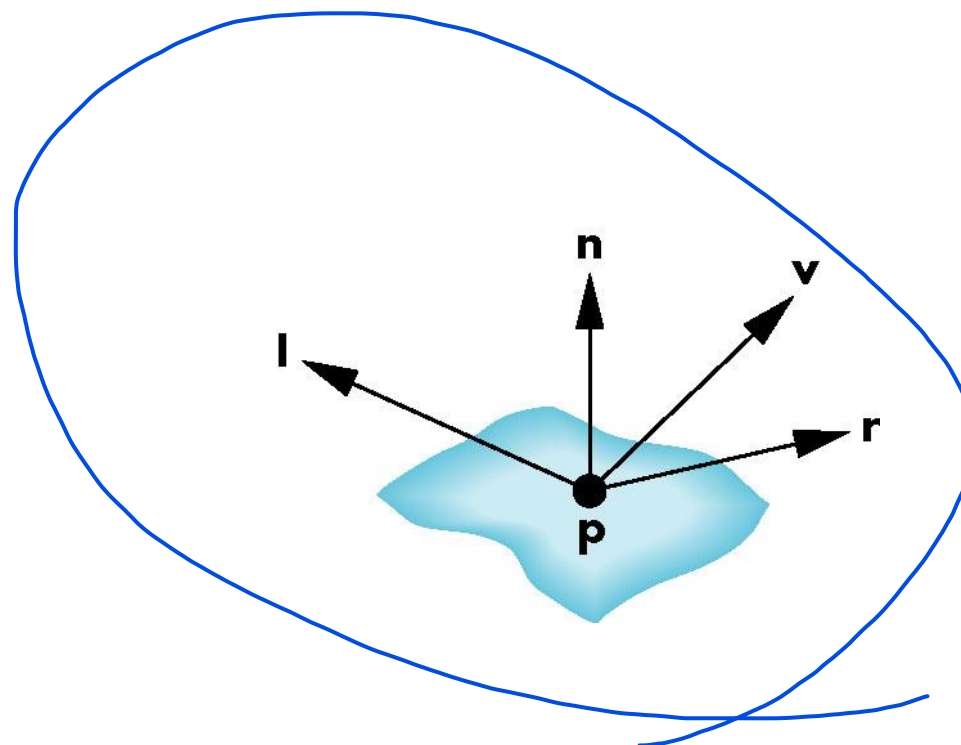
Phong Reflection Model

- A simple model that can compute rapidly
- Three components (light-material interactions)

- _____
- _____
- _____

- Using four vectors

- \mathbf{n} : _____
- \mathbf{v} : to the _____ or COP
- \mathbf{l} : to _____ source
- \mathbf{r} : perfect _____



Ambient Reflection

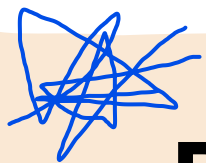
- Same at every point on the surface
- Ambient reflection coefficient

$$\mathbf{k}_a = (k_{ar}, k_{ag}, k_{ab}), \quad 0 \leq k_{ar}, k_{ag}, k_{ab} \leq 1$$

- Amount reflected
 - Some is absorbed and some is reflected
 - Three components (red, green, blue)
- Ambient reflection term in rendering equation

$$\mathbf{I}_a = \mathbf{k}_a \mathbf{L}_a$$

- Can be any of the individual light sources
 - Can be a _____ ambient term



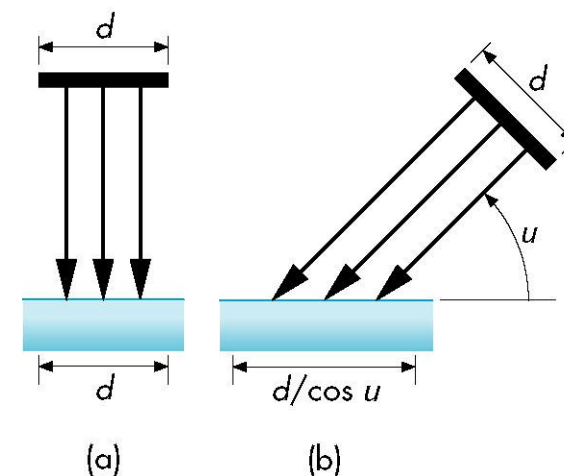
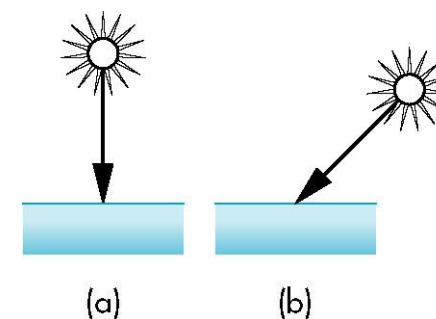
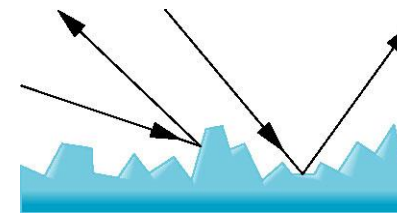
Diffuse Reflection

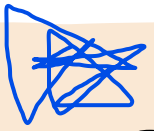
- Light scattered equally in all directions
 - Perfectly diffuse surface
 - ➔ So rough that there is no preferred angle of reflection
- _____'s law
 - Amount of light reflected is proportional to vertical component of incoming light
 - Reflected light $\propto \cos u$
- Diffuse reflection term
 - Incorporating a distance term

$$\cos u = \mathbf{l} \cdot \mathbf{n}$$

$$\mathbf{I}_d = \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d$$

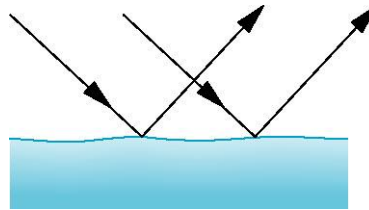
$$\mathbf{I}_d = \frac{\mathbf{k}_d}{k_c + k_l d + k_q d^2} (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d$$





Specular Reflection

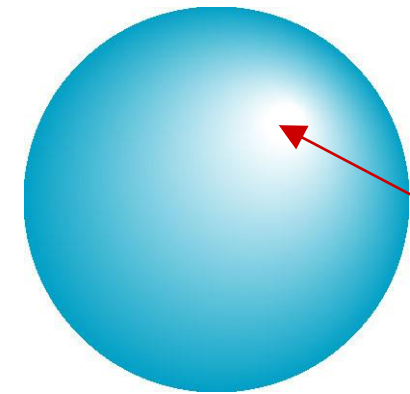
- Smooth surfaces show specular highlights



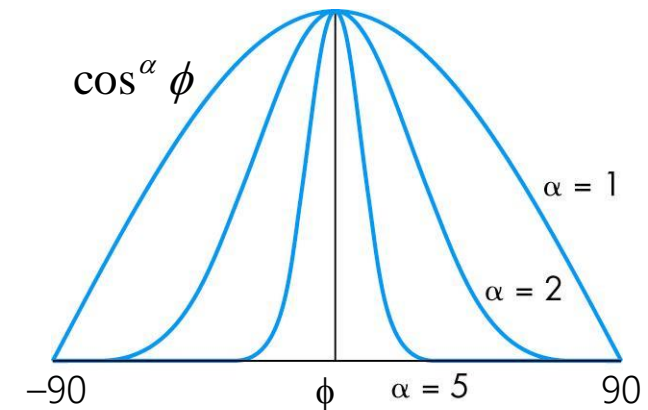
- Specular reflection term

$$\mathbf{I}_s = \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s$$

- α : _____ coefficient
 - $\alpha \rightarrow \infty$: mirror
 - $100 < \alpha < 200$: metal
 - $5 < \alpha < 10$: plastic



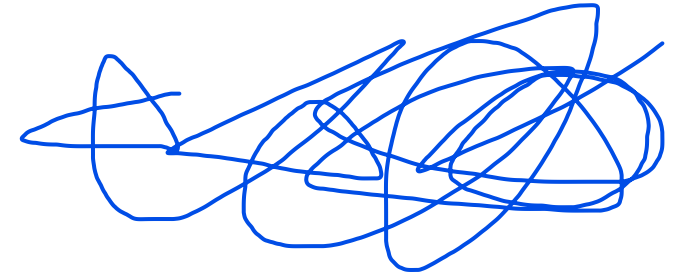
Specular Highlight



Computation of Reflection

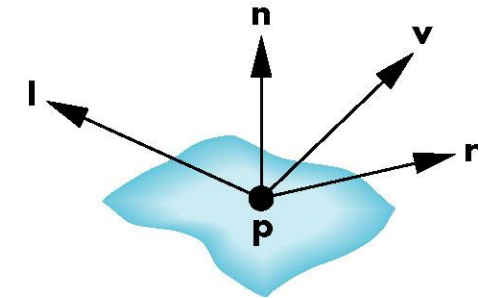
- Light sources
 - Each light source has separate _____, _____, and _____ terms + separate red, green, blue components = nine coefficients
$$(L_{ar}, L_{ag}, L_{ab}, L_{dr}, L_{dg}, L_{db}, L_{sr}, L_{sg}, L_{sb})$$
- Material properties
 - Matching light source properties
 - Nine coefficients: $(k_{ar}, k_{ag}, k_{ab}, k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb})$
 - _____ coefficient: α

Adding up the Components



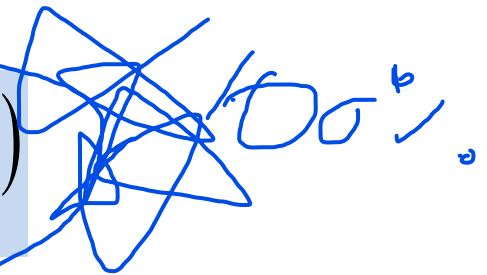
- For each light source and each color component, the Phong model can be written
 - Most surfaces are neither ideal diffusers nor perfectly specular

$$\begin{aligned}\mathbf{I} &= \mathbf{I}_a + \mathbf{I}_d + \mathbf{I}_s \\ &= \mathbf{k}_a \mathbf{L}_a + \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s\end{aligned}$$



- Including the _____ term

$$\mathbf{I} = \mathbf{k}_a \mathbf{L}_a + \frac{1}{k_c + k_l d + k_q d^2} \left(\mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s \right)$$



Computation of Vectors

- Normal vectors
- Ideal reflector

- Angle of incidence == angle of reflection

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

$$\begin{aligned}\mathbf{r} &= \mathbf{l} + 2((\mathbf{l} \cdot \mathbf{n})\mathbf{n} - \mathbf{l}) \\ &= 2(\mathbf{l} \cdot \mathbf{n})\mathbf{n} - \mathbf{l}\end{aligned}$$

- Halfway vector $\mathbf{h} = \frac{\mathbf{l} + \mathbf{v}}{|\mathbf{l} + \mathbf{v}|}$
- Half-angle:

$$\begin{aligned}\theta + \psi &= (\theta - \psi) + \phi \\ \therefore 2\psi &= \phi\end{aligned}$$

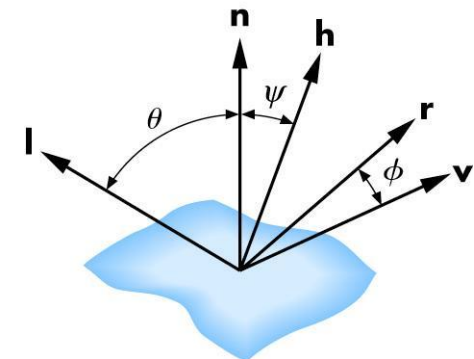
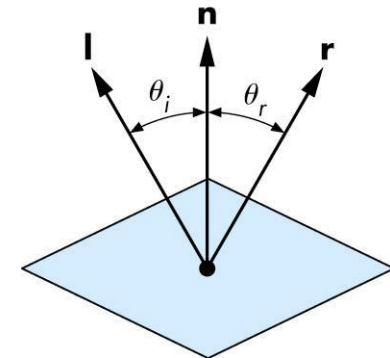
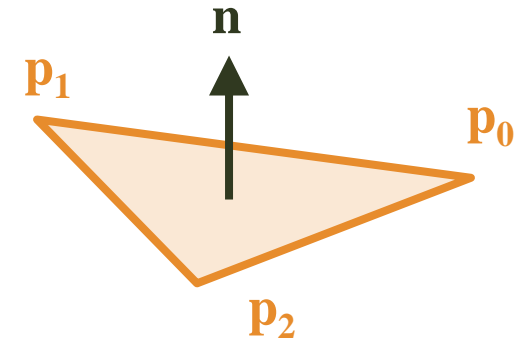
$$\mathbf{I}_s = k_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s$$

Phong Model

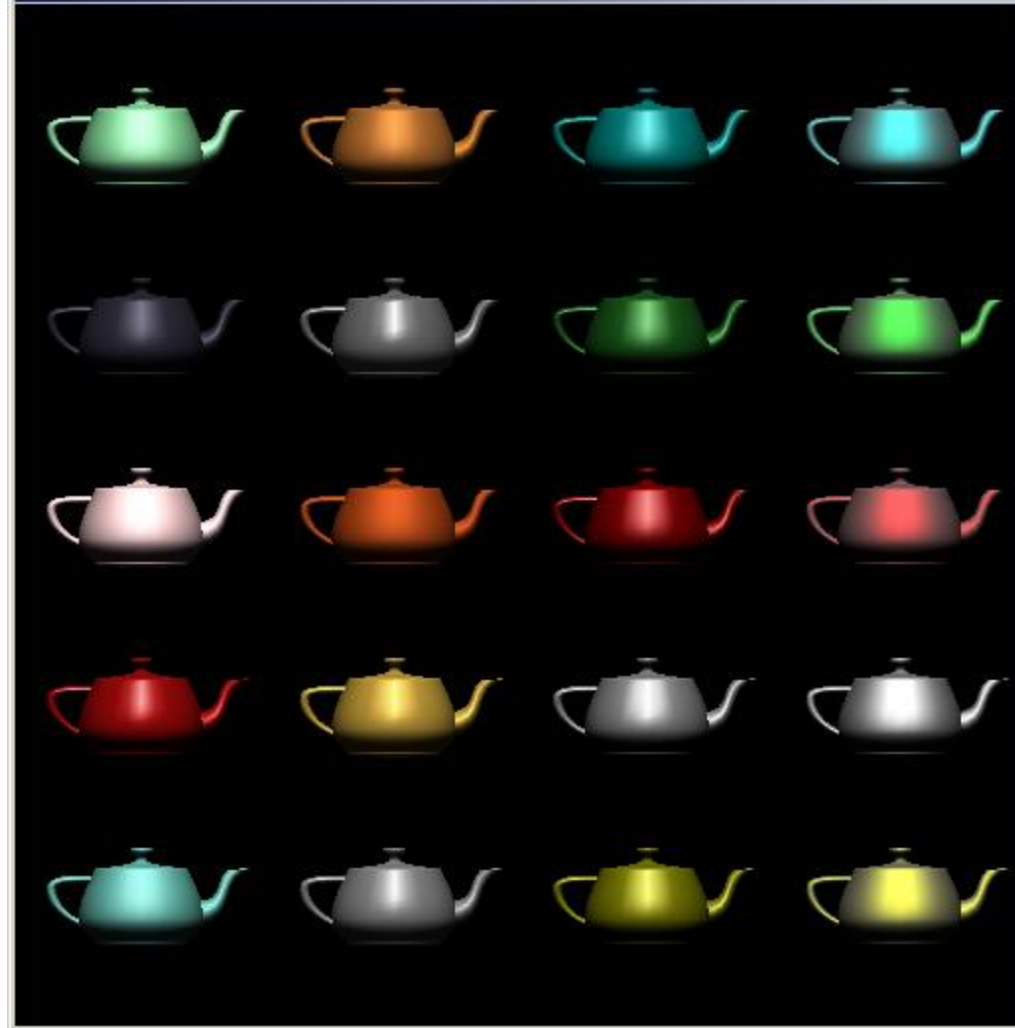


$$\mathbf{I}_s = k_s (\mathbf{n} \cdot \mathbf{h})^\beta \mathbf{L}_s$$

Blinn Model



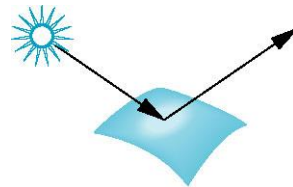
Utah Teapots with Different Material Properties



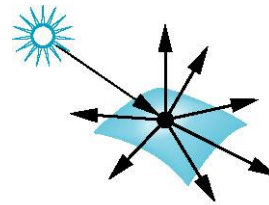
Summary

- Shading → light-material interaction

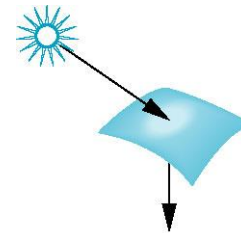
- Surface types



(a)



(b)



(c)

- Light sources → point light, directional light, and spotlight

- Phong reflection model = ambient + diffuse + specular

$$\mathbf{I} = \mathbf{I}_a + \mathbf{I}_d + \mathbf{I}_s$$

$$= \mathbf{k}_a \mathbf{L}_a + \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s$$

- attenuation

$$\mathbf{I} = \mathbf{k}_a \mathbf{L}_a + \frac{1}{k_c + k_l d + k_q d^2} \left(\mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s \right)$$

