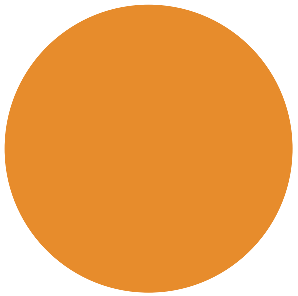
Lighting

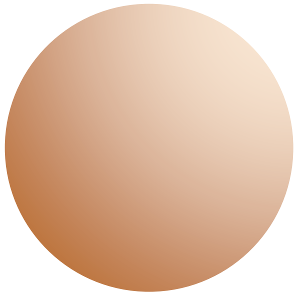
9TH WEEK, 2021

Why We Need Shading

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

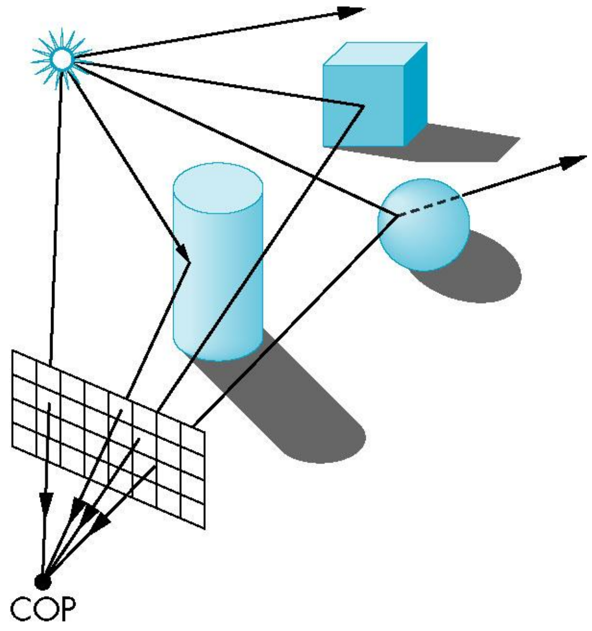


- But we want



Shading

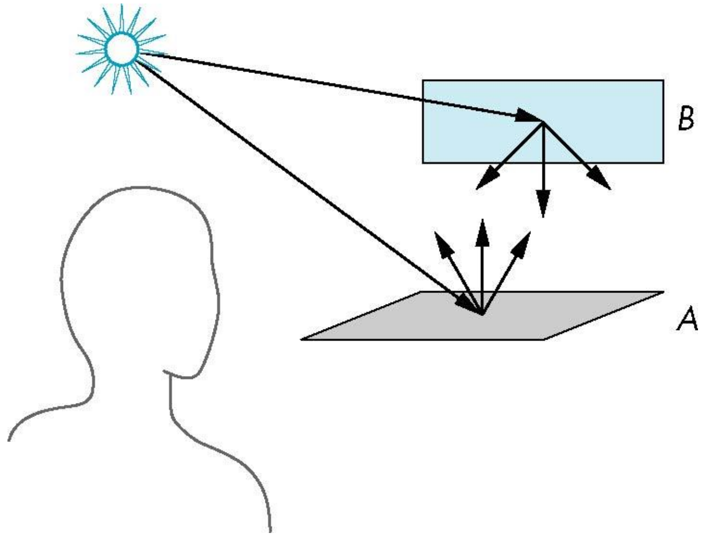
- Determining a color for each filled pixel
- Light-material interactions cause each point to have a different color or shade
- Need to consider
  - Light sources
  - Material properties
  - Location of viewer
  - Surface orientation



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

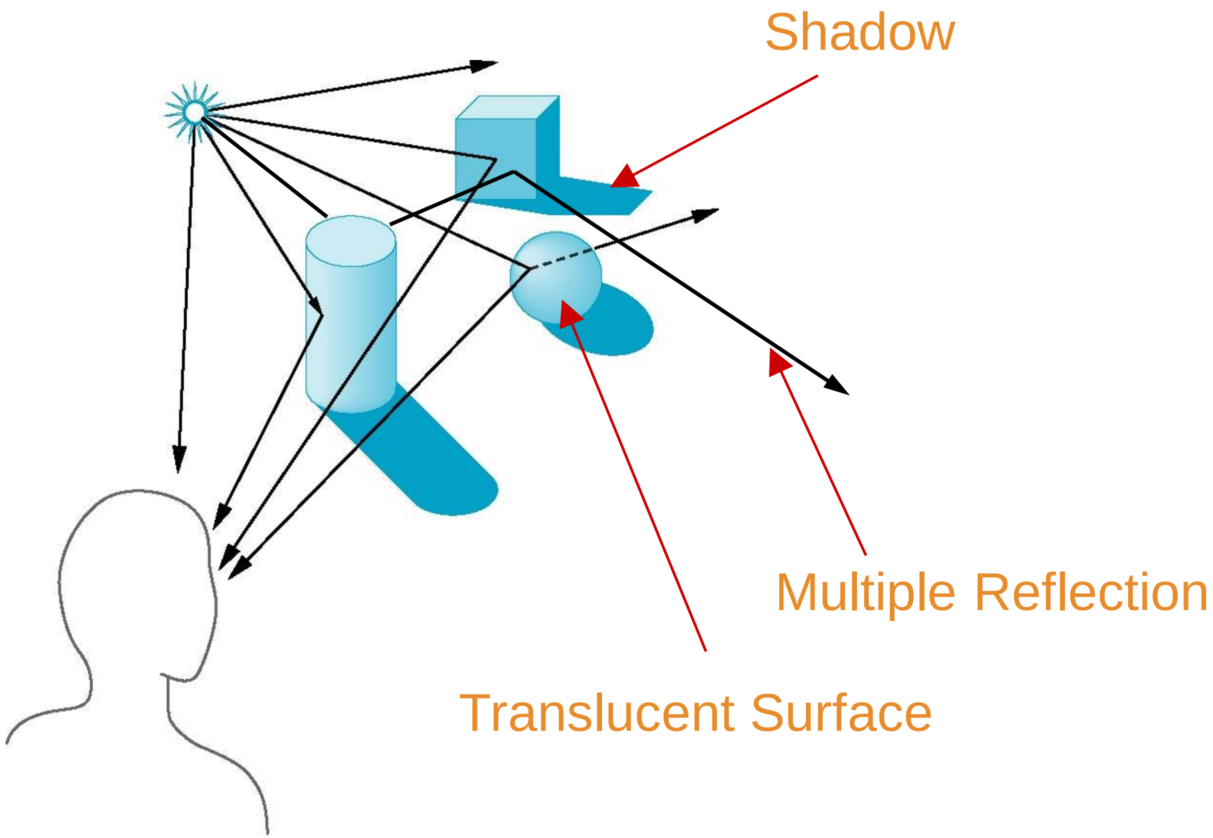


Rendering Equation

- The infinite scattering and absorption of light can be described by the *rendering equation*
  - Cannot be solved in general
  - Ray tracing is a special case for perfectly reflecting surfaces

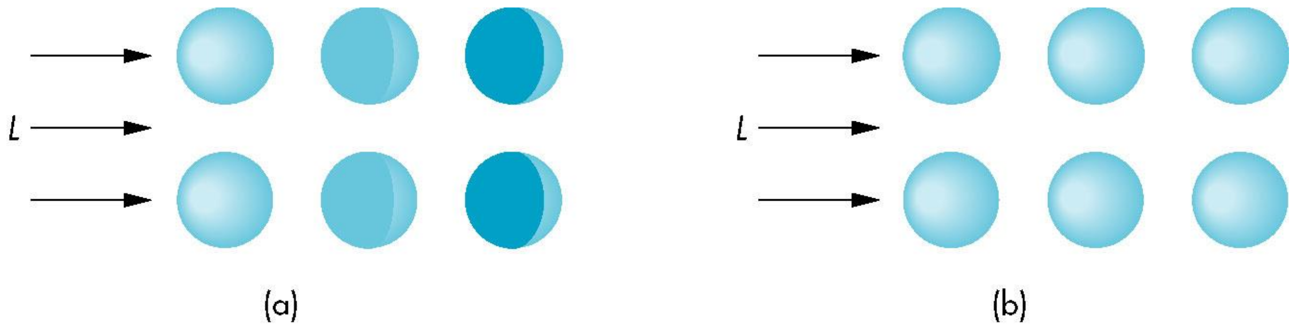
- Rendering equation is global and includes
  - Shadows
  - Multiple scattering from object to object

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 (→ local 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

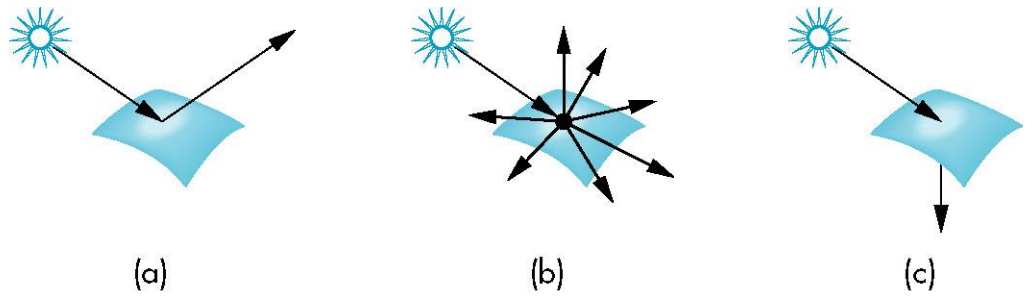
- Light that strikes an object is partially absorbed and partially scattered (reflected)

- The amount <u>reflected</u> 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

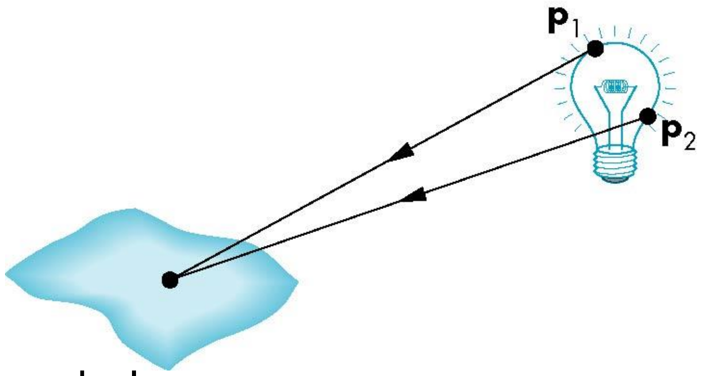
Surface Types

- 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
- <u>Specular</u> surfaces – mirror
  - Scattering reflected light in a narrow range of angle
- <u>Diffuse</u> surfaces – chalk, clay
  - Scattering reflected light all directions
- <u>Translucent</u> surfaces – glass, water
  - Refraction



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:
  - Point light
  - Distant light (directional light)
  - Spotlight

Point Light Sources

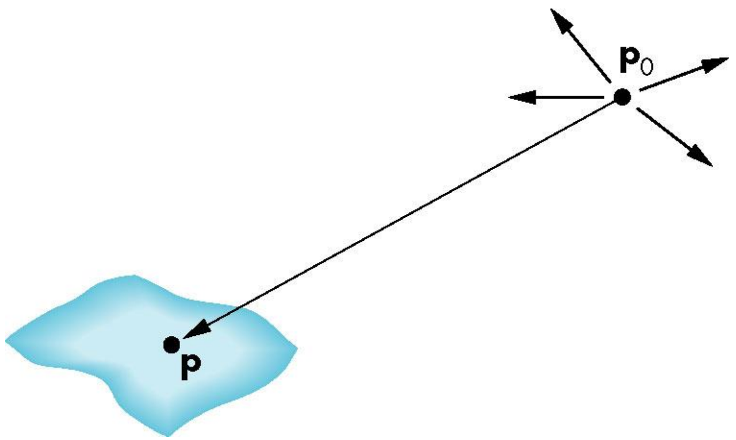
- Emitting light equally in all directions
  - $\mathbf{p}_0$: the location of a point light source

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

  - Attenuation
    - Proportional to the inverse square distance

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

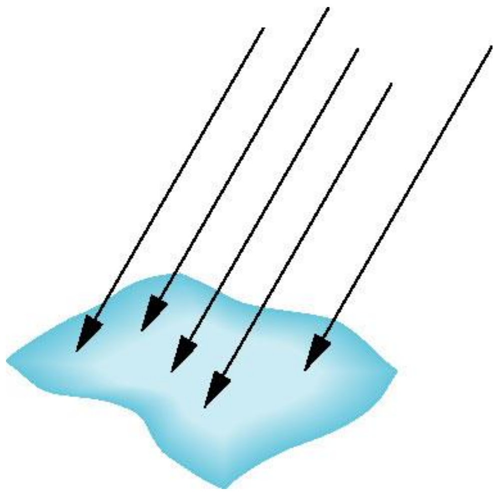
$$\mathbf{I}(\mathbf{p}, \mathbf{p}_0) = \frac{1}{k_c + k_l d + k_q d^2} \mathbf{I}(\mathbf{p}_0)$$



Directional Light Sources

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

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



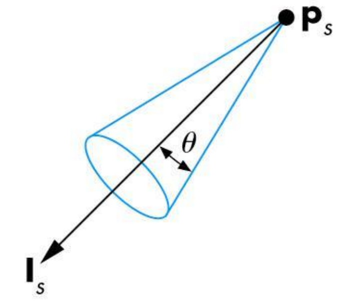
Spotlight Sources

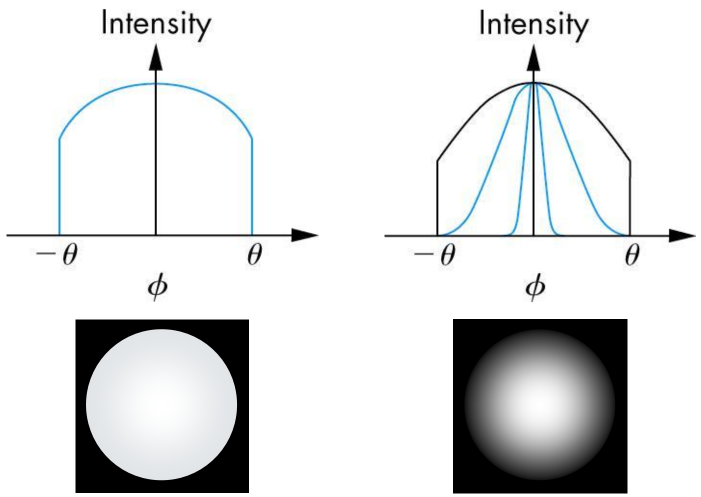
- Characterized by a narrow range of angle through which light is emitted
  - $\mathbf{p}_s$: apex of a cone
  - $\mathbf{l}_s$: direction of pointing
  - θ : angle to determine width
- Distribution of light
  - Concentrating in the center

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

  - Light intensity drop off

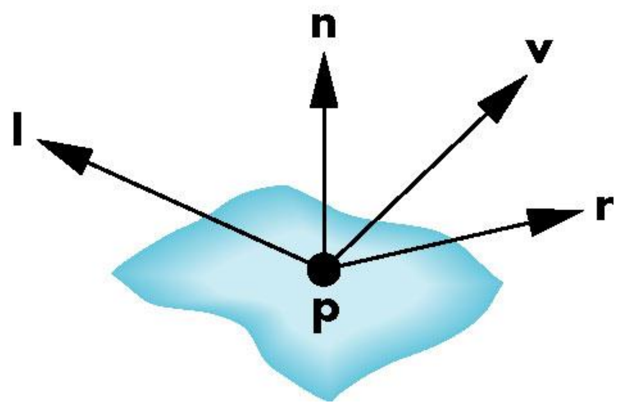
$$\cos^e\phi = (\mathbf{s}\cdot\mathbf{l}_s)^e$$





Phong Reflection Model

- A simple model that can compute rapidly
- Three components (light-material interactions)
  - Ambient
  - Diffuse
  - Specular
- Using four vectors
  - **n**: normal
  - **v**: to the viewer or COP
  - **l**: to light source
  - **r**: perfect reflector



Ambient Reflection

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

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

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

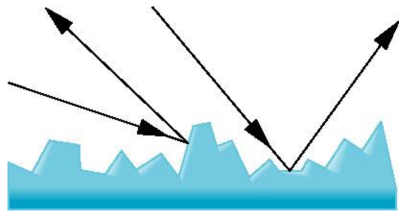
$$\boxed{\mathbf{I}_a = \mathbf{k}_a \mathbf{L}_a}$$

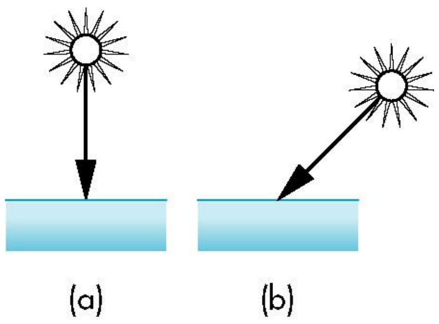
  - Can be any of the individual light sources
  - Can be a <u>global</u> ambient term

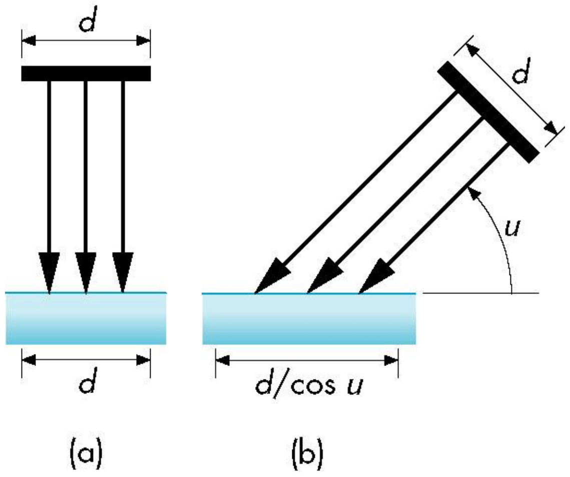
Diffuse Reflection

- Light scattered equally in all directions
  - Perfectly diffuse surface
  - ➔ So rough that there is no preferred angle of reflection
- Lambert's law
  - Amount of light reflected is proportional to vertical component of incoming light
    - Reflected light $\propto \cos u$ $\qquad \cos u = \mathbf{l} \cdot \mathbf{n}$
- Diffuse reflection term $\qquad \boxed{\mathbf{I}_d = \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d}$
  - Incorporating a distance term

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

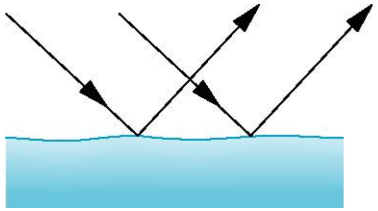


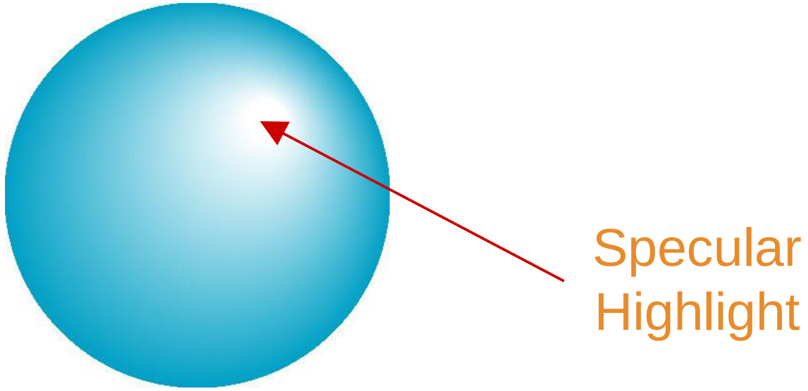




Specular Reflection

- Smooth surfaces show specular highlights

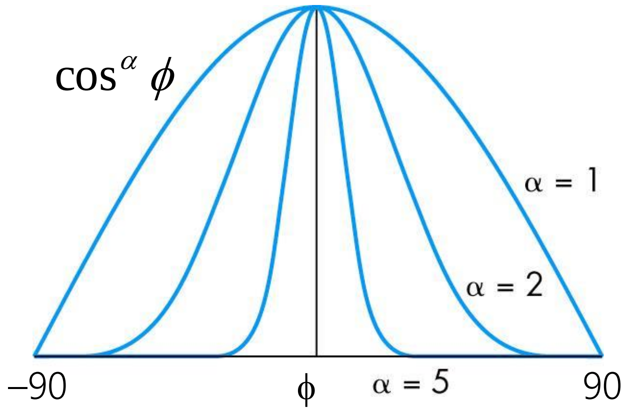




- Specular reflection term

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

  - α: <u>shininess</u> coefficient
    - α → infinite : mirror
    - 100 < α < 200 : metal
    - 5< α < 10 : plastic



Computation of Reflection

- Light sources
  - Each light source has separate ambient, diffuse, and specular terms + separate red, green, blue components = nine coefficients

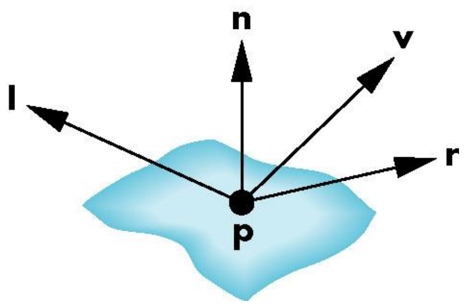
$$\left(L_{ar}, L_{ag}, L_{ab}, L_{dr}, L_{dg}, L_{db}, L_{sr}, L_{sg}, L_{sb}\right)$$

- Material properties
  - Matching light source properties
  - Nine coefficients: $\left(k_{ar}, k_{ag}, k_{ab}, k_{dr}, k_{dg}, k_{db}, k_{sr}, k_{sg}, k_{sb}\right)$
  - Shininess 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

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



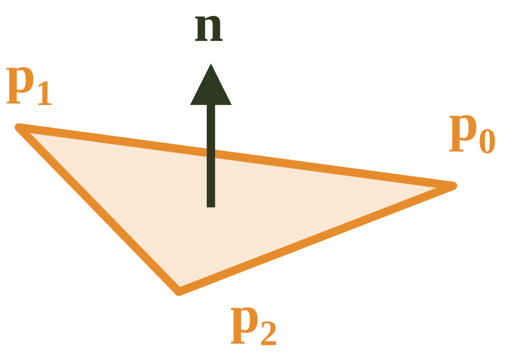
- Including the <u>distance</u> term

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

Computation of Vectors

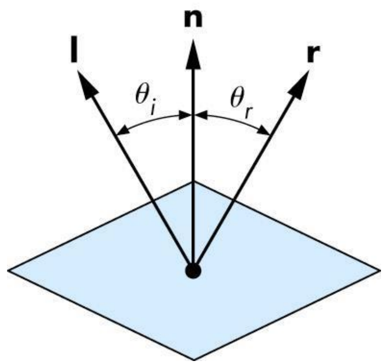
- Normal vectors

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



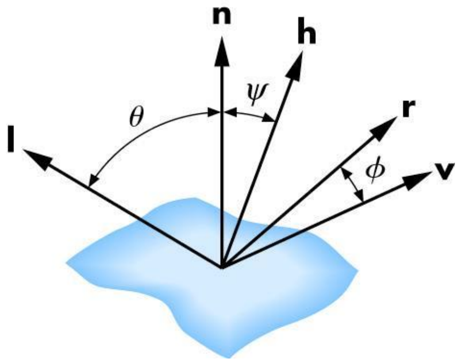
- Ideal reflector
  - Angle of incidence == angle of reflection

$$\mathbf{r} = \mathbf{l} + 2((\mathbf{l} \cdot \mathbf{n})\mathbf{n} - \mathbf{l})$$
$$= 2(\mathbf{l} \cdot \mathbf{n})\mathbf{n} - \mathbf{l}$$



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

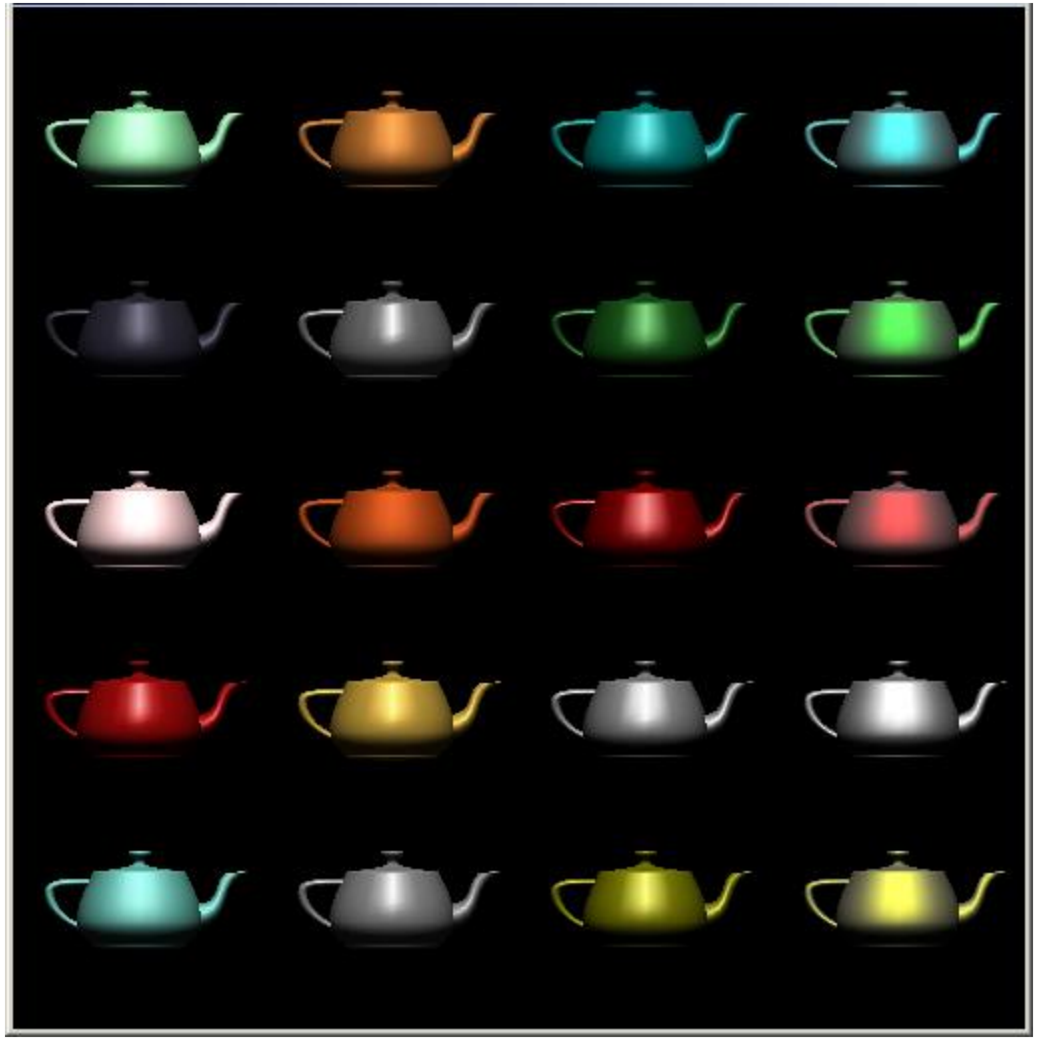
$$\theta + \psi = (\theta - \psi) + \phi$$
$$\therefore 2\psi = \phi$$



$$\mathbf{I}_s = \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^{\alpha} \mathbf{L}_s \quad \Rightarrow \quad \mathbf{I}_s = \mathbf{k}_s (\mathbf{n} \cdot \mathbf{h})^{\beta} \mathbf{L}_s$$

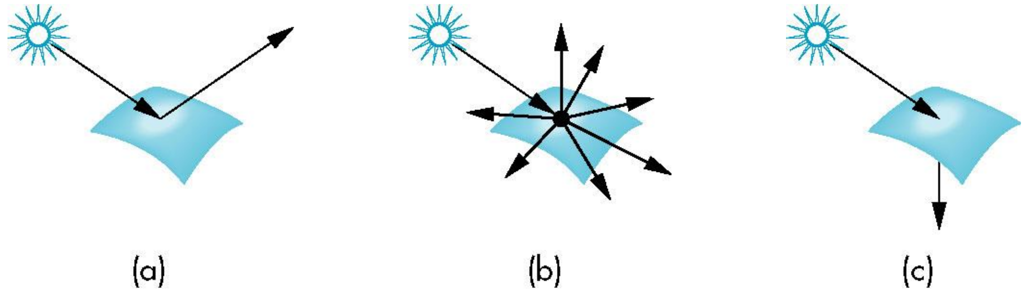
Phong Model Blinn Model

Utah Teapots with Different Material Properties

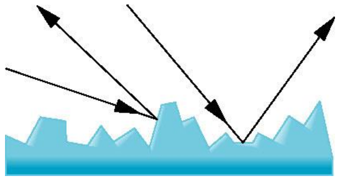


Summary

- Shading ➔ light-material interaction
- Surface types



- Light sources ➔ point light, directional light, and spotlight
- Phong reflection model = ambient + diffuse + specular

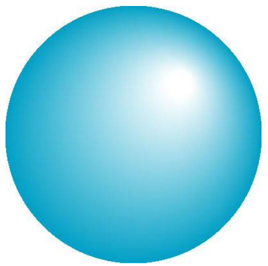


$$\mathbf{I} = \mathbf{I}_a + \mathbf{I}_d + \mathbf{I}_s$$

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

  - attenuation

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



수고하셨습니다