# COSE436

# Lecture 9: Lighting & Shading

Oct 16, 2024

Won-Ki Jeong
(wkjeong@korea.ac.kr)

KOREA UNIVERSITY

# Outline

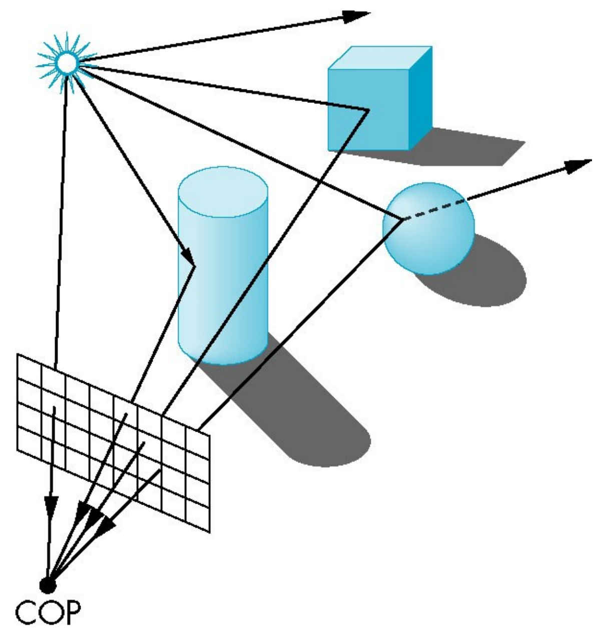
- Light-material interactions
- Phong reflection model
- Polygonal model shading

# Outline

- Light-material interactions
- Phong reflection model
- Polygonal model shading

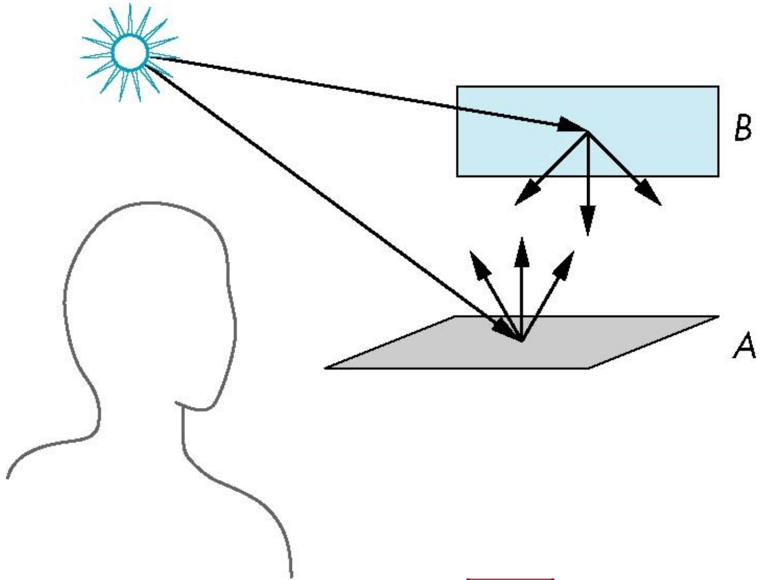
# Shading

- Enhance realism in computer graphics
- 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 & Absorption

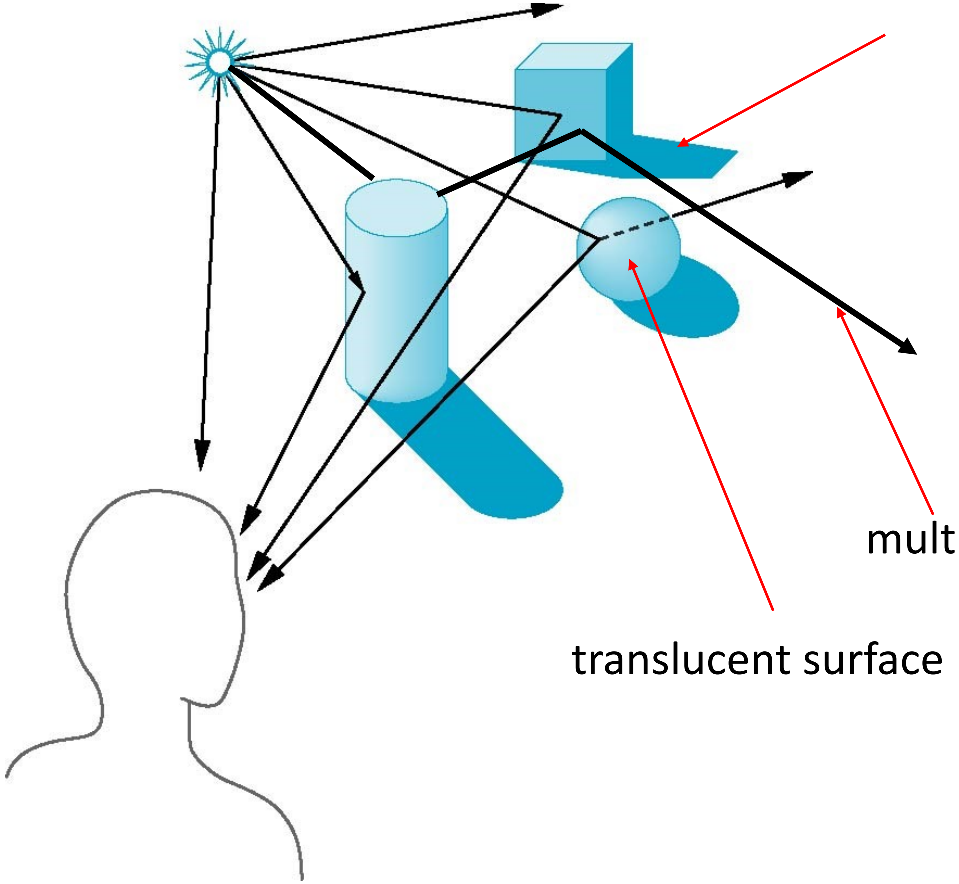
- Light strikes A
  - Some scattered
  - Some absorbed
- Some of scattered light strikes B
  - Some scattered
  - Some absorbed
- Some of this scattered light strikes A and so on



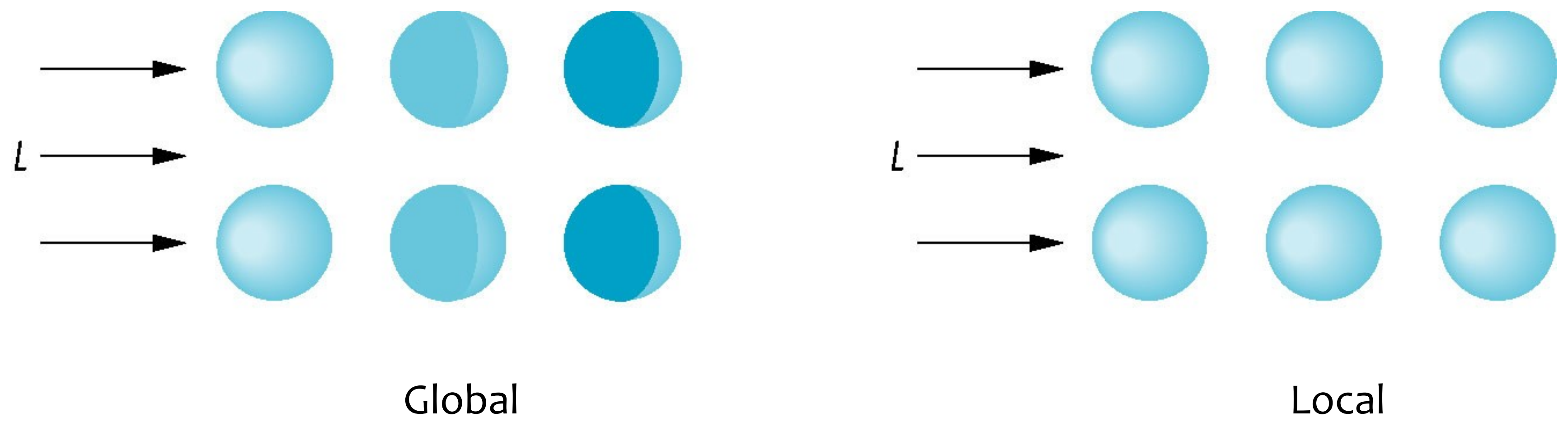
# Rendering Equation

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

# Global Effect



# Local vs. Global Rendering



# Local vs. Global Rendering

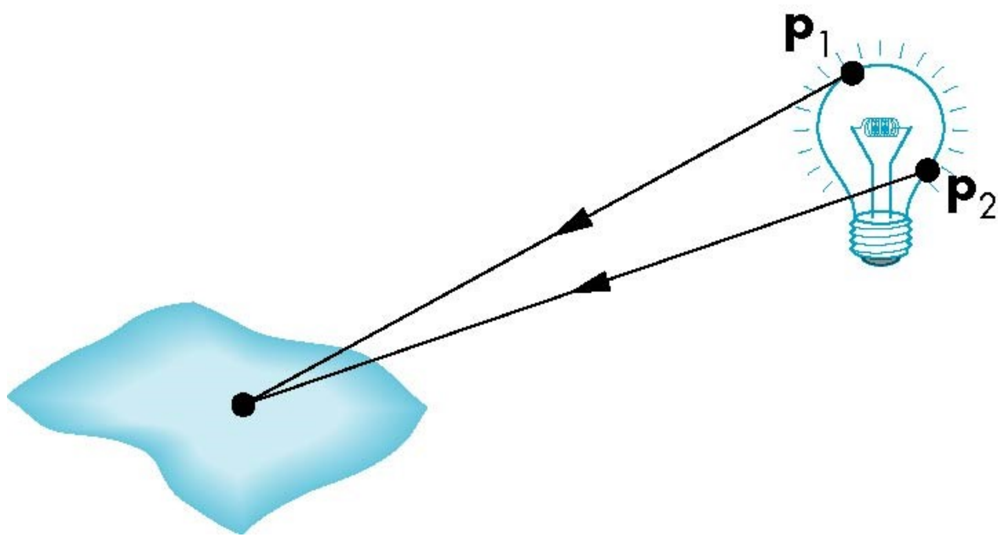
- Correct shading requires a global calculation involving all objects and light sources
  - Incompatible with pipeline model which shades each polygon independently (local rendering)
- However, in real time computer graphics, we are happy if things "look right"
  - Many techniques exist for approximating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

# Light-Material Interaction

- Light is partially absorbed and partially scattered (reflected)
- How the color of object determined?
  - ex) red surface under white light looks red
- The reflected light is scattered based on the smoothness and orientation of the surface

# Light Sources in Real World

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



# Light Models: Point Light

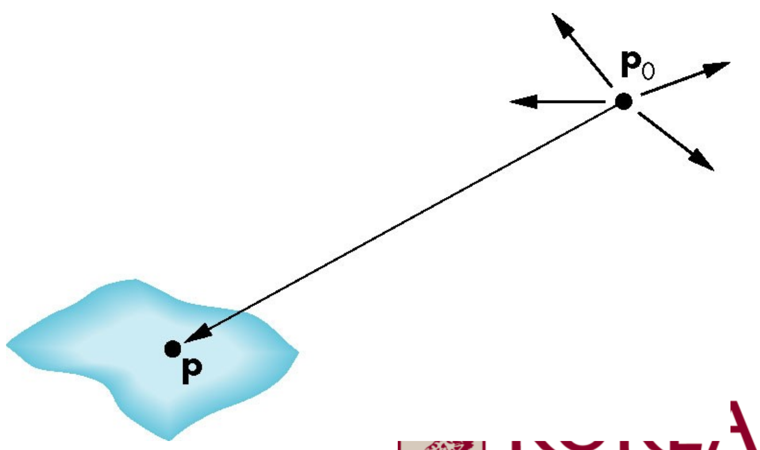
- Emitting light equally in all directions
  - $\mathbf{p}_0$: the location of a point light source

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

  - Attenuation
    - Proportional to the inverse square distance

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

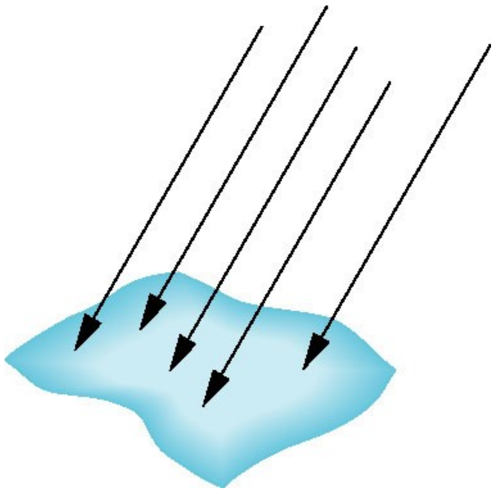
$$\mathbf{I}(\mathbf{p}, \mathbf{p}_0) = \frac{1}{a + bd + cd^2} \mathbf{I}(\mathbf{p}_0)$$



# Light Models: Distant Light

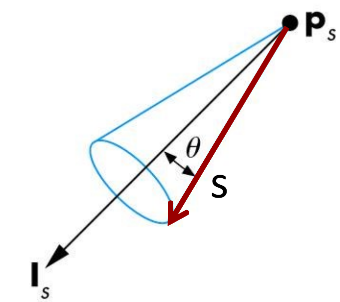
- Light source is infinitely far away
- No attenuation
- Light rays are parallel

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



# Light Models: Spot Light

- Restrict the range of emitted light
  - $\mathbf{p}_s$: apex of a cone
  - $\mathbf{l}_s$ : direction of pointing
  - θ : angle to determine width

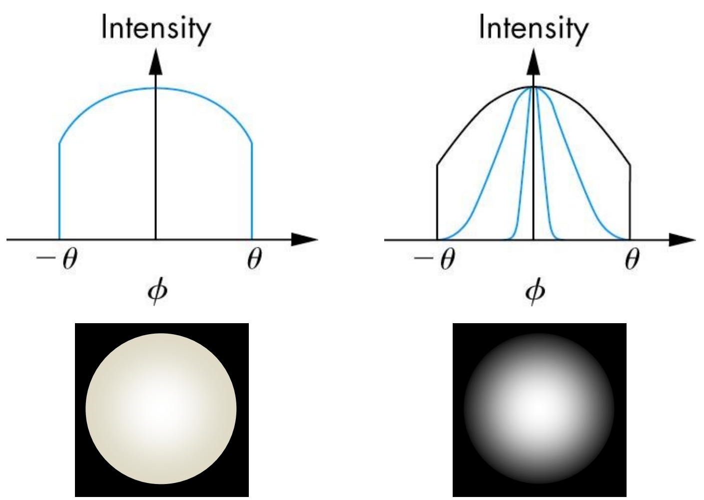



- Distribution of light
  - Concentrating in the center

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

  - Light intensity drop off

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

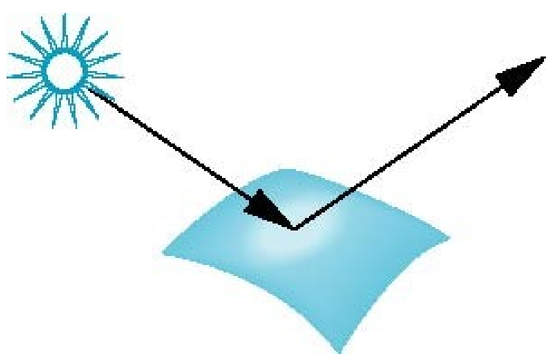


# Light Models: Ambient Light

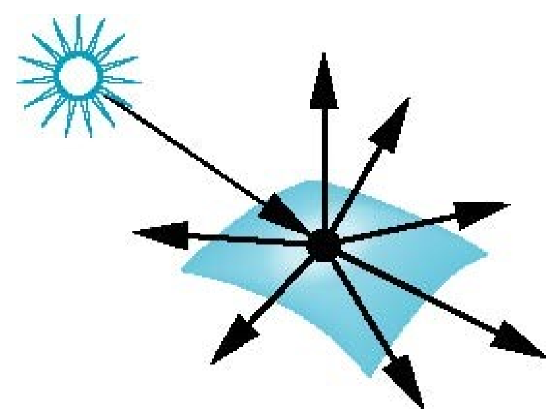
- Uniform lighting everywhere
- No directions

# Surface Types

- The smoother a surface is, the more reflected light is concentrated in the direction a perfect mirror would reflect the light
- A very rough surface scatters light in all directions



smooth surface



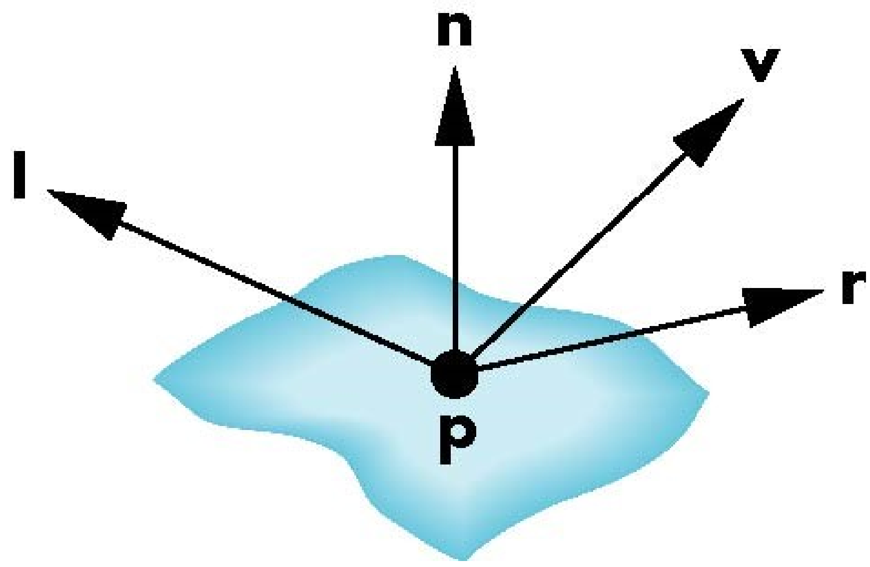
rough surface

# Outline

- Light-material interactions
- Phong reflection model
- Polygonal model shading

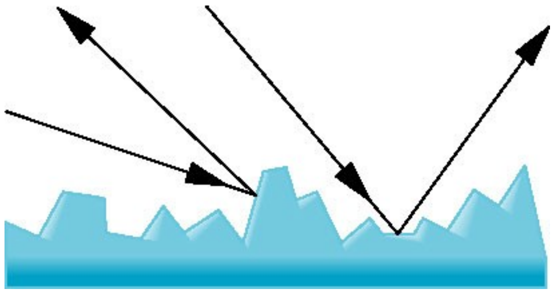
# Phong Reflection Model

- A simple model that can be computed rapidly
- Has three components
  - Diffuse
  - Specular
  - Ambient
- Uses four vectors
  - To light source (l)
  - To viewer (v)
  - Normal (n)
  - Perfect reflector (r)

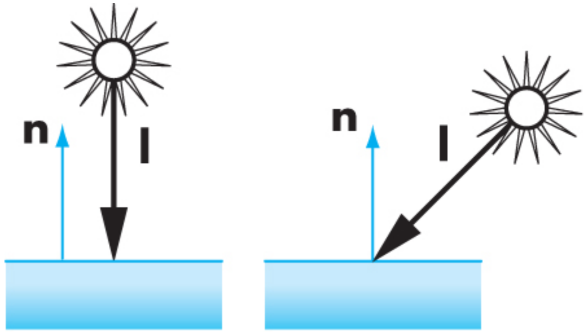


# Lambertian Surface

- <u>Perfectly diffuse</u> reflector
- Light scattered equally in all directions



- Amount of light reflected is proportional to the vertical component of incoming light
  - reflected light : (a) > (b)



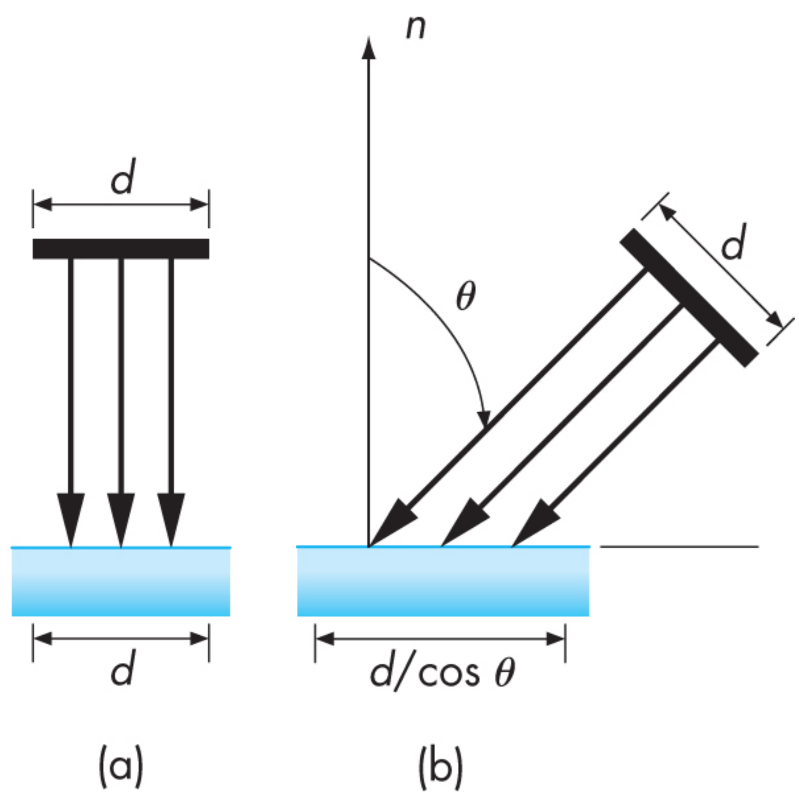
# Diffuse Reflection

- Diffuse reflection term

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

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

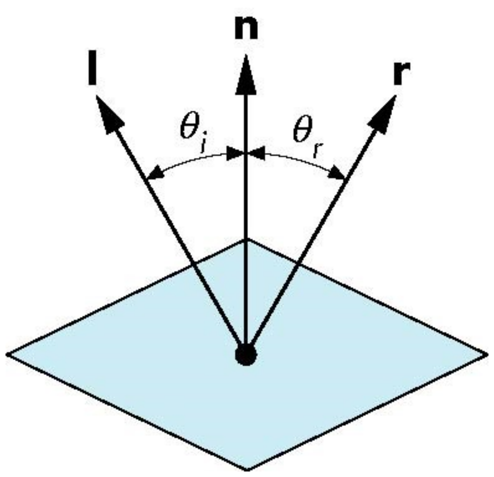
$0 \le \mathbf{k}_d \le 1$ : absorption coefficient



# Ideal Reflector

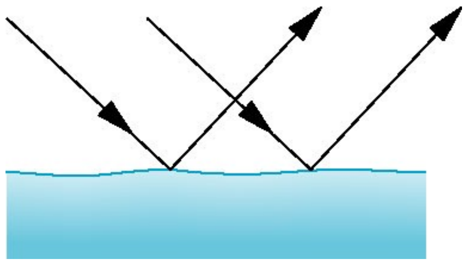
- Perfectly specular reflector
- Normal is determined by local orientation
- Angle of incidence = angle of reflection
- The three vectors must be coplanar

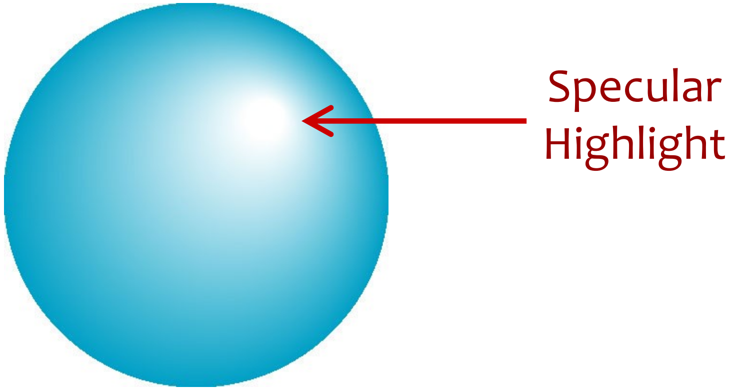
$$\mathbf{r} = 2(\mathbf{l} \cdot \mathbf{n})\mathbf{n} - \mathbf{l}$$



# Specular Reflection

- Smooth surfaces show specular highlights

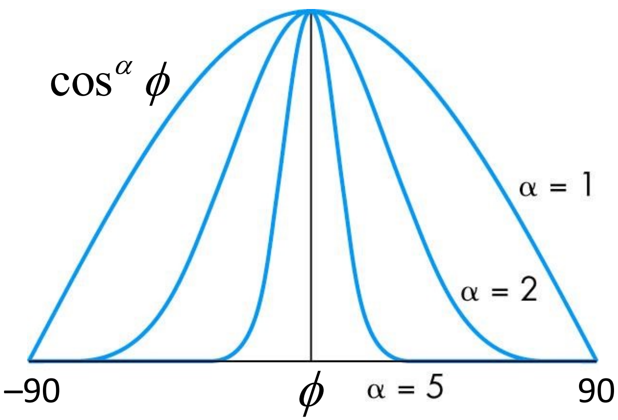




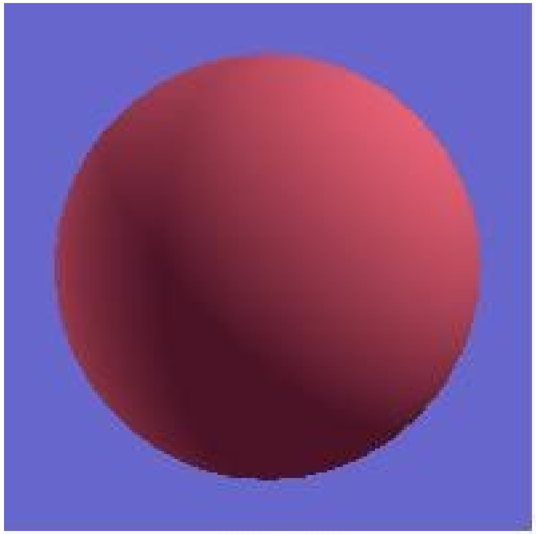

- Specular reflection term

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

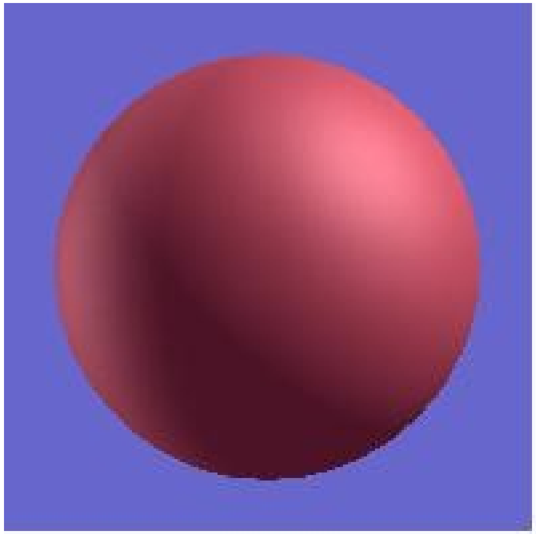
  – $\alpha \rightarrow$ infinite : mirror
  – $100 < \alpha < 200$ : metal
  – $5 < \alpha < 10$ : plastic



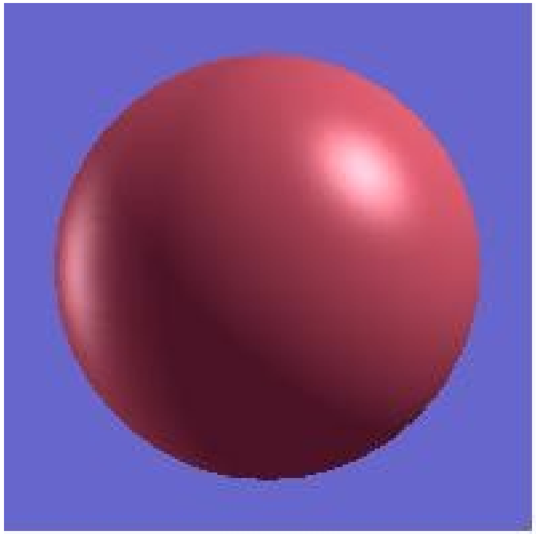
# Specular Parameter



α = 0



α = 4



α = 16

Perlin

# Ambient Reflection

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

$$\boxed{\mathbf{I}_a = \mathbf{k}_a \mathbf{L}_a} \quad 0 \leq k_a \leq 1$$

  - k: Amount reflected
    - Some is absorbed and some is reflected
  - Three components (red, green, blue)
- Ambient reflection term in rendering equation
  - Individual light sources, a global ambient term

# Computation of Reflection

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

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

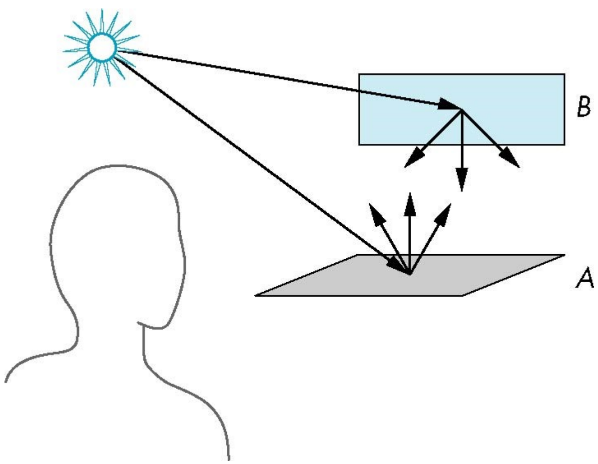
- Material properties
  - Matching light source properties
  - Amount of reflection
  - Nine coefficients:

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

  - Shininess coefficient: α

# Distance Term

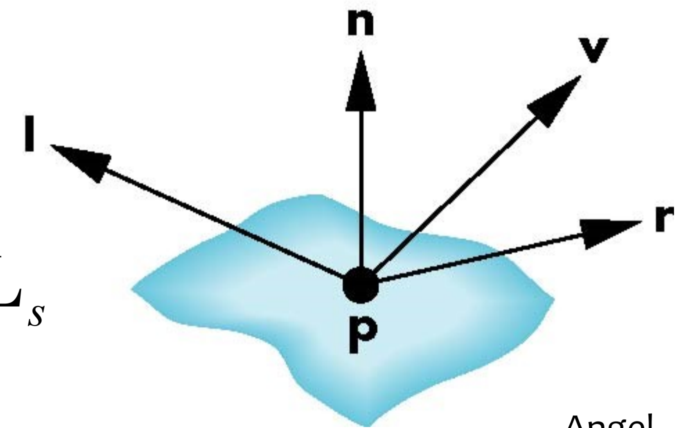
- The light from a point source that reaches a surface is inversely proportional to the square of the distance between them
- We can add a factor of the form $1/(a + bd + cd^2)$ to the diffuse and specular terms
- The constant and linear terms soften the effect of the point source



# Adding Up the Components

- For each light source

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




Angel

- With distance term

$$\mathbf{I} = \mathbf{k}_a \mathbf{L}_a + \frac{1}{a + bd + cd^2} \left( \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^\alpha \mathbf{L}_s \right)$$

# Modified Phong Model

- Reflection direction depends on the surface normal
  - Need to be computed on-the-fly

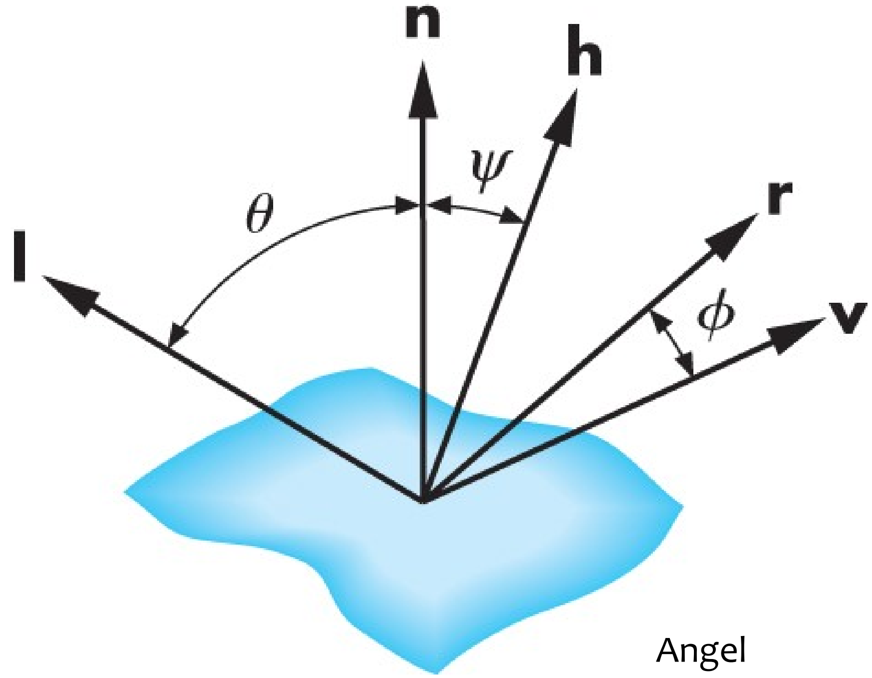
$$\mathbf{I} = \mathbf{k}_a \mathbf{L}_a + \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{r} \cdot \mathbf{v})^{\alpha} \mathbf{L}_s$$

- Can we approximate it with normal-independent term?

# The Halfway Vector

- **h** is normalized vector halfway between **l** and **v**

$$\mathbf{h} = (\mathbf{l} + \mathbf{v}) / |\mathbf{l} + \mathbf{v}|$$




Angel

# Modified Phong Model

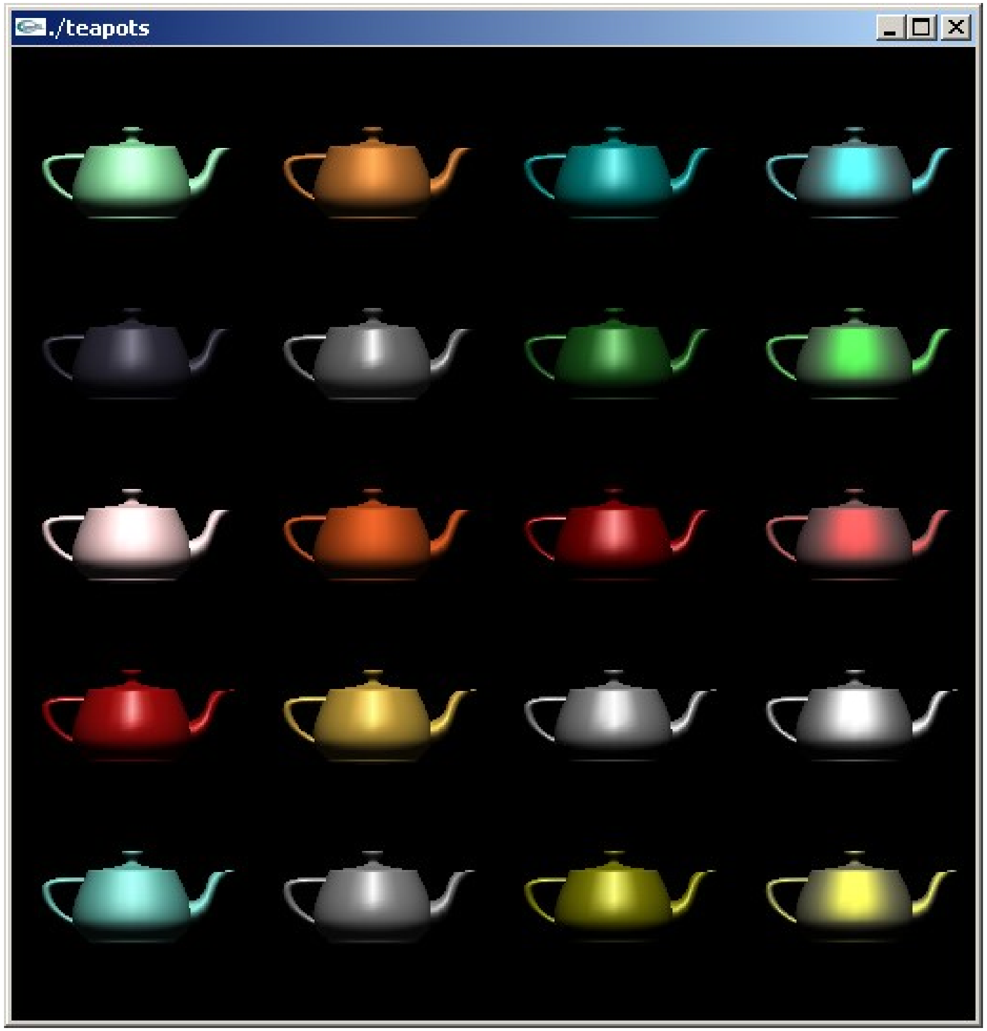
- Replace $(\mathbf{v} \cdot \mathbf{r})^{\alpha}$ by $(\mathbf{n} \cdot \mathbf{h})^{\beta}$
- $\beta$ is chosen to match shininess
- What is the benefit?

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

$$\downarrow$$

$$\mathbf{I} = \mathbf{k}_a \mathbf{L}_a + \mathbf{k}_d (\mathbf{l} \cdot \mathbf{n}) \mathbf{L}_d + \mathbf{k}_s (\mathbf{n} \cdot \mathbf{h})^{b} \mathbf{L}_s$$

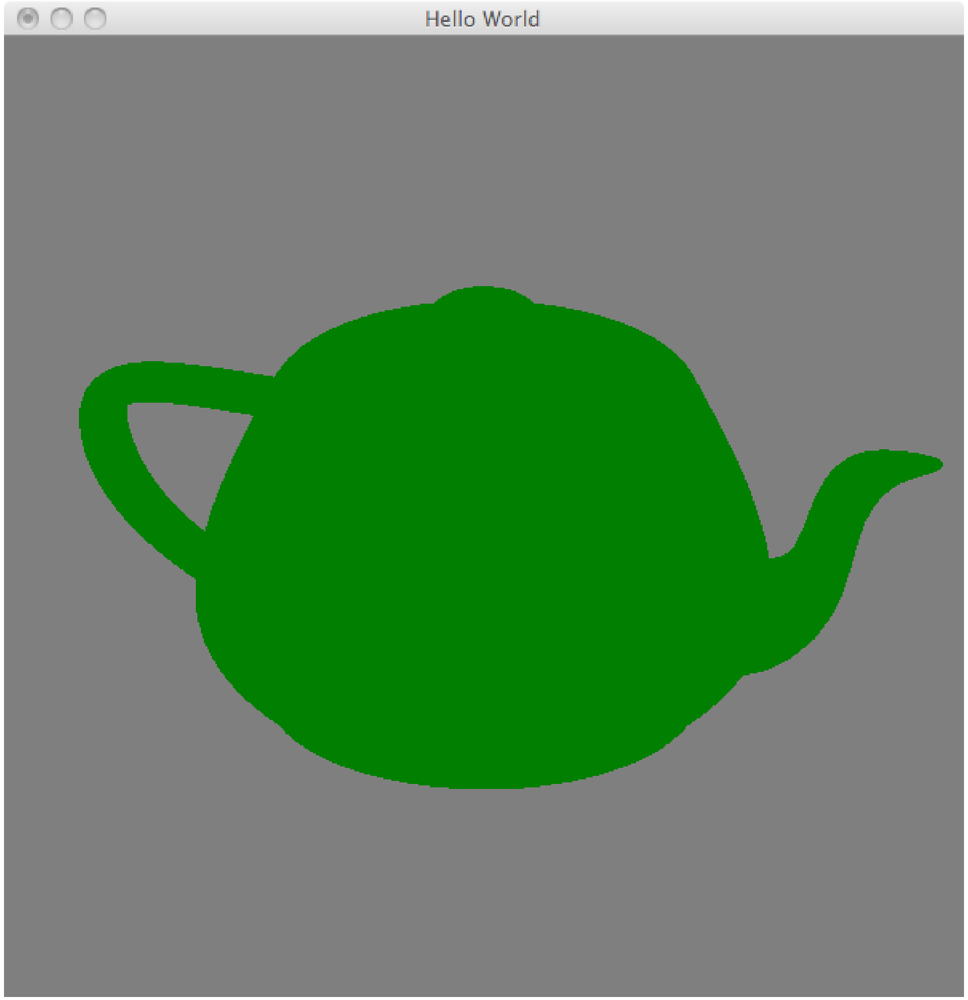
# Example: Phong Model



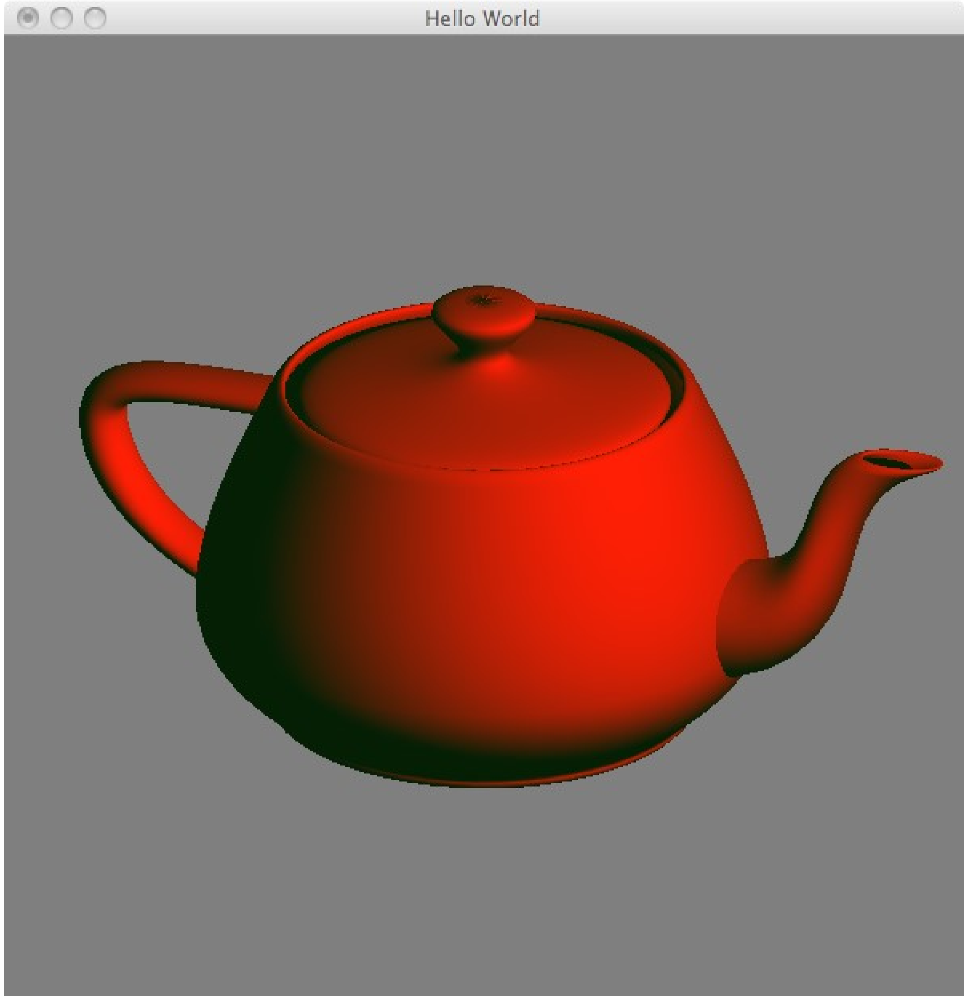

Angel

# Example: No Illumination

# Example: Ambient



# Example: Diffuse



# Example: Specular

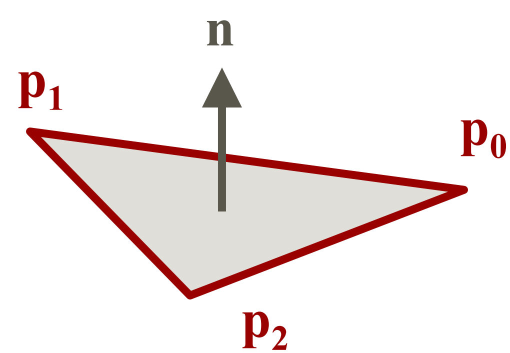
# Outline

- Light-material interactions
- Phong reflection model
- Polygonal model shading

# Computing Normals

- Planes

$$\mathbf{n} = (p_1 - p_0) \times (p_2 - p_0)$$

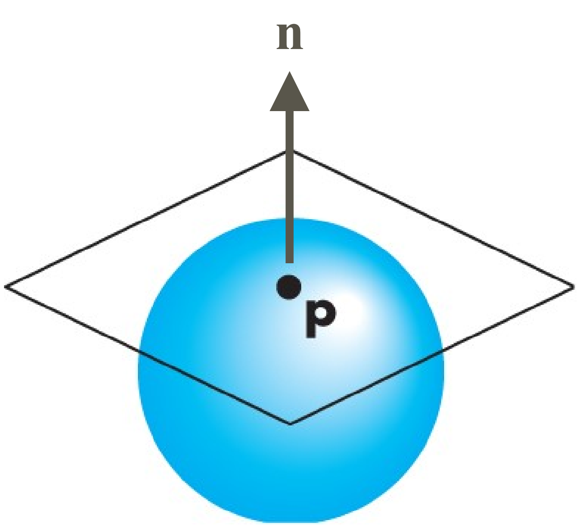



- Parameteric form

$$\partial \mathbf{p}/\partial u = [\partial x/\partial u, \partial y/\partial u, \partial z/\partial u]^T$$

$$\partial \mathbf{p}/\partial v = [\partial x/\partial v, \partial y/\partial v, \partial z/\partial v]^T$$

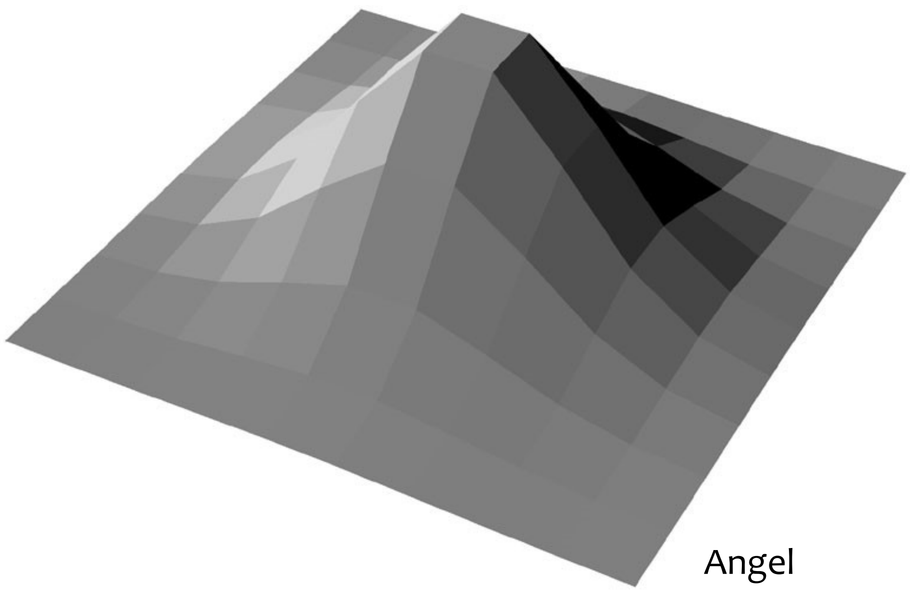
$$\mathbf{n} = \partial \mathbf{p}/\partial u \times \partial \mathbf{p}/\partial v$$



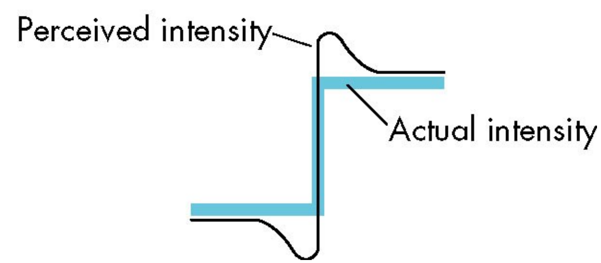

Angel

# Flat Shading

- Constant shading per polygon
  - Assume the polygon is flat
  - Incorrect color perception



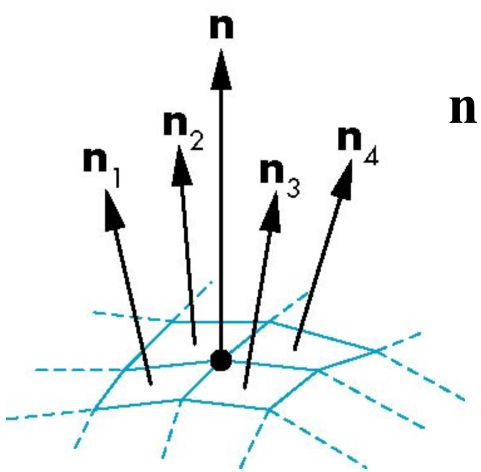
Angel




KOREA UNIVERSITY

# Smooth Shading: Gouraud

- Shading per vertex
- Linear interpolation of colors across polygon
- Vertex normal is an average of neighbor polygon normals



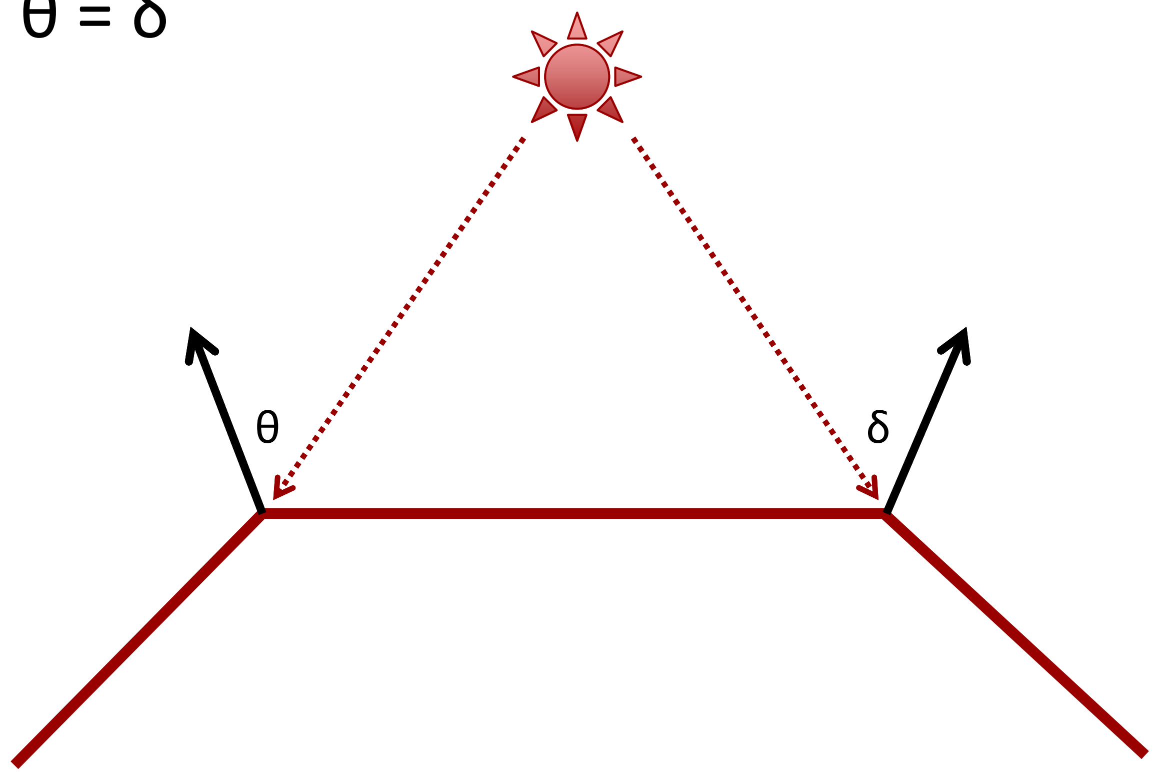

$$\mathbf{n} = \frac{\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4}{|\mathbf{n}_1 + \mathbf{n}_2 + \mathbf{n}_3 + \mathbf{n}_4|}$$

Angel

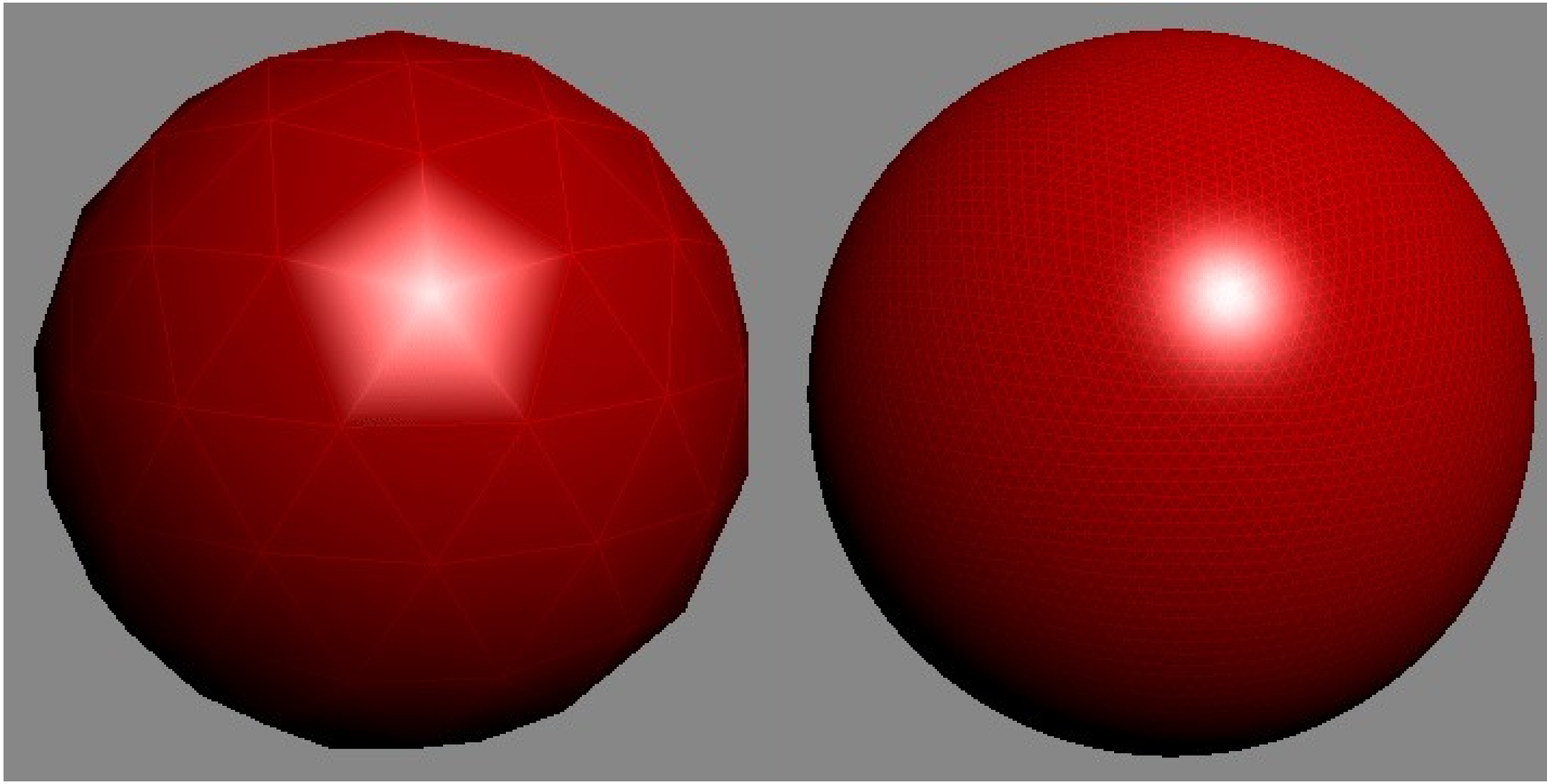
# Problems of Gouraud Shading

- Coarse geometry

$\theta = \delta$



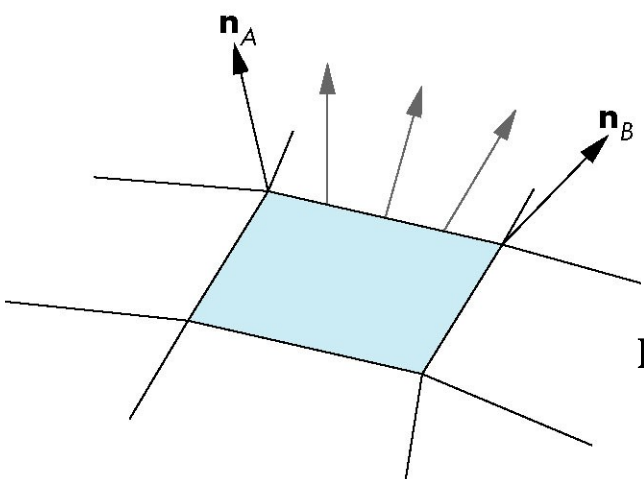
# Gouraud Shading Example



Wikipedia

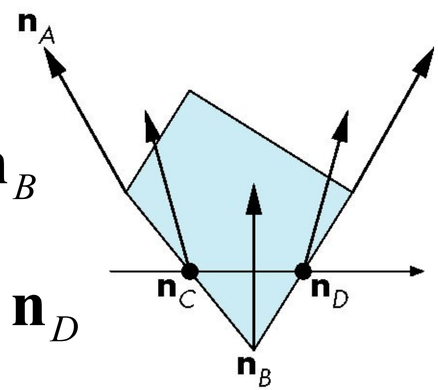
# Smooth Shading: Phong

- Shading per pixel
- Interpolating normals, not colors



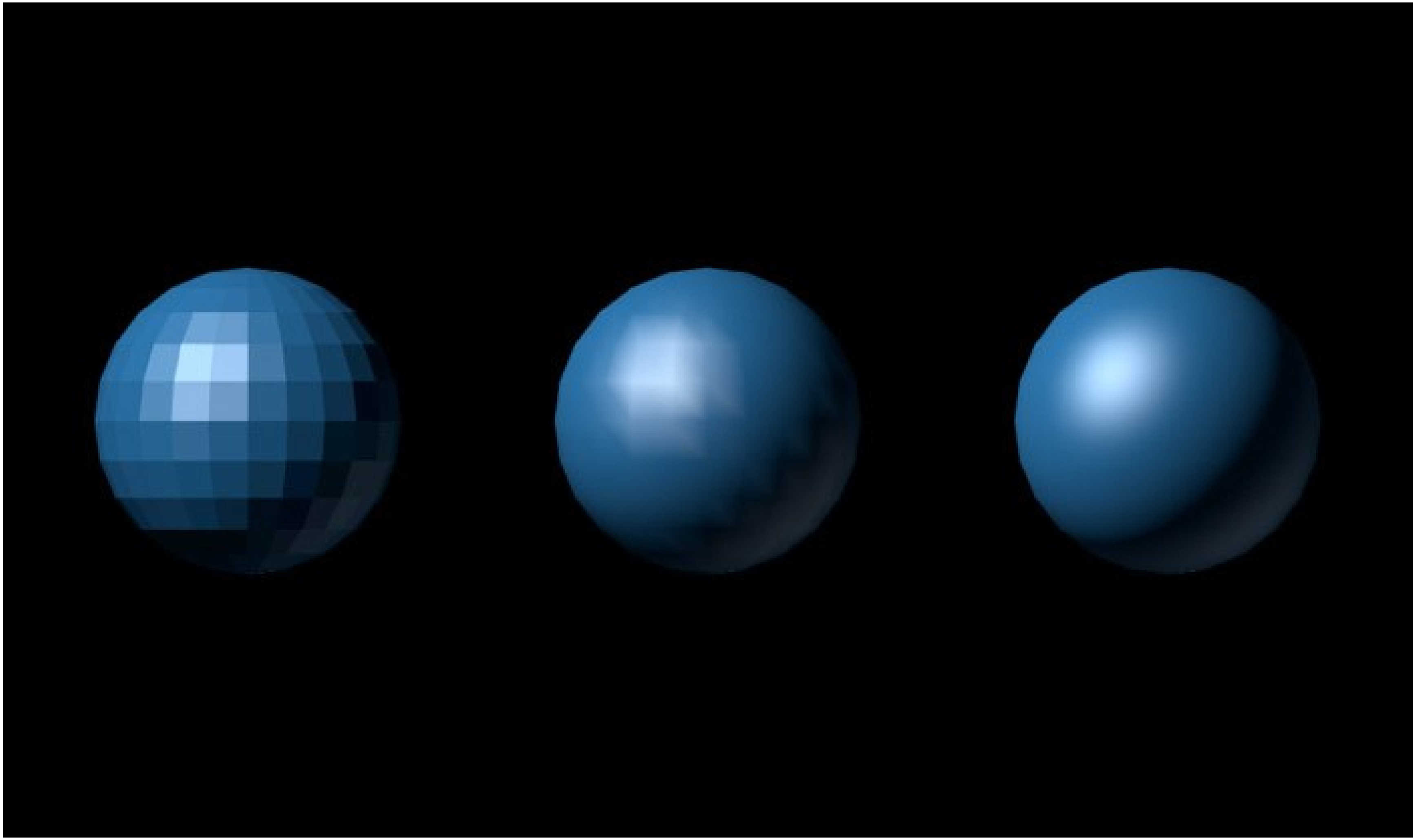

$$\mathbf{n}(\alpha) = (1-\alpha)\,\mathbf{n}_A + \alpha\,\mathbf{n}_B$$

$$\mathbf{n}(\alpha,\beta) = (1-\beta)\,\mathbf{n}_C + \beta\,\mathbf{n}_D$$




Angel

# Flat vs. Gouraud vs. Phong



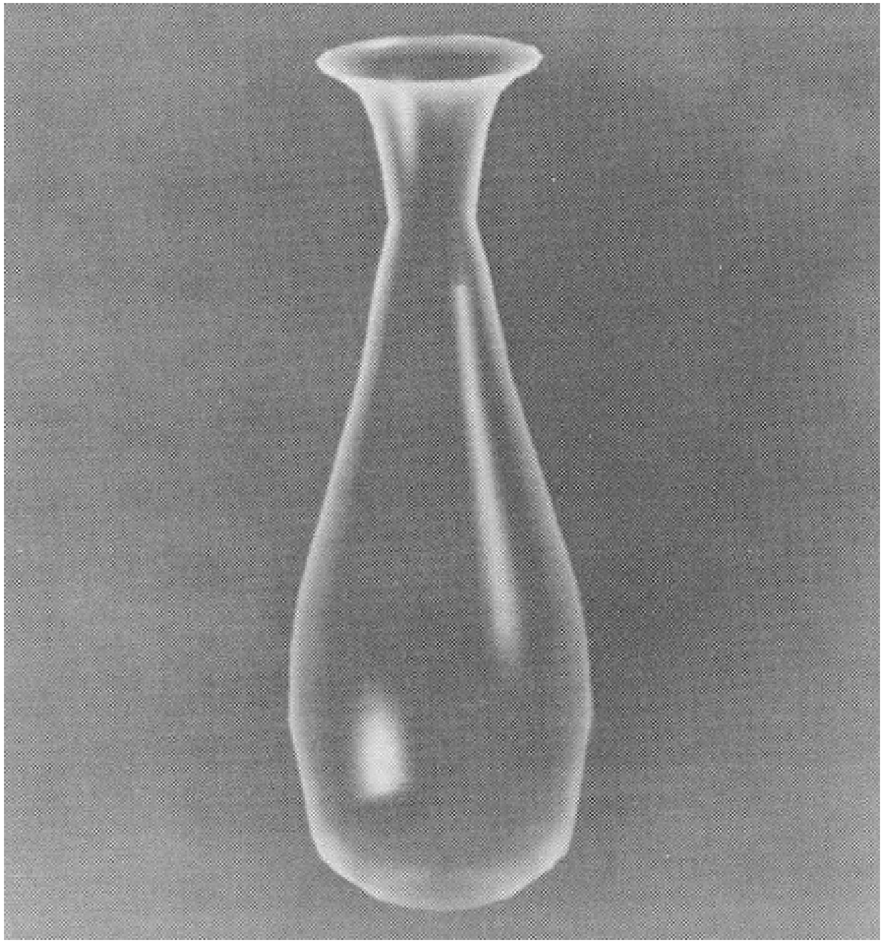
# Gouraud vs. Phong Shading

- Gouraud is more efficient than Phong
- Phong produces smoother results than Gouraud, especially for coarse polygonal counts
- Phong produces specular highlights
- OpenGL implements Gouraud by default
  - In Shader, you are responsible for shading type (you should implement everything on your own)

# Summary

- Light-material interactions
  – Light types
  – Surface types
- Phong reflection model
  – Diffuse, specular, ambient
- Polygonal model shading
  – Gouraud, Phong

# Questions?



Phong shading image from Phong's original paper

B. T. Phong*, Illumination for computer generated pictures*, Communications of ACM 18 (1975), no. 6, 311–317.