Computer Graphics (CS 543)
Lecture 7b: Intro to lighting, Shading and Materials + Phong Lighting Model

Prof Emmanuel Agu

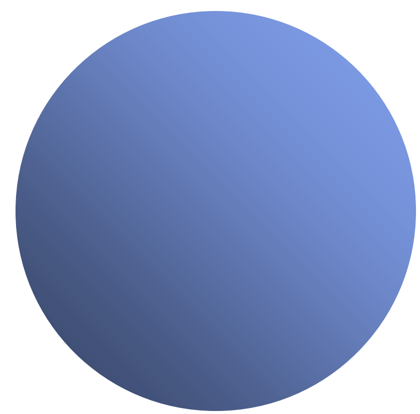
Computer Science Dept.

Worcester Polytechnic Institute (WPI)

Why do we need Lighting & shading?

- Has **visual cues** for humans (shape, light position, viewer position, surface orientation, material properties, etc)

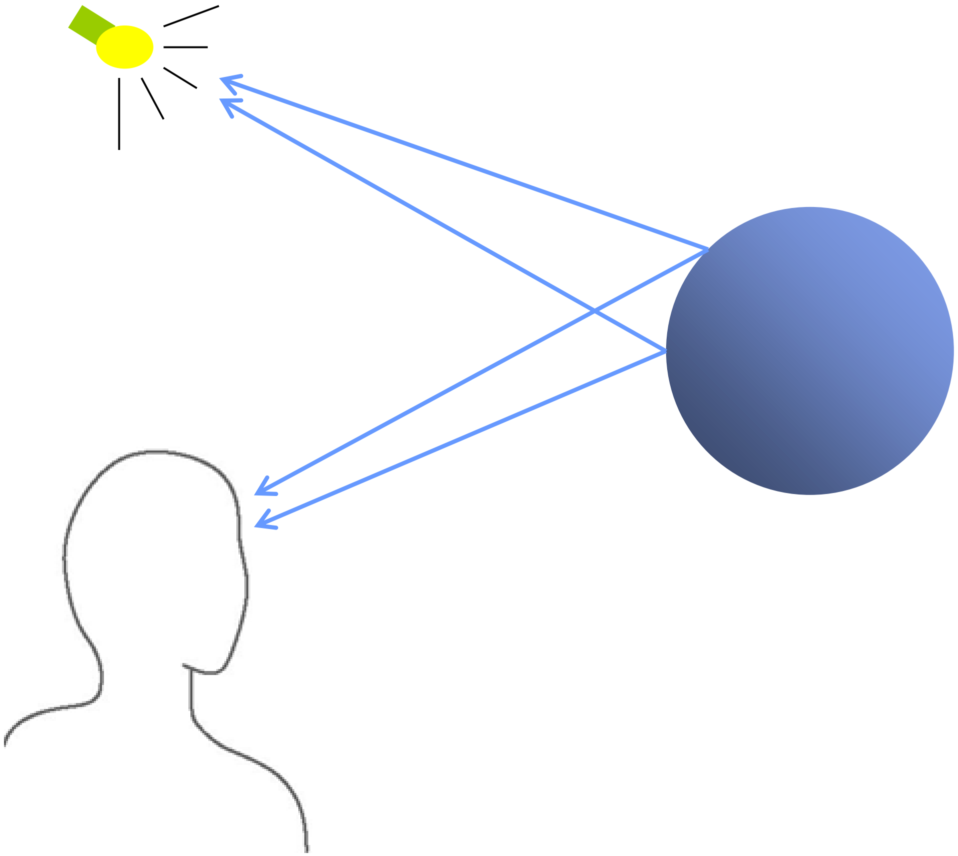
Sphere without lighting & shading



Sphere with lighting & shading

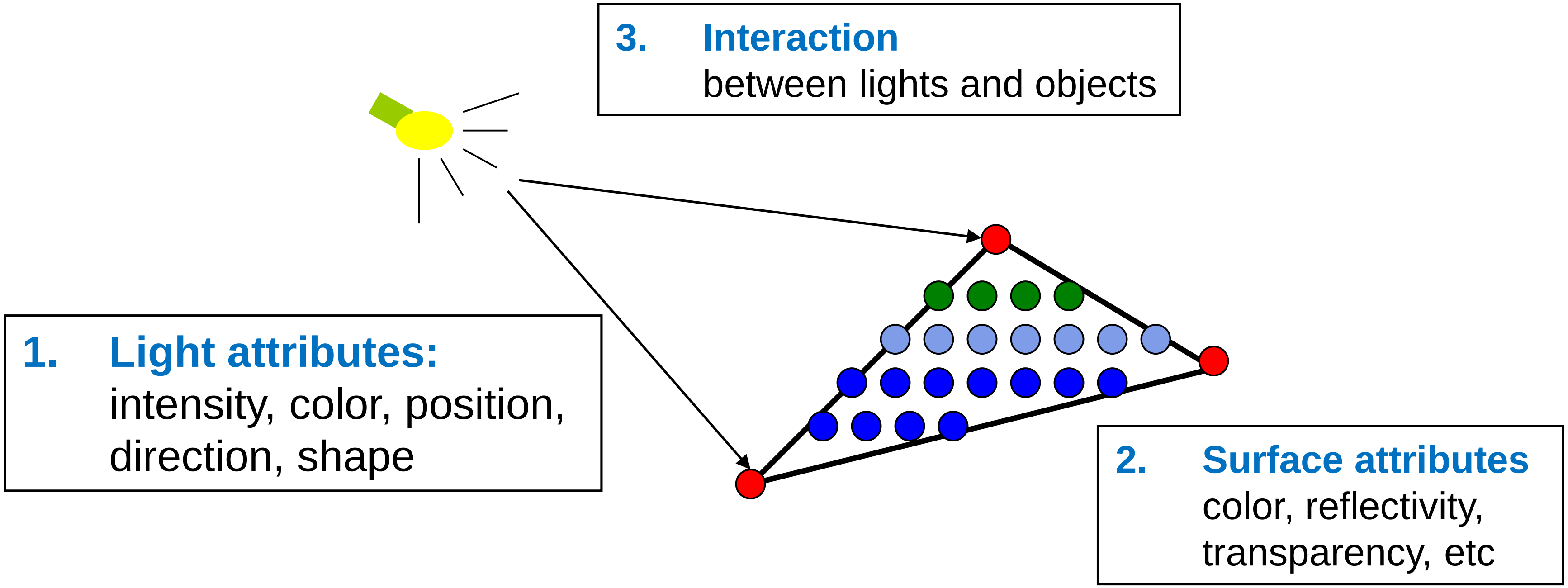
What Causes Shading?

- Shading caused by different angles with light, camera at different points



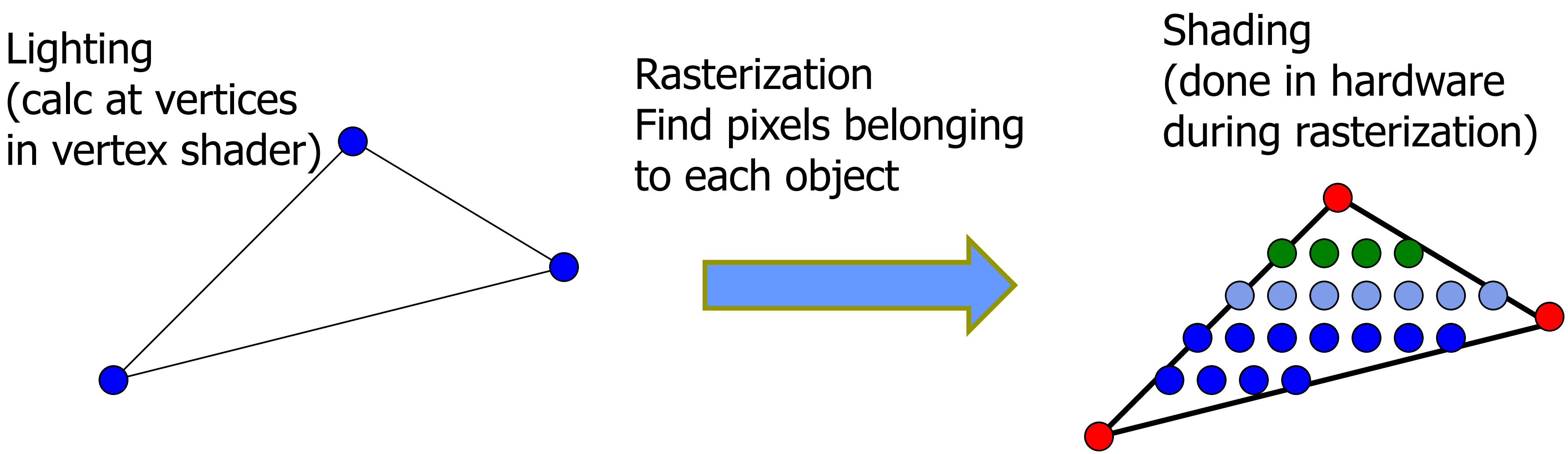
Lighting?

- **Lighting problem:** Calculate surface color based on angle of surface with light, viewer
- Programmer writes vertex shader code to calculate lighting **at vertices**!
- Equation for lighting calculation = **lighting model**



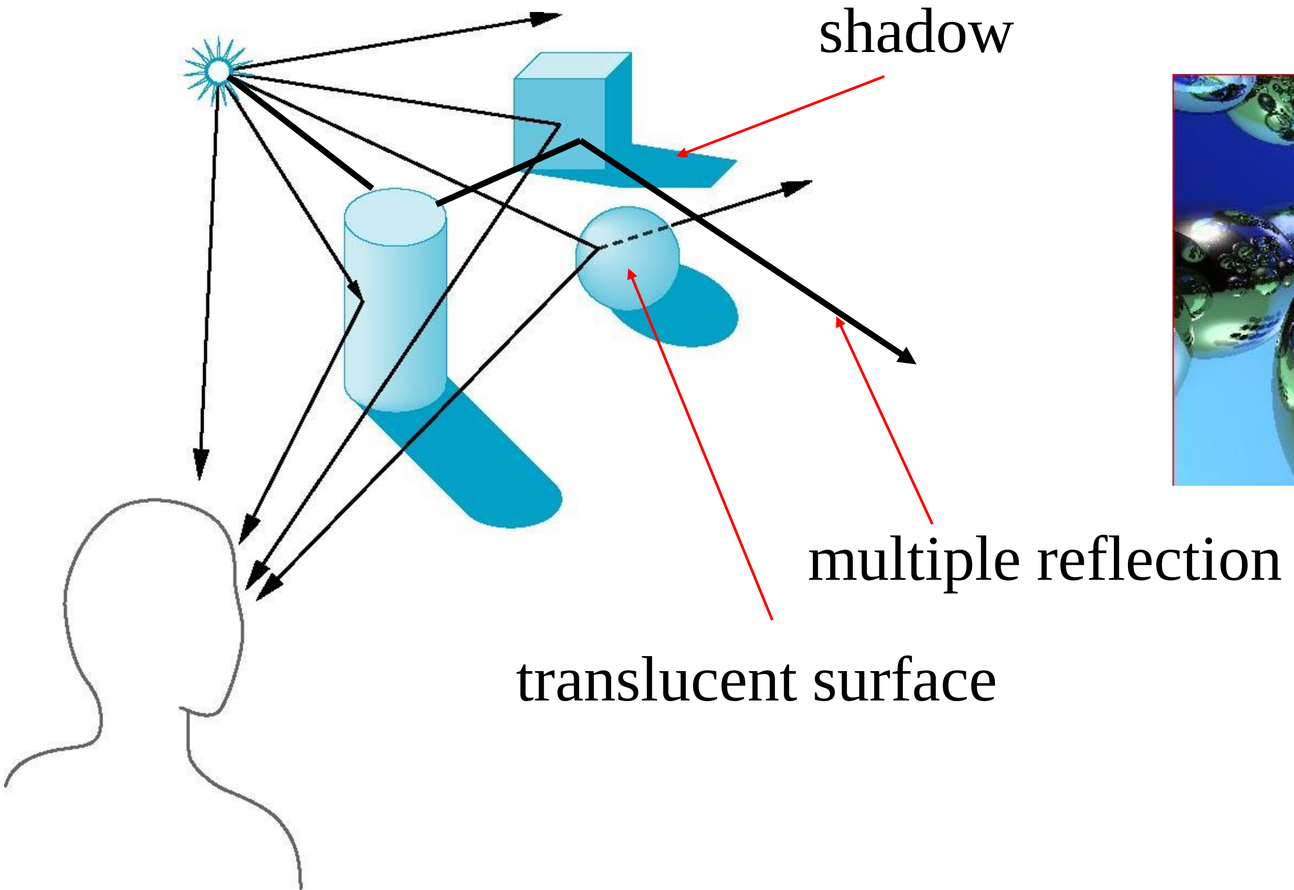
Shading?

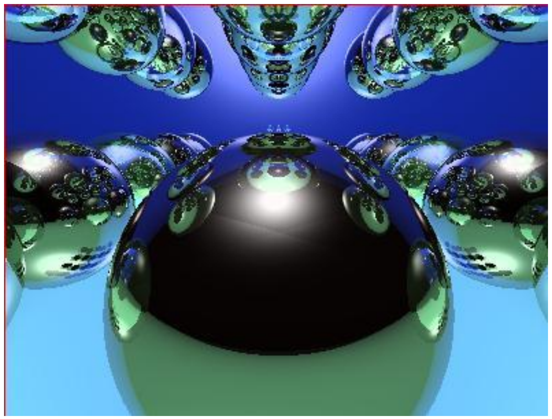
- After triangle is rasterized (converted to pixels)
  - Per-vertex lighting calculation means color at vertices is accurate, known (red dots)
- Shading: Graphics hardware figures out color of interior pixels (blue dots)
- How? Assume linear change => interpolate



Global Illumination (Lighting) Model

- Global illumination: model interaction of light from all surfaces in scene (track multiple bounces)

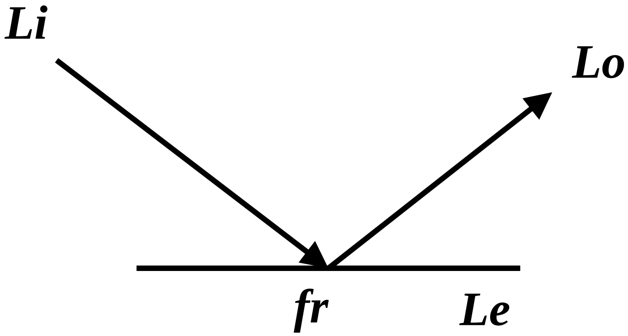




Rendering Equation

- The infinite reflection, scattering and absorption of light is described by the ***rendering equation***
  - Includes many effects (Reflection, Shadows, etc)
- Mathematical basis for all global illumination algorithms

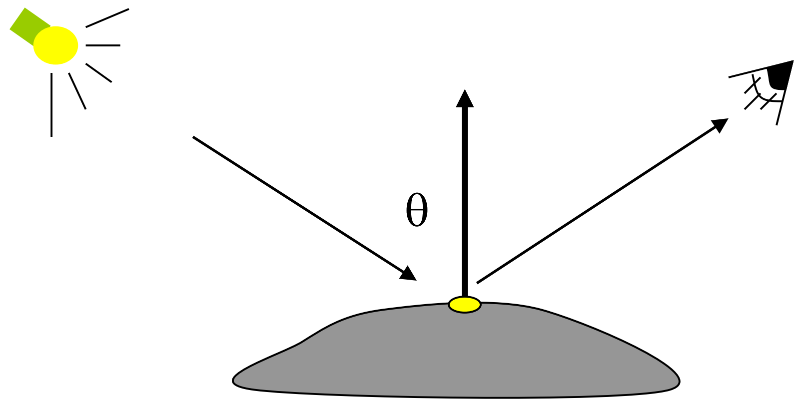
$$L_o = L_e(x,\vec{\omega}) + \int_{\Omega} fr(x,\vec{\omega}',\vec{\omega}) Li(x,\vec{\omega}')(\vec{\omega}' \cdot \vec{n}) d\vec{\omega}'$$



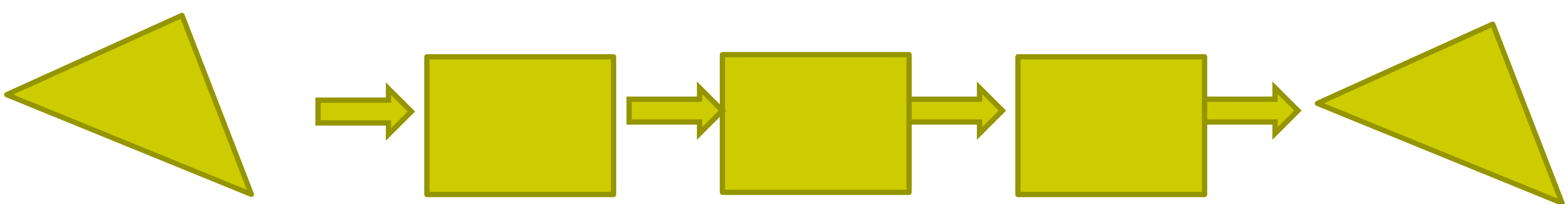
- Lo is outgoing radiance
- Li incident radiance
- Le emitted radiance,
- ***fr*** is bidirectional reflectance distribution function (BRDF)
  - Fraction of incident light reflected by a surface

Local Illumination (Lighting) Model

- One bounce!
  - Doesn’t track inter-reflections, transmissions (e.g. OpenGL)

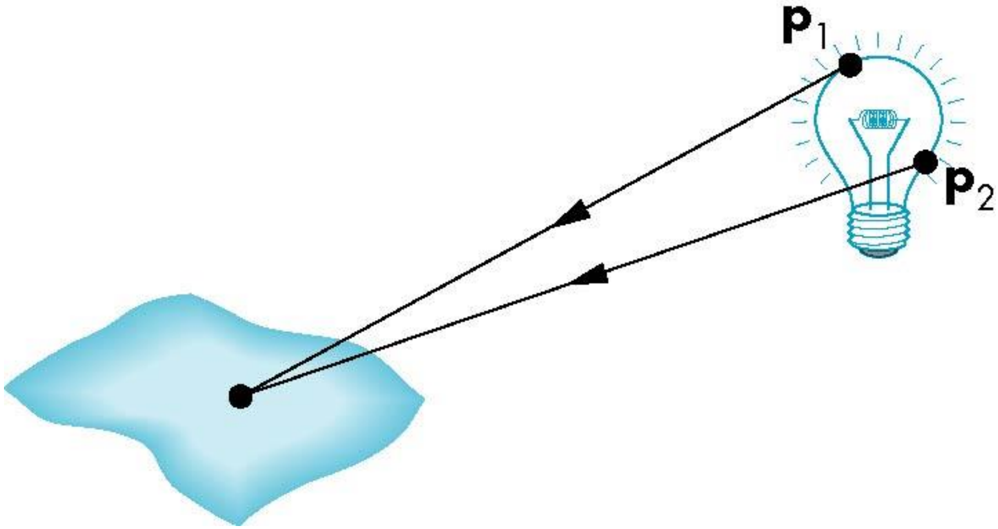


- Global Illumination (GI) is accurate, looks real
  - But raster graphics pipeline (e.g. OpenGL) renders each polygon independently (local rendering), no GI



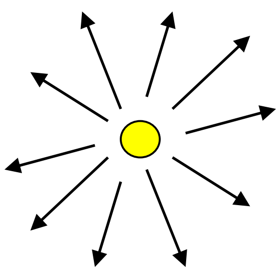
Light Sources

- General light sources are difficult to model (e.g. light bulb)
- Why? We must compute effect of light coming from all points on light source

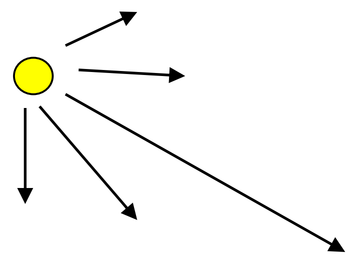


Light Sources Abstractions

- We generally use simpler light sources
- Abstractions that are easier to model

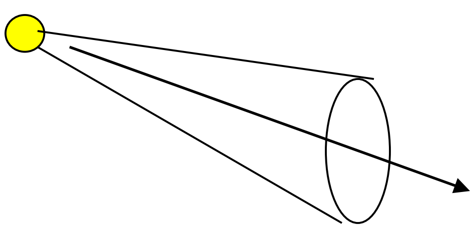


Point light

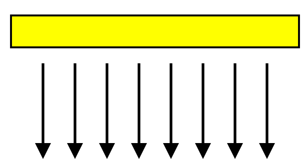


Directional light

Light intensity can be **independent** or **dependent** of the distance between object and the light source



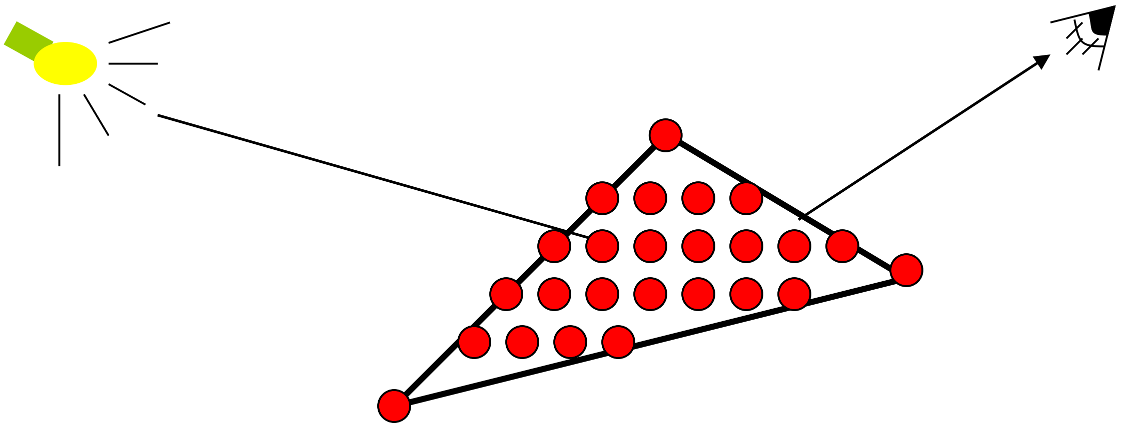
Spot light



Area light

Light-Material Interaction

- White light strikes object, some wavelengths (colors) absorbed, some reflected
- Fraction reflected determines object color and brightness
  - **Example:** A surface looks red under white light because red component of light is reflected, other wavelengths absorbed



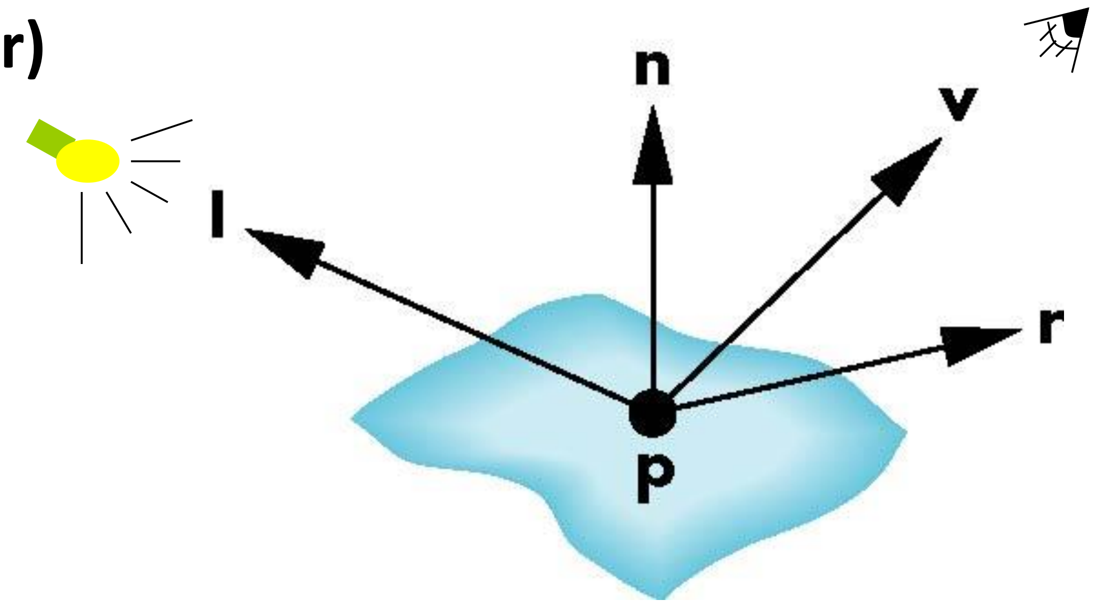
Phong Model

- Simple lighting model that can be computed quickly
- 3 components
  - Diffuse
  - Specular
  - Ambient
- Compute each component separately
- Vertex Illumination =

  ambient + diffuse + specular
- Materials reflect each component differently

Phong Model

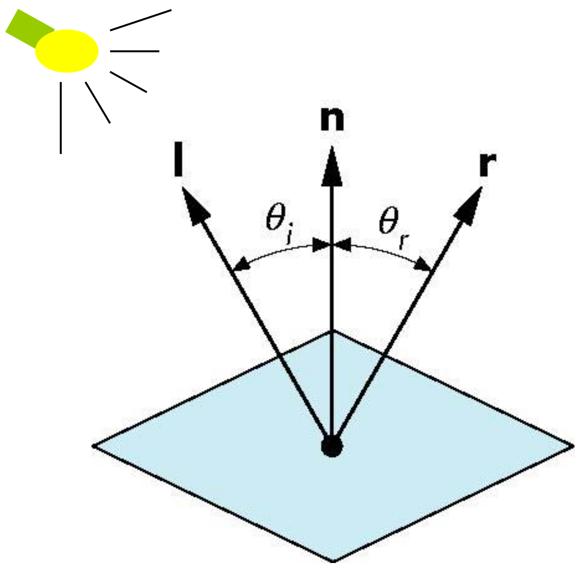
- Compute lighting (components) at each vertex (P)
- Uses 4 vectors, from vertex
  - To light source **(l)**
  - To viewer **(v)**
  - Normal **(n)**
  - Mirror direction **(r)**



Mirror Direction?

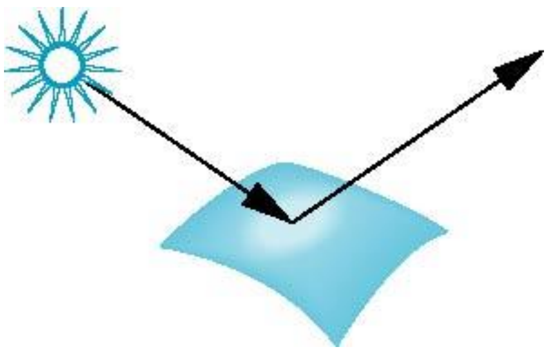
- Angle of reflection = angle of incidence
- Normal is determined by surface orientation

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

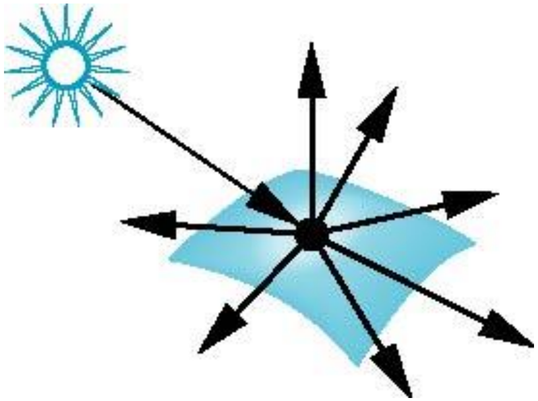


Surface Roughness

- **Smooth surfaces:** more reflected light concentrated in mirror direction
- **Rough surfaces:** reflects light in all directions



smooth surface

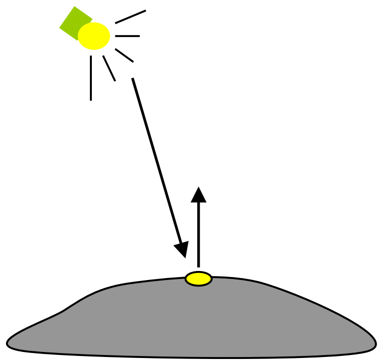


rough surface

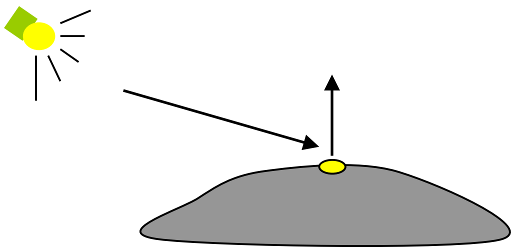
Diffuse Lighting Example

Diffuse Light Calculation

- How much light received from light source?
- Based on Lambert's Law



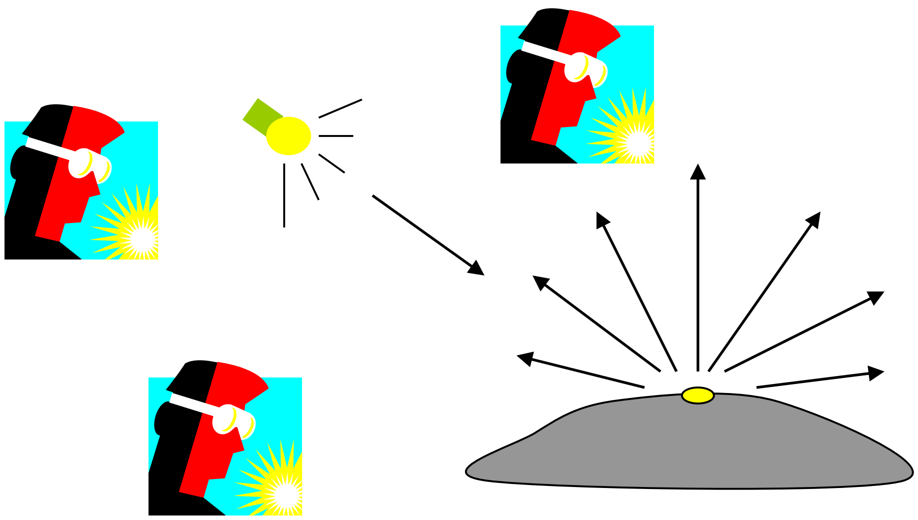
Receive more light



Receive less light

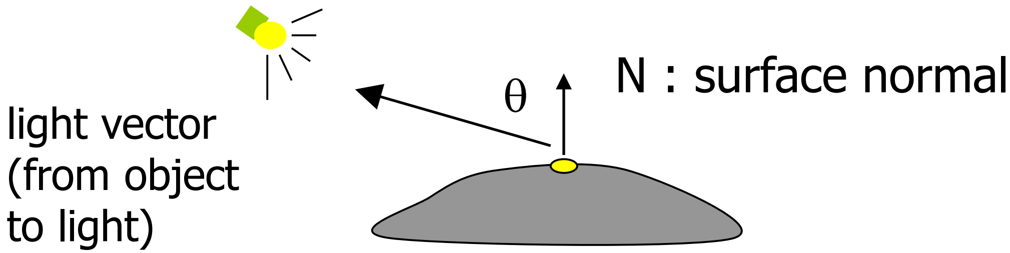
Diffuse Light Reflected

- Illumination surface received from light source, reflected equally in all directions



Eye position does not matter

Diffuse Light Calculation



- Lambert's law: radiant energy D a small surface patch receives from a light source is:

$$D = I \times k_D \cos(\theta)$$

  - I: light intensity
  - θ: angle between light vector and surface normal
  - k_D: Diffuse reflection coefficient.

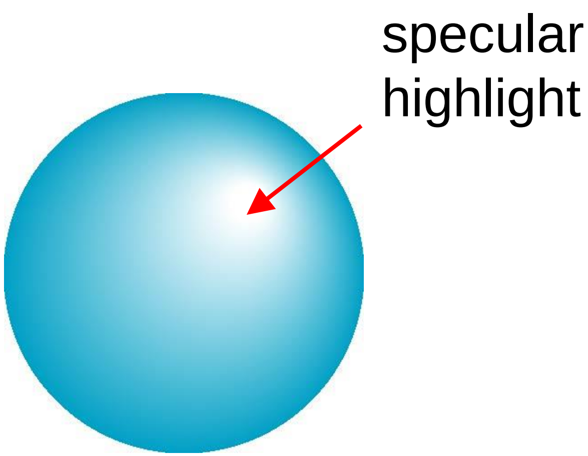
    Controls how much diffuse light surface reflects

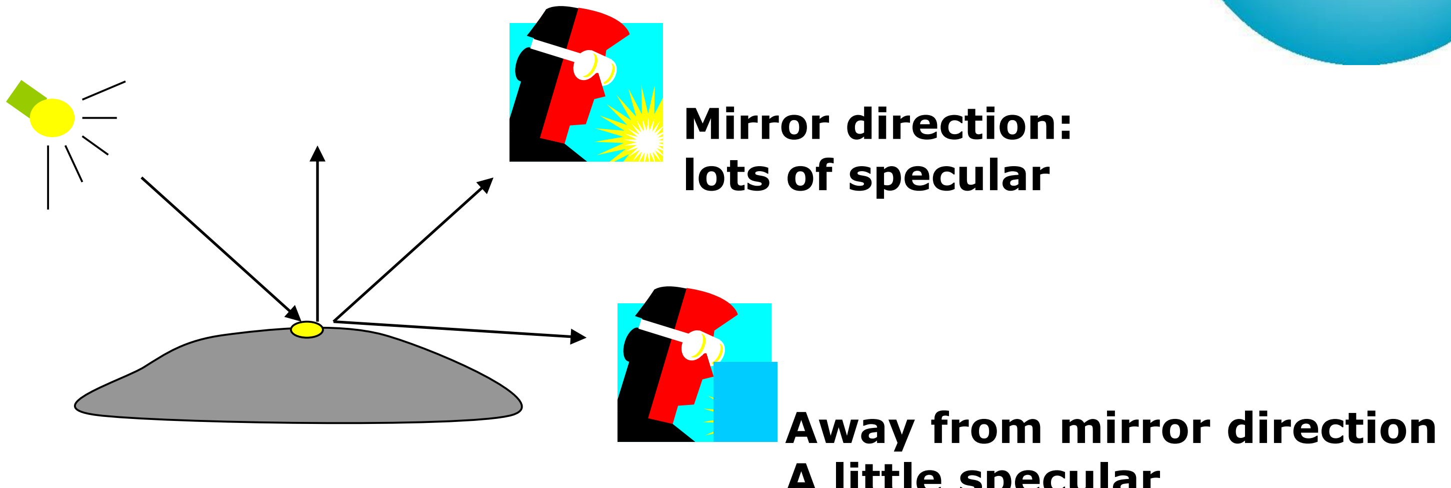
Specular light example

Specular?
Bright spot on object

Specular light contribution

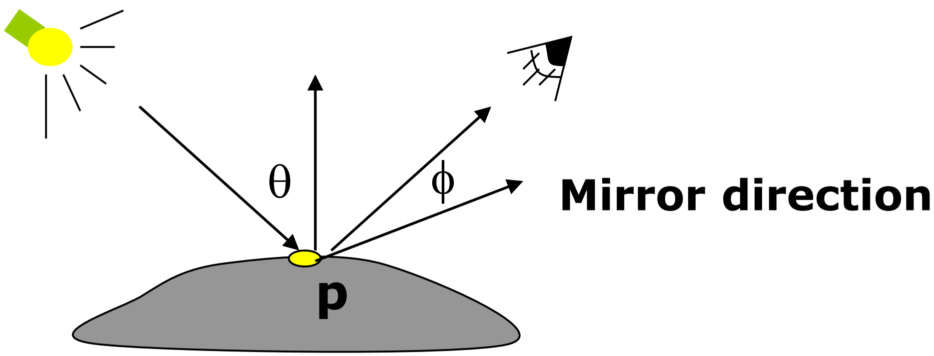
- Incoming light reflected out in small surface area
- Specular depends on viewer position relative to mirror direction
- Specular bright in **mirror direction**
- Drops off away from mirror direction





Specular light calculation

- ϕ is deviation of view angle from mirror direction
- Small ϕ = more specular



incoming intensity

$$I_s = k_s\, \mathbf{I} \cos^{\alpha}\phi$$

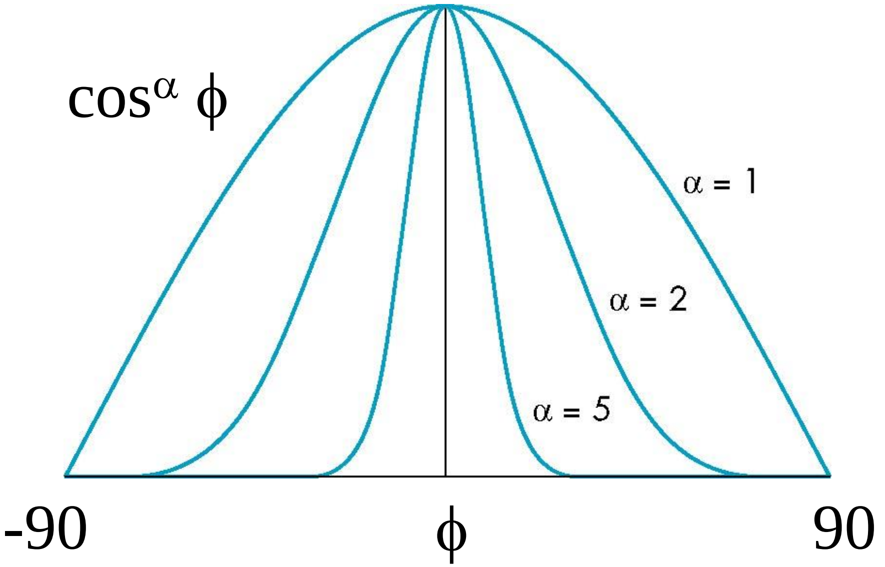
reflected intensity

Absorption coef

shininess coef

The Shininess Coefficient, α

- α controls falloff sharpness
- High α = sharper falloff = small, bright highlight
- Low α = slow falloff = large, dull highlight
  - α between 100 and 200 = metals
  - α between 5 and 10 = plastic look



Specular light: Effect of ‘α’

$$I_s = k_s \, \mathbf{I} \cos^{\alpha}\phi$$

α = 10

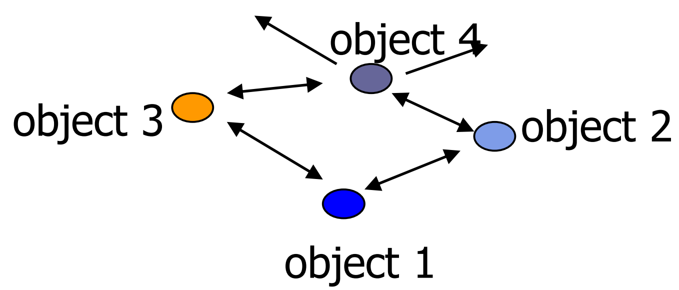
α = 30

α = 90

α = 270

Ambient Light Contribution

- Very simple approximation of global illumination
  (Lump 2nd, 3rd, 4th, …. etc bounce into single term)
- **Assume to be a constant**
- No direction!
  - Independent of light position, object orientation, observer's position or orientation



Ambient = Ia x Ka ← constant

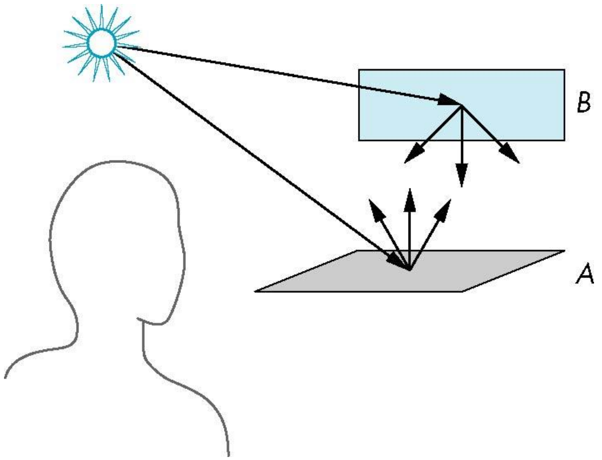
Ambient Light Example

Ambient: background light, scattered by environment

Light Attentuation with Distance

- Light reaching a surface **inversely proportional** to square of distance **d**
- We can multiply by factor

  of form $1/(ad + bd + cd^2)$ to **diffuse** and **specular** terms



Adding up the Components

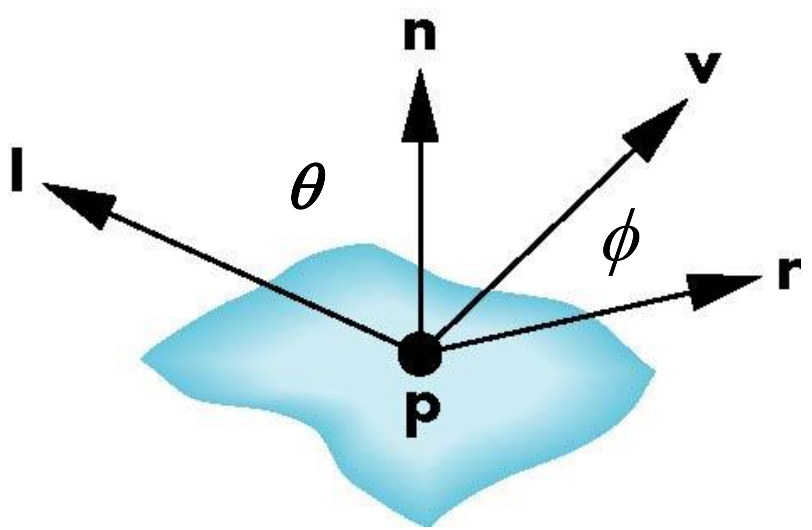
- Adding all components (no attentuation term) , phong model for each light source can be written as

diffuse + specular + ambient

$$I = k_d\, I_d \cos\theta \;+\; k_s\, I_s \cos\phi^{\,\alpha} \;+\; k_a\, I_a$$

$$= k_d\, I_d\, (l \cdot n) \;+\; k_s\, I_s\, (\mathbf{v} \cdot \mathbf{r})^{\alpha} \;+\; k_a\, I_a$$

- **Note:**
  - $\cos\theta = \mathbf{l} \cdot \mathbf{n}$
  - $\cos\phi = \mathbf{v} \cdot \mathbf{r}$



Separate RGB Components

- Can separate red, green and blue components. Instead of:

$$I = k_d I_d (l \cdot n) + k_s I_s (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_a I_a$$

- We computing lighting for RGB colors separately

$$I_r = k_{dr} I_{dr} \mathbf{l} \cdot \mathbf{n} + k_{sr} I_{sr} (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_{ar} I_{ar}$$ Red

$$I_g = k_{dg} I_{dg} \mathbf{l} \cdot \mathbf{n} + k_{sg} I_{sg} (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_{ag} I_{ag}$$ Green

$$I_b = k_{db} I_{db} \mathbf{l} \cdot \mathbf{n} + k_{sb} I_{sb} (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_{ab} I_{ab}$$ Blue

- Above equation is just for one light source!!
- For N lights, repeat calculation for each light

Total illumination for a point P = Σ (Lighting for all lights)

Coefficients for Real Materials

Material	Ambient Kar, Kag,kab	Diffuse Kdr, Kdg,kdb	Specular Ksr, Ksg,ksb	Exponent, α
Black plastic	0.0 0.0 0.0	0.01 0.01 0.01	0.5 0.5 0.5	32
Brass	0.329412 0.223529 0.027451	0.780392 0.568627 0.113725	0.992157 0.941176 0.807843	27.8974
Polished Silver	0.23125 0.23125 0.23125	0.2775 0.2775 0.2775	0.773911 0.773911 0.773911	89.6

Figure 8.17, Hill, courtesy of McReynolds and Blythe

Modified Phong Model

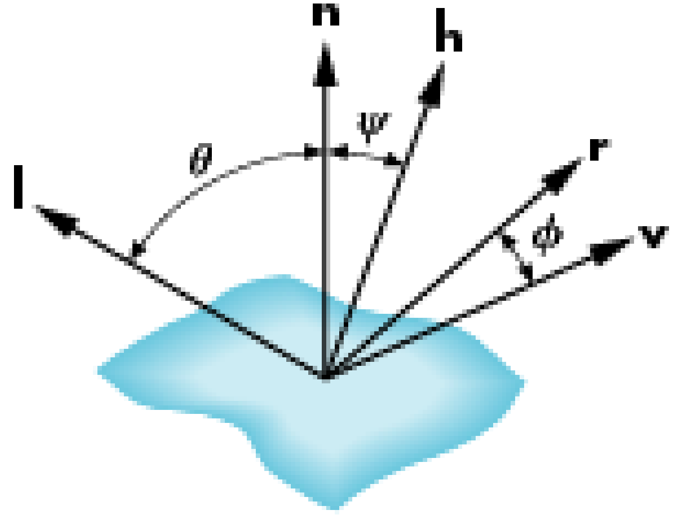
$$I = k_d I_d \, \mathbf{l} \cdot \mathbf{n} + k_s I_s (\mathbf{v} \cdot \mathbf{r})^{\alpha} + k_a I_a$$

$$I = k_d I_d \, \mathbf{l} \cdot \mathbf{n} + k_s I_s (\mathbf{n} \cdot \mathbf{h})^{\beta} + k_a I_a$$

Used in OpenGL

- Blinn proposed using **halfway vector,** more efficient
- **h** is normalized vector halfway between **l** and **v**
- Similar results as original Phong

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



References

- Interactive Computer Graphics (6th edition), Angel and Shreiner
- Computer Graphics using OpenGL (3rd edition), Hill and Kelley