CGT 520
Computer Graphics

Computer Graphics Technology Dept.

Purdue University

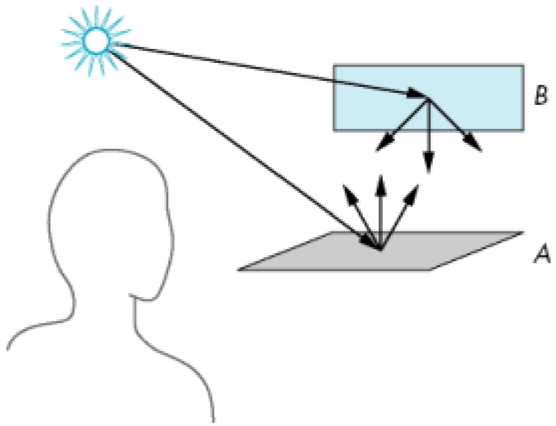
Outline

- Introduction
- Light sources
- The Phong reflection model

Object Appearance

- **Problem**:

Real object appearance is influenced by complex light and material interactions.

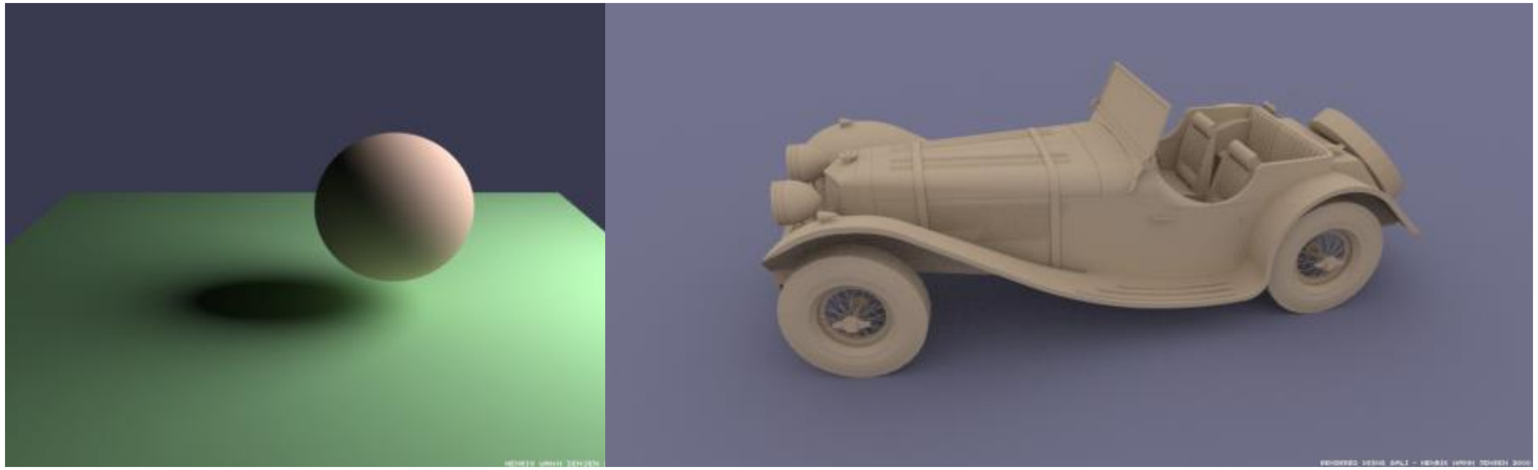


Direct and indirect illumination

Goal: Develop simple (fast) light models based loosely on physical reality.

Global Illumination

- In reality: object appearance depends on **all** other objects in the scene (interreflections, shadows, light scattering)



Global illumination effects

- Solution by solving for global energy balance : radiosity, ray tracing. But not yet possible in real time for complex scenes.

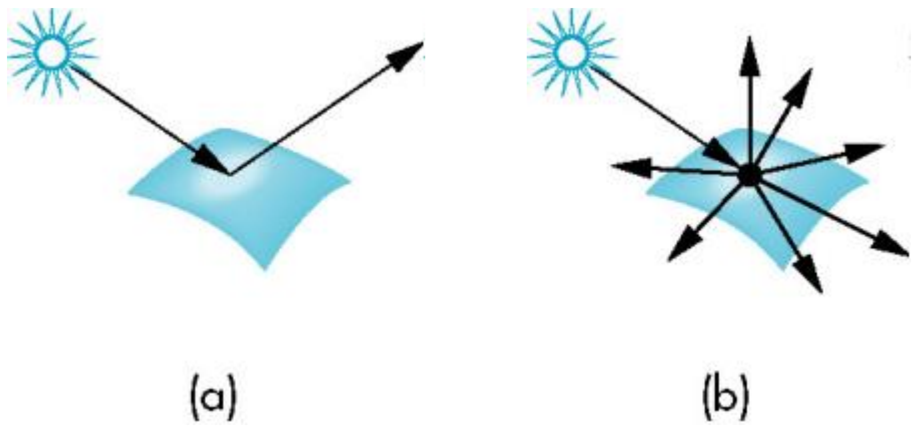
Materials

- Light-surface interaction governs object appearance

Diffuse, shiny and reflective materials.

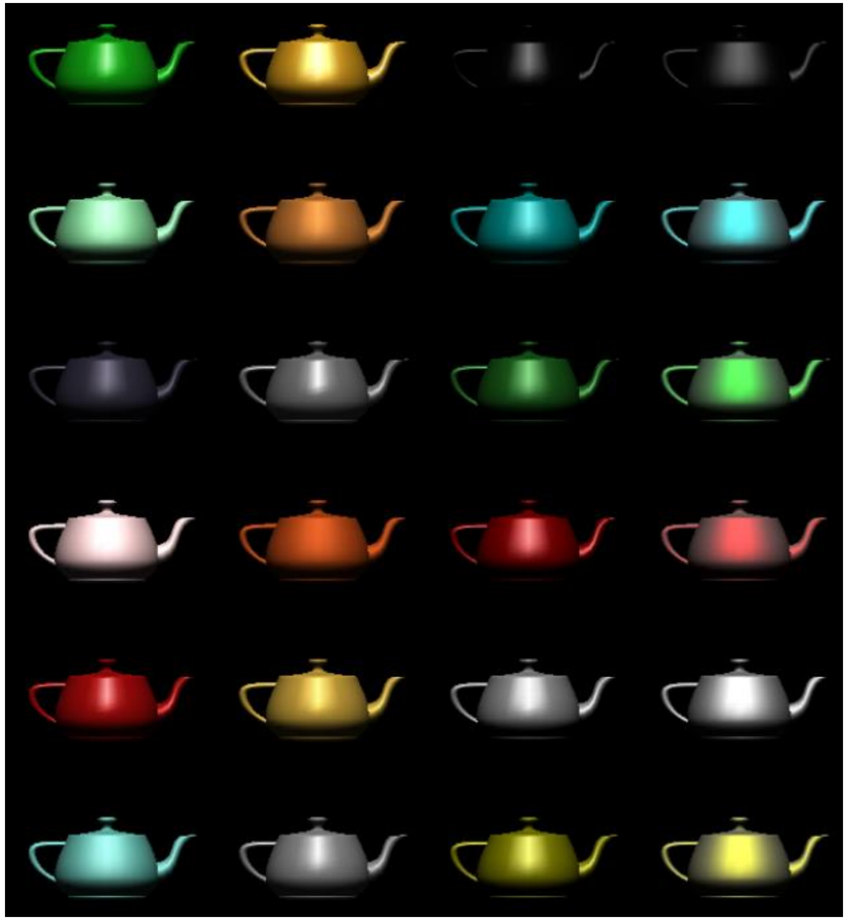
Material properties

- Material properties determine what happens to light rays after they strike a surface



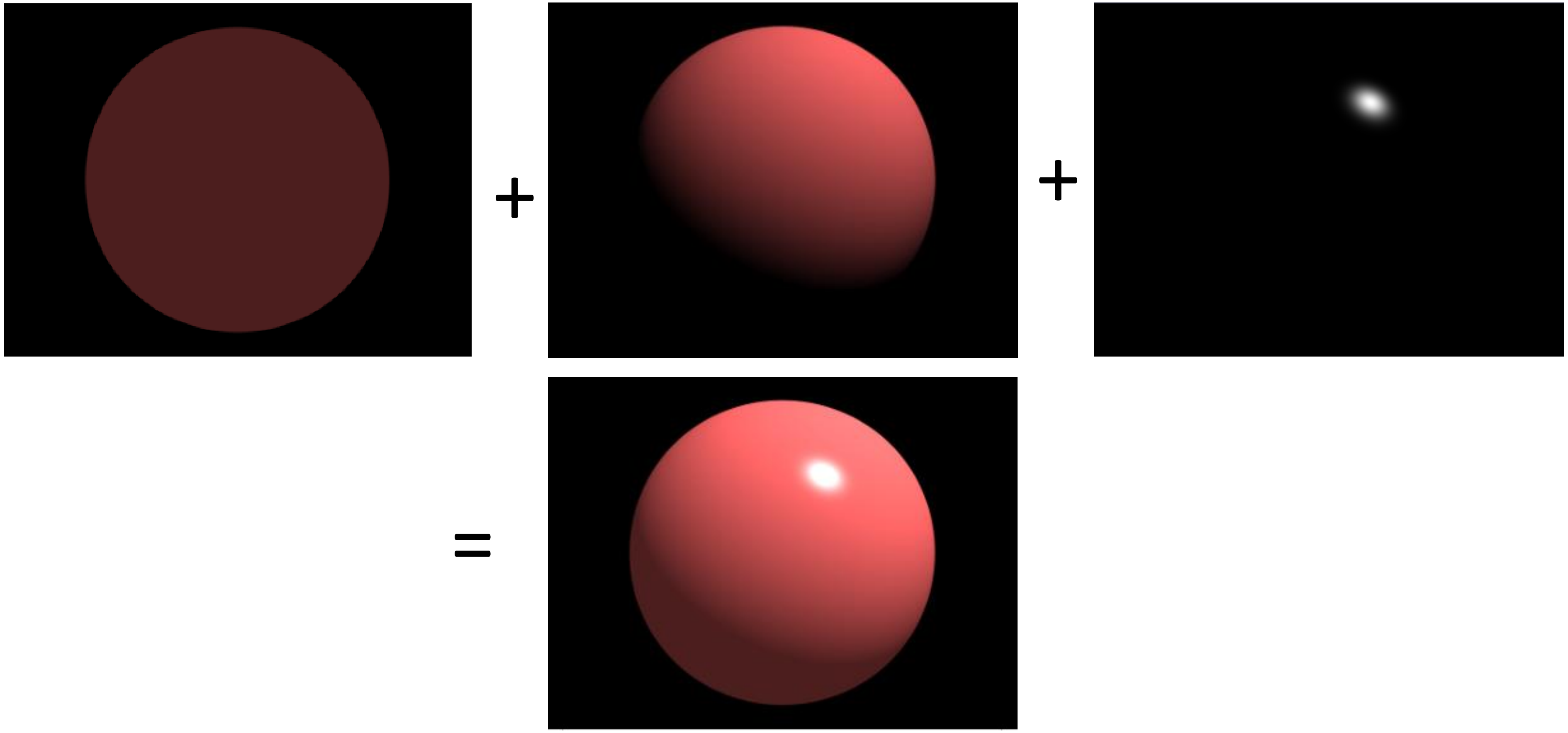
Reflective, diffuse, transparent surfaces.

Simplified models for real time rendering



- Local illumination: Assume object appearance only depends on local material and geometric properties

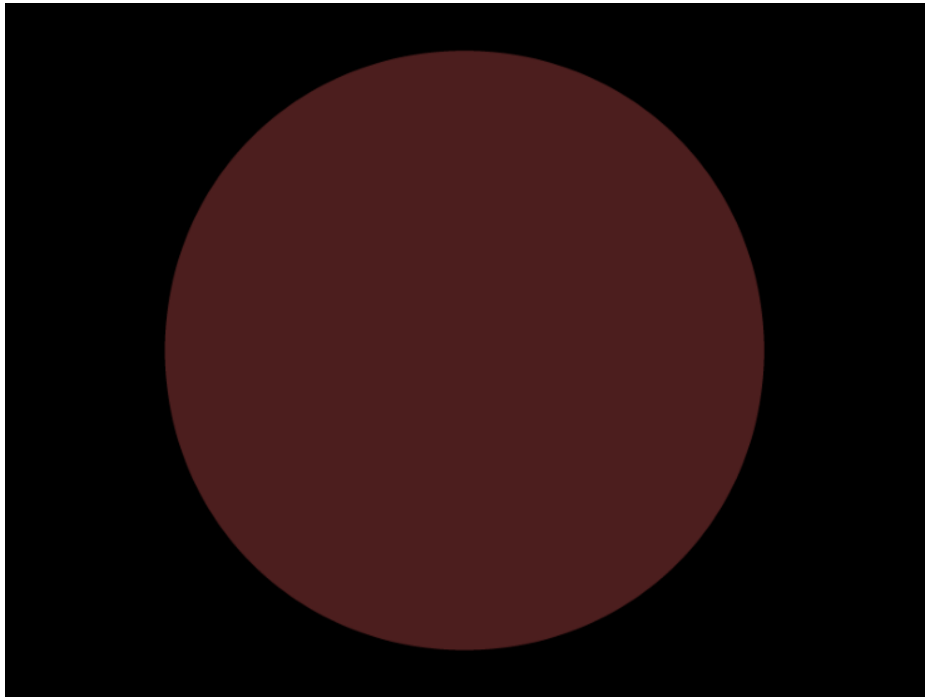
Simplified models for real time rendering



- We will use a combination of 3 terms (ambient, diffuse and specular) to compute the final appearance

Ambient term

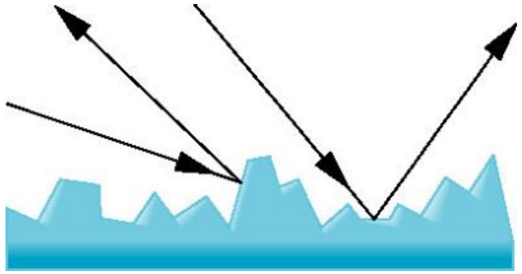
- Indirect lighting, due to global illumination effects



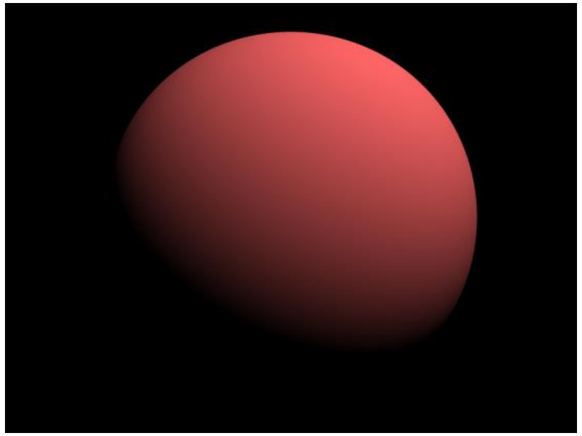
- Simplification: Constant illumination term which does not depend on surface position or orientation

Diffuse term

- Direct lighting on a rough surface which reflects light in all directions

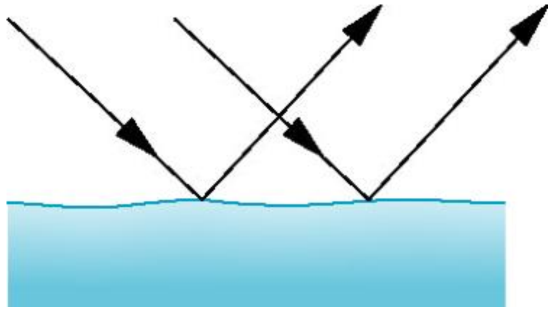


- Simplification: appearance depends only on surface orientation and light direction

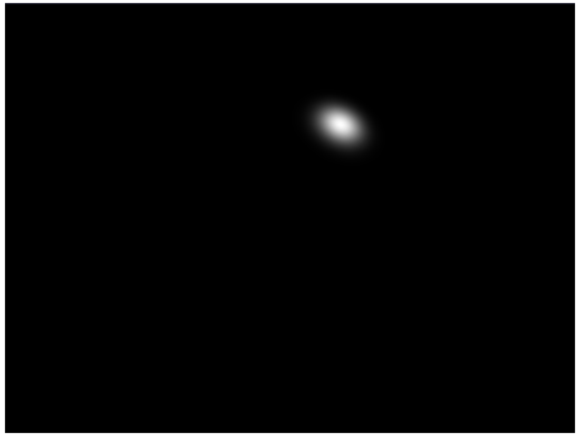


Specular term

- Direct lighting on a smooth, reflective surface



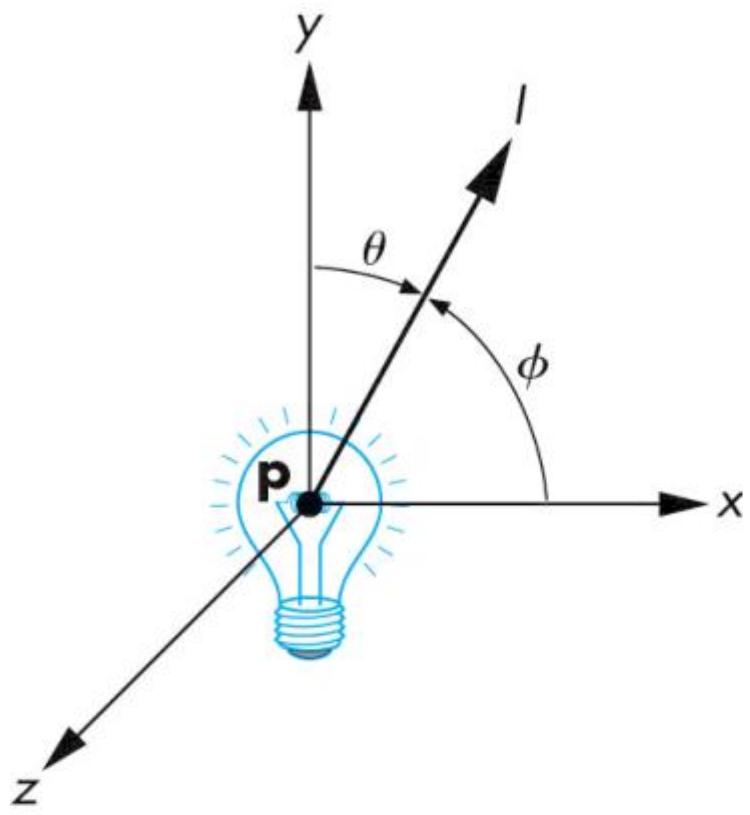
- Simplification: appearance depends on surface orientation, light direction and viewer position



Real light sources

Illumination function $I(x, y, z, \theta, \phi, \lambda)$

- The emitted light is a function of
  - Position: x, y, z
  - Direction: ϕ, θ
  - Wavelength: λ



Simplified light sources

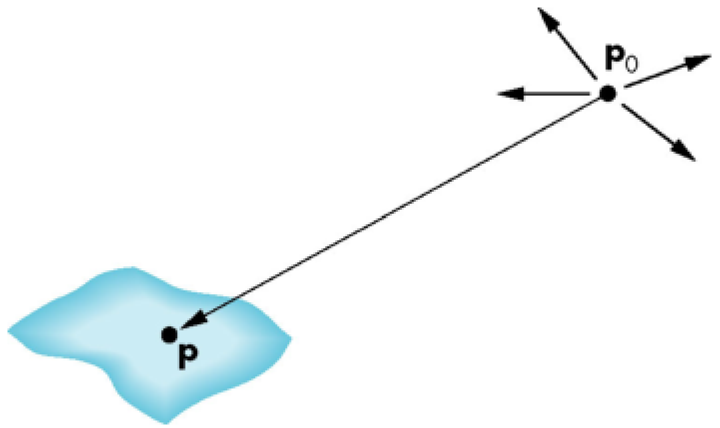
- We will use the tristimulus theory of human vision to simplify the wavelength dependence of the illumination function
- Light sources are characterized by rgb color $\boldsymbol{I} = \begin{bmatrix} I_r \\ I_g \\ I_b \end{bmatrix}$

Ambient light source

- Ambient light sources represent light which seems to come from "everywhere"
- Ambient light sources have no position or directional dependence
- Ambient light sources can be described with only a color:

$$\boldsymbol{I_a} = \begin{bmatrix} I_{ar} \\ I_{ag} \\ I_{ab} \end{bmatrix}$$

Point light source

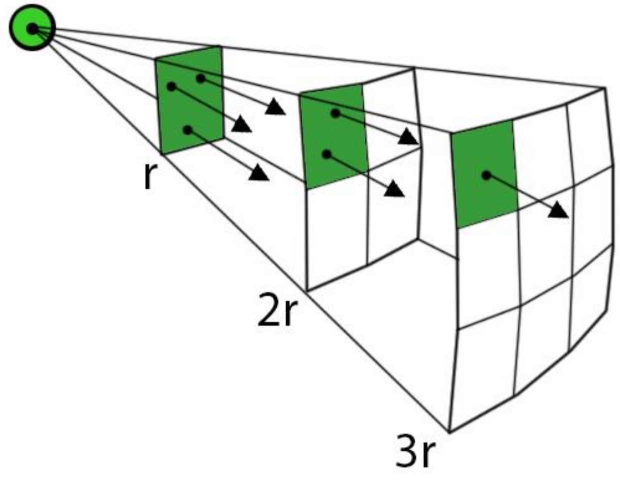


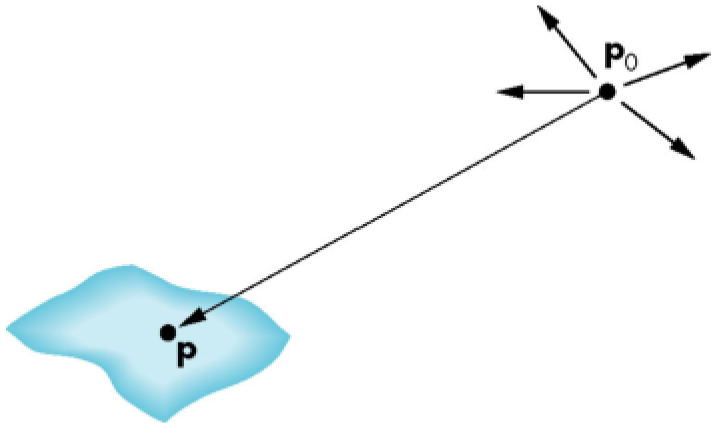
- Point light sources have no area (light is emitted from a single point)
- Light is emitted equally in all directions (no directional dependence)

$$\boldsymbol{I}(\boldsymbol{p_0}) = \begin{bmatrix} I_r(p_0) \\ I_g(p_0) \\ I_b(p_0) \end{bmatrix}$$

Point light source

- The light intensity received at the surface is less than the light emitted
- Inverse square law: Light received at p is inversely proportional to the squared distance to the light source
- $i(p, p_0) = \frac{1}{||p - p_0||^2} I(p_0)$





The inverse square law

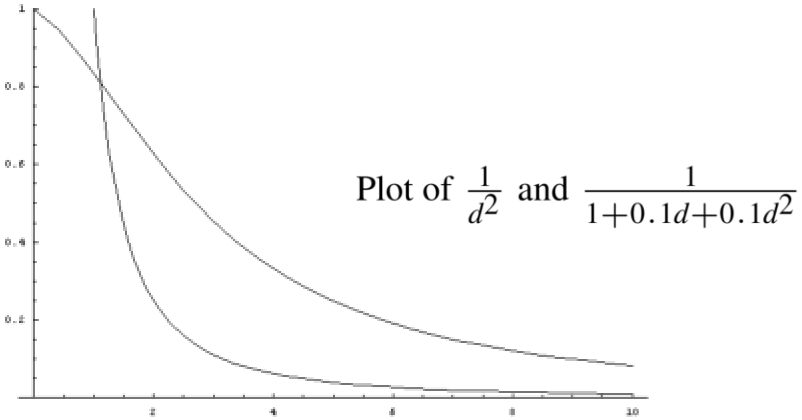
- Even though the inverse square law is a physically accurate description of light attenuation, it can lead to problems
  - harsh lighting
  - very dim objects far away from lights
- One solution: place many light sources in the scene
- Another solution: tweak the attenuation equation
  - The quadratic attenuation model

The inverse square law

- Let the distance from light to the surface be $d = ||p - p_0||$
- Instead of $^1/_{d^2}$ use the **quadratic attenuation** term

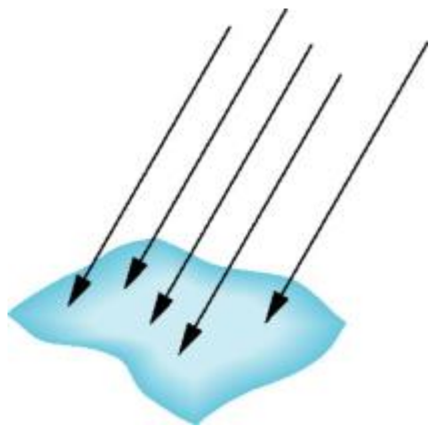
$$\frac{1}{a + bd + cd^2}$$

- Where a, b, c are chosen by the artist/designer/programmer



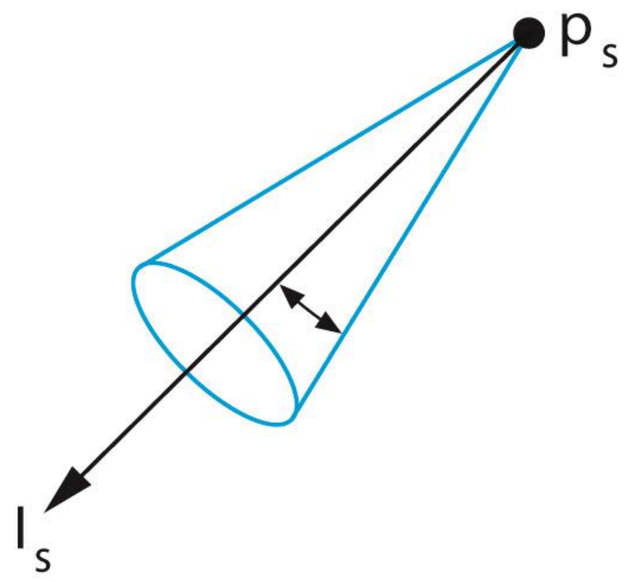
Directional light sources

- No positional dependence, characterized by a direction
- All light rays are parallel
- Models a point light at an infinite distance (like the sun)



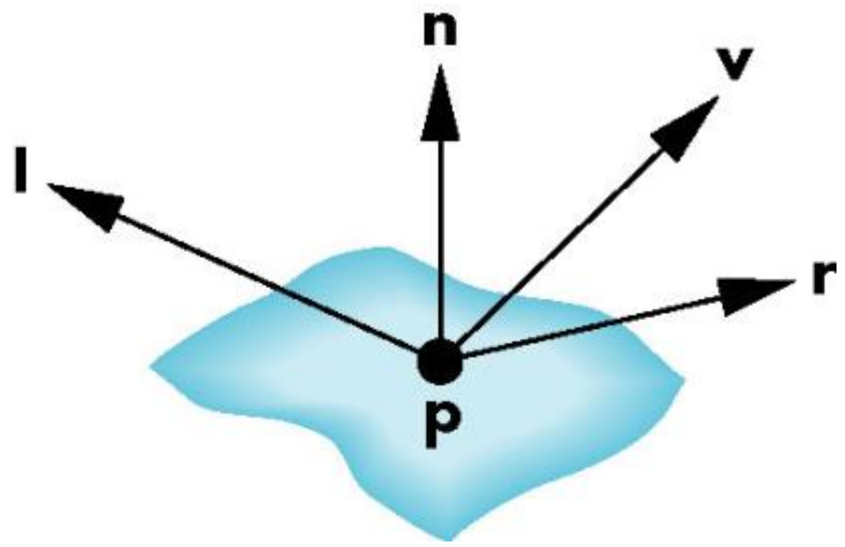
Spot light

- A point light that emits light within a cone
- Has position, direction, cone angle, color



Phong reflection model

- A local lighting model which depends on the following vectors when computing the color of point p
  - l: direction to the light source
  - n: normal (perpendicular) to the surface
  - v: direction to the viewer / camera
  - r: reflection direction (depends on n and l)



Phong: 3 types of light-material interaction

The Phong model combines the lighting contributions from

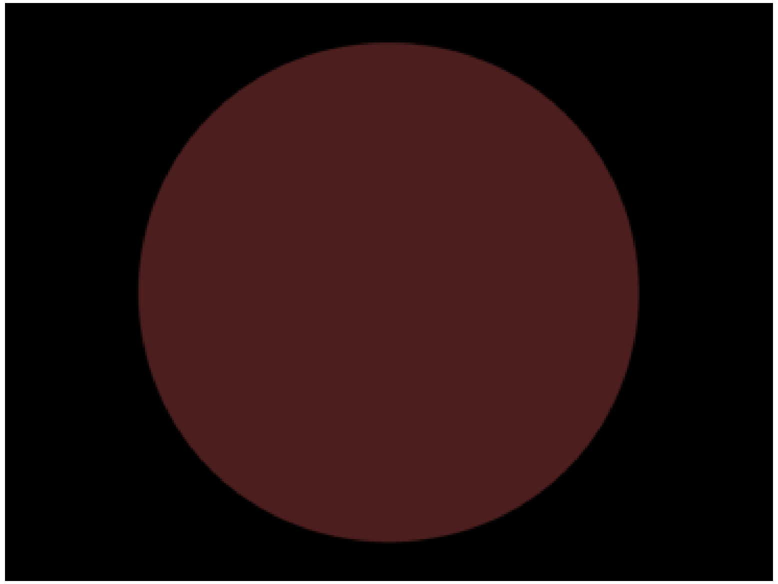
- Ambient
- Diffuse
- Specular

using a quadratic attenuation model

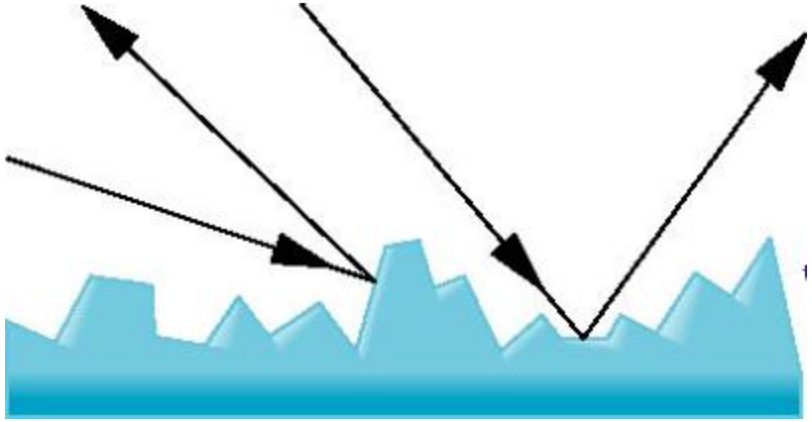
The ambient term

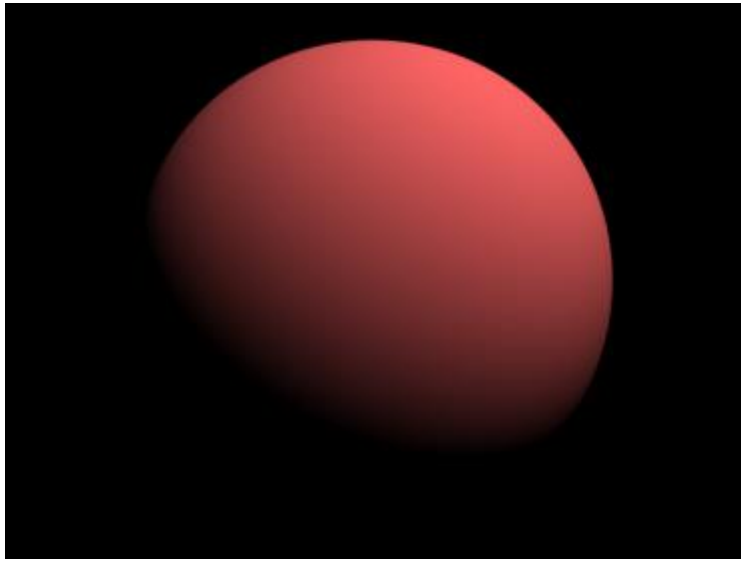
The ambient color of every point on a surface is constant

- $I_a = kaLa$
- k_a must be positive
- The 3 color components of k_a are referred to as the "ambient color" of the surface
- L_a is the ambient light color



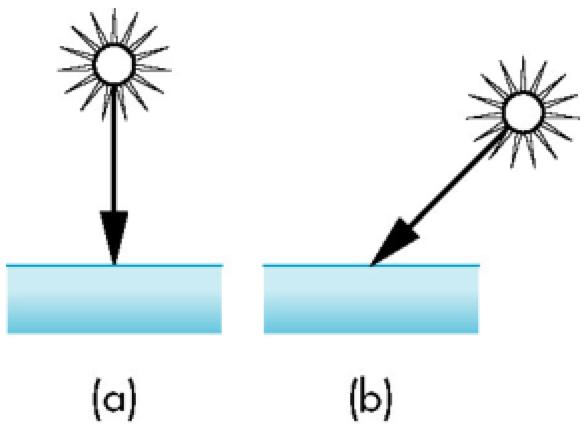
The diffuse term





- A perfectly diffusion surface (Lambertian) reflects light equally in all directions
- A point, p, on a surface looks the same to all viewers
- Diffuse reflectance R_d does not depend on v (view direction)
- However, R_d does depend on n and l

Lambert's law



- Lambert's law states that

$$R_d \propto cos\theta$$

where θ is the angle between the light direction and the surface normal

- If n and l are unit vectors then $cos\theta = n \cdot l$
- Then we can choose a diffuse coefficient k_d and let

$$R_d = k_d(n \cdot l)$$

- Taking attenuation into account we have

$$R_d = \frac{k_d}{a + bd + cd^2}(n \cdot l)$$

The diffuse term

- Since it is meaningless to reflect a negative fraction of incoming light, we clamp the cosine term

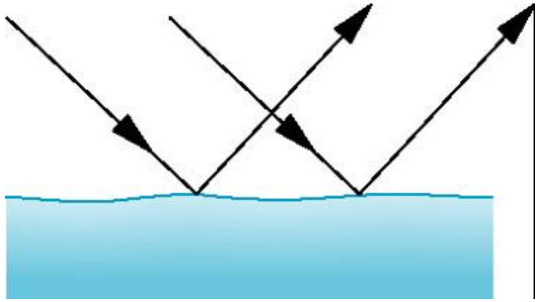
$$R_d = \frac{k_d}{a + bd + cd^2} \max((n \cdot l), 0)$$

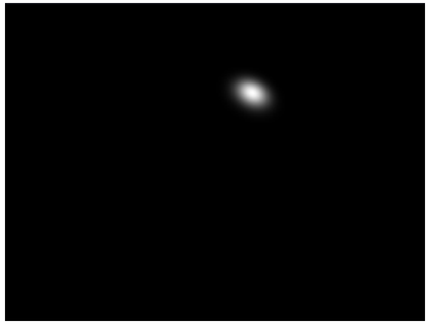
- The diffuse intensity is then given by

$$I_d = \frac{k_d}{a + bd + cd^2} \max((n \cdot l), 0) L_d$$

- k_d is the diffuse material color, and L_d is the diffuse light color

The specular term





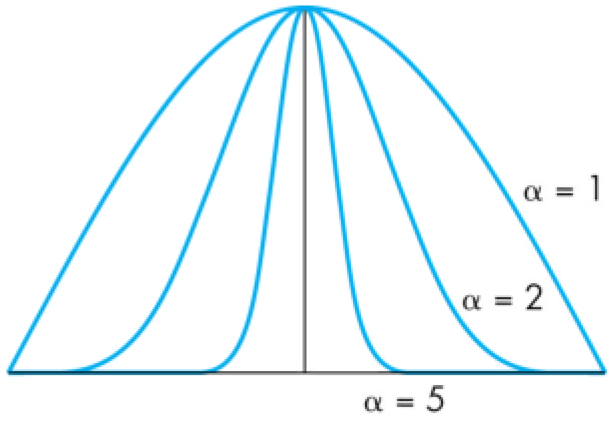
- Smooth specular surfaces act like a mirror. The reflection term, R_s, depends on the reflection vector, r.

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

- k_s: specular material color
- L_s: specular light color
- α : shininess
- ϕ: angle between r and v

The specular term

- As the exponent α increases the specular highlight becomes smaller and sharper



- If r and v are normalized, we can use the dot product here too

$$I_s = k_s\, Ls\, \max(0, r \cdot v)^{\alpha}$$

Warning

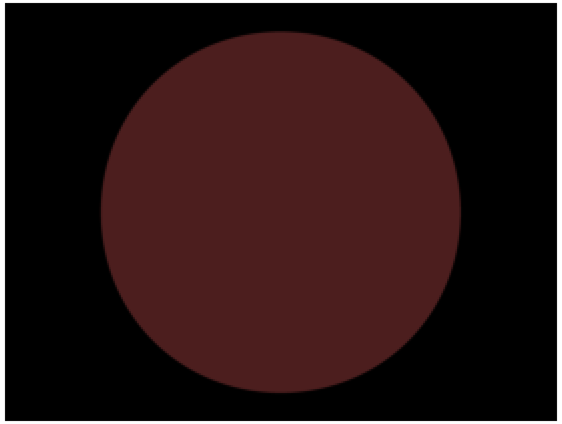
$$I_s = k_s\, Ls \max(0, r \cdot v)^{\alpha}$$

- Be careful, the book and several other resources get this wrong
- They instead write

$$I_s = k_s\, Ls \max(0, (r \cdot v)^{\alpha})$$

- What is the difference?

The Phong model



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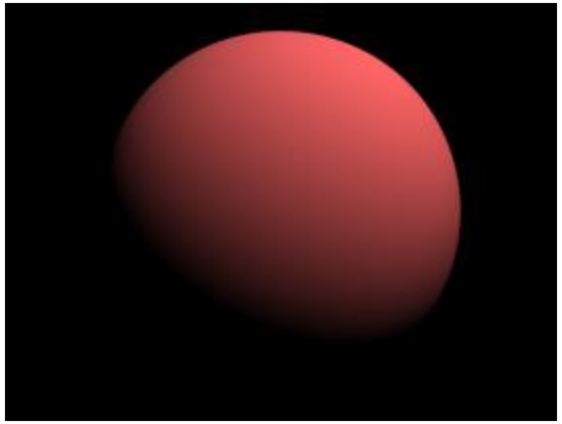

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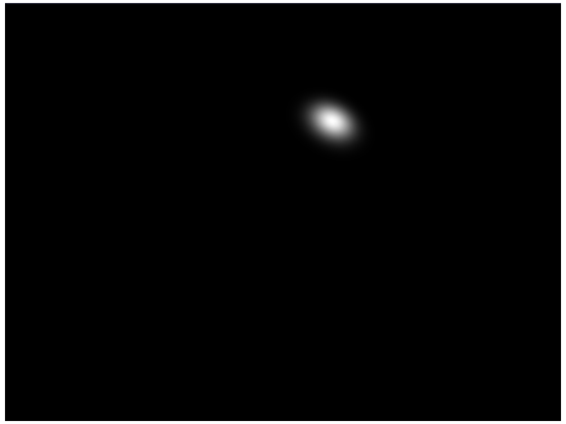

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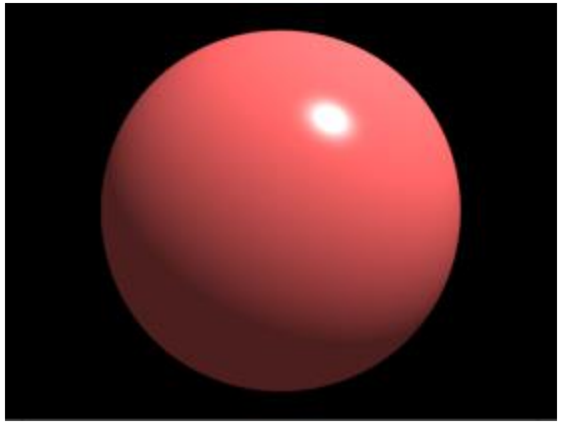


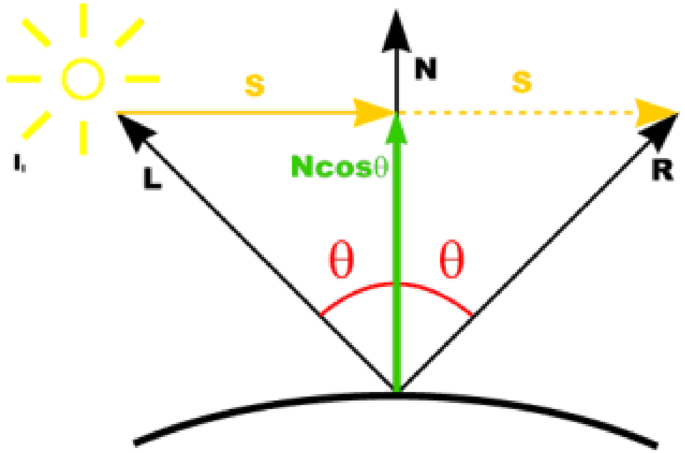
$$I = ka\, La + \frac{1}{a+bd+cd^2}\left(k_d\, Ld \max(0,\ n \cdot l) + k_s\, Ls \max(0, r \cdot v)^{\alpha}\right)$$

- For multiple light sources, sum up the contributions from each light

In glsl

- Relevant functions in glsl
  - `dot(u,v)` : dot product between u and v
  - `pow(x, y):` return x^y
    - Undefined if $x<0$ or if $x=0$ and $y \le 0$
  - `max(x, y):` return maximum of x and y
  - `reflect(I, N):` computes the reflection vector
    - `I` is incident (incoming) light vector. This opposite of what we assume in Phong derivation
    - `N` is surface normal
    - Call `vec3 r = reflect(-l, n)` for outward facing vectors

How is reflection vector computed?



- Assume ideal reflection: angle of incidence = angle of reflection θ
- $L + S = N \cos\theta$
- $N \cos\theta + S = R$
- *From the first equation:* $S = N \cos\theta - L$
- *Plugging into the second eqn:* $N \cos\theta + N \cos\theta - L = R$
- *Then* $R = 2N \cos\theta - L$
- *Since N and L are unit vectors:* $R = 2N\,(N \cdot L) - L$