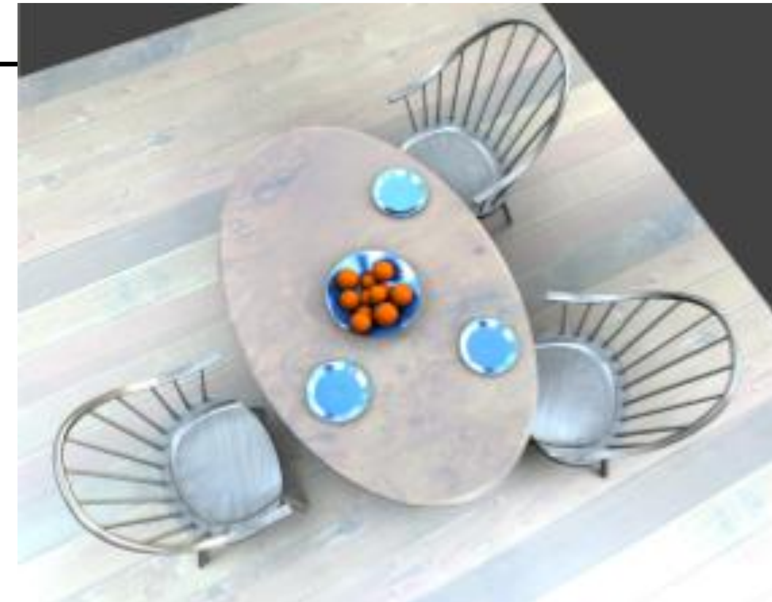
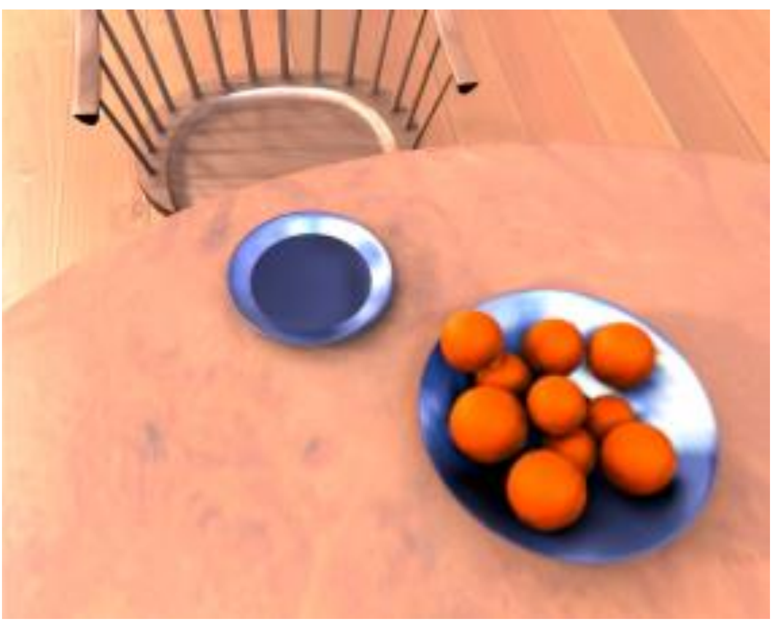
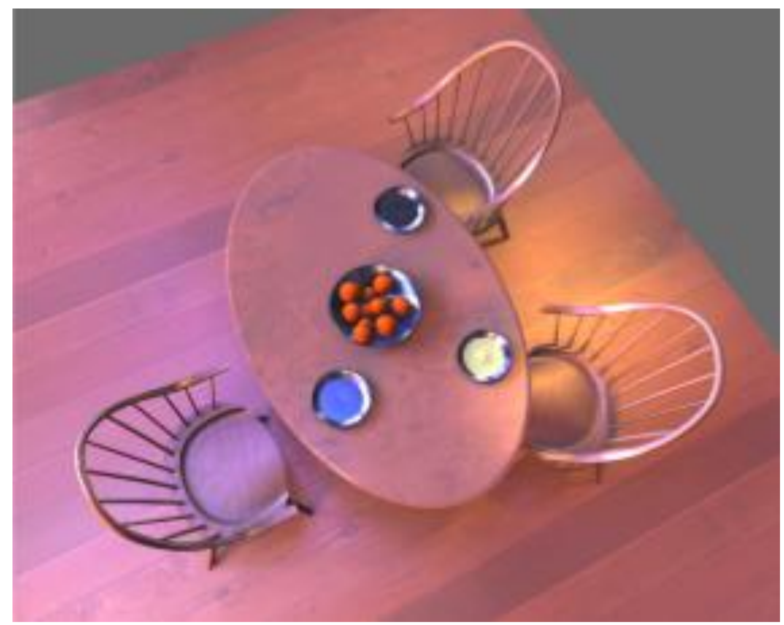
Topic 10:

Lighting & Reflection models

- Lighting & reflection
- The Phong reflection model
    - diffuse component
    - ambient component
    - specular component

Spot the differences

Terminology

Illumination

- The transport of luminous flux from light sources between points via direct and indirect paths

Lighting

- The process of computing the luminous intensity reflected from a specified 3-D point

Shading

- The process of assigning a color to a pixel

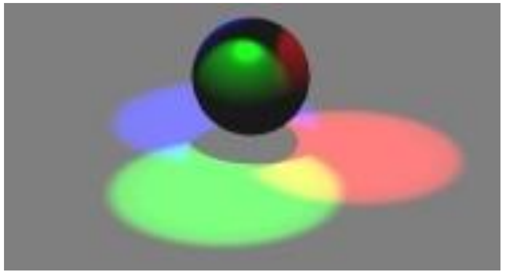
Illumination Models

- Simple approximations of light transport
- Physical models of light transport

Two Components of Illumination

Light Sources

- Emission Spectrum (color)
- Geometry (position and direction)
- Directional Attenuation



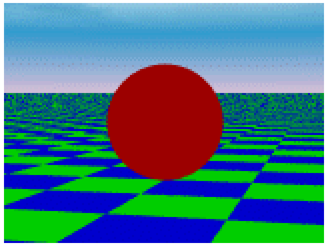
Surface Properties (Reflectors)

- Reflectance Spectrum (color)
- Geometry (position, orientation, and micro-structure)
- Absorption
- Transmission

Ambient Light Source

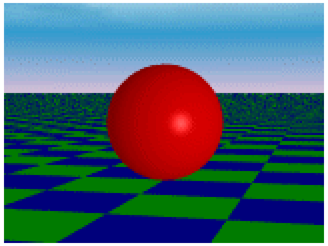
Even though an object in a scene is not directly lit it will still be visible. This is because light is reflected indirectly from nearby objects. A simple *hack* that is commonly used to model this indirect illumination is to use of an *ambient light source*. Ambient light has no spatial or directional characteristics. The amount of ambient light incident on each object is a constant for all surfaces in the scene. An ambient light can have a color.

The amount of ambient light that is reflected by an object is independent of the object's position or orientation. Surface properties are used to determine how much ambient light is reflected.



Directional Light Sources

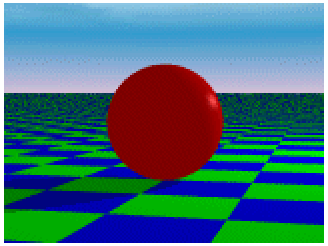
All of the rays from a directional light source have a common direction, and no point of origin. It is as if the light source was infinitely far away from the surface that it is illuminating. Sunlight is an example of an infinite light source.

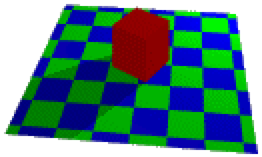


The direction from a surface to a light source is important for computing the light reflected from the surface. With a directional light source this direction is a constant for every surface. A directional light source can be colored.

Point Light Sources

The point light source emits rays in radial directions from its source. A point light source is a fair approximation to a local light source such as a light bulb.



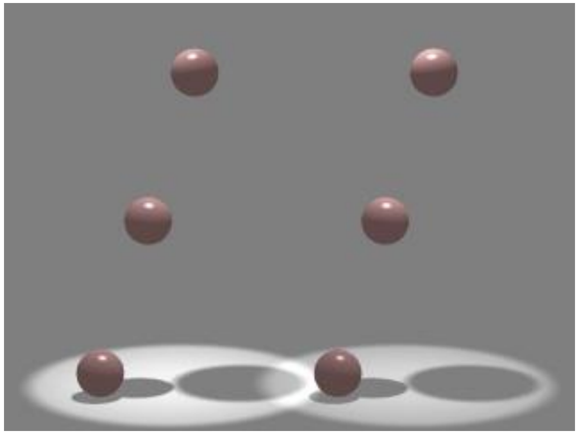


The direction of the light to each point on a surface changes when a point light source is used. Thus, a normalized vector to the light emitter must be computed for each point that is illuminated.

Other Light Sources

Spotlights

- Point source whose intensity falls off away from a given direction
- Requires a color, a point, a direction, parameters that control the rate of fall off

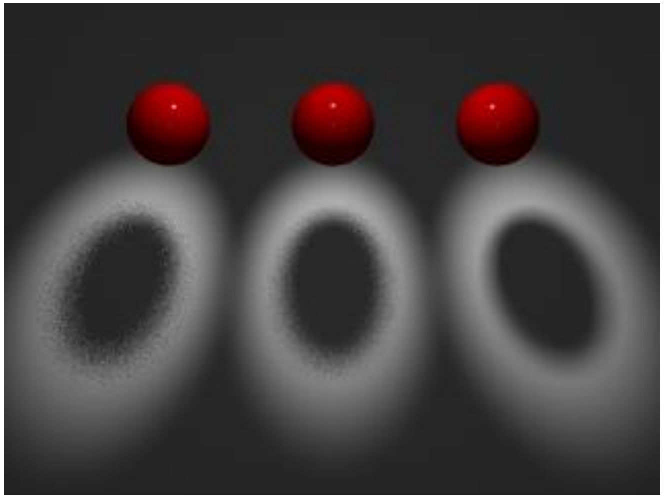


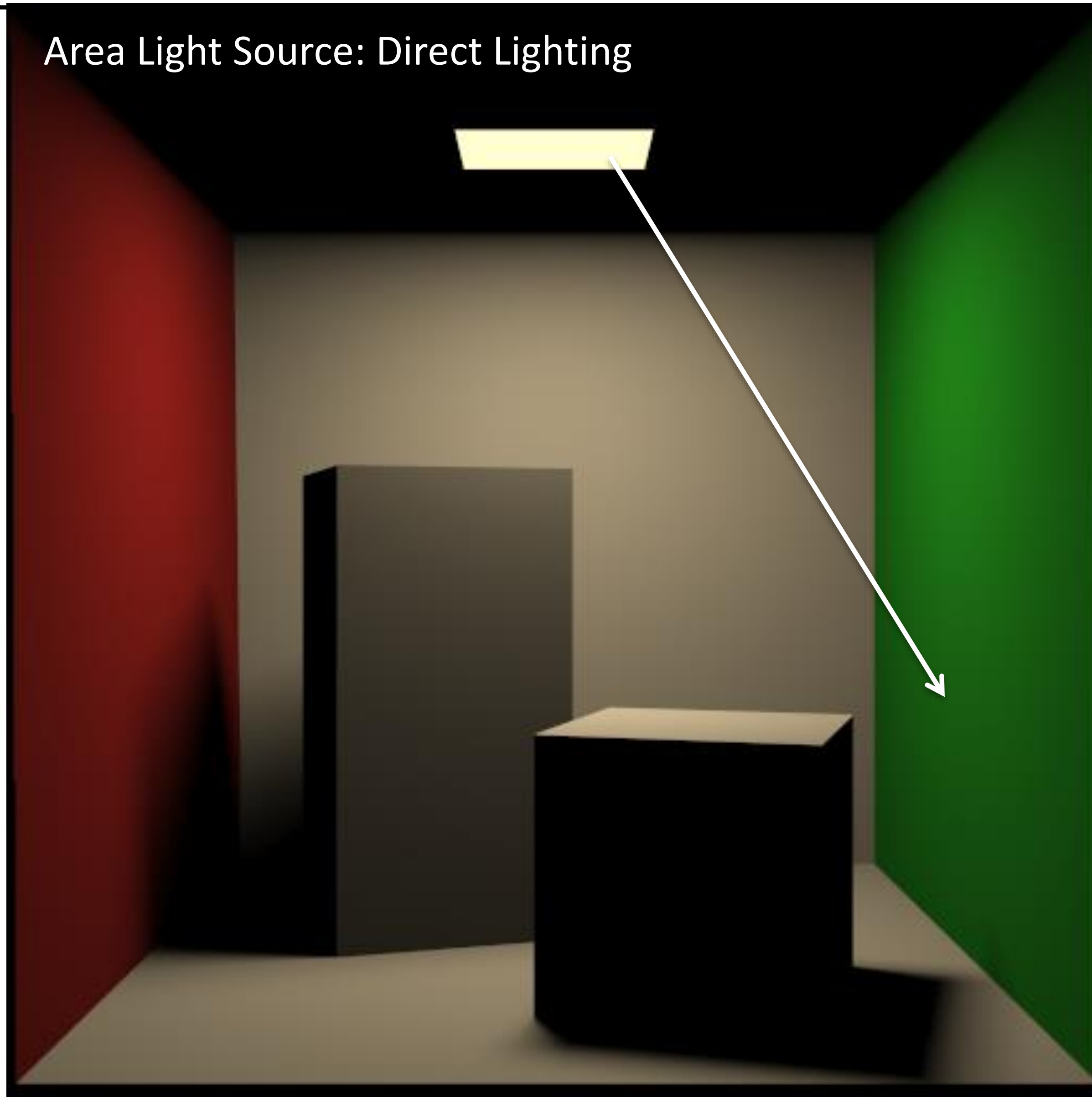
Area Light Sources

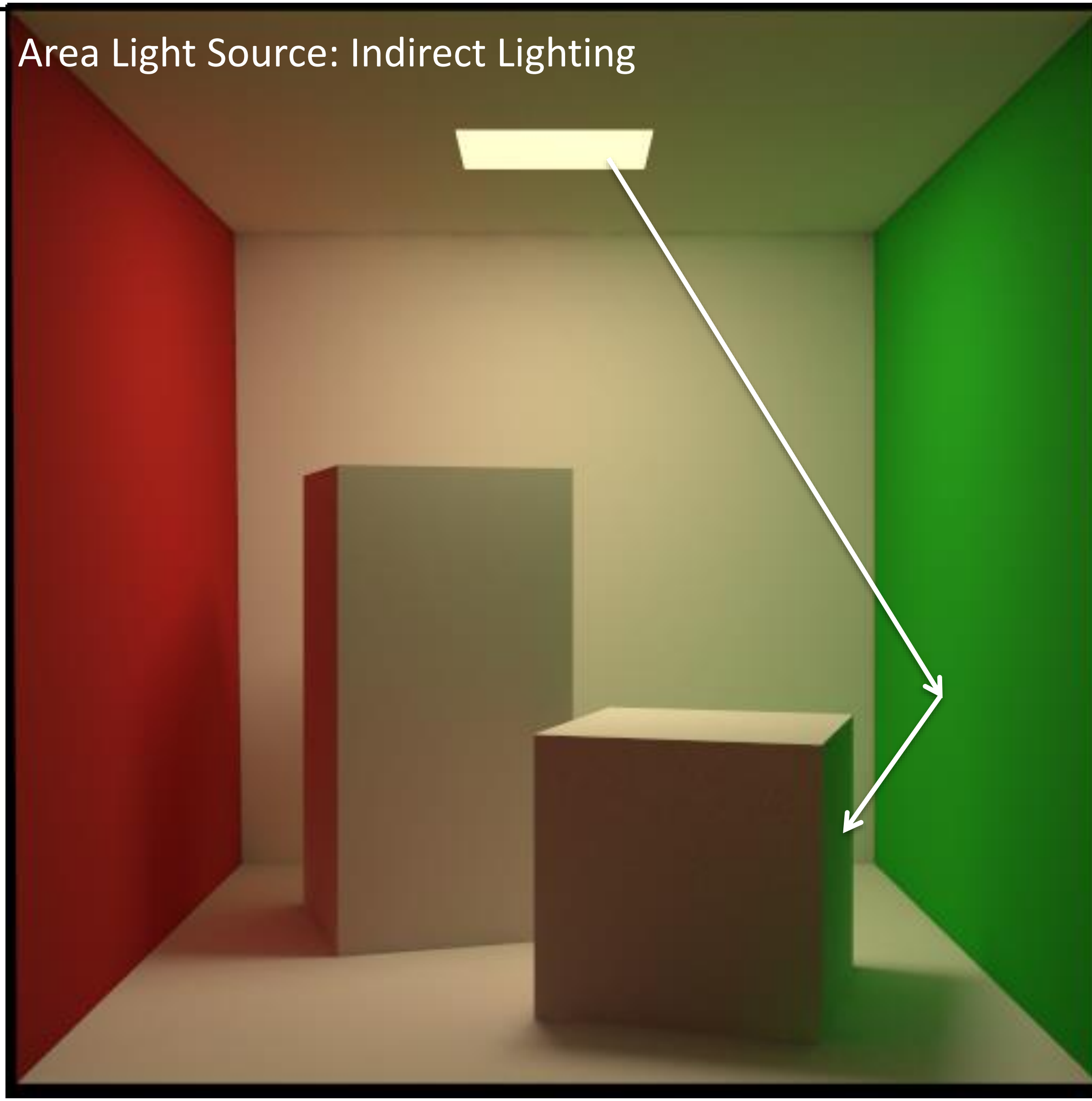
- Light source occupies a 2-D area (usually a polygon or disk)
- Generates *soft* shadows

Extended Light Sources

- Spherical Light Source
- Generates *soft* shadows

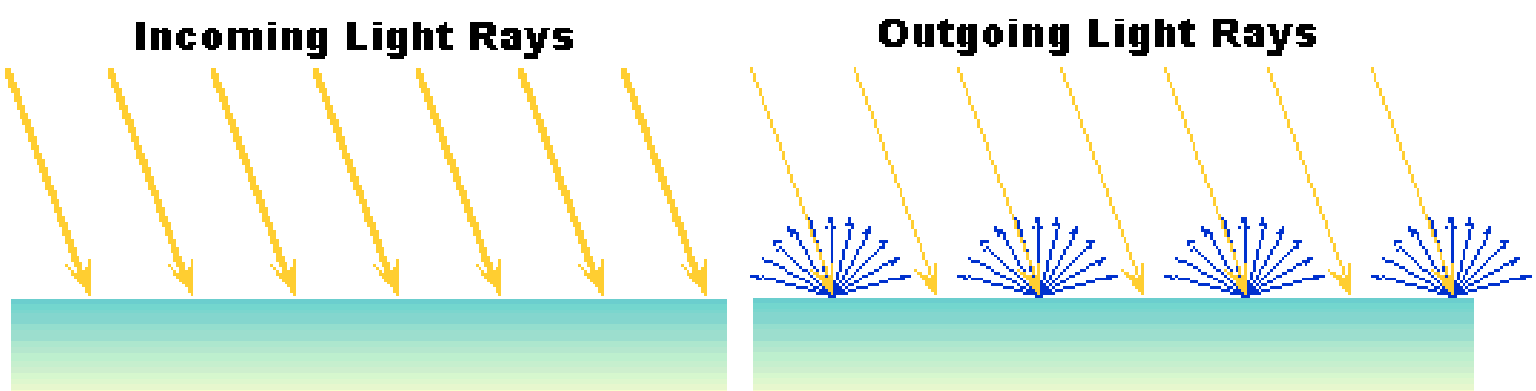



Area Light Source: Direct Lighting

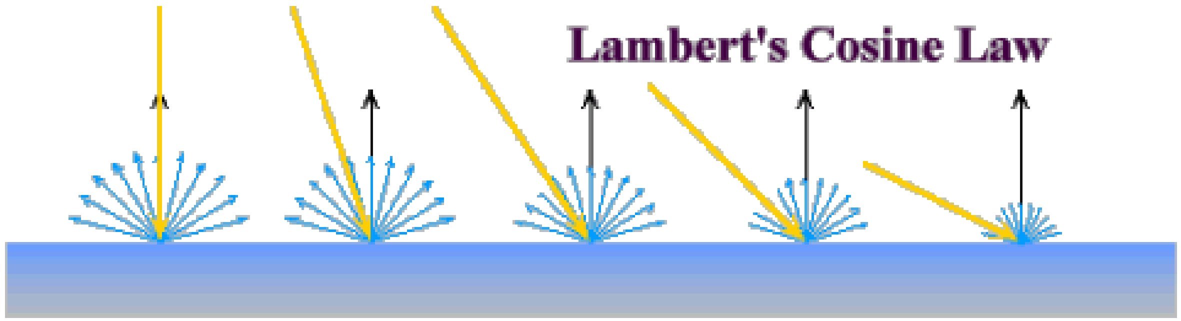

Area Light Source: Indirect Lighting

Ideal Diffuse Reflection

First, we will consider a particular type of surface called an *ideal diffuse reflector*. An ideal diffuse surface is, at the microscopic level a very rough surface. Chalk is a good approximation to an ideal diffuse surface. Because of the microscopic variations in the surface, an incoming ray of light is equally likely to be reflected in any direction over the hemisphere.



Lambert's Cosine Law



Ideal diffuse reflectors reflect light according to *Lambert's cosine law*, Lambert's law states that the reflected energy from a small surface area in a particular direction is proportional to cosine of the angle between that direction and the surface normal.

Computing Diffuse Reflection

The angle between the surface normal and the incoming light ray is called the angle of incidence.

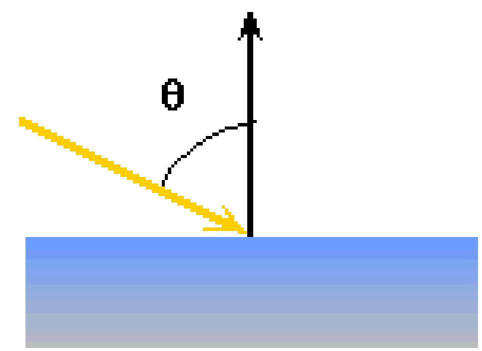
I_{light} : intensity of the incoming light.

k_d : represents the diffuse reflectivity of the surface at that wavelength.

What is the range of k_d

$$I_{diffuse} = k_d I_{light} \left(\bar{n} \cdot \bar{l} \right)$$

$$I_{diffuse} = k_d I_{light} \cos\theta$$



Specular Reflection

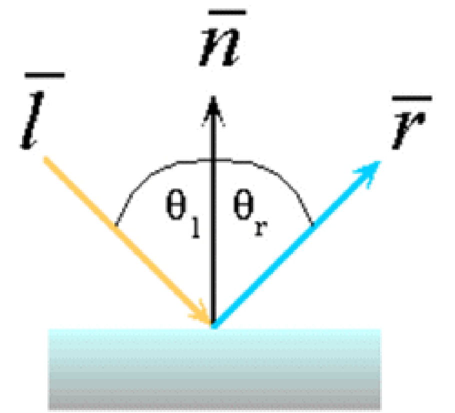
When we look at a shiny surface, such as polished metal, we see a highlight, or bright spot. Where this bright spot appears on the surface is a function of where the surface is seen from. The reflectance is view dependent.

Snell's Law

Reflection behaves according to Snell's law:

- The incoming ray, the surface normal, and the reflected ray all lie in a common plane.
- The angle that the reflected ray forms with the surface normal is determined by the angle that the incoming ray forms with the surface normal, and the relative speeds of light of the mediums in which the incident and reflected rays propagate according to the following expression. (Note: n_l and n_r are the indices of refraction)

$$n_l \sin\theta_l = n_r \sin\theta_r$$

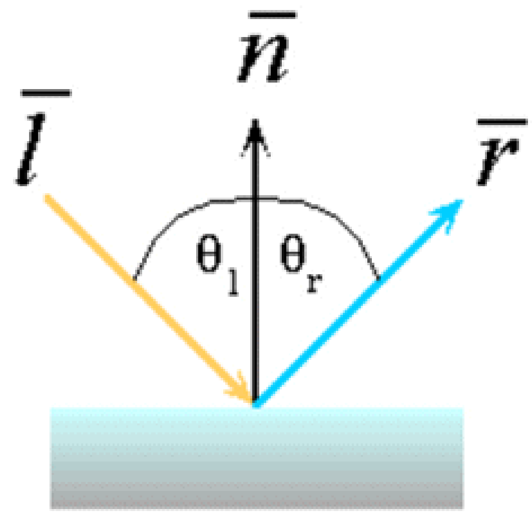


Reflection

Reflection is a very special case of Snell's Law where the incident light's medium and the reflected rays medium is the same. Thus

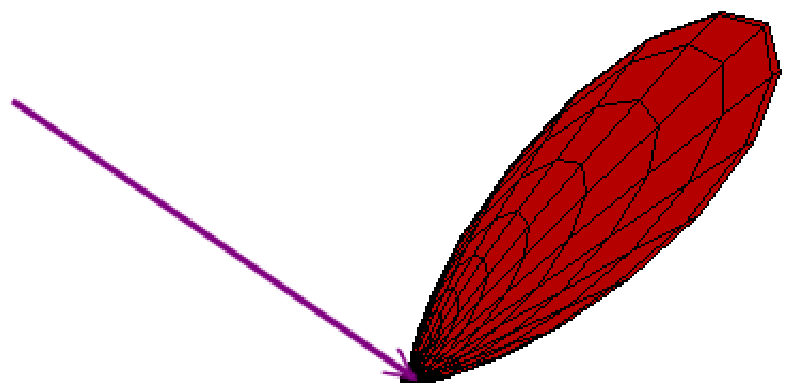
angle of incidence = angle of reflection

$$n_l \sin\theta_l = n_r \sin\theta_r$$



Non-ideal Reflectors

Snell's law, applies only to ideal *mirror* reflectors.

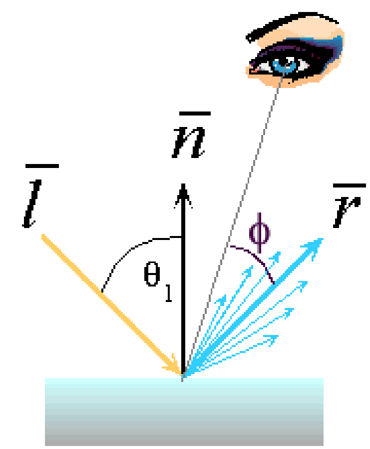


In general, most of the reflected light travels in the direction of the ideal ray. However, because of microscopic surface variations we might expect some of the light to be reflected just slightly offset from the ideal reflected ray. As we move farther and farther, in the angular sense, from the reflected ray we expect to see less light reflected.

Phong Illumination

Phong Illumination approximates specular fall-off with no physical basis, yet it is one of the most commonly used illumination models in computer graphics.

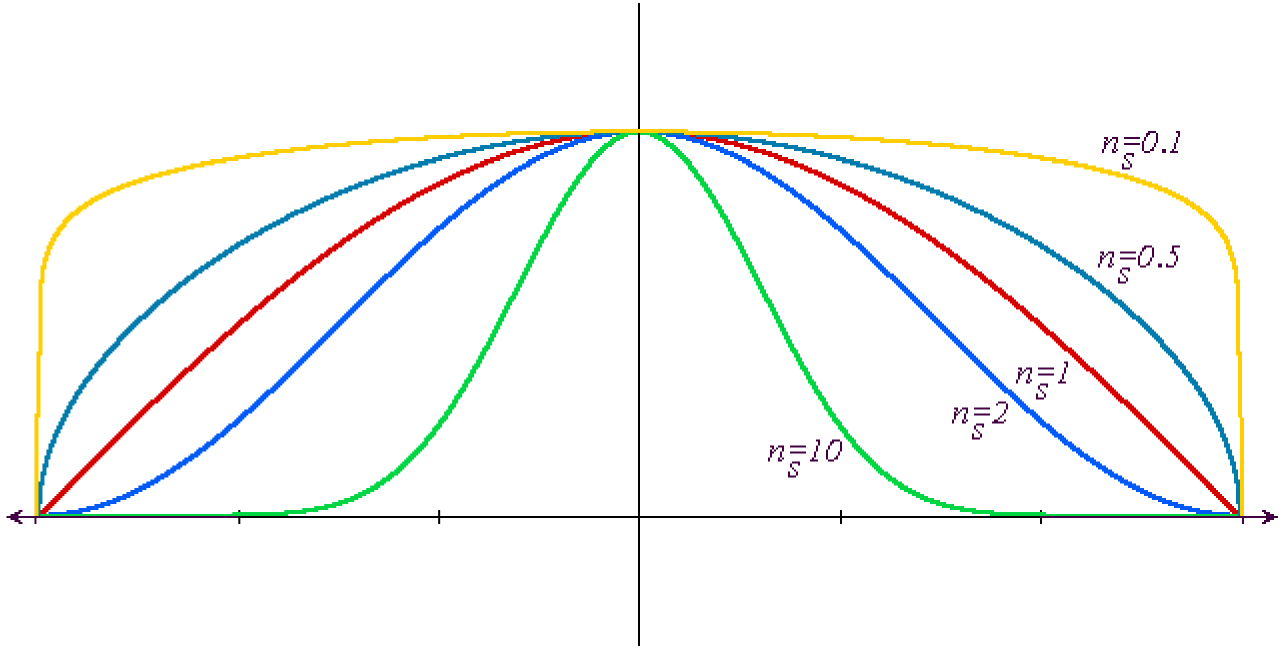
$$I_{\text{specular}} = k_s I_{\text{light}} \cos^{n_{\text{shiny}}} \phi$$



The cosine term is maximum when the surface is viewed from the mirror direction and falls off to 0 when viewed at 90 degrees away from it. The scalar n_{shiny} controls the rate of this fall off.

Effect of the n_{shiny} coefficient

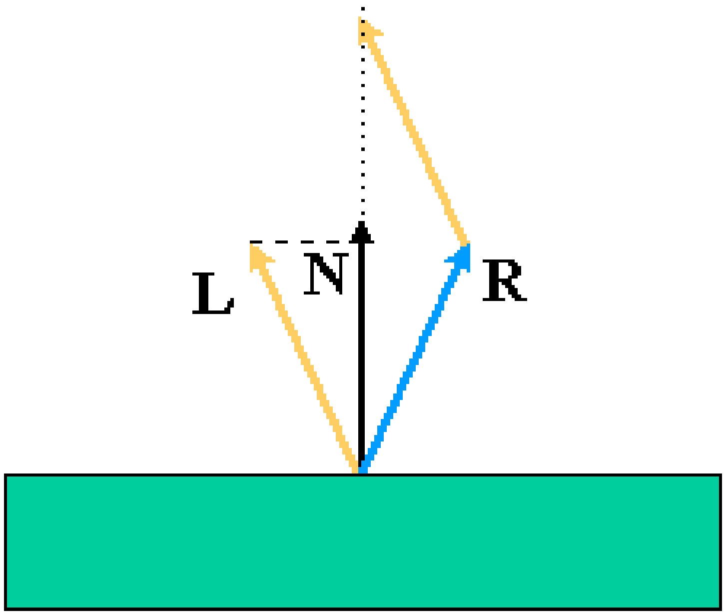
The diagram below shows the how the reflectance drops off in a Phong illumination model. For a large value of the n_{shiny} coefficient, the reflectance decreases rapidly with increasing viewing angle.



Computing Phong Illumination

$$I_{specular} = k_s\, I_{light}\, (V.R)^{shiny}$$

$$\hat{R} + \hat{L} = \left(2\left(\hat{N} \cdot \hat{L}\right)\right)\hat{N}$$

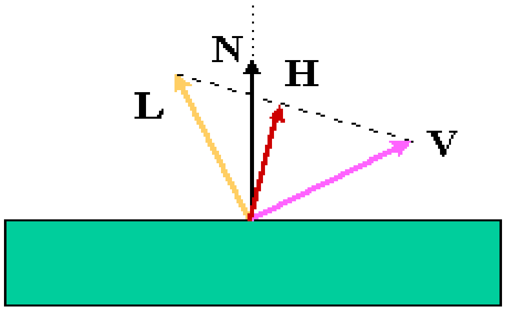


Blinn & Torrance Variation

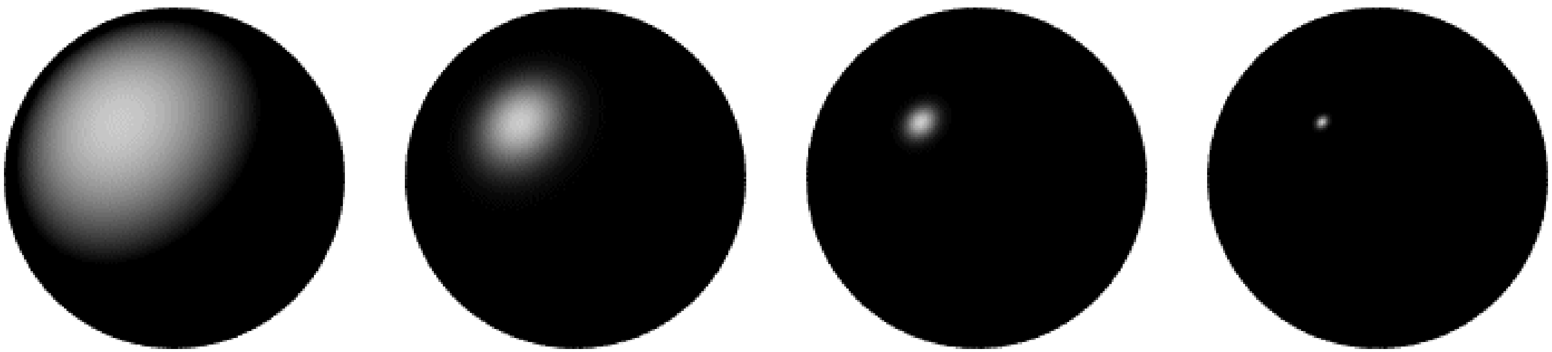
In this equation the angle of specular dispersion is computed by how far the surface's normal is from a vector bisecting the incoming light direction and the viewing direction.

$$I_{specular} = k_s \, I_{light} \, (N.H)^{shiny}$$

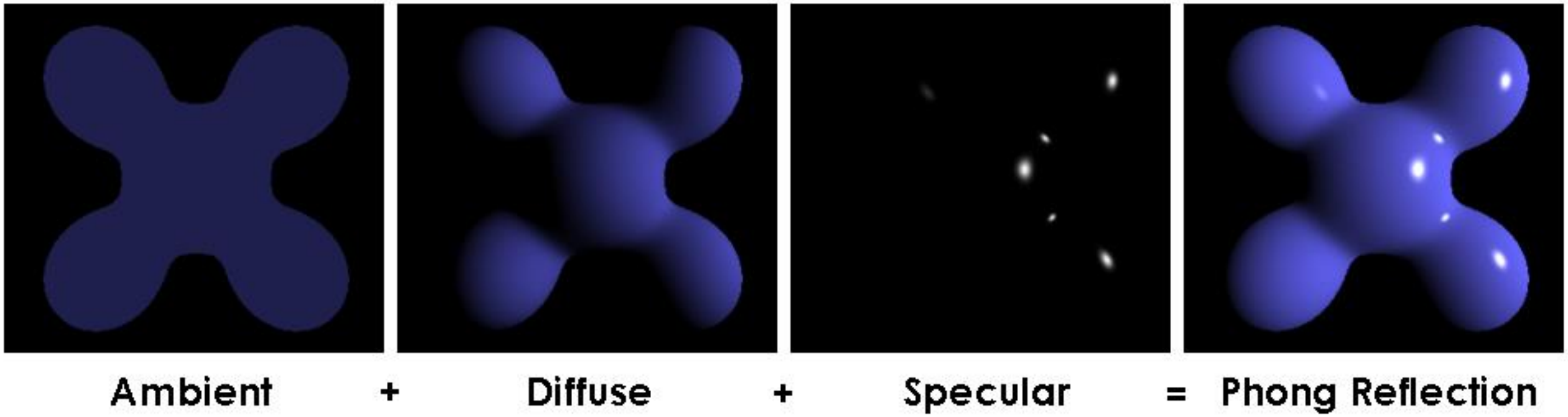
$$\hat{H} = \frac{\hat{L} + \hat{V}}{\left|\hat{L} + \hat{V}\right|}$$



Phong Examples



Phong Illumination: The General Equation



$$\boldsymbol{I_o(N,V,L) = k_a I_a + I_i \,[\, k_d}\ max(0,\ \boldsymbol{N.L}) + \boldsymbol{k_s}\ max(0,(\boldsymbol{V.R}))^{n}\,]$$

Where do we Illuminate?

To this point we have discussed how to compute an illumination model at a point on a surface.

Which points on the surface is the illumination model applied?

Illumination can be costly…

…and then God said "let there be shading"

Topic 11:

Shading

- Introduction to Shading
- Flat Shading
- Interpolative Shading
  - Gouraud shading
  - Phong shading
  - Triangle scan-conversion with shading

Shading: Motivation

Suppose we know how to shade any point on an object, for example, using the Phong illumination model.

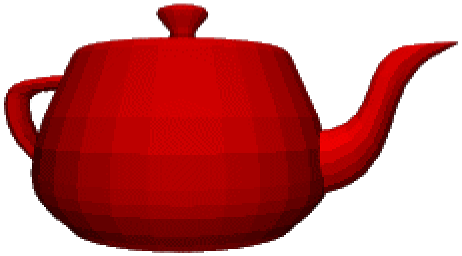
How do we shade an entire polygon mesh?

Answer:
Shade projected visible pixels using an illumination model.

What is good and bad about this?

Flat Shading

Apply only one illumination calculation for each face.



Which point on the facet do we illuminate?

Pros?

Cons?

Gouraud Shading

Apply the illumination model at vertices and interpolate the color intensity across faces.

Remember bilinear interpolation?

Pros?

Cons?

Phong Shading

Not to be confused with Phong Illumination model.

Apply the illumination model at every point on the face.

Calculate the normal at any point in a face by interpolating the vertex normals.of that face.

Pros?

Cons?

Silhouettes?