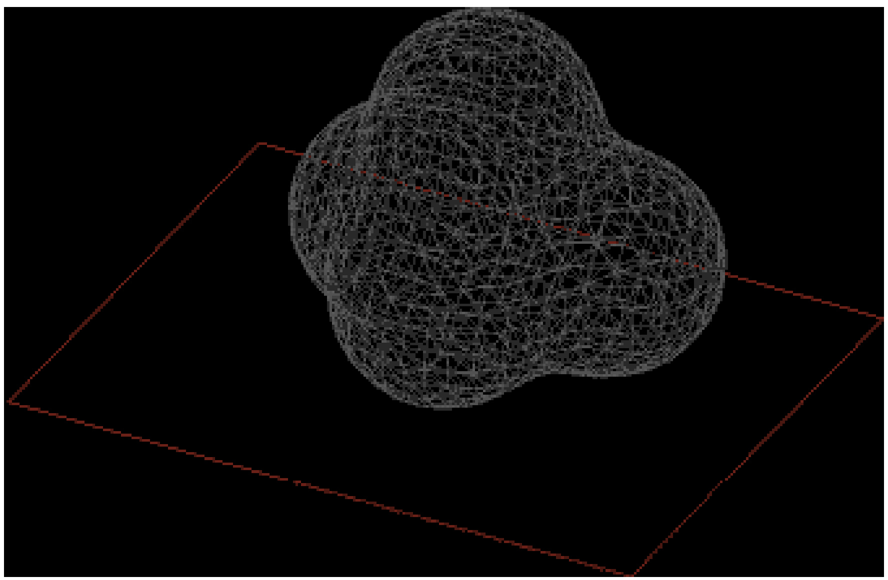
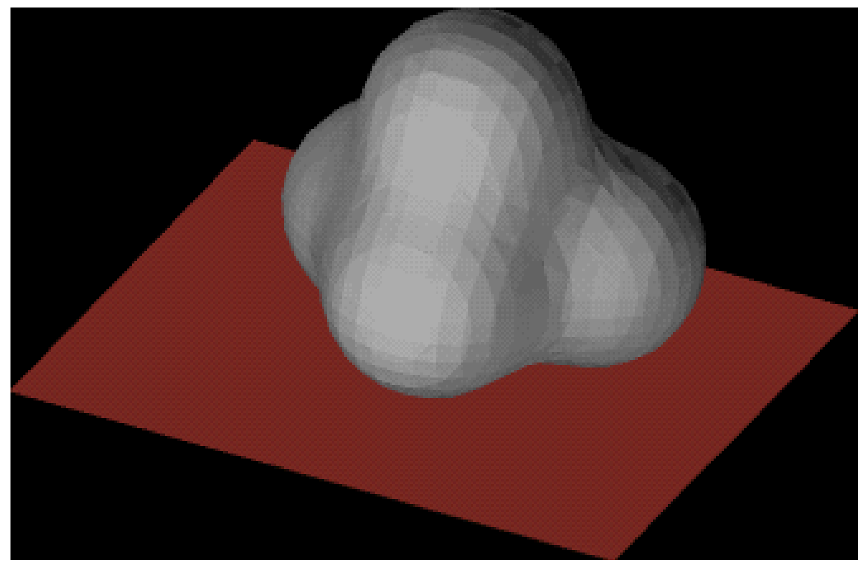
Illumination Models

Overview

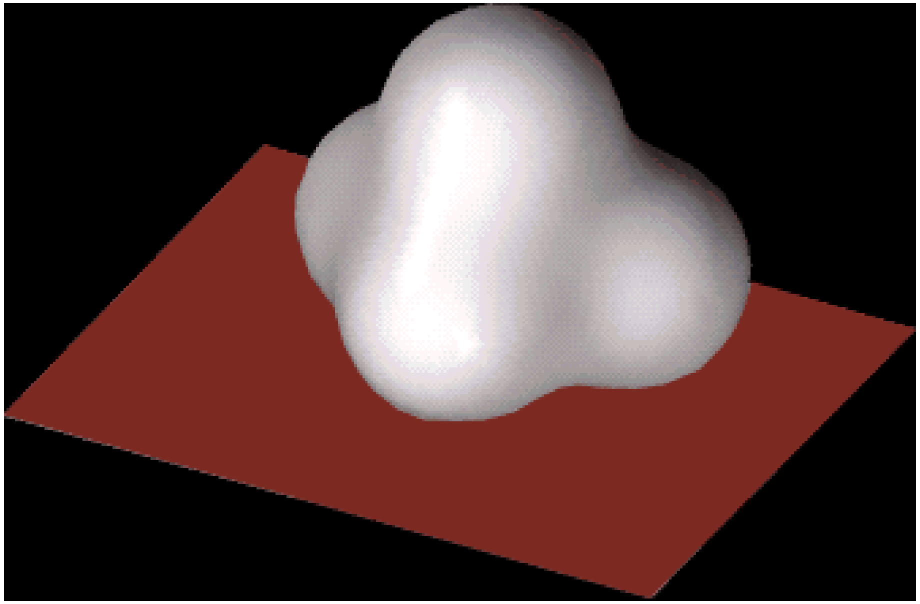


Wire Frame

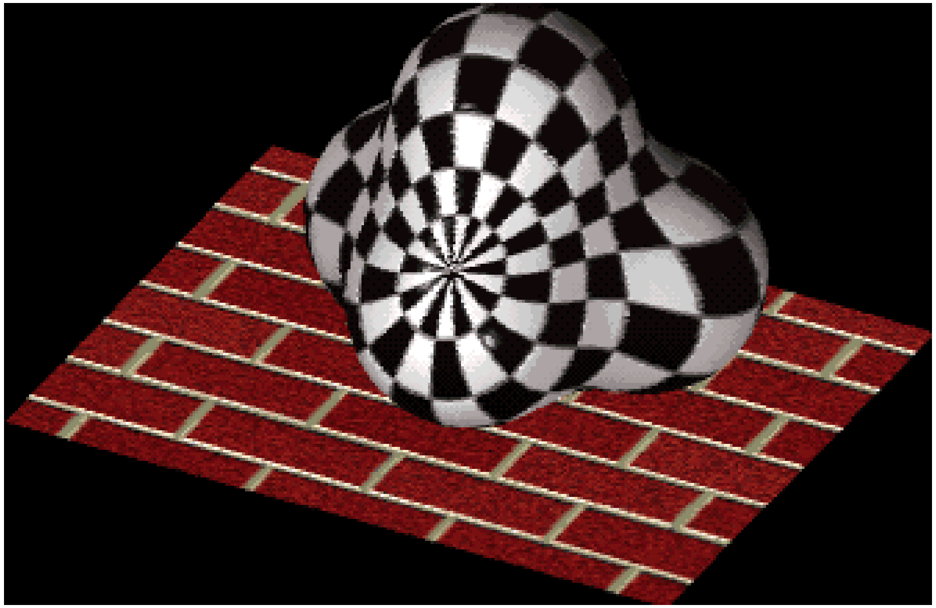


Flat Shading

Overview continued

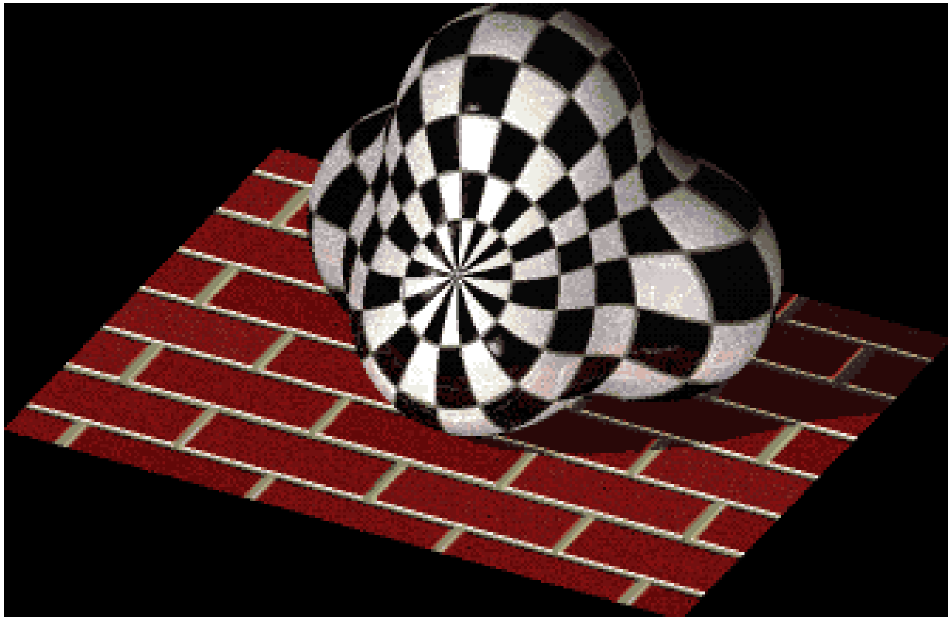


Gourad shading

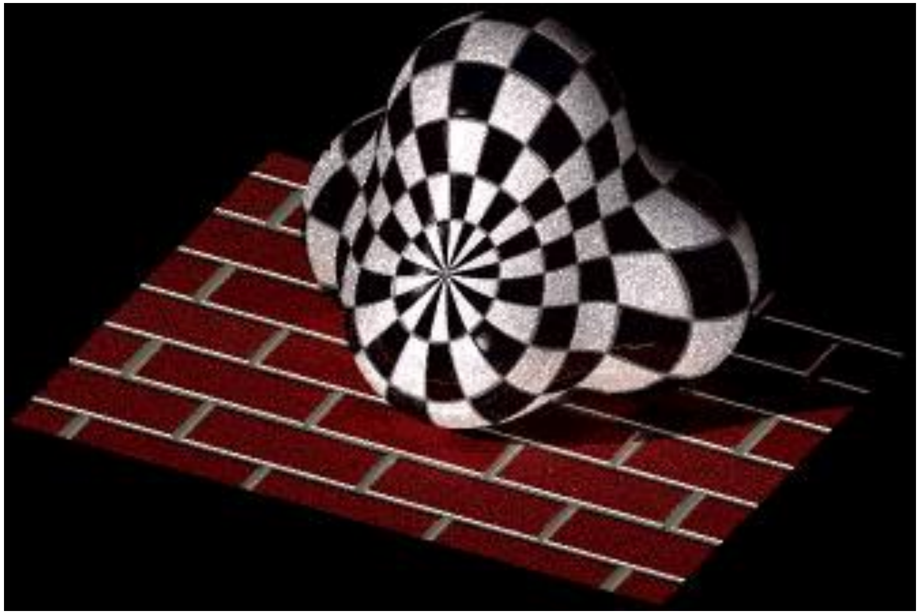


Phong shading with texture mapping

Overview continued

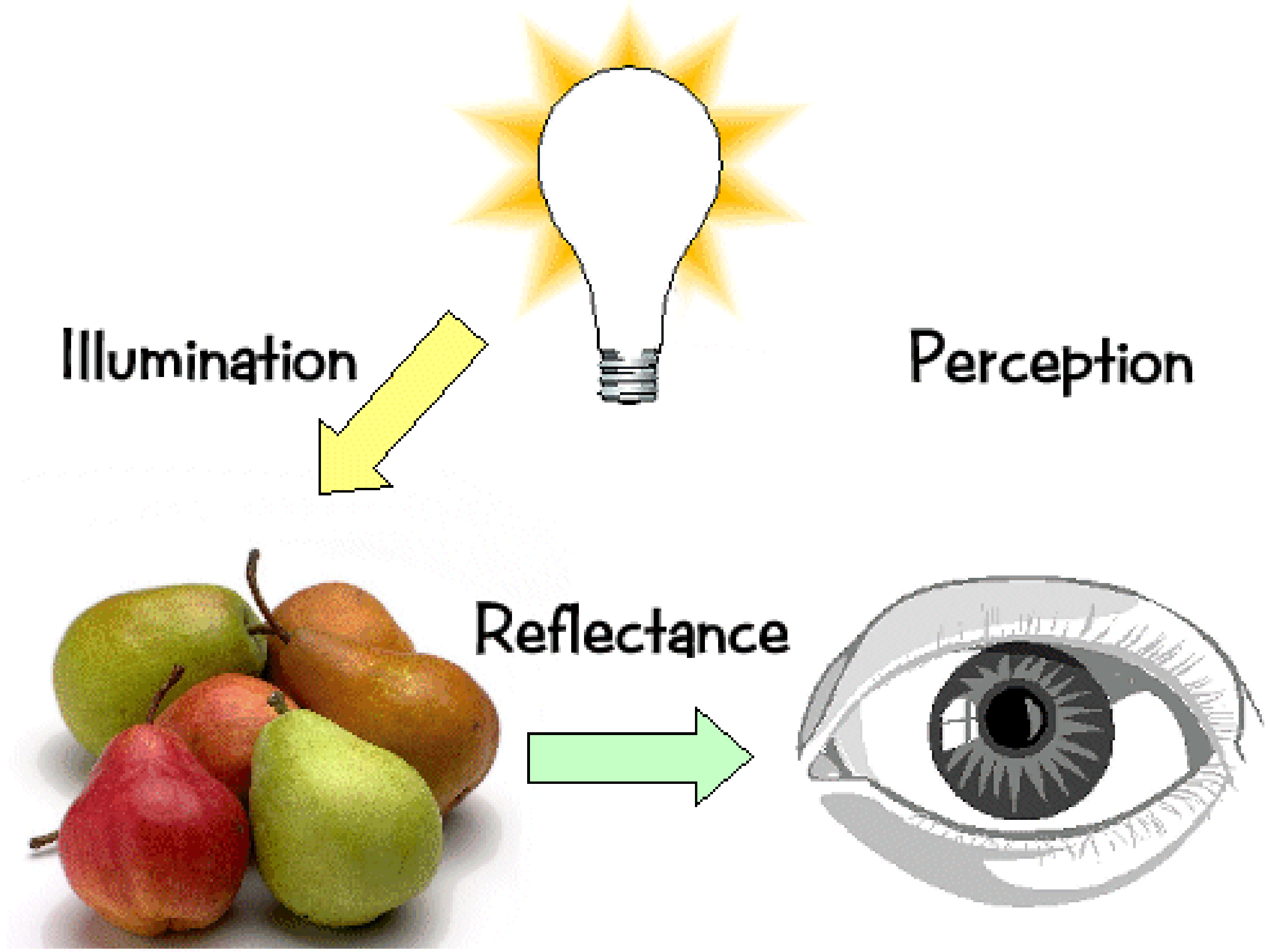


Ray Tracing



Radiosity

How we see objects



Lighting

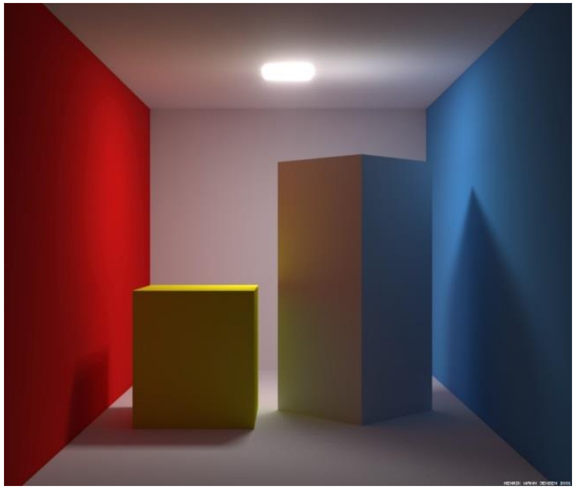
- Remember, we know how to rasterize
  - Given a 3-D triangle and a 3-D viewpoint, we know which pixels represent the triangle
- But what color should those pixels be?

Lighting

- If we're attempting to create a realistic image, we need to simulate the *lighting* of the surfaces in the scene
  - Fundamentally simulation of *physics* and *optics*
  - As you'll see, we use a lot of approximations (a.k.a perceptually based hacks) to do this simulation fast enough

Definitions

- **Illumination**: the transport of energy from light sources to surfaces & points
  - Note: includes *direct* and *indirect illumination*

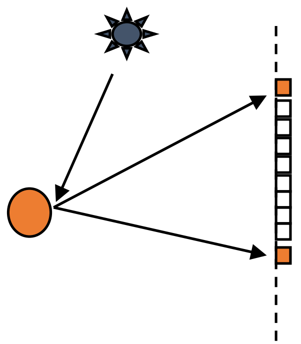


Images by Henrik Wann Jensen

Definitions

- **Lighting**: the process of computing the luminous intensity (i.e., outgoing light) at a particular 3-D point, usually on a surface
- **Shading**: the process of assigning colors to pixels

(why the distinction?)



Definitions

- Illumination models fall into two categories:
  - **Empirical**: simple formulations that approximate observed phenomenon
  - **Physically based**: models based on the actual physics of light interacting with matter
- We mostly use empirical models in interactive graphics for simplicity
- Increasingly, realistic graphics are using physically based models

Components of Illumination

- Two components of illumination: light sources and surface properties
- Light sources (or *emitters*)
  - Electromagnetic radiation
  - Spectrum of emittance (i.e., color of the light)
  - Geometric attributes
    - Position
    - Direction
    - Shape
  - Intensity
  - Directional attenuation
  - Polarization

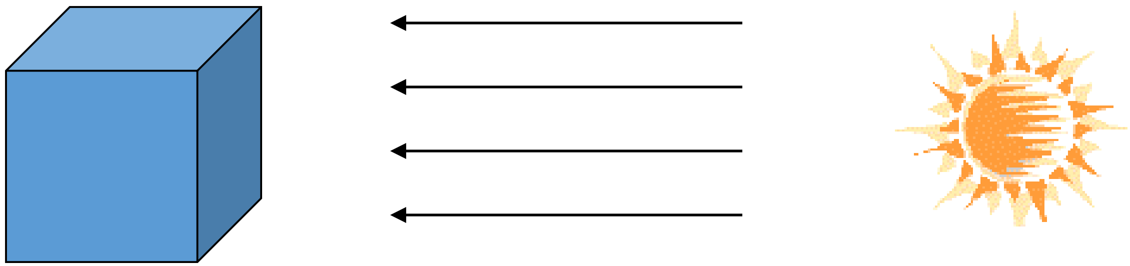
Components of Illumination

- Surface properties
  - Reflectance spectrum (i.e., color of the surface)
  - Subsurface reflectance
  - Geometric attributes
    - Position
    - Orientation
    - Micro-structure
  - Absorption
  - Transmission

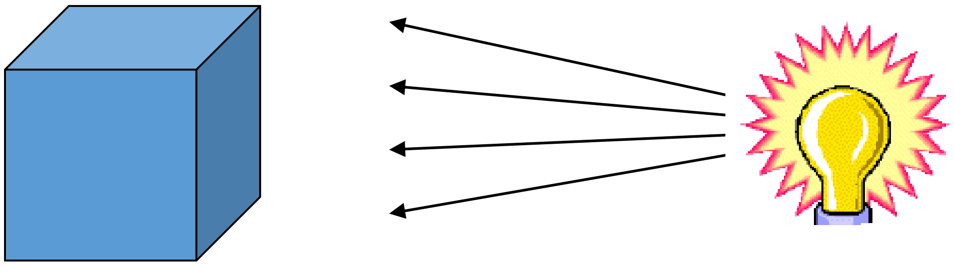
Making realistic images

- Illumination models
  - Calculating accurate values for the correct illumination of surfaces
- Rendering(shading) Methods
  - Applying lighting effects to the visible surfaces on screen (pixel by pixel)

Types of light sources



Directional light source



Point light source

Ambient Light Sources

- Objects not directly lit are typically still visible
  - e.g., the ceiling in this room, undersides of desks

- This is the result of *indirect illumination* from emitters, bouncing off intermediate surfaces

- Too expensive to calculate (in real time), so we use a hack called an *ambient light source*
  - No spatial or directional characteristics; illuminates all surfaces equally
  - Amount reflected depends on surface properties

Ambient light

- An assumption that there is a constant amount of background light that illuminates every surface.
- Unscientific approximation of inter-reflection by a constant value
- Equal light in all directions
  - Has no spatial or directional characteristics

$$I_{amb} = K_a I_a$$

Ia=ambient light Intensity of a light source

Ka=Ambient reflectance of a surface

The Physics of Reflection

- Ideal diffuse reflection
  - An *ideal diffuse reflector*, at the microscopic level, is a very rough surface (real-world example: chalk)
  - Because of these microscopic variations, an incoming ray of light is equally likely to be reflected in any direction over the hemisphere:

Lambert's Cosine Law

- Ideal diffuse surfaces reflect according to *Lambert's cosine law*:

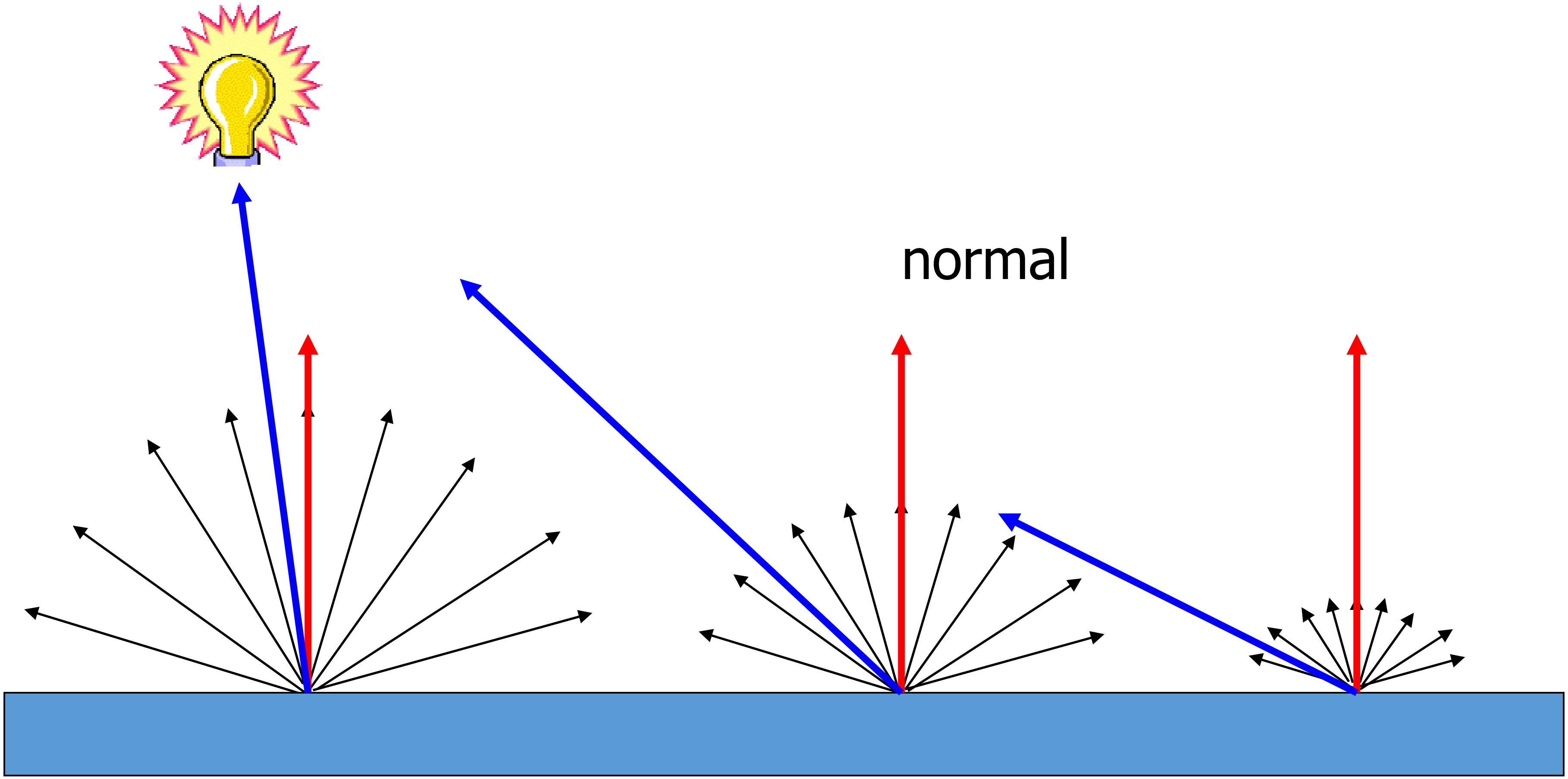
  The energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal

- Note that the reflected intensity is independent of the viewing direction, but does depend on the surface orientation with regard to the light source

Diffuse reflector

- Incoming light is scattered equally in all directions
- Viewed brightness does not depend on viewing direction
- Brightness does depend on direction of illumination

Lambert’s Law



Lambert's Law (Mathematical)

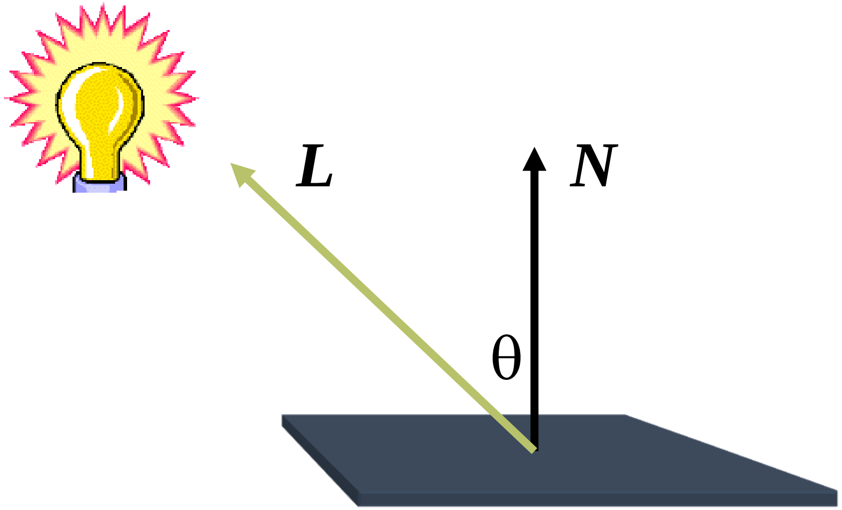
$$I_{diffuse} = K_d I_{light} \cos\theta$$

$$= K_d I_{light} (N \cdot L)$$

I_{light} : Light souce Intensity

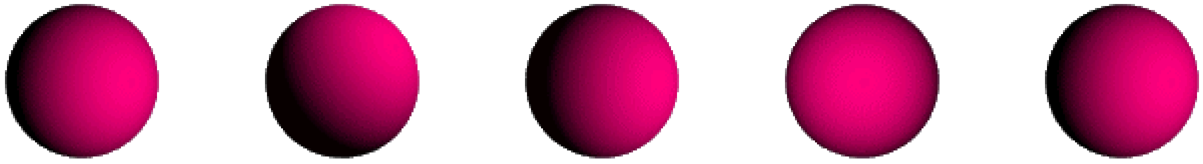
K_d : Surface reflectance coefficient [0,1]

θ : Light/Normal angle



Diffuse Lighting Examples

- We need only consider angles from 0° to 90° (*Why?*)
- A Lambertian sphere seen at several different lighting angles:

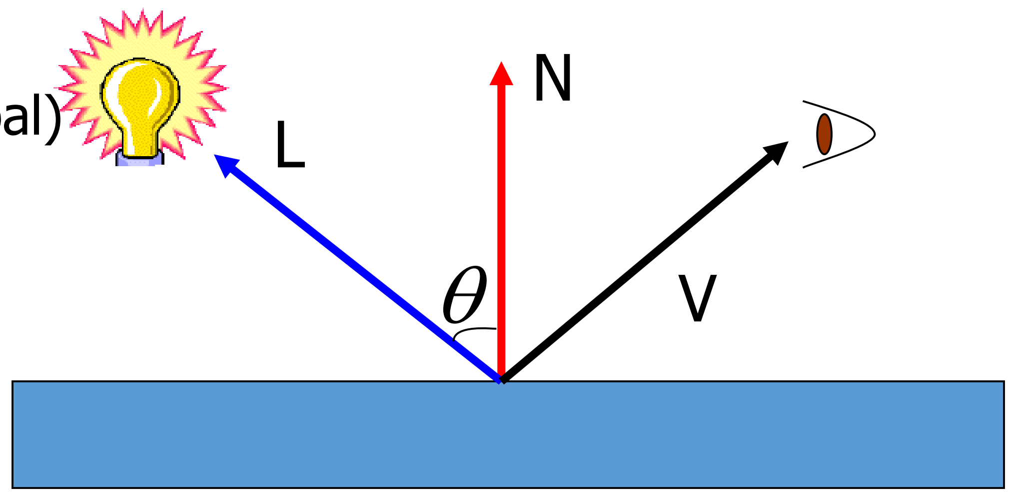


Ambient + Diffuse Illumination

$$I_{d+a} = K_a I_a + K_d I_{light} \cos\theta$$

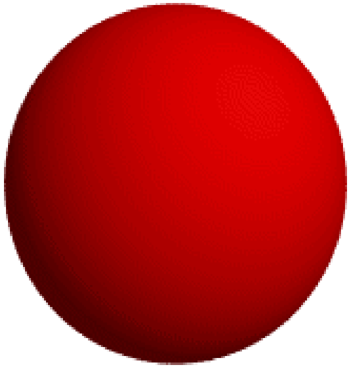
$$= K_a I_a + K_d I_{light}(N \cdot L)$$

I_{light} : Light souce Intensity
K_d : Surface reflectance coefficient [0,1]
: Light/Normal angle
K_a : Ambent reflectance (local)
I_a : Ambient light intensity (global)

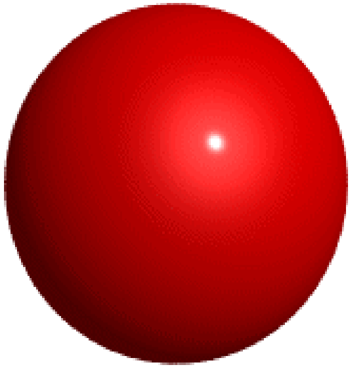


Specular Reflection

- Shiny surfaces exhibit *specular reflection*
    - Polished metal
    - Glossy car finish



Diffuse Lighting



Plus Specular Highlight

- A light shining on a specular surface causes a bright spot known as a *specular highlight*
- For shiny surfaces, part of the incident light reflects coherently
- Where these highlights appear is a function of the viewer's position, so specular reflectance is view dependent

The Physics of Reflection

- At the microscopic level a specular reflecting surface is very smooth

- Thus rays of light are likely to bounce off the microgeometry in a mirror-like fashion

- The smoother the surface, the closer it becomes to a perfect mirror

Reflections

Ideal Diffuse

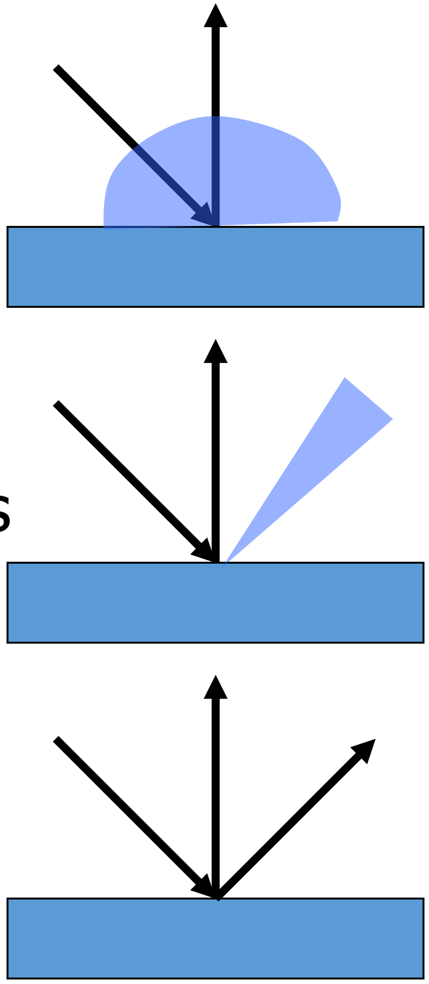
Matte, Lambert's law

Specular

Glossiness and highlights

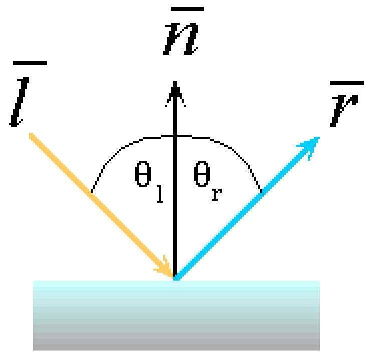
Ideal Specular

Mirror, Reflection law



The Optics of Reflection

- Reflection follows *Snell's Laws:*
  - The incoming ray and reflected ray lie in a plane with the surface normal
  - The angle that the reflected ray forms with the surface normal equals the angle formed by the incoming ray and the surface normal:

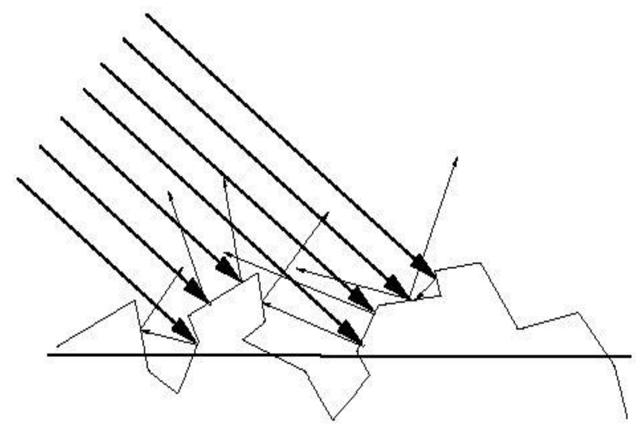


$$\theta_{(l)ight} = \theta_{(r)eflection}$$

Non-Ideal Specular Reflectance

•Snell's law applies to perfect mirror-like surfaces, but aside from perfect mirrors (and chrome) few surfaces exhibit perfect specularity

•How can we capture the "softer" reflections of surface that are glossy rather than mirror-like?



•One option: model the microgeometry of the surface and explicitly bounce rays off of it

•Or…

Non-Ideal Specular Reflectance: An Empirical Approximation

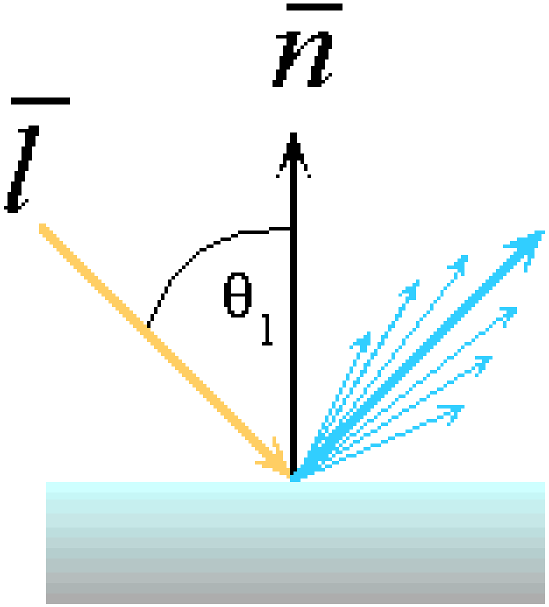
- In general, we expect most reflected light to travel in direction predicted by Snell’s Law

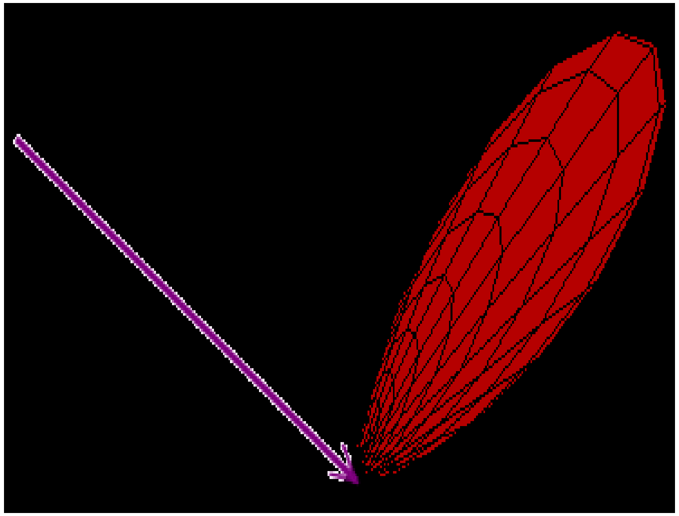
- But because of microscopic surface variations, some light may be reflected in a direction slightly off the ideal reflected ray

- As the angle from the ideal reflected ray increases, we expect less light to be reflected

Non-Ideal Specular Reflectance: An Empirical Approximation

- An illustration of this angular falloff:





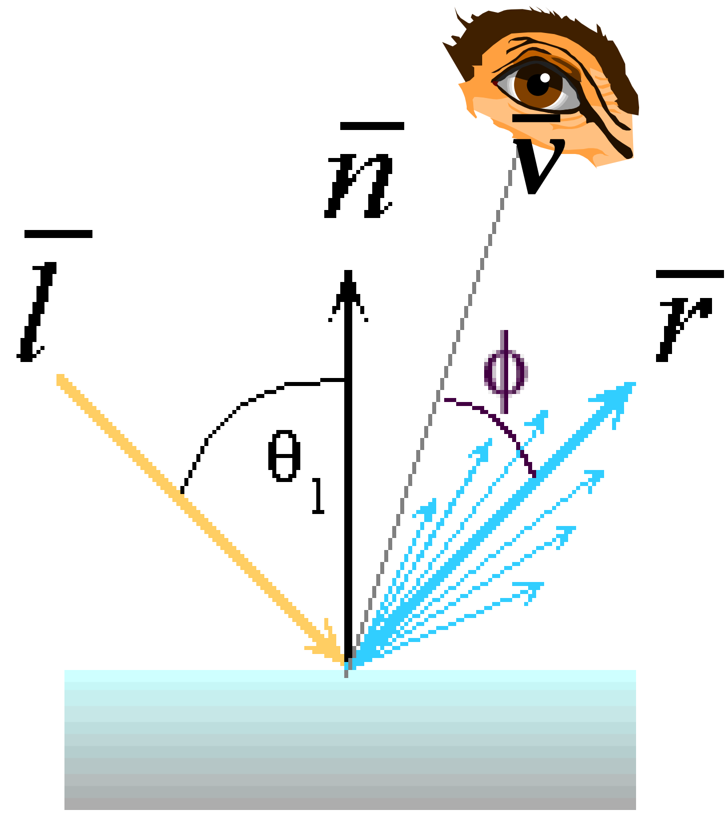
- How might we model this falloff?

Phong Lighting

- The most common lighting model in computer graphics was suggested by Phong:

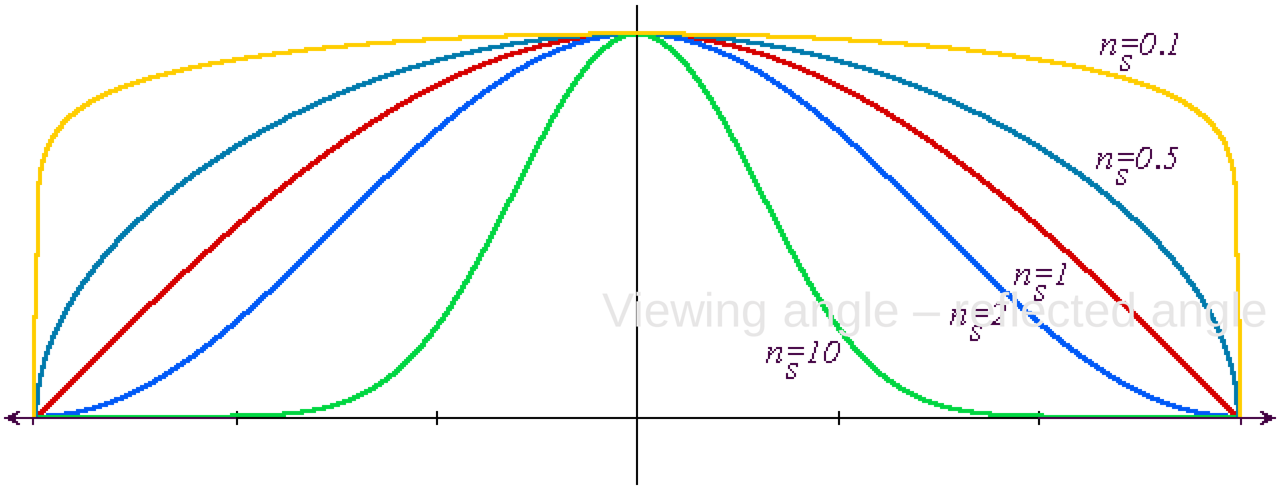
$$I_{specular} = k_s I_{light} (\cos\phi)^{n_{shiny}}$$

- The n_{shiny} term is a purely empirical constant that varies the rate of falloff
- Though this model has no physical basis, it works (sort of) in practice



Phong Lighting: The n_{shiny} Term

- This diagram shows how the Phong reflectance term drops off with divergence of the viewing angle from the ideal reflected ray:



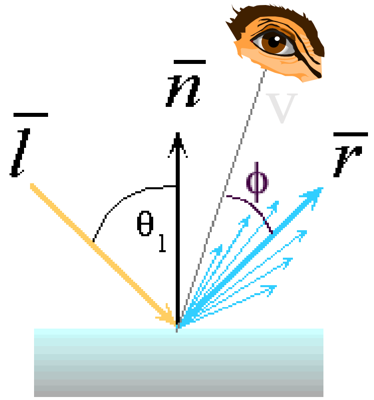
- *What*

Calculating Phong Lighting

- The **cos** term of Phong lighting can be computed using vector arithmetic:

$$I_{specular} = k_s I_{light} \left(\bar{v} \cdot \bar{r} \right)^{n_{shiny}}$$

- V is the unit vector towards the viewer
- R is the ideal reflectance direction



$$\bar{r} = \left(2 \left(\bar{n} \cdot \bar{l} \right) \right) \bar{n} - \bar{l}$$

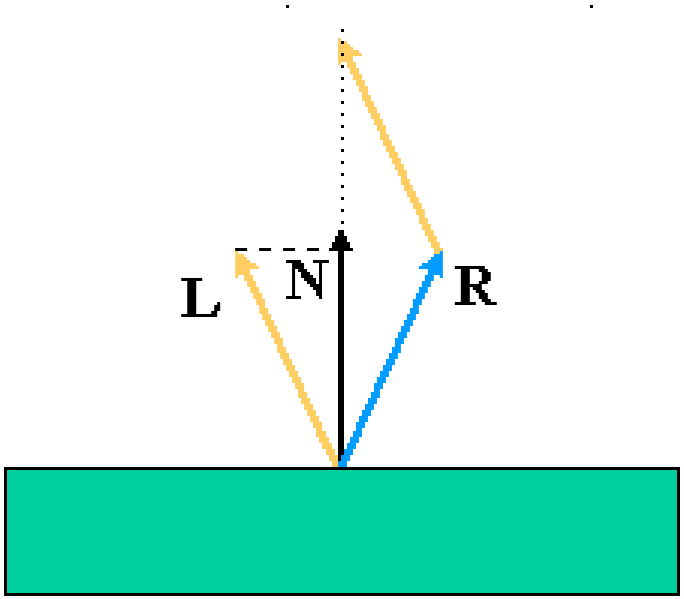
- An aside: we can efficiently calculate r?

Calculating The R Vector

$$\bar{r} = \left(2\left(\bar{n} \cdot \bar{l}\right)\right)\bar{n} - \bar{l}$$

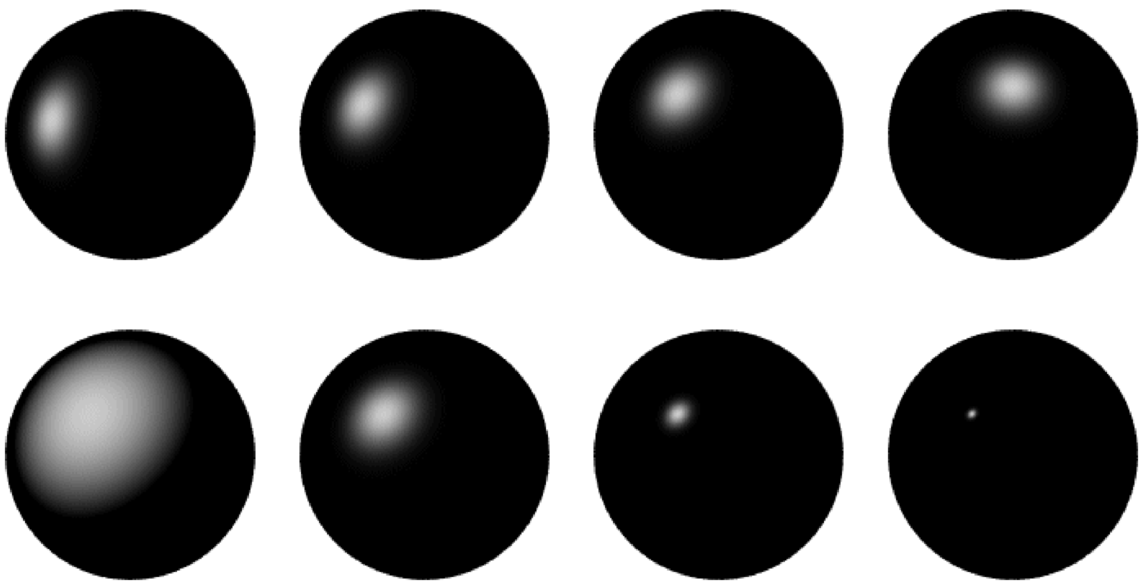
- This is illustrated below:

$$\bar{r} + \bar{l} = \left(2\left(\bar{n} \cdot \bar{l}\right)\right)\bar{n}$$



Phong Examples

- These spheres illustrate the Phong model as l and n_{shiny} are varied:



Putting it all together

- Combining ambient, diffuse, and specular illumination

$$I = K_a I_a + K_d I_{light\_d} \cos\theta + K_s I_{light\_s} (\cos\phi)^{ns}$$

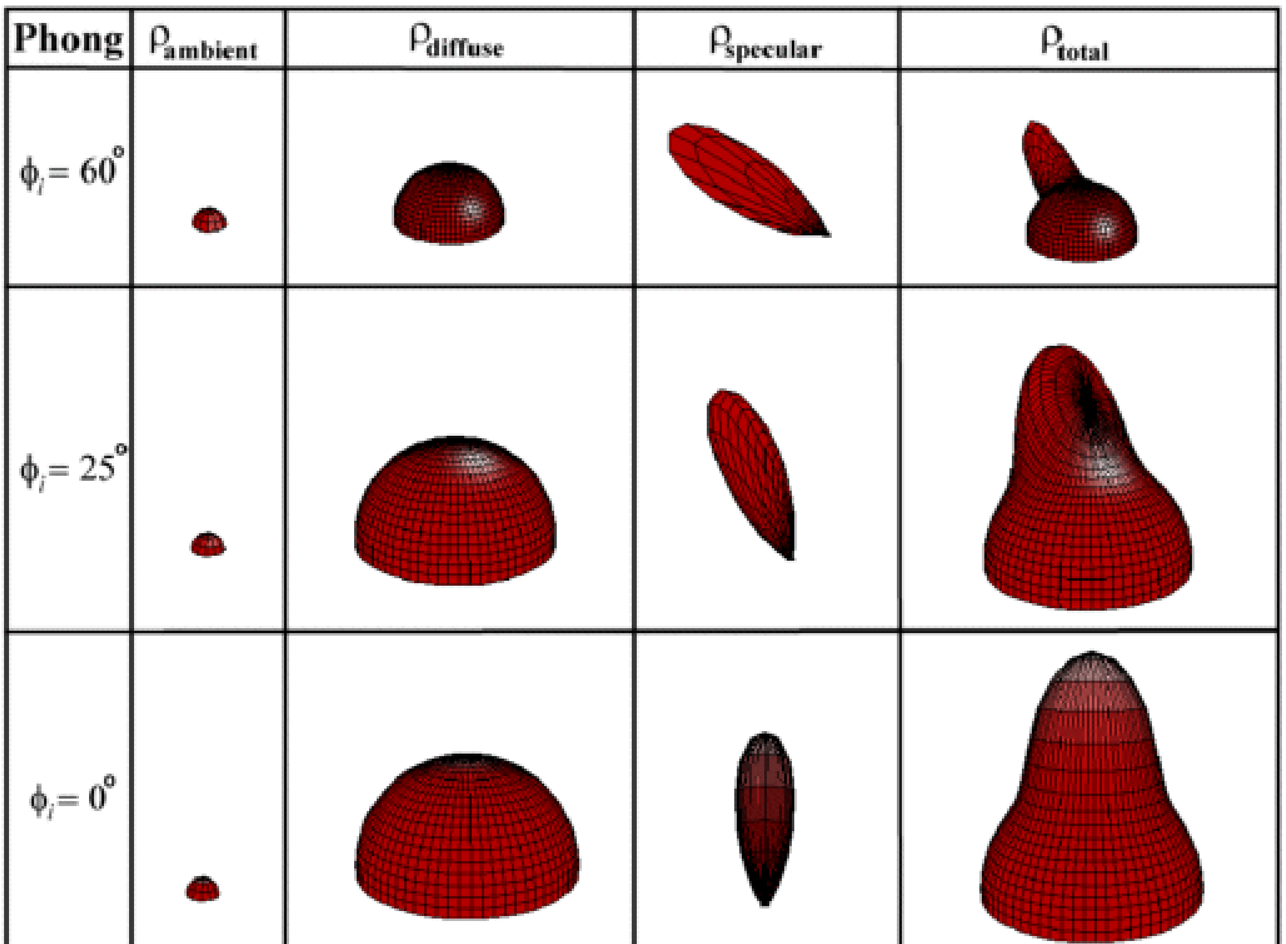
With multiple light sources

- Let’s combine ambient, diffuse, and specular components:

$$I_{total} = k_a I_{ambient} + \sum_{i=1}^{\#lights} I_i \left(k_d \left(\bar{n} \cdot \bar{l}_i \right) + k_s \left(\bar{v} \cdot \bar{r}_i \right)^{n_{shiny}} \right)$$

- Commonly called *Phong lighting*
  - Note: once per light
  - Note: once per color component
  - *Do k_a, k_d, and k_s vary with color component?*

Phong Lighting: Intensity Plots



Lighting Review

- Lighting Models
  - Ambient
    - Normals don’t matter
  - Lambert/Diffuse
    - Angle between surface normal and light
  - Phong/Specular
    - Surface normal, light, and viewpoint