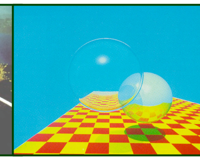




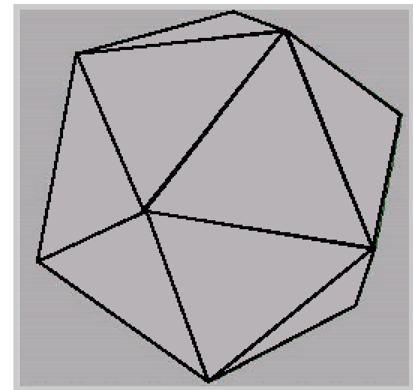

Chap.6
Local Illumination



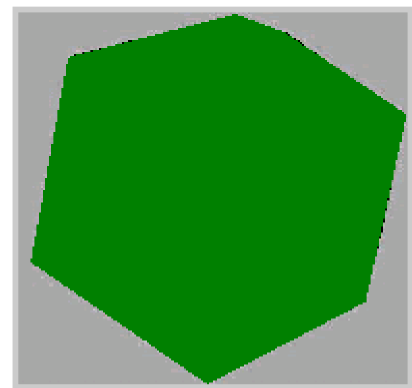
Ensino de Informática (3326) - 4º ano, 2º semestre
Engenharia Electrotécnica (2287) - 5º ano, 2º semestre
Engenharia Informática (2852) - 4º ano, 2º semestre

Motivation

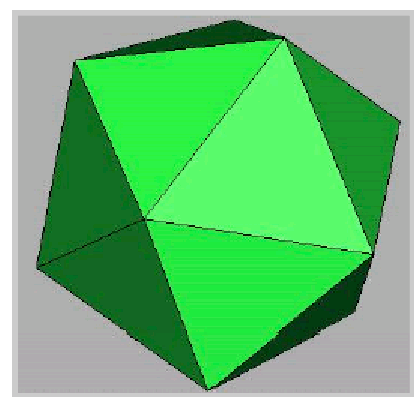
- Illumination model = approximation of real-world illumination
- 3D feel, depth perception
- For most OpenGL applications, we use the Phong illumination model because it is time efficient and good enough at representing the real world.



Wireframe



Without Illumination



Direct Illumination

Light Source Independent Illumination Models

- Depth Shading
  - Color or intensity determined solely by "depth" of polygon.
  - Darker colors or intensities at lower elevations.
  - Effective in modeling terrain or surface data
  - Avoids complex calculations of lighting dependent models
  - Simulates realism
- Depth Cueing
  - Reduce intensity of pixel as the distance from the observer increases
  - Simulates reduction in clarity as distances from the observer increases
  - Image fades in the distance
  - Often used in medical imaging

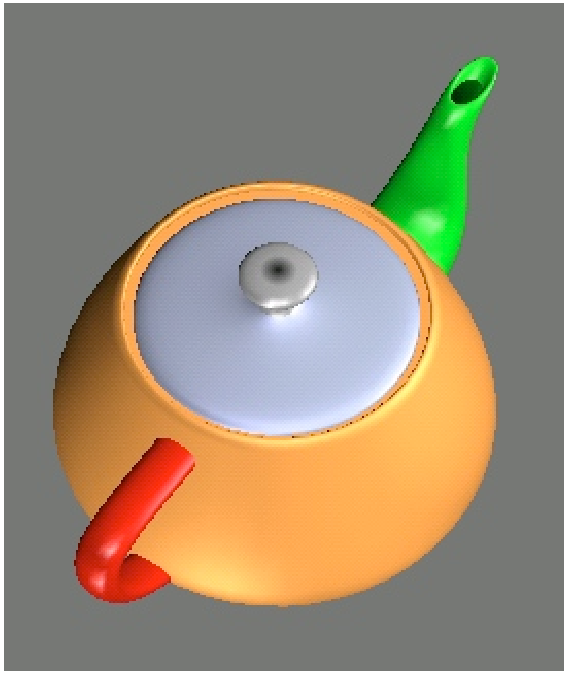
Light Source Dependent Illumination Models

- What an object looks like depends on
  - Properties of the light source such as color, distance from object, direction from object, intensity of source
  - Surface characteristics of object such as color and reflectance properties
  - Location of the observer
- Light striking a surface of an object can be
  - Reflected (Diffuse reflection & Specular reflection)
  - Absorbed
  - Transmitted (Translucent or transparent)
  - Combination of all three

From: http://jedi.ks.uiuc.edu/~johns/raytracer/raygallery/stills.html

Lighting-based Illumination Models

- Direct or Local Illumination
  - Single interaction of light & objects
  - Real-time supported by OpenGL
  - Example: *Phong illumination model*
- Indirect or Global Illumination
  - Multiple interaction of light & objects: *inter-objects reflections, shadows, refractions*
  - Not real-time (yet)
  - Examples: *raytracing, radiosity, photon mapping …*



Overview: lighting-based models

- Direct or Local Illumination
  - Light types
  - Light sources (emission)
  - Surface materials (reflectance)
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections

Light types

- **Ambient** light
  - It comes from all directions; when it strikes the surface, it is scattered equally in all directions.
  - Scattering consequence: it does not depend on the viewpoint (viewer).
- **Diffuse** light
  - It comes from one direction; when it strikes the surface, it is scattered equally in all directions.
  - Scattering consequence: it does not depend on the viewpoint (viewer).
- **Specular** light
  - It comes from one direction; it tends to bounce off the surface in a preferred direction.
  - Scattering consequence: it does depend on the viewpoint (viewer).

Light types (cont.)

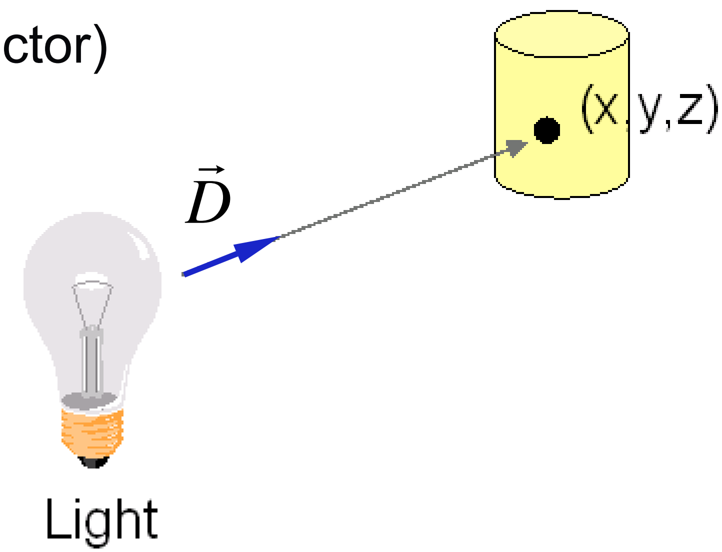
- **Ambient** light
  - It can be used to give a feel for the *main color in a room*.
  - Source light contributions:
    - backlighting is a room has a large ambient component
    - a spotlight outdoors has a tiny ambient component
- **Diffuse** light
  - It is the light type that is *closest to the color of light*.
  - Source light contributions:
    - any light coming from a particular position or direction
- **Specular** light
  - It is the light type that is *….*
  - Source light contributions:
    - a well-collimated laser beam bouncing off a high-quality mirror produces almost 100 percent specular reflection
    - shiny metal or plastic has a high specular component
    - chalk or carpet has almost none.

Ligth sources and material

- **Light sources**
  - Types:
    - ambient, positional, directional, and spot light sources
  - Color
    - The emitted light color is given by the amount of red, green, and blue light.
  - Number
    - Light sources can individually be turned off and off.
  - Emitted light types: ambient, diffuse, specular
- **Surface material**
  - It specifies how light is reflected (and absorted)
    - The color of the surface material is given by the percentage of incoming red, green, and blue components that are reflected in various directions.
    - Different surfaces may have very different properties; some are shiny, and preferentially reflect light in certain directions,while others scatter incoming light equally in all directions. Most surfaces are somewhere in between.
  - Emitted light type: **emitted**
  - Reflected light types: ambient, diffuse, specular

Modeling Light Sources

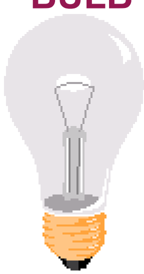
- Light source model: $I_L(P, \vec{D}, \lambda)$
  - describes the intensity of energy,
  - leaving a light source
  - arriving at location $P(x, y, z)$
  - from direction $\vec{D}$ (normalized vector)
  - with wavelength λ



Light Source Types

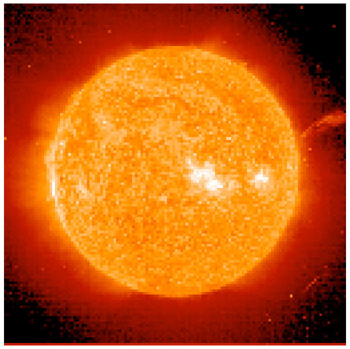
- They are:
  - **Ambient** light source
  - **Point** light source
  - **Directional** light source
  - **Spot** light source

BULB



point light source

SUN

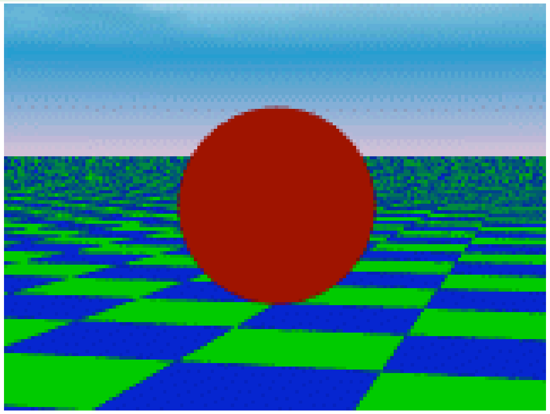


directional light source

LAMP??

spot light source

Ambient Light Source



- An object not directly lit is still visible
  - Caused by light reflected from other surfaces
- Modelled by a single ambient light source
  - Instead of computing surface reflections, specify **constant ambient light** for all surfaces
  - Defined solely by ambient RGB light intensities
- Intensity of ambient light of intensity I_L arriving at a point $P(x,y,z)$:

$$\boxed{I(P, I_L) = I_L}$$

Global Ambient Light in OpenGL

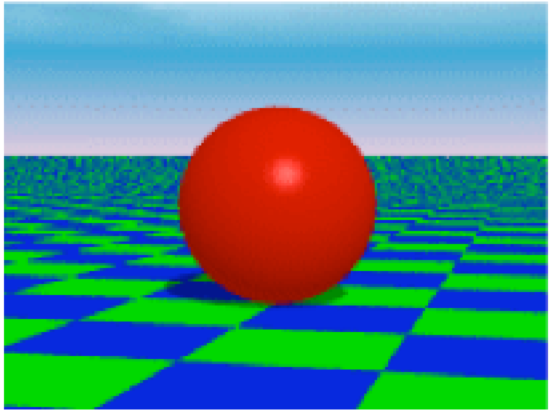
- It is not from any particular source.
- It allows us to see objects in the scene even when no light sources are specified.
- Its RGBA intensity is specified by using the **`GL_LIGHT_MODEL_AMBIENT`** parameter as follows:

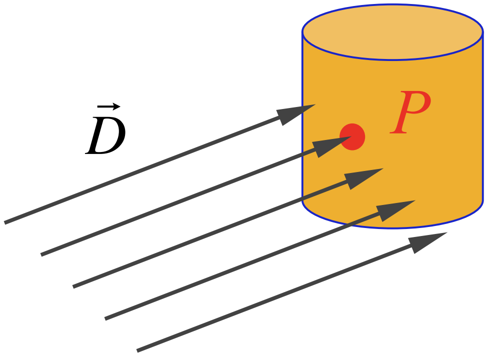
Example: (Global Ambient Light)

```
// sets global ambient light
GLfloat lmodel_ambient[]={0.2,0.2,0.2,1.0};
glLightModelfv(GL_LIGHT_MODEL_AMBIENT, lmodel_ambient);
```

Directional Light Source

- Models Point Light Source at Infinity (e.g., Sun)
  - Defined by intensities of emitted RGB light for all types, and
  - direction $\vec{D}$
- Direction important to compute reflected light
- Intensity of point light of intensity I_L arriving at a point $P(x,y,z)$:

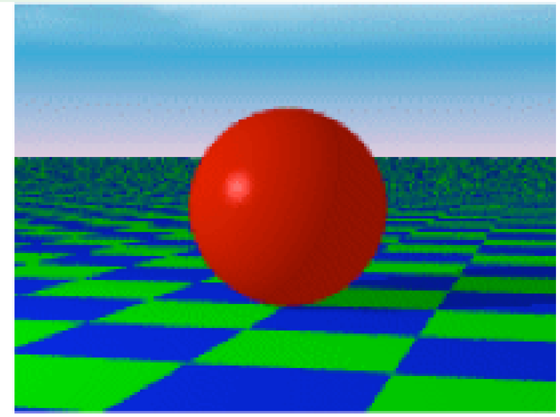




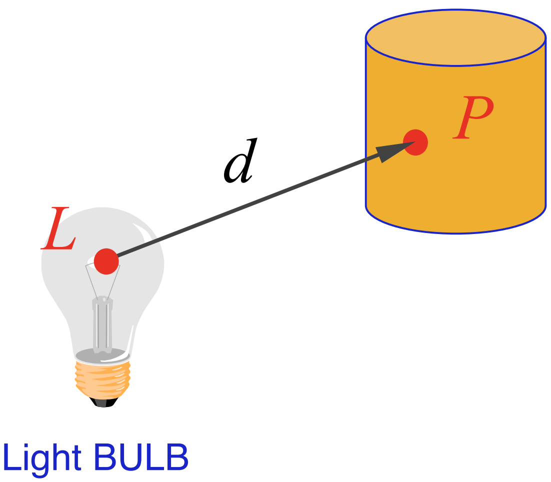
$$\boxed{I(P,\vec{D},I_L) = I_L}$$

No attenuation with distance

Point Light Source



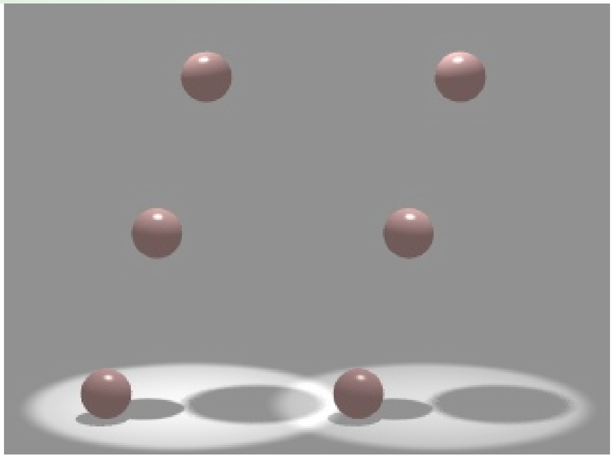
- Light emitted *radially* from single point in all directions (omni-directional source)
  - Defined by intensities of emitted RGB light for all types,
  - position $L(x,y,z)$, and
  - factors (k_c, k_l, k_q) for attenuation with distance d to $P(x,y,z)$
- Intensity of point light of intensity I_L arriving at a point $P(x,y,z)$:



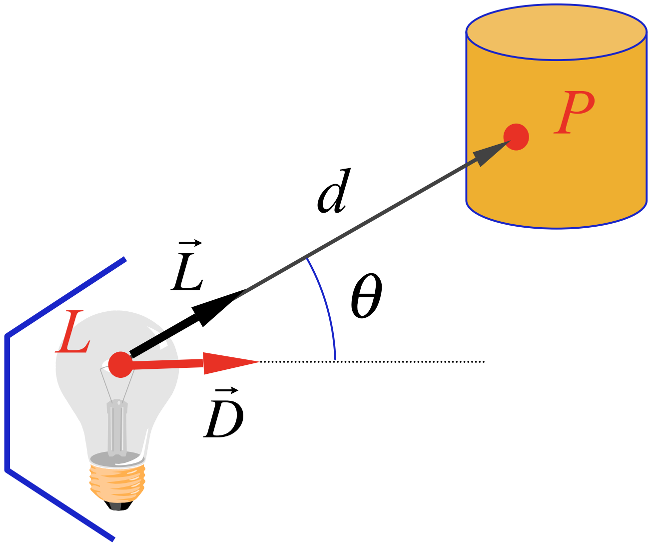
$$I(P,L,k_c,k_l,k_q,I_L) = \frac{I_L}{k_c + k_1 d + k_q d^2}$$

Spot Light Source

- Light emitted in a cone (Luxo Jr. lamp)
  - Defined by intensities of emitted RGB light for all types,
  - position L, direction D, spot cut-off exponent
  - constant, linear and quadratic attenuation (k_c, k_l, k_q)
- Intensity of spot light of intensity I_L arriving at a point $P(x,y,z)$:



$$I(P,L,k_c,k_1,k_q,I_L) = \frac{I_L\left(\vec{D}\cdot\vec{L}\right)}{k_c + k_1 d + k_q d^2}$$



SPOT Light

Direction and Position of Light Sources in OpenGL

- **Directional light source**. It is located infinitely far away from the scene.
- **Positional or point light source**. Its distance to the scene is finite.

Example: (Directional Light Source)

```
// sets GL_LIGHT0 with direction (x=1.0,y=1.0,z=1.0) at an
infinite position (w=0.0) in homogeneous coordinates
Glfloat light_position[]={1.0,1.0,1.0,0.0};
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

Example: (Positional or Point Light Source)

```
// sets GL_LIGHT0 at the position (x=1.0,y=1.0,z=1.0) that is
finite (w≠0.0) in homogeneous coordinates
Glfloat light_position[]={1.0,1.0,1.0,1.0};
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

Direction and Position of Light Sources in OpenGL (cont.)

- Like a point light source, a spot light is also a positional light source.
- **Point light source**. By default, the spotlight feature is disabled because the **GL_SPOT_CUTOFF** parameter is 180.0 degrees. This value means that light is emitted in all directions (the angle at the cone's apex is 360 degrees, so it isn't a cone at all).
- **Spot light source**. The value for **GL_SPOT_CUTOFF** is restricted to being within the range [0.0,90.0].

Example: (Spot Light Source)

```
// sets GL_LIGHT0 as a spotlight with a cutoff angle of 30 degrees
glLight(GL_LIGHT0, GL_SPOT_CUTOFF, 30.0);

// sets spotlight's direction or the light cone axis
Glfloat spot_direction[]={-1.0,-1.0,0.0};
glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, spot_direction);
```

Color of Light Sources in OpenGL

- OpenGL allows us to associate 3 different color-related parameters with **<u>any</u>** particular light :
  - **GL_AMBIENT**. It refers to the RGBA intensity of the ambient light that a particular light source adds to the scene. Default RGBA values: (0.0,0.0,0.0,1.0) ⇒no ambient light
  - **GL_DIFFUSE**. It refers to the RGBA intensity of the diffuse light that a particular light source adds to the scene. Default RGBA values: (1.0,1.0,1.0,1.0) for LIGHT0 (⇒bright, white diffuse light) and (0.0,0.0,0.0,0.0) for any other light.
  - **GL_SPECULAR**. It refers to the RGBA intensity of the specular light that a particular light source adds to the scene. Default RGBA values: (1.0,1.0,1.0,1.0) for LIGHT0 and (0.0,0.0,0.0,0.0) for any other light.

Color of Light Sources in OpenGL (cont.)

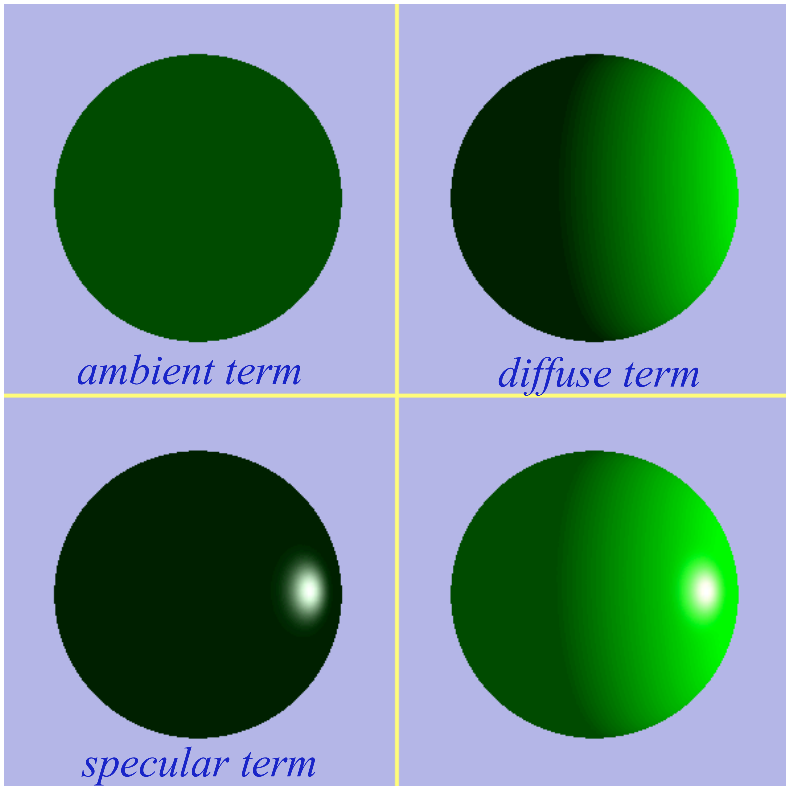
Example: (Color of Ambient, Diffuse, and Specular Light)

```
// sets the ambient component of GL_LIGHT0
Glfloat light_ambient[]={0.0,0.0,1.0,1.0};    // blue color
Glfloat light_diffuse[]={1.0,1.0,1.0,1.0};    // white color
Glfloat light_specular[]={1.0,1.0,1.0,1.0};   // white color

glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient);
glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse);
glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular);
```

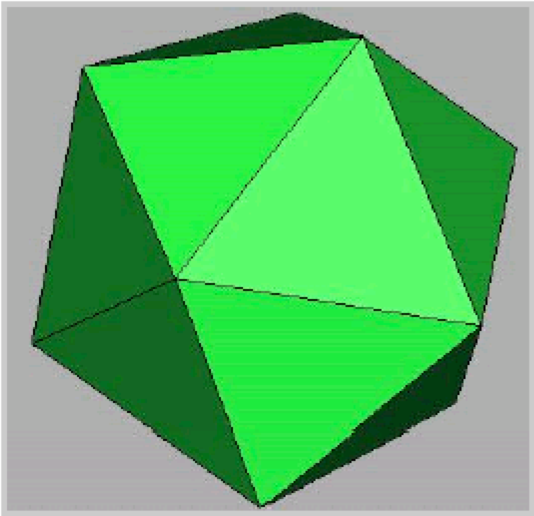
Lighting Components

- The image to the right shows the effects of ambient (top left), diffuse (top right), specular (bottom left), and all 3 combined (bottom right).



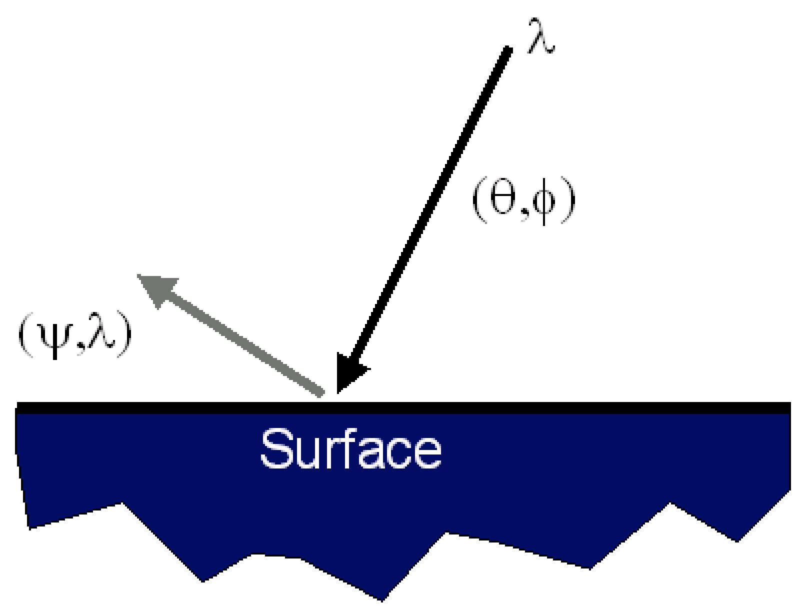
Overview: lighting-based models

- Direct Illumination
  - Emission at light sources
  - Scattering at surfaces
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections



Modeling Surface Reflection

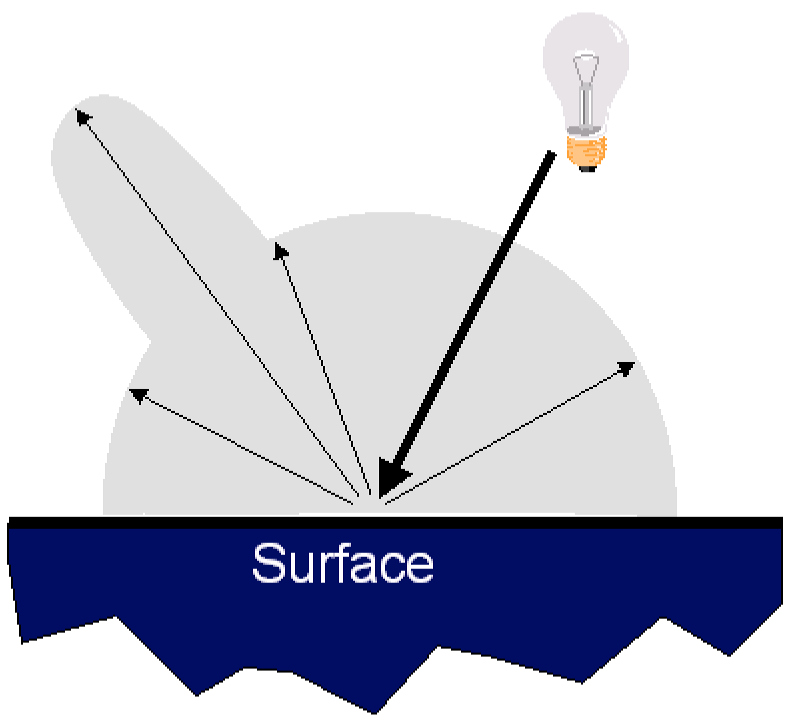
- $R(\theta,\phi,\gamma,\psi,\lambda)$
  - Describes the amount of incident energy
  - arriving from direction (θ,ϕ)
  - leaving in direction (γ,ψ)
  - with wavelength λ



Reflectance Model

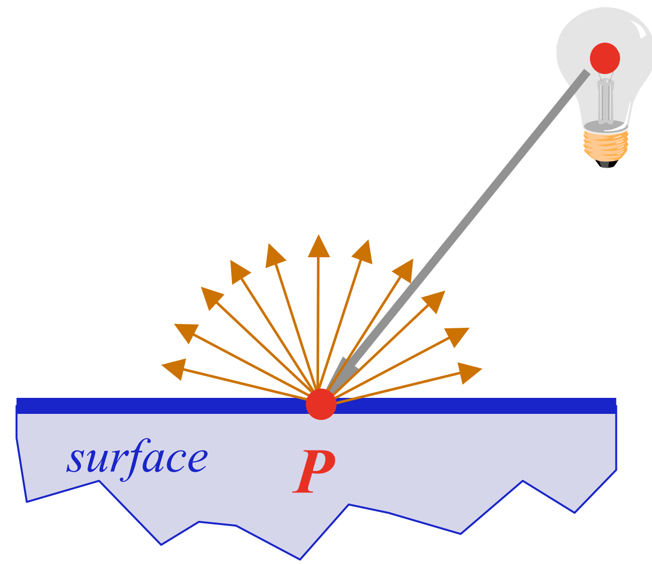
- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - Ambient

Based on model proposed by Phong



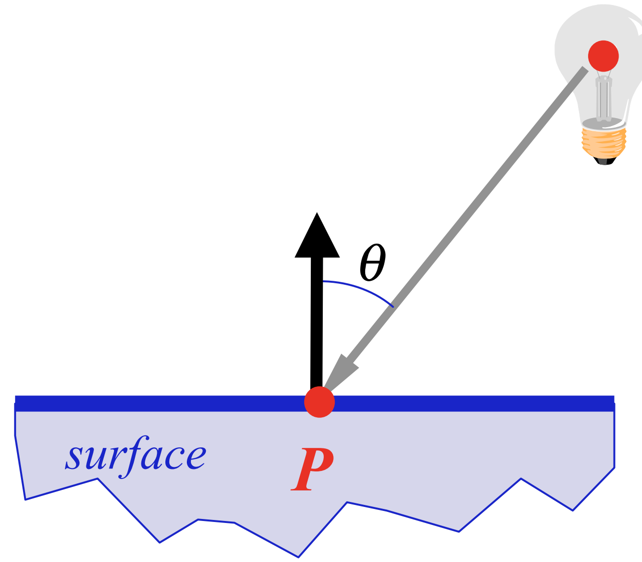
Diffuse Reflection

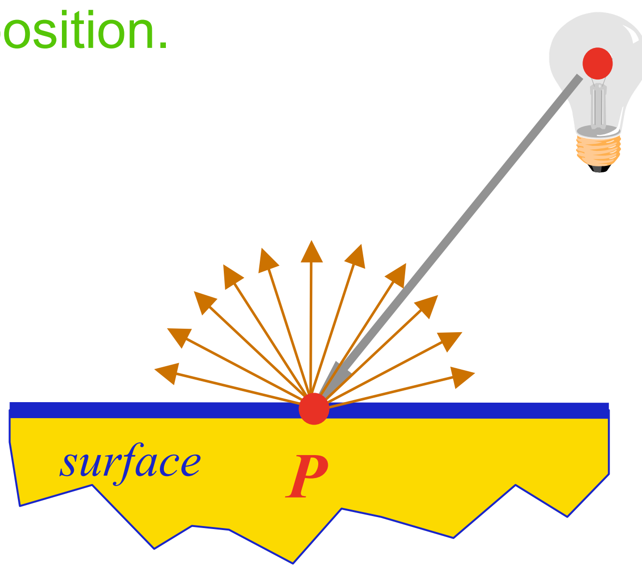
- An ***ideal diffuse reflector***, at the microscopic level, is a very rough surface (real-world example: chalk)
- Because of these microscopic variations, an incoming ray of light is equally likely to be reflected in all directions over the hemisphere.
- That is, one assumes that **surface reflects equally in all directions**.

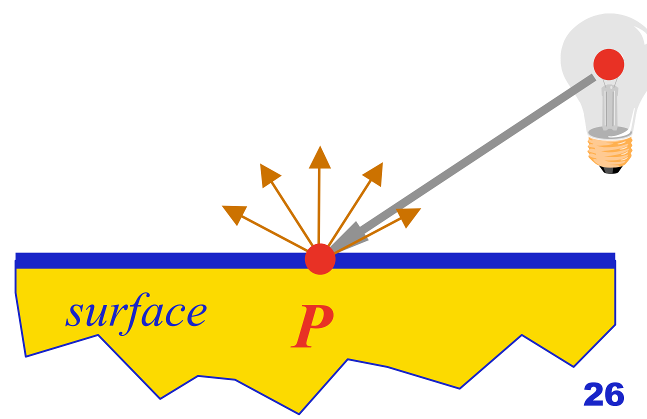


Diffuse Reflection

- How Much Light is Reflected?
  - Depends on angle θ of incident light.
  - The greater θ is, the less light is reflected.
  - The amount of reflected light is dependent on the position of the light source and the object, but independent of the observer's position.







Diffuse Reflection

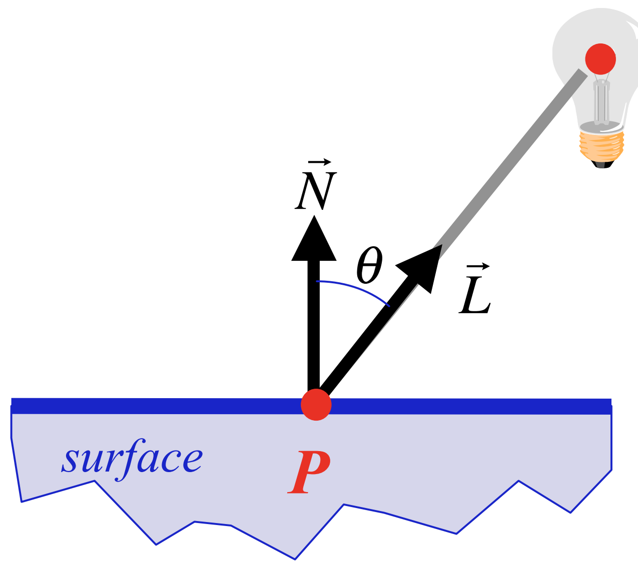
$$I_D = K_D I \cos\theta$$

with $\cos\theta = \dfrac{\vec{N}.\vec{L}}{\|\vec{N}\|\|\vec{L}\|} = \vec{N}.\vec{L}$,

being $\vec{N}$ e $\vec{L}$ unit vectors

- Lambertian Model
  - Lambert's cosine law (dot product)

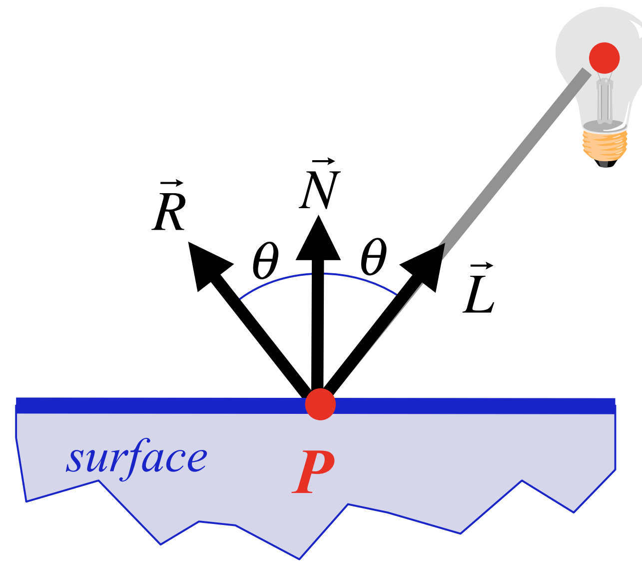
    The intensity of light diffuse I_D reflected from a surface point $P(x,y,z)$ is proportional to the cosine of the angle between the vector $\vec{L}$ to the light source and the normal vector $\vec{N}$ perpendicular to the surface.
  - I_D = *reflected diffuse light intensity*
  - I = light source intensity at $P(x,y,z)$
  - K_D = surface reflection coefficient ($0 <= K_D <= 1$)
  - θ = must be between 0 and 90 degrees



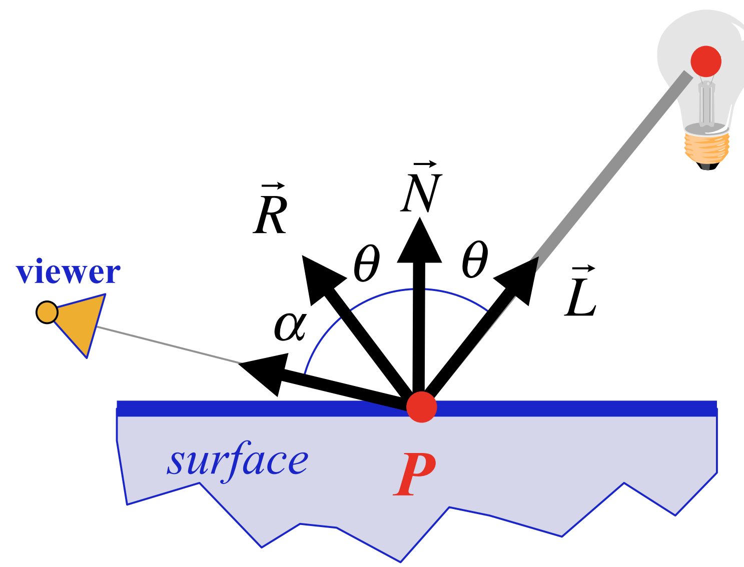
$$I_D = K_D \left(\vec{N} \cdot \vec{L}\right) I$$

Specular Reflection

- Reflection is Strongest Near Mirror Angle
  - Examples: mirrors, metals
  - Visible when the angle of incidence of the light from the point light source is equal to the angle of reflection toward the observer.



- How Much Light is Seen?
  - Depends on angle of incident light
  - And angle to viewer
  - For a non-perfect reflector, intensity of reflected light decreases rapidly as angle to observer increases beyond the angle of incidence.



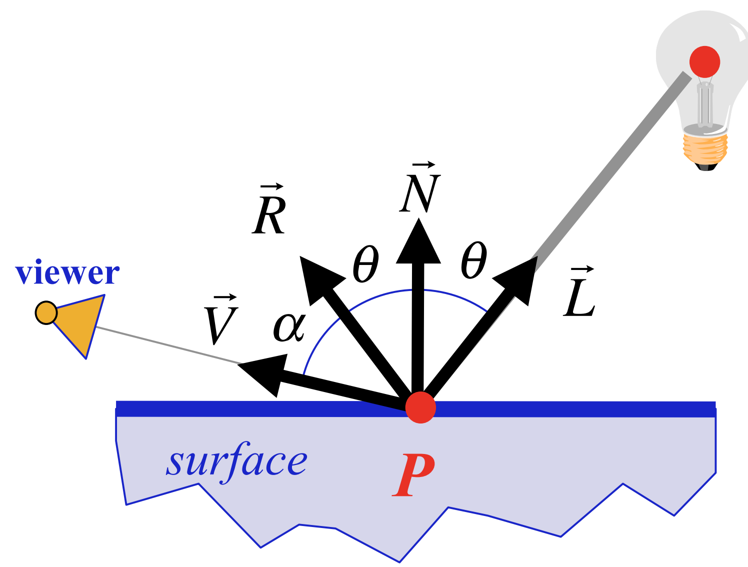
Specular Reflection

$$I_S = K_S I (\cos\alpha)^n$$

$$\text{with } \cos\alpha = \frac{\vec{V}.\vec{R}}{\|\vec{V}\|\|\vec{R}\|} = \vec{V}.\vec{R},$$

being $\vec{V}$ e $\vec{R}$ unit vectors

- Phong Model
  - $(\cos\,\alpha)^n$
  - *n = specular reflection exponent (perfect reflector n=∞)*
  - *I_S = reflected specular light intensity*
  - I = light source intensity at $P(x,y,z)$
  - K_S = coefficient of reflected specular light ($0 <= K_S <= 1$)
  - θ = must be between 0 and 90 degrees



$$\boxed{I_S = K_S\left(\vec{V}\cdot\vec{R}\right)^n I}$$

Emissive light from an area light source

- It is produced by an **area light source**, not a point light source.
- Represents light emitting directly from one polygon or disc of an object.
- This is necessary because some real-world objects like lamps do emit light.
- So, if a lamp is part of the scene, we have to specify not only its positional light source, but also its surface material as emitting material of light.

material emission ≠ (0,0,0,0)

$$\boxed{I_{EL} = I_E}$$

Emissive light from an area light source in OpenGL

- By specifying an RGBA color for GL_EMISSION, you can make an object appear to be giving off light of that color.
- Since most real-world objects (except lights) do not emit light, so we can use this feature mostly to simulate lamps and other light sources in a scene.
- However, an area light source does not actually act as a light source. It is necessary to create a light source and position it at the same location as the lighting object to create such effect.

Example: (Emissive light from material)

```
Glfloat mat_emission[]={0.3,0.2,0.2,0.0};
glMaterialfv(GL_FRONT, GL_EMISSION, mat_emission);
```

Ambient Reflection

- Represents Reflection of All Indirect Illumination
  - Ambient light is the illumination of an object caused by reflected light from other surfaces.
  - To calculate this exactly would be very complicated.
  - A simple model assumes ambient light is uniform in the environment.

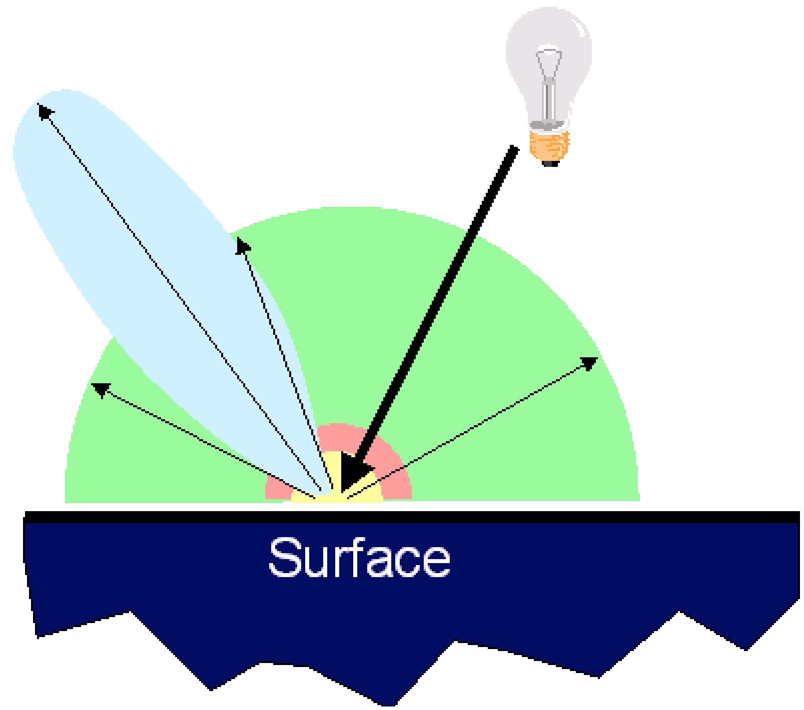
  - I_{AL} = *reflected ambient light intensity*
  - K_A = coefficient of reflected ambient light
  - I_A = *ambient light intensity*

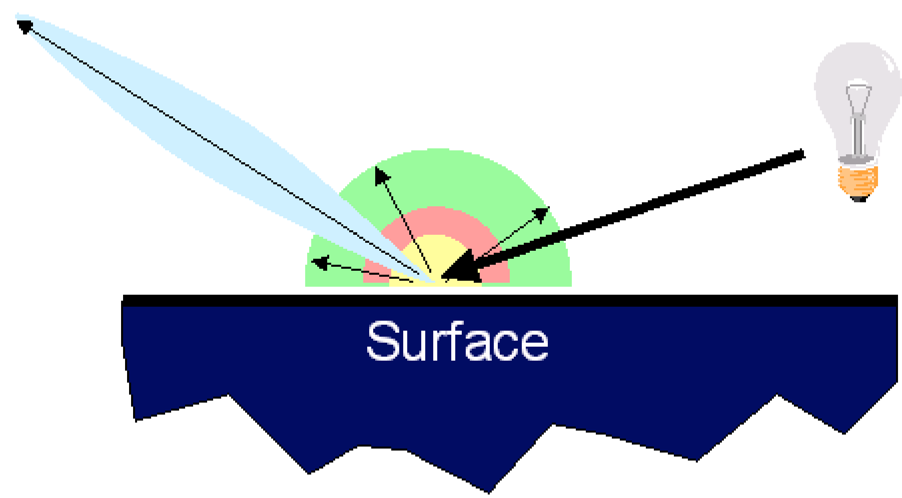
$$\boxed{I_{AL} = K_A I_A}$$

This is a total hack (avoids complexity of global illumination)!

Reflectance Model

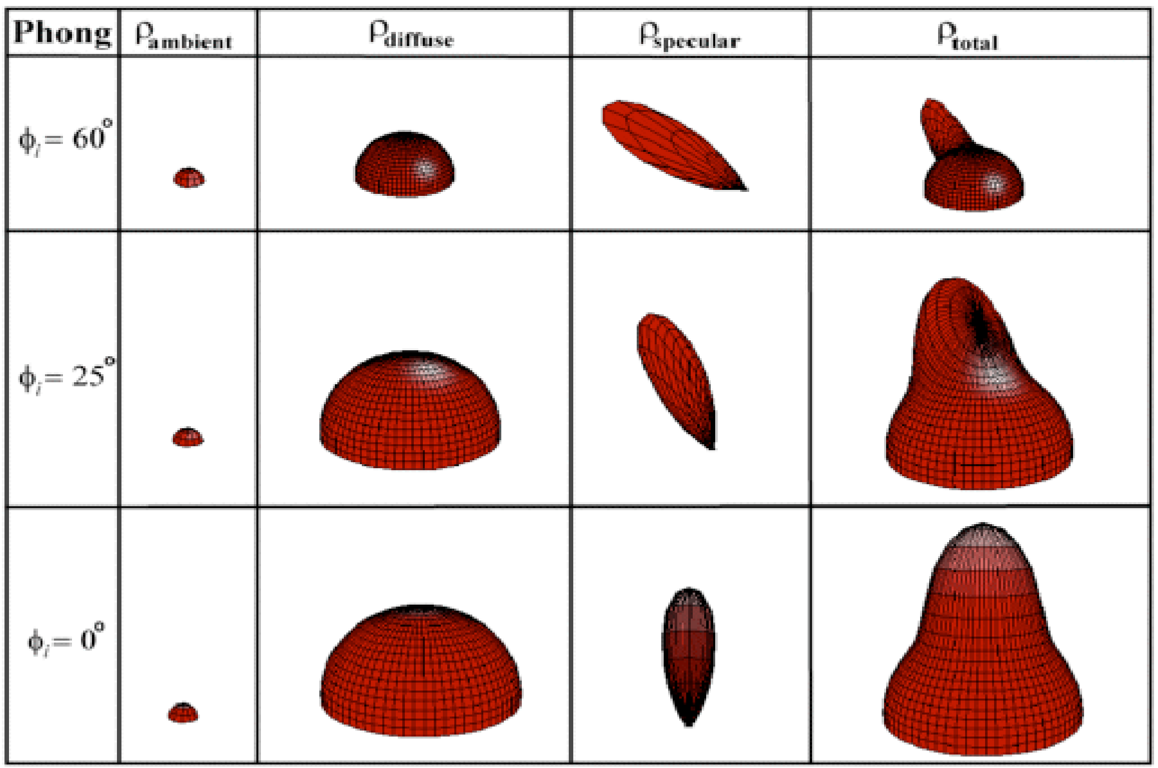
- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"





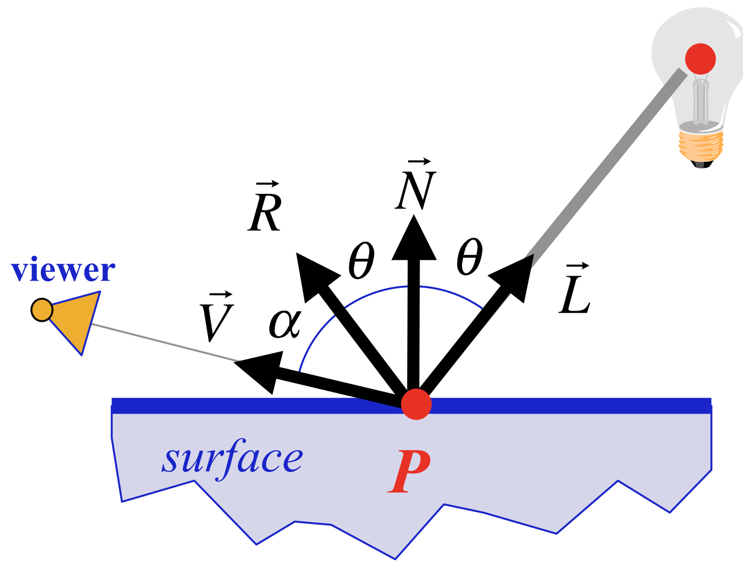
Reflectance Model

- Sum Diffuse, Specular, Emission, and Ambient



Surface Illumination Calculation

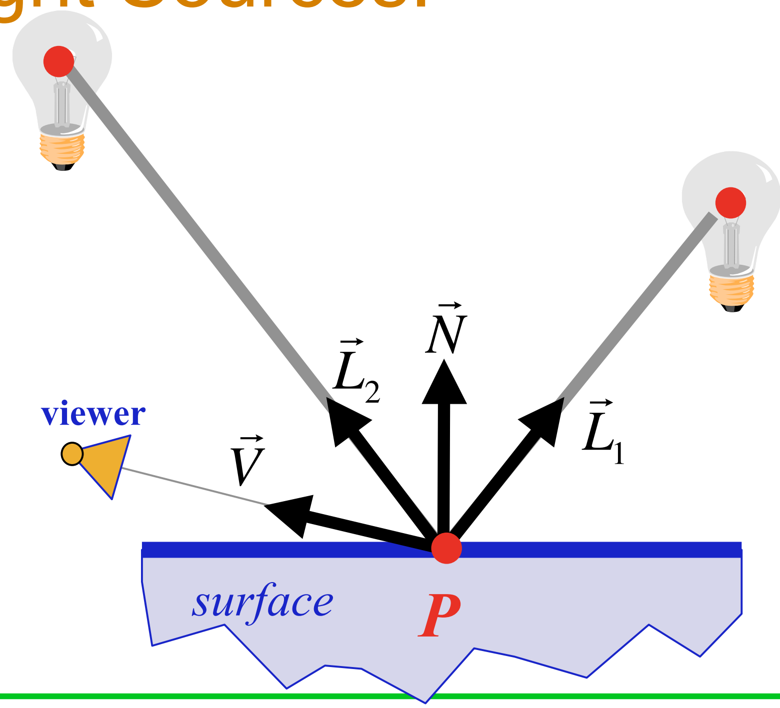
- Single Light Source:



$$I = I_E + K_A I_A + K_D\left(\vec{N}\cdot\vec{L}\right)I + K_S\left(\vec{V}\cdot\vec{R}\right)^n I$$

Surface Illumination Calculation

- Multiple Light Sources:



$$I = I_E + K_A I_A + \sum_{i=1}^{\#\,lights} [K_D(\vec{N} \cdot \vec{L}_i) + K_S(\vec{V} \cdot \vec{R}_i)^n] I_i$$

Materials in OpenGL

- The material properties of an object define how it interacts with light sources to produce a final color.
- Material properties are defined using:

```
glMaterial{fi}(GLenum face,GLenum pname,T param);
glMaterial{fi}v(GLenum face,GLenum pname,T *params);
```

- Objects can have different materials for front and back facing polygons.

Materials properties in OpenGL

- **GL_AMBIENT**, **GL_DIFFUSE**, **GL_AMBIENT_AND_DIFFUSE**, and **GL_SPECULAR** are used to define how the material interacts with the equivalent components from the light source.
- **GL_SHININESS** controls the size of the specular highlight.
- **GL_EMISSION** controls how much light the object appears to emit on its own.

Color Material in OpenGL

- Normally when lighting is enabled, the primary color (specified by `glColor()`) is ignored.
- However, it can be convenient to change material colors using `glColor()` rather than calling `glMaterial()`. This is possible if you enable color material:

```
glEnable(GL_COLOR_MATERIAL);
```

- Which material component (ambient, diffuse, ambient and diffuse, or specular) and which face (front, back, or both) affected by color material can be controlled with:

```
glColorMaterial(GLenum face, GLenum mode);
```

Normals in OpenGL

- The current normal is set with:

```
void glNormal3{bsifd}(TYPE nx, TYPE ny, TYPE nz);
void glNormal3{bsifd}v(const TYPE *v);
```

- Normals should be of unit length for correct results. If the modelview matrix might change the length of your normals, you can have OpenGL renormalize them using:

```
glEnable(GL_NORMALIZE);
```

- If you are scaling uniformly, a cheaper alternative to `GL_NORMALIZE` is:

```
glEnable(GL_RESCALE_NORMAL);
```

The Lighting Model in OpenGL

- The lighting model can be modified using:

```
void glLightModel{if}(GLenum pname, TYPE param);
void glLightModel{if}v(GLenum pname, const TYPE *param);
```

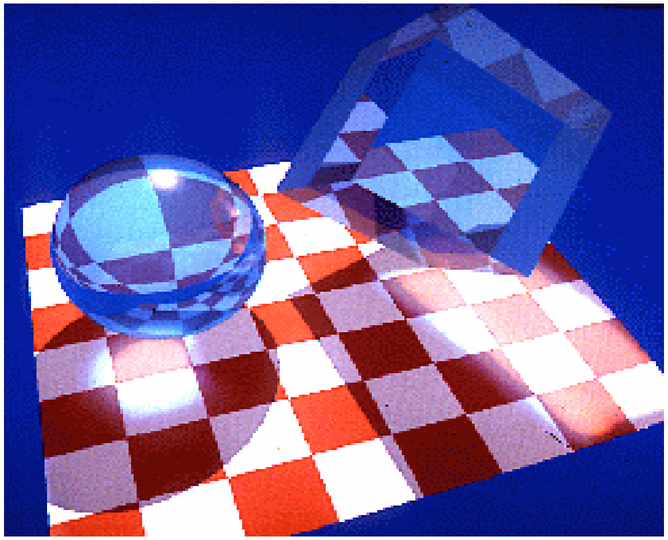
- Properties you can modify include:
  - **GL_LIGHT_MODEL_AMBIENT** – controls the global ambient light applied to all objects
  - **GL_LIGHT_MODEL_LOCAL_VIEWER** – controls whether the viewer is infinitely far away (cheaper) or located at the camera position (more accurate)
  - **GL_LIGHT_MODEL_TWO_SIZE** – controls whether lighting is calculated separately for front and back faces
  - **GL_LIGHT_MODEL_COLOR_CONTROL** – allows you to have OpenGL interpolate the specular color separately and apply it after texturing, to preserve highlights

Overview:

lighting-based models

- Direct Illumination
  - Emission at light sources
  - Scattering at surfaces

- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections



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