Computer Graphics 2013

12. Illumination and shading

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Lighting & Shading

Without light … we don't see much of our scene!

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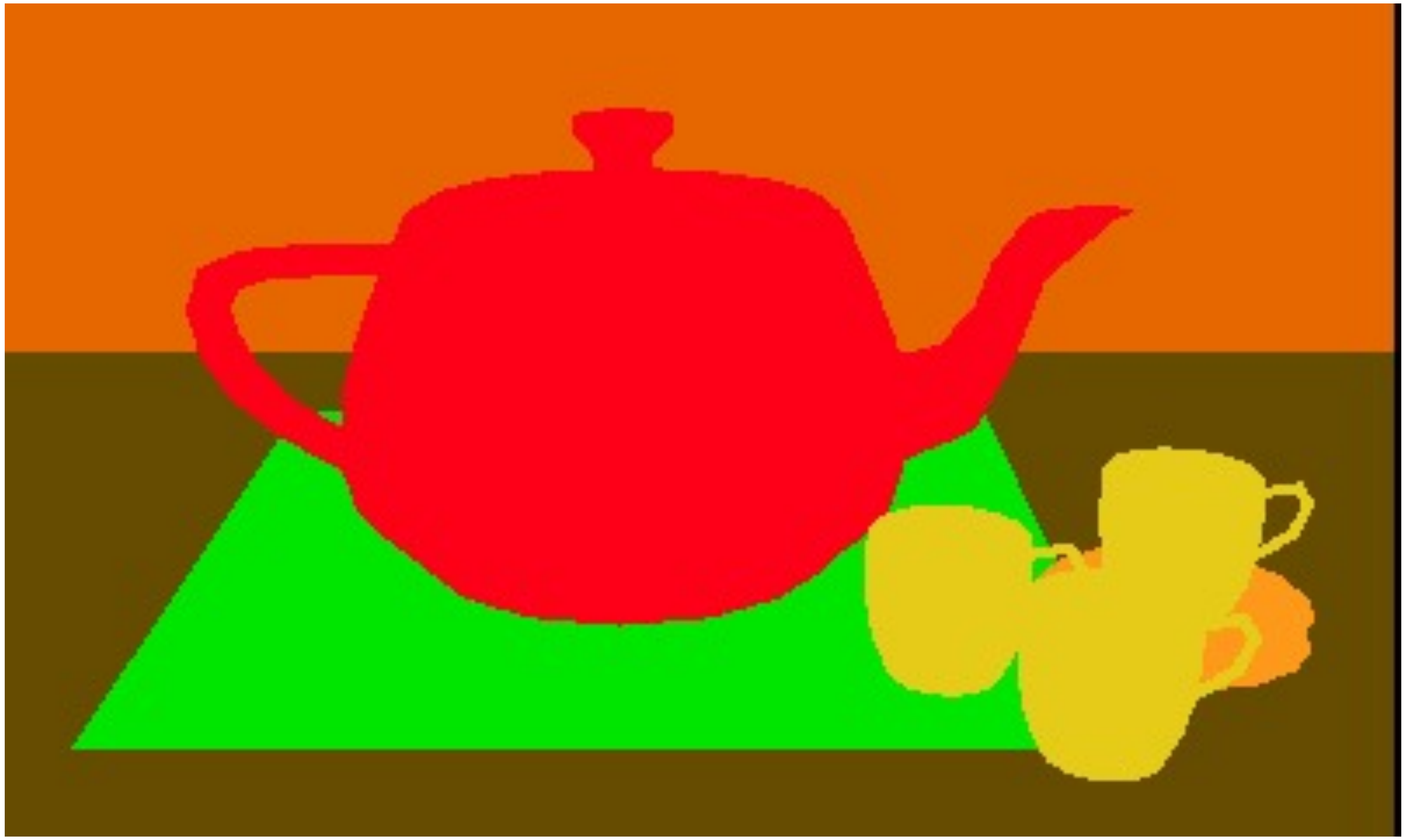
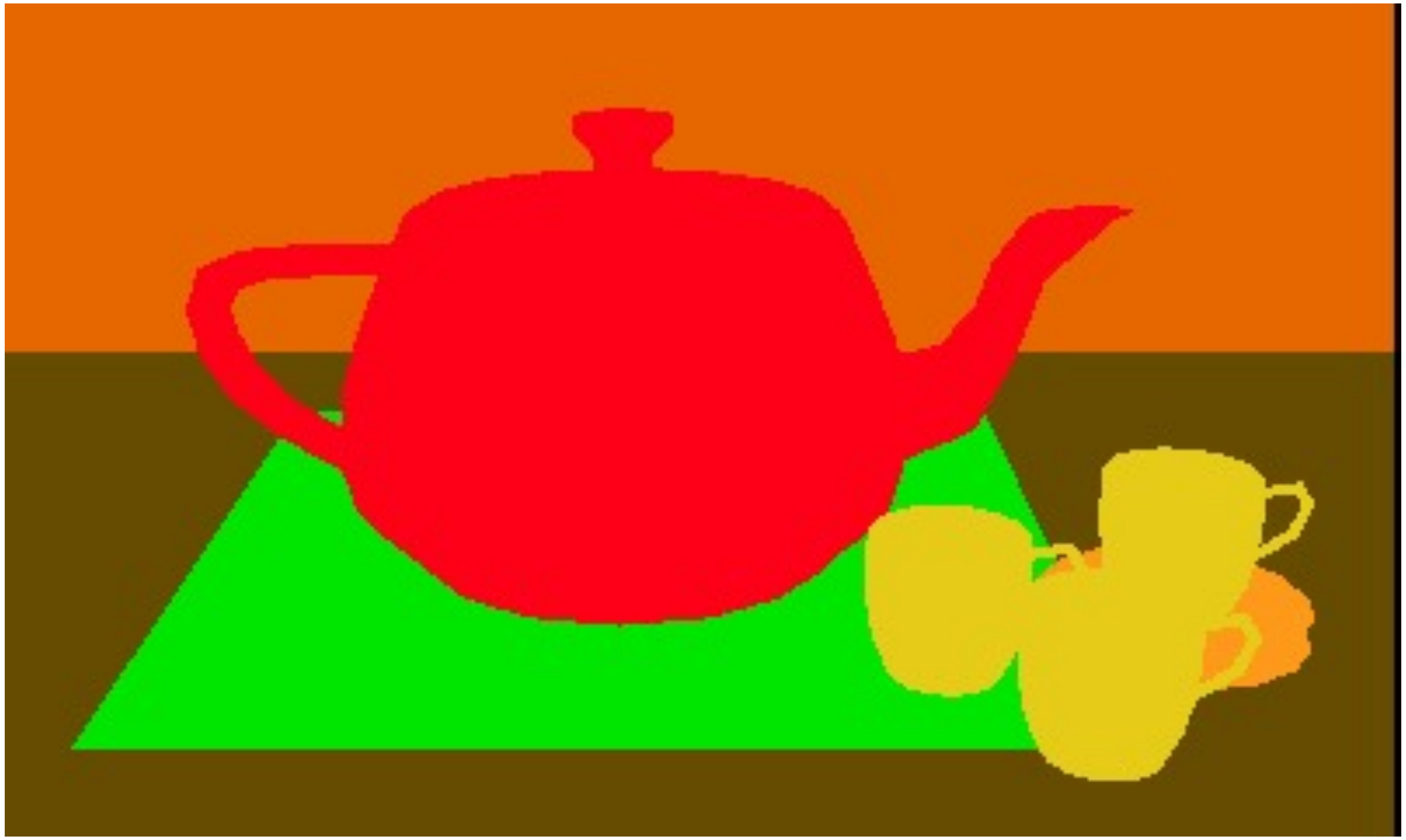


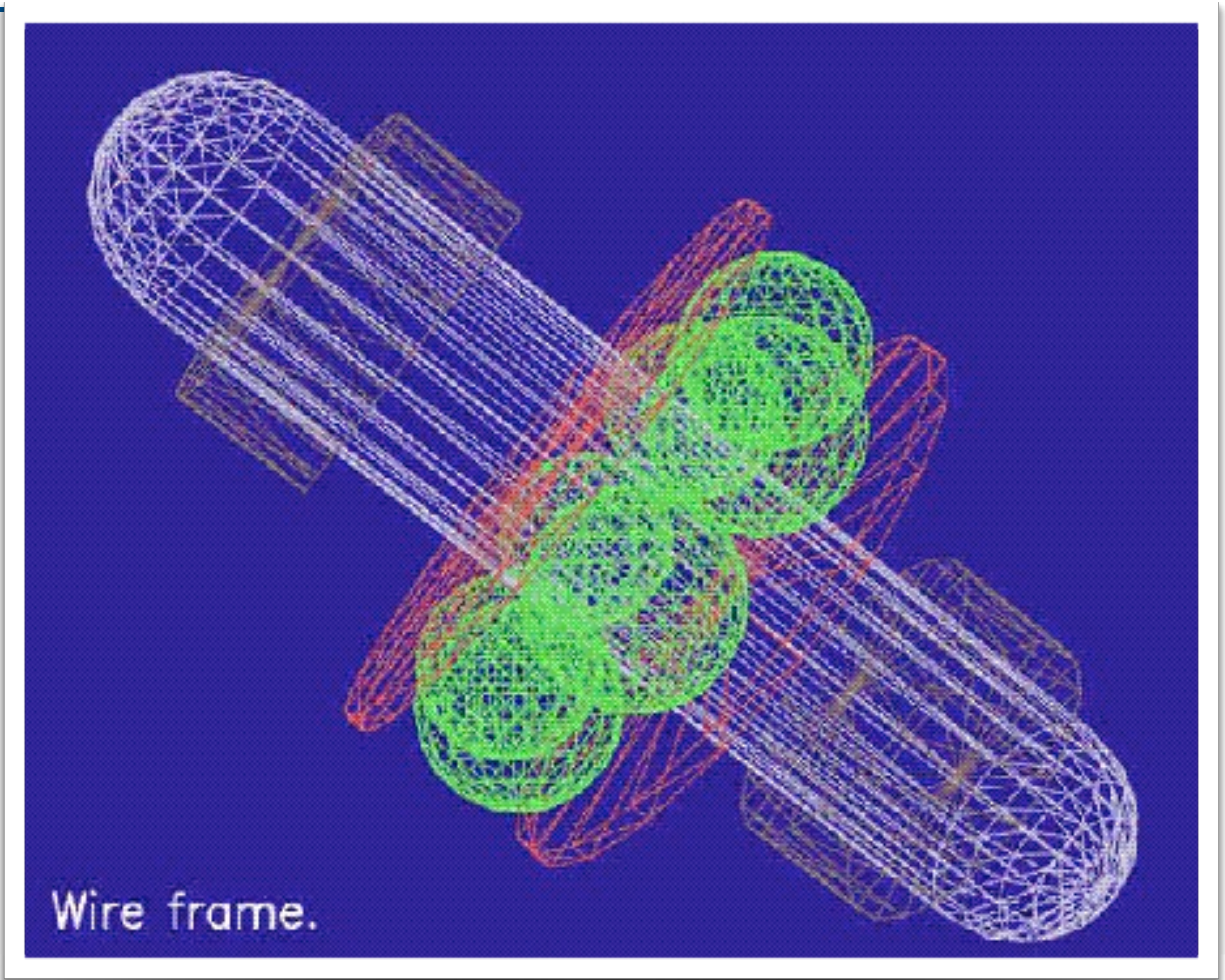
Lighting & Shading

Without light … we don't see much of our scene!

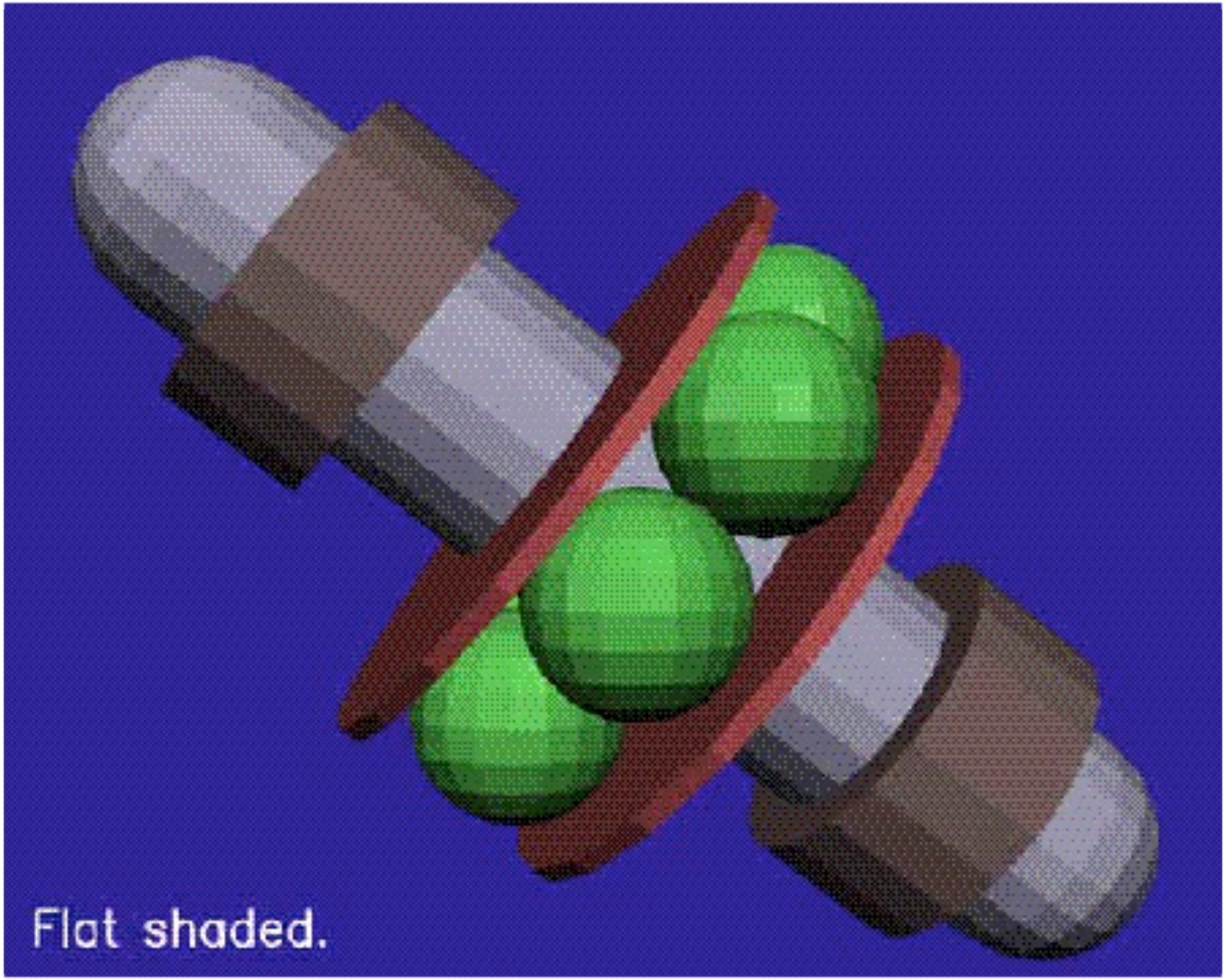


Without shading, objects do not look three dimensional!

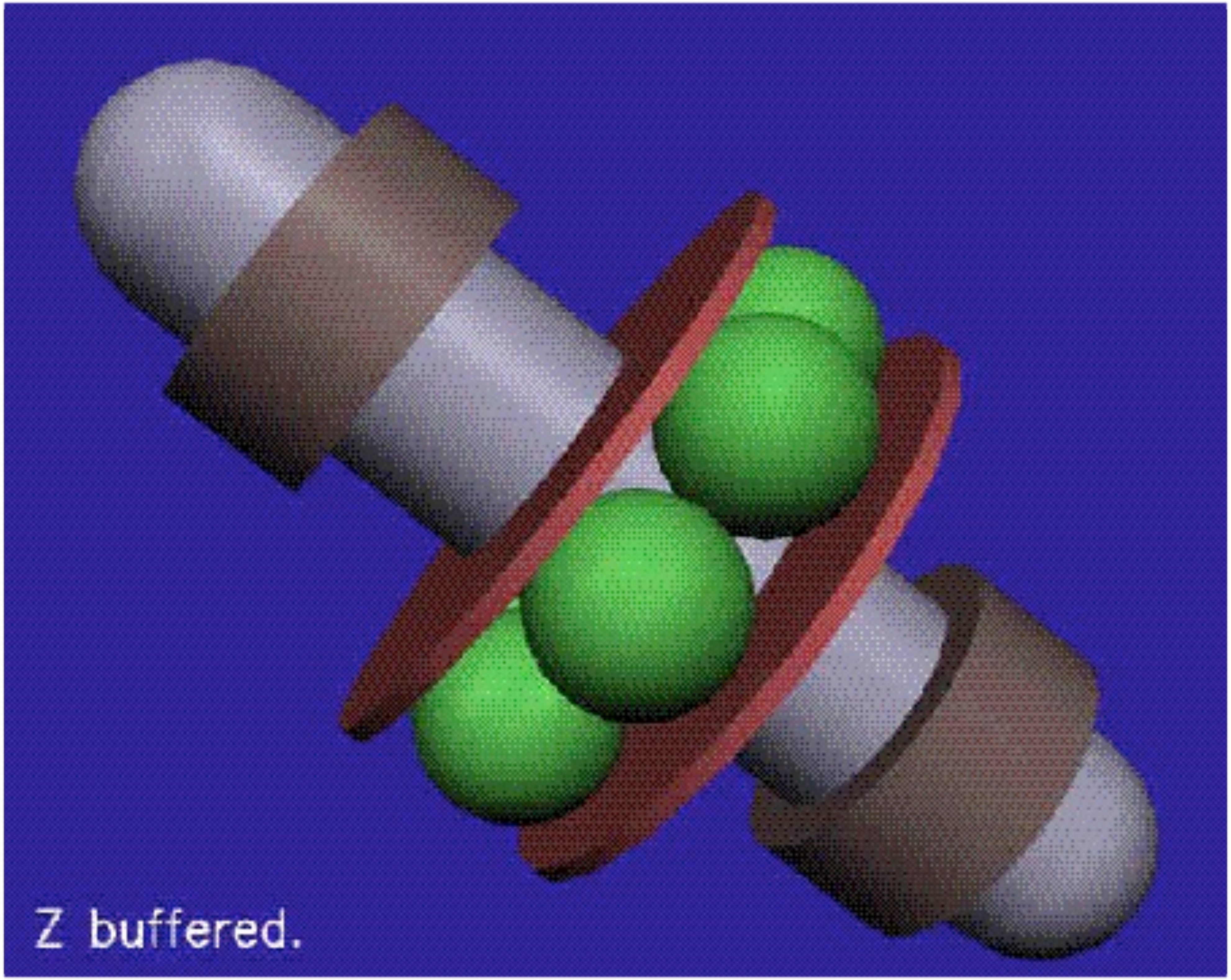
Lighting & Shading



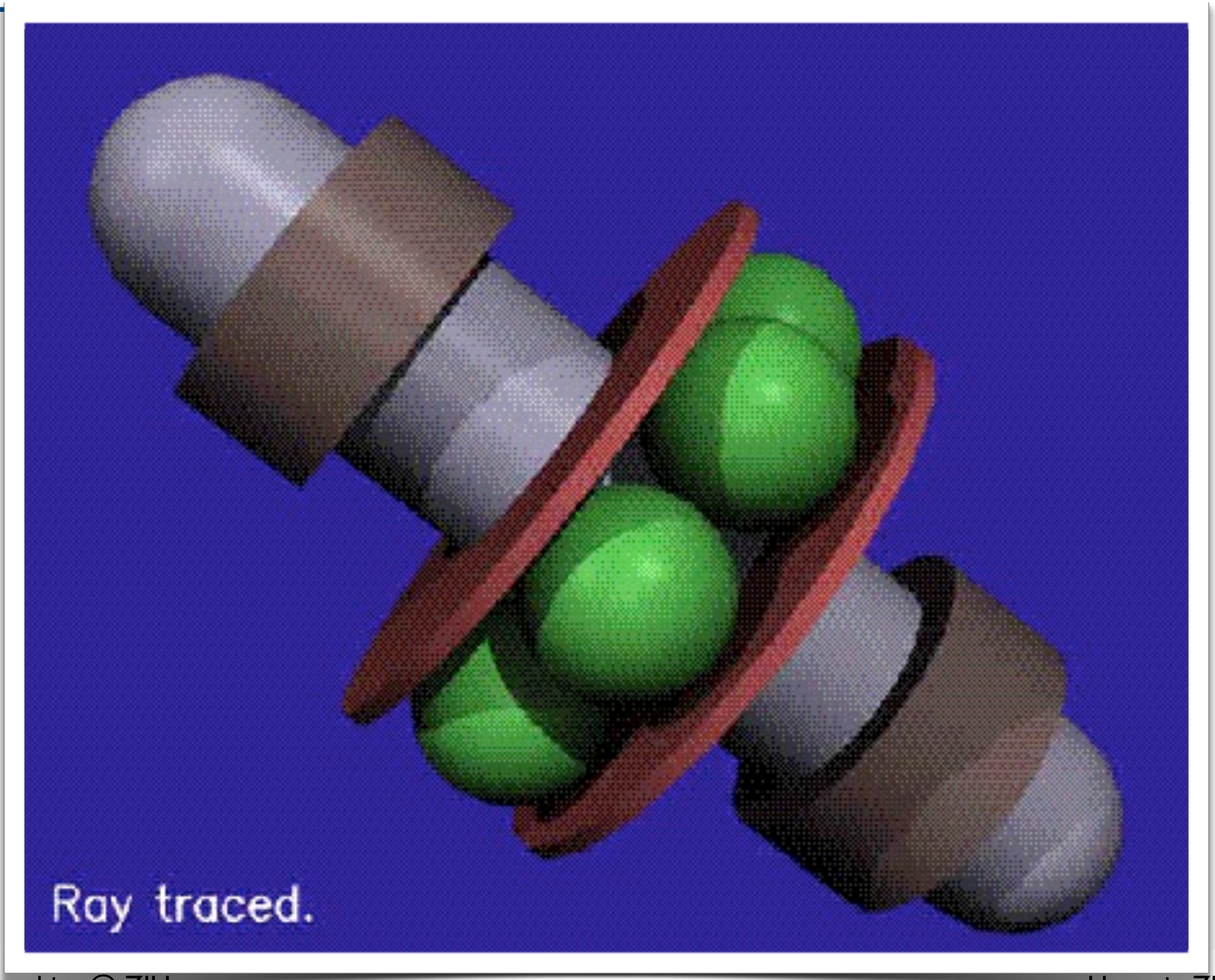
Lighting & Shading



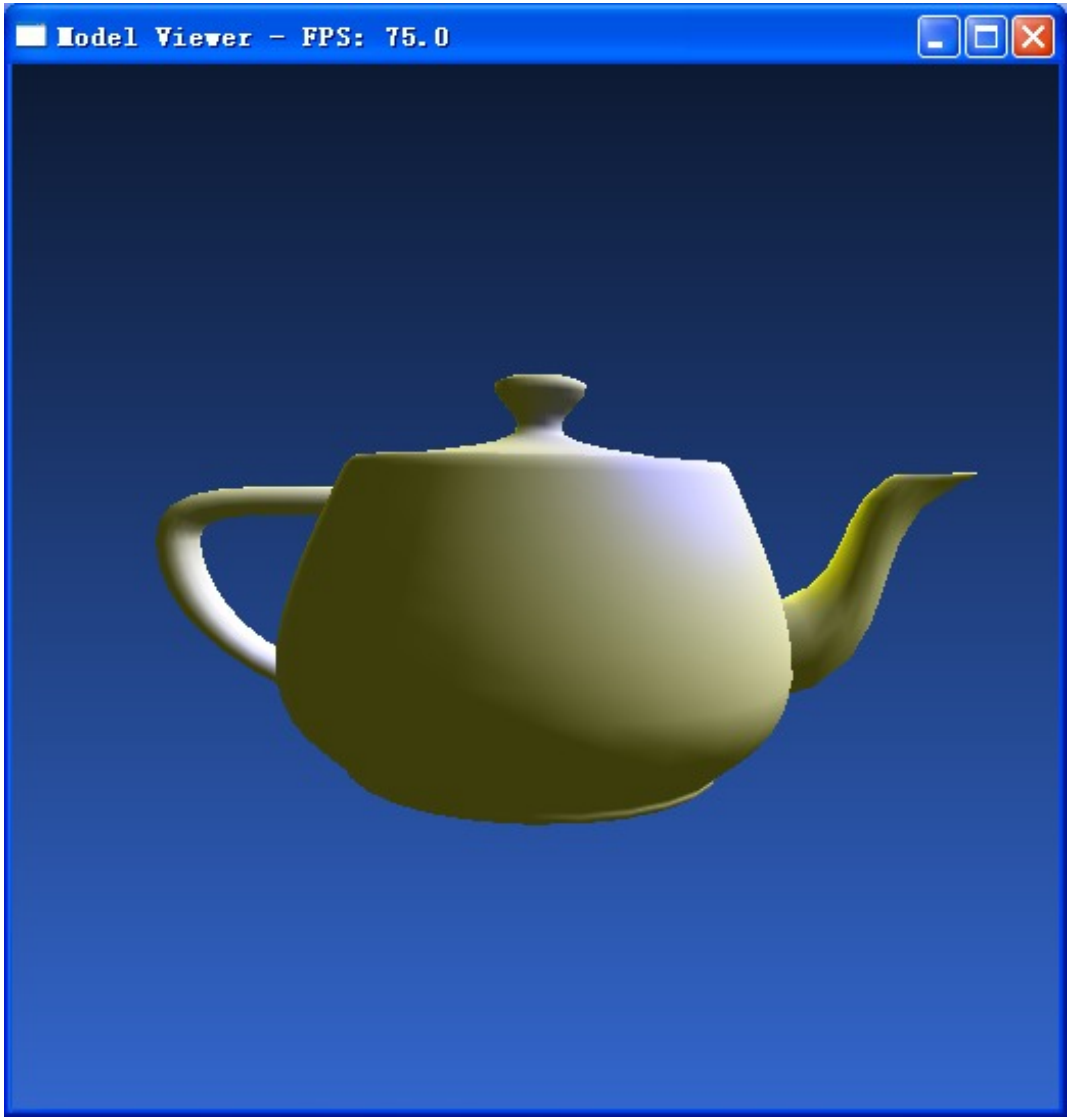
Lighting & Shading



Lighting & Shading



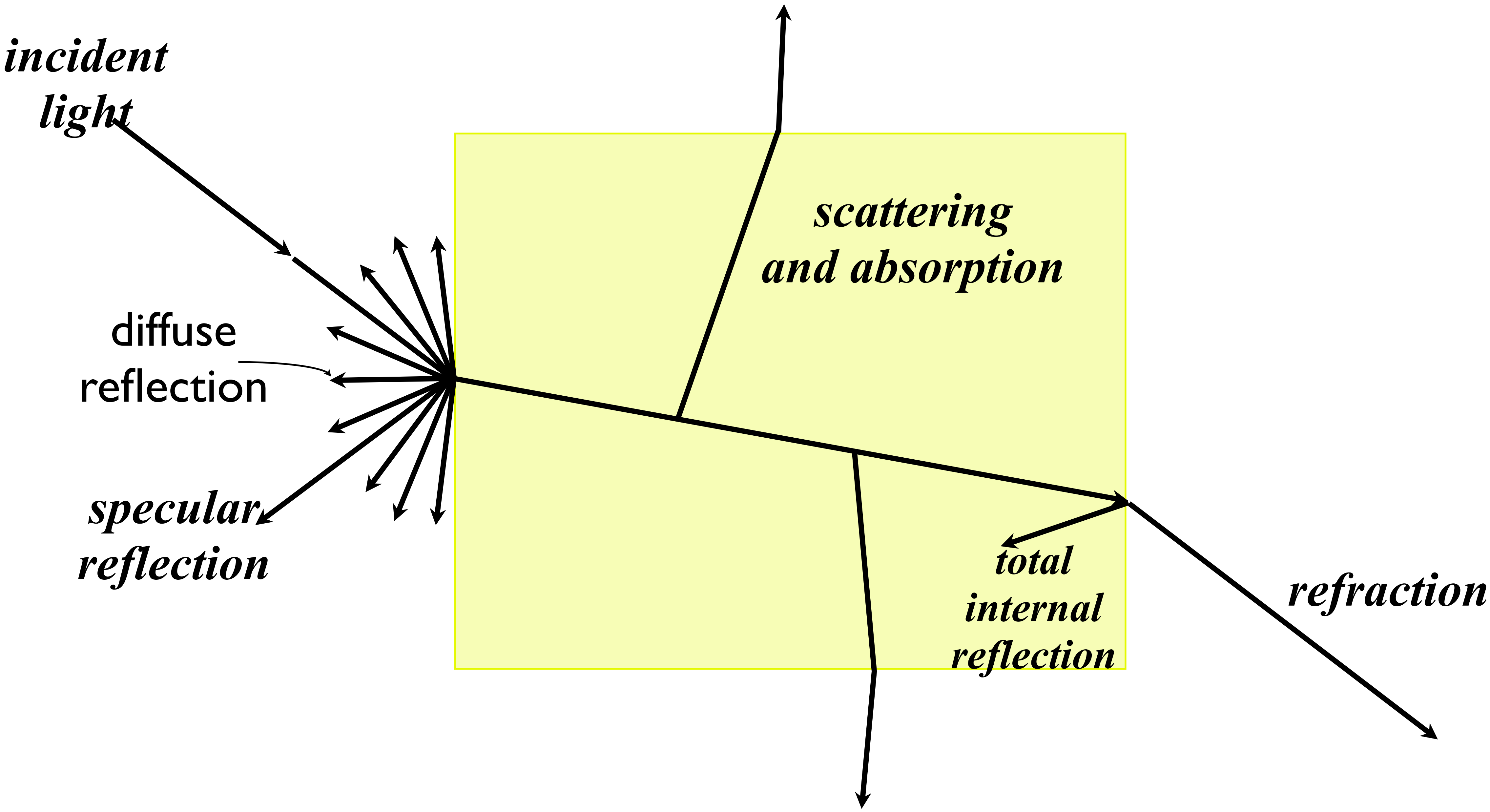
Demo – Multi-light



Illumination

- ***Illumination*** is the complete description of all the light striking a particular point on a particular surface
- ***Color*** at a point on an object is decided by the properties of the light leaving that point
- Knowing the ***illumination*** and the ***surface physics*** at a point on a surface, we can determine the properties of the light leaving that point
- In order to generate realistic images we need to understand how light interacts with the surface of objects

Interaction of light with a Solid



Interaction of Light

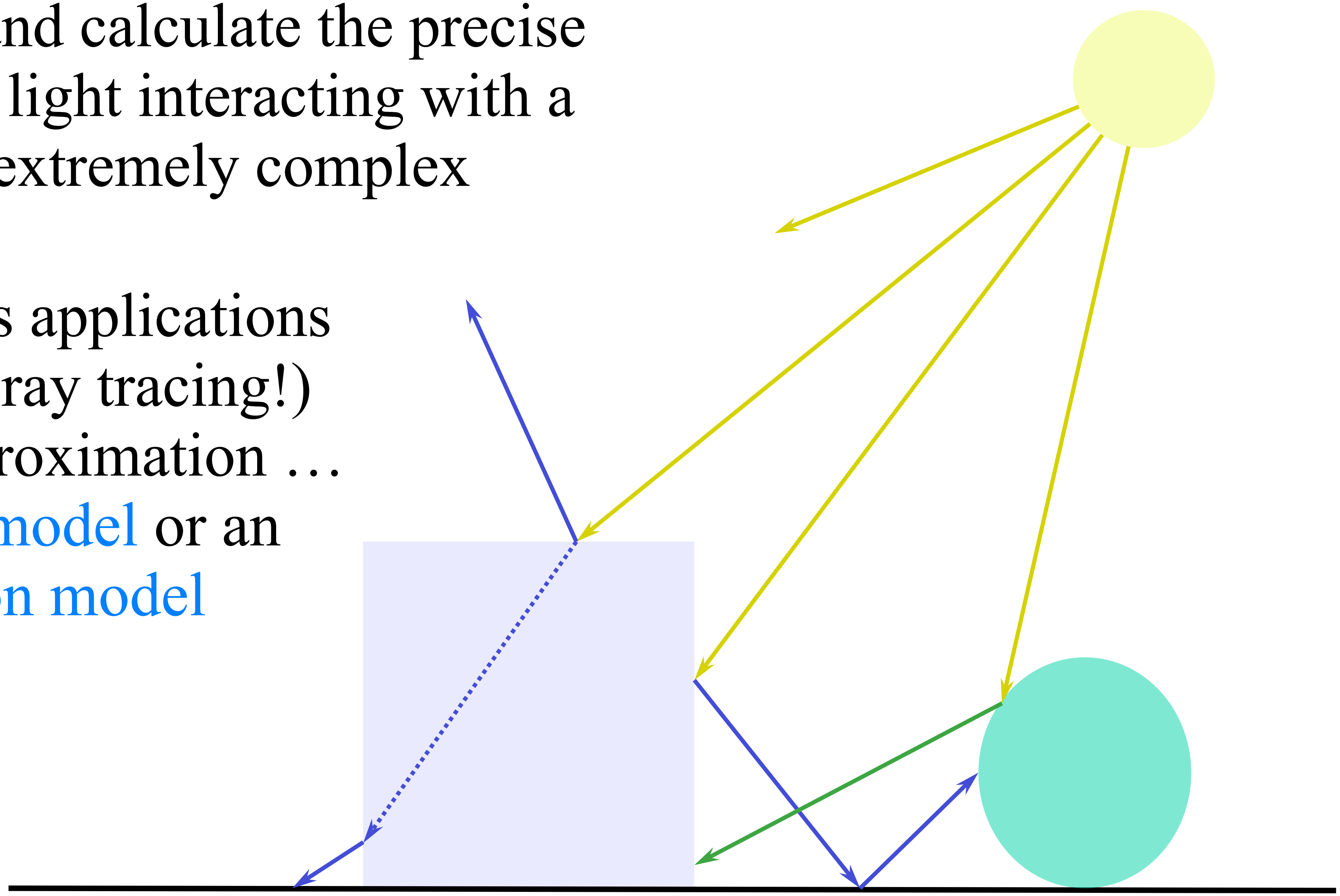
- There are two illumination phenomena of importance
  - **interaction of light** with the boundaries between materials
  - **scattering and absorption of light** as it passes through the material

- Boundaries between materials are surfaces which make up the environment
- Light striking a boundary is either reflected or transmitted. For opaque materials light is absorbed on passing through the boundary

Light interaction in a Scene

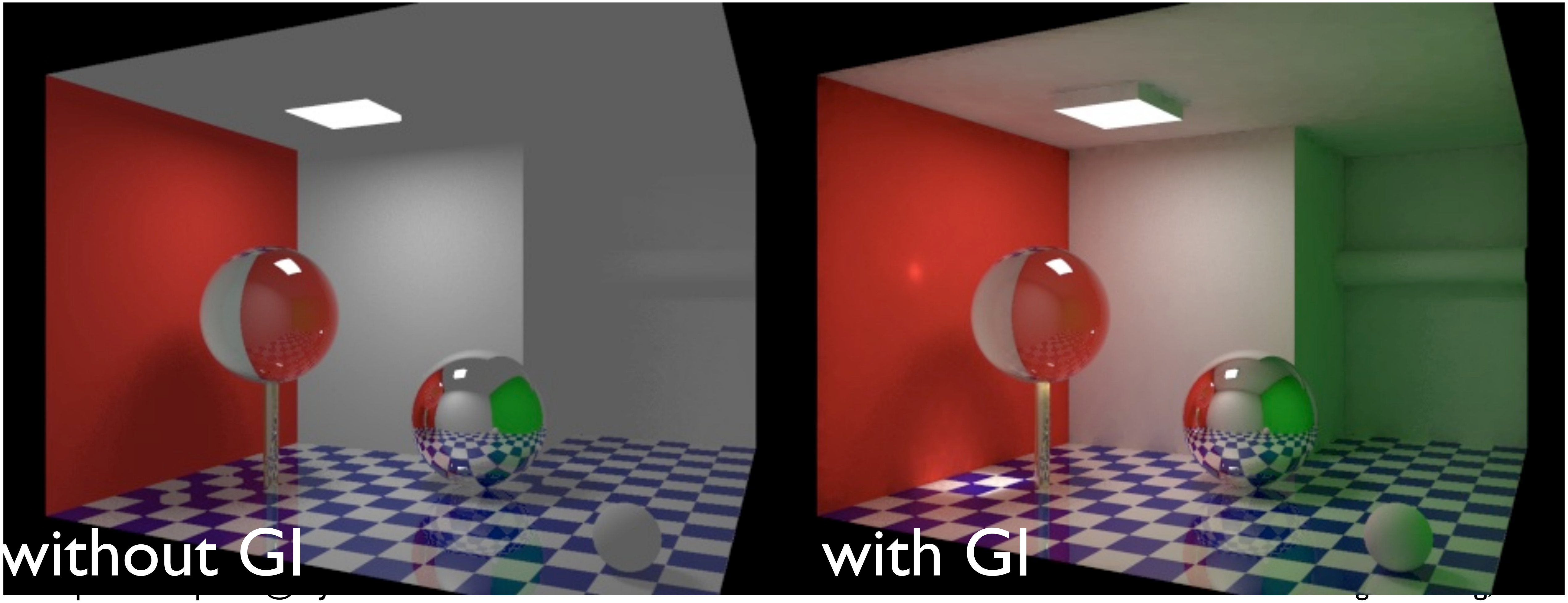
To simulate and calculate the precise physics of light interacting with a surface is extremely complex

Most graphics applications (including ray tracing!) use an approximation … a lighting model or an illumination model

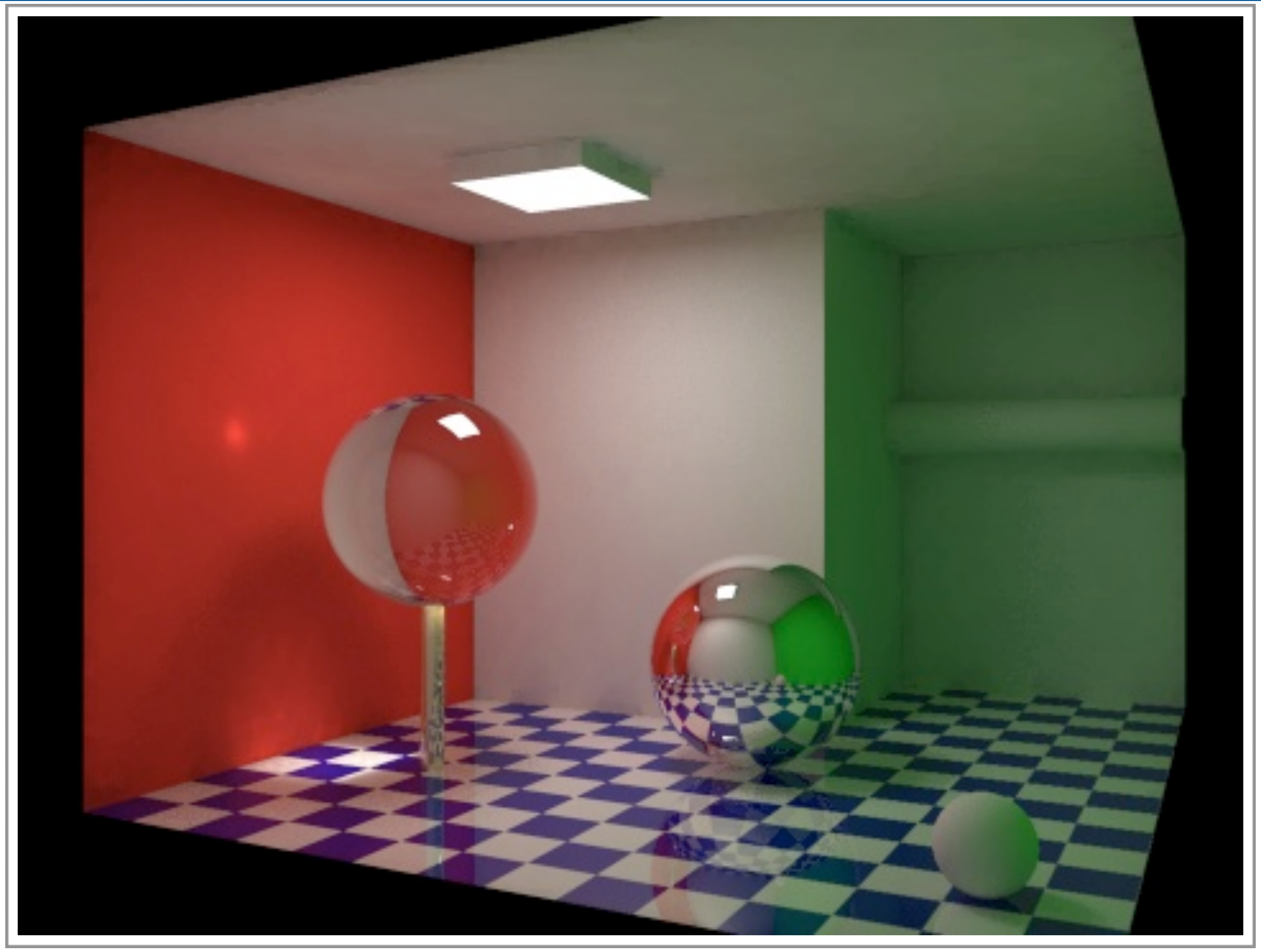


Illumination models

- A surface point could be illuminated by
  - ***local illumination***, light directly emitted by light sources
  - ***global illumination***, light reflected from and transmitted through its own and other surfaces



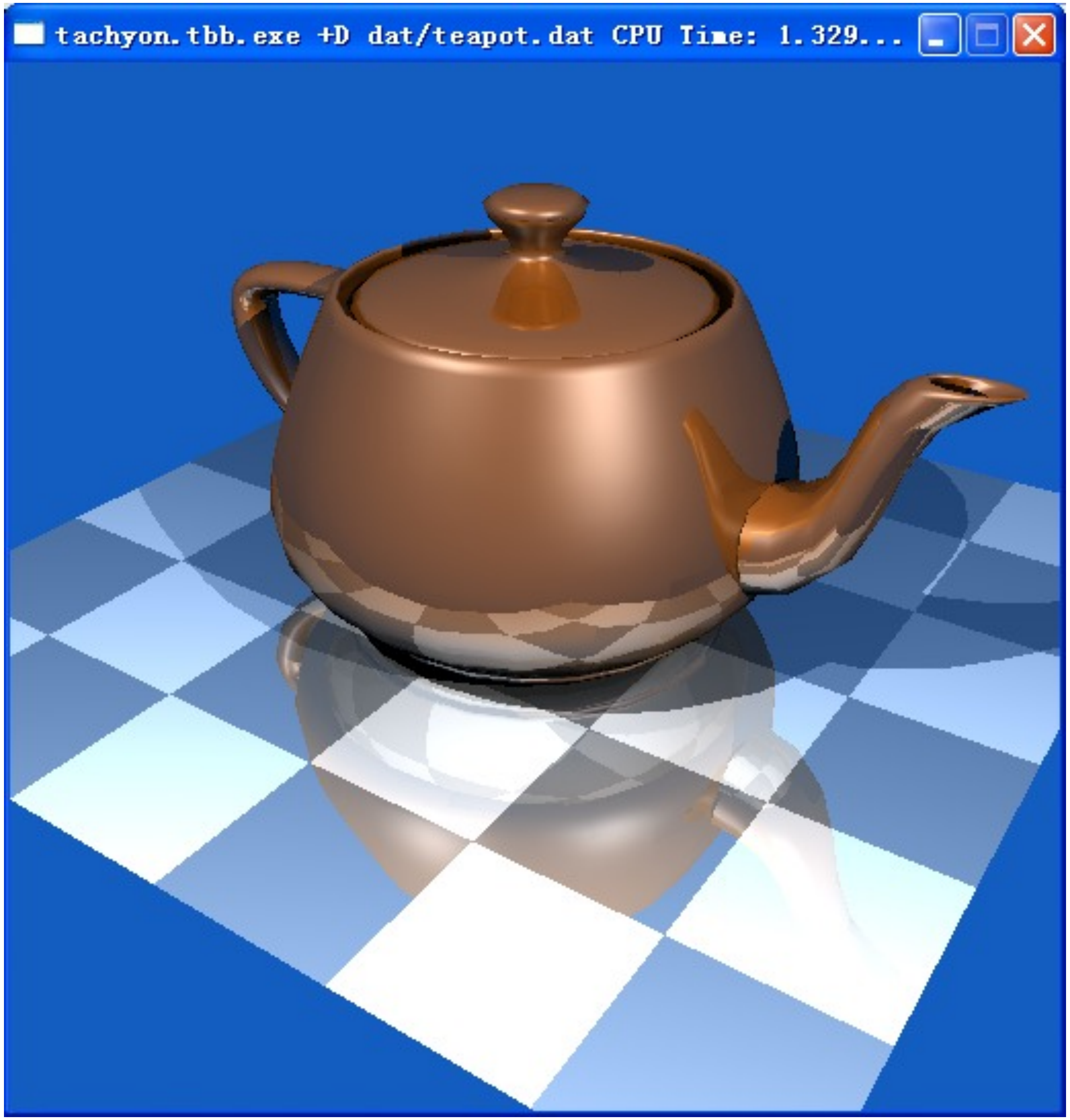
Illumination models

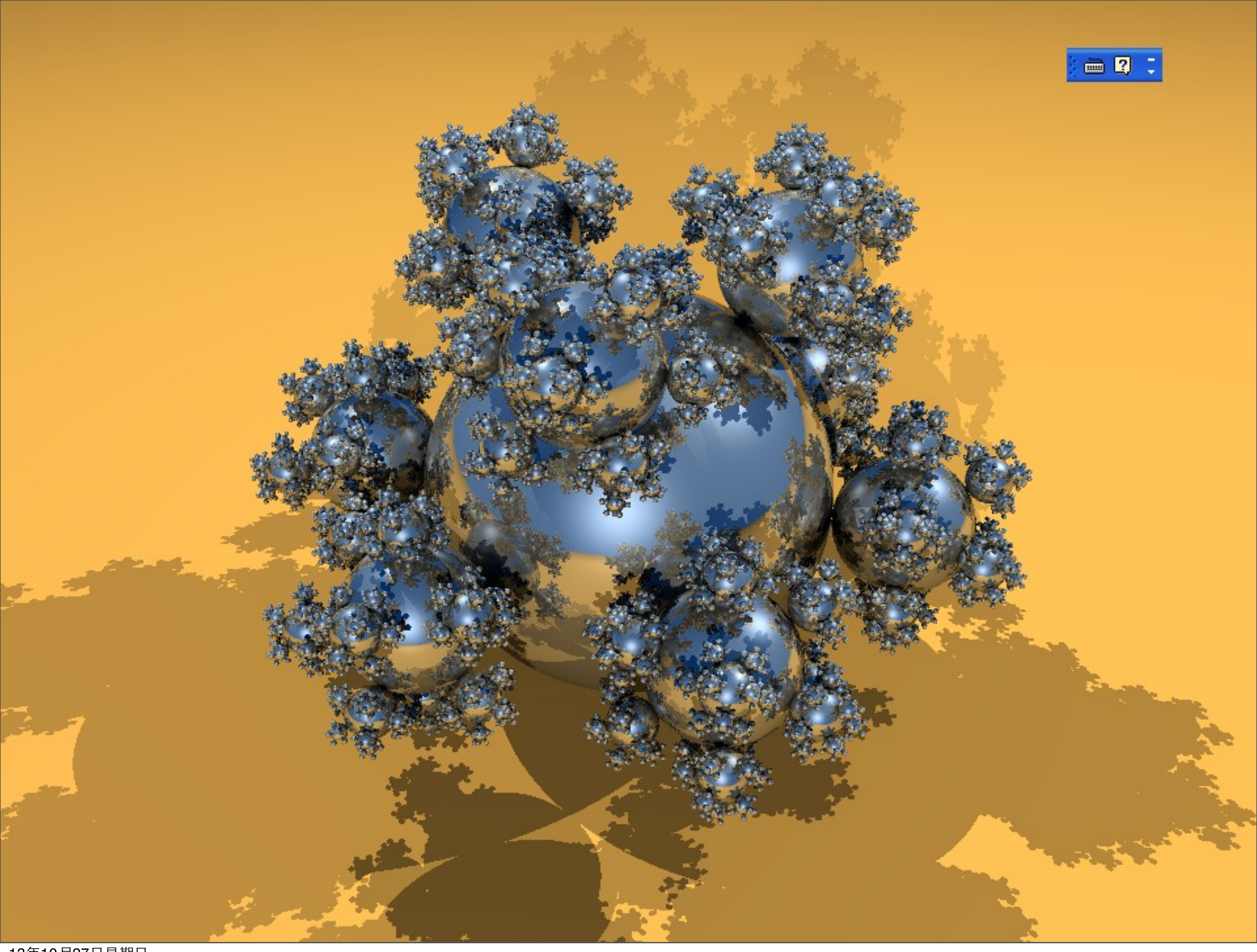


- ***Illumination models***
  - express the factors which determine the surface color at a given point on a surface
  - compute the color at a point in terms of both local and global illumination

Global Illumination – ray tracing

Global Illumination – ray tracing



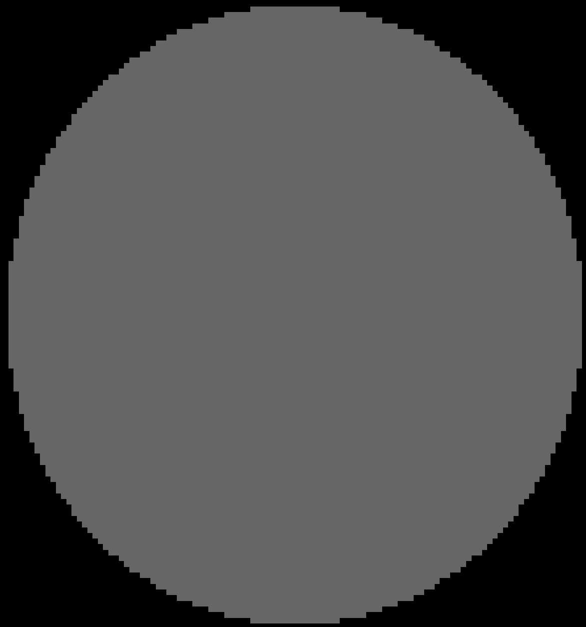


Reflection Models

- ***Illumination models*** used for graphics initially were often approximate models
- Main goal was to model the interaction of light with matter in a way that appears ***realistic*** and is ***fast***
- ***Reflection Models*** are the simplest of illumination models
- ***Reflection models*** assume
  - ***local illumination*** only. No global illumination
  - light is only ***reflected*** from the surface. There is no transmission through the object
  - there is ***no propagation*** media. Surfaces are in vacuum

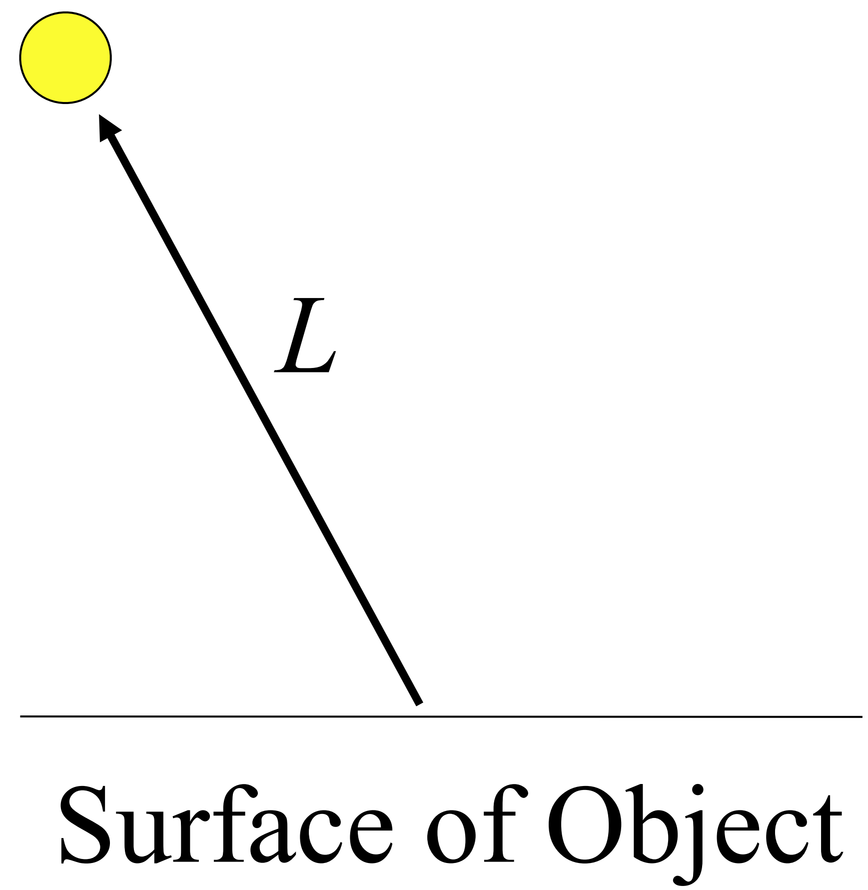
Ambient Light

- In reality, parts of the object not directly illuminated by the light source are not completely dark
- These parts are lit by global illumination i.e. light reflected by the surrounding environment; light that is reflected so many times that doesn't seem to come from any where
- This light is approximated by adding a constant light called ambient light
- The ambient light is $I_a k_a$, where I_a is the intensity of ambient light and k_a is the materials *ambient reflection coefficient* ranging from 0 to 1



Light Vectors

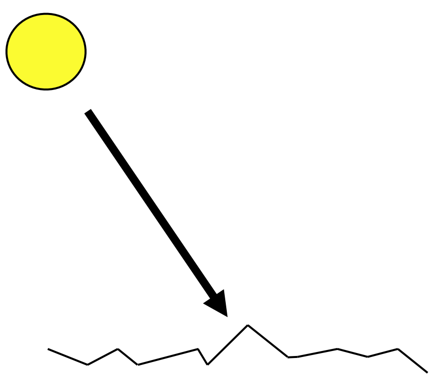
- When considering light, we look at the vector between the light and the object
- Take the vector **from the object to the light!**



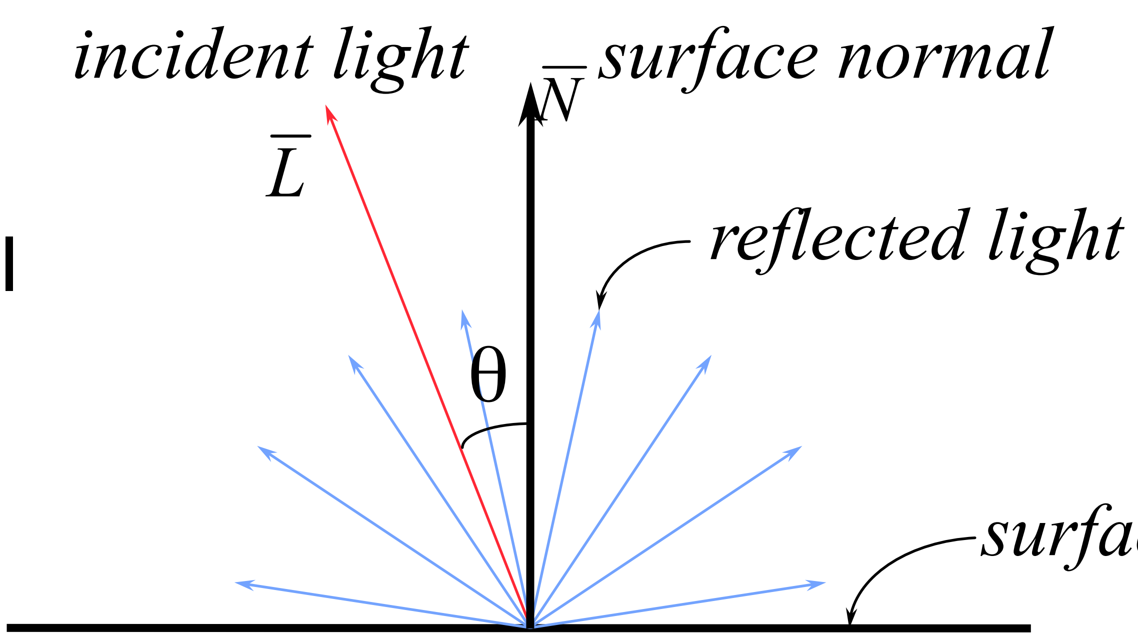
Diffuse Reflection

- **Diffuse** reflection also called **Lambertian** reflection is a characteristic of dull, matte surfaces like chalk
- Amount of light reflected from a point on the surface is equal in all directions
- The brightness depends on the angle between the direction to the light source and the surface normal
- The brightness is independent of the viewing direction

$$I_d = I_p k_d \cos(\theta)$$

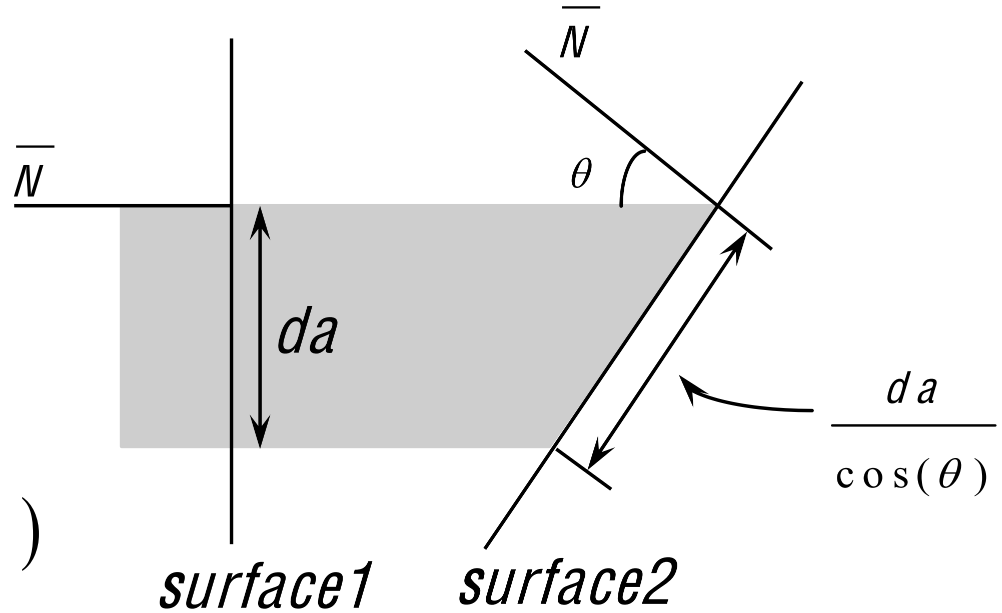


Microscopic view of a rough (matte) surface



Diffuse Reflection

- If the beam of light has a cross-sectional area da and is inclined to the surface at an angle θ then the beam intercepts the area $da / \cos(\theta)$



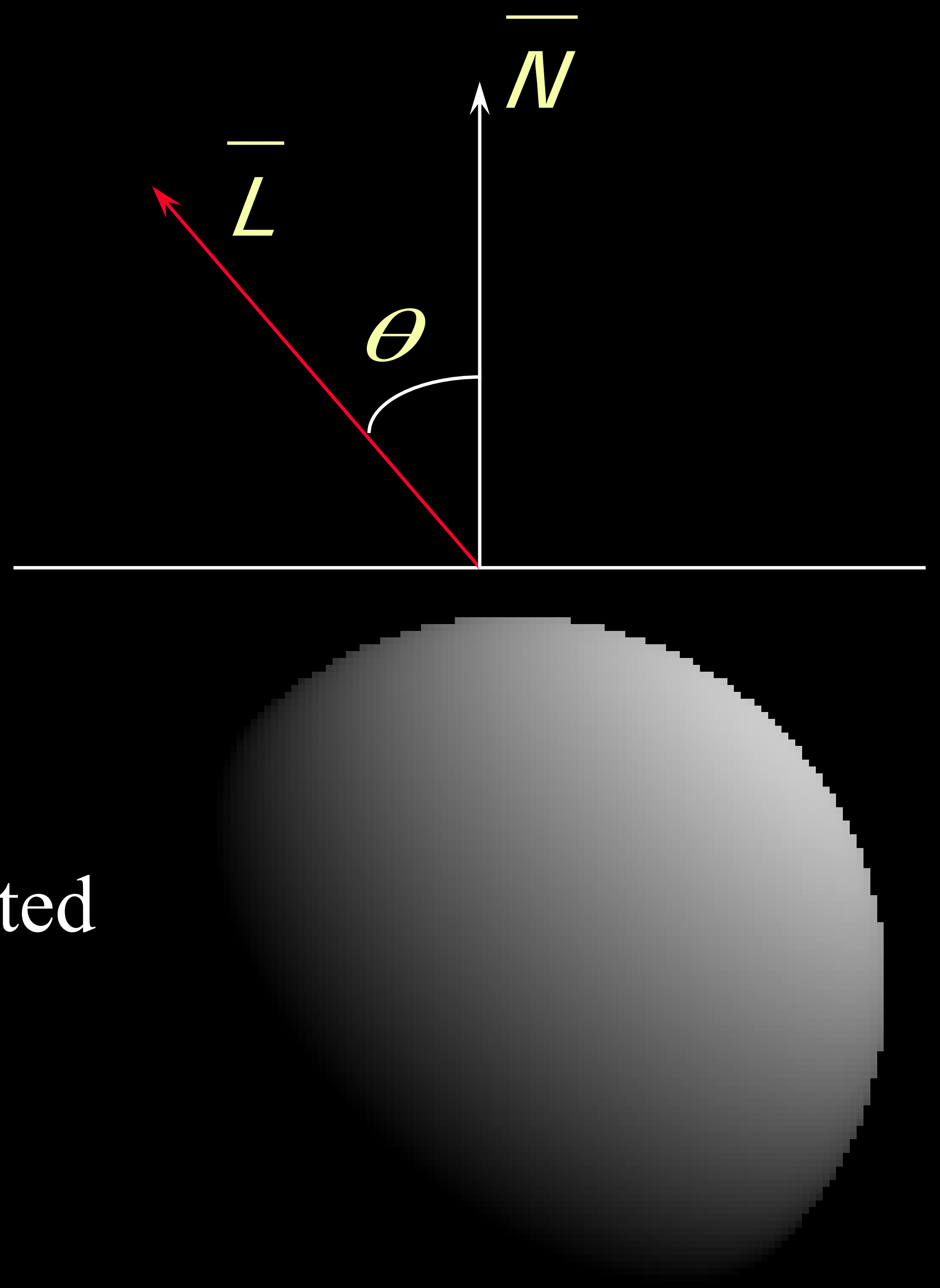
- The amount of light energy that falls on a surface is proportional to $\cos(\theta)$
- The diffuse illumination equation is $I_d = I_p k_d \cos(\theta)$ where, I_p is the point light source intensity, k_d is the materials diffuse reflection coefficient ranging from 0 to 1. and θ must be between 0^0 and 90^0 for the point to be lit

Diffuse Reflection

- With $\overline{N}$ and $\overline{L}$ normalized the diffuse illumination equation could also be written as

$$I_d = I_p k_d (\overline{N} \bullet \overline{L})$$

- With the diffuse reflection the part of the surface not illuminated by the light is dark



Illumination equation

- By adding the ambient term to the diffuse reflection the illumination equation is

$$I = I_a k_a + I_p k_d (\overline{N} \bullet \overline{L})$$

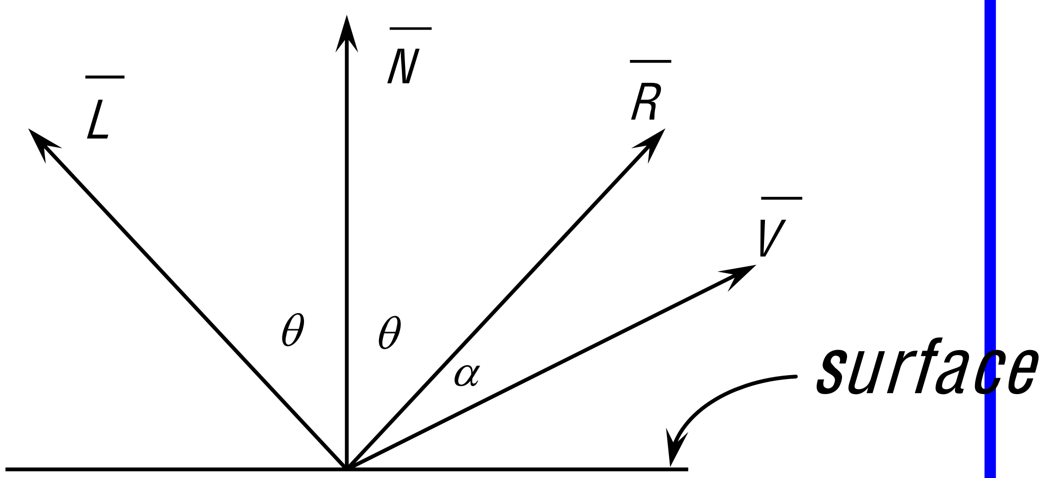
$k_a = 0.2, \quad k_d = 0.4$

$k_a = 0.2, \quad k_d = 0.6$

$k_a = 0.2, \quad k_d = 0.8$

Specular Reflection

- *Specular reflection* is exhibited by shiny surfaces like plastics
- In case of a perfect mirror light is reflected only in the reflection direction $\bar{R}$. For the viewer to see the reflected light, his direction $\bar{V}$ should be same as the reflected direction i.e. angle $\alpha = 0$
- Natural shiny surfaces reflect light unequally in different directions
- This is captured by the *Phong illumination model*



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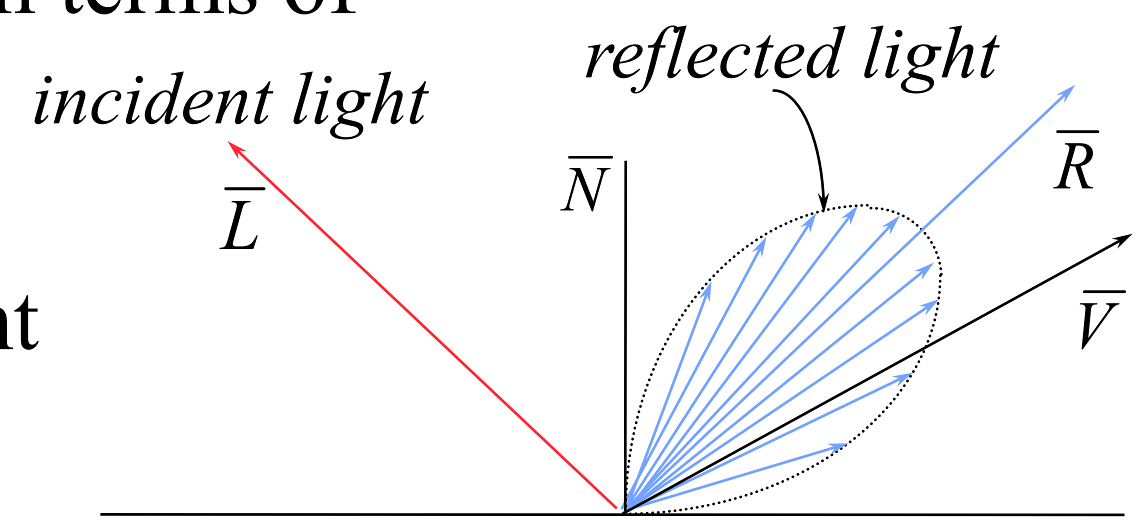
Phong Illumination Model

- These two types of reflection together make up the phong illumination model
  - Diffuse reflectance
  - Specular reflectance
- So, lighting depends on the properties of the surface as well as the light itself
  - Light Properties
  - Material Properties

Phong Illumination Model

- Developed by Phong Bui-Tuong (1975) is a popular model for non-perfect reflectors
- Specular reflection of shiny objects is considered. It assumes that maximum specular reflection occurs at $\alpha = 0$
- The light calculation depends on the viewing direction
- Reflected intensity is modeled in terms of
  - Ambient component
  - Diffuse reflection component
  - Specular reflection component



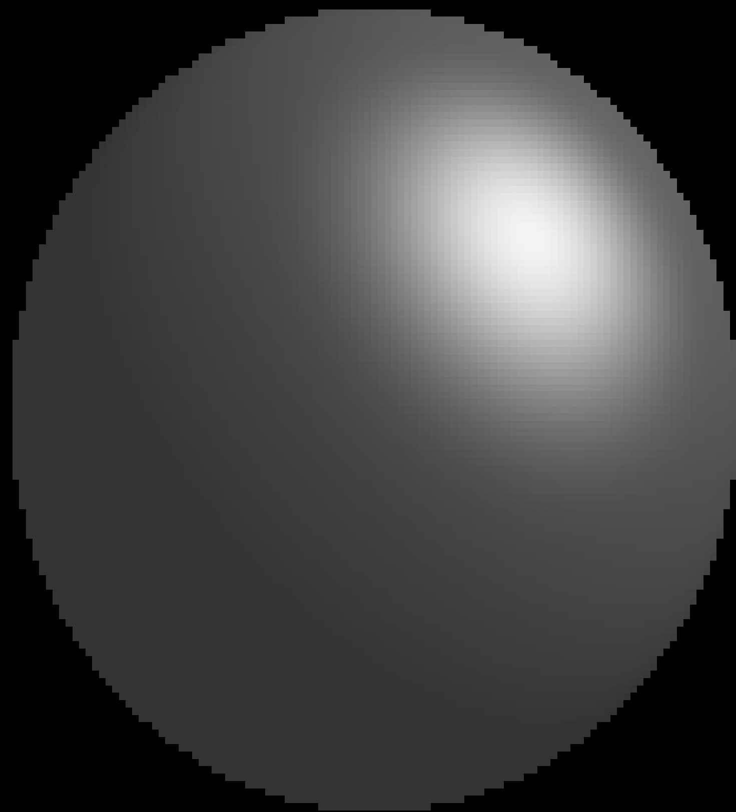
Phong Illumination model

- The illumination equation in its simplest form is given as

$$I = I_a k_a + I_p k_d(\overline{N} \bullet \overline{L}) + I_p k_s(\overline{R} \bullet \overline{V})^n$$

where, k_s is the materials *specular reflection coefficient* ranging between 0 and 1, n is the *specular reflection exponent* is the material property the object,

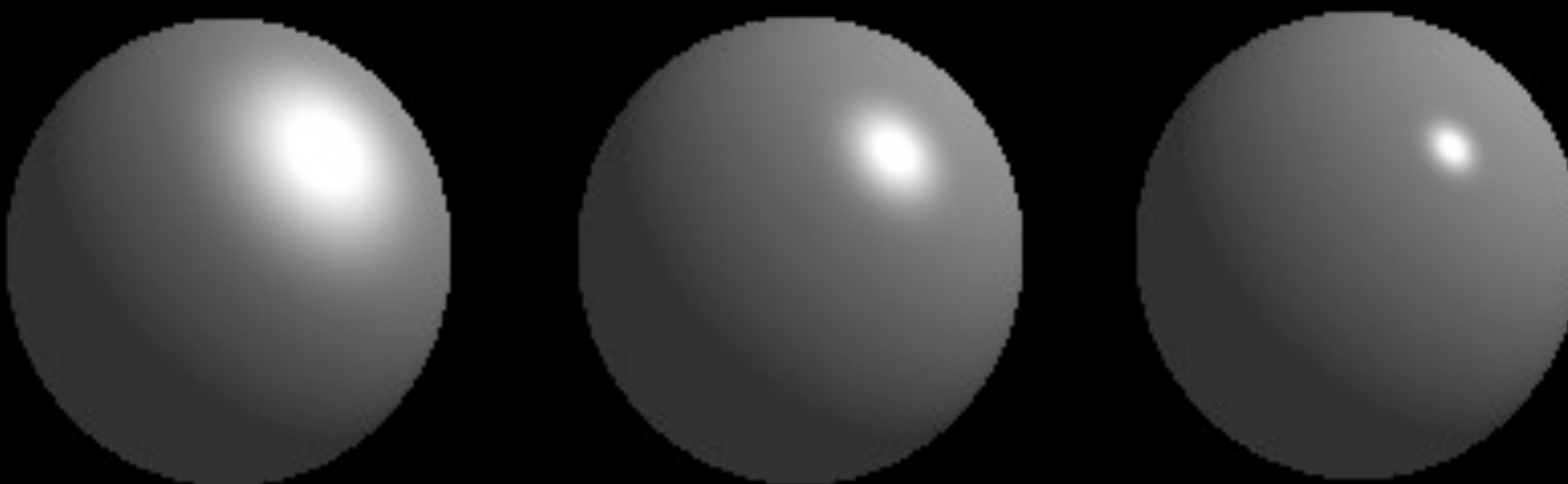
$\overline{R}$ is the *reflected ray vector* and $\overline{V}$ is the *view vector*



$k_a = 0.2, \quad k_d = 0.2, \quad k_s = 0.6, n = 4$

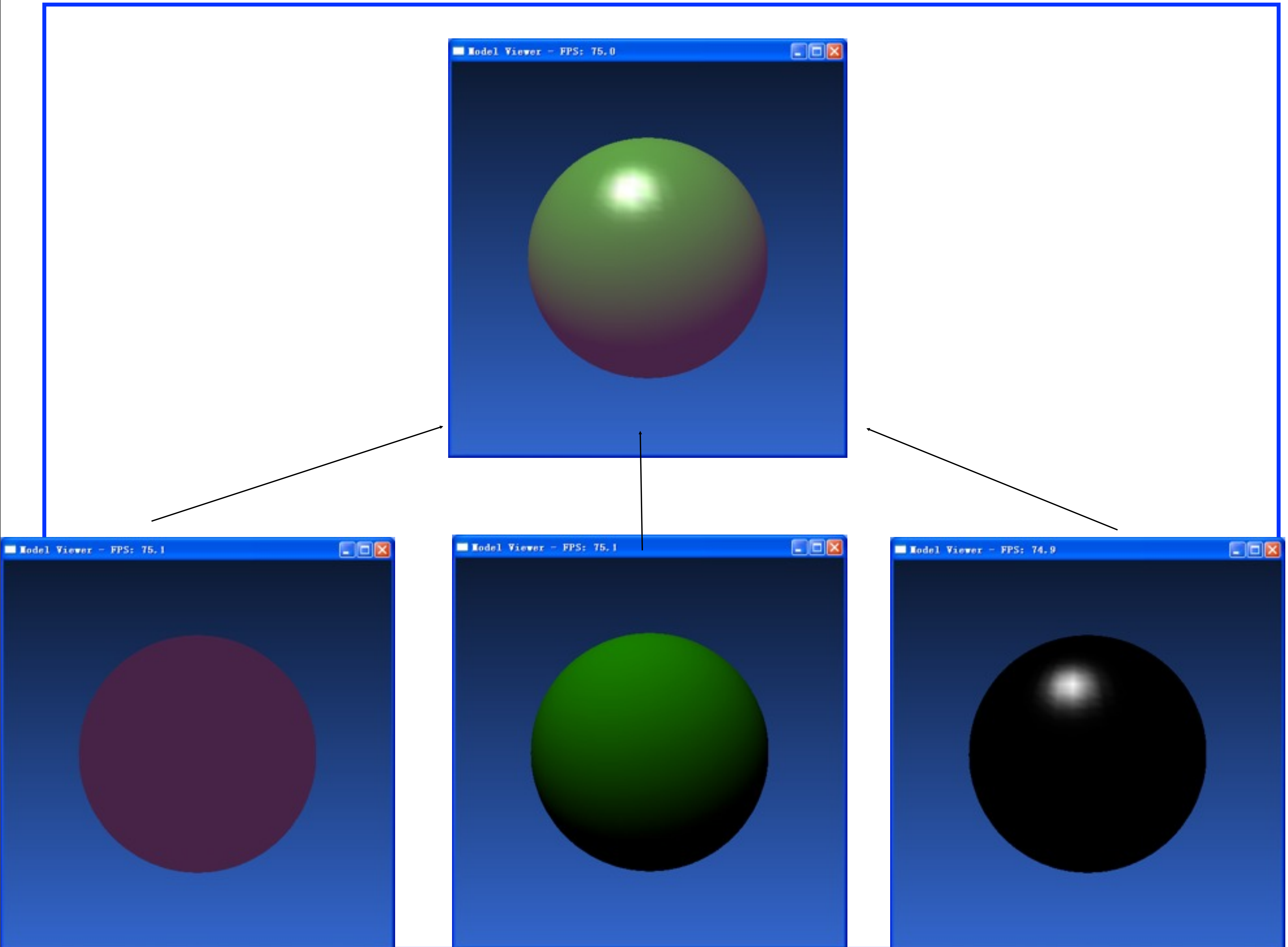
Phong Illumination model

- The *specular reflection exponent* ***n*** controls the shine/gloss of the surface. The surface is more glossy as n increases and the shine becomes sharper



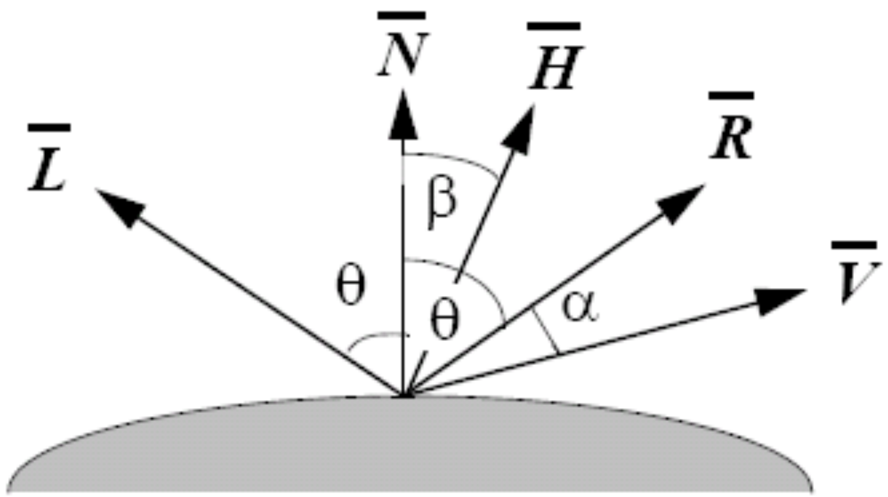
$n = 4$ $n = 16$ $n = 64$

Difference between illumination models


Model Viewer - FPS: 75.0
Model Viewer - FPS: 75.1
Model Viewer - FPS: 75.1
Model Viewer - FPS: 74.9

Halfway vector

$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{V}}{\|\mathbf{L} + \mathbf{V}\|}$$



- H is used to simplify the computation of dot(V, R) => dot(H,N)

Multiple Light Sources

- In case of multiple light sources, the terms for each light source are summed. So for ***m*** light sources the illumination equation is

$$I = I_a k_a + \sum_{1 \le i \le m} I_{pi} [k_d (\overline{N} \bullet \overline{L}_i) + k_s (\overline{R}_i \bullet \overline{V})^n]$$

- With summation it is possible that the value of *I* might exceed the maximum displayable pixel value
  - it could be avoided with proper selection of material
  - the resulting value of *I* could be clamped to the maximum value
  - divide each pixel value by the peak value of *I*

Colored objects

- The color of objects is set by appropriate setting of the ambient and the diffused reflection coefficients
- Specular coefficient is not decided by the color
- There are now three intensity equations

$$I_r = I_a k_{ar} + I_p[k_{dr}(\overline{N} \bullet \overline{L}) + k_s(\overline{R} \bullet \overline{V})^n]$$

$$I_g = I_a k_{ag} + I_p[k_{dg}(\overline{N} \bullet \overline{L}) + k_s(\overline{R} \bullet \overline{V})^n]$$

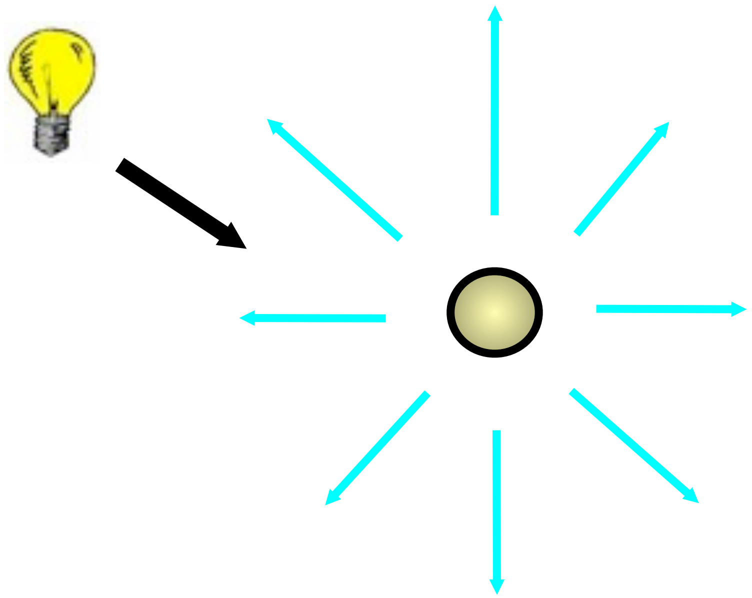
$$I_b = I_a k_{ab} + I_p[k_{db}(\overline{N} \bullet \overline{L}) + k_s(\overline{R} \bullet \overline{V})^n]$$

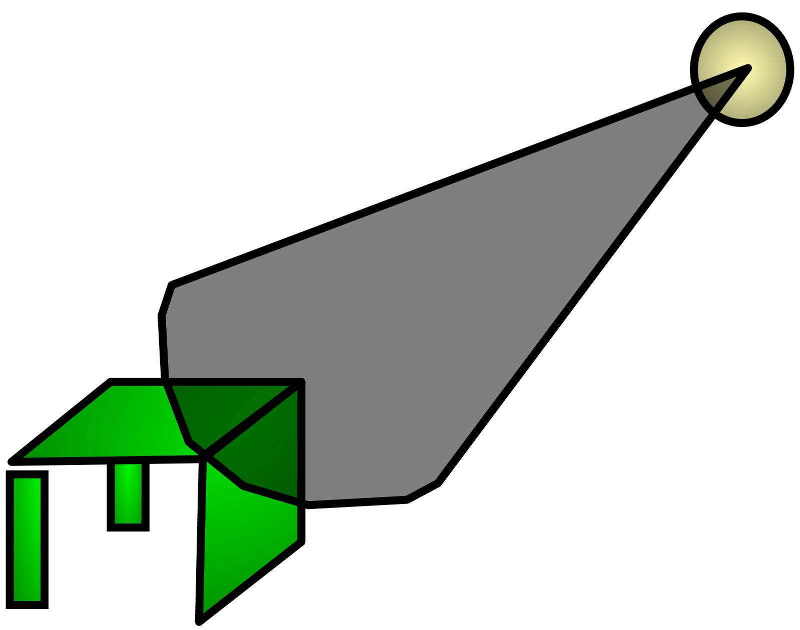
- Summarizing these three equations as single expression

$$I(r,g,b) = I_a k_a(r,g,b) + I_p[k_d(r,g,b)(\overline{N} \bullet \overline{L}) + k_s(\overline{R} \bullet \overline{V})^n]$$

OpenGL Lighting Model

- The OpenGL lighting model is simple.
- Types of lights
  - **Ambient light** is light that has been reflected so much that it doesn't seem to come from anywhere and illuminates from all directions equally
  - **Point lights** – rays emanate in all directions. Small compared to objects in the scene
  - **Spot lights** – rays emanate in a narrow range of angles





Lights in OpenGL

- Most implementations of OpenGL can have up to 8 lights in the scene
  - Each light can have a diffuse and a specular component
  - Each light can also have an ambient component (light that is reflected off of so many surfaces, we can't tell where it comes from)
  - Lights are referred to by the macros GL_LIGHT0, GL_LIGHT1, … , GL_LIGHT8
  - We set the properties of lights with calls to the function "glLightfv" (v stands for vector)

Lights in OpenGL

- glLightfv(Light #, Property, Array of Vals)
  - Light # = One of GL_LIGHT*i*
  - Property, one of
    - GL_AMBIENT
    - GL_DIFFUSE
    - GL_SPECULAR
    - GL_POSITION = where is the light?
  - Array of values = value for the property

Shading

- Shading is the process of determining the colors of all the pixels covered by a surface using an illumination model
- Simplest method is to
  - determine surface visible at each pixel
  - compute normal of the surface
  - evaluate light intensity and color using an illumination model
- This is quite expensive. The shading methods could be made efficient by customizing for specific surface representation

Shading Models

- Shading Models give a technique to determine the colors of all the pixels covered by a surface using appropriate illumination model
- Polygonal meshes are commonly used for representing complex surfaces
- The geometric information is available only at the vertices of a polygon
- Interpolative shading models could be used to increase the efficiency substantially

Constant Shading

- It is the simplest of the shading models and is also called as ***faceted shading*** or ***flat shading***
- One polygon receives only one intensity value
- Illumination model is applied only once for each polygon
- Makes the following assumptions
  - light source is at infinity, so $\bar{N} \cdot \bar{L}$ is constant across a polygon face
  - viewer is at infinity, so $\bar{R} \cdot \bar{V}$ is constant across the polygon face
  - polygon represents the actual surface being modeled

Constant Shading

- It is a fast technique for shading as it involves very less calculations
- If the polygons are very small (say one pixel large) when projected on the screen then the result is as good as any interpolative technique
- Usually used for coarse preview of scenes

OpenGL uses the normal of the **first vertex** of a single polygon to determine the color.

glShadeModel(GL_FLAT);

Gouraud Shading

- It is an interpolative shading method, also called *intensity* ***interpolation shading*** or ***color interpolation shading***
- Involves the following steps
  - Normals are computed at the vertex as the average of the normals of all the faces meeting at that vertex
  - Intensity at each vertex is calculated using the normal and an illumination model
  - For each polygon the intensity values for the interior pixels are calculated by linear interpolation of the intensities at the vertices

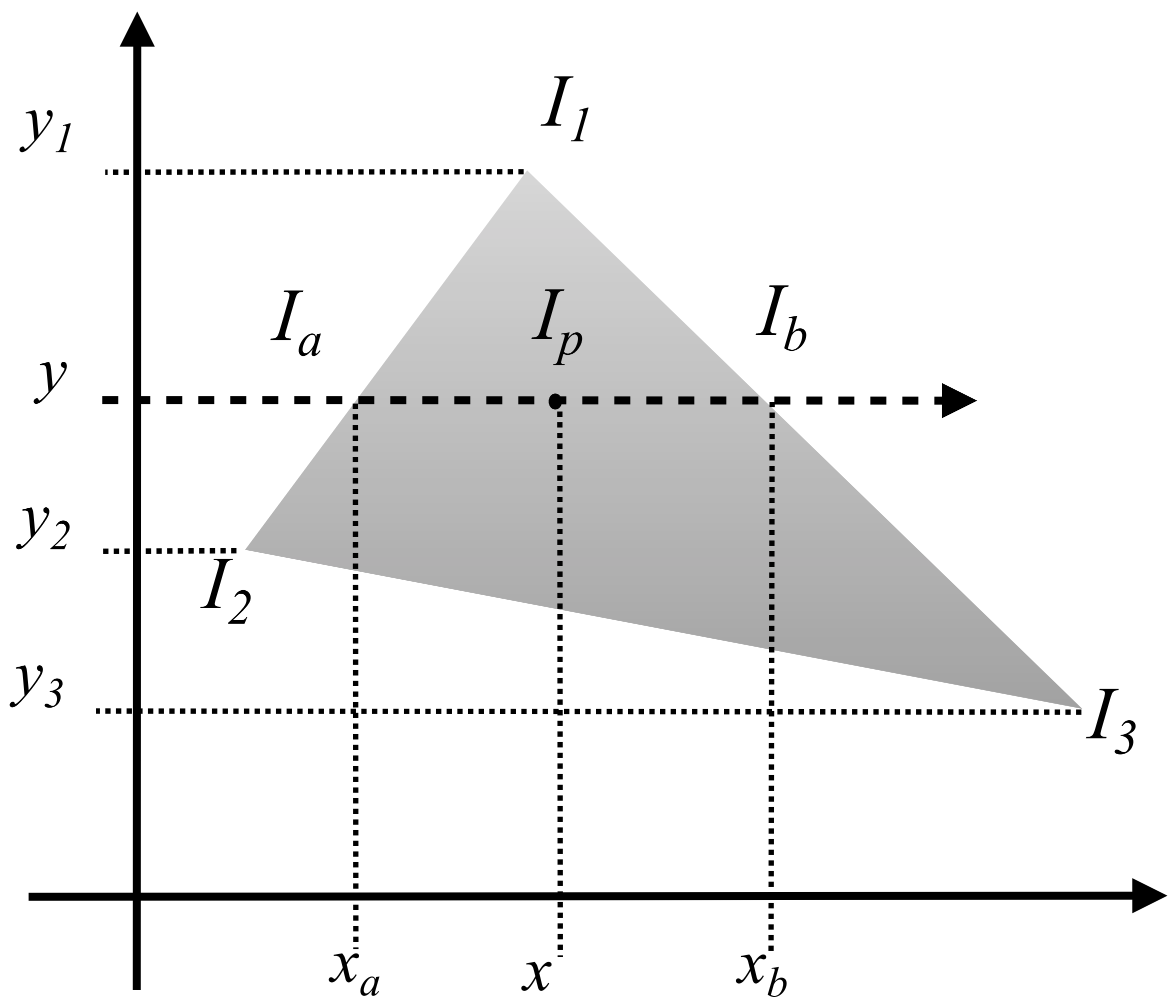
Gouraud Shading

- Intensity I_p at a point is calculated as

$$I_a = I_1 + (I_2 - I_1)\frac{y - y_1}{y_2 - y_1}$$

$$I_b = I_1 + (I_3 - I_1)\frac{y - y_1}{y_3 - y_1}$$

$$I_p = I_a + (I_b - I_a)\frac{x - x_a}{x_b - x_a}$$



Gouraud Shading

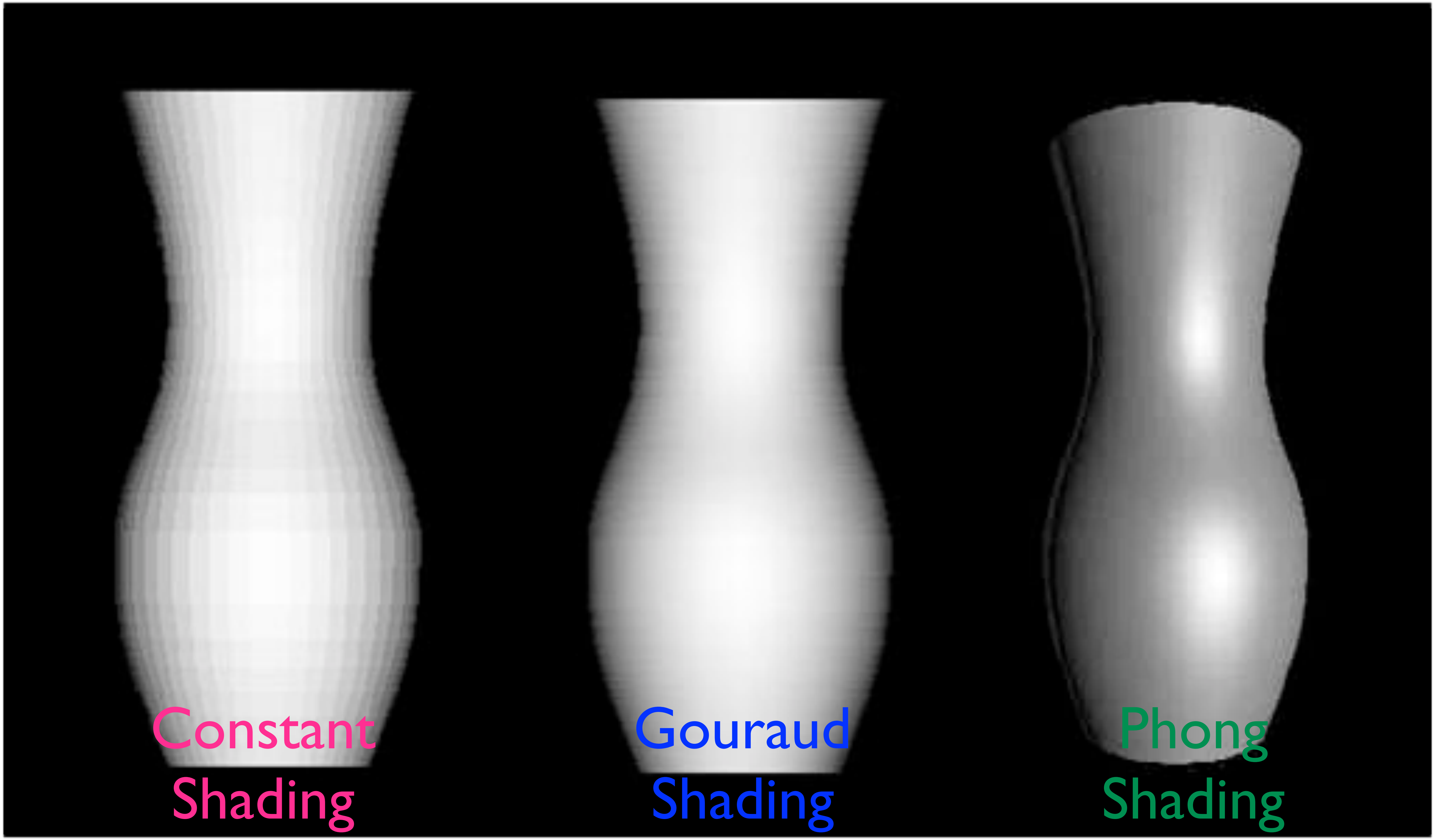
Might miss specular highlights, if the highlight doesn't fall at the vertex

```
glShadeModel(GL_SMOOTH);
```

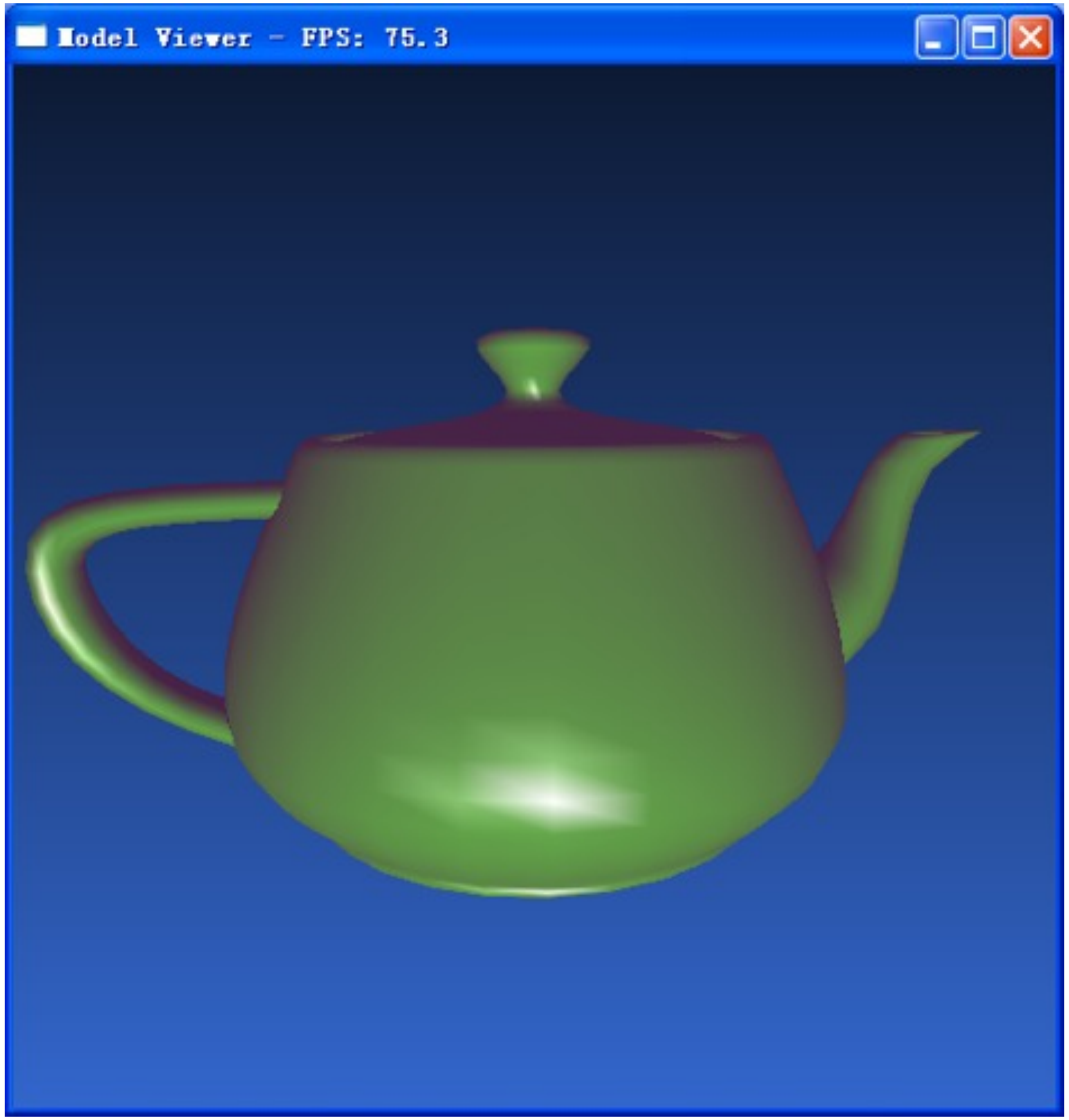
Phong Shading

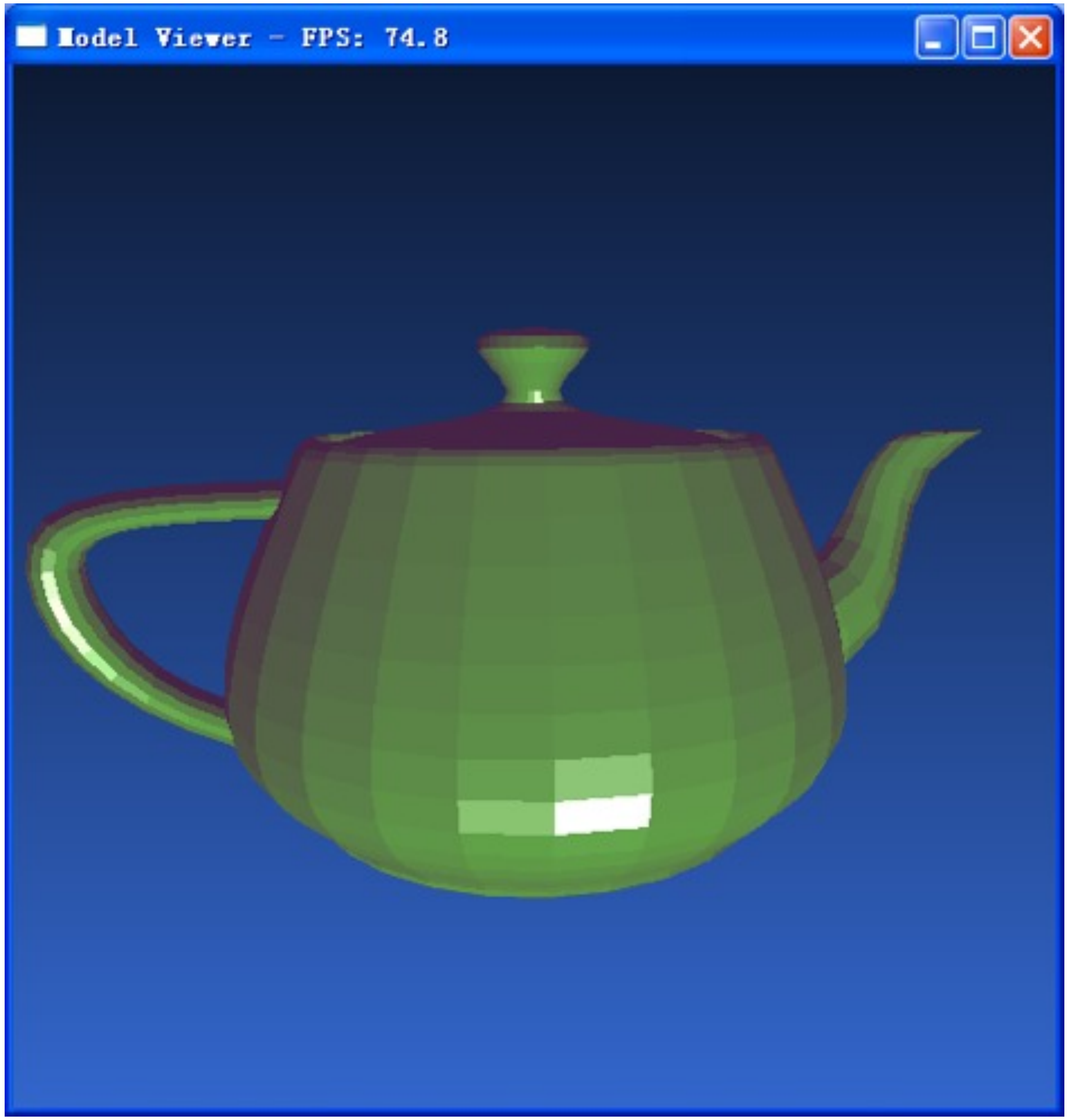
- It is an interpolative shading method, also called:
  - **normal-vector interpolation shading**
- Involves the following steps
  1. Normals are computed at the vertex as the average of the normals of all the faces meeting at that vertex
  2. For each polygon
     the value of the normal for the surface occupied by each interior pixel is calculated by linear interpolation of the normals at the vertices
- Specular reflections are also incorporated
- Interpolation of normals is done exactly like intensity interpolation in Gouraud shading

Phong Shading



Demo – OpenGL Shade Model



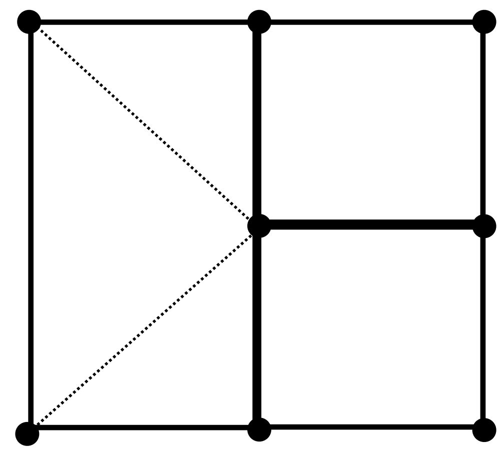


Problems with Interpolated Shading

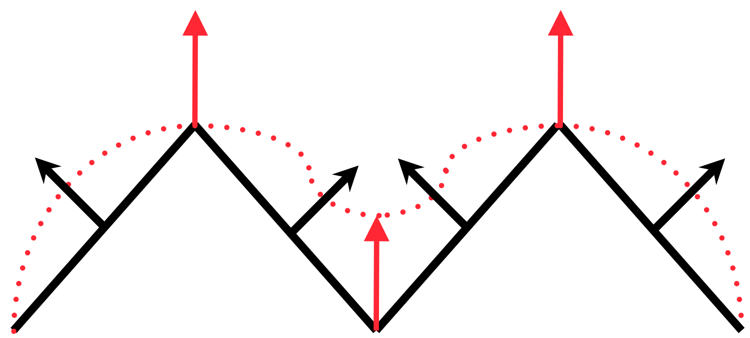
- Polygon silhouette :
  - The silhouette edge of the mesh is always a polygon
- Solution :
  - finer subdivision for the entire surface
  - finer subdivision only along silhouette (view dependent)

Problems with Interpolated Shading

- Problems at shared vertices
  - avoid such cases



- Unrepresentative vertex normals
  - subdividing the polygons before calculating normals



Lighting in OpenGL

Steps of specifying lighting in OpenGL

1. Define normal vectors for each vertex of every object.
2. Create, position, and enable one or more light sources.
3. Select a lighting model.
4. Define material properties for the objects in the scene.

Specifying Materials in OpenGL

General form:

glMaterialf(face, parameter,value);
glMaterialfv(face, parameter,*array);

face **is** GL_FRONT, GL_BACK, GL_FRONT_AND_BACK

parameter **is:**

GL_AMBIENT **four values that specify the ambient RGBA reflectance of the material.** (0.2,0.2,0.2,1.0)

GL_DIFFUSE **four values that specify the diffuse RGBA reflectance of the material.** (0.8,0.8,0.8,1.0)

GL_SPECULAR **four values that specify the ambient RGBA reflectance of the material.** (0.0,0.0,0.0,1.0)

GL_SHININESS **specifies the specular reflectance exponent of the material.** 0.0

Demo - Materials