Illumination models and surface rendering methods

Unit 6

Illumination and surface rendering model

- Once visible surface has been identified by hidden surface algorithm, a shading model is used to compute the intensities and color to display for the surface. For realistic displaying of 3d scene it is necessary to calculate appropriate color or intensity for that scene.
- **Illumination model or a lighting model** is the model for calculating light intensity at a single surface point. Sometimes also referred to as a **shading model**.
- An illumination model is also called ***lighting model*** and some times called as a ***shading model*** which is used to calculate the intensity of light that we should see at a given point on the surface of a object.
- A surface-rendering algorithm uses the intensity calculations from an illumination model.

Components of Illumination model

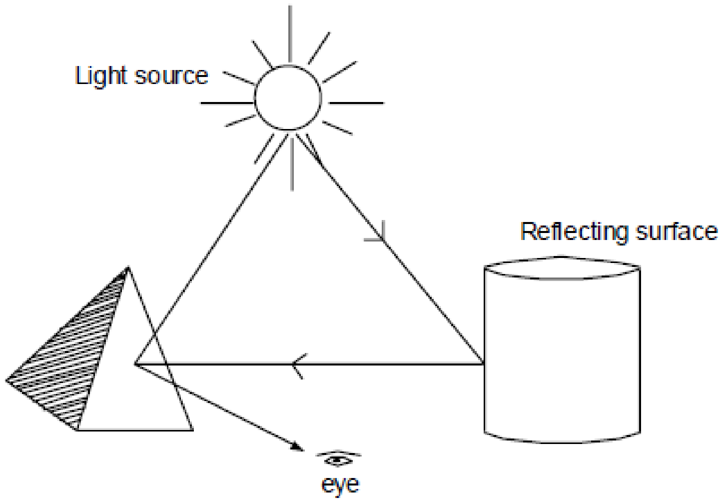
- **Light Sources:** type , color, and direction of the light source
- **Surface Properties :** réflectance, opaque/transparent, shiny/dull.

Illumination And Rendering

- An ***illumination model*** in computer graphics
  - also called a ***lighting model*** or a ***shading model***
  - used to calculate the color of an illuminated position on the surface of an object
  - Approximations of the physical laws
- A ***surface-rendering method*** determine the pixel colors for all projected positions in a scene

Light Source

- Object that radiates energy are called light sources, such as sun, lamp, bulb, fluorescent tube etc.
- Sometimes light sources are referred as light emitting object and light reflectors. Generally light source is used to mean an object that is emitting radiant energy e.g. Sun.
- ***Total Reflected Light*** = Contribution from light sources + contribution from reflecting surfaces



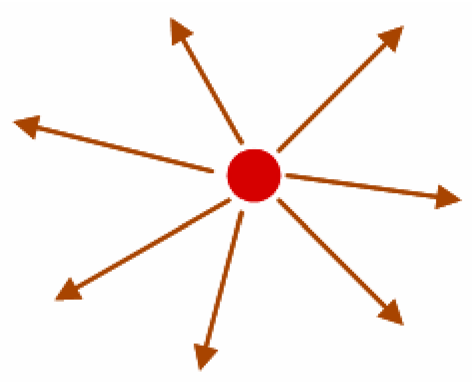
Light Source..

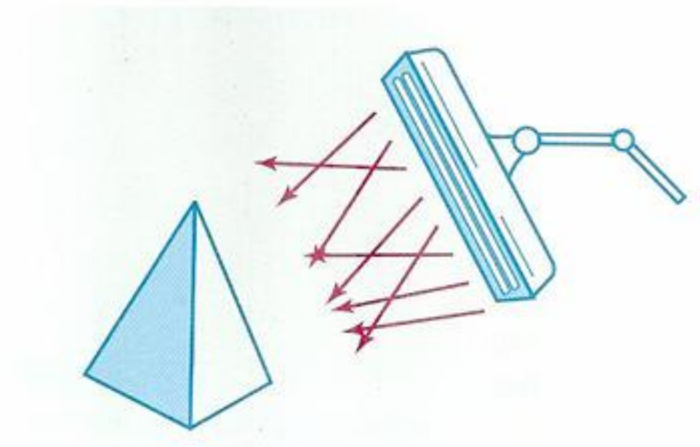
Point Source:

Point source is the simplest light emitter e.g. light bulb. when light source model is a reasonable approximation for sources whose dimensions are small compared to the size of objects in a scene.

Distributed Light Source:

area of source is not small compared to the surfaces in the scene e.g. Fluorescent lamp


Point Light Source


Distributed Light Source

Reflection of light:

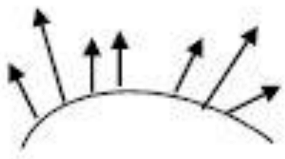
When light is incident on opaque surface ***part of it is reflected*** and ***part of it is absorbed***.

$\therefore$ I = A+R

- The amount of incident light reflected by a surface depends on the type of material. Shining material reflects more incident light and dull surface absorbs more of the incident light. For transparent surfaces, some of the incident light will be reflected and some will be transmitted through the material.

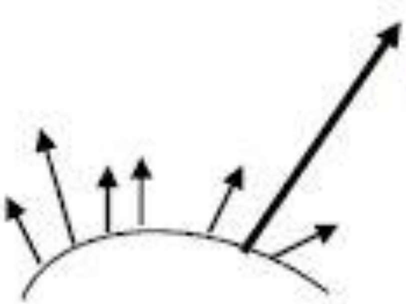
Distributed light source

- When light is incident on an opaque surface part of it is reflected and part of it is absorbed.
- Surface that are rough or grainy, tend to scatter the reflected light in all direction which is called **diffuse reflection**.



Diffuse reflection

- When light sources create highlights, or bright spots, called **specular reflection**



Specuular reflection

Light Source..

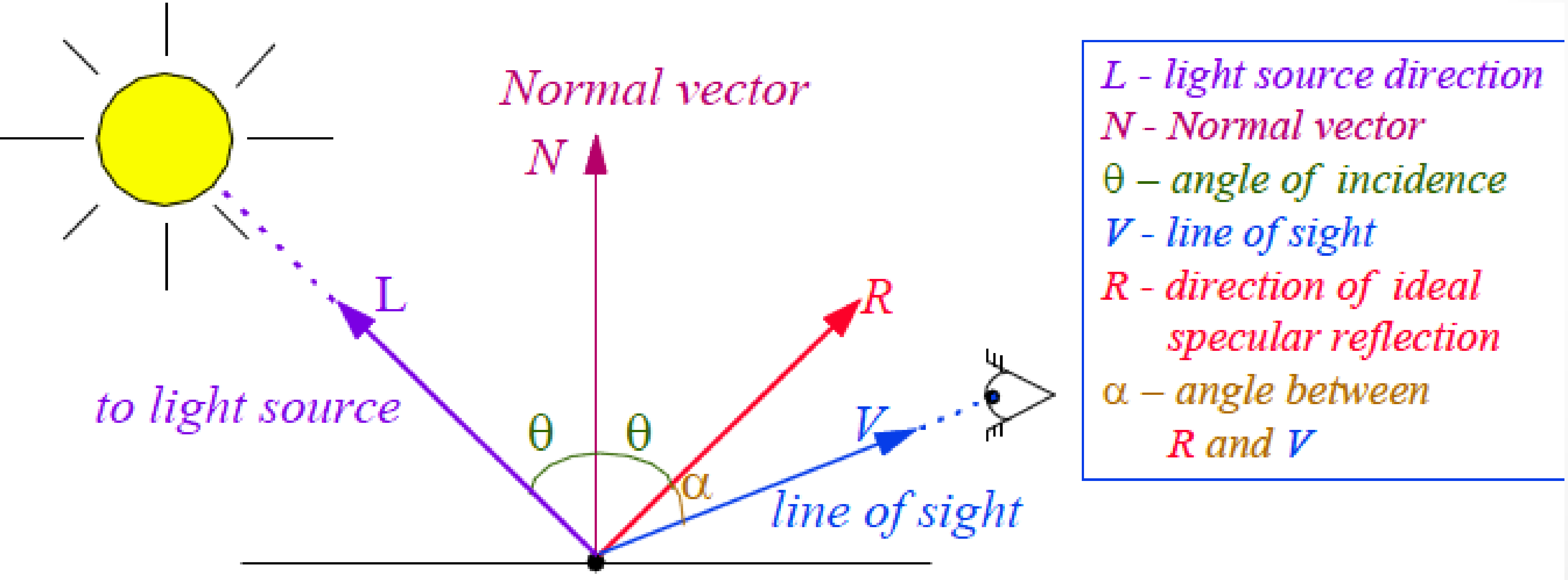
- ***Point source***: Simplest model for a light emitter like tungsten filament bulb
- ***Distributed light source***: The area of the source is not small compared to the surfaces in the scene like fluorescent light on any object in a room
- ***Diffuse reflection:*** Scatter reflected light in all direction by rough or grainy surfaces.
- ***Specular-reflection***: highlights or bright spots created by light source, particularly on shiny surfaces than on dull surfaces.

Illumination models:

Illumination models are used to calculate light intensities that we should see at a given point on the surface of an object. Lighting calculations are based on the optical properties of surfaces, the background lighting conditions and the light source specifications. All light sources are considered to be ***point sources***, specified with a co-ordinate position and an intensity value (color). Some illumination models are:

1. **Ambient Light**
2. **Diffuse Reflection**
3. **Specular Reflection and phong model**

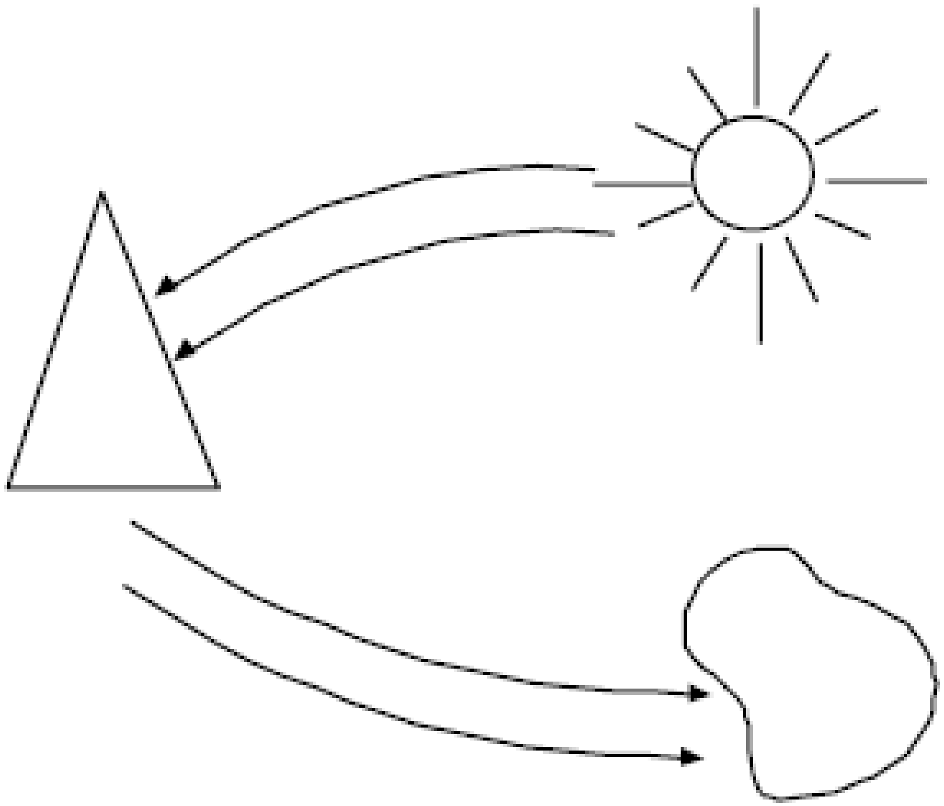
Some useful concept



1. Ambient light:

- This is a simplest illumination model
- We can think of this model, which has no external light source-self-luminous objects. A surface that is not exposed directly to light source still will be visible if nearby objects are illuminated.
- The combination of light reflections form various surfaces to produce a uniform illumination is called ambient light or background light.
- Also called background light
- **Ambient light** means the **light** that is already present in a scene, before any additional **lighting** is added. It usually refers to natural **light**, either outdoors or coming through windows etc. It can also mean artificial **lights** such as normal room **lights**.

1. Ambient light:



1. Ambient light ...

- Multiple reflection of nearby (light-reflecting) objects yields a uniform illumination
- A form of diffuse reflection independent of the viewing direction and the spatial orientation of a surface
- Ambient light has no spatial or directional characteristics and amount on each object is a constant for all surfaces and all directions. In this model, illumination can be expressed by an illumination equation in variables associated with the point on the object being shaded. The equation expressing this simple model is

$$I = K_a$$

Where I is the resulting intensity and K_a is the object's intrinsic intensity.

1. Ambient light ...

- If we assume that ambient light impinges equally on all surface from all direction, then

$$I = I_a K_a$$

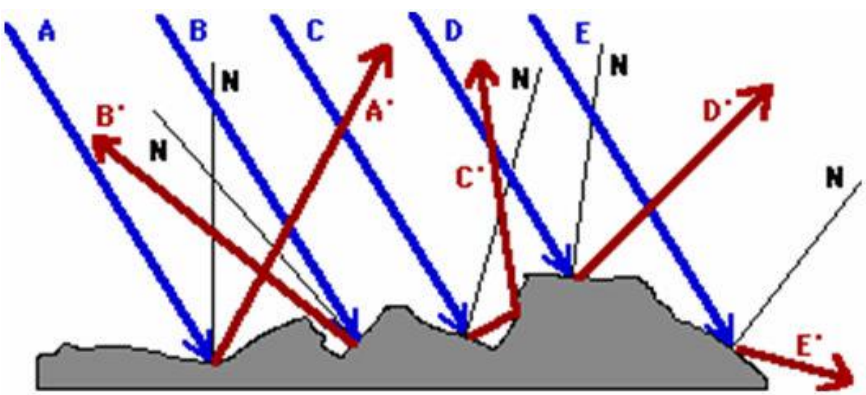
Where I_a is ***intensity of ambient light***.

K_a is ***object's intrinsic intensity***.

The amount of light reflected from an object's surface is determined by K_a , the ambient-reflection coefficient. K_a ranges from 0 to 1.

2. Diffuse Reflection

- Objects illuminated by ambient light are uniformly illuminated across their surfaces even though light are more or less bright in direct proportion of ambient intensity.
- Surfaces are rough
- Incident light is scattered with equal intensity in all directions
- Surfaces appear equally bright from all direction.
- Such surfaces are called ***ideal diffuse reflectors*** (also referred to as ***Lambertian reflectors***)



Diffuse Reflection From a Surface

2. Diffuse Reflection…

- Illuminating object by a point light source, whose rays enumerate uniformly in all directions from a single point. The object's brightness varies form one part to another, depending on the direction of and distance to the light source.
- Color of an object is determined by the color of the diffuse reflection of the incident light.
- If any object surface is red then there is a diffuse reflection for red component of light and all other components are absorbed by the surface.

2. Diffuse Reflection…

The ***diffuse-reflection coefficient***, or ***diffuse reflectivity,*** **kd** (varying from 0 to 1) define the fractional amount of the incident light that is diffusely reflected.

The parameter k_d (actually function of surface color)depends on the reflecting properties of material so for highly reflective surfaces, the k_d nearly equal to 1.

If a surface is exposed only to ambient light, we can express the intensity of the diffuse reflection at any point on the surface as:

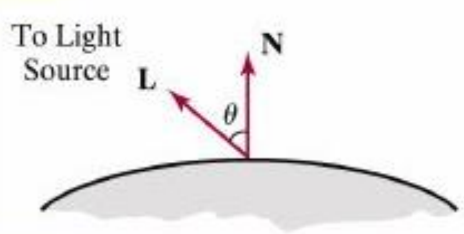
$\mathbf{I_{amb},Diff = k_d \cdot I_a}$, (where I_a = intensity of ambient light)

2. Diffuse Reflection…

If N is the unit normal vector to a surface and L is the unit direction vector to the point light source from a position on the surface then **cos θ = N.L** *(**Lambertian Cosine Law**)* and the diffuse reflection equation for single point source illumination is:

$$I_L, \text{diff} = k_d \,.\, I_L \cos\theta = k_d\, I_L\, (N.L)$$

$$I_{diff} = k_d I_l \cos\theta = k_d I_l (N \cdot L)$$



I_l : the intensity of the light source

k_d : diffuse reflection coefficient,

N : the surface normal (unit vector)

L : the direction of light source, (unit vector)

When cosΘ is
+ve surface is illuminated
-ve light source is behind the surface

2. Diffuse Reflection...

We can combine the ambient and point source intensity calculations to obtain an expression for the total diffuse reflection. Thus, we can write the total diffuse reflection equation as:

$$I_{Diff} = k_d \cdot I_a + k_d \, I_L \, (N.L)$$

ambient

Diffuse for single point

Lambert's Cosine Law:

The intensity of diffuse reflection due to ambient light is;

$$I_{adiff} = k_a I_a$$

The radiant energy from any small surface dA in any direction relative to surface normal is proportional to cos θ. That is, brightness depends only on the angle θ between the light direction L and the surface normal N.

∴ Light intensity **α cos θ**.

If I_l is the intensity of the point light source and k_d is the diffuse reflection coefficient, then the diffuse reflection for single point-source can be written as;

$$I_{pdiff} = k_d I_l \cos\theta$$

$$I_{pdiff} = k_d I_l (N \cdot L)$$

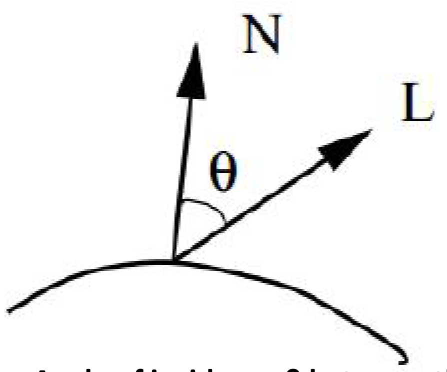


Fig: Angle of incidence θ between the unit light-source direction vector L and the unit surface normal

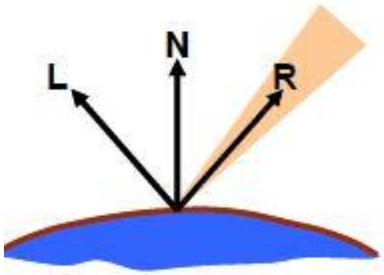
∴ **Total diffuse reflection (Idiff) = Diff (due to ambient light)+Diff. due to pt.source.**

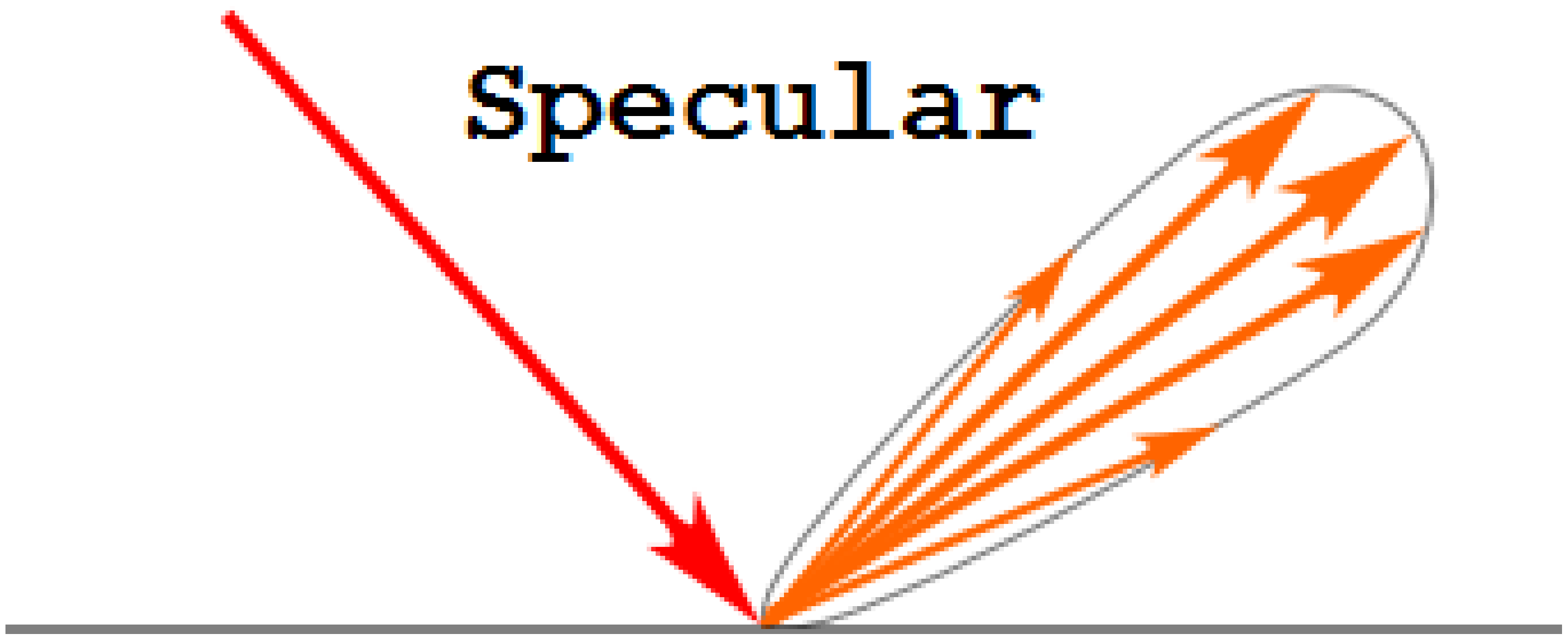
$$I_{diff} = I_{adiff} + I_{pdiff}$$

$$I_{diff} = k_a I_a + k_d I_l (N \cdot L)$$

3. Specular reflection and phong model

- When we look at an illuminated shiny surface, such as polished metal, a person's forehead, we see a highlight or bright spot, at certain viewing direction. Such phenomenon is called **specular reflection**.
- It is the result of total or near total reflection of the incident light in a concentrated region around the " specular reflection angle = angle of incidence".
- Perfect reflector (mirror) reflects all lights to the direction where angle of reflection is identical to the angle of incidence
- It accounts for the ***highlight***




Specular

3. Specular reflection and phong model

Let SR angle = angle of incidence as in figure.

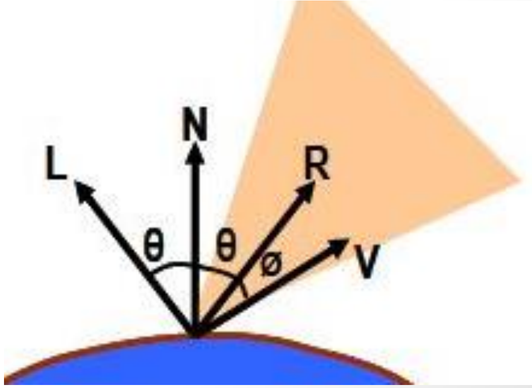
N - unit vector normal to surface at incidence point

R - unit vector in the direction of ideal specular reflection.

L - unit vector directed to words point light source.

V - unit vector pointing to the viewer from surface.

Ø– the viewing angle relative to the specular reflection direction.



3. Specular reflection and phong model

- For ideal reflector (perfect mirror), incident light is reflected only in the specular reflection direction.

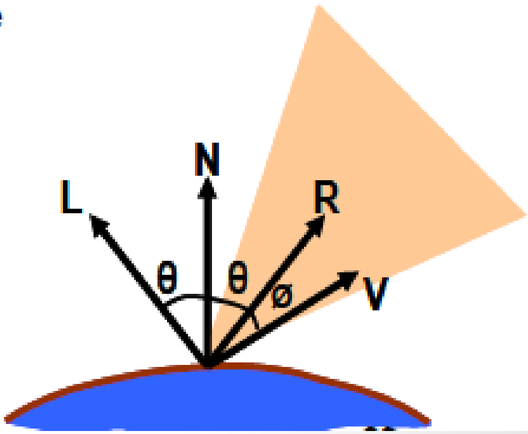
  V & R concide (Ø = 0)
- Shiny surface have narrow Ø and dull surface wider Ø .
- An empirical model for calculating specular-reflection range developed by Phong Bui Tuong-called ***Phong*** specular reflection model (or simply ***Phong model***), sets the intensity of specular reflection proportional to $\cos^{ns} \phi$ → 0 to 90^0 .
- Specular reflection parameter n_s is determined by type of surface
- Intensity of specular reflection depends upon material properties of the surface and θ . Other factors such as the polarization and color of the incident light.
- \- For monochromatic specular intensity variations can approximated by ***SR coefficient*** $W(\theta)$

3. Specular reflection and phong model

- Sets Intensity of specular reflection proportional to $\cos^{n_s}\phi$
  - $n_s \rightarrow$ specular reflection parameter (depends on surface)
  - $\emptyset$ ranges from 0 to 90^0 ($\cos\emptyset$ varies from 0 to 1)
- Intensity of specular reflection depends on:
  - Material properties of surface
  - Angle of incidence θ
  - Other factors such as polarization and color of the incident light
- Monochromatic specular intensity variations can be approximated using **specular-reflection coefficient**, $W(\theta)$ for each surface

$$I_{spec} = w(\theta) I_l \cos^{n_s}\phi$$

- At $\theta = 90^0$, $w(\theta) = 1 \rightarrow$ all incident light is reflected



3. Specular reflection and phong model

- Fresnal's law of reflection describe specular reflection intensity with and using w(θ) , Phong specular reflection model as

$$I_{spec} = w(\theta)\, I_L \cos^{ns} Ø$$

  - Where I_l is intensity of light source. is viewing angle relative to SR direction R. For a glass, we can replace w(θ) with constant Ks specular reflection coefficient.

So,

$$I_{spec} = K_s\, I_L \cos^{ns} Ø$$

$$= K_s\, I_L\, (V.R)^{ns} \quad \textit{since}\ \cos Ø = V.R$$

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3. Specular reflection and phong model

$$I_{spec} = k_s I_l \cos^{n_s} \phi = k_s I_l (R \cdot V)^{n_s}$$

N = unit normal Vector
L = unit vector towards light source
R = unit vector to specular reflection direction
V = unit vector towards viewer
ϕ = angle between R and V

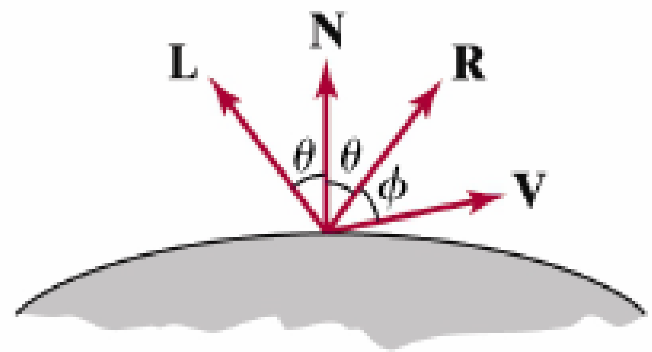


Figure 10-16

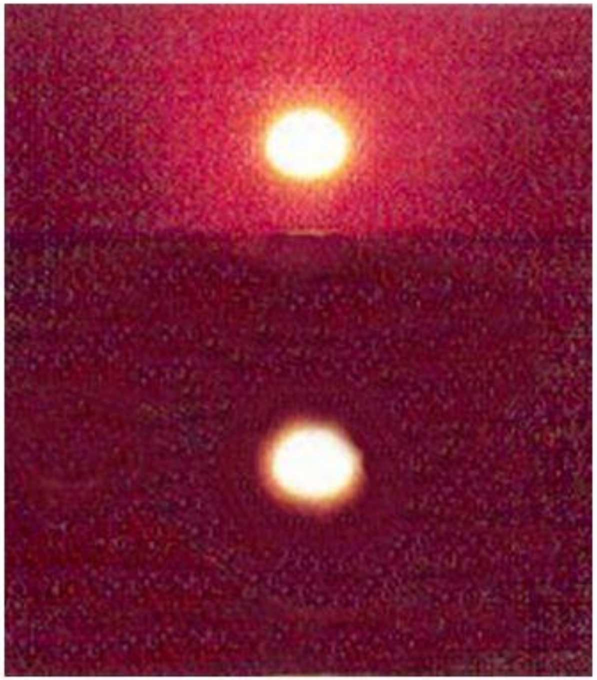
Specular reflection angle equals angle of incidence θ.

I_l : intensity of the incident light

k_s : color-independent specular coefficient

n_s : specular reflection parameter (depends upon surface)

TWO KIND OF REFLECTIONS



Specular reflection

Diffuse reflection

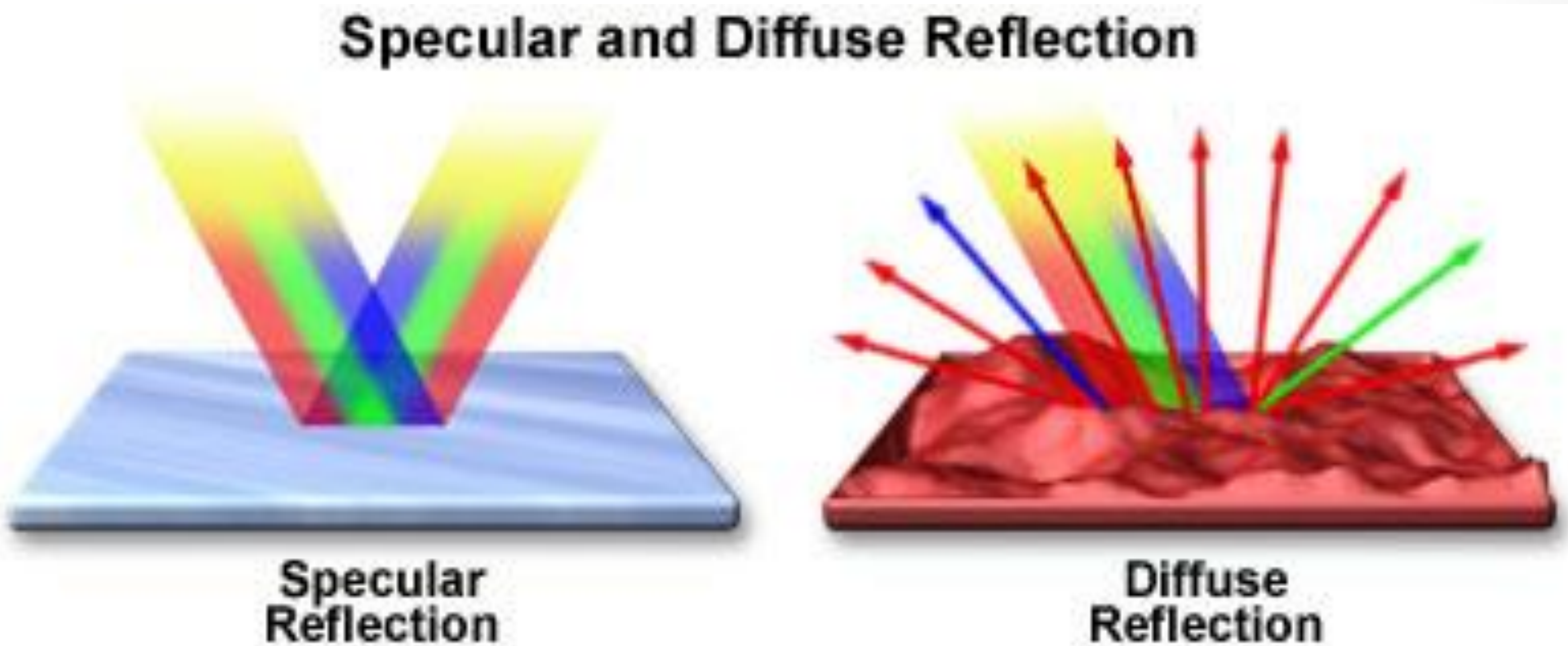
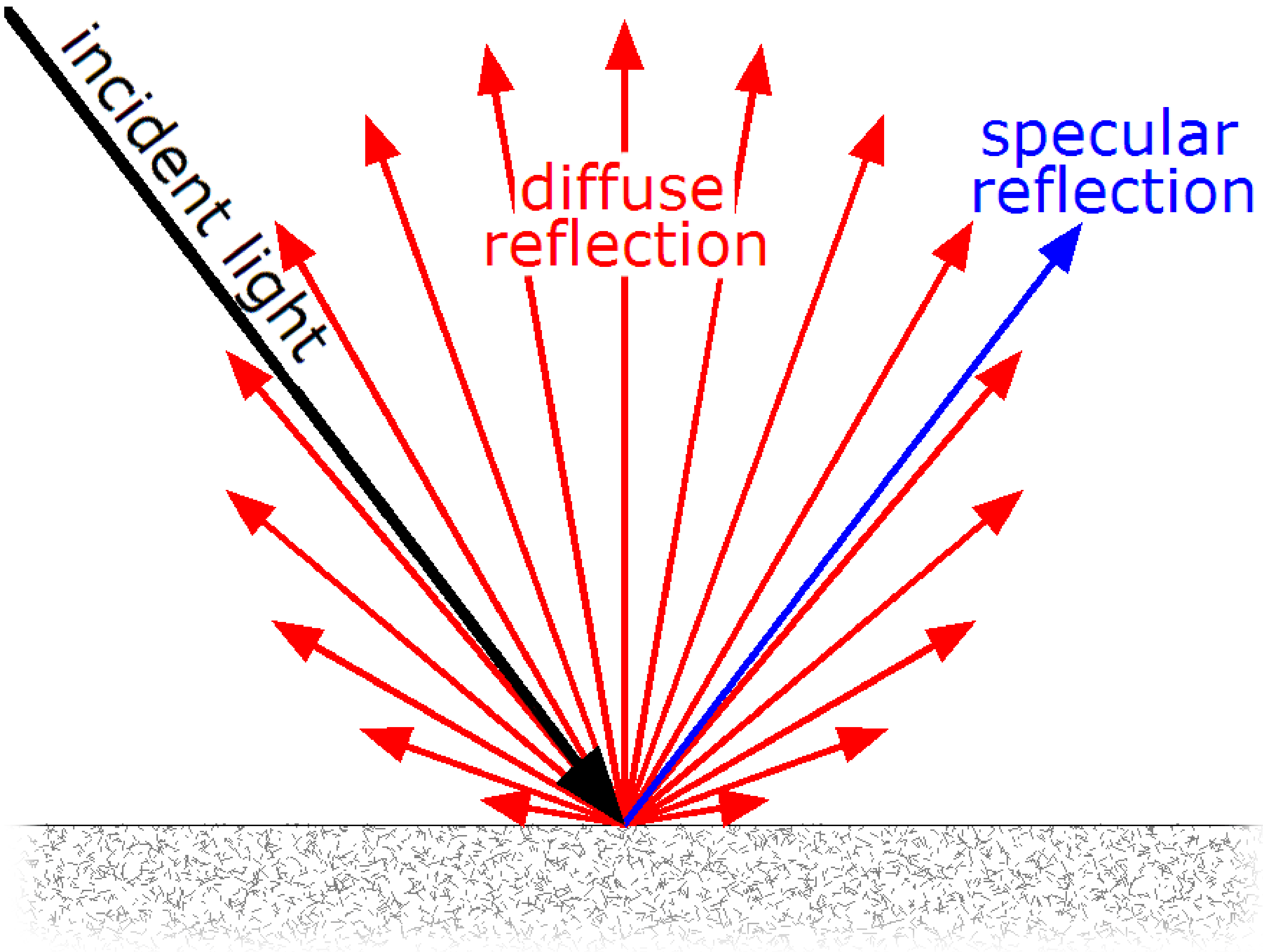

Specular and Diffuse Reflection
Specular Reflection
Diffuse Reflection

Figure 1


incident light
diffuse reflection
specular reflection

Intensity Attenuation

As radiant energy from a point light source travels through space, its amplitude is attenuated by the factor **$1/d^2$,** where d is the distance that the light has traveled.

This means that *a surface close to the light source (small* ***d)*** *receives higher incident intensity from the source than a distant surface (large* ***d).***

Therefore to produce realistic lighting effects, illumination model should take intensity attenuation into account. Otherwise we are likely to illuminate all surfaces with same intensity.

- For a point light source attenuation factor is $1/d^2$.
- And for a distributed light source attenuation factor is given by **inverse quadratic attenuation function**, **$f(d) = 1/(a_0 + a_1 d + a_2 d^2)$.**

Intensity Attenuation

- Intensity attenuation must be considered for producing realistic lighting effects.
- Intensity of radiant energy at a point *d* distance far from source is attenuated by $1/d^2$
- **attenuation factor $1/d^2$** *produces* too much intensity variation
- Using inverse linear quadratic function of d for intensity attenuation as:

$$f(d) = \frac{1}{a_0 + a_1 d + a_2 d^2}$$

  - a_0 can be adjusted to prevent f(d) from becoming too large when d is very small
  - Magnitude of attenuation function is limited to 1 as

$$f(d) = \min\left(1, \frac{1}{a_0 + a_1 d + a_2 d^2}\right)$$

The Phong illumination model considering attenuation is:

$$I = k_a I_a + \sum_{i=1}^{n} f(d_i) I_{li} \left[k_d (N.L_i) + k_s (N.H_i)^{n_s} \right]$$

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Color Consideration

- For RGB description, each color in a scene is expressed in terms of R,G and B components
- Various methods:
  - Described by considering the RGB components for e.g. (k_{dR}, k_{dG}, k_{dB}) of diffuse reflection coefficient vector
    - e.g. For blue light $(k_{dR}=k_{dG}=0)$

$$I_B = k_{aB} I_{aB} + \sum_{i=1}^{n} f(d_i) I_{lBi} \left[k_{dB} (N.L_i) + k_{sB} (N.H_i)^{n_s} \right]$$

  - Described by specifying components of diffuse and specular color vectors for each surface and retaining the reflectivity (k) as a single valued constants

$$I_B = k_a S_{dB} I_{aB} + \sum_{i=1}^{n} f(d_i) I_{lBi} \left[k_d S_{dB} (N.L_i) + k_s S_{sB} (N.H_i)^{n_s} \right]$$

  - Described by specifying wavelength for a color specification. This specification is useful to specify color as more than three components

$$I_B = k_a S_{d\lambda} I_{a\lambda} + \sum_{i=1}^{n} f(d_i) I_{l\lambda i} \left[k_d S_{d\lambda} (N.L_i) + k_s S_{s\lambda} (N.H_i)^{n_s} \right]$$

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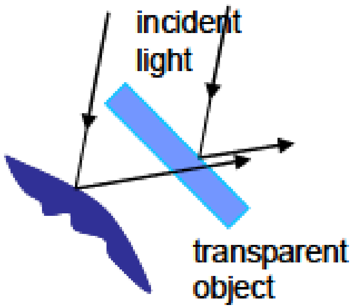
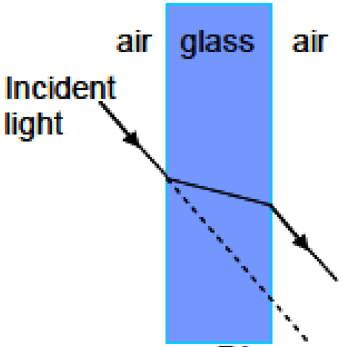
Transparency

- Transparent surface produces both reflected and transmitted light
- Light intensity depends on relative transparency and position of light source or illuminated object behind or in front of the transparent surface
- To model transparent surface, intensity contribution of light from various sources (illuminated objects) that are transmitted from the surface must be considered in the intensity equation
- Both diffuse and specular reflection take place on transparent surface
- Diffuse effects are important for partially transparent surfaces such as frosted glass
- The Snell's law is used to calculate the refracted ray direction

$$\sin\theta_r = \frac{\eta_i}{\eta_r}\sin\theta_i$$





Transparency

- Transmitted intensity I_{trans} through a transparent surface from a background object and Reflected intensity I_{refl} from the transparent surface with ***transparency coefficient*** k_t is given by

$$I = (1-k_t)I_{refl} + k_t I_{trans}$$

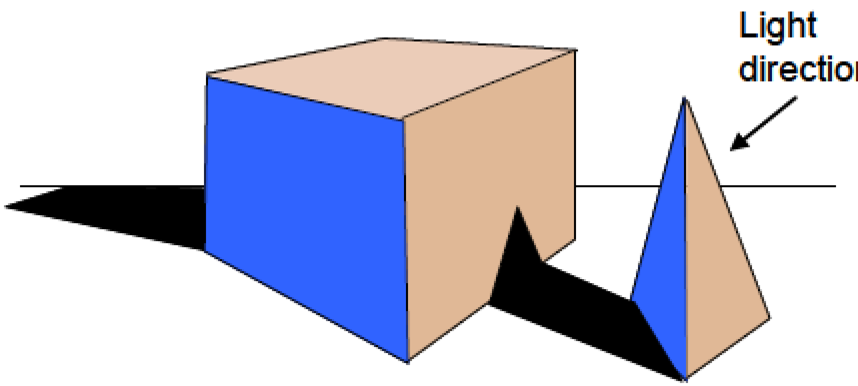
where $(1-k_t)$ is ***opacity factor***

Transparency effects Implementation:

1. *Process opaque objects first to determine depths for visible opaque surfaces.*
2. *Depth positions of the transparent objects are compared to the values previously stored in the depth buffer.*
3. *If any transparent surface is visible, its reflected intensity is calculated and combined with the opaque-surface intensity previously stored in the frame buffer.*
4. *Visible transparent surfaces are then rendered by combining their surface intensities with those of the visible and opaque surfaces behind them.*

Shadow

- Hidden surface method with light source at the view position can be used
- The shadow area for all light sources are determined and these shadows could be treated as a surface pattern arrays



Shadow

- Shadow can help to create realism. Without it, a cup, e.g., on a table may look as if the cup is floating in the air above the table.
- By applying hidden-surface methods with pretending that the position of a light source is the viewing position, we can find which surface sections cannot be "seen" from the light source => shadow areas.
- We usually display shadow areas with ambient-light intensity only.

Polygon Rendering Method (Surface Shading Method)

- Objects usually polygon-mesh approximation
- Illumination model is applied to fill the interior of polygons
- Curved surfaces are approximated with polygon meshes
  - But polyhedra that are not curved surfaces are also modeled with polygon meshes
- **Two ways** of polygon surface rendering:
  1. Single intensity for all points in a polygon
  2. Interpolation of intensities for each point in a polygon
- Methods:

  1. Constant Intensity Shading

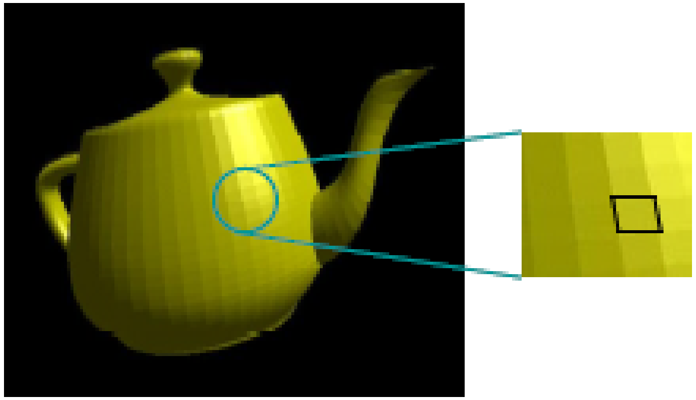
  2. Gouraud Shading

  3. Phong Shading

1. Constant Intensity Shading

-Fast and simple method for rendering an object with polygon surface

-Each polygon shaded with single intensity calculated for the polygon



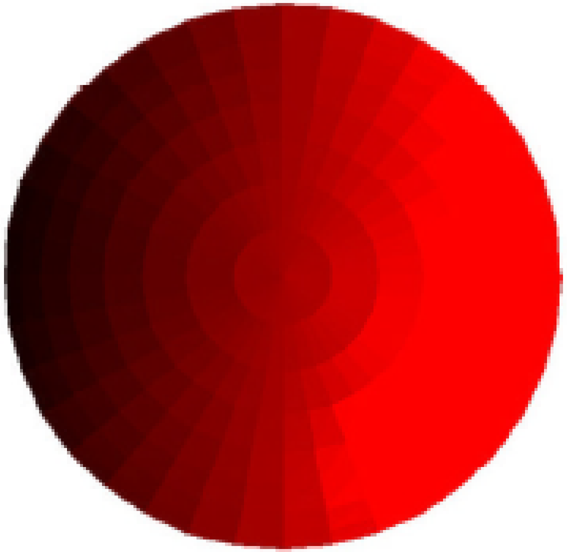
PROCEDURE

1. Take a point on the object surface and calculate the intensity
2. Render the surface with same intensity throughout the surface
3. Repeat above procedure for each polygon surface

ASSUMPTIONS

1. Object is a polyhedron
2. light sources should be sufficiently (i.e. **N.L** and attenuation function are constant)
3. Viewing position is sufficiently far (i.e. **V.R** is constant over the surface)

DRAWBACK: intensity discontinuity at the edges of polygons



2. Gouraud Shading

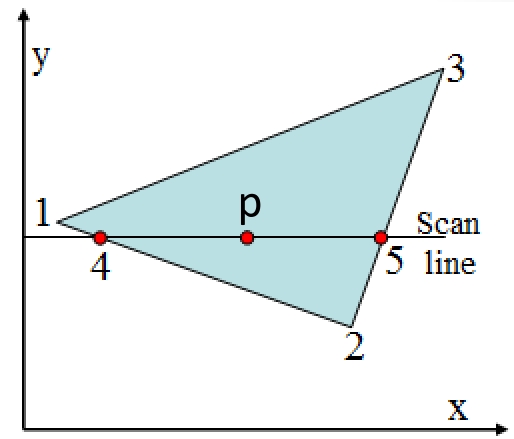
- Intensity interpolation method
- Renders a polygon surface by linearly interpolating intensity values across the surface.
- Intensity discontinuity at the edges of polygons is eliminated by matching intensity values of each polygon with adjacent polygons

PROCEDURE

1. Determine the average unit normal vector at each polygon vertex
2. Calculate each of the vertex intensities by applying an illumination model
3. Linearly interpolate the vertex intensities over the polygon surface

2. Gouraud Shading…..

- For Gouraud shading, the intensity at point 4 is linearly interpolated from the intensities at vertices 1 and 2.
- The intensity at point 5 is linearly interpolated from intensities at vertices 2 and 3.
- An interior point p is then assigned an intensity value that is linearly interpolated from intensities at positions 4 and 5.



$$\mathbf{I_4} = \frac{y_4 - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y_4}{y_1 - y_2} I_2 \qquad \mathbf{I_p} = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x_5 - x_4} I_5$$

2. Gouraud Shading…..

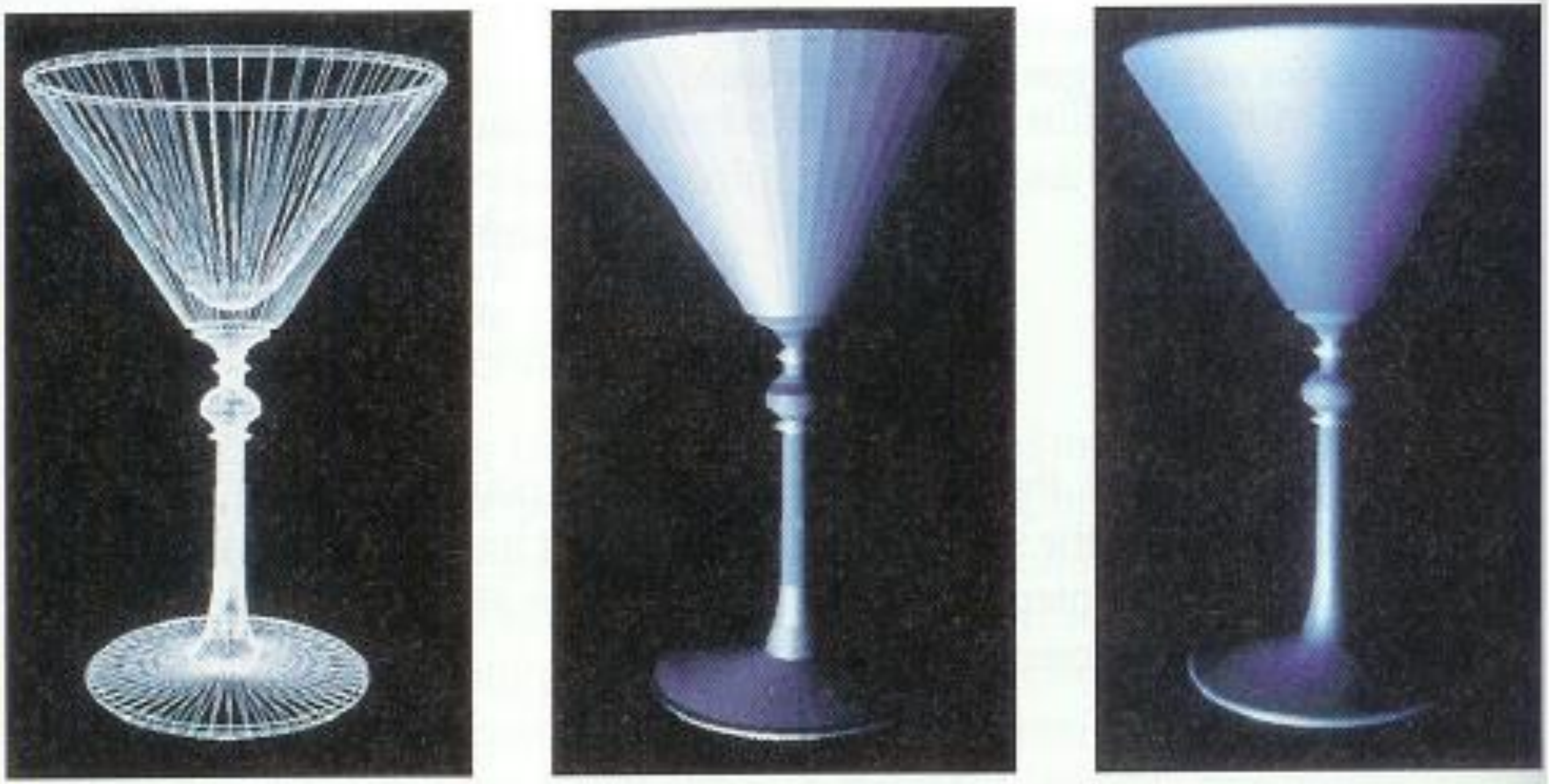
Advantages:

Removes discontinuities of intensity at the edge compared to constant shading model

Limitations:

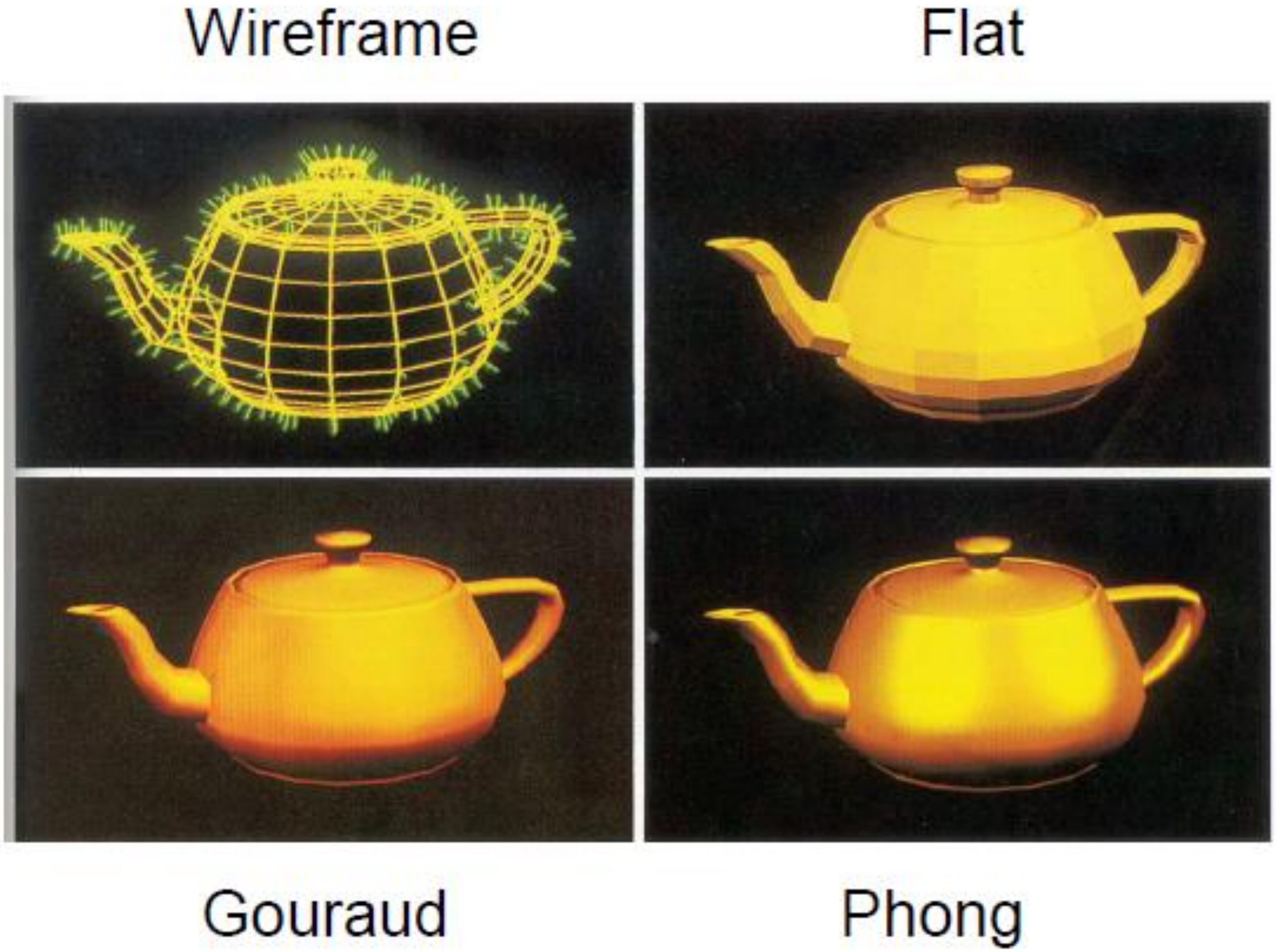
Highlights on the surface are sometimes displayed with anomalous(irregular) shapes and linear intensity interpolation can cause bright or dark intensity streaks, called ***Mach Bands*** to appear on the surfaces. Mach bands can be reduced by dividing the surface into a greater number of polygon faces or Phong shading (*requires more calculation*).

Surface Rendering



Polygon Approximation   Flat Shading   Gouraud Shading

Polygon Shading Algorithms

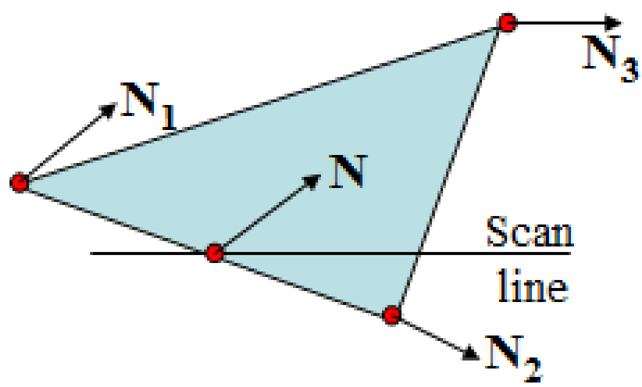


3.Phong Shading

- A more accurate method for rendering a polygon surface is Phong shading, or normal vector interpolation shading which first interpolate normal vectors, and then apply the illumination model to each surface point. It displays more realistic highlights on a surface and greatly reduces the Mach-band effect.
- A polygon surface is rendered using Phong shading by carrying out the **following steps**:
  - Determine the average unit normal vector at each polygon vertex.
  - Linearly interpolate the vertex normals over the surface of the polygon.
  - Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points.

3.Phong Shading

The normal vector **N** for the scan-line intersection point along the edge between vertices 1 and 2 can be obtained by vertically interpolating between edge endpoint normal:



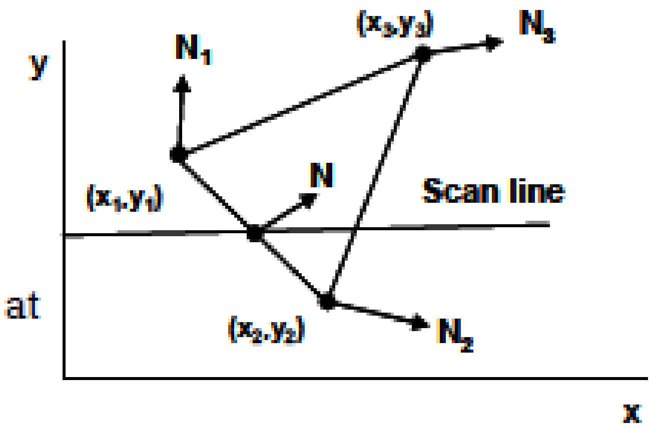
$$N = \frac{y - y_2}{y_1 - y_2} N_1 + \frac{y_1 - y}{y_1 - y_2} N_2$$

Incremental methods are used to evaluate normal between scan lines and along each individual scan line (as in Gouraud). At each pixel position along a scan line the illumination model is applied to determine the surface intensity at that point. Intensity calculations using an ***approximated normal vector*** at each point along the scan line produce more accurate results than the ***direct interpolation of intensities***, as in Gouraud shading but it requires considerable more calculations.

3.Phong Shading

- More accurate method for rendering
- Interpolate normal vectors and apply illumination model to each surface point
- **PROCEDURE**

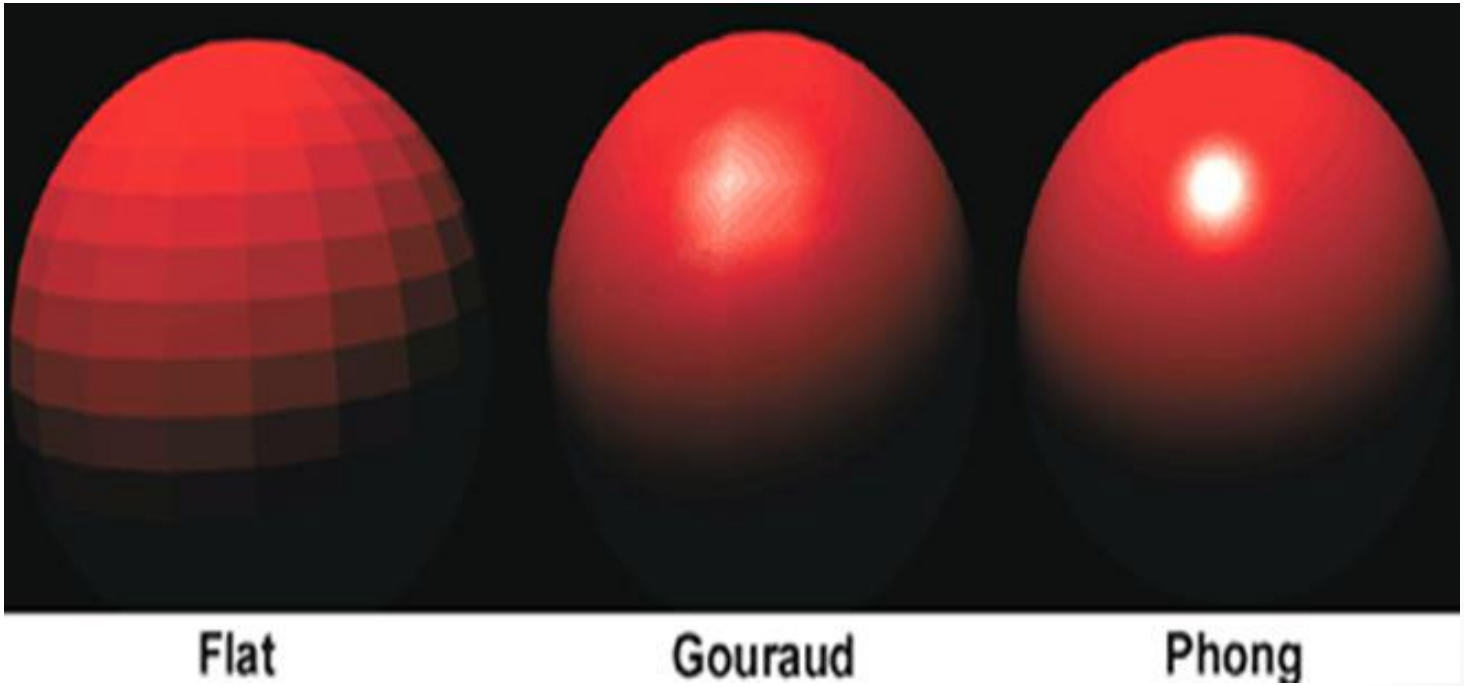
1. Determine average unit normal vectors at each polygon vertex
2. Linearly interpolate the vertex normals over the surface of the polygon
3. Apply an illumination model along each scan line to calculate projected pixel intensities for the surface points



$$N = \frac{y - y_2}{y_1 - y_2} N_1 + \frac{y_1 - y}{y_1 - y_2} N_2$$

Gouraud Vs Phong Shading

- Gouraud shading is faster than Phong shading
- Phong shading is more accurate



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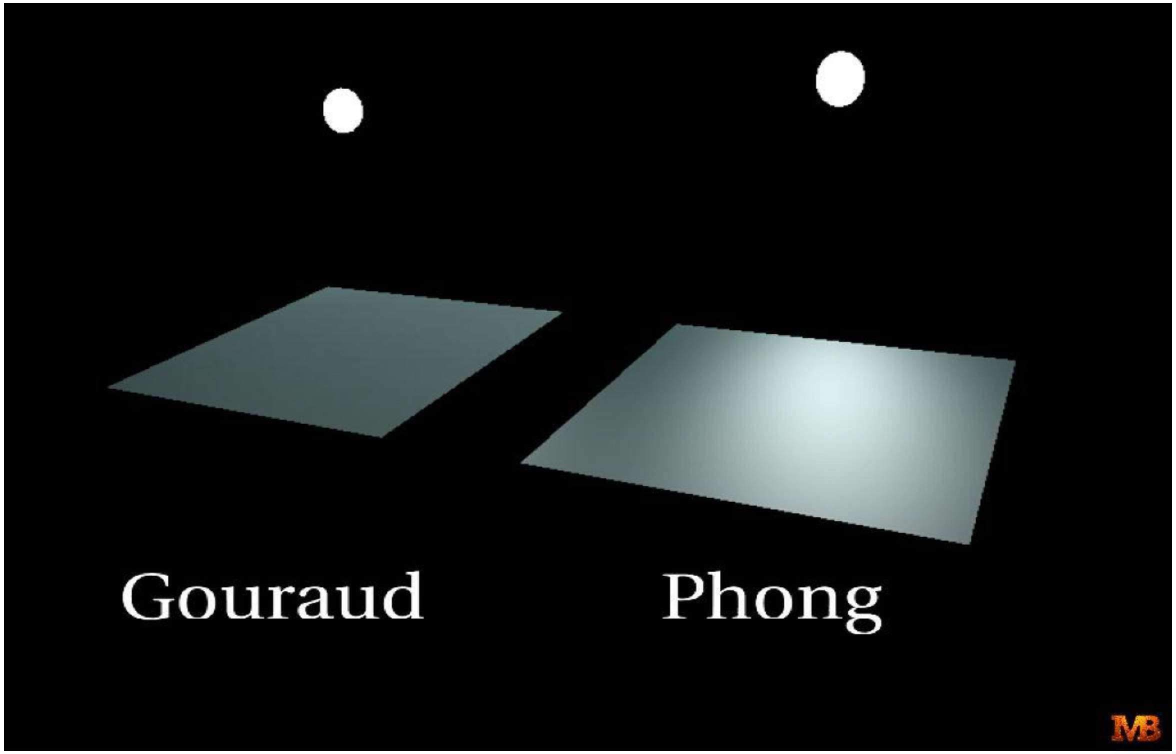

Finished !!!