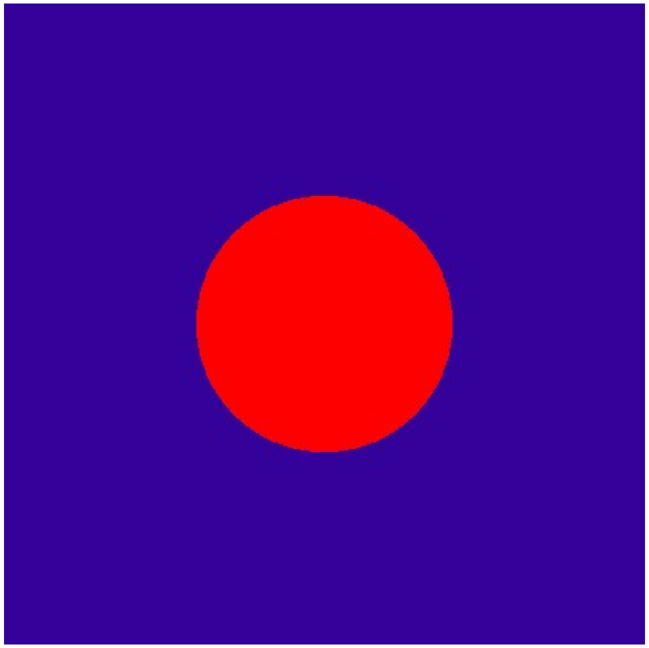
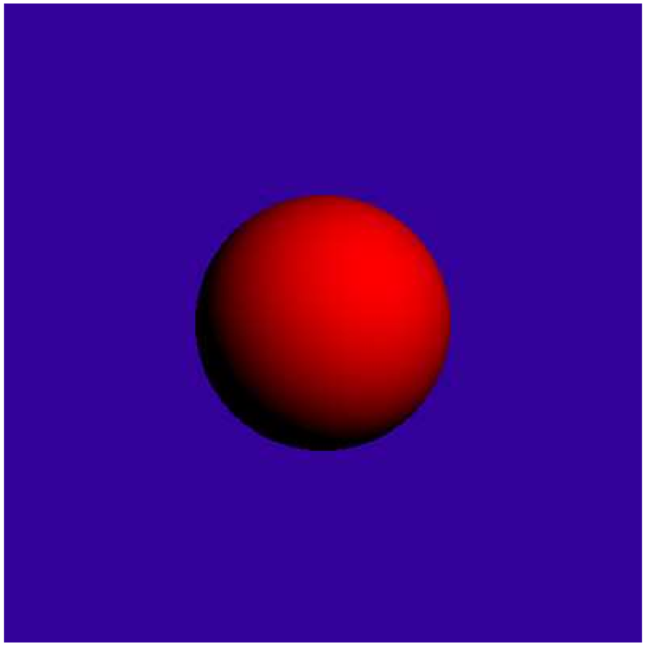
Computer Graphics

Illumination Models & Surface Rendering Methods

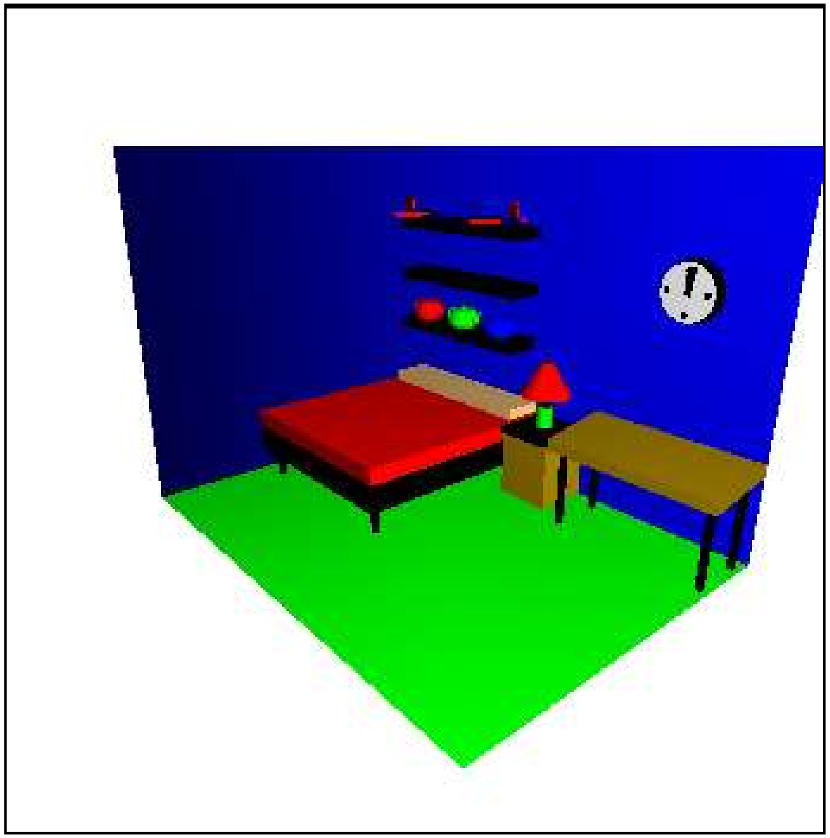
Why Lighting?

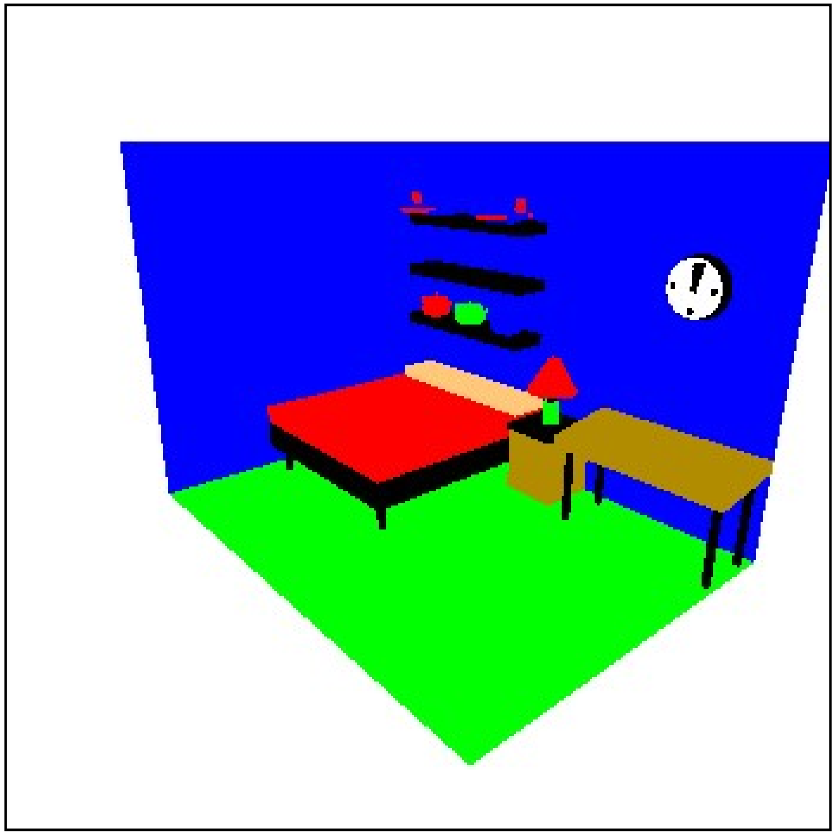
- If we don't have lighting effects nothing looks three dimensional!





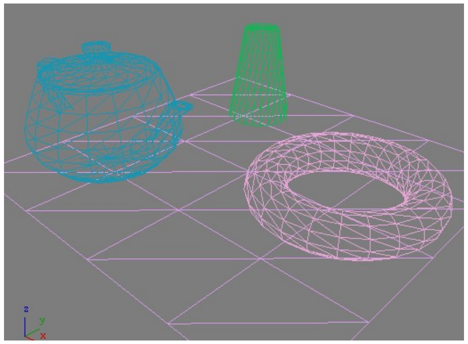
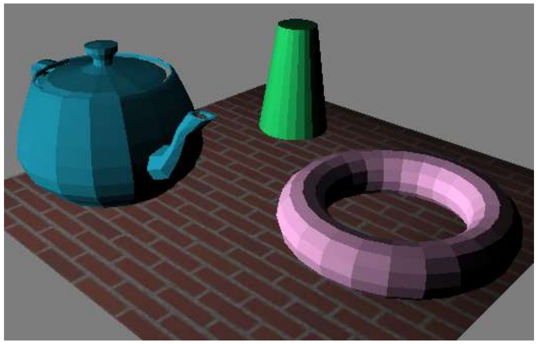
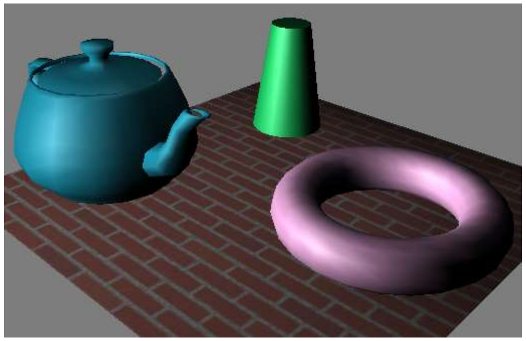
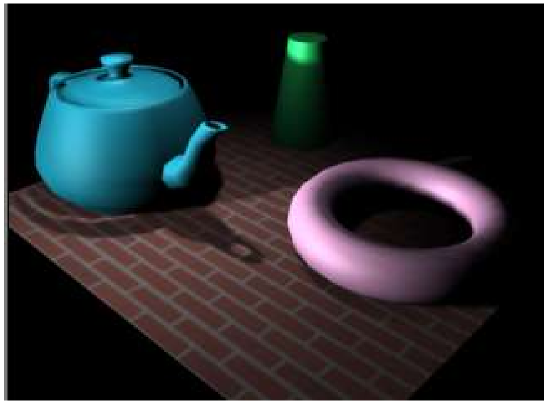
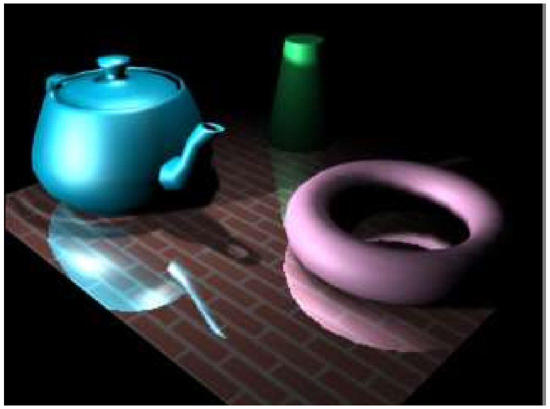
Why Lighting? (cont...)





Introduction

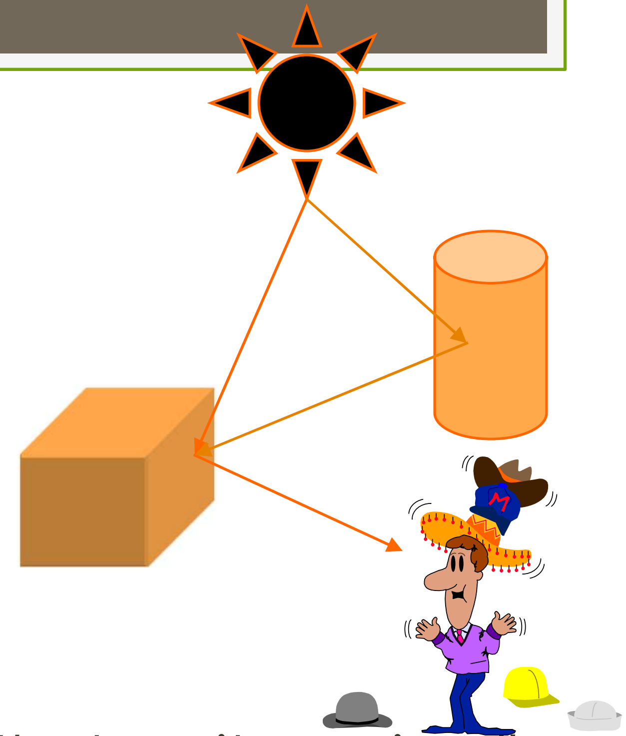
- Realistic displays of a scene
  - Perspective projections of objects
  - Applying lighting effects

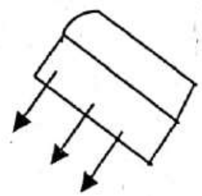
Introduction (Contd.)

- Illumination model
  - Lighting model or Shading model
  - Calculate the intensity of light for a given point on the surface of an object
- Surface-Rendering algorithm
  - Use the intensity of a given point to determine the light intensity for all projected pixel position in a polygon

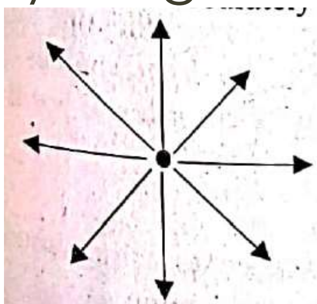
Light Sources



- Types of light source
  - light source (direct)
  - light reflector (indirect)
- Two light emitter models
  - Point light source: The source that emit rays in all direction (e.g. Bulb)
  - Distributed (Area) light source: rays originate from the finite area (e.g. tubelight)



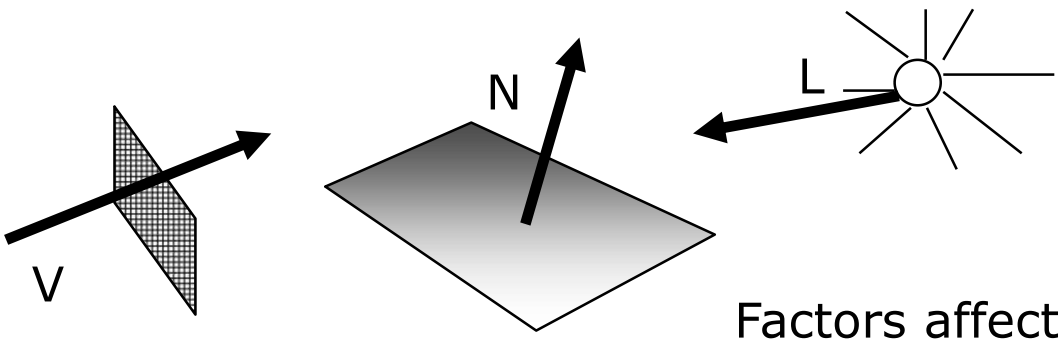
distributed light source



point source

Illumination Models

- Concerning methods for calculating light intensity
  - Also called *Lighting* Models
  - An approximation for physical optical laws

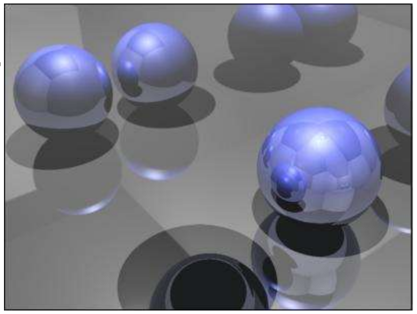


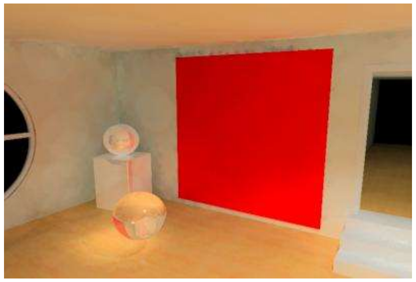
Factors affecting illumination models
- Position
- Orientation
- Material
- Light source
- Viewer

Types of illumination models

- Local Illumination Models
  - Only considering the interchanges of the light sources

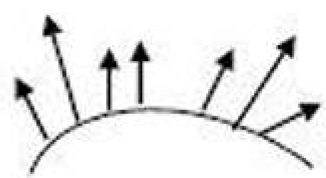
- Global Illumination Models
  - Concerning the interchange of light between all surfaces





Reflected Light

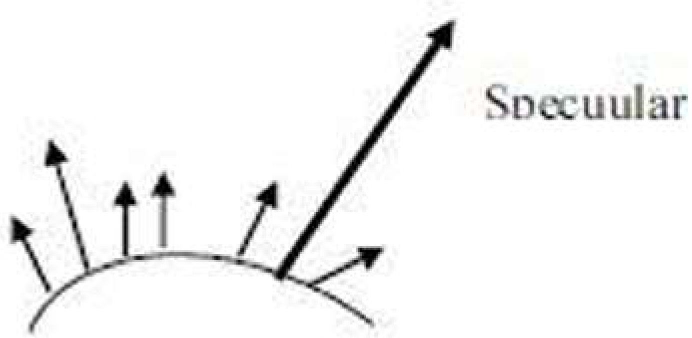
- When light is incident on a surface, some part of it is reflected, some part is absorbed and some part is transmitted through the material.
- Diffuse reflection
  - Rough or graining surface tend to scatter the reflected in all direction
  - With diffuse reflection, the surface appears equally bright from all viewing direction

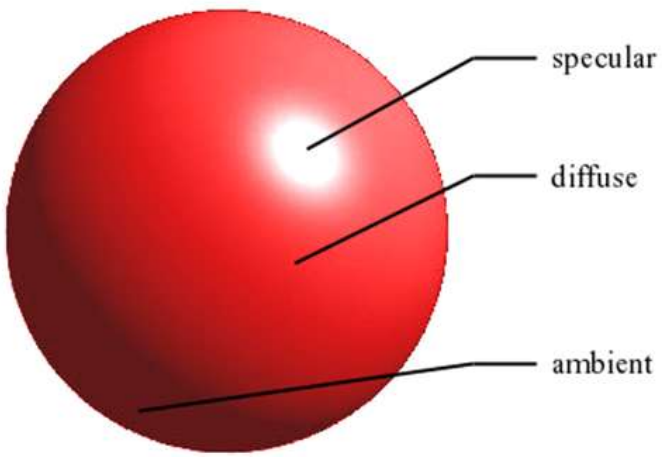


Diffuse reflection

Reflected Light

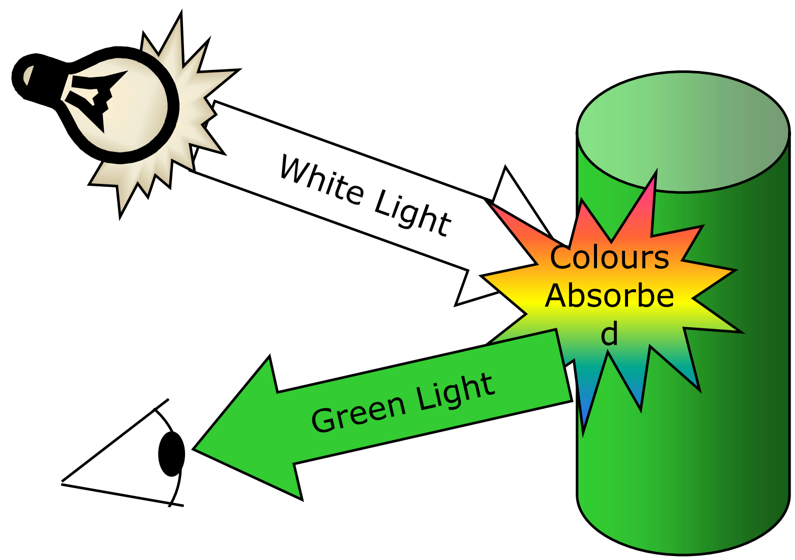
- Specular reflection
  - In addition to diffuse reflection, light sources create highlights or bright spots.
  - This is more pronounced on shiny surfaces.





Reflected Light

- The colours that we perceive are determined by the nature of the light reflected from an object
- For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object

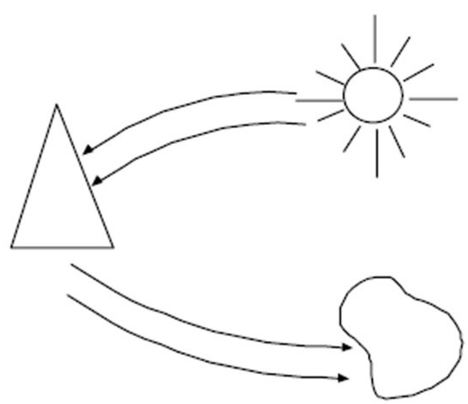


Background

- Illumination model (Shading Model) is used to Calculate intensity of light that we see at a given point on the surface of an object.
- Intensity calculations are based on the optical properties of surfaces, the background lighting conditions and the light source.
- Surface Rendering algorithm uses the intensity calculation from an illumination model to determine the light intensity of all pixel positions for various surfaces in the scene
- Photorealism in computer graphics involves two elements:
  - Accurate graphical representations of object
  - Good physical descriptions of lighting effect in scene
- Illumination model: derived from physical laws that describe surface light intensities

Basic Illumination Model

- Ambient Light → Background Light
  - Object not exposed directly to a light source but still is visible if nearby objects are illuminated
  - It is non directional light source that is the product of multiple reflections from surrounding environment.
  - Simple way to model the combination of light reflections from various surfaces to produce a uniform illumination call ambient light or background light



Basic Illumination Model

- Ambient Light → Background Light
  - Has no spatial or directional characteristics
  - Amount of ambient light incident on each object is a constant for all surfaces and over all directions but the intensity of reflected light depends upon optical properties of the surface
  - Ambient light produces flat shading → not desirable in general, so scenes are illuminated with other light source together with ambient light
  - If I_a is amount of ambient light incident on any surface, the ambient light reflection is given by,

    $I = K_a * I_a$

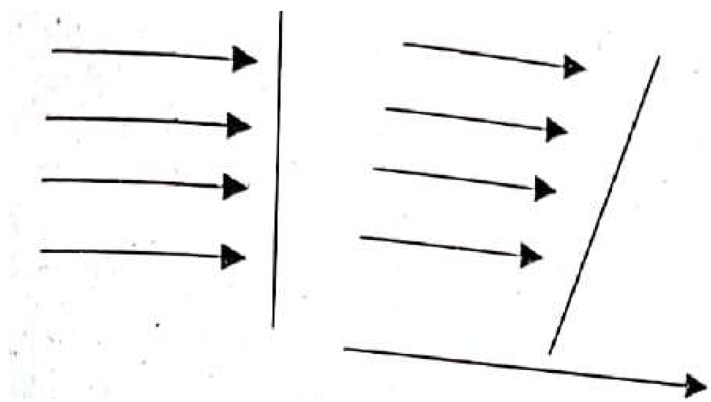
    Where, K_a = ambient reflectivity or ambient reflection coffiecient which ranges from 0 to 1. (depends on material property)

Basic Illumination Model

- Diffuse Reflection
  - Diffuse reflection are constant over each surface in a scene independent of viewing direction → *ideal diffuse reflectors*
  - Amount of incident light that is diffusively reflected is defined with a surface parameter K_d called diffuse-reflection coefficient (diffuse reflectivity)
  - Value of K_d is between 0 to 1. For highly reflecting surface $K_d \rightarrow 1$ and for dull surface $K_d \rightarrow 0$
  - Diffuse reflection intensity when scene illuminated only with ambient light:

$$I_{ambdiff} = K_a I_a$$

  - 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 and distance to the light source.
  - Surface perpendicular to the direction of incident light appears brighter than one with oblique angle to the direction of the incoming light.



Basic Illumination Model

- Diffuse Reflection
  - Follow lambert's cosine law → radiant energy from a small surface area *dA* is proportional to the cosine of angle *θ* between surface normal and incident light direction
  - If θ is angle of incidence between incoming light direction and the surface normal then the intensity in projected area of a surface path perpendicular to light direction is proportional to cosθ.
  - If the incoming light from the source is perpendicular to the surface at particular point, that point is fully illuminated
  - As the angle of illumination moves away from the surface normal, the brightness of the point drops off.
  - If I_1 is the intensity of the point light source, then the diffuse reflection equation for a point on the surface is

$$I_{1diff} = K_d I_1 \cos\theta$$

  - A surface is illuminated by a point source only if the angle of incidence is in the range of 0 degree to 90 degree for which cosθ is in the range of 0 to 1. When cosθ is negative, the light source is behind the surface.

Basic Illumination Model

- Diffuse Reflection
  - If $\vec{N}$ is unit normal vector to a surface and $\vec{L}$ is direction vector to the point source from a position on the surface then,

$$\vec{N}.\vec{L} = \cos\theta$$

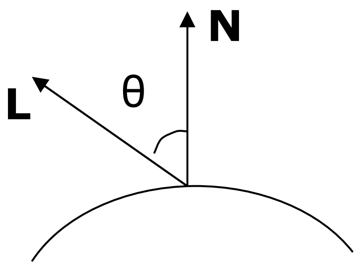
So,

$$I_{1diff} = K_d I_1 (\vec{N}.\vec{L})$$

- We can combine the ambient and point source intensity calculation to obtain an expression for total diffuse reflection

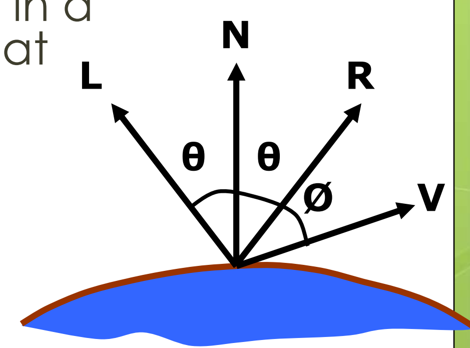
$$I_{diff} = K_a I_a + K_d I_1 (\vec{N}.\vec{L})$$

where both Ka and Kd depends upon surface material properties and are assigned value in the range from 0 to 1



Specular Reflection

- Bright spot seen at an illuminated shiny surface when viewed at certain direction
  - Polished metal surface, person's forehead, apple etc. exhibit specular reflection
- In fact an image of light source
- Result of total or near total reflection of incident light in a concentrated region around the specular reflection at an angle θ
- Fig:
  - **L** → unit vector pointing to light source
  - **N** → unit surface normal vector
  - **R** → unit vector in direction of specular reflection
  - **V** → unit vector pointing viewer



- Ideal reflector exhibit specular reflection in the direction of R only (i.e Ø=0) but for non-ideal case specular reflection is seen over finite range of viewing positions
- Phong model, developed by Phong Bui-Tuong, is used to calculate the specular reflected range.

Phong Model

- Intensity of specular reflection: proportional to

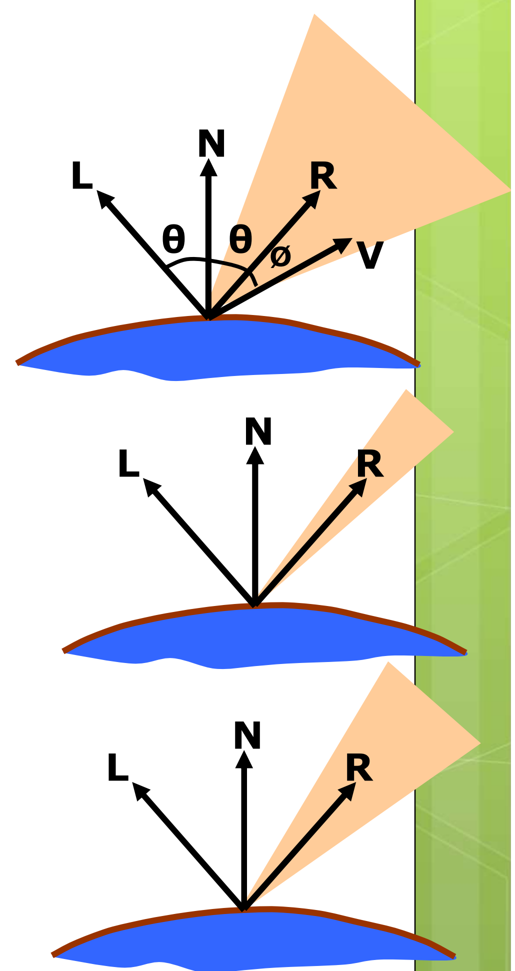
$$\cos^{n_s} \phi$$

  - n_s → **specular reflection parameter** (depends on surface)
  - Ø ranges from 0 to 90^0 (i.e *cos Ø* varies from 0 to 1)
- A very shinny surface is modeled with a large value for n_s and duller surface is assigned smaller values. For perfect reflector n_s is infinite
- Phong model calculate the specular reflection light intensity using **specular-reflection coefficient**, *w(θ)* for each surface

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

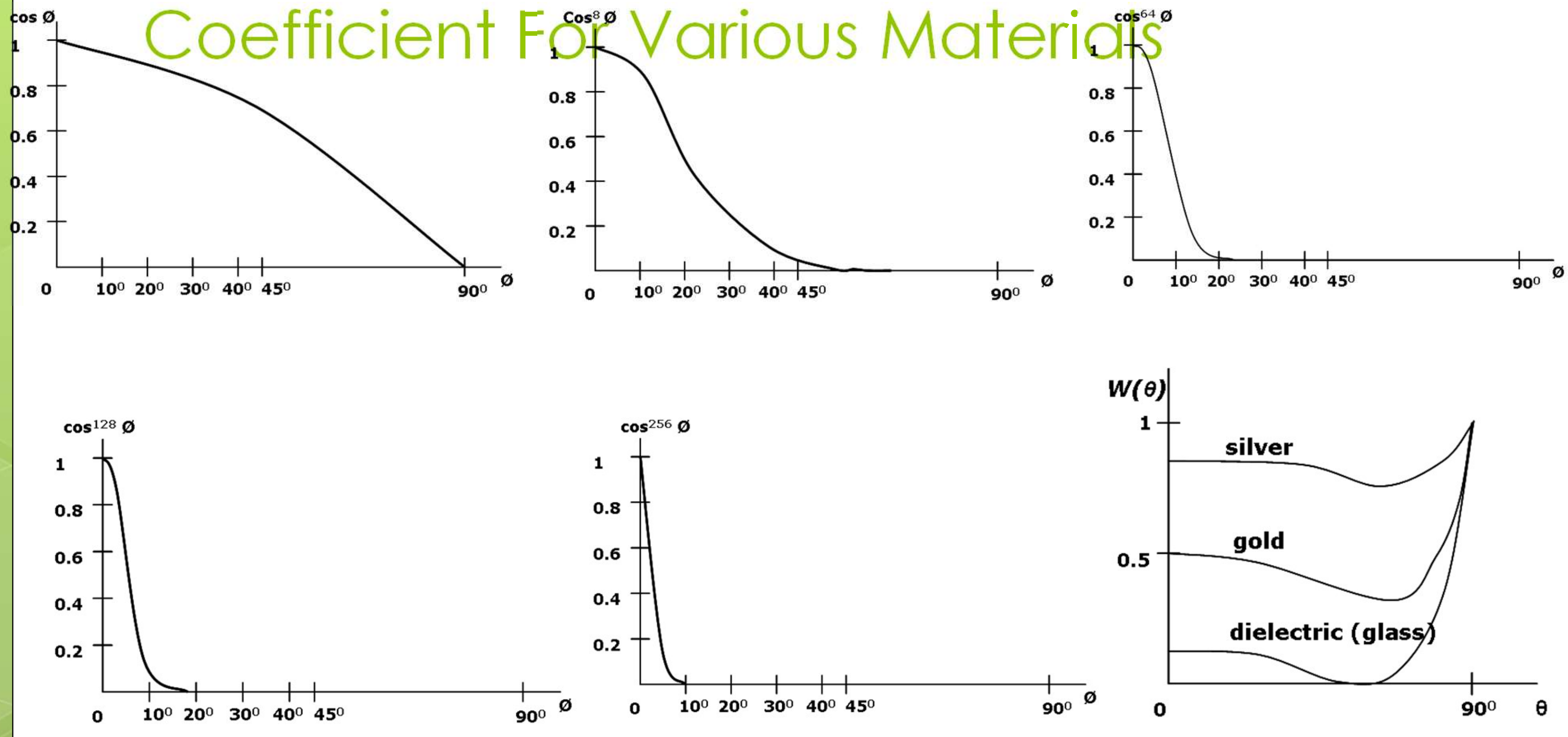
where I_1 = incident light intensity

- At *θ = 90⁰*, *w(θ)* = 1 → all incident light is reflected



$$\cos^{n_s}\phi$$

Plot For and Specular Reflection Coefficient For Various Materials



Phong Model (contd...)

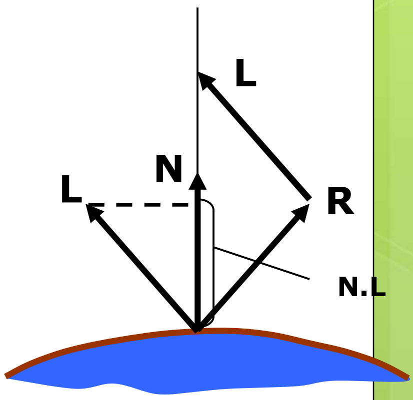
- Simplified form: assume *w(θ) = k_s = constant*

$$I_{spec} = k_s I_l (\vec{V}.\vec{R})^{n_s}$$

- Vector **R** can be evaluated from vectors **L** an **N** as:

  R + **L** = (2**N.L**)**N**

  i.e **R** = (2**N.L**)**N** – **L**



- If we add ambient light and diffuse reflection component then total intensity is given as:

$$\begin{aligned} I &= I_{diff} + I_{spec} \\ &= k_a I_a + k_d I_l (\vec{N}.\vec{L}) + k_s I_l (\vec{V}.\vec{R})^{n_s} \end{aligned}$$

- For multiple light sources (n light sources)

$$I = k_a I_a + \sum_{i=1}^{n} I_{li} \left[k_d (\vec{N}.\vec{L}_i) + k_s (\vec{V}.\vec{R}_i)^{n_s} \right]$$

Intensity Attenuation

- For realistic lighting effects, we should take account the intensity attenuation.
- The intensity of radiant energy at a point *d* distance far from source is attenuated by $1/d^2$ *where d is the distance that the light has traveled*
- Using merely $1/d^2$ as attenuation factor for our simple single point light source model, too much intensity variation is produced when *d* is small and a little variation when *d* is large
- So, realistic image can't be produced by just considering $1/d^2$.
- Graphical packages have compensated the problem by using inverse linear quadratic function of d for intensity attenuation as:

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

where d is the distance of light source. a0, a1 and a2 are called "constant attenuation", "linear attenuation" and "quadratic attenuation". These are properties of light

- The Phong illumination model considering attenuation is:

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

Polygon Rendering Methods

- 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
  - Single intensity for all points in a polygon
  - Interpolation of intensities for each point in a polygon
- Methods:
  - Constant Intensity Shading
  - Gouraud Shading
  - Phong Shading

Constant Intensity Shading

- Flat shading
  - Each polygon shaded with single intensity calculated for the polygon
- Useful for displaying general appearance of a curved surface
- Assumption made for Accurate rendering conditions:
  - Object is a polyhedron and not an curved surface approximation
  - All light sources should be sufficiently far from the surface (i.e **N.L** and attenuation function are constant over the polygon surfaces)
  - Viewing position is sufficiently far (i.e **V.R** is constant over the surface)
- Drawback: intensity discontinuity at the edges of polygons

Flat rendering

Gouraud rendering

Flat rendering

Gouraud rendering

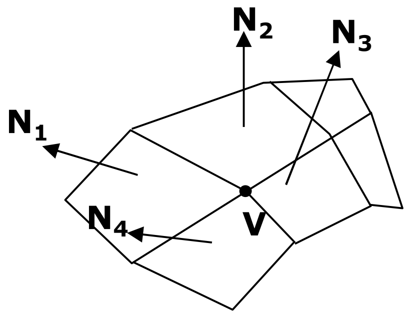
Gouraud Shading

- Calculation Steps:
  - Determine the average unit normal vector at each polygon vertex
  - Calculate each of the vertex intensities by applying an illumination model
  - Linearly interpolate the vertex intensities over the polygon surface
- Intensity discontinuity at the edges of polygons is eliminated
- Drawback:
  - **Mach bands**: bright and dark intensity
    linear interpolation of intensities
  - Could miss specular reflection
    - Could be reduced by dividing the surfac
      of polygons or by using other methods, such as *Phong shading*

Gouraud Shading (contd...)

- Average Unit Normal: Obtained by averaging the surface normals of all polygons sharing the vertex

$$N_v = \frac{\sum_{k=1}^{n} N_k}{\left|\sum_{k=1}^{n} N_k\right|}$$

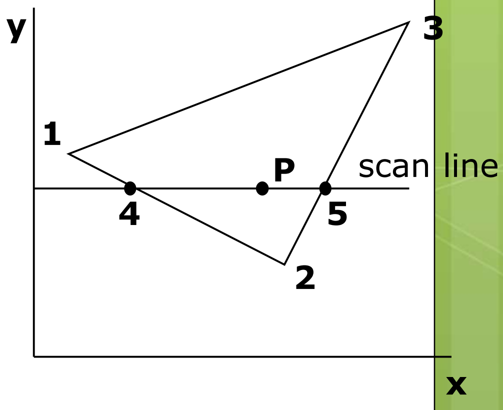


- Intensity interpolation:
  - Along the polygon edges are obtained by interpolating intensities at the edge ends

$$I_4 = \frac{y_4 - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y_4}{y_1 - y_2} I_2$$

$$I_5 = \frac{y_5 - y_2}{y_3 - y_2} I_3 + \frac{y_3 - y_5}{y_3 - y_2} I_2$$

$$I_p = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x_5 - x_4} I_5$$

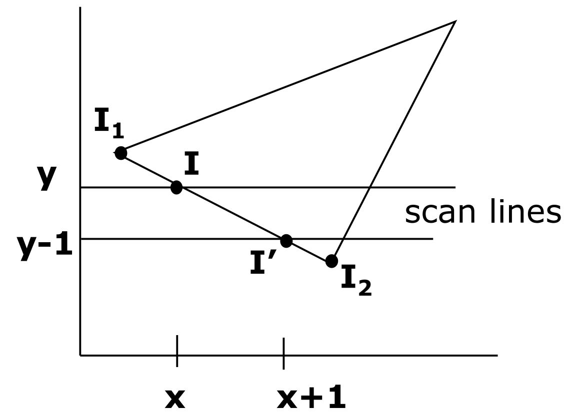


Gouraud Shading (contd...)

Recursive Calculation along the scan line ??

Recursive calculation along the edge

$$I' = I + \frac{I_2 - I_1}{y_1 - y_2}$$

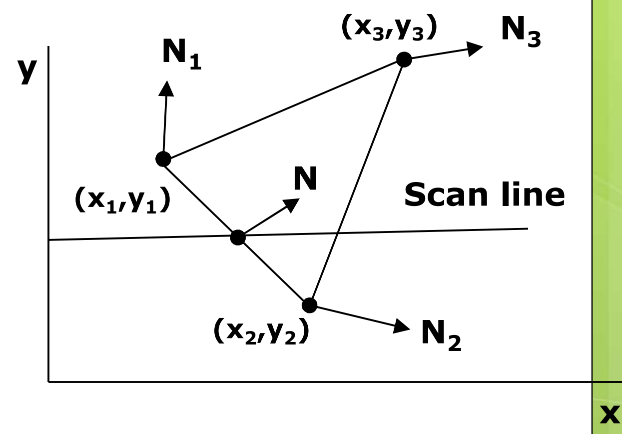


Gouraud rendering

Phong rendering

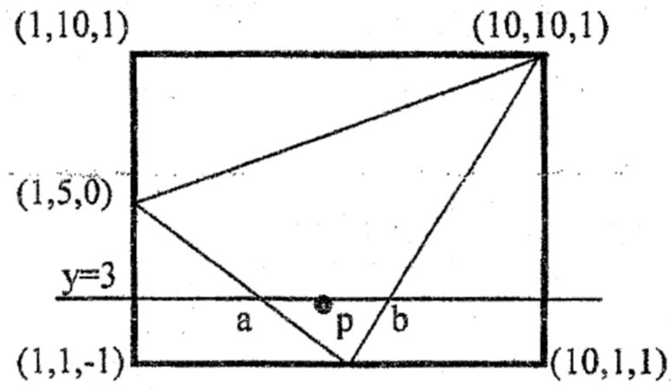
Phong Shading

- More accurate method for rendering
- Fundamental: *Interpolate normal vectors and apply illumination model to each surface point*
- Calculation steps:
  - Determine average unit normal vectors 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
- **Trade-off**: requires considerably more calculations



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

8.



Find out intensity of light reflected from the midpoint P on scan line y = 3 in the above given figure using Gouraud shading model. Consider a single point light source located at positive infinity on Z-axis and assume vector to the eye as (1,1,1). Given d = 0, K = 1, $I_a = 1$, $I_L = 10$, Ks = 2, Ka = Kd=0.8 for use in a simple illumination model.