(14.2)

ILLUMINATION MODELS

Impt. 1. **Ambient Light**

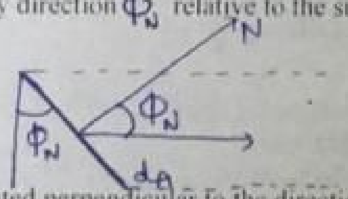
- A surface that is not exposed directly to a light source can be made visible by making nearby objects illuminated.
- A general level of brightness for a scene can be set using basic illumination model. This is a simple way to model the combination of light reflections from various surfaces to produce a uniform illumination called the ambient light, or background light.
- Ambient 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.
- Level of ambient light is set with parameter I_a and each surface is illuminated with this constant value.

Impt. 2. **Diffuse Reflection**

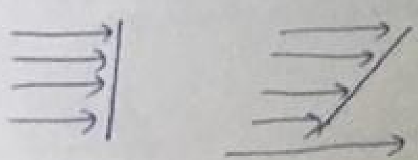
- Diffuse reflections are constant over each surface in a scene, independent of the viewing direction. The fractional amount of the incident light that is diffusely reflected can be set for each surface with parameter K_d, the diffuse-reflection coefficient or diffuse reflectivity.
- Value of K_d lies between interval 0 to 1. If highly reflected surface is needed, K_d is set near to 1, otherwise K_d is set near to 0. K_d is a function of surface color and is a constant for time begin.
- If surface is exposed only to ambient light, then the intensity of the diffuse reflection at any point on the surface is

$$I_{ambdiff} = K_d I_a$$

- Assume that the diffuse reflections from the surface are scattered with equal intensity in all directions, independent of the viewing directions. Such surfaces are referred to as ideal diffuse reflectors or Lambertian reflectors, since radiated light energy from any point on the surface is governed by Lambert's cosine law-> This law states that the radiant energy from any small surface area dA in any direction ϕ_N relative to the surface normal is proportional to $\cos \phi_N$.

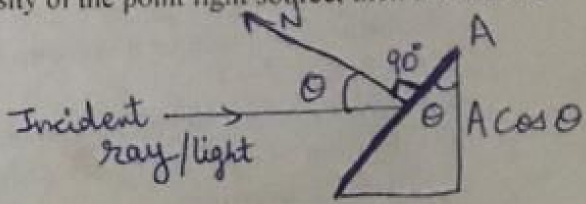


- A surface that is oriented perpendicular to the direction of the incident light appears brighter than if the surface were tilted at an oblique angle to the direction of the incoming light



- If the angle of incidence between the incoming light direction and the surface normal as θ, then the projected area of a surface patch perpendicular to the light direction is proportional to cos θ. If the incoming light from the source is perpendicular to the surface at a particular point, that point is fully illuminated. As the angle of illumination moves away from the surface normal, the brightness of a point drops off. If I_l is the intensity of the point light source, then the diffuse reflection equation for a point on the surface is

$$I_{l,diff} = K_d I_l \cos\theta$$



- A surface is illuminated by a point source only if $0° < \theta < 90°$, otherwise if θ is –ve then the light source is behind the surface.
- 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 and the equation is

$$I_{l,diff} = K_d I_l (N \cdot L)$$

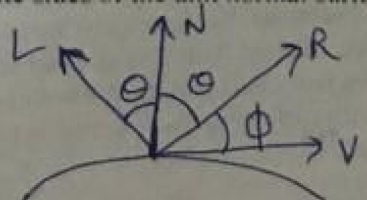
- Total Diffuse reflection can be obtained by combining the ambient and point source intensity as

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

where K_a Ambient-reflection coefficient to modify the ambient light intensity I_a for each surface.

Imp 3. **Specular Reflection and the Phong Mudel**

- When we look at an illuminated shiny surface, such as polished metal, an apple, we see a highlight, or bright spot, at certain viewing directions. This phenomenon, called specular reflection, is the result of total, or near total, reflection of the incident light in a concentrated region around the specular-reflection angle.
- Fig. shows, specular reflection angle equals the angle of incident light, with the two angles measured on opposite sides of the unit normal surface vector N.



R: unit vector in the direction of ideal specular reflection.
L: unit vector directed towards the point light source.
V: unit vector pointing to the viewer from the surface position.
ϕ : Viewing angle relative to specular-reflection direction R.

When ϕ=θ then vectors V & R are coincident and we see only reflected light.

- shiny surfaces have a narrow specular-reflection range
- dull surfaces have a wider reflection range.

$\cos^{n_s}\phi$, where $0^\circ \leq \phi \leq 90^\circ$ or $0 < \cos\phi < 1$

- Phong specular-reflection model – Calculates the specular-reflection range. This model is developed by Phong Bui Tuong and model is also known as Phong Model. It sets the intensity of specular reflection proportional to $\cos^{n_s}\phi$. Value of specular-reflection parameter n is determined by the type of surface (a very shiny surface is modeled with a large value for n, say 100 or more and for dull surfaces value may be smaller to say 1). For a perfect reflector, n, is infinite.

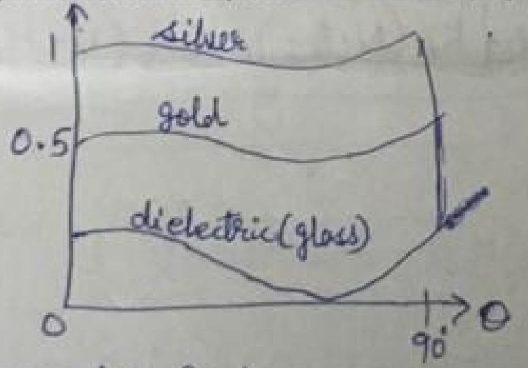
- Specular-reflection coefficient ($W(\theta)$) gives the model monochromatic specular intensity variations, over the range $0^\circ \leq \theta \leq 90^\circ$. ($W(\theta)$) to increase as the angle of incidence increases.
- Phong specular-reflection model

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

Where I_l is the intensity of the light source, and ϕ is the viewing angle relative to the specular-reflection direction R. (refer fig. 14.14)
Since V & R are unit vectors in the viewing specular-reflection directions, $\cos\phi$ can be calculated as a dot product V.R. Assuming specular-reflection coefficient is a constant, the intensity of specular reflection at a surface-point is

$$I_{spec} = K_s I_l (V \cdot R)^{n_s}$$

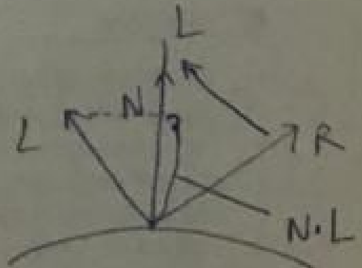
- Intensities of specular reflection depends on the material properties.



Other formulae are:

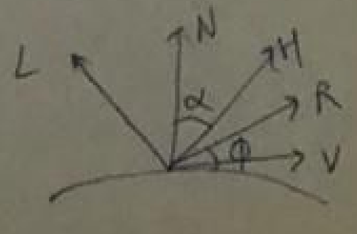
①. Calculation of vector R by considering Projections onto the direction of the normal vector N.

$$R + L = (2\,N \cdot L)N$$
$$\Rightarrow R = (2N \cdot L)N - L$$



②. Halfway vector along bisector of angle b/w L & V

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



4. Combined Diffuse and Specular Reflectdons with Multiple Light Sources

For a single Point light source, combined diffuse and specular reflections from a Point on an illuminated surface as

$$I = I_{diff} + I_{spec}$$
$$= k_a I_a + k_d I_l (N \cdot L) + k_s I_l (N \cdot H)^{n_s}$$

Light reflection at any surface point is calculated by summing the contributions from the individual sources.

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

5 Warn Model

- The Warn model provides a method for simulating studio lighting effects by controlling light intensity in different directions.
- Light sources are modeled as points on a reflecting surface, using the Phong model for the surface points. Then the intensity in different directions is controlled by selecting values for the Phong exponent.In addition, light controls and spotlightingcan be simulated in the warn model. Flaps are used to control the amount of light emitted by a source in various directions. Two flaps are provided for each of the **x**, y, and z directions. Spotlights are used to control the amount of light emitted within a cone with apex at a point-source position.

6 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 a higher incident Intensity from the source than a distant surface (large ***d***). Therefore, for realistic lighting effects intensity attenuation is necessary, otherwise all surface would illuminate with the same intensity.

- Inverse quadratic attenuation function is given as

$$f_d = \frac{1}{a_0 + a_1 d + a_2 d^2}$$

where a_0, a_1 & a_2 are the coefficients to obtain a variety of lighting effects for a scene.

- With a given set of attenuation coefficients, the magnitude of the attenuation function can be limit to 1, as

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

Using this function, basic illumination model can be written as

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

where d_i is the distance light has travelled from light source i.

7. Color considerations

- The basic illumination model considers only monochromatic lighting effects. To incorporate color, the intensity equation is to be written as a function of the color properties of the light **sources** and object surfaces.

For an RGB description, each color in a scene is expressed in terms of red, green, and blue components. We then specify the RGB components of light source intensities and surface colors, and the illumination model calculates the RGB components of the reflected light.
One way to set surface colors is by specifying the reflectivity coefficients as three-element vectors. The diffuse reflection coefficient vector, for example, would then have RGB components (k_{dR}, k_{dG}, k_{dB}). If blue surface is required for an object, select a non-zero value in the range from 0 to 1 for k_{dB}, & put $k_{dR} = k_{dG} = 0$.

Mathematically,

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

8. Transparency

- A transparent surface produces both reflected and transmitted light.
- The relative contribution of the transmitted light depends on the degree of transparency of the surface and whether any light sources or illuminated surfaces are behind the transparent surface.
- Both diffuse and specular transmission can take place at the surfaces of a transparent object.

Snell's Law: Angle of refraction θ_r is calculated from the angle of incidence θ_i, the index of refraction η_i of the incident material and the index of refraction η_r of the refracting material

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

unit ~~transmitt~~ transmission vector T in the refraction direction θ_r is,

$$T = \left(\frac{\eta_i}{\eta_r} \cos\theta_i - \cos\theta_r\right) N - \frac{\eta_i}{\eta_r} . L$$

where N is the unit surface normal & L is the unit vector in the direction of the light source.

We can combine the transmitted intensity I_{trans} through a surface from a background object with the reflected intensity I_{refl} from the transparent surface using a transparency coefficient k_t. Parameter k_t is assigned a value b/w 0 & 1 to specify how much of background light is to be transmitted. Total surface intensity is calculated as

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

$(1-k_t)$ term is the opacity factor.

8. Shadows

(from Book)

Reference/Resources:
Computer Graphics, C version, 2nd Edition, D. Hearn, M.P. Baker
Pearson Education