Illumination Model

- An illumination model, also called a lighting model and sometimes referred to as a shading model, is used to calculate the **intensity of light** that we should see at a given point on the surface of an object.

- Surface rendering means ***a procedure for applying a lighting model to obtain*** pixel intensities for all the projected surface positions in a scene.

- A surface-rendering algorithm uses the intensity calculations from an illumination model to determine the light intensity for all projected pixel positions for the various surfaces in a scene.

- Surface rendering can be performed by applying the illumination model to every visible surface point

LIGHT SOURCES

- light sources are referred to as ***light- emitting*** sources; and reflecting surfaces, such as the walls of a room, are termed ***light- reflecting sources***
- **A luminous object, in general, can be both a light source and a light reflector.**
- The simplest model for a light emitter is a point source.

- When light is incident on an opaque surface, part of it is reflected and part is absorbed.
- The amount of incident light reflected by a surface depends on the **type of material. Shiny materials reflect more of the incident light, and dull surfaces** absorb more of the incident light.
- for an illuminated transparent surface, some of the incident light will be reflected and some will be transmitted through the material

- Surfaces that are rough, or grainy, tend to scatter the reflected light in all directions.

  This scattered light is called diffuse reflection.

- In addition to diffuse reflection, light sources create highlights, or bright spots, called specular reflection.

- This highlighting effect is more pronounced on shiny surfaces than on dull

Ambient Light

- In our basic illumination model, we can set a general level of brightness for a scene. 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. The amount of ambient light incident on each object is a constant for all surfaces and over all directions.

Diffuse Reflection

- Diffuse reflections are constant over each surface in a scene

- 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.

- Parameter ***k_d is assigned a constant value in the interval* 0 to 1.**

- we want a highly reflective surface, we set the value of ***k_d near 1*. *This produces a*** bright surface with the intensity of the
reflected light near that of the incident light.

- To simulate a surface that absorbs most of the incident light, we set the reflectivity to a value near **0.**

- 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

$$I_{ambdiff} = k_d I_a$$

- we assume that the diffuse reflections from the surface are scattered with equal intensity in all directions, independent of the viewing directions.

- Such surfaces are sometimes referred to as ideal diffuse reflectors. They are also called ***Lambertian reflectors***, ***since radiated light energy from any point on the*** surface is governed by Lambert’s cosine law.

- If we denote 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*** .

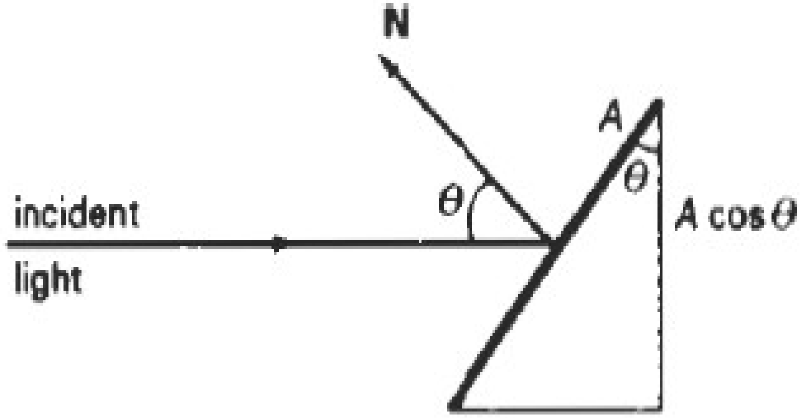

Figure 14-8
An illuminated area projected perpendicular to the path of the incoming light rays.

Thus, the amount of illumination (or the "number of incident light rays" cutting across the projected surface patch) depends on 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 the 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 can be written as

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

- A surface is illuminated by a point source only if the angle of incidence is in the range 0° to *90 ° (cos 0 is in the interval from 0 to 1)*.
- *When* cos *ϴ is negative, the* light source is "behind" the surface.

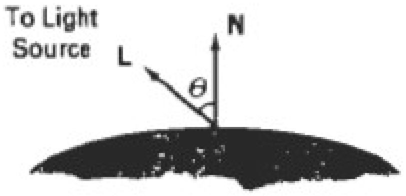

Figure 14-9
Angle of incidence θ between the unit light-source direction vector **L** and the unit surface normal **N**.

- 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

$$\cos \Theta = \mathbf{N} \cdot \mathbf{L}$$

and the diffuse reflection equation for single point-source illumination is

$$I_{l,diff} = k_d \, I_l \, N . L$$

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

- In addition, many graphics packages introduce an ambient-reflection coefficient ***k_a to modify the ambient light*** intensity *I, for each surface. This simply provides us with an additional parameter* to adjust the light conditions in a scene.

- Using parameter k_a we can write the total diffuse reflection equation as

$$I_{l,diff} = k_a I_a + k_d I_l (N.L)$$

- where both k_a ***and*** k_d ***depend on surface material properties and are assigned values***

in the range from **0 to 1**

Specular Reflection and *the Phong Model*

- **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.

- The specular-reflection angle equals the angle of the incident light.

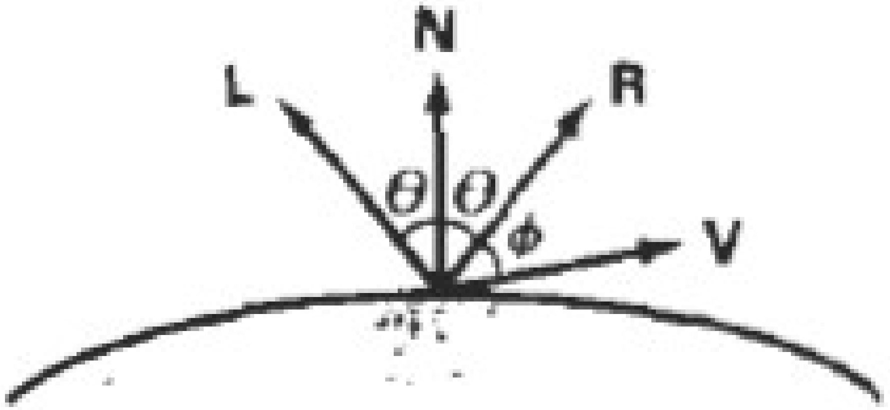

Figure 14-12
Specular-reflection angle equals angle of incidence θ.

- In this figure, we use R to represent the unit vector in the direction of ideal specular reflection; L to represent the unit vector directed toward the point light source; and V as the unit vector pointing to the viewer from the surface position.
- Angle Θ ***is the viewing angle relative to the specular-reflection direction*** R.
- For an ideal reflector (perfect mirror), incident light is reflected only in the specular-reflection direction. In this case, we would only see reflected light when vectors V and R coincide ***(Θ = 0)***.

- Phong model, sets the intensity of specular reflection proportional to cos $^{n_s}\Theta$.
- Angle Θ can be assigned values in the range *0 to **90**, **so that cos** Θ **varies from 0 to 1***.
- ***The*** value assigned to ***specular-reflection parameter*** n_s ***is determined by the type of surface*** that we want to display.
- **A very shiny surface is modeled with a large value** for n_s ***(say, 100 or more), and smaller values (down to 1) are used for duller surfaces***.
- For a perfect reflector, n_s ***is infinite***.

- We can approximately model monochromatic specular intensity variations using a specular-reflection coefficient, W(ϴ) for each surface.
- ***In general***, W(ϴ) ***tends to increase as the*** angle of incidence increases.
- Using the spectral-reflection function W(ϴ), *we can* write the Phong specular- reflection model as

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

- Since V and R are unit vectors in the viewing and specular-reflection directions, we can calculate the value of cos Ɵ with V . R
- Assuming the specular-reflection coefficient is a constant, we can determine the intensity of the specular reflection at **a surface point with the calculation**

$$I_{spec} = k_s I_l (V.R)^{ns}$$

- simplified Phong model is obtained by using the halfway vector H between L and V to calculate the range of specular reflections.
- If we replace V.R in the Phong model with the dot product N . H, this simply replaces the empirical cos Ө calculation with the empirical cos α *calculation*

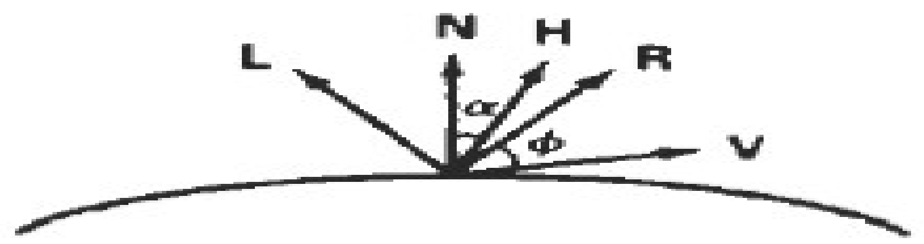

Figure 14-18
Halfway vector **H** along the bisector of the angle between **L** and **V**.

halfway vector is obtained as

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

Combined Diffuse and Specular Reflections with Multiple Light Sources

For a single point light source, we can model the combined diffuse and specular reflections from a point on an illuminated surface as

$$
\begin{aligned}
I &= I_{\text{diff}} + I_{\text{spec}} \\
&= k_a I_a + k_d I_l (\mathbf{N} \cdot \mathbf{L}) + k_s I_l (\mathbf{N} \cdot \mathbf{H})^{n_s}
\end{aligned}
\tag{14-9}
$$

- If we place more than one point source in a **scene, we obtain the light reflection** at any surface point by summing the contributions from the individual sources:

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

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 spotlighting, used by studio photographers can be simulated in the Warn model.
- Flaps are used to control the amount of light emitted by a source In various directions

Intensity Attenuation

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

- a general inverse quadratic attenuation function can be set up as

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

A user can then fiddle with the coefficients a_o, a_1, and a_2 , to obtain a variety of lighting effects for a scene. The value of the constant term a_o can be adjusted to prevent **f(d) from becoming too large when d is very small.**

With a given set of attenuation coefficients, we can limit the magnitude of the attenuation function to 1 with the calculation

$$f(d) = \min\left(1, \frac{1}{a_0 + a_1 d + a_2 d^2}\right) \tag{14-12}$$

Using this function, we can then write our basic illumination model as

$$I = k_a I_a + \sum_{i=1}^{n} f(d_i) I_{li} [k_d (\mathbf{N} \cdot \mathbf{L}_i) + k_s (\mathbf{N} \cdot \mathbf{H}_i)^{n_s}] \tag{14-13}$$

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

Colour Considerations

- Most graphics displays of realistic scenes are in colour. But the illumination model discussed *so far considers only monochromatic lighting effects*.

- *To incorporate colour*, we need to write the intensity equation as a function of the colour properties of the light sources and object surfaces.

- One way to set surface colors is by specifing
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 we want an object to have **a blue surface, we select a nonzero value in the range** from 0 to **1 for the blue reflectivity component,** k_{dB} **, while the red and green reflectivity**
components are set to **zero** $(k_{dR}=0, k_{dG}=0)$

- Any nonzero **red or green components** in the incident light are **absorbed, and only the blue component is reflected.** The intensity calculation for this example reduces to the single expression

$$I_B = k_{aB} I_{aB} + \sum_{i=1}^{n} f_i(d) I_{lBi} [k_{dB}(\mathbf{N} \cdot \mathbf{L}_i) + k_{sB}(\mathbf{N} \cdot \mathbf{H}_i)^{n_s}]$$

- Surfaces typically are illuminated with white light sources, and in general we can set surface color so that the reflected light has nonzero values for all three RGB components.
- Calculated intensity levels for each color component can be **used to** adjust the corresponding electron gun in an RGB monitor.
- In his original specular-reflection model, Phong set parameter $\boldsymbol{k_s}$ *to a constant* value independent of the surface color. This produces specular reflections that are the same color as the incident light (usually white),

Transparency

- A transparent surface, in general, 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

- 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.
- We assign parameter k_t , a value between 0 and 1 to specify how much of the background light is to be transmitted.
- Total surface intensity is then calculated as

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

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

For highly transparent objects, we assign k_t a value near 1. Nearly opaque objects transmit very little light from background objects, and we can set k_t to a value near 0 for these materials (opacity near 1). It is also possible to allow k_t to be a function of position over the surface, so that different parts of an object can transmit more or less background intensity according to the values assigned to k_t.

Shadows

- By applying a hidden-surface method with a light source at the view position, we can determine which surface sections cannot be "seen" from the light source.
- These are the shadow areas.
- Once we have determined the shadow areas for all light sources, the shadows could be treated as surface patterns and stored in pattern arrays

- Surfaces that are visible from the view position are shaded according to the lighting model, which can be combined with texture patterns.

- We can display shadow areas with ambient-light intensity only, or we can combine the ambient light with specified surface textures.