CSI422/502 Lecture 31

Some physics....

An **extensive** or “bulk” quantity pertains to an extended object. Examples: Volume, Weight, Mass, Gross National Product, Area, Length, Electric Charge, Energy, Power ...

Light Energy emitted, reflected or absorbed by a GIVEN AREA during a PARTICULAR PERIOD of time.

Light Power (=Energy/Time) is the rate of Light Energy transfer.

(Electric energy is sometimes measured in Kilowatt-hours. Food energy is measured in Calories.

Electric power is usually measured in Kilowatts or Watts. Food (people) power is measured in Calories per Day.)

An **intensive** or “local” quantity pertains to a point in an object or an average over space. Examples: Density = Mass/Volume; Average National Income.

Light Intensity is Light Power per unit Area.

The Light Intensity of light reflected toward the viewer determines the BRIGHTNESS of one SPOT in an image.

Diffuse *reflection of a non-directional or* ***ambient*** *light source:*

All surfaces are illuminated the same way independently of the surface orientation. (The surface orientation is perpendicular to the surface normal.)

The image has the same intensity no matter what angle is between the normal and the viewer.

Diffuse *reflection of a directional light source:* The light comes from a particular direction **L**. The intensity at the surface is proportional to the cosine of the angle between **L** and the surface normal **N**

The reflection has the same intensity independent of viewing angle, (just like ambient lighting of the diffuse reflector.)

So, the image intensity is independent of viewing direction, but is proportional to angle between the surface normal and the light direction.

Specular reflection of a directional light source: Vector **L** is the direction from the surface point to the light. The reflection intensity varies with all the **L**, **N** and direction **V** to viewer: It is most intense in the direction **R** given by Snell's law for perfect mirrors:

The "angle of reflection" (away from the normal in the same plane as the normal and incident light ray) equals the "angle of incidence" (away from the normal in the same plane, in the opposite direction).

The **Phong model of specular reflection** is one of several (shading models) used to calculate the image intensity from L, N, and V together with parameters. It is a compromise between efficiency and realism.

Idea: Given **L**, the unit vector in the direction of the light source,

R is the (unit vector pointing in the) direction of reflection as if the surface were a perfect mirror (Snell's law).

Of course, some light is diffused off into other directions..

V is the direction toward the **viewer**

Phong's idea: The shinyness of specular reflection is modelled by the numeric EXPONENT n_s in the formula for the specular contribution to intensity:

$$k_s(\text{specular reflectivity})I_s(\text{source Intensity})(\mathbf{V}\cdot\mathbf{R})^{n_s}$$

Please examine the plots of $\cos^{n_s}(\phi)$ against angle between **V** and **R** in fig. 10-18 of HB.

Exponent of 256 is practical!

Approximate Phong: Use halfway vector **H** midway between **L** and **V** (instead of **R**) because the normal is not needed.

We show illustrations from Foley and Van Damm, including the **Warn Model** in which special **angular intensity distributions** define each light source. Such distributions model the lights used in photography studios.

Diffuse and Specular Reflections from n Light Sources:

I (R or G or B intensity reflected from surface corresponding to one pixel) $=$

$$I_{\text{ambient-diffusive}} + \sum_{\text{light source } l=1}^{n} \left[I_{l,\text{diff}} + I_{l,\text{spec}} \right]$$

$$k_{\text{ambient}} I_{\text{ambient}} + \sum_{l=1}^{n} I_l \left[k_d(\mathbf{N} \cdot \mathbf{L}(l)) + k_s(\mathbf{V}(\text{viewer}) \cdot \mathbf{R}(l))^{n_s} \right]$$

The faster-to-compute halfway-vector approximation gives:

$$k_{\text{ambient}} I_{\text{ambient}} + \sum_{l=1}^{n} I_l \left[k_d(\mathbf{N} \cdot \mathbf{L}(l)) + k_s(\mathbf{N} \cdot \mathbf{H})^{n_s} \right]$$

where

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

(angle between **N**,**H** approximates angle between **V**,**R**)

Extensions to this lighting/shading model:

(1) Surface Light Emissions: Add a constant term $I_{\text{surfemission}}$.

(or simulate with light sources...)

(2) Intensity Attenuation, distance to viewer dependent:

Multiply into I_{diff} a factor depending on the distance to the viewer.

Use exponential falloff for haze: Absorption probability of one photon is constant, so average absorption rate per distance the photons travel is proportional to the intensity (proportional to number of photons per sec. through unit area). So intensity satisfies $dI/dr = -kI$, $k > 0$. Solution is a falling exponential.

(3) Intensity Attenuation, distance from light to object dependent:

Use inverse-square-law for point or small light sources within the world. Light power is uniformly distributed over a sphere whose area is proportional to r^2, where r is distance to the source.

Approximate larger light sources (globes, lighting fixtures) by inverse of a quadratic polynomial; the constant and coefficient of linear term express empirical properties of the light source.

$$f_{\text{radatten}}(d_l \text{ (distance to light) }) = \frac{1}{a_0 + a_1 d_l + a_2 d_l^2}$$

Close to the light, $a_0 + a_1 d_l$ predominates.

At large distances, $a_2 d_l^2$ predominates.

(4) Spotlights: Multiply into intensity a direction-to-light dependent factor.

The **Warn** model includes “barndoors”, more complicated angular dependencies than

$$\cos^{a_l} \text{(light-to-object angle)}$$

(5) RGB color: do intensity for each color separately: Each of RGB has its own **reflectivity** k_R, k_B, k_B and **intensity** I_R, I_G, I_B which are multiplied separately:

$$k_R I_R \quad k_G I_G \quad k_B I_B$$

Colored shiny surfaces:

- Diffuse reflectivities express the color.
- Use white specular reflectivity ($k_R = k_G = k_B = 1.0$).
- Choose different colors for different light sources if you like.

Other Color representations:

1. (CMY) Subtractive (primary dye colors) Cyan (absorbs Red), Magenta (absorbs Green), Yellow (absorbs Blue).

   Vector equation to convert RGB to CMY:

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

2. (HSB or HSV) Hue (reddness vs greeness, etc.), Saturation (purity, red ranges to pink ranges to white), Brightness or Value (any color with brightness 0 equals black)

3. (YIQ) Used by the USA color television standard NTSC, affectionately called “Never The Same Color”. Y is luminance designed so color broadcasts are backwardly with black-and-white TVs where the black-and-white TV displays the Y value only.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

See Foley, Van Dam, Feiner and Hughes....

Hue is a psychological/perceptual term. It correlates with the physical quantity of **dominant wavelength** (place on the spectrum where spectral intensity is greatest).

Saturation (perceptual) correlates with **excitation purity** (how narrow is the range on the spectrum where the intensity is significant).

Lightness (of reflecting objects)/Brightness (of luminous objects) correlates with **luminance** (power intensity times eye's response to the spectrum color).

(Human) sensory responses are generally

Logarithmic with Intensity

Equal intensity ratios seem to give equal gradation of perceived brightness of light and loudness of sound.