## Ambient light

- The *illumination equation* is:

$$I = k_a$$

  where $k_a$ is the object's *intrinsic intensity.* Non-reflexive, self-luminous objects.

- Diffuse, nondirectional source of light:

$$I = I_a k_a$$

  where $k_a$ is the *embient-reflection coefficient* in the range $[0, 1]$. It is a *material property.*

## Diffuse reflection

- Lambertian reflection:

$$I = I_p k_d \langle L, N \rangle$$

  where $I_p$ is the point light source's intensity, $k_d$ is the materials diffuse reflection coefficient, $L$ is the unit vector towards the light and $N$ is the normal to the surface.

- Directional light source, infinitely distant, characterized by fixed $L$.

- Ambient light plus point/directional light:

$$I = I_a k_a + I_p k_d \langle L, N \rangle$$

## Attenuation

- The illumination equation is:

$$I = I_a k_a + f_{at} I_p k_d \langle L, N \rangle$$

- Plain inverse-quadratic law:

$$f_{at} = \frac{1}{d_L^2}$$

where $d_L$ is the distance to the light.

- A more useful form:

$$f_{at} = \min\left(\frac{1}{c_1 + c_2 d_L + c_3 d_L^2}\right)$$

where $c_1, c_2, c_3$ are properties of the light source.

## Color

- A simple approach is to have a separate model for the components of the color model (one of such models is RGB, another one is HSV, yet another one is CMYK).
- Illumination equations:

$$\begin{aligned} I_R &= I_{aR} k_a O_{dR} + f_{at} I_{pR} k_d O_{iR} \langle L, N \rangle \\ I_G &= I_{aG} k_a O_{dG} + f_{at} I_{pG} k_d O_{iG} \langle L, N \rangle \\ I_B &= I_{aB} k_a O_{dB} + f_{at} I_{pB} k_d O_{iB} \langle L, N \rangle \end{aligned}$$

  where $(O_{dR}, O_{dG}, O_{dB})$ are the objects diffuse color, which is the *object's property*.

## Atmospheric attenuation and depth cuing

- *Depth cuing* means distant objects are rendered with lower intensity.
- Account for shift of colors due to the atmosphere.
- Intensity equation (where $\lambda$ is an arbitrary wave length, typically $\lambda \in \{R, G, B\}$):

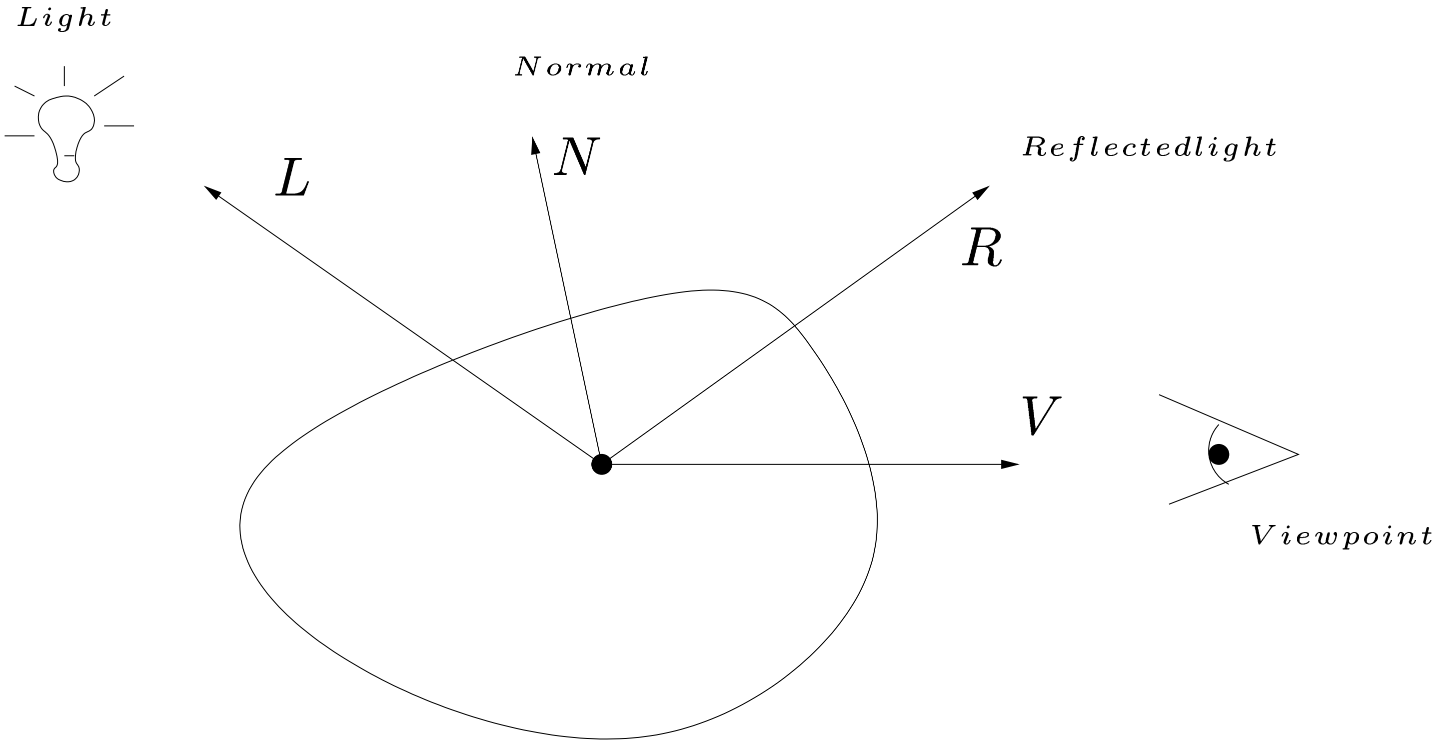
$$I'_\lambda = s_o I_k + (1 - s_o) I_{dc\lambda}$$

  where $I_{dc\lambda}$ is the *depth-cue color*.

- Linear interpolation of $s_o$ relative to the depth of the object:

$$s_o = s_b + \frac{(z_o - z_b)(s_f - s_b)}{(z_f - z_b)}$$

## Vectors in the definition of the Phong model



## Phong illumination model

- Let $V$ be the unit vector towards the viewpoint.
- Illumination equation:

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + f_{at} I_{p\lambda} \left[ k_s O_{d\lambda} \langle N, L \rangle + k_s O_{s\lambda} \langle R, V \rangle^n \right]$$

  where $k_s$ is the *specular reflection coefficient* and $O_{s\lambda}$ is the object's *specular color*. The power $n$ ranges from 1 to approximately 100.

- $R$ is the *reflected vector* obtained by the formula

$$R = -(L - 2\langle L, N \rangle N)$$

  (remember that $L$ points towards the lights, and thus the minus sign.

## Multiple light sources

- The illumination equation for $m$ point and directional lights:

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + \sum_{i=1}^{m} f_{at} I_{p\lambda} \left[ k_s O_{d\lambda} \langle N, L \rangle + k_s O_{s\lambda} \langle R, V \rangle^n \right]$$

  where $V$ is the unit vector towards the viewpoint.

- If the maximal pixel intensity is exceeded, it may be clamped to the maximum intensity value.