Models of Local Illumination

Graphics Systems /

Computer Graphics and Interfaces

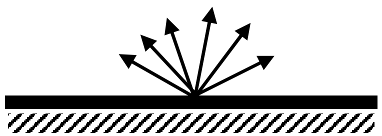
Models of Local Illumination

The **lighting models** expressing the lighting components that define the intensity of light reflected from a given surface, allowing the calculation of the color of each point of the surface of the objects in the image.

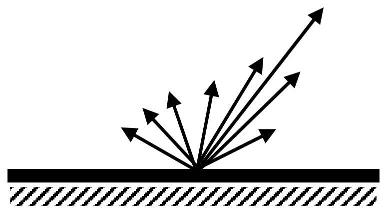
The incident light is reflected on the face in two ways:

Diffuse reflection: reflects light in all directions with equal intensity value due to the roughness of the reflecting surface.

Specular Reflection: light sources produce over-illuminated areas on the reflective surface.



Diffuse Reflection



Specular Reflection
+ Soft

Models of Local Illumination
Elementary Model

Elemental Illumination Model

a) Ambient lighting

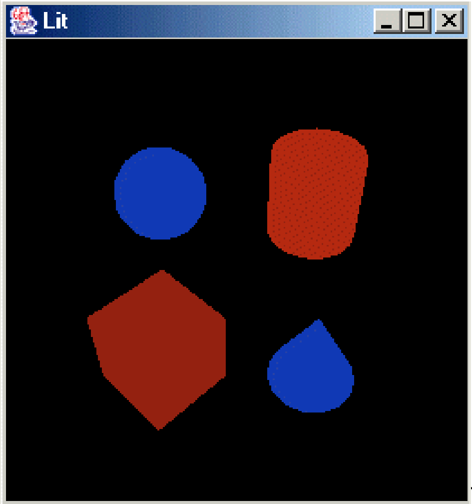
Corresponds to a diffuse light, where many light rays come from the reflection point.

$I = k_a . I_a$ $\qquad$ k_a: Coef. ambient reflection (diffuse) of the face;

varies between 0 and 1

I: Intensity observed

Intensity I_a is constant in all directions. If we consider only this component to set the light reflected by the object, then all the faces have the same illumination intensity as shown in the Figure



The reflected light is uniform across the face and independent of the position of the observer.

The edges are not distinguished.

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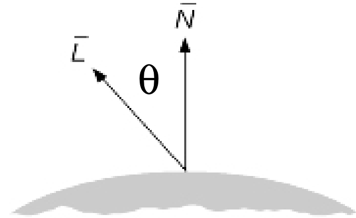
b) Diffuse Reflection

The diffuse reflection due to a **point light source** is calculated according to Lambert's law: the intensity of reflected light depends on the angle of illumination.

The intensity of the light in the observed object varies depending on the orientation of the surface and the distance from the light source.

$$I = \frac{k_d . I_p}{d + d_0} \cos(\theta)$$

Note: The intensity of reflected light does not depend on the position of the observer. Depends on the angle of incidence of light.



(For the Lambert law, the denominator should be d^2...)

<u>The unit vectors are:</u>
θ: angle of incidence of the light source
N: Surface normal (unit vector)
L: The radius direction of illumination (r. incident)
I_p: intensity light source
K_d: Diffuse reflection coefficient

$$\cos(\theta) = N \cdot L$$

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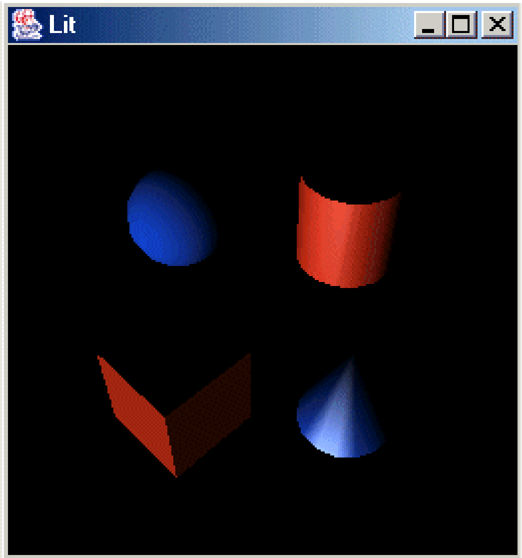
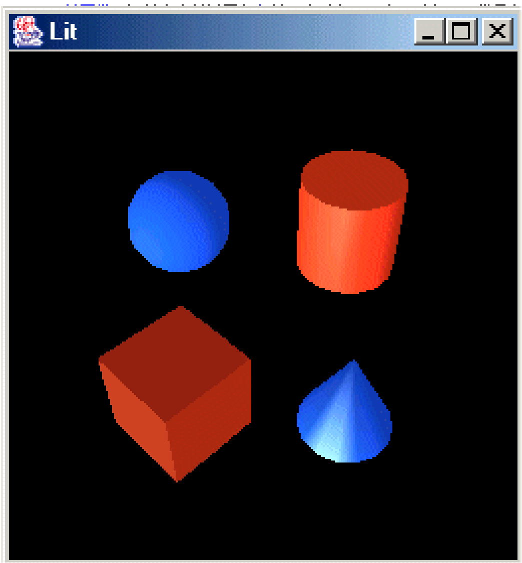
Adding the two components:

$$I = k_a I_a + \frac{k_d . I_p}{d + d_0} N.L$$



Only diffuse component



Ambient + diffuse component

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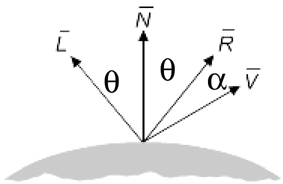
c) Specular Reflection / Phong Model

Observable reflection on polished / shiny surfaces.



R : Direction of maximum reflection
α : Angle between ***R*** and the direction of the observer ***V***.

$$\boxed{I_s = \frac{k_s.I_p}{d + d_0}\cos^n(\alpha)}$$

The **specular reflection** depends on the position of the observer. $\boldsymbol{K_s}$ is a constant that depends on the material as well as the exponent ***n***.
(Strictly speaking, we should use a function ***W (Θ)*** instead of $\boldsymbol{K_s}$...)

In an ideal specular surface (ideal mirror), light is reflected only in the direction ***R***.

In a non-ideal one, the direction ***R*** will have the greatest intensity of reflection; other directions have lower intensities.

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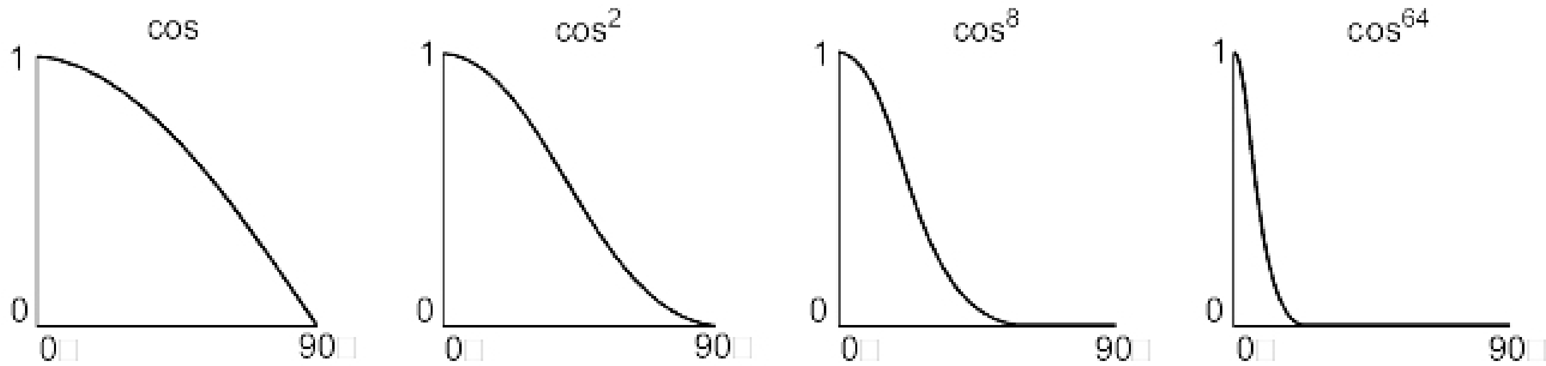
Specular Reflection / Phong Model

The intensity of the specular reflection is proportional to **$\cos^n(\alpha)$**In which **n** depends on the surface characteristics (value 1 for non polished faces and 200 for perfectly polished faces).



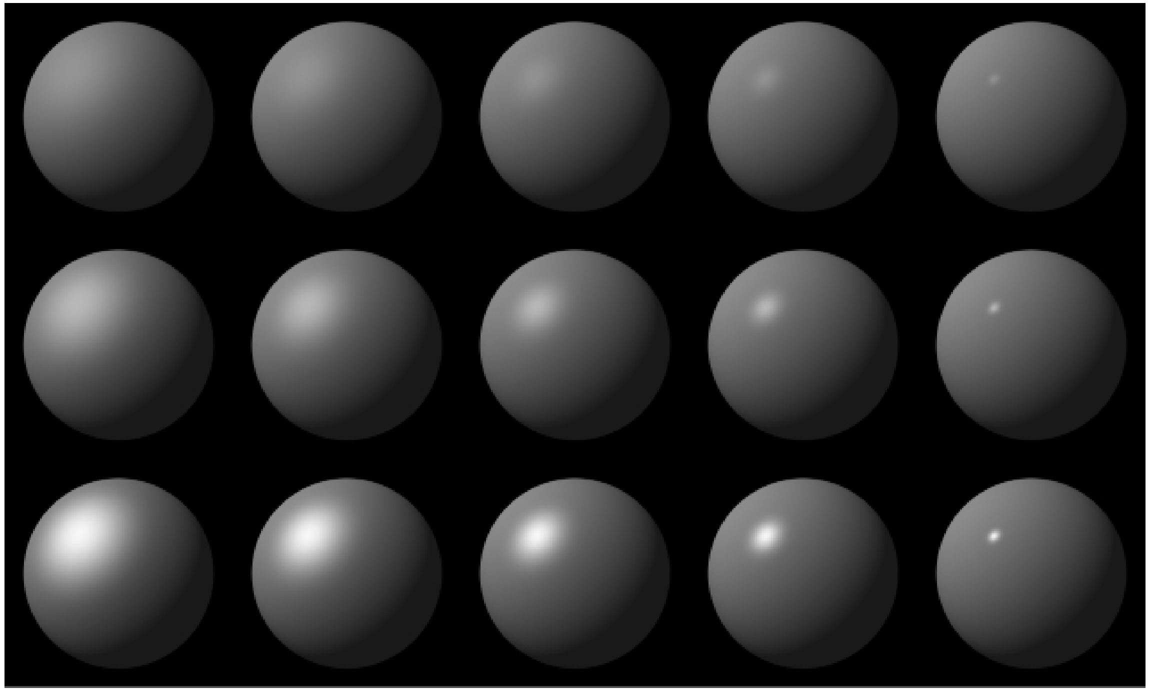
$$I_s = \frac{k_s.I_p}{d+d_0}\cos^n(\alpha)$$

Being **V** and **R** normalized vectors:

$$I_s = \frac{k_s.I_p}{d+d_0}(V.R)^n$$

Models of Local Illumination

Specular Reflection / Phong Model



Phong lighting model for the different values of $\mathbf{k_s}$ and $\mathbf{n}$. $\mathbf{I_a}$=$\mathbf{I_p}$= 1.0, $\mathbf{k_a}$= 0.1, $\mathbf{k_d}$= 0:45.

From left to right: $\mathbf{n}$= 3.0, 5.0, 10.0, 27.0, 200.0.

From top to bottom: $\mathbf{k_s}$= 0.1, 0.25, 0.5.

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Elementary Model

- The previous expression is:

$$I = k_a I_a + I_p \left[\frac{k_d}{d + d_0} N.L + \frac{k_s}{d + d_0} (R.V)^n \right]$$

- Reflection coefficients:
  - K_a and K_d are usually equal

- Can be decomposed into color components (RGB or other):
  - I, I_a, I_p
  - k_a, k_d
  - k_s

- *Usually, n is not decomposed in RGB*

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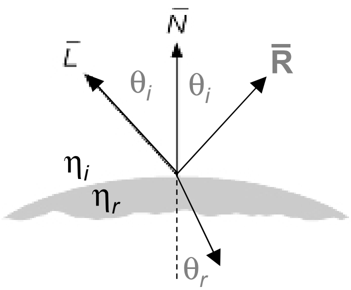
d) Refraction (in transparent objects)

When the object is transparent, it is necessary to provide the light that passes through a face: it is called **transmitted light** or **refracted light**.



Since to the speed of light is different in different materials, the angle of refraction results different of the angle of incidence.

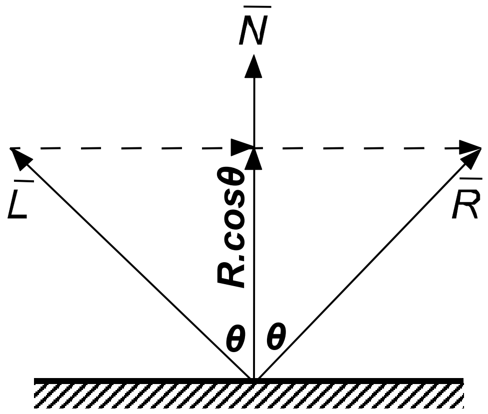
η_i : refractive index of material 1 (air)
η_r : refractive index of material 2 (watter)

Snell's Law:

$$\sin(\theta_r) = \frac{\eta_i}{\eta_r}\sin(\theta_i)$$

Models of Local Illumination

Calculating the vector R is complex...

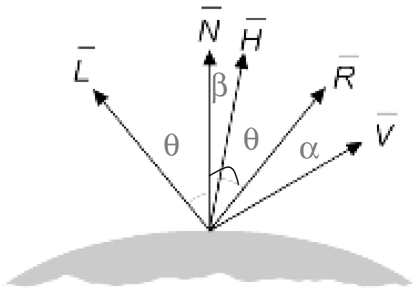


$$\vec{L}+\vec{R}=\vec{N}.2.|R|.\cos\theta$$

Where: $$\vec{R}=2.\vec{N}.\left(\vec{N}.\vec{L}\right)-\vec{L}$$

A simplified formulation considers the ***halfway vector H,*** by calculating ***N.H,*** instead of ***R.V***. It is an approximation, although crude ...

$$I=k_a I_a+\sum_{ls}[k_d.(N.L_{ls})+k_s.(N.H_{ls})^n].I_{ls}$$



How to determine ***H***?

Models of Local Illumination
Elementary Model

For flat surfaces, we can consider the light source and the observer are sufficiently far from the object:

> ***V, N*** and ***L*** are constant over the entire surface in the calculation of ***cos θ=R.V*** (Approximation that results well, with fewer calculations).

On non-planar surfaces, this is not possible ...

The calculation of ***N.H*** requires fewer operations than the calculation ***V.R***.

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

The calculation of ***H*** involves only the sum of ***L*** and ***V*** and a normalization

Models of Local Illumination

Model presented in the recommended bibliography

- Attenuation factor of illumination with distance from the light source:
  - Intended to replace the denominators (distance)

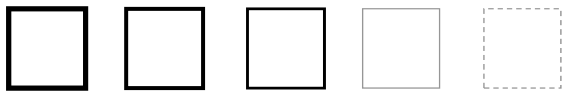
$$f_{att} = \min\left(1, \frac{1}{k_c + k_l d + k_q d^2}\right)$$

- Color lights and Objects:
  - Use of coefficients "*k*" scalar
  - Introduction of values "O_λ" colored

$$I_\lambda = k_a I_{a\lambda} O_{d\lambda} + f_{att} I_{p\lambda} \left[k_d O_{d\lambda} (N.L) + k_s O_{s\lambda} (R.V)^n \right]$$

- Atmospheric attenuation:
  - Do not confuse with attenuation of lighting ...

(Observer)



Models of Local Lighting

Local illumination, Improved Model (Recommended book)

1. Attenuation factor of the light source f_{att}

With the Phong model, if the projection of two parallel faces with the same physical characteristics appear overlaped, the observer could not distinguish between the beginning and the end of one another, regardless of the distance from the observer to each face. The attenuation factor intend to decrease luminance with distance from the light source to the illuminated point.

$$I = k_a I_a + f_{att}.[k_d (N.L_{ls}) + k_s.(V.R_{ls})^n].I_{ls}$$

The attenuation factor is defined as:

$$f_{att} = \min\left(1, \frac{1}{k_c + k_l d + k_q d^2}\right)$$

$K_c K_l K_q$, are user-defined constants that characterize the light source.

In the book:
$K_c = C_1$
$K_l = C_2$
$K_q = C_3$

The factor $1 / d_L^2$ would not work well. For far light sources, this factor does not vary sufficiently. If the light source is nearby, very large variations result between similar objects.

Models of Local Lighting

Local illumination, Improved Model (Recommended book)

- OpenGL:

  – Example:

```
glLightf (GL_LIGHT0, GL_CONSTANT_ATTENUATION, Kc)
glLightf (GL_LIGHT0, GL_LINEAR_ATTENUATION, Kl)
glLightf (GL_LIGHT0, GL_QUADRATIC_ATTENUATION, Kq)
```

Note: all contributions of the light source GL_LIGHT0 will be attenuated, ie, specular, diffuse and even the ambient!

- In OpenGL, there is:

  -Ambient Light

  -Participation (percentage) of <u>each light source</u> for the Ambient Light

Models of Local Lighting

Local illumination, Improved Model (Recommended book)

2. Color

The colors of light and surfaces are treated considering different equations for each component of the colour spectrum.

- Typically, the spectrum is reduced down to RGB Components ...
  - The **diffuse color** of an object is defined by **(O_{dR}, O_{dG}, O_{dB}).**
  - The light source is characterized by intensities for each component: **(I_{pR}, I_{pG}, I_{pB})**
- The lighting model is defined by three equations, one for each component **(R, G, B)**:

$$I_\lambda = k_a I_{a\lambda} O_{d\lambda} + f_{att} I_{p\lambda} \left[k_d O_{d\lambda} (N.L) + k_s O_{s\lambda} (R.V)^n \right]$$

$$I_R = k_a I_{aR} O_{dR} + f_{att}.[k_d.O_{dR}(N.L) + k_s.O_{sR}(V.R)^n].I_{pR}$$

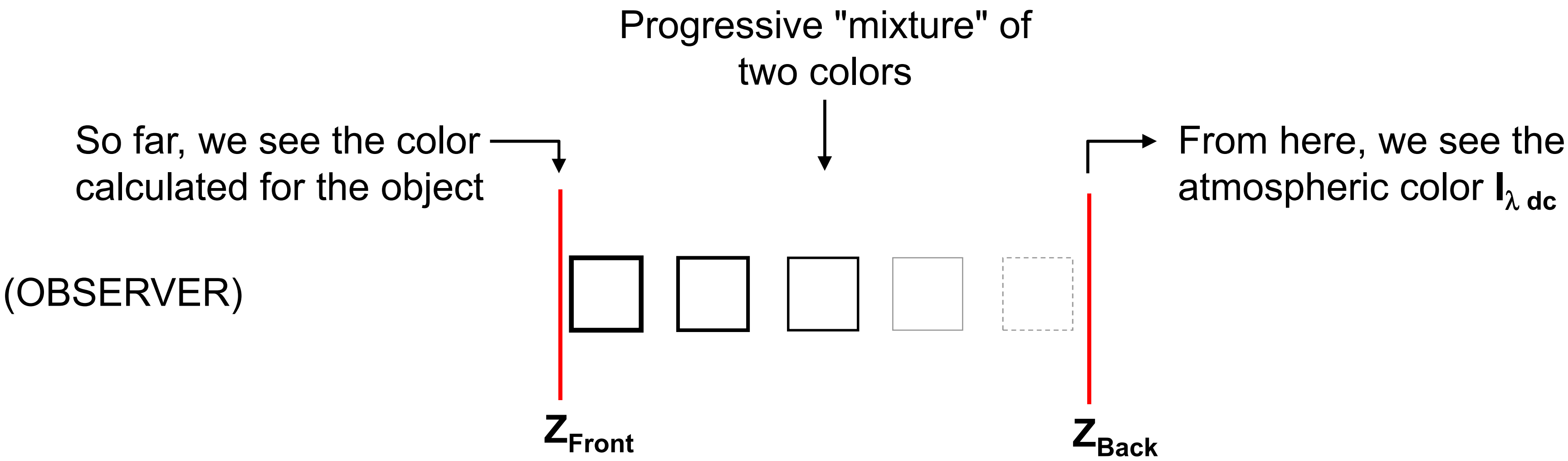
$$I_G = k_a I_{aG} O_{dG} + f_{att}.[k_d.O_{dG}(N.L) + k_s.O_{sG}(V.R)^n].I_{pG}$$

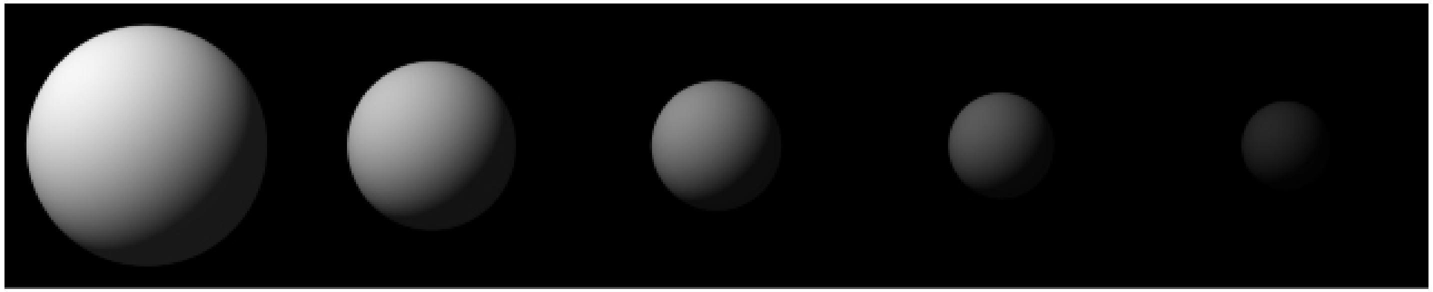
$$I_B = k_a I_{aB} O_{dB} + f_{att}.[k_d.O_{dB}(N.L) + k_s.O_{sB}(V.R)^n].I_{pB}$$

Models of Local Lighting

Local illumination, Improved Model (Recommended book)

3. Atmospheric attenuation (With Z decreasing with the distance to the observer)





Models of Local Lighting

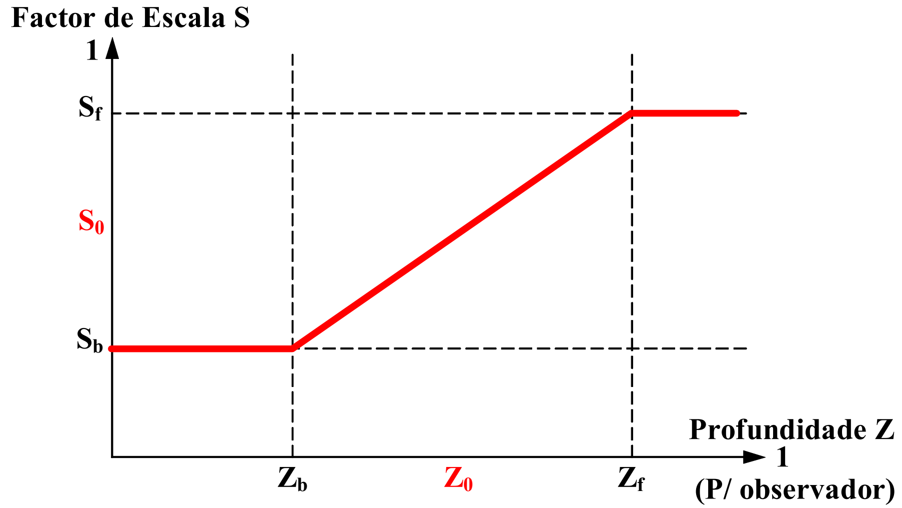
Local illumination, Improved Model (Recommended book)

- Atmospheric attenuation

$$I'_\lambda = s_0 I_\lambda + (1 - s_0) I_{dc\lambda}$$

- With:

$$s_0 = s_b + \frac{(z_0 - z_b)(s_f - s_b)}{z_f - z_b}$$



Being:

- I'_λ: Lighting / color with atmospheric attenuation
- I_λ: Lighting / color of the object without atmospheric attenuation
- $I_{dc\lambda}$: Lighting / color of the "atmosphere"
- s_f, s_b: Scale factors (typical val. 1 and 0, respectively)
- z_0: Object distance
- z_f, z_b: Distance to the planes *front* and *back*