FLAME UNIVERSITY

EVERLASTING learning

FUNDAMENTALS OF COMPUTER GRAPHICS (CSIT304)

ILLUMINATION AND SHADING

CHIRANJOY CHATTOPADHYAY

Associate Professor,

FLAME School of Computation and Data Science

SURFACE RENDERING METHOD

- Realistic displays of a scene are obtained by
  - Generating **perspective projections** of objects
  - **Applying** **natural lighting effects** to the **visible surfaces**

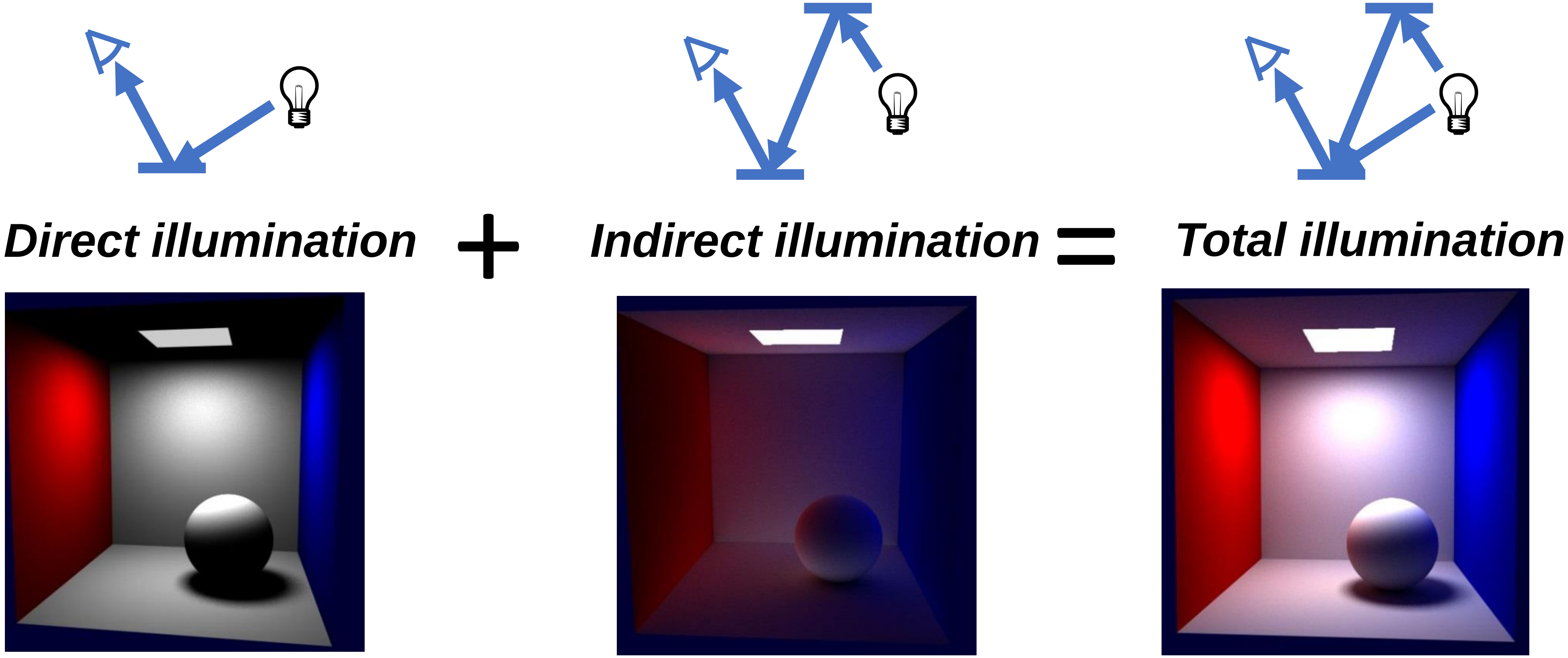
- An **illumination model** is used **to calculate the color of an illuminated position on the surface of an object**.

- A **surface-rendering method** uses the **color calculations from an illumination model**
  - To determine the **pixel colors for all projected positions in a scene.**

ILLUMINATION VS SHADING

Illumination	Shading
Refers to the process of simulating the way that light interacts with objects in a virtual scene.	It is the process of calculating the color and intensity of each pixel in the image based on the illumination model.
It involves calculating how light from different sources illuminates the surfaces of objects and how that light is reflected or absorbed by those surfaces.	It involves determining how much light is received by each pixel on the object's surface and to determine the final color and brightness of that pixel.
The goal is to create a realistic lighting environment that accurately portrays the interplay of light and shadow in the scene.	Shading is used to create the illusion of depth, texture, and curvature in an image.
Concerned with simulating the behavior of light in a virtual scene	Involves calculating the final colors and intensities of pixels in an image *based on the illumination model*

GLOBAL ILLUMINATION



DIFFUSE INTER-REFLECTION

Total illumination
(normal image)

DIFFUSE INTER-REFLECTION

Direct illumination

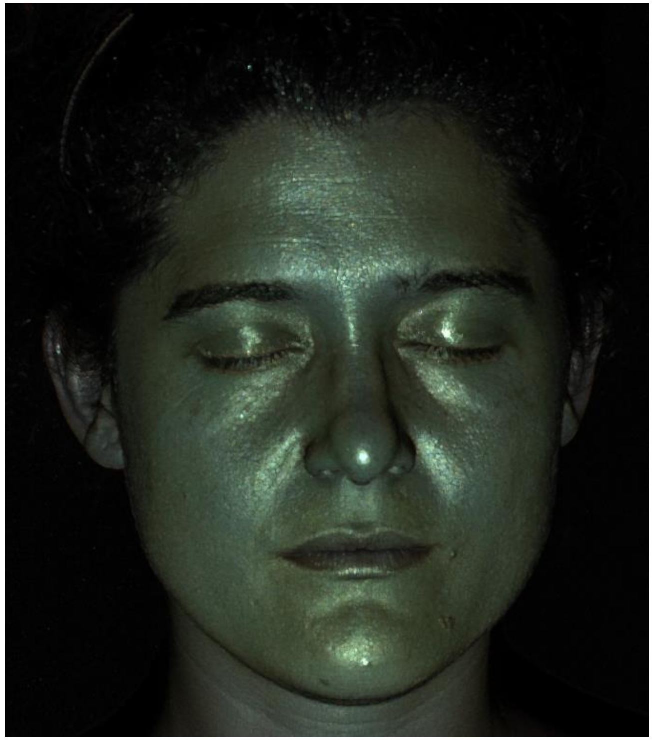
DIFFUSE INTER-REFLECTION

Indirect illumination
(Diffuse interreflection)

HUMAN FACE

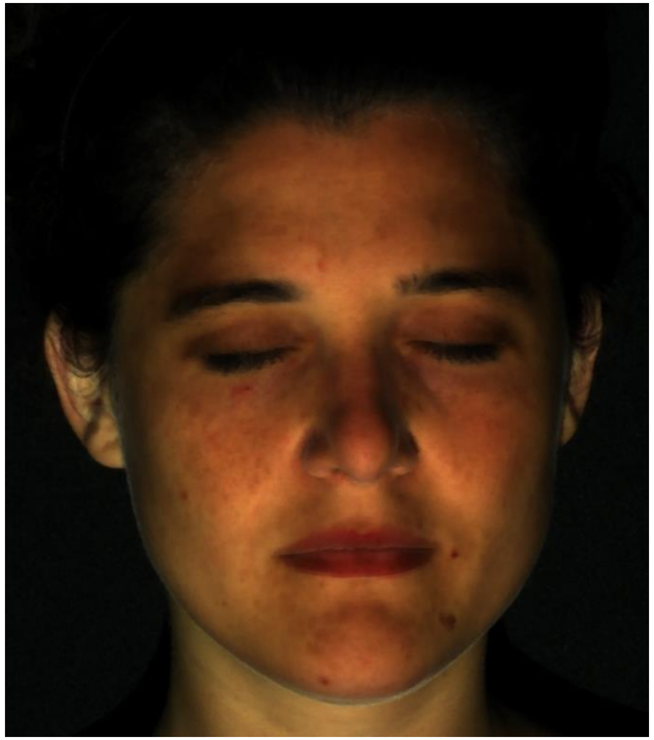
Total illumination
(normal image)

HUMAN FACE



Direct illumination

HUMAN FACE

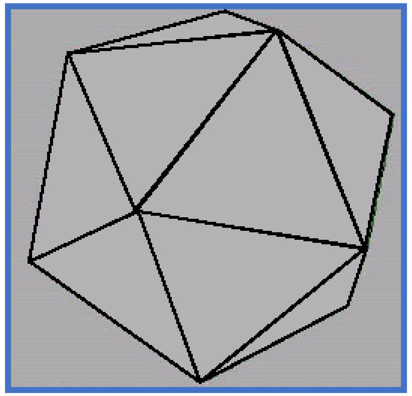


Indirect illumination

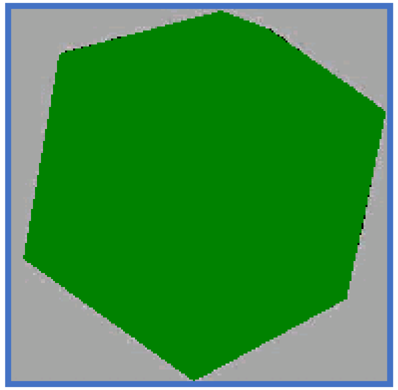
ILLUMINATION MODELS

ILLUMINATION

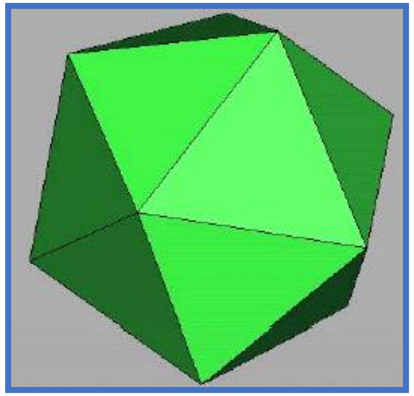
- How do We Compute Radiance for a Sample Ray?
  - Must derive computer models for ...
    - Emission at light sources
    - Scattering at surfaces
    - Reception at the camera



Wireframe



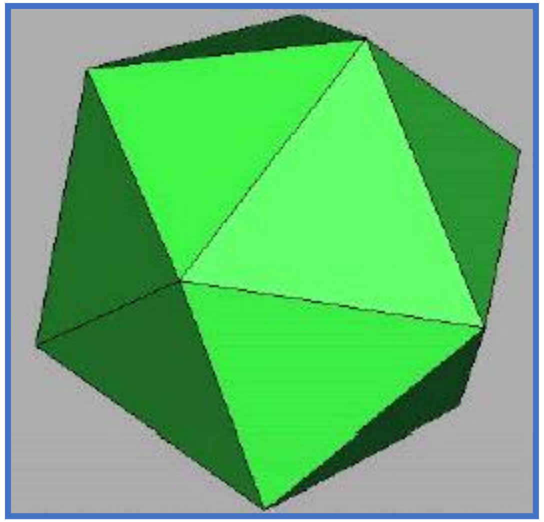
Without Illumination



Direct Illumination

OVERVIEW

- Direct Illumination
  - Emission at light sources
  - Scattering at surfaces
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections



Direct Illumination

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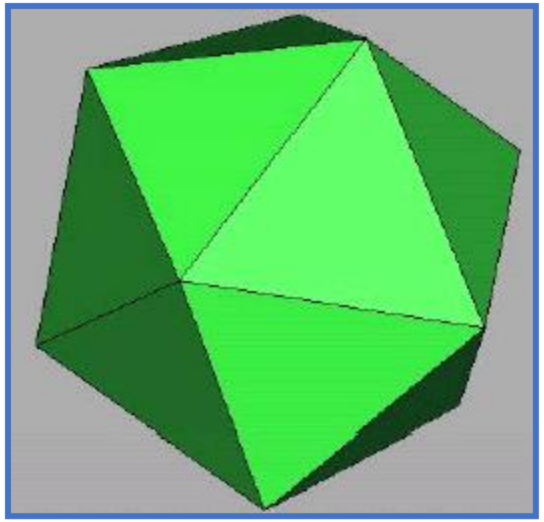
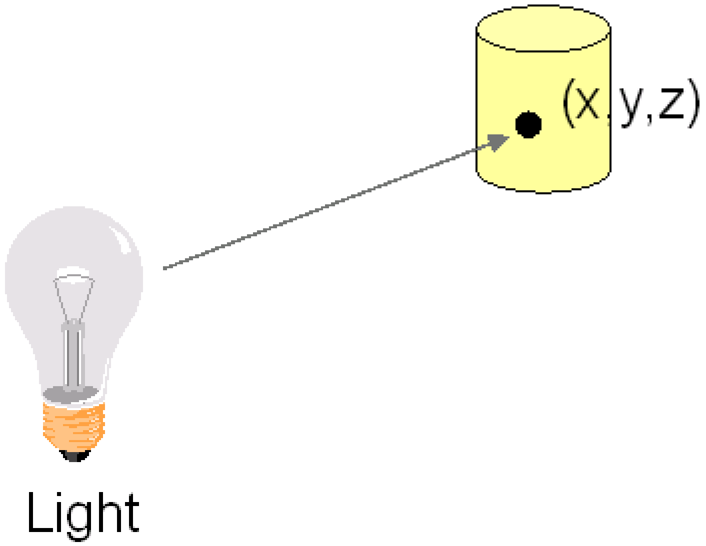


Direct Illumination

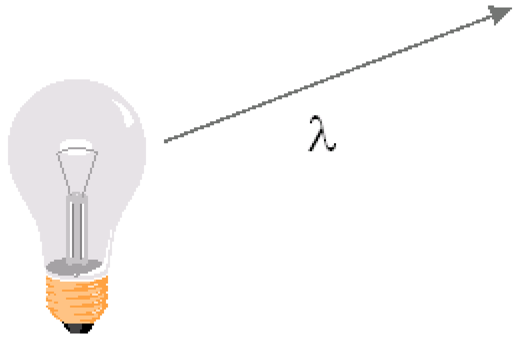
MODELING LIGHT SOURCE

- $I_L(x,y,z,\theta,\phi,\lambda)$
  - Describes the intensity of energy,
  - Leaving a light source
  - Arriving at location (x, y, z)
  - From direction (θ, ϕ)
  - With wavelength λ



EMPIRICAL MODEL

- Ideally Measure Irradiant Energy for “All” Situations
  - Too much storage
  - Difficult in practice

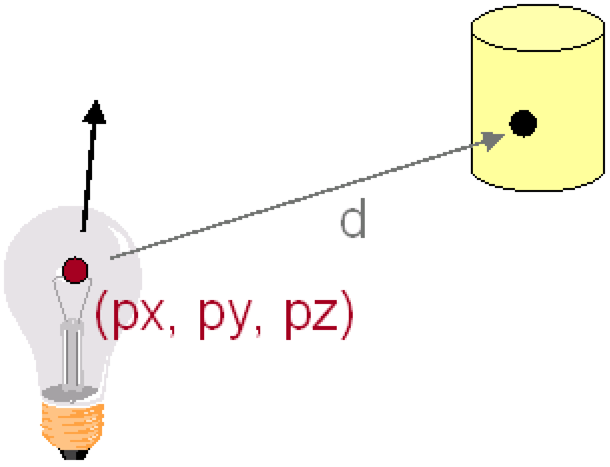


POINT LIGHT SOURCE

Radial Intensity Attenuation

$$I \propto \frac{1}{d^2}$$

- Models Omni-Directional Point Source (E.g., Bulb)
  - Intensity (I_0)
  - Position (px, py, pz)
  - Factors (k_c, kl, k_q) for attenuation with distance (d)



$$I_L = \frac{\mathrm{I_0}}{\mathrm{k_c} + \mathrm{k_1} d + \mathrm{k_q} d^2}$$

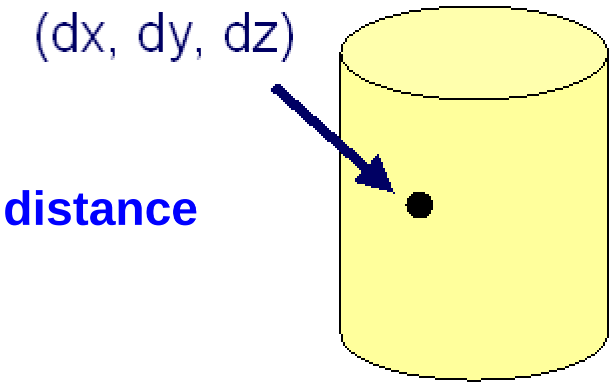
The numerical values for the coefficients can then be adjusted to produce optimal attenuation effects

When d = Infinity?

DIRECTIONAL LIGHT SOURCE

- Models Point Light Source at Infinity (E.g., Sun)
  - Intensity (I_0)
  - Direction (dx,dy,dz)

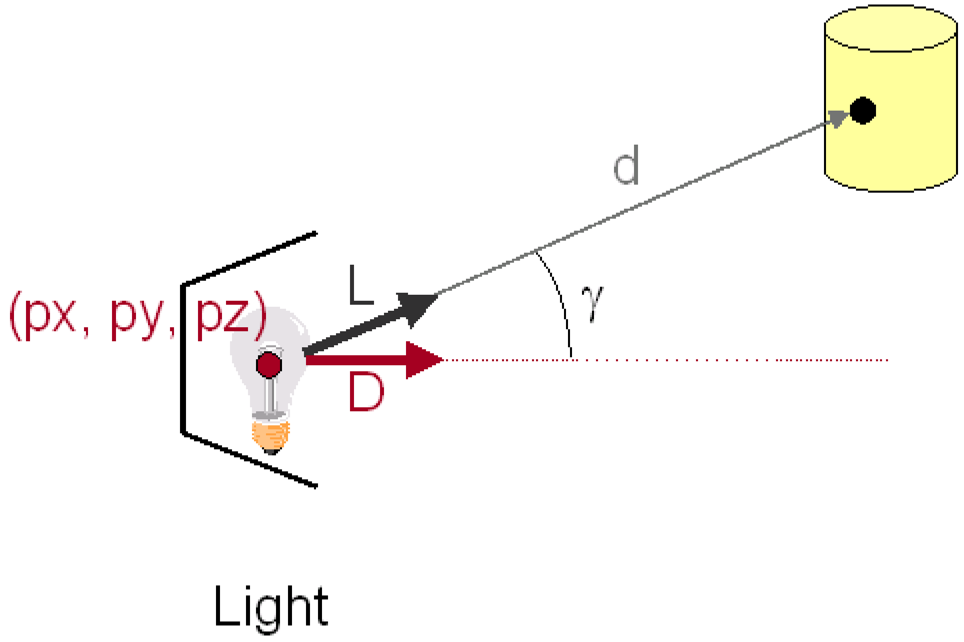
No attenuation with distance



$$\boxed{I_L = \mathrm{I}_0}$$

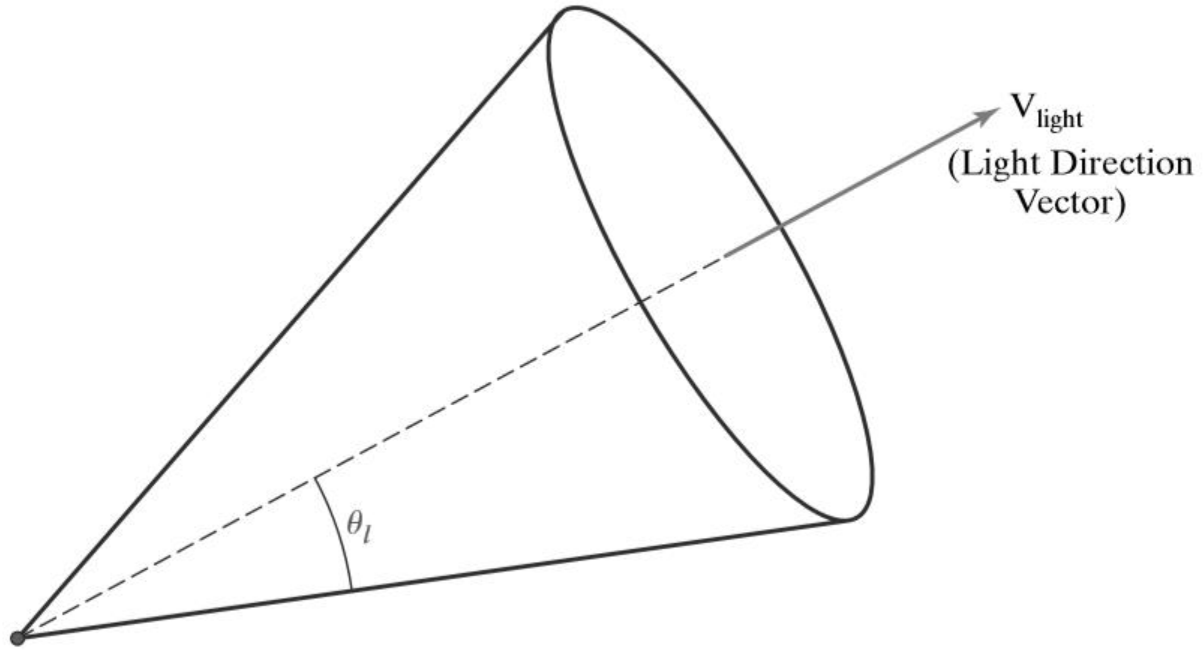
SPOT LIGHT SOURCE

- Models Point Light Source with Direction
  - Intensity (I_0),
  - Position (px, py, pz)
  - Direction (dx, dy, dz)
  - Attenuation



$$I_L = \frac{\mathrm{I_0(D \cdot L)}}{\mathrm{k_c} + \mathrm{k_1}d + \mathrm{k_q}d^2}$$

DIRECTIONAL LIGHT SOURCES



- A directional point light source.
- The unit light-direction vector defines the axis of a light cone,
- Angle θ_l defines the angular extent of the circular cone.

ANGULAR INTENSITY ATTENUATION

The greater the value for the attenuation exponent a_l the smaller the value of the angular intensity-attenuation function for a given value of angle $\phi > 0°$.

- Attenuate the light intensity
  - Angularly about the source
  - Radially out from the point-source position.

$$f_{\text{angatten}}(\phi) = \cos^{a_l}\phi, \qquad 0° \le \phi \le \theta$$

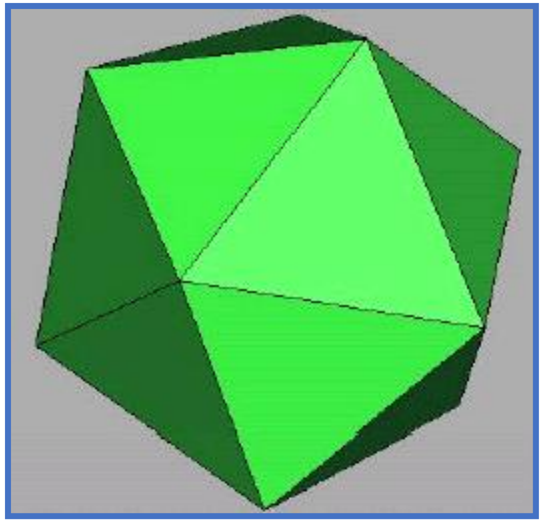
- The attenuation exponent a_l is assigned some positive value
- Angle ϕ is measured from the cone axis.

$$f_{l,\text{angatten}} = \begin{cases} 1.0, & \text{if source is not a spotlight} \\ 0.0, & \text{if } \mathbf{V}_{\text{obj}} \cdot \mathbf{V}_{\text{light}} = \cos\alpha < \cos\theta_l \\ & \quad \text{(object is outside the spotlight cone)} \\ (\mathbf{V}_{\text{obj}} \cdot \mathbf{V}_{\text{light}})^{a_l}, & \text{otherwise} \end{cases}$$

- The general equation for angular attenuation
- V_{light} = unit vector in the light-source direction (along the cone axis)
- V_{obj} = unit vector in the direction from the light source to an object position.

OVERVIEW

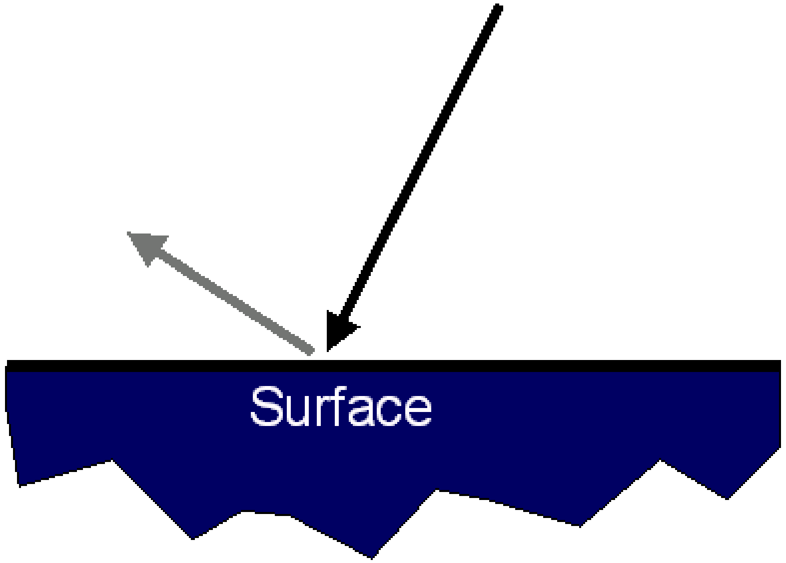
- Direct Illumination
  - Emission at light sources
  - Scattering at surfaces
- Global Illumination
  - Shadows
  - Refractions
  - Inter-object reflections



Direct Illumination

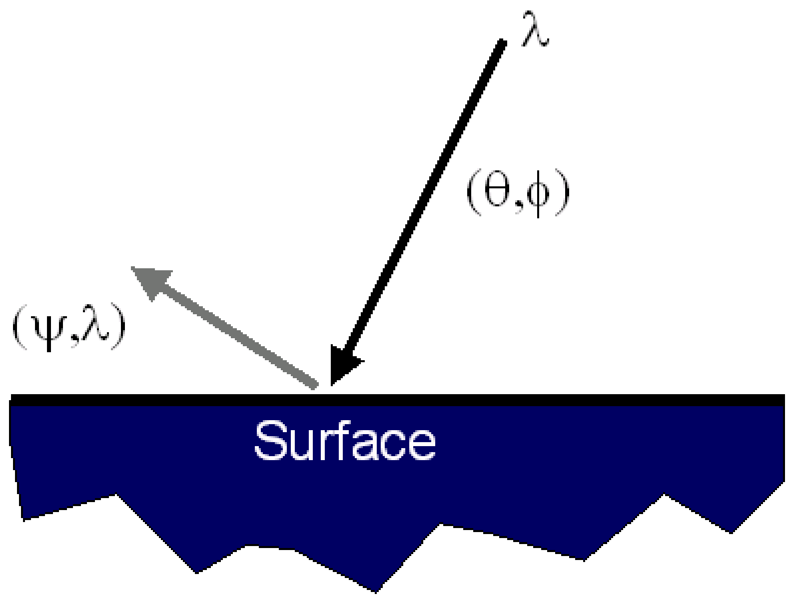
MODELING SURFACE REFLECTION

- $R_s(\theta,\phi,\gamma,\psi,\lambda)$
  - Describes the amount of incident energy
  - Arriving from direction (θ, ϕ)
  - Leaving in direction (γ, ψ)
  - With wavelength λ



EMPIRICAL MODEL

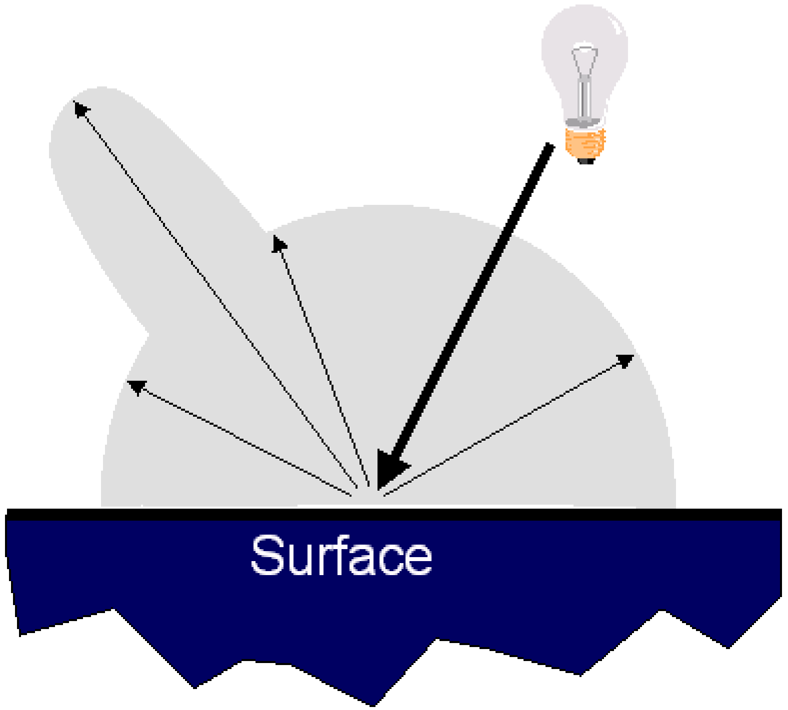
- Ideally Measure Radiant Energy for "All" Combinations of Incident Angles
  - Too much storage
  - Difficult in practice



REFLECTANCE MODEL

- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"

Based on model
proposed by Phong



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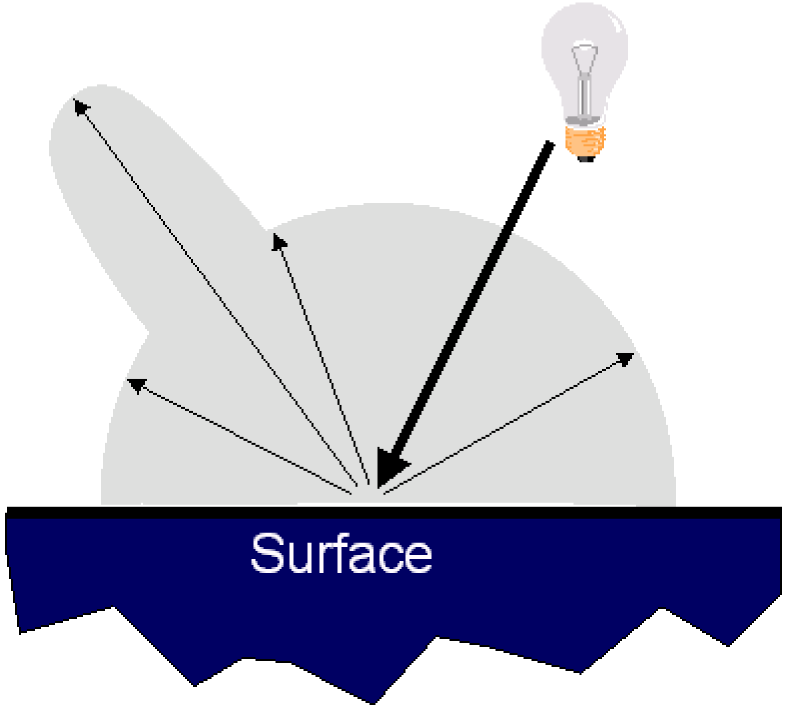
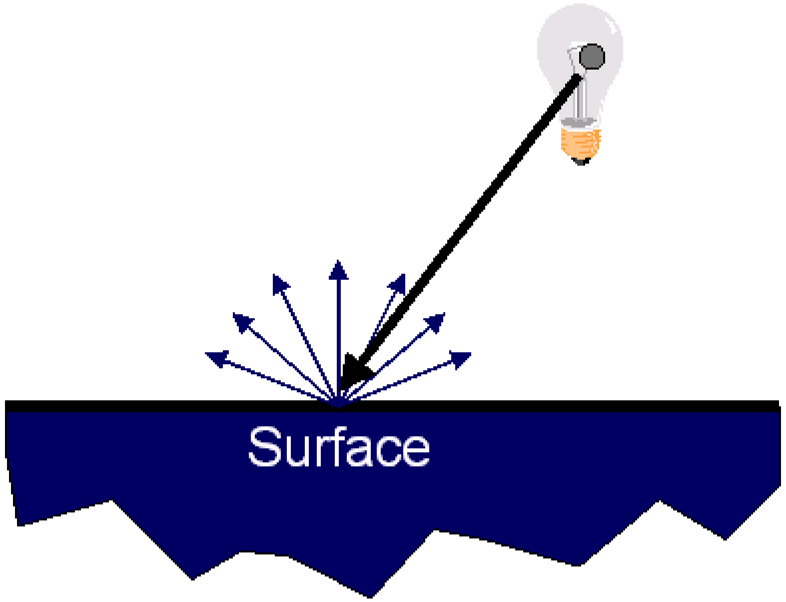


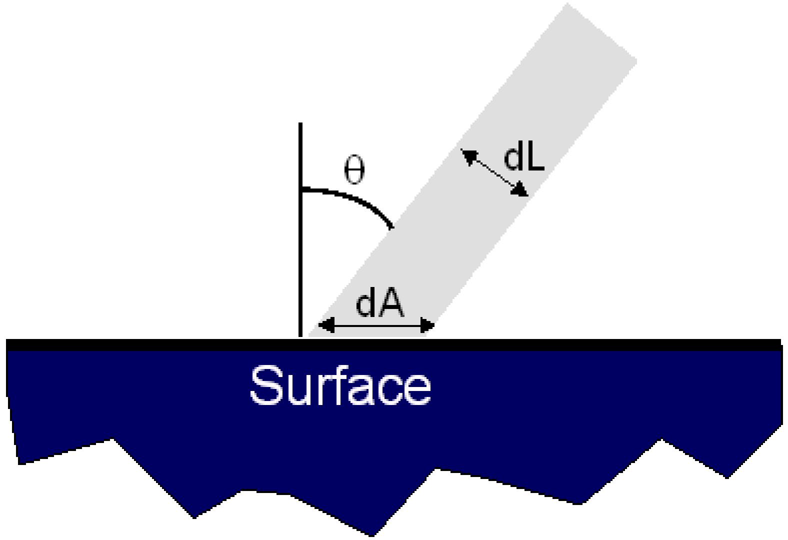
DIFFUSE REFLECTION

- Assume Surface Reflects Equally in All Directions
  - Examples: chalk, clay



DIFFUSE REFLECTION

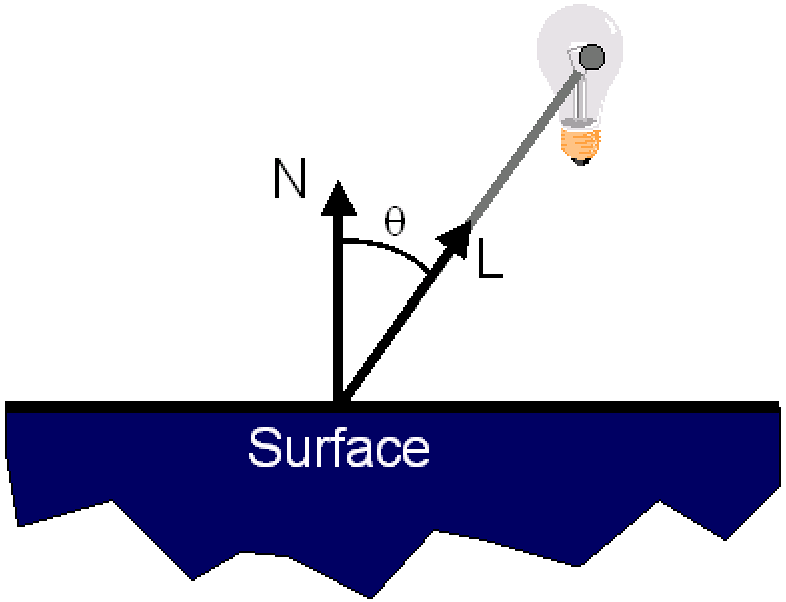
- How Much Light is Reflected?
  - Depends on angle of incident light
  - $dL = dA \cos \Theta$



DIFFUSE REFLECTION

- Lambertian Model
  - Cosine law (dot product)

$$\boxed{I_D = K_D(\mathrm{N} \cdot \mathrm{L})I_L}$$



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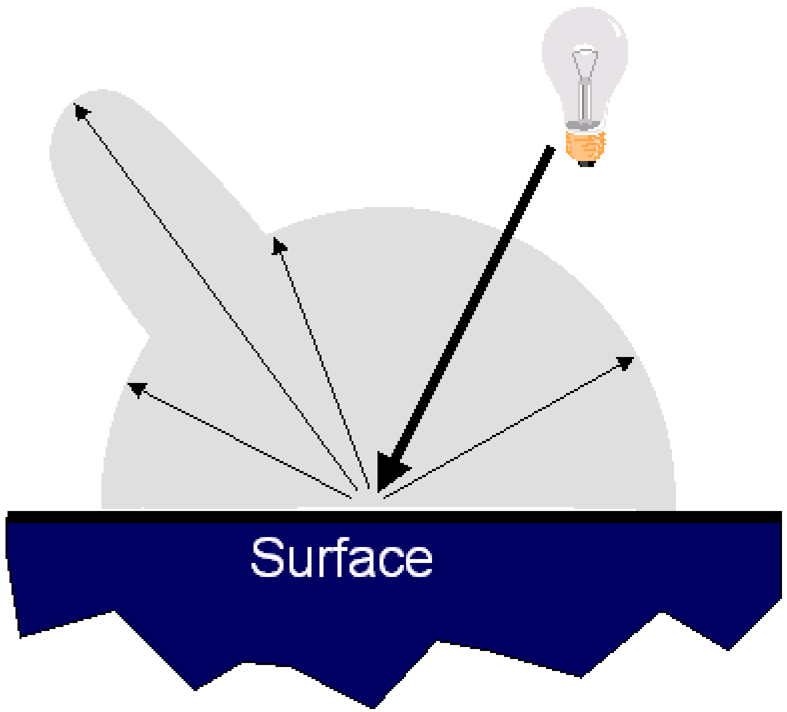
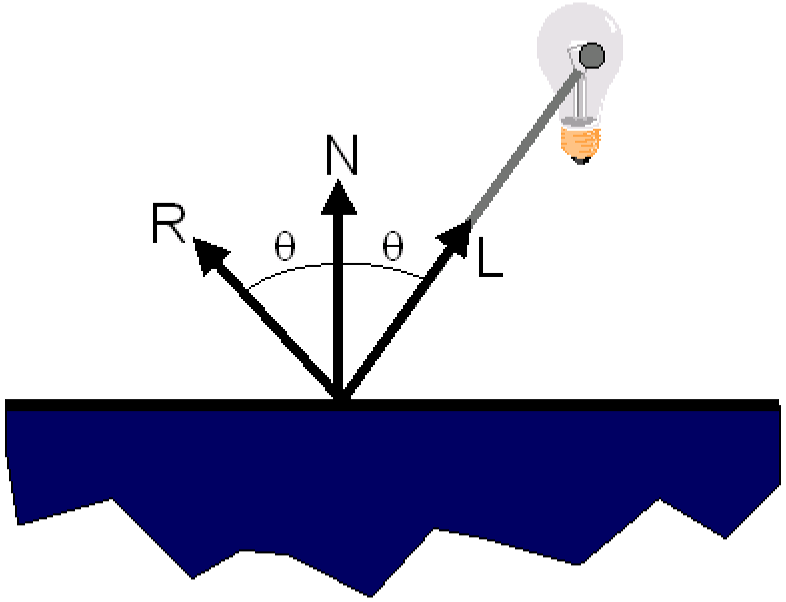


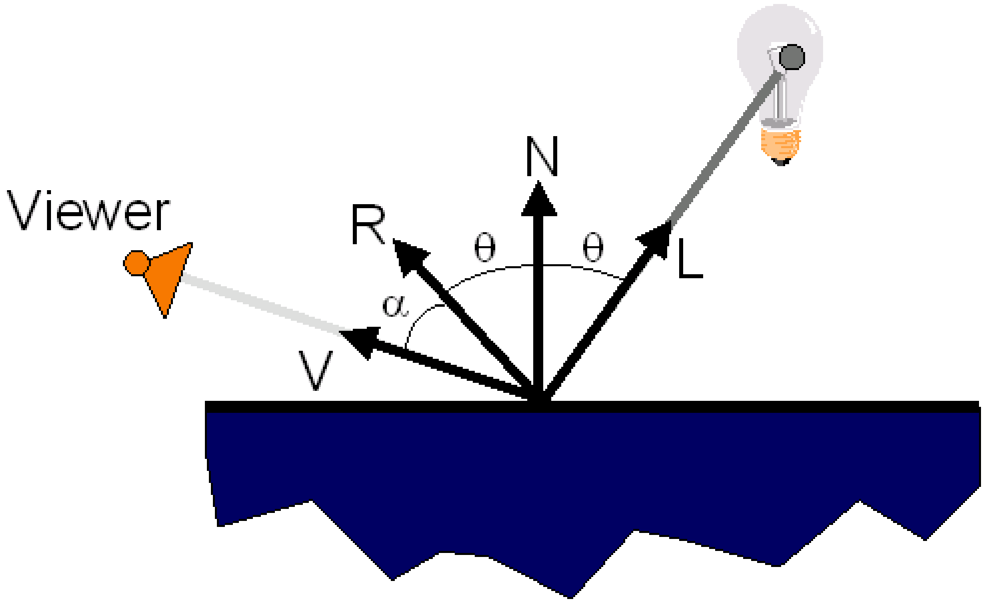
SPECULAR REFLECTION

- Reflection is Strongest Near Mirror Angle
  - Examples: mirrors, metals



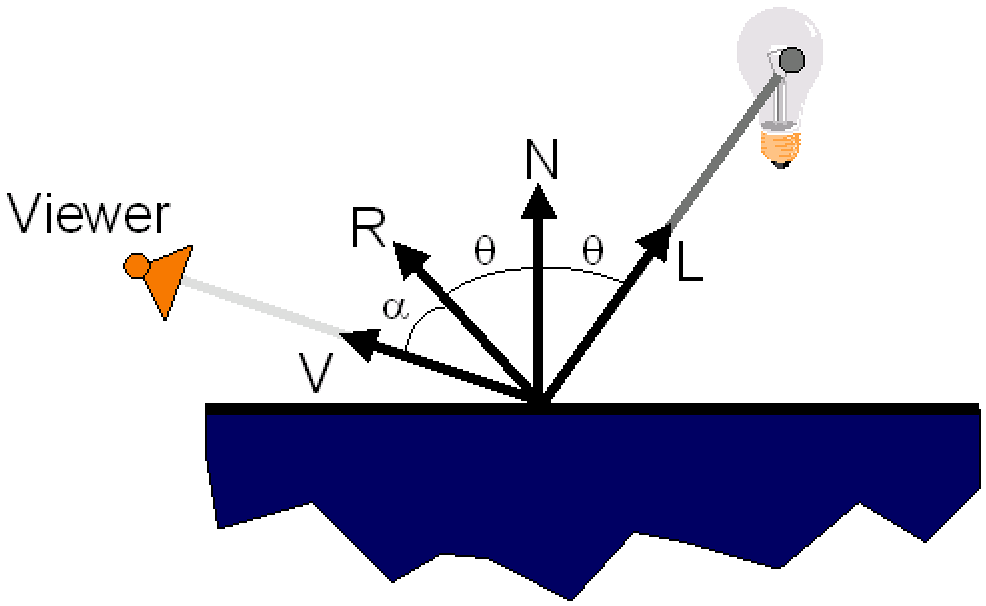
SPECULAR REFLECTION

- How Much Light is Seen?
  - Depends on angle of incident light and angle to viewer



SPECULAR REFLECTION

- Phong Model
  - $\{\cos(\alpha)\}^n$

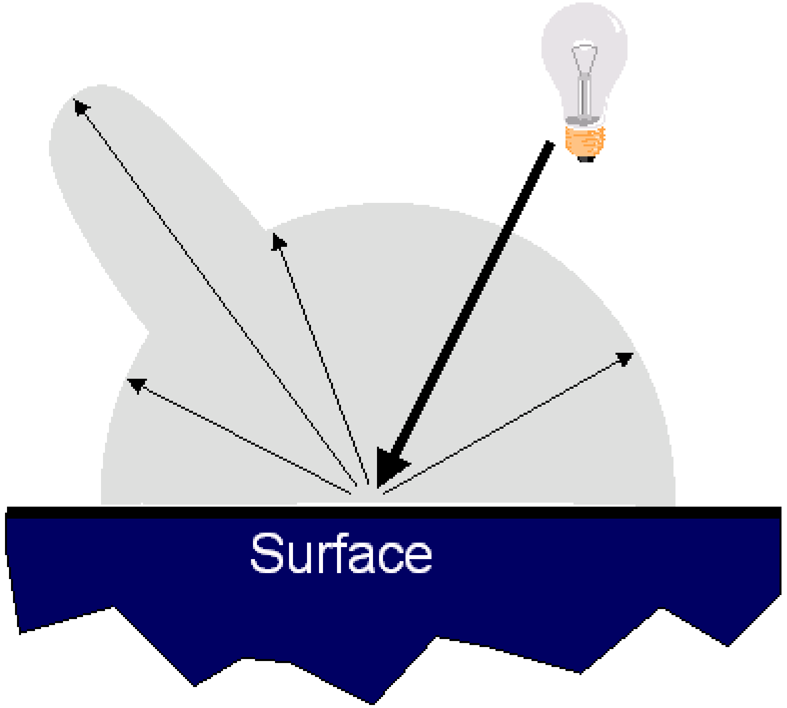


$$I_S = K_S(\mathrm{V} \cdot \mathrm{R})^n I_L$$

REFLECTANCE MODEL

- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"

Based on model proposed by Phong



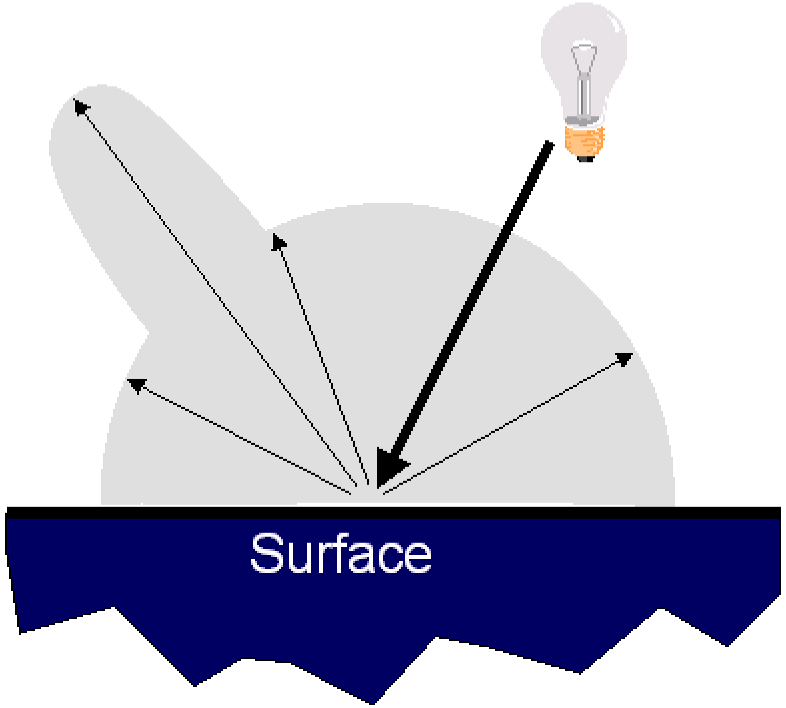
EMISSION

- Represents Light Emitting Directly From Polygon

REFLECTANCE MODEL

- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"

Based on model proposed by Phong

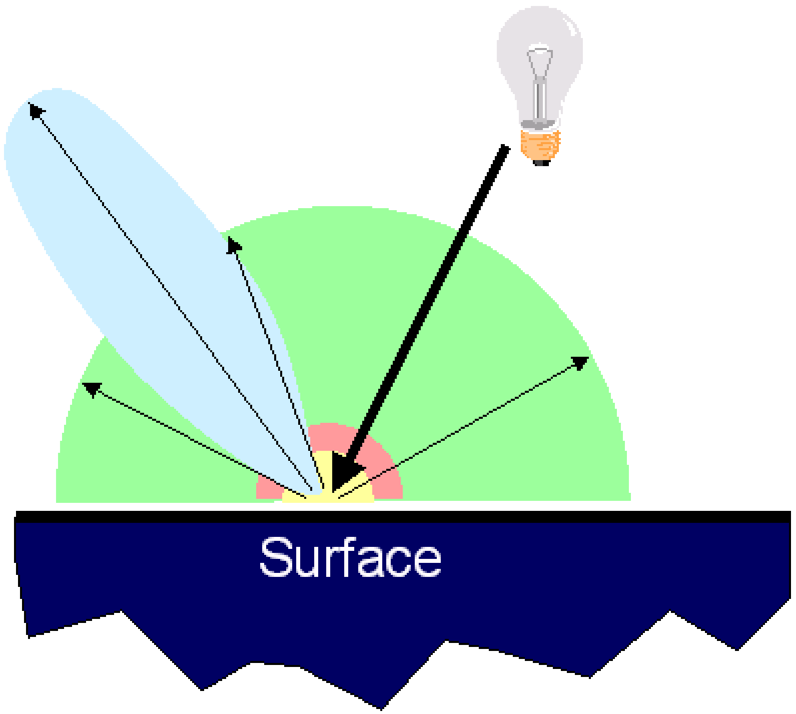


AMBIENT TERM

- Represents Reflection of All Indirect Illumination

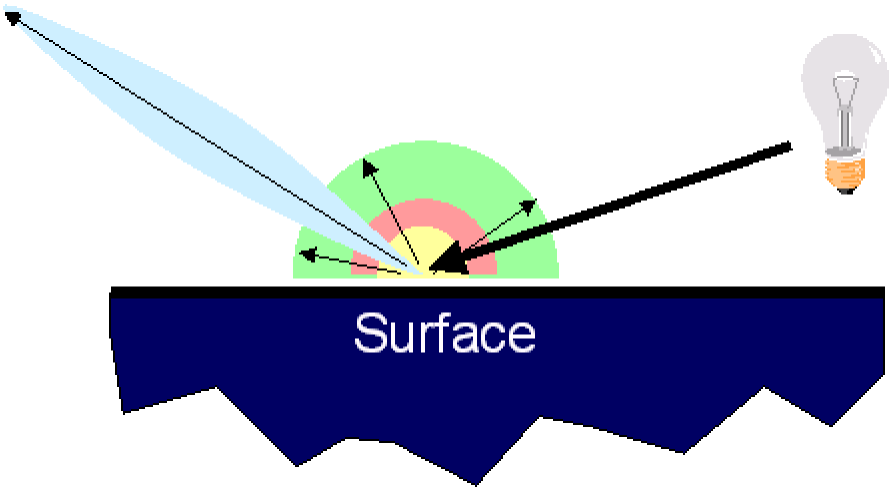
REFLECTANCE MODEL

- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"



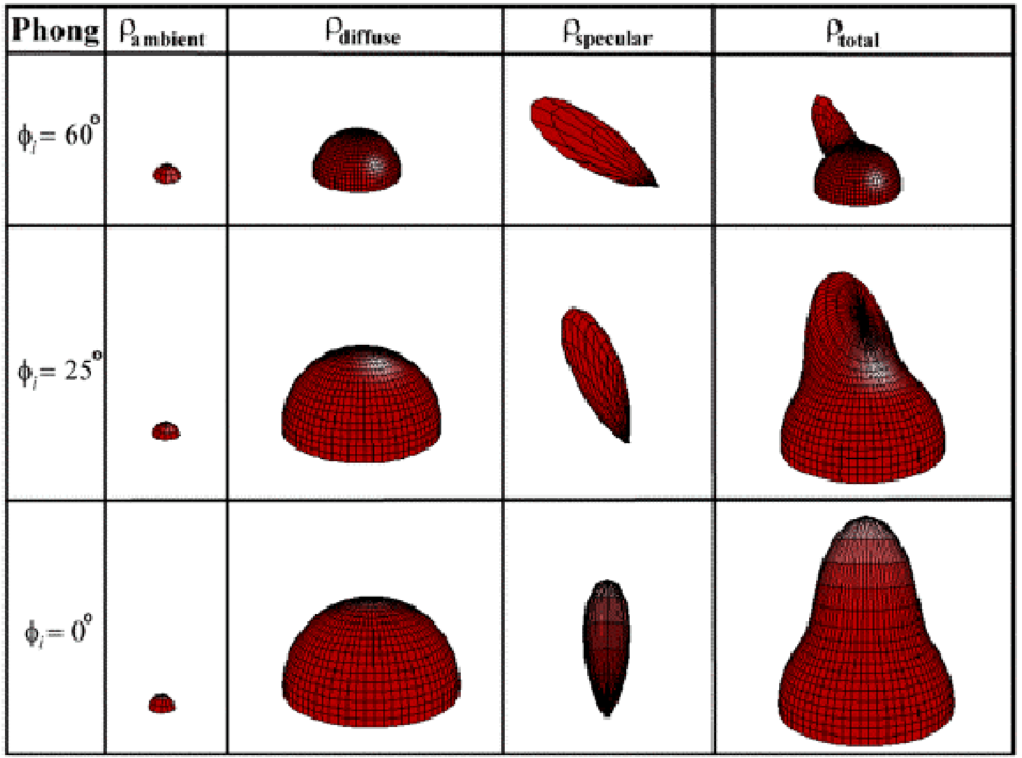
REFLECTANCE MODEL

- Simple Analytic Model:
  - Diffuse reflection +
  - Specular reflection +
  - Emission +
  - "Ambient"



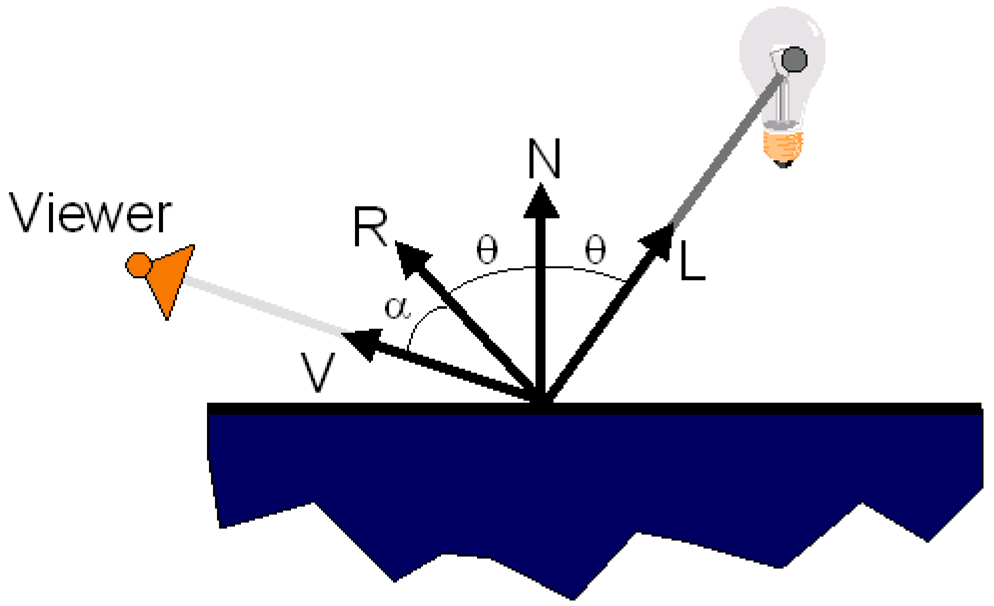
REFLECTANCE MODEL

- Sum Diffuse, Specular, Emission, and Ambient



SURFACE ILLUMINATION CALCULATION

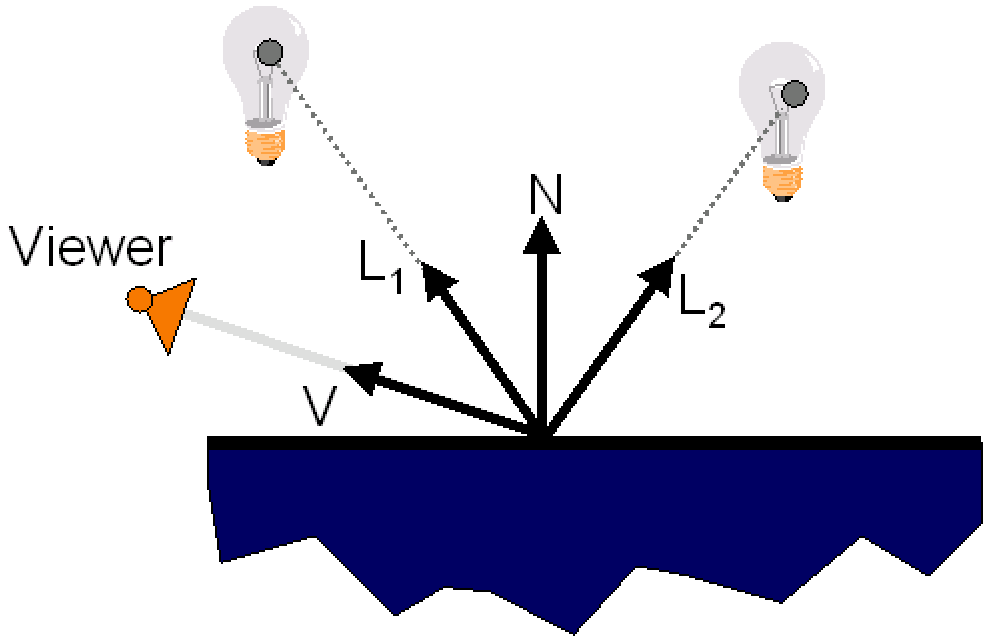
- Single Light Source:



$$I = I_E + K_A I_{AL} + K_D(N \cdot L)I_L + K_S(\mathrm{V} \cdot \mathrm{R})^n I_L$$

SURFACE ILLUMINATION CALCULATION

- Multiple Light Sources:



$$I = I_E + K_A I_{AL} + \sum_i \left(K_D (N \cdot L_i) I_i + K_S (\mathrm{V} \cdot \mathrm{R}_i)^n I_i\right)$$

OVERVIEW

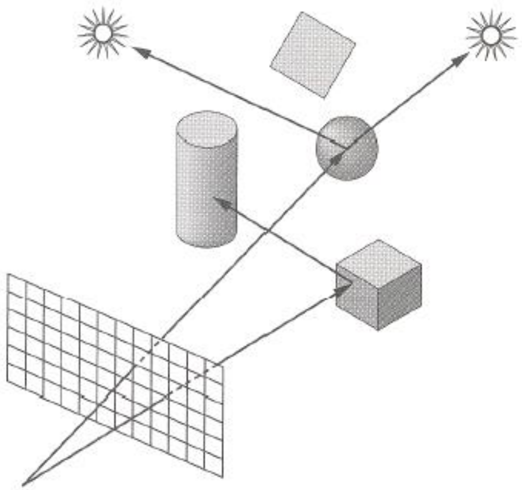
- Direct Illumination
    - Emission at light sources
    - Scattering at surfaces
- Global Illumination
    - Shadows
    - Refractions
    - Inter-object reflections

Global Illumination

GLOBAL ILLUMINATION

SHADOWS

- Shadow Terms Tell Which Light Sources are Blocked
  - Cast ray towards each light source L_i
  - $S_i = 0$ if ray is blocked, $S_i = 1$ otherwise



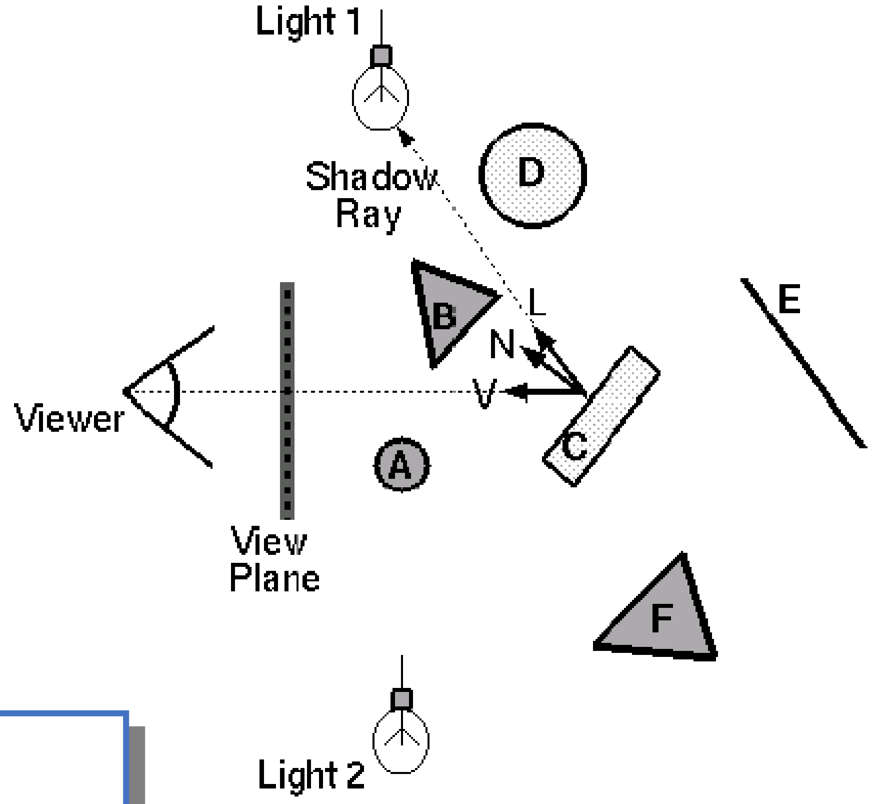
Shadow Term

$$I = I_E + K_A I_A + \sum_L (K_D (N \cdot L) + K_S (\mathrm{V} \cdot \mathrm{R})^n) S_L I_L$$

RAY CASTING

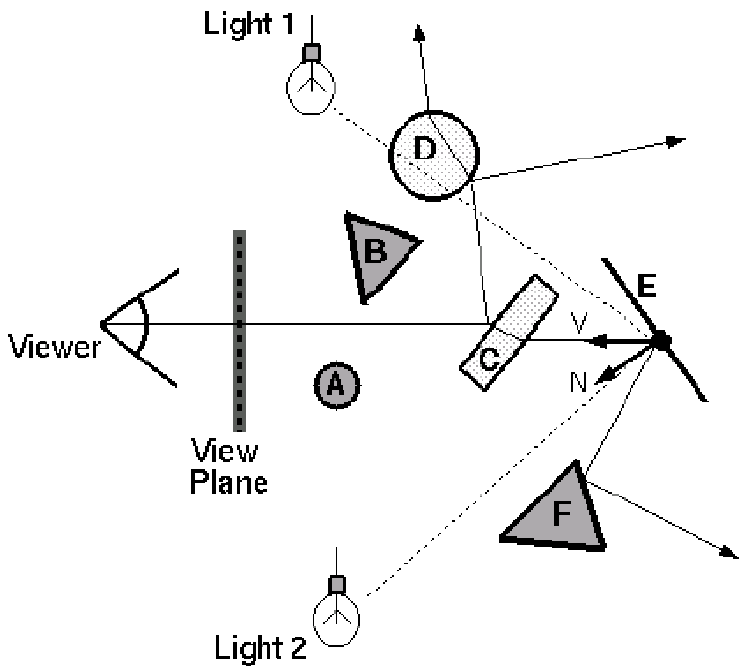
- Trace Primary Rays from Camera
  - Direct illumination from unblocked lights only

$$I = I_E + K_A I_A + \sum_L (K_D(N \cdot L) + K_S(\mathrm{V} \cdot \mathrm{R})^n) S_L I_L$$



RECURSIVE RAY TRACING

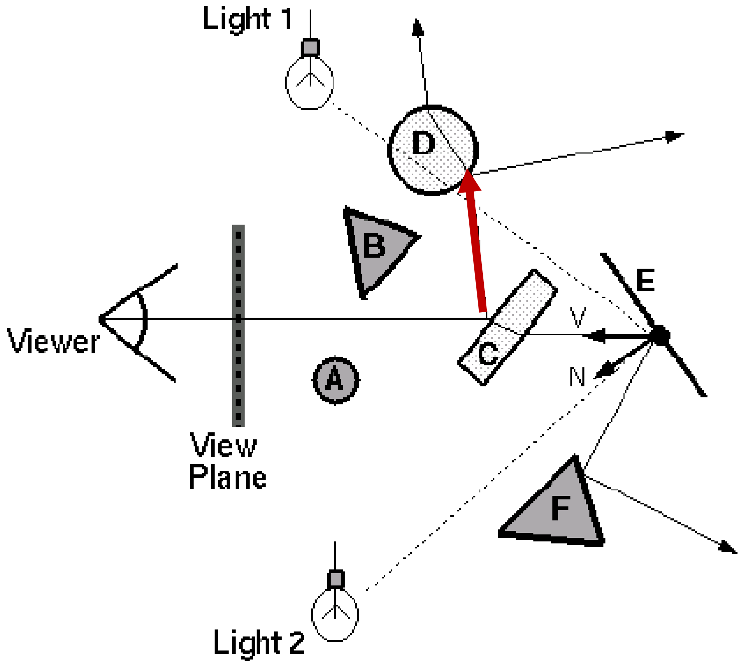
- Also Trace Secondary Rays from Hit Surfaces
  - Global illumination from mirror reflection and transparency



$$I = I_E + K_A I_A + \sum_L (K_D(N \cdot L) + K_S(\mathrm{V} \cdot \mathrm{R})^n) S_L I_L + K_S I_R + K_T I_T$$

MIRROR REFLECTION

- Trace Secondary Ray in Direction of Mirror Reflection
  - Evaluate radiance along secondary ray and include it into illumination model

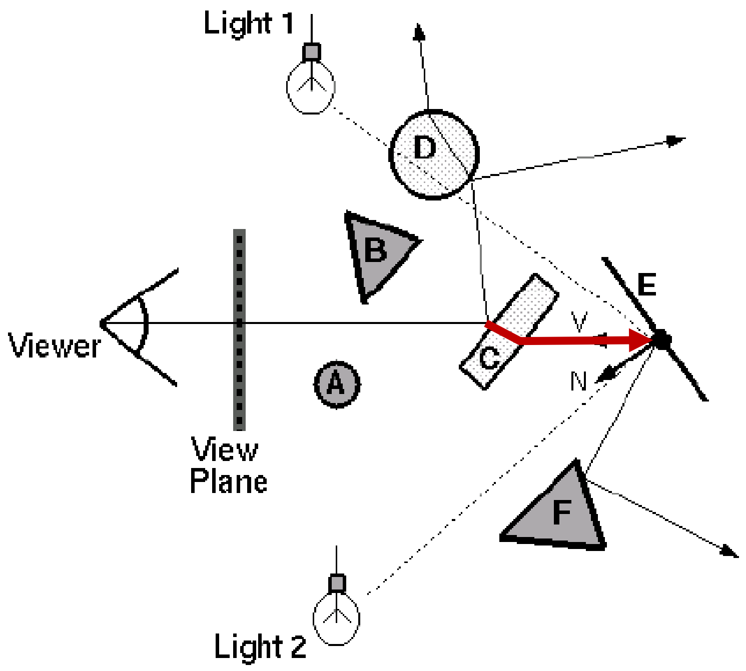


Radiance for mirror reflection ray

$$I = I_E + K_A I_A + \sum_L (K_D(N \cdot L) + K_S(\mathrm{V} \cdot \mathrm{R})^n) S_L I_L + K_S I_R + K_T I_T$$

TRANSPARENCY

- Trace Secondary Ray in Direction of Refraction
  - Evaluate radiance along secondary ray and include it into illumination model

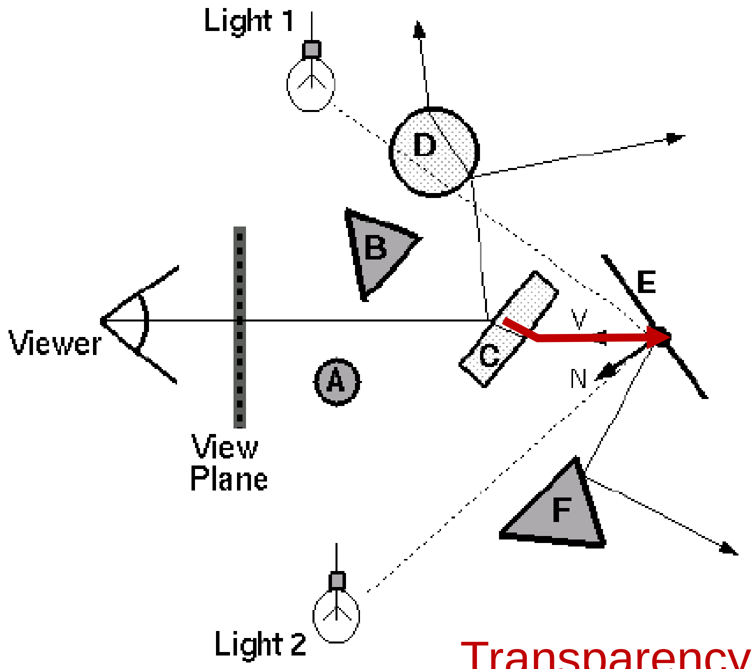


$$I = I_E + K_A I_A + \sum_L (K_D(N \cdot L) + K_S(V \cdot R)^n) S_L I_L + K_S I_R + K_T I_T$$

Radiance for refraction ray

TRANSPARENCY

- Transparency coefficient is fraction transmitted
  - $K_T = 1$ if object is translucent, $K_T = 0$ if object is opaque
  - $0 < K_T < 1$ if object is semi-translucent

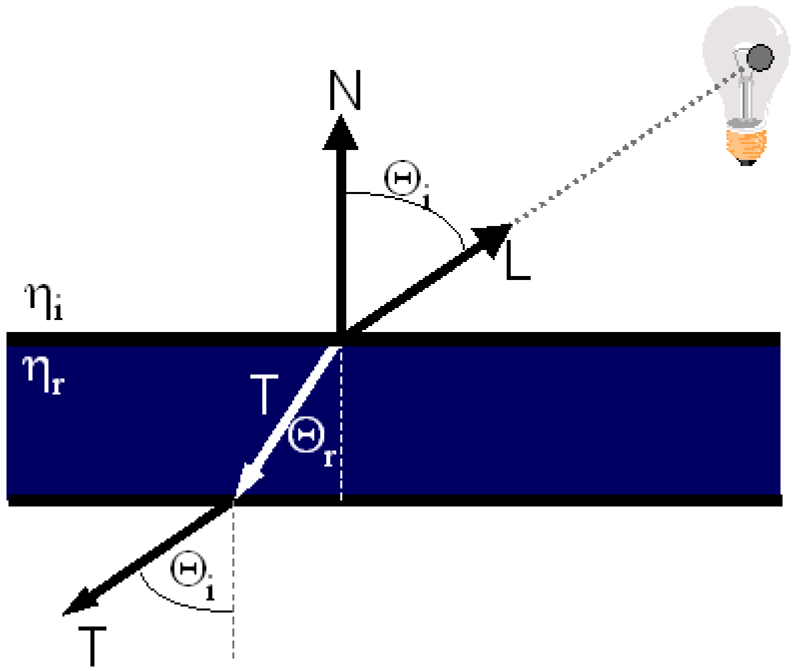


Transparency Coefficient

$$I = I_E + K_A I_A + \sum_L (K_D(N \cdot L) + K_S(\mathrm{V} \cdot \mathrm{R})^n) S_L I_L + K_S I_R + K_T I_T$$

REFRACTIVE TRANSPARENCY

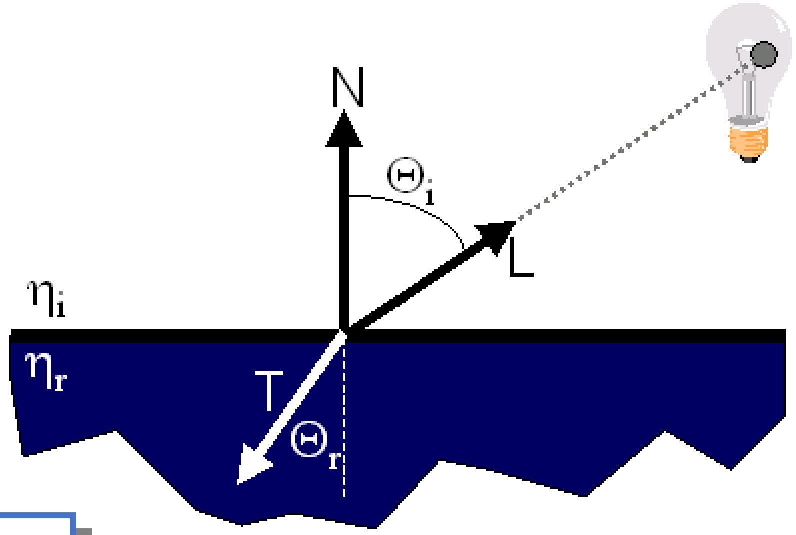
- For Thin Surfaces, Can Ignore Change in Direction
  - Assume light travels straight through surface



$$\boxed{T \cong -L}$$

REFRACTIVE TRANSPARENCY

- For Solid Objects, Apply Snell's Law:
  - $\eta_r \sin \Theta_r = \eta_i \sin \Theta_i$



$$T = \left(\frac{\eta_i}{\eta_r} \cos \Theta_i - \cos \Theta_r \right) N - \frac{\eta_i}{\eta_r} L$$

SUMMARY

- Direct Illumination
  - Ray casting
  - Usually use simple analytic approximations for light source emission and surface reflectance

- Global illumination
  - Recursive ray tracing
  - Incorporate shadows, mirror reflections,

    and pure refractions

ILLUMINATION TERMINOLOGY

- Radiant power [flux] (Φ)
  - Rate at which light energy is transmitted (in Watts).
- Radiant Intensity (I)
  - Power radiated onto a unit solid angle in direction(in Watt/sr)
- Radiance (L)
  - Radiant intensity per unit projected surface area(in Watts/m^2sr)
- Irradiance (E)
  - Incident flux density on a locally planar area (in Watts/m^2)
- Radiosity (B)
  - Exitant flux density from a locally planar area (in Watts/m^2)

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THANK YOU