# Lighting and Reflectance

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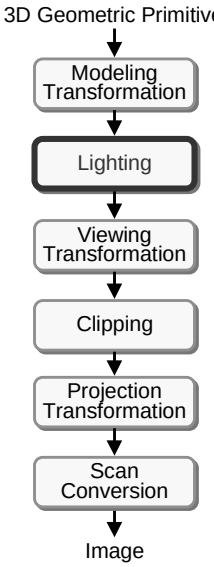
C0S 426, Fall 1999

## 3D Rendering Pipeline




Transform into 3D world coordinate system

Simulate direct illumination and reflectance

Transform into 3D camera coordinate system

Clip primitives outside camera's view

Transform into 2D camera coordinate system

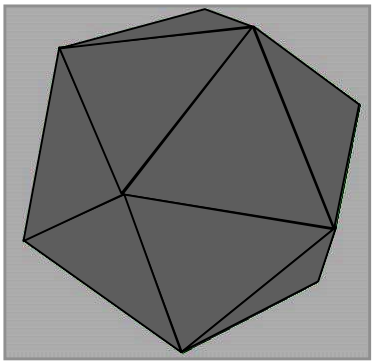
Draw pixels (includes texturing, hidden surface, etc.)

## Illumination

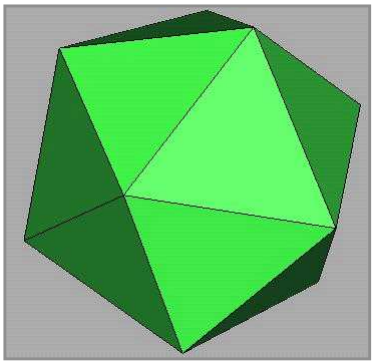
- Model the transport from light sources to a camera through a 3D model

## Illumination

- Provides visual cues



Without Illumination



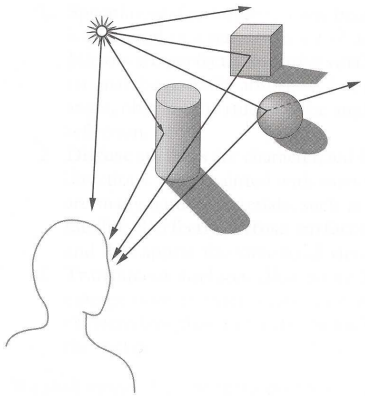
With Illumination

## Video

- Luxo Jr.

## Goal

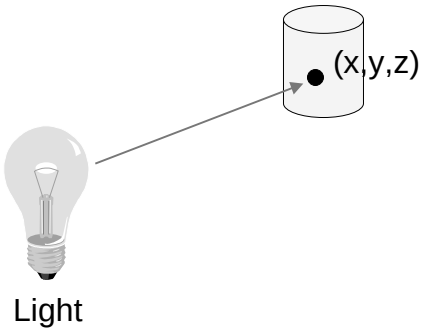
- Must derive computer models for ...
  - Emission at light sources
  - Scattering at surfaces
  - Reception at the camera



- Desirable features …
  - Accurate
  - Concise
  - Efficient to compute

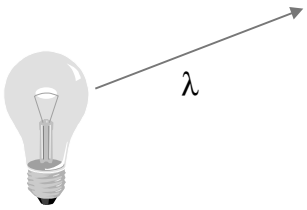
## Modeling Light Sources

- $I_L(x,y,z,\theta,\phi,\lambda)$ …
  - describes the intensity of energy,
  - leaving a light source, …
  - arriving at location(x,y,z), ...
  - from direction $(\theta,\phi)$, ...
  - with wavelength $\lambda$



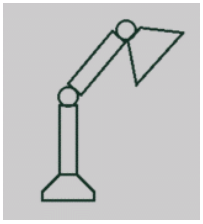

## Empirical Models

- Ideally measure irradiant energy for “all” situations
  - Too much storage
  - Difficult in practice



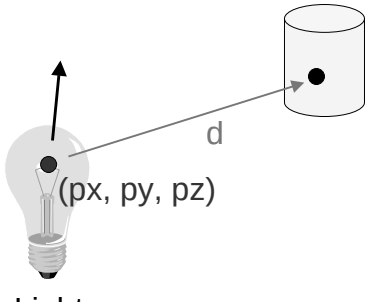
## OpenGL Light Source Models

- Simple mathematical models:
  - Point light
  - Directional light
  - Spot light



## Point Light Source

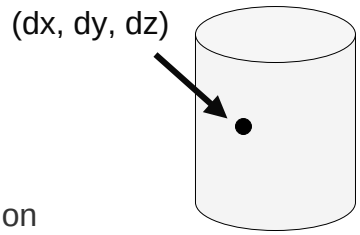
- Models omni-directional point source (e.g., bulb)
  - intensity ($I_0$),
  - position (px, py, pz),
  - factors ($k_c$, $k_l$, $k_q$) for attenuation with distance (d)




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

## Directional Light Source

- Models point light source at infinity (e.g., sun)
  - intensity ($I_0$),
  - direction (dx,dy,dz)

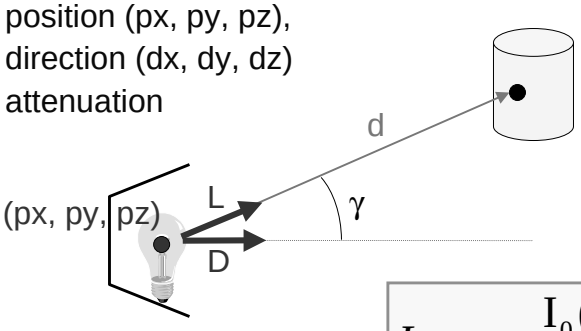



No attenuation with distance

$$I_L = I_0$$

## Spot Light Source

- Models point light source with direction (Luxo)
  - intensity ($I_0$),
  - position (px, py, pz),
  - direction (dx, dy, dz)
  - attenuation

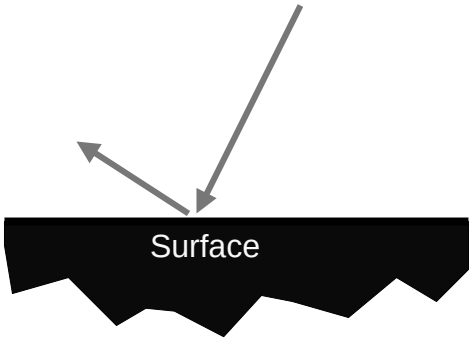



Light

$$I_L = \frac{I_0 (D \bullet L)}{k_c + k_l d + k_q d^2}$$

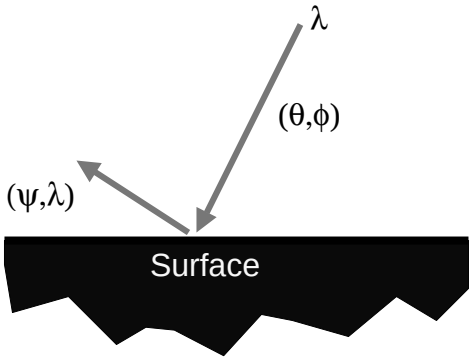
## Modeling Surface Reflectance

- $R_s(\theta,\phi,\gamma,\psi,\lambda)$ ...
  - describes the amount of incident energy,
  - arriving from direction $(\theta,\phi)$, ...
  - leaving in direction $(\gamma,\psi)$, …
  - with wavelength $\lambda$




## Empirical Models

- Ideally measure radiant energy for “all” combinations of incident angles
  - Too much storage
  - Difficult in practice

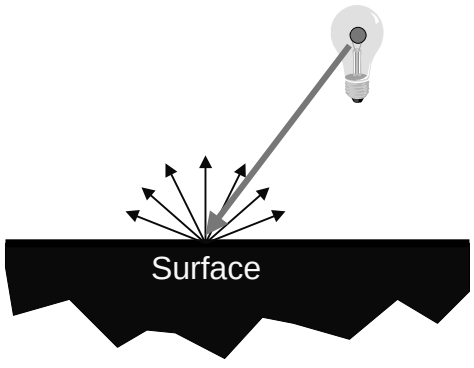


## OpenGL Reflectance Model

- Simple mathematical model:
  - emission +
  - diffuse reflections +
  - specular reflections +
  - “ambient” term

## Diffuse Reflection

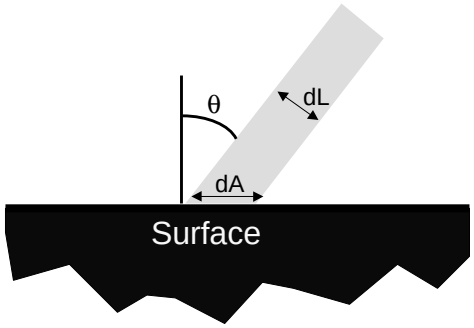
- Assume surface reflects equally in all directions
  - Examples: chalk, clay



## Diffuse Reflection

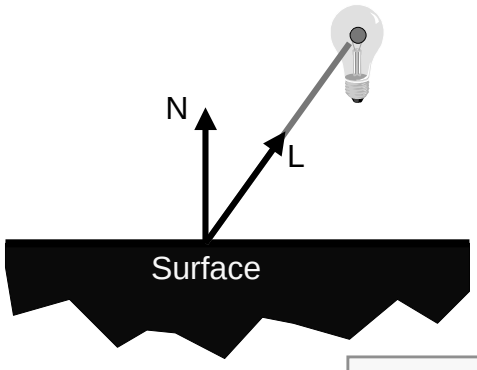
- How much light is reflected?
  - Depends on angle of incident light

$$dL = dA\cos\Theta$$




## Diffuse Reflection

- Lambertian model
  - cosine law (dot product)

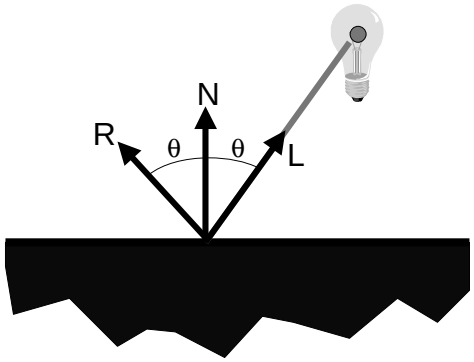



$$I_D = K_D(N \bullet L)I_L$$

## Specular Reflection

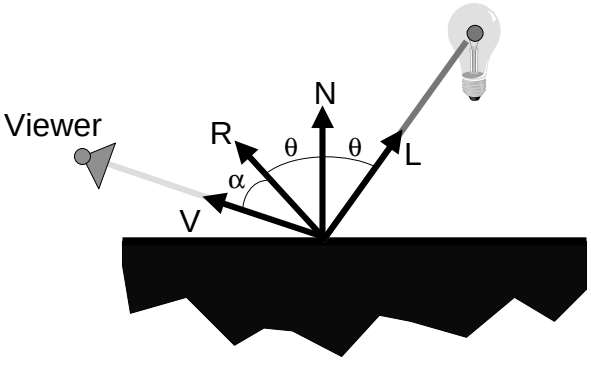


- Reflection is strongest near mirror angle
  - Examples: mirrors, metals




## Specular Reflection

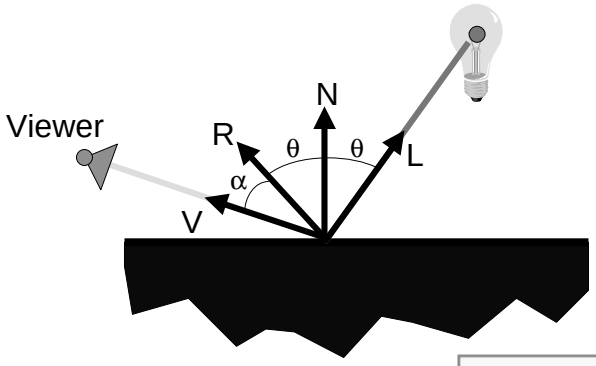
- How much light is seen?
  - Depends on angle of incident light and angle to viewer



## Specular Reflection



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

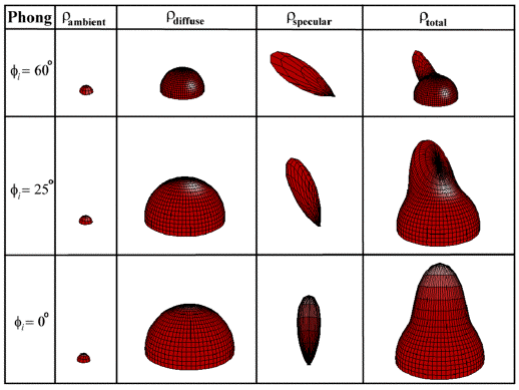



$$I_S = K_S (V \bullet R)^n I_L$$

## Phong Illumination Model



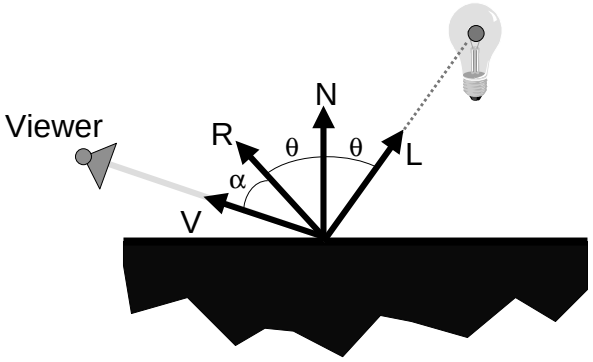
- Sum emission, diffuse, specular, and ambient




Leonard McMillan, MIT

## Surface Illumination Calculation

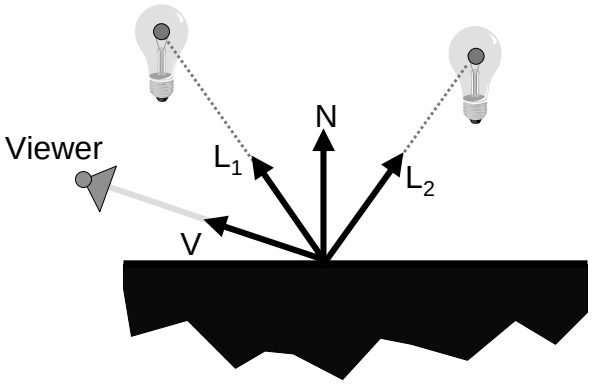
- Single light source:




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

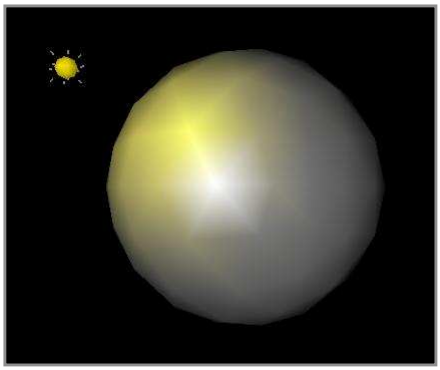
## Surface Illumination Calculation

- Multiple light sources:




$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

## Example



Cosmo worlds

## Summary

- Model light sources
  - Point
  - Directional
  - Spot
- Model surface reflections
  - Diffuse
  - Specular
  - Ambient