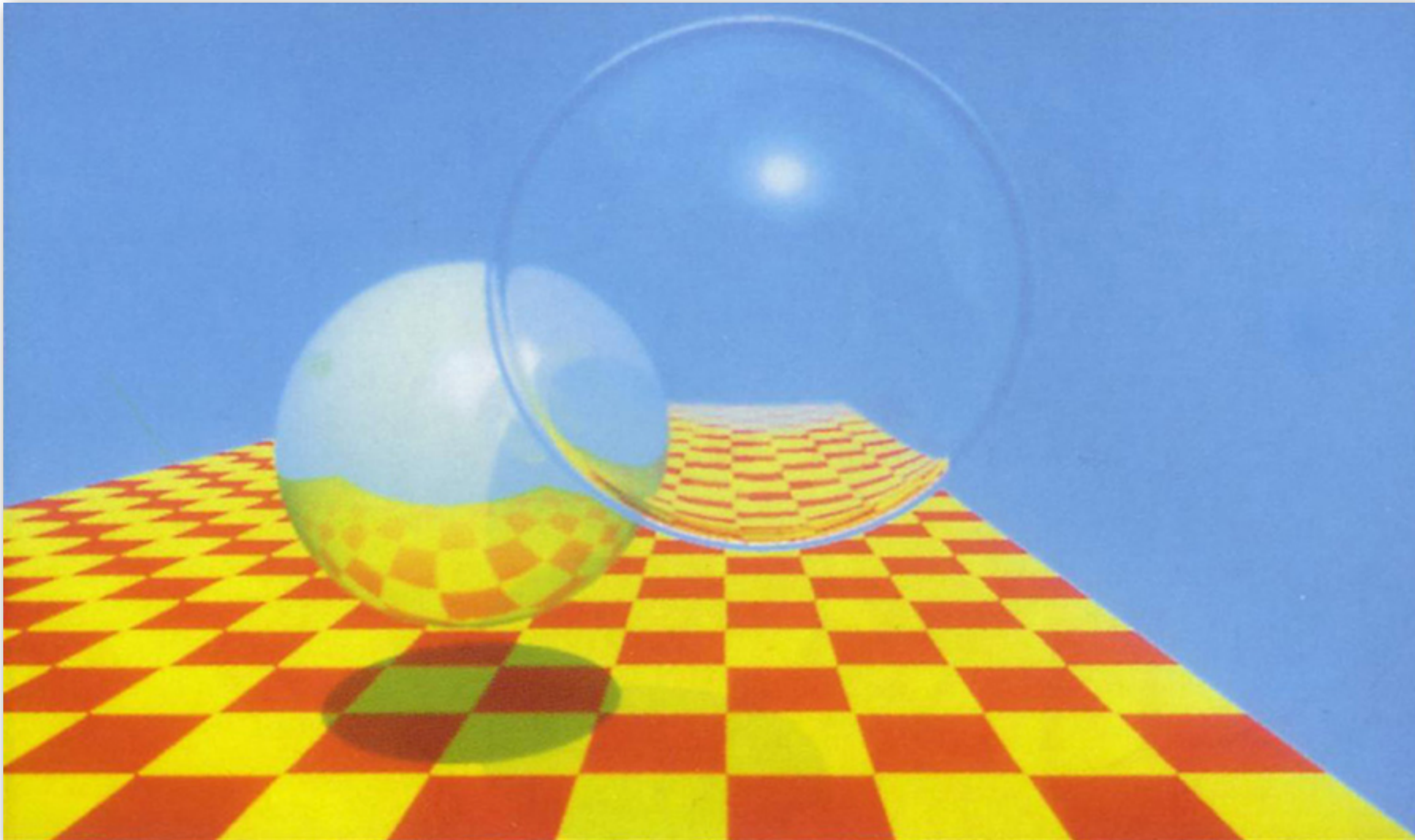
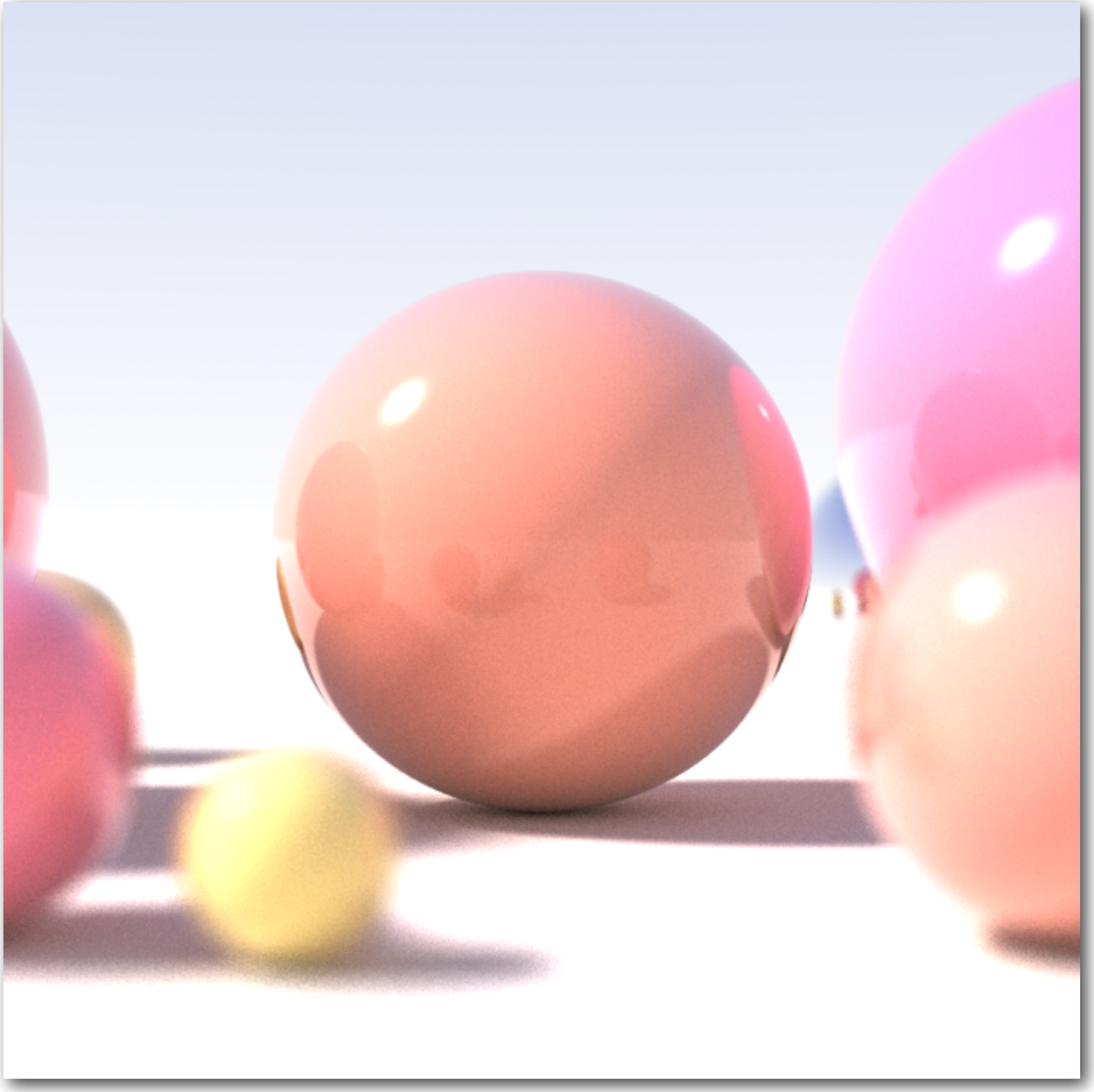
Direct Illumination

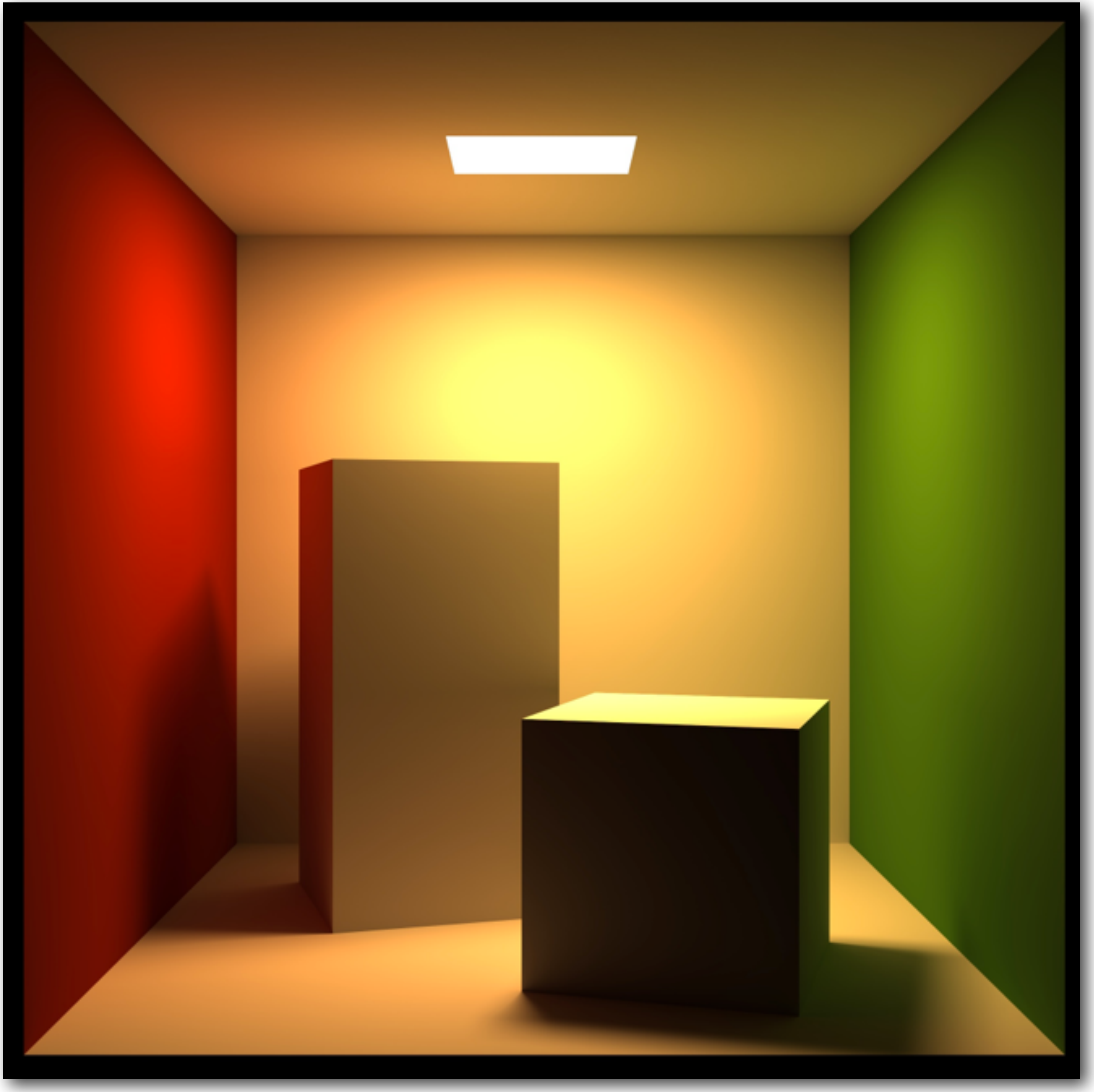
Connelly Barnes

CS 4810: Graphics

Acknowledgment: slides by Jason Lawrence, Misha Kazhdan, Allison Klein, Tom Funkhouser, Adam Finkelstein and David Dobkin








Artwork by Andrey Kobushenko

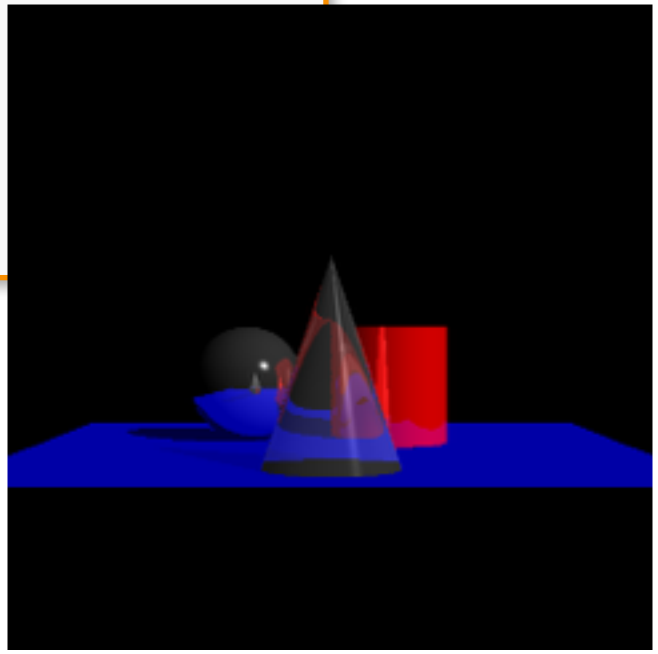
Recall: Ray Casting

```
Image RayCast(Camera camera, Scene scene, int width, int height)
{
    Image image = new Image(width, height);
    for (int i = 0; i < width; i++) {
        for (int j = 0; j < height; j++) {
            Ray ray = ConstructRayThroughPixel(camera, i, j);
            Intersection hit = FindIntersection(ray, scene);
            image[i][j] = GetColor(scene, ray, hit);
        }
    }
    return image;
}
```

Without Illumination

Recall: Ray Casting

```
Image RayCast(Camera camera, Scene scene, int width, int height)
{
    Image image = new Image(width, height);
    for (int i = 0; i < width; i++) {
        for (int j = 0; j < height; j++) {
            Ray ray = ConstructRayThroughPixel(camera, i, j);
            Intersection hit = FindIntersection(ray, scene);
            image[i][j] = GetColor(scene, ray, hit);
        }
    }
    return image;
}
```

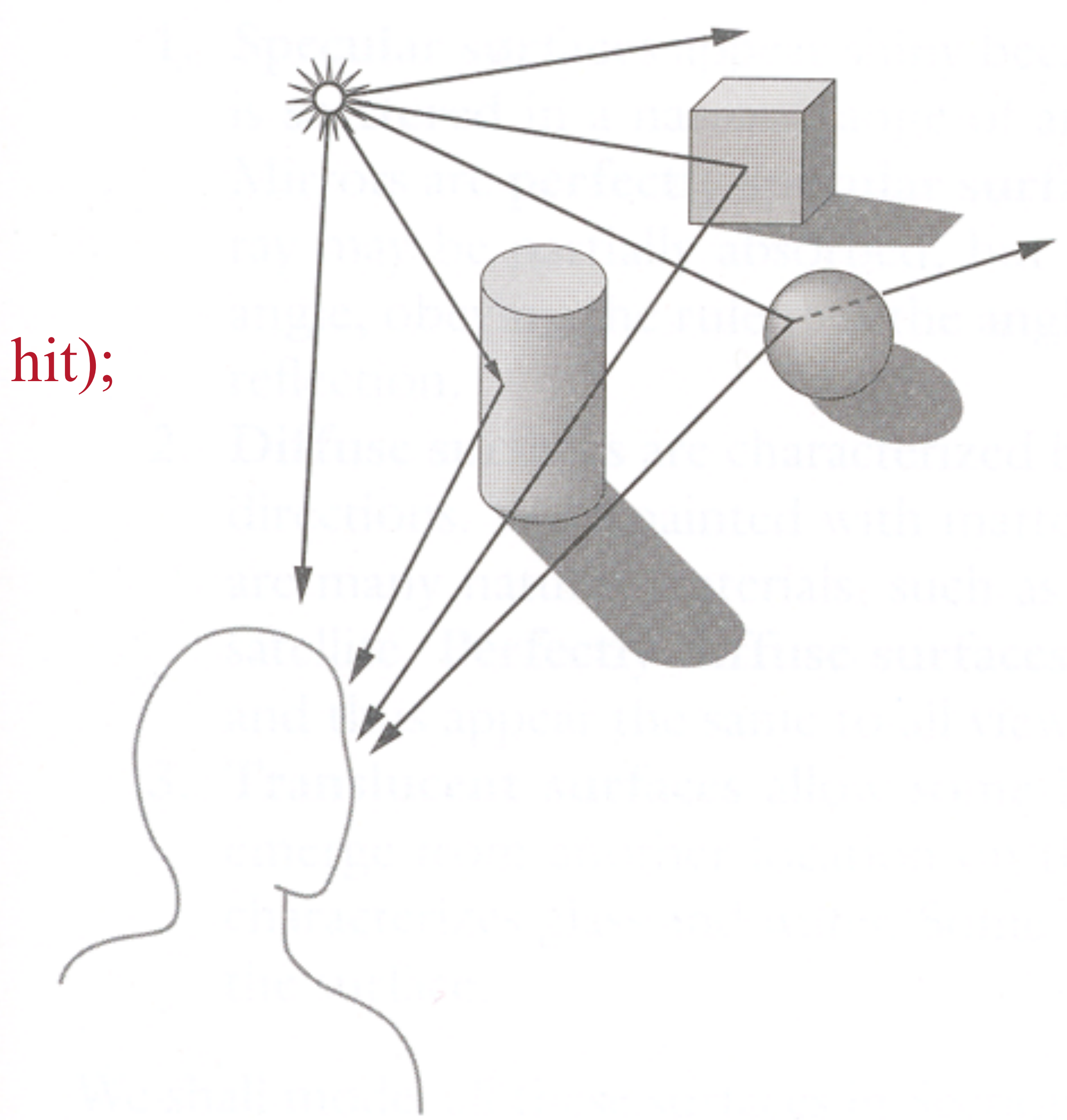


With Illumination

Illumination

- How do we compute radiance for a sample ray?

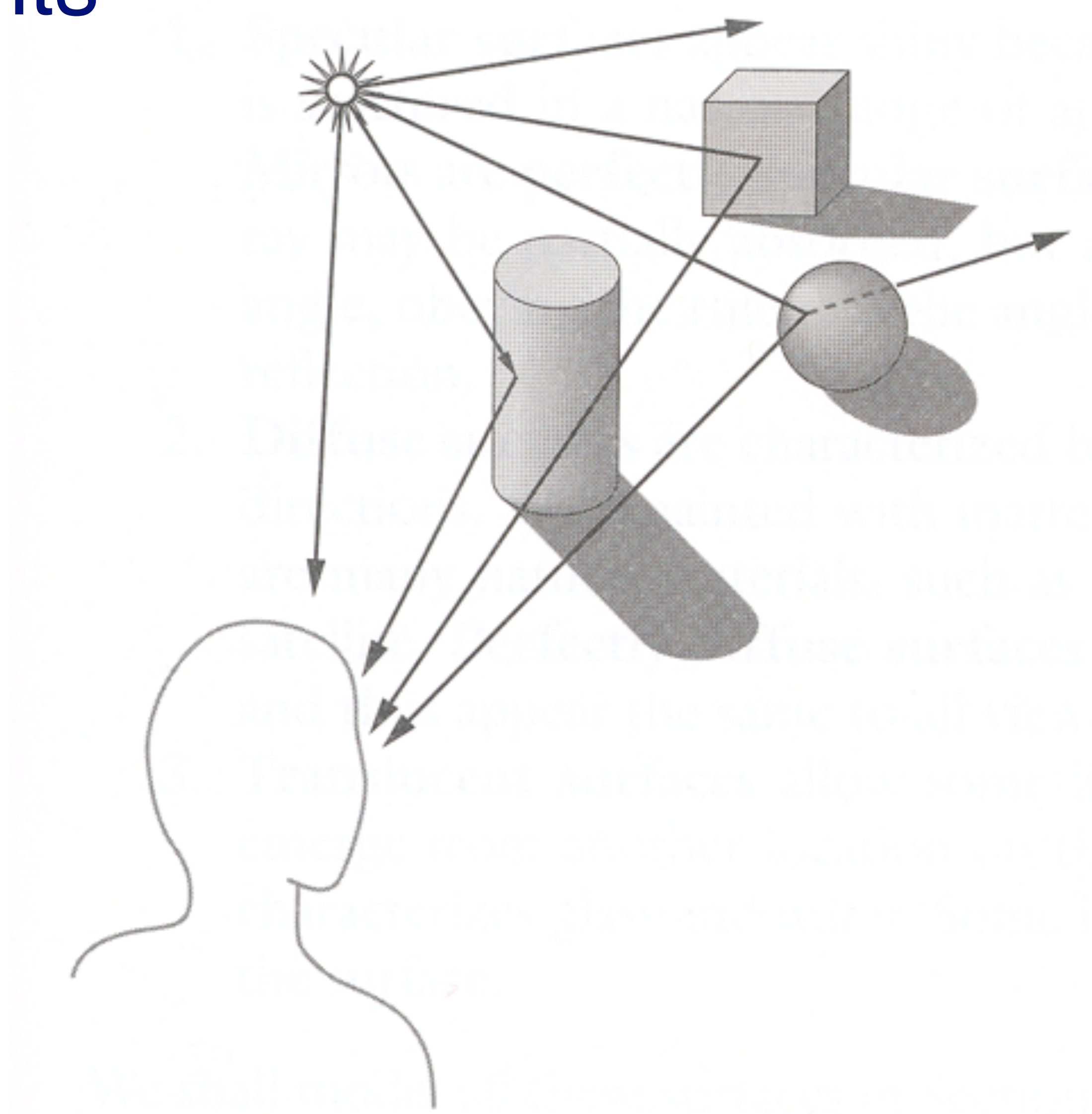
image[i][j] = GetColor(scene, ray, hit);



Angel Figure 6.2

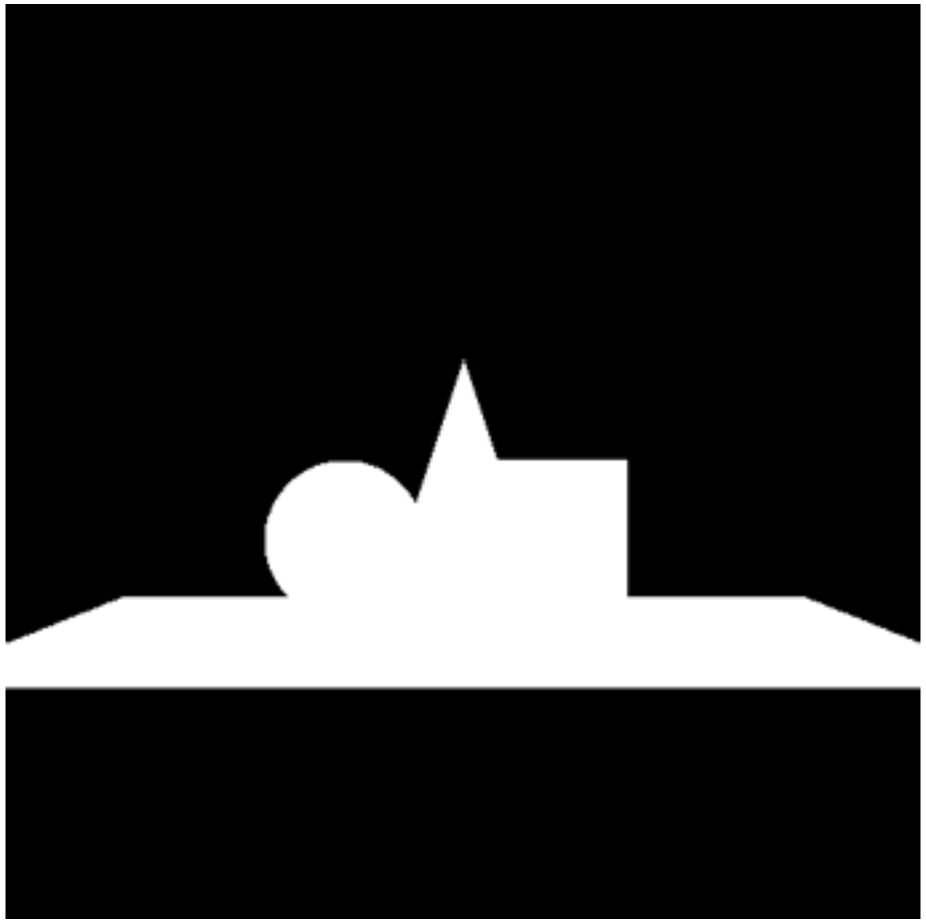
Goal

- Must derive models for ...
  - o Emission at light sources
  - o Direct light on surface points
  - o Scattering at surfaces
  - o Reception at the camera
- Desirable features …
  - o Concise
  - o Efficient to compute
  - o “Accurate”



Overview

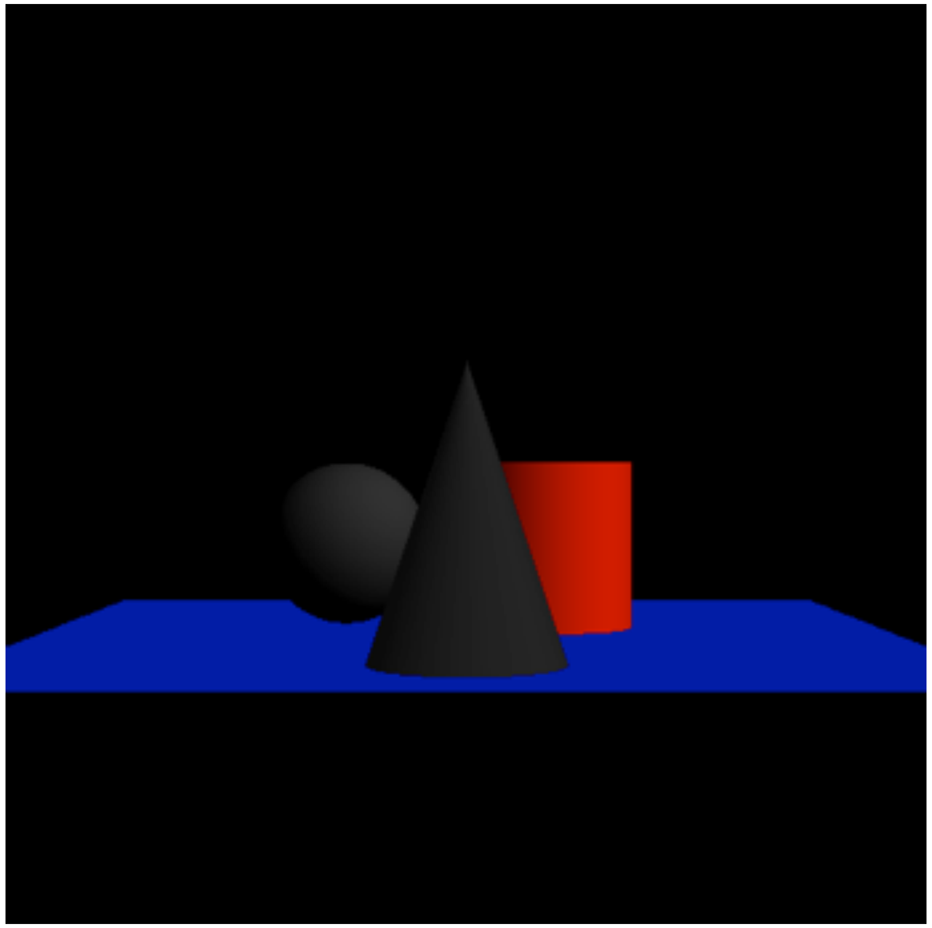
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Intersection Testing

Overview

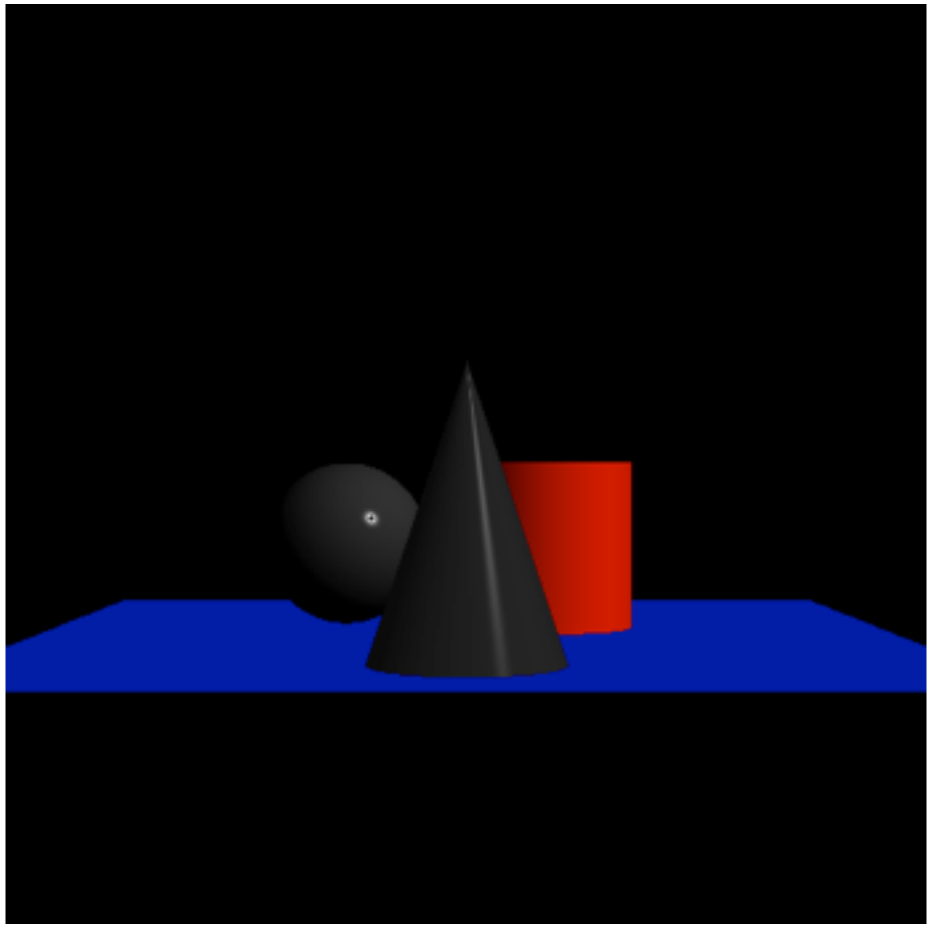
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Lambertian Shading

Overview

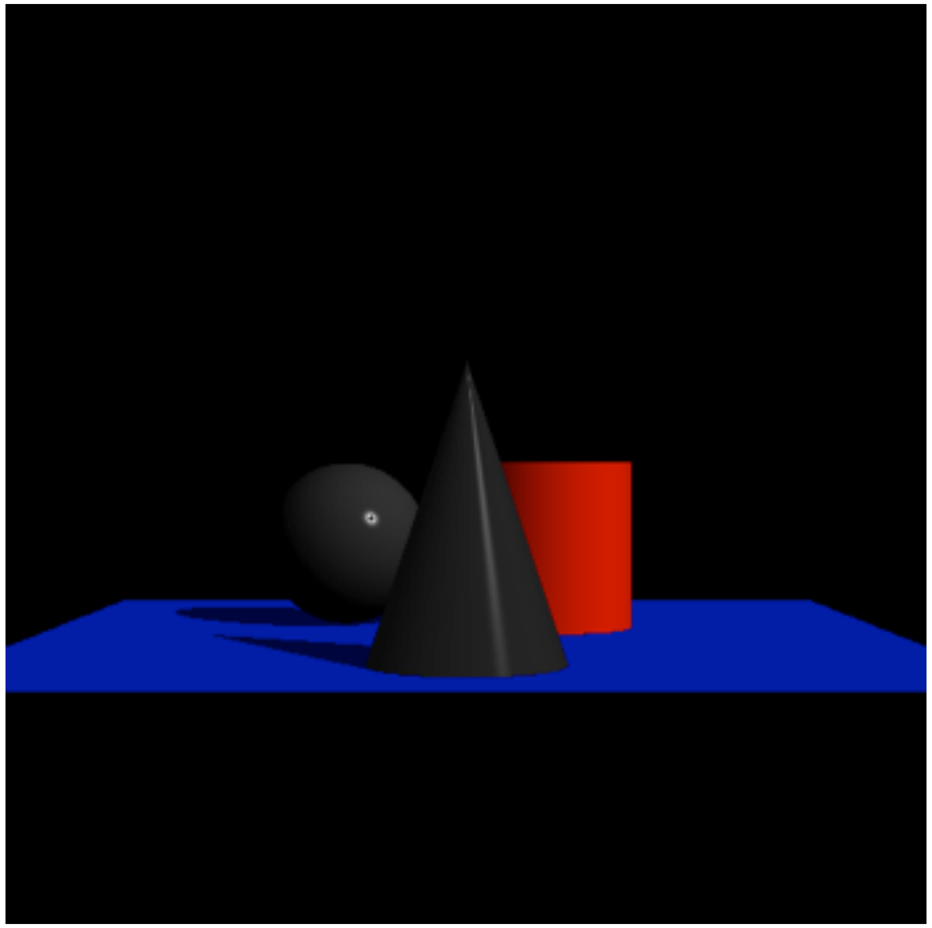
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Phong Shading

Overview

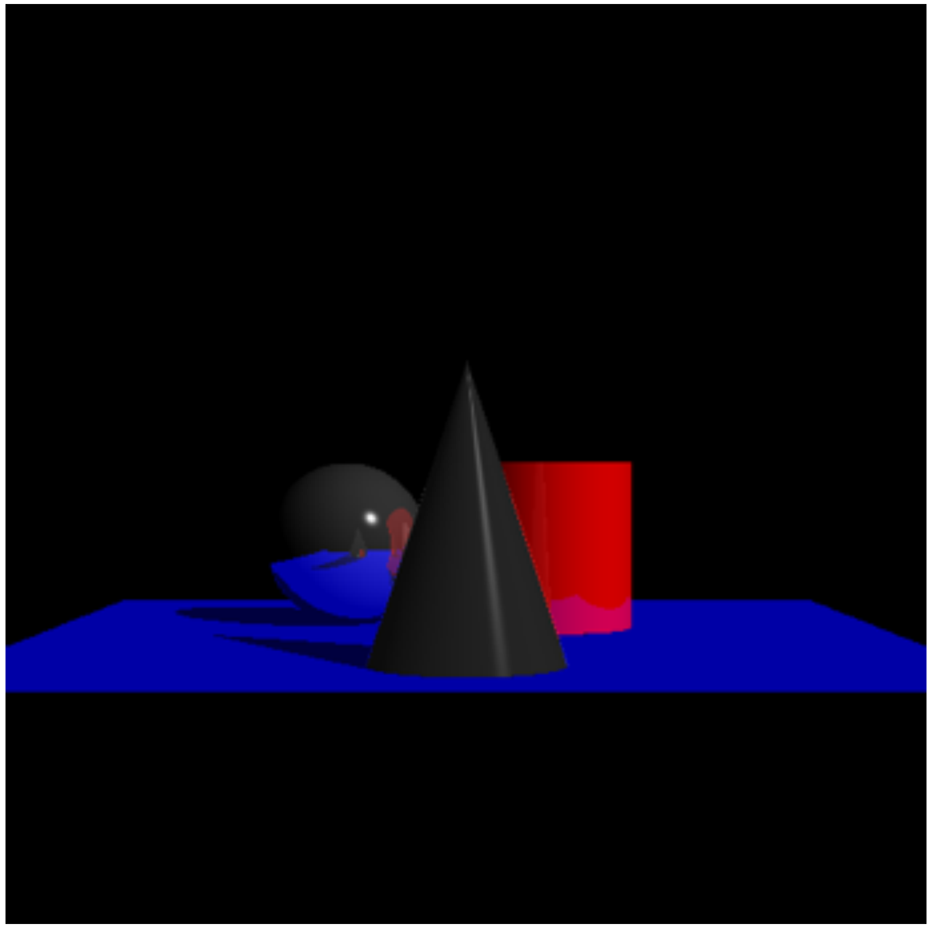
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Shadow Computation

Overview

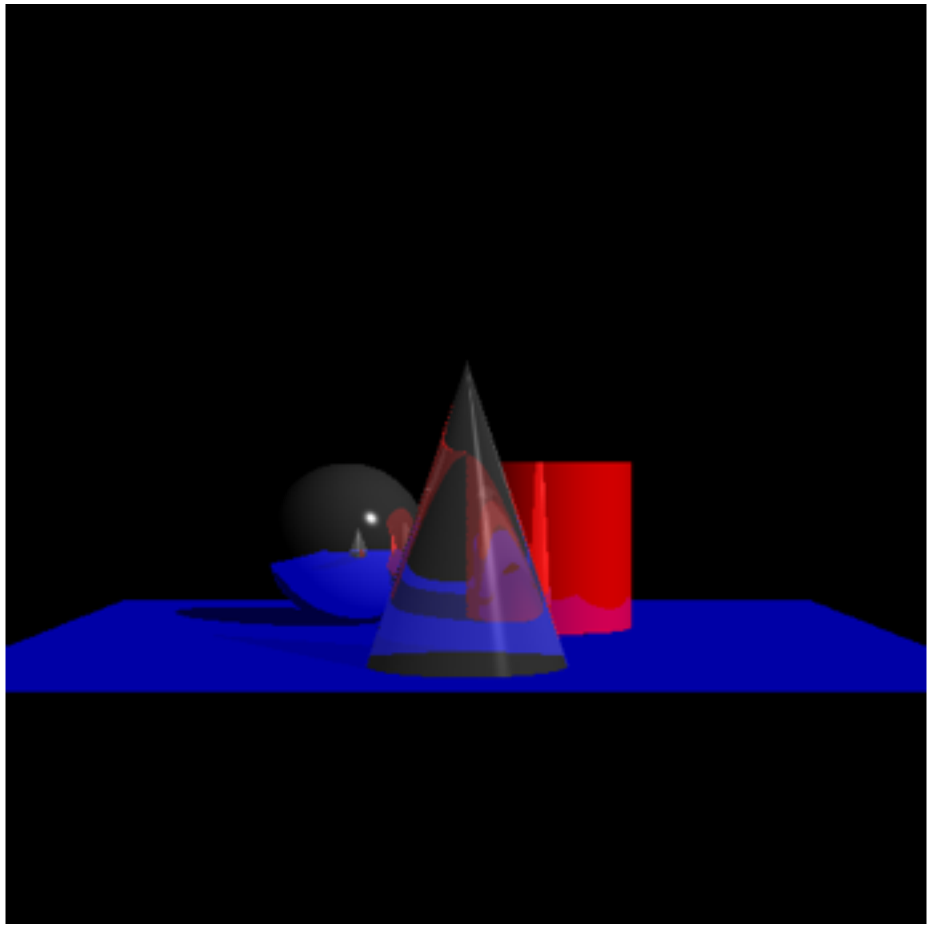
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Reflective Bouncing

Overview

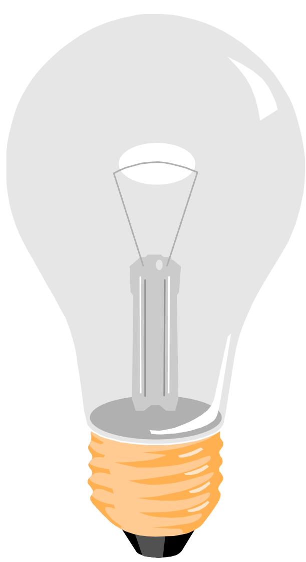
- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Refractive Bouncing

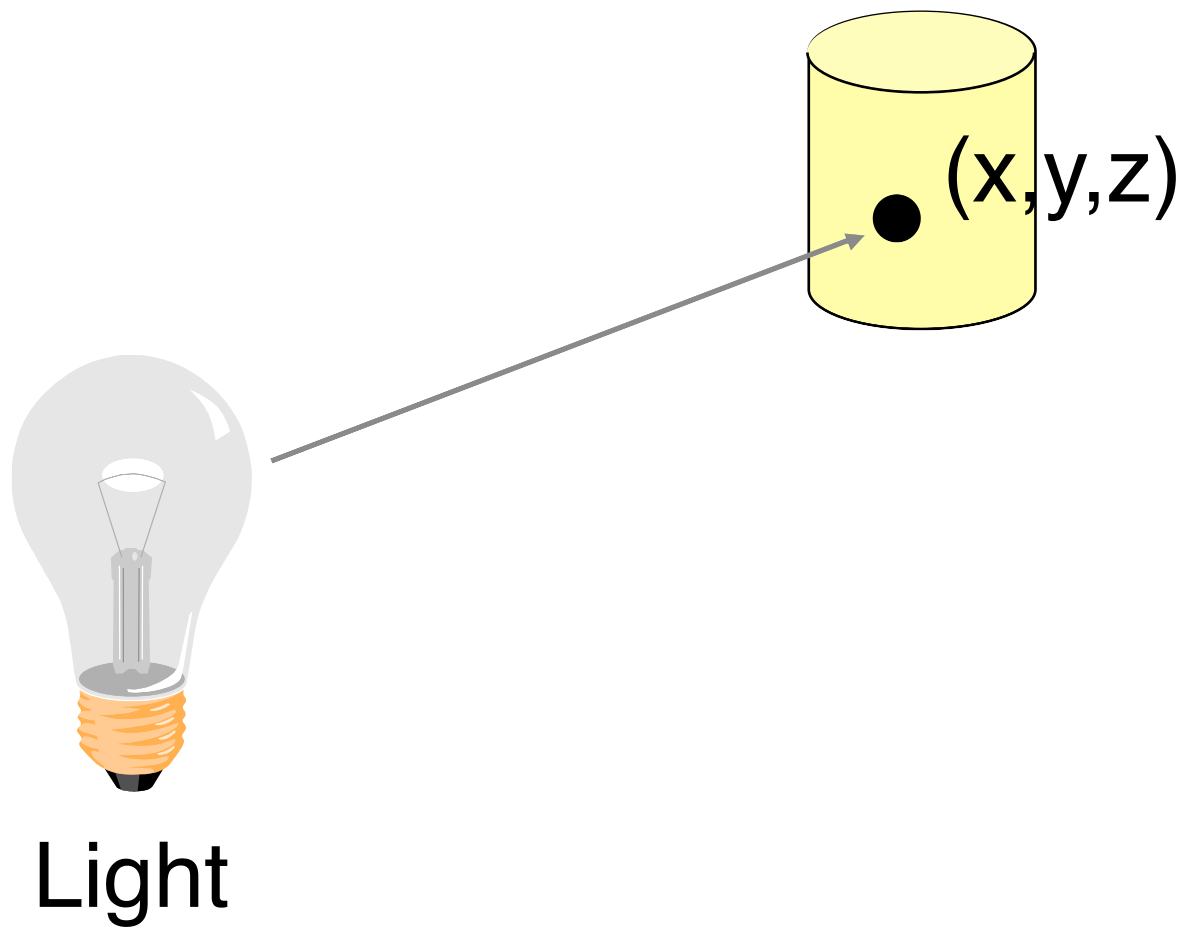
Overview

- Direct Illumination
  - o Emission at light sources
  - o Direct light at surface points
- Global illumination
  - o Shadows
  - o Inter-object reflections
  - o Transmissions



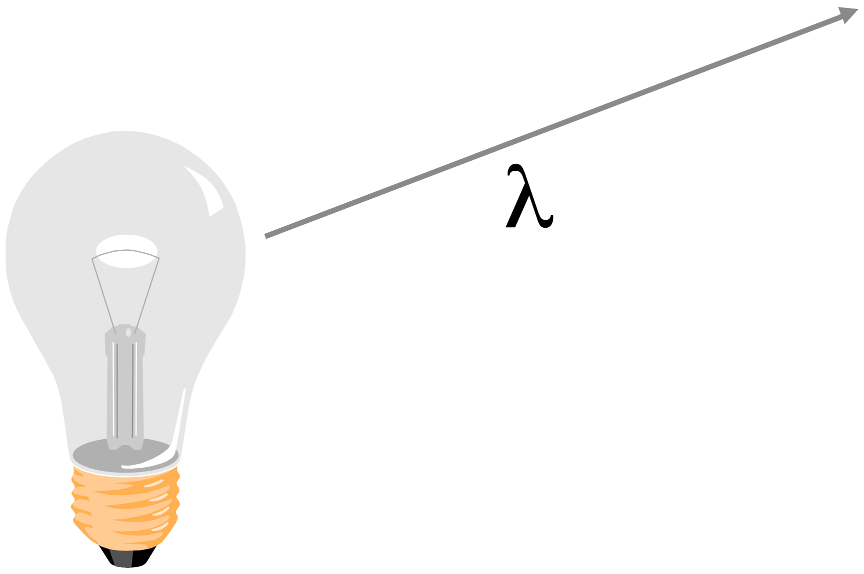
Modeling Light Sources

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



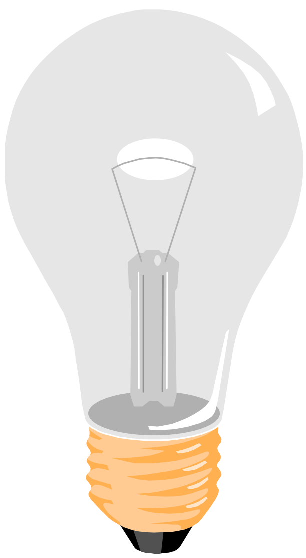
Empirical Models

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

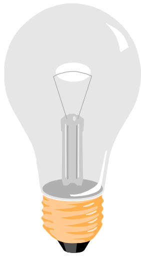


Simplified Light Source Models

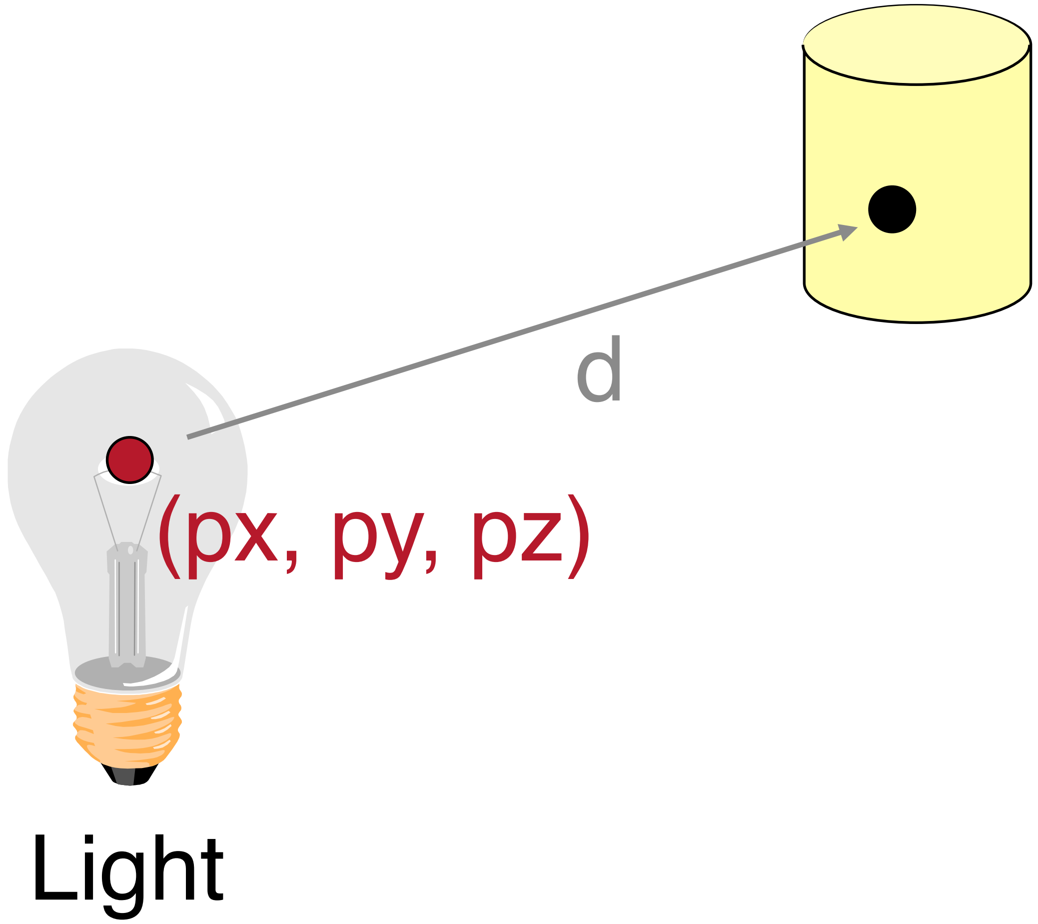
- Simple mathematical models:
  - o Point light
  - o Directional light
  - o Spot light



Point Light Source



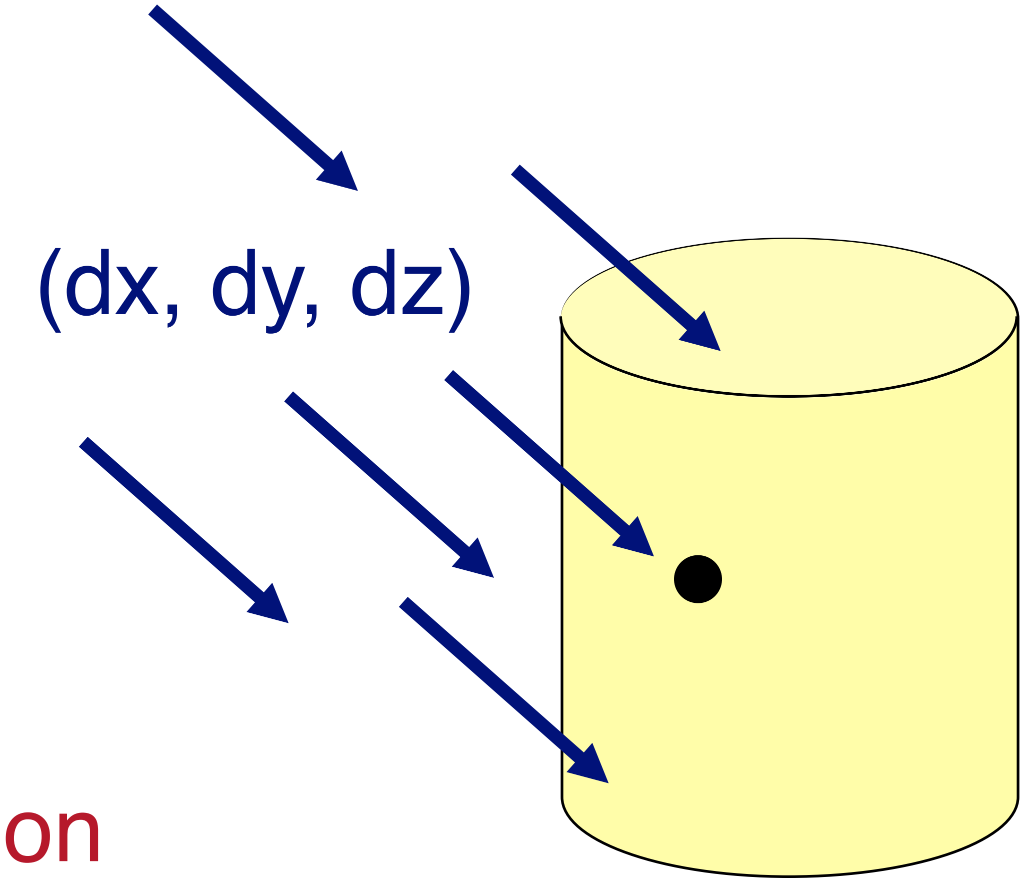
- Models omni-directional point source
  - intensity (I_0),
  - position (px, py, pz),
  - factors (k_c, k_l, k_q) for attenuation with distance (d)



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

Directional Light Source

- Models point light source at infinity
  - intensity (I_0),
  - direction (dx,dy,dz)

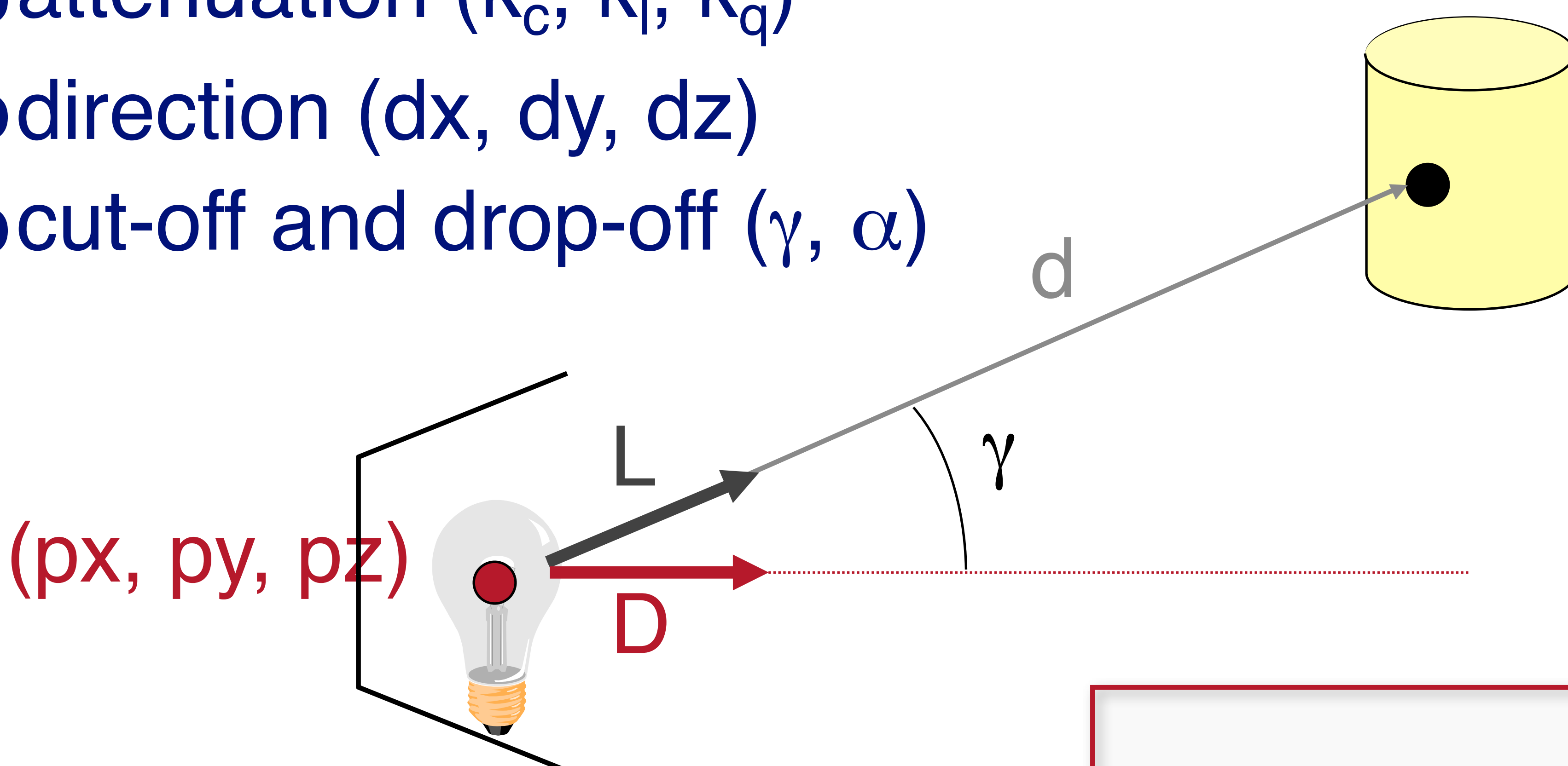


No attenuation with distance

$$I_L = I_0$$

Spot Light Source

- Models point light source with direction
  - intensity (I_0),
  - position (px, py, pz),
  - attenuation (k_c, k_l, k_q)
  - direction (dx, dy, dz)
  - cut-off and drop-off (γ, α)



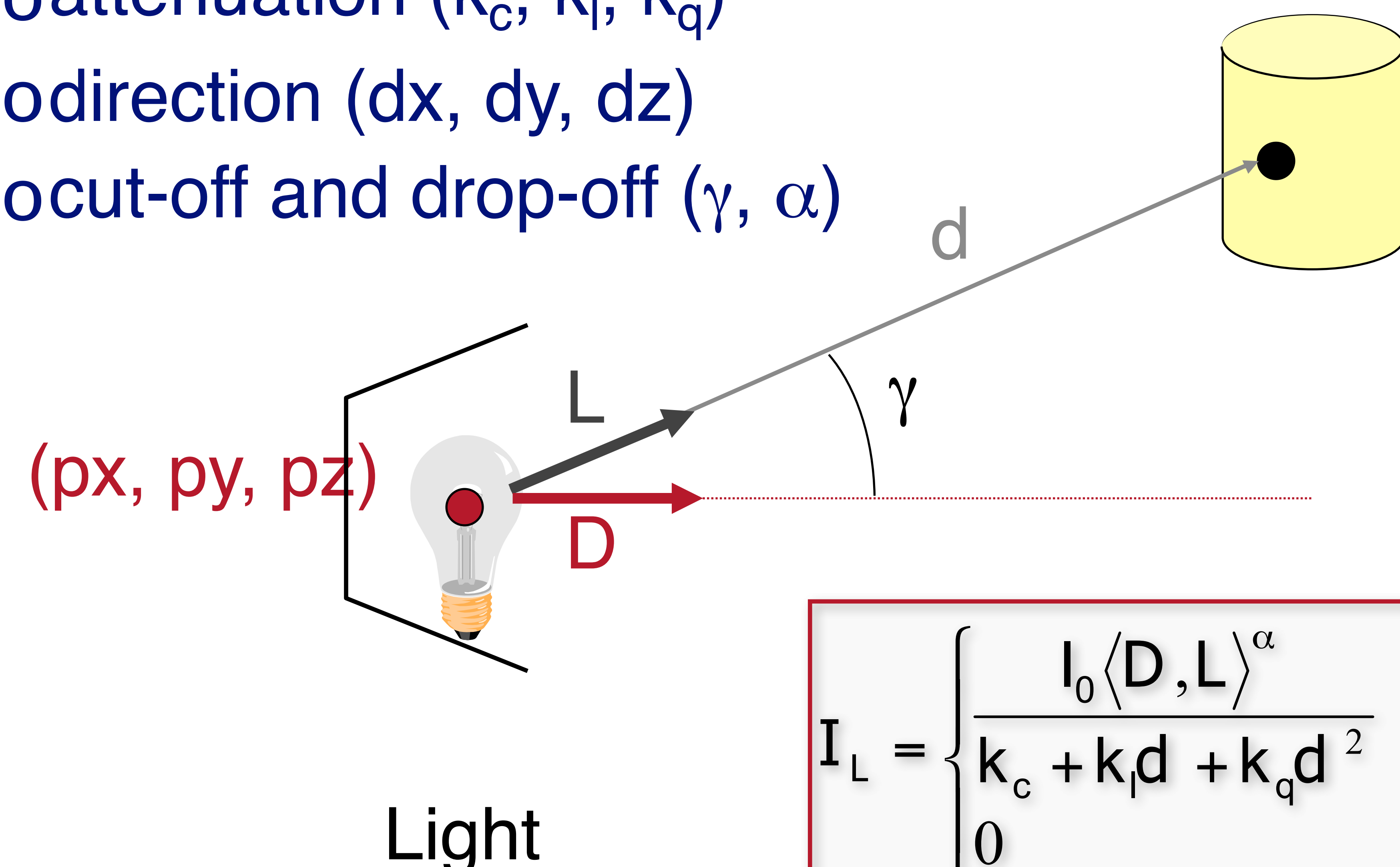
Light

How can we modify point light to decrease as γ increases?

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

Spot Light Source

- Models point light source with direction
  - o intensity (I_0),
  - o position (px, py, pz),
  - o attenuation (k_c, k_l, k_q)
  - o direction (dx, dy, dz)
  - o cut-off and drop-off (γ, α)



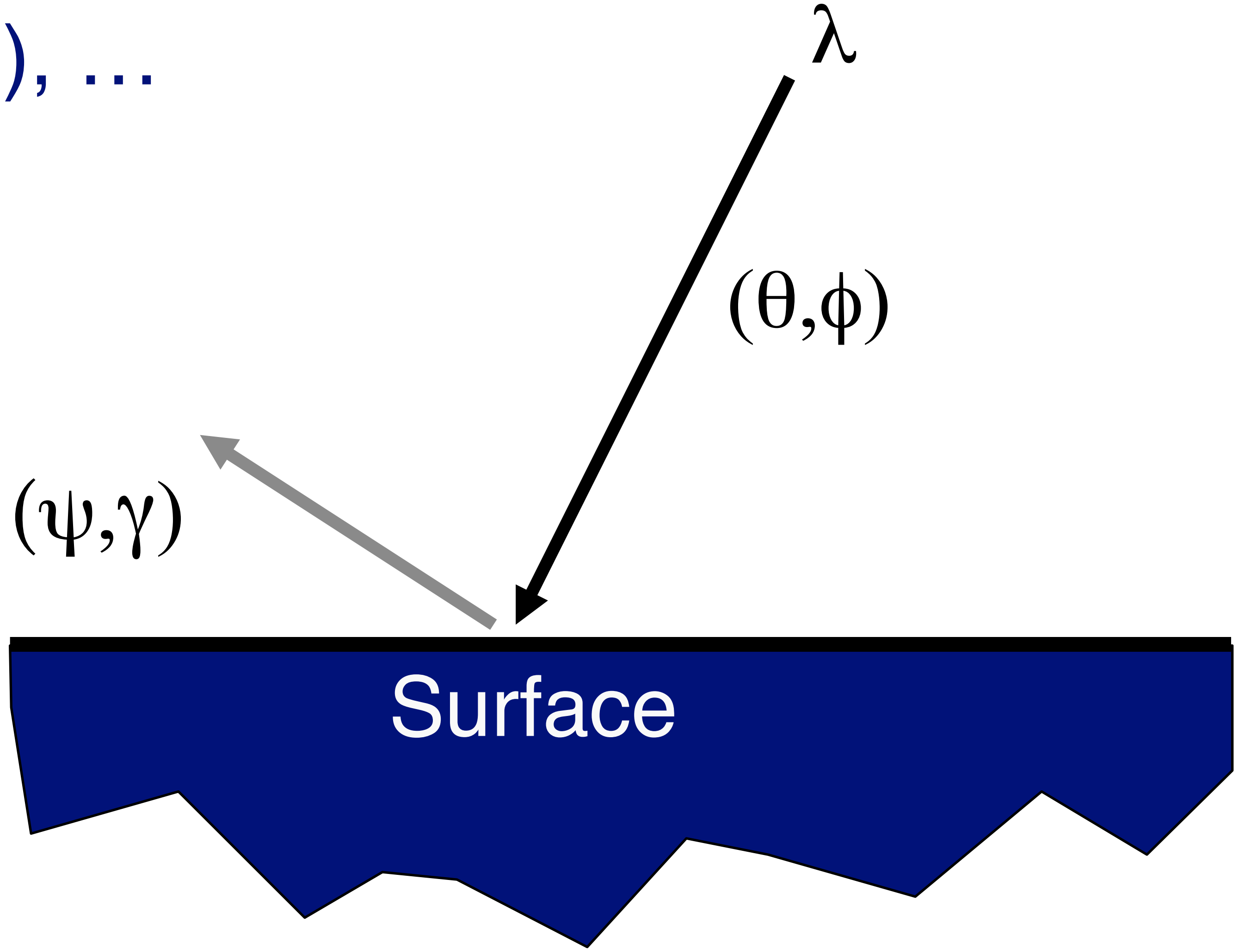
$$I_L = \begin{cases} \dfrac{I_0 \langle D, L \rangle^{\alpha}}{k_c + k_l d + k_q d^2} & \text{if } \langle D, L \rangle < \cos(\gamma) \\ 0 & \text{otherwise} \end{cases}$$

Overview

- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Transmissions
  - Inter-object reflections

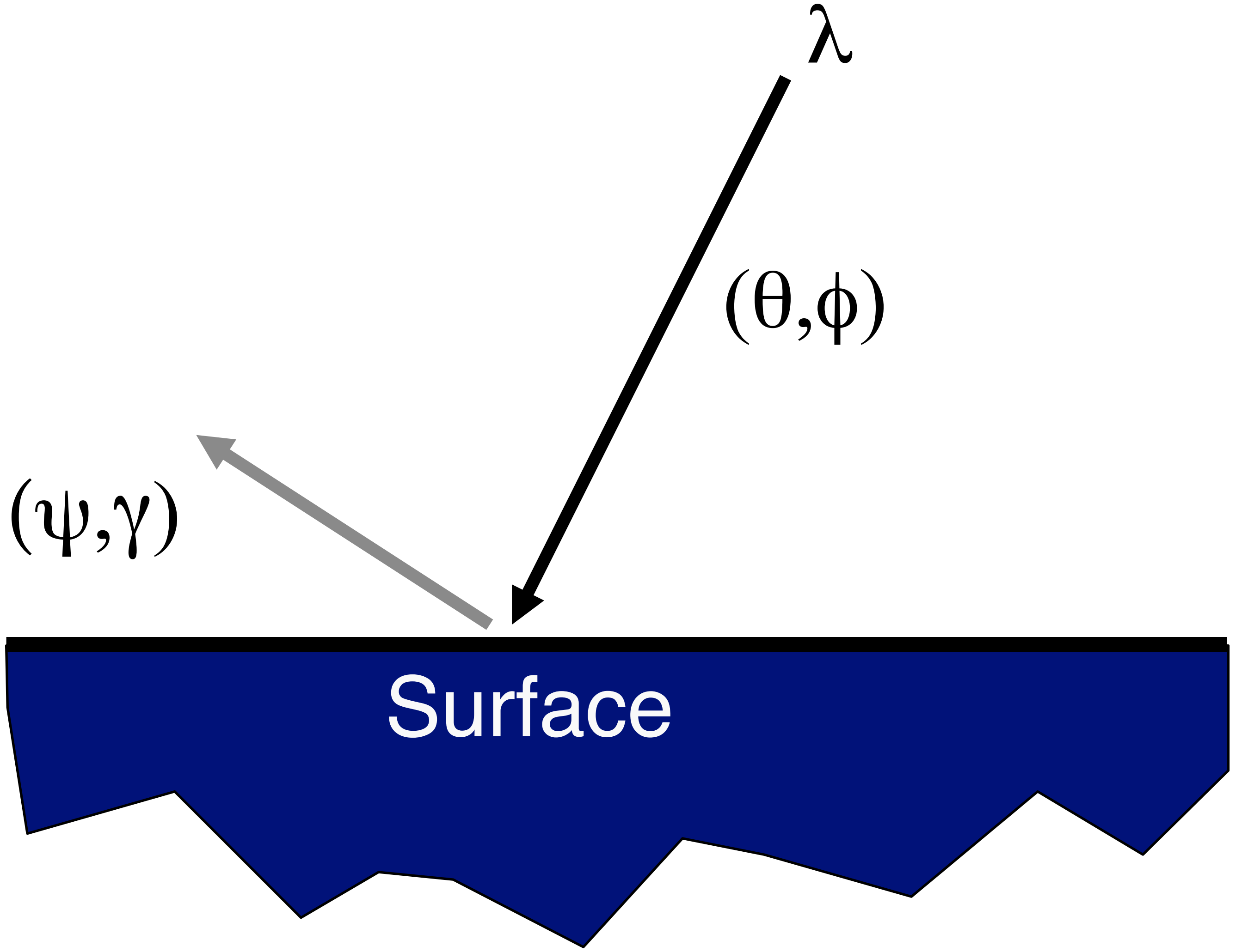
Modeling Surface Reflectance

- $R_s(\theta,\phi,\lambda,\gamma,\psi)$ ...
  - describes the fraction of incident energy,
  - arriving from direction (θ,ϕ), ...
  - with wavelength λ, ...
  - leaving in direction (γ,ψ), …

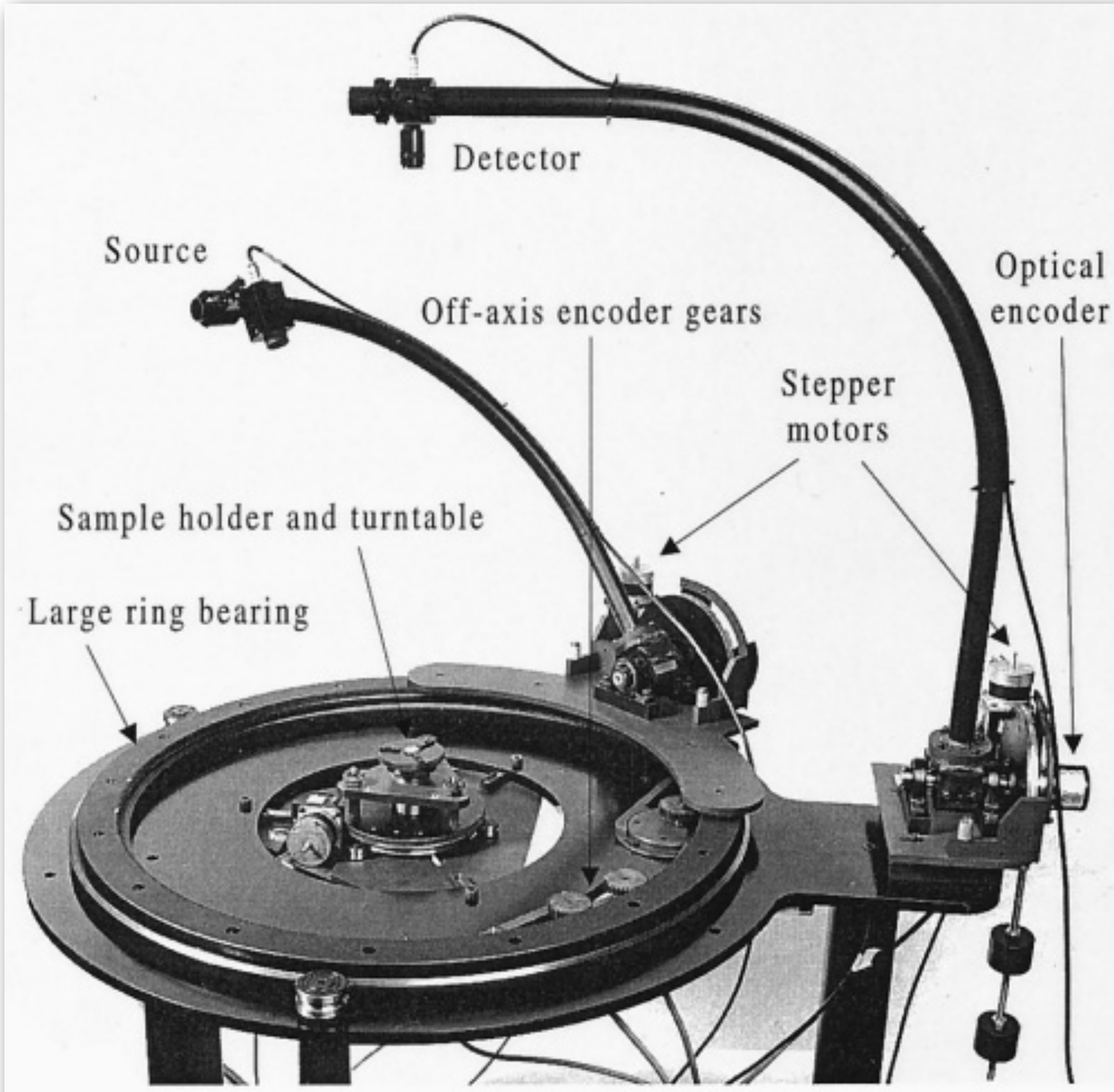


Empirical Models

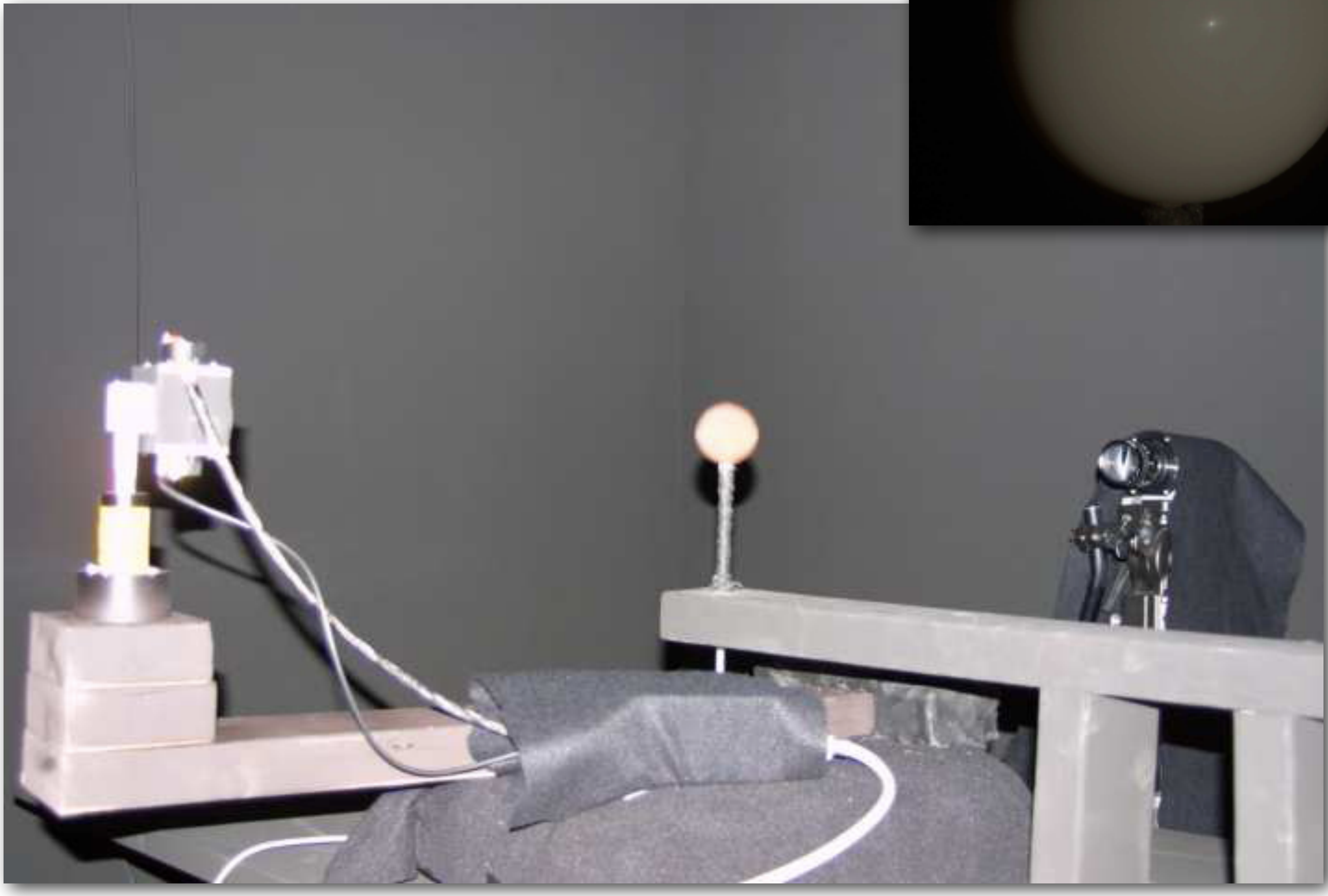
- Ideally measure radiant energy for "all" combinations of incident angles
  - Too much storage
  - Difficult in practice

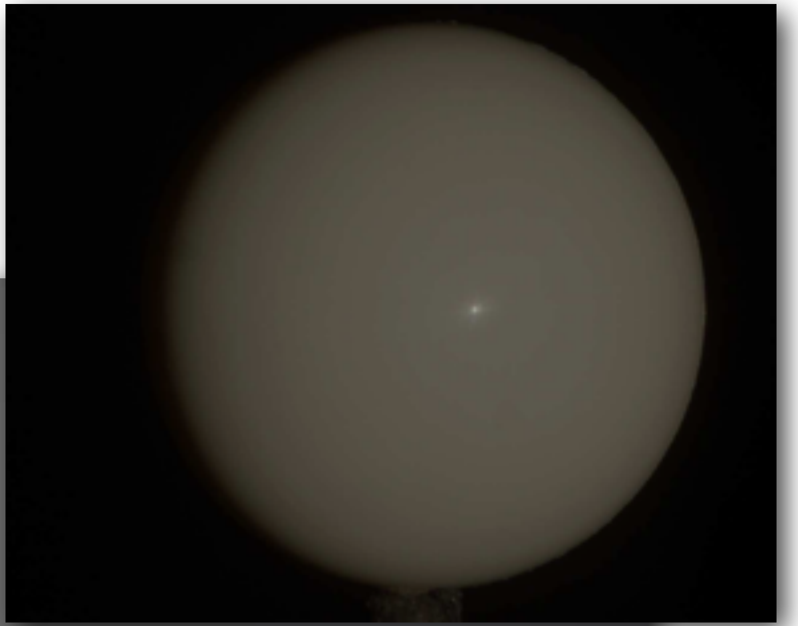


Gonioreflectometry



Gonioreflectometry



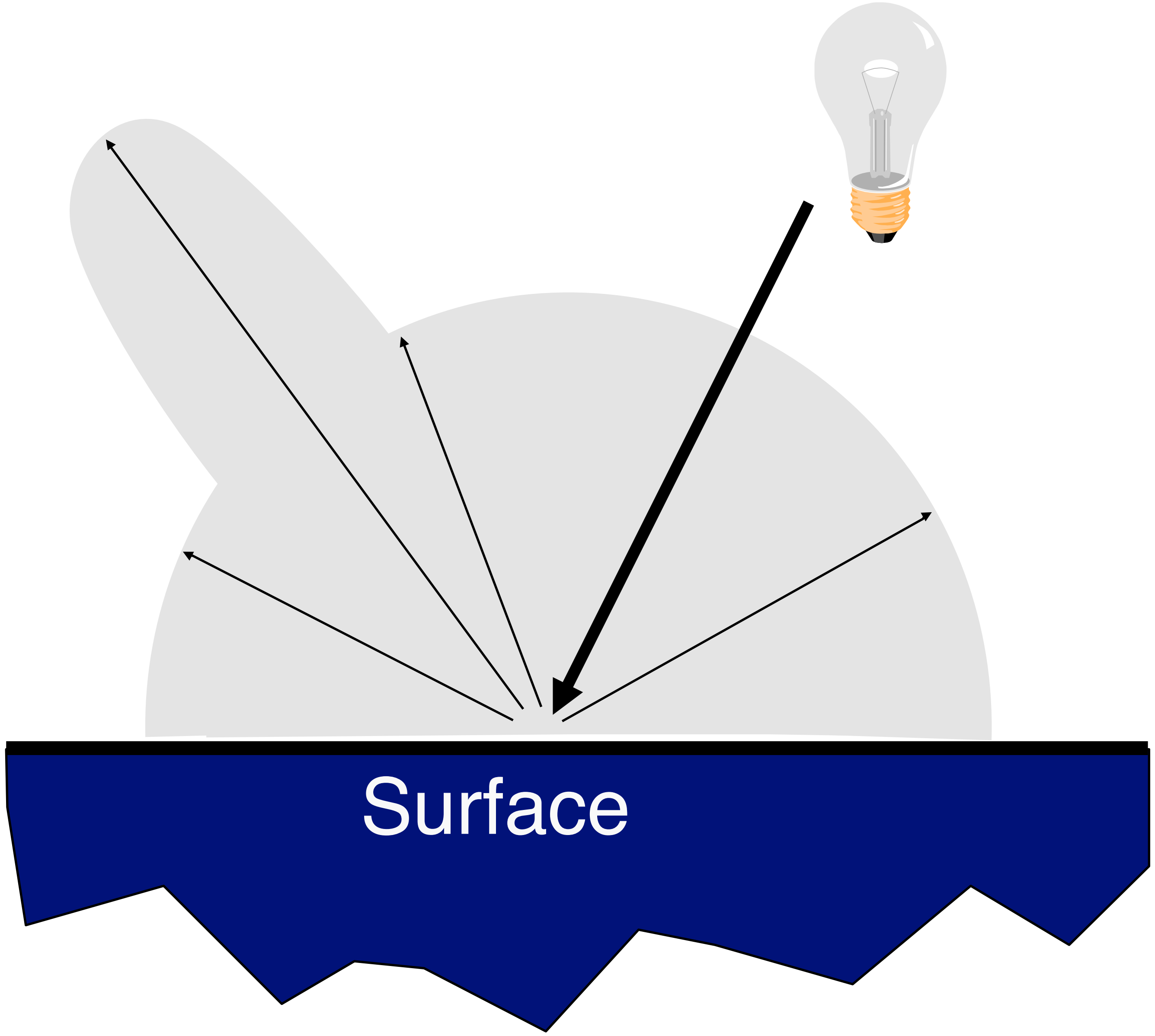


[Matusik et al. 2003]

Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”

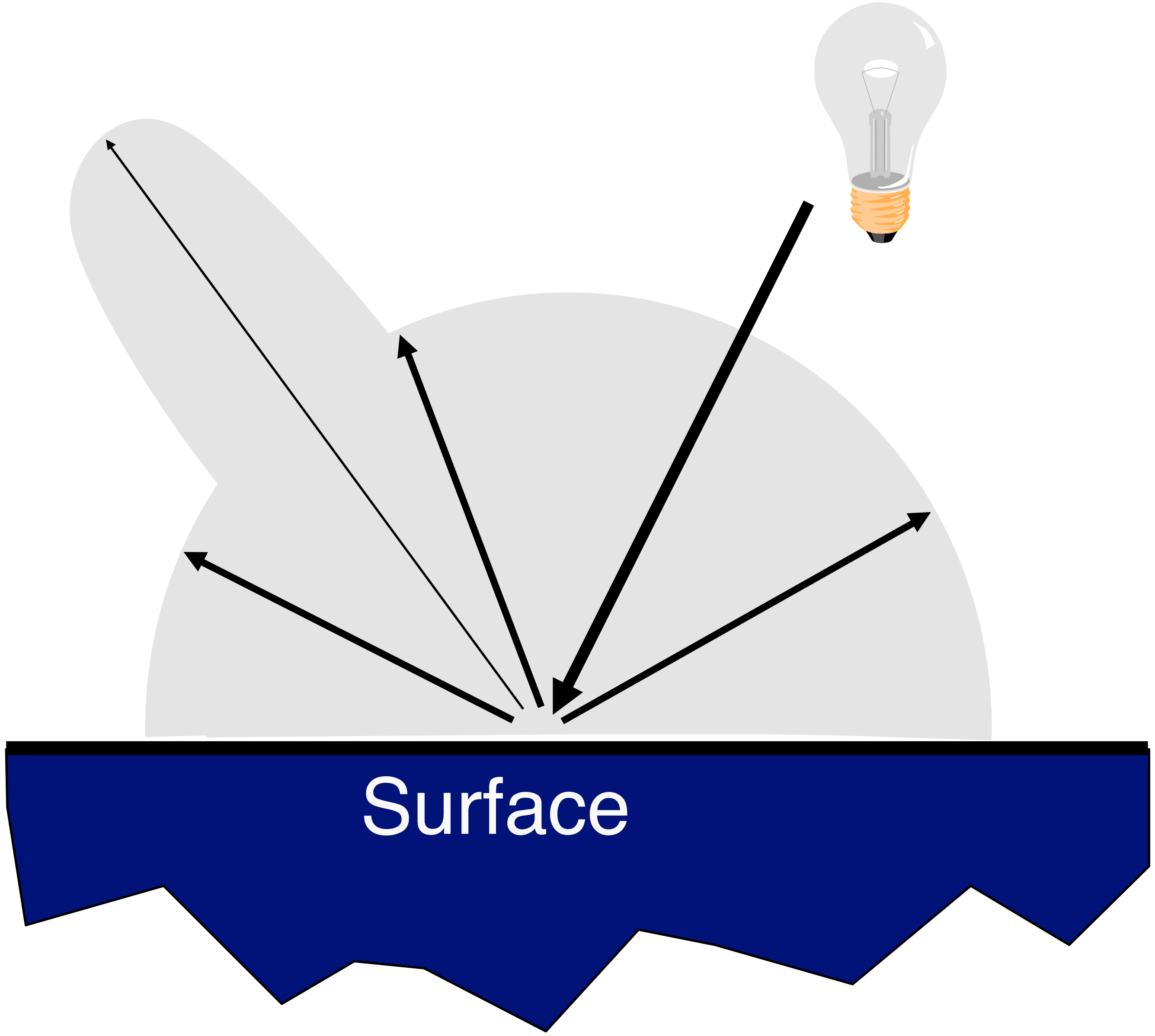
Based on model proposed by Phong



Simple Reflectance Model

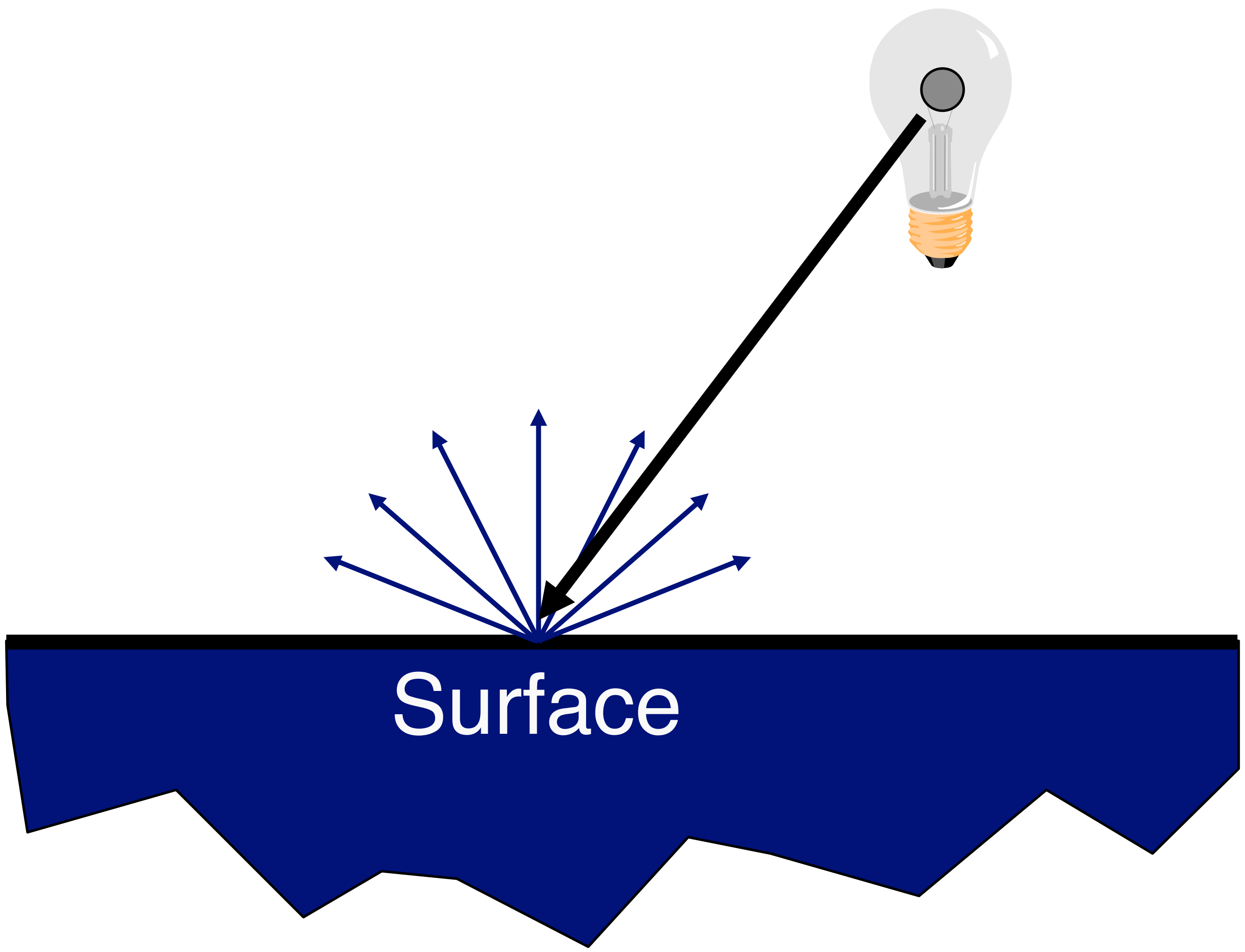
- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - "ambient"

Based on model proposed by Phong



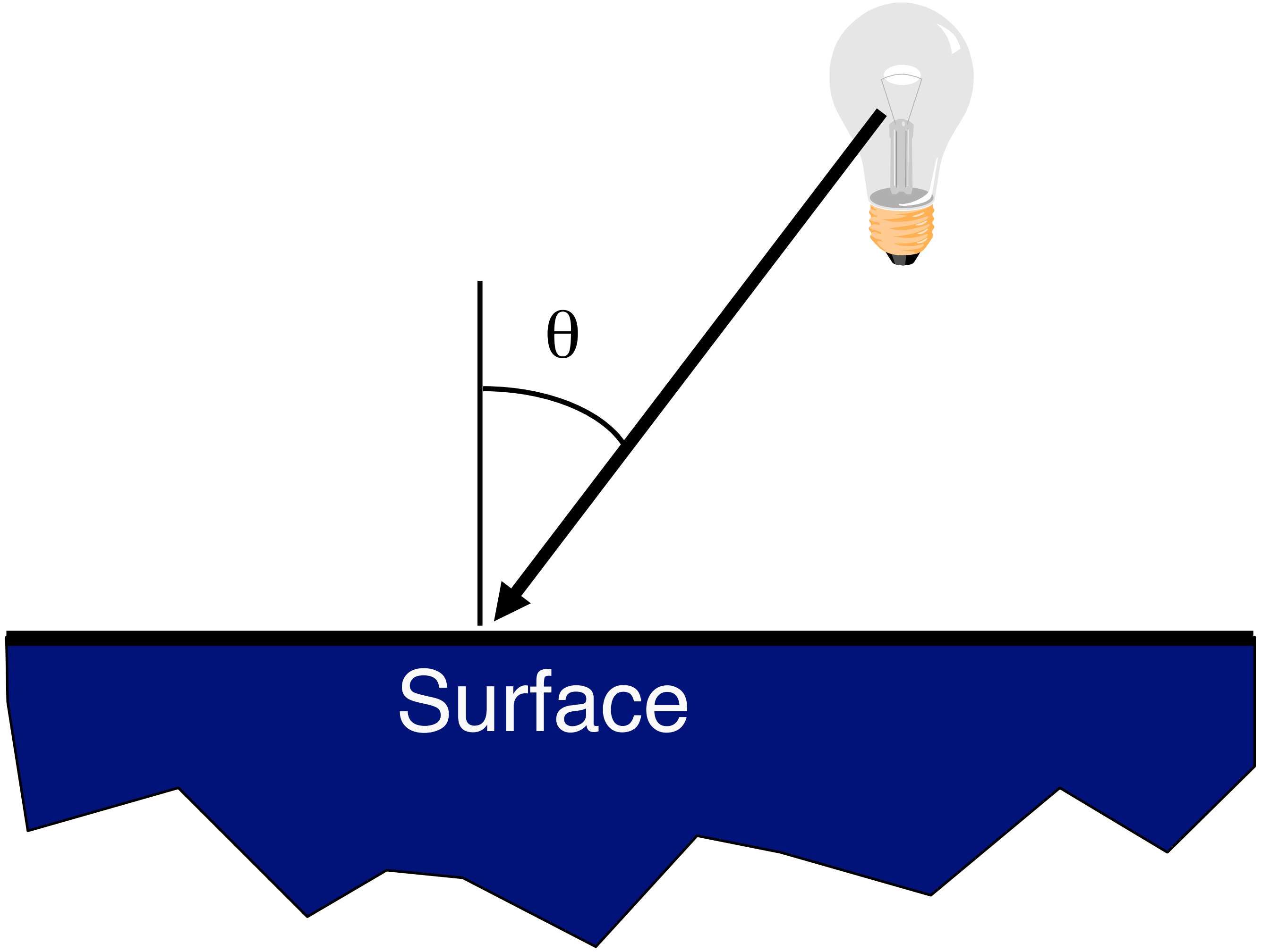
Diffuse Reflection

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



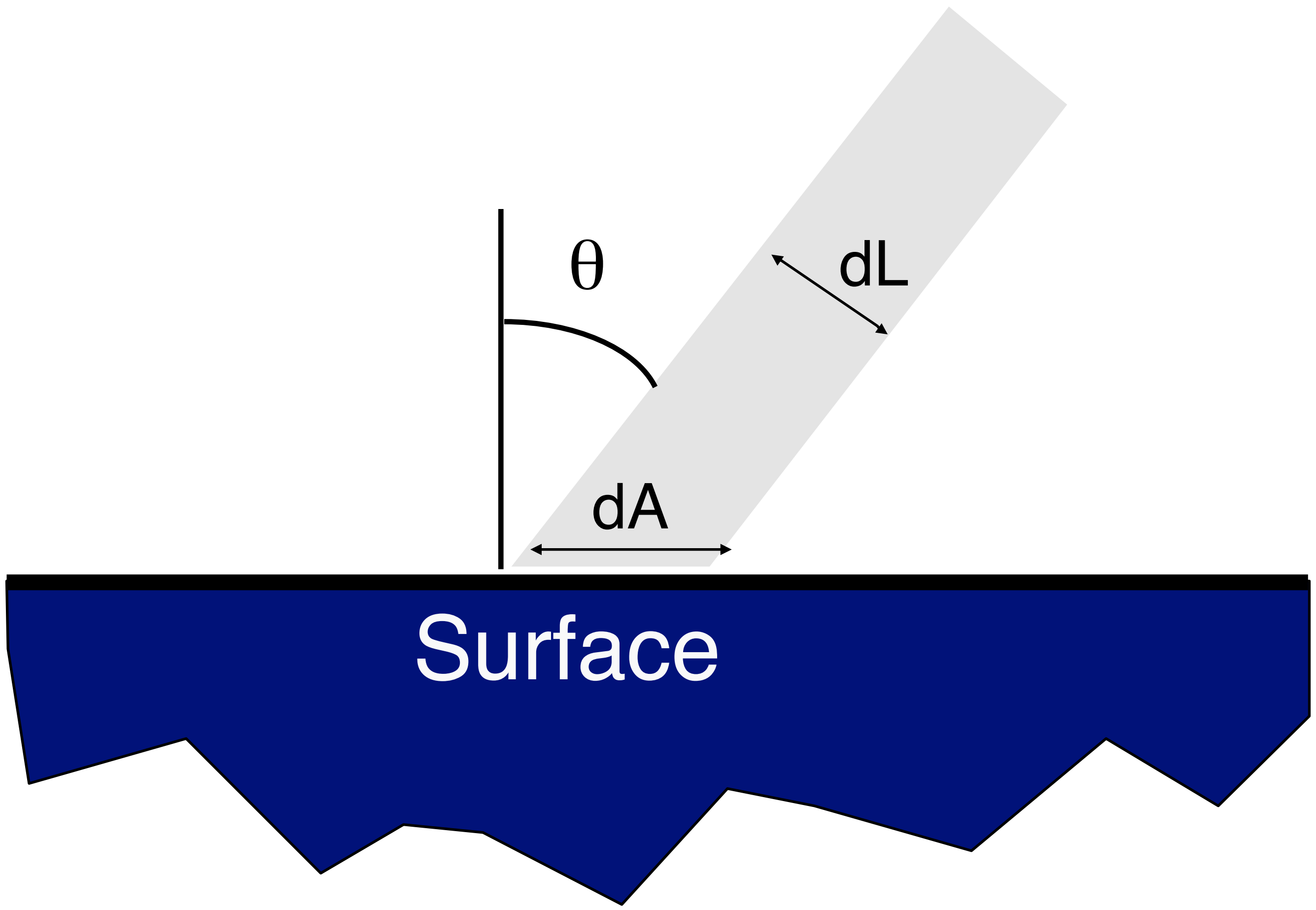
Diffuse Reflection

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



Diffuse Reflection

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

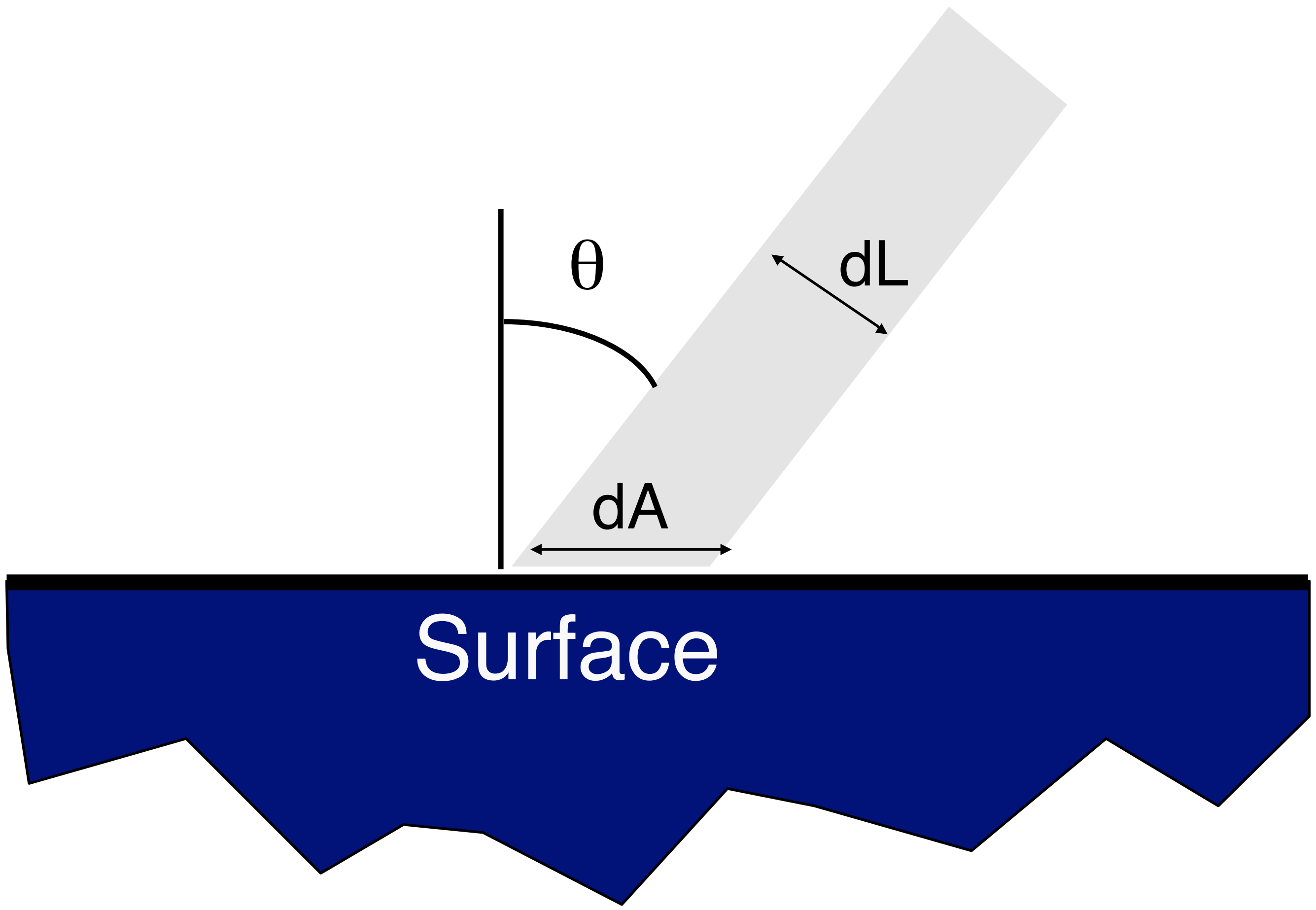


Think of a flashlight!

Diffuse Reflection

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

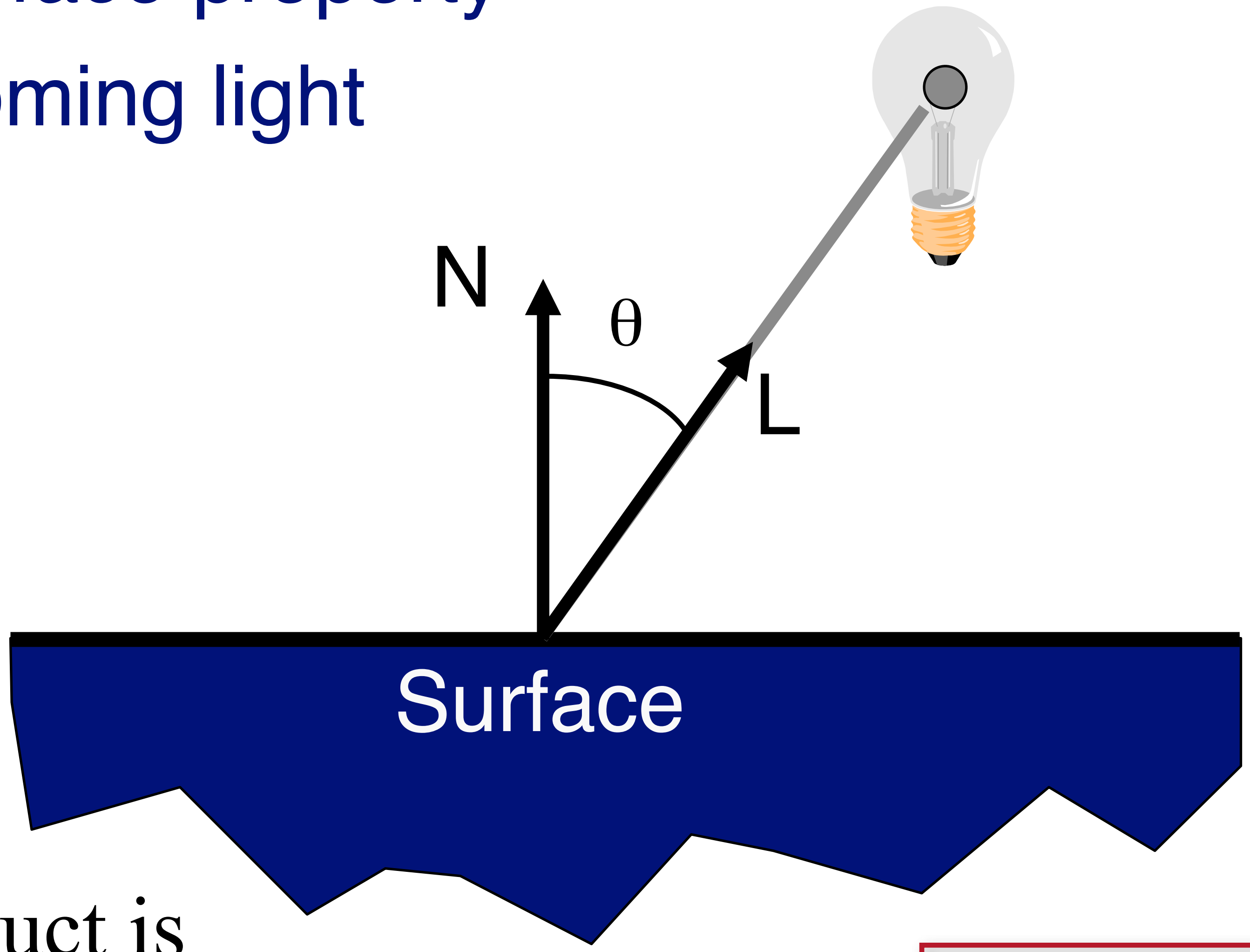
$$dL = dA \cos \Theta$$



Think of a flashlight!

Diffuse Reflection

- Lambertian model
  - o cosine law (dot product)
  - o K_D is surface property
  - o I_L is incoming light



(If the dot product is less than zero, then I_D is zero)

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

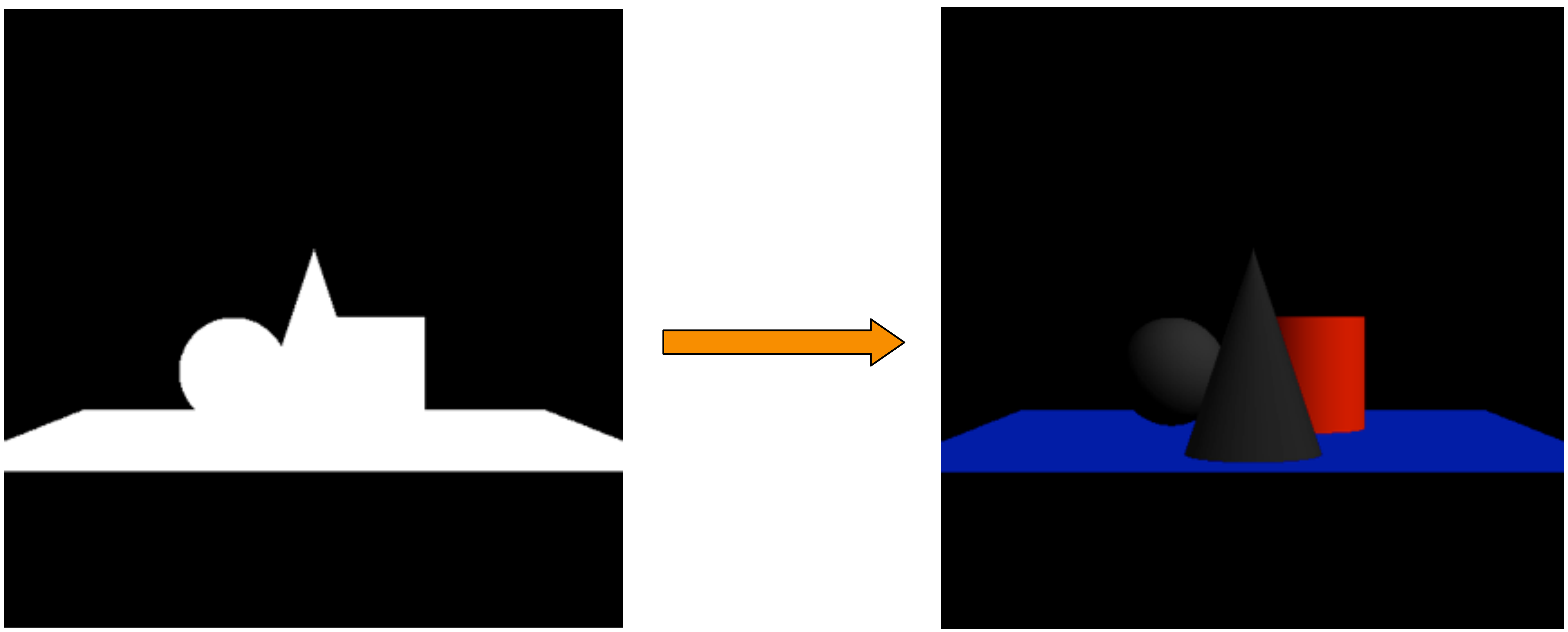
Diffuse Reflection

- Note that lights and surface properties have R,G, and B components!
  - So amount of red light reflected is not necessarily equal to amount of green light, etc.
  - You will need to run calculation below on EACH color channel
  - This holds true for all lighting calculations

$$I_{D\_Red} = K_{D\_RED}(N \bullet L)I_{L\_RED}$$

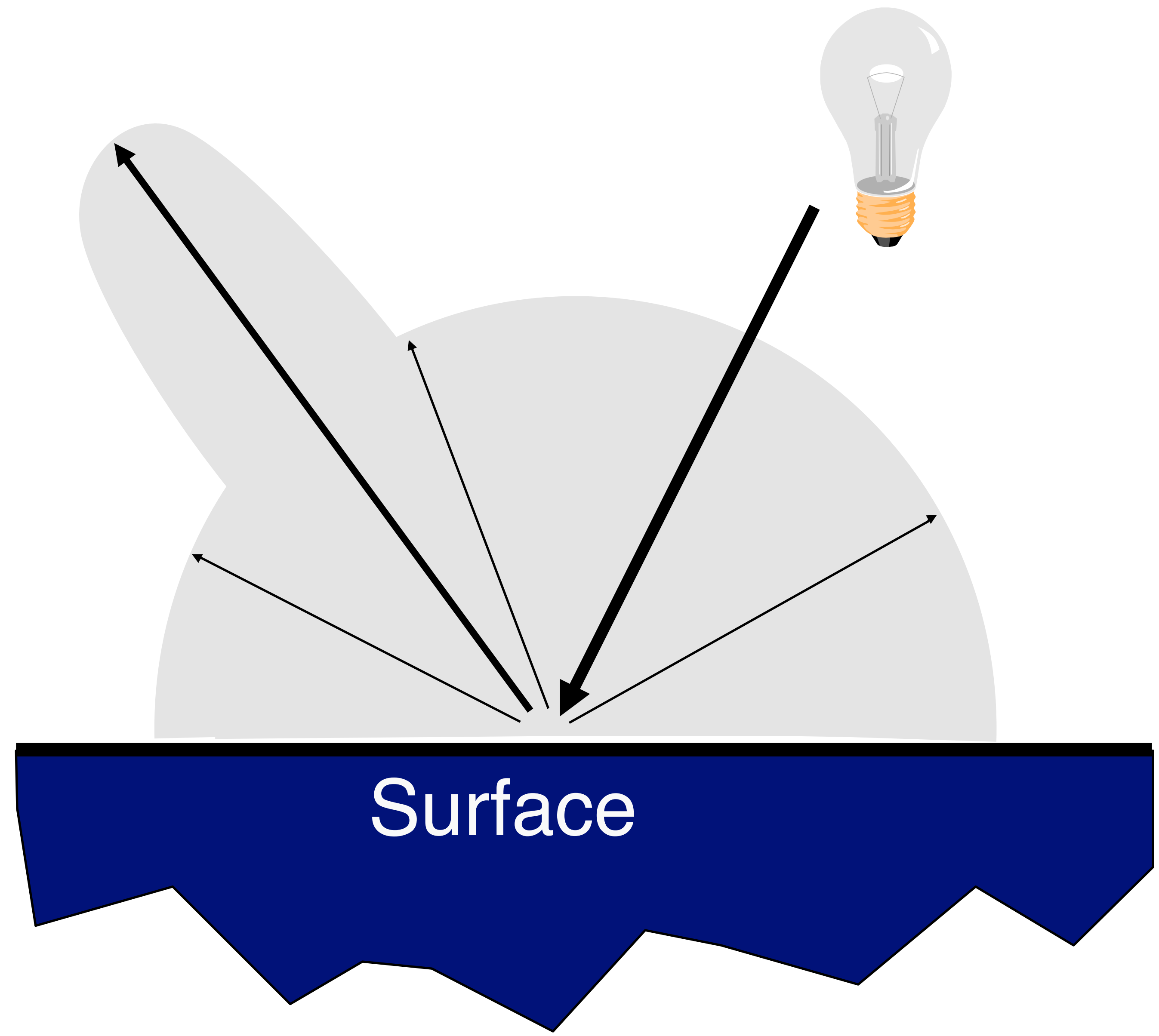
Diffuse Reflection

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



Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”

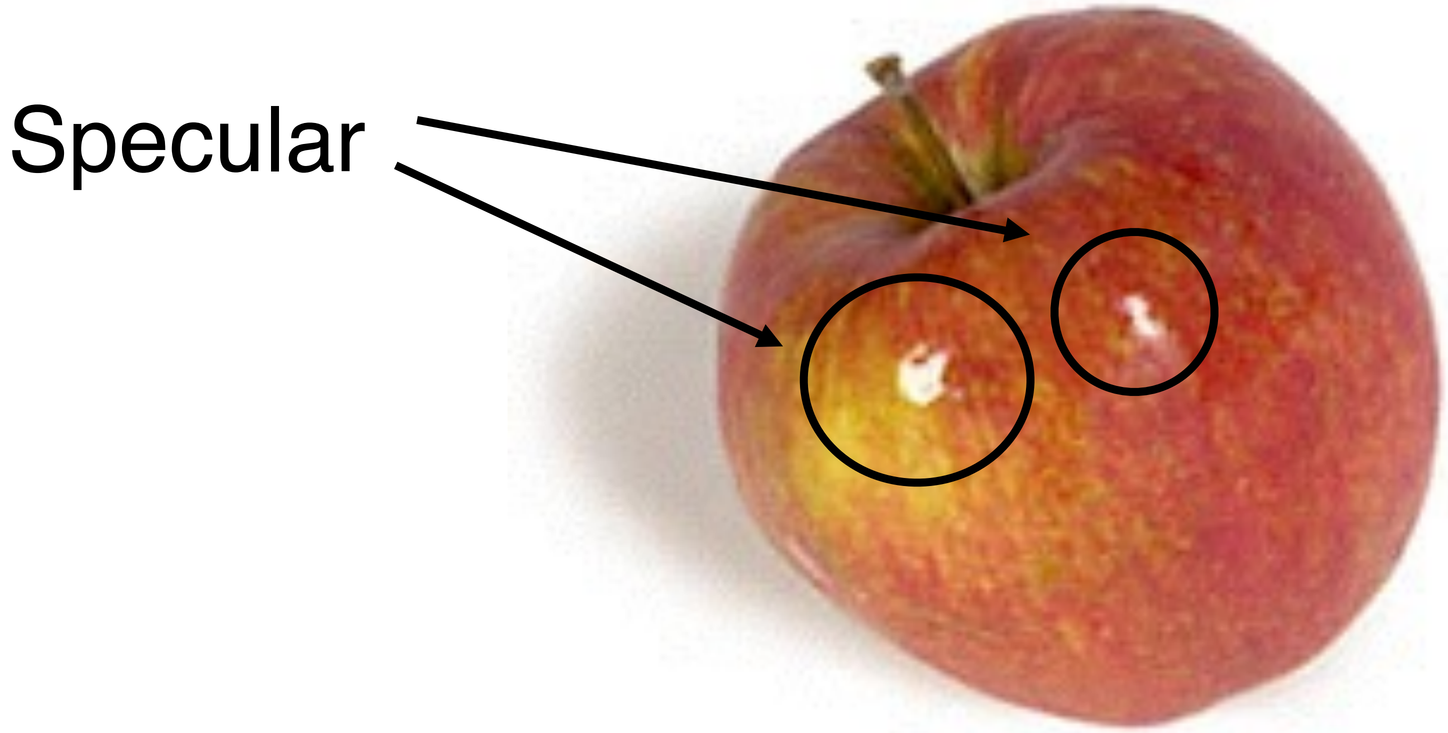


Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: non-metallic "shiny" surfaces

Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: non-metallic shiny surfaces



Specular Reflection

How much light is seen?

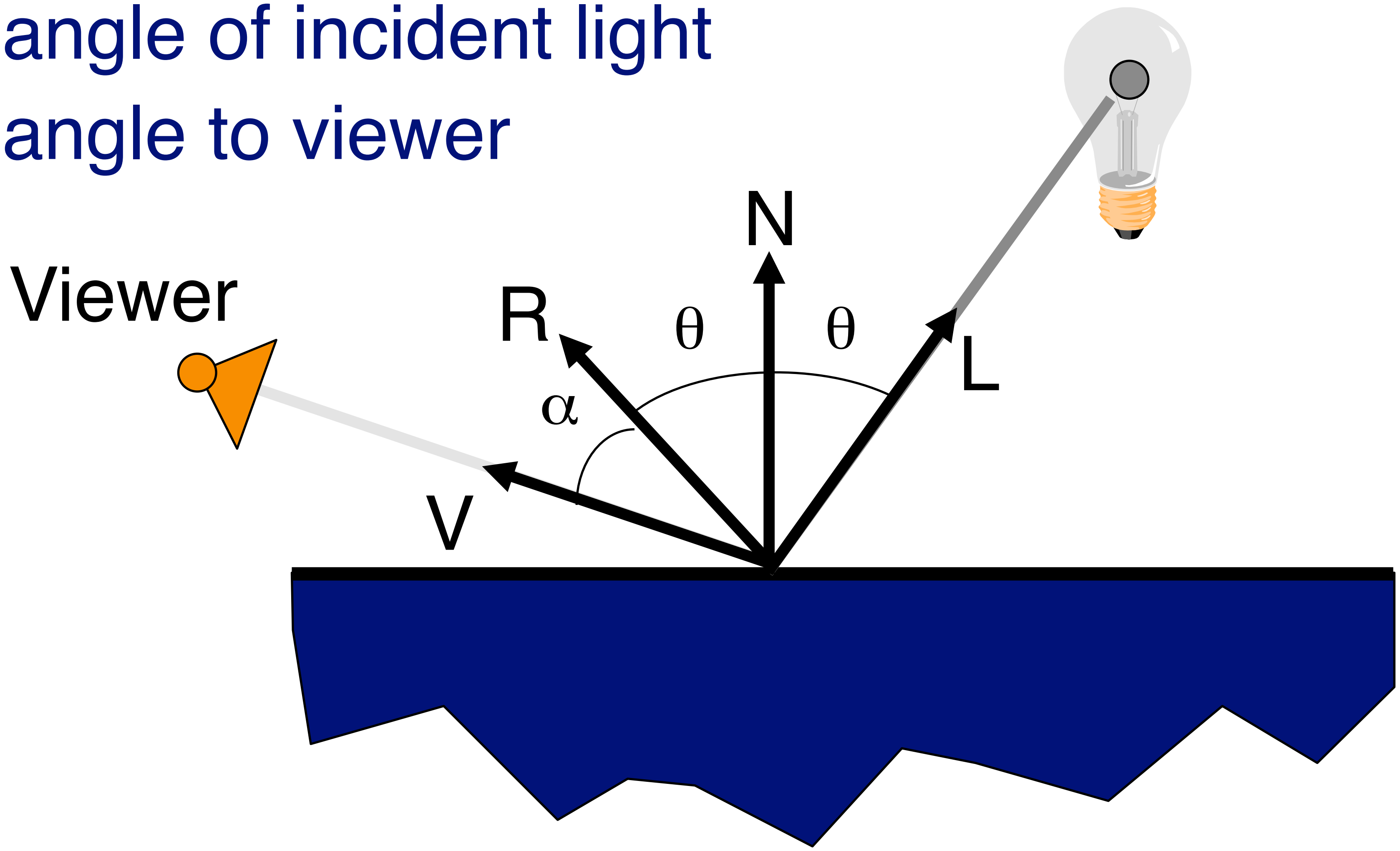
Depends on:

- angle of incident light
- angle to viewer

N: Normal
L: Light direction
R: Reflected light direction

$$R = -L + 2(N \cdot L)N$$

V: View direction

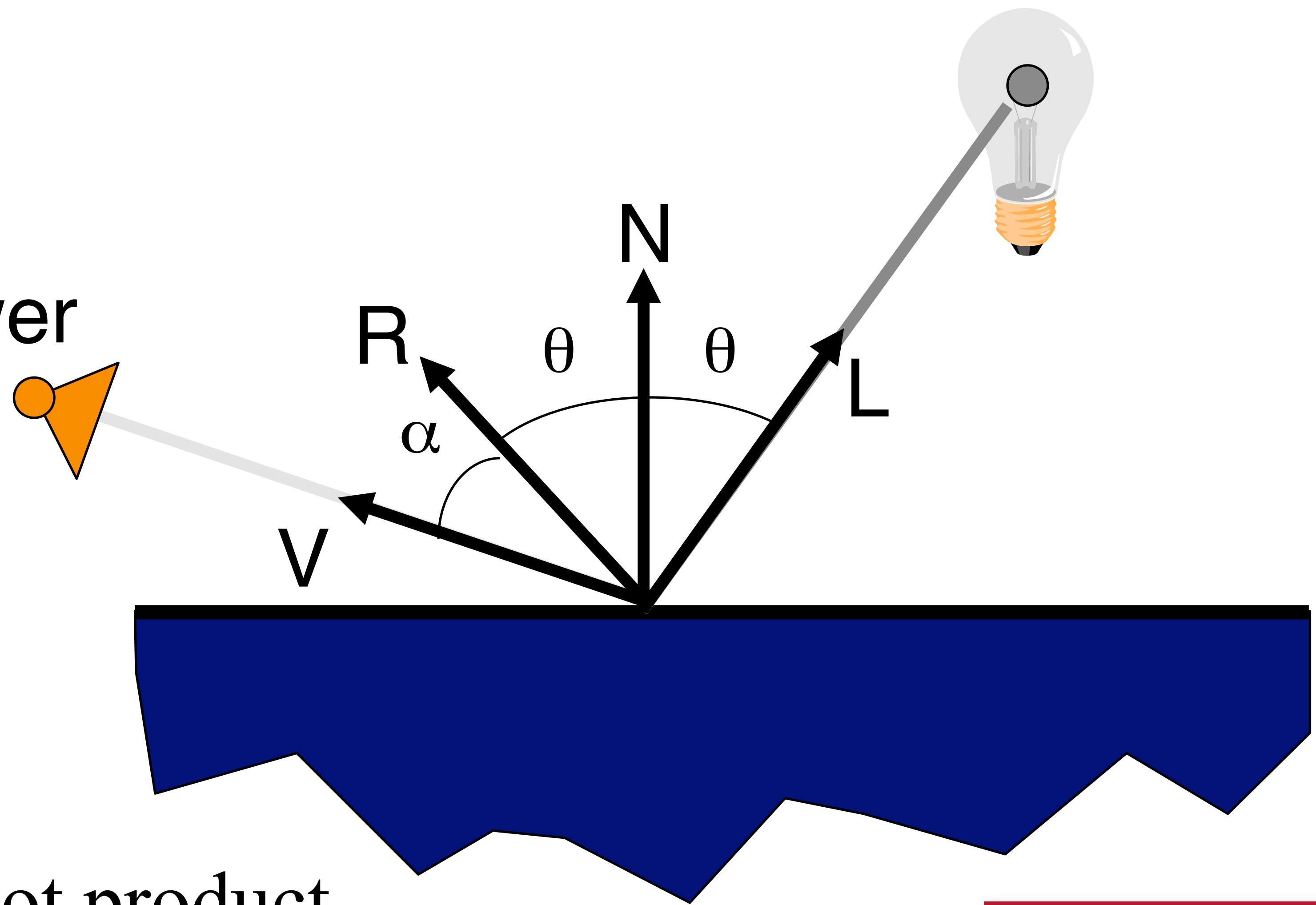


Specular Reflection

- Phong Model

  ocos$(\alpha)^n$

This is a physically-motivated hack!

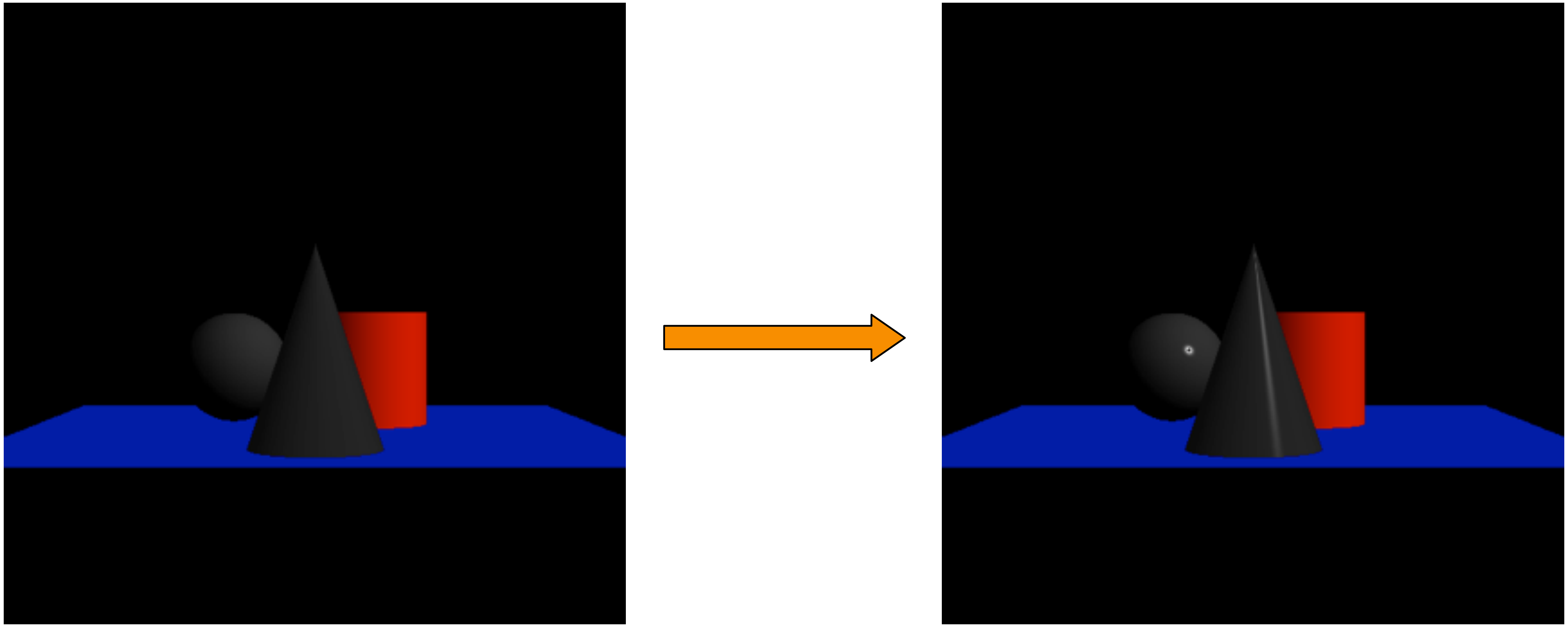


(Again, if dot product is negative, then I_S should be set to zero)

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

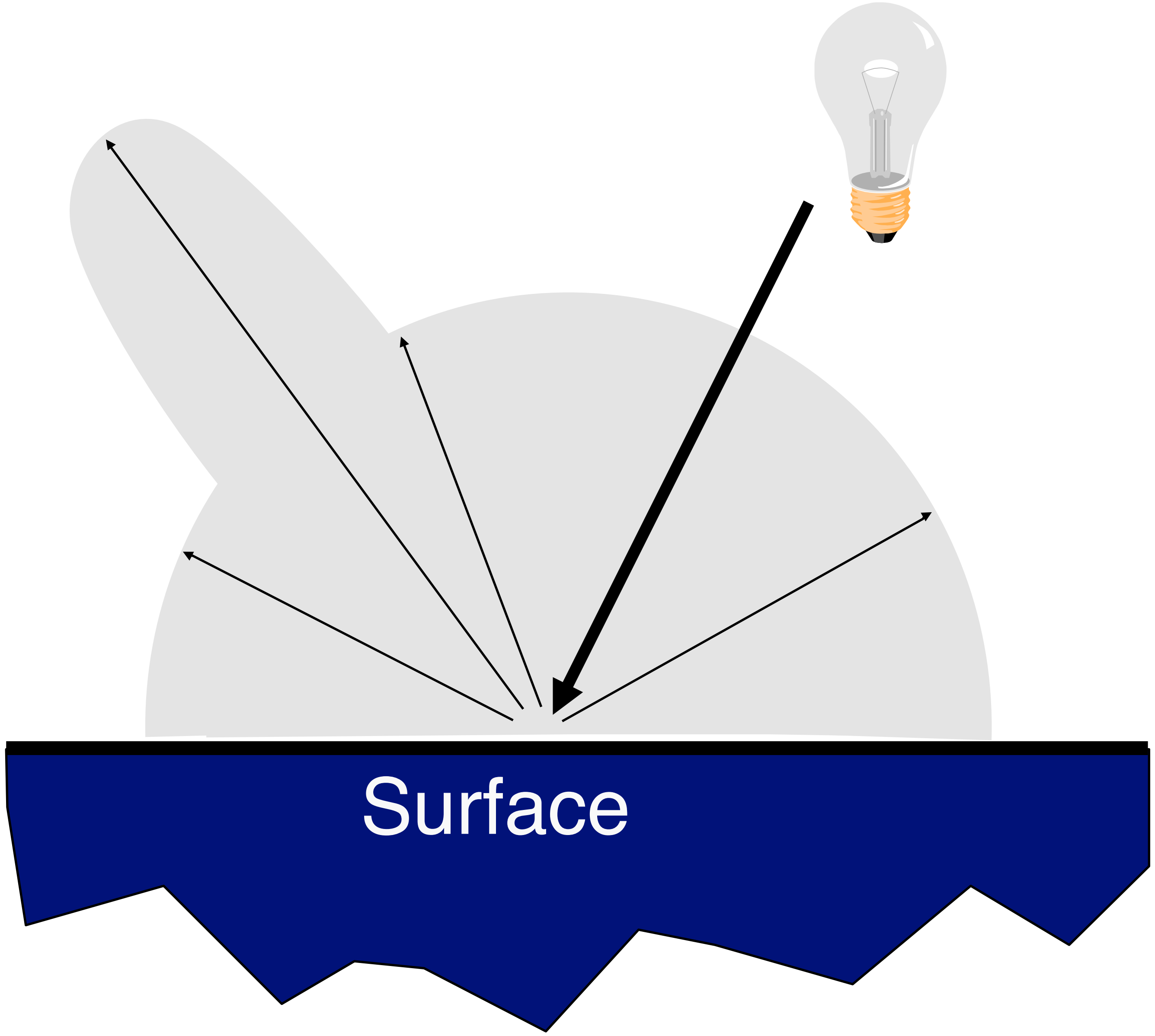
Specular Reflection

- Reflection is strongest near mirror angle
  - o Examples: non-metallic shiny surfaces



Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - "ambient"



Emission

Represents light emanating directly from a surface that cannot be described by the three light sources

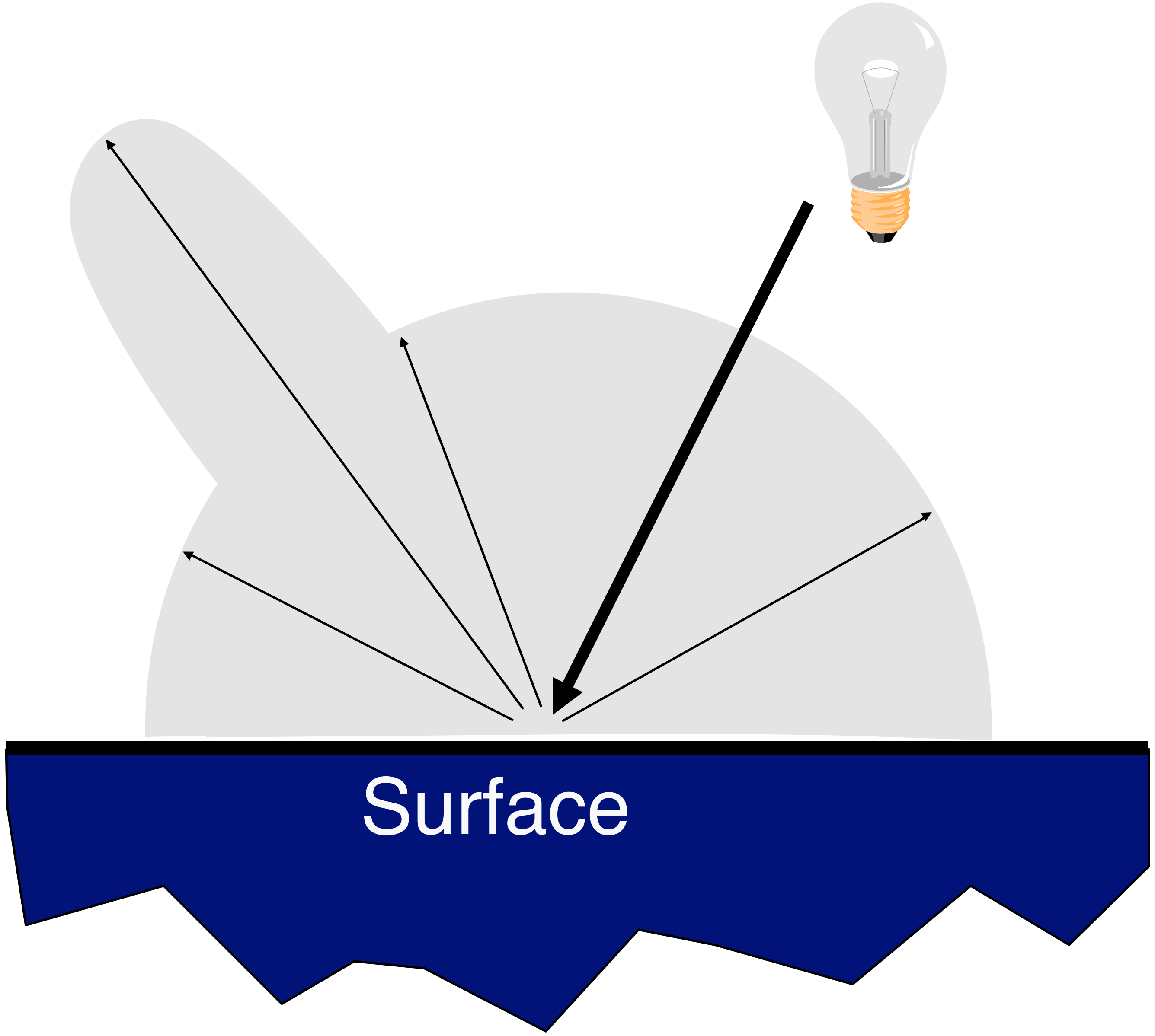
Emission ≠ 0

Emission

$$I = I_E$$

Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - “ambient”



Ambient Term

- Represents reflection of all indirect illumination

This is a total hack (avoids complexity of global illumination)!

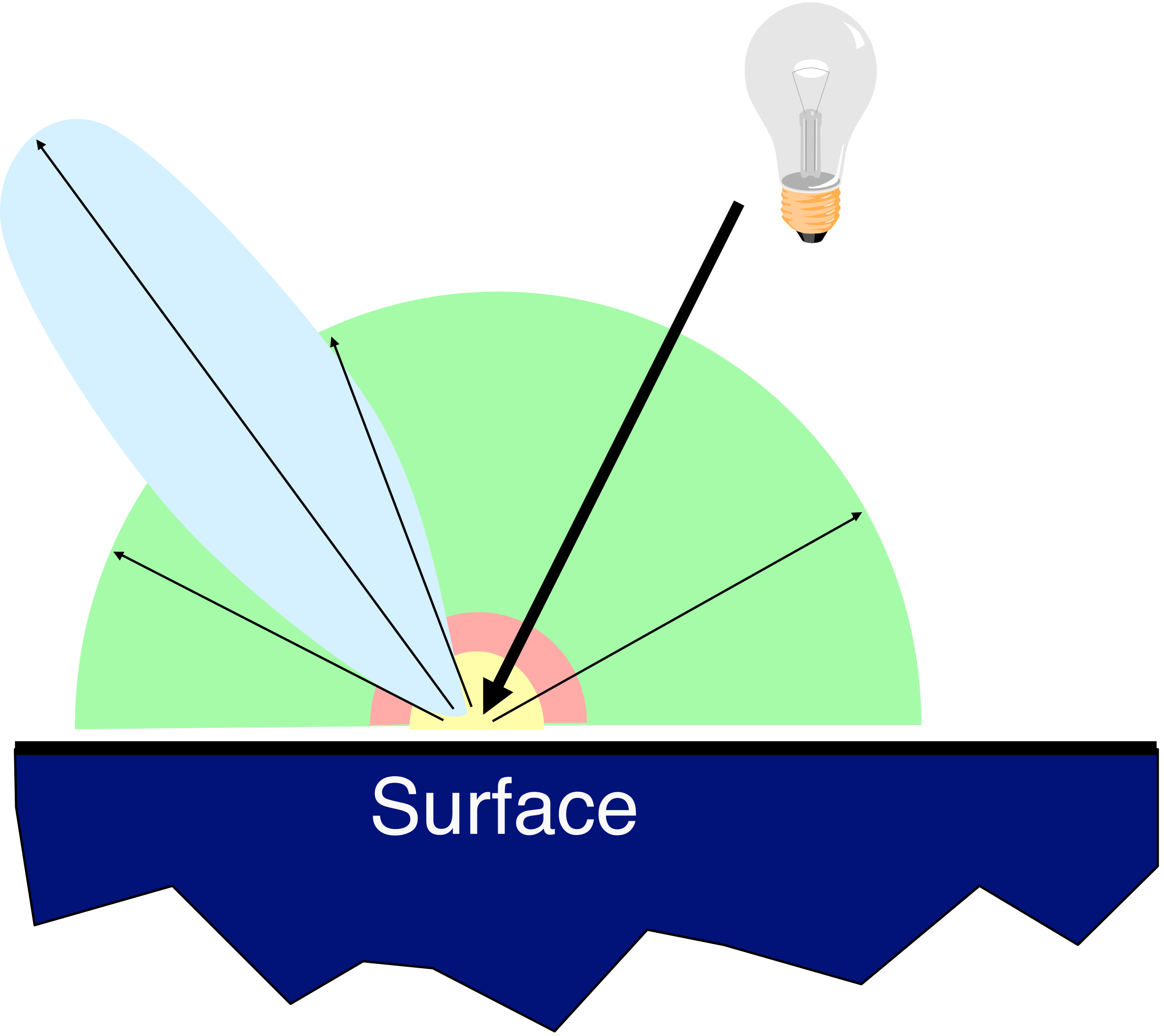
Ambient Term

- Represents reflection of all indirect illumination

$$I_A = K_A I_{AL}$$

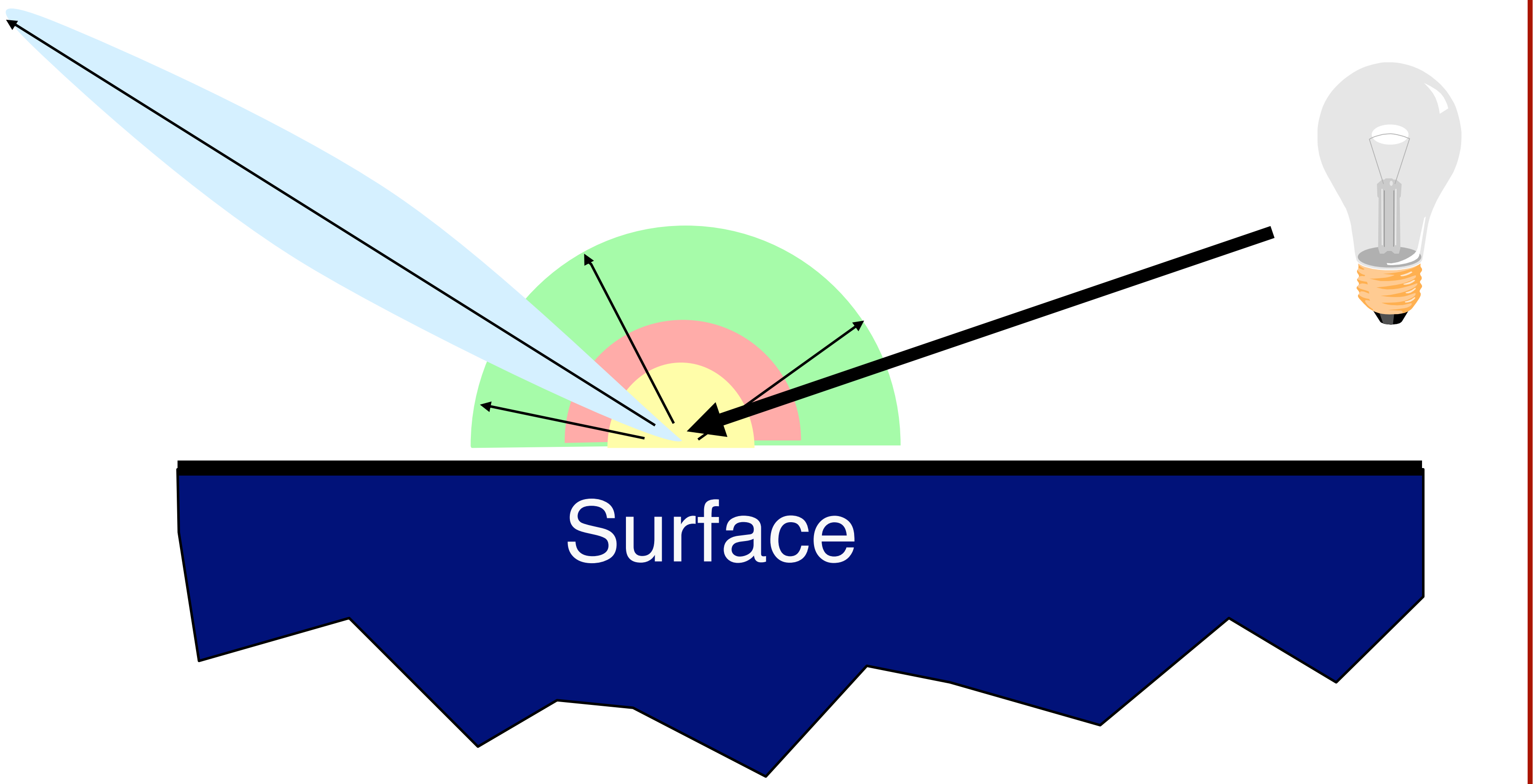
Simple Reflectance Model

- Simple analytic model:
  - o diffuse reflection +
  - o specular reflection +
  - o emission +
  - o "ambient"



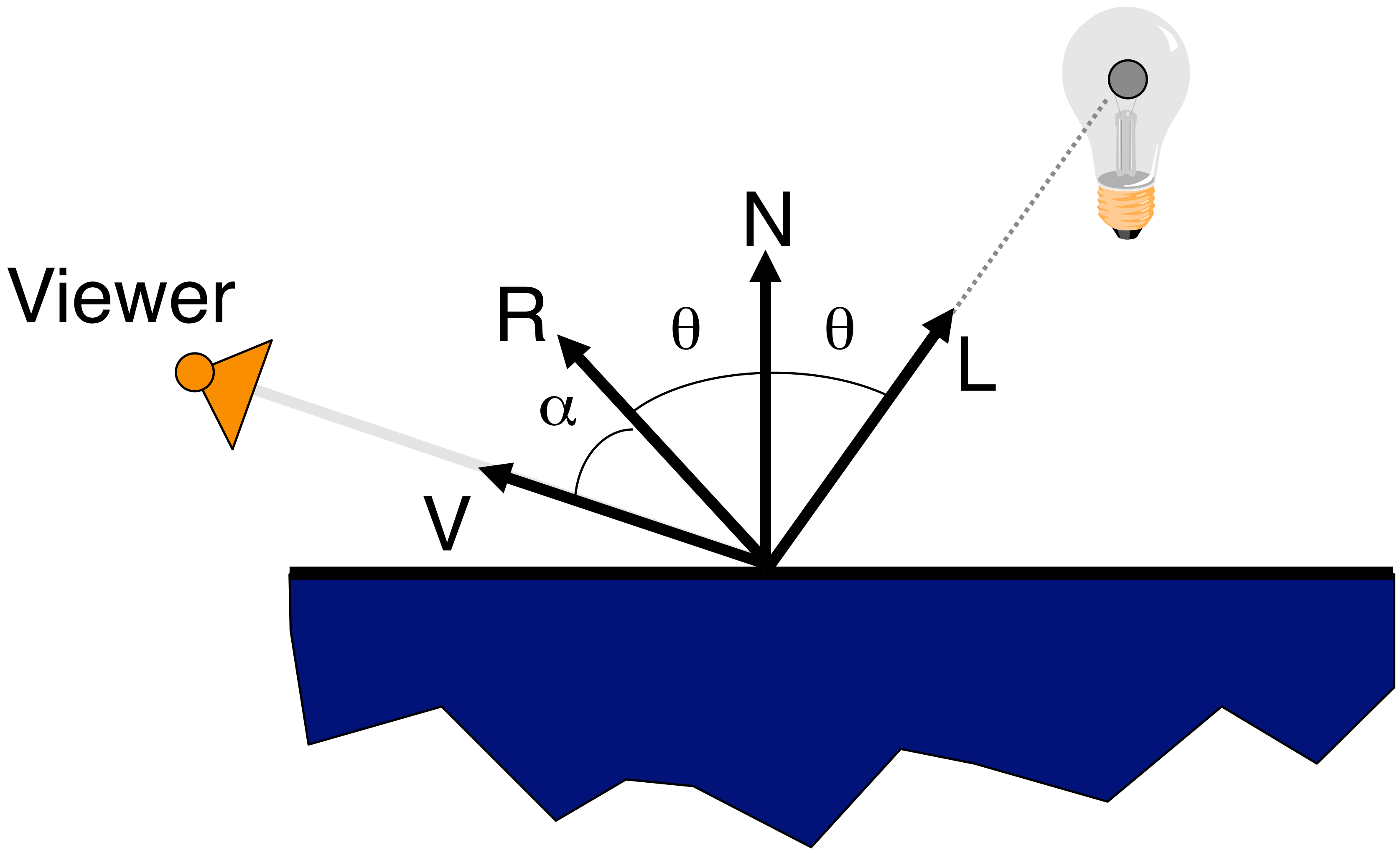
Simple Reflectance Model

- Simple analytic model:
  - o diffuse reflection +
  - o specular reflection +
  - o emission +
  - o “ambient”



Surface Illumination Calculation

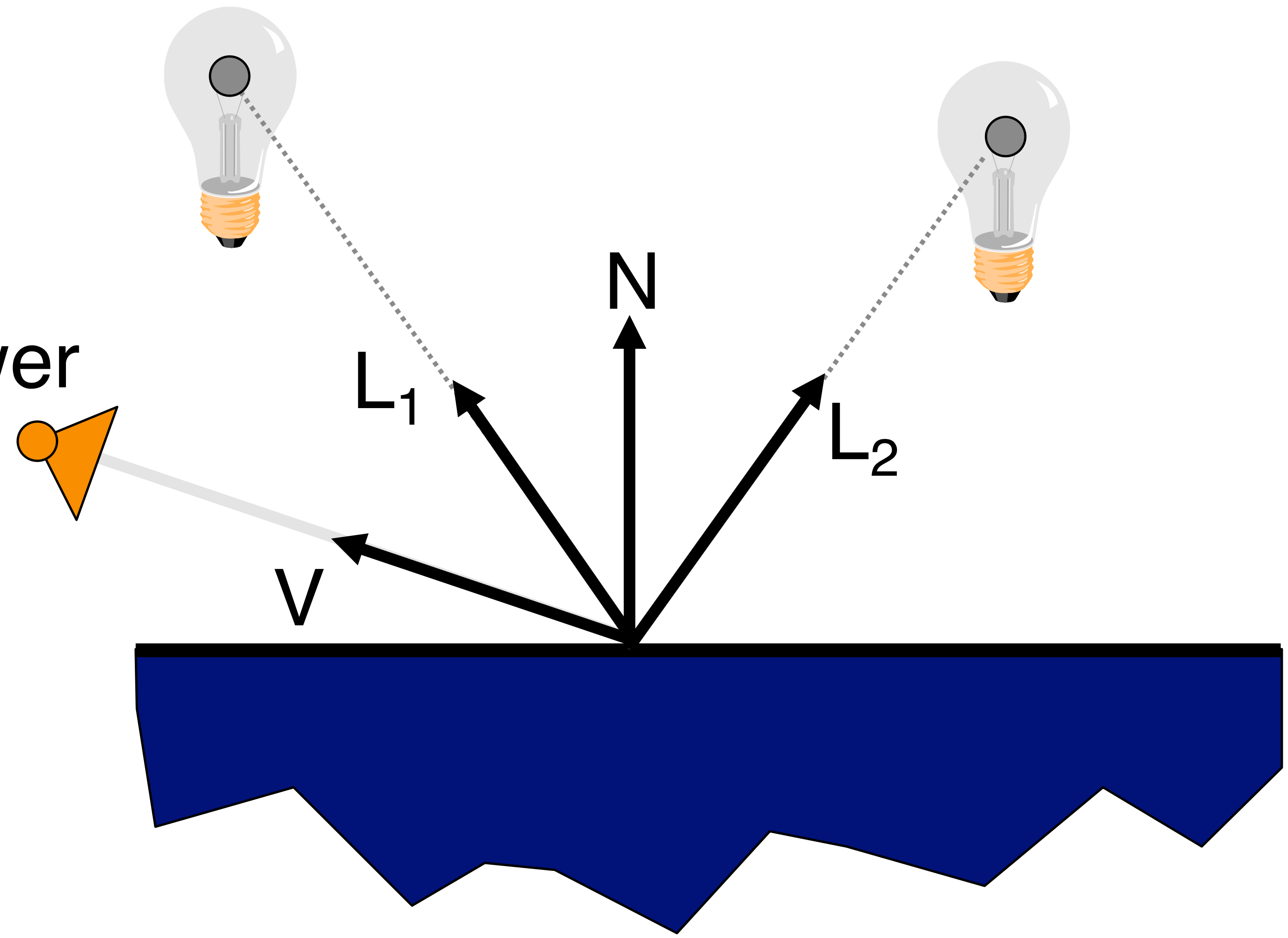
- Single light source :



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

Surface Illumination Calculation

- Multiple light sources:



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

Next Lecture

- Direct Illumination
  - Emission at light sources
  - Direct light at surface points
- Global illumination
  - Shadows
  - Transmissions
  - Inter-object reflections