Direct Illumination

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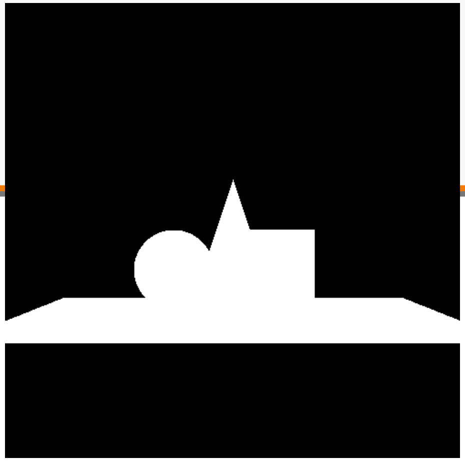
(601.457/657)

HB Ch. 14.1, 14.2

FvDFH 16.1, 16.2

Ray Casting

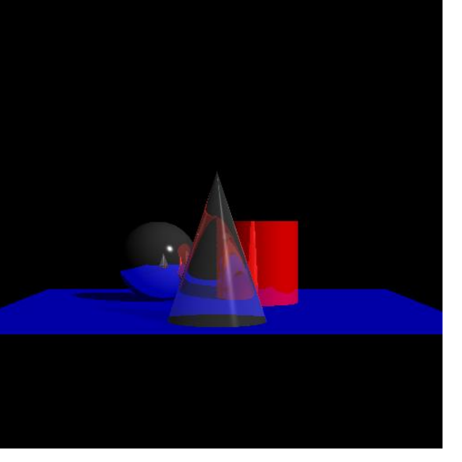
```
Image RayCast( Camera camera , Scene scene , int width , int height )
{
    Image image( width , height );
    for( int j=0 ; j<height ; j++ ) for( int i=0 ; i<width ; i++ )
    {
        Ray< 3 > ray = ConstructRayThroughPixel( camera , i , j );
        Intersection hit = FindIntersection( ray , scene );
        image(i,j) = GetColor( scene , ray , hit );
    }
    return image;
}
```



Without Illumination

Ray Casting

```
Image RayCast( Camera camera , Scene scene , int width , int height )
{
    Image image( width , height );
    for( int j=0 ; j<height ; j++ ) for( int i=0 ; i<width ; i++ )
    {
            Ray< 3 > ray = ConstructRayThroughPixel( camera , i , j );
            Intersection hit = FindIntersection( ray , scene );
            image(i,j) = GetColor( scene , ray , hit );
    }
    return image;
}
```

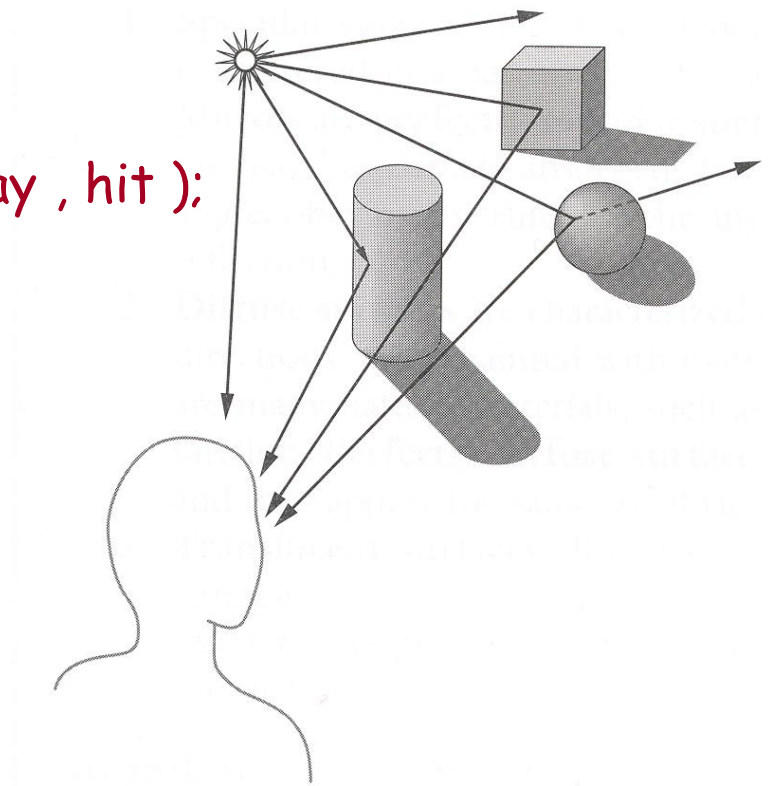


With Illumination

Illumination

- How do we compute radiance for a sample ray?

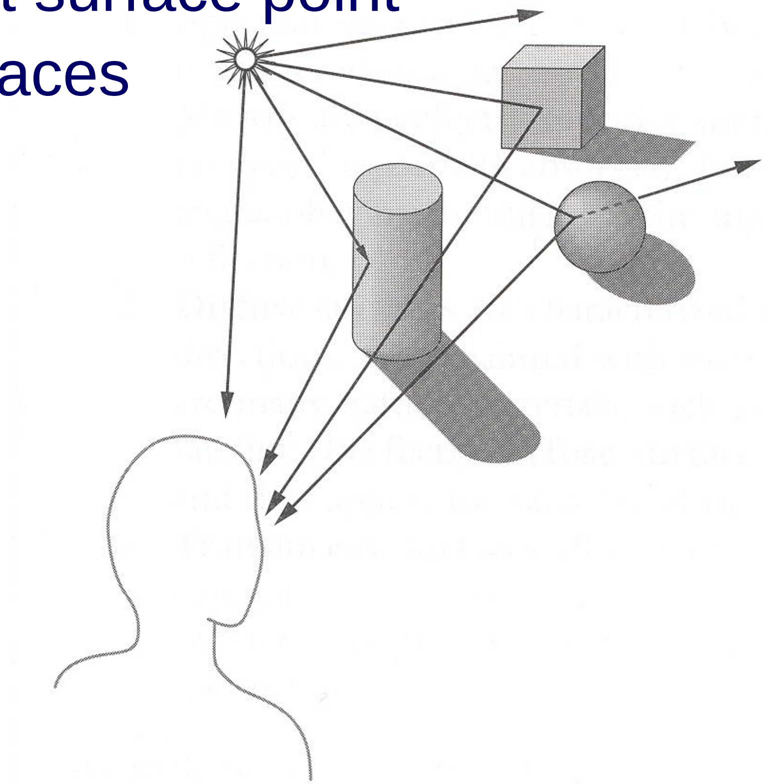
image(i,j) = GetColor(scene , ray , hit);



Angel Figure 6.2

Goal

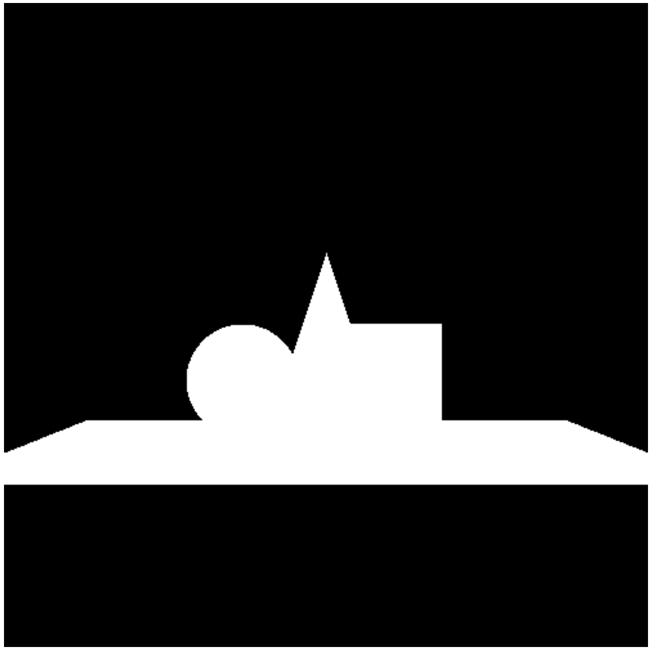
- Must derive models for ...
  - Emission at light sources
  - Reflected (direct) light at surface point
  - Scattering between surfaces



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

Overview

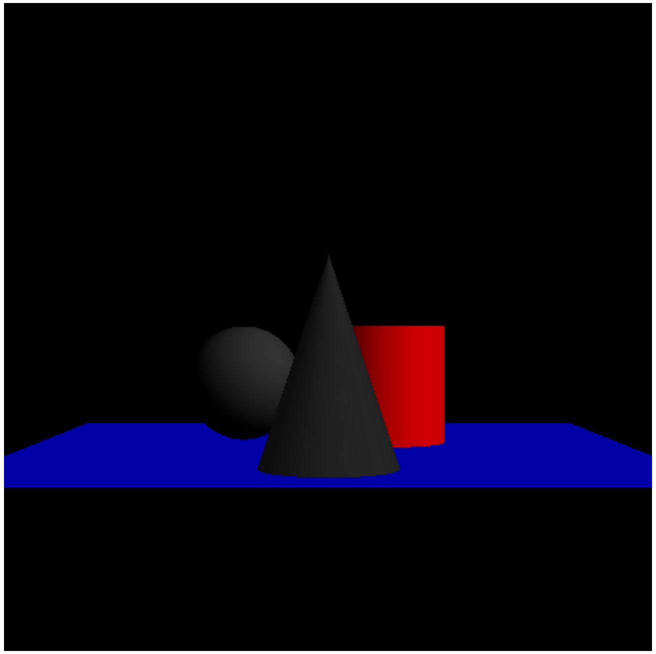
- Direct Illumination
  - Emission at a light source
  - Reflected (direct) light at surface point
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Intersection Testing

Overview

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

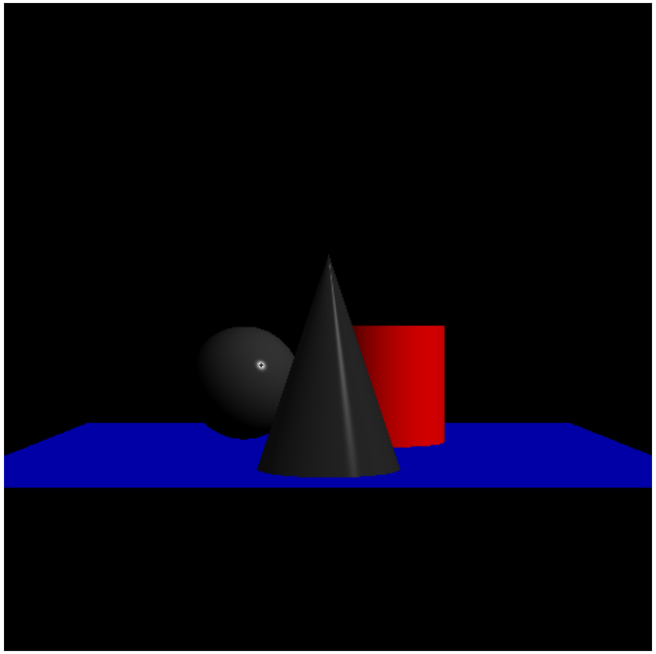


Lambertian Shading

Overview

- Direct Illumination
  - Emission at light sources
  - Reflected (direct) light at surface points

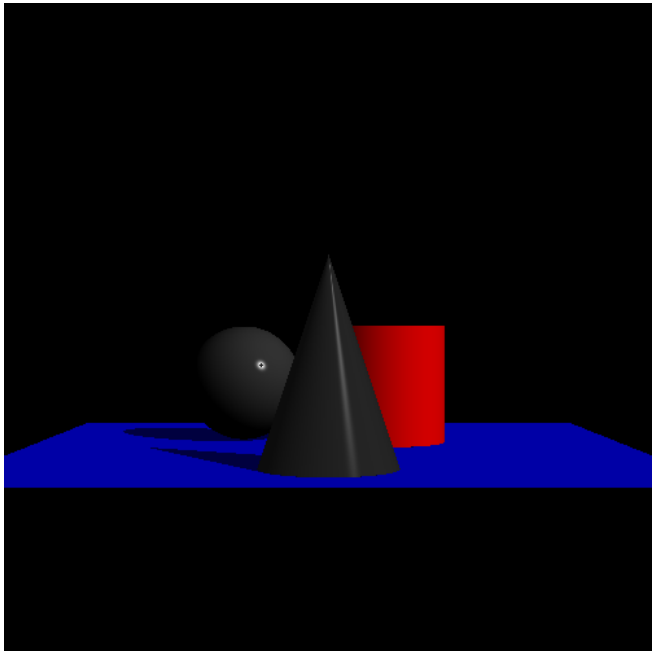
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Phong Shading

Overview

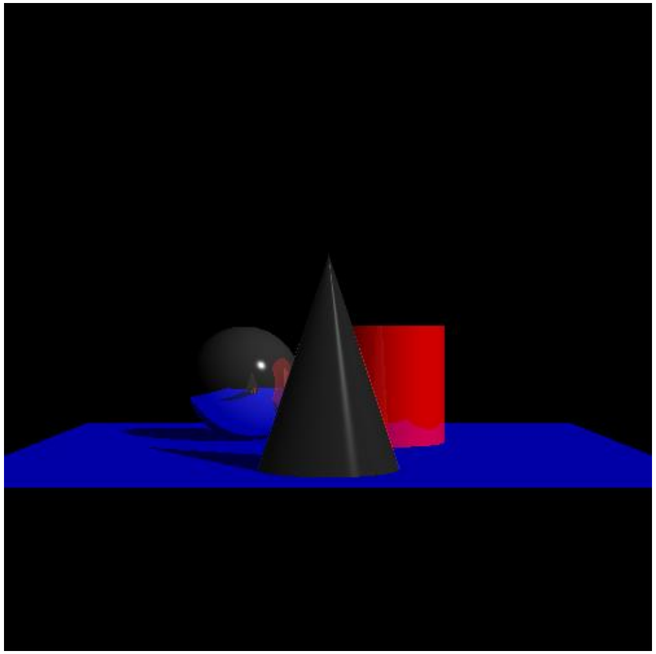
- Direct Illumination
  - Emission at light sources
  - Reflected (direct) light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Shadow Computation

Overview

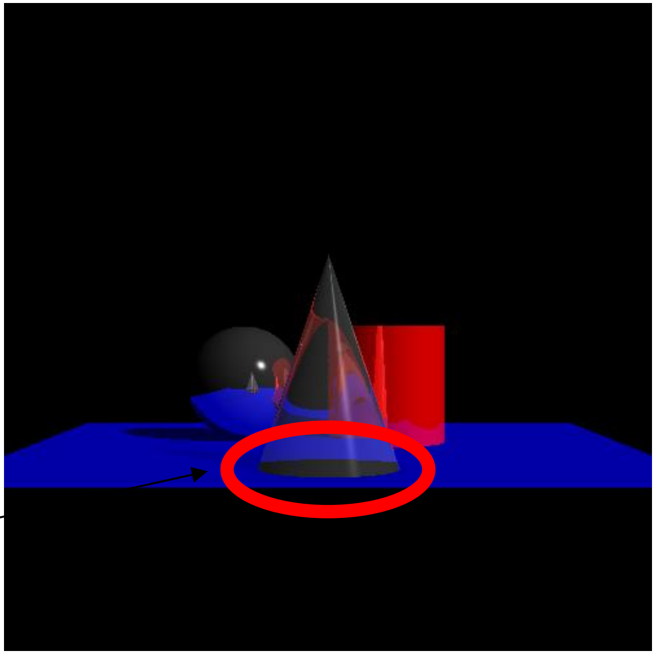
- Direct Illumination
  - Emission at light sources
  - Reflected (direct) light at surface points
- Global illumination
  - Shadows
  - Inter-object reflections
  - Transmissions



Reflections

Overview

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



Ignore this

Refractions

Overview

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  - Emission at light sources
  - Reflected (direct) light at surface point
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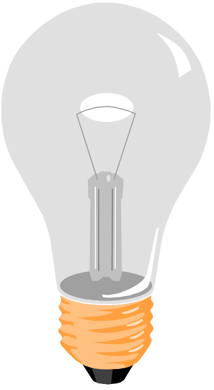
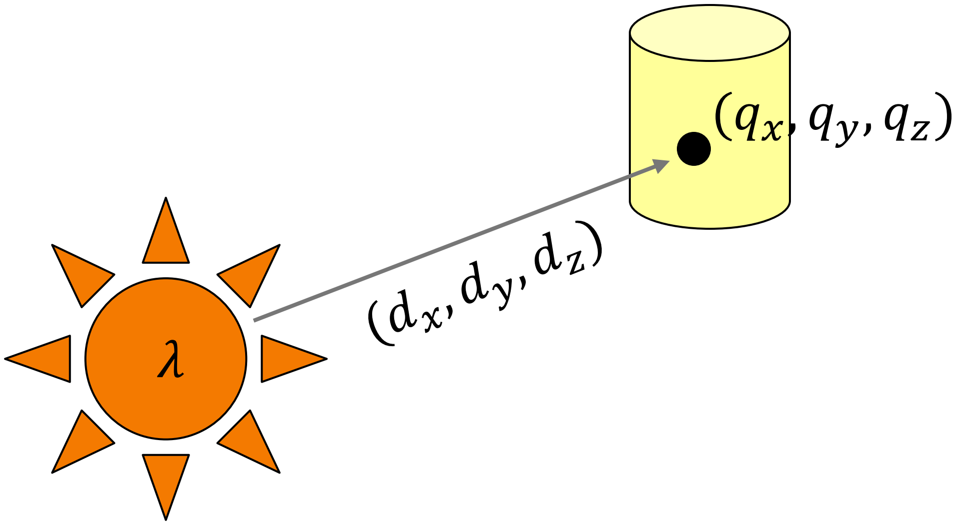
  - Shadows
  - Inter-object reflections
  - Transmissions



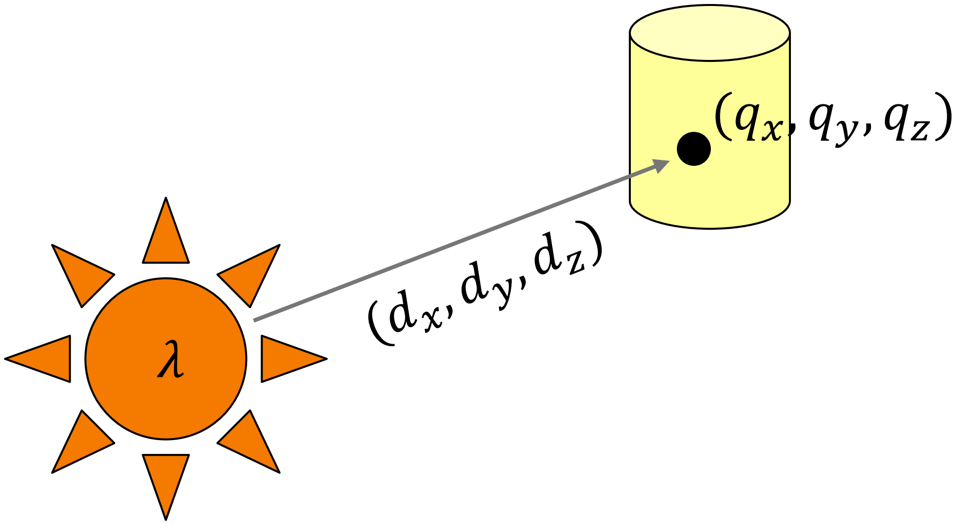
Modeling Light Sources

- $I_L(q, d, \lambda)$ describes the intensity of energy (I):
    - arriving at q,
    - from direction d,
    - with wavelength λ



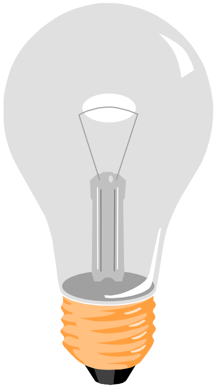
Empirical Models

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



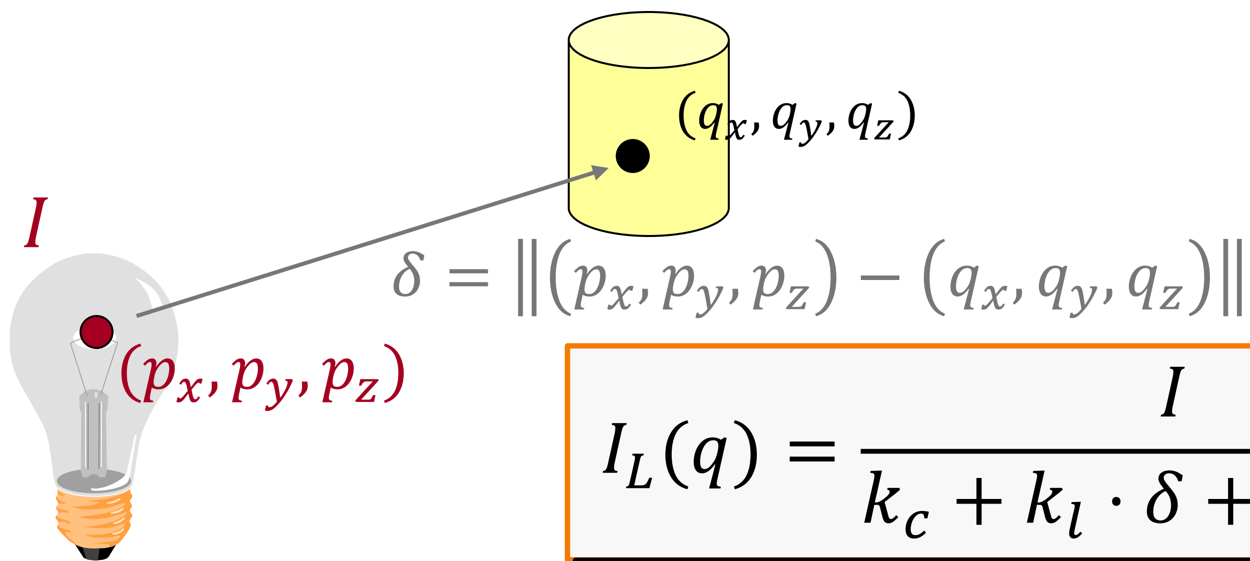
Simplified Light Source Models

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



Point Light Source

- Models omni-directional point source
  - intensity I, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - factors (k_c, k_l, k_q) for attenuation with distance (δ)

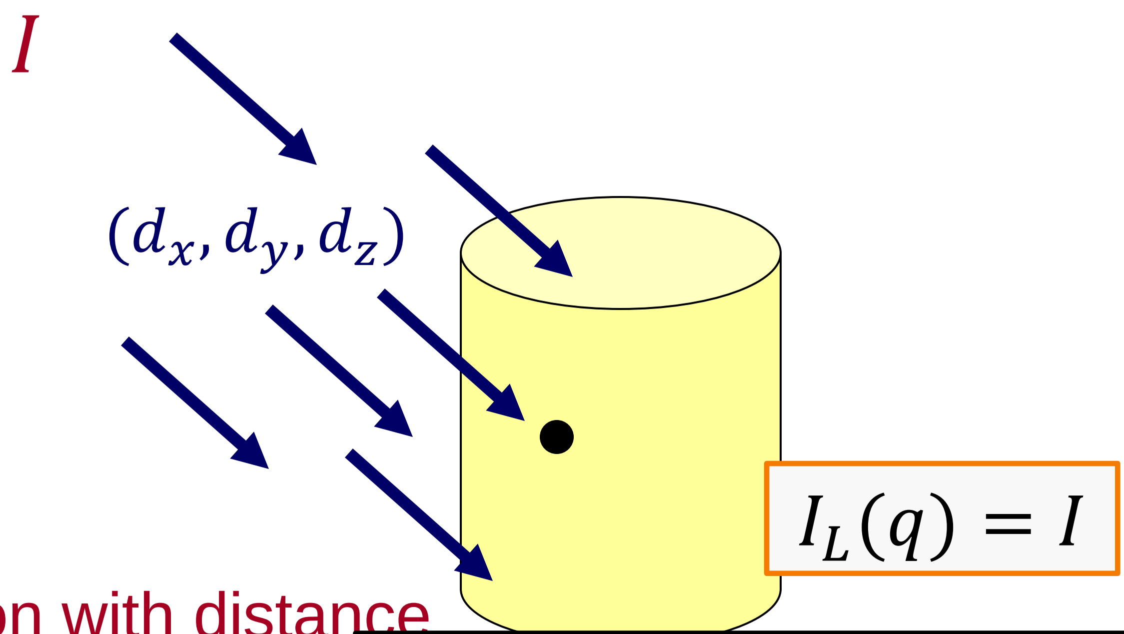


$$I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}$$

The light hitting a surface point q comes in from direction $q - p$.

Directional Light Source

- Models point light source at infinity
  - intensity I, (typically a three-channel value)
  - direction $\vec{d} = (d_x, d_y, d_z)$



No attenuation with distance

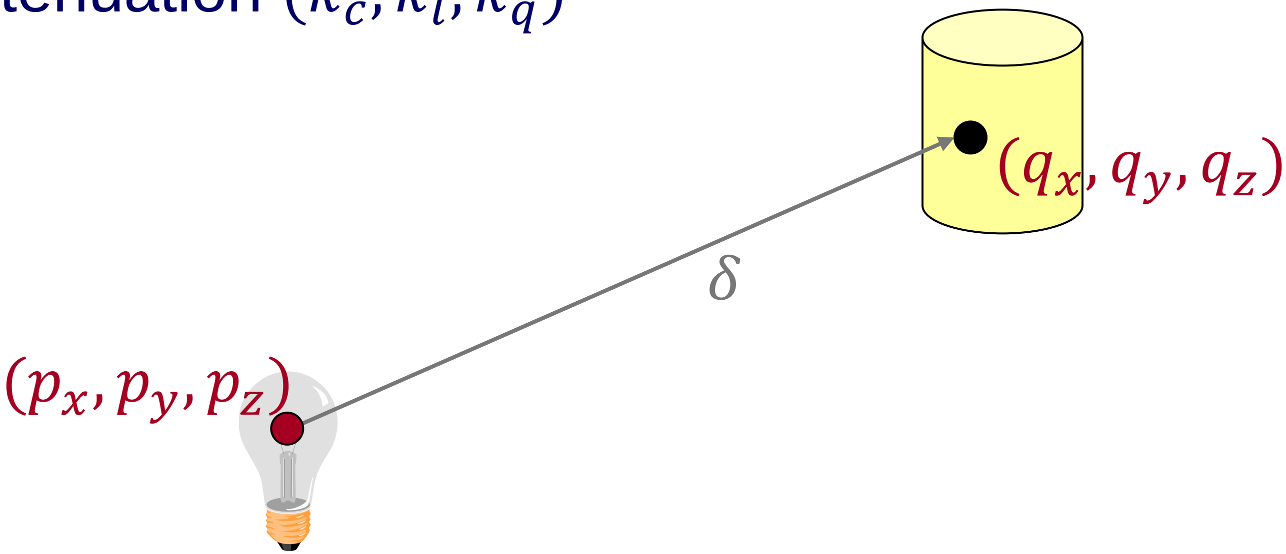
⇓

$k_c = 1, k_l = k_q = 0$

The light hitting a surface point p comes in from direction $\vec{d}$.

Spot Light Source

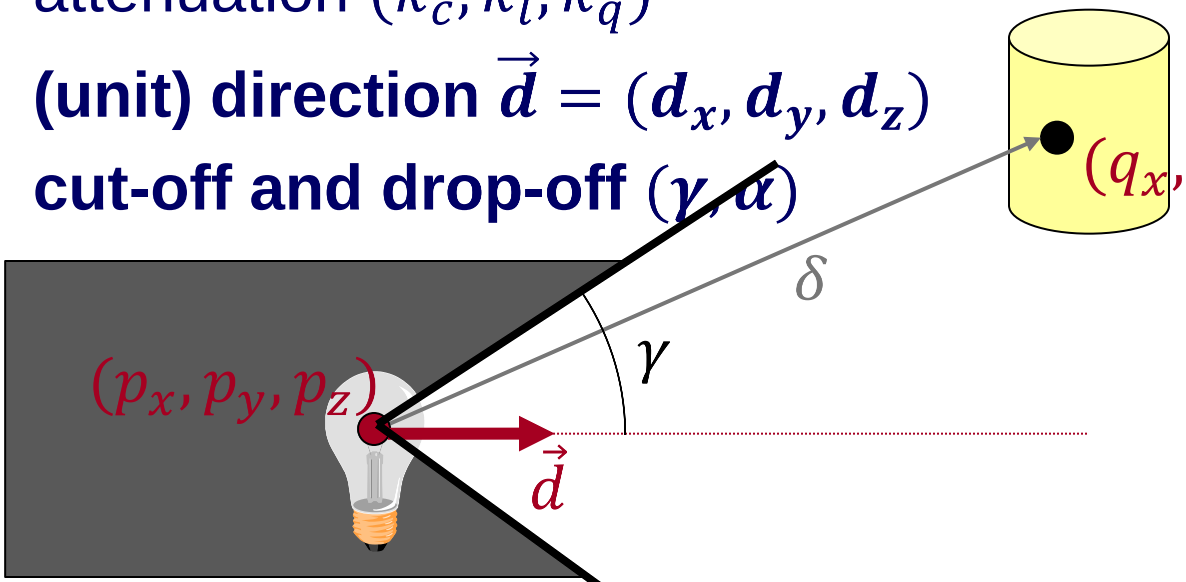
- Models point light source
  - intensity I, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation (k_c, k_l, k_q)



$$I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}$$

Spot Light Source

- Models point light source with direction and fall-off
  - intensity I, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation (k_c, k_l, k_q)
  - **(unit) direction $\vec{d} = (d_x, d_y, d_z)$**
  - **cut-off and drop-off (γ, α)**



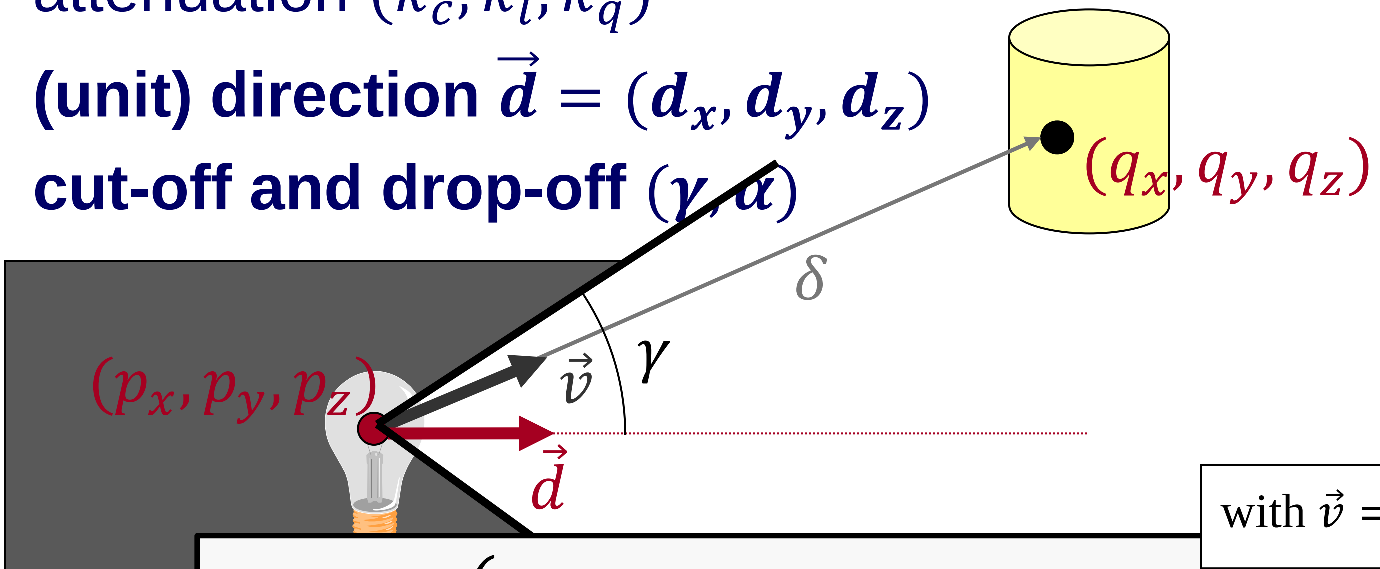
Light

How can we modify the intensity of a point light to decrease as γ increases?

$$I_L(q) = \frac{I}{k_c + k_l \cdot \delta + k_q \cdot \delta^2}$$

Spot Light Source

- Models point light source <u>with direction and fall-off</u>
  - intensity I, (typically a three-channel value)
  - position $p = (p_x, p_y, p_z)$,
  - attenuation (k_c, k_l, k_q)
  - **(unit) direction $\vec{d} = (d_x, d_y, d_z)$**
  - **cut-off and drop-off (γ, α)**



with $\vec{v} = \frac{q-p}{|q-p|}$

$$I_L(q) = \begin{cases} \dfrac{I \cdot \langle \vec{d}, \vec{v} \rangle^\alpha}{k_c + k_l \cdot \delta + k_q \cdot \delta^2} & \text{if } \langle \vec{d}, \vec{v} \rangle > \cos\gamma \\ 0 & \text{otherwise} \end{cases}$$

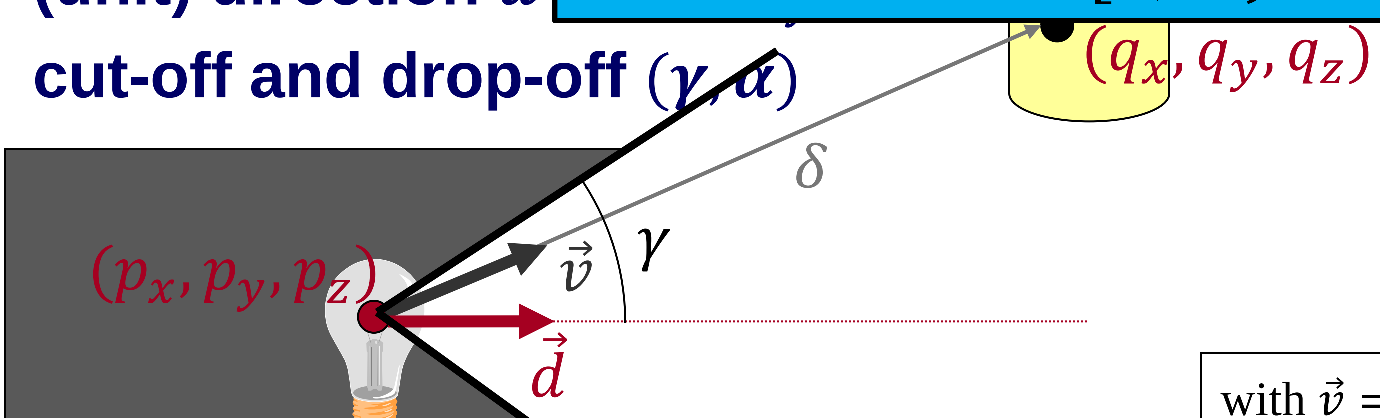
Spot Light Source

- Models poin
  - intensity I,
  - position $p = (p_x, p_y$
  - attenuation $(k_c, k_l,$
  - **(unit) direction $\vec{d}$**
  - **cut-off and drop-off (γ, α)**

The light hitting a surface point q comes in from direction $q - p$ (not $\vec{d}$).

$$\gamma \in \left[0, \frac{\pi}{2}\right) \text{ so that } \left\langle \vec{d}, \vec{v} \right\rangle \in [0,1].$$

$$\alpha \in [0, \infty)$$



with $\vec{v} = \frac{q-p}{|q-p|}$

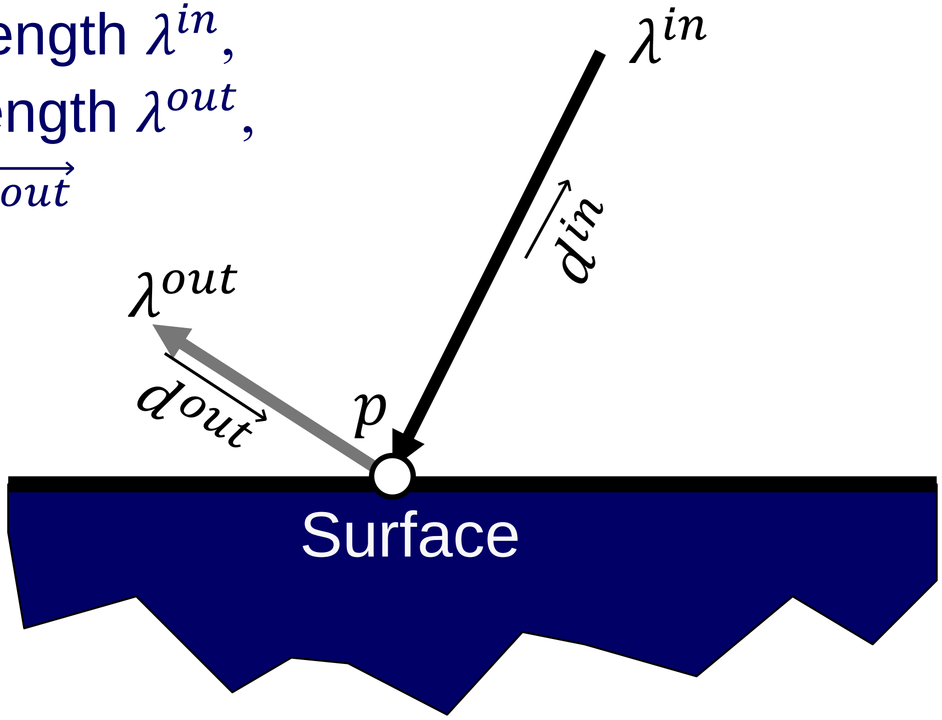
$$I_L(q) = \begin{cases} \dfrac{I \cdot \langle \vec{d}, \vec{v} \rangle^{\alpha}}{k_c + k_l \cdot \delta + k_q \cdot \delta^2} & \text{if } \langle \vec{d}, \vec{v} \rangle > \cos\gamma \\ 0 & \text{otherwise} \end{cases}$$

Overview

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

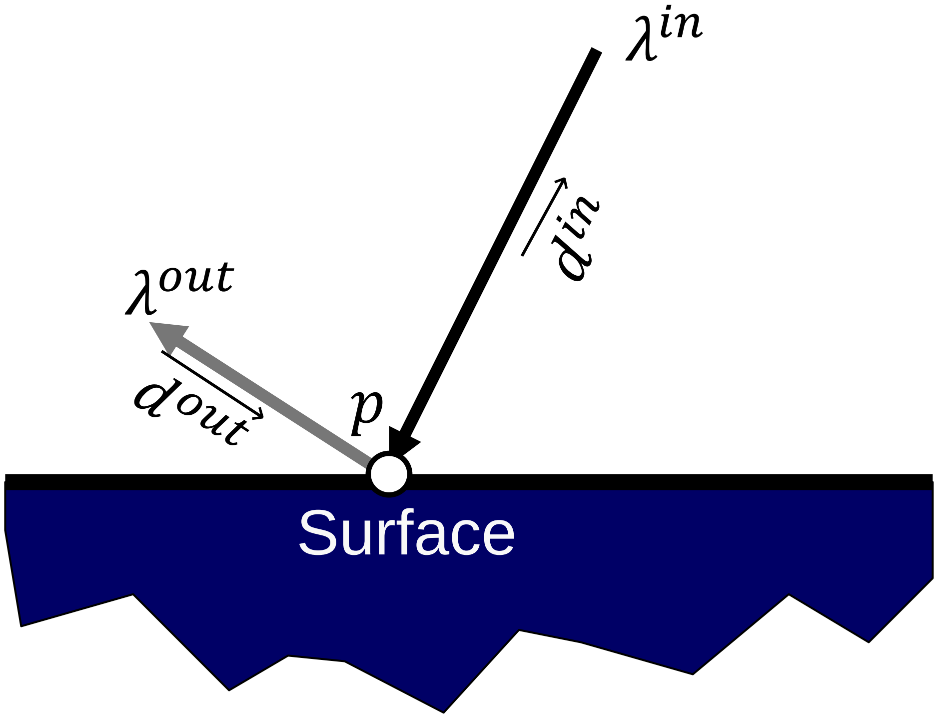
Modeling Surface Reflectance

- $R_S(p, \overrightarrow{d^{in}}, \lambda^{in}, \overrightarrow{d^{out}}, \lambda^{out})$ describes the fraction of incident energy (R) at the surface (S),
  - arriving at point p
  - from direction $\overrightarrow{d^{in}}$,
  - with incoming wavelength λ^{in},
  - with outgoing wavelength λ^{out},
  - leaving in direction $\overrightarrow{d^{out}}$



Empirical Models

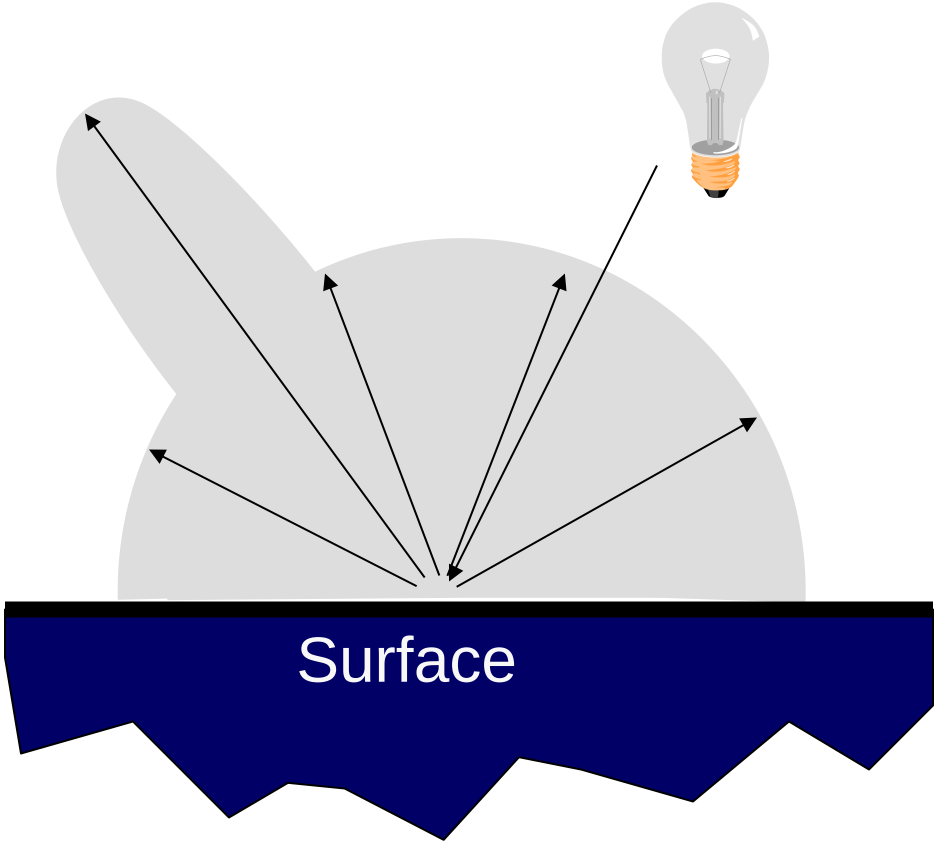
- Ideally measure radiant energy for all combinations of incident angles, all surface positions, and all combinations of incoming and outgoing wavelengths
  - Too much storage
  - Difficult in practice



Simple Reflectance Model

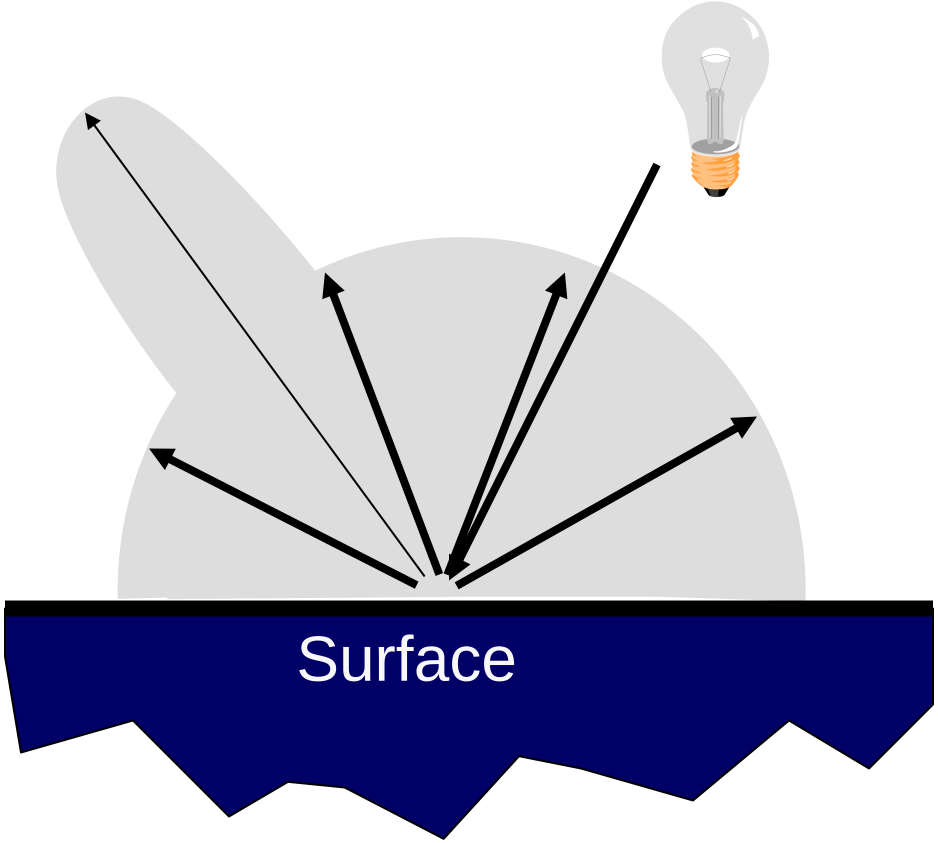
- Simple analytic model:
  - diffuse reflection +
  - specular reflection +
  - emission +
  - "ambient"

Based on model proposed by Phong



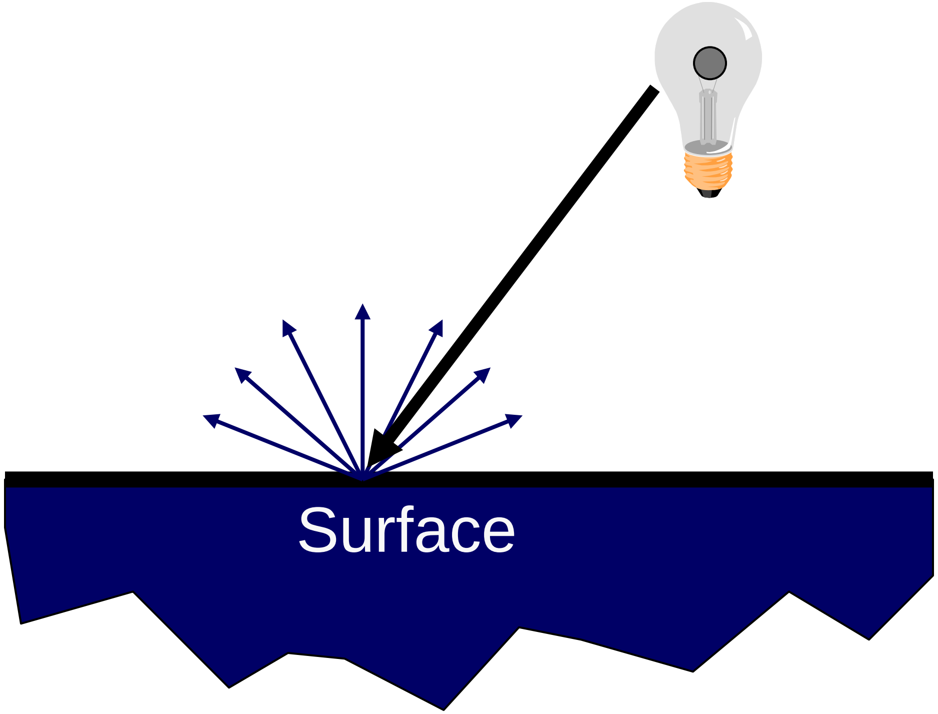
Simple Reflectance Model

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



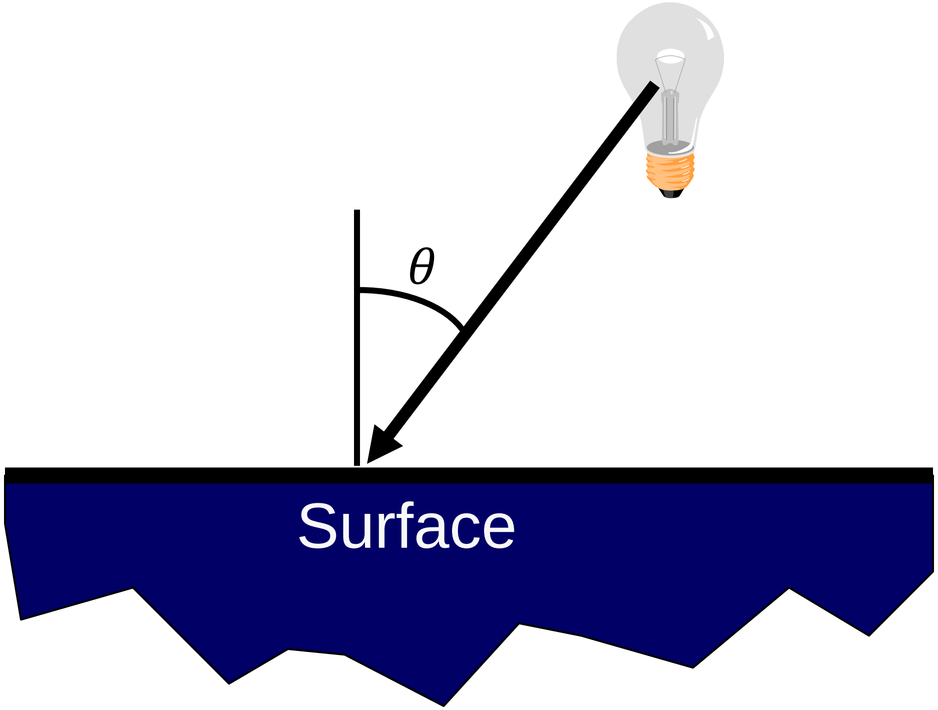
Diffuse Reflection

- Assume surface intensity is viewer independent
  - Examples: chalk, clay



Diffuse Reflection

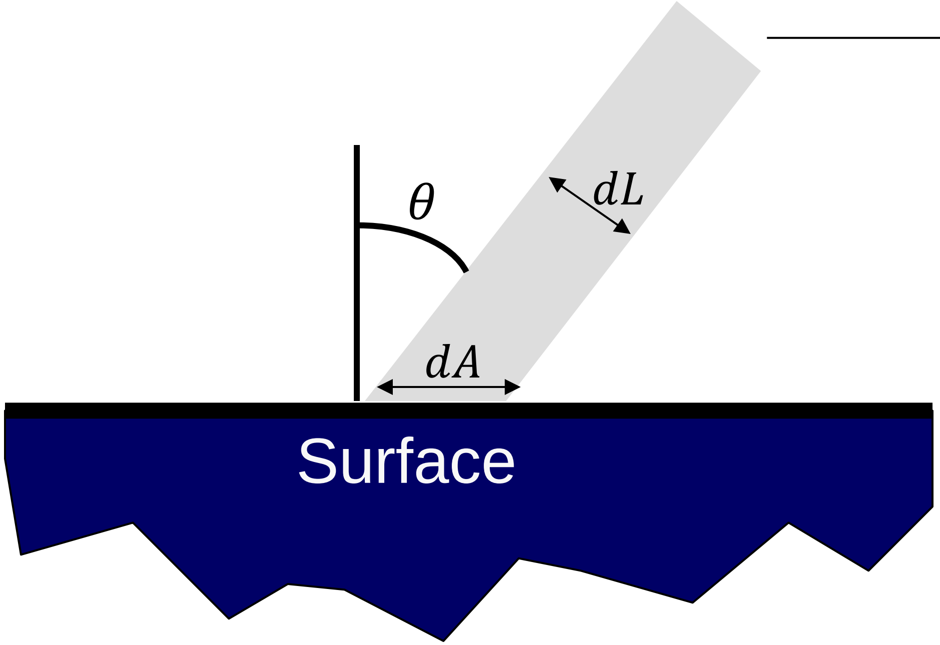
- How much light is reflected?
  - Lambertian: Only depends on angle of incident light

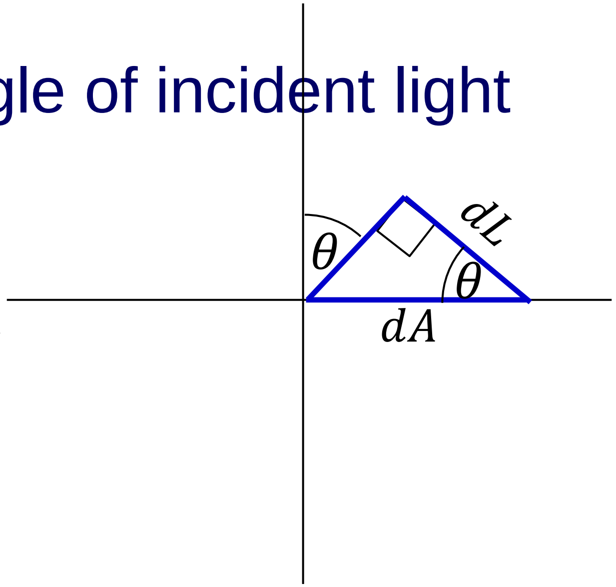


Diffuse Reflection

- How much light is reflected?
  - Lambertian: Only depends on angle of incident light

$$dL = dA \cdot \cos\theta$$





Diffuse Reflection

- How much light is reflected?
  - Lambertian: Only depends on angle of incident light

$$dL = dA \cdot \cos\theta$$

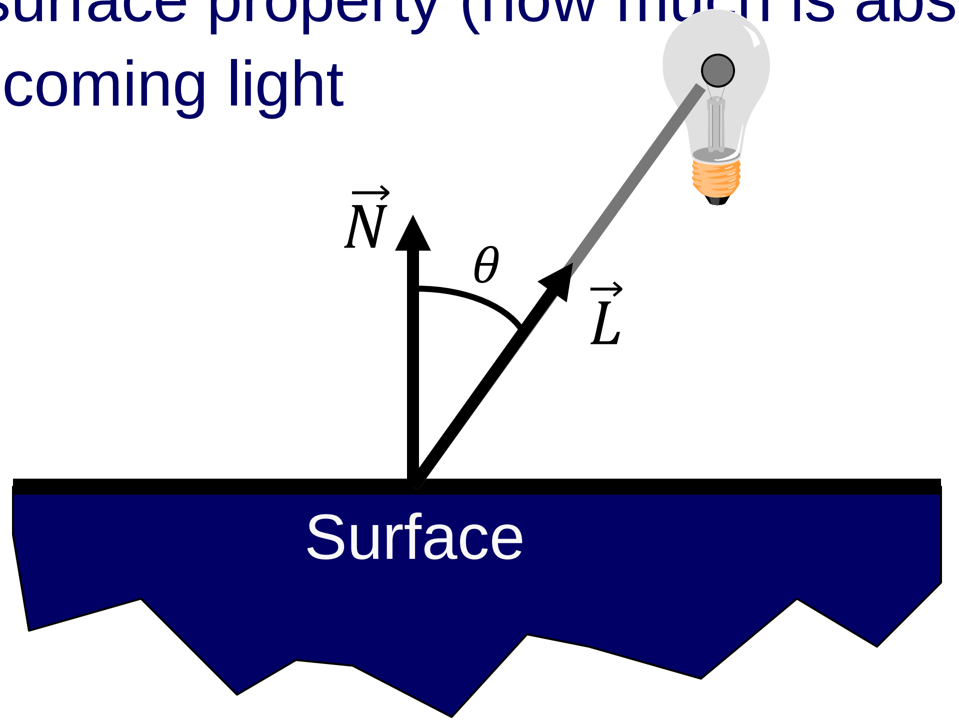
A unit cross-sectional area of light on the incoming beam is spread across a patch of surface with area $1/\cos\theta$.

⇒ A unit area on the surface "sees" only $\cos\theta$ of the light coming through a unit cross-sectional are of light on the incoming beam.

Diffuse Reflection

Lambertian model:

- cosine law: $\cos\theta = \langle \vec{N}, \vec{L} \rangle$, with $\vec{N}$ and $\vec{L}$ unit vectors
- K_D is surface property (how much is absorbed)
- I_L is incoming light



$$I_D = K_D \cdot \langle \vec{N}, \vec{L} \rangle \cdot I_L$$

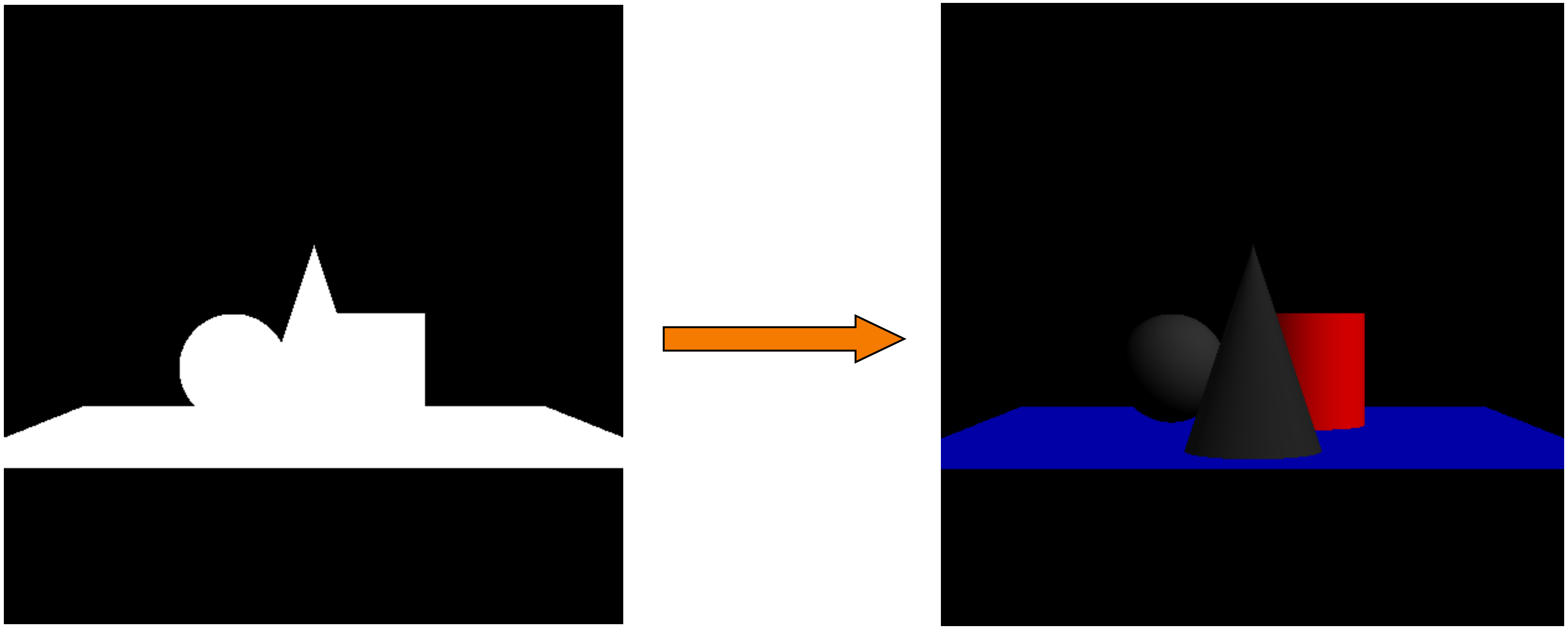
Diffuse Reflection

- Light/surface properties have RGB components!
  - Run calculation on EACH color channel
  - This holds true for all lighting calculations

$$I_D^C = K_D^C \cdot \langle \vec{N}, \vec{L} \rangle \cdot I_L^C, \qquad C \in \{R, G, B\}$$

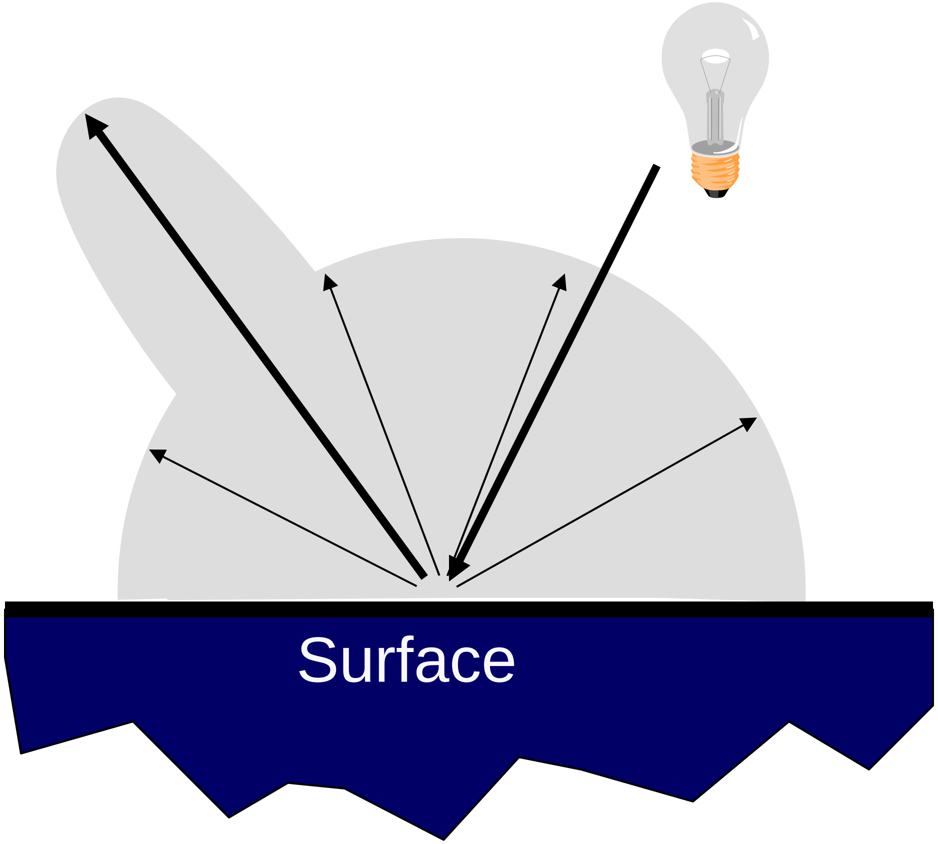
Diffuse Reflection

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



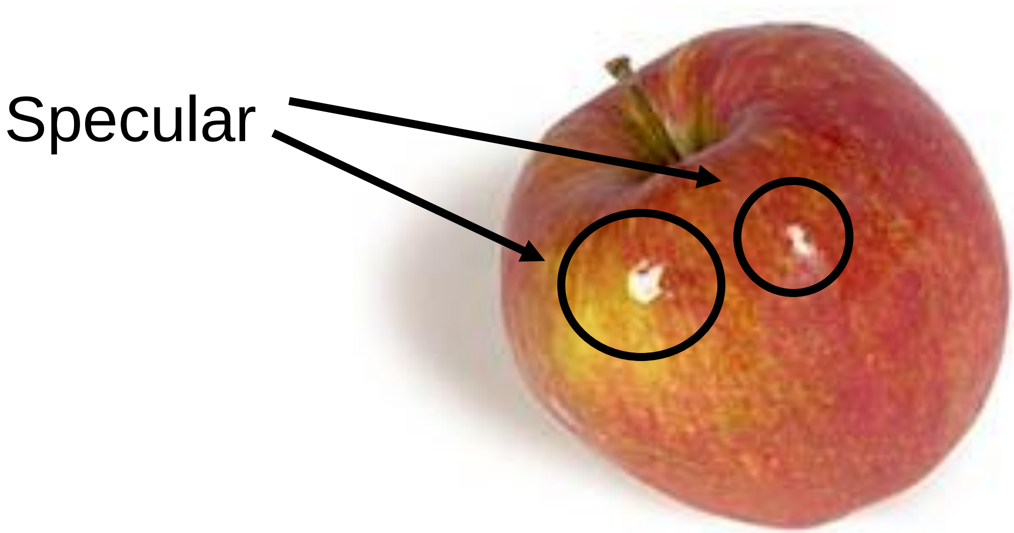
Simple Reflectance Model

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



Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: metals, shiny apples



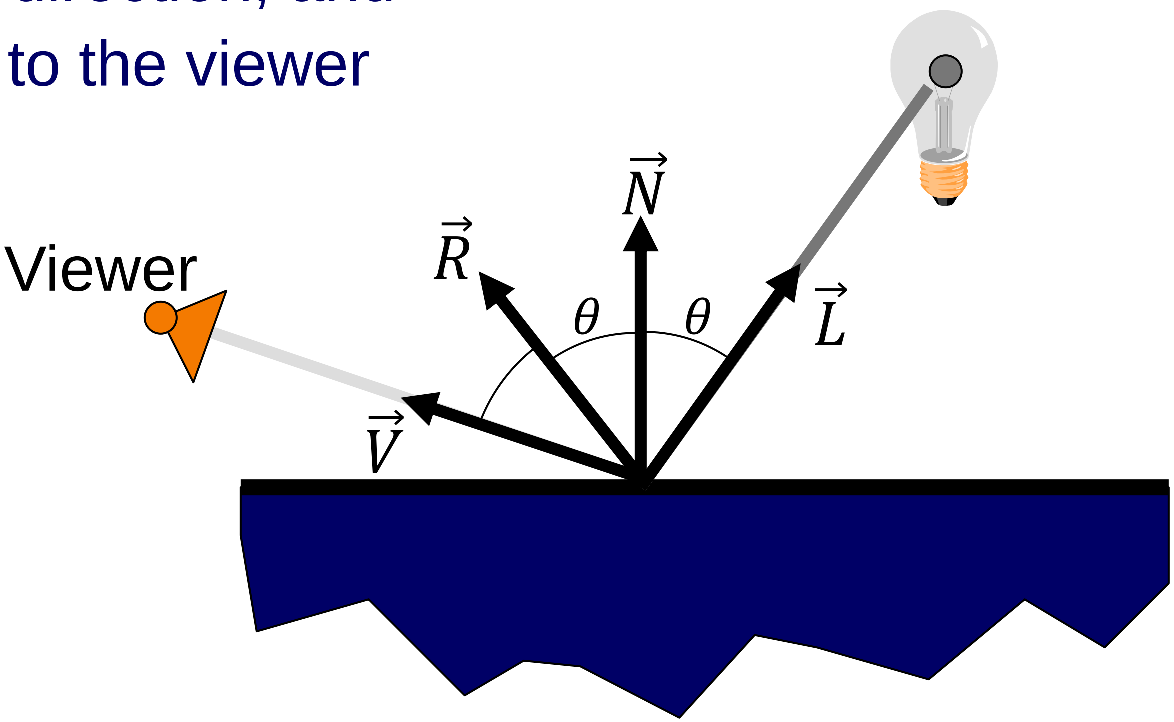
Specular Reflection

How much light is seen?

Depends on how well the:

- reflected direction, and
- direction to the viewer

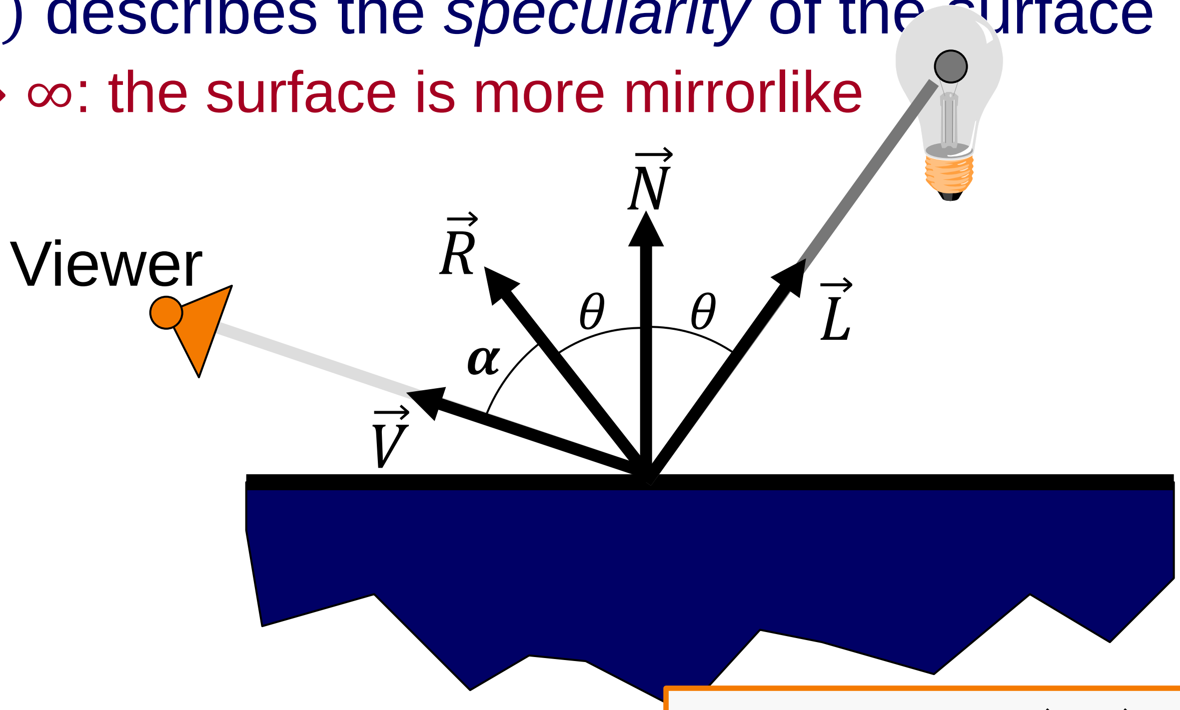
line up.



Specular Reflection

Phong Model:

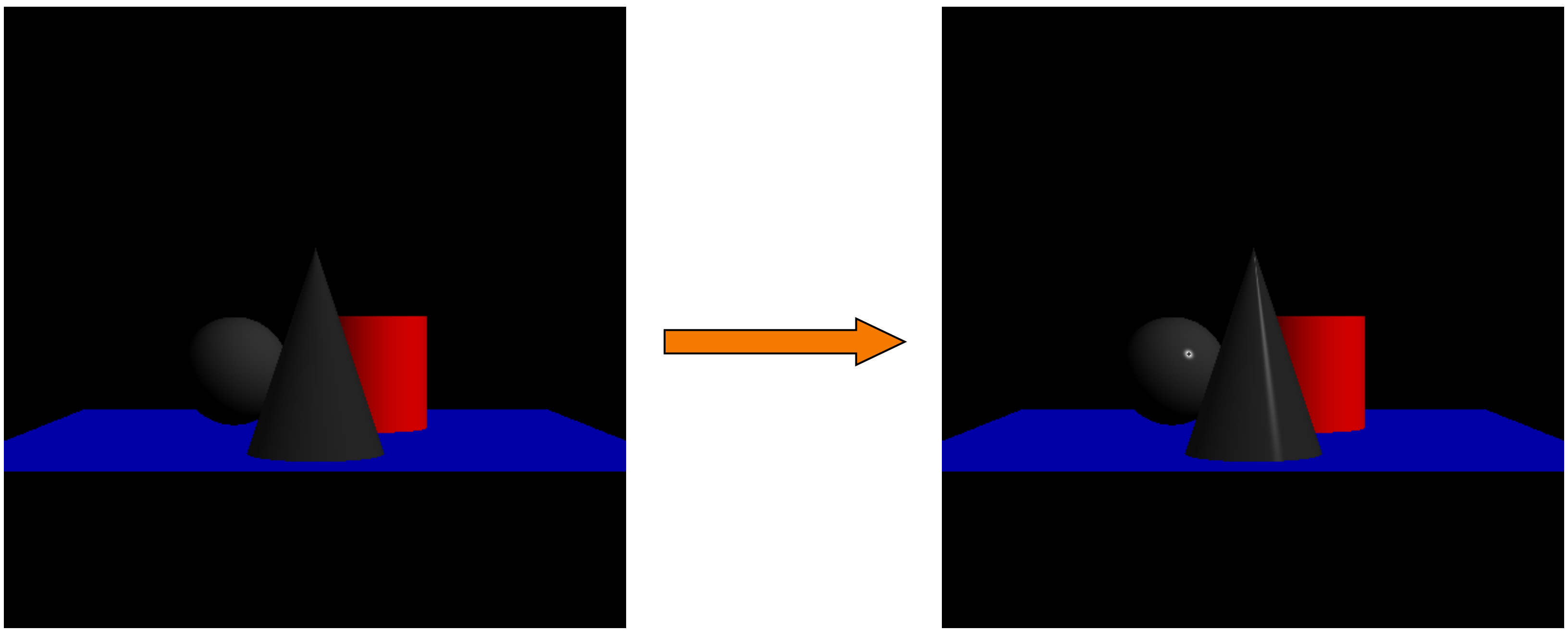
- $\cos(\alpha) = \langle \vec{V}, \vec{R} \rangle \in [-1,1]$ describes how aligned the reflected and view directions are
- $n \in [0, \infty)$ describes the *specularity* of the surface
  - » As $n \to \infty$: the surface is more mirrorlike



$$I_S = K_S \cdot \langle \vec{V}, \vec{R} \rangle^n \cdot I_L$$

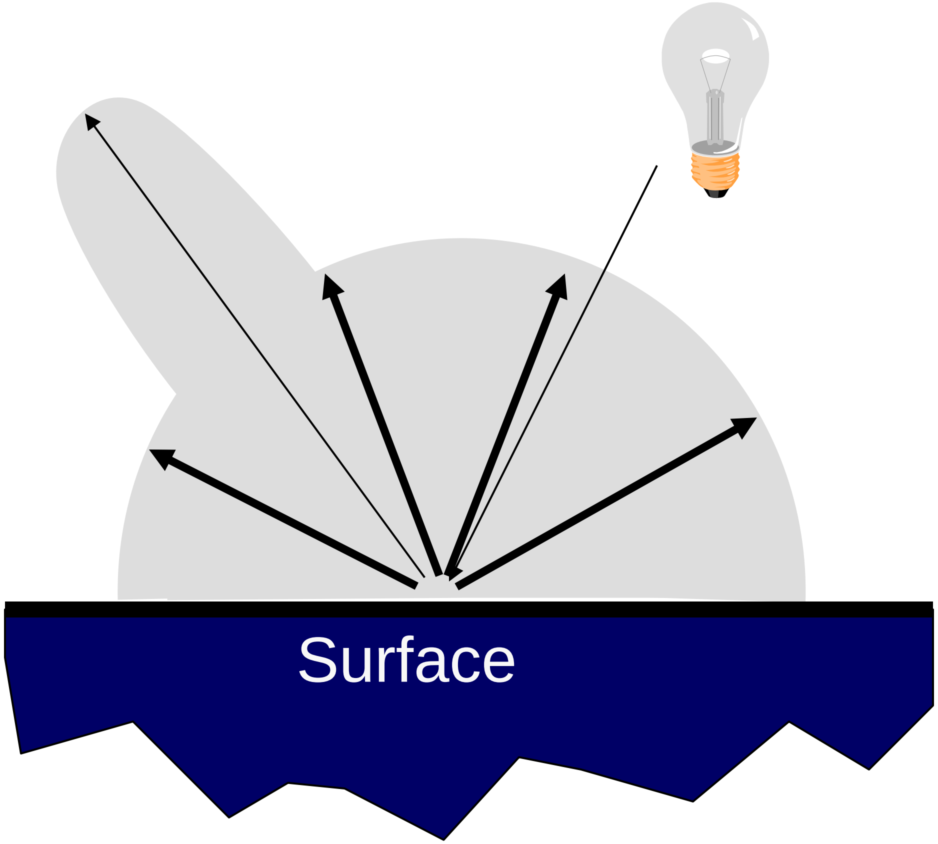
Specular Reflection

- Reflection is strongest near mirror angle
  - Examples: metals, shiny apples



Simple Reflectance Model

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



Emission

Represents light emanating uniformly from a surface that cannot be described by the three light sources (e.g. area lights)

Emission $\neq 0$

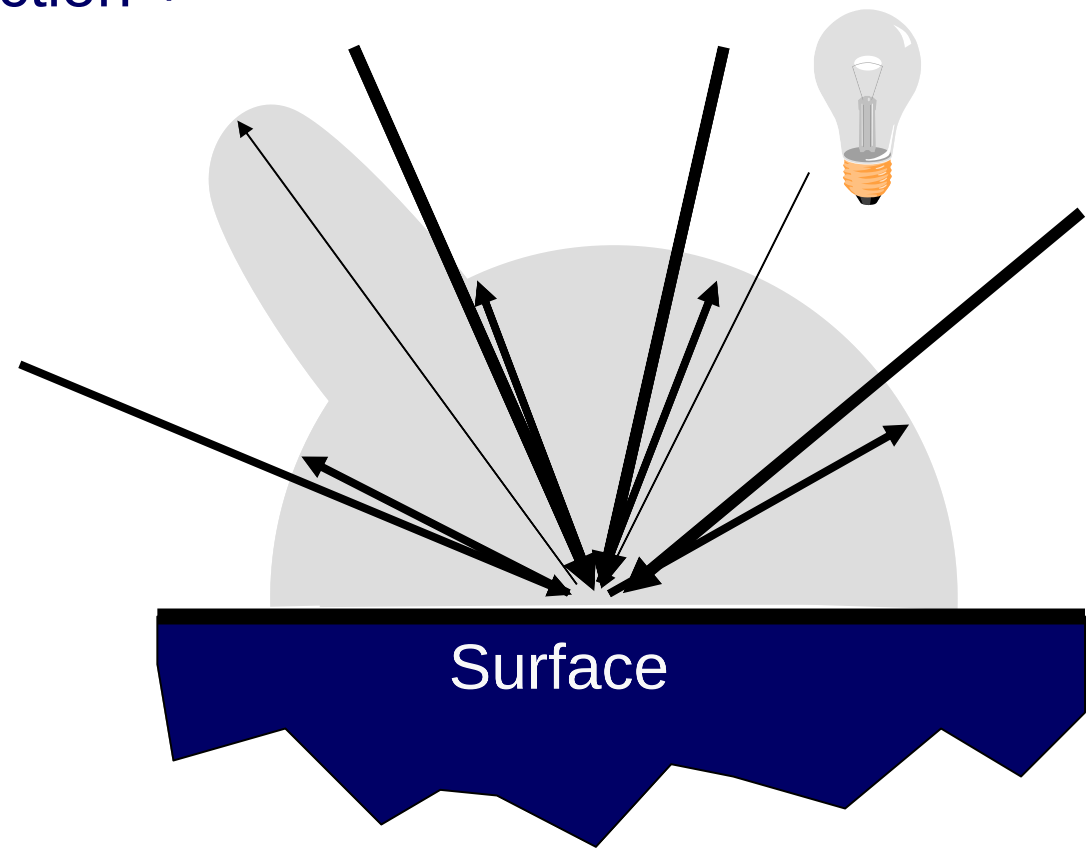
Emission

$$I_E = I_E$$

Emission ≠ 0

Simple Reflectance Model

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



Ambient Term

- Represents reflection of a <u>given</u> light source from all indirect illumination

<u>Note</u>:
In some implementations this term represents the combined contribution from all light sources.

This is a hack to avoid the complexity of global illumination!

Ambient Term

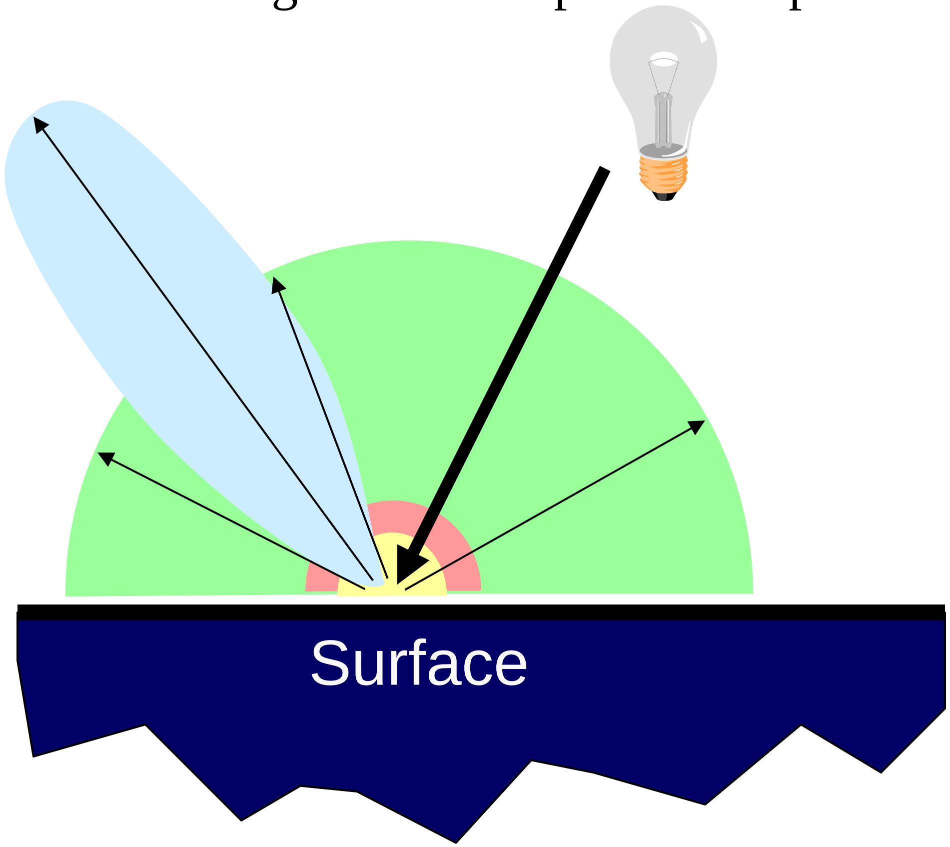
- Represents reflection from all indirect illumination
  - I_L^A describes the amount of light from light L that is distributed uniformly (ambiently) across the scene.

$$I_A = K_A \cdot I_L^A$$

Typically $K_A = K_D$ describe the "color" of the surface.

Simple Reflectance Model

- Simple analytic model:
  - diffuse reflection + ← Light position dependent
  - specular reflection + ← Light + viewer position dependent
  - emission +
  - “ambient”



Simple Reflectance Model

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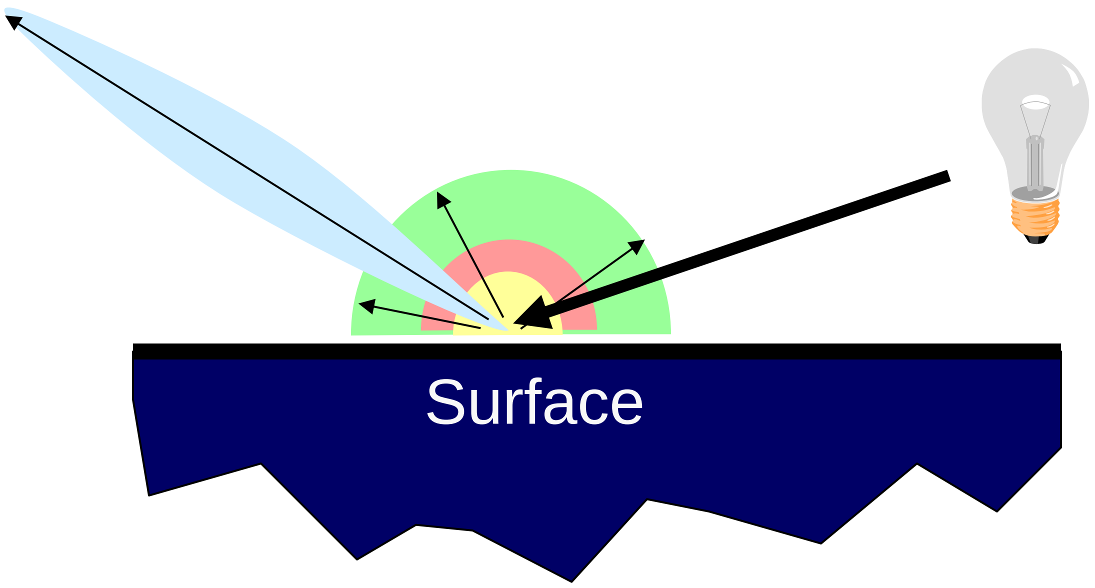
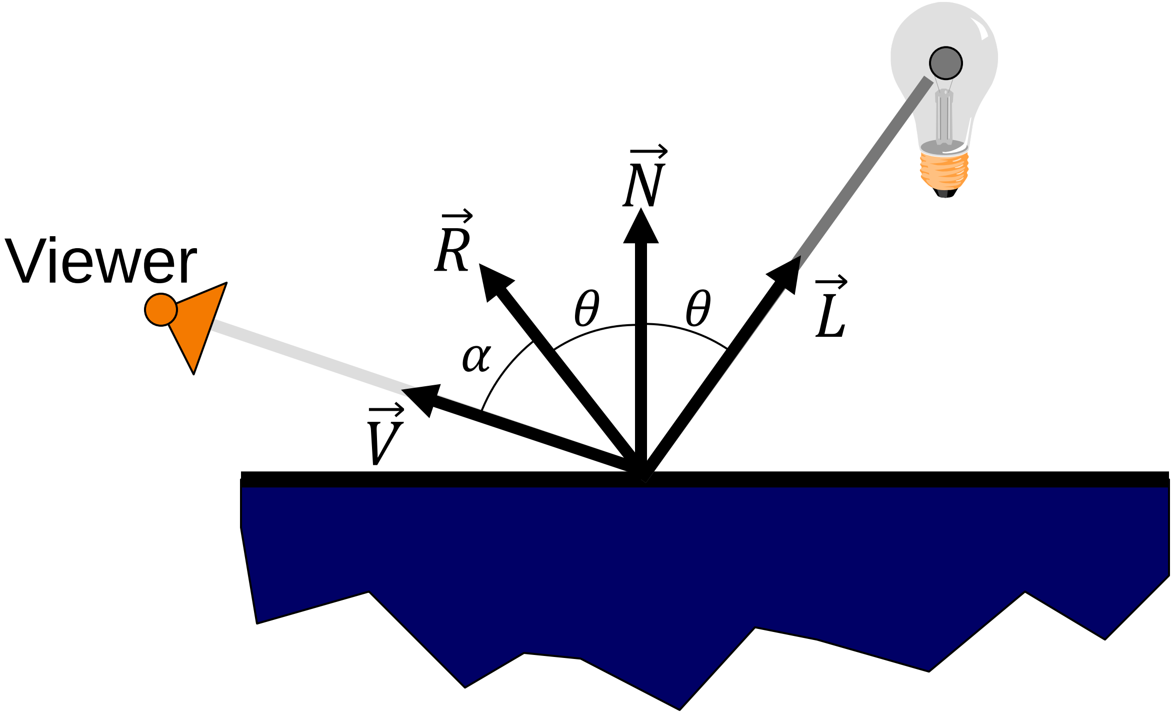


Surface Illumination Calculation

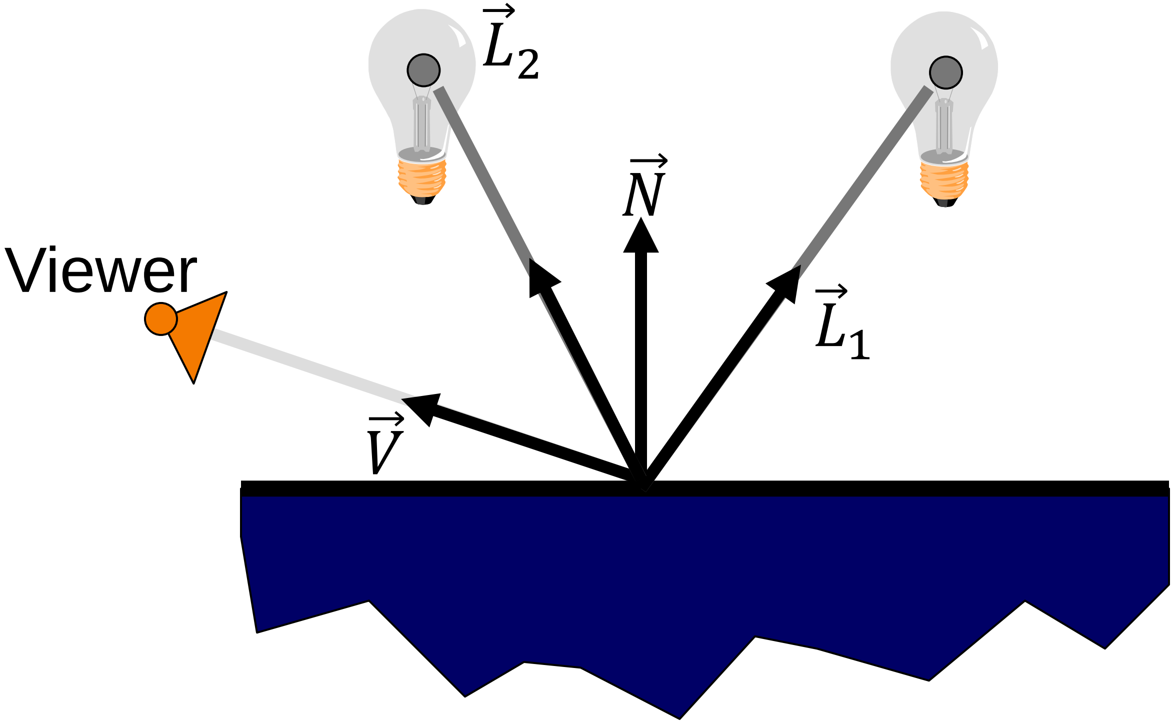
- Single light source:



$$I = I_E + K_A \cdot I_L^A + \left(K_D \cdot \langle \vec{N}, \vec{L} \rangle + K_S \cdot \langle \vec{V}, \vec{R} \rangle^n \right) \cdot I_L$$

Surface Illumination Calculation

- Multiple light source:



$$I = I_E + \sum_L \left[K_A \cdot I_L^A + \left(K_D \cdot \langle \vec{N}, \vec{L} \rangle + K_S \cdot \langle \vec{V}, \vec{R} \rangle^n \right) \cdot I_L \right]$$