Global Illumination

Connelly Barnes

CS 4810: Graphics

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

Overview

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

Shadows

- Shadow term tells if light sources are blocked
  - Cast ray towards each light source L_i. If the ray is blocked, do not consider the contribution of the light.

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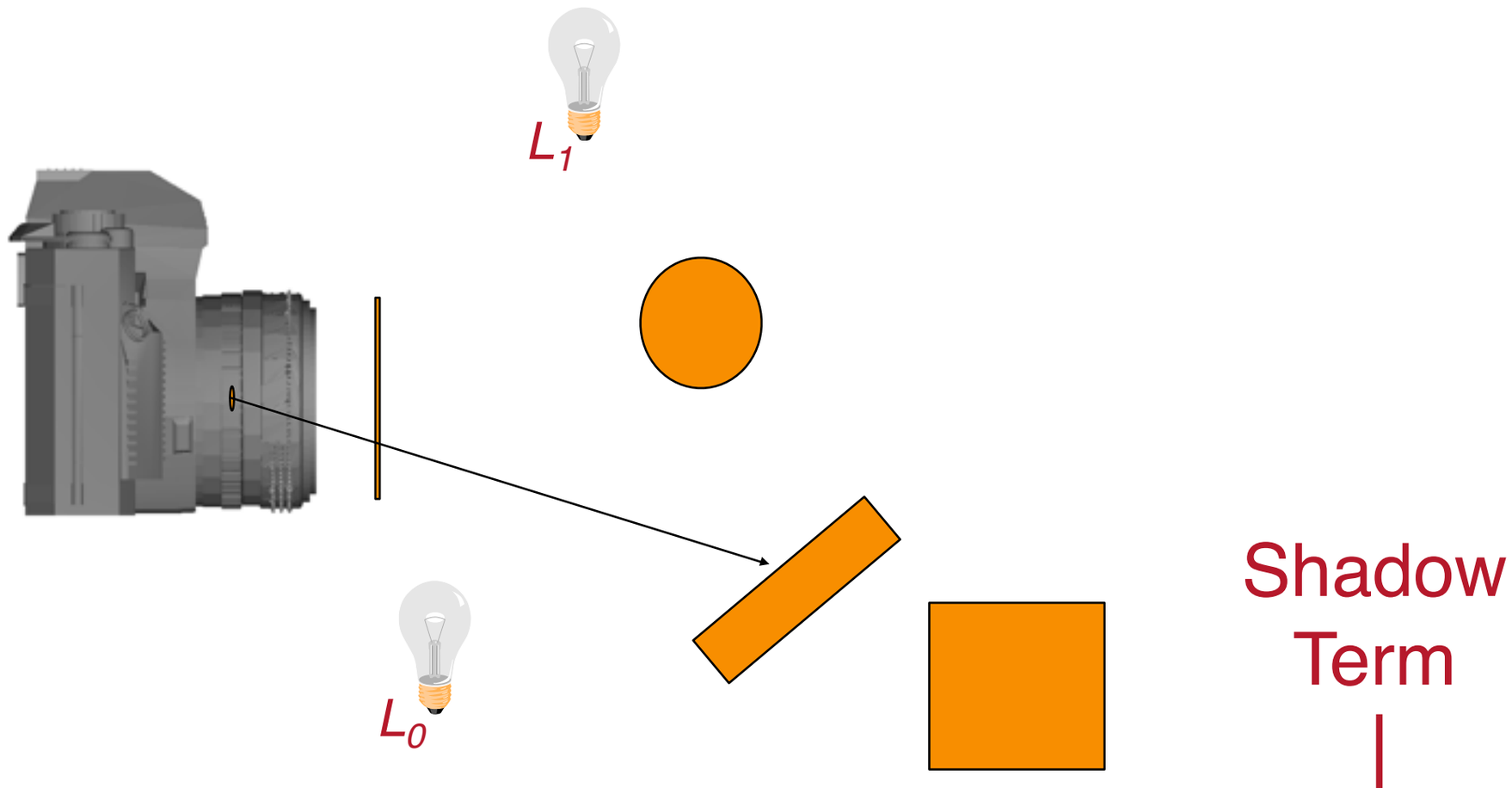
  - Cast ray towards each light source L_i
  - $S_i = 0$ if ray is blocked, $S_i = 1$ otherwise



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

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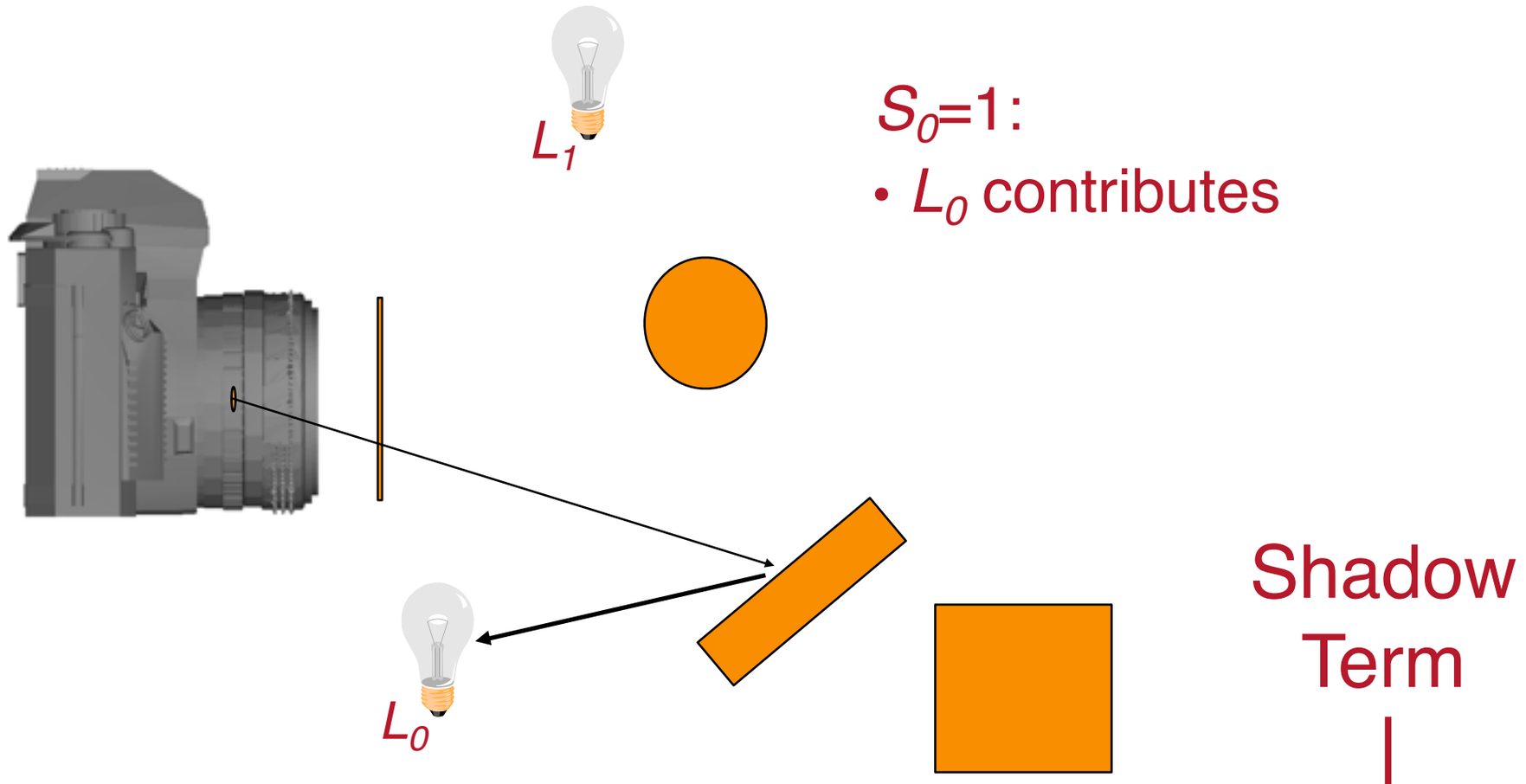

S_0=1:
- L_0 contributes

Shadow Term

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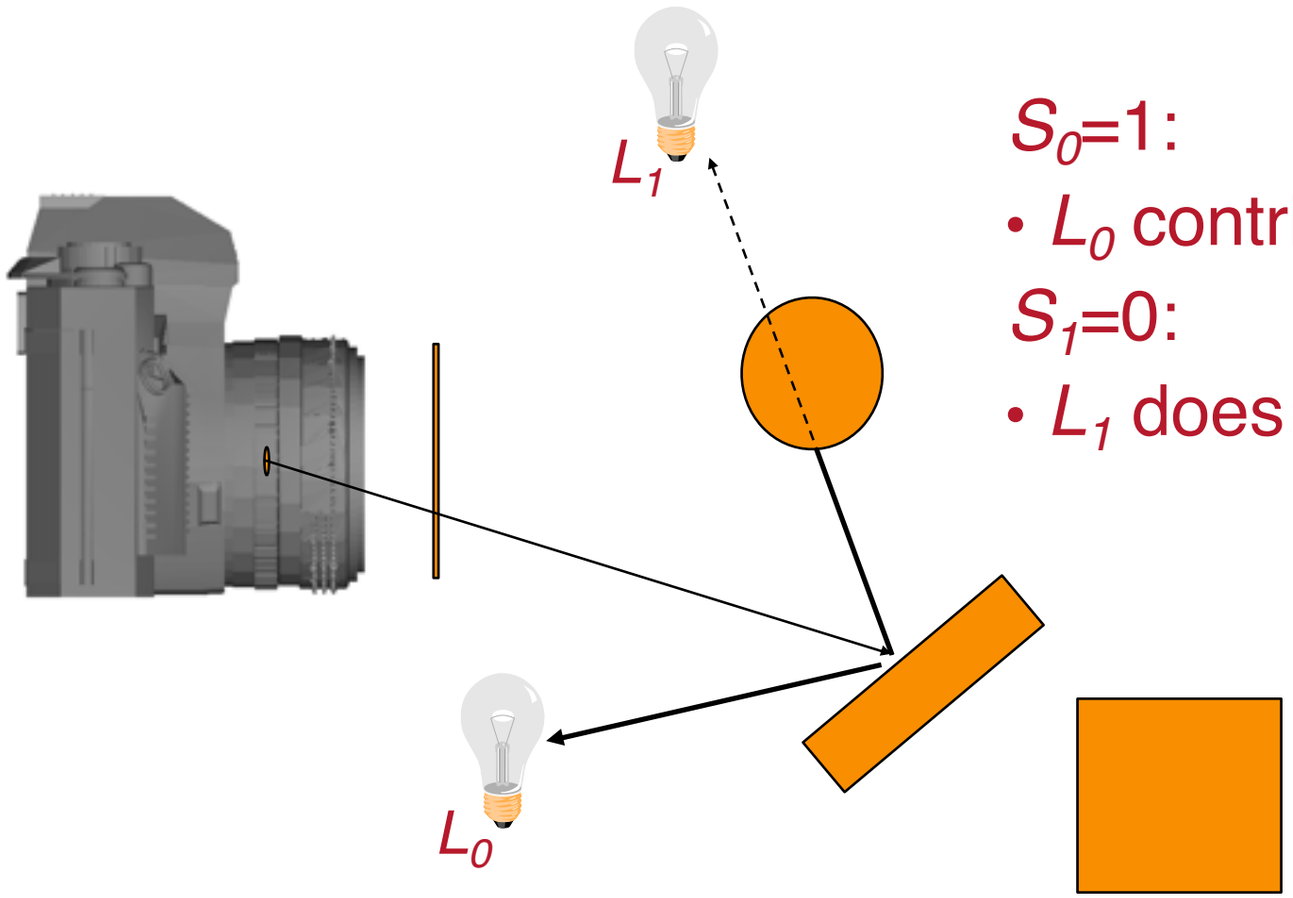


S_0=1:
- L_0 contributes

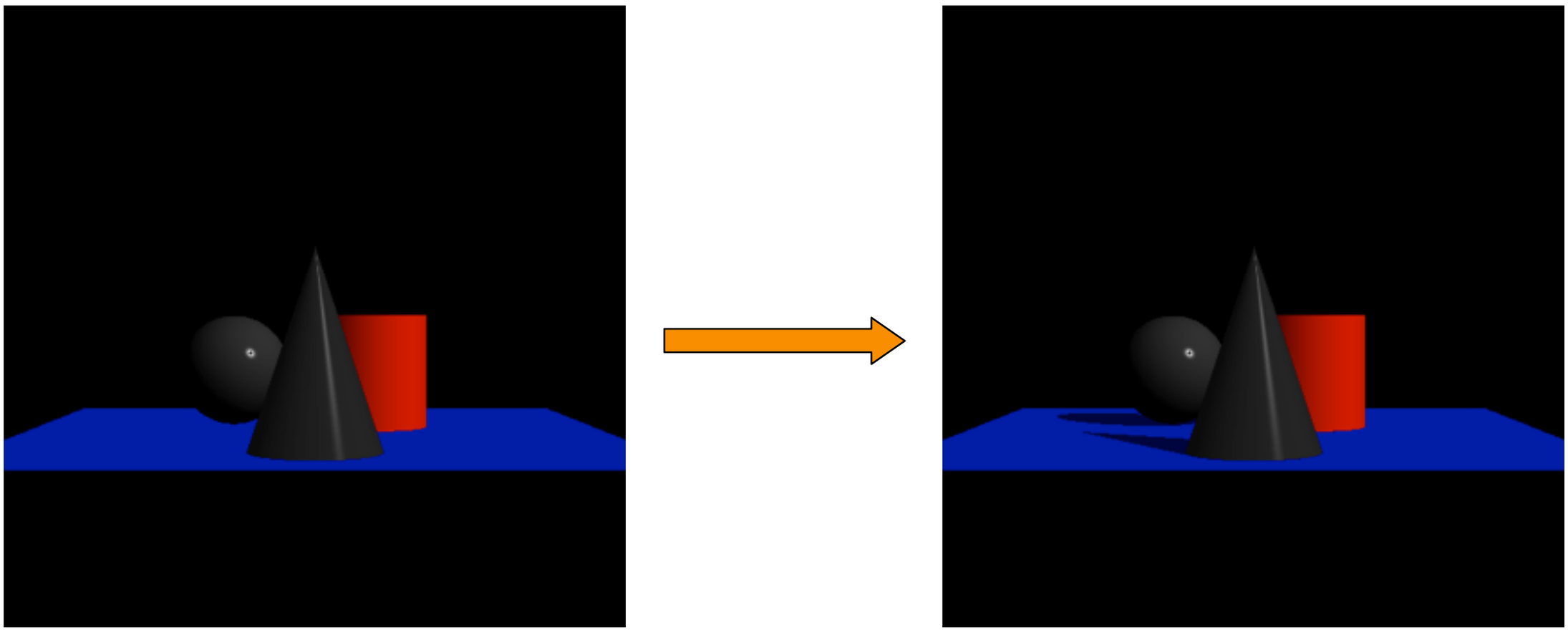
S_1=0:
- L_1 does not contribute

Shadow Term

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

Ray Casting

- Trace primary rays from camera
  - Direct illumination from unblocked lights only



Recursive Ray Tracing

- Also trace secondary rays from hit surfaces
  - Consider contributions from:
    1. Reflected Rays
    2. Refracted Rays

Mirror Reflections

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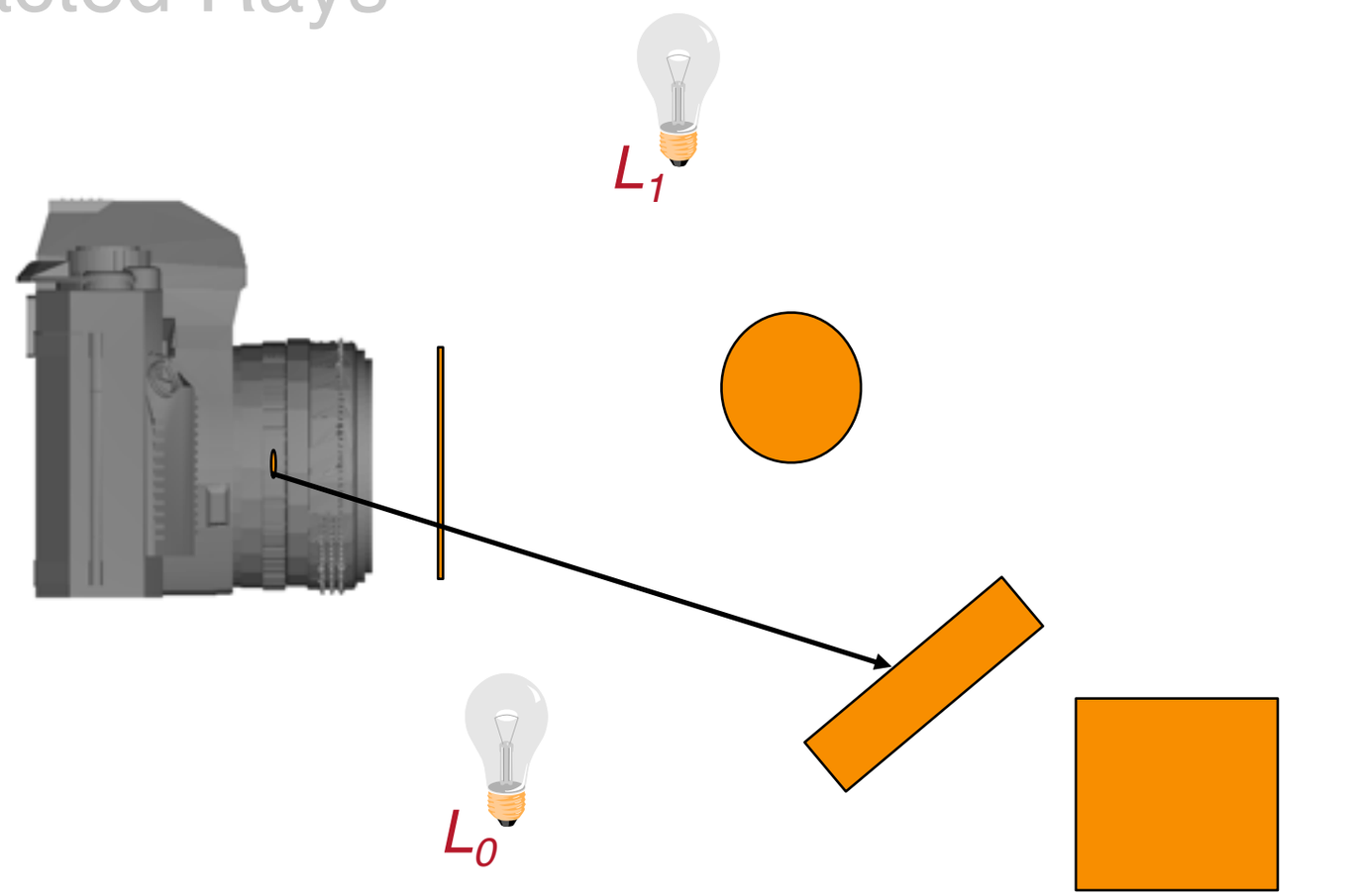

Radiance for mirror reflection ray

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

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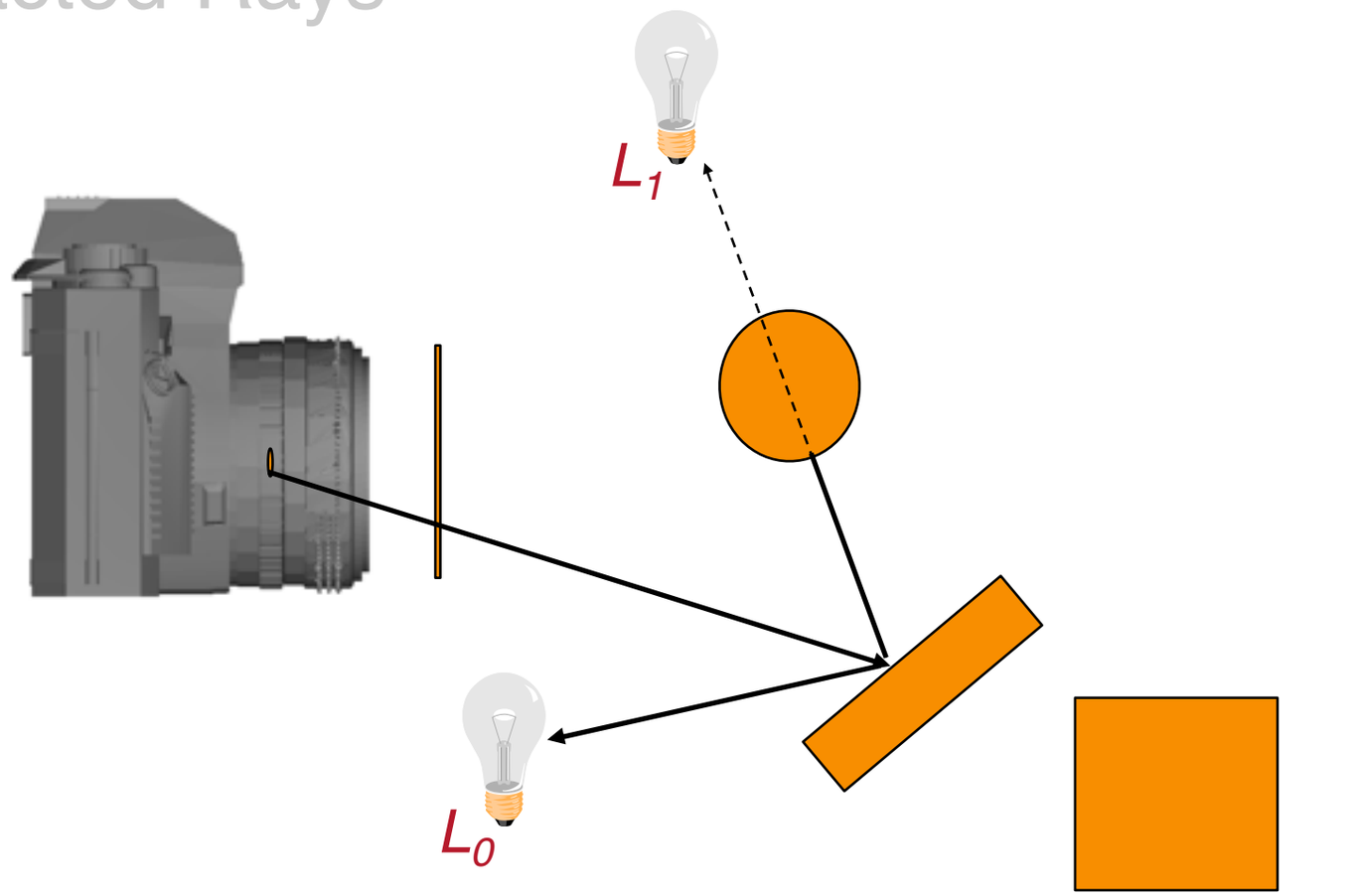

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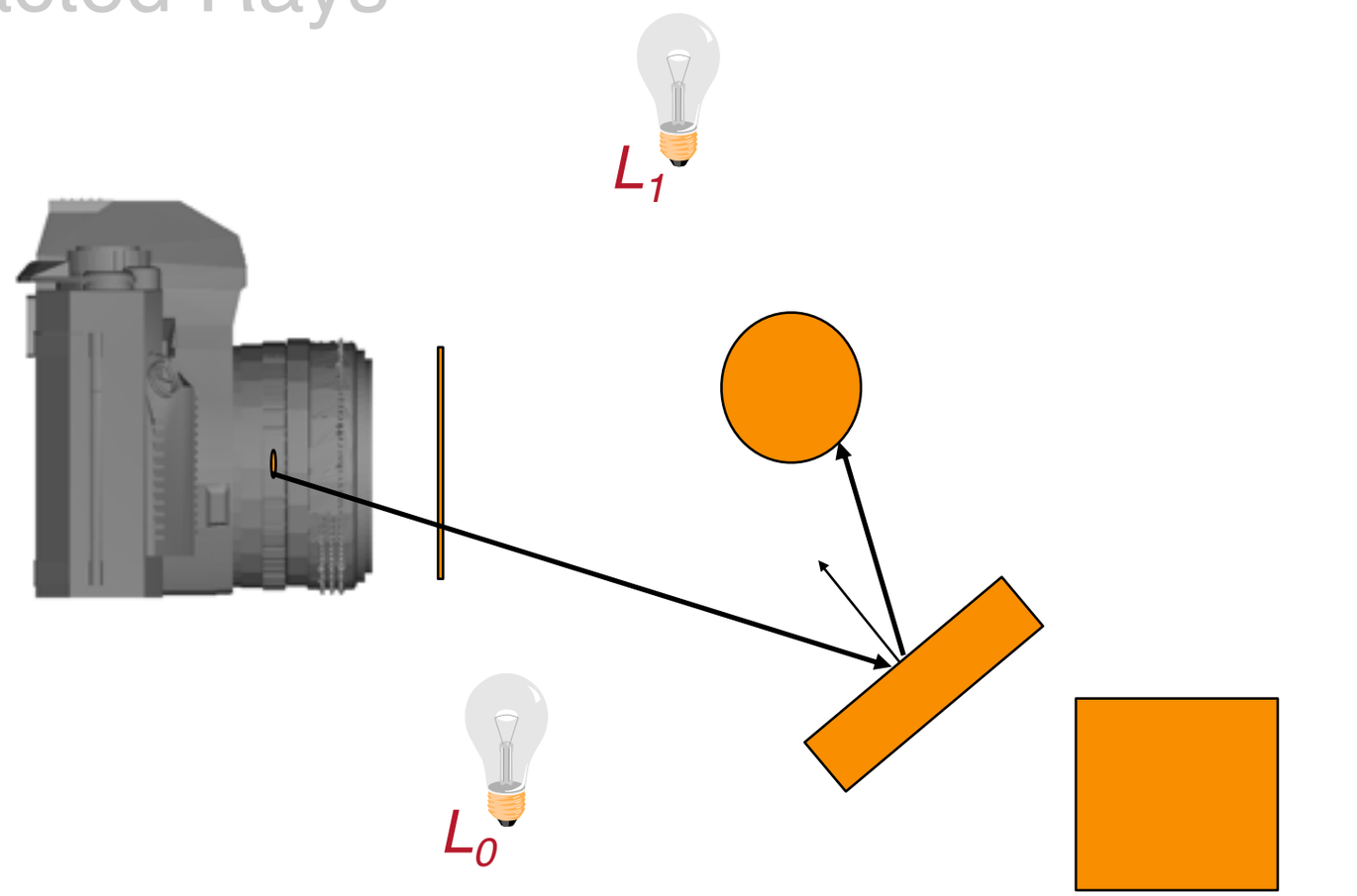

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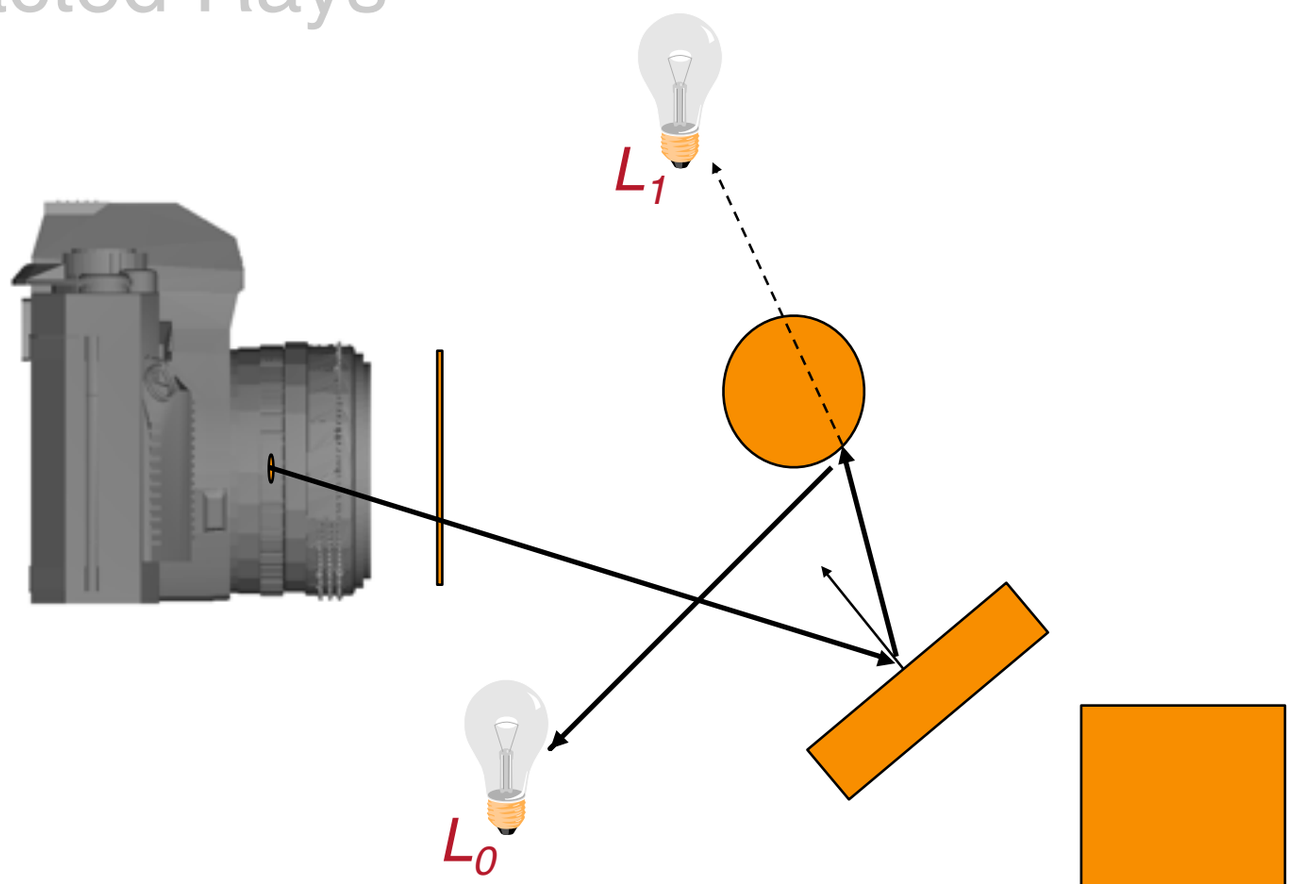

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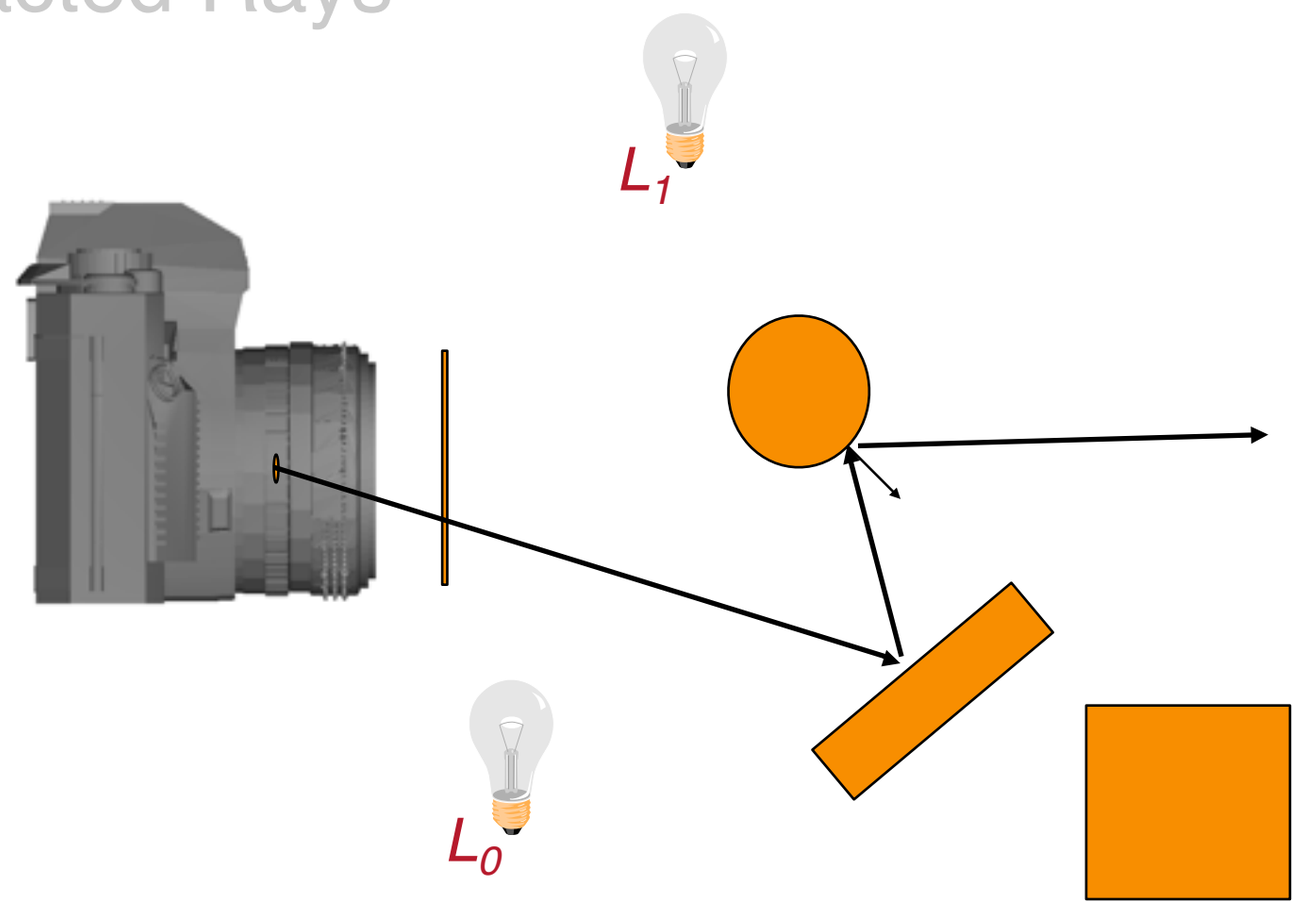

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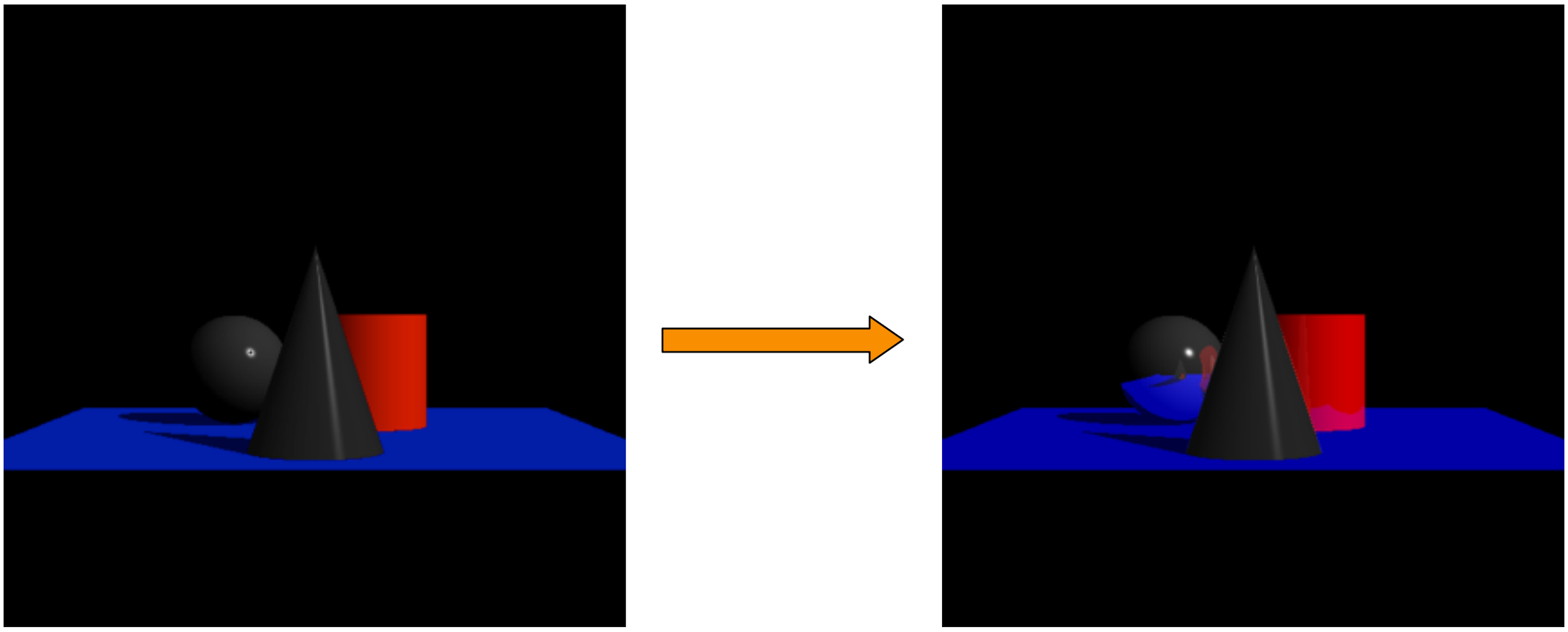

Transparent Refraction

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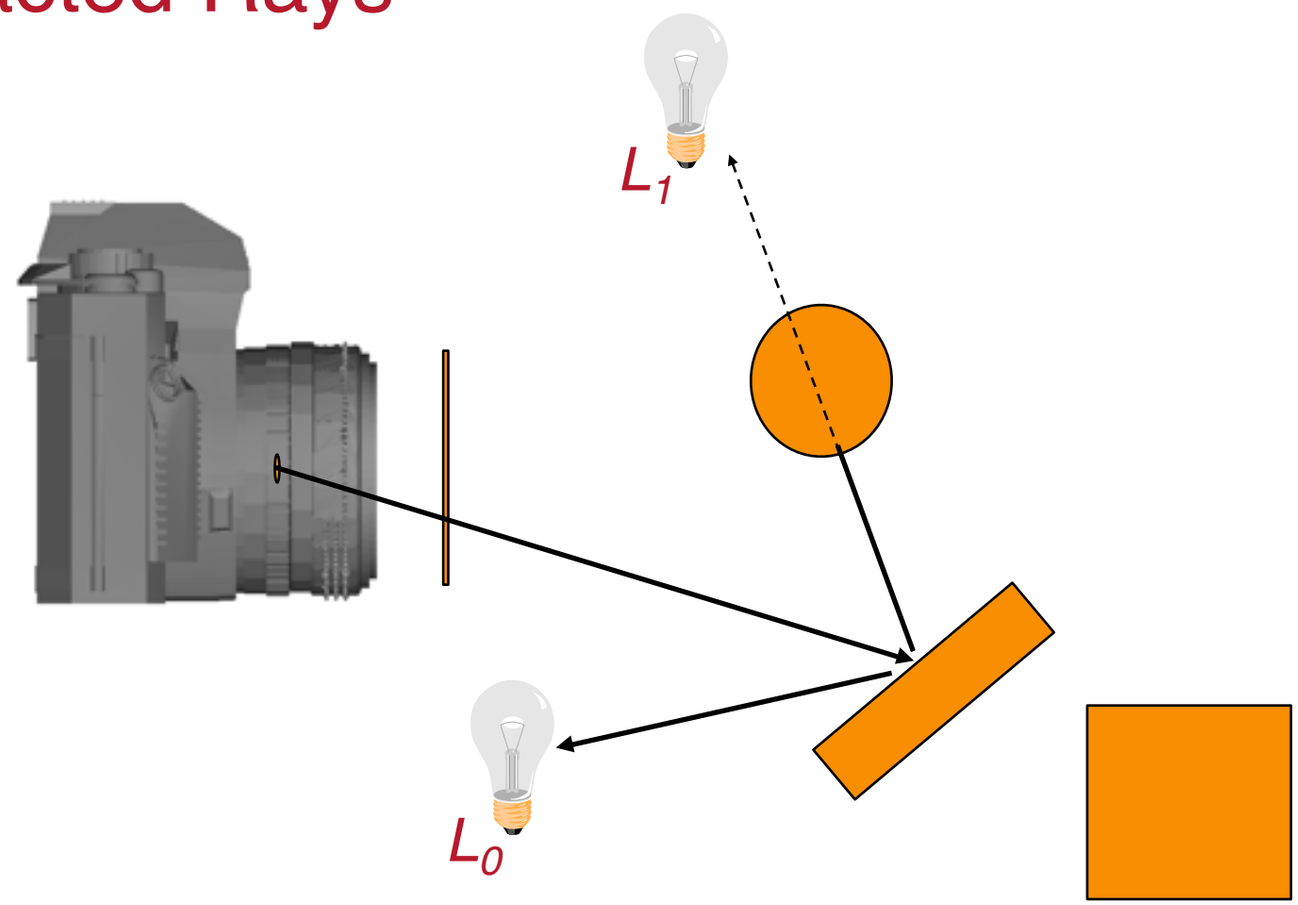

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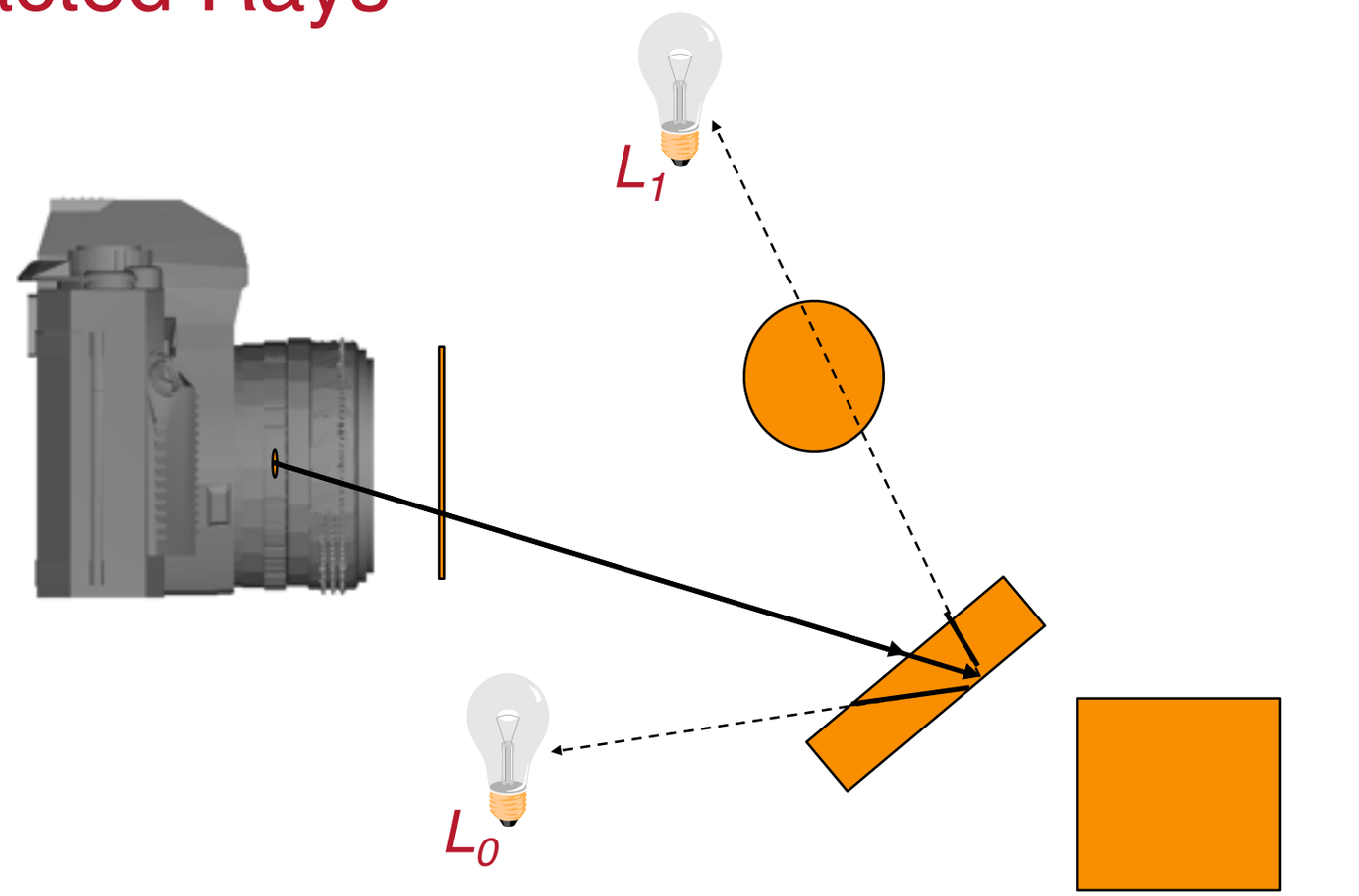

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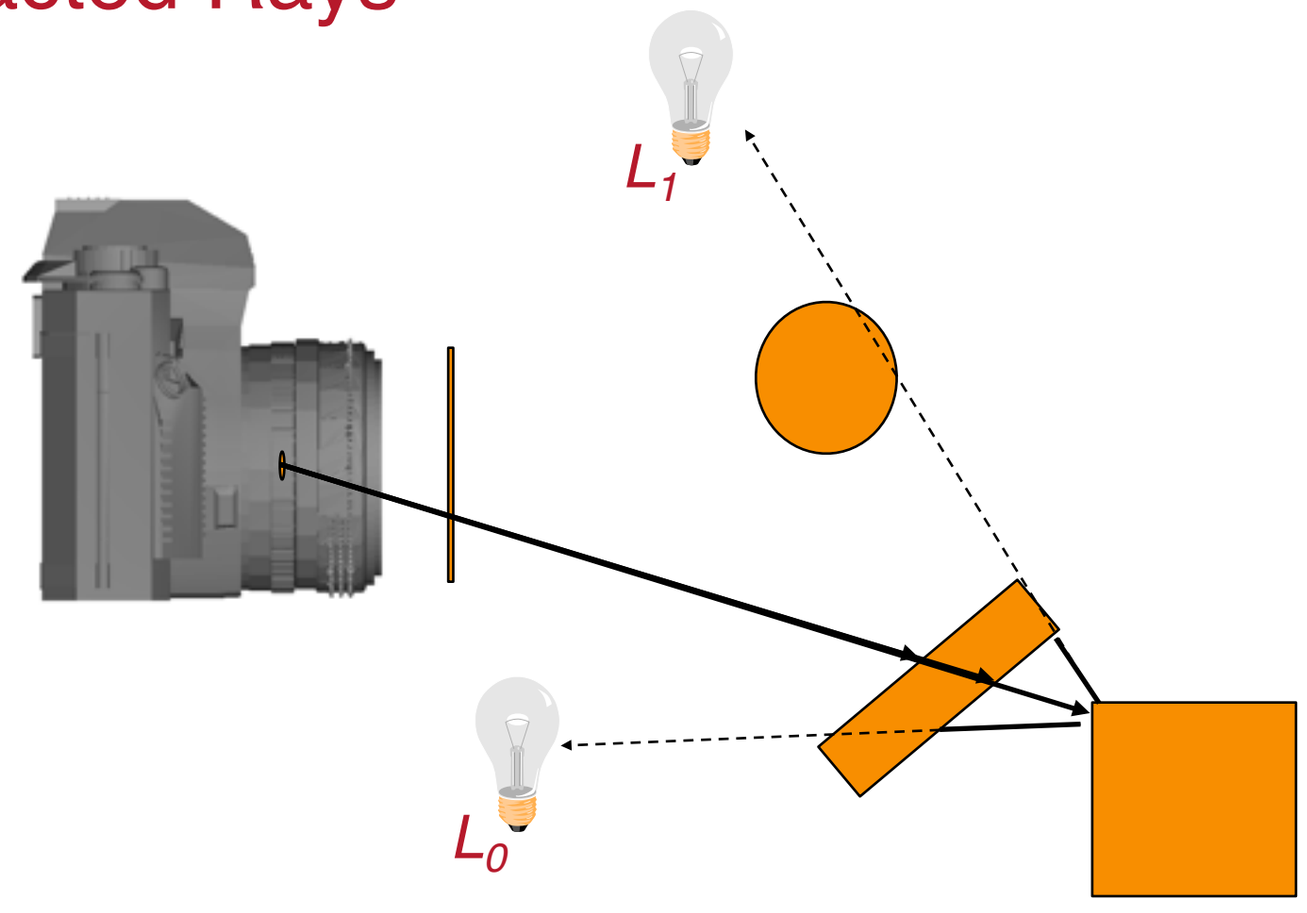

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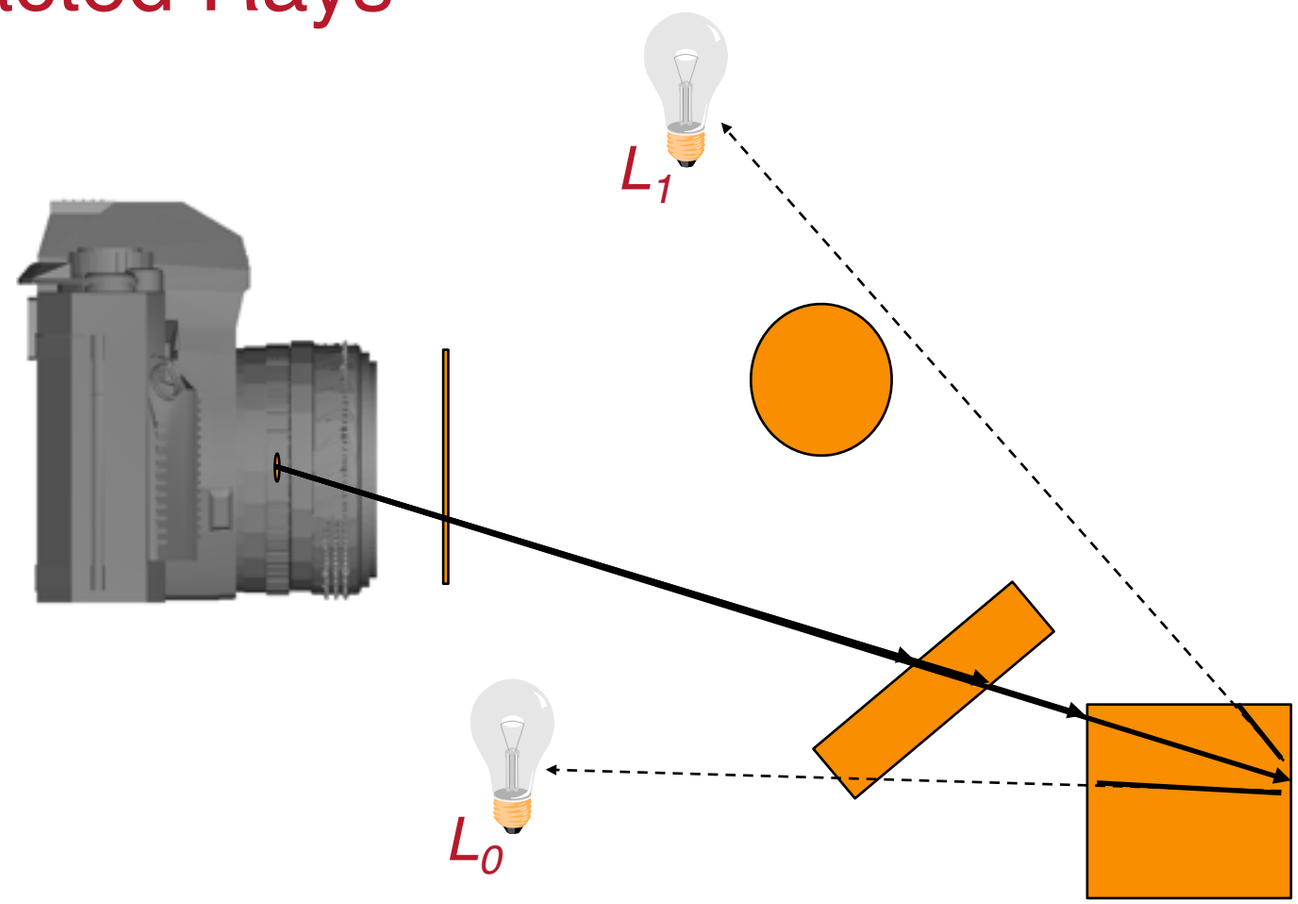

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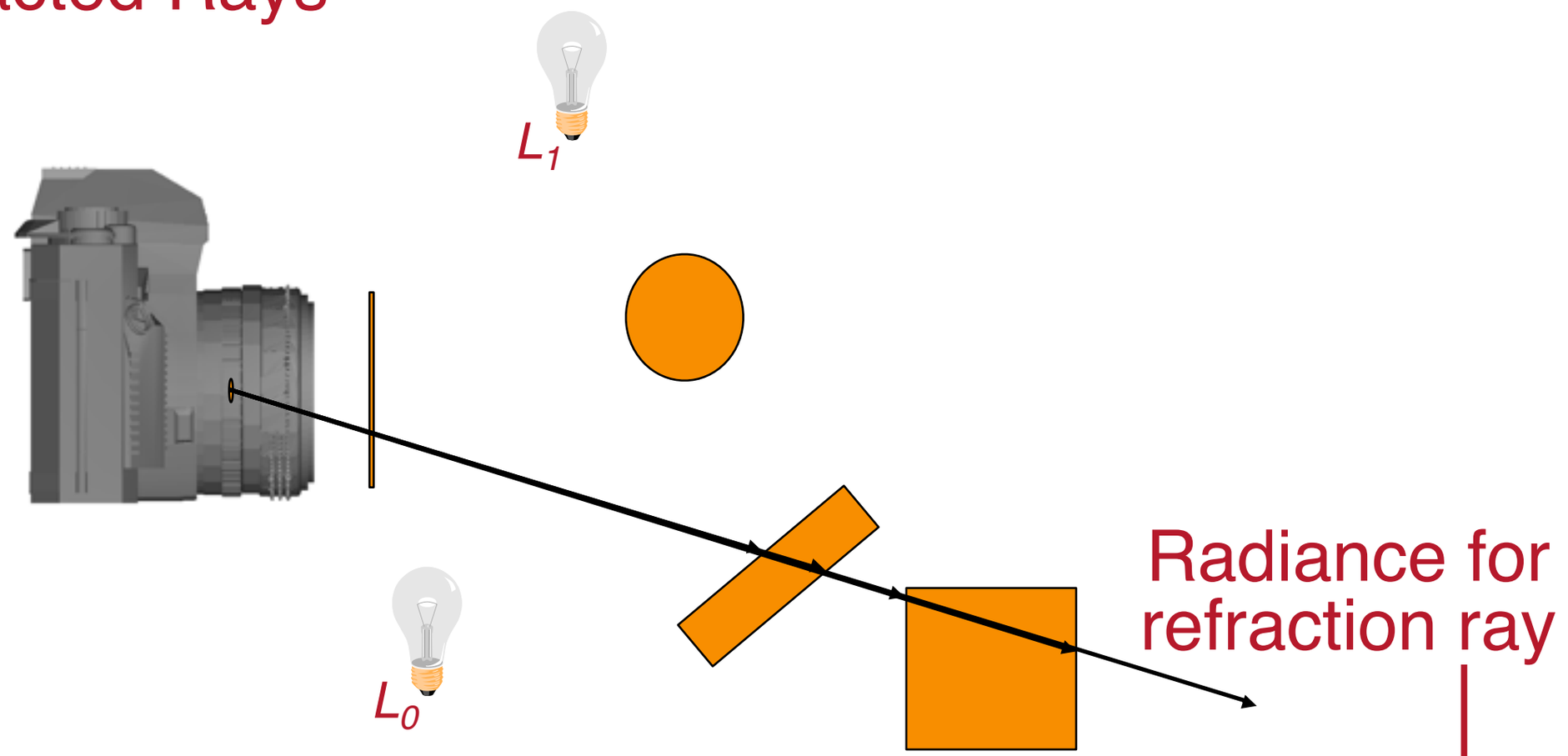

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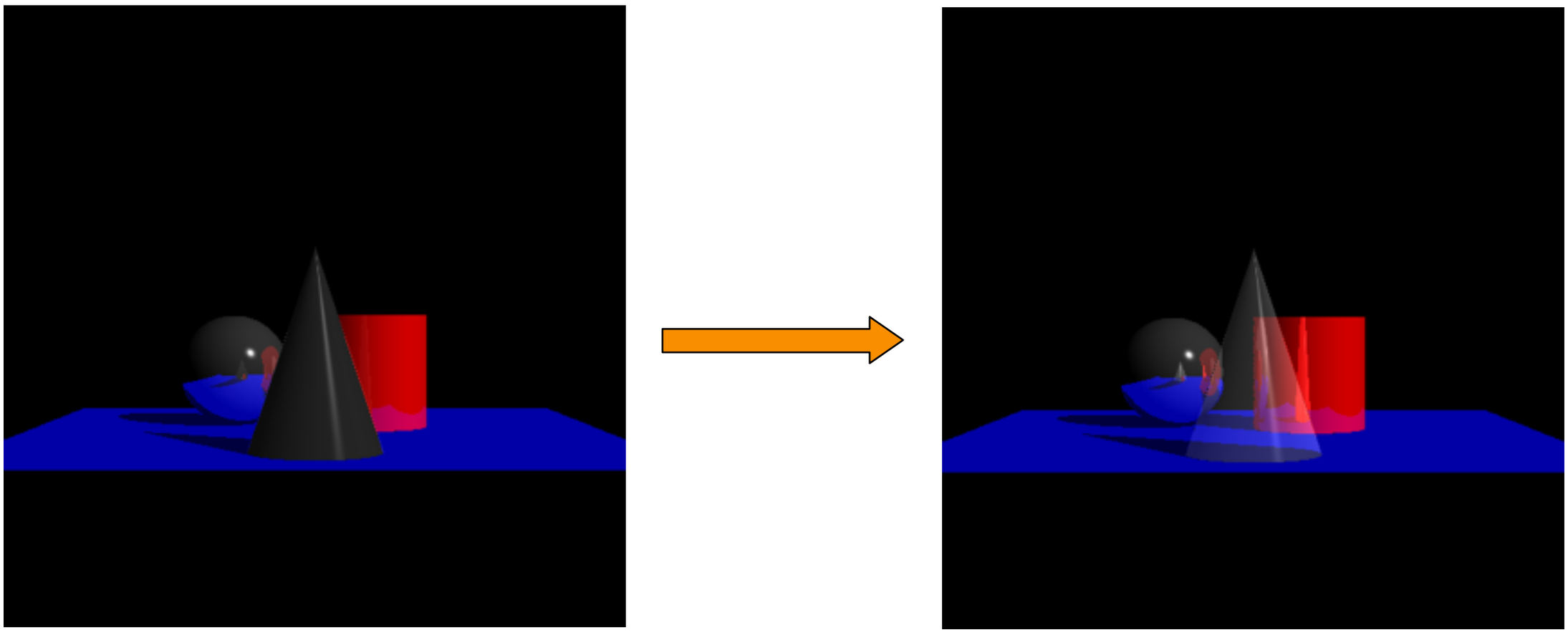
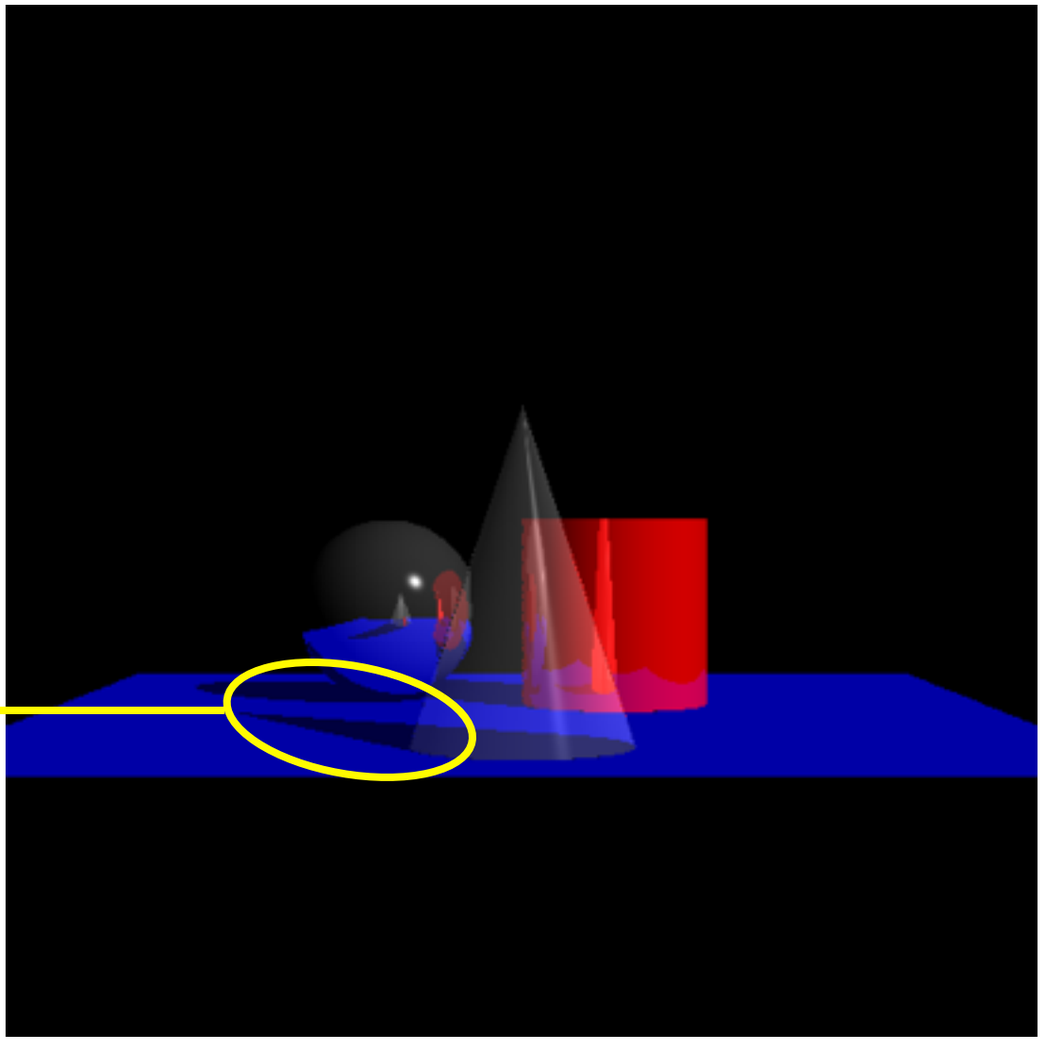


Transparency and Shadow

- Problem:
  - If a surface is transparent, then rays to the light source may pass through the object



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  - Need to modify the shadow term so that instead of representing a binary (0/1) value, it gives the fraction of light passing through.

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  - o If a surface is transparent, then rays to the light source may pass through the object
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  - o Accumulate transparency values as the ray travels to the light source.

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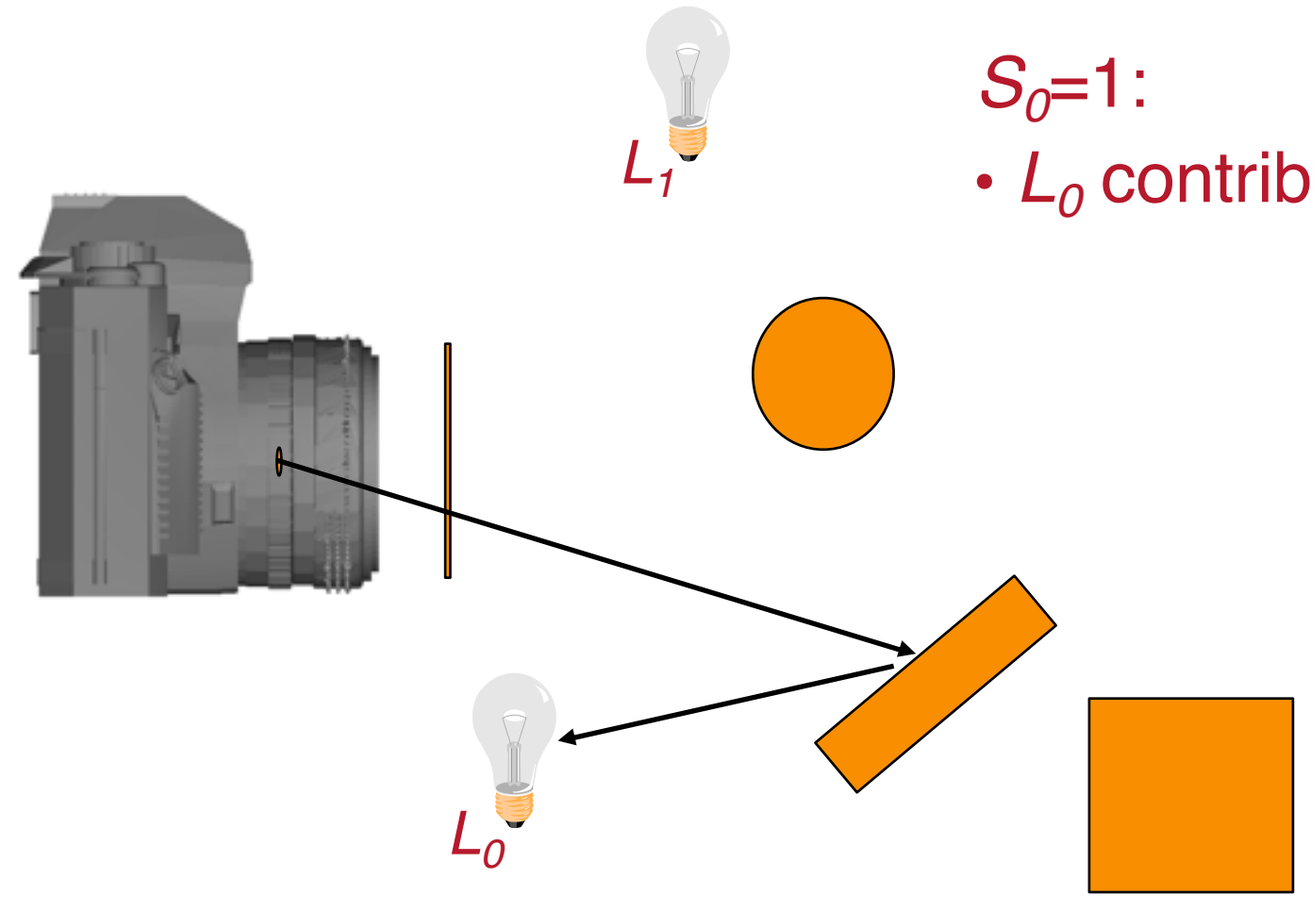
Transparency and Shadow

- Accumulate transparency values as the ray travels to the light source.



S_0=1:
- L_0 contributes fully

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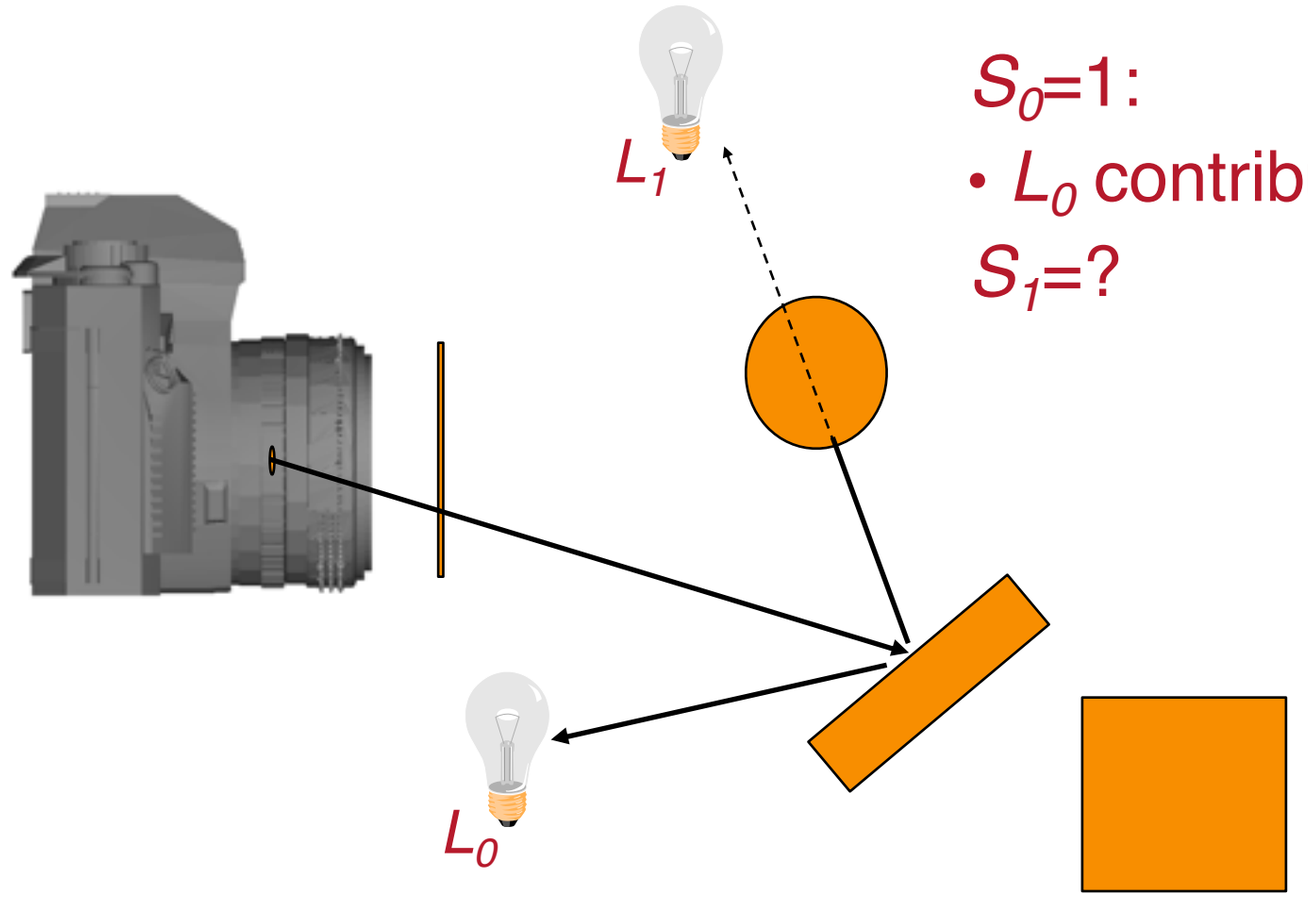

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S_1=?

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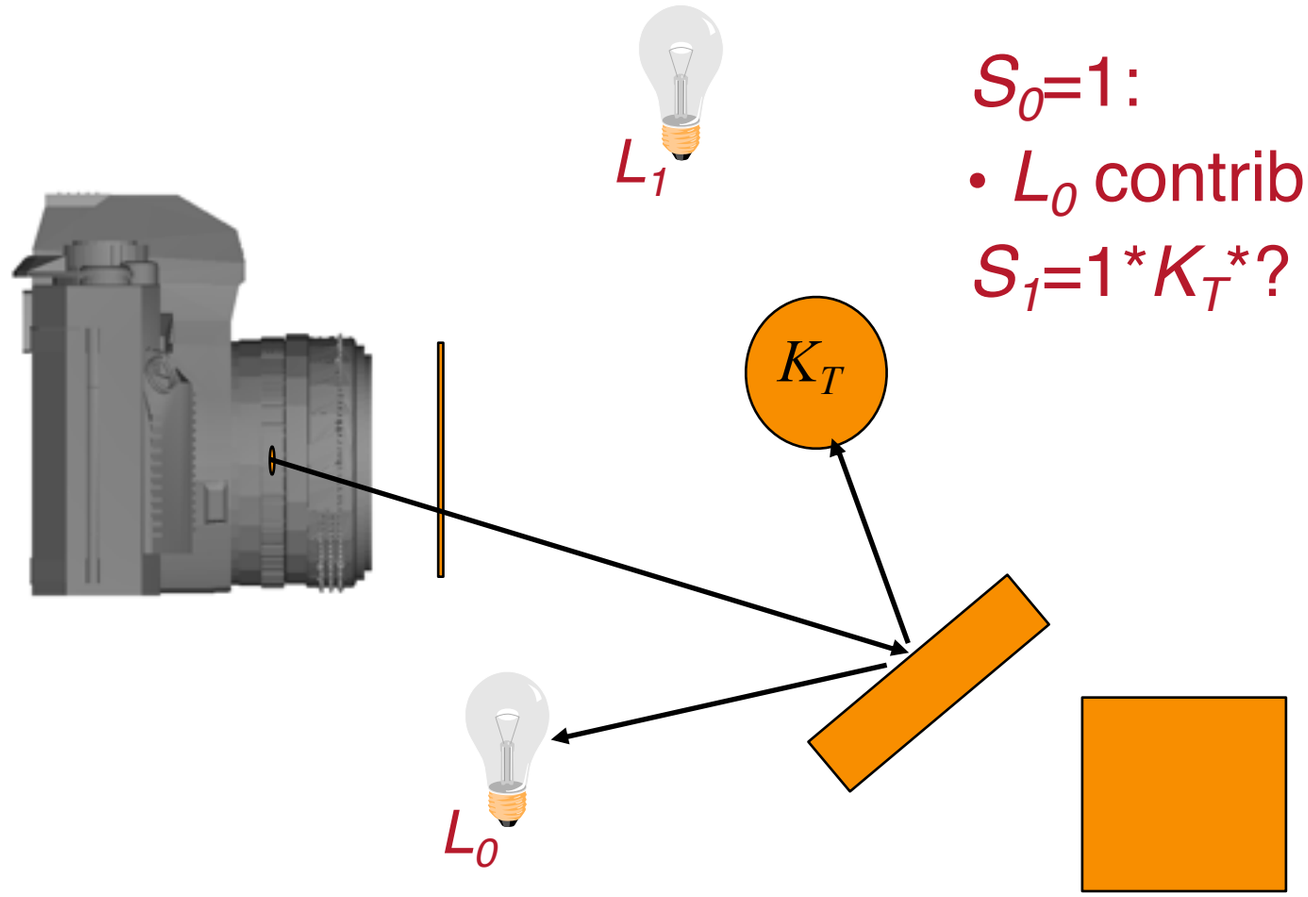

S_0=1:
- L_0 contributes fully

S_1=1*K_T*?

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

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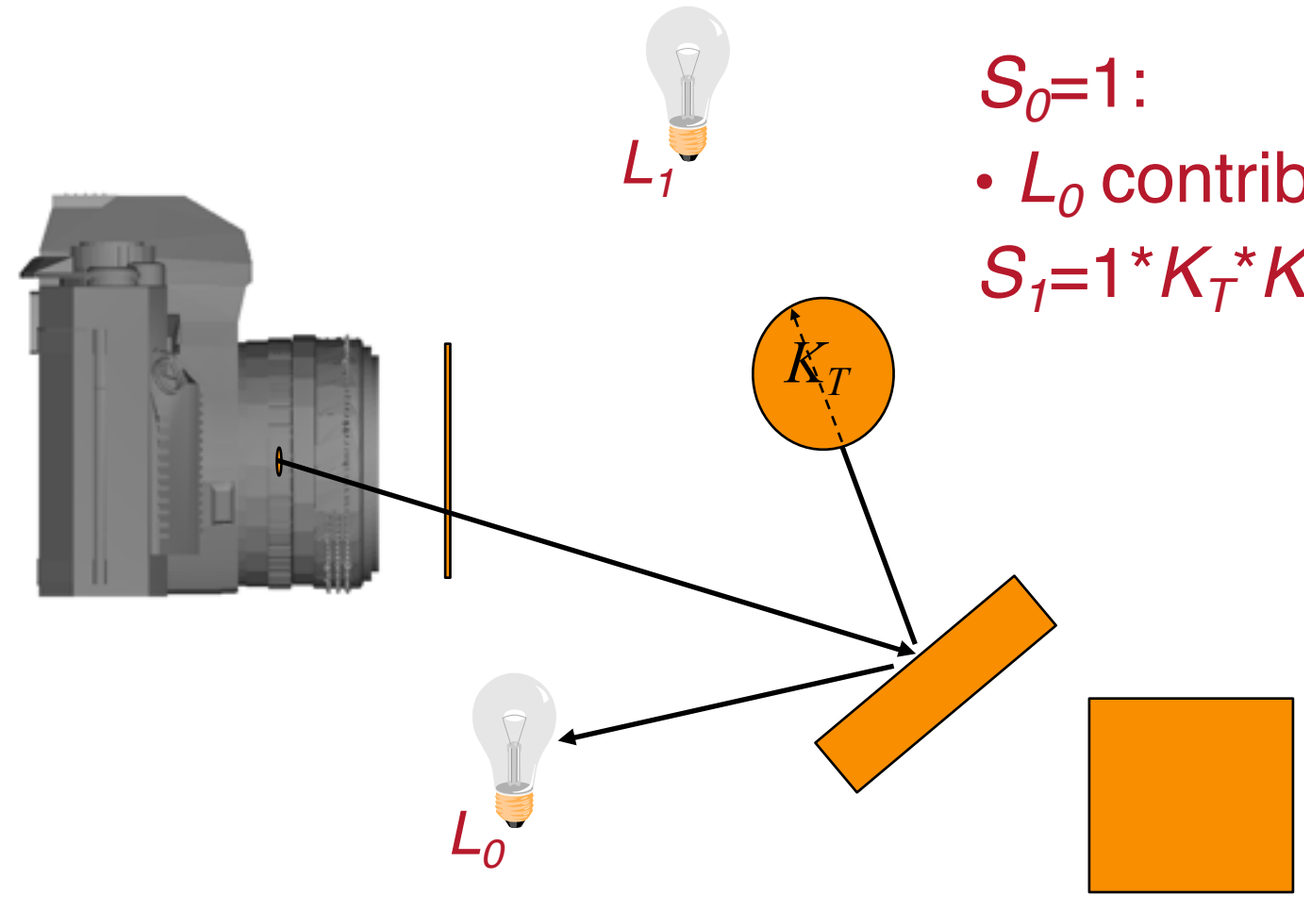

S_0=1:

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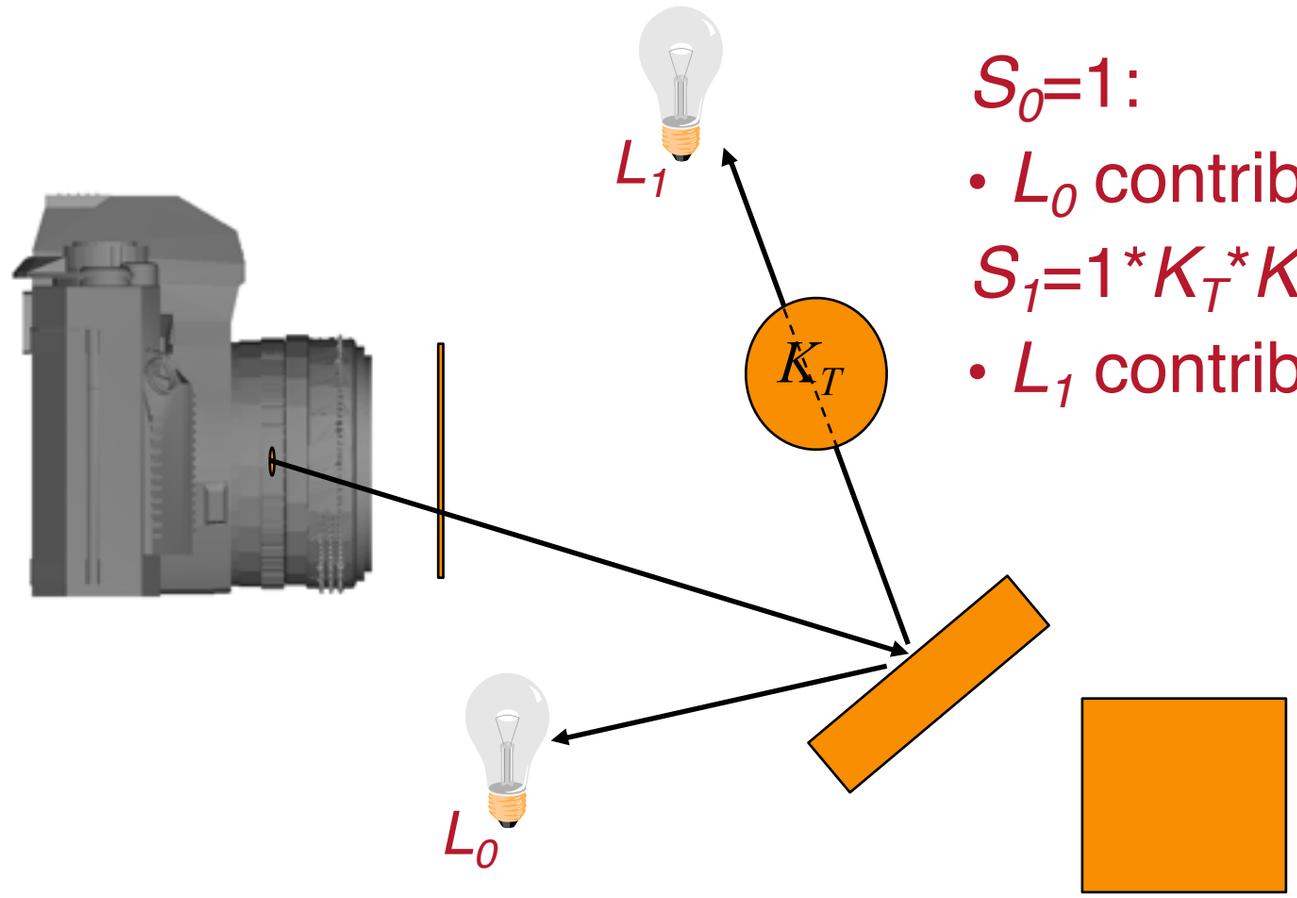
S_1=1*K_T*K_T*?

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

Transparency and Shadow

- Accumulate transparency values as the ray travels to the light source.



S_0=1:
- L_0 contributes fully

S_1=1*K_T*K_T:
- L_1 contributes partially

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

Transparency and Shadow

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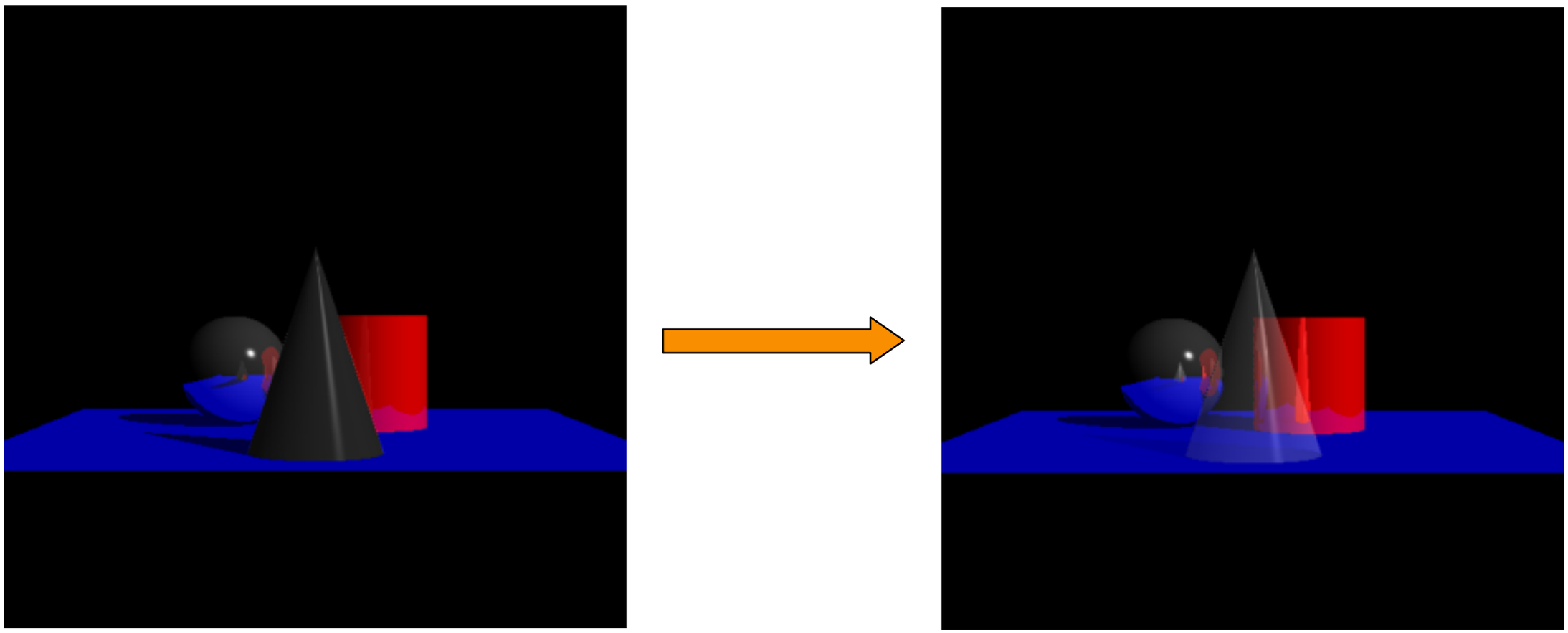
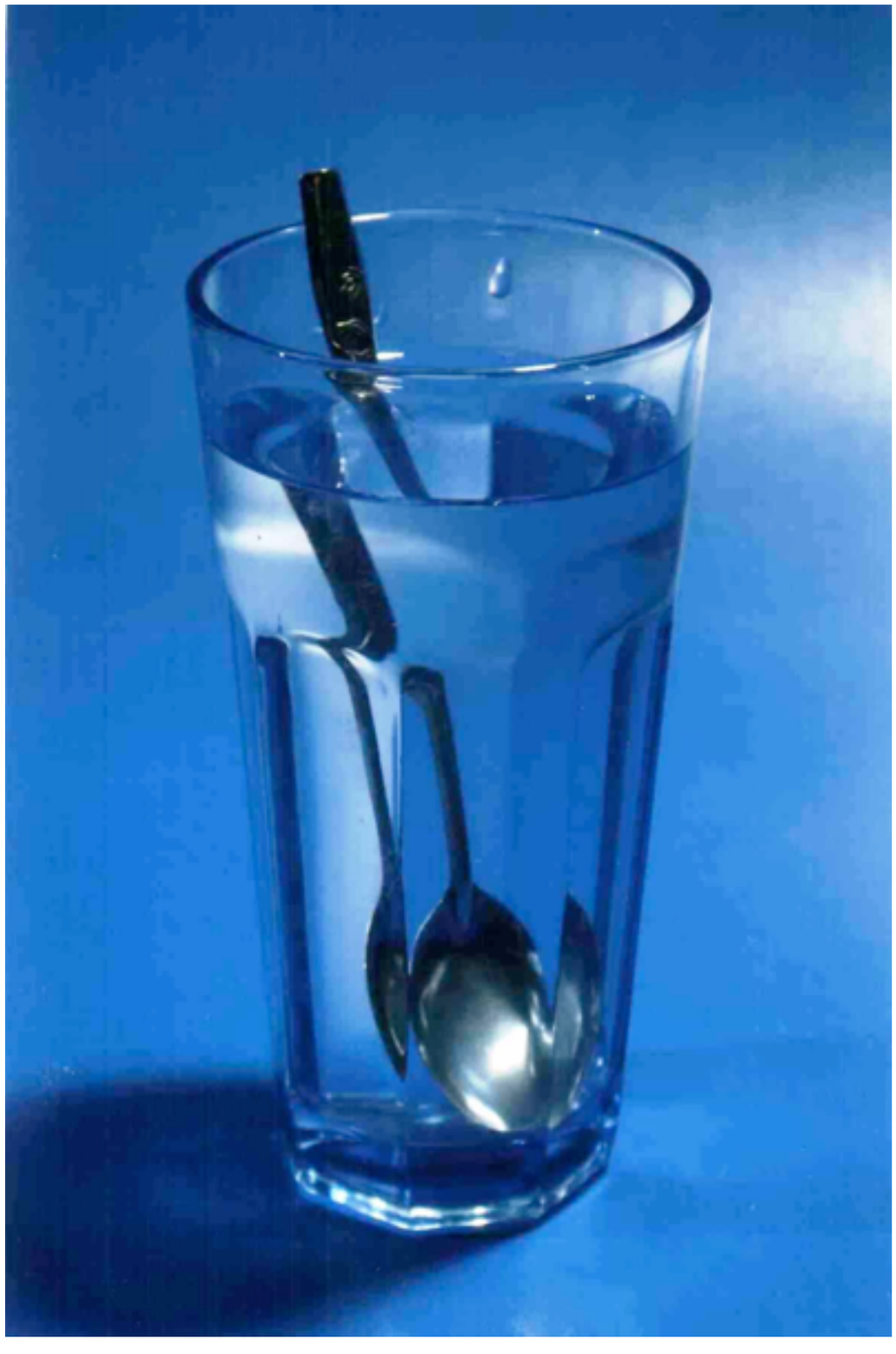


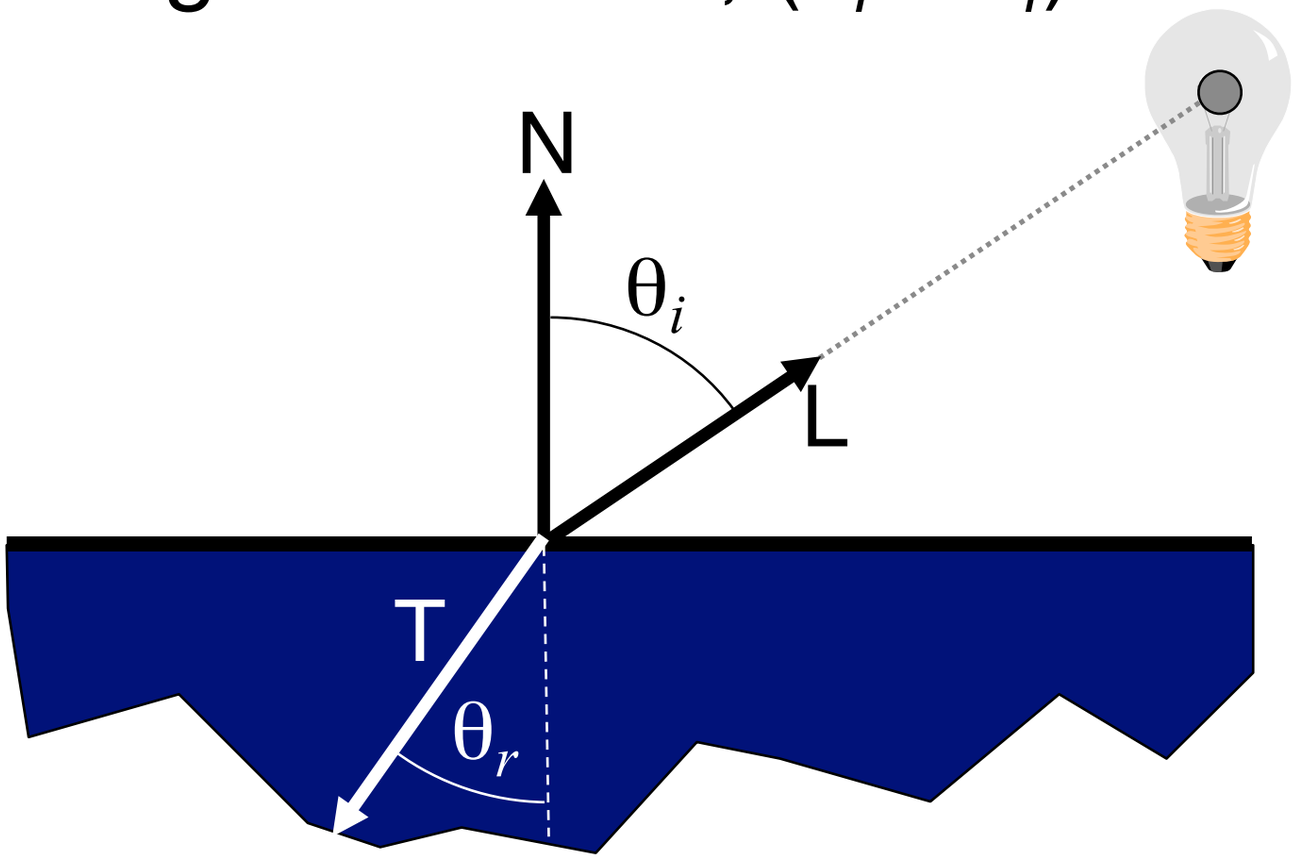
Transparent Refraction

- When a ray of light passes through a transparent object it can bend.



Transparent Refraction

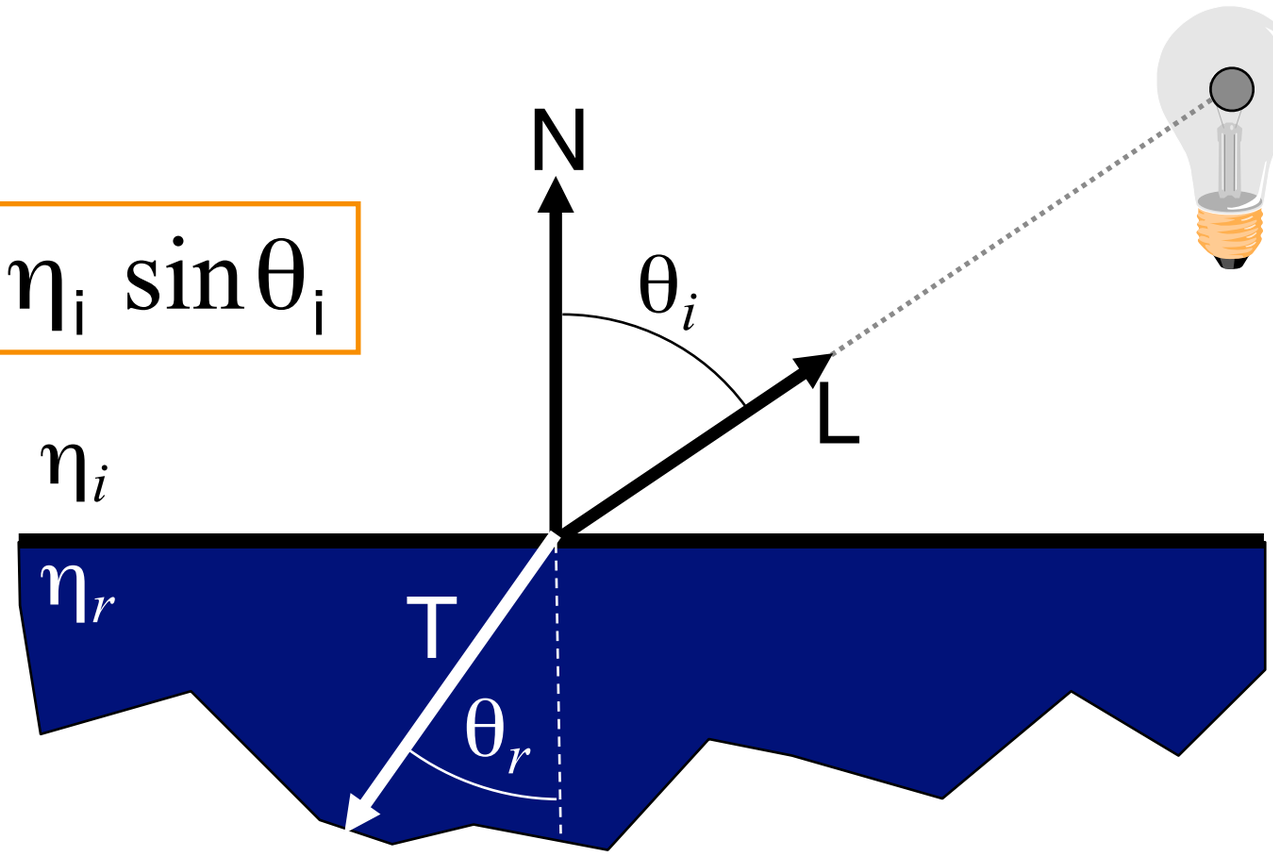
- When a ray of light passes through a transparent object, the ray of light can bend, ($\theta_i \neq \theta_r$).



Snell's Law

- The way that light bends is determined by the indices of refraction of the internal and external materials η_i and η_r:

$$\eta_r \sin\theta_r = \eta_i \sin\theta_i$$



The index of refraction of air is η=1.

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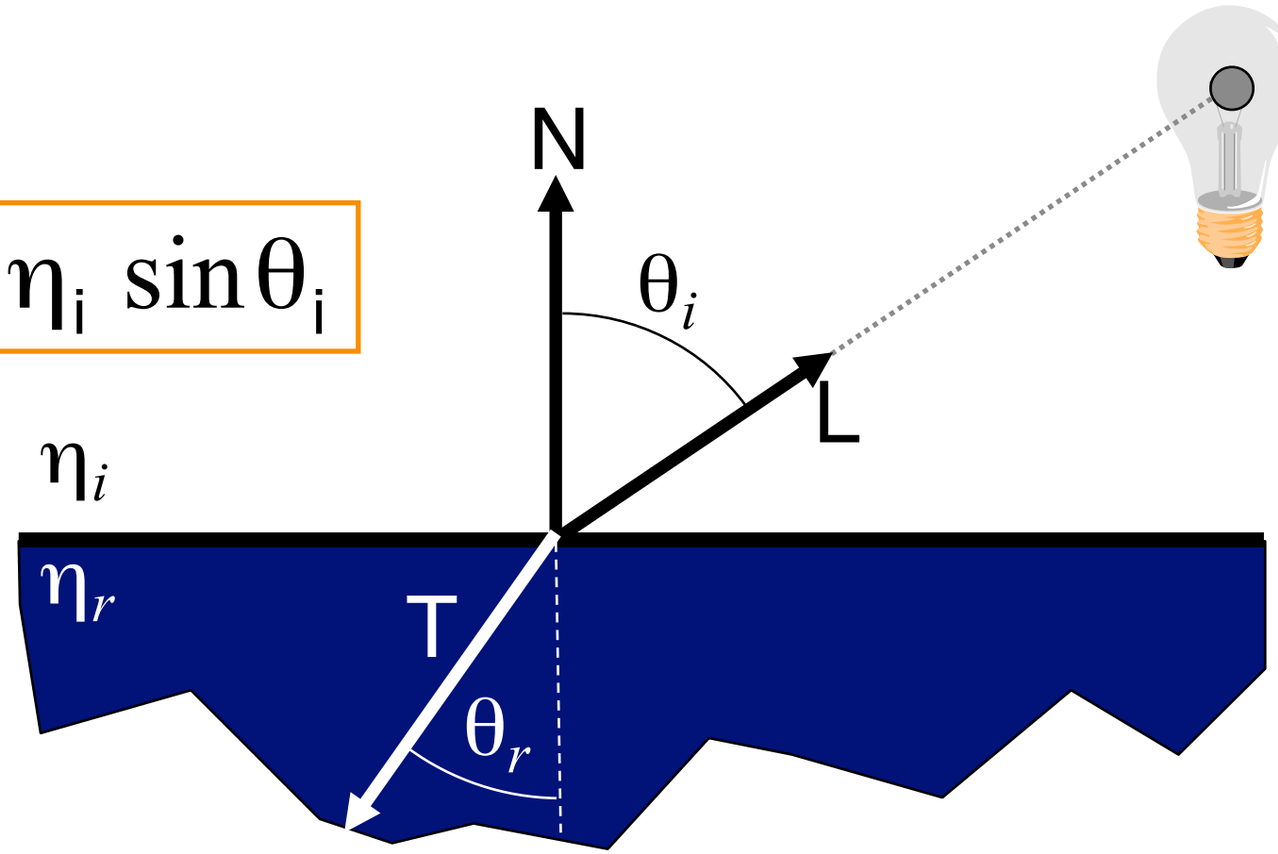

$$T = \left(\frac{\eta_i}{\eta_r}\cos\theta_i - \cos\theta_r\right)N - \frac{\eta_i}{\eta_r}L$$

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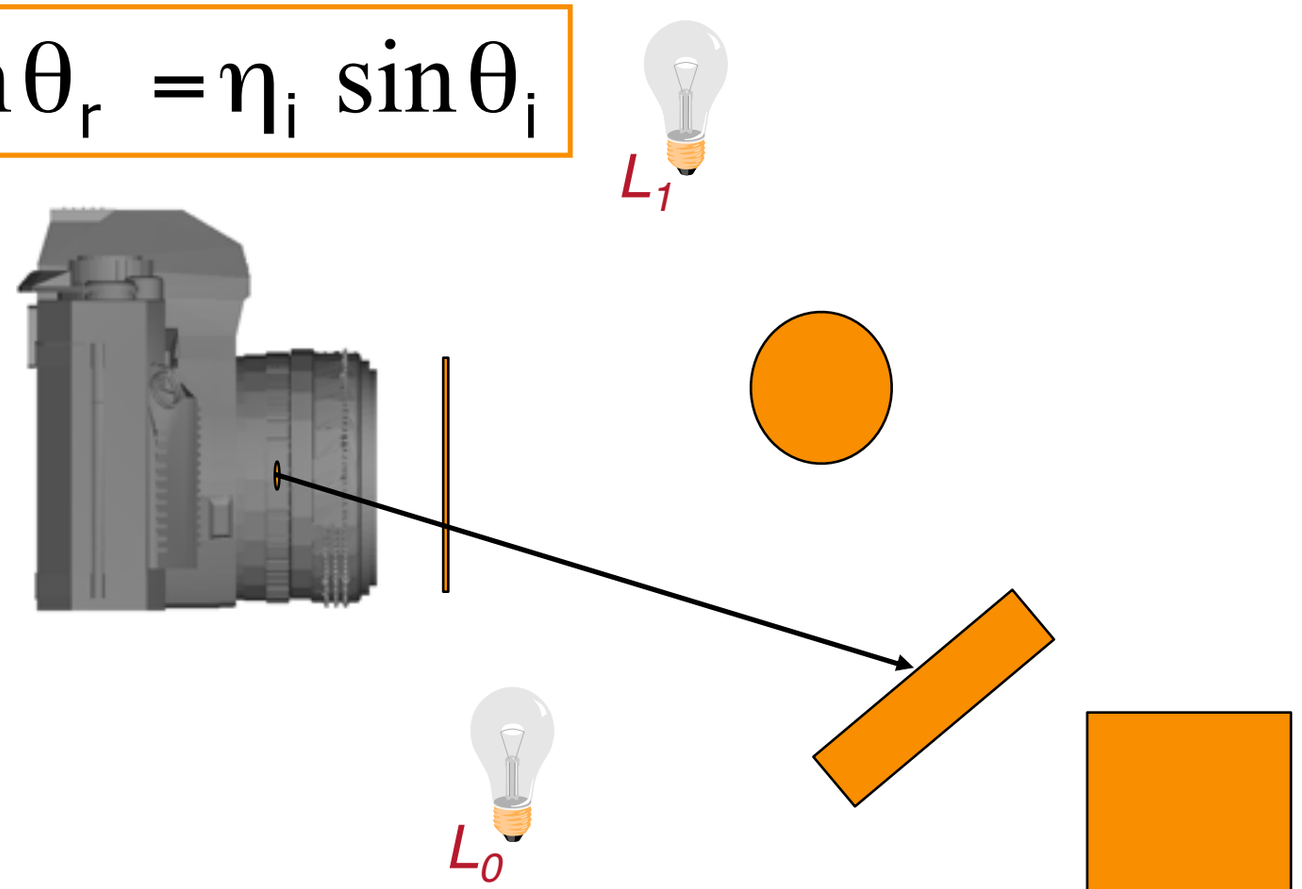

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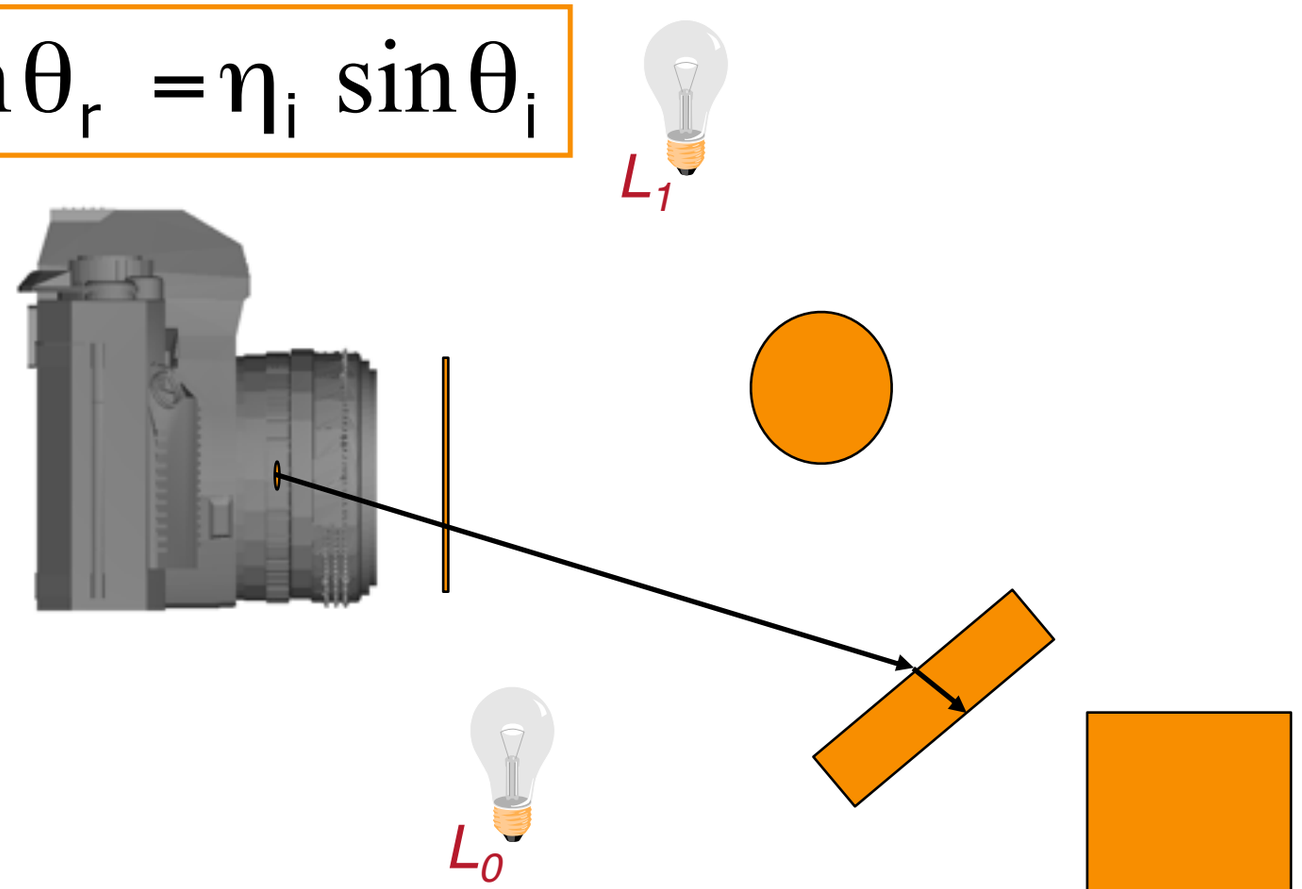

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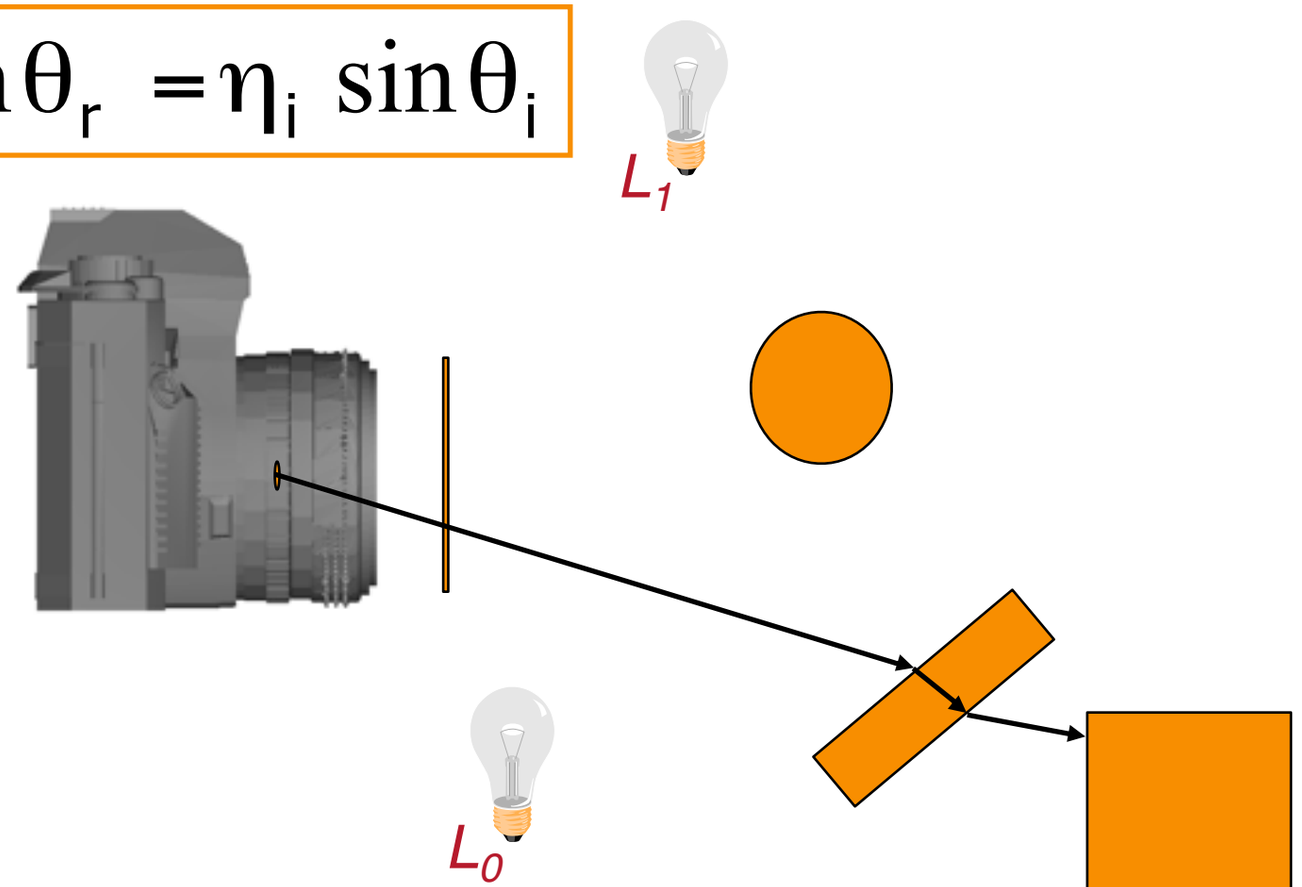

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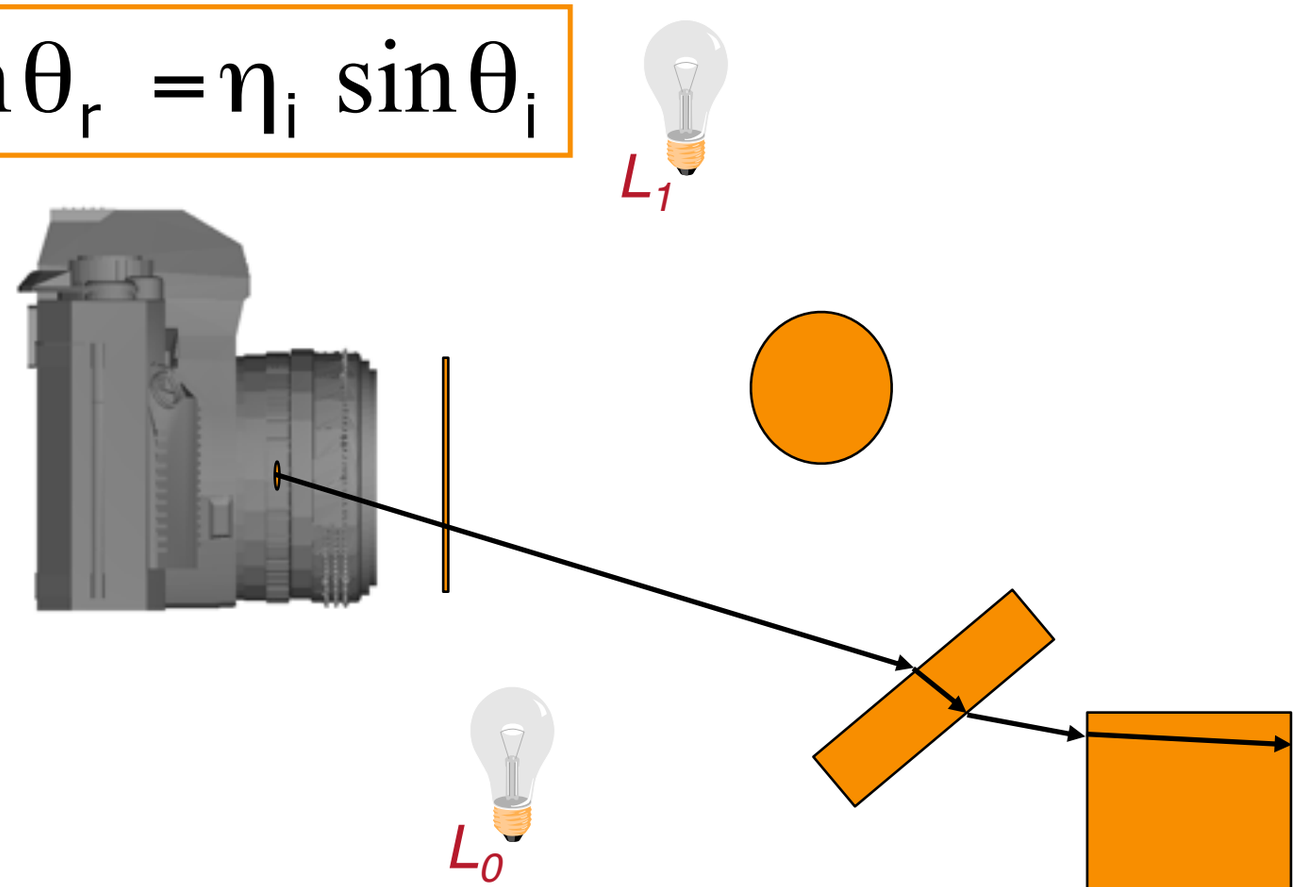

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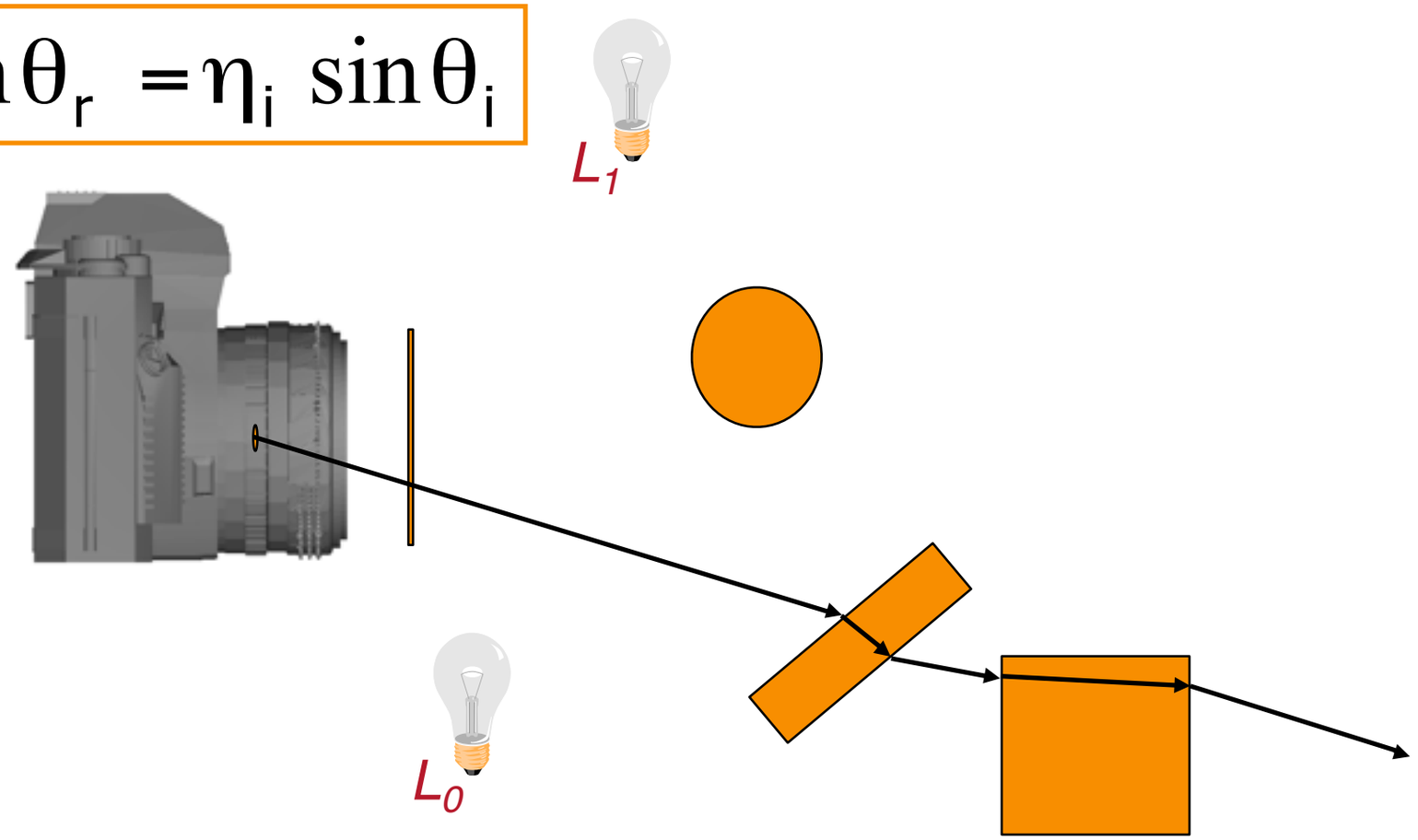

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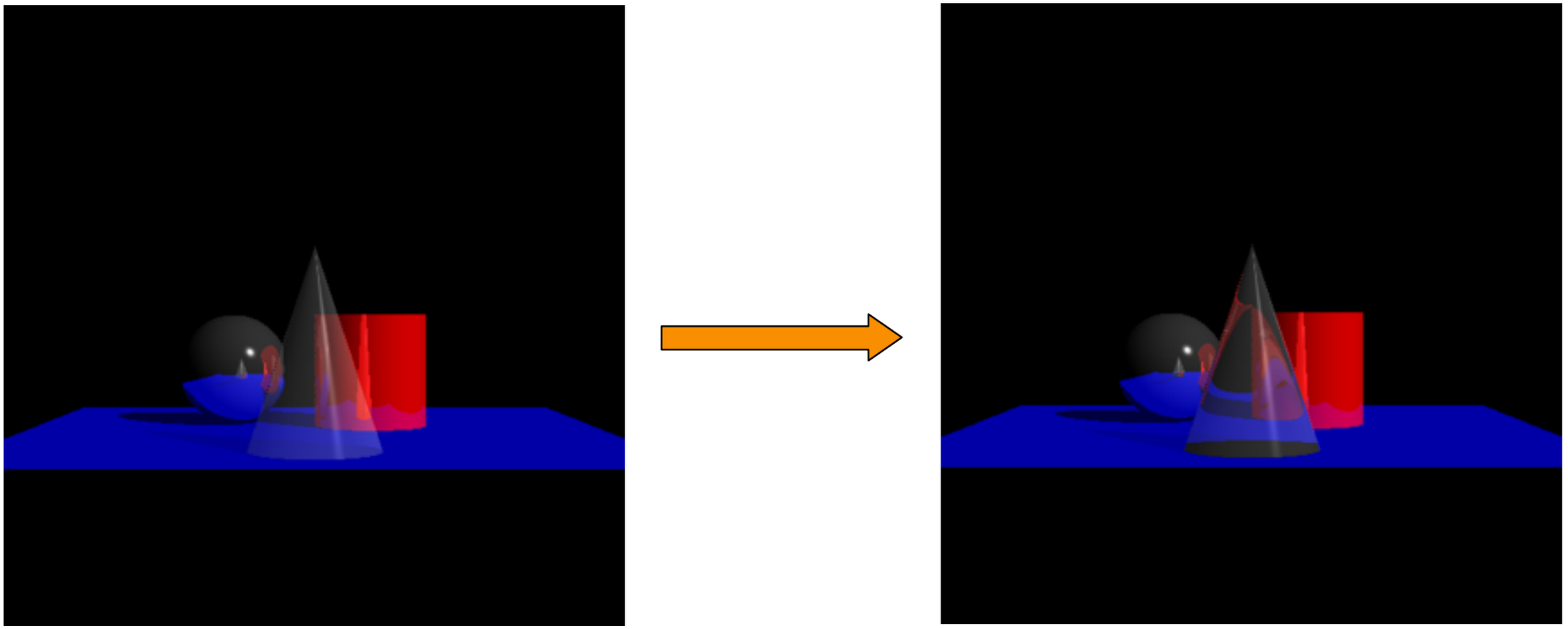

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- Problem:
  - If a surface is transparent, then rays to the light source may not travel in a straight line
  - This is difficult to address with ray-tracing

General Issue

- How do we determine when to stop recursing?

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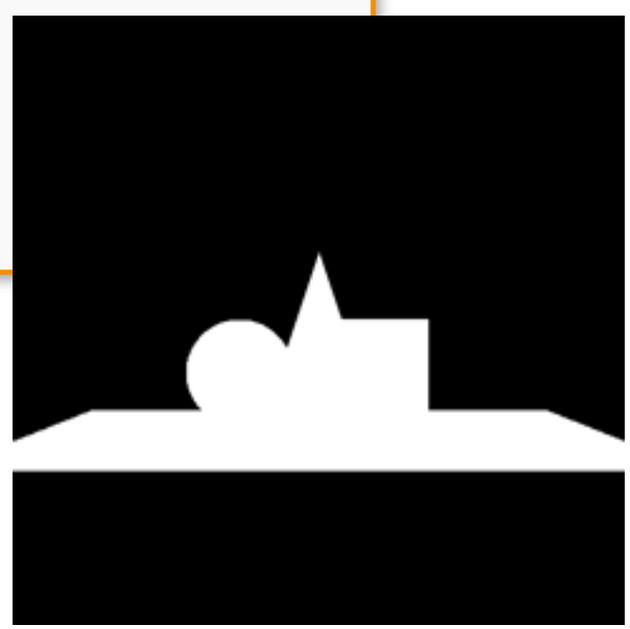
- How do we determine when to stop recursing?
  - Depth of iteration
    - » Bounds the number of times a ray will bounce around the scene
  - Cut-off value
    - » Ignores contribution from bounces that contribute very little

Putting it all Together

```
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

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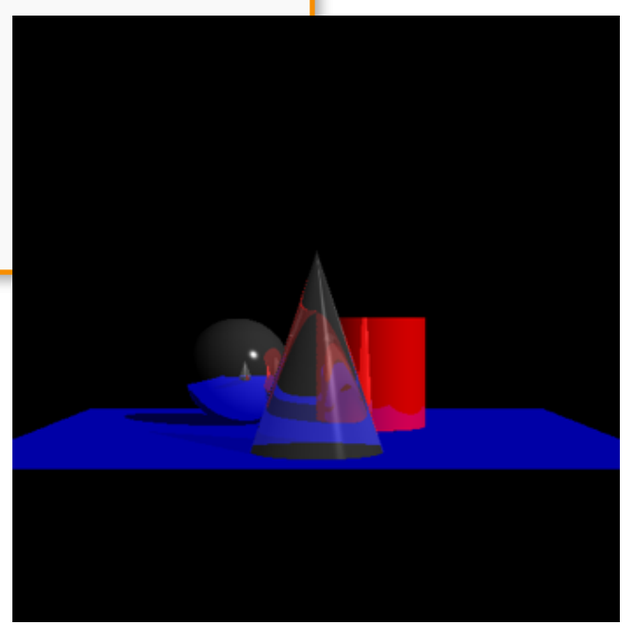

With Illumination

Putting it all Together

```
Pixel GetColor(scene, ray, depth, cutOff){
        Pixel p(0,0,0)
        Ray reflect, refract
        Intersection hit=FindIntersection(ray, scene);
        if ( hit ){
                p += GetSurfaceColor(hit.position);

                reflect.direction = Reflect( ray.direction, hit.normal)
                reflect.position = hit.position + reflect.direction*ε
                if( depth >0 && hit.kSpec>cutOff)
                        p += GetColor(scene, reflect, depth-1, cutOff/hit.kSpec)*hit.kSpec

                refract.direction = Refract( ray.direction, hit.normal, hit.ir)
                refract.position = hit.position + refract.direction*ε
                if( depth >0 && hit.kTran>cutOff)
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$$I = I_E + K_A I_A + \sum_L (K_D (N \bullet L) + K_S (V \bullet R)^n) I_L S_L + K_S I_R + K_T I_T$$

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Why do we need the ε terms?

Putting it all Together

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}
```
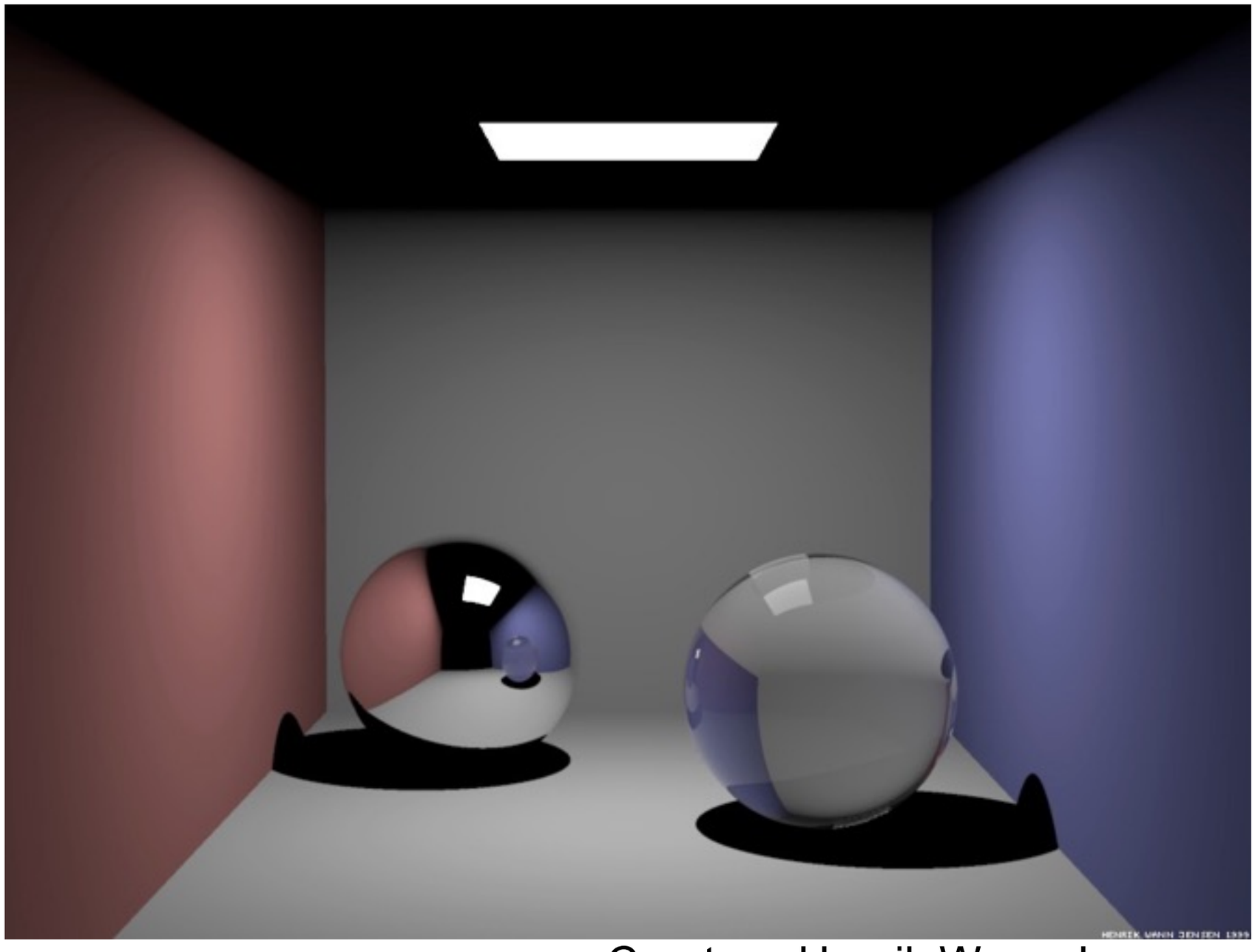

Why do we need the ε terms?

To ensure that the new ray does not hit its starting location!

Illumination Examples

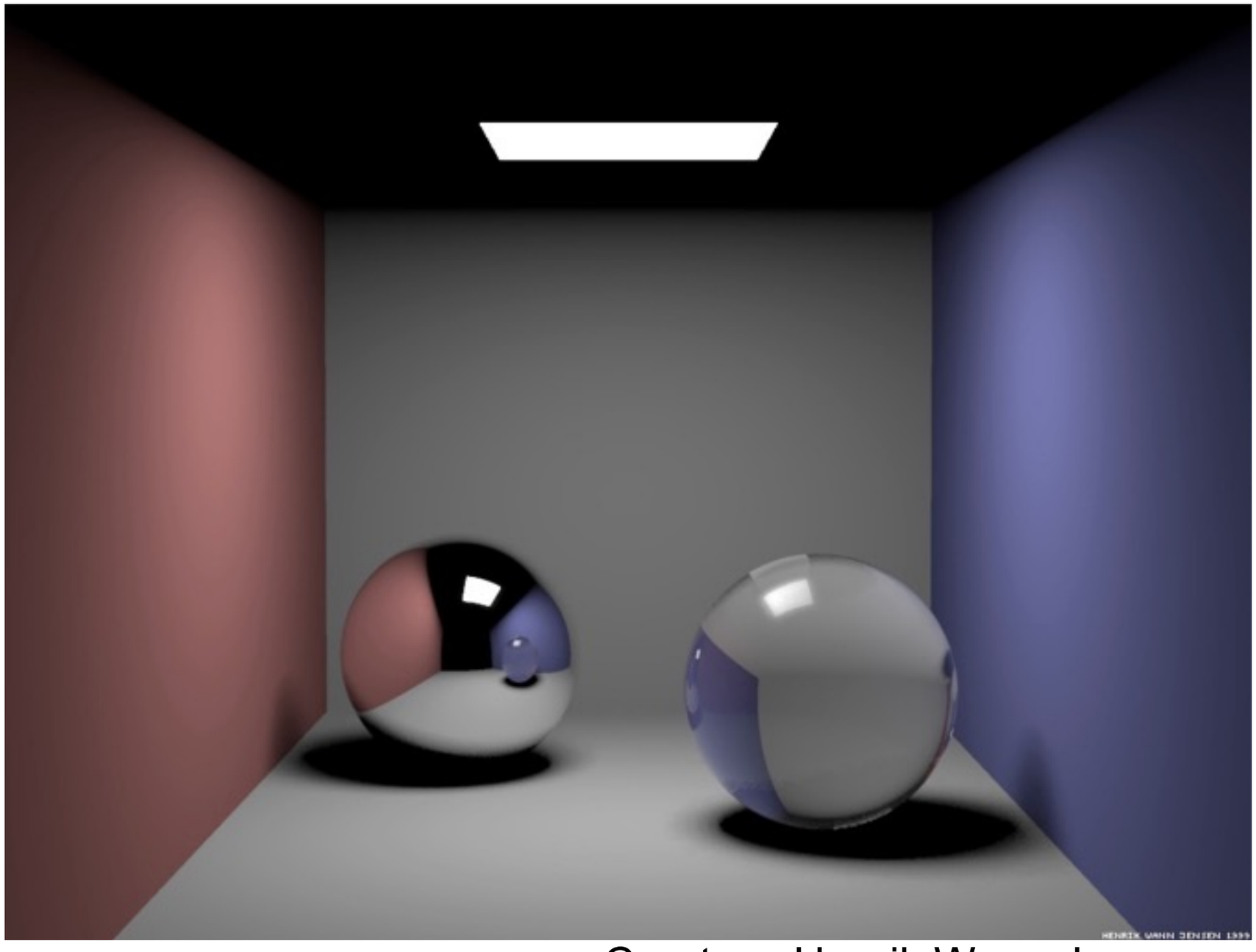
- Ray casting (direct illumination)



Courtesy Henrik Wann Jensen

Illumination Examples

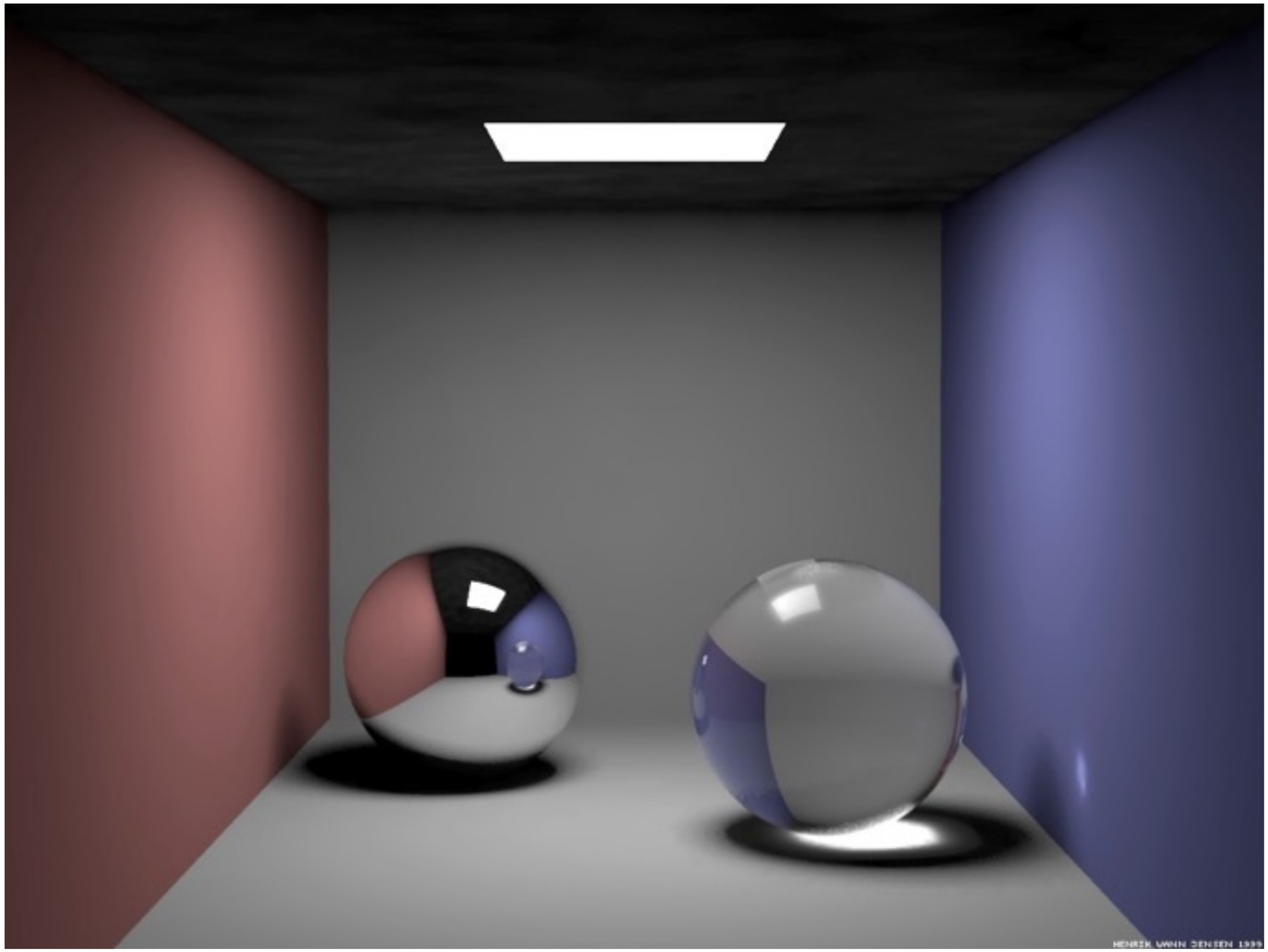
- Soft Shadows



Courtesy Henrik Wann Jensen

Illumination Examples

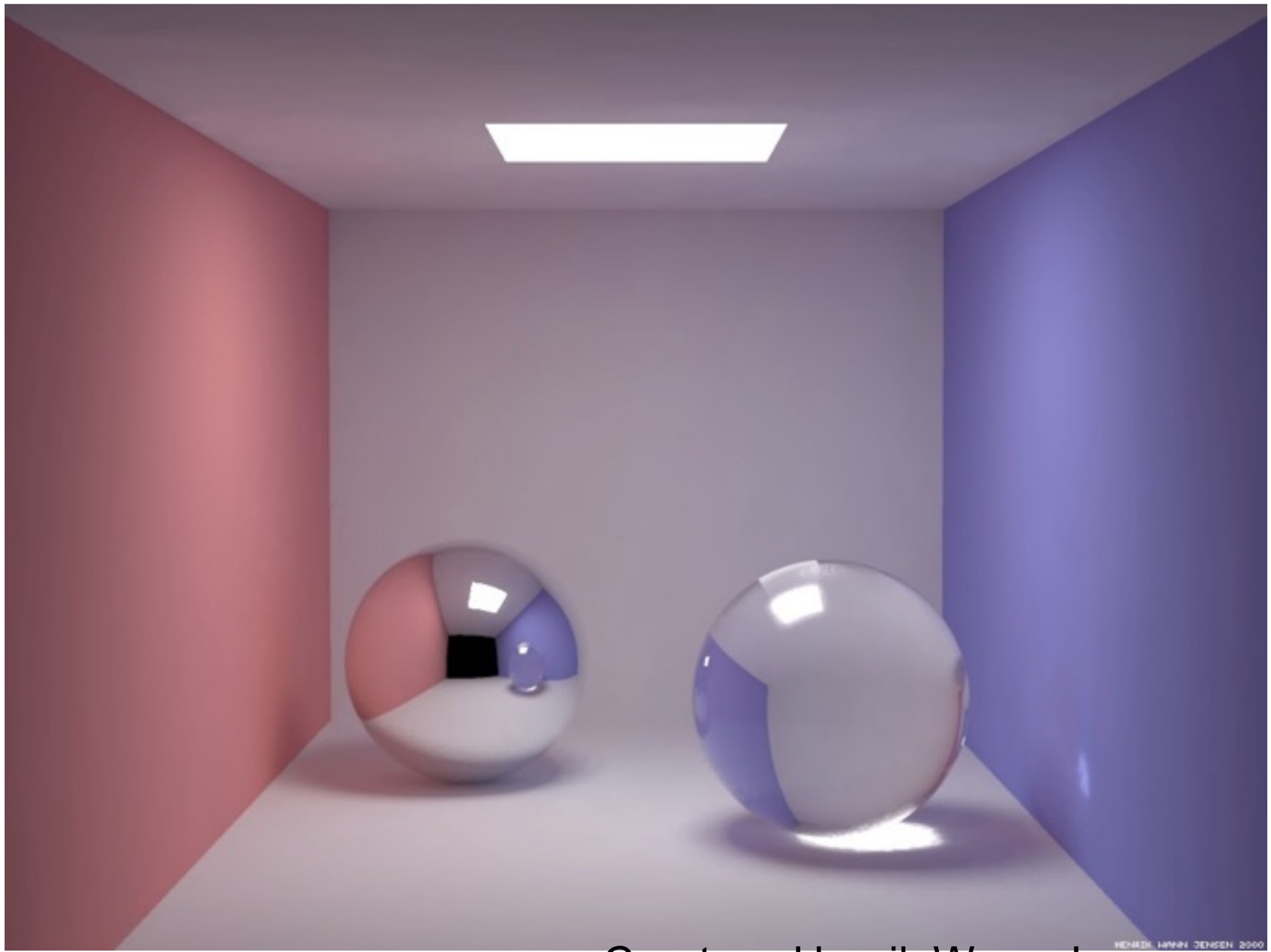
- Caustics



Courtesy Henrik Wann Jensen

Illumination Examples

- Full Global Illumination



Courtesy Henrik Wann Jensen

Recursive Ray Tracing

- GetColor is a recursive function

```
Image RayTrace(Camera camera, Scene scene, int width, int height
                    int depth, float cutOff){
    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);
            image[i][j] = GetColor(scene, ray, depth, cutOff);
        }
    }
    return image;
}
```

Summary

- Ray casting (direct Illumination)
  - Usually use simple analytic approximations for light source emission and surface reflectance
- Recursive ray tracing (global illumination)
  - Incorporate shadows, mirror reflections, and pure refractions

All of this is an approximation so that it is practical to compute