Discussion 07:

Path Tracing and Material Modeling

Computer Graphics and Imaging
UC Berkeley CS184/284A, Spring 2019

Let’s re-orient ourselves!

Where are we?

Course Roadmap

Rasterization Pipeline

Core Concepts
- Sampling
- Antialiasing
- Transforms

Geometric Modeling

Core Concepts
- Splines, Bezier Curves
- Topological Mesh Representations
- Subdivision, Geometry Processing

Lighting & Materials

Cameras & Imaging

Rasterization

Transforms & Projection

Texture Mapping

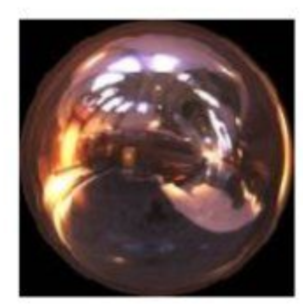
Visibility, Shading, Overall Pipeline

Intro to Geometry

Curves and Surfaces

Geometry Processing

Today: Ray-Tracing & Acceleration



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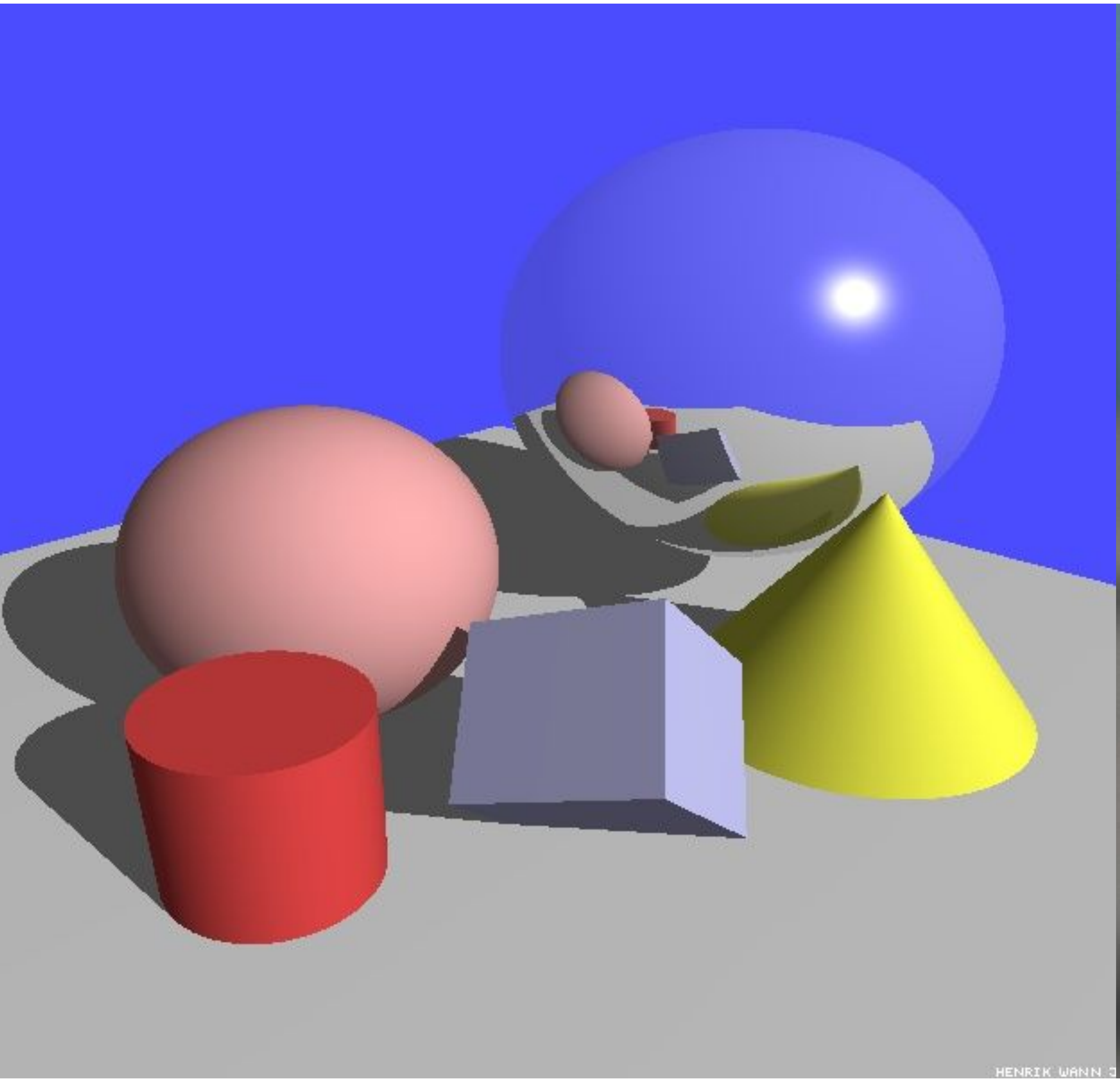
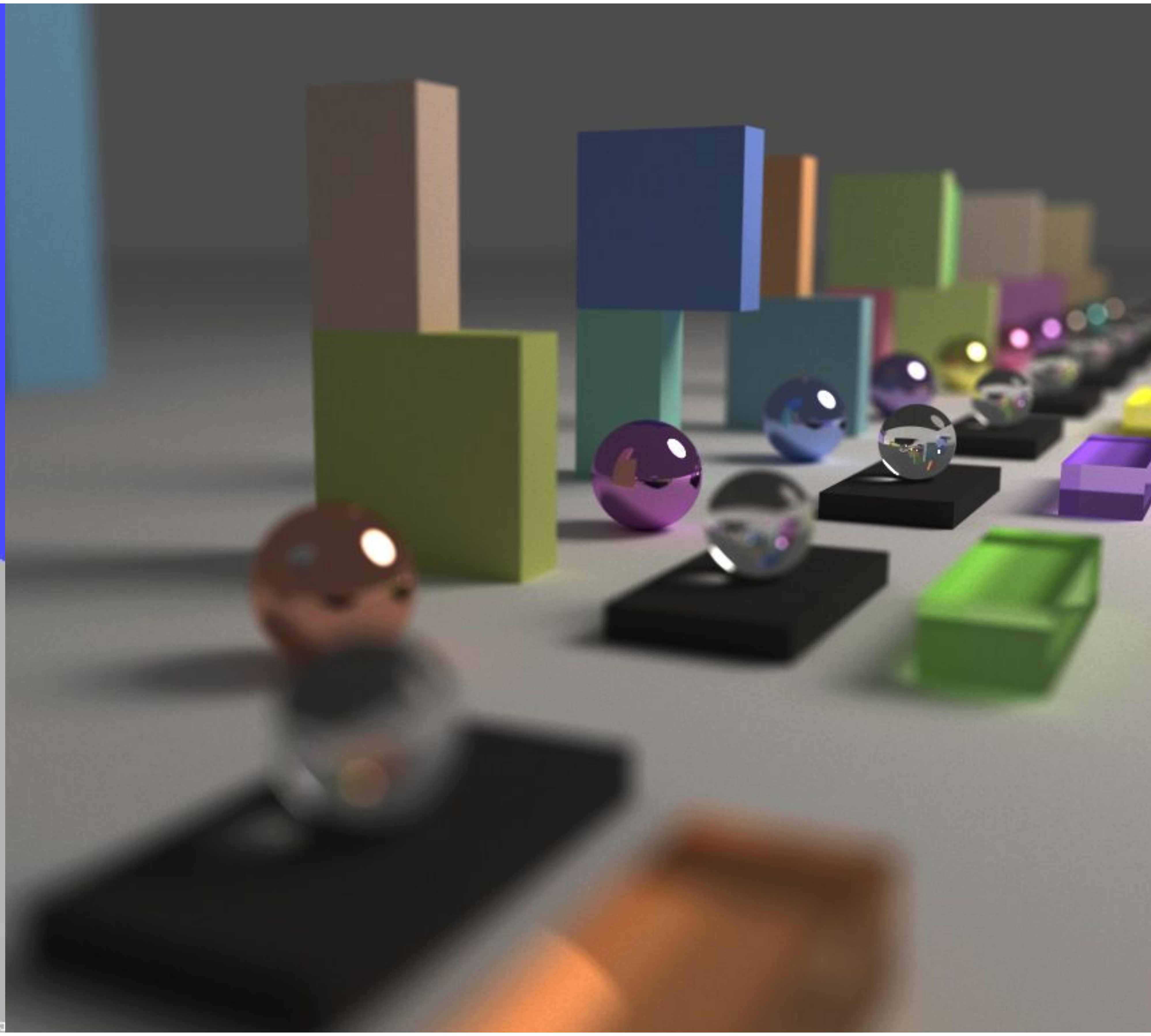
Ren Ng

Path Traced Global Illumination (AKA Proj3-1 and 3-2!)

Ray Tracing vs. Path Tracing



Ray tracing

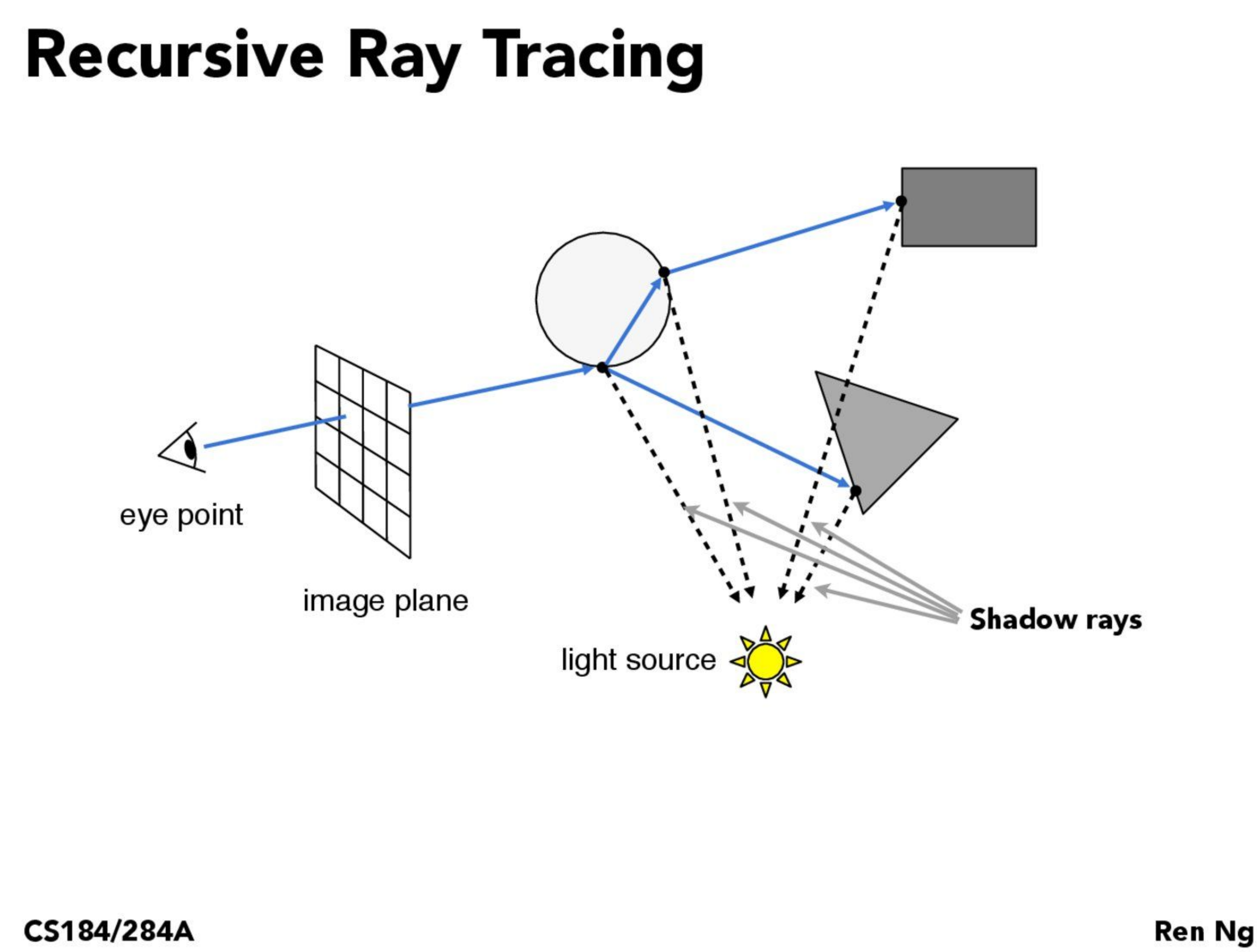


Path tracing

What method will you use to render this?

Path Tracing at a High Level

- Shoot a ray from eye into scene
- Intersect with object
- Figure out how that point is lit
    - (how? — this is the meat of path tracing)



Now let's walk through what we did in Proj 3-1!

Rays and Intersections

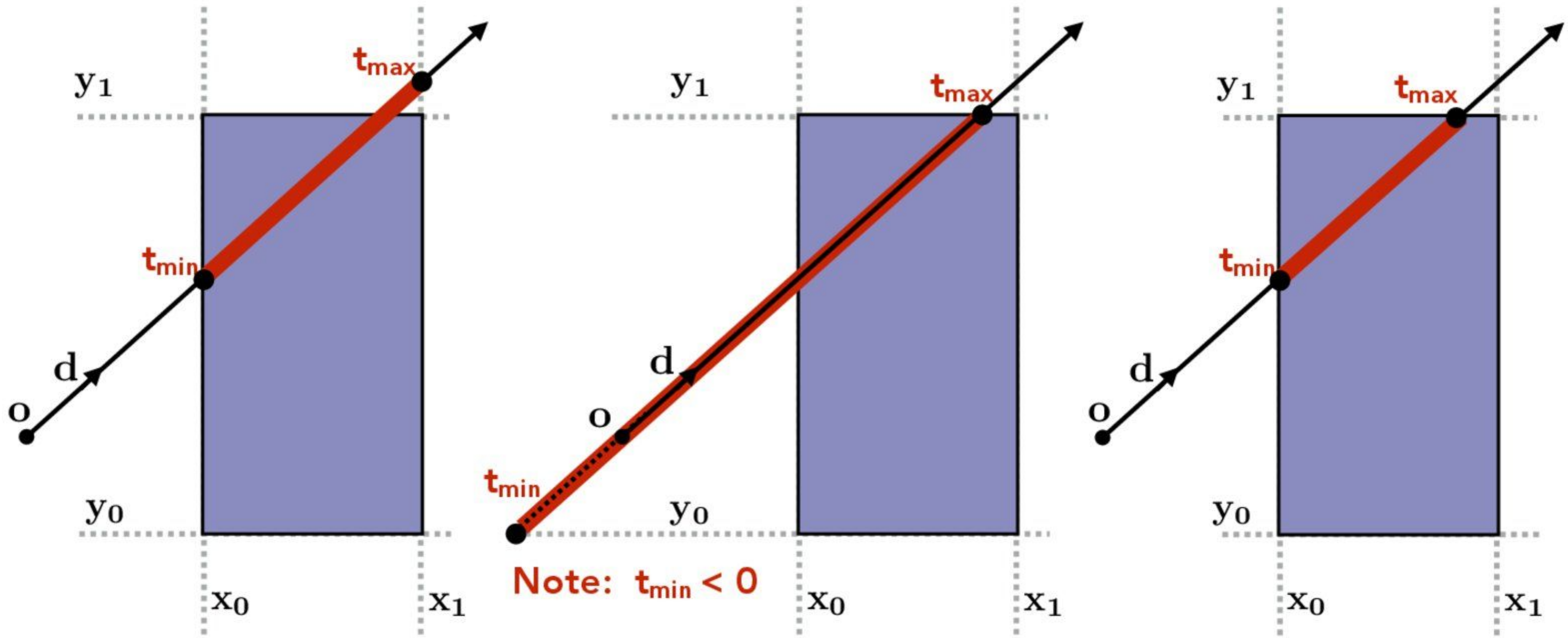
- Iterate over each pixel, and generate some number of samples (1 through the center, or more than one randomly)
- Generate a ray in camera space, and transform that into a ray in world space
- Intersections against two primitives: triangles and spheres
  - How many possible intersections against triangles?
  - How many against spheres?

BVHs and BBox Ray Intersections

- Only an optimization — does this affect correctness?
- Constructing a BVH tree, then testing intersections against that hierarchy
  - Why do we test against both left and right nodes, regardless of success?

Ray Intersection with Axis-Aligned Box

2D example; 3D is the same! Compute intersections with slabs and take intersection of t_{min}/t_{max} intervals



Intersections with x planes

Intersections with y planes

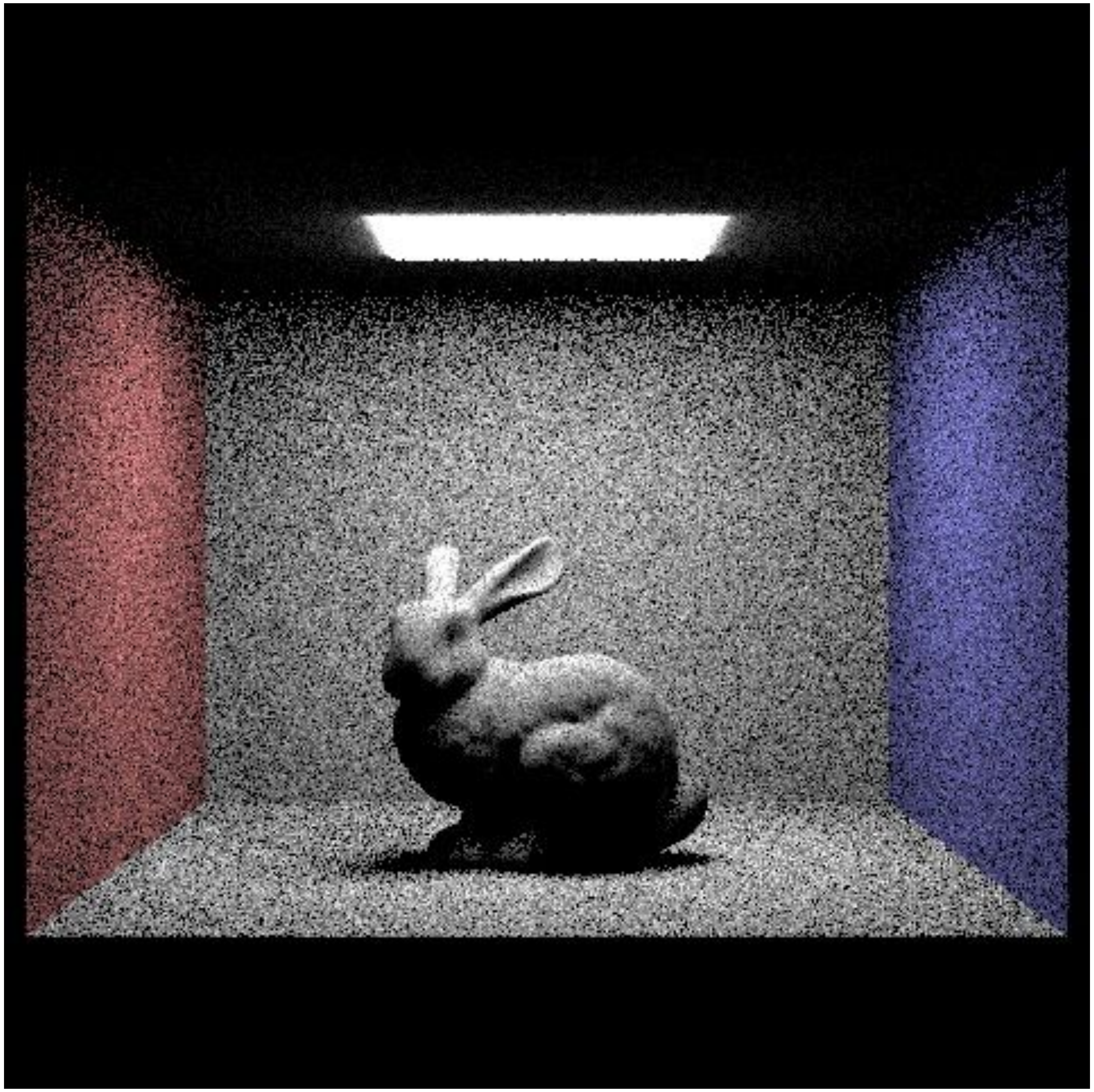
Final intersection result

How do we know when the ray misses the box?

Direct Illumination

- Hemisphere lighting
  - From your hit point, randomly sample a direction (uniformly from hemisphere) and cast a ray that way
  - If this ray hits something, then get the emitted light from that "something"
  - Then scale by the hit point's BSDF (why?), cosine factor (why?), and pdf (why?)

Direct Illumination



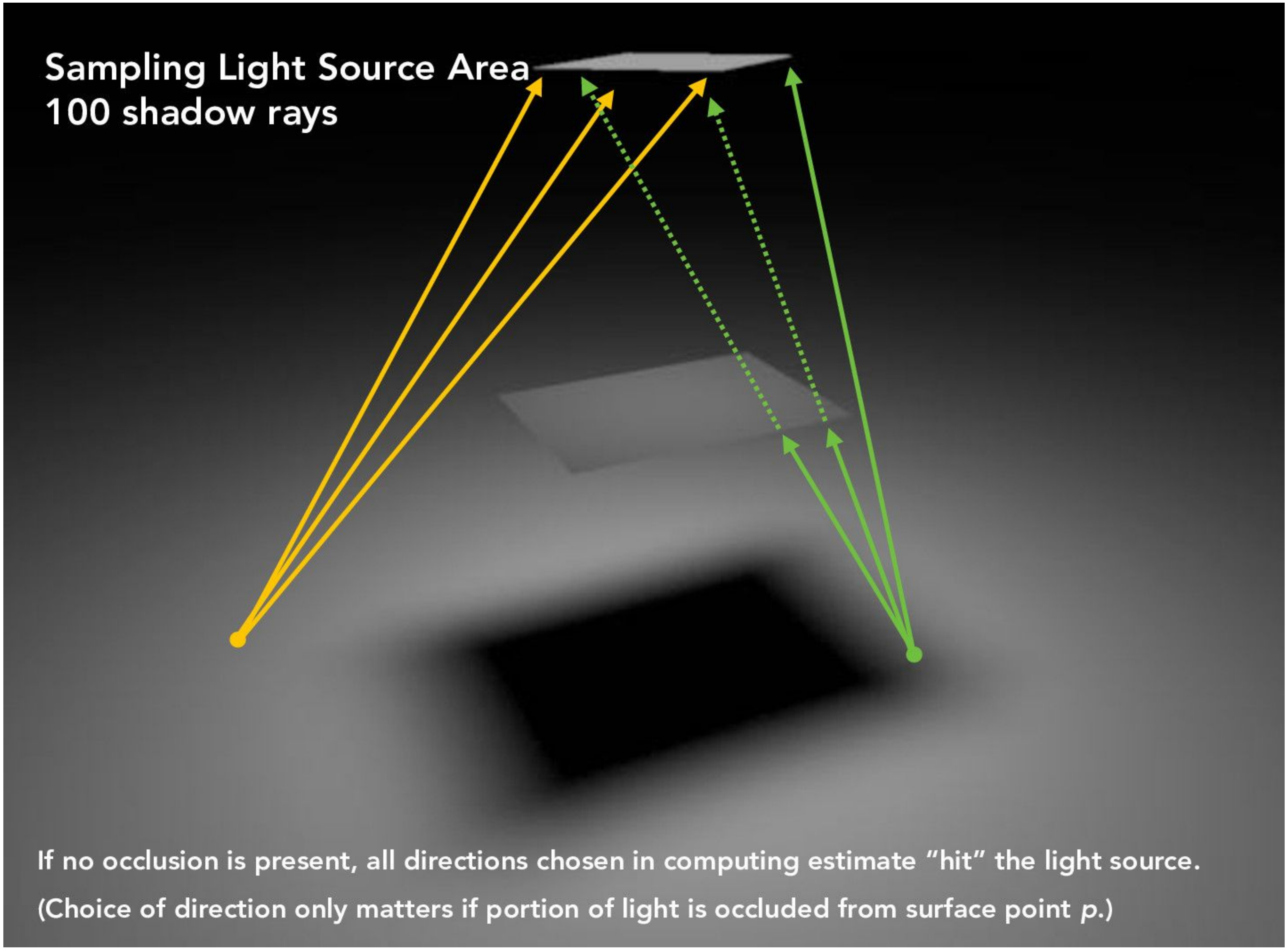
Why is this *correct*, but *noisy*?

How do we improve this?

Direct Illumination

- Importance Sampling
  - We still have a hit point, but rather than sampling a random direction, sample a ray that we know connects the hit point and a point on the light
  - This time, we need a shadow ray — why?

Direct Illumination



Global Illumination

- We broke this into three functions:
  - Zero bounce radiance
  - At least one bounce radiance
    - One bounce radiance

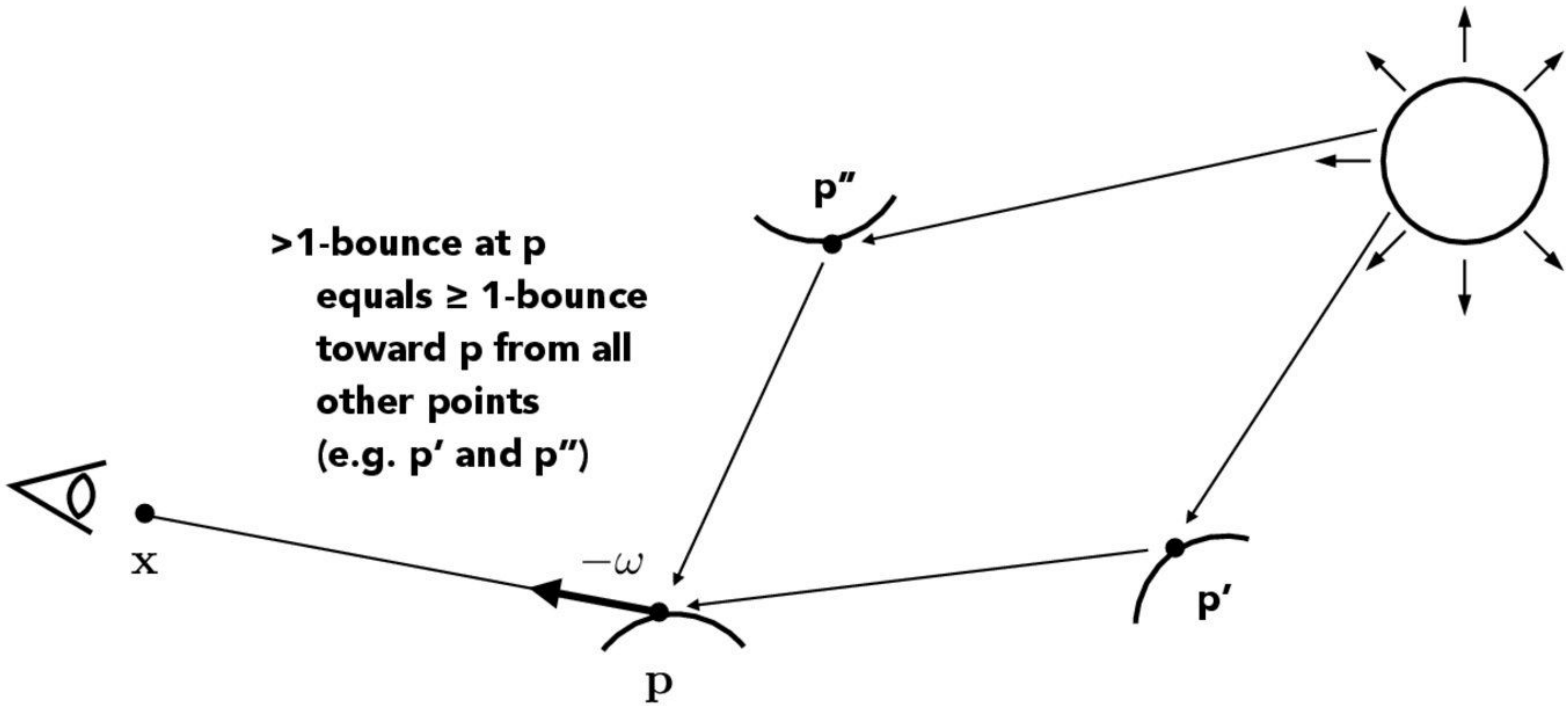
Path Tracing Pseudocode

```
AtLeastOneBounceRadiance(p, wo)                    // out at p, dir wo
   L = OneBounceRadiance(p, wo);                   // direct illum

   wi, pdf = p.brdf.sampleDirection();             // Imp. sampling
   p’ =  intersectScene(p, wi);
   cpdf = continuationProbability(p.brdf, wi, wo);
   if (random01() < cpdf)                          // Russ. Roulette
      L += AtLeastOneBounceRadiance(p’, -wi)  // Recursive est. of
      * p.brdf(wi, wo) * costheta / pdf / cpdf;// indirect illum
   return L;


OneBounceRadiance(p, wo)                           // out at p, dir wo
    return DirectLightingSampleLights(p, wo); // direct illum
```

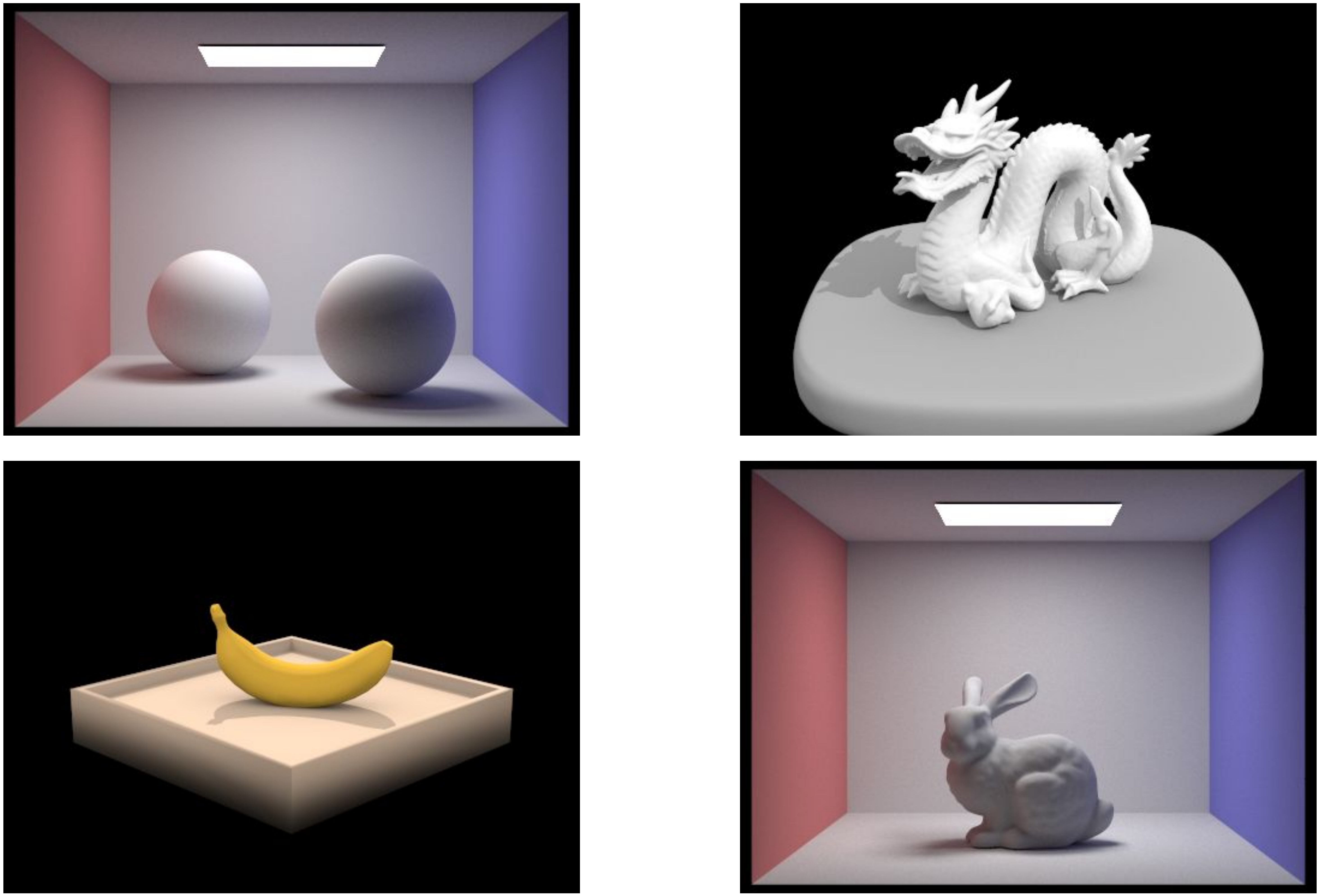
Consider Evaluation of >1 Bounce of Light



At p, consider light contributions from paths of varying bounce-length

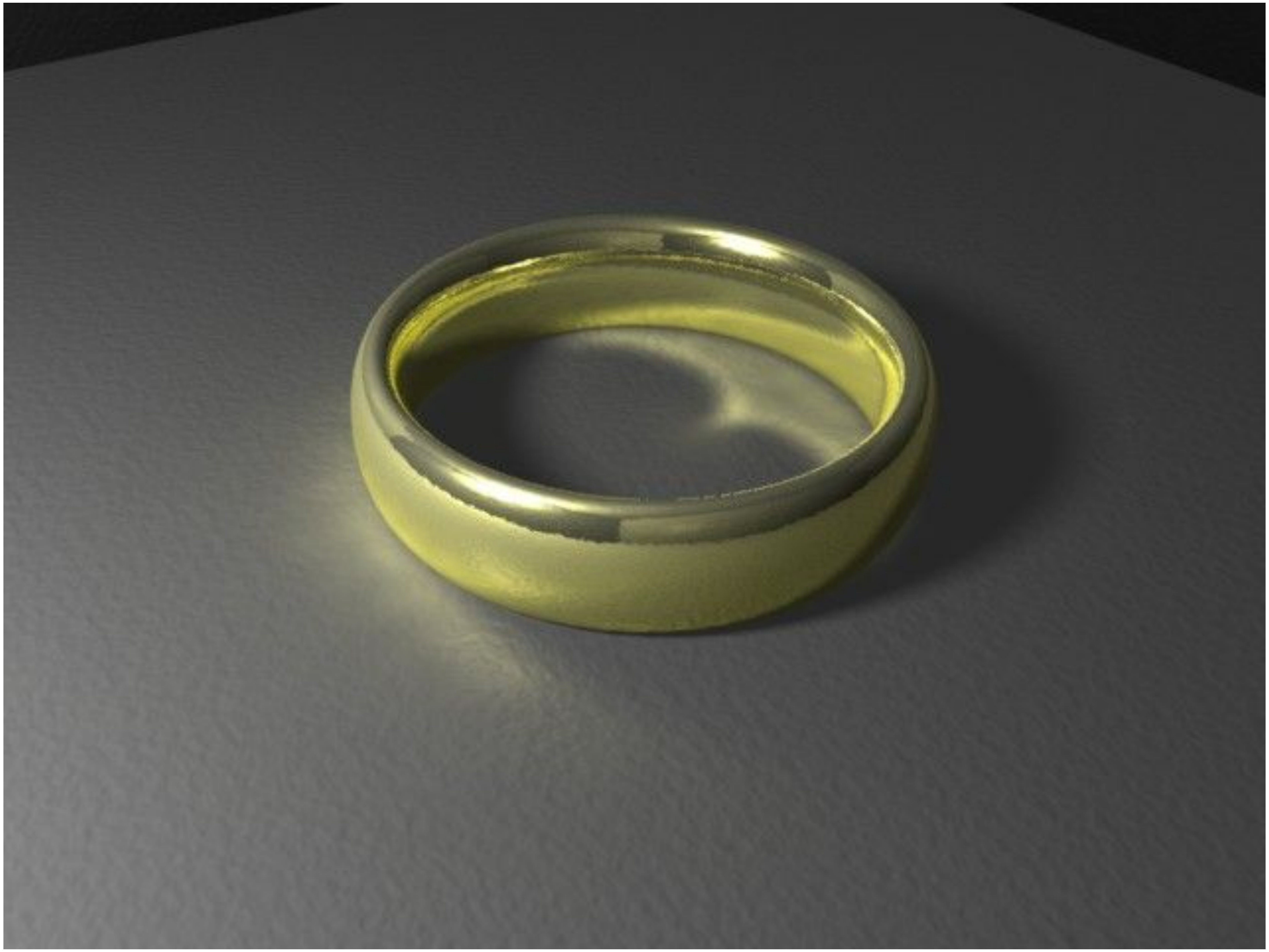
- 0-bounce: light emitted from p (p is on a light source)
- 1-bounce: from light to p to x ("direct illumination")
- >1-bounce: from light to at least one other point to p to x ("indirect illumination")

Now we can render scenes like:



What's the difference w/ or w/o GI?

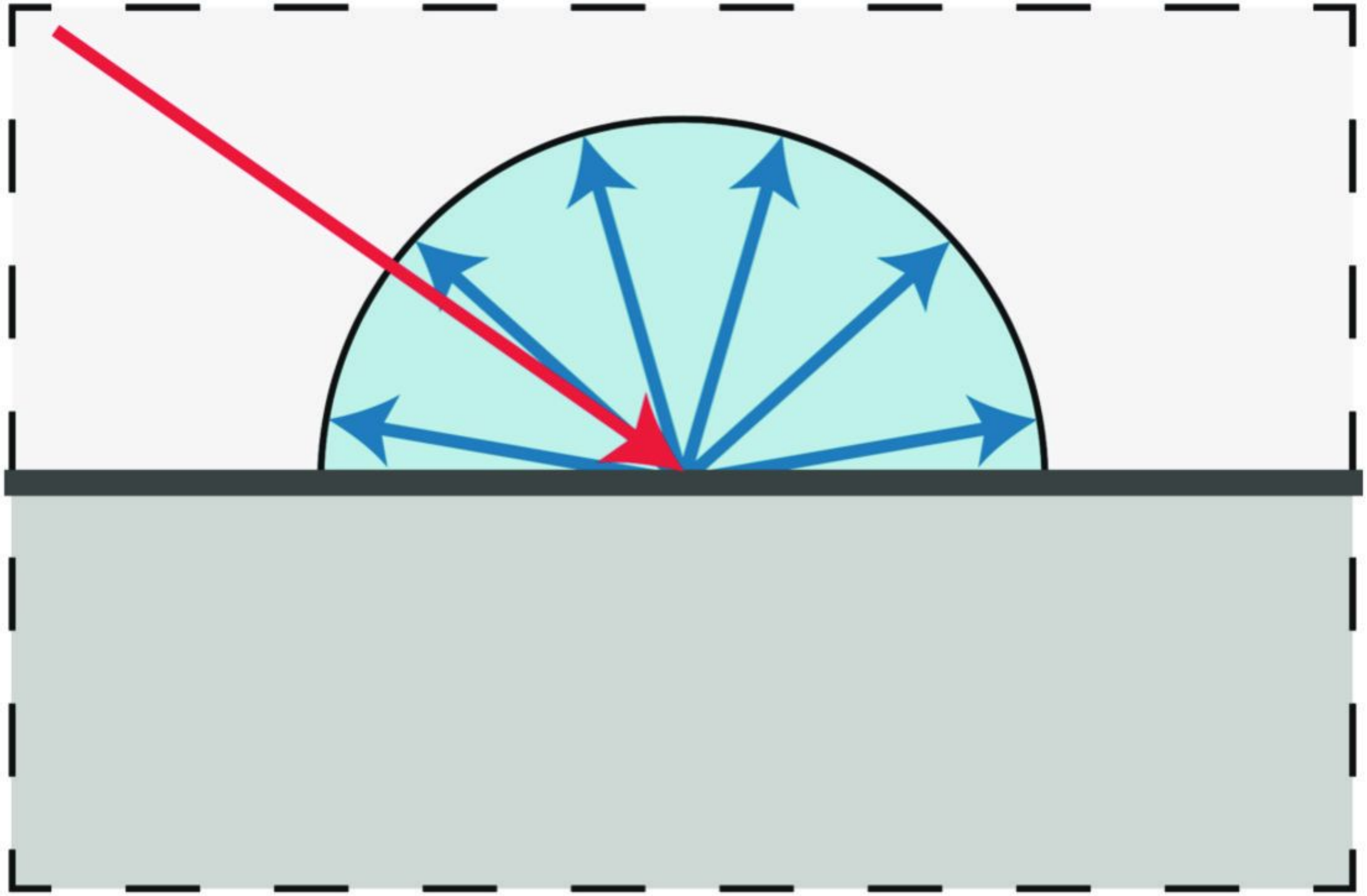
Is Path Tracing Suitable to Render This Scene?



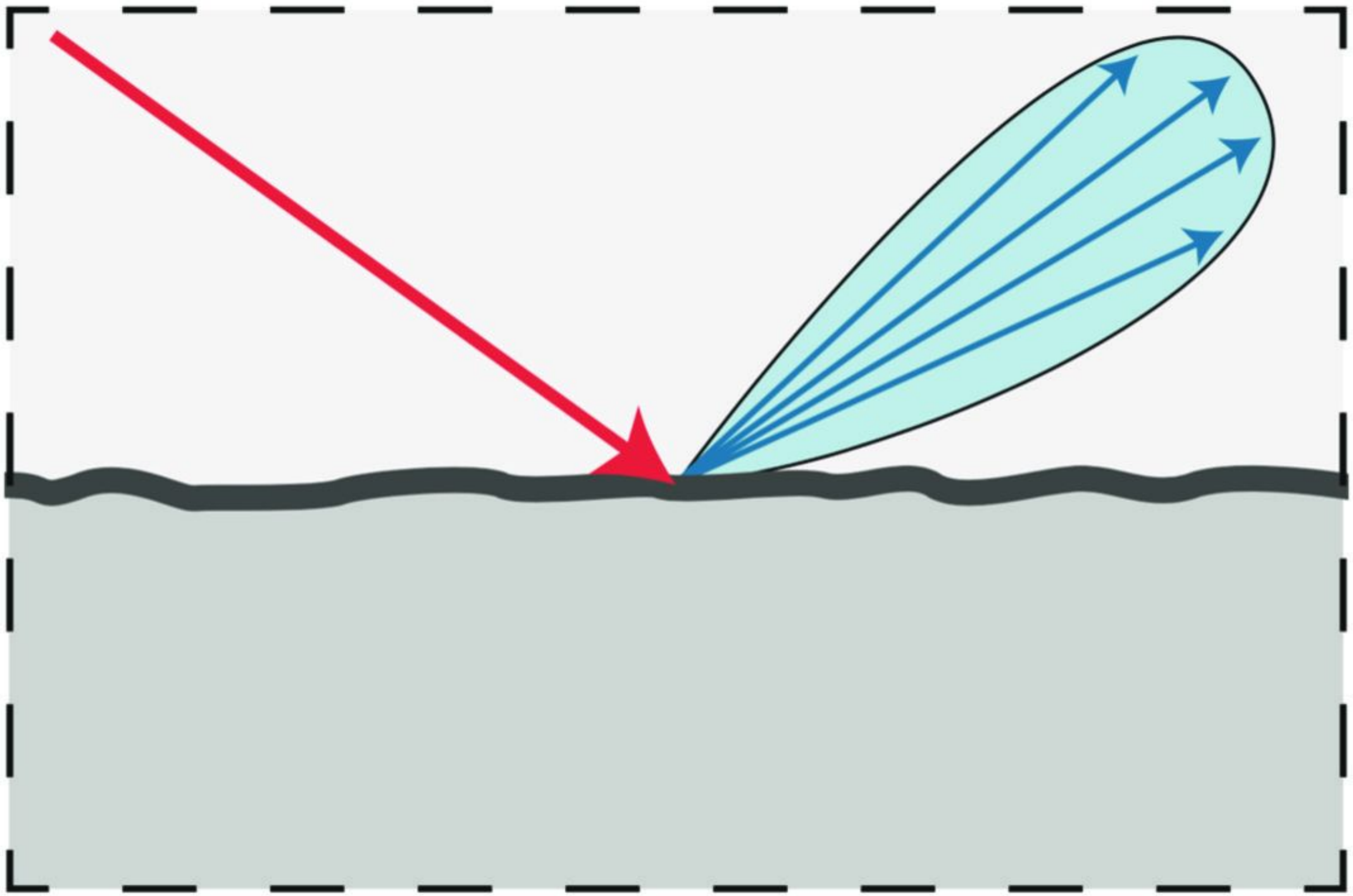
Material

What materials will you use to render this?

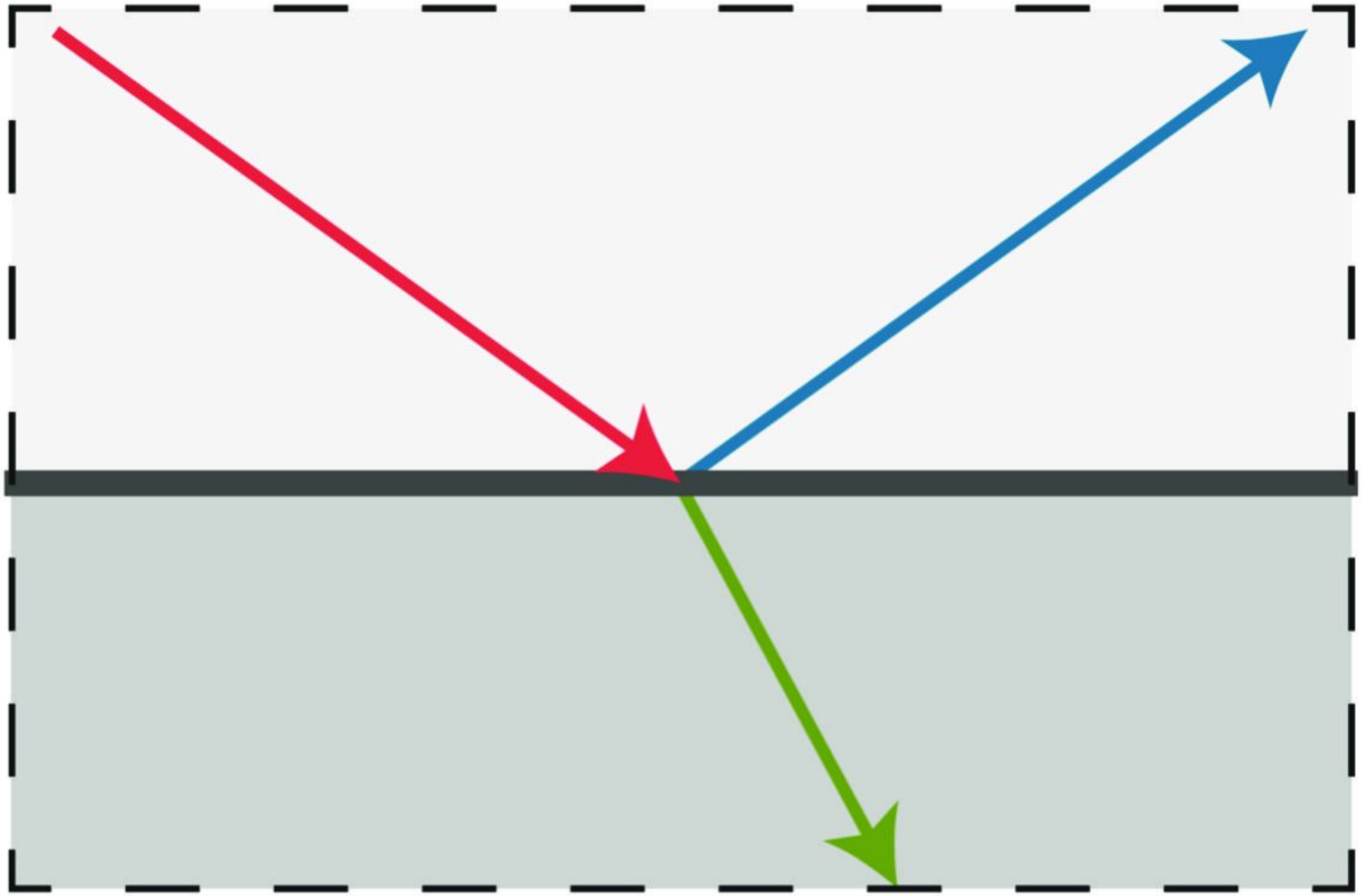
What is this material?

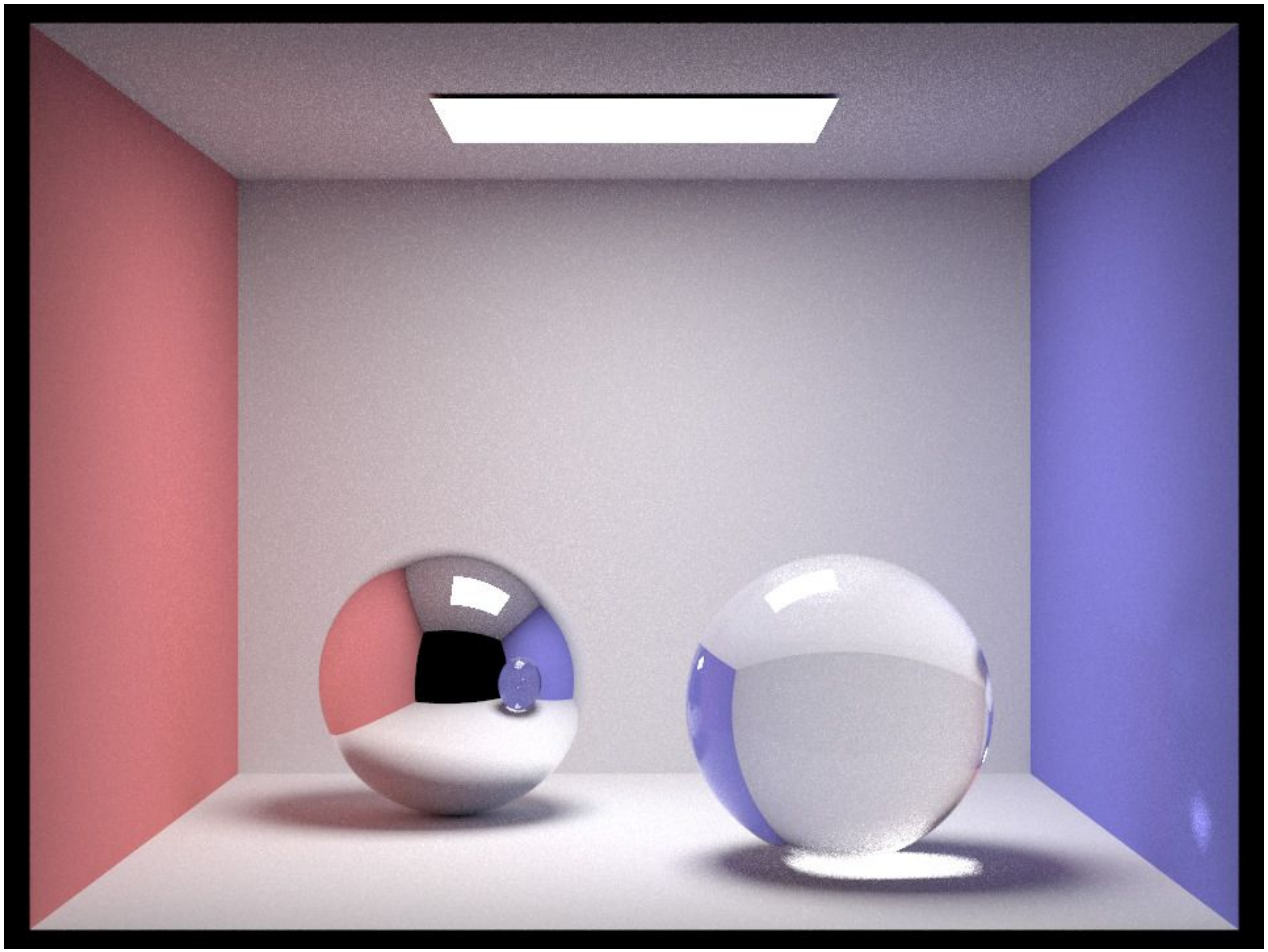


What is this material?



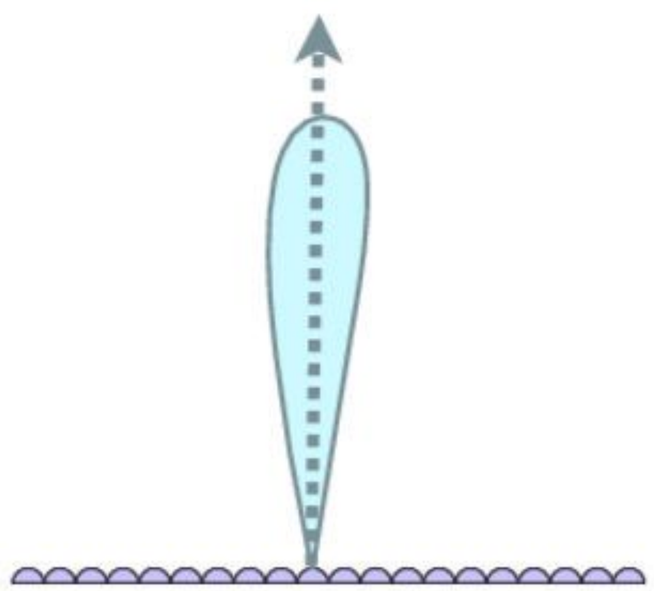
What is this material?



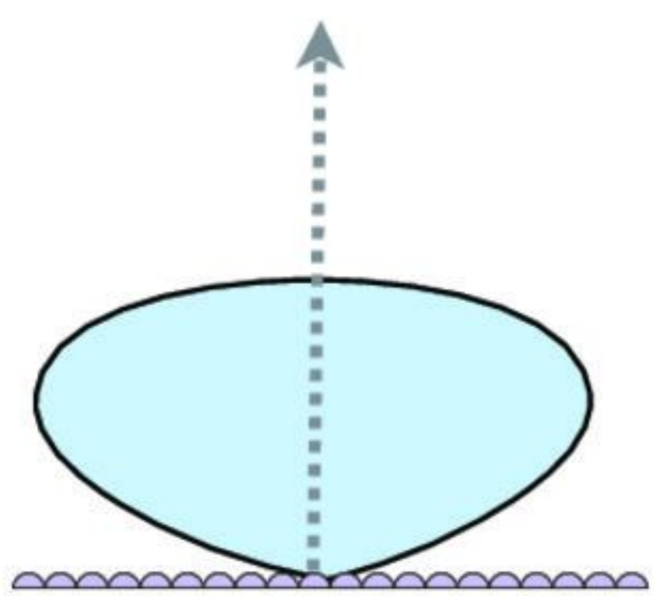


Microfacet BRDF

- Key: the distribution of microfacets' normals
  - Concentrated <==> glossy



  - Spread <==> diffuse

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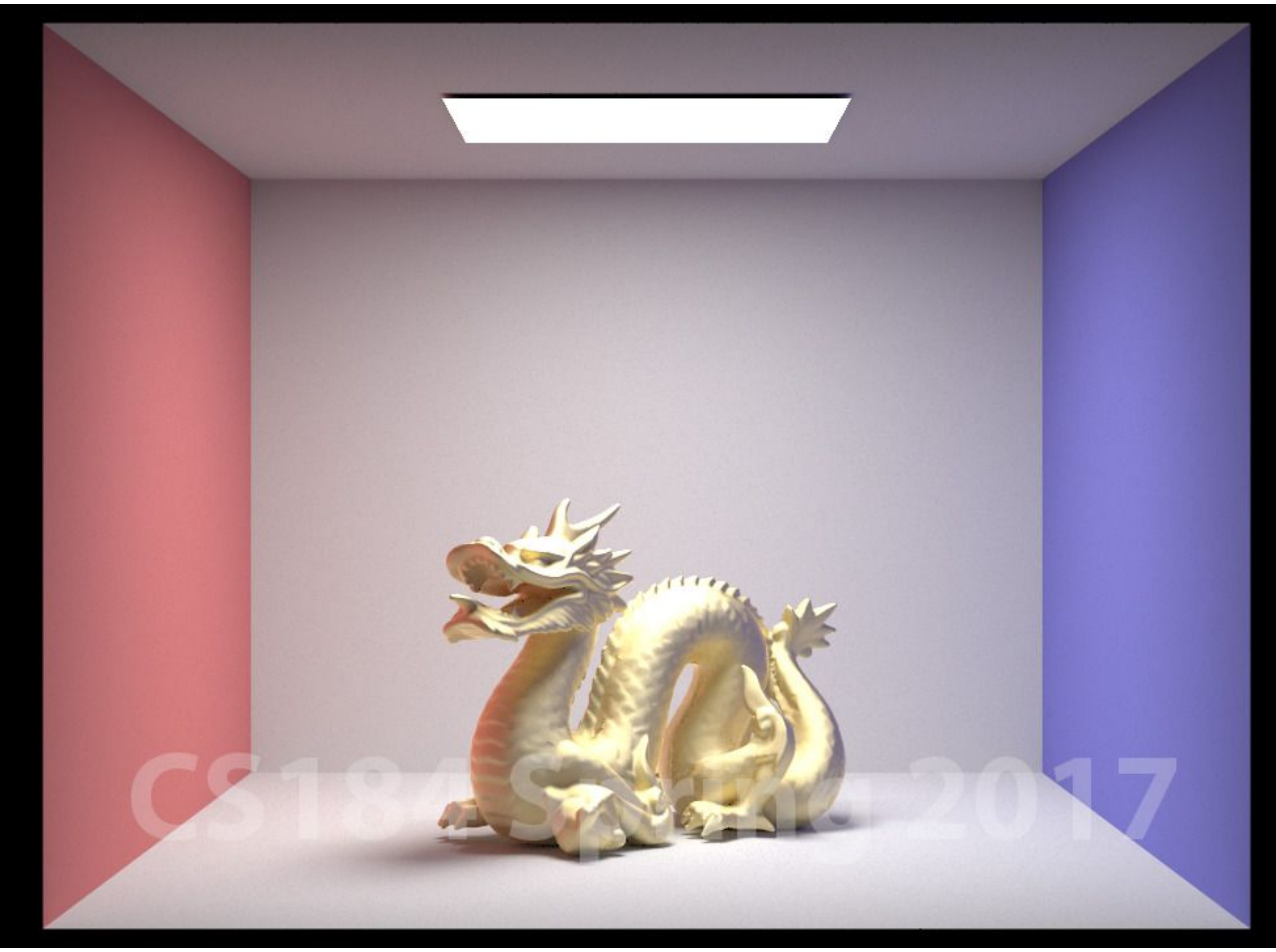
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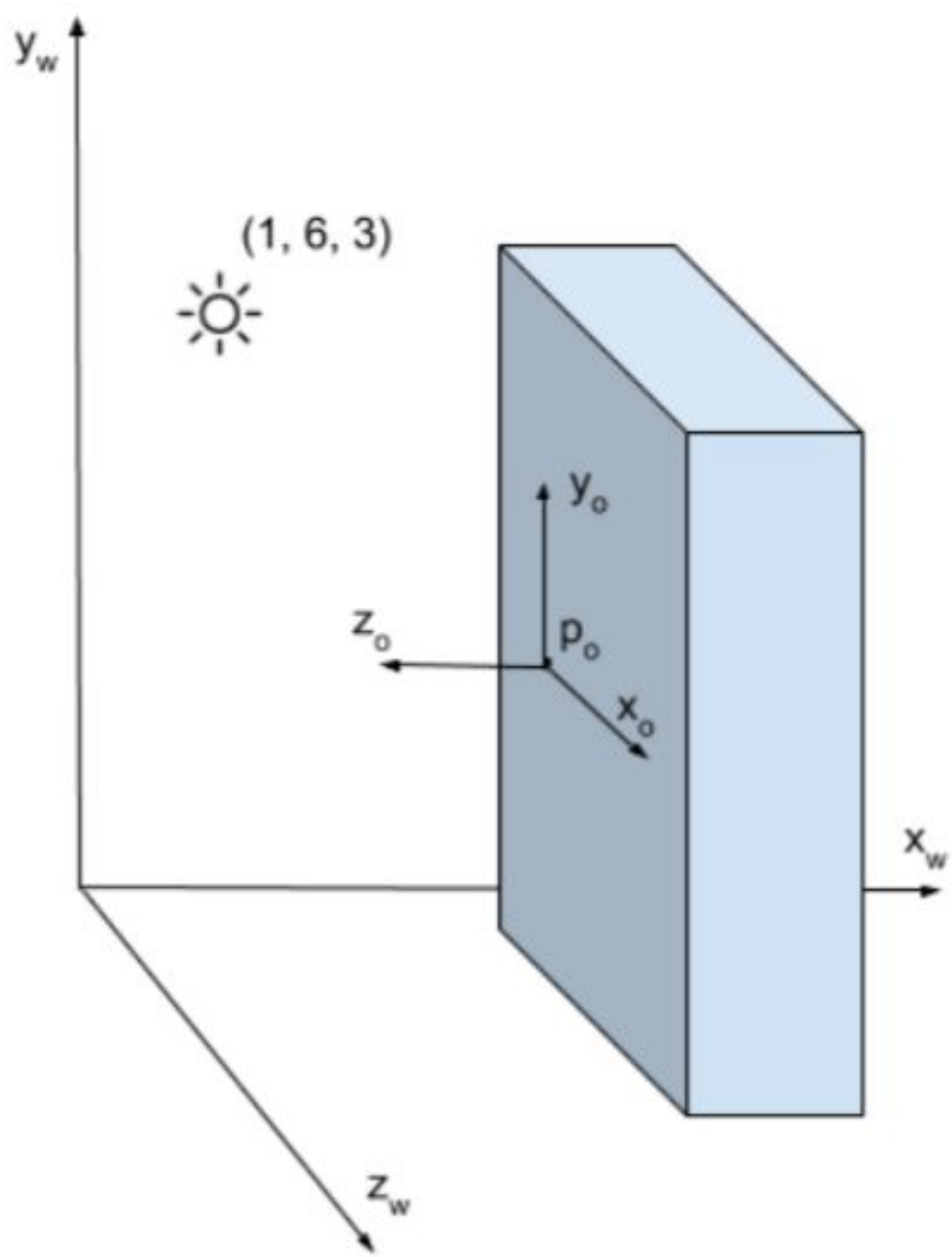
Past Midterms

Sp18 Exam 1

(c) Suppose we are trying to calculate the diffuse Lambertian term of the shaded color for a surface point p_o, as shown below.



Sp18 Exam 1

In world coordinates, let $p_o = (3, 4, 3)$ be the origin of the object's coordinate system, and let the object's local axes be $x_o = (0, 0, 1), y_o = (0, 1, 0), z_o = (-1, 0, 0)$. The scene has a single point light, located at $p_l = (1, 6, 3)$, also in world coordinates.

i. (3 points) What is the homogeneous change of coordinates matrix from object to world space? That is, what is the matrix M_{o2w} such that $M_{o2w}\, x_{obj} = x_{world}$? Hint: it should be in the form

$$M_{o2w} = \begin{bmatrix} \mathbf{u} & \mathbf{v} & \mathbf{w} & \mathbf{o} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

ii. (3 points) The diffuse Lambertian term of a surface shading calculation has the form

$$L_d = k_d \left(\frac{I}{r^2} \right) \max(0, n \cdot l)$$

For this light, $k_d = 1$, $I = 16$. What is r^2 for the given point on the surface with respect to the light?

Sp18 Exam 1

iii. (3 points) What is l in object coordinates, normalized?

iv. (3 points) Putting it all together, what is the diffuse Lambertian term L_d?

Sp18 Exam 1

(a) Ray-Cylinder Intersection

i. (4 points) In lecture, we have seen how to determine the points of intersection of a ray with a box or a sphere. In this question we will perform a similar derivation of the intersection points of a ray and a cylinder. Recall the equation for an infinitely-long cylinder aligned along the z-axis with radius r:

$$x^2 + y^2 - r^2 = 0$$

Consider a ray with origin $\mathbf{o} = (-2, -2, -2)$ and direction $\mathbf{d} = (1, 1, 1)$, with a ray equation $\mathbf{r}(t) = \mathbf{o} + t\mathbf{d}$. Calculate any and all t-value(s) for intersection with this ray and the infinitely-long cylinder aligned along the z-axis with radius 2. Write the smaller intersection time into t_0 and the larger into t_1.

$t_0 =$ ______________

$t_1 =$ ______________