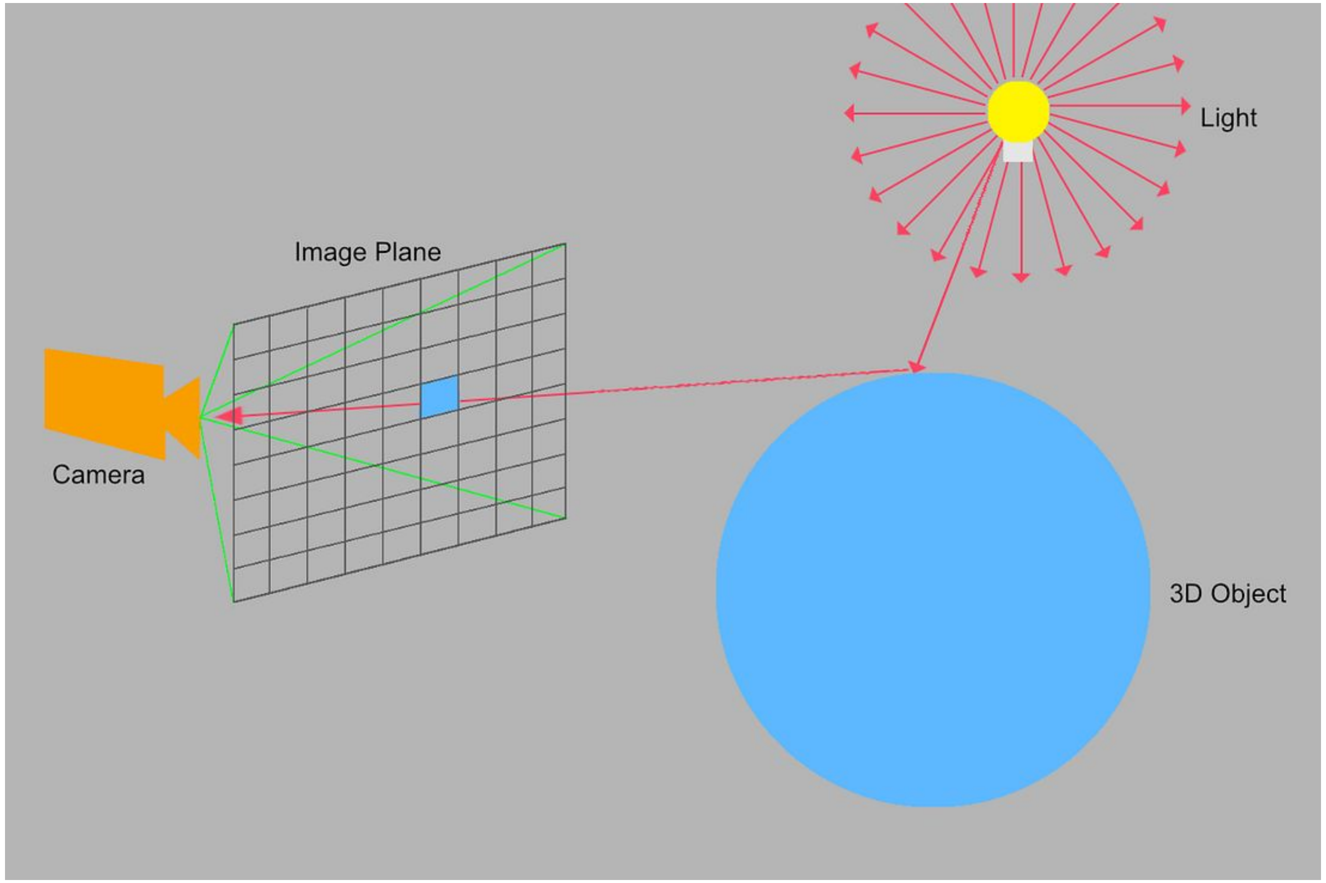
GPU-Accelerated Ray Tracing

By: Zeyad Al Awwad

Ray Tracing: Basic Idea

Track the paths of millions of light rays as they interact with the environment

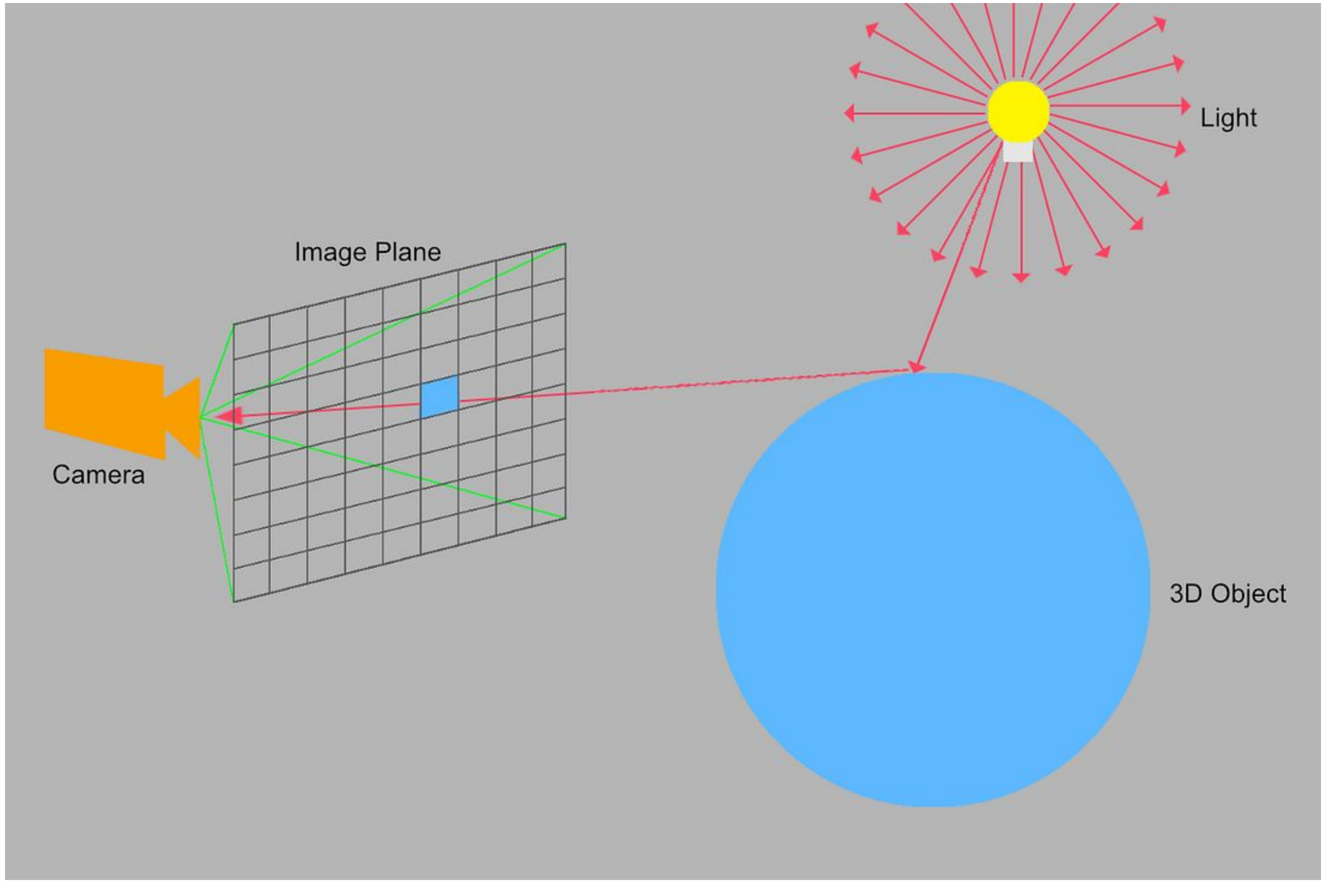


Source: https://si-ashbery.medium.com/raytracing-309fc44307e6

Ray Tracing: Basic Idea

Track the paths of millions of light rays as they interact with the environment

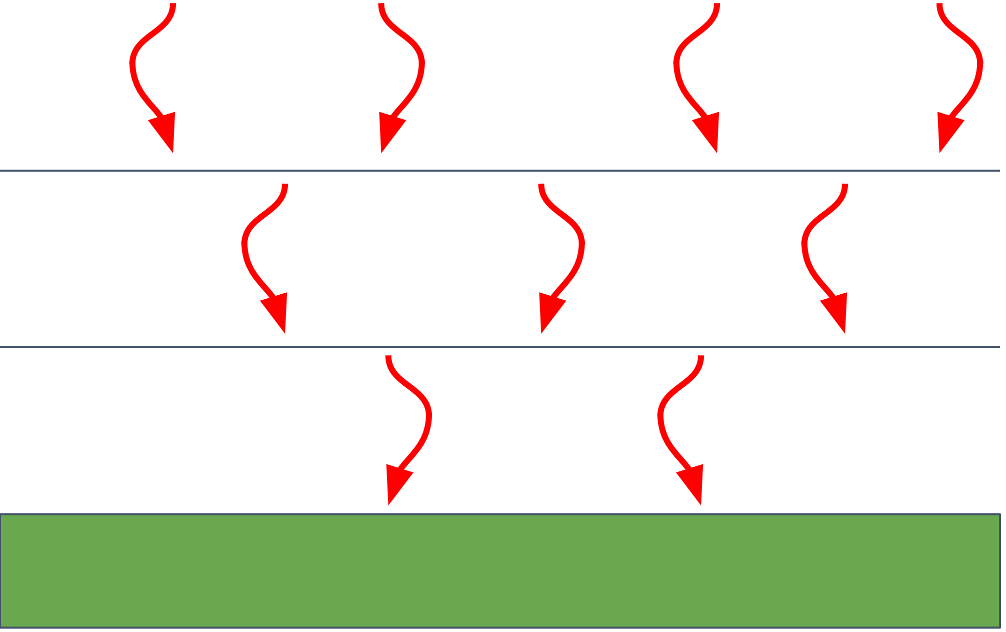
3D Renderer
Cast from the camera



Optical Simulation
Cast from light sources

Source: https://si-ashbery.medium.com/raytracing-309fc44307e6

In climate modeling, we solve radiative equilibrium problems involving integrals



Every layer has a temperature, pressure, composition, opacity, etc
All coupled through radiation!
(and convection)

Scientific Applications

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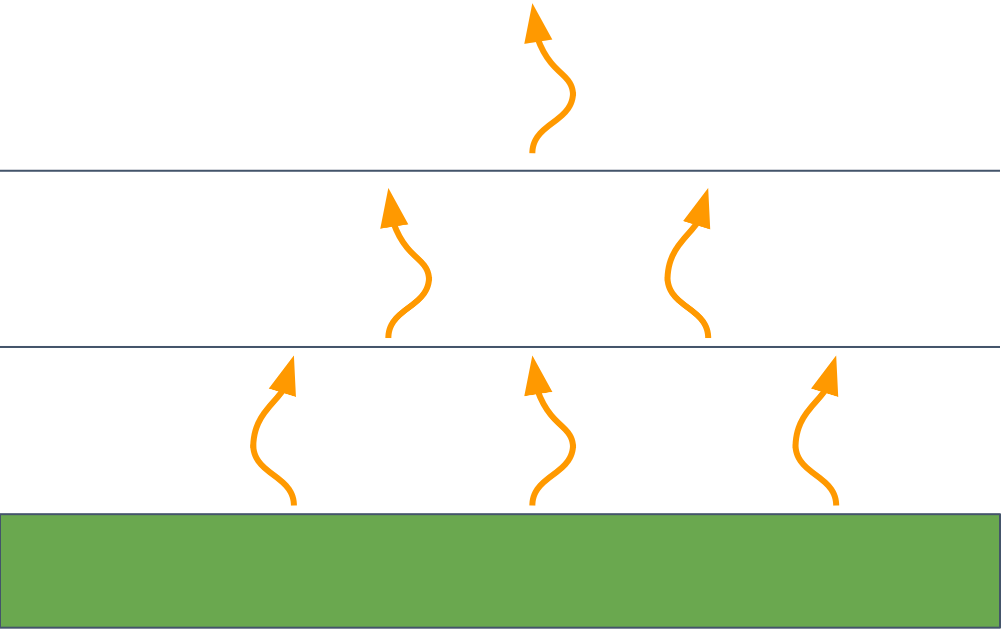

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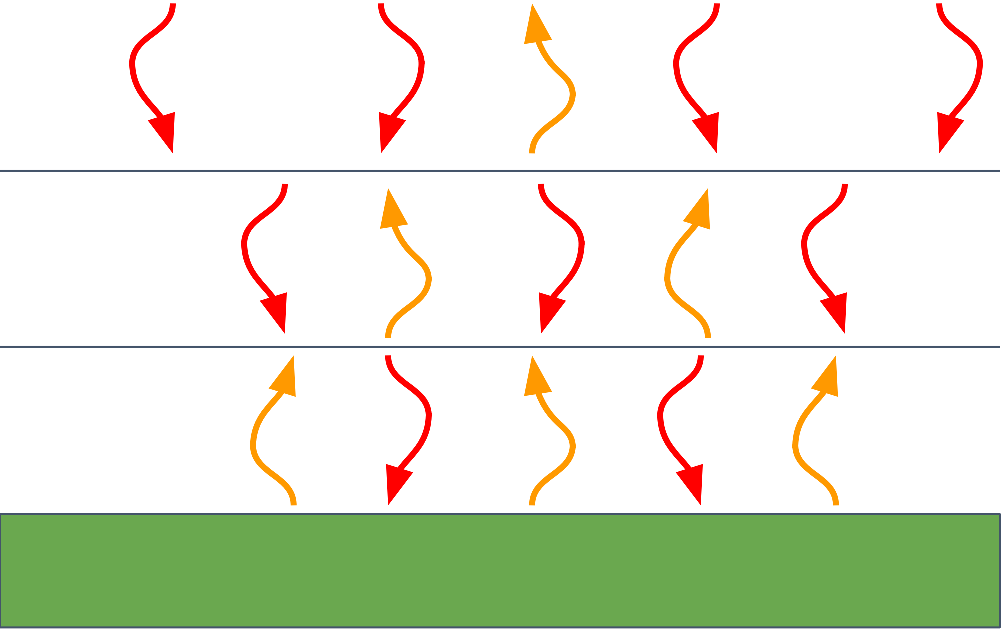
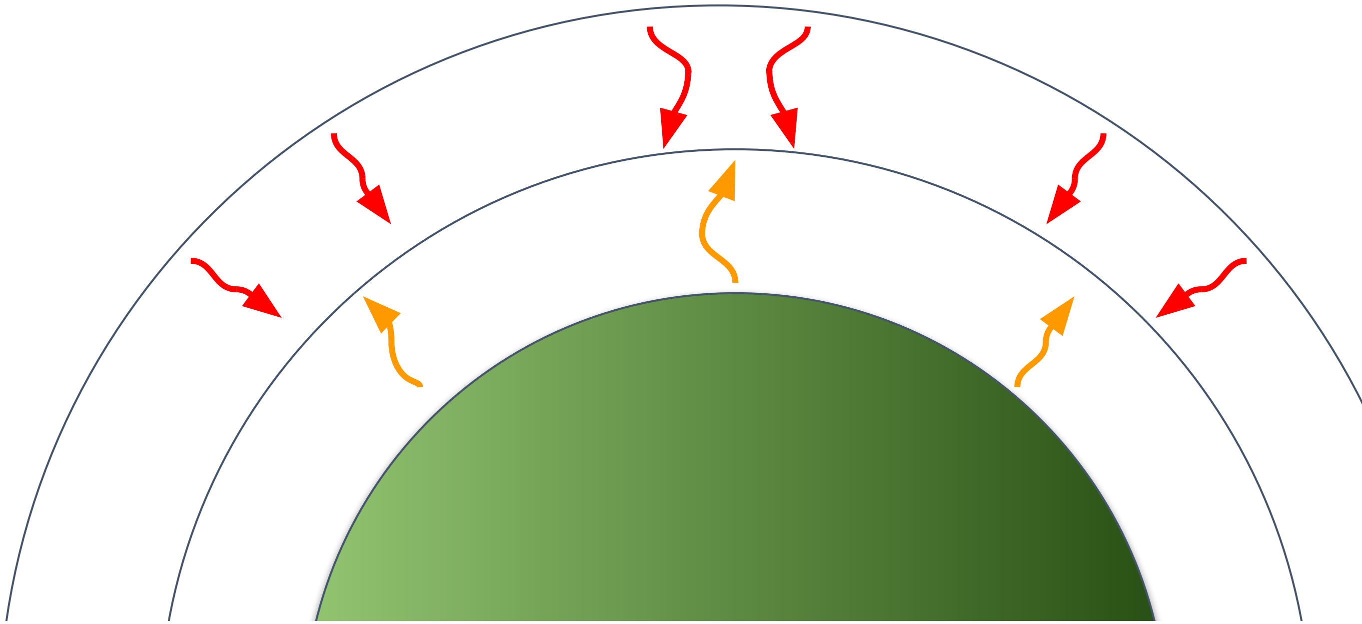
Scientific Applications

It turns out to be a scalable Monte Carlo integrator for 3D radiation problems!





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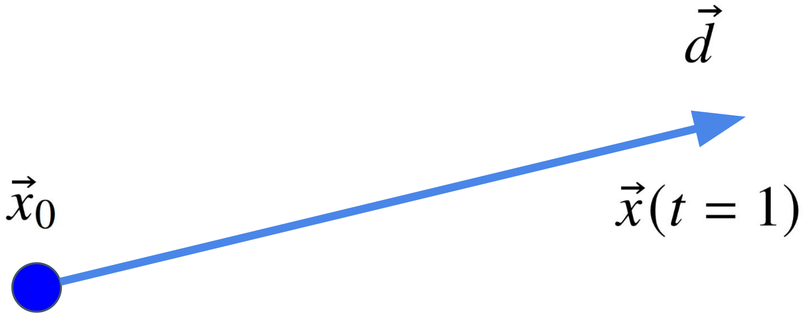
Parameterized Geometry

Light rays are modeled with a parameterized equation

$$\vec{x}(t) = \vec{x}_0 + t \cdot \vec{d}$$



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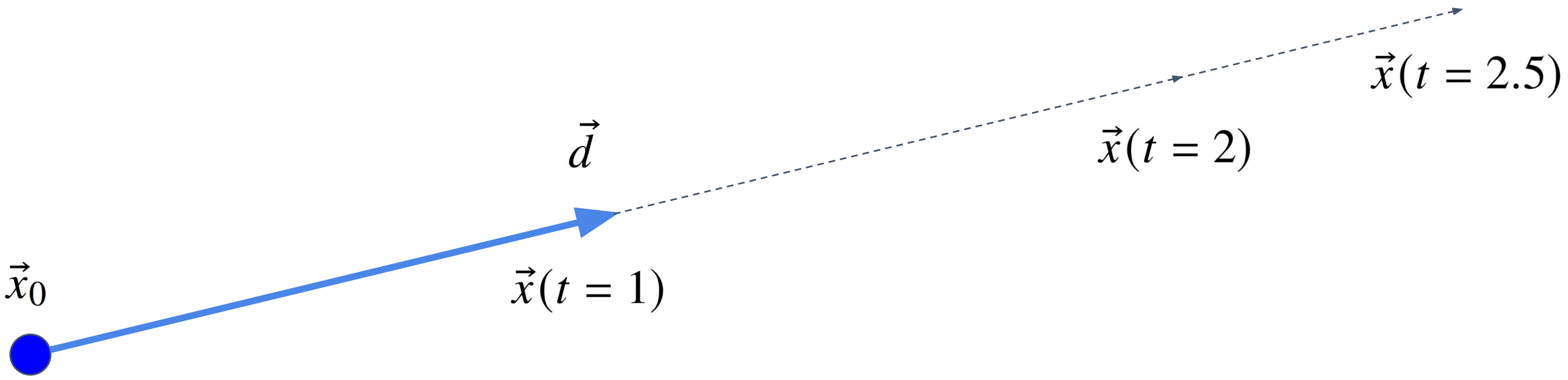

Parameterized Geometry

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$$\vec{x}(t) = \vec{x}_0 + t \cdot \vec{d}$$

Shape intersections come from implicit equations, where you solve for *t*

Circles

$$t^2\ \vec{d} \cdot \vec{d} + t\ 2\vec{d} \cdot \Delta\vec{x} + \Delta\vec{x} \cdot \Delta\vec{x} = r^2$$

Triangles

$$\begin{bmatrix} x_a - x_b & x_a - x_c & x_d \\ y_a - y_b & y_a - y_c & y_d \\ z_a - z_b & z_a - z_c & z_d \end{bmatrix} \begin{bmatrix} \beta \\ \gamma \\ t \end{bmatrix} = \begin{bmatrix} x_a - x_p \\ y_a - y_p \\ z_a - z_p \end{bmatrix}$$

Being solved on every thread (need to be careful with register use!)

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$$t = \frac{b \pm \sqrt{b^2 - 4ac}}{2a}$$

Triangles

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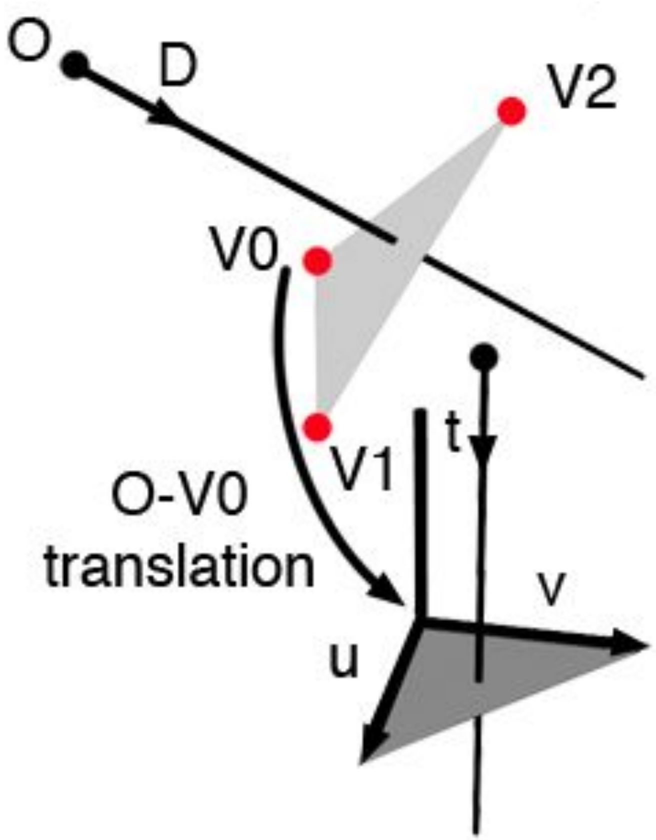
Moller-Trumbore Method

Transforming to barycentric coordinates greatly simplify triangle intersections

$$T = O - A$$
$$E_1 = B - A$$
$$E_2 = C - A$$

$$P = (D \times E_2)$$
$$Q = (T \times E_1)$$



Source: https://www.scratchapixel.com/lessons/3d-basic-rendering/ray-tracing-rendering-a-triangle/moller-trumbore-ray-triangle-intersection.html

Moller-Trumbore Method

Transforming to barycentric coordinates greatly simplify triangle intersections

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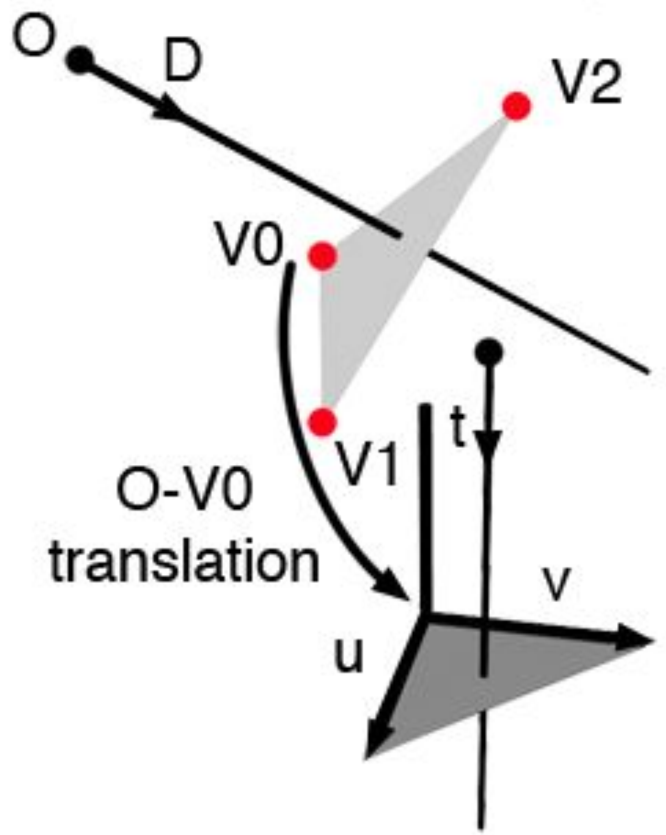
$$P = (D \times E_2)$$
$$Q = (T \times E_1)$$

$$\begin{bmatrix} t \\ u \\ v \end{bmatrix} = \frac{1}{P \cdot E_1} \begin{bmatrix} Q \cdot E_2 \\ P \cdot T \\ Q \cdot D \end{bmatrix}$$



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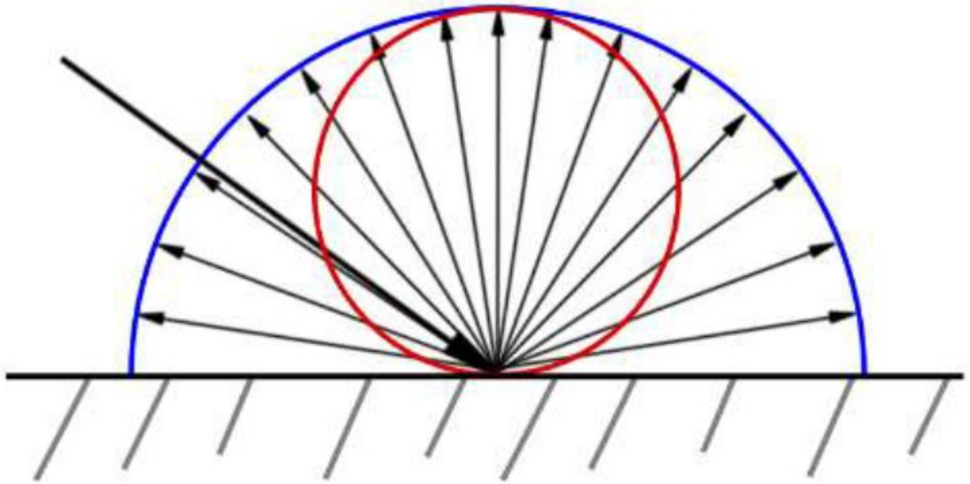
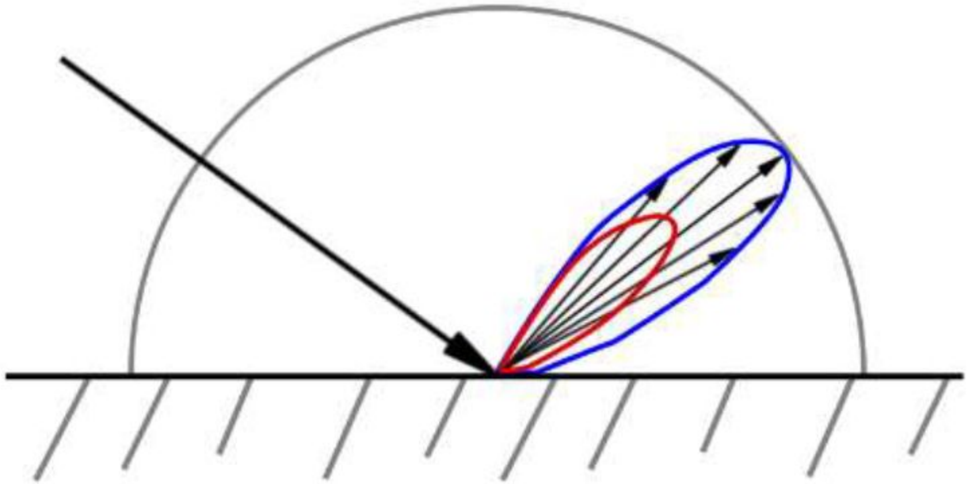
At each intersection, we may create a new ray (a “bounce”) based on effects like

Diffuse Reflections



“Matte” materials

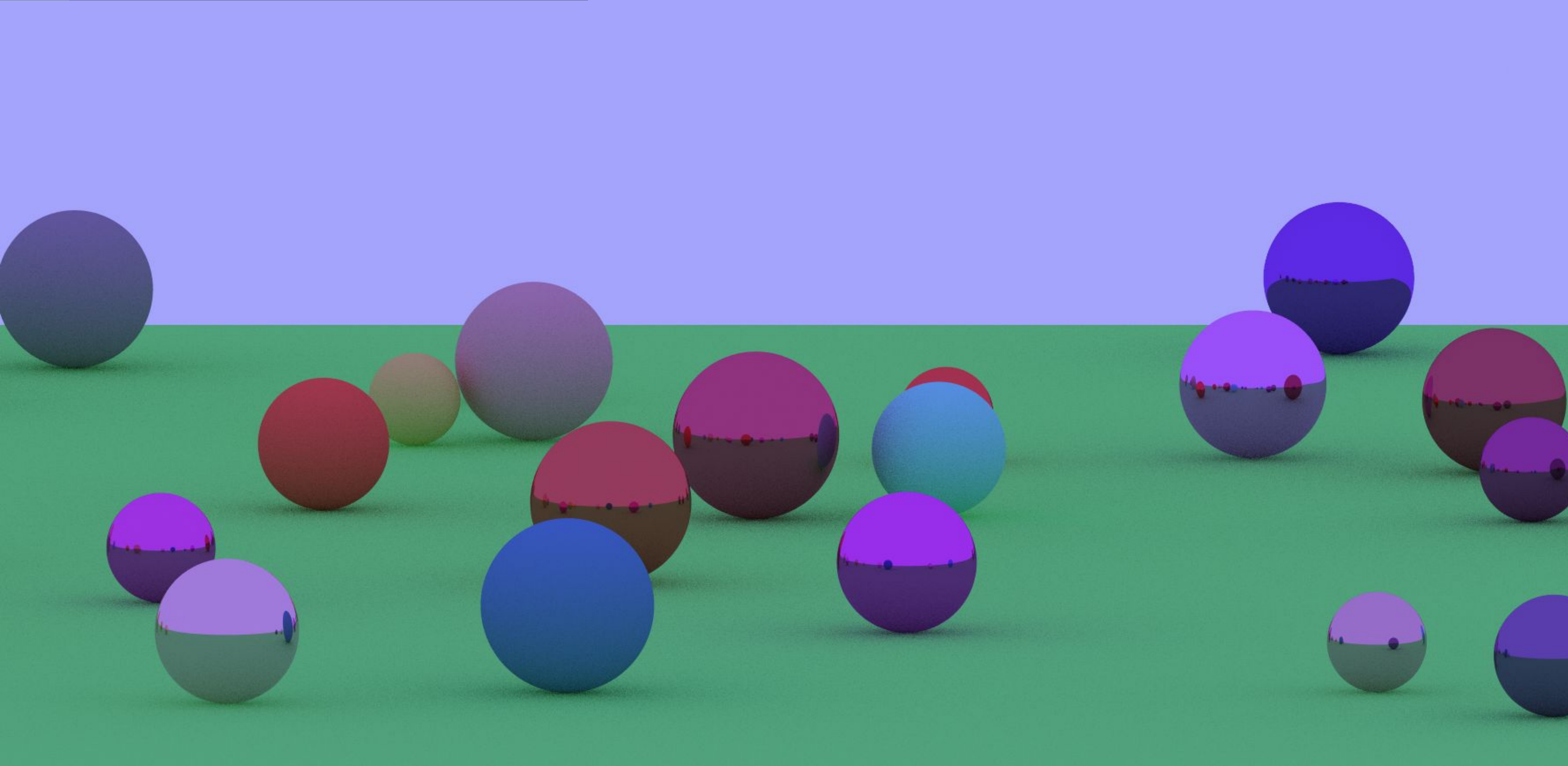
Specular Reflections



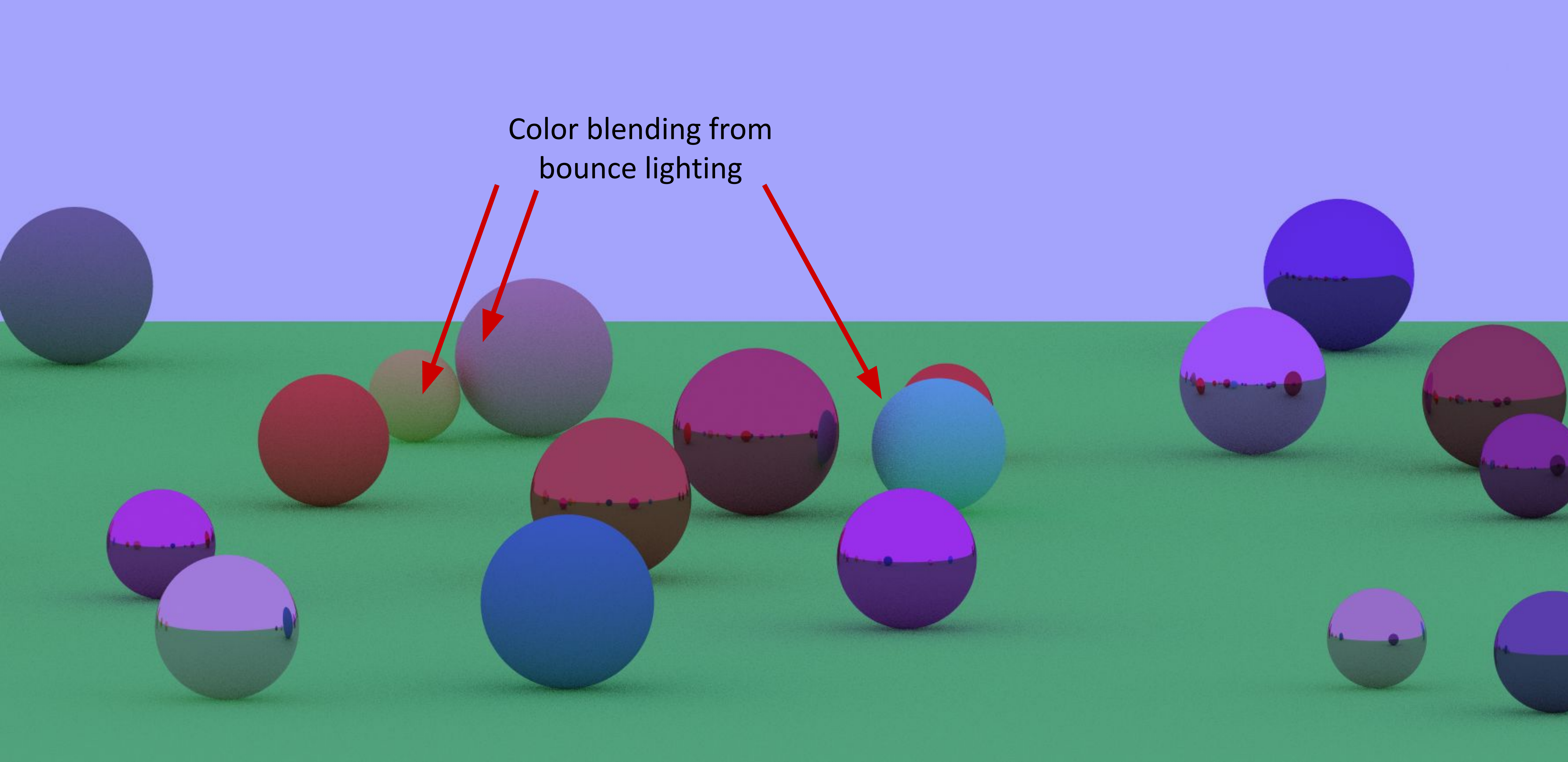
“Glossy” materials

Currently implementing refraction (transparency) and absorption (heating)

Results



Results



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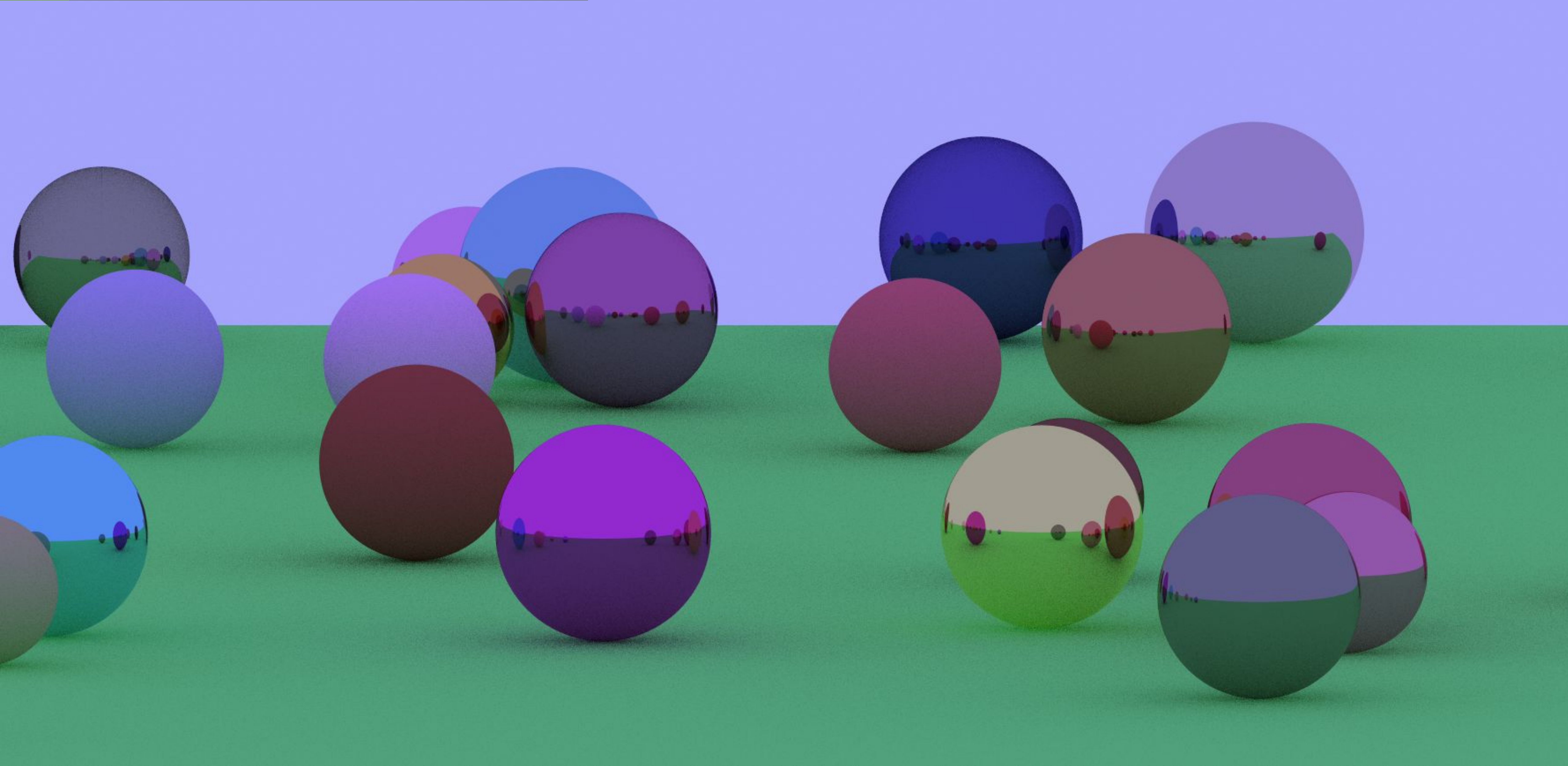

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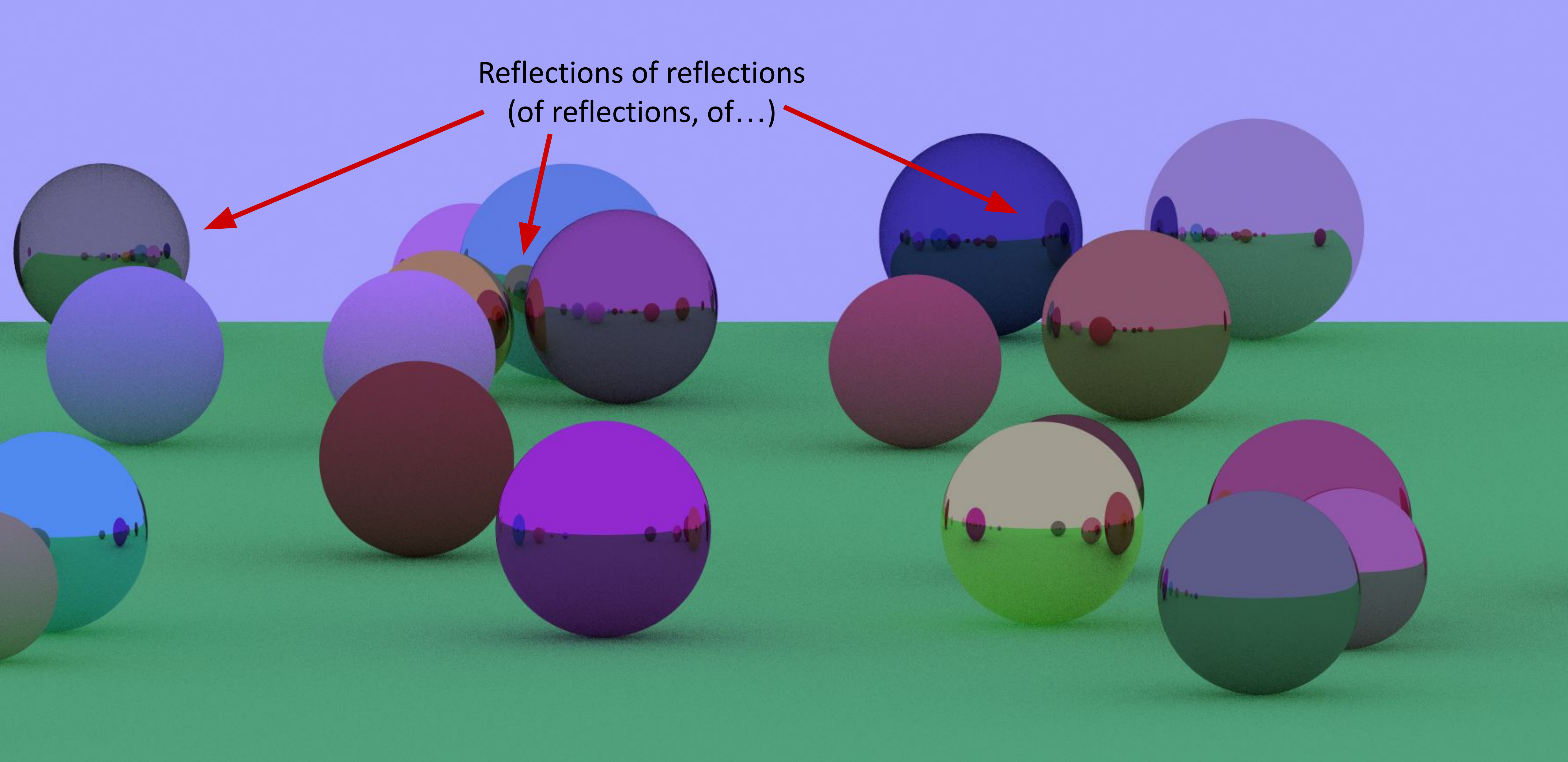

Current Performance

Vastly faster than CPU ray tracing, but not as fast as commercial solutions

1. Handles ~25 million rays per second
   - I gave up on my CPU implementation after a few minutes
2. Need to manage registers more carefully
   - Had to reduce thread count to 256, but I hope to get it up to 512
3. Inefficient intersections (collision detection)
   - I currently check every object, but there are much smarter solutions

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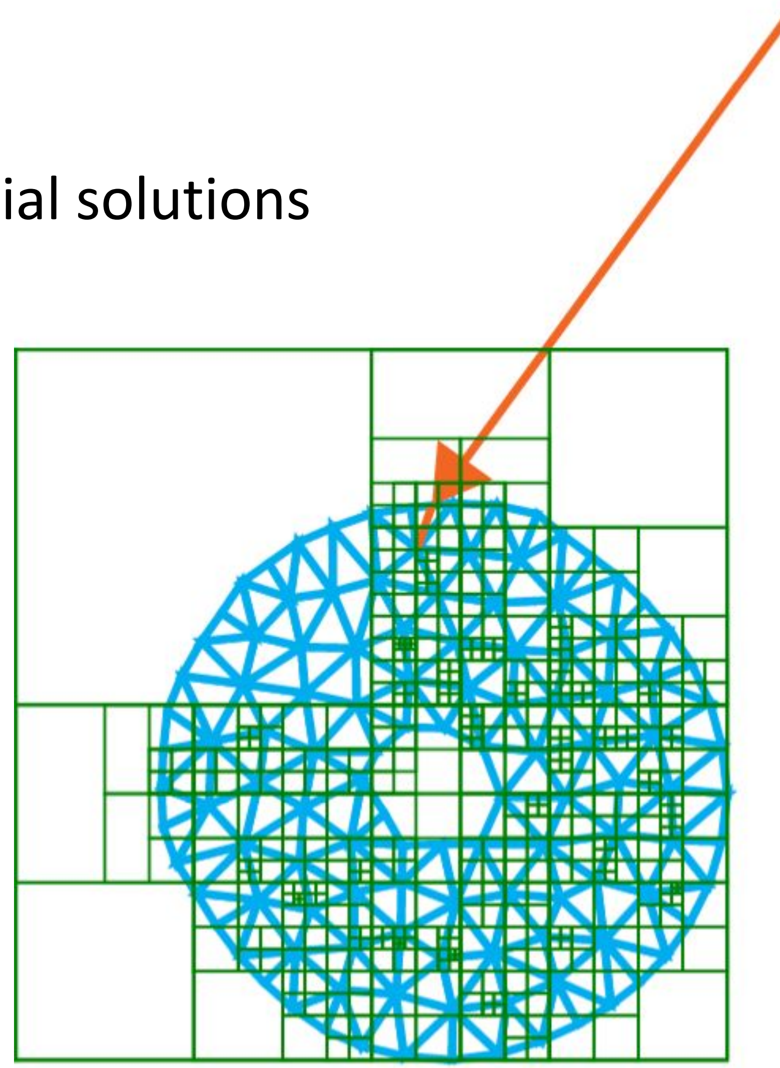
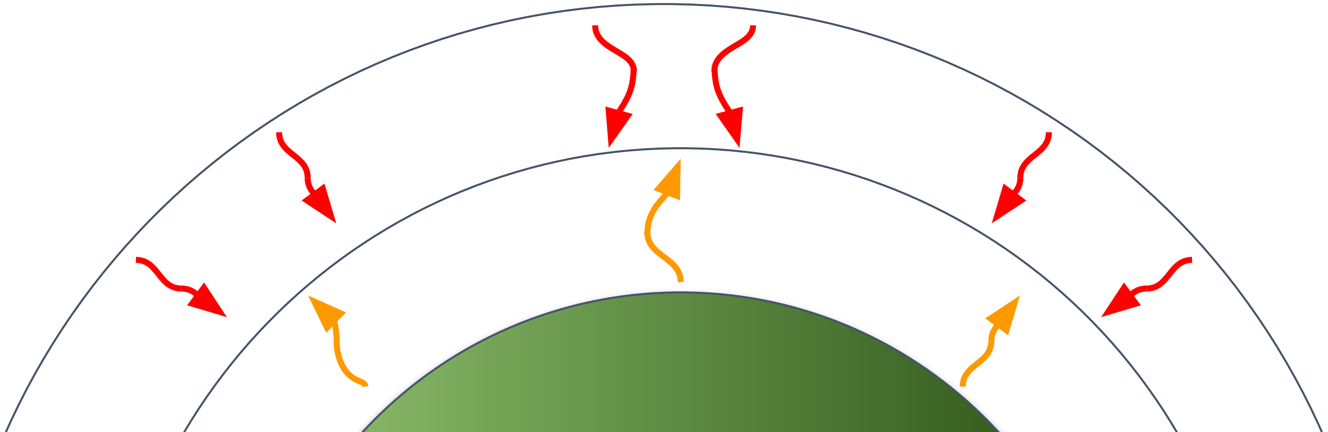


Short-Term Plan

In the next two weeks, I hope to

1. Add a bit more physics into the model
   - Most importantly, refraction and thermal absorption (and maybe scattering?)
2. Build an atmospheric model with this infrastructure
   - Model the radiative transfer of a simple theoretical planet
3. Examine some cool physical phenomena
   - Show how runaway greenhouse effects and ice-albedo feedbacks emerge from these models



Long-Term Plan

Over the course of my thesis, I hope to

1. Add way more physics to the model
   - 3D effects like clouds and exotic effects like molecular spectra, pressure broadening, etc
2. Switch to Nvidia's Optix library for fast intersections
   - Should give 1000x better performance for the current computational bottleneck
3. Integrate with data from data from telescopes and advanced models
   - Model exoplanets using general circulation models (GCM) and real data from stars

Call for Collaboration

If anyone is interested in getting state-of-the-art ray tracing in Julia

1. Nvidia’s Optix library is extremely well optimized
   - Uses fast collision detection and specialized hardware (RT cores)
2. Currently accessible only in C/C++
   - Fine for game engines, but a hindrance to scientific computing
3. A proof-of-concept Optix.jl interface exists
   - Not an actual library (yet) - let's make it one!