Assignment 1:
Exploring OpenGL Programming

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1 INTRODUCTION

In this assignment, I implemented a basic ray tracing renderer. The system supports core functionalities such as ray-geometry intersection, BVH acceleration, and direct illumination integration. Additionally, I implemented several advanced features including multiple light sources, area lights (soft shadows), and environment lighting.

The following sections detail the implementation corresponding to each requirement.

2 IMPLEMENTATION DETAILS

2.1 Requirement 1: Compile & Configure [Must]

I successfully compiled the source code and configured the environment using CMake.

- **Dependency Management**: I resolved network issues by manually managing third-party libraries (e.g., `fmt`, `googletest`) in a `manual_deps` directory.
- **MSVC Compatibility**: I fixed several compiler-specific errors in `accel.cpp` by replacing template `Cast` functions with explicit vector construction to avoid template deduction failures.

2.2 Requirement 2: Ray-Triangle Intersection [Must]

In `src/accel.cpp`, I implemented the **Möller-Trumbore algorithm** in the `TriangleIntersect` function.

- The function solves for barycentric coordinates (u, v) and distance t.
- I added validity checks to ensure $u \geq 0, v \geq 0, u + v \leq 1$, and that t falls within the valid ray interval.

2.3 Requirement 3: Ray-AABB Intersection [Must]

In `src/accel.cpp`, I implemented the **Slab Method** in `AABB::intersect`.

- For each axis (x, y, z), I calculated the entry (t_{min}) and exit (t_{max}) intervals.
- The ray intersects the AABB if the intersection of intervals on all axes is valid ($t_{enter} \leq t_{exit}$) and overlaps with the ray's time range.

2.4 Requirement 4: BVH Construction [Must]

In `include/rdr/bvh_tree.h`, I implemented the BVH construction logic.

- **Heuristic**: I utilized the **Median Split** method.
- **Implementation**: I used `std::nth_element` to sort primitives based on their centroids along the longest axis of the bounding box, splitting them into left and right child nodes recursively.

2.5 Requirement 5: Integrator & Refraction [Must]

Integrator. In `src/integrator.cpp`, I implemented `IntersectionTestIntegr`
It recursively traces rays. If a ray hits a refractive surface, it spawns a new ray and continues tracing; if it hits a diffuse surface, it computes direct lighting.

Refraction. In `src/bsdf.cpp`, I implemented `PerfectRefraction::sample` based on **Snell's Law**. I handled the incident direction (negating `wo`) and Total Internal Reflection (TIR) using the `Refract` function.

2.6 Requirement 6: Direct Lighting [Must]

In `src/integrator.cpp`, I implemented the `directLighting` function.

- It calculates the contribution from light sources using the Lambertian model ($Albedo \times \cos\theta$).
- It casts a **Shadow Ray** to test for occlusion. I explicitly set `shadow_ray.t_min = 1e-4f` to prevent self-intersection (Shadow Acne).

2.7 Requirement 7: Anti-aliasing [Must]

In `IntersectionTestIntegrator::render`, I implemented anti-aliasing via multi-ray sampling.

- The renderer loops spp times for each pixel.
- I used `sampler.getPixelSample()` to generate sub-pixel coordinates with random offsets, averaging the results to produce smooth edges.

2.8 Requirement 8: Multiple Light Sources [Optional]

In `directLighting`, I replaced the hardcoded single light logic with a loop that iterates over all lights in the scene:

```
Vec3f L_total(0.0f);
for (const auto &light : scene->getLights()) {
    // Sample and accumulate contribution from each lig
    // ...
    L_total += contribution;
}
return L_total;
```

2.9 Requirement 9: Area Lights & Soft Shadows [Optional]

I implemented area light support by utilizing the `light->sample()` interface in `directLighting`.

- Instead of using a fixed light position, I sample a random point on the light source surface.
- When combined with multiple samples per pixel (SPP), this naturally produces **Soft Shadows** (penumbra) for area lights, as demonstrated in the results.

2.10 Requirement 10: Environment Lighting [Optional]

In `src/integrator.cpp`, I modified the `Li` function to handle rays that miss scene geometry:

```
if (!intersected) {
    if (scene->hasInfiniteLight()) {
        // Sample environment map for background col
        return scene->getInfiniteLight()->Le(interac
    }
    break;
}
```

This allows the renderer to use environment maps for background illumination.

3 RESULTS

3.1 Basic Feature Verification

Figure 1 shows the result of the `cbox_no_light_refract.json` scene.

- **Refraction**: The glass sphere correctly refracts the background.
- **Hard Shadow**: The point light source creates sharp shadows.

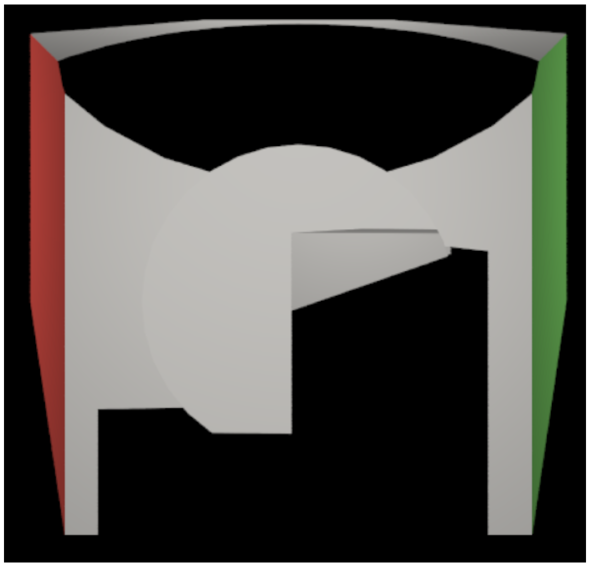

Fig. 1. Cornell Box with Glass Sphere. Verifies Refraction and Basic Tracing.

3.2 Advanced Feature Verification

Figure 2 shows the result of the `cbox.json` scene.

- **Soft Shadows**: The shadows cast by the boxes have soft gradients, confirming that the Area Light sampling and Multiple Light support are working correctly.
- **Noise-free**: The image is clean, validating the fix for shadow acne (t_{min} offset).

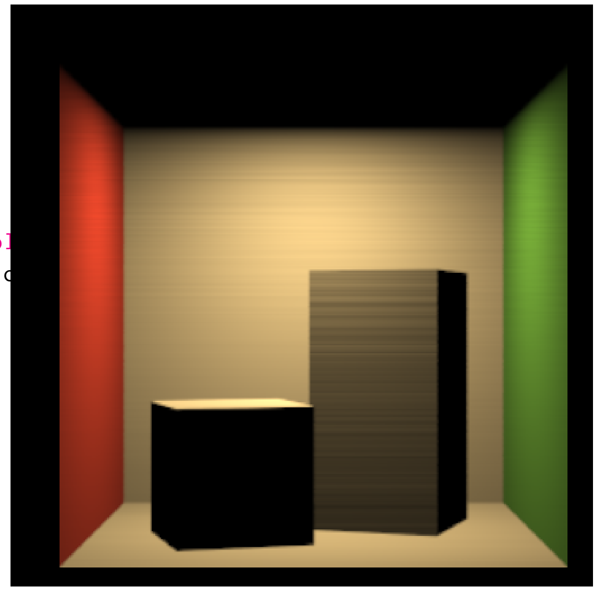

Fig. 2. Cornell Box with Soft Shadows. Verifies Area Lights and Multiple Light Sources.

4 CONCLUSION

I have successfully implemented a functional ray tracer. All mandatory requirements were met, and I additionally implemented support for multiple light sources, area lights (soft shadows), and environment lighting logic.