A5 Project Proposal
Title: A Snooker Table (Raytracer)

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1 Purpose

As a gamer who owns an RTX3080, I have always wondered what ray tracing is, which motivated me to study Computer Graphics. In A4, I have the chance to implement a simple version of the ray tracer, but this is not what I want, I want something better, something that can make a better image! I hope A5 is the opportunity, to try to implement what I learn about ray tracing, and to see what I can take away from this course.

2 Statement

The scene I am making will be a special "Snooker table". Why is the scene special? The snooker table will have a giant mirror table surface, which can glossily reflect everything on the table. To avoid confusion, the table surface will have some degree of roughness and we still can see it is a surface. Some snooker balls have metal surfaces that can reflect other balls. Some snooker balls will be pure crystal balls that light can refract through. Some snooker balls are made of blurry crystal balls and light may have glossy refraction. The other snooker balls will be solid balls that will have some texture on the surface and leave some shadows on the snooker tables. It will be interesting to see the snooker balls reflect/refract each other, which can confuse the players. The snooker cue will be a long and thin truncated cone that is put near the snooker balls. Eventually, there is going to be a snooker motion blurring simulation as the final scene.

To create the above scene, I will implement a ray tracer that supports reflection, refraction, glossy reflection, and glossy transmission, so the snooker table will look fancier than the traditional snooker table. Anti-aliasing, texture mapping, and soft shadow will be applied to make the scene look more realistic. Eventually, a fisheye projection will create a global view of the snooker table; and a motion-blurring simulation will make the scene look more dynamic.

After completing this project, I hope to learn about the various raytracing techniques that make the scene more real and fancy. When my friends ask me about ray tracing in the future, I hope that I can explain to them what is going on and show my piece of work to demonstrate the theory.

3 Technical Outline

The features of **Glossy Reflection**, **Glossy Refraction**, **Stochastic Sampling Anti-Aliasing**, and **Snooker Ball Motion Blur Simulation** will be configured the environment variable. A bash file will be created and it contains the configuration to turn the feature on/off. For example, $GLOSSY\_REFRLECTION = 1/0$ will turn **Glossy Reflection** on/off. By default, all of them are turned off. More detailed instructions will be provided in the README.

3.1 Snooker Table Arrangement (Scene)

The ultimate goal is to ray tracing a snooker table. I will model a snooker table where the snooker balls are racked up and placed in their starting positions. The 15 red balls should be placed in a triangle and positioned just behind the foot spot. The pink ball is placed in front of the triangle and the black is placed behind the foot spot. The brown, green, and yellow balls should be placed on the other side of the table.

3.2 Reflection

To achieve reflection, I will try to calculate the reflection direction based on the surface normal and the incoming ray. [1] It should be symmetrical to the incident ray about the normal. Then, I will recursively trace the reflection ray within some recursion threshold. The surface color will be the original color plus the reflective color. The Schlick-Fresnel Approximation may also be useful to estimate the Fresnel effect for reflection. [2]

3.3 Refraction

To achieve refraction, I need to simulate the blending of light as it passes through transparent materials. The light ray bends according to Snell's Law

$$n_1 s \sin\theta_1 = n_2 \sin\theta_2$$

where n is the indices of refraction for air and glass. As such, I can generate the refraction ray, which will behave similarly to the reflection ray after leaving the crystal snooker ball.

3.4 Glossy Reflection and Refraction

Glossy reflection happens when the surface is not sharp but instead has a soft and blurred appearance. To achieve this, we can generate multiple rays around the mirror reflection direction. The angle of those rays will be determined by the material of the surface. Glossy refraction is achieved in a similar way as glossy reflection. In particular, there will be an ideal refraction direction and multiple rays within the refracting object. The number of refraction rays may determine the strength of the "blur" effect and it will be tested out during the actual implementation.

3.5 Stochastic Sampling Anti-Aliasing

Instead of casting rays from the center of each pixel, we can generate random sample points within each pixel's area. This will help avoid the regular grid pattern that produces aliasing. For example, using some functions like rand_float() to generate random points and cast the rays from random sample points. This then averages out high-frequency details. [3]

3.6 Soft Shadow

To create soft shadows, we need to simulate shadows that have gradual transitions from light to dark instead of sharp edges. I may be using area light and cast multiple shadow rays toward different random points on the area light's surface. Each shadow ray represents a different part of the area light source, giving a different result based on whether the light is blocked.

The more rays that reach the light source, the brighter the point will be. Then calculate the shadow intensity as the ratio of rays that reach the light to the total rays cast. This approach will then make a smooth and soft shadow edge. This may help implement the algorithm. [4]

3.7 Primitive: Cylinder and Cone

In addition to the default primitives, I will create the cylinder and cone to produce snooker cue. To construct a cylinder, the radius R is fixed and the points' coordination can be calculated as $x^2 + y^2 = R^2$, the height of the cylinder should be kept in a range.[5] The cone can be constructed in a similar way as the cylinder. In addition, we can calculate the slope of the cone by $k = \tan(\theta)$ and the radius can be calculated as $R(z) = kz$. More details can be found in the textbook.

3.8 Primitive: Torus

To construct the torus primitive, it has the tube (Minor) radius R_1 and a torus (Major) radius R_2. The relationship between two radus can be calculated as $(\sqrt{x^2 + y^2} - R_1)^2 + z^2 = R_1^2$. The intersection of the torus follow a quartic equations, where the detailed formulation can be referenced from [6]

3.9 Texture Mapping

To make the scene a snooker table, I will use some texture mapping on the table edges or some of the snooker balls. This may be done with the use of some online textures. [7]

To be specific, the texture will be loaded as 2D arrays and they will be mapped to the objects in the scene, pixel to pixel.

3.10 Snooker Ball Motion Blur Simulation

To simulate the effect of snooker ball moving in the scene, we are to create a blurred effect that mimics real-world motion.

To achieve this, the entire scene will be sampled in a given time interval, and the moving object will have a given start and end position. Then, we can find the position

$$P_t = P_0 + (P_1 - P_0) \cdot \frac{t - t_0}{t_1 - t_0}$$

The Ray() itself will only have a time parameter and the ray is traced depending on the time. Eventually, we will collect the color across the time interval and average down depending on the number of "captures" we do in the time interval. [8]

4 Bibliography

The following materials are used as sources of help when I am trying to understand ray tracing better and making this proposal. During the actual implementation, I may or may not use the following materials, but also seek additional sources.

[1] Scratchapixel. (n.d.). How does it work? Introduction to ray tracing. https://www.scratchapixel.com /lessons/3d-basic-rendering/introduction-to-ray-tracing/light-transport-ray-tracing-whitted.html

[2] Majercik, Zander. (2021). The Schlick Fresnel Approximation. 10.1007/978-1-4842-7185-8_9. pp. 110

[3] M.A. Dippé and E.H. Wold. Anti-aliasing through stochastic sampling. Computer Graphics, 19(3):69–78, July 1985.

[4] Rendering soft shadows. (n.d.). http://raytracerchallenge.com/bonus/area-light.html

[5] Create a Cylinder. (n.d.). https://space.mit.edu/RADIO/CST_online/mergedProjects/3D/common_struct /common_struct_cylinder.htm

[6] Skala, Vaclav. Line-Torus Intersection for Ray Tracing: Alternative Formulations. Department of Computer Science and Engineering, University of West Bohemia. Web. http://www.VaclavSkala.eu.

[7] Snooker Pool Table Cloth (Baize, Worsted Billiard, Felt Fabric). (n.d.). Free PBR — TextureCan. https://www.texturecan.com/details/527/#google_vignette

[8] Shkurko, Konstantin & Yuksel, Cem & Kopta, Daniel & Mallett, Ian & Brunvand, Erik. (2017). Time Interval Ray Tracing for Motion Blur. IEEE Transactions on Visualization and Computer Graphics. PP. 1-1. 10.1109/TVCG.2017.2775241. p3

5 Objectives

Full UserID:________________________ **Student ID:**________________________

___ 1: **Snooker Table arrangement (Scene)** is created and rendered. The snooker balls are placed in the correct position.

___ 2: **Mirror Reflection** is observed on the snooker table.

___ 3: **Refraction** is observed on clear crystal snooker balls.

___ 4: **Glossy Reflection and Refraction** are observed on glossy solid snooker balls.

___ 5: **Stochastic sampling anti-aliasing** is used, and a pair of comparison pictures is generated.

___ 6: **Soft Shadow** is observed under the objects in the scene.

___ 7: **Additional Primitives** (Cylinders and Cones) are used as snooker cues in the scene.

___ 8: **Additional Primitives** (Torus) is used together with cylinders and cones to model the legs of the table

___ 9: **Texture mapping** is used for some specific snooker balls and they look like real snooker balls

___ 10: **Snooker Ball Motion Simulation** is visualized and an individual scene picture is captured for it

A4 extra objective: super sampling will be implemented in A4 as an additional feature and some of A4 codes will be carried forward in A5. Therefore, those parts should be ignored and not counted toward A5's objectives

6 Declaration

I have read the statements regarding cheating in the CS488/688 course handouts. I affirm with my signature that I have worked out my own solution to this assignment, and the code I am handling in is my own.

7 Signature: