Principles of Rendering - Real-time Rendering

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Abstract

This document is for my Real Time Rendering assignment. A glass marble is chosen for this assignment and I will be analyzing the properties of the object and my method of achieving the effects.

1 Introduction

Firstly, my object chosen for this assignment consists of signed distance functions for modeling and basic environment to present and test reflection and refractions.

The marble itself and a sphere with one-or-more slightly-twisted ellipsoid(s) inside the sphere. There are however, some miniature bubbles inside the sphere which also cause a caustic effect, this feature is set as an extension as defining such primitive is somewhat challenging with a structured Signed Distance Field.

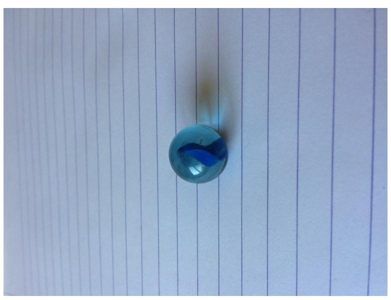

Figure 1: *A photo of the object in an interior environment with a light from the window.*

The glass marble in Figure 1 exhibits:

1. Caustic properties overall, such as refraction of the colors from the supporting plain.
2. Specular highlight reflected from the light source is intense but has a sharp fall-off.
3. Specular highlight also shows uneven surfaces/micro-facets caused by scratch-marks and finger prints.Not shown clearly in the figure above but this is discovered heuristically.
4. Shadow casted onto the surface is not completely opaque as the light refracts through the glass.
5. Murky effects inside the marble.
6. Stated above, tiny bubbles exist inside the marble, this is for extension.
7. Outer surface has some marks, will be done as extension if time allows.
8. Has a distinctly strong light in one direction.

The caustics effects can be achieved with relative ease using Signed Distance Functions as suggested by my lecturer. After reading some articles and examples on [Inigo Quilez 2017] and [ShaderToy User - andregc 2015] have given me enough information to start implementing and testing the scenes in GLSL.

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2 Method Overview

Firstly, the basic ray-marching technique used in this assignment is referenced from multiple ShaderToy demonstrations such as: [ShaderToy User - andregc 2015] and [ShaderToy User - eddietree 2015]. The principle is unchanged but I have two separate versions - one for the outer surface and one for the inner volume.

procedure RAYMARCH($dir - d, iterCount - i, depth - d, distance - dist, position - p, increment - inc$) ▷ Raymarching for depth.
  while $i < iterCount$ **do** ▷ We have our precision limited.
    $dist \leftarrow querySDF(p + d * dir)$
    $d \leftarrow depth + dist$
    $if dist < epsilon || d >= marchRange, break$
  $p \leftarrow p + dir * d$
  return $d, dist, p$

After setting up my model view, lighting data and ray-marching vectors, I call my first ray-march on the surface and the inside of the marble to establish combined lighting factors for specular, ambient-occlusion and caustic shadows for later use.

The ambient-occlusion can be found from Richard Southern's "rendering examples" which samples from [ShaderToy User - mhnewman 2017]. It iterates and increments depth values and take their differences with the object distance in a ray-marched scene and returned as a coefficient.

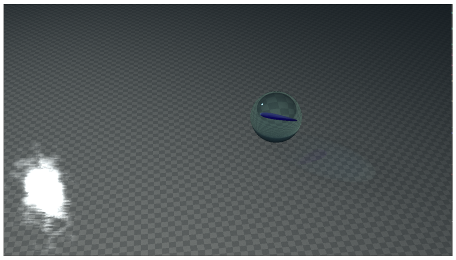
For the shadow factor, I have blended two shadow factors of the object into a single caustic shadow. I first ray-march into the marble and obtain a projection of the marble onto the supporting plain. Then I produce a soft shadow disregarding the refraction of the rays. By mixing two components, I can obtain a somewhat-believable caustic shadow effect.

For the specular highlight, I used a generated noise map with scratchy effects mapped into the roughness parameter for a slightly-distorted shine to the highlight. The use of micro-facet through deriving terms such as the geometric attenuation, Schlick approximation for the Fresnel factor, are sampled from Richard Southern's rendering lectures - [Ric].

After the preparation stage, I start the official ray-marching for primitive diffuse colors for the object. When rays are returning a color, I apply my overall lighting factors with the ray color to produce the lighting with the diffuse.

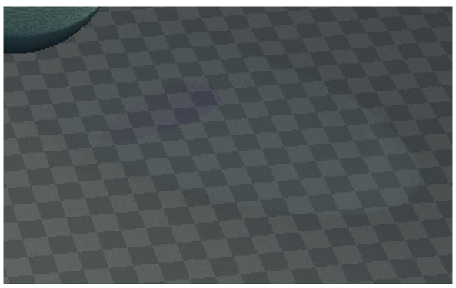
The diffuse color has its tint statically set as a constant, the lighting is made from a directional light and a spotlight. To get a fragment's color, we have to access and modify the ray color from its data structure during each refraction. We then determine the ray's intersected material. If it's something inside the glass, we assign their own diffuse color, for general caustics we blend the resulting colors with the glass tint.

3 Results



The result of the method above produces caustic effects quite well when direct lighting is not very intense on the object as intense light bleaches the details of the refraction.

Additionally, the artifact from using signed-distance functions persist. As our camera move towards the horizon line or zoom out too far from the object, the object with gradually merge with the ground plane or the background due to ray-marching limitations.



The shadow is projected and blends well with soft decay, the main issue this has is that the projection of the inside is too apparent compared to the reference.

Performance-wise, the scene is able to be run with animation but at a lower frame rate due to multiple heavy real-time ray marching.

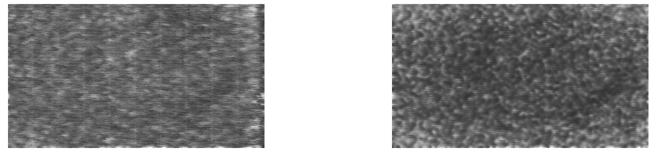
4 Evaluation

Overall, the marble itself has its caustic effects done adequately. However the performance of the scene can probably be improved through less code duplication and more efficient use of data. The extensions of producing procedural inner bubbles scratch-marks are not achieved.

The bubbles inside the marble can theoretically be generated through a procedural noise map from the CPU side on which the bubble positioning and sizes can be mapped and defined with signed distance functions.

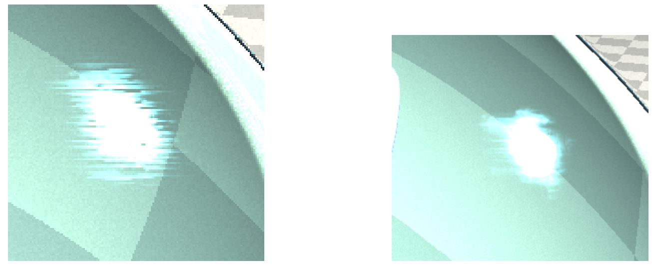
A similar technique can be used for the scratch marks on the surface but with a different noise map. For each spot of extrema (in either 3 or 4 of the color+alpha channels), it might be possible to define a displacement pattern with another channel.

Having a realistic animation where the inside of the marble rotates around the pitch axis of the marble's rotation with a synchronized interval so no sliding is visible.



(a) *Scratch mark noise map* **(b)** *Smudging with the scratch mark*

Figure 2: *The two possible gloss maps providing a specular pattern.*



(a) *a) from above, applied for roughness mapping* **(b)** *b) from above, applied for roughness mapping*

Figure 3: *A comparison between the noise patterns used for the roughness factor during specular calculation. The first map shows distinct scratches whereas the other has smudge applied on top of it.*

References

INIGO QUILEZ, 2017. Website for conventional signed distance field articles and examples. `http://iquilezles.org/index.html`.

Realtime shading, a derivation of popular reflectance models. `https://mybu.bournemouth.ac.uk/bbcswebdav/pid-1430378-dt-content-rid-7195565_2/courses/077997/shading.pdf`, year = 2018, author = Richard Southern, notes = P22 36.

SHADERTOY USER - ANDREGC, 2015. Glass with caustic. `https://www.shadertoy.com/view/4lB3D1`.

SHADERTOY USER - EDDIETREE, 2015. Cosmic marble. `https://www.shadertoy.com/view/llSSWW`.

SHADERTOY USER - MHNEWMAN, 2017. Sdf ambient occlusion. `https://www.shadertoy.com/view/XlXyD4`.