Brennen Taylor

Real-Time Physically Based Wet Microfacet Surface Rendering

Problem Summary

Physically based rendering utilizing a microfacet model, most commonly the Cook-Torrance model, has gained recent popularity over the last decade in real-time simulation usage. The extension of shaders to support more complex operations, as well as the increase in GPU computation ability, has allowed for an entirely physically based lighting pipeline. However, these simulations tend to utilize texture hacks when rendering wet surfaces rather than correctly modeling the physical behavior of microfacet surfaces covered by a layer of water. This technique requires more memory for storing "wet" textures, as well as the technique lacks physical accuracy. In this work, I plan to address this problem by introducing a physically based simulation of wet microfacet surfaces, utilizing the existing Cook-Torrance lighting model.

This problem is important for two domains; both the video game industry, and the self-driving car industry. In video games, artists want to model dynamic environments as realistically as possible. As GPUs continue to increase in computational power, while continuing to experience a memory bottleneck, it would be useful to model wet surfaces via a computational method rather than storing separate textures for surfaces. In addition, the wet surfaces, if modeled using a physically correct model, would look physically accurate under all lighting conditions in a dynamic simulation. In the auto industry, wet surfaces continue to be problematic. As self-driving networks are beginning to be trained on virtual simulations, it is important that wet surfaces be modeled as accurately as possible in order to train a more useful model. By using a physically accurate wet surface model, these virtual simulation environments can be shifted even closer to real world behavior, and thus allow for more accurate trained neural networks.

Previous Work

Previous work in rendering wet surfaces primarily falls into two categories, the study of how light interacts with a wet surface in the real world, and the proposal of simulation techniques to model wet surface behavior.

One specific work [1] explores the probability of absorption or reflectance of light at every boundary in the material fully submerged by a layer of water case. This model explores multiple reflectance cases in which water that transmits through the air-water boundary initially would then have a percentage of reflectance that would then experience total internal reflectance off the bottom of the water-air boundary. Over multiple bounces, this causes less light to return to the eye and thus the surface appears darker.

Another work [2] explores how light behaves in a basic model of a material submerged by water. In this work, they use photon tracing and model three main propagations of light; the reflectance of light at the air-water boundary, the reflectance of light off the material, and the total internal reflectance at the water-air boundary. In addition, this work explores the subsurface scattering of light in a dry and wet porous material, discussing how a wet porous material experiences a greater amount of light scattering as the light propagates through the surface.

A third work [3], a blog post series by Sebastien Lagarde, a well-known AAA rendering engine game developer, explores the behavior of physically based wet surfaces. While I discovered this blog series after designing the model I propose in this work with John, there are many similarities between the model I designed and the author's. Notably, the use of a double layered BRDF was the overall model of light interaction with the wet surface in both cases. The author's work pointed me to a fourth work [4], which proposes a model for handling an arbitrary number of BRDF layers. The author's model also incorporated a model of surface porosity, as well as the absorption of light experienced as light travels through the water layer.

Description of Work

My work for this project fell into two categories, designing a model for wet surface rendering, and implementing that model.

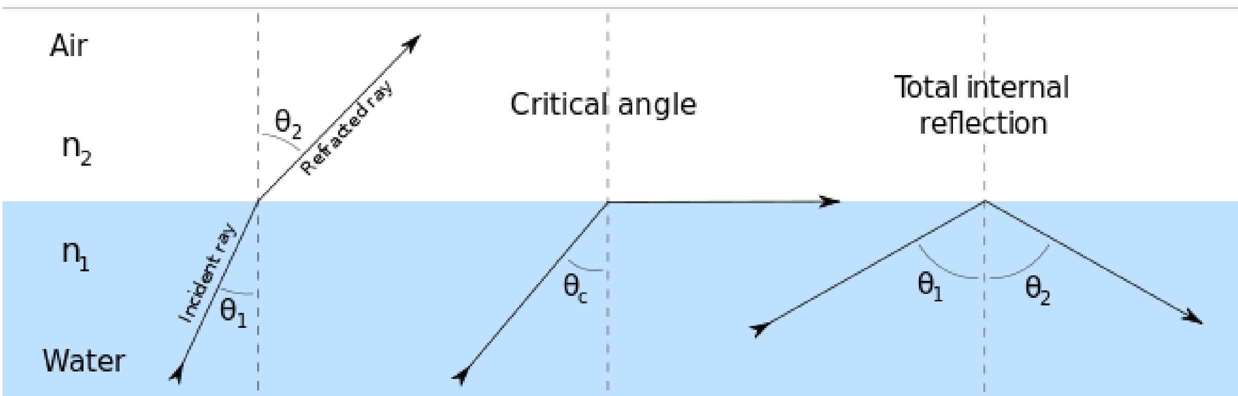

Figure 1: Air-water surface boundary.

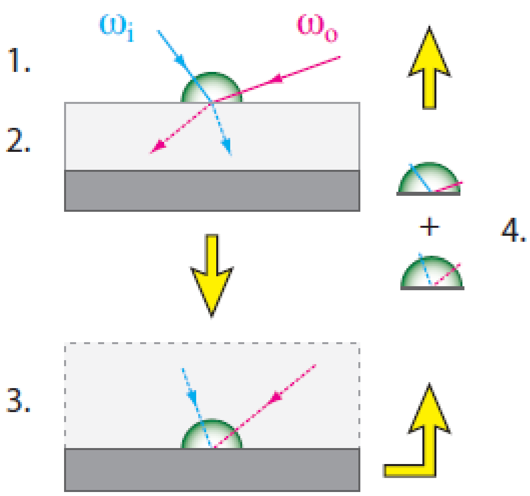

Figure 2: Multi-layer BRDF.

First, I will discuss designing the model. After viewing related work, I decided to model the wet surface as a BDRF with two layers; an air-water layer and a water-material layer, such as in Figure 2. For the air-water layer, I wanted mirror like reflection of the surface at a shallow viewing angle, while a steep viewing angle would not cause much reflection at all. To model this, I selected the Fresnel effect. Next, I simulated the amount of light transmitted through the water that was reflected back by the material. For this reflection, I use the Cook-Torrance model as I want the simulation to remain as physically accurate as possible. Finally, the reflected light that returned to the water-air boundary experienced possible total-internal reflection, as in Figure 1. I simulate this by approximating the amount of the returned specular lobe that is allowed to transmit through the water-air boundary, and add this into the total returned reflection. In total, the final equation is as follows:

$$R = R_{reflected}(L, V) + CookTorrance(L', V') * Transmitted(V', -N)$$

For the implementation of the model, I chose to implement the project in Direct3d 11. I followed the original Cook-Torrance paper for many of the physically based rendering equations, using a few of the approximations mentioned in the frostbite presentation as well [5], specifically the GGX distribution function and derivation for the geometry function, as well as Schlick's approximation for fresnel. The implementation of the lighting model was straightforward as I am very familiar with renderer architecture as well as the Direct3D API.

Results

For this project, my results are visual. I have not yet found a good way to measure the correctness of the wet surface rendering. One idea I have had for measuring the realism my model would be a user study. Another method would be the construction of an offline path tracer which would physically model the wet surfaces in a known way. I could then use this as a ground truth for comparing against my method and evaluating the physically accuracy of my real-time method.

Next, I show the results of three different physical materials; concrete, plywood, and stone. For each material, I show three pictures from different viewing angles. First, a top down view in which the main difference between the models is a slight change in hue and saturation. Second, I show a viewing angle of about 45 degrees. This view specifically shows the darkening effect we would expect to see in a wet surface compared to a lighter, dry surface. At this angle, the water layer does not contribute a reflection of the environment. Finally, I show a very shallow viewing angle which highlights the mirror like reflection caused by a reflection off the smooth, water layer on the top of the material. Through this reflection, it is possible to still see the darker, material surface underneath.

Concrete

Figures 3, 4 and 5 show the concrete material in the three different viewing angles. This material experiences all the physical phenomenon we would expect, from the darkening of the underlying material, to the change in saturation and hue, to even the mirror like reflection of light off the water.

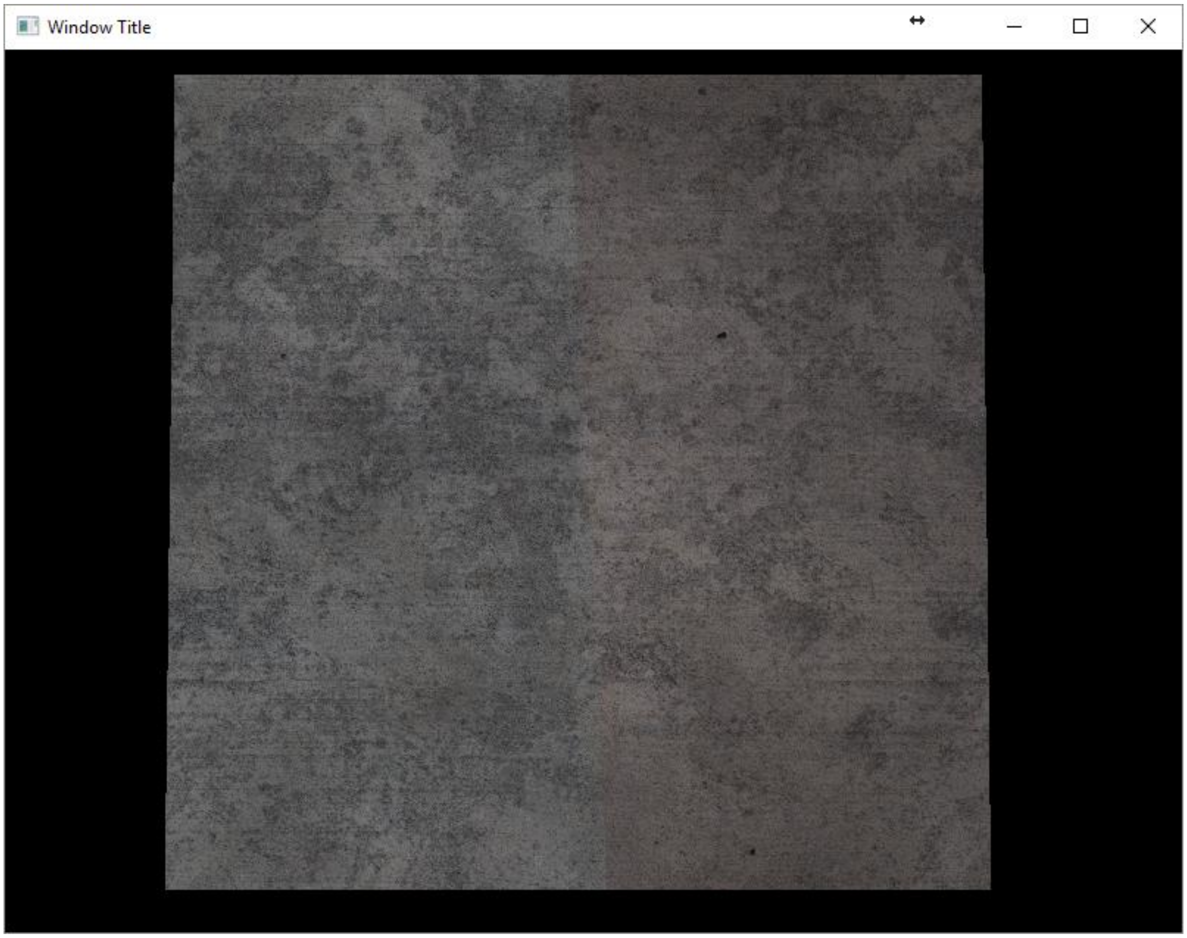

Figure 3: Top View. Dry is on the left, wet is on the right.

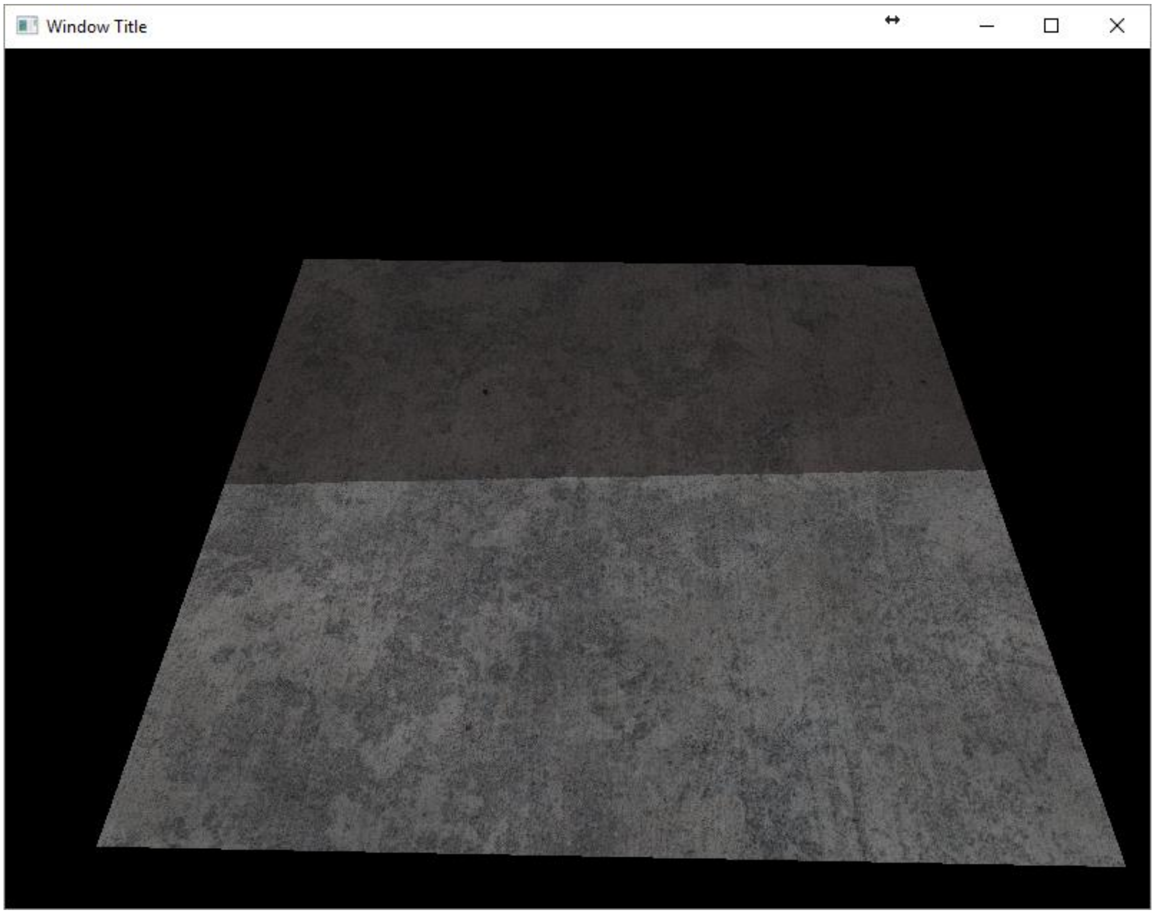

Figure 4: 45-degree view. Dry is on the bottom while wet is on the top.

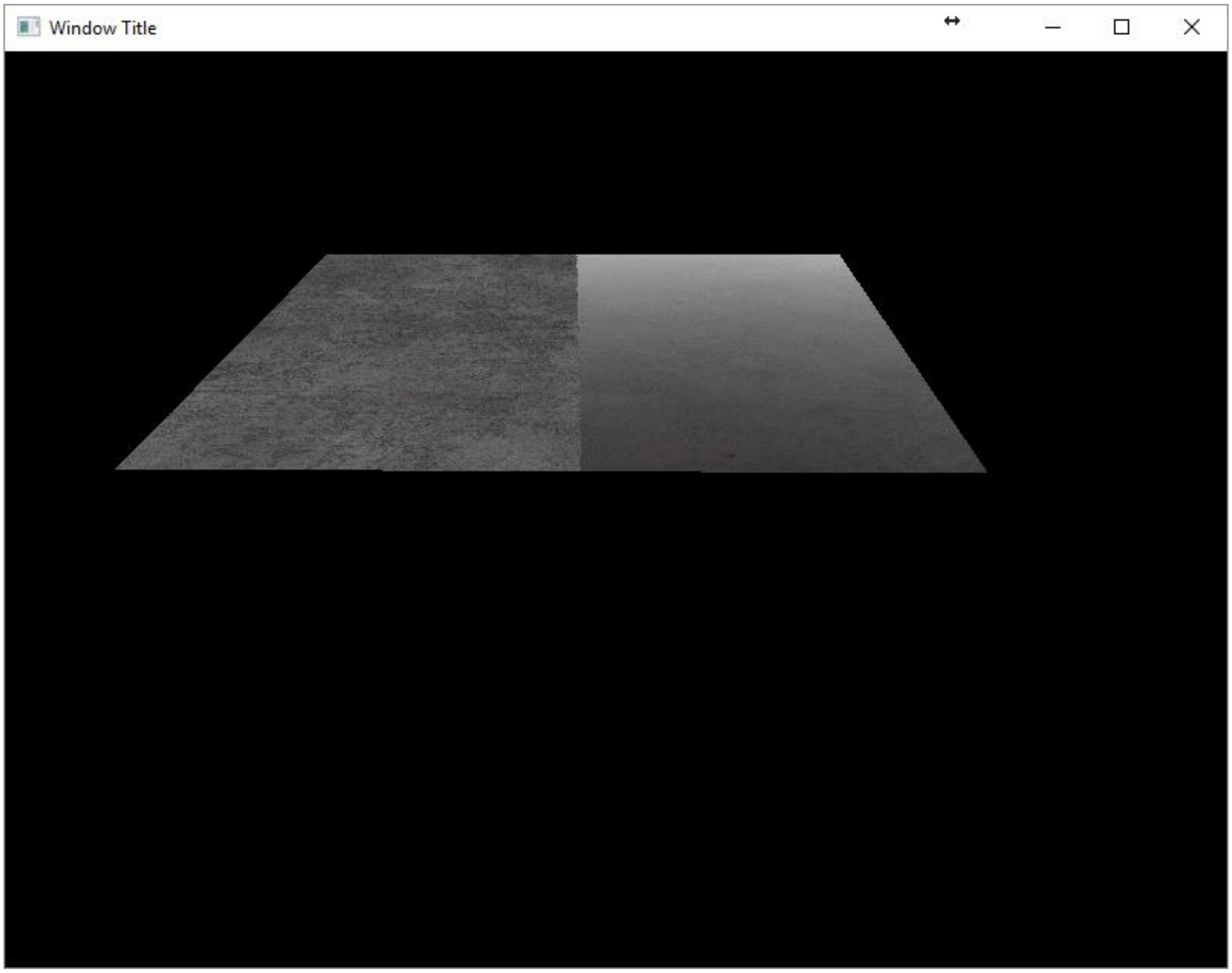

Figure 5: Shallow View. Dry is on the left while wet is on the right.

Plywood

Figures 6, 7 and 8 show the plywood material in the three different viewing angles. This material also experiences all the physical phenomenon we would expect, from the darkening of the underlying material, to the change in saturation and hue, to even the mirror like reflection of light off the water.

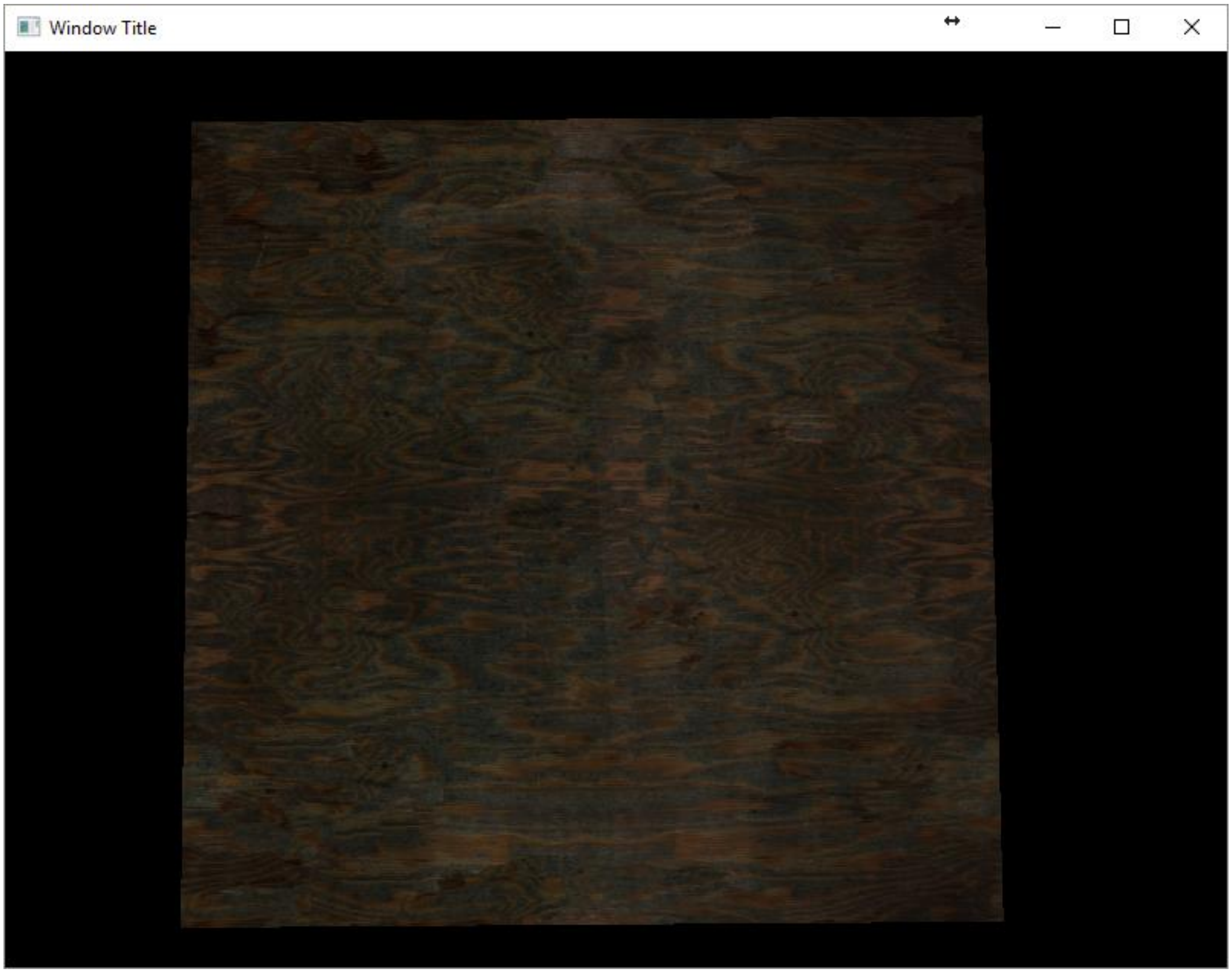

Figure 6: Top View. Dry is on left while wet is on right.

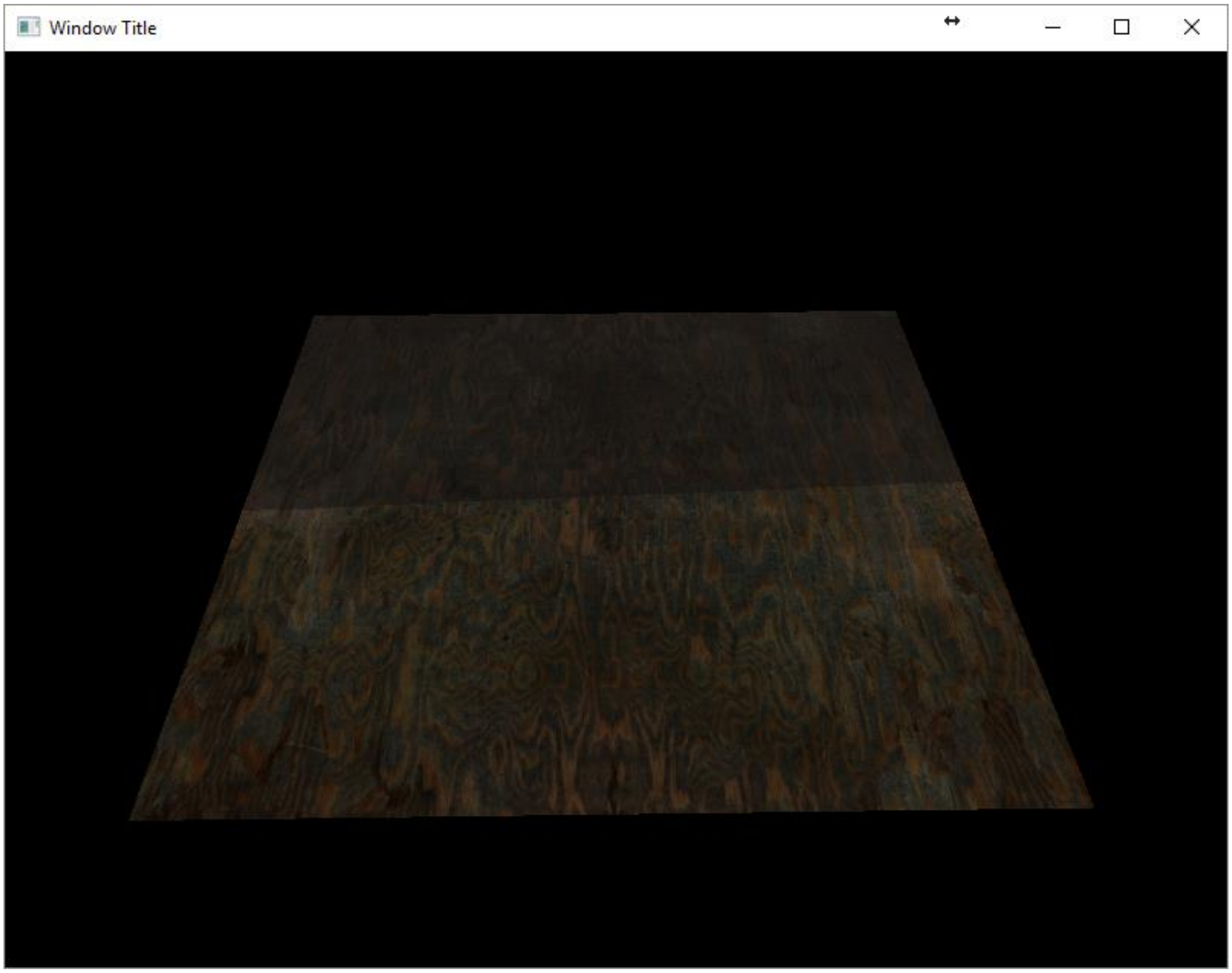

Figure 7: 45-degree view. Dry is on bottom and wet is on top.

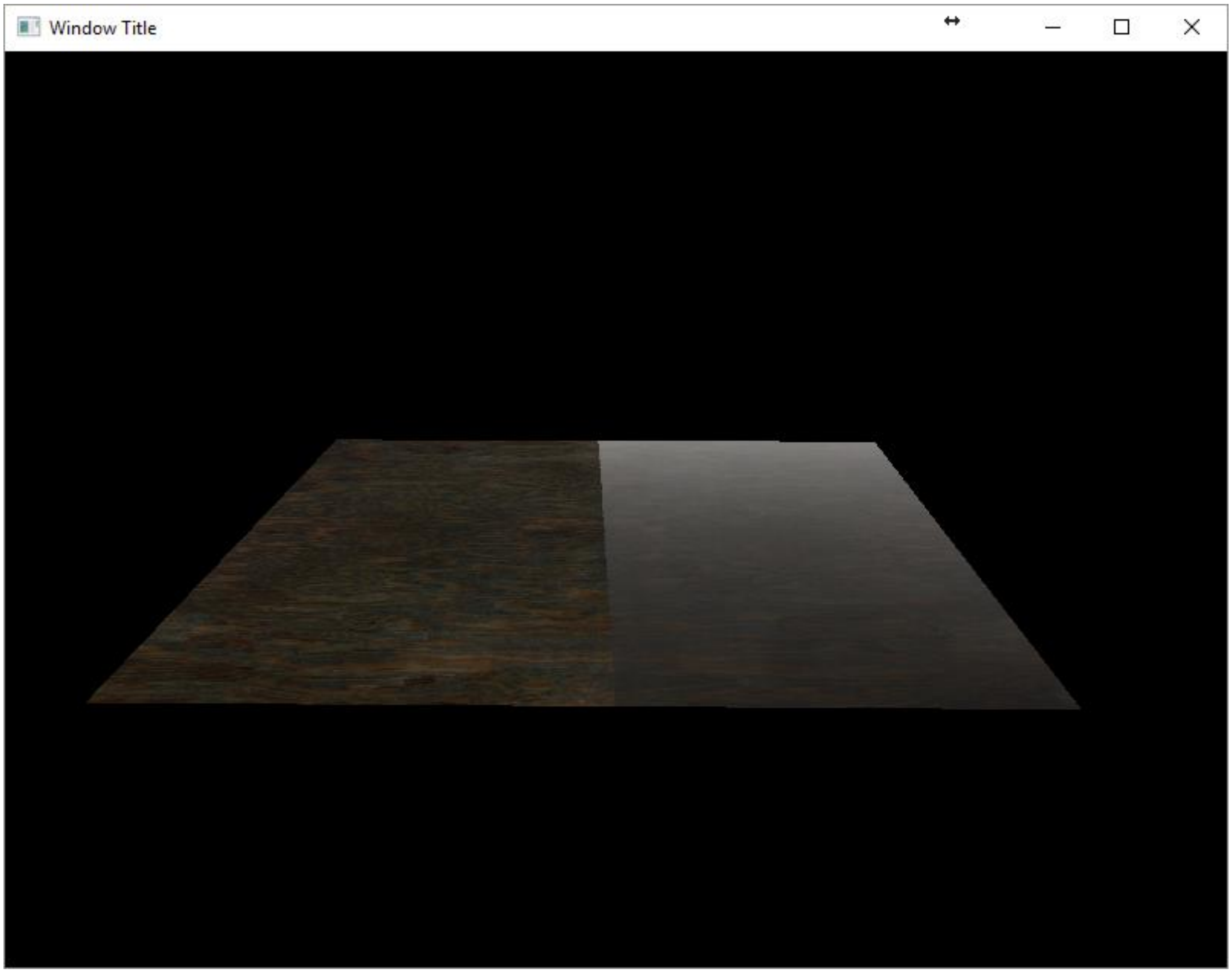

Figure 8: Shallow view. Dry is on left and wet is on right.

Stone Bricks

Figures 9, 10 and 11 show the stone brick material in the three different viewing angles. This material is different in that it is difficult to see a change in saturation or hue in the top down viewing angle. However, it still experiences the physical phenomenon we would expect, from the darkening of the underlying material to even the mirror like reflection of light off the water surface.

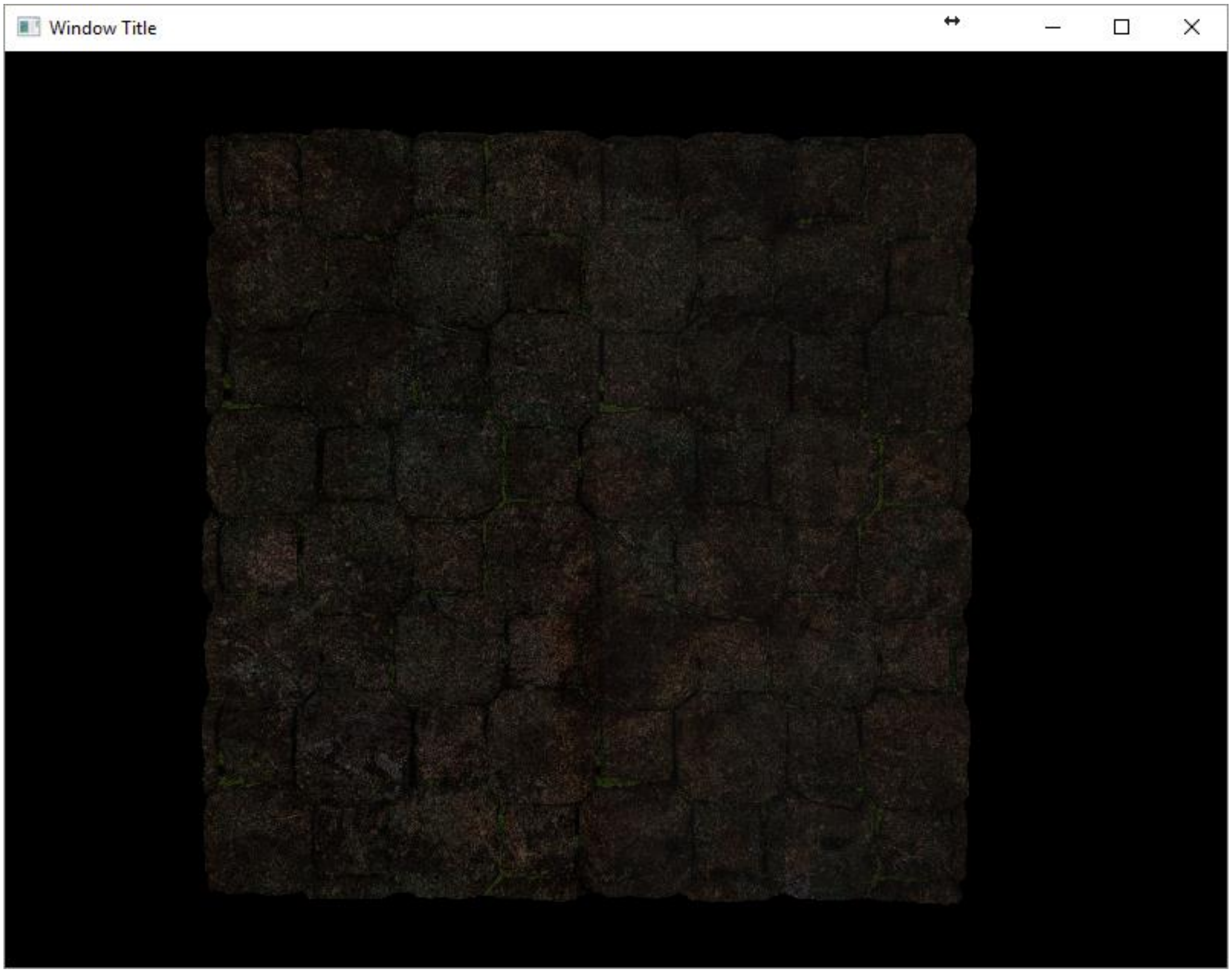

Figure 9: Top view. Dry is on left and wet is on right.

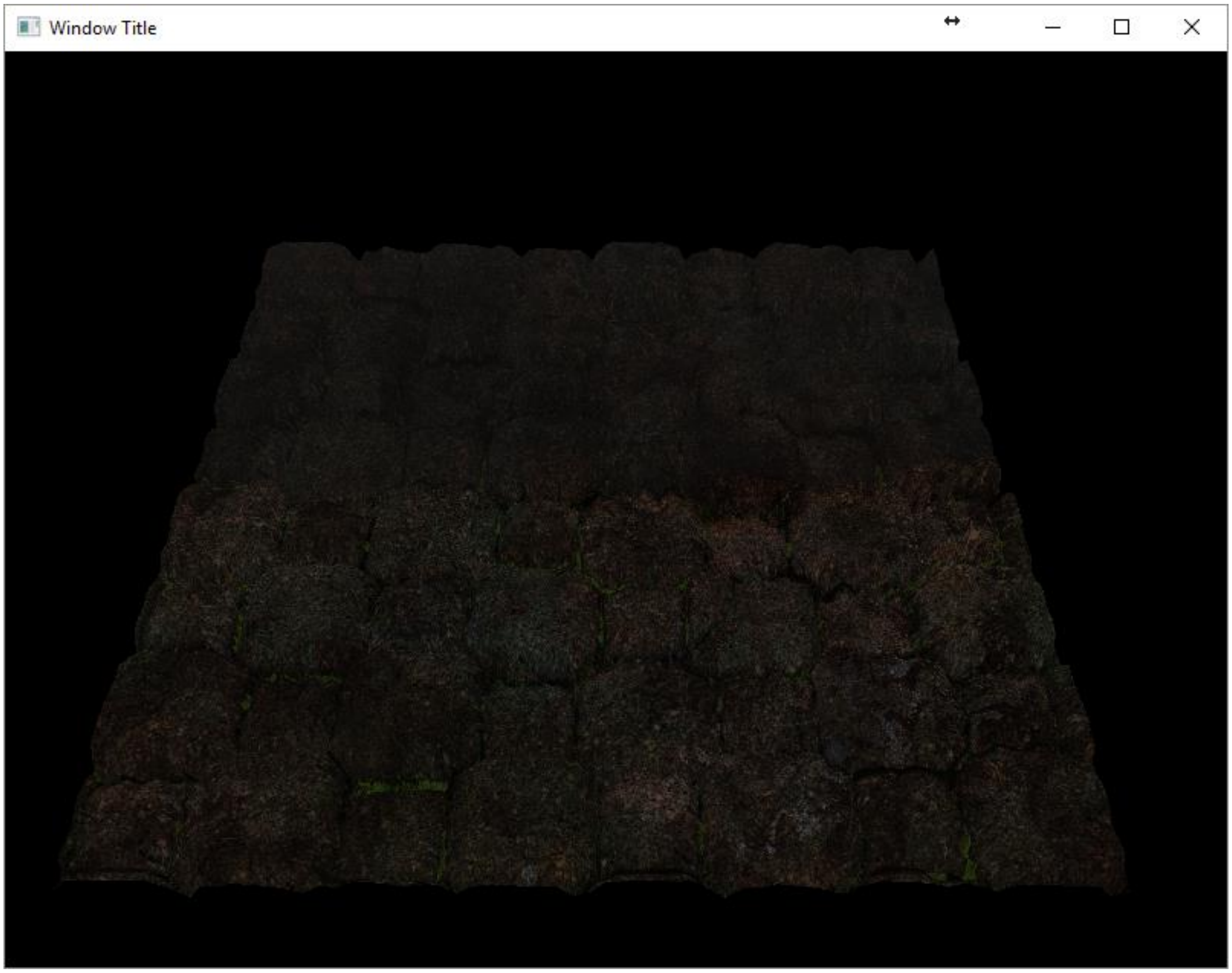

Figure 10: 45-degree view. Dry is on bottom and wet is on top.

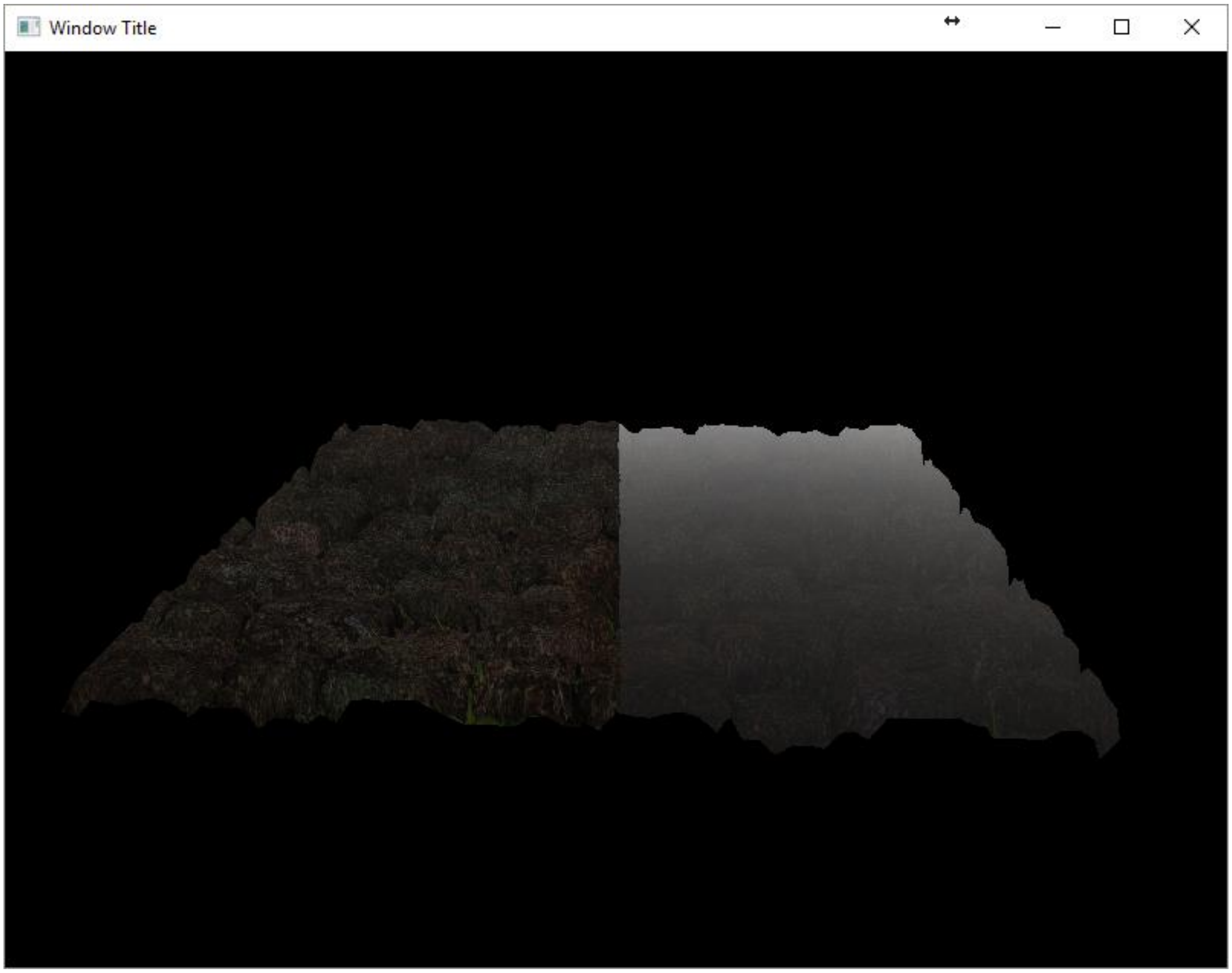

Figure 11: Shallow view. Dry is on left and wet is on right.

Analysis of Work

New Results

At first, I believed my work modifying the model of wet surface rendering [1] to be physically accurate and experience physical phenomena to be a novel contribution. However, throughout the final project process, I discovered a blog series that explored the very domain I am working in for my project. In this blog series, the author explores a similar model to the one I propose in this work, based on a published multi-layered BRDF model [4]. The authors model also included some physical phenomena I was unaware of, such as the absorption of light by the water layer, as well as the effect a porous material would have on the darkening of a material when wet. As a result, I have found that my contribution is not novel after all, but rather very similar to work conducted before, although it remains unpublished [3]. I think there is still room for contribution however, specifically in establishing the physically accurate wet surface model, and a proposal of a more physically accurate model of water within the microfacets of a model.

Meeting Goals

I feel like throughout this project, I was able to meet my goals. I was able to accomplish much of my original goal of exploring wet surface rendering and adapting previous work to model wet surface rendering in a physically accurate manner. Specifically, I was able to implement a model of physically based wet surface lighting that incorporated the reflection of lighting hitting the top layer of water, the interaction of transmitted light that passed through the water boundary with the material, and the total internal reflection of light reflected off the material surface. This was the first goal I wanted to accomplish.

In addition, I had hoped to model the behavior of wet surfaces where the material is not fully submerged. Rather, the surface would have a water level that was within the microfacets themselves. However, after implementing the original model, I found that there was still behavior of that model I would rather explore first. Notably, the surfaces still did not look dark enough when wet, compared to when dry. After some additional research and reading [3], I found that I was missing a model of the light absorption that would take place as light traveled through the layer of water. I then incorporated this behavior, based on the model proposed by [4] as well as an exploration of the spectral absorption of water by [3], into my model. The result was that surfaces appeared darker and more realistic when wet.

Future Work

There are a few important next steps in a continuation of this work which I plan to explore in my PhD research. One step is to include and modify a model of porosity of materials into my wet surface lighting model. As mentioned by previous work [3], a slight amount of subsurface scattering being filled will cause a material to appear darker when wet. While my model seems to look accurate for some surfaces, plywood, concrete, I believe it could look better for porous surfaces, concrete or stone as the model is missing the porous contribution. One step we would like to explore that might be a good model for this behavior will be an exploration of modeling water that is within the microfacet surfaces, but not submerging the entire surface.

Another next step would be to explore the effect of secondary bounces of light after a total internal reflection. As of now, I have chosen not to model this extra light as doing so would increase the computational complexity of the real time wet surface method. However, this additional light might have a visually noticeable contribution, as well as causes energy to be lost. A planned extension of my model to support extra bounces would be an additional Cook-Torrance interaction with the material to represent additional bounces, and a probability of percentage contribution parameter that controls how much of that additional Cook-Torrance reflectance would be recontributed.

References

[1] John Lekner and Michael C. Dorf, "Why some things are darker when wet," Appl. Opt. **27**, 1278-1280 (1988)

[2] Henrik Wann Jensen, Justin Legakis, and Julie Dorsey. 1999. Rendering of wet materials. In *Proceedings of the 10th Eurographics conference on Rendering* (EGWR'99), G. Ward and D. Lischinsky (Eds.). Eurographics Association, Aire-la-Ville, Switzerland, Switzerland, 273-282.

[3] Lagarde, Sébastien . "Water drop 3a – Physically based wet surfaces." Physically based wet surfaces, 8 Sept. 2013, seblagarde.wordpress.com/2013/03/19/water-drop-3a-physically-based-wet-surfaces/.

[4] Weidlich, Wilkie, "Arbitrarily Layered Micro-Facet Surfaces", http://www.cg.tuwien.ac.at/research/publications/2007/weidlich_2007_almfs/

[5] https://www.slideshare.net/DICEStudio/moving-frostbite-to-physically-based-rendering