CS348B Report: Summertime Iridescence

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1 Introduction

Iridescence is a beautiful optical phenomena. We were interested in modelling the iridescence found in both natural and man-made objects — in particular, we wished to apply iridescence to surfaces more complex than just simple spheres like bubbles. With summer vacation just around the corner, we decided to create a beach scene featuring a pair of iridescent sunglasses and an iridescent shell.

2 Iridescence

Iridescence occurs as a result of light waves reflecting off of layered surfaces and interfering within the layered system in such a way that hue changes with the angle of observation and angle of illumination. Thin film interference is one model of this phenomena, and the model that we chose to implement.

2.1 Thin Film Interference

We based our implementation of thin film interference on the "Thin Film Interference for Computer Graphics" tutorial [1]. First, we created a new BRDF called `ThinFilmReflectance` to calculate how much light is reflected given ω_o and ω_i. This required us to calculate the Fresnel amplitude reflection and transmission coefficients:

$$r_s = \frac{n_i \cos\theta_i - n_j \cos\theta_j}{n_i \cos\theta_i + n_j \cos\theta_j}$$

$$t_s = \frac{2n_i \cos\theta_i}{n_i \cos\theta_i + n_j \cos\theta_j}$$

$$r_p = \frac{n_j \cos\theta_i - n_i \cos\theta_j}{n_j \cos\theta_i + n_i \cos\theta_j}$$

$$t_s = \frac{2n_i \cos\theta_i}{n_j \cos\theta_i + n_i \cos\theta_j}$$

We can then use these Fresnel coefficients to determine the reflected intensity:

$$\alpha = \rho_{1|0}\rho_{1|2}$$

$$\beta = \tau_{0|1}\tau_{1|2}$$

$$I_T = (\frac{n_2 \cos\theta_2}{n_0 \cos\theta_0})\frac{|\beta|^2}{|\alpha|^2 - 2\alpha\cos\varphi + 1}$$

$$I_R = 1 - I_T$$

where $\rho_{i|j}$ and $\tau_{i|j}$ denote the amplitude reflection and transmission coefficients for a light wave going from medium i to medium j, n_i denotes the index of refraction of medium i, and φ is the phase of the light wave.

We approximated the final reflected intensity by calculating the I_R of three discrete wavelengths — red, green, and blue — and creating an `RGBSpectrum` using these I_R as components. We used the following wavelength values, which are taken from the tutorial: red = 650 nm, green = 510 nm, and blue = 475 nm.

We then created a new `ThinFilm` material that uses our `ThinFilmReflectance` BRDF. Figure 1 demonstrates the `ThinFilm` material with different input parameters on two killeroo models.

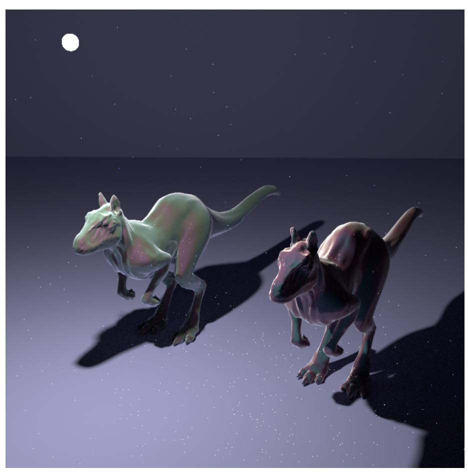


Figure 1: Left killeroo: external IOR = 1, thin film IOR = 1.55, internal IOR = 1.66, thin film thickness = 500. Right killeroo: external IOR = 1, thin film IOR = 1.5, external IOR = 1.7, thin film thickness = 410.

2.2 Height Mapping

One problem that we encountered when applying the `ThinFilm` material to our sunglasses and seashell models was that both models were relatively flat and smooth, and thus were very poor at showing off iridescence. Figure 2 demonstrates the seashell model with the `ThinFilm` material and reasonable parameters.

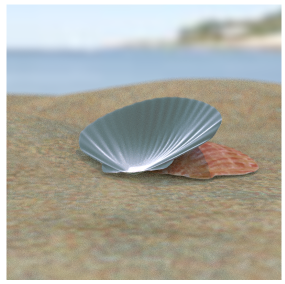


Figure 2: External IOR = 1, thin film IOR = 1.55, internal IOR = 1.66, thin film thickness = 500

To remedy this, we augmented the `ThinFilm` material to take in an additional height map, which is just an image that encodes an offset that is added to the film's thickness. This effectively allows us to model thin films that vary in thickness, which more accurately represents real life thin films. Figure 3 shows some example height maps and the effect they produce.

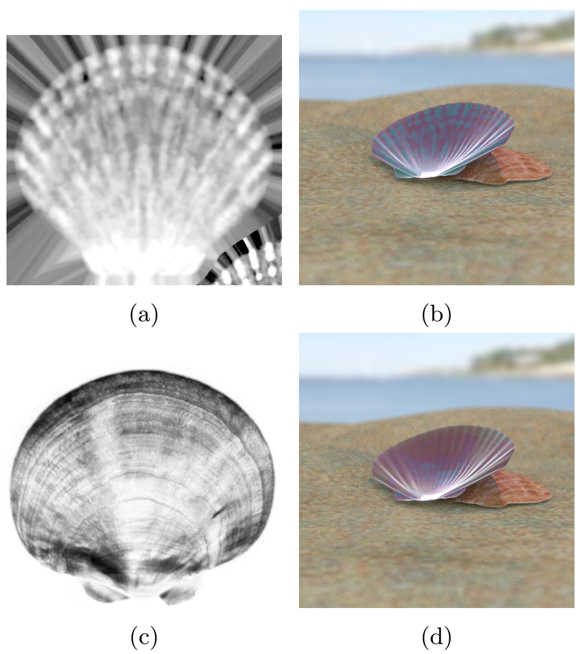


Figure 3: The result of rendering with different height maps, using the same parameters as in Figure 2

2.3 Sunglasses

In order to make sunglasses iridescent, manufacturers coat the surface of the lenses with thin, alternating layers of reflective coatings. These reflective coatings are composed of dielectric materials or metals such as titanium/titanium dioxide and chromium/chromium oxide [3]. We could not find any literature on the thicknesses of these coatings, so for our final image we simply picked a thickness that resulted in a nice gradient.

As previously mentioned, the model we chose for the sunglasses had very flat lenses, and failed to showcase iridescence as strongly as we wanted. To remedy this, we used a thickness map, shown in Figure 4, where the lenses would have a thicker film near the outside edge than in the center, which led to a richer variation in color.

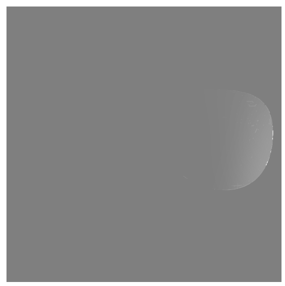
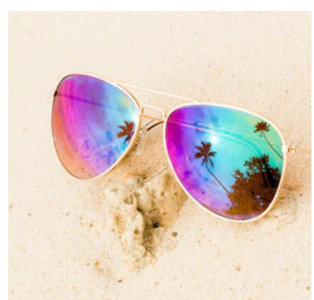


Figure 4: Thickness map for the sunglasses lens, used in our final image

Sunglasses lenses are also reflective and transmissive, as can be seen in Figure 5. Thus, we added `SpecularReflection` and `SpecularTransmission` components to the `ThinFilm` material. Our results can be seen in Figure 6.

(a)



(b)

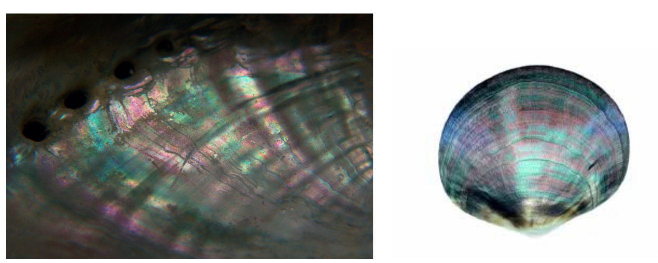
Figure 5: Some reference images showing the reflective and transmissive aspects of iridescent sunglasses. Sources: (a) http://www.lovethispic.com/uploaded_images/167914-Sunglasses-On-The-Beach.jpg (b) https://image.shutterstock.com/image-photo/sunglasses-on-beach-260nw-221347978.jpg

Figure 6: Zoomed-in shot of the sunglasses in our final image. Note the reflection of the palm trees and underside of the umbrella in the right lens, and the temple visible on the edge of the left lens.

2.4 Seashell

Nacre is what produces iridescence in seashells. At a microscopic level, nacre is composed of alternating layers of aragonite platelets and elastic biopolymers; the aragonite platelets are so thin that they interfere with light waves, which is what produces the iridescence [4]. Although thin film interference isn't a completely accurate model of nacre, it is a decent enough approximation; that being said, a more physically accurate model of structural coloration would be an interesting topic to explore in the future.

At a macroscopic level, many seashell surfaces are richly patterned with grooves and bumps, as can be seen in Figure 8. Although passing in a height map allowed us to create pretty iridescent patterns, the smoothness of our shell model and the lack of surface texture led resulted in some pretty boring and fake looking shells (see Figure 3).



(a) (b)

Figure 7: Some reference images showing the texture of a shell surface. Sources: (a) https://asknature.org/strategy/weak-interfaces-make-material-tough/ (b) https://www.researchgate.net/figure/The-iridescence-color-of-a-polished-shell-of-the-mollusk-Pinctada-Margaritifera-from-the$_{f}ig1_{2}$4361894

To remedy this, we created a bump map to represent the fine ridges found inside many shells. Adding a bump map greatly improved the result, as can be seen by comparing Figure 8c with Figure 3d.

(a) Height map (b) Bump map (c) Result

Figure 8: The result of rendering the shell model with both a height map, for variation in color, and a bump map, to simulate a textured surface

3 Sand

To model the sand, we first developed a set of small "dunes" in Blender by subdividing and displacing portions of a plane.

Then, we applied subdivision and a map for displacement to add a little bit of ripple to the sand. Following this we used a hair particle system with two different ico sphere shapes, shown in Figure 9 as our "grains" of sand, which was a technique outlined by a Blender user for modeling realistic sand [2]. Weights were painted on the visible portions of the dunes so that grains would only appear where the camera would see them.

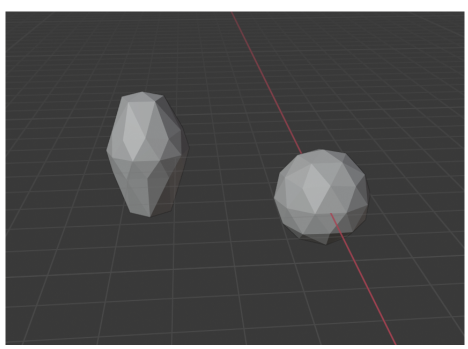
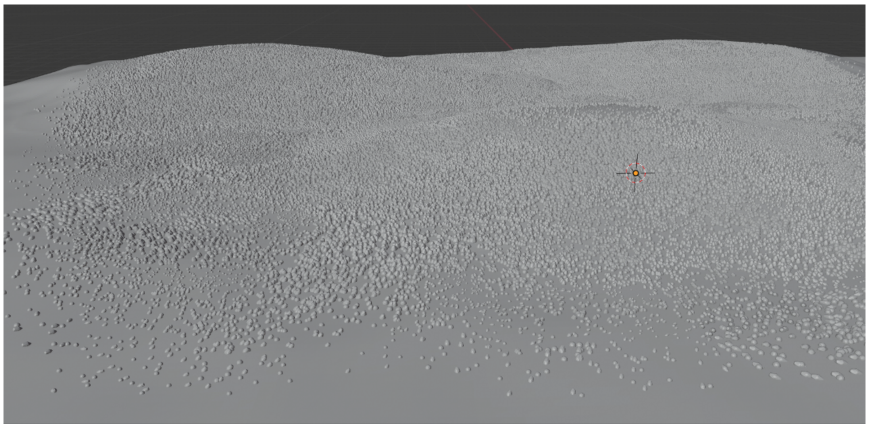
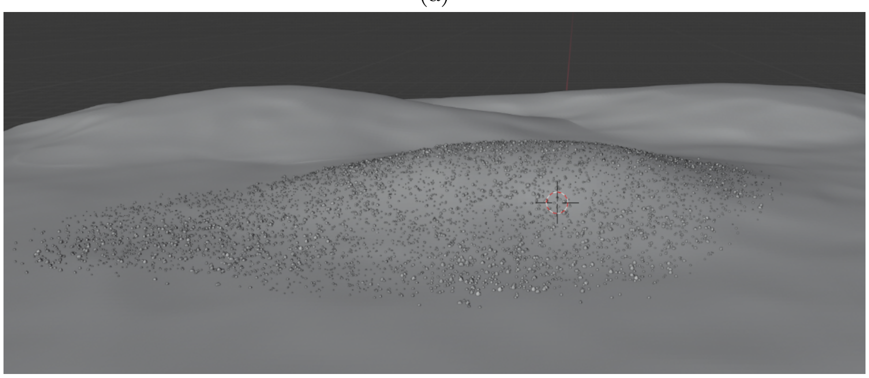


Figure 9: Two IcoSpheres used as individual sand grains in our particle system

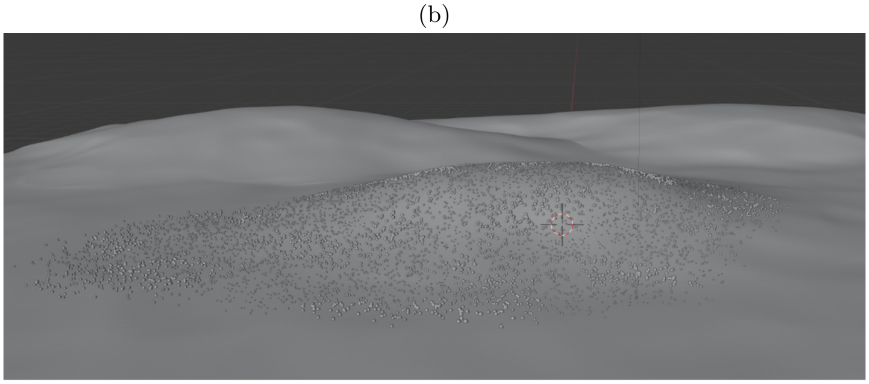
One large mesh with several thousand grains was exported first (Figure 10a), then two smaller meshes with fewer grains (Figure 10b and 10c), mainly dispersed on the foremost hill where we get the closest view. These three meshes were stacked together in the final scene to create a thicker clustering of grains.



(a)



(b)



(c)

Figure 10: Three different sand meshes which were then combined

In order to give some realistic shine and variation to the sand, we used the Disney material's "fake" subsurface scattering for the main mesh, and additionally a matte material with a sand colored texture for a sprinkling of grains throughout.

For the subsurface scattering, without concrete measurements for scattering distances of different wavelengths for sand, we started off with a basic sand color and experimented with different inputs to the `scatterdistance` until we got an appealing output.

4 Scene

Meshes for the sunglasses, shell, umbrella, and palm trees were found for free from websites TurboSquid and CGTrader. We imported them into Blender and placed them to create a balanced composition, then exported them as .ply files so they would be correctly positioned in pbrt. Most of the meshes came with textures; all other textures, especially all height and bump maps, were created using GIMP.

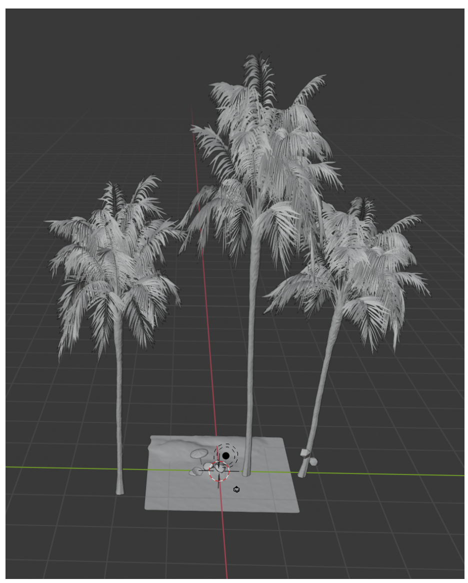


Figure 11: Scene in blender with all objects placed

We used an environment map for lighting and background, with an additional black body light to create the shadows from the umbrella and additional palm trees meshes seen in Figure 11.

We also widened the lens radius for an added sense of depth, with the background dunes blurred out slightly.

5 Results and Conclusion

Figure 12: Final image (1080 x 1920, 4096 spp)

By developing a method of rendering iridescence that involves varying thicknesses, we were able to convincingly render iridescent sunglasses and shells.

We overcame many failed attempts at subsurface scattering in the sand by using the Disney material, but later realized that normal subsurface materials would have worked well had our sand mesh been an entire volume rather than a displaced plane with grains of sand embedded in it. For future models of sand, it would also be more convincing if we create more realistically shaped sand grains rather than simple IcoSpheres.

In the future, it may be interesting to combine both subsurface scattering and iridescence, which we attempted to do in the shell but ultimately did not figure out.

6 Acknowledgements

We would like to thank Hubert Teo, our project TA, for all of his help and guidance on our project. He was a tremendous resource and our final image would not have been possible without his great advice. We would also like to thank Brennan Shacklett for his support and feedback.

7 Contributions

Jennifer wrote the thin film interference BRDF, created a new iridescence material, researched and fine-tuned the various iridescence parameters, and created custom texture maps for the shell

Cynthia acquired the various models, created the final scene in Blender, modelled the sand, and created thickness maps for the sunglasses lenses

References

[1] Bacterius. Thin film interference for computer graphics. https://www.gamedev.net/articles/programming/graphics/thin-film-interference-for-computer-graphics-r2962. [Online; accessed 2019-05-30].

[2] Carlo. Creating realistic close up sand material. https://blender.stackexchange.com/questions/102825/creating-realistic-close-up-sand-material. [Online; accessed: 2019-06-05].

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[4] Wikipedia contributors. Nacre — Wikipedia, the free encyclopedia. https://en.wikipedia.org/wiki/Nacre, 2019. [Online; accessed 2019-05-30].