Soap Bubble Clusters with Swirly Bokeh Background

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OVERVIEW

We aim to create a bubble cluster photography with Bokeh effect background. The idea of bubless as the front object is inspired from the beautiful forms and colors of bubble clusters as well as the interesting physics laws that come with them. The backfound effect is inspired from photography produced with Lomography Petzval Bokeh 58 art lens. We divided our work into two technical parts: the Bokeh effect background and the bubble cluster simulation.

PART1: BACKGROUND (Zhenzhi Xia)

Unlike the most rendering systems that generate images where the entire scene is in sharp focus and mimics the performance of a pinhole camera, this background scene that requires some deliberate blurring is created by a more real camera lens of optimized Petzval lens. Petzval lens was designed by the German-Hungarian mathematics professor Josef Maximilian Petzval in 1840 in Vienna. This type of doublet lens which was very sharp in the center, but due to field curvature, the plane of focus and relative illumination fall off quite sharply as going away from the center of the image. This artifact, however, ideally suits for portrait, and it became the standard lens for portrait photographers. Here we would like to further modify the parameters of the Petzval lens through some lens design knowledge and wave optics.

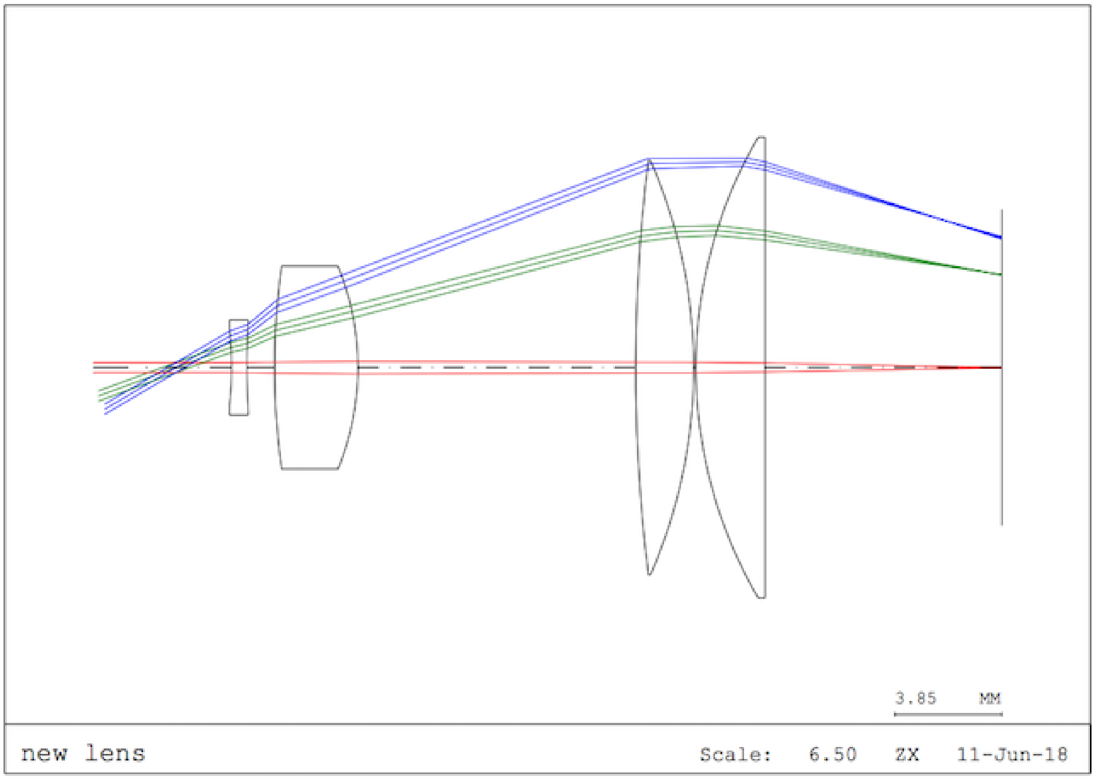
Realistic Camera Plugin

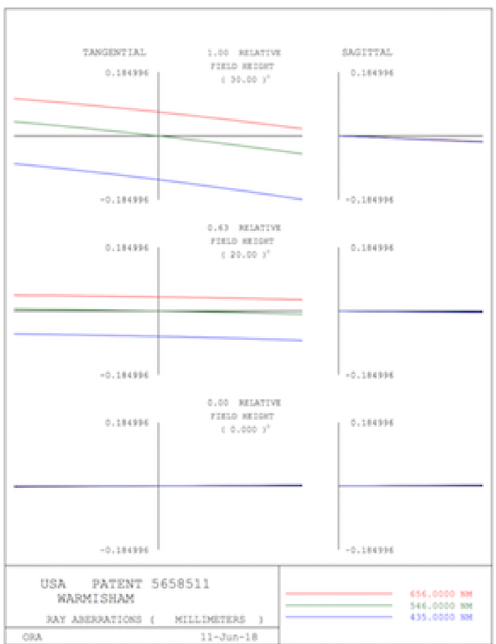
Refer to the assignment offered from previous year's CS348b, a camera plugin for pbrt that simulates the traversal of light through these lens assemblies onto the film plane of a virtual camera is applied. Usually random ray bundles are traced from object space to image space and each ray at the object space is conjugated to a point on the final image. The standard algorithm for tracing a ray through the lens is given in the image below. The propagation of a ray through a lens surface involves both finding the point of intersection between the ray and the surface and the refraction of the ray as it crosses the interface between the two media.

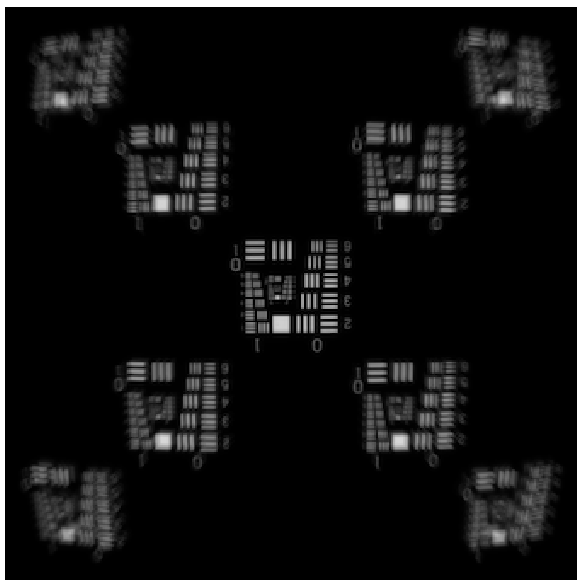
R = Ray(point on film plane, point on rear-most element)
For each lens element E_i, from rear to front,
    p = intersection of R and E_i
    If p is outside clear aperture of E_i
        ray is blocked
    Else if medium on far side of $E_i \neq$ medium on near side
        compute new direction for R using Snell's law

Lens Design and Aberrations

Benefiting from the realistic camera plugin, a lens system is designed to be fed into the camera simulator. The starting point for this lens design is a patent lens of 100mm focal length and 50deg field of view. Since the swirly Bokeh pattern results mostly from the aberrations of astigmatism and coma, it is important that we introduce more aberrations off-axis while keeping the on-axis image in focus as we would like to position the bubbles in the middle. The ray aberrations plot and 2D simulation of the image of the newly designed lens are shown below.







Since asymmetry of the lens system introduces astigmatism, it's more desirable to put the aperture stop in the front. The drawback is that the rays tend to be more easily cut out at the edges of the lens, thus the vignetting effect is observed. But in some cases of photography, a small amount of vignetting is also desired.

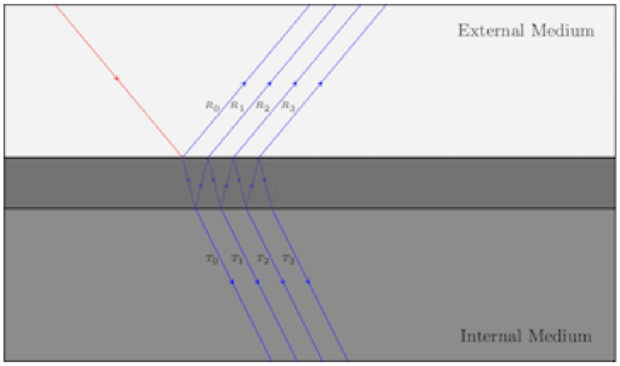
Render Bokeh effect with Background

The realistic camera is then applied to the landscape scene downloaded from pbrt scenes as background where a swirly artistic Bokeh pattern more visible at the edge of the frame.

PART2: BUBBLE CLUSTERS (Jun Li)

Thin Film Interference

Wave interference of light is sometimes neglected in computer graphics since it requires interpreting light as waves instead of particles (photons) and can sometimes be hard to simulate. In our project we simulated thin film interference. When a light wave comes into contact with a film layer, it reflects and refracts multiple times inside the layer system, and interferes with itself in the process. Examples of thin film interference are soap bubbles, gasoline rainbow patterns, or even animal wings.



The Fresnel equations provide a quantitative description of how much of the light will be transmitted or reflected at an interface. The light reflected from the upper and lower surfaces will interfere. The degree of constructive or destructive interference between the two light waves depends on the difference in their phase. This difference in turn depends on the thickness of the film layer, the refractive index of the film, and the angle of incidence of the original wave on the film.

To simulate thin film interference, we extended bxdf to a bubble material class. We used the following equations to compute reflection/transmission coefficients for s-polarized and p-polarized light, as well as the final fresnel coefficient for the interference:

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

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

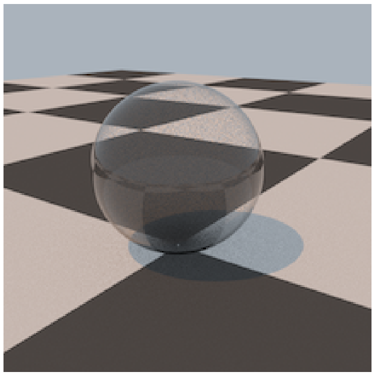
$$r_p = \frac{n_j \cos\theta_i - n_i \cos\theta_j}{n_i \cos\theta_j + n_j \cos\theta_i}$$

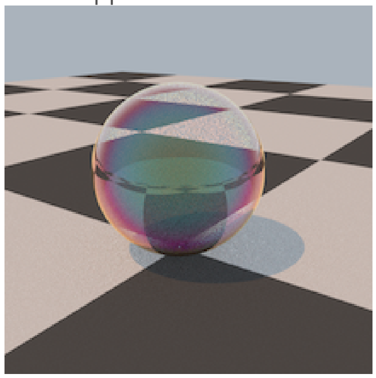
$$t_p = \frac{2 n_i \cos\theta_i}{n_i \cos\theta_j + n_j \cos\theta_i}$$

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

We used refraction rate of bubble = 1.4, and simulated interference of red, green, blue lights with wavelength 650, 510, 475 nanometers, respectively.

Without and with thin film interfereice applied:





Bubble Cluster Geometry

A bubble is the minimal energy surface of a type formed by a soap film. In relation to its volume, it has the smallest surface. Plateau’s Laws and later works, we were able to simulate bubble clusters according to this pattern.

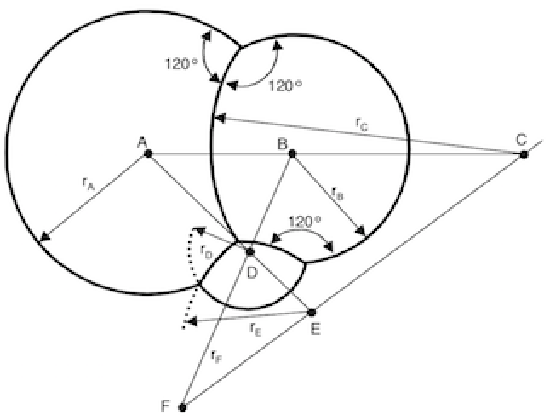
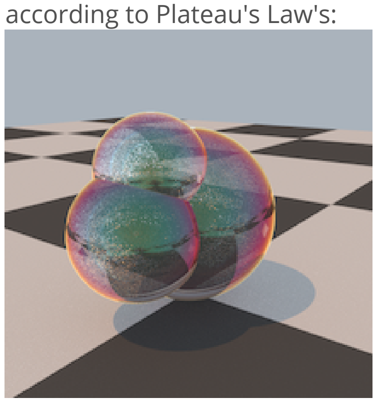


Fig. 4. Curvatures of triple bubble shells.

We used the following equations as well as the SSS sin rules to compute the relative coordinates of all the centers:

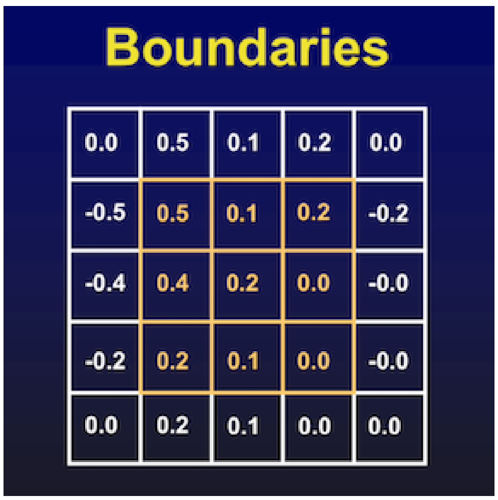
$$\frac{1}{r_B} = \frac{1}{r_A} + \frac{1}{r_C}, \qquad AB^2 = r_A^2 + r_B^2 - r_A r_B.$$

Two and three bubbles collision according to Plateau's Law's:

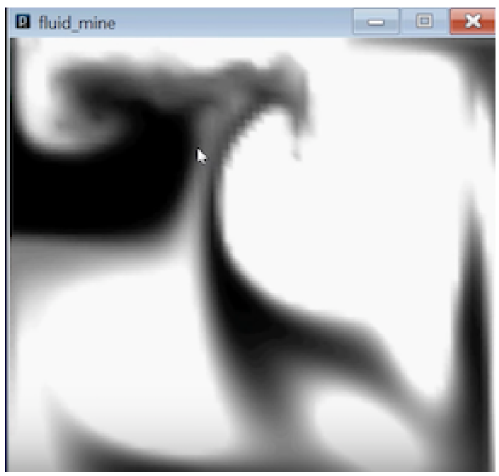


Fluid Simulation and Stereographic Projection (future work for better effect)

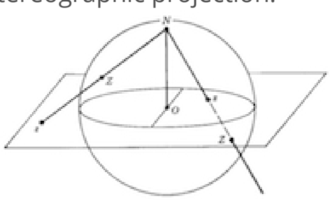
This section describes an implementation that did not show our desired effect. We aimed to simulate the fluid dynamics on a more reflective bubble. We adapted the real-time fluid dynamic simulation model by Jon Stam with source code provided.



0.0	0.5	0.1	0.2	0.0
-0.5	0.5	0.1	0.2	-0.2
-0.4	0.4	0.2	0.0	-0.0
-0.2	0.2	0.1	0.0	-0.0
0.0	0.2	0.1	0.0	0.0



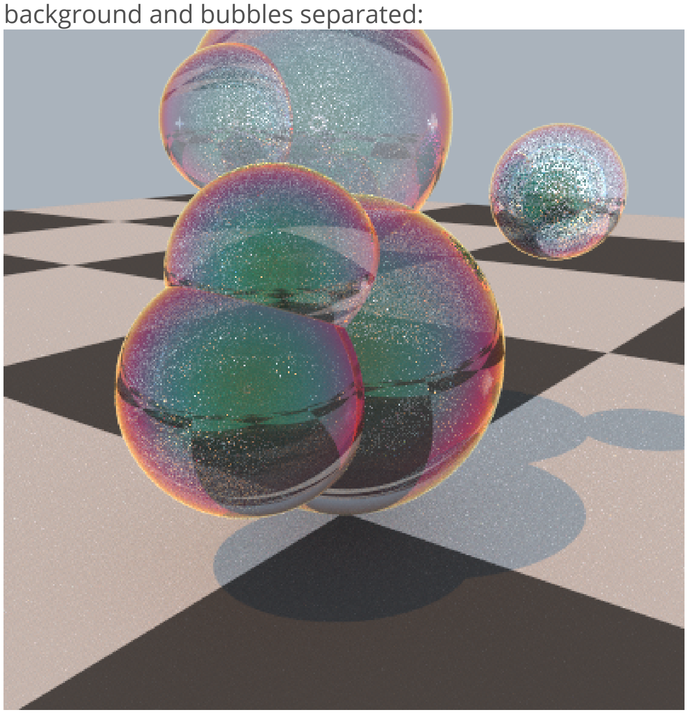
Stereographic projection:



This model simulates fluid using a state machine, like one for Game of Lifes. We created a state grid of size 100 by 100, then we used half stereographic projection to project each hemisphere of the bubble to the grid. To some extent, the distortion from the projection should correspond to the natural distortion on soap film due to gravity.

PART3: FINAL IMAGES

Our combined image does not sample well due to our technical limitation. Below are better quality images with background and bubbles separated:



(Halton sampler, 512 samples/pixel, resolution 400 400)


(Halton sampler, 256 samples/pixel, resolution 1280 960)

Reference

[1] A. Glassner, "Soap bubbles. 2 [Computer graphics]," in IEEE Computer Graphics and Applications, vol. 20, no. 6, pp. 99-109, Nov/Dec 2000.
[2] Bacterius, "Thin Film Interference for Computer Graphics", Graphics and GPU Programming, Apr 2013, https://www.gamedev.net/articles/programming/graphics/thin-film-interference-for-computer-graphics-r2962/.
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[4] Kolb, Craig, Don Mitchell, and Pat Hanrahan. "A realistic camera model for computer graphics." Proceedings of the 22nd annual conference on Computer graphics and interactive techniques. ACM, 1995.
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[6] David Eppstein, “The Graphs of Planar Soap Bubbles”, Symposium on Computational Geometry Rio de Janeiro, Brazil, June 2013.
[7] Syvokin, Viktor P., and Michael D. Thorpe. "Fast calculation of bokeh image structure in camera lenses with multiple aspheric surfaces." International Optical Design Conference. Optical Society of America, 2014.
[8] https://graphics.stanford.edu/wikis/cs348b-07/Assignment3.