This is the authors' preprint. The definitive version is available at https://dl.acm.org/doi/10.1145/3641234.3671056

Edible Caustics: Designing Caustics of Jelly via Differentiable Rendering

Daiki Inokoshi
Shibaura Institute of Technology
Tokyo, Japan
al20116@shibaura-it.ac.jp

Yuki Yabumoto
Shibaura Institute of Technology
Tokyo, Japan
ma23194@shibaura-it.ac.jp

Junpei Fujikawa
Shibaura Institute of Technology
Tokyo, Japan
ma22121@shibaura-it.ac.jp

Yoshinori Dobashi
Hokkaido University
Hokkaido, Japan
doba@ime.ist.hokudai.ac.jp

Takashi Ijiri
Shibaura Institute of Technology
Tokyo, Japan
ijiri@shibaura-it.ac.jp

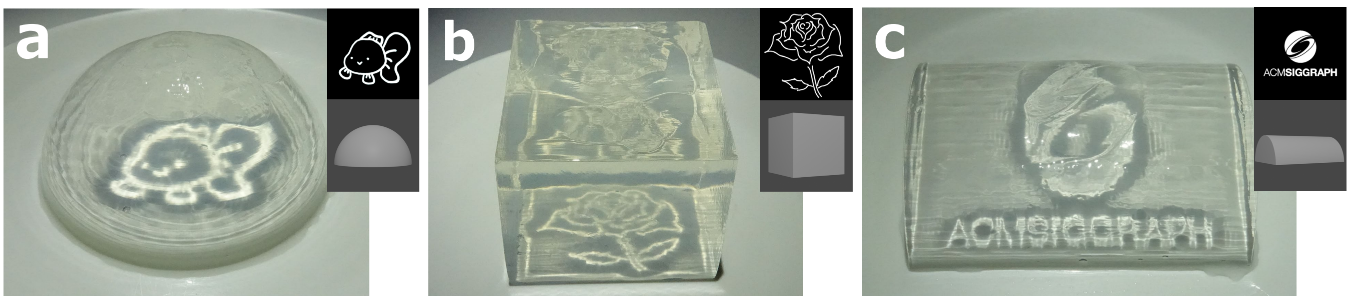

Figure 1: Jellies created with our method, providing caustic patterns of a goldfish (a), a rose (b), and the SIGGRAPH logo (c). Each panel displays the target image and the initial shape.

CCS CONCEPTS

• **Computing methodologies → Rendering**.

KEYWORDS

differentiable rendering, caustic patterns, jelly modeling

ACM Reference Format:
Daiki Inokoshi, Yuki Yabumoto, Junpei Fujikawa, Yoshinori Dobashi, and Takashi Ijiri. 2024. Edible Caustics: Designing Caustics of Jelly via Differentiable Rendering. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Posters (SIGGRAPH Posters '24), July 27 - August 01, 2024.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3641234.3671056

1 INTRODUCTION

Transparent candies, such as jelly, have long been globally popular for their attractive and beautiful appearance. Jelly, in particular, exhibits distinctive visual traits—it is not only see-through but also refracts incoming light, creating caustic patterns on its base and surroundings. However, modeling jelly shapes considering the emerging caustic patterns poses a significant challenge.

SIGGRAPH Posters '24, July 27 - August 01, 2024, Denver, CO, USA

ACM ISBN 979-8-4007-0516-8/24/07.
https://doi.org/10.1145/3641234.3671056

The computational modeling of food is important topic in computer science. Numerous researchers have leveraged computational tools to design the shapes and appearances of various foods. For instance, methodologies have been developed to model jellies with lenticular-lens patterns that induce invisible interiors [Yoshimoto et al. 2023], embed QR codes in cookies [Miyatake et al. 2022], and fabricate flower jelly using three-dimensional (3D) printing [Miyatake et al. 2021]. While these studies have successfully achieved specific appearances or functionalities in foods, the caustic patterns of transparent candies have not been addressed.

Our goal is to create jellies with desired caustic patterns. We achieve this by optimizing the jelly shape so that its caustic pattern closely matches a given image while ensuring a smooth surface. We employ differentiable rendering techniques to solve this optimization problem. Once the optimal jelly shape is obtained, we fabricate a jelly mold using a 3D printer and use it to create jelly. To demonstrate the feasibility of our approach, we produce jellies with various caustic patterns (Fig. 1).

2 METHOD

Fig. 2 provides an overview of the jelly creation process using our method. The user first selects an initial shape from options such as a hemisphere, a cube, a half-cylinder, or a rectangular prism, and provides a grayscale target image (a). Subsequently, we optimize the jelly shape by iteratively performing rendering the caustic pattern of the current shape and modifying the shape to minimize the difference between the rendered caustic pattern and the target image (b). The optimized shape is then used to fabricate a jelly mold

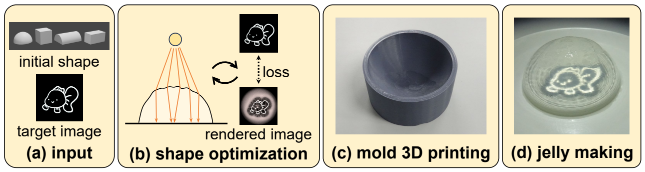

Figure 2: Workflow of jelly creation.

(c) from which jelly is created. When illuminated by a point light from above, the resulting caustic pattern becomes visible (d).

We consider a scene wherein a single point light is positioned above the jelly model, and a rendering screen is placed at the bottom of the jelly (Fig. 2b). In this setup, we optimize the jelly shape π such that the caustic pattern $I(\pi)$ generated by π on the screen closely matches the target image I_t, as,

$$\arg\min_{\pi} \|I(\pi) - I_t\|_2^2 + \lambda \sum_{\mathbf{v}_i \in \pi} \|L(\mathbf{v}_i)\|_2^2 \tag{1}$$

where the second term is for smoothing the shape, $L(\mathbf{v}_i)$ represents the Laplacian for a vertex $\mathbf{v}_i$ of π, and λ is a coefficient. Due to the soft nature of jelly, making sharp shapes is difficult; this smoothing term ensures that the resulting shape is smooth and feasible for representation with jelly.

We solve this optimization problem using the widely-used open-source differentiable renderer, Mitsuba 3 [Jakob et al. 2022]. In our implementation, we utilize a height map texture to represent the deformation of the jelly shape and iteratively update the height map during optimization. The second term in Eq. (1) is approximated by applying the Laplacian filter to the height map. Additionally, we employ hierarchical coarse-to-fine optimization by upsampling the height map at specific intervals. In our experiment, we utilize the Adam optimizer with a learning rate of 3.0×10^{-5} and perform 1000 optimization iterations. We set the number of rays per pixel during rendering to 256, λ to 1.0×10^7, and the refractive index of the jelly to 1.35.

Given an optimized jelly shape, we constructed a jelly mold model and fabricated it using a 3D printer, Creality Ender-3 S1 Pro, and PLA material. Although we used a fused deposition modeling printer due to its ease of fabrication, we will continue to explore alternative printers for more precise modeling in the future. Subsequently, we created jelly as follows: we dissolved 12 g of agar and 45 g of granulated sugar in 300 ml of hot water, heating the mixture until fully dissolved, and then solidified it using the mold.

3 RESULTS AND DISCUSSION

To evaluate the feasibility of our method, we created jellies with various caustic patterns, such as line drawings and characters. Fig. 1 presents photographs of three jellies with their target images and initial shapes. These results indicate that our method enables the creation of jellies with distinct caustic patterns.

In our experiment, we used a computer equipped with an AMD Ryzen 9 3900X and a GeForce RTX 2070 SUPER. The optimization process described in Eq. (1) took less than 10 min, which we think a reasonable computation time for modeling new jelly shapes.

To validate the effectiveness of the smoothing term in Eq. (1), we produced jelly molds and jellies with and without the smoothing term. Fig. 3 provides a comparison. When the smoothing term was not applied (Fig. 3a, b), the resulting model exhibited sharp shapes that were difficult to represent with jelly, leading to noisy caustic patterns. Conversely, when employing the smoothing term, we obtained a smoother shape, resulting in clearer caustic patterns (Fig. 3c, d).

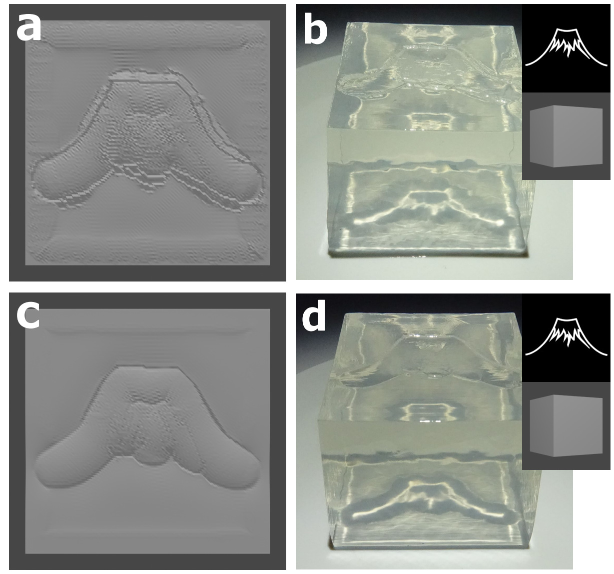

Figure 3: Comparison between jelly shapes without the smoothing term (a, b) and with the smoothing term (c, d). Panels (a, c) depict the top surfaces of the 3D mold models, while panels (b, d) show actual jellies with caustic patterns.

4 CONCLUSION

In summary, we have introduced a method for designing jelly shapes with desired caustic patterns. We formulated an optimization problem that considers caustic patterns and surface smoothness, utilizing differentiable rendering to solve it. The creation of jellies with various caustic patterns demonstrates the feasibility of our approach. One future work involves investigating the minimum thinness and complexity of caustic lines that our method can reproduce. Additionally, we would like to extend our method to produce more precise caustic patterns for target images with gradients, generate colored caustic patterns, and provide edible tags.

ACKNOWLEDGMENTS

This work was supported in part by JSPS Grant-in-Aid for Scientific Research (B) 23K24965.

REFERENCES

W. Jakob, S. Speierer, N. Roussel, and D. Vicini. 2022. DR.JIT: A Just-in-Time Compiler for Differentiable Rendering. *ACM ToG* 41, 4 (2022), 124:1–124:19.

M. Miyatake, K. Narumi, Y. Sekiya, and Y. Kawahara. 2021. Flower Jelly Printer: Slit Injection Printing for Parametrically Designed Flower Jelly. In *Proc. CHI 21*. 425:1–425:10.

Y. Miyatake, P. Punpongsanon, D. Iwai, and K. Sato. 2022. Interiqr: Unobtrusive Edible Tags Using Food 3D Printing. In *Proc. UIST 22*. 84:1–84:11.

T. Yoshimoto, N. Kasahara, and H. Miyashita. 2023. Fabrication of Edible lenticular lens. In *ACM SIGGRAPH 2023 Posters (SIGGRAPH '23)*. Article 46, 2 pages.