Edible Chromatic Caustics: Designing Colored Caustics of Jelly via Differentiable Rendering

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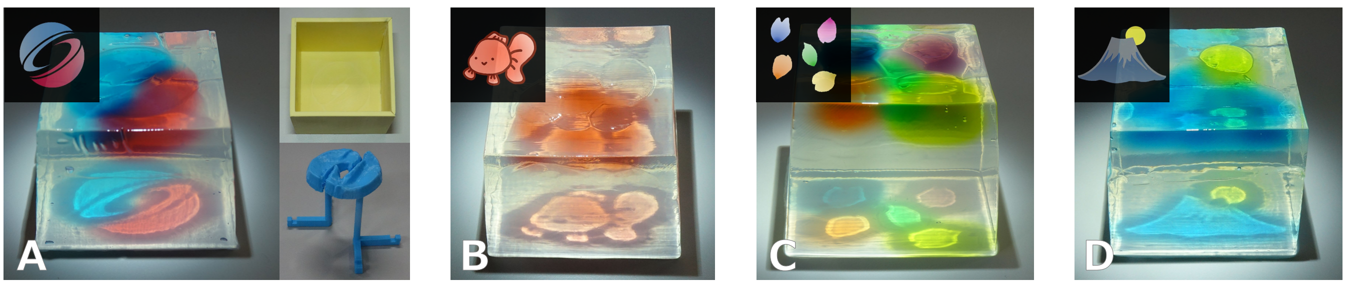

Figure 1: Jellies created using the proposed method. Each pane shows the target image and jelly illuminated by white light. Pane (A) additionally shows a jelly mold comprising the outer cavity (right top) and the inner cores (right bottom).

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1 INTRODUCTION

Transparent candies have long been popular worldwide because of their beautiful appearance. In particular, jelly (a jello-style dessert) has a distinctive visual feature; it allows the visualization of its interior and creates caustic patterns on the surface beneath it by refracting light. The shape and color of the caustic patterns are determined by the shape, refractive index, color (absorption coefficient), and internal structure of the jelly. Fine-tuning these features of a jelly to achieve a desired caustic pattern is challenging.

Some researchers have proposed methods for creating jellies with various visual features. For instance, Miyatake et al. [2021] developed a three-dimensional (3D) printer that fabricates flower jelly by injecting colored jelly into base jelly. Yoshimoto et al. [2024] created a lens array with jelly, achieving a novel interaction with food. The most closely related work to our study is edible caustics [Inokoshi et al. 2024], a method for designing jelly shapes that generate desired caustic patterns. However, this method does not support colored caustics.

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This study aims to create jellies with a desired colored caustic pattern. To achieve this, we propose a two-step optimization process. We first optimize the surface shape of the base jelly and then optimize the geometry and color of the embedded colored jelly inclusions. We employed a differentiable renderer, Mitsuba 3 [Jakob et al. 2022], for the optimization. After the optimization, we fabricate a jelly mold comprising an outer cavity and inner cores using a 3D printer and create jelly with the mold. The proposed method enables the creation of jellies with various colored caustic patterns (Fig. 1), providing novel culinary experiences.

2 METHOD

Fig. 2 shows a workflow of the proposed method. The inputs are the initial shape and target color image (Fig. 2a). To simplify fabrication, we assume that the hue of the target image is piecewise constant; it may contain multiple regions with uniform hue, whereas the saturation and brightness may vary within each region. Given these inputs, we create a jelly that generates a colored caustic pattern matching the target image under white overhead illumination. Specifically, we modify the surface shape of a transparent base jelly to control the caustic intensity and embed colored jelly in the base to provide color to the caustics. To create such jelly, we optimize the surface shape of the base jelly (Sec. 2.1) as well as the color and geometry of the colored jelly inclusions (Sec. 2.2).

2.1 Computing Surface Shape of Base Jelly

We first compute the surface shape of a transparent base jelly. We consider a 3D scene in which a point light is placed above the jelly (Fig. 2b) and optimize the jelly shape π so that the caustic pattern rendered on the screen placed beneath the jelly, $R(\pi)$, matches the grayscale target image I^t_{gray}, similarly to [Inokoshi et al. 2024],

$$\pi^* = \arg\min_{\pi} \|R(\pi) - I^t_{gray}\|^2 + \lambda_1 \sum_{\mathbf{v}_i} \|L(\mathbf{v}_i)\|^2, \quad (1)$$

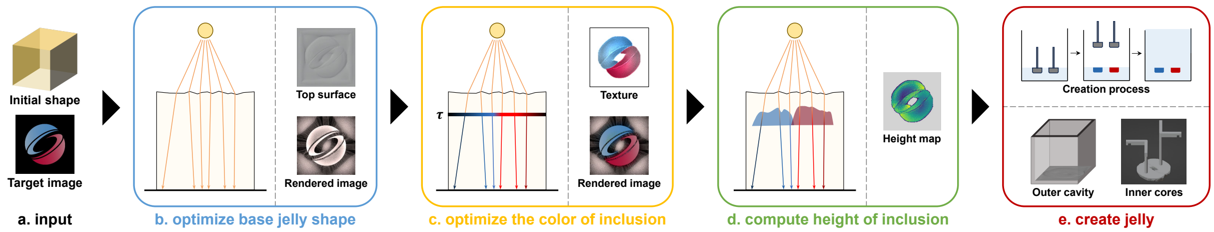

Figure 2: Workflow for creating jelly with desired colored caustics.

where $\mathbf{v}_i$ are vertices on the upward-facing surface of π, $L(\cdot)$ is a Laplacian operator, and λ_1 is a coefficient. We solve this optimization using Mitsuba 3. Following [Inokoshi et al. 2024], we parameterize the deformation of the upward-facing surface of π using a height map texture and perform coarse-to-fine optimization. We set $\lambda_1 = 10^7$, the number of rays per pixel during rendering to 256, and the refractive index of the jelly to 1.35.

2.2 Computing Embedded Colored Jelly

We next compute the shape and color (absorption coefficients) of embedded colored jelly inclusions. As in Fig. 2c, we place a thin plane with a RGB-transmittance texture τ in the base jelly model. At a pixel (i, j) for a channel $c \in \{R, G, B\}$, the texture value $\tau_{ij,c} \in [0, 1]$ denotes the ratio of transmitted intensity $I^o_{ij,c}$ to incident intensity $I^i_{ij,c}$; $\tau_{ij,c} = I^o_{ij,c}/I^i_{ij,c}$. We implement this using the specular_transmittance component of Mitsuba 3. We optimize τ so that the rendered caustics $R(\pi^*, \tau)$ matches the target color image I^t:

$$\tau^* = \arg\min_{\tau} \|M \odot (R(\pi^*, \tau) - I^t)\|^2 + \lambda_2 \|L(\tau)\|^2, \qquad (2)$$

where M denotes a binary mask of the target image (1: foreground, 0: background), and $\odot$ denotes the pixel-wise product.

After obtaining τ^*, we determine the shape and color of the embedded colored jelly inclusions. We apply k-means to the per-pixel RGB transmittance values of τ^* to obtain hue-consistent pixel clusters. We also apply Gaussian smoothing to τ^* independently within each cluster.

According to the Beer–Lambert law, the per-pixel transmittance satisfies the following: $I^o_{ij,c}/I^i_{ij,c} = \exp(-\alpha_{ij,c} d_{ij}) = \tau^*_{ij,c}$, where $\alpha_{ij,c}$ denotes the absorption coefficient and d_{ij} denotes the optical path length (i.e., inclusion height). Based on our piecewise-constant-hue assumption, we model the absorption as constant within each cluster. We estimate the absorption coefficient for each cluster κ by assuming a constant reference height d_0 and taking the mean within cluster κ as follows: $\alpha^\kappa_c = \frac{1}{|\kappa|} \sum_{(i,j)\in\kappa} \frac{-\ln \tau^*_{ij,c}}{d_0}$, where $|\kappa|$ denotes the number of pixels in κ. The height is then computed as $d_{ij} = -\ln \tau^*_{ij,c}/\alpha^\kappa_c$. For the height, we use the average across the three channels. In this study, we set $\lambda_2 = 10^{-3}$ and $d_0 = 5$ mm.

2.3 Cooking (Fabricating) Jelly

Given the surface shape of the base jelly as well as the shape and absorption coefficients of the embedded colored jelly inclusions, we fabricate a jelly mold comprising an outer cavity and inner cores using a 3D printer. We then create a jelly through the following process (Fig. 2e): (i) pour a transparent jelly liquid (composition: 100 g water, 4 g agar, 15 g granulated sugar) into the outer cavity until the inner cores are immersed and cool it to solidify. (ii) remove the inner cores, fill the hollows with a colored jelly liquid, and cool it to solidify. (iii) pour the transparent jelly liquid into the outer cavity up to the top and cool it to solidify.

We colored the jelly based on visual inspection. When white light enters a jelly of thickness d_0 with absorption coefficients (α_R, α_G, α_B), the transmitted light color is given by ($e^{-\alpha_R d_0}$, $e^{-\alpha_G d_0}$, $e^{-\alpha_B d_0}$). For each cluster, we computed the corresponding color and mixed red, green, and blue food dyes to match the perceived color as closely as possible.

3 RESULTS AND CONCLUSION

To illustrate the feasibility of the proposed method, we created jellies with various caustic patterns as shown in Fig. 1 (see also the supporting video). The figure demonstrates that each jelly produces a colored caustic pattern that closely resembles the target image. For instance, the SIGGRAPH Logo jelly (A) successfully reconstructs the red and blue regions, while the goldfish jelly (B) reproduces a caustic pattern with a red gradient. In addition, the jelly in (C) demonstrates caustics with multiple regions with different colors, whereas the jelly in (D) exhibits caustics where two regions with different colors contact.

In this study, we proposed a method for designing jelly that generates colored caustic patterns resembling a provided target image. Particularly, the proposed method is a two-step optimization process, in which we first compute the surface shape of transparent base jelly and then determine the shape and color of embedded colored jelly inclusions. We demonstrate that this method enables the generation of jelly with various caustic patterns. Nevertheless, this method is limited to a target image with piecewise-constant hues, and it represents the gradients in the caustic pattern only by modifying the inclusion thickness. Our future work includes automating the current visually guided dye mixing process and creating jelly inclusions with smooth multi color gradients.

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