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Material Perception in Interactive 3D Food Animation: Combining Procedural Modelling, Shading and Motion Cues

Qianyue Xu

Shenzhen College of International Education, Shenzhen, China
emilyxu23158@163.com

Abstract. Computer graphics can communicate not only object geometry but also perceived physical properties through surface appearance, illumination, and motion. This study investigates how static visual cues and dynamic motion cues work together to communicate contrasting materials in an interactive 3D food animation. A Chinese New Year food scene was developed using OpenSCAD and Three.js, contrasting a brittle almond pastry with a soft, translucent crystal osmanthus cake. Procedural modeling, triplanar texture mapping, physically based material parameters, multi-source lighting, geometry switching, particle effects, vertex deformation, and secondary motion were combined to construct the two material behaviors. An audience evaluation involving 22 participants was conducted using five-point rating scales. Overall visual quality received a mean rating of 4.09/5, while material-behavior consistency received 3.95/5. The almond pastry received a perceived-brittleness score of 3.86/5, while the crystal cake received a softness/elasticity score of 3.95/5. Crumb particles and post-movement wobbling were the most frequently identified cues for brittleness and softness, respectively.

Keywords: Computer graphics, material perception, procedural modelling, visual perception, animation, material cues

1. Introduction

Three-dimensional computer graphics is widely used in animation, games, product visualization, education, and interactive media. A convincing digital object depends not only on geometric shape, but also on material appearance, lighting, rendering, and motion. Procedural methods provide an efficient way to control these elements: rule-based modeling can generate adjustable geometry, procedural noise can introduce natural surface variation , and physically based rendering can simulate consistent interactions between light and materials [1-3]. These techniques are particularly useful when multiple coordinated states of the same object must be created and animated.

Human observers can also infer physical properties from visual information before touching an object. Features such as color, roughness, gloss, transparency, shape, and illumination contribute to judgments of whether a material appears hard, soft, dry, wet, or elastic [4]. Motion provides additional information: deformation can affect perceived stiffness, image motion can contribute to the perception of liquid-like materials, and breaking behavior can influence judgments of hardness

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and softness [5-7]. Previous research further suggests that expectations about familiar materials affect how their physical behavior is interpreted [8].

Material perception is also relevant to perceptual neuroscience. Hiramatsu et al. found that material information changes from relatively image-based representations in earlier visual areas toward more perceptually meaningful representations in higher regions of the ventral visual pathway [9]. Komatsu and Goda similarly describe material perception as involving both visual processing and broader multisensory knowledge [10]. The present project uses these findings only as a perceptual framework; it does not directly measure neural activity.

The project therefore asks whether a digital material becomes more convincing when its appearance and motion communicate consistent physical properties. Two contrasting foods were created: a brittle almond pastry and a soft translucent crystal osmanthus cake. The almond pastry uses baked surface cues, geometry switching, and crumb particles, whereas the crystal cake uses transparency, deformation, and delayed wobbling. These contrasting material behaviors are implemented in an interactive Three.js food animation.

2. Design and methods

2.1. Perceptual and production framework

The completed interactive scene contains two contrasting food systems, as shown in Figure 1. The almond pastries are presented on a ceramic plate, while the translucent crystal cakes are placed inside a bamboo steamer. These two objects provide the visual basis for comparing brittle and elastic material behavior.

The conceptual and production framework of the project is summarized in Figure 2. Static cues such as color, roughness, gloss, transparency, and highlights are mainly produced through geometry, texture maps, shader parameters, material settings, and lighting. Dynamic cues such as fracture, particle emission, deformation, wobbling, and energy decay are produced through the animation and shader systems. The project combines these cues according to the intended material: the almond pastry pairs a rough opaque surface with fracture and crumbs, whereas the crystal cake pairs translucency and gloss with deformation and secondary motion.The intended perceptual result is therefore produced by the consistency between static and dynamic information.

Figure 1. Final interactive scene showing the contrasting almond pastry and crystal cake (picture credit: original)

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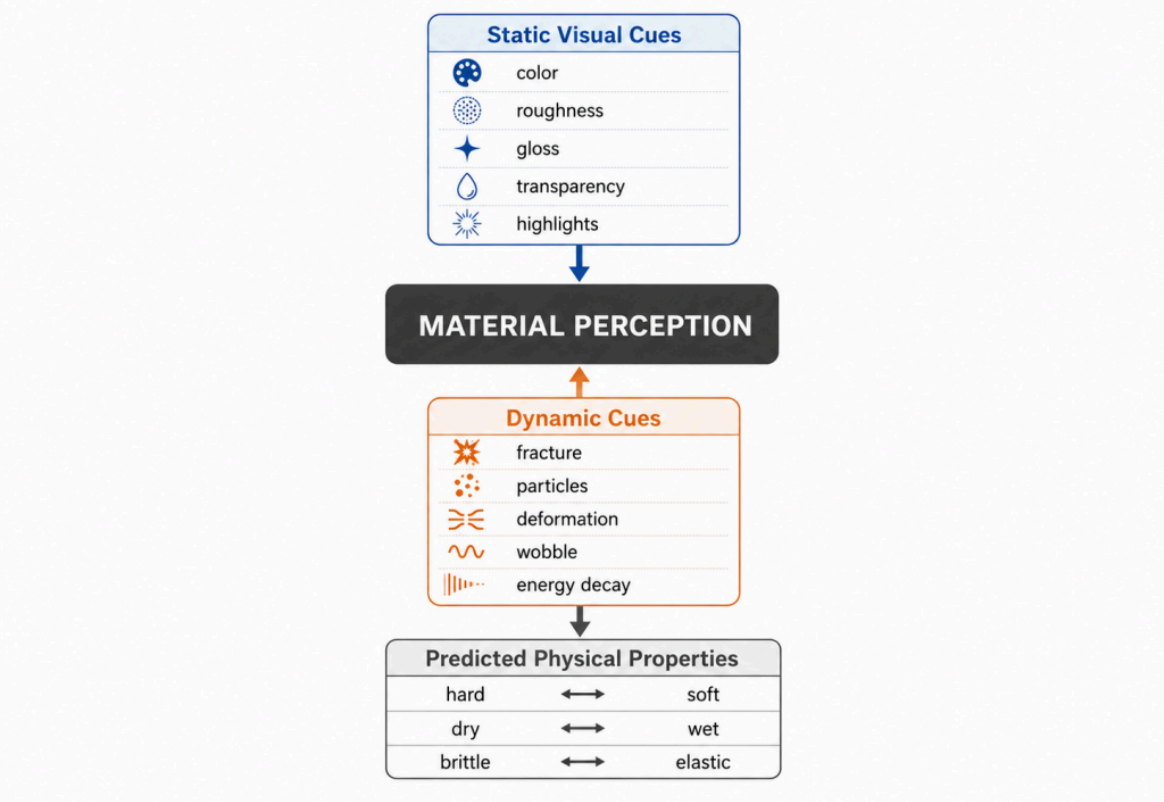

Figure 2. perceptual framework connecting static and dynamic CG cues with inferred physical properties (picture credit: original)

2.2. Procedural modelling

The major geometry was procedurally modeled in OpenSCAD and exported as STL files for use in Three.js. The food references were first decomposed into simpler components. The almond pastry was treated as a flattened cylindrical form with decorative top relief, repeated side ridges, internal filling, and separately generated bite geometry. The crystal cake was constructed as a rounded flower-like structure with repeated lobes and internal osmanthus elements. The bamboo steamer used circular walls, binding bands, supports, and floor slats. Adjustable parameters controlled dimensions such as diameter, height, groove spacing, petal arrangement, and bite size.The main modeling stages and supporting scene objects are shown in Figure 3, while the coordinated whole and bitten food states are compared in Figure 4.

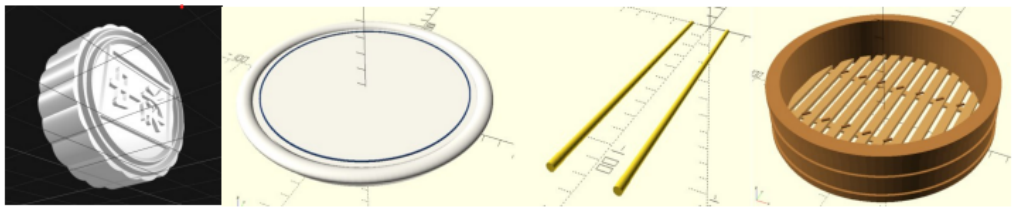

Figure 3. Procedural modeling stages in OpenSCAD, showing initial STL, adjustable parameters for the almond pastry, and coordinates for the ceramic plate, chopsticks and bamboo steamer (picture credit: original)

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Multiple coordinated geometry states were required for the eating animation. The almond pastry was exported as a whole body, bitten shell, and internal core, while the crystal cake included coordinated whole and bitten body states. OpenSCAD uses a Z-up coordinate system while the Three.js scene uses Y as its vertical direction, so each imported STL is rotated by

$$R_x = -\frac{\pi}{2} \tag{1}$$

The whole and bitten meshes are also aligned using the same reference center. If the states were centered independently, changing from one mesh to another could produce a visible spatial jump.

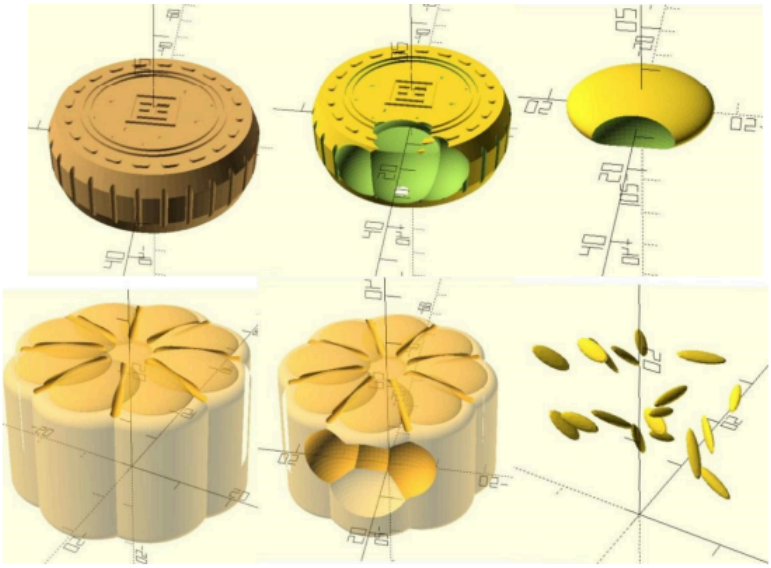

Figure 4. Whole and bitten geometry states aligned within a common reference coordinate system (picture credit: original)

The actual dimensions of the imported almond mesh were also used to position the pastries. In an early version, manually estimated offsets caused the three pastries to visibly intersect. After scaling, the final dimensions can be represented as

$$d = d_{source}s,\ h = h_{source}s \tag{2}$$

where s is the Three.js scale factor.

2.3. Texture mapping and material shading

The almond pastry was designed to communicate dryness, baked texture, and brittleness through its static surface appearance.The almond pastry uses triplanar texture mapping because the imported STL geometry does not provide useful UV coordinates. As illustrated in Figure 5, the texture is projected from the X, Y, and Z directions and blended according to the orientation of the surface. The final color can be represented in simplified form as

$$C = w_xT_x + w_yT_y + w_zT_z \tag{3}$$

where Tx, Ty, and Tz are the texture samples projected from the three axes, and wx,wy, and wz are blending weights calculated from the surface normal.

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A surface facing mainly one direction therefore receives a stronger contribution from the corresponding projection. This allows the texture to cover the top, sides, and grooves of the STL geometry without manual UV unwrapping.

Eight texture maps were used: base-color and roughness maps for the outer shell, side ridges, crumb structure, and internal filling. Procedural noise was added to create irregular baked color variation. This use of algorithmic irregularity is conceptually related to procedural texture-generation methods such as Perlin's work [2].

Figure 5. Texture and shading pipeline for the almond pastry (picture credit: original)

The crystal cake uses an opposite surface strategy. A physically based transparent material combines transmission, thickness, index of refraction, clearcoat, transparency, and low roughness. Transmission allows light to travel through the material; index of refraction affects how the light is redirected; and clearcoat strengthens the exterior glossy highlight. These parameters were selected to produce visual cues associated with wetness, translucency, and softness, which are important dimensions of visual material perception [4].

2.4. Lighting and rendering

Lighting was designed not only to illuminate the scene but also to preserve the perceptual differences between the two materials. A warm multi-light configuration was used. Ambient and hemisphere lights establish overall visibility and environmental warmth. A directional key light defines the main form and creates the primary cast shadows. A softer fill light prevents darker regions from losing surface detail, while a rim light and front accent light strengthen silhouettes and specular highlights.

This setup is particularly important for the crystal cake. Transparency alone does not guarantee that a transparent object remains visually readable. If its boundaries have insufficient contrast, the form can visually disappear into the background. Rim and front accent lighting therefore create brighter edges and highlights that make transmission, transparency, and clearcoat more visible. Conversely, directional shading on the almond pastry emphasizes molded ridges, roughness, and the exposed interior.

The renderer uses ACES Filmic tone mapping to control strong highlights and PCF soft shadows to reduce excessively hard shadow edges. Additional contact shadows visually connect the food and serving objects to the table. Steam particles above the bamboo steamer further reinforce the interpretation of freshly served food.The progressive effect of texture, shader adjustment, and final lighting on the pastry surface is shown in Figure 6.

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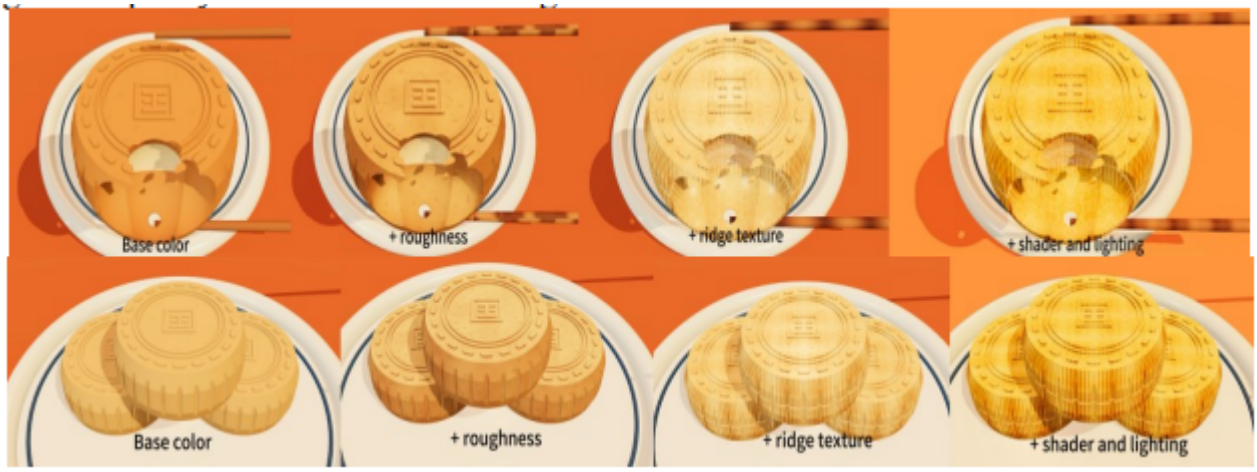

Figure 6. Development of almond material appearance through lighting and rendering (picture credit: original)

2.5. Animation and dynamic material cues

The complete interaction is implemented as a state-based animation system. Each state represents a specific action, such as approaching, gripping, lifting, biting, revealing the cross-section, or exiting. The almond and crystal-cake sequences are summarized as a flowchart in Figure 7. Dividing the animation into states allows the timing of the chopsticks, food geometry, particles, and scene transitions to be controlled independently while still forming one continuous sequence.

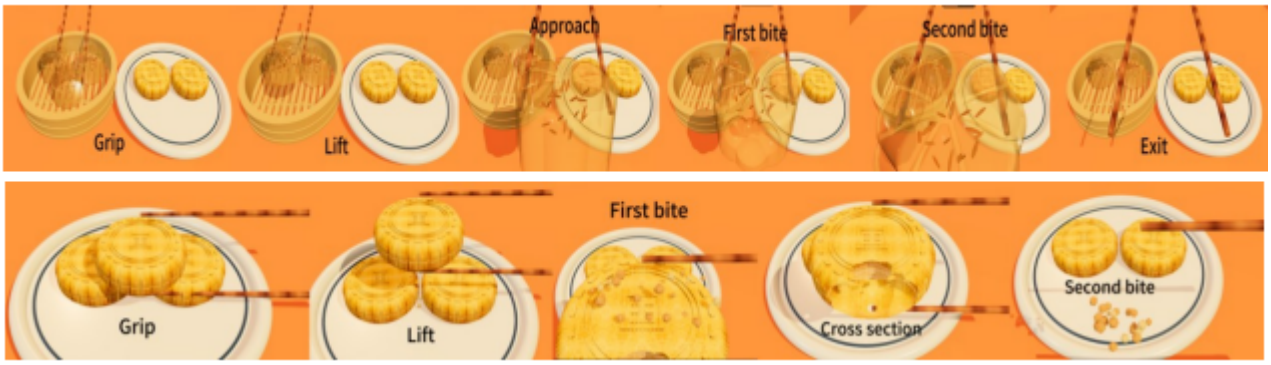

Figure 7. State-based animation storyboard illustrating the contrasting brittle and elastic responses(picture credit: original)

Movement between important positions uses interpolation together with cubic easing:

$$E(t) = \begin{cases} 4t^3, t < 0.5, \\ 1 - \frac{(-2t+2)^3}{2}, t \geq 0.5. \end{cases} \quad (4)$$

Here, t represents the normalized progress of an animation segment, ranging from 0 at the beginning to 1 at the end, while E(t) is the eased progress value used to interpolate between the starting and target positions. During the first half of the movement, the cubic term gradually increases the speed of the object. During the second half, the function gradually reduces the speed as the object approaches its destination. The main purpose of this easing function is therefore to avoid

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abrupt starts, stops, and constant-speed motion, making movements such as chopstick approach, lifting, biting, and serving-object transitions appear smoother and less mechanical.

The almond bite combines geometry switching with particle animation. At the first bite position, the complete pastry is hidden and replaced with the bitten shell and filling. At the same moment, crumb particles are emitted from the bite region. Individual particles receive different initial velocities, angular velocities, sizes, and lifetimes, while gravity pulls them downward. The visual synchronization of geometry change and particle motion makes the bite appear more like fracture than a simple model swap.

Previous research indicates that greater deformation and persistent motion can provide visual evidence of lower stiffness [5]. This relationship is conceptually illustrated in Figure 8 and informed the design of the crystal-cake wobble.

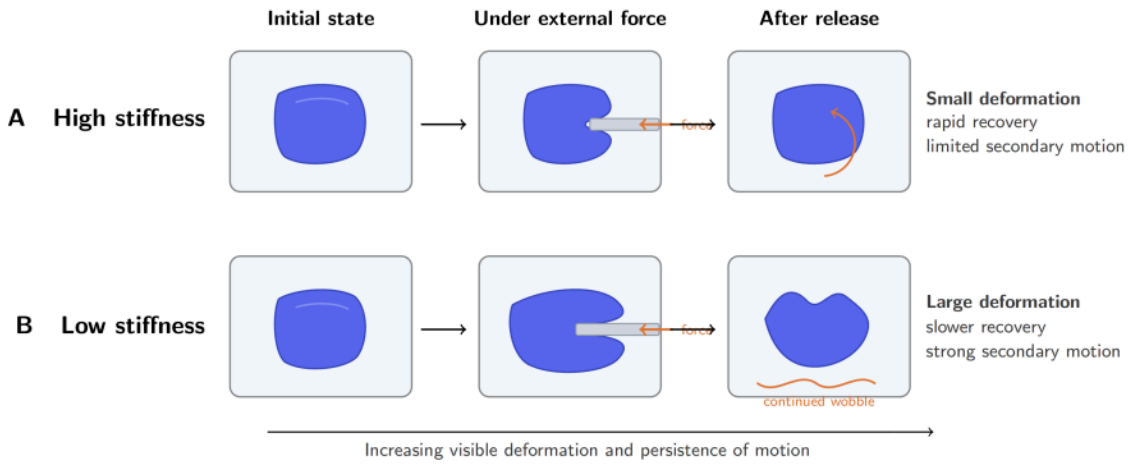

Figure 8. Conceptual comparison of deformation and recovery cues associated with high- and low-stiffness materials, inspired by Paulun et al. [5]

The crystal cake uses an intentionally different motion system. A custom vertex shader combines several waves:

$$x\prime = x + Ahsin(\omega_1 t + \phi_1) \tag{5}$$

$$y\prime = y + Ahcos(\omega_2 t + \phi_2)$$

$$z\prime = z + Ahsin(\omega_3 t + \phi_3)$$

where A is wobble energy, h is a height-dependent weight, t is time, and ϕ represents phase.

The lower region is more strongly anchored, while the upper part deforms more freely. External actions such as steamer movement, lifting, or shaking inject energy into the cake. Instead of disappearing immediately, this energy decays exponentially:

$$A(t) = A_0 e^{-\lambda t} \tag{6}$$

This produces delayed secondary motion: the steamer or chopsticks may stop, but the cake continues to wobble briefly. Additional squash-and-stretch is applied during biting. The system is intended as a perceptual approximation rather than a physically exact simulation of gelatin or biological tissue.

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3. Audience evaluation and results

3.1. Participants and procedure

To evaluate the final animation beyond the authors' own judgment, an anonymous questionnaire was completed by 22 participants. All participants viewed the same final animation before answering the questions. Five-point ordinal scales were used for the principal measures, with larger values representing stronger or more positive judgments.

The participants represented different levels of previous CG experience. Five reported no experience, nine had seen CG work but had never created it, four had some experience through classes or personal projects, one described themselves as familiar with CG, and three reported regular work with 3D or animation. Thus, 14 of 22 participants (63.6%) had no direct hands-on experience creating CG (Table 1).

The principal measures were Modeling Quality, Material Rendering, Animation Naturalness, Material–Behavior Consistency, Overall Visual Quality, Perceived Almond Brittleness, and Perceived Crystal Softness/Elasticity. Participants were also asked to identify which cues affected their material judgments and which material was communicated more successfully.

For each five-point measure, the arithmetic mean and sample standard deviation were calculated to summarize the overall rating and the variation between participants. Because the evaluation was a small descriptive audience study rather than a controlled psychophysical experiment, no claim of statistical significance is made.

Table 1. Audience evaluation of the final animation

Measure	Mean/5	SD
Modelling quality	4.00	0.87
Material rendering	3.91	0.92
Animation naturalness	3.91	0.92
Material -Behaviour consistency	3.95	1.00
Overall visual quality	4.09	0.81
Almond Brittleness	3.86	0.89
Crystal Softness/ Elasticity	3.95	0.95

3.2. Overall ratings

The audience ratings were generally positive. Overall Visual Quality received the highest mean score at 4.09/5 (SD = 0.81), followed by Modeling Quality at 4.00/5 (SD = 0.87) (Figure 9). Material–Behavior Consistency received 3.95/5 (SD = 1.00), indicating that viewers generally considered the motion of the foods compatible with the materials suggested by their appearance. Material Rendering and Animation Naturalness each received 3.91/5 (SD = 0.92).

The material-specific ratings also supported the intended contrast. Perceived Almond Brittleness received 3.86/5 (SD = 0.89), while Crystal Softness/Elasticity received 3.95/5 (SD = 0.95). Fourteen of 22 participants (63.6%) rated the almond pastry as very or extremely brittle, while 16 of 22 (72.7%) rated the crystal cake as very or extremely soft and elastic.

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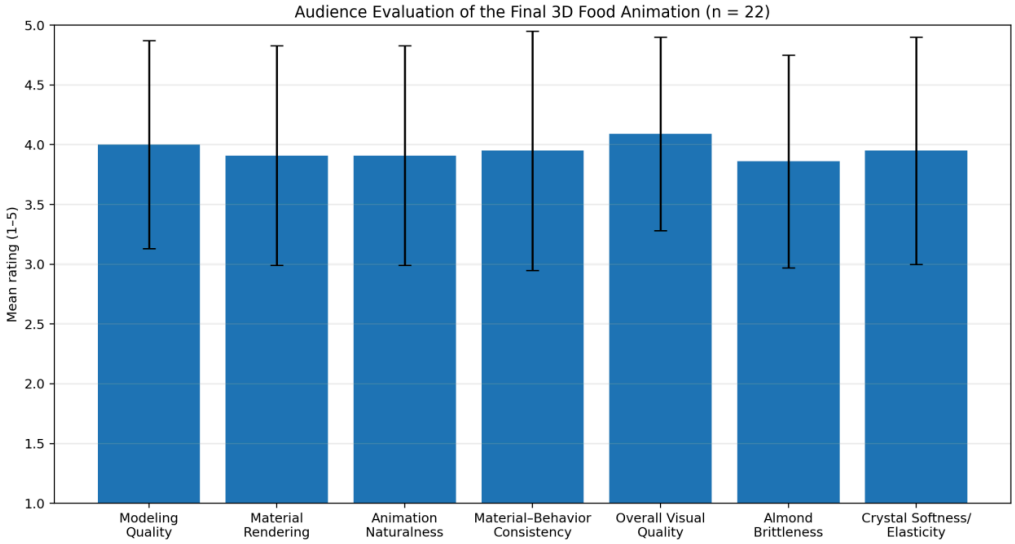

Figure 9. Mean audience ratings for seven aspects of the completed animation. Error bars represent sample standard deviation (n=22) (picture credit: original)

3.3. Material cue selection

The questionnaire also asked participants to identify the cues that influenced their judgments. For the almond pastry, crumb particles were selected by 13 of 22 participants (59.1%), making them the most frequently identified cue of brittleness (Figure 10). The internal filling exposed after the bite was selected by 10 participants (45.5%), baked color variation by 7 (31.8%), rough surface texture by 5 (22.7%), and chopstick interaction by 5 (22.7%).

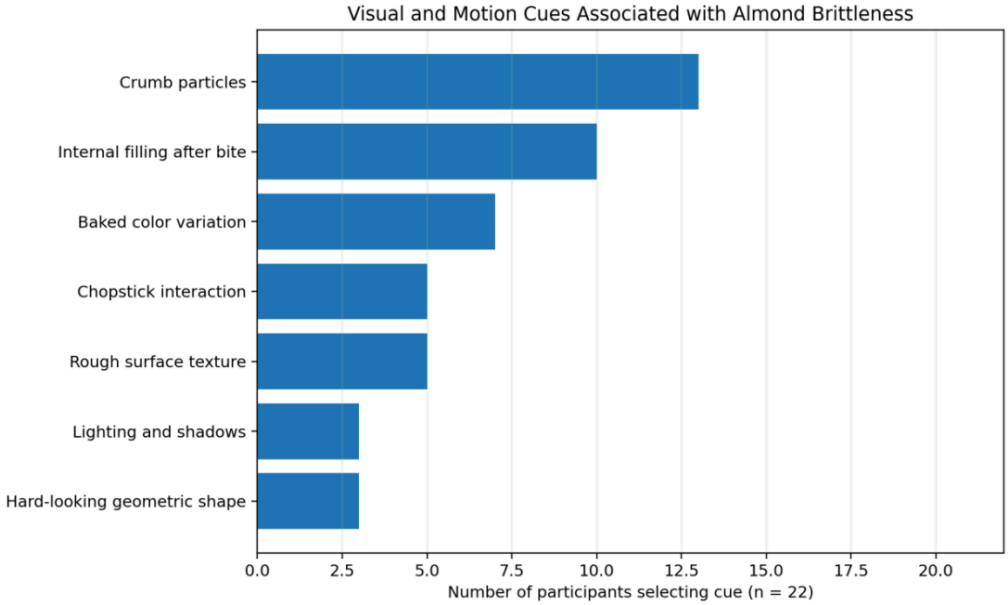

Figure 10. Frequency of visual and motion cues selected as contributors to almond-pastry brittleness. Multiple selections were permitted (n=22) (picture credit: original)

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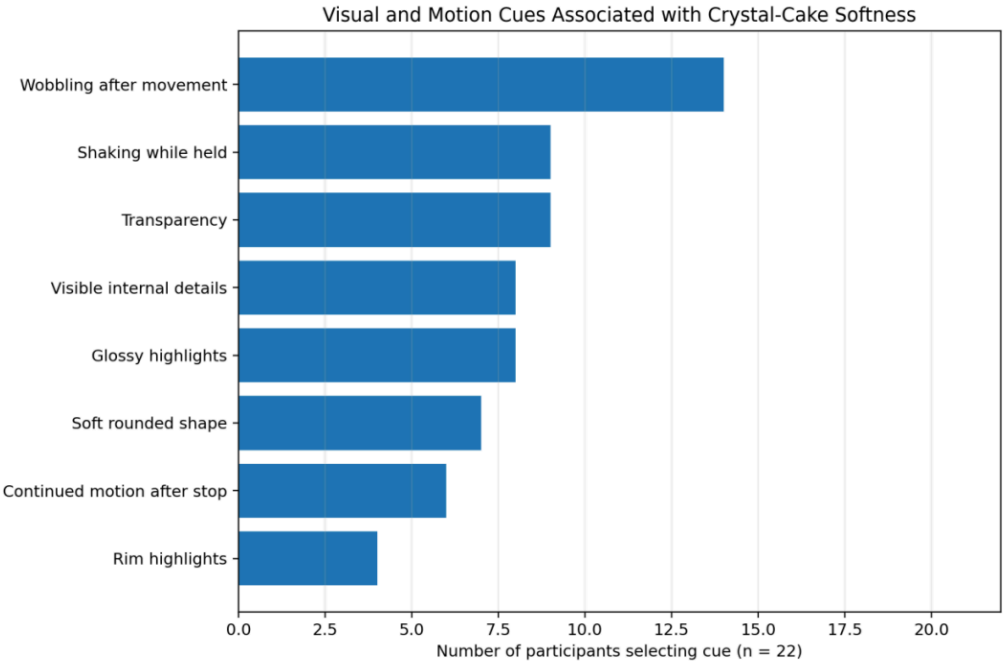

Figure 11. Frequency of visual and motion cues selected as contributors to crystal-cake softness and elasticity. Multiple selections were permitted (n=22) (picture credit: original)

For the crystal cake, the most frequently selected cue was wobbling after movement, chosen by 14 of 22 participants (63.6%). Transparency and shaking while held by the chopsticks were each selected by 9 participants (40.9%). Glossy highlights and visible internal details were each selected by 8 (36.4%), while six participants identified continued movement after the steamer stopped (Figure 11).

When asked which material was communicated more successfully, 15 of 22 respondents (68.2%) considered both materials equally convincing. Six respondents (27.3%) favored the crystal cake, while one participant (4.5%) considered the almond pastry much more convincing. The distribution therefore suggests that both systems communicated their intended qualities, with a modest preference toward the crystal cake.

4. Discussion

The audience evaluation supports the principal design proposition of the project: material information can be communicated through a combination of surface appearance and dynamic behavior. Both target materials received ratings close to four on a five-point scale, and Material–Behavior Consistency achieved 3.95/5. This suggests that viewers generally perceived the animation as compatible with the material qualities established through rendering.

The cue-selection results provide stronger evidence about how these impressions were formed. For the almond pastry, the most frequently identified signal was not color or roughness, but the crumb-particle effect, selected by 59.1% of participants. Schmid and Doerschner similarly found that optical and mechanical cues interact when observers judge breaking materials [7]. In the present project, roughness and baked coloration establish a relatively dry, rigid visual appearance, while the release of fragments provides additional dynamic evidence associated with brittleness.

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For the crystal cake, post-movement wobbling was selected by 63.6% of participants, making it the most frequently identified cue across either material. This corresponds closely with previous studies showing that deformation and motion strongly influence perceived stiffness and liquid-like material qualities [5, 6]. The result suggests that the wobble was not merely an aesthetic embellishment; it contributed directly to the material interpretation.

Static and dynamic cues therefore appear to perform complementary roles. Transparency, low roughness, and highlights establish the crystal cake's initial translucent and wet appearance, while deformation confirms that it should be interpreted as soft. Conversely, the opaque and baked almond surface creates a harder initial expectation, while crumb emission supports brittle behavior.

The results are also consistent with the role of material expectations described by Alley et al. [8]. Familiar objects generate expectations about how they should behave under force. In the current project, the appearance-motion relationship was intentionally congruent: the pastry breaks and scatters, whereas the crystal cake deforms and wobbles. The positive Material–Behavior Consistency score suggests that this relationship was broadly perceived as coherent.

From a perceptual-neuroscience perspective, these results should still be interpreted cautiously. Hiramatsu et al. suggest that material information changes from image-based representations in earlier visual areas toward more perceptually meaningful representations in higher ventral regions [3]. This proposed progression is summarized conceptually in Figure 12.The current questionnaire measures conscious perceptual judgments rather than neural responses. It therefore does not demonstrate that any particular brain region was activated. Instead, the project shows how CG can produce controlled combinations of optical and motion cues that could later serve as stimuli in a more controlled perception or neuroscience study.

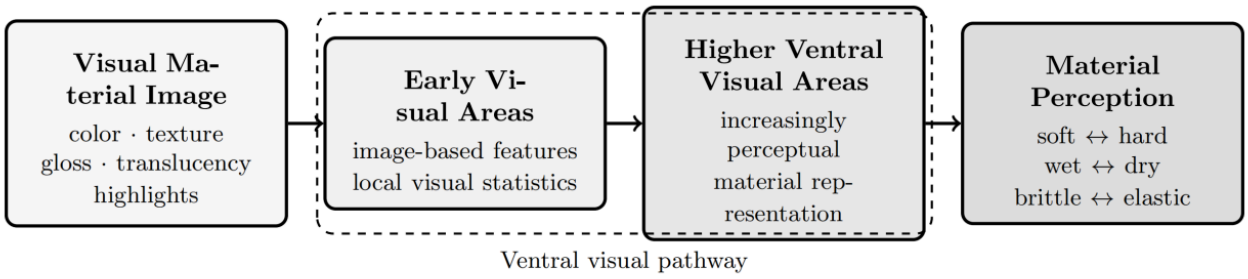

Figure 12. Conceptual schematic of the progression from image-based visual information toward higher-level material representation along the ventral visual pathway, inspired by Hiramatsu et al. [9]

5. Limitations and future work

Although the audience evaluation was generally positive, it measured only viewers' conscious judgments after watching the animation and did not directly examine the neural processes underlying material perception. Animation Naturalness received a mean score of 3.91/5, and several participants also suggested that the chopstick movement and gripping behavior could be made more natural.

Future work could use the current CG system to create controlled matched and mismatched material conditions—for example, pairing the almond pastry with either brittle fracture or jelly-like wobbling. Behavioral ratings could then be combined with eye tracking or EEG to investigate how attention and neural responses change when an object's motion is consistent or inconsistent with its

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expected material properties. Such experiments could extend the project from a visual demonstration into a platform for studying perceptual and multisensory material processing.

6. Conclusion

This study presents an interactive computer-graphics project in which procedural modeling, material shading, lighting, rendering, and animation are combined to communicate contrasting physical material properties. The almond pastry uses baked color variation, roughness, geometry switching, exposed filling, and crumb particles to suggest dryness and brittleness. The crystal osmanthus cake combines transparency, transmission, glossy highlights, vertex deformation, squash-and-stretch, and delayed secondary motion to suggest softness and elasticity.

The audience evaluation with 22 participants produced generally positive results. Overall Visual Quality received 4.09/5, while Material–Behavior Consistency received 3.95/5. The almond pastry received a brittleness score of 3.86/5, and the crystal cake received a softness/elasticity score of 3.95/5. More importantly, crumb particles were the most frequently identified cue of almond brittleness, while post-movement wobbling was the most frequently identified cue of crystal softness.

These findings suggest that successful digital material representation depends on realistic surface rendering as well as behavior that matches the viewer's expectations of the material. Rendering and animation should therefore be treated as coordinated sources of perceptual information rather than as separate visual effects. This approach provides a practical connection between computer graphics, material perception, and future perceptual-neuroscience research.

References

[1] Parish, Y. I. H., & Müller, P. (2001). Procedural modeling of cities. *Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH 2001)*, 301–308. Los, Angeles, California, USA. doi:10.1145/383259.383292.

[2] Perlin, K. (1985). An image synthesizer. *Proceedings of the 12th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '85)*, 287–296. San Francisco, California, USA. doi:10.1145/325334.325247.

[3] Pharr, M., Jakob, W., & Humphreys, G. (2023). *Physically based rendering: From theory to implementation* (4th ed.). The MIT Press. Cambirdge, Massachusetts, USA.

[4] Fleming, R. W. (2014). Visual perception of materials and their properties. *Vision Research, 94*, 62–75. doi:10.1016/j.visres.2013.11.004.

[5] Paulun, V. C., Schmidt, F., van Assen, J. J. R., & Fleming, R. W. (2017). Shape, motion, and optical cues to stiffness of elastic objects. *Journal of Vision, 17*(1), article 20, 1–22. doi:10.1167/17.1.20.

[6] Kawabe, T., Maruya, K., Fleming, R. W., & Nishida, S. (2015). Seeing liquids from visual motion. *Vision Research, 109*, 125–138. doi:10.1016/j.visres.2014.07.003.

[7] Schmid, A. C., & Doerschner, K. (2018). Shatter and splatter: The contribution of mechanical and optical properties to the perception of soft and hard breaking materials. *Journal of Vision, 18*(1), article 14, 1–32. doi:10.1167/18.1.14.

[8] Alley, L. M., Schmid, A. C., & Doerschner, K. (2020). Expectations affect the perception of material properties. *Journal of Vision, 20*(12), article 1, 1–20. doi:10.1167/jov.20.12.1.

[9] Hiramatsu, C., Goda, N., & Komatsu, H. (2011). Transformation from image-based to perceptual representation of materials along the human ventral visual pathway. *NeuroImage, 57*(2), 482–494. doi:10.1016/j.neuroimage.2011.04.056.

[10] Komatsu, H., & Goda, N. (2018). Neural mechanisms of material perception: Quest on Shitsukan. *Neuroscience, 392*, 329–347. doi:10.1016/j.neuroscience.2018.09.001.