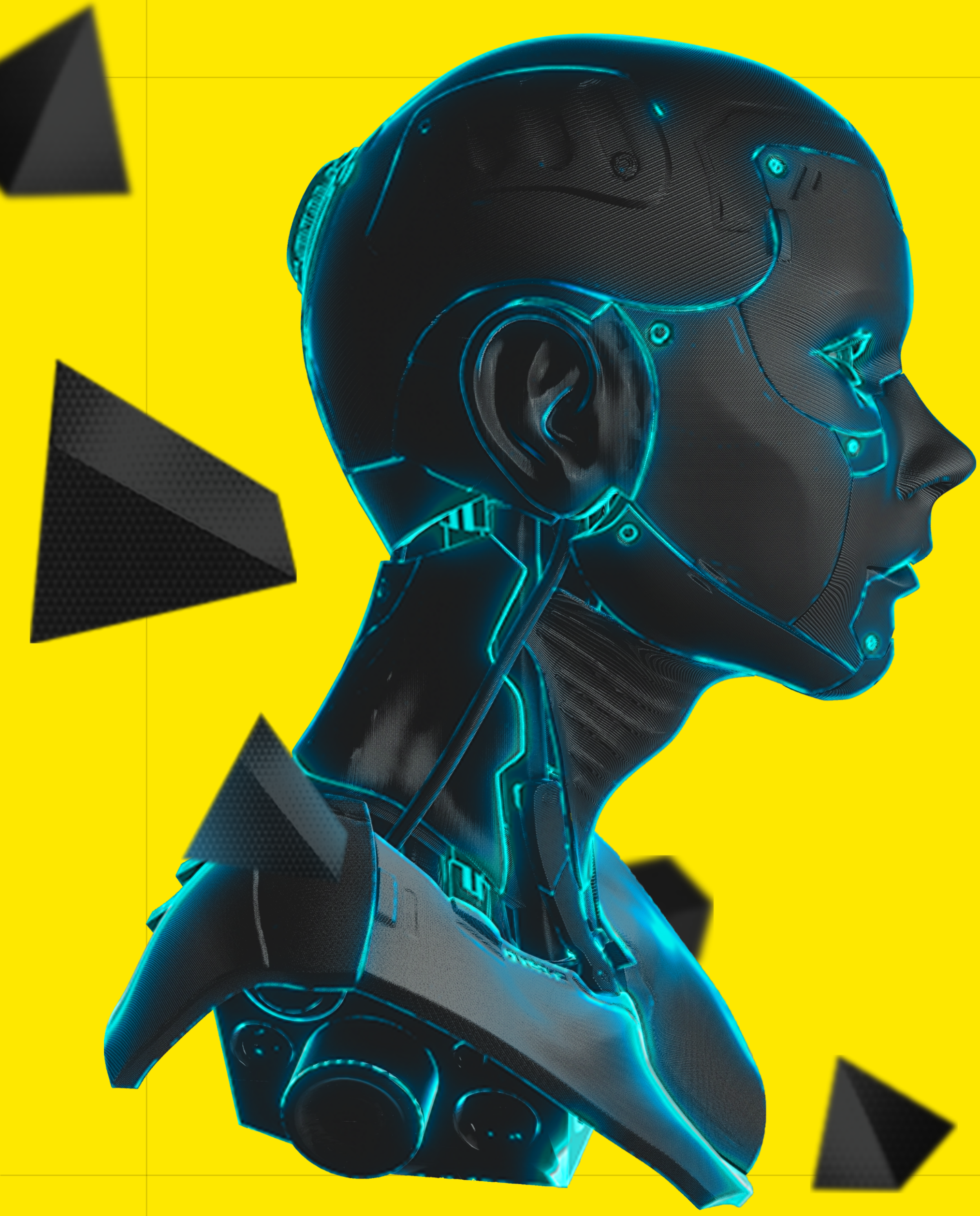
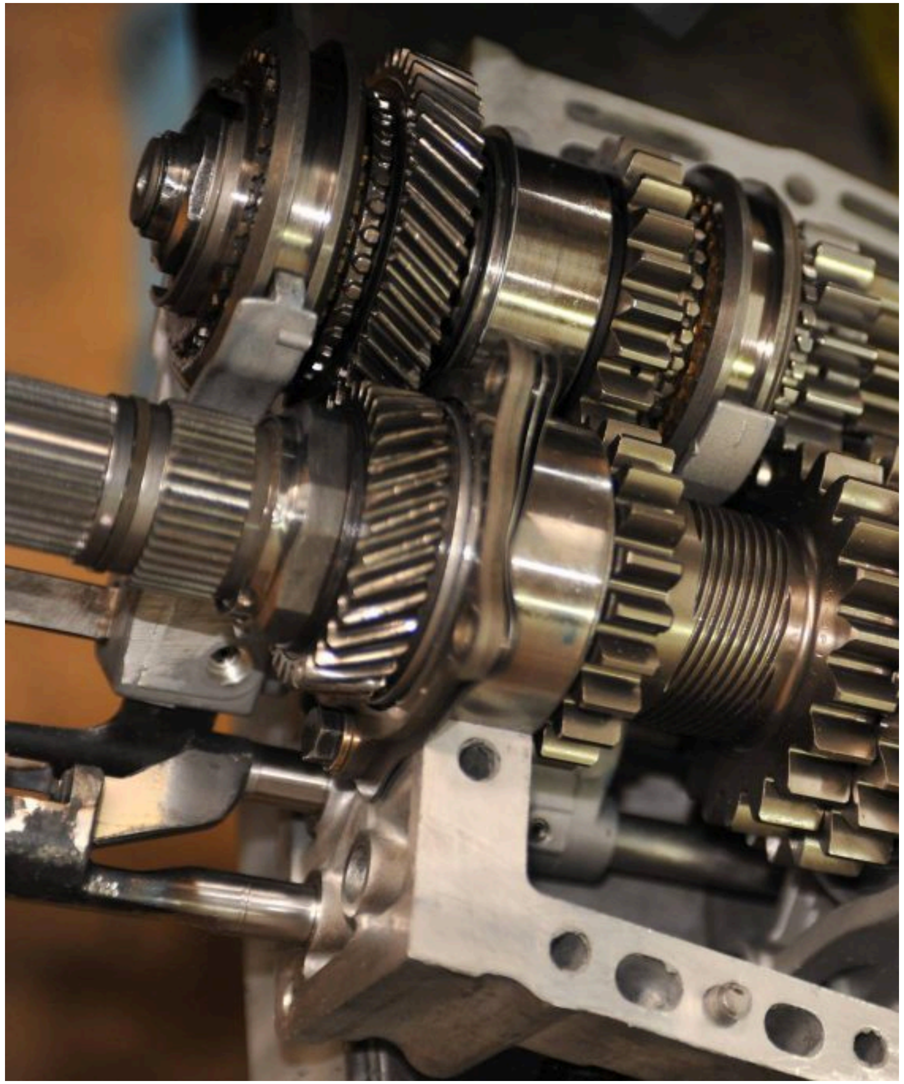


SIGGRAPH 2021

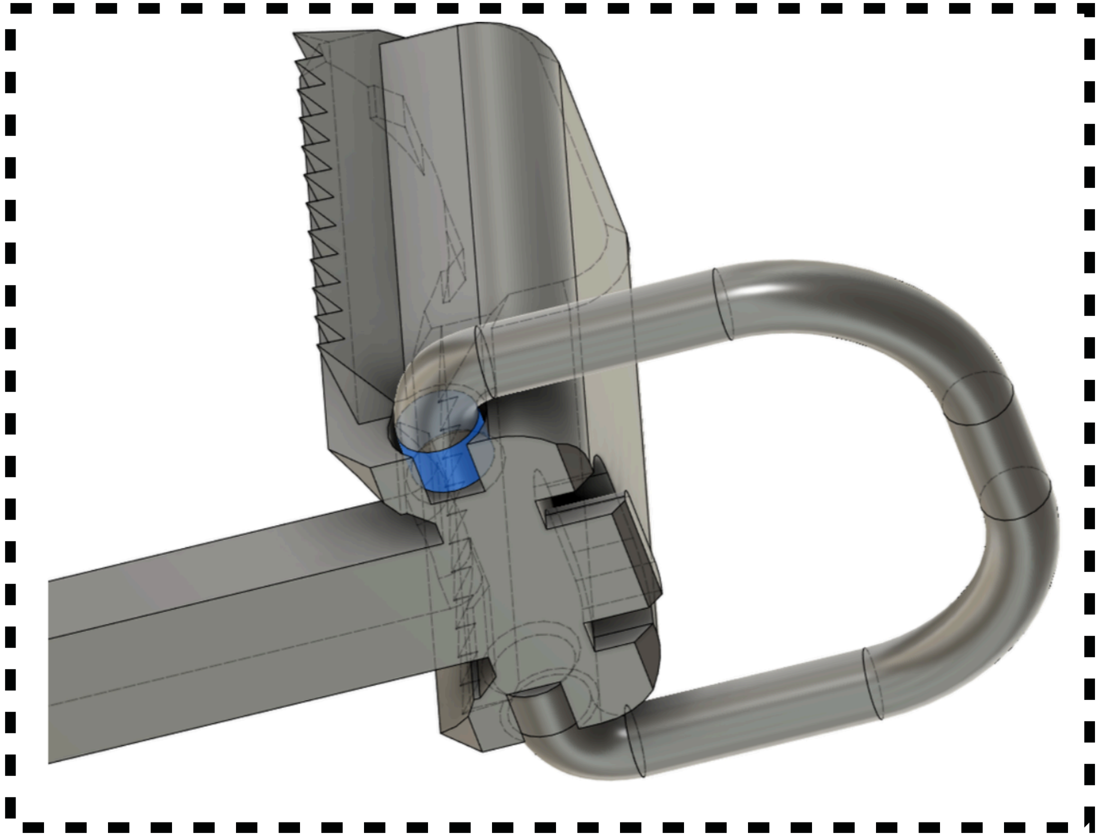
GUARANTEED GLOBALLY INJECTIVE 3D DEFORMATION PROCESSING

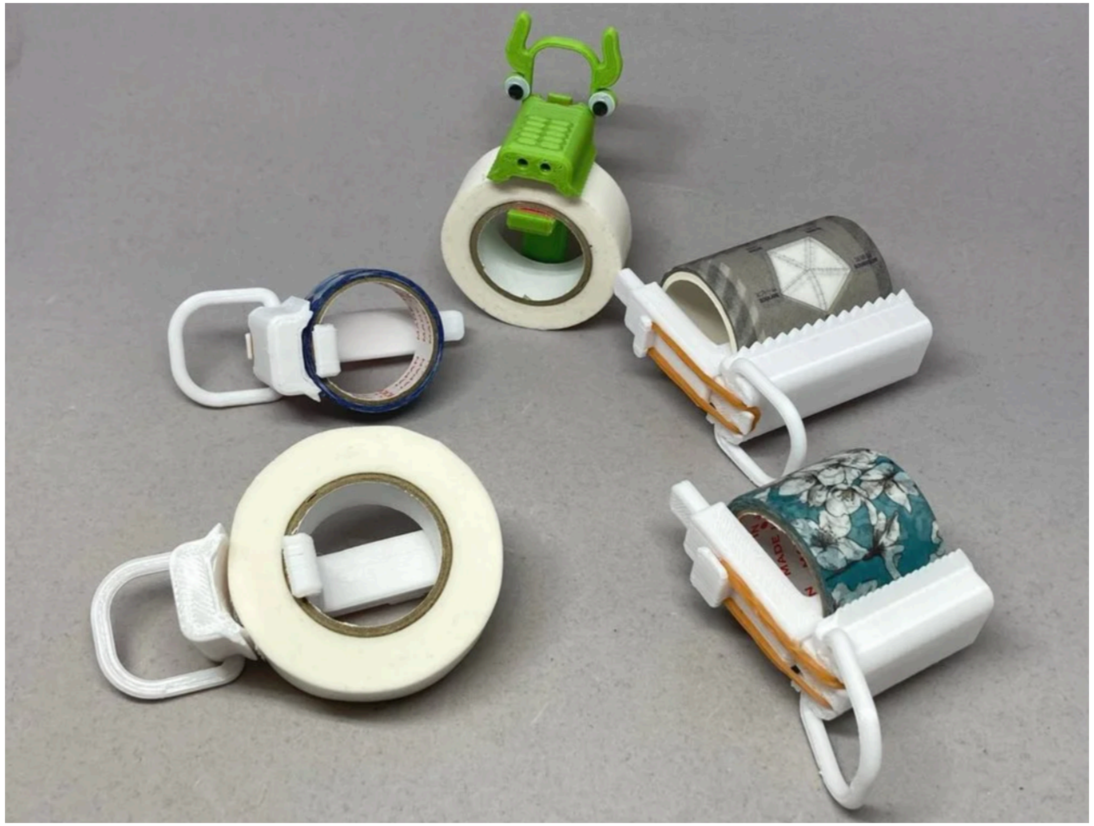
Yu Fang*, Minchen Li*, Chenfanfu Jiang,
Danny M. Kaufman

Guaranteed Globally Injective 3D Deformation Processing



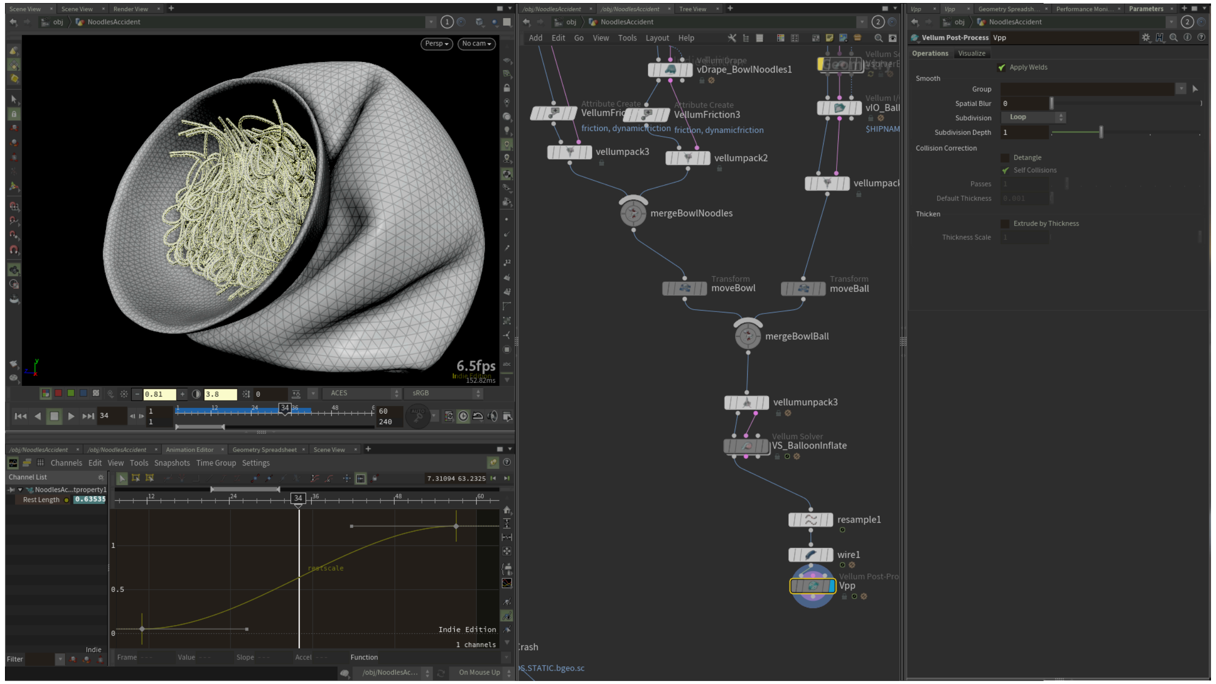
Contacts in Real-life



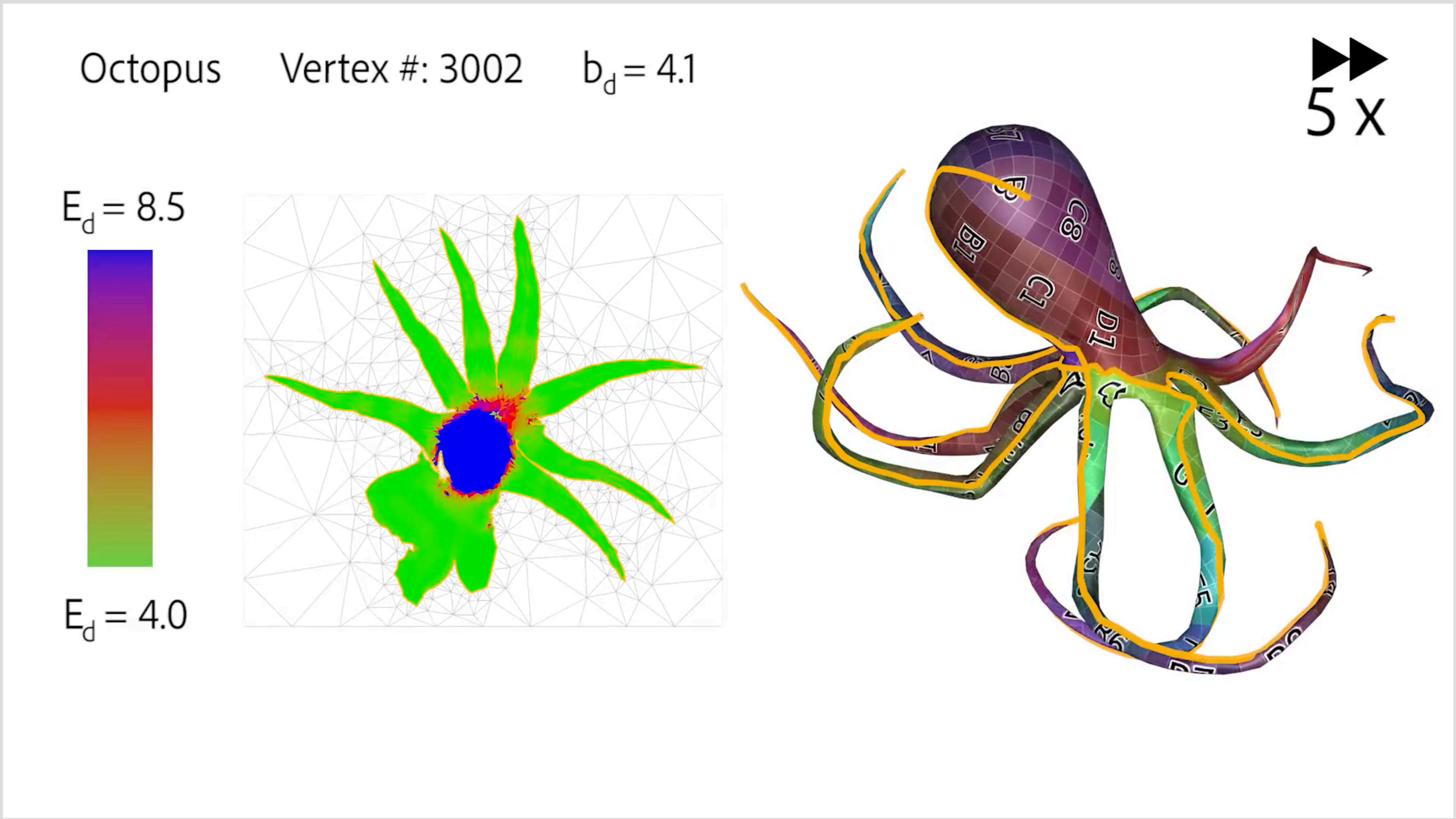


Fabrication

Animation


6.5fps
vDrape_BowlNoodles1
VellumFriction3
friction, dynamicfriction
vellumpack3
vellumpack2
mergeBowlNoodles
Transform
moveBowl
Transform
moveBall
mergeBowlBall
vellumunpack3
Vellum Solver
VS_BalloonInflate
resample1
wire1
Vpp
Indie Edition
1 channels
Vellum Post-Process Vpp
Apply Welds
Smooth
Group
Spatial Blur
Subdivision
Loop
Subdivision Depth
Collision Correction
Detangle
Self Collisions
Thicken
Extrude by Thickness


3D Modeling

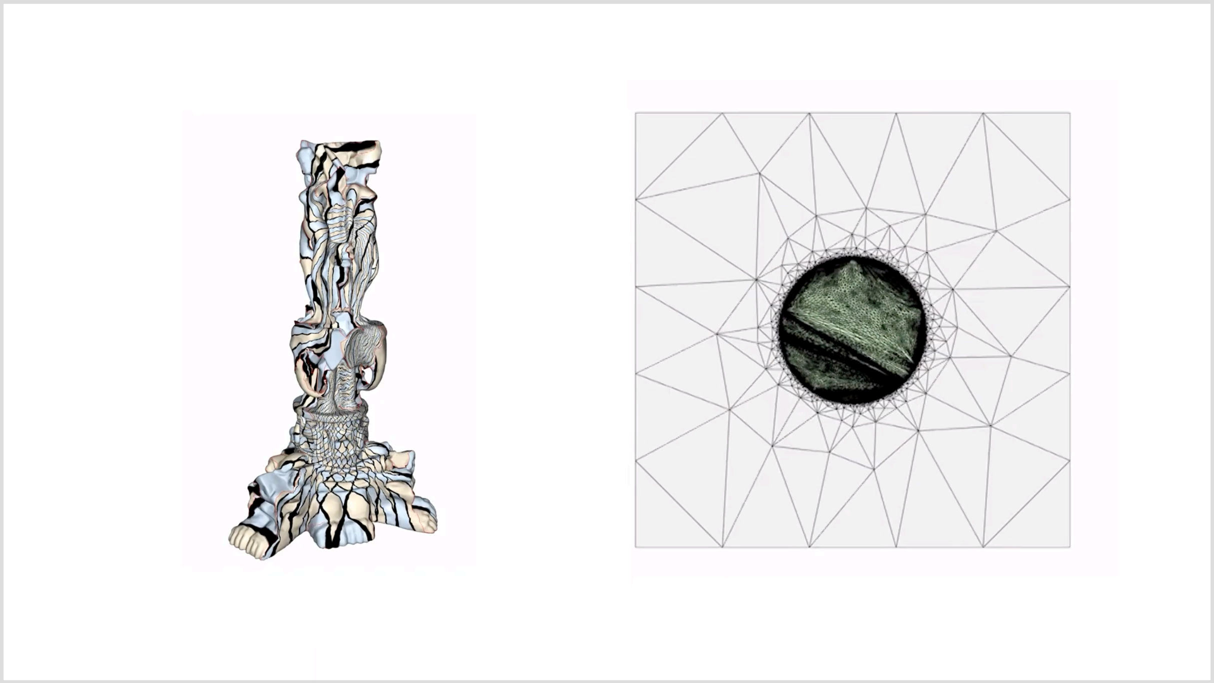


[Li et al. 2018]

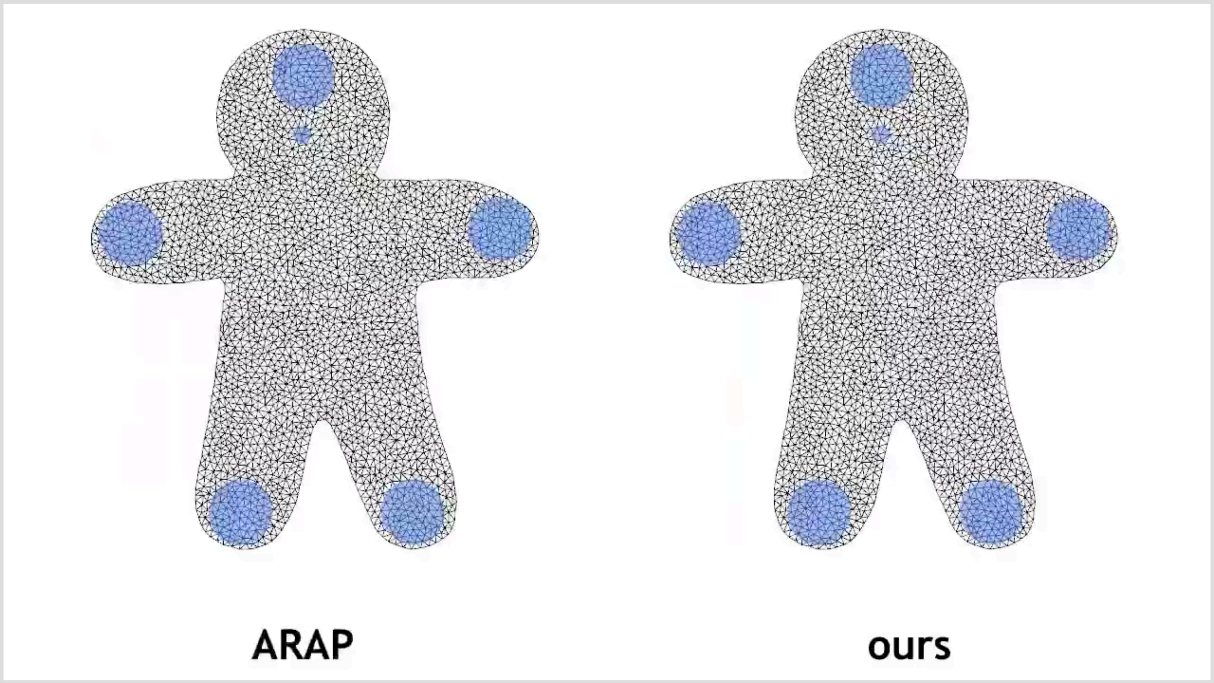
Mapping

Prior Work 2D

[Schüller et al. 2013, Smith and Schaefer 2015, Kovalsky et al. 2016, Jiang et al. 2017, Zhu et al. 2018, Su et al. 2020, …]

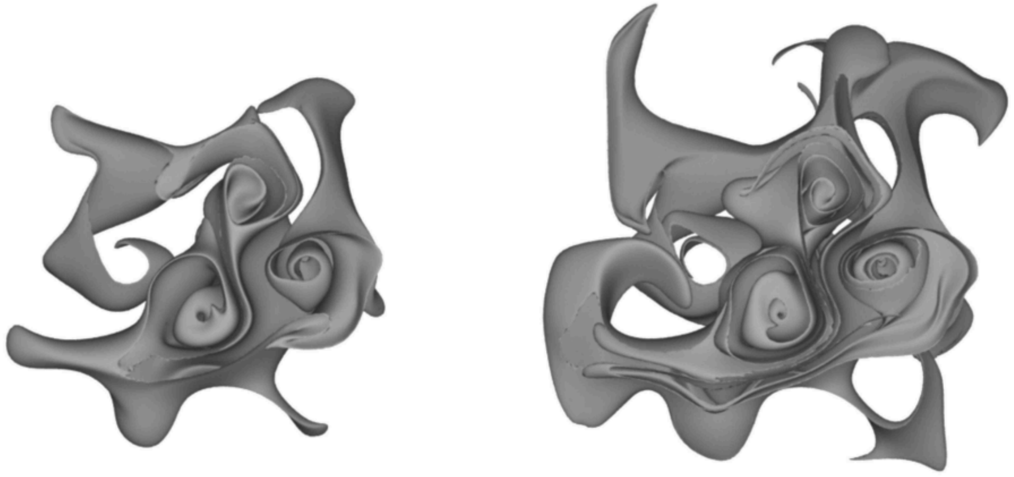


[Jiang et al. 2017]



[Schüller et al. 2013]

Iterative Contact Processing Methods



[Brochu and Bridson 2009]

[Harmon et al. 2011]

[Jiang et al. 2017]

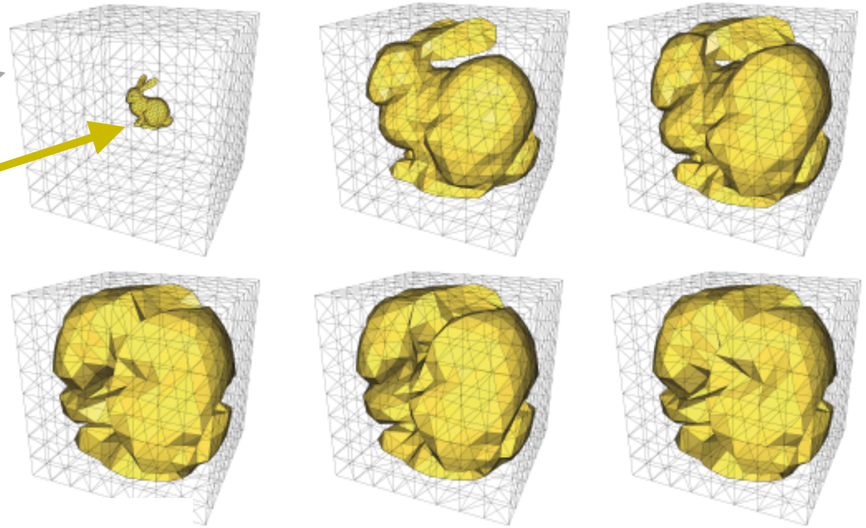
Iterative Contact Processing Failure (intersection)

Scaffolding Methods

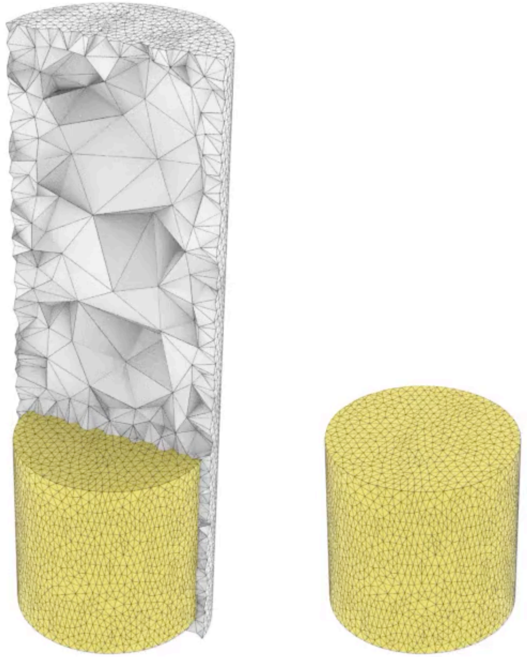
[Müller et al. 2015, Jiang et al. 2017]

Scaffolding:

Primary Mesh:



Locking behavior:



Scaffolding Framework [Jiang et al. 2017] result.

Problem

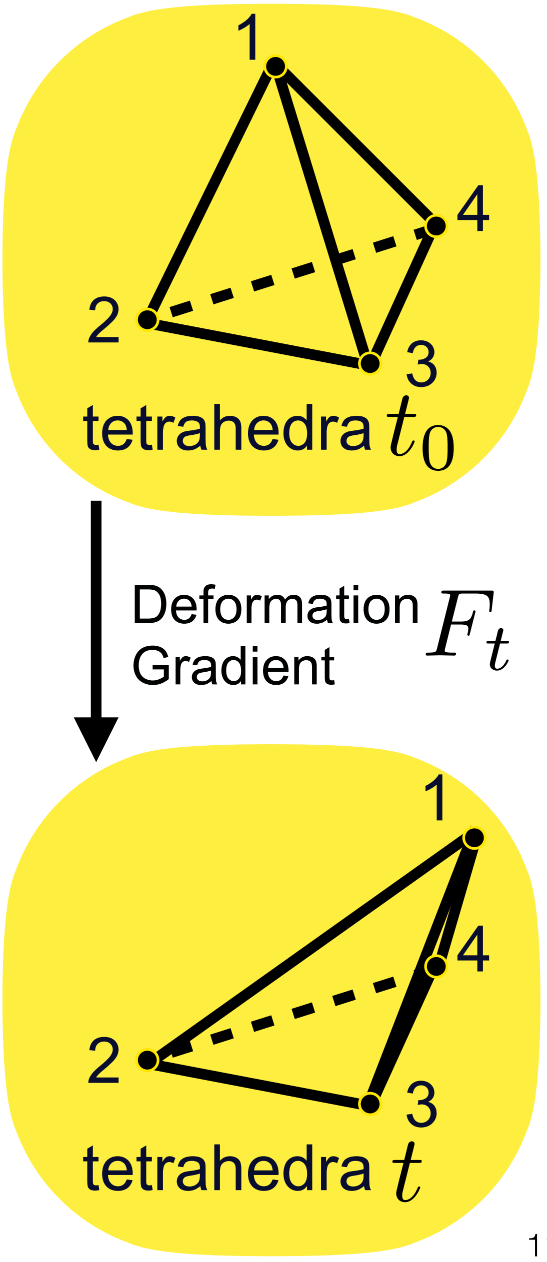
$$\boxed{x^* = \arg\min_x E_{\bar{x}}(x)}$$

Energy: $E_d(x, \bar{x}) = \sum_{t \in T} v_t \Psi\left(F_t\right)$

SVD

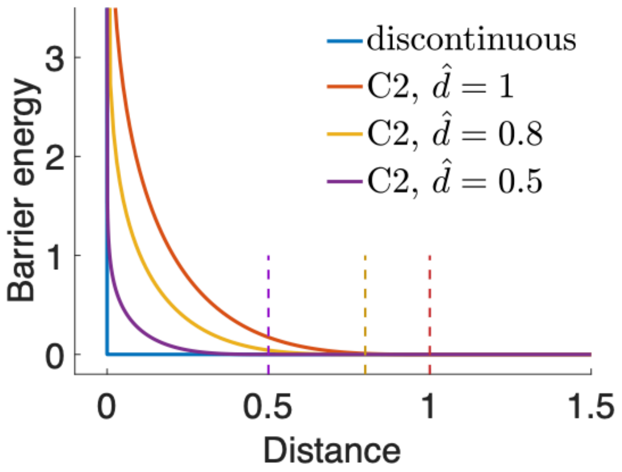
Neo-Hookean: $E = \frac{\mu}{2}(|\sigma|^2 - 3) - (\mu - \frac{\lambda}{2}\log(\sigma_1\sigma_2\sigma_3)) \times \log(\sigma_1\sigma_2\sigma_3)$

Symmetric Dirichlet: $E = \kappa(\sigma_1^2 + \frac{1}{\sigma_1} + \sigma_2^2 + \frac{1}{\sigma_2} + \sigma_3^2 + \frac{1}{\sigma_3})$



IPC Barrier Energy

$$\boxed{x^* = \arg\min_x E_{\bar{x}}(x)}$$



IPC Barrier: $B(x) = \kappa \sum_{i \in C} b(d_i(x), \hat{d})$

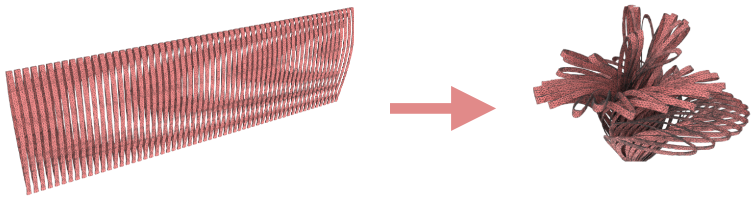
All Pairs (those far away contributes zero)

$$b(d, \hat{d}) = \begin{cases} -(d - \hat{d})^2 \ln\left(\frac{d}{\hat{d}}\right), & 0 < d < \hat{d} \\ 0 & d \geq \hat{d} \end{cases}$$

$b()$ is C2 Continuous

$d()$ may be C0 continuous (Edge-Edge case), mollification is introduced!

Artificial Time Stepping

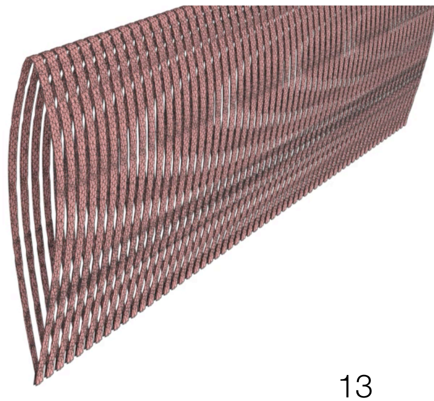


$$\boxed{x^* = \arg\min_x E_{\bar{x}}(x)}$$

Directly Minimize

$x^0 \quad x^1 \quad x^2 \quad \cdots \quad x^t \quad x^{t+1} \quad \cdots \quad x^*$

Time step $M\dot{x} = -\nabla E(x)$ to progressively optimize



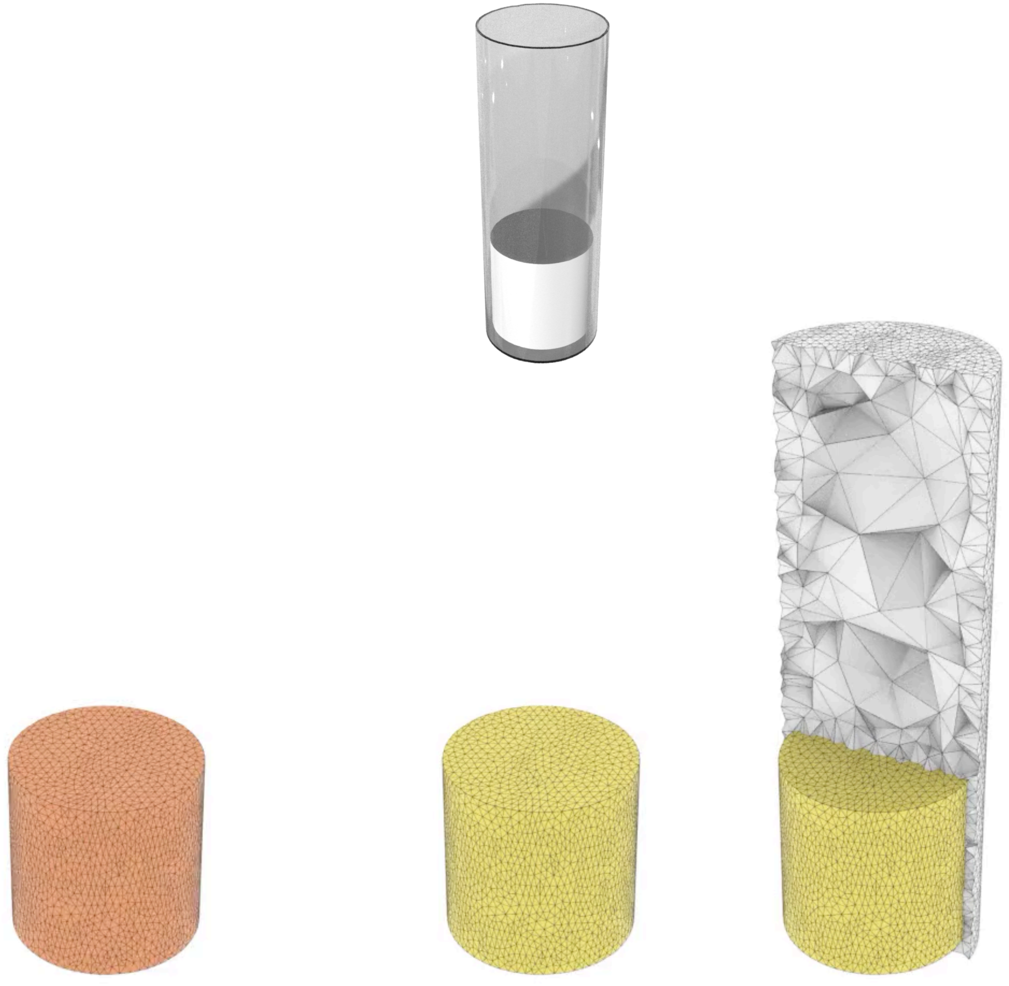
Time discretization (implicit Euler):

Artificial step size

$$x^{t+1} = \arg\min_x \frac{1}{2}\|x - x^t\|_M^2 + hE(x, \bar{x}, u(t))$$

Mass matrix

Scaffolding Comparison



IDP SCAF [Jiang et al. 2017]

IDP SCAF [Jiang et al. 2017]

Time-Varying Boundary Conditions

Goal: a set of positionally constrained $\mathcal{B} \subset [1, n]$

Satisfy moving Dirichlet boundary condition $x_k = \tilde{x}_k, \; k \in \mathcal{B}$

Penalty term: $P(x,t) = \frac{\kappa_{\mathrm{B}}}{2} m_k \| x_k - \tilde{x}_k^{t+1} \|^2$

Solution:

Solver with static BC

While $||x_k - \tilde{x}_k^{t+1}||_\infty > 10^{-6}$ **do**

Solve $E = \frac{1}{2}||x - x^t||_M^2 + hE_{\bar{x}}(x)$

$g, H = \nabla E, \nabla^2 E$

$x+ = \alpha(-H^{-1}g), \alpha$ is from line search

Solver with moving BC

While $||x_k - \tilde{x}_k^{t+1}||_\infty > 10^{-6}$ **do**

Solve $E = \frac{1}{2}||x - x^t||_M^2 + hE_{\bar{x}}(x) + P(x,t)$

$g, H = \nabla E, \nabla^2 E$

$x+ = \alpha(-H^{-1}g), \alpha$ is from line search

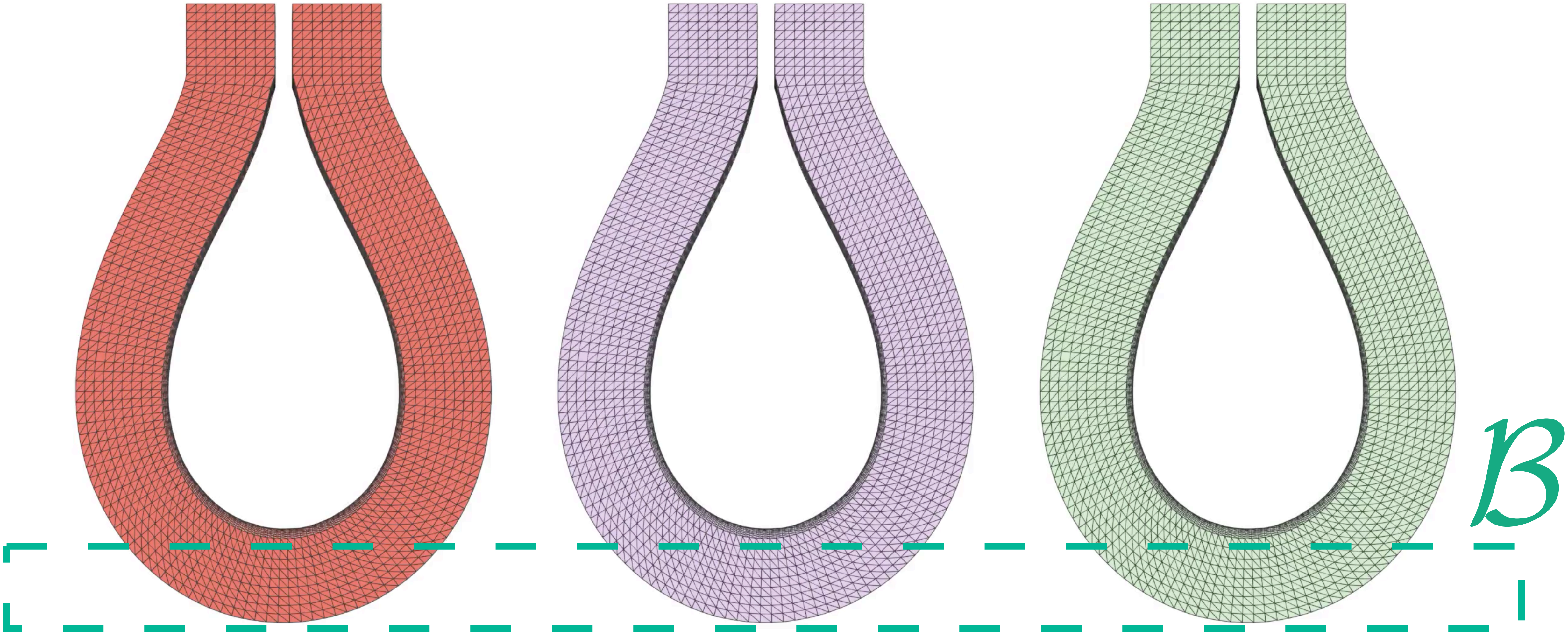
$\kappa_{\mathcal{B}} = 2\kappa_{\mathcal{B}}$

Solve $E = \frac{1}{2}||x - x^t||_M^2 + hE_{\bar{x}}(x), \text{s.t.} x_k = \tilde{x}_k, k \in \mathcal{B}$

$g, H = \nabla E, \nabla^2 E$

$x+ = \alpha(-H^{-1}g), \alpha$ is from line search

Time-Varying Boundary Conditions



Plastic + Elastic + Barrier **Elastic + Barrier** **Elastic**

Applications

(1) Normal Flow

Flow Speed

$$E(x, N^t) = B(x) - \gamma \frac{1}{2} x^T L x - \beta x^T N^t$$

Normal Direction

(2) Animation Repair

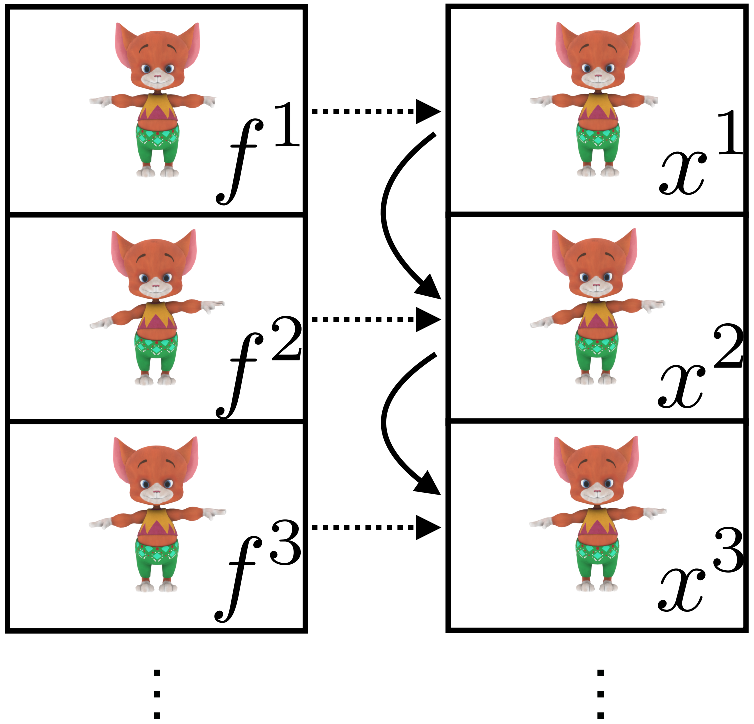
Input animation frame

$$\boxed{x^s} = \arg\min_x \frac{1}{2}||x - f^s||^2_M + hE(x, \boxed{f^s})$$

Repaired output animation frame

$$E(x, \bar{x}) = \underbrace{\Psi_{\text{memb}}(x, \bar{x})}_{\text{Membrane Energy}} + \underbrace{\Psi_{\text{bend}}(x, \bar{x})}_{\text{Shell Bending Energy}} + B(x)$$

Input:

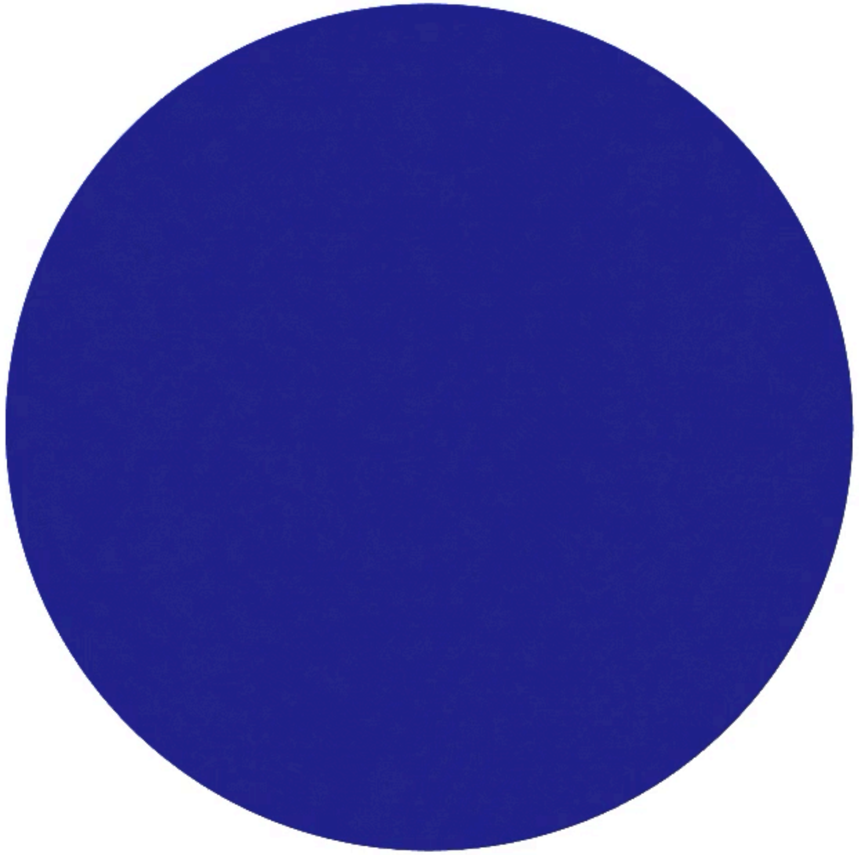


Repaired:

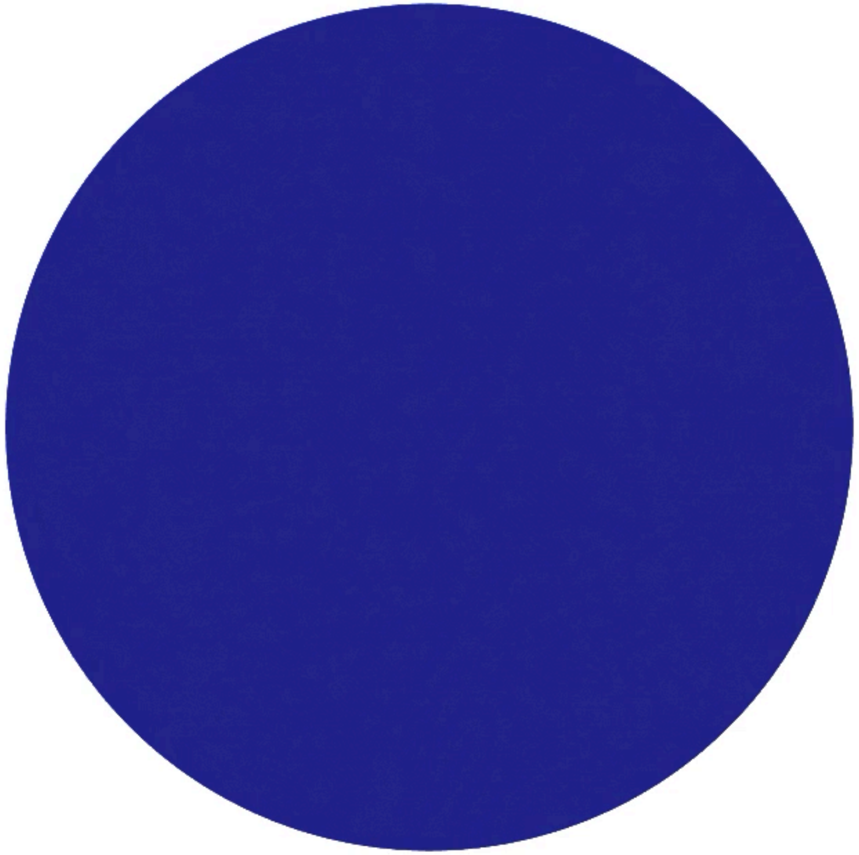
(3) Min-max distortion—2D

Exponential Factor

$$E_p(x, \bar{x}) = r(p) \sum_{t \in T} v_t \big(\Psi(F_t)\big)^{p}, \quad r(p) = \frac{1}{p}\big(\Psi(I)\big)^{(1-p)}$$



p = 1



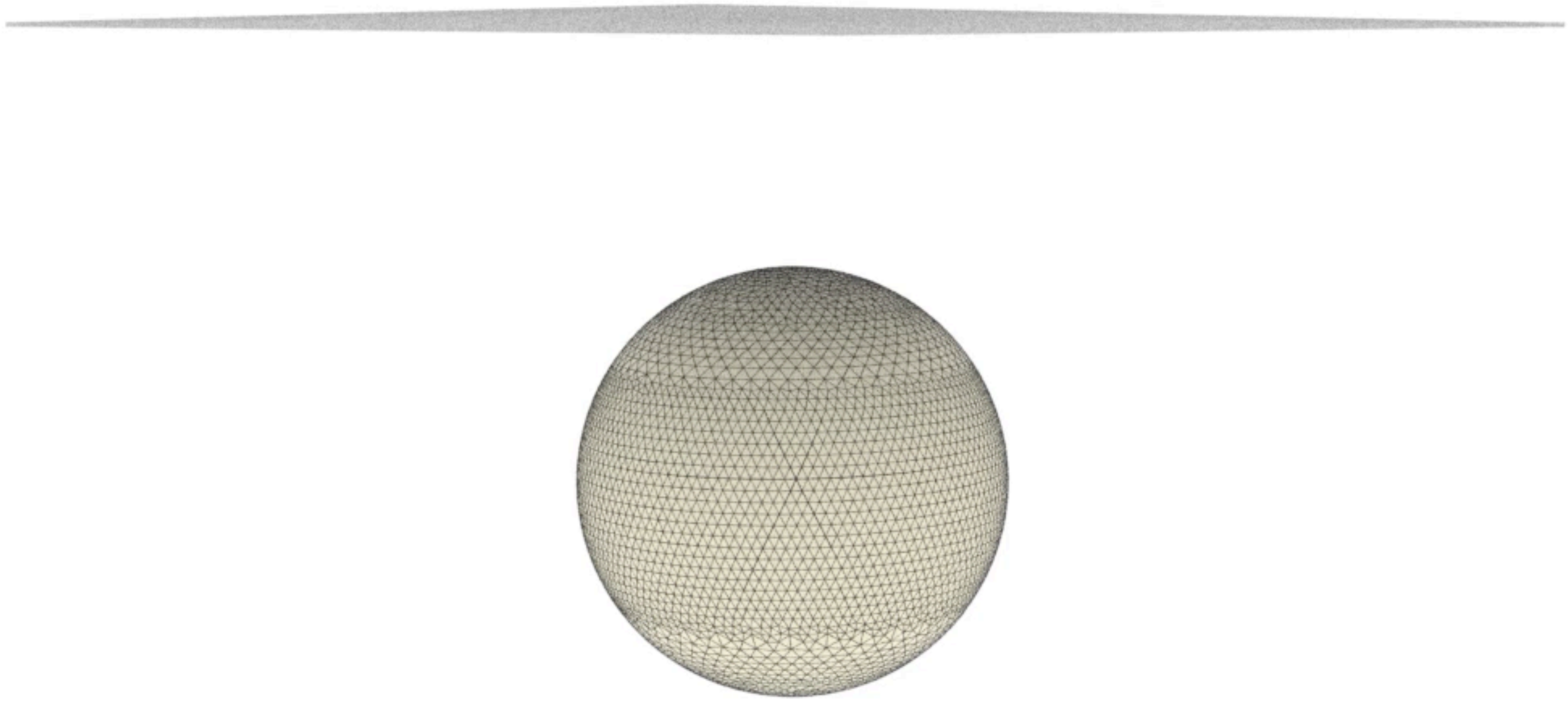
p = 10

(3) Min-max distortion—3D

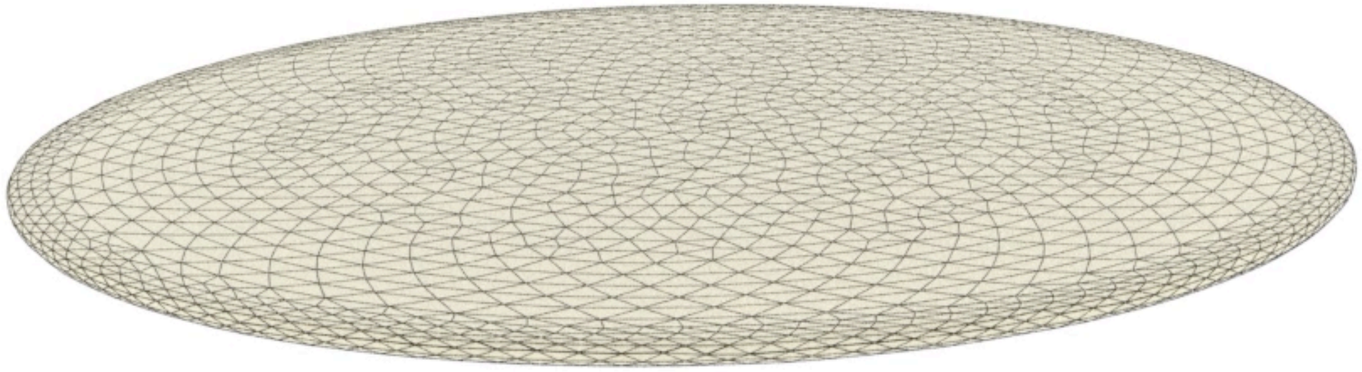
p = 1

p = 5

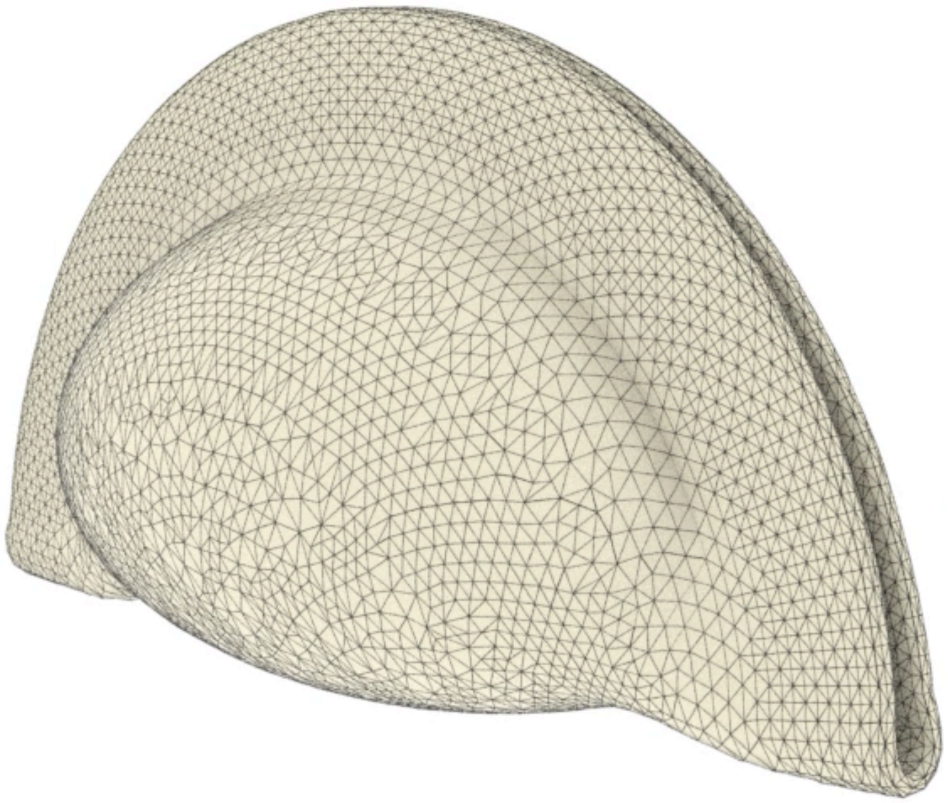
(4) Modeling — Squash



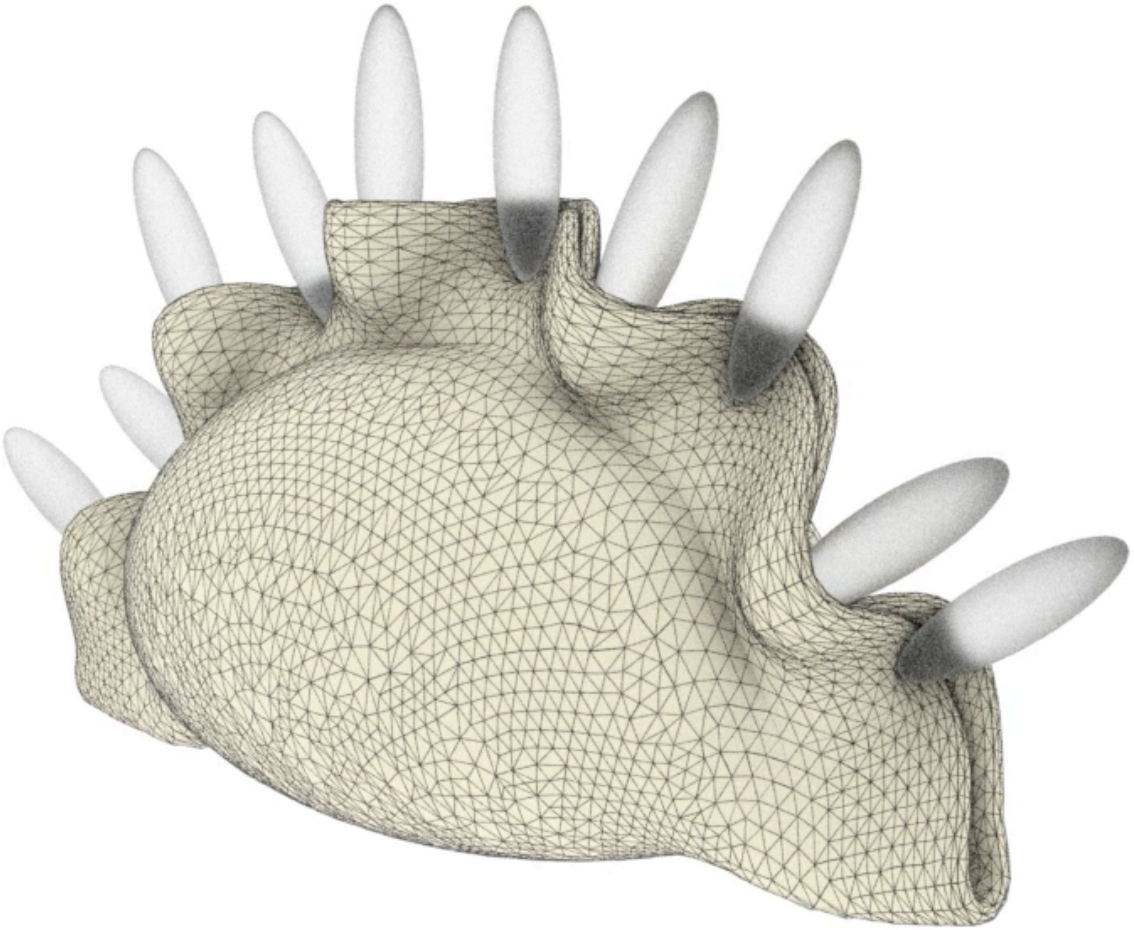
(4) Modeling—Wrap



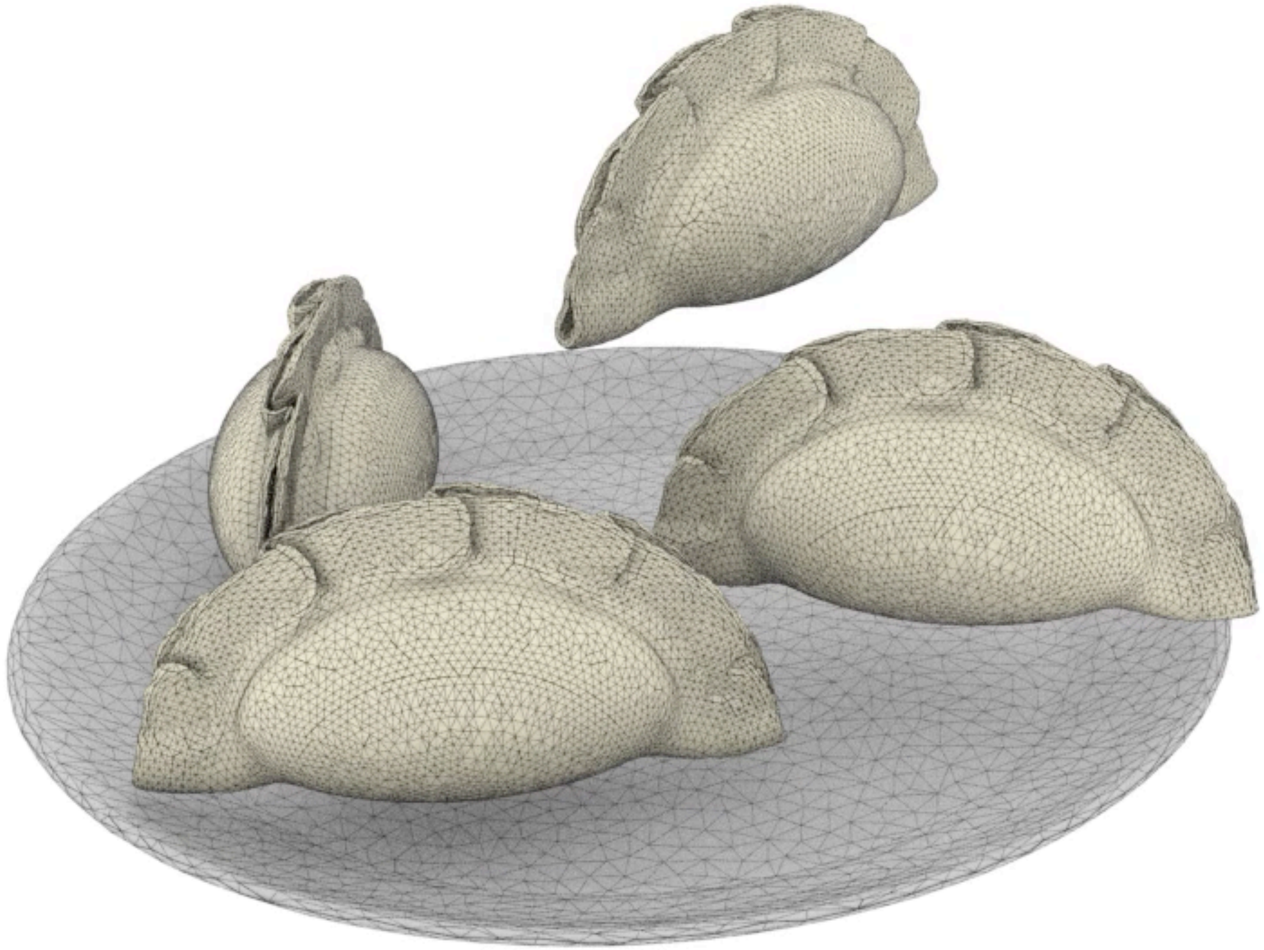
(4) Modeling — Pinch



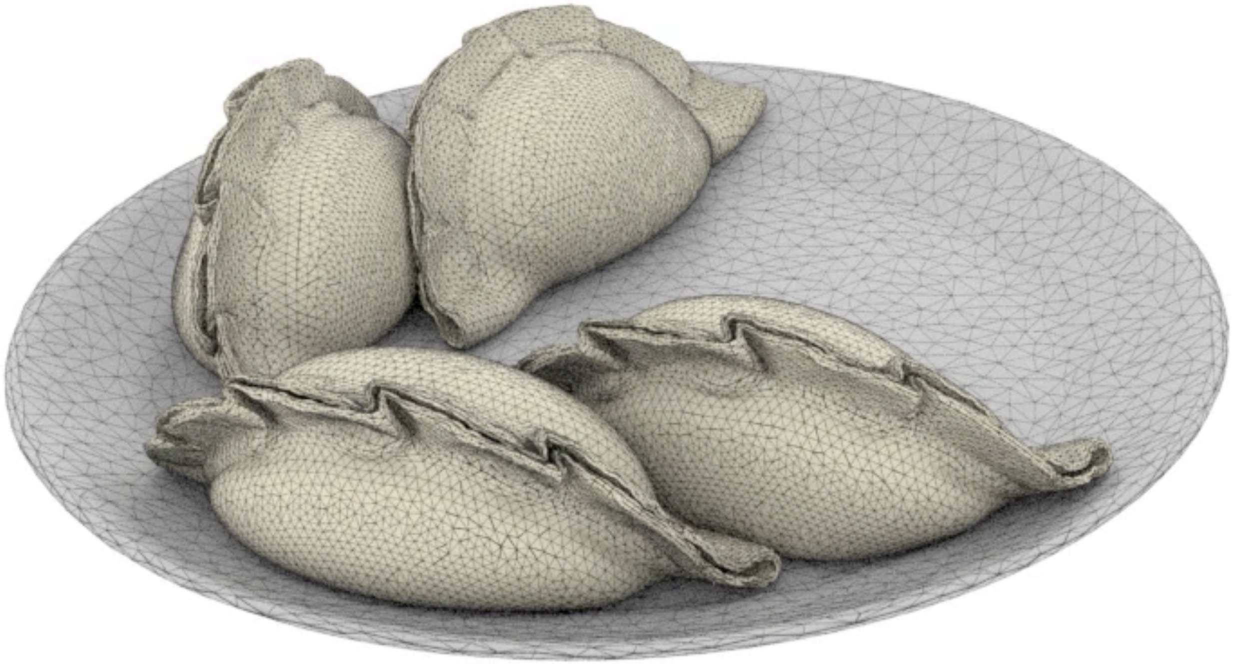
(4) Modeling—Squeeze



(4) Modeling—Layout



(4) Modeling—Layout

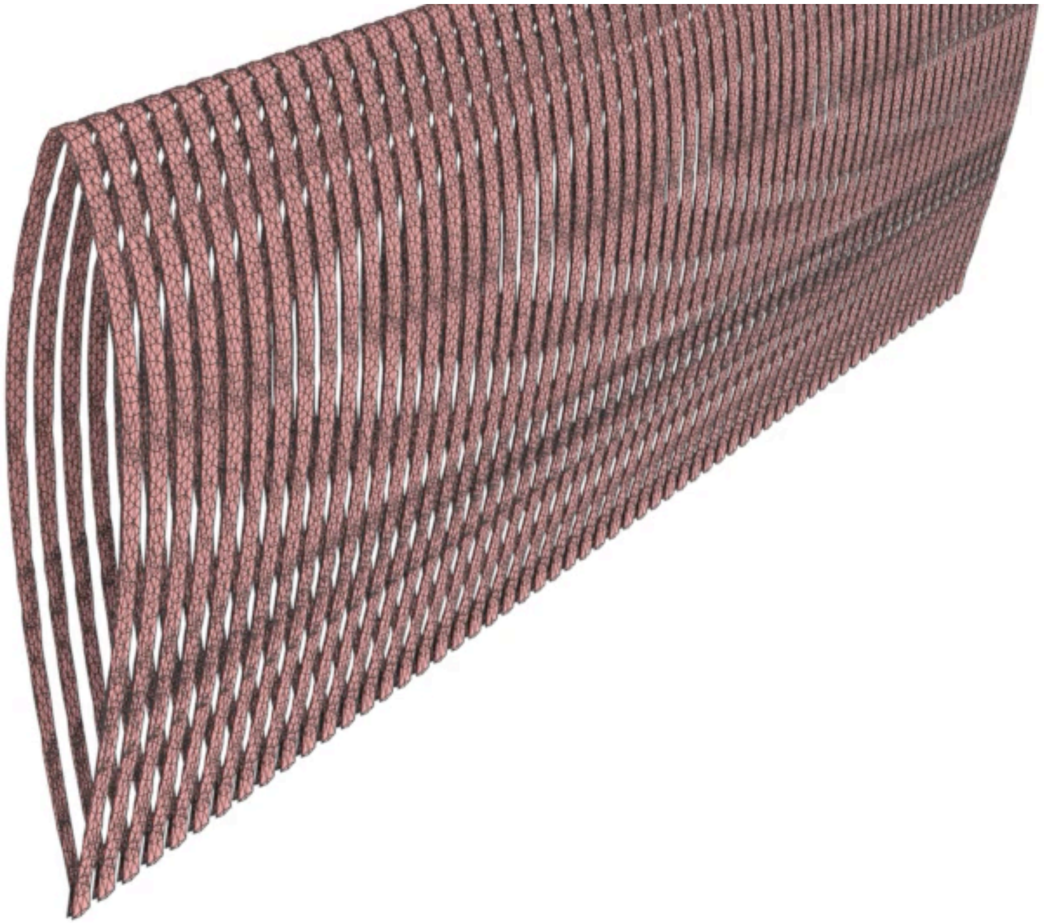


Enjoy

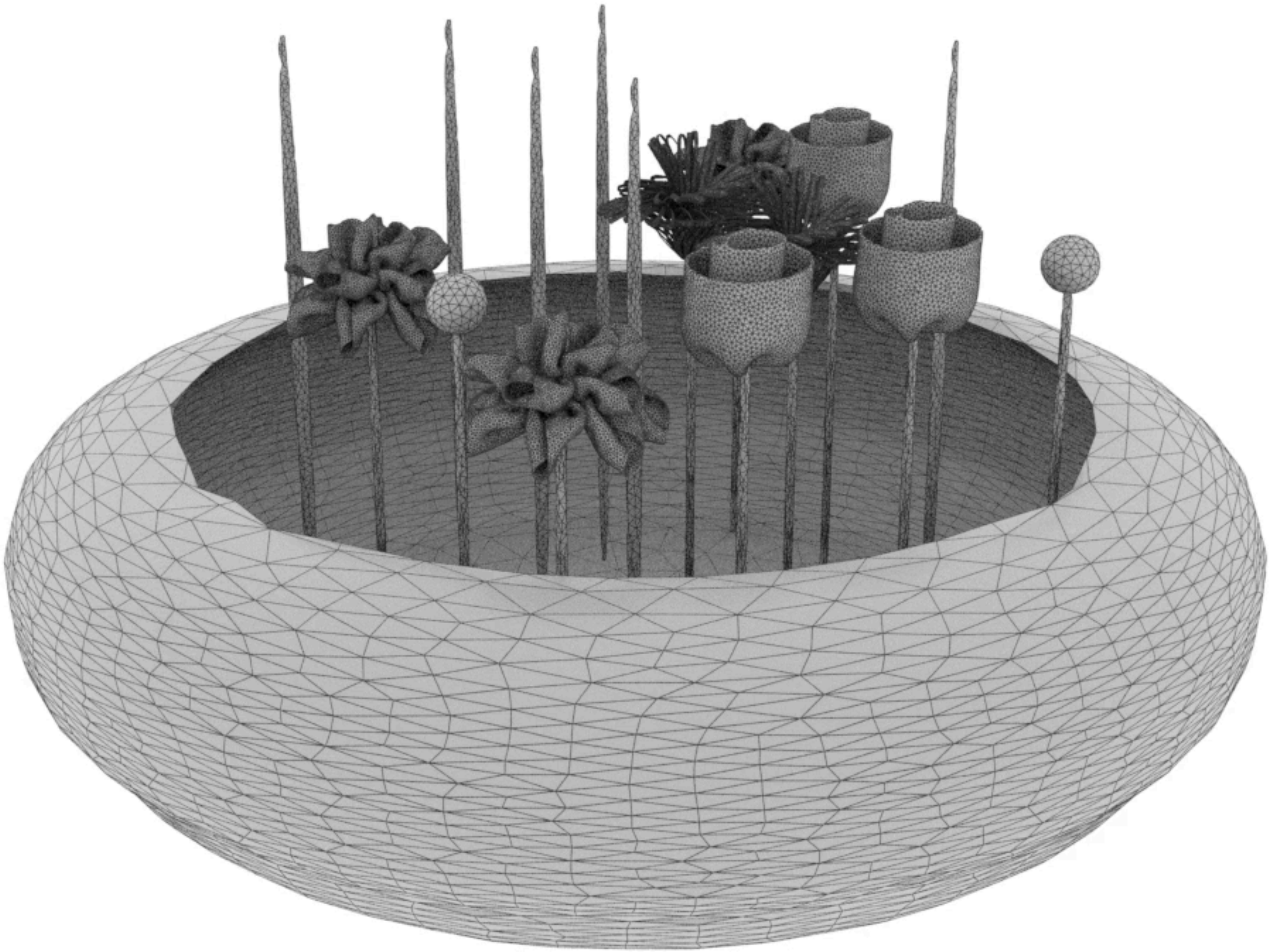
(4) Modeling—Bend

(4) Modeling—Copy Paste

(4) Modeling—Wind



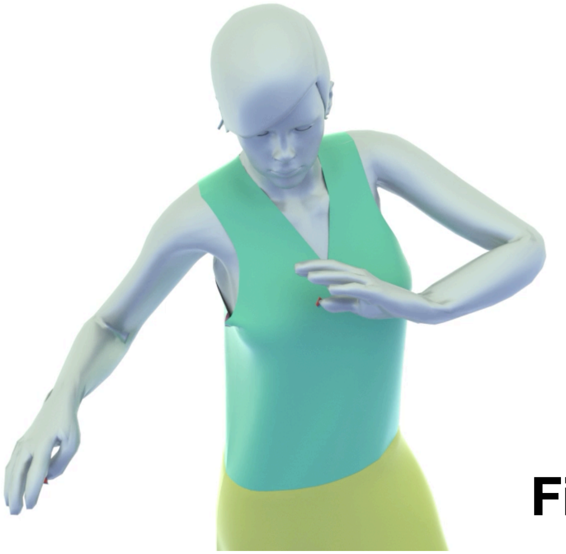
(4) Modeling—Flower



Enjoy

Conclusion

Intersected



Fixed (IDP)

Thanks!

谢谢!