中国科学技术大学
University of Science and Technology of China

GAMES 301: 第6讲

参数化应用1 – 艺术设计

傅孝明
中国科学技术大学

Art design

Peeling art

Computational Peeling Art Design


www.okadas.com
https://www.youtube.com/watch?v=JIOUHAkQdc4
NOW I'VE SEEN EVERYTHING

Popular art form

Peeling art examples

Problem: cut generation

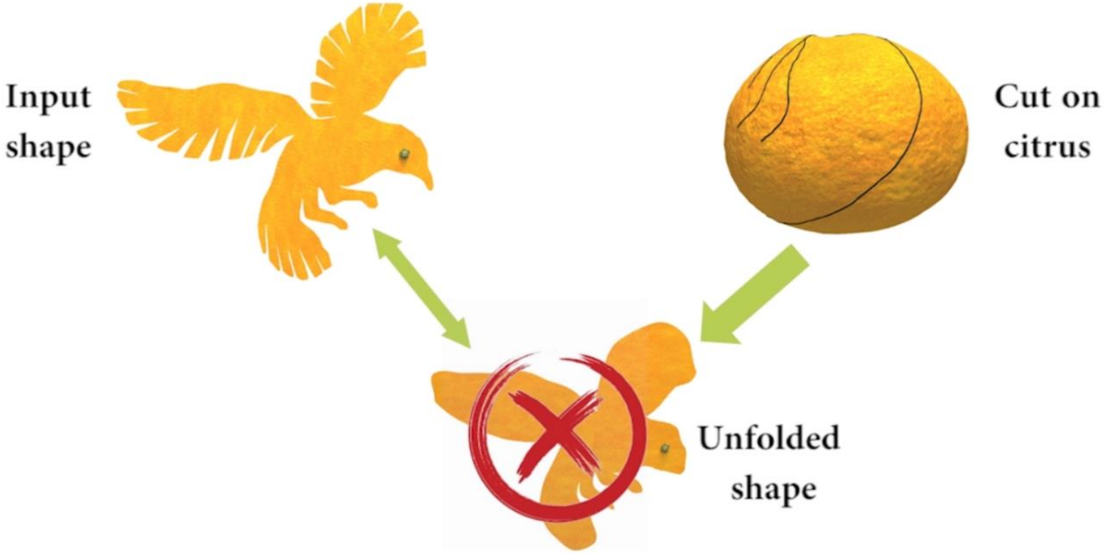
complex, tedious, time consuming

Peeling art design problem

Input shape

Challenges

- Non-trivial to optimize the similarity
- Unsuitable input shape

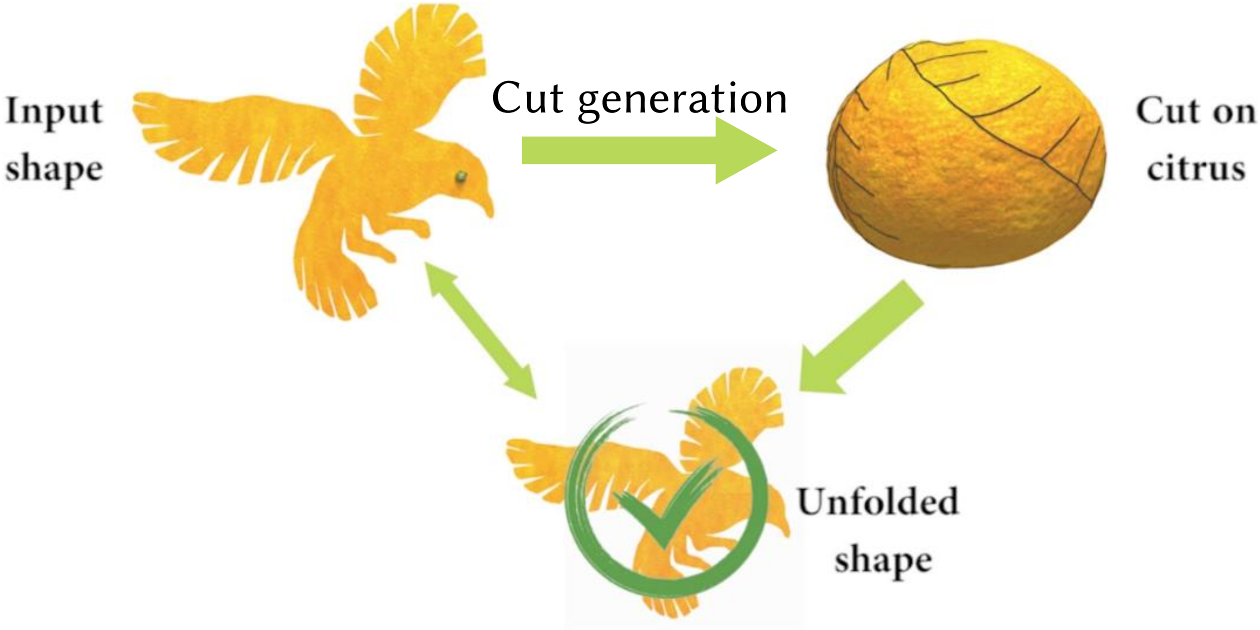


Existing work: cut generation

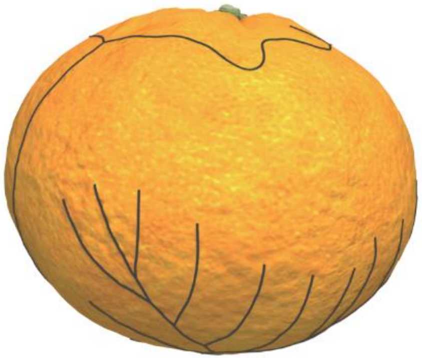
- Minimum spanning tree method [Chai et al. 2018; Sheffer 2002; Sheffer and Hart 2002]
- Mesh segmentation approaches [Julius et al. 2005; Lévy et al. 2002; Sander et al. 2002, 2003; Zhang et al. 2005; Zhou et al. 2004]
- Simultaneous optimization [Li et al. 2018; Poranne et al.2017]
- Variational method [Sharp and Crane 2018]

unfolded shapes ≠ input shapes

Our approach



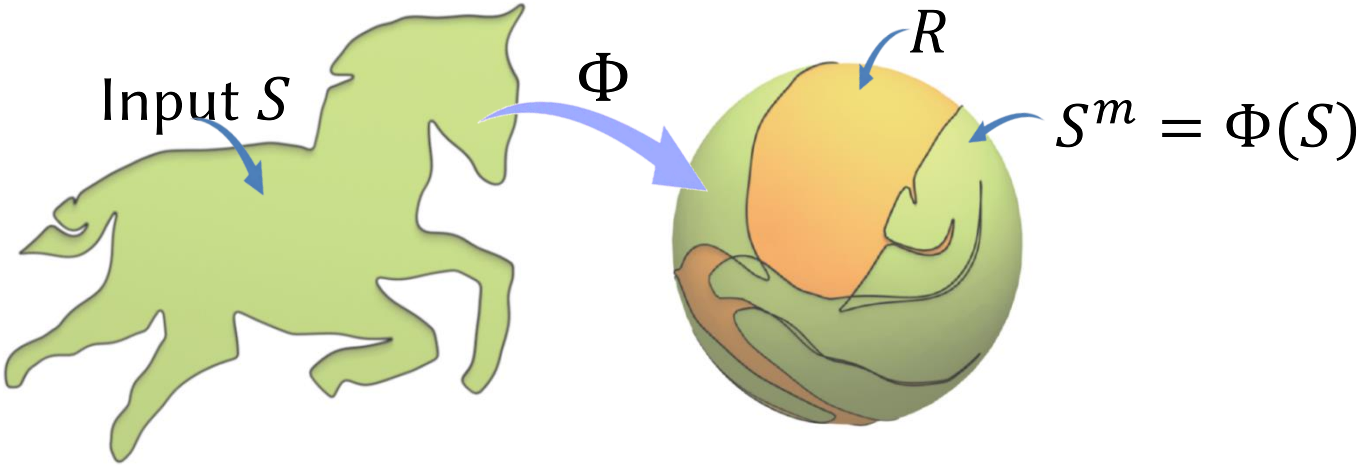
Key idea



Cut generation
Difficult

Mapping computation
Easy

Mapping computation



Two goals:

1. Low isometric distortion
2. Area of R approaches zero

$$\min E_{iso}(S^m, S) + wE_{shr}(R)$$

Isometric energy

- ARAP distortion metric [Liu et al. 2008]

$$E_{iso}(S^m, S) = \sum_{i=1}^{N_f} Area(f_i) ||J_i - R_i||_F^2$$

R_i is an orthogonal matrix

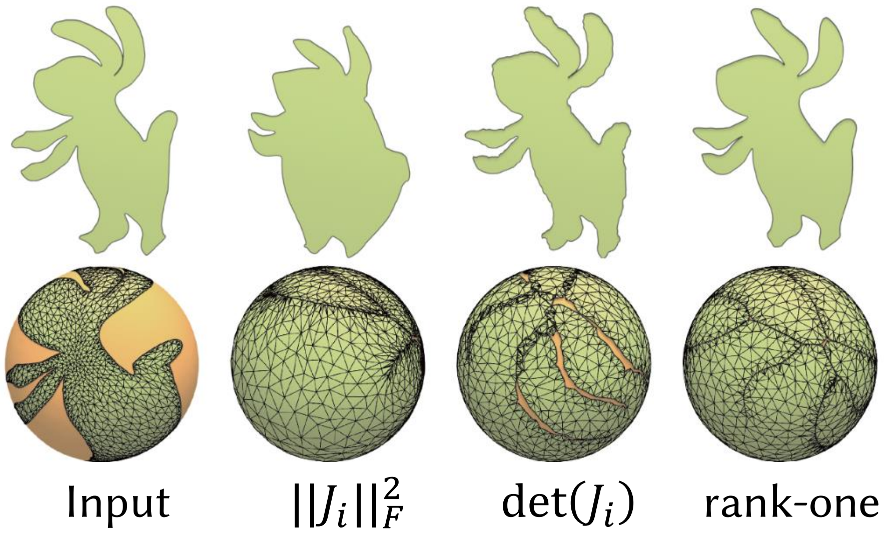
Shrink energy

- Our novel rank-one energy

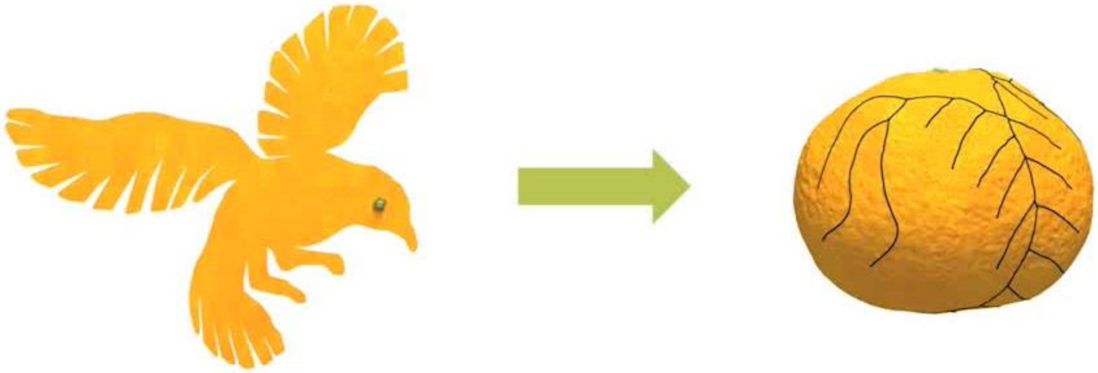
$$E_{shr}(R) = \sum_{i=1}^{N_{R_f}} Area(t_i)||J_i - B_i||_F^2$$

B_i is a rank one matrix

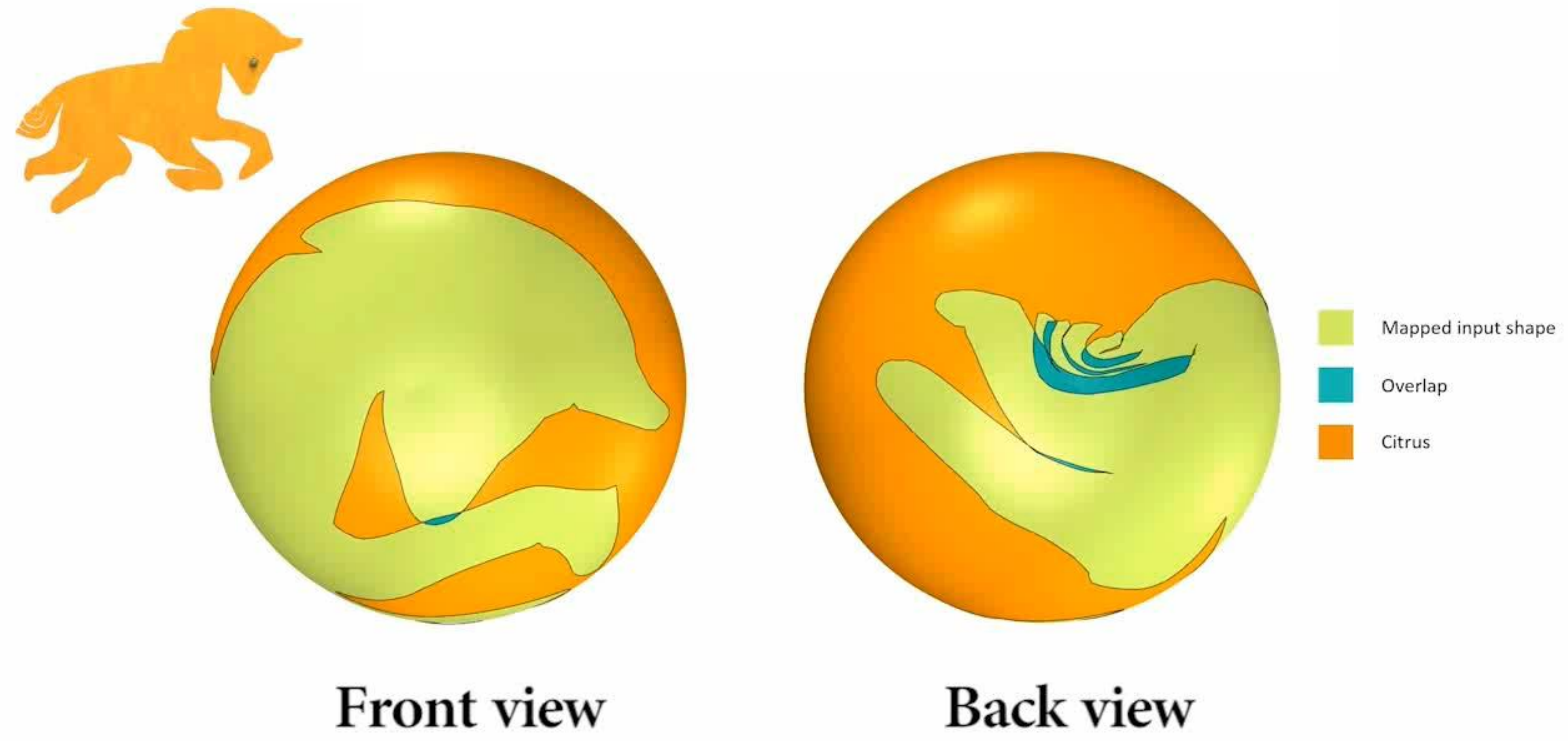
- Other choices
  - Frobenius energy $||J_i||_F^2$
  - Determinant energy $\det(J_i)$



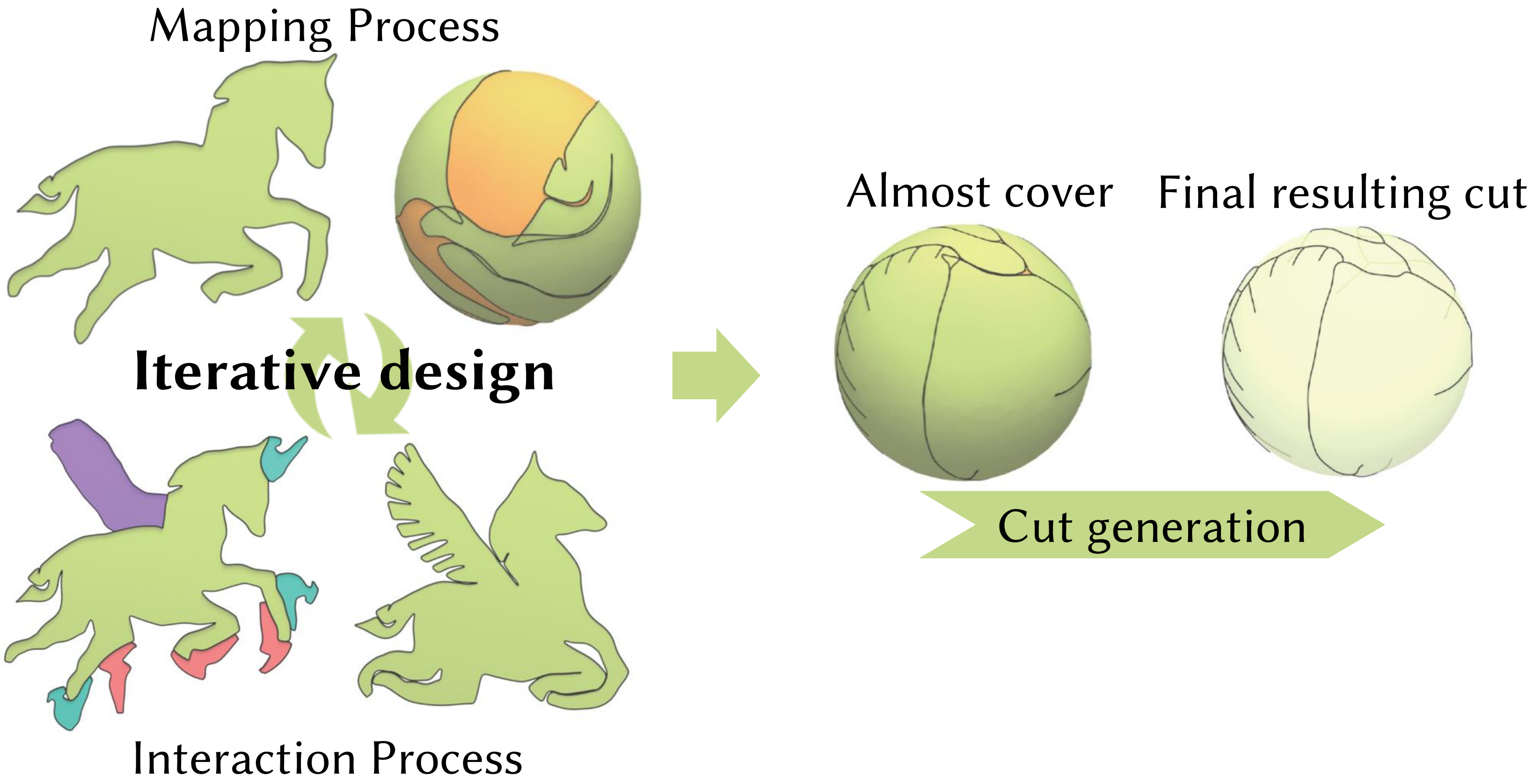
Suitable input



Unsuitable input

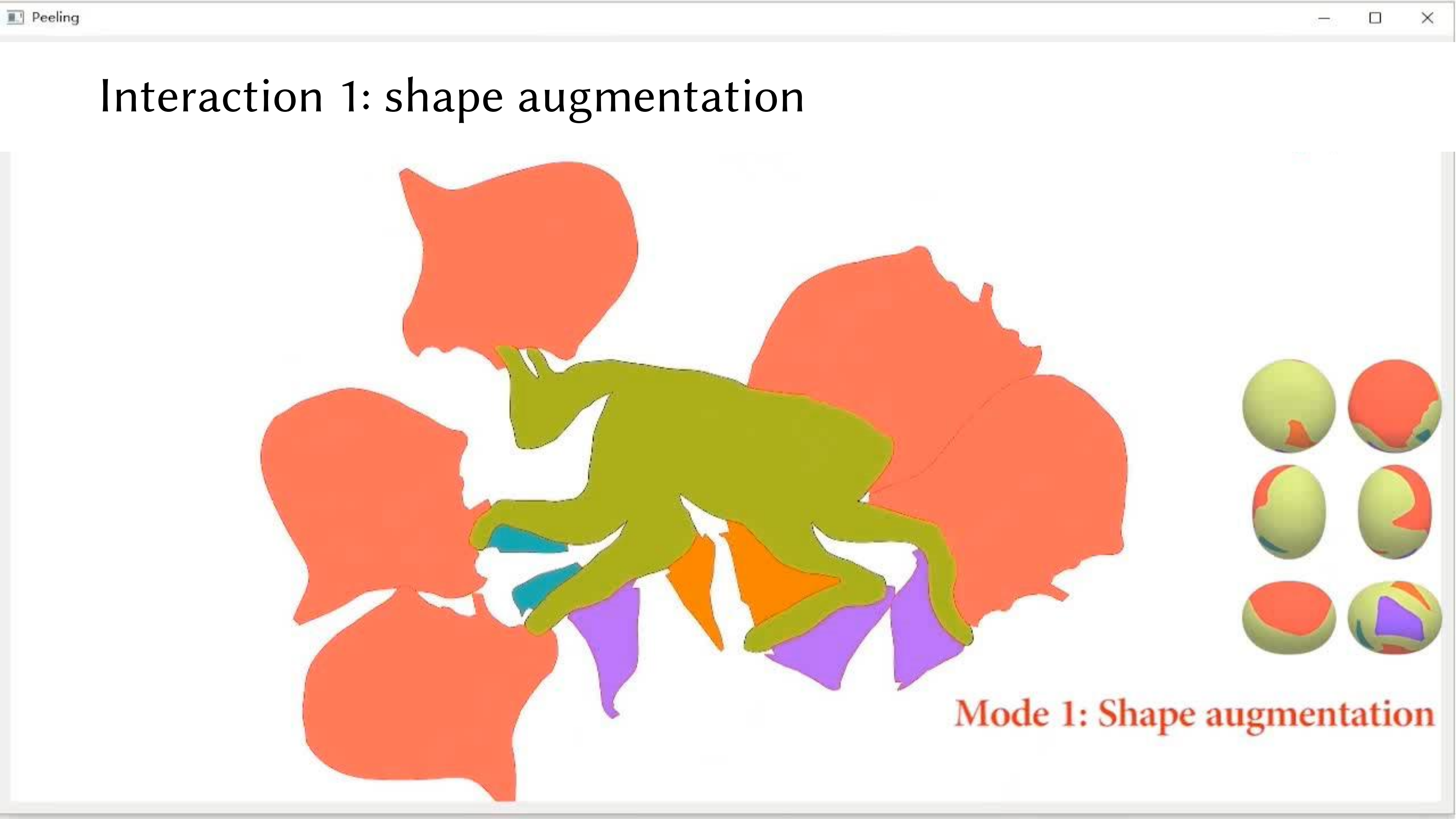


Iterative interaction

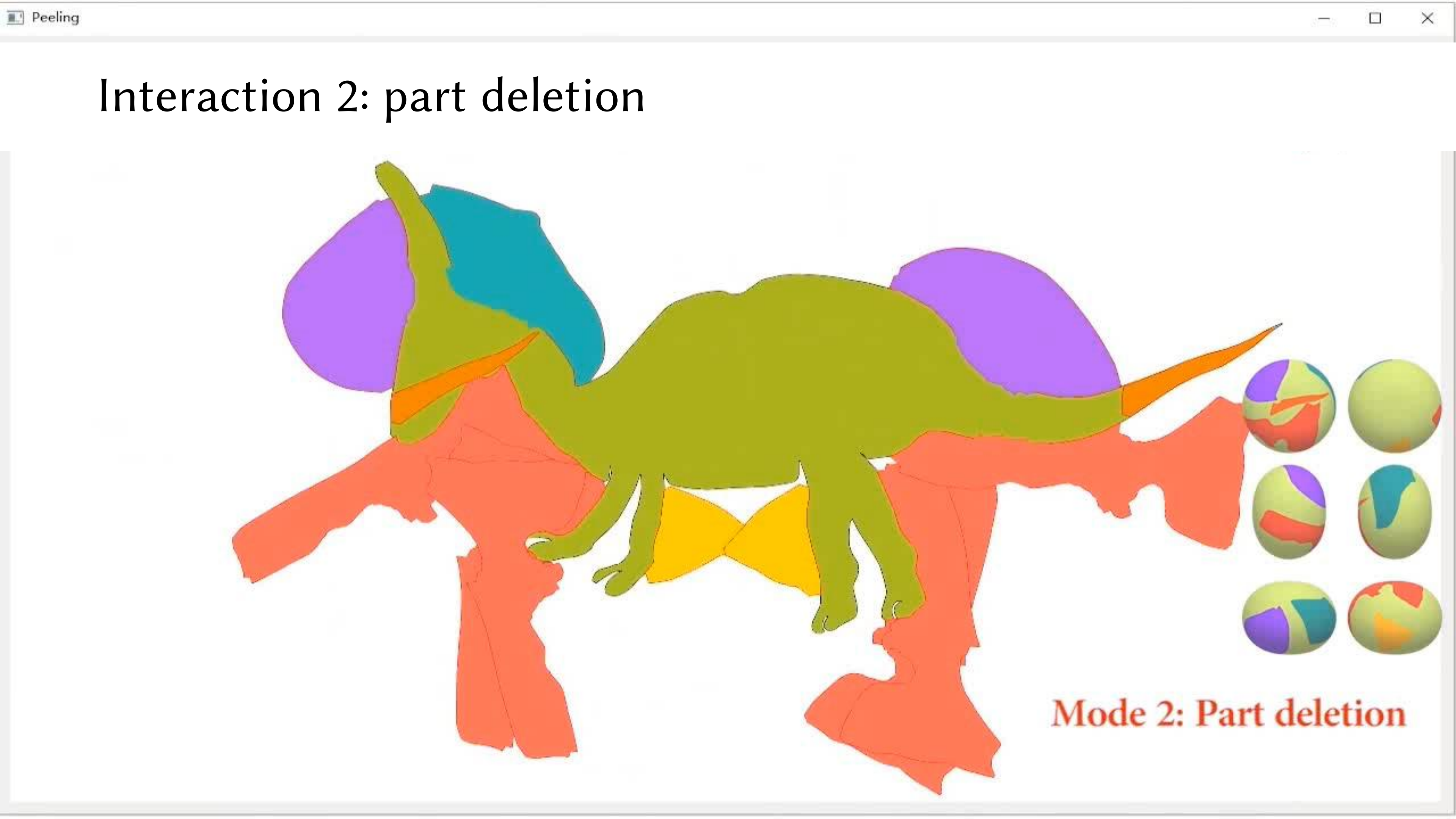


Interaction place

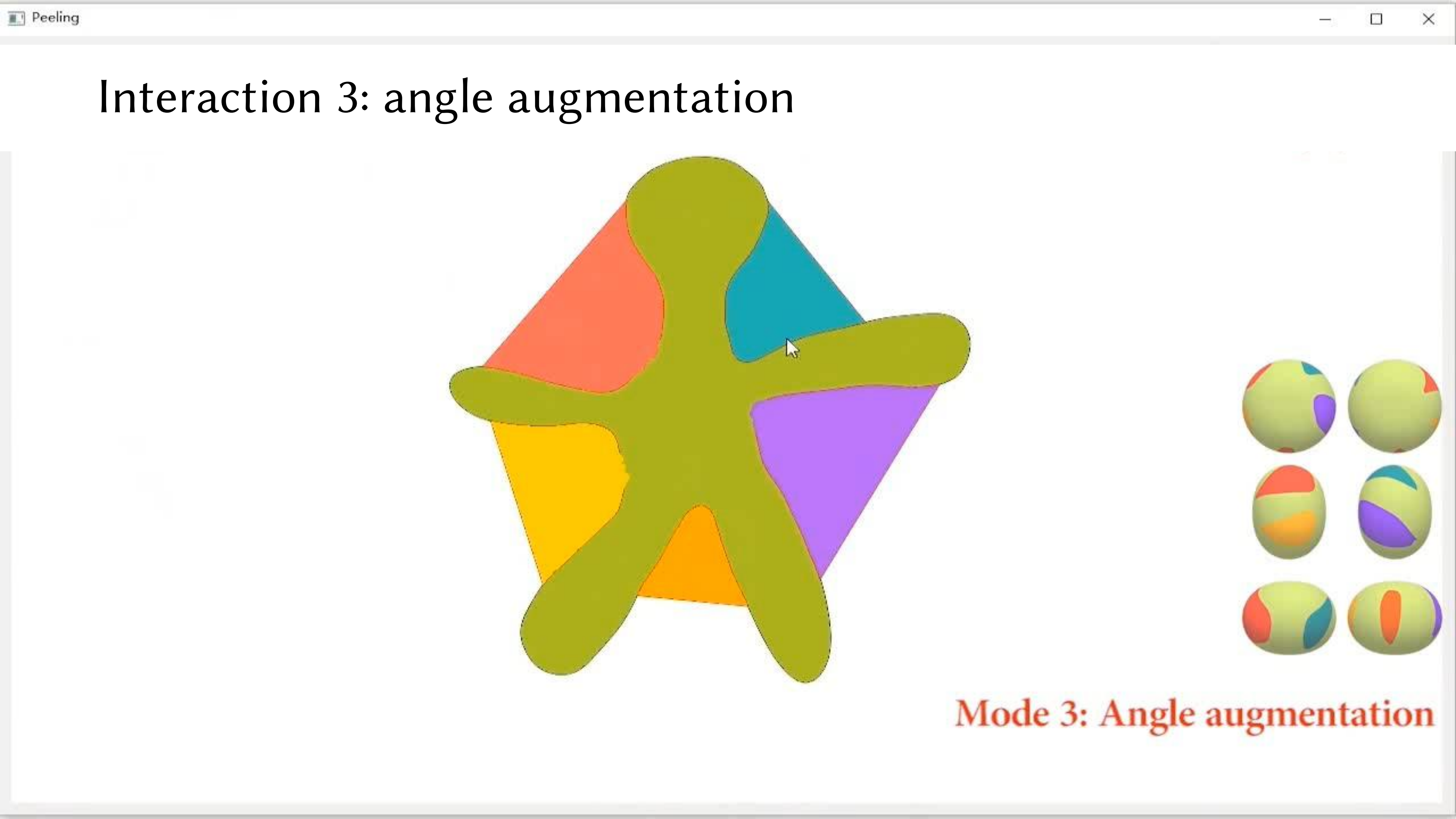
Interaction 1: shape augmentation



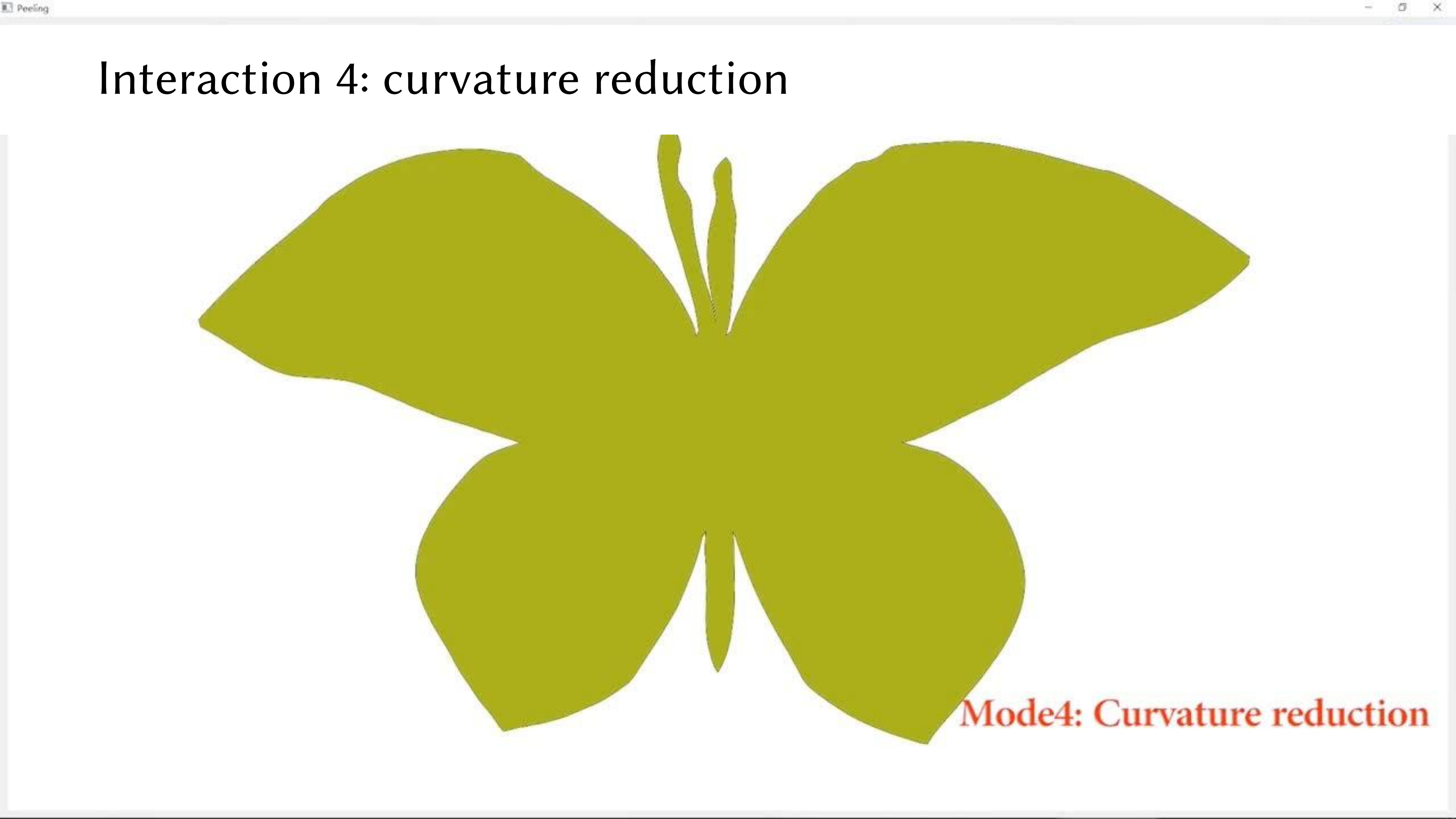
Interaction 2: part deletion



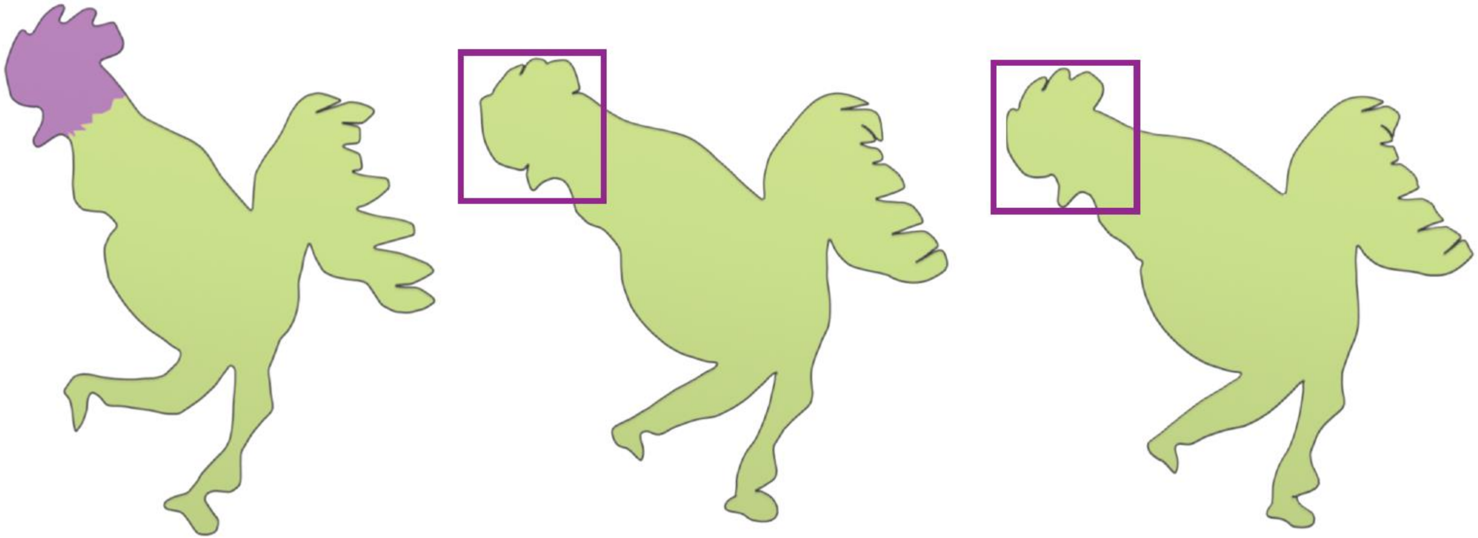
Interaction 3: angle augmentation



Interaction 4: curvature reduction



Interaction 5: pre-processing

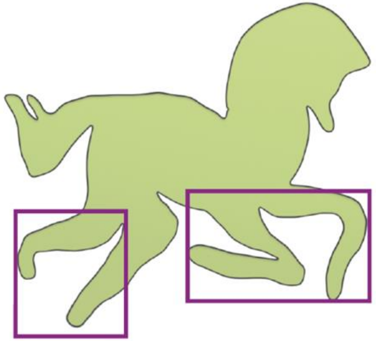


Input
with specify area

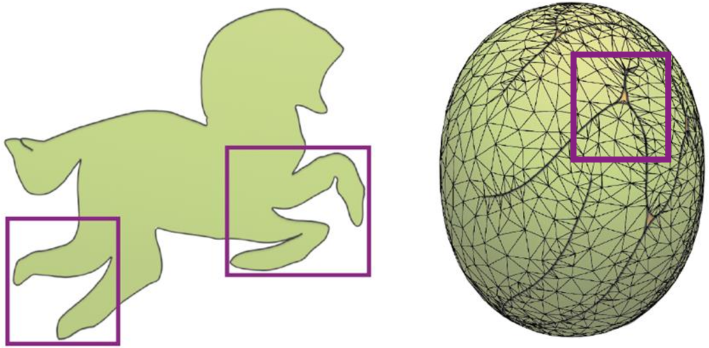
Unprocessed
high distortion

Processed
low distortion

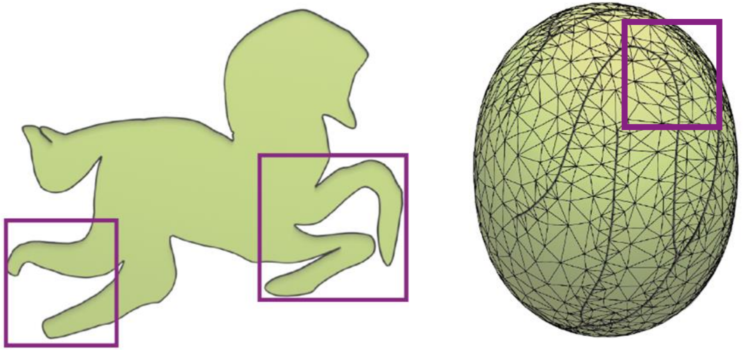
Interaction 5: pre-processing



Input with specify area

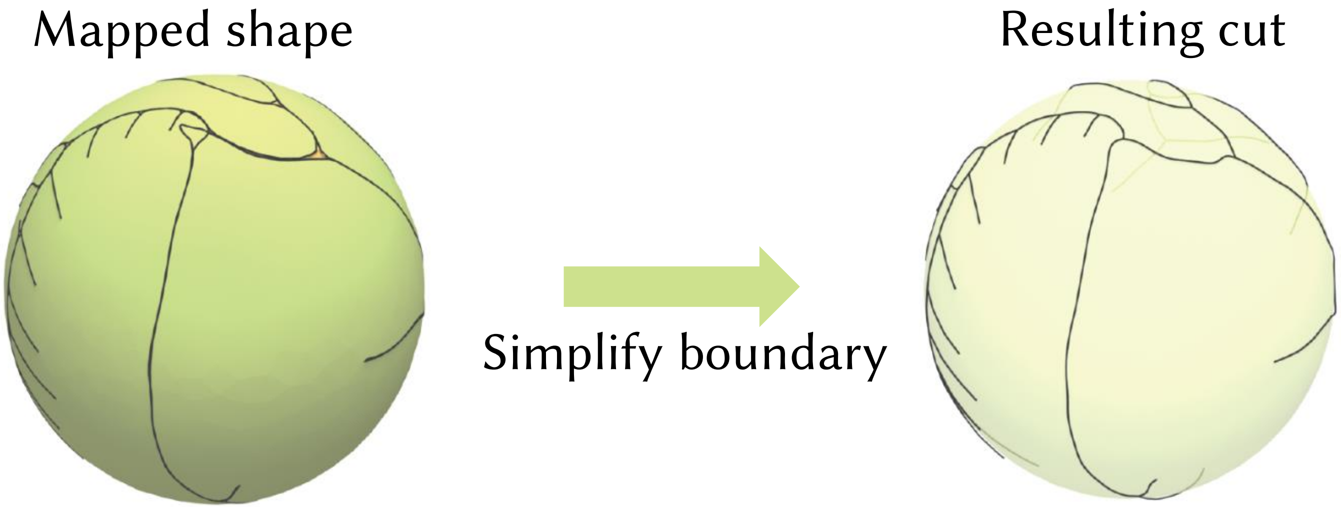


Unprocessed: high distortion

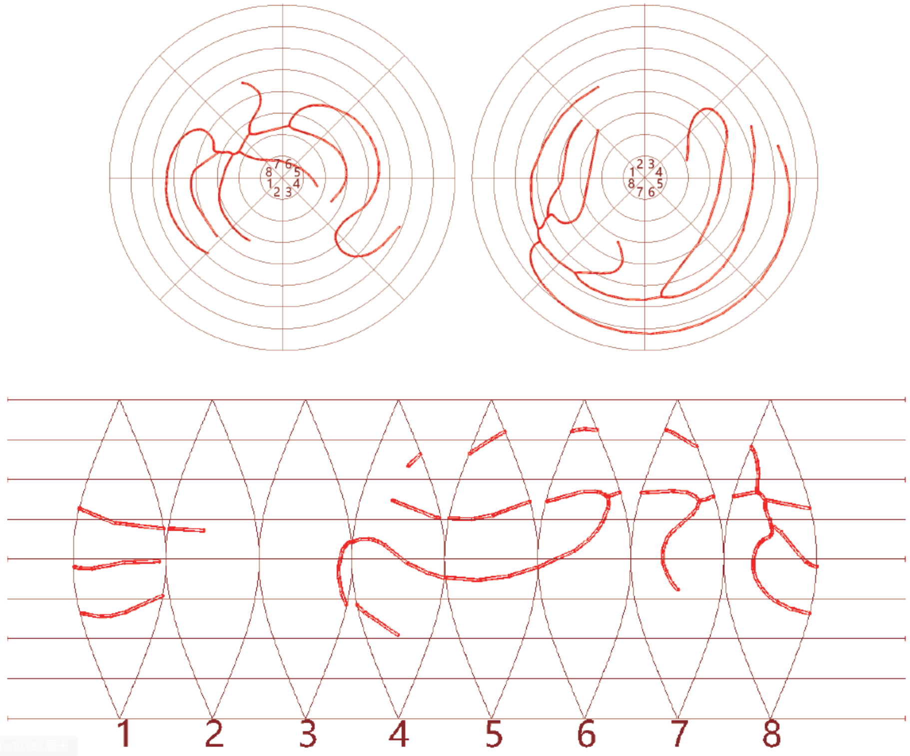


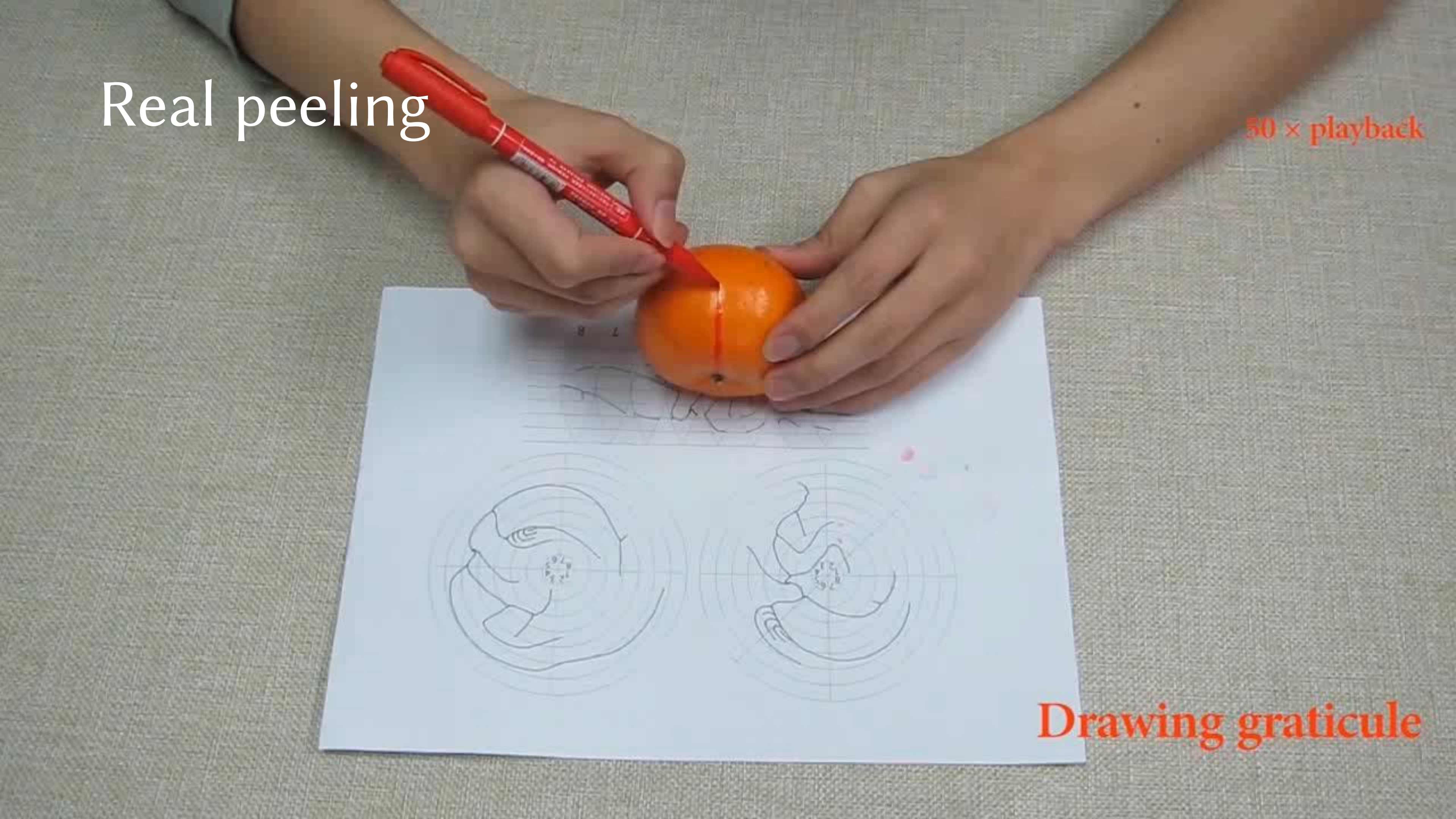
Processed: low distortion

Cut generation

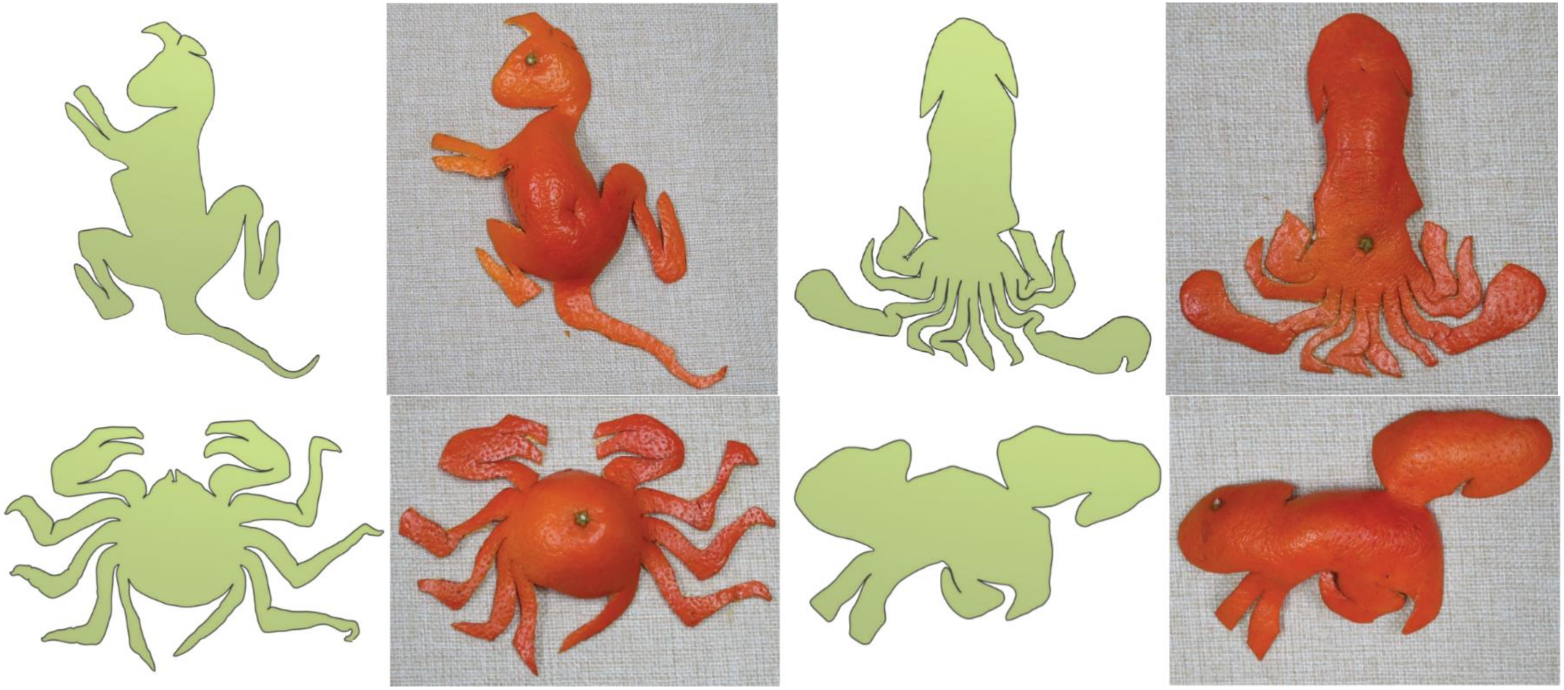


Real peeling




Real peeling
50 × playback
Drawing graticule

Shapes designed by Yoshihiro Okada



Comparison to Yoshihiro Okada

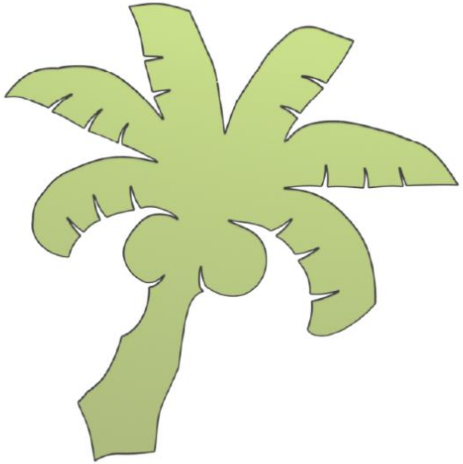
Okada's

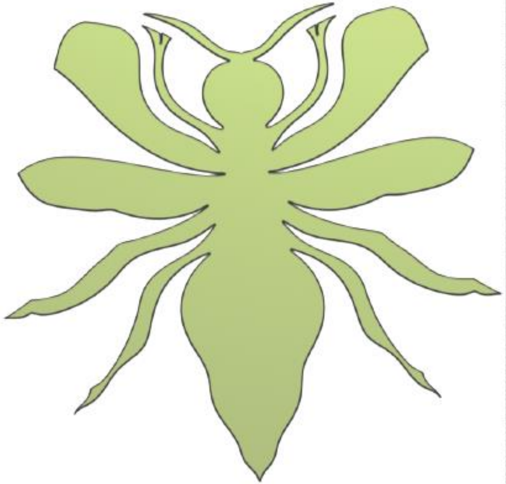
Ours

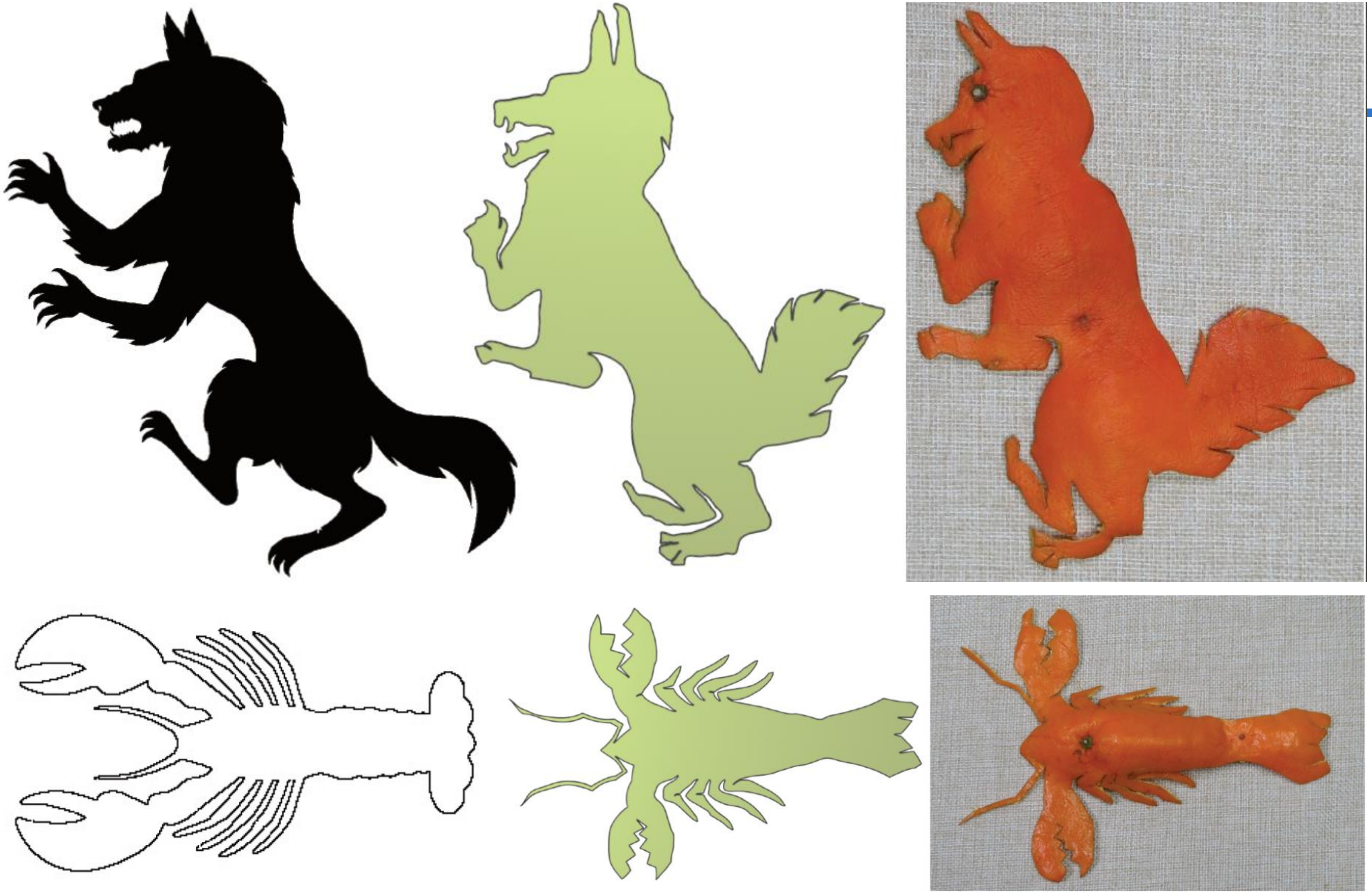
Dove　Eagle　Shrimp

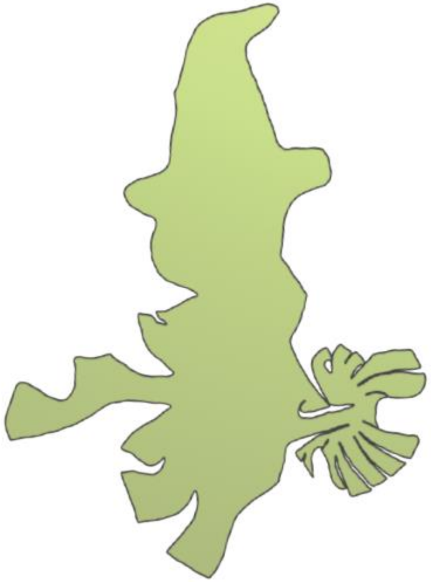

Designing shapes
20 × playback

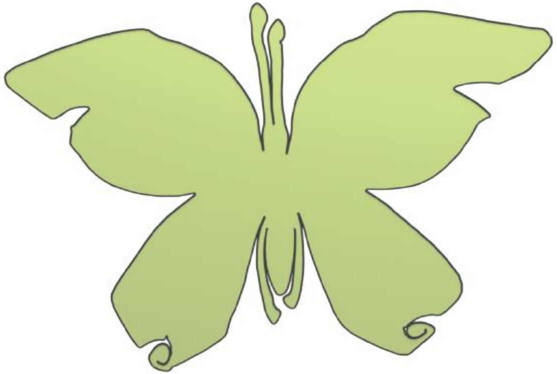
Our results

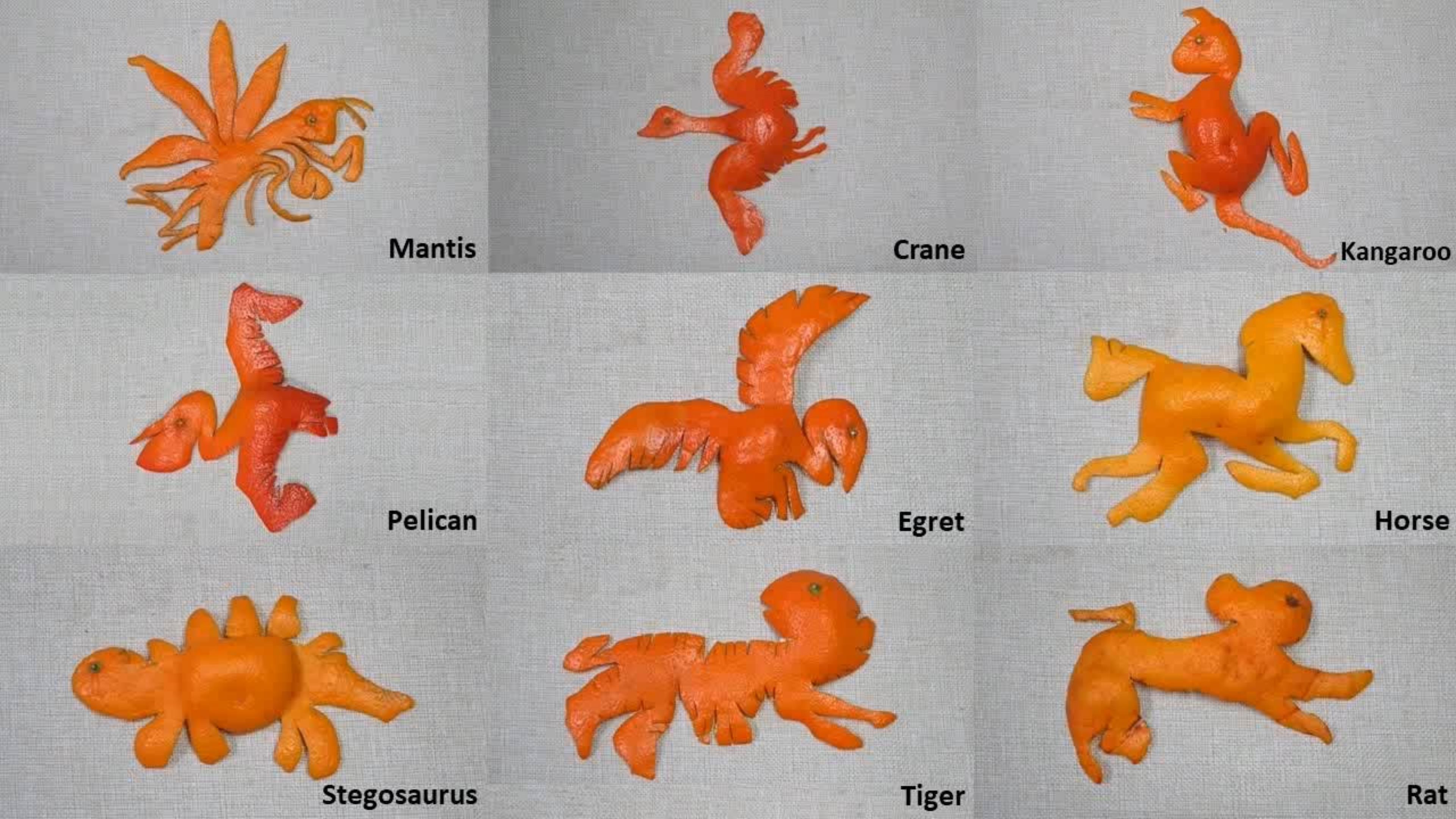



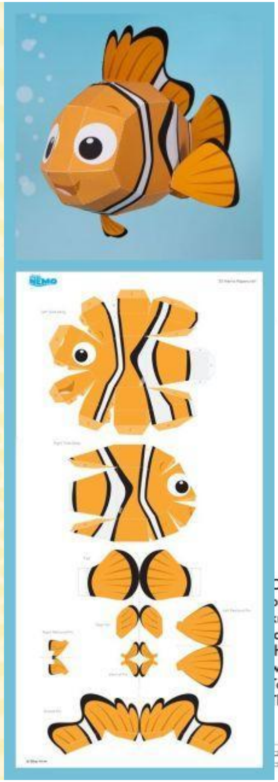



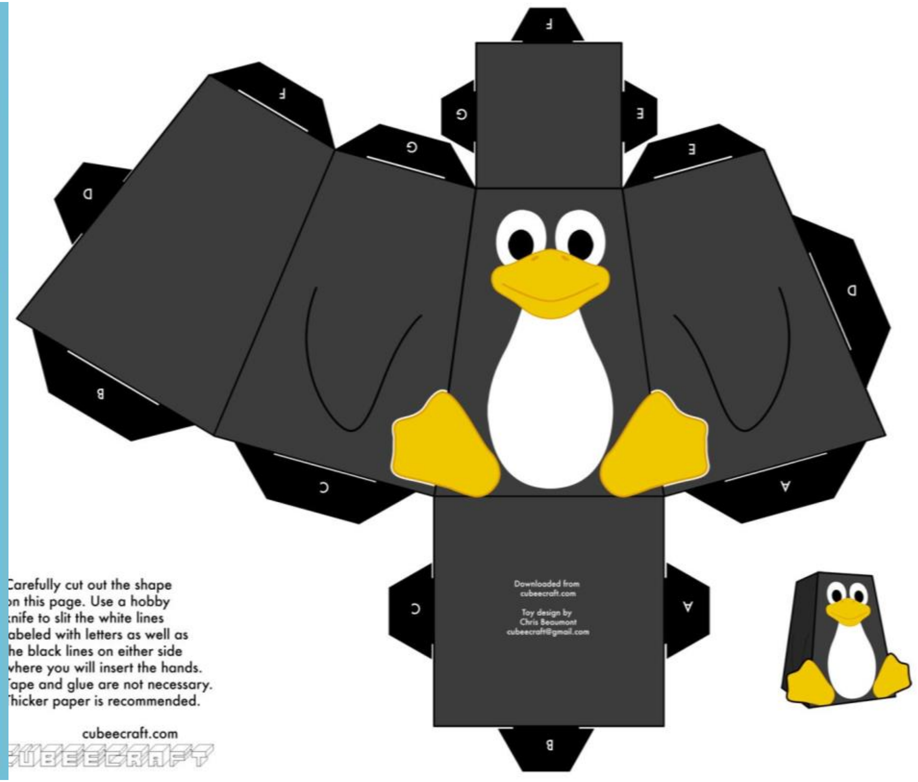


Mantis
Crane
Kangaroo
Pelican
Egret
Horse
Stegosaurus
Tiger
Rat

Papercraft

Paper craft


狮 子
剪切
折叠
反折
身体
鬃毛
底面
耳朵
制作步骤
1. 将狮子身体和底面折叠、粘贴在一起。
2. 将耳朵、鬃毛分别折叠、粘贴到身体上。

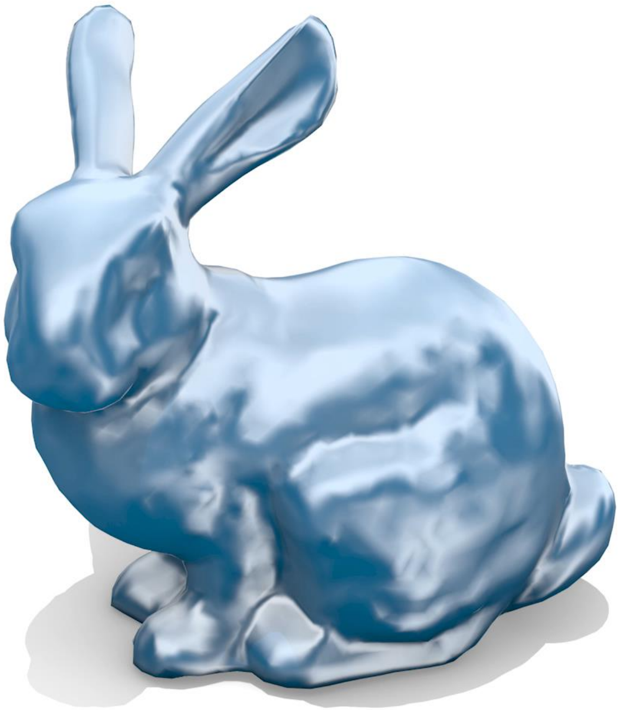



Carefully cut out the shape
on this page. Use a hobby
nife to slit the white lines
abeled with letters as well as
he black lines on either side
where you will insert the hands.
ape and glue are not necessary.
hicker paper is recommended.
cubeecraft.com
Downloaded from cubeecraft.com
Toy design by Chris Beaumont
cubeecraft@gmail.com

Developable Surfaces

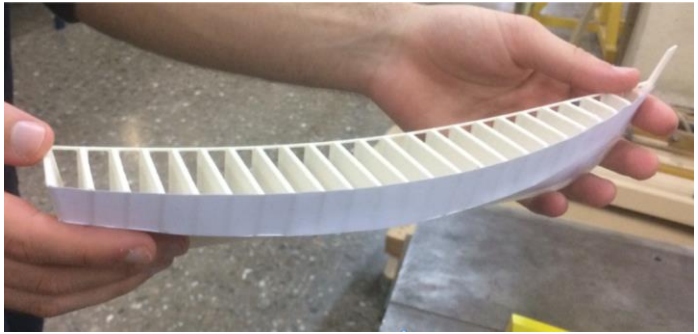
Twice differentiable

Zero Gaussian curvature



Developable Surfaces

Origami

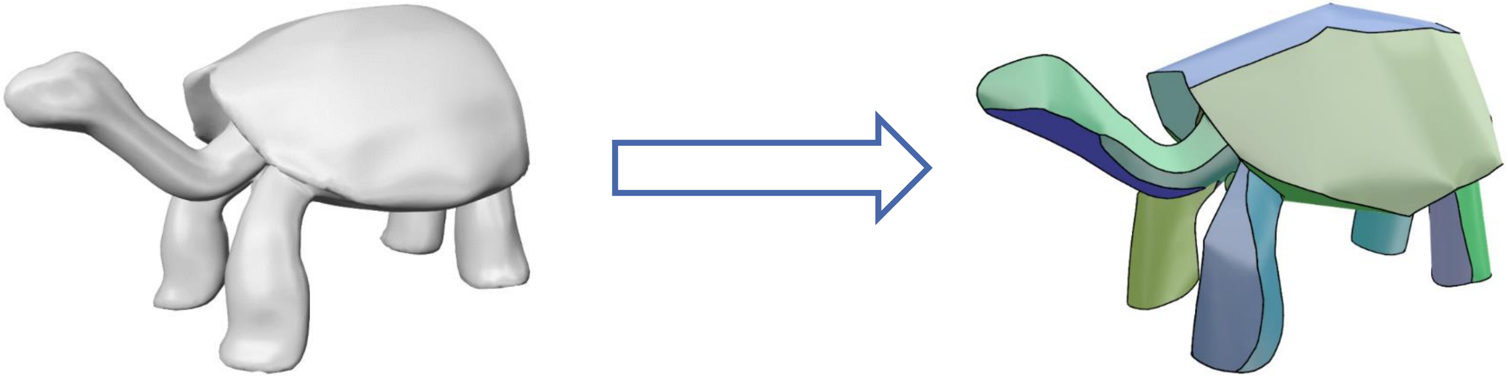


Ship hulls

Clothing

Architecture

Goal



Not globally developable

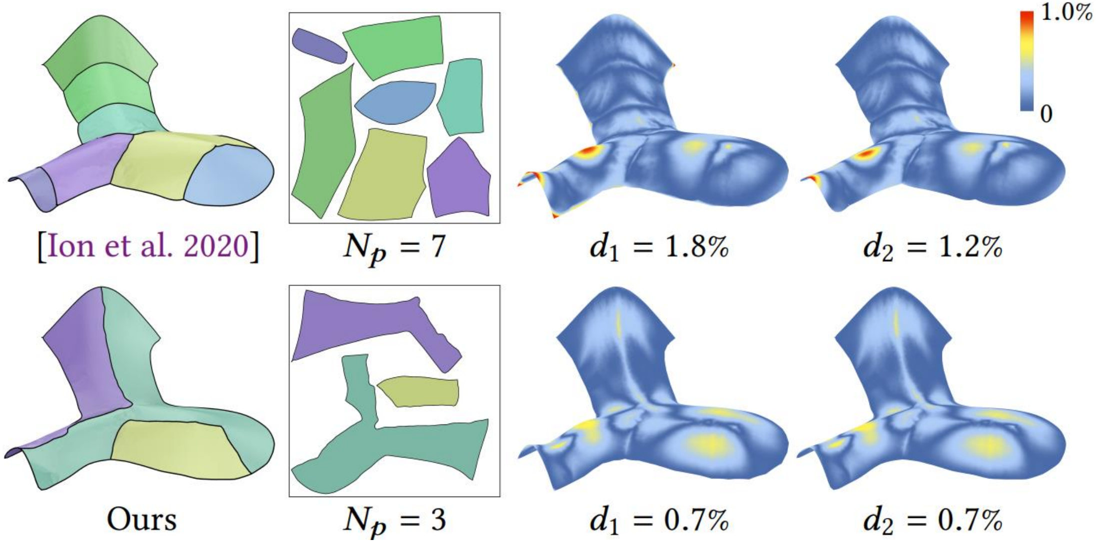
Piecewise developable approximation

Small number of patches

High similarity

Challenges

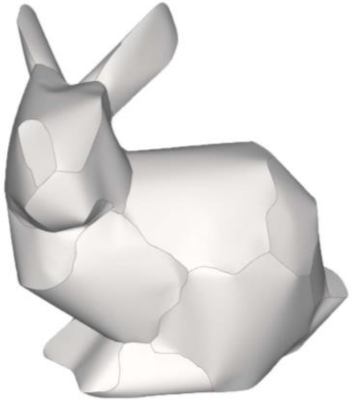
- Determining the numbers, placements and shapes of patches under the developability and similarity constraints



Related Work

Segmentation-based

[Shatz et al. 2006]



[Ion et al. 2020]

Pro: explicit patches

Con: large approximation error

Deformation-based

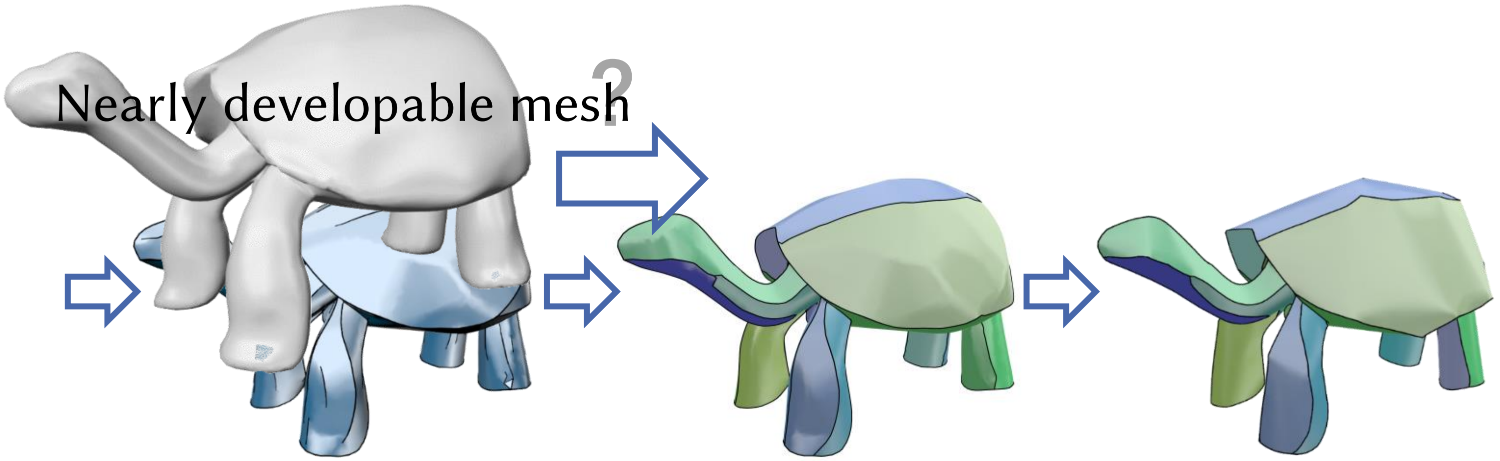
[Stein et al. 2018]

[Binninger et al. 2021]

Pro: seam curves

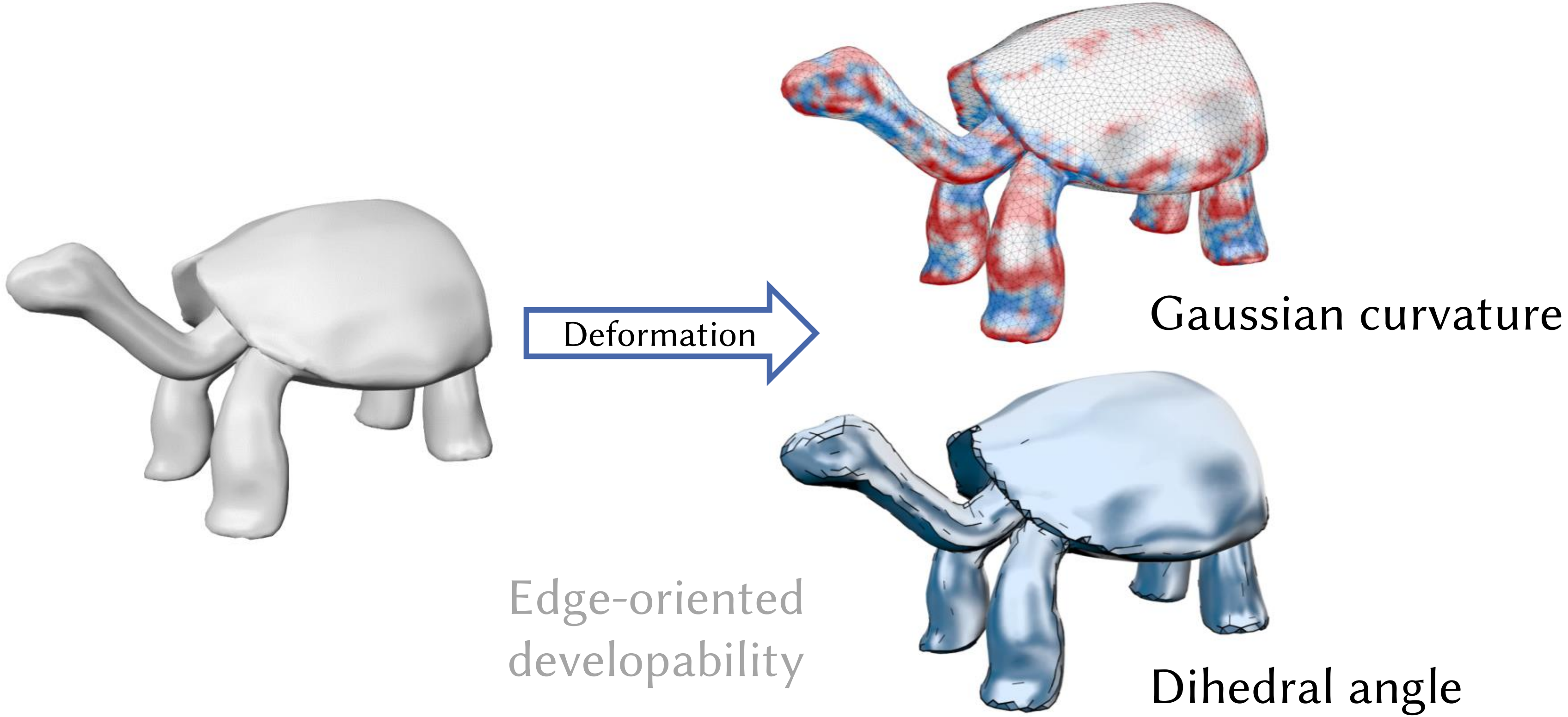
Con: no explicit patch layouts

Key Idea & Method Overview



Deformation Segmentation Refinement

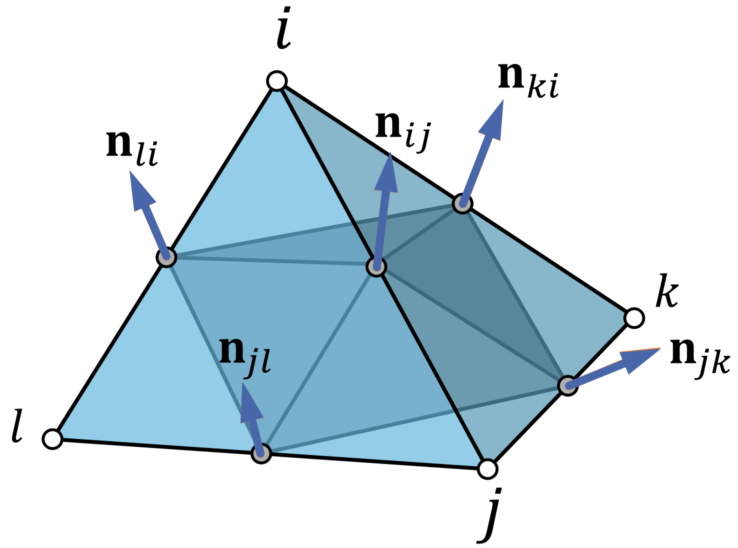
Method – Deformation



Edge-oriented Developability

Developable surface $\xrightarrow{\text{Gauss map}}$ A set of curves

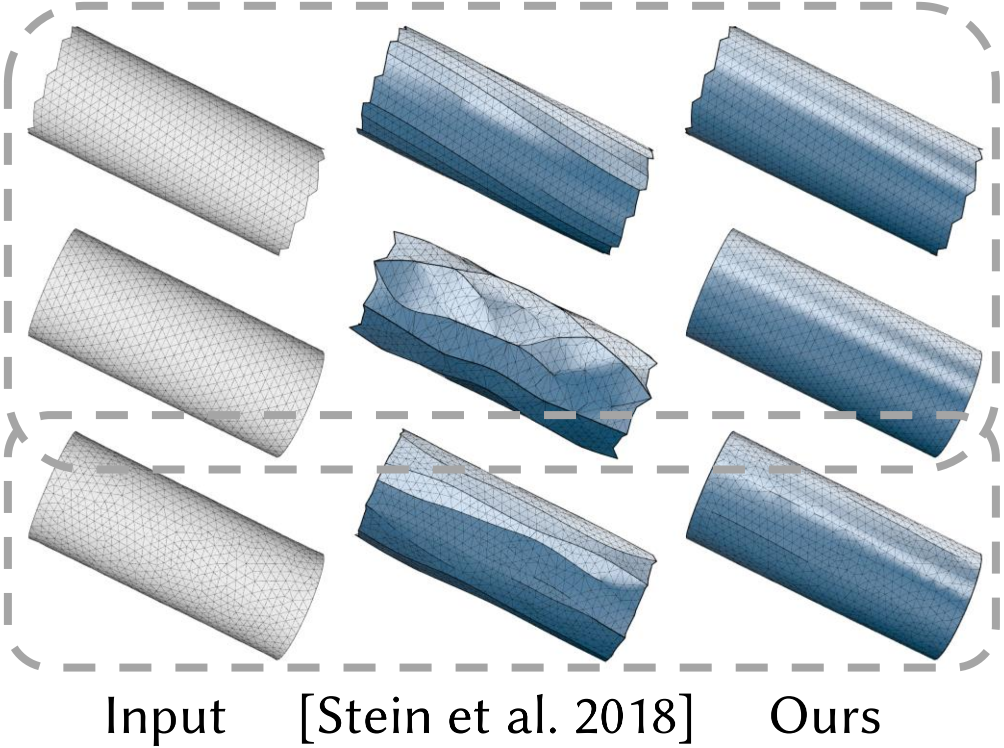
$$\det(\mathbf{n}_{ij}, \mathbf{n}_{jl}, \mathbf{n}_{jk}) = 0$$
$$\det(\mathbf{n}_{ij}, \mathbf{n}_{jk}, \mathbf{n}_{ki}) = 0$$
$$\det(\mathbf{n}_{ij}, \mathbf{n}_{ki}, \mathbf{n}_{li}) = 0$$
$$\det(\mathbf{n}_{ij}, \mathbf{n}_{li}, \mathbf{n}_{jl}) = 0$$



The Gauss map degenerates if the determinant condition is satisfied

Edge-oriented Developability

- Weaker than the definition in [Stein et al. 2018]
- Some special examples satisfy our edge-oriented definition directly



Deformation Optimization

$$\min_{\mathcal{V}_d} \quad \omega_{\text{dev}} E_{\text{dev}} + \omega_{\text{app}} E_{\text{app}} + \omega_{\text{dis}} E_{\text{dis}}$$

Developability Approximation Distortion

Challenges:

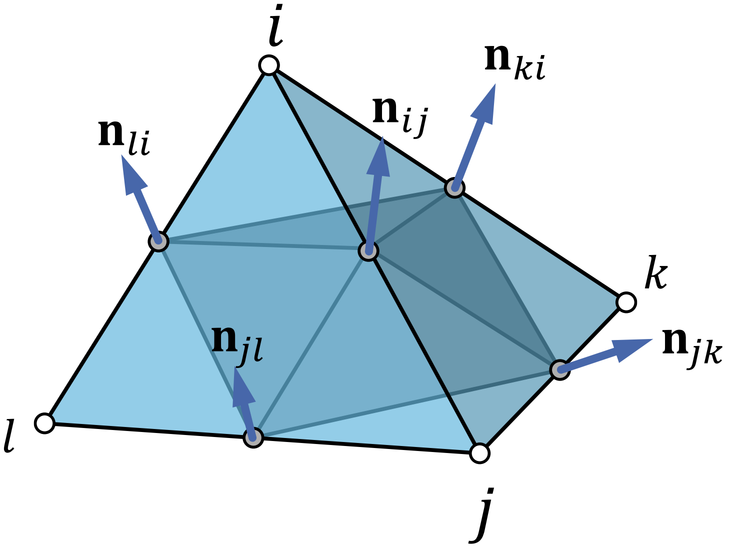
- Highly nonlinear
- Hard to minimize

⇒ Auxiliary variables

Deformation Energy – Developability

$$E_{\text{dev}} = \sum_{ij \in \mathcal{E}} \Big(\|[\mathbf{n}_{ij}, \mathbf{n}_{ki}, \mathbf{n}_{il}] - P_r([\mathbf{n}_{ij}, \mathbf{n}_{ki}, \mathbf{n}_{il}])\|_F^2 + \|[\mathbf{n}_{ij}, \mathbf{n}_{jk}, \mathbf{n}_{lj}] - P_r([\mathbf{n}_{ij}, \mathbf{n}_{jk}, \mathbf{n}_{lj}])\|_F^2 \Big) + \sum_{ijk \in \mathcal{F}} \|[\mathbf{n}_{ij}, \mathbf{n}_{jk}, \mathbf{n}_{ki}] - P_r([\mathbf{n}_{ij}, \mathbf{n}_{jk}, \mathbf{n}_{ki}])\|_F^2$$

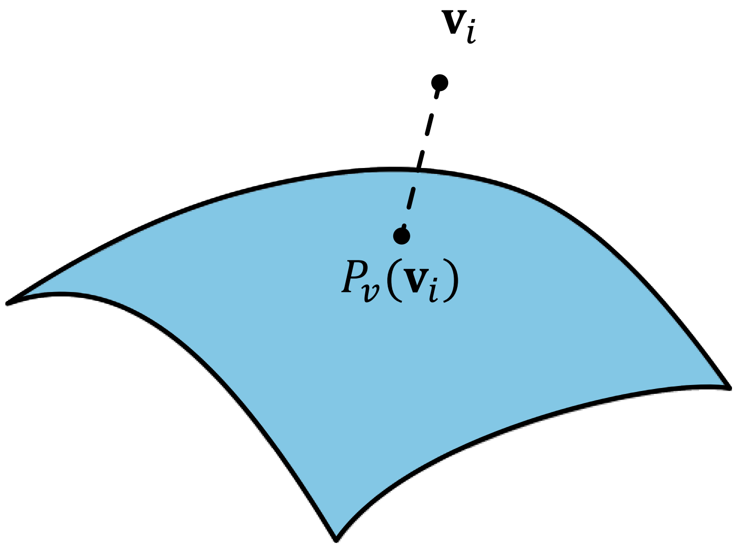
The projection to the rank-two matrix space



Deformation Energy – Approximation

$$E_{\text{app}} = \sum_{i \in \mathcal{V}} \|\mathbf{v}_i - \boxed{P_v(\mathbf{v}_i)}\|_2^2$$

The projection to the input mesh

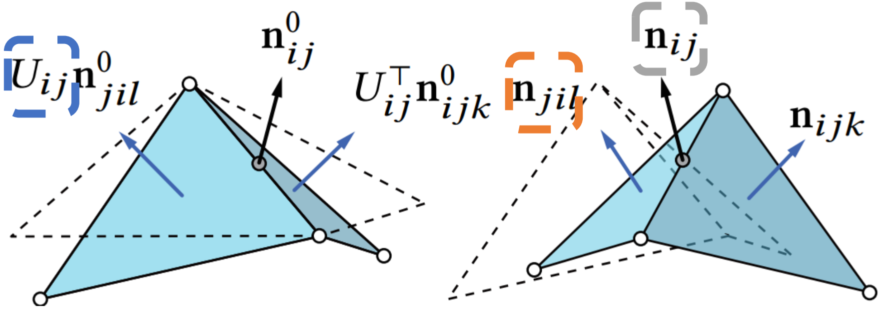


Deformation Energy – Distortion

$$E_{\text{dis}} = E_{\text{shape}} + \omega_{\text{sim}} E_{\text{sim}}$$

$$E_{\text{shape}} = \frac{1}{2} \sum_{ij \in \mathcal{E}} \|\mathbf{e}_{ij} - s_{ij} R_{ij} \mathbf{e}^0_{ij}\|_2^2 +$$
$$\|\mathbf{e}^0_{ij}\|_2^2 \left(\|\mathbf{n}_{ijk} - R_{ij} U_{ij} \mathbf{n}^0_{ijk}\|_2^2 + \|\mathbf{n}_{jil} - R_{ij} U^\top_{ij} \mathbf{n}^0_{jil}\|_2^2 \right)$$

$$E_{\text{sim}} = \frac{1}{2} \sum_{ijk \in \mathcal{F}} (s_{ij} - s_{jk})^2 + (s_{jk} - s_{ki})^2 + (s_{ki} - s_{ij})^2$$



$$\mathbf{n}_{ij} = R_{ij} \mathbf{n}^0_{ij}$$

$$\mathbf{n}_{ijk} = R_{ij} U_{ij} \mathbf{n}^0_{ijk}$$

Scaling s_{ij}

Deformation optimization

repeat

$P_r(\cdot) \leftarrow \texttt{UpdatePr}(A), \forall A \in \mathcal{A}_{ij};$

$R_{ij} \leftarrow \texttt{UpdateR}(\mathbf{v}_i, s_{ij}, U_{ij}, \mathbf{n}_{ijk}, P_r(\cdot));$

$U_{ij} \leftarrow \texttt{UpdateU}(R_{ij}, \mathbf{n}_{ijk});$

$P_v(\cdot) \leftarrow \texttt{UpdatePv}(\mathbf{v}_i);$

$\mathbf{v}_i \leftarrow \texttt{UpdateV}(s_{ij}, R_{ij}, P_v(\cdot));$

$\mathbf{n}_{ijk} \leftarrow \texttt{UpdateN}(U_{ij}, R_{ij});$

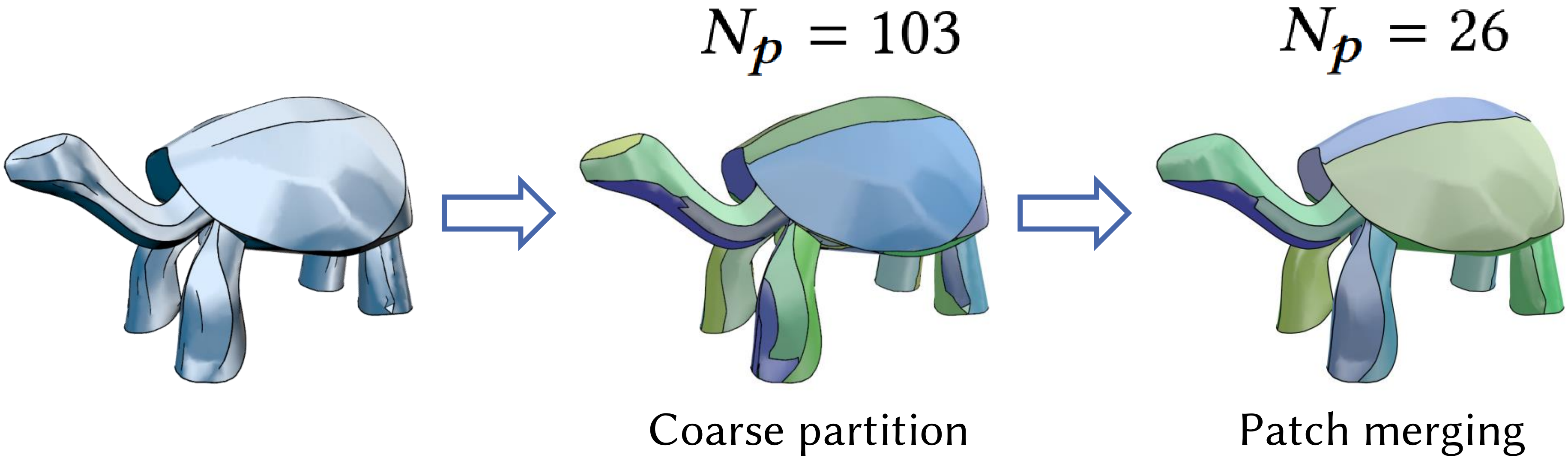
$s_{ij} \leftarrow \texttt{UpdateS}(\mathbf{v}_i, R_{ij});$

$k \leftarrow k + 1;$

until $k < N$;

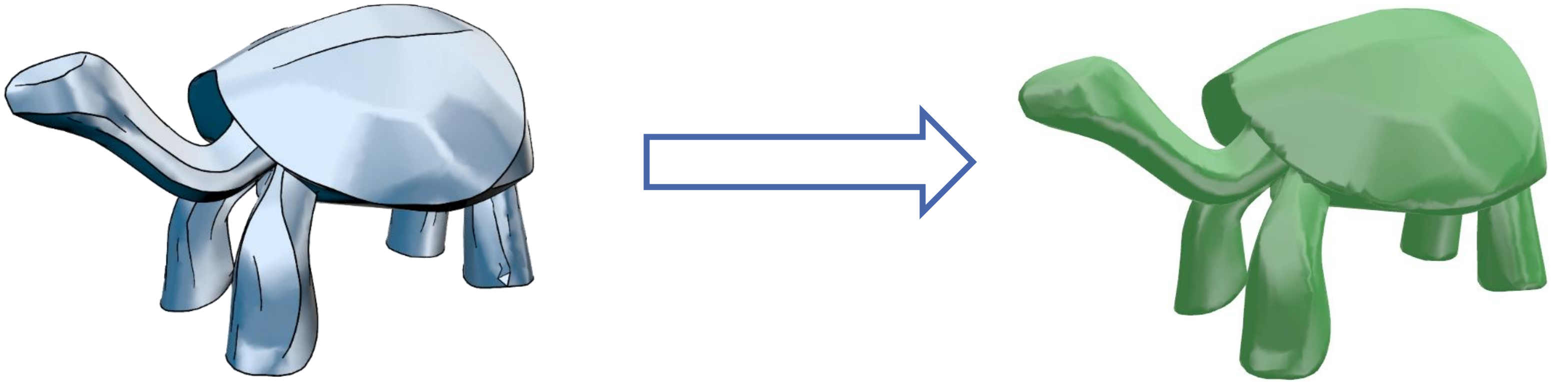
Block nonlinear Gauss–Seidel method

Method – Segmentation



Segmentation – Coarse partition

$N_p = 2$



Segmentation algorithm
in [Tong et al. 2020]

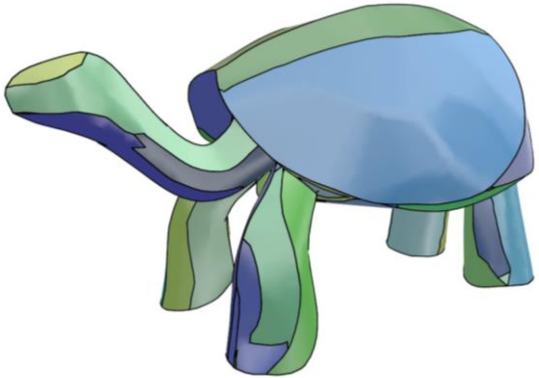
Step-by-step

Segmentation – Patch merging

$N_p = 103$

Minimum area $\mathrm{P}_{\min}$

$\mathrm{P} = \arg\min_{\mathrm{P}\in\mathcal{P}_{\min}} \mathrm{Str}(\mathrm{P}, \mathrm{P}_{\min})$ Straightness



$\mathrm{Len}(\mathrm{P}, \mathrm{P}_{\min}) > \epsilon_{\mathrm{len}}$ Length

$\mathrm{Cur}(\mathrm{P}, \mathrm{P}_{\min}) < \boxed{\epsilon_{\mathrm{cur}}}$ Curvature

Iterative strategy

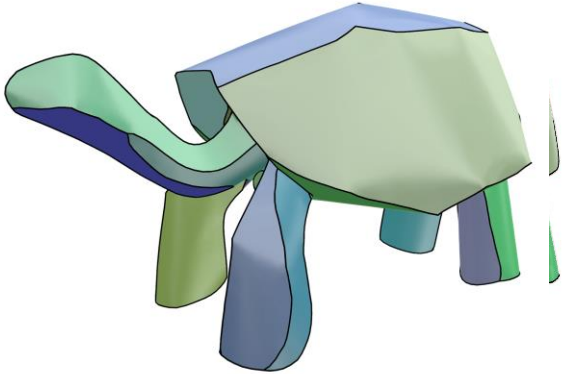
Method – Refinement

- Small approximation error
- Smooth patches
- Smooth seam curves

Method – Refinement

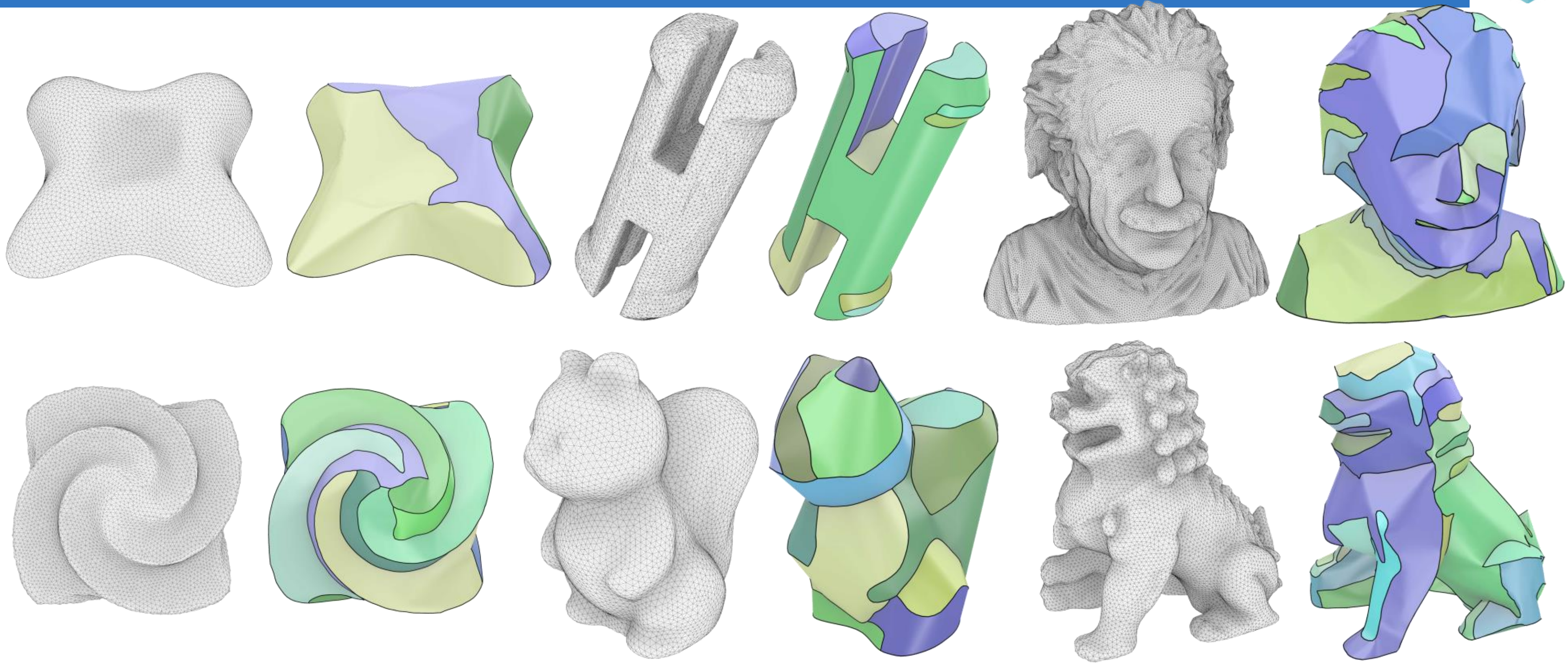
Method in [Ion et al. 2020]:

- $\boxed{\text{DOG projection}}$ The distance to $\mathcal{M}_d$
- Developability
- Smoothness
- Seam smoothness
- ~~Connectedness~~

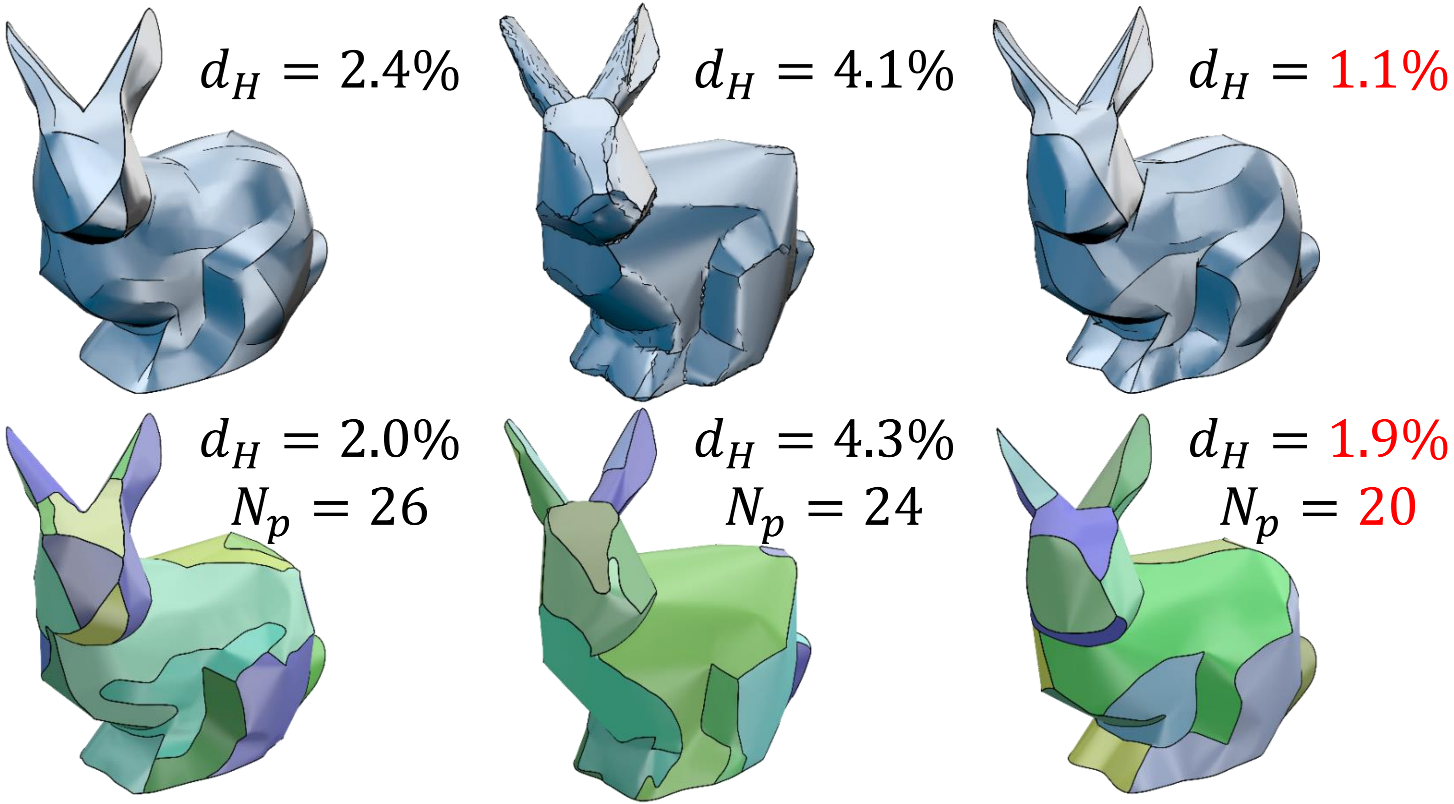


Cut overlaps

More Examples



Comparisons

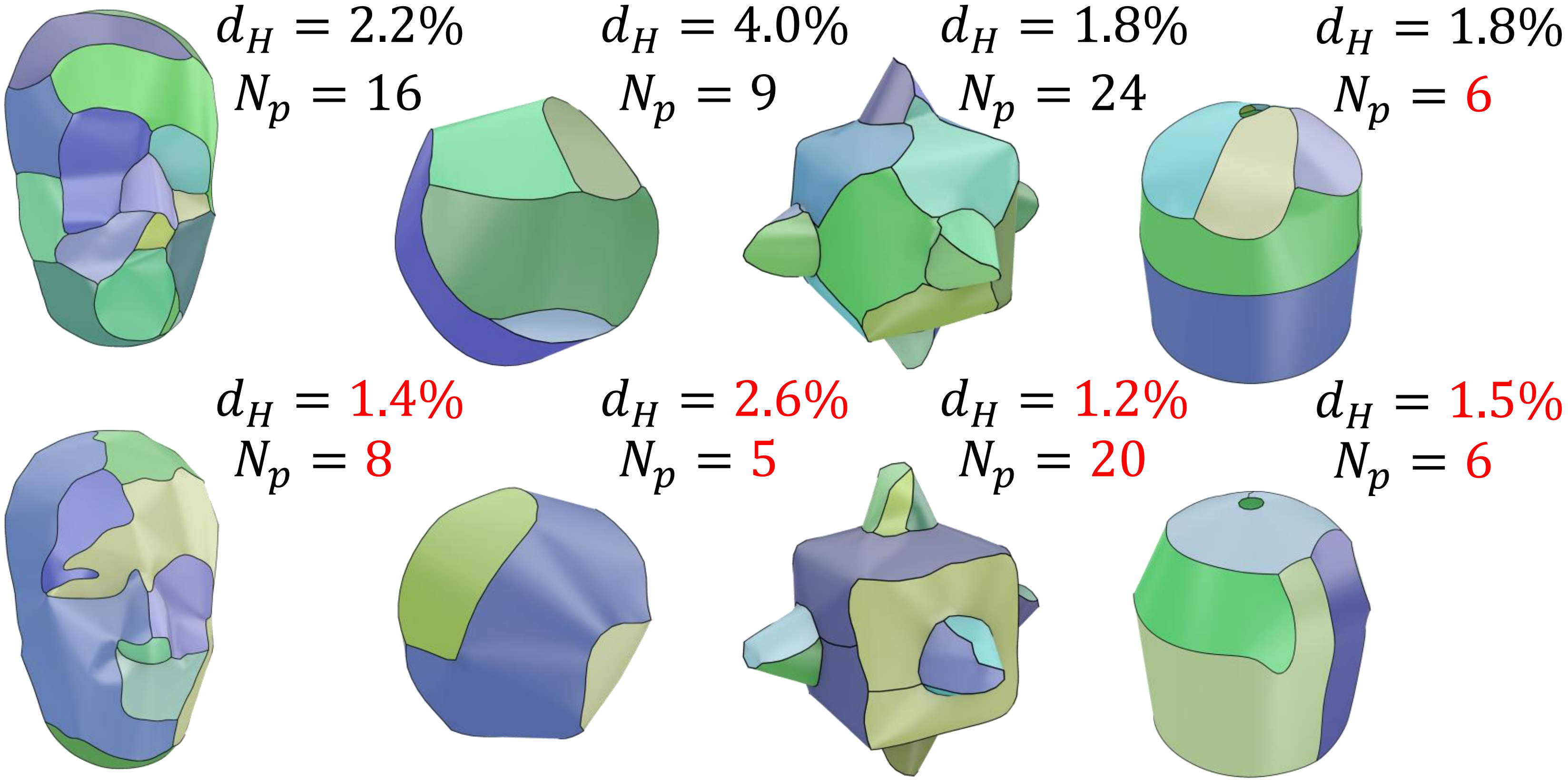


[Stein et al. 2018] [Binninger et al. 2021] Ours

Comparisons

[Ion et al. 2020]

Ours



Fabrication

Fabrication

谢 谢 ！