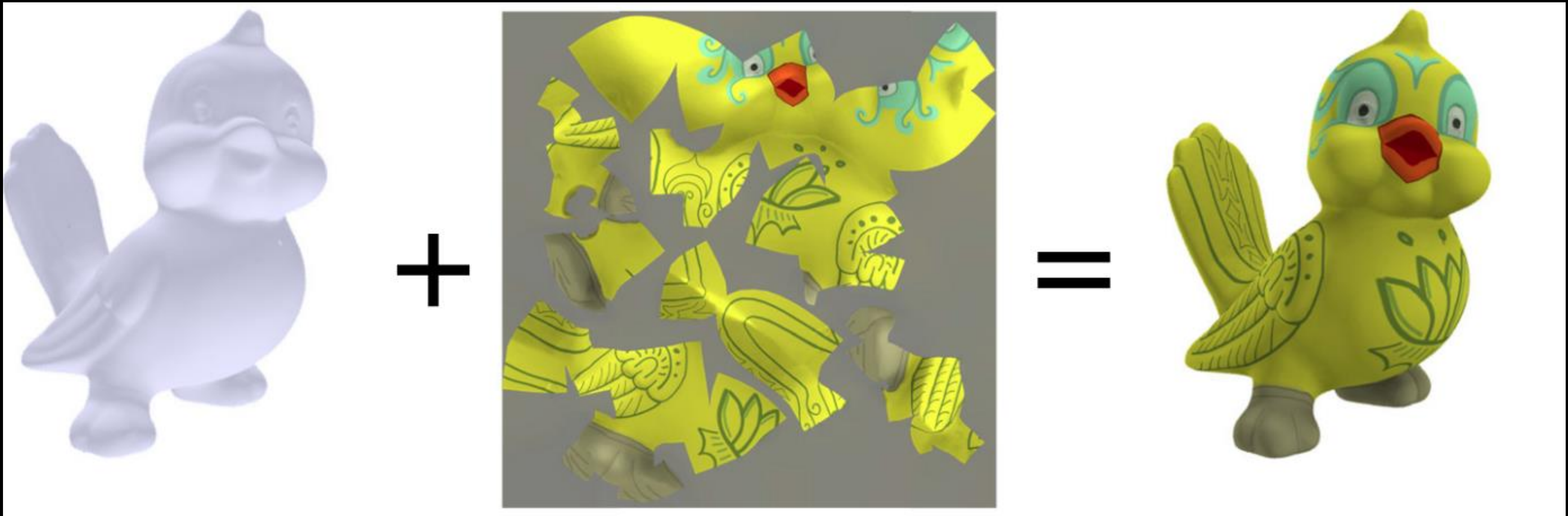
Atlas Generation: Cutting, Parameterization, Packing

Xiao-Ming Fu
GCL, USTC

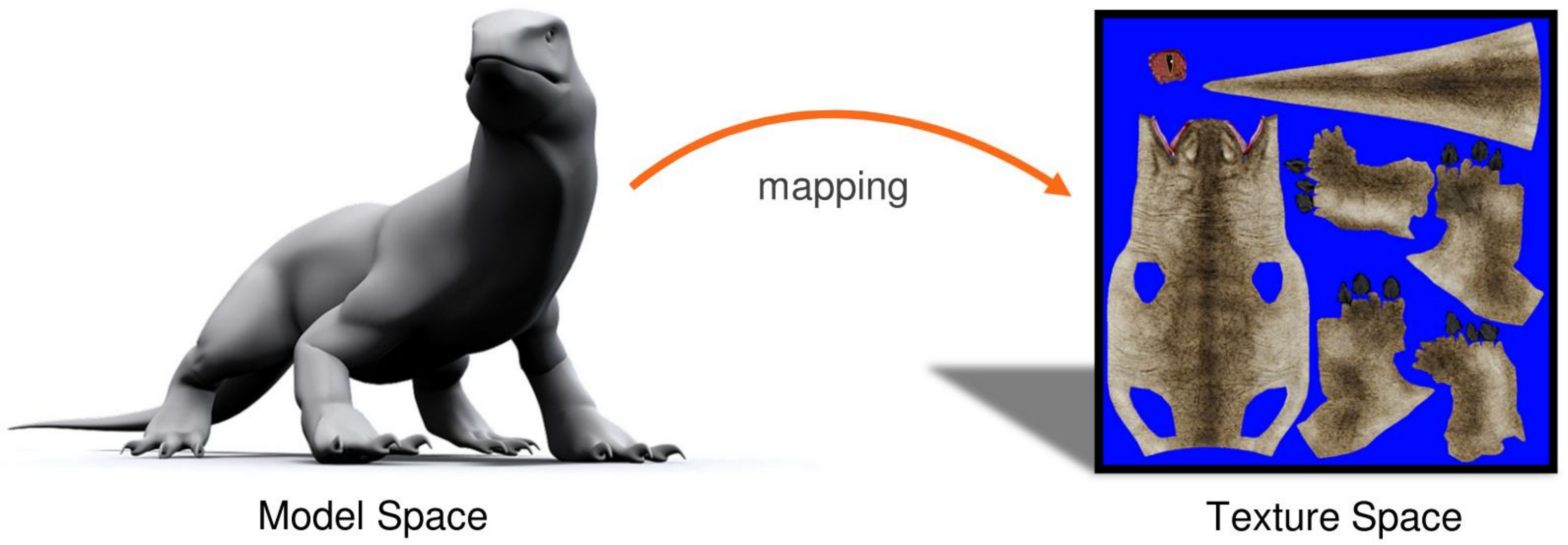
Texture Mapping

- Texture mapping is a method for defining high frequency detail, surface texture, or color information on a computer-generated graphic or 3D model.



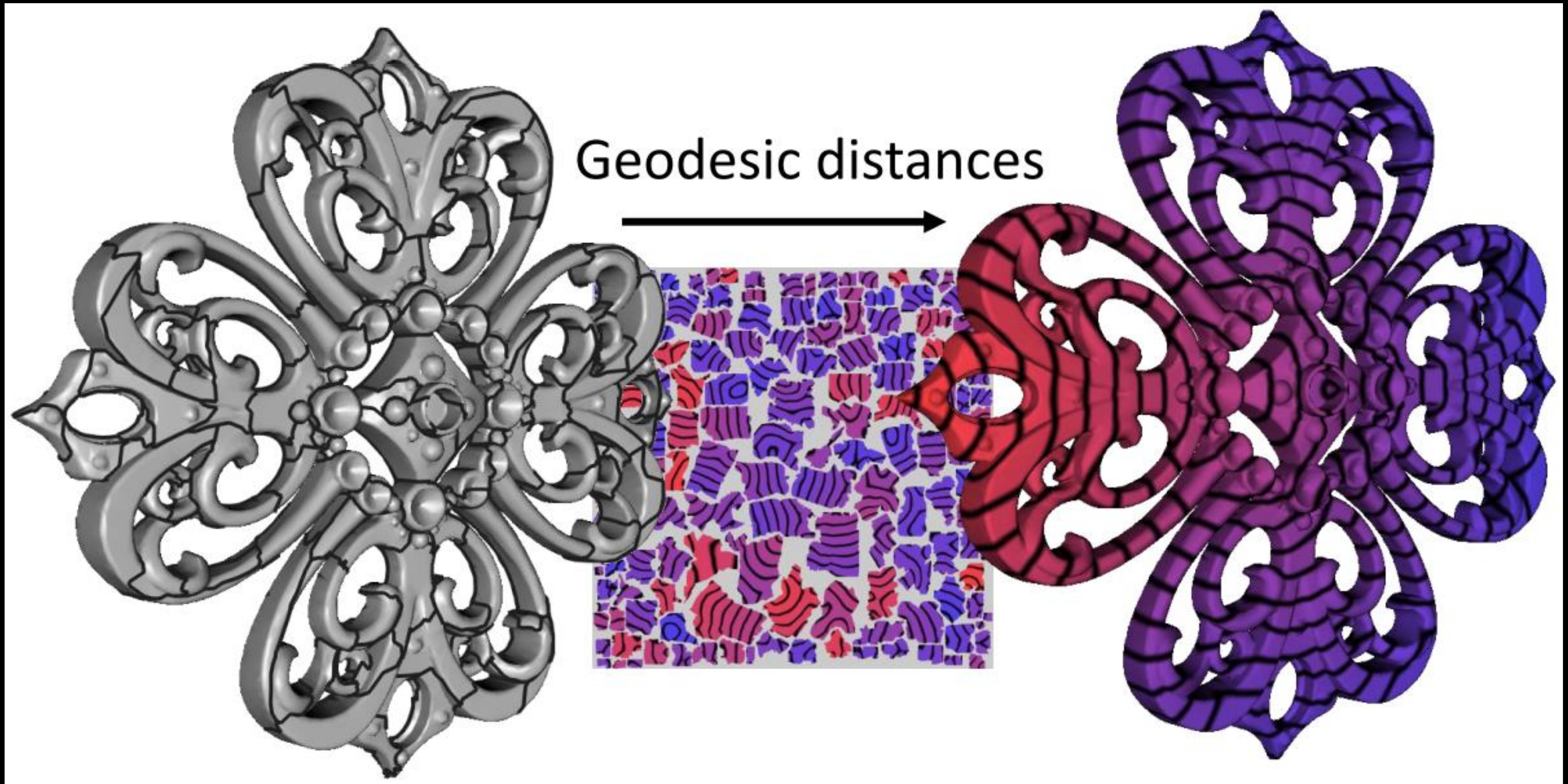
Atlas

- Requires defining a **mapping** from the model space to the texture space.



Applications

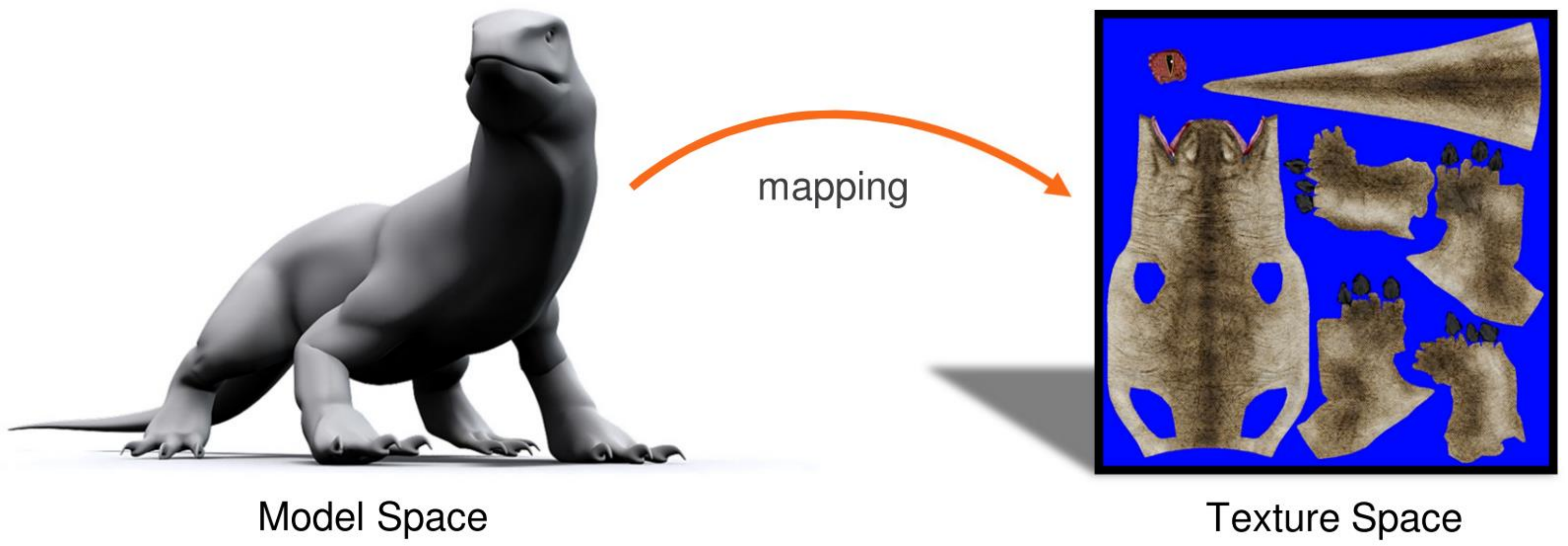
- Signal storage
- Geometric processing



Gradient-Domain Processing within a Texture Atlas, SIGGRAPH 2018

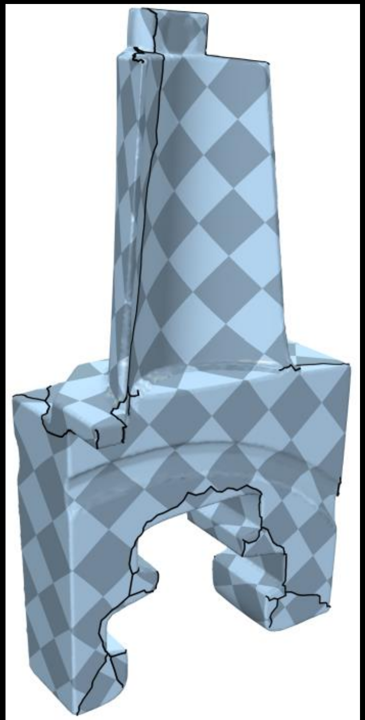
Generation Process

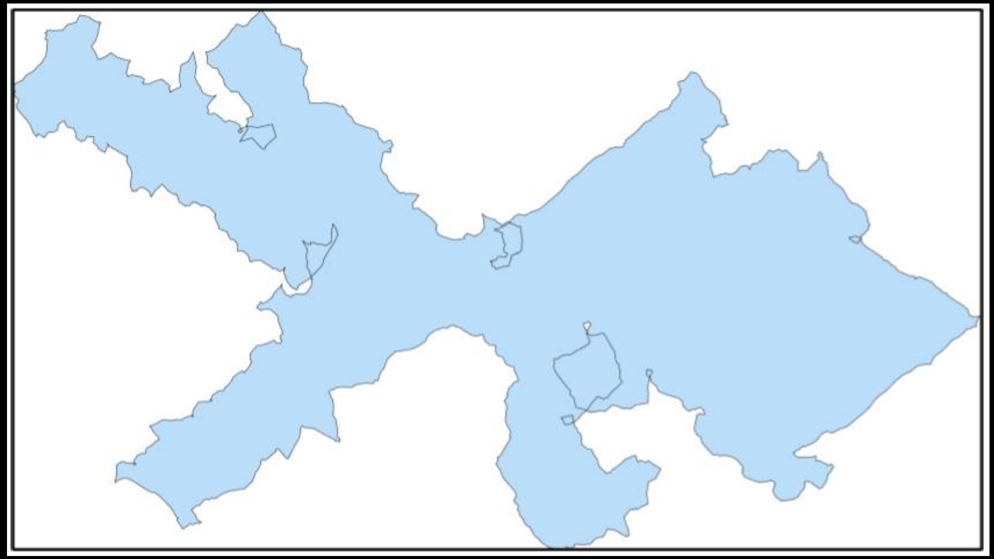
- Cutting: compute seams that are as short as possible to segment an input mesh into charts
- Parameterization: parameterize the charts with as little isometric distortion as possible
- Packing: pack the parameterized charts into a rectangular domain.



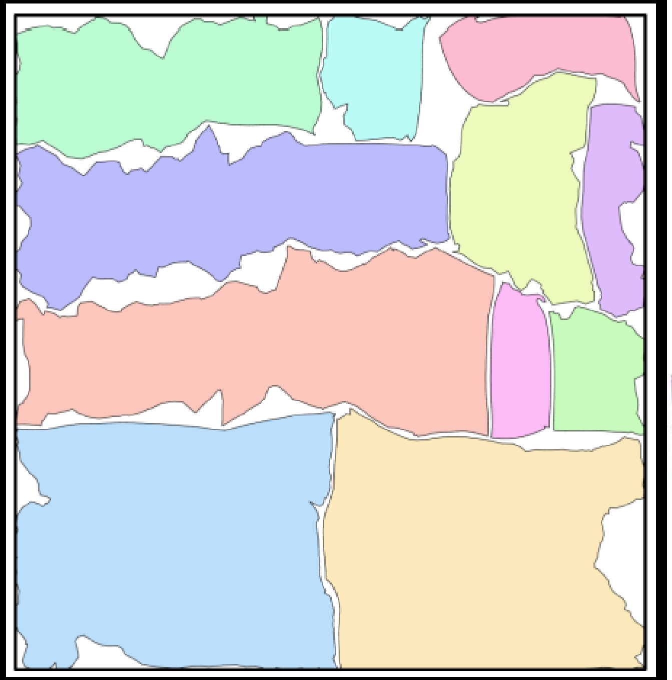
Atlas Refinement

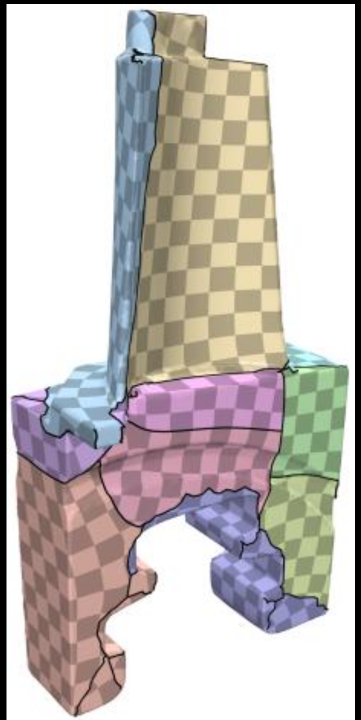
Cutting → Parameterizations → Packing





May not bijective





Cutting

Sphere-based Cut Construction for Planar Parameterizations, SMI 2018

Goal

- A cut construction method that satisfies
  - The distortion of a subsequent planar parameterization is low.
  - The cuts are feature-aligned, resulting in visual beauty.
  - The cuts are short.

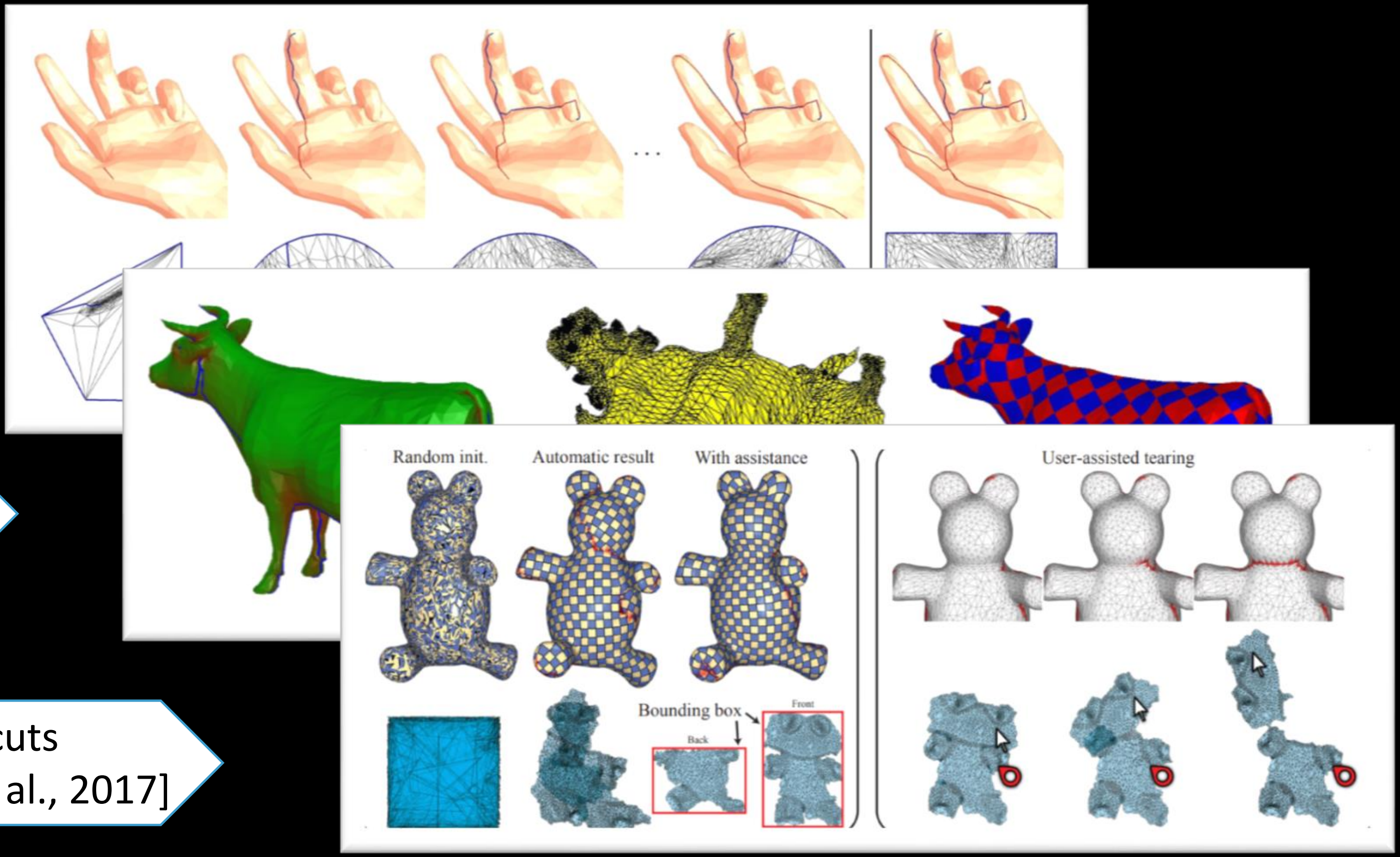
- It is challenging to satisfy all the above requirements.

Previous Work

Geometry Images
[Gu et al., 2002]

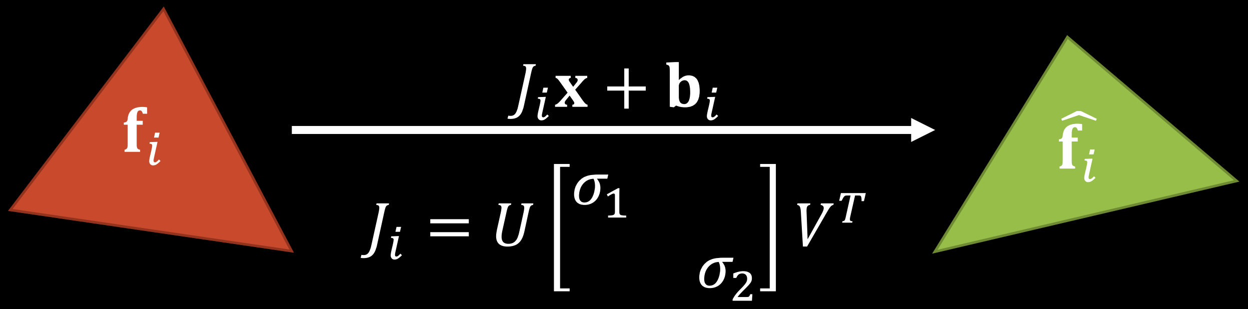
Seamster
[Sheffer and Hart, 2002]

Autocuts
[Poranne et al., 2017]



Method

Mapping, Parameterization & Distortion



- Distortion metrics
  - Conformal distortion (angle preserving) [Hormann et al., 2000]

$$d_i^{\mathrm{conf}} = \frac{1}{2}\left(\frac{\sigma_1}{\sigma_2} + \frac{\sigma_2}{\sigma_1}\right) = \frac{1}{2}\frac{\|J_i\|^2}{\det J_i}$$

  - Areal distortion (area preserving) [Fu et al., 2015]

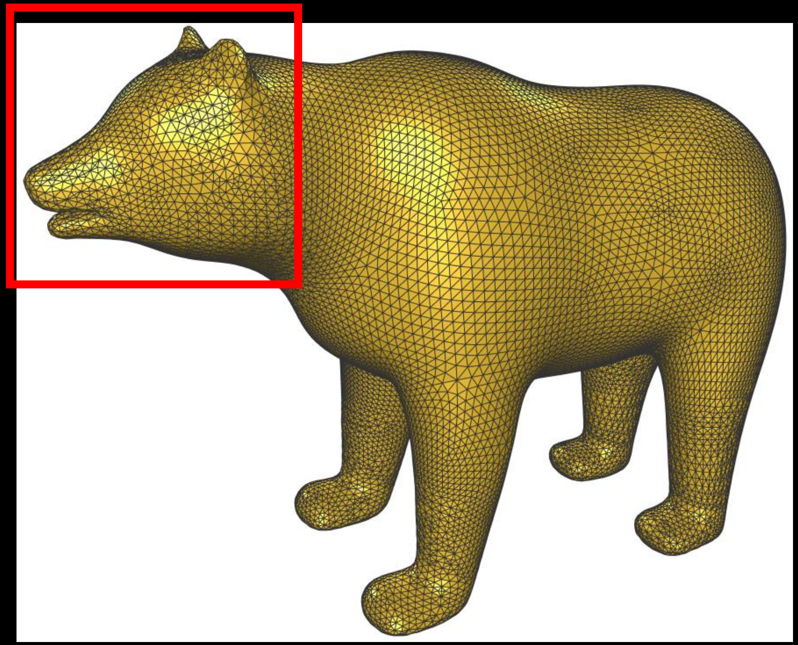
$$d_i^{\mathrm{area}} = \frac{1}{2}\left(\det J_i + (\det J_i)^{-1}\right)$$

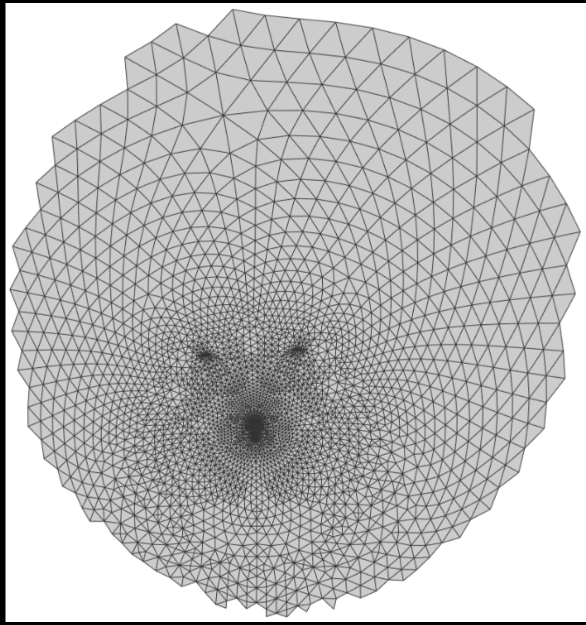
  - Isometric distortion (isometry preserving) [Fu et al., 2015]

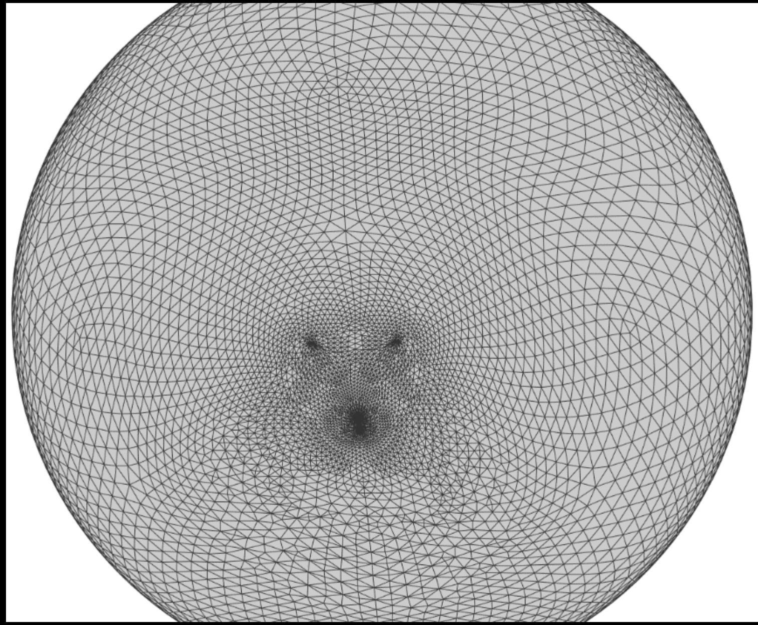
$$d_i^{\mathrm{iso}} = \alpha d_i^{\mathrm{conf}} + (1-\alpha) d_i^{\mathrm{area}}$$

Key Observation

- The high isometric distortion mainly appears at the extrusive regions when a mesh is parameterized onto a constant curvature domain (such as a sphere or the plane) as conformal as possible.







Pipeline

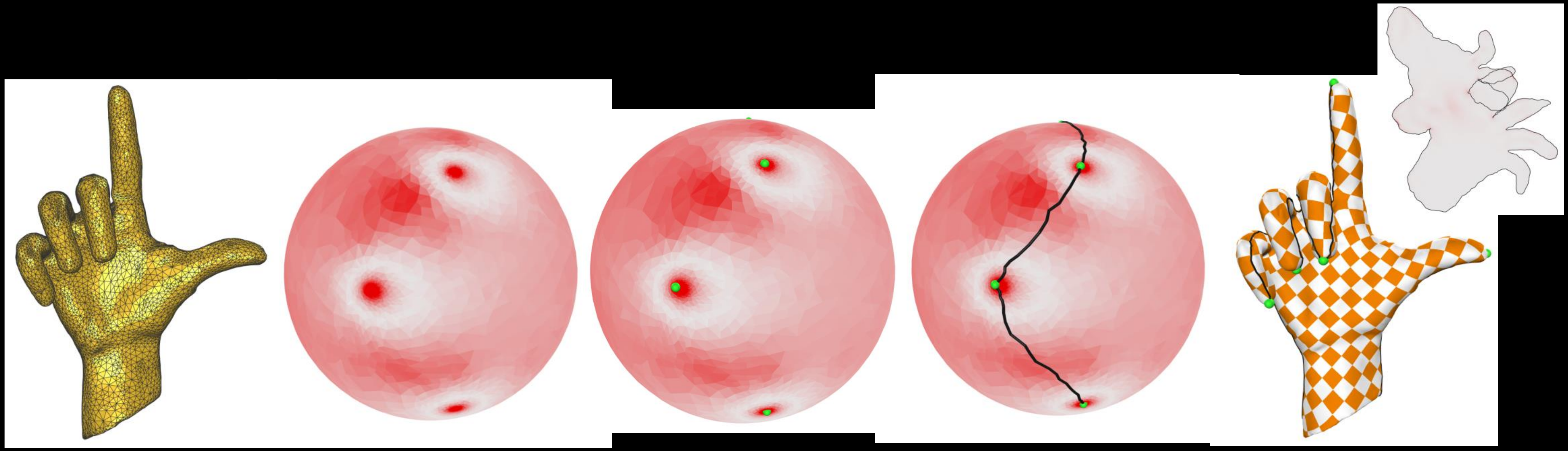
Input a closed genus-zero triangular mesh

Step 1: parameterize to a sphere ACAP

Step 2: find feature points by hierarchical clustering

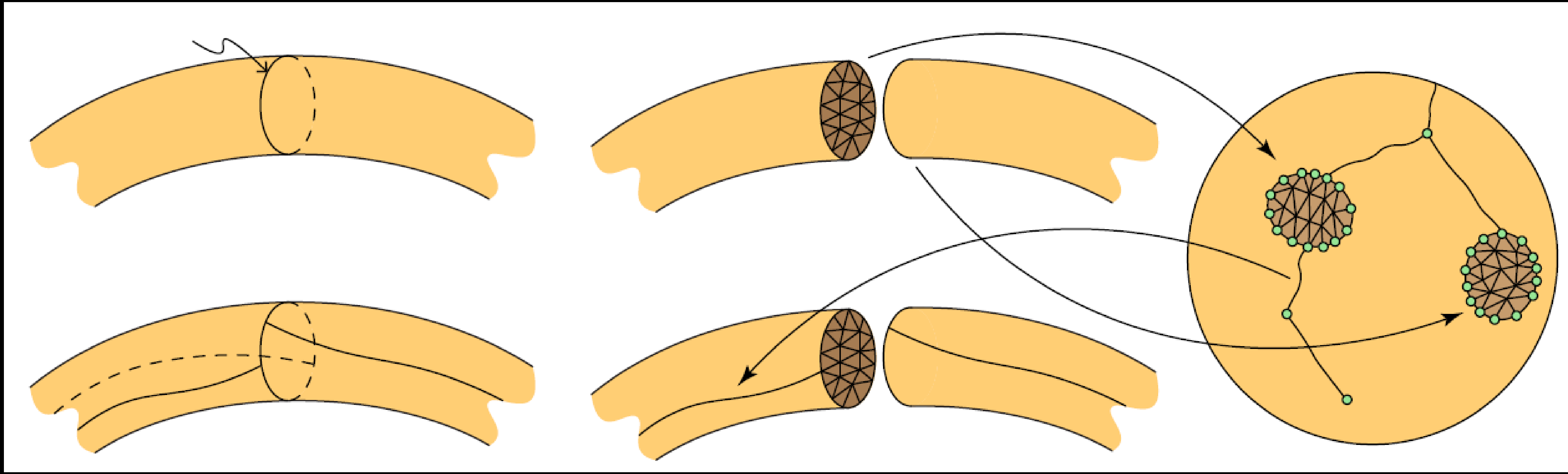
Step 3: cut by a minimal spanning tree

Output an open mesh of disk topology

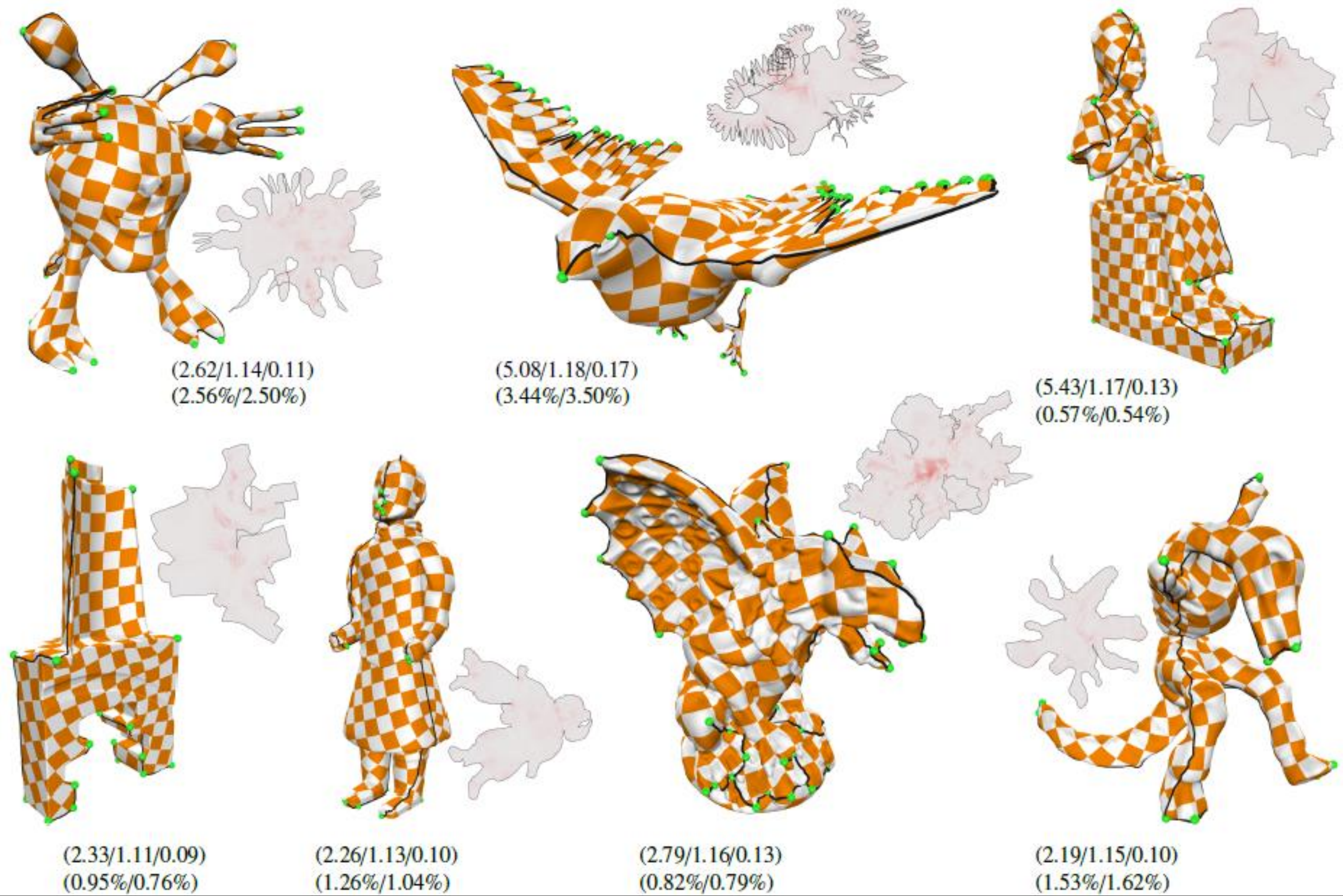


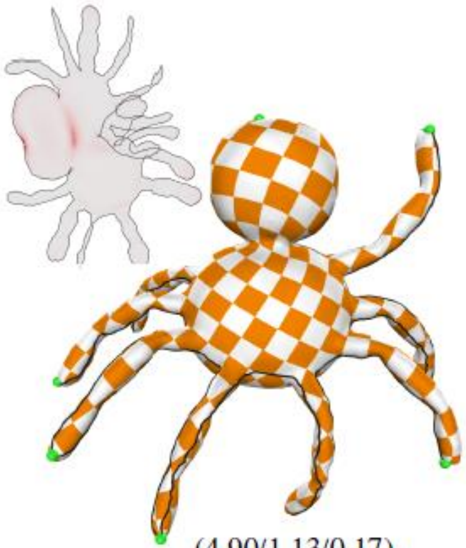
High-Genus Cases

- Cut along handles [Dey et al., 2013] → Fill the holes → Apply our algorithm

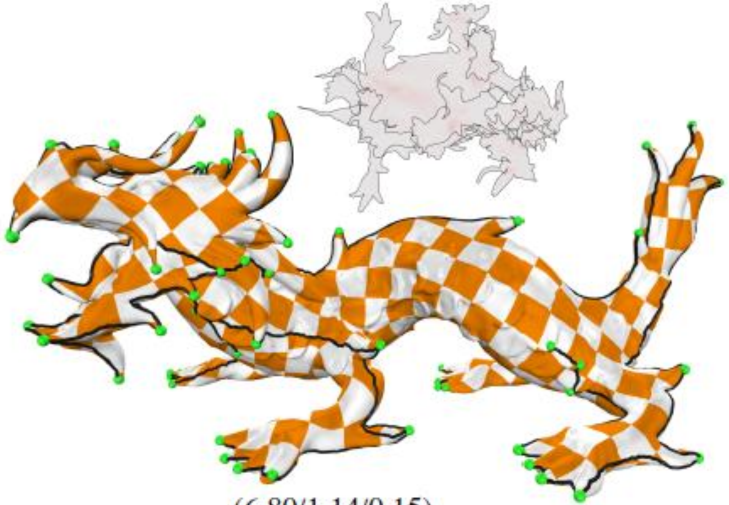


Results


(2.62/1.14/0.11)
(2.56%/2.50%)
(5.08/1.18/0.17)
(3.44%/3.50%)
(5.43/1.17/0.13)
(0.57%/0.54%)
(2.33/1.11/0.09)
(0.95%/0.76%)
(2.26/1.13/0.10)
(1.26%/1.04%)
(2.79/1.16/0.13)
(0.82%/0.79%)
(2.19/1.15/0.10)
(1.53%/1.62%)

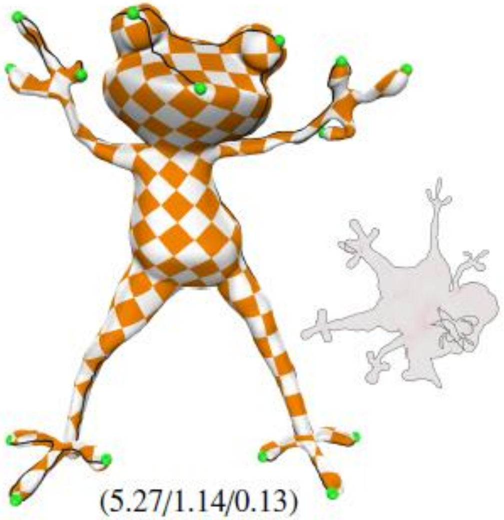


(4.90/1.13/0.17)
(2.42%/2.85%)



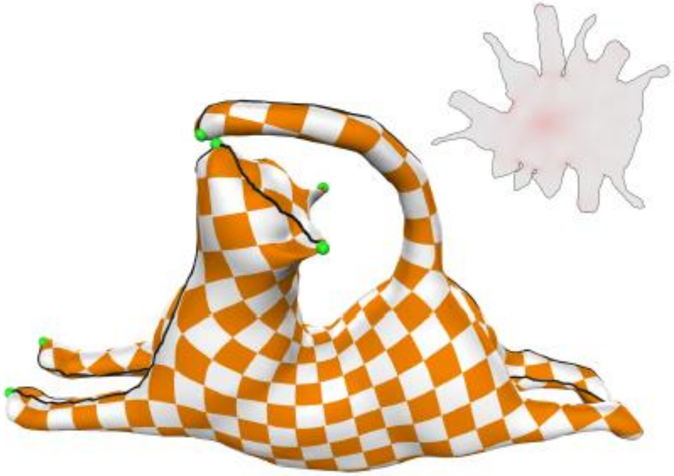
(6.80/1.14/0.15)
(1.46%/1.52%)

(3.21/1.14/0.12)
(1.96%/1.74%)

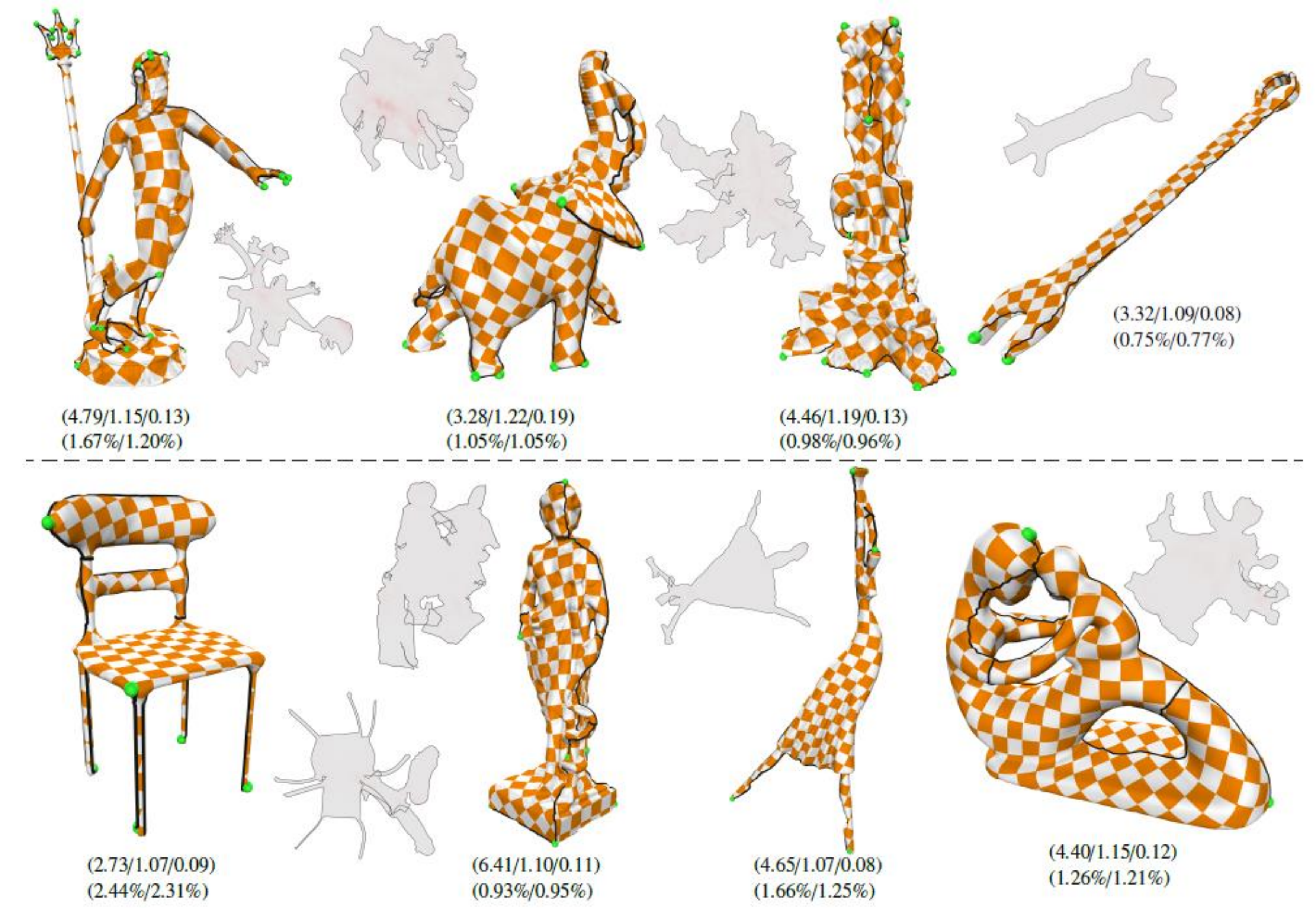


(5.27/1.14/0.13)
(2.34%/2.26%)

(4.36/1.16/0.17)
(0.87%/0.88%)

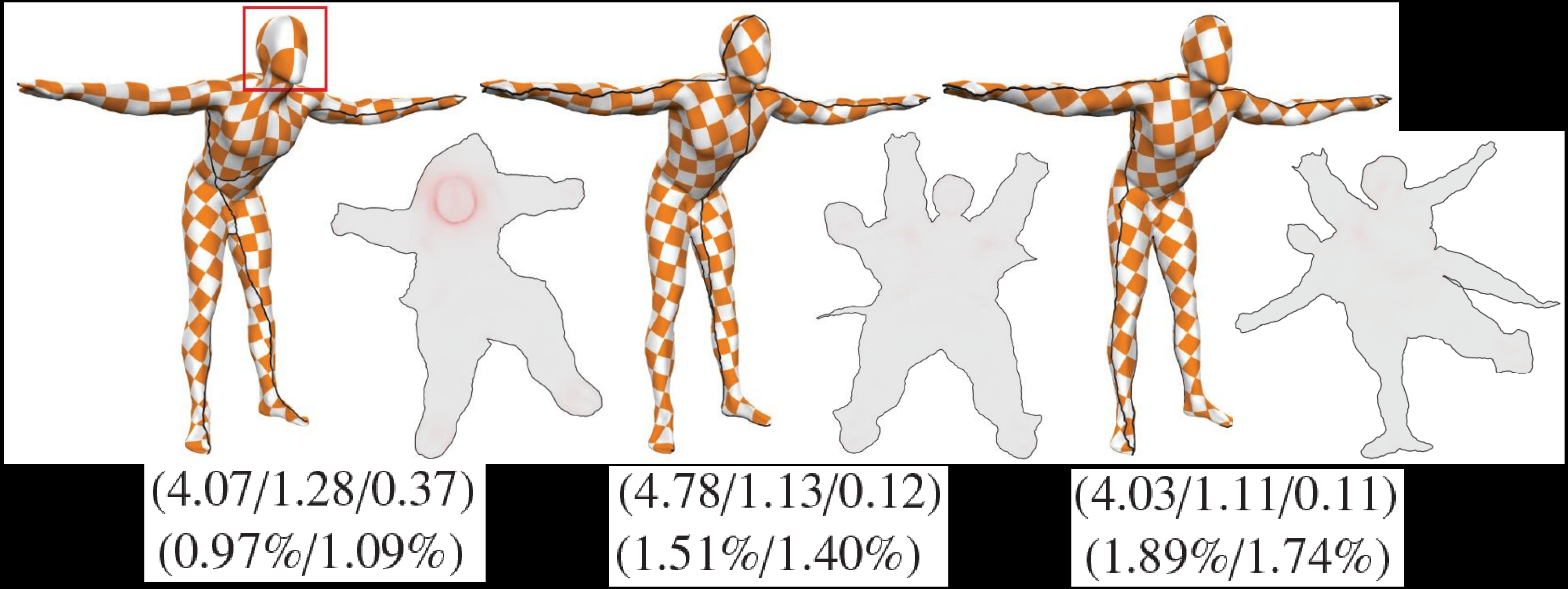


(6.00/1.18/0.21)
(1.52%/1.51%)

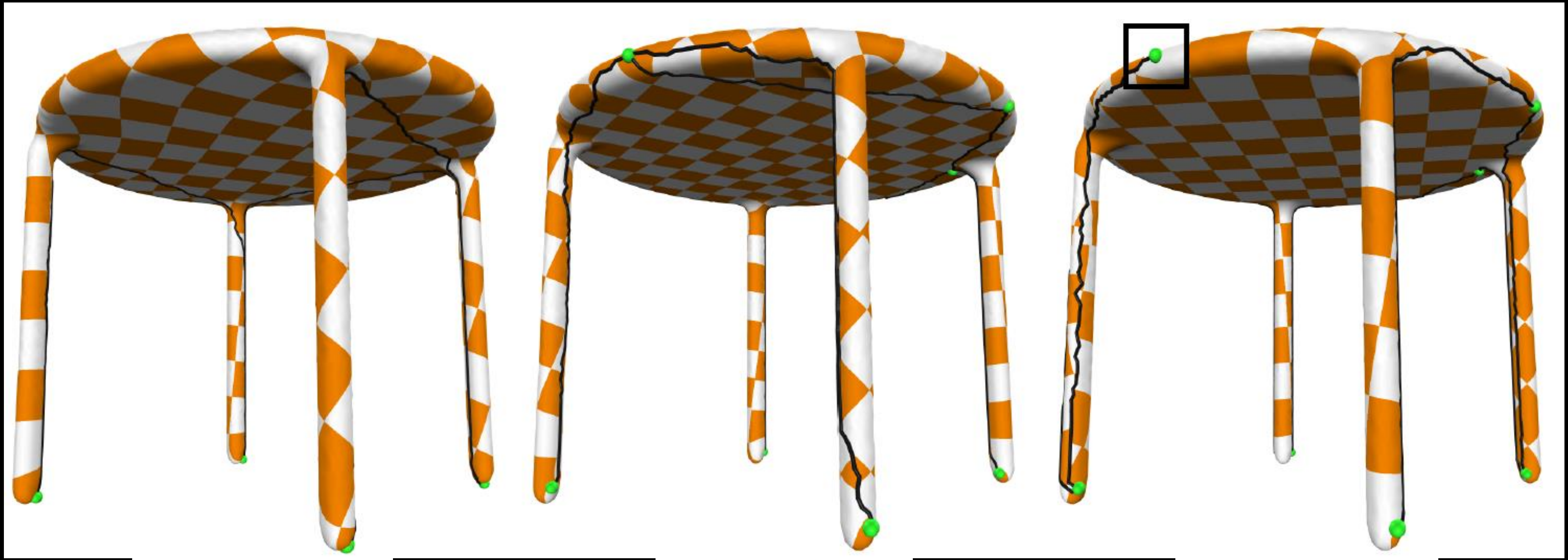


(4.79/1.15/0.13)
(1.67%/1.20%)
(3.28/1.22/0.19)
(1.05%/1.05%)
(4.46/1.19/0.13)
(0.98%/0.96%)
(3.32/1.09/0.08)
(0.75%/0.77%)
(2.73/1.07/0.09)
(2.44%/2.31%)
(6.41/1.10/0.11)
(0.93%/0.95%)
(4.65/1.07/0.08)
(1.66%/1.25%)
(4.40/1.15/0.12)
(1.26%/1.21%)

Comparison with Geometry Image [Gu et al., 2002]



Comparison with Seamster [Shaffer and Hart, 2002]

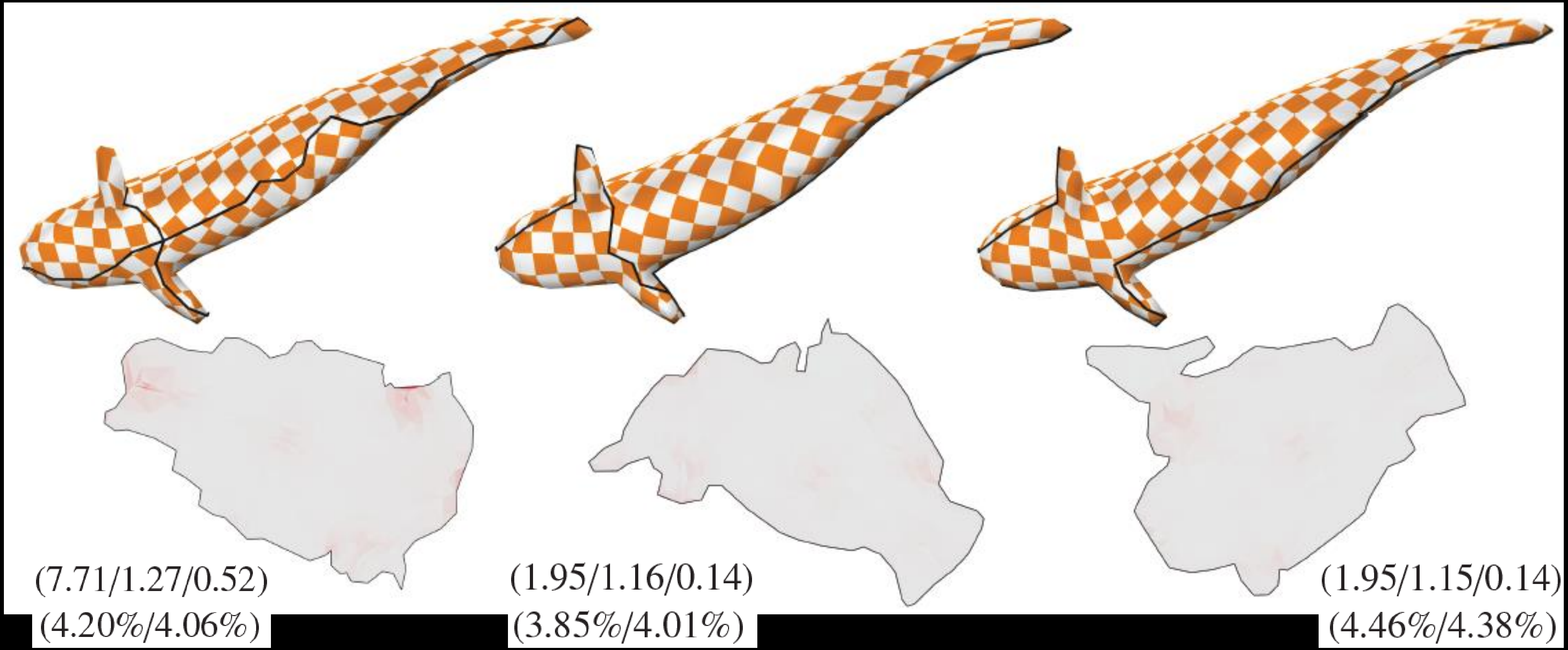


(3.81/1.09/0.11)
(1.44%/1.23%)

(4.58/1.05/0.13)
(1.26%/1.14%)

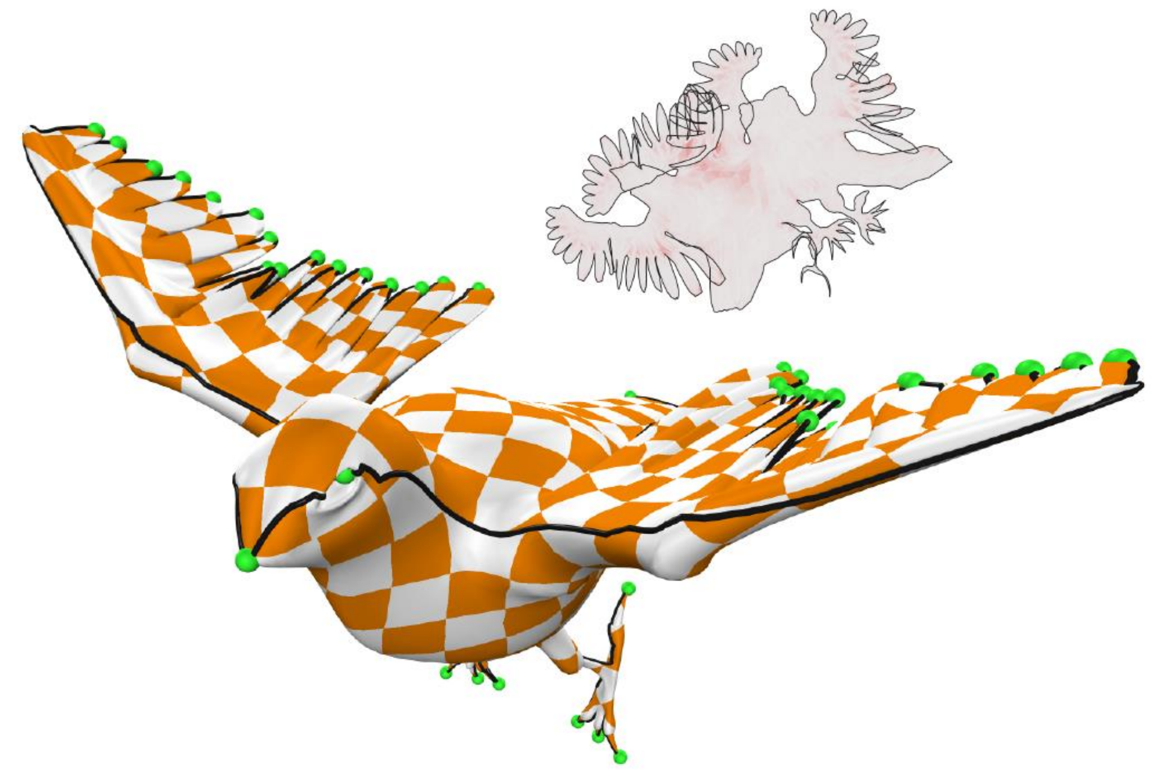
(4.44/1.04/0.09)
(1.68%/1.43%)

Comparison with Autocuts [Poranne et al., 2017]



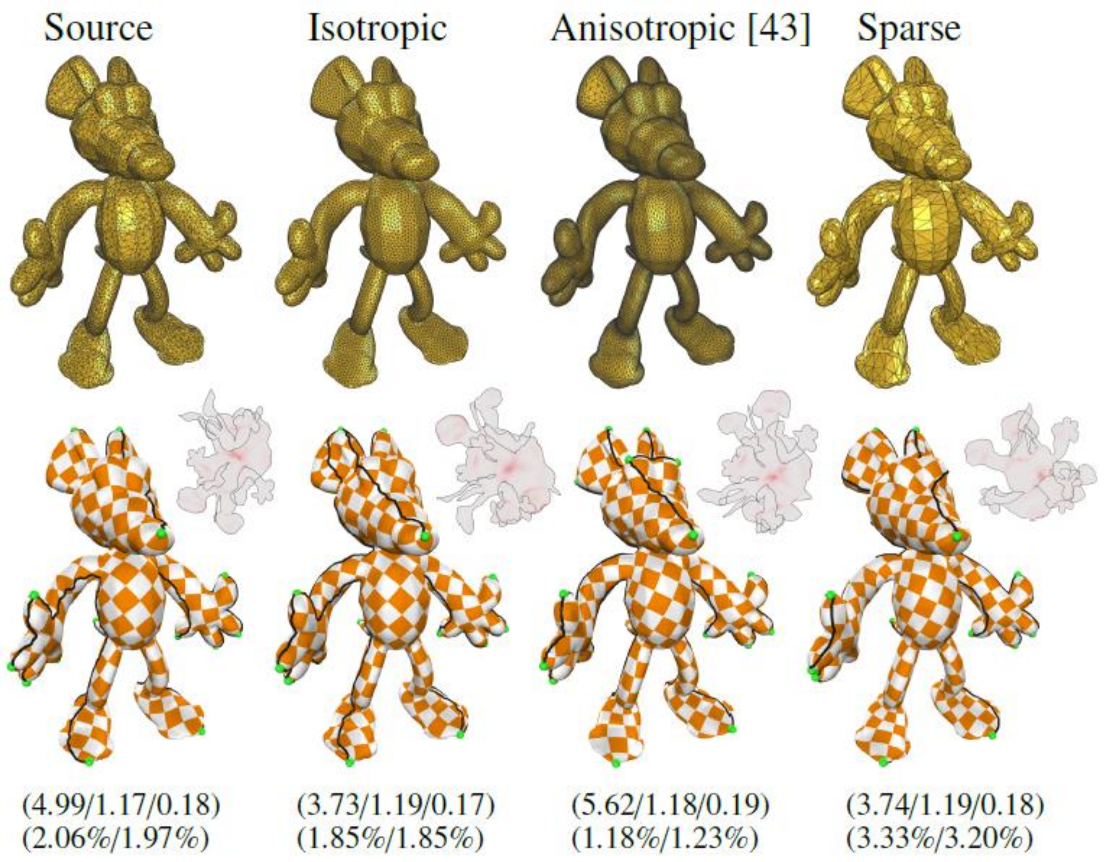
Conclusion

- We present a sphere-based method for constructing high-quality cuts…
  - ACAP spherical parameterization
  - Hierarchical clustering
  - Cut on the sphere
- such that the subsequent planar parameterization can have low isometric distortion.



Limitations and Discussions

- Theoretical guarantees
- Tessellations

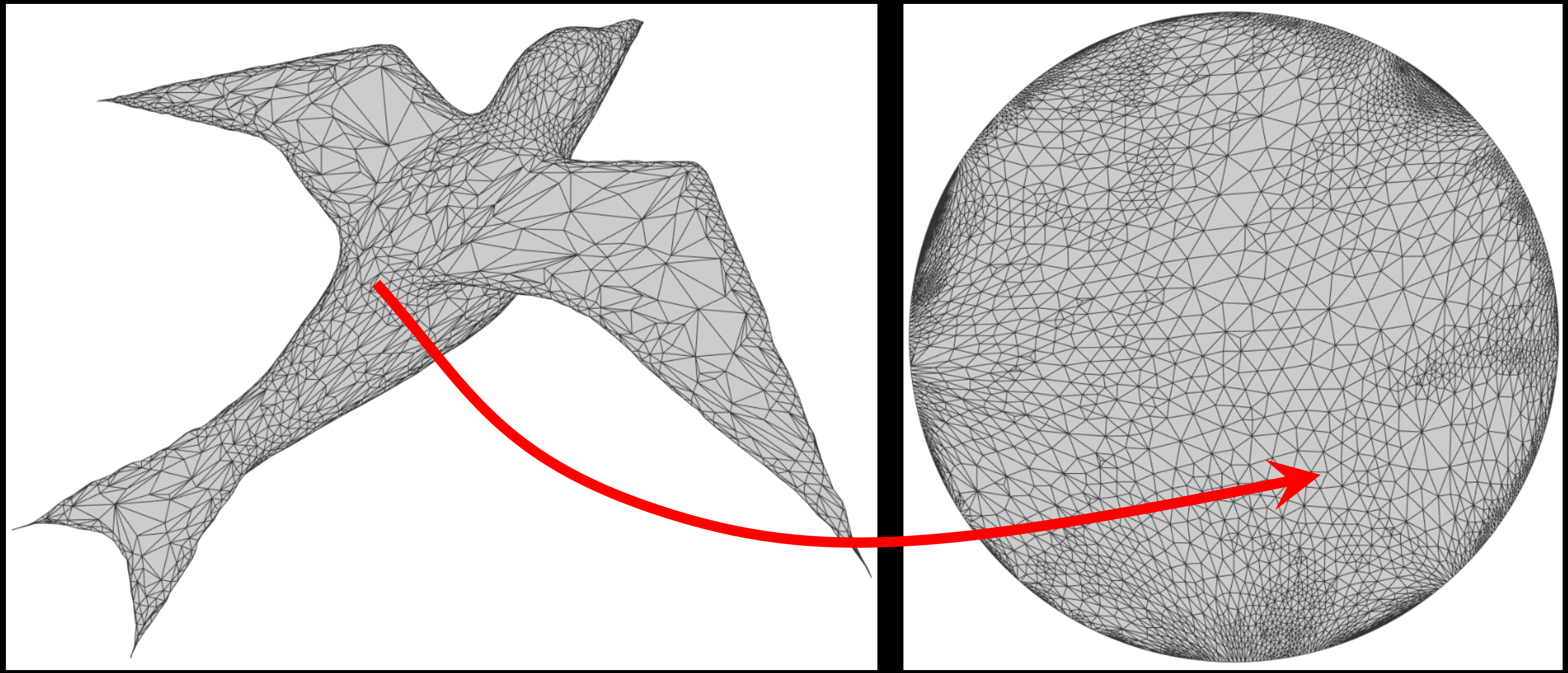


Parameterization

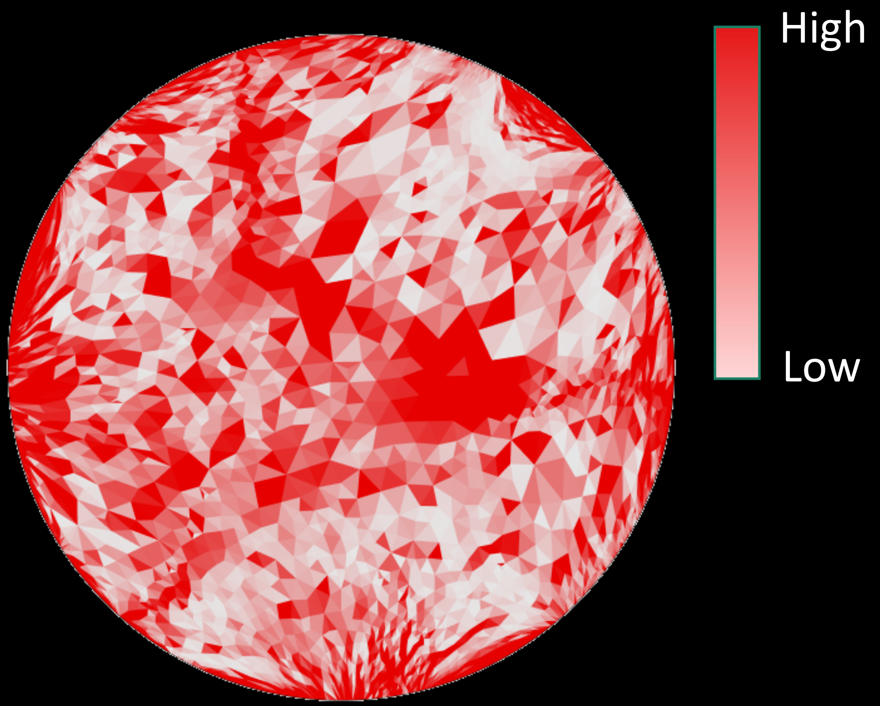
Progressive Parameterizations, *SIGGRAPH 2018*

Foldover-free parameterizations

- Maintenance-based method



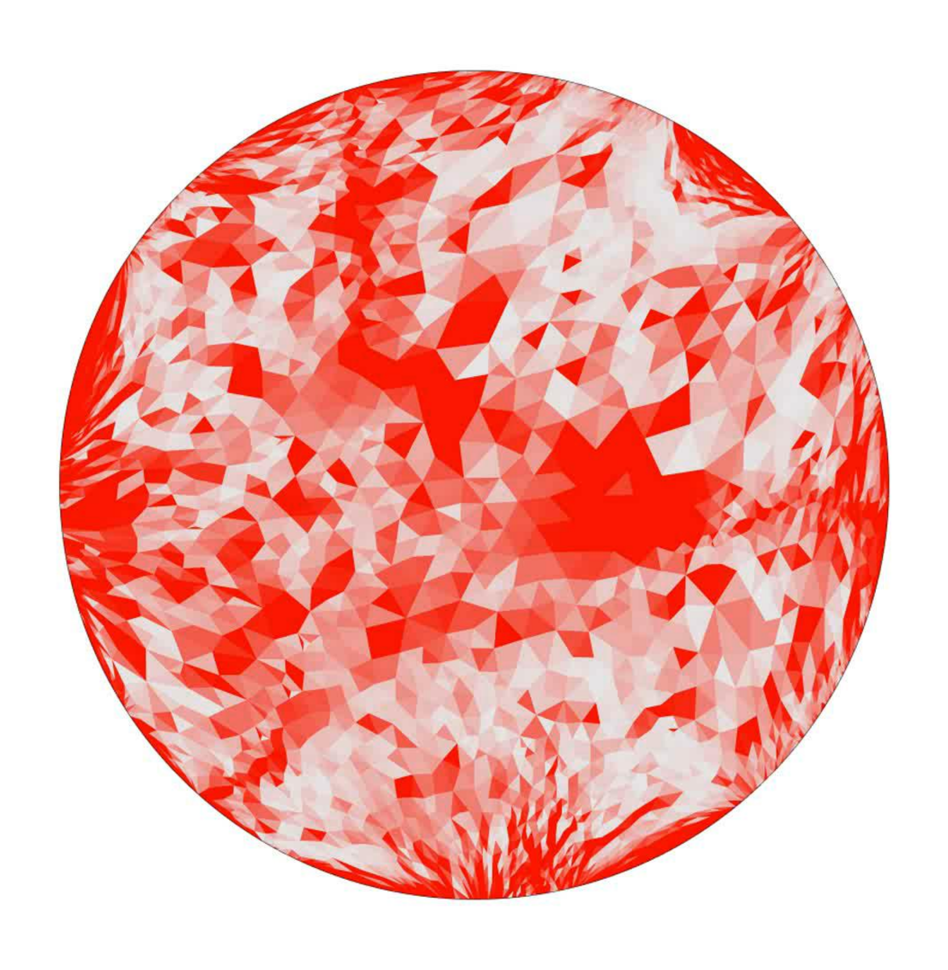
Convex boundary



High distortion

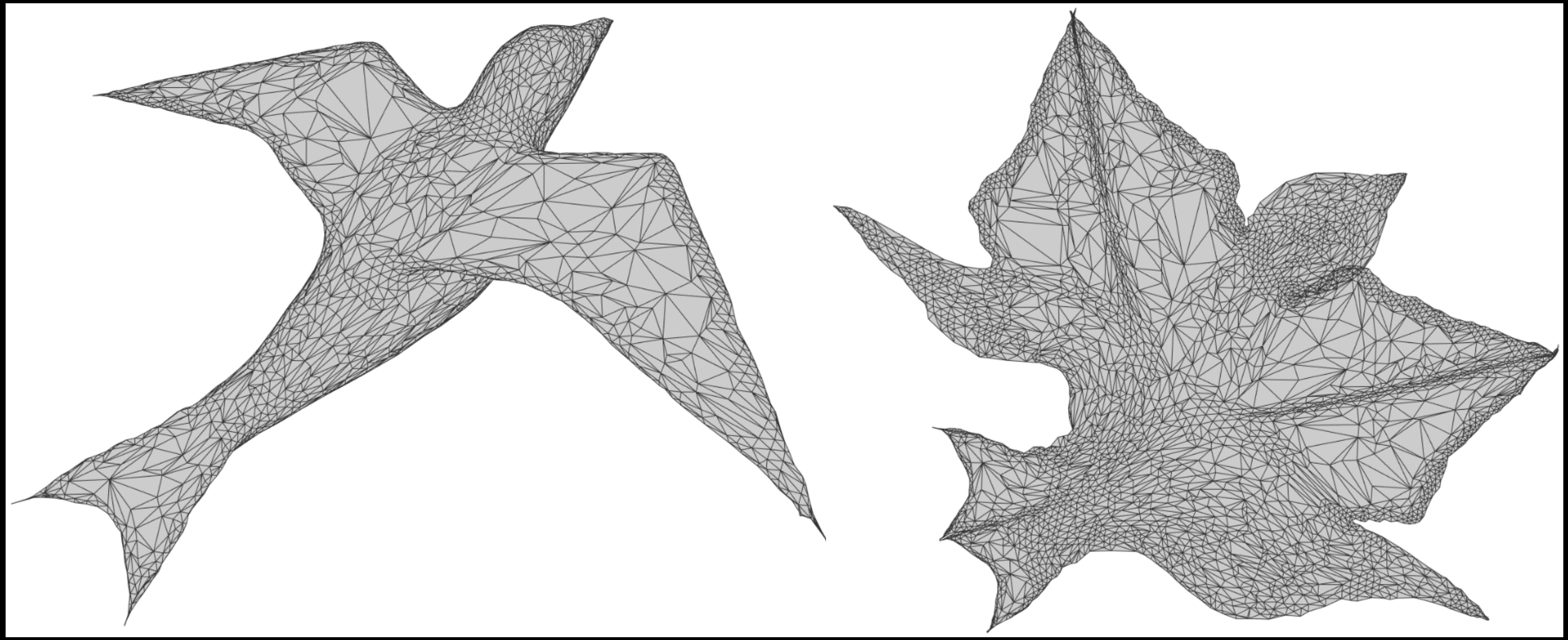
Foldover-free parameterizations

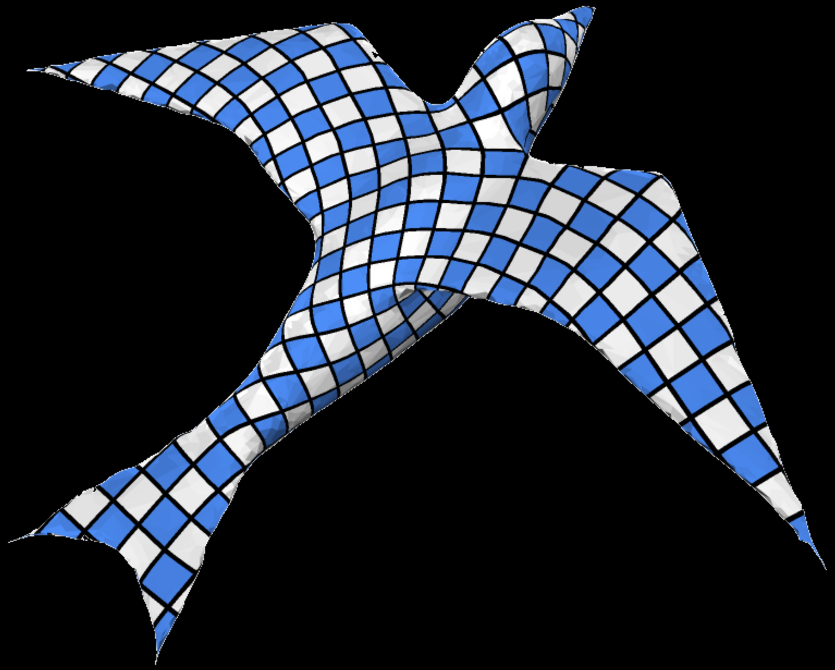
- Maintenance-based method



Foldover-free parameterizations

- Maintenance-based method





Parameterization

Texture mapping

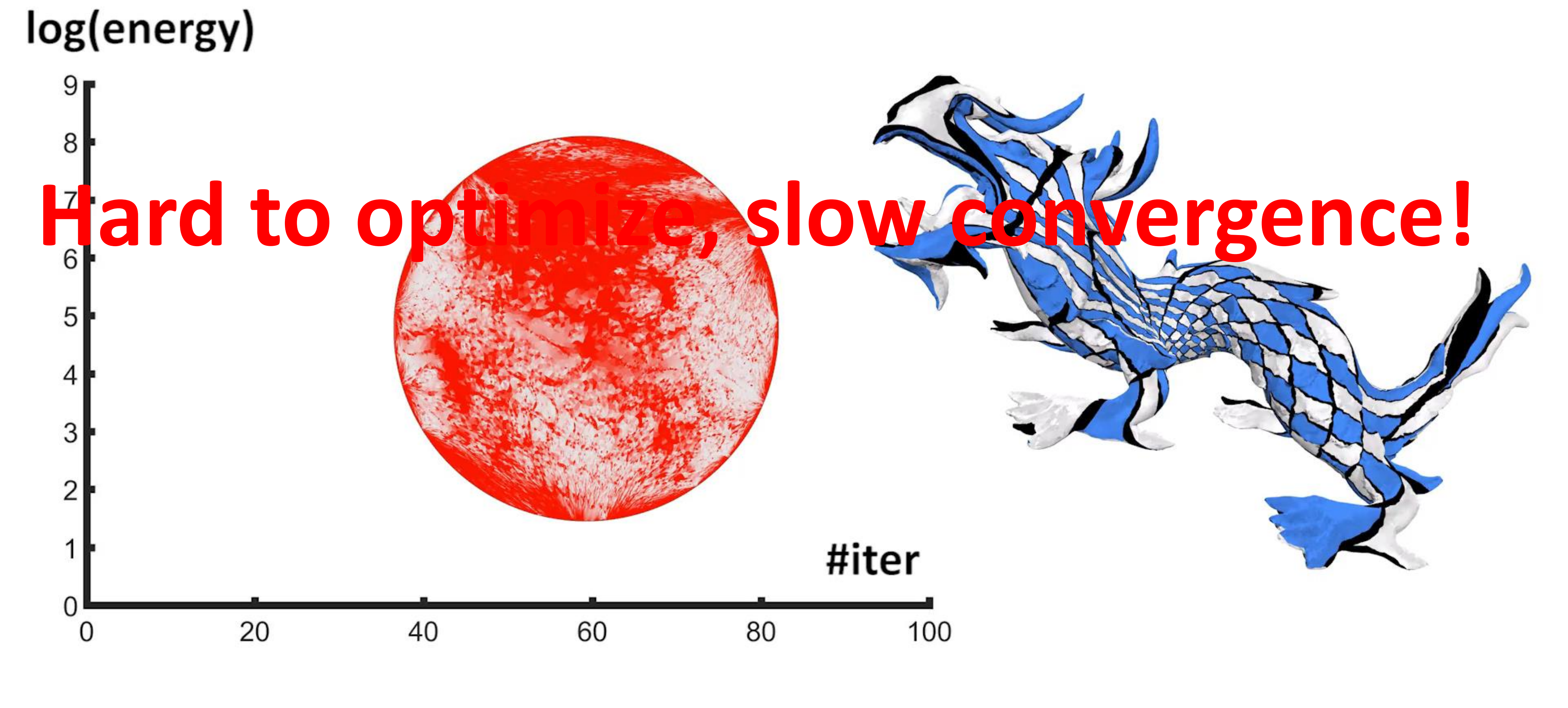
Foldover-free parameterizations

- Maintenance-based method
  - Block coordinate descent methods [Fu et al. 2015; Hormann and Greiner 2000]
  - Quasi-Newton method [Smith and Schaefer 2015]
  - Preconditioning methods [Claici et al. 2017; Kovalsky et al. 2016]
  - Reweighting descent method [Rabinovich et al. 2017]
  - Composite majorization method [Shtengel et al. 2017]
  - ……

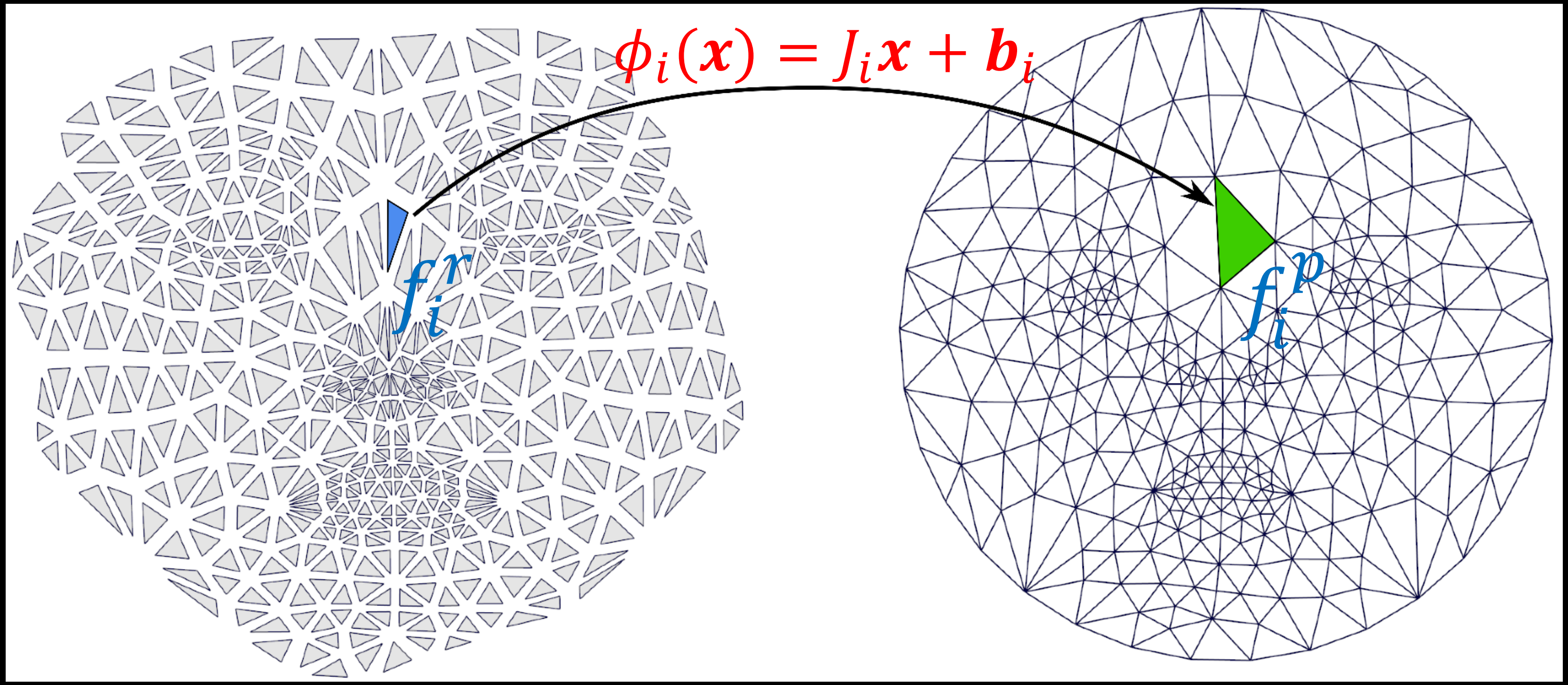
Various solvers!

Challenge

Extremely large distortion on initializations



Reference-guided distortion metric



Reference M^r: A set of individual triangles

Parameterized mesh M^p

Symmetric Dirichlet metric:

$$D(f_i^r, f_i^p) = \frac{1}{4}\left(\|J_i\|_F^2 + \left\|J_i^{-1}\right\|_F^2\right) = \frac{1}{4}\left(\sigma_i^2 + \sigma_i^{-2} + \tau_i^2 + \tau_i^{-2}\right)$$

σ_i, τ_i: singular values of J_i

Opt value = 1 when $\sigma_i = \tau_i = 1$

Formulation

$$\min_{M^p} E(M^r, M^p) = \sum_{i=1}^{N_f} \omega_i D(f_i^r, f_i^p)$$
$$\text{s.t.} \quad \det J_i > 0, \qquad i = 1, \dots, N_f.$$

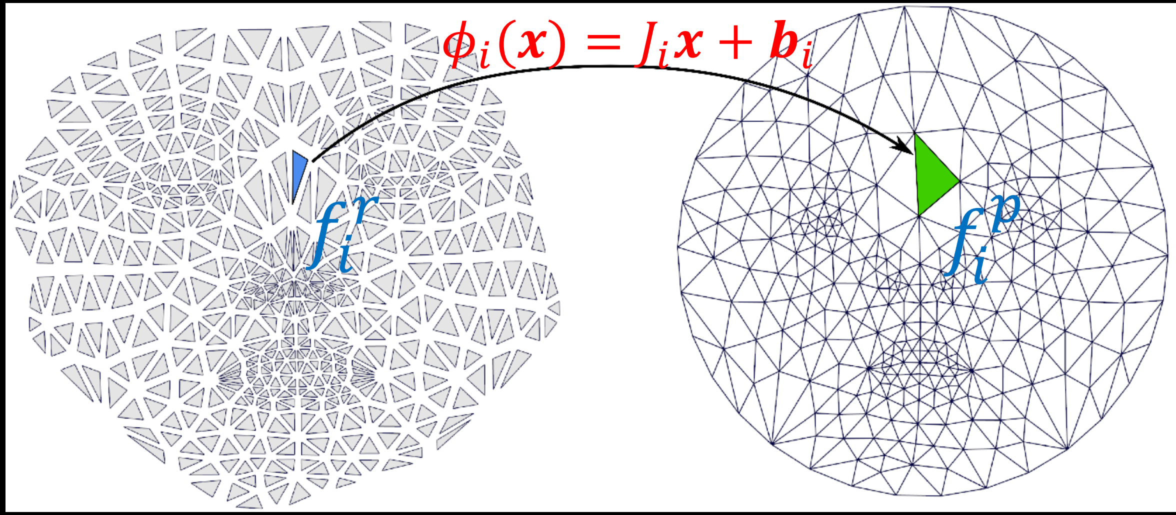
Low distortion

Foldover-free constraints

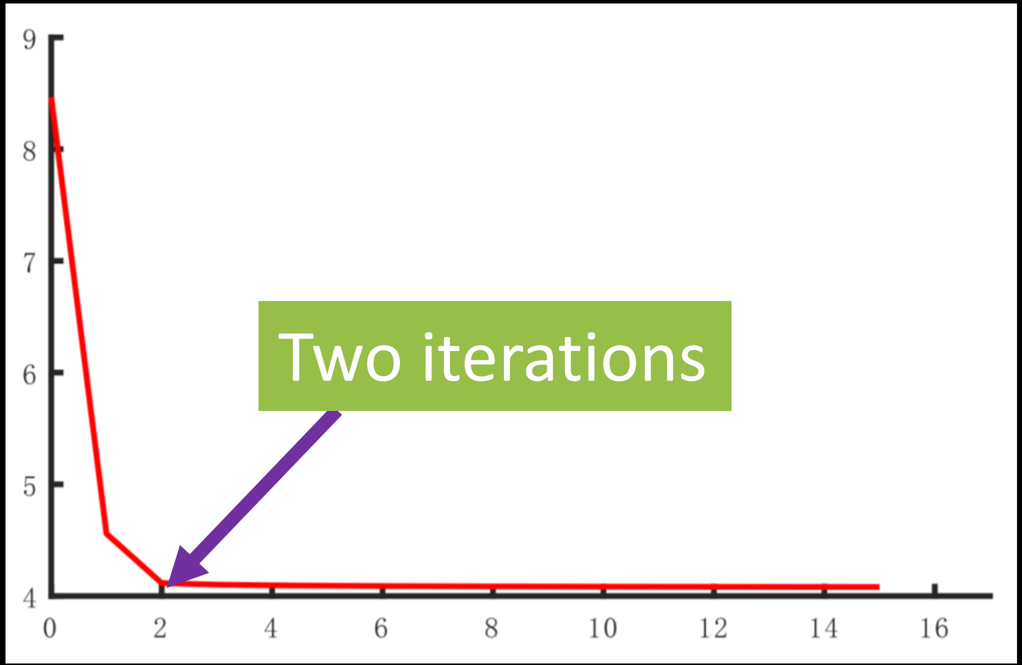
Exsiting methods choose *the triangles f_i of input mesh M* as reference triangles.

The energy is *numerically difficult to optimize*, leading to numerous iterations and high computational cost.

Progressive reference

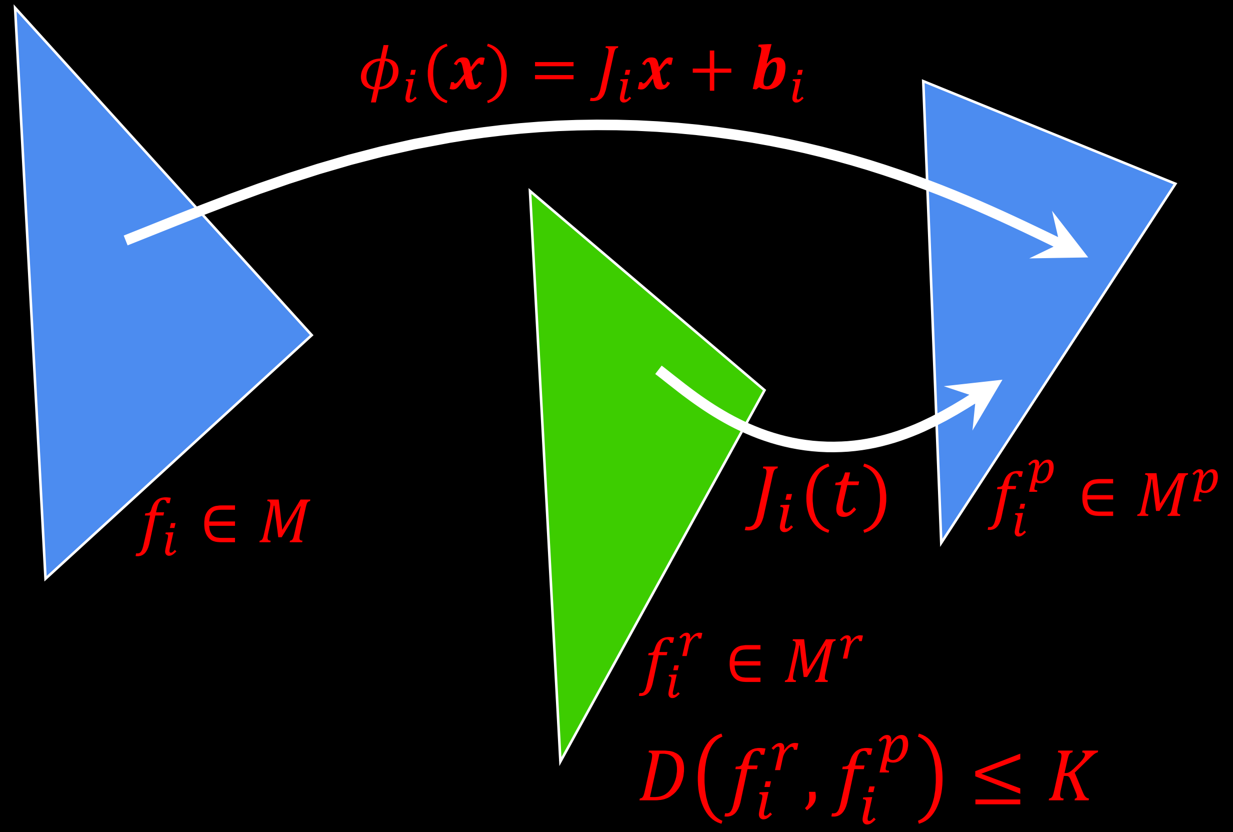


If $D(f_i^r, f_i^p) \le K, \forall i$, only a few iterations in the optimization of $E(M^r, M^p)$ are necessary.

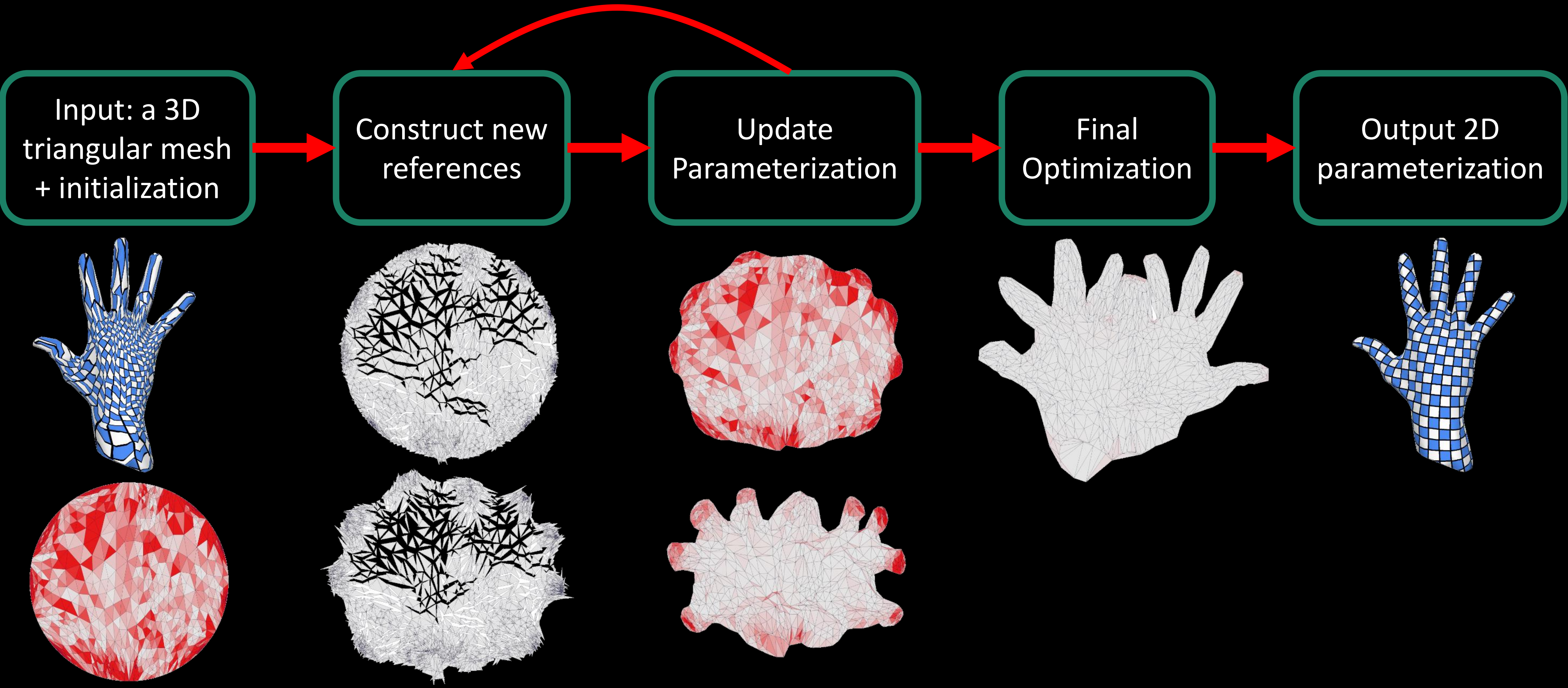


Progressive reference

- Progressively approach f_i

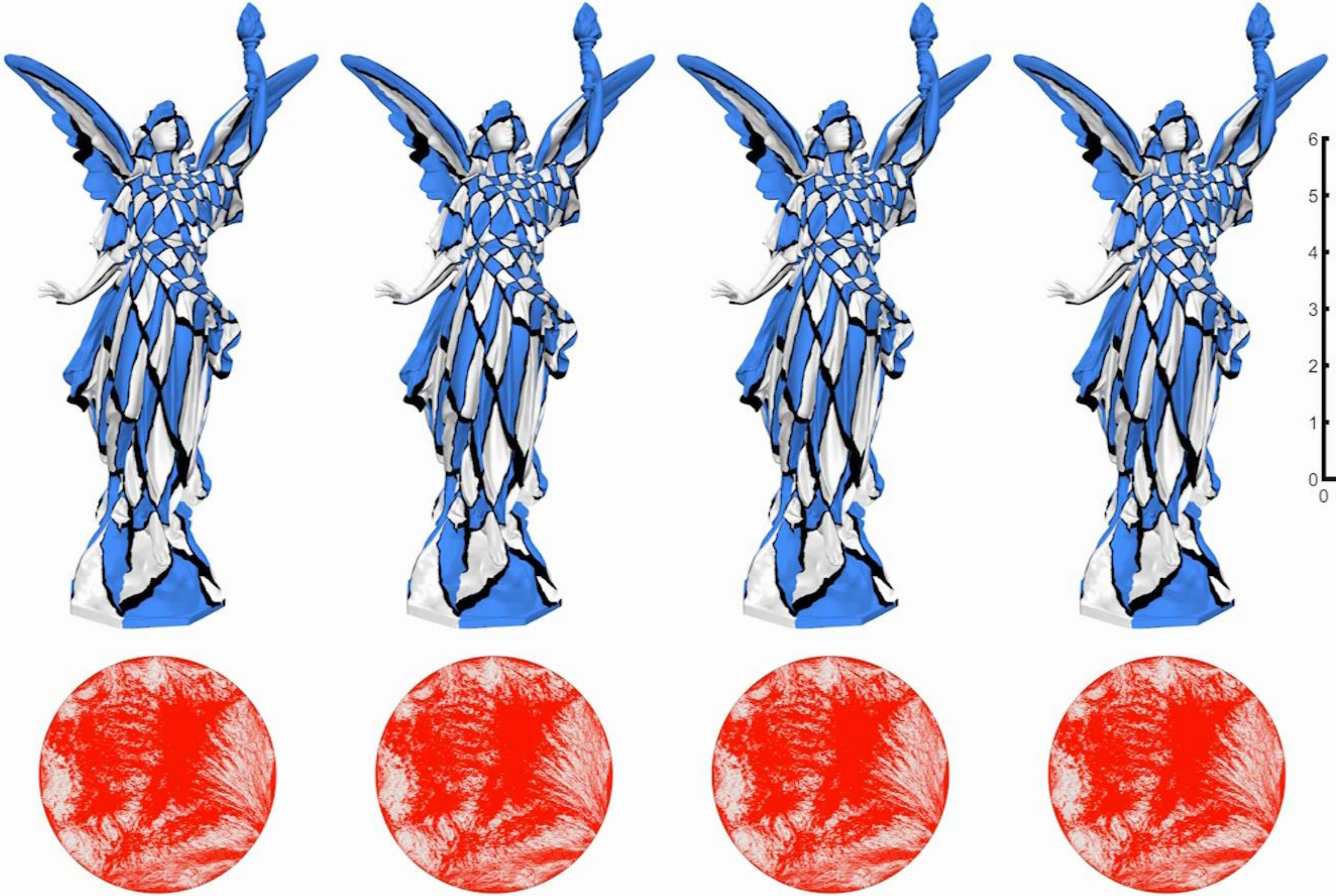


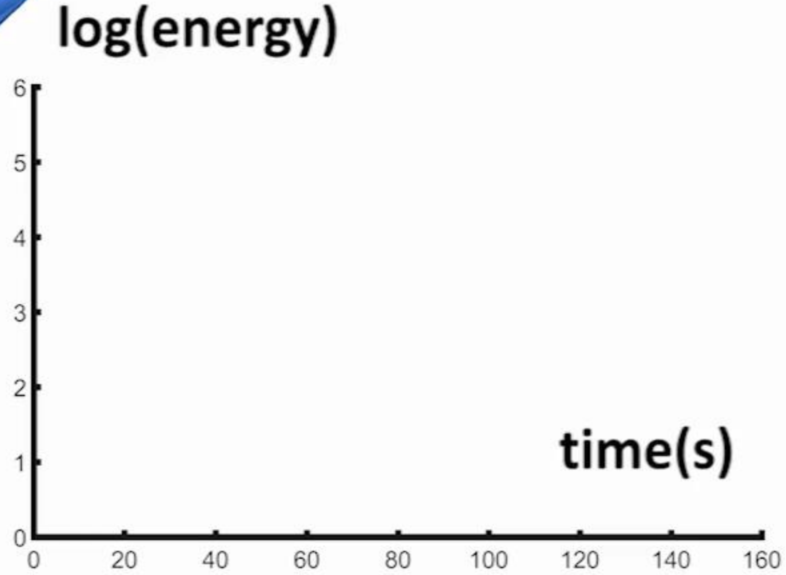
Progressive Parameterizations [Liu et al. 2018]



AKVF [Claici et al. 17] **CM** [Shtengel et al. 17] **SLIM** [Rabinovich et al. 17] **Ours**

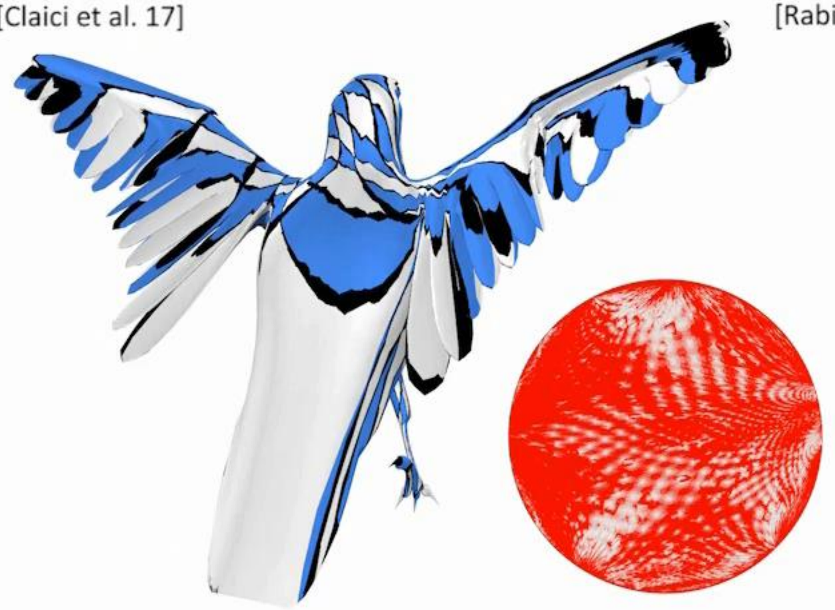
2x playback



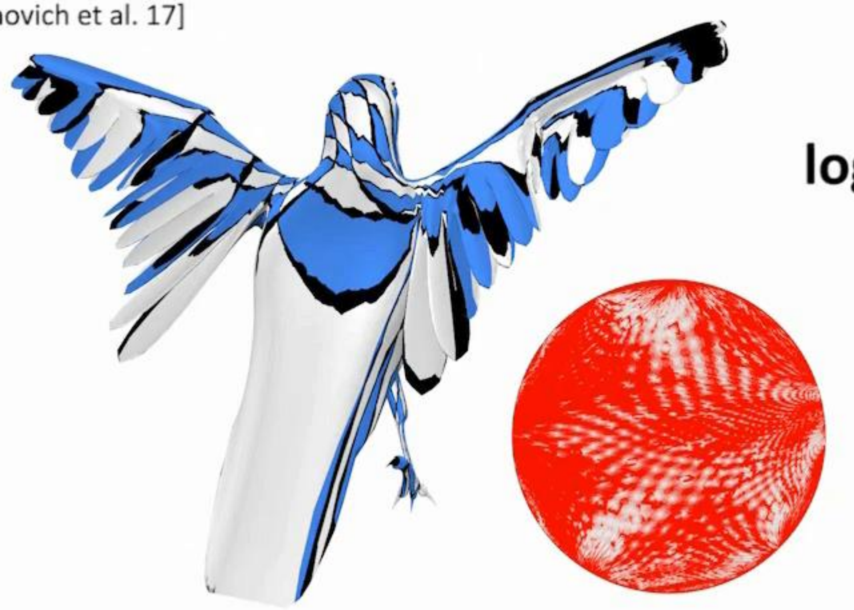


#V: 900k, #F: 1792k

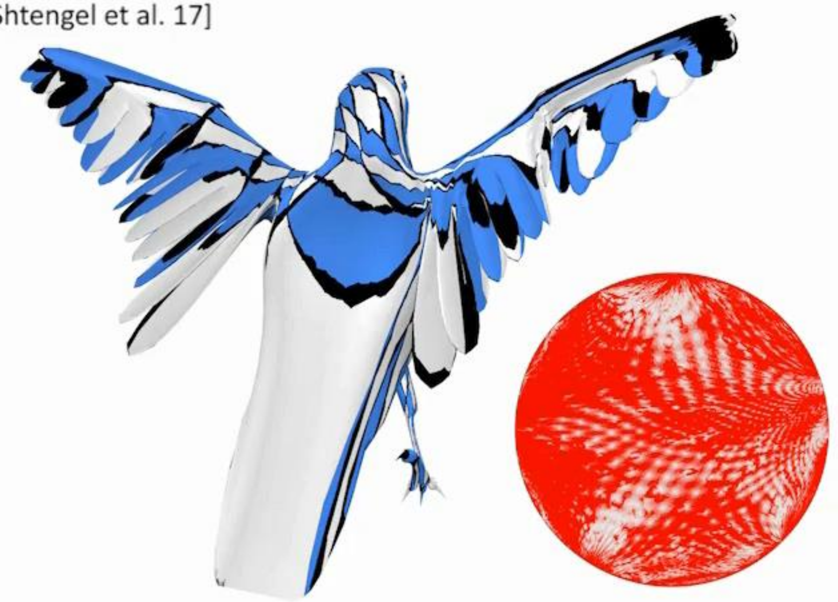
AKVF
[Claici et al. 17]



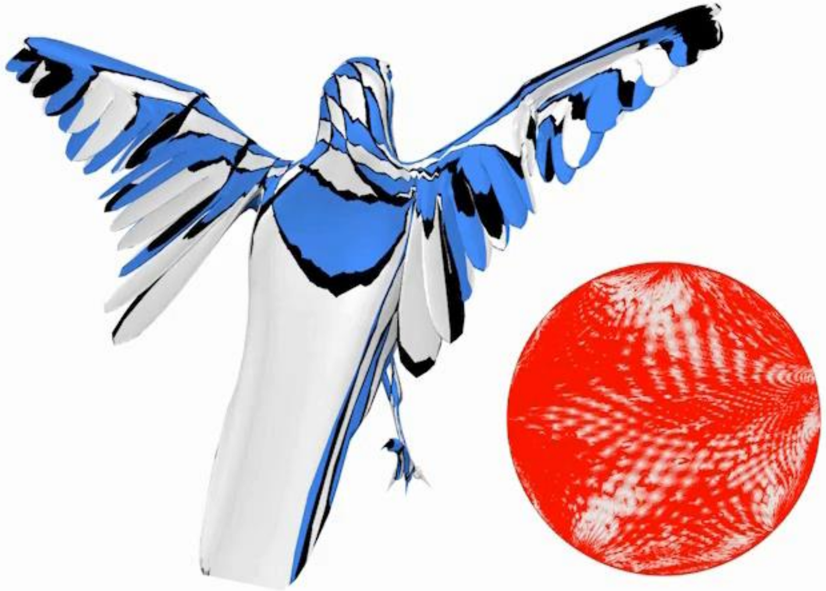
SLIM
[Rabinovich et al. 17]



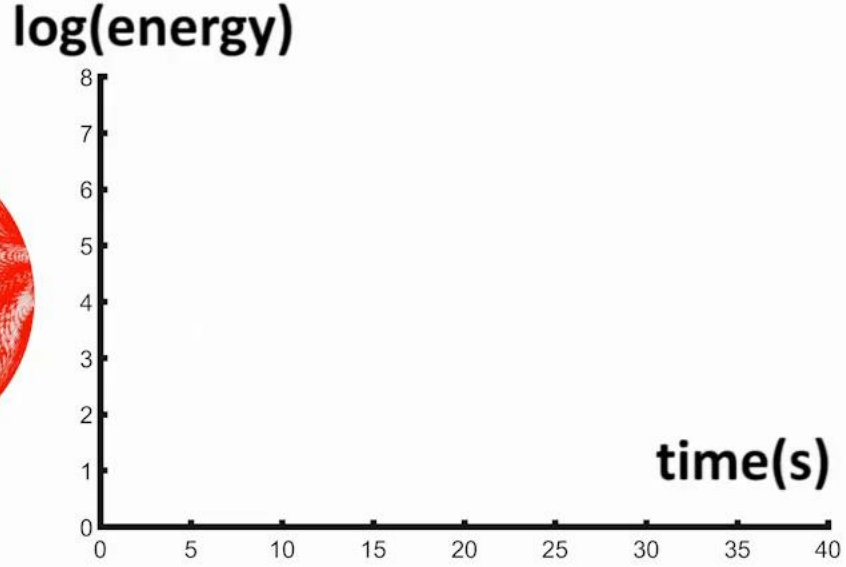
CM
[Shtengel et al. 17]



Ours



playback



#V: 195k, #F: 382k

Conclusions

- Progressive parameterizations: a novel and simple method to generate low isometric distortion parameterizations with no foldovers.

✓ Thinks from the view of reference triangle.

✓ Exhibits strong practical reliability and high efficiency.

✓ Demonstrates the practical robustness on a large data set containing 20712 models

Future works

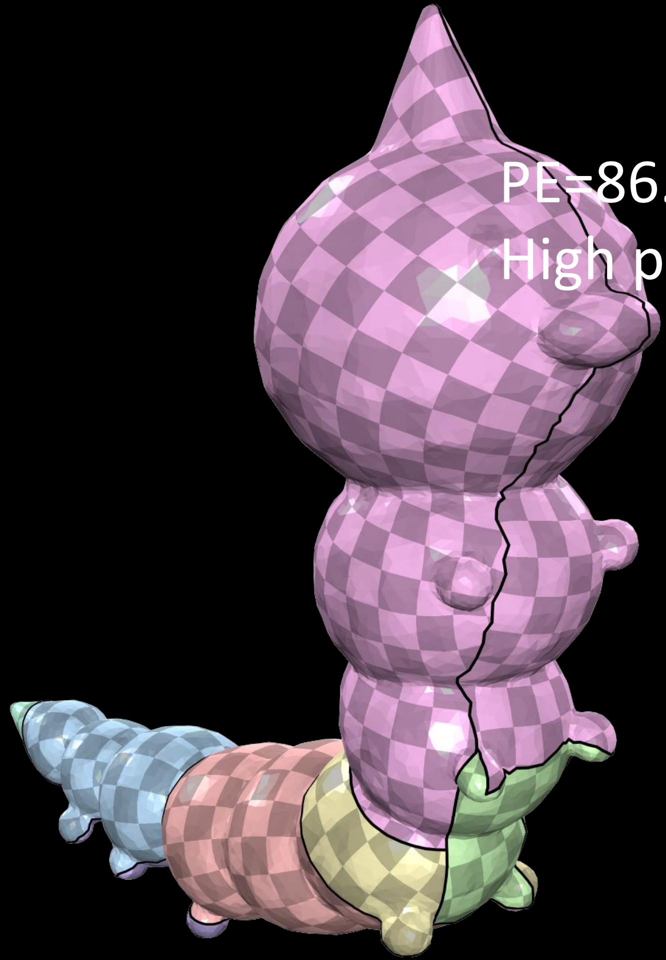
- Real-time parameterizations/deformation.

- Theoretical guarantee/analysis.

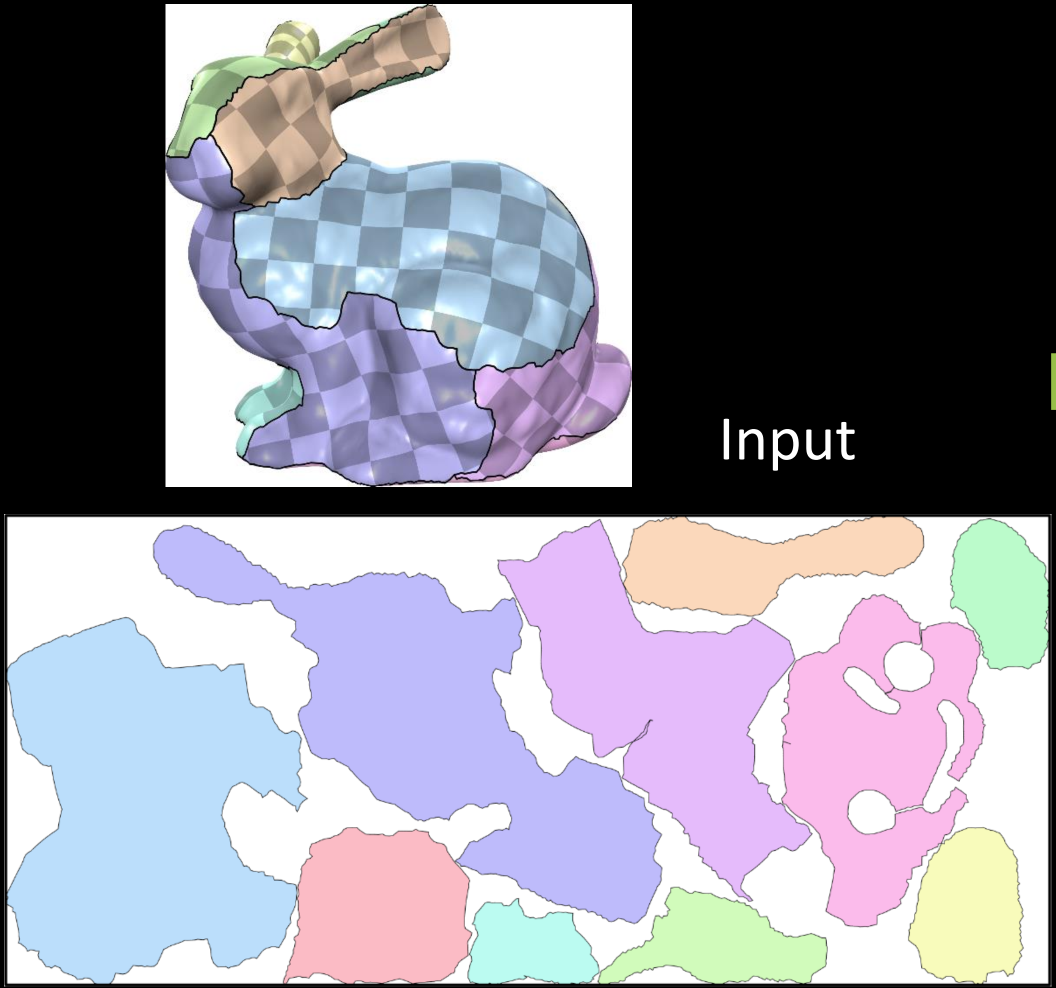
Packing

Atlas Refinement with Bounded Packing Efficiency, *SIGGRAPH 2019*

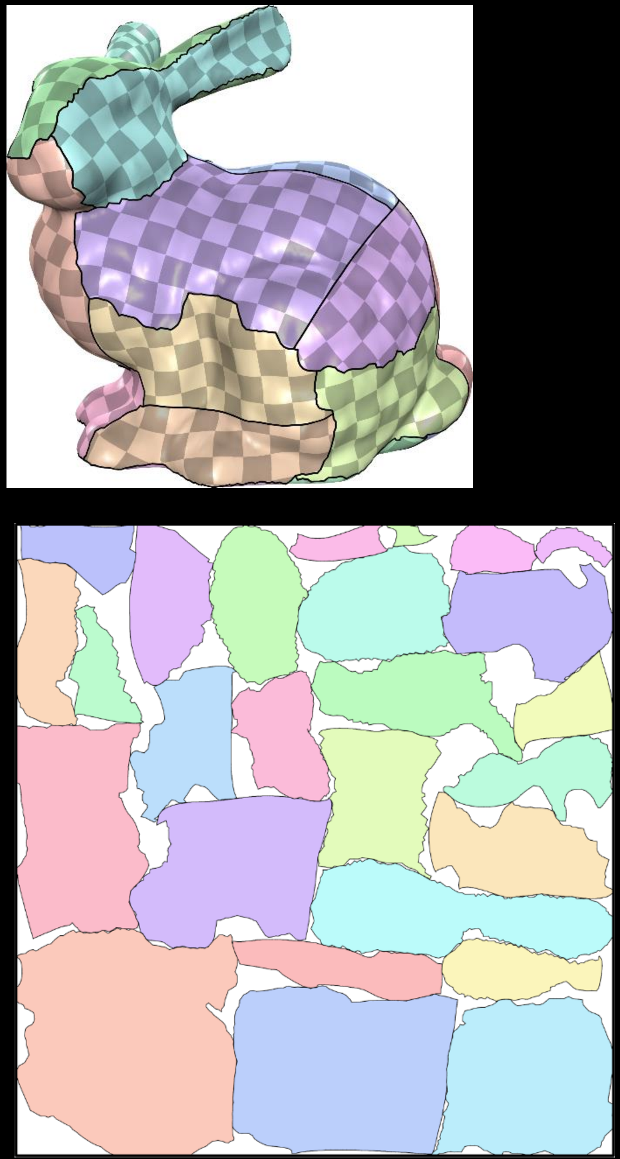
Packing Efficiency (PE)



Atlas Refinement



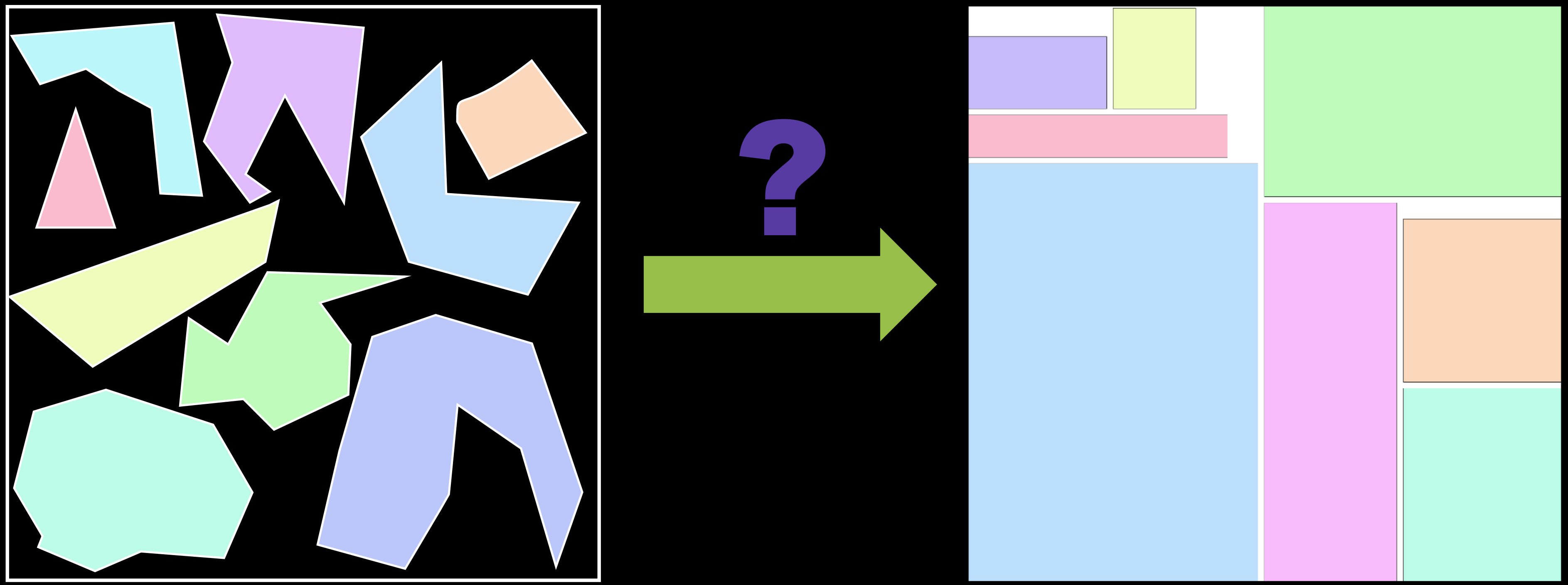
Input



Bijective
High PE

Motivation

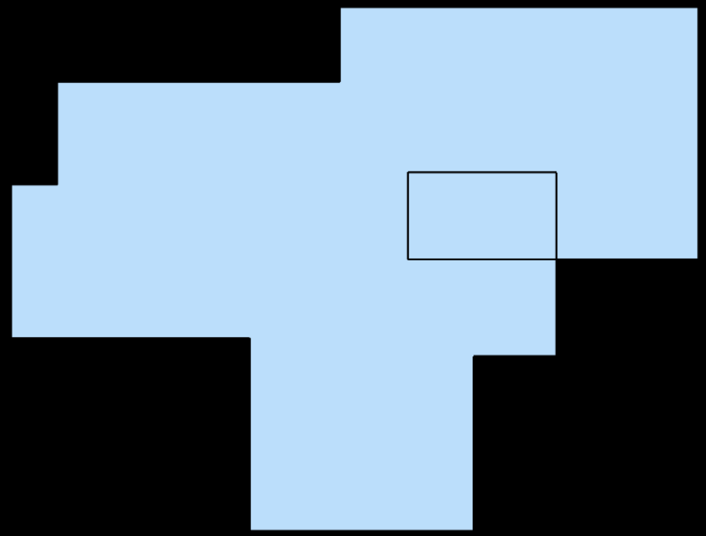
Packing Problems



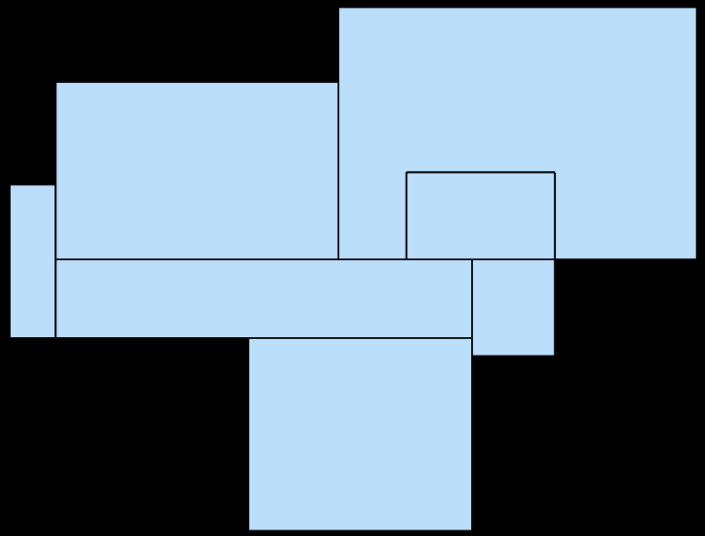
Irregular shapes
Hard to achieve high PE

Rectangles
Simple to achieve high PE
Widely used in practice

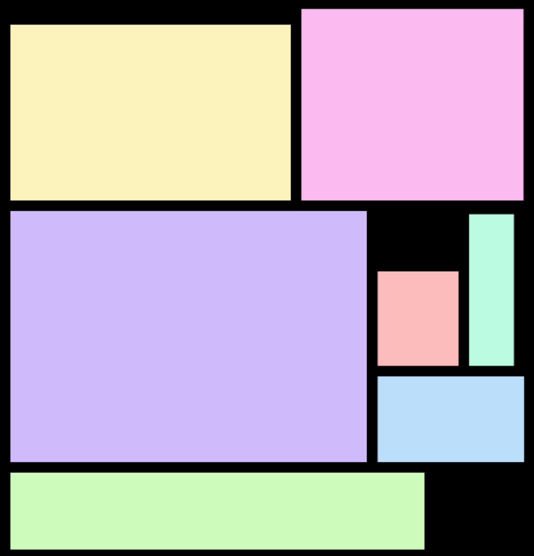
Axis-Aligned Structure



Axis-aligned structure



Rectangle decomposition



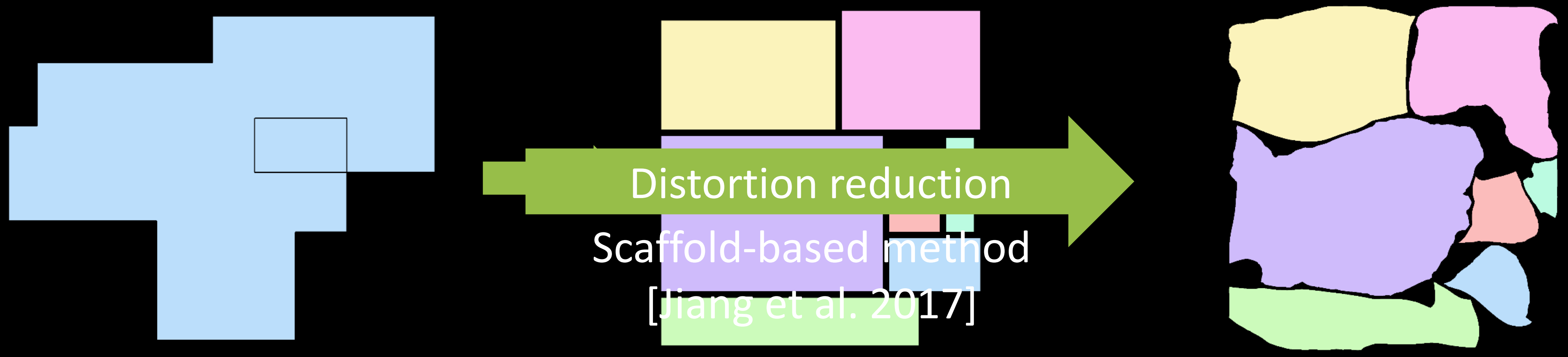
High PE (87.6%)!

General Cases

Not axis-aligned

Axis-aligned
Higher distortion

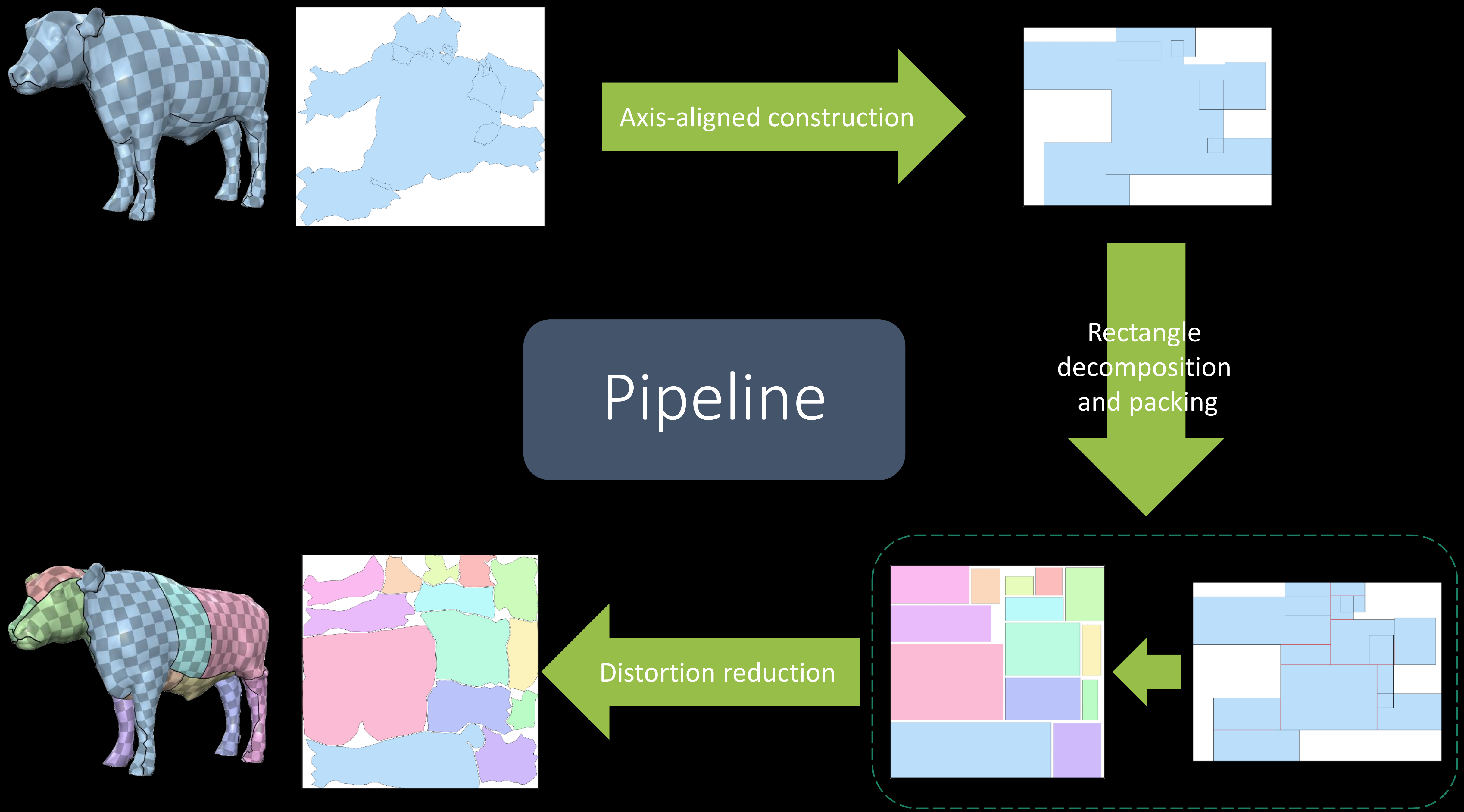
Distortion Reduction

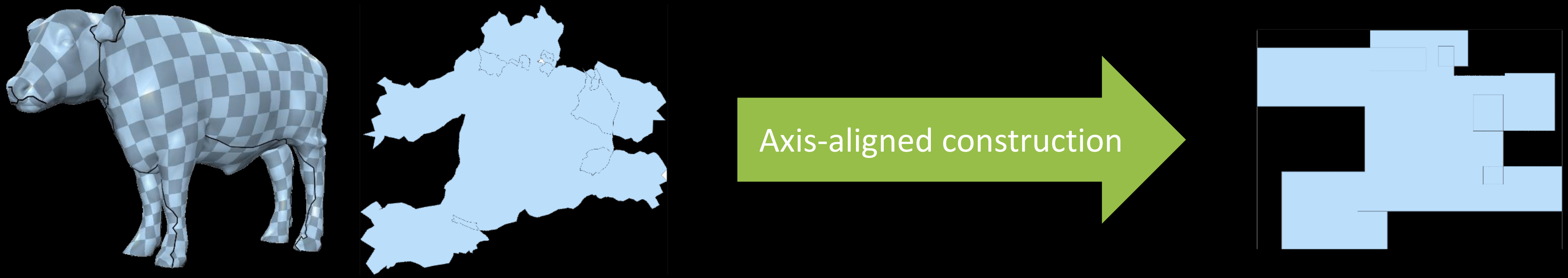


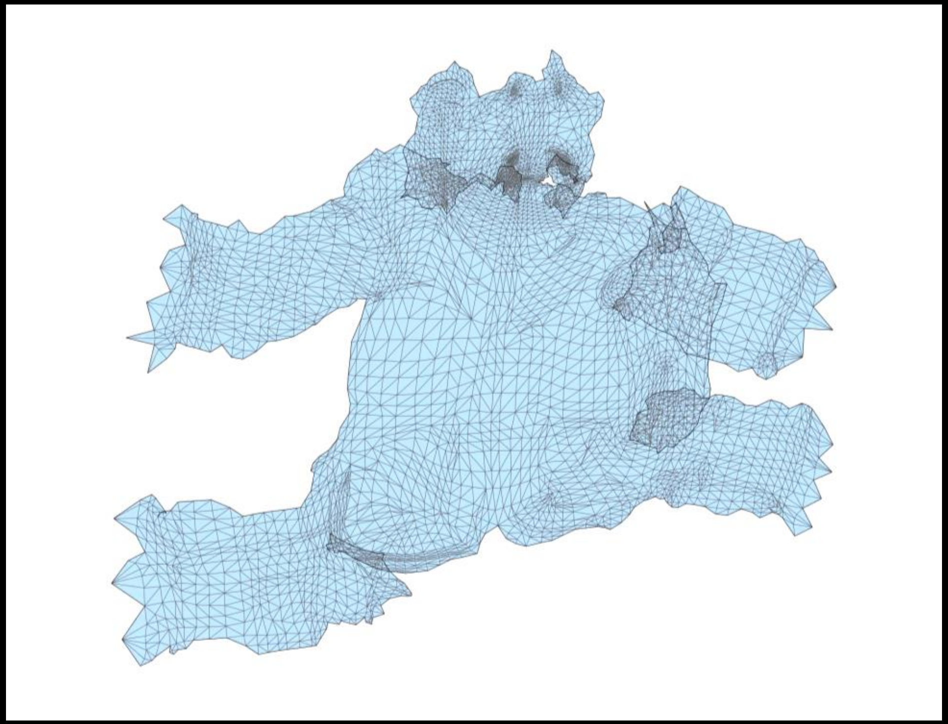
Axis-aligned
High distortion

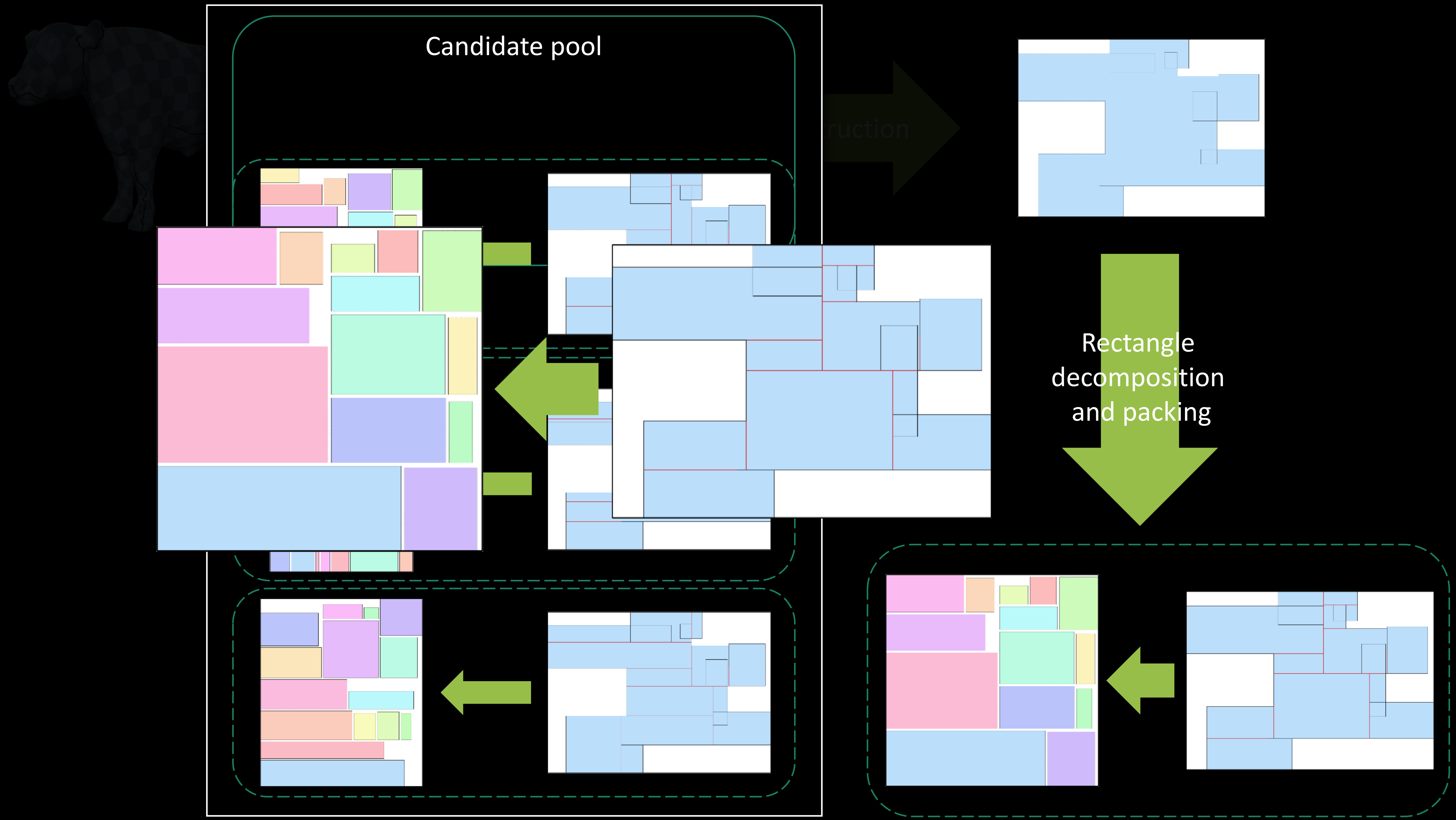
Bijective & High PE
High distortion

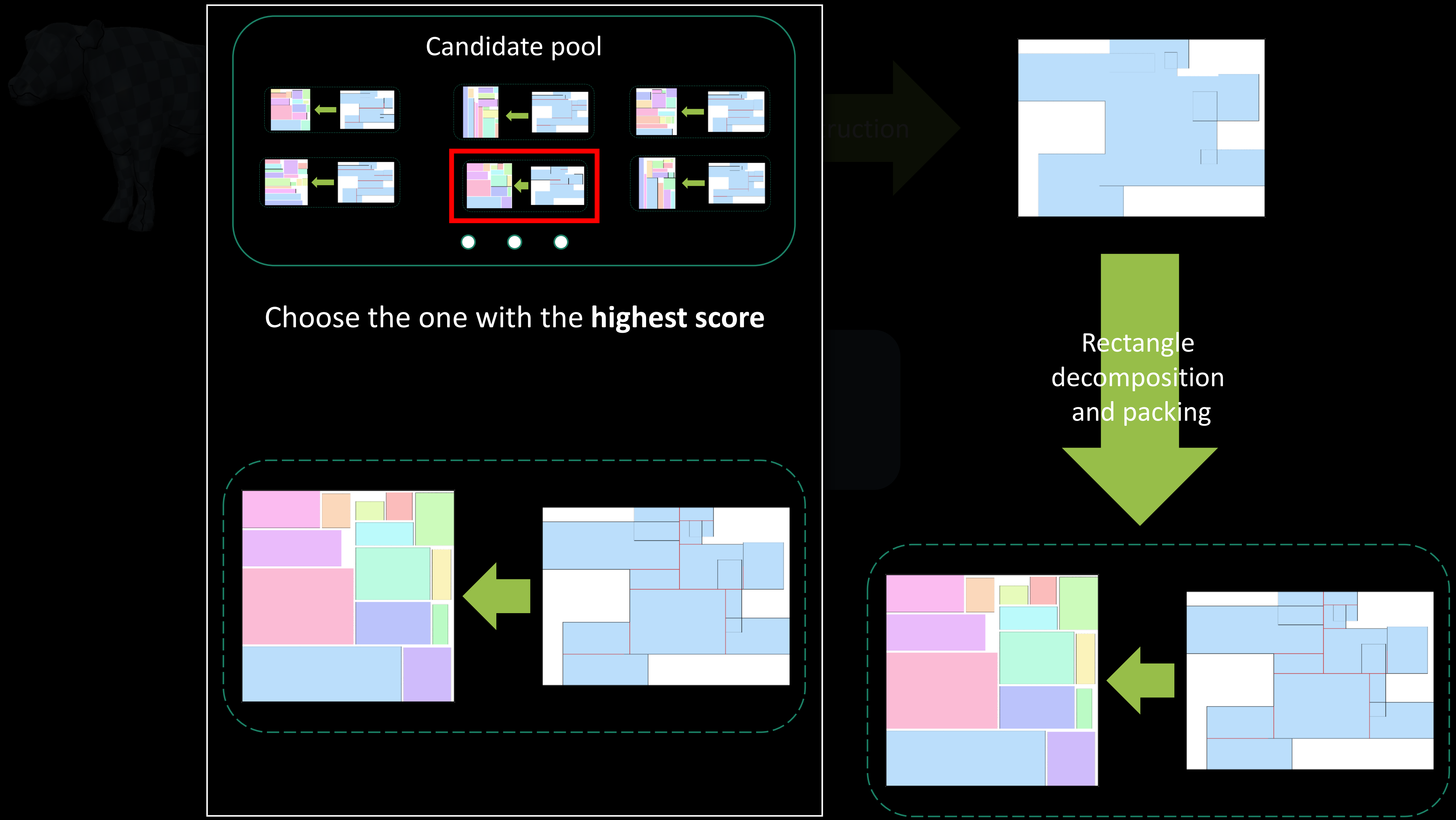
Bijective & High PE
Low distortion
Bounded PE

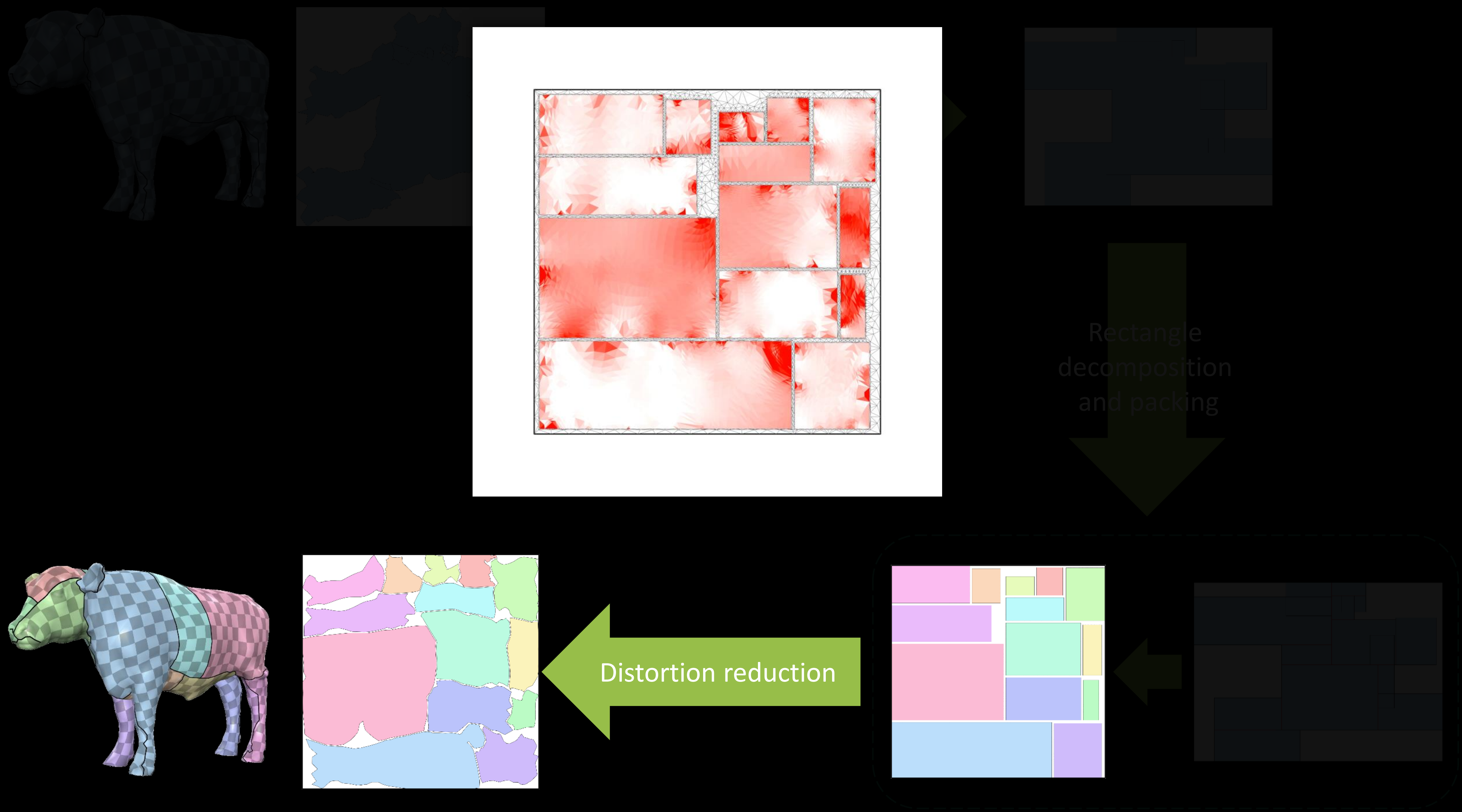

Axis-aligned construction
Rectangle decomposition and packing
Pipeline
Distortion reduction

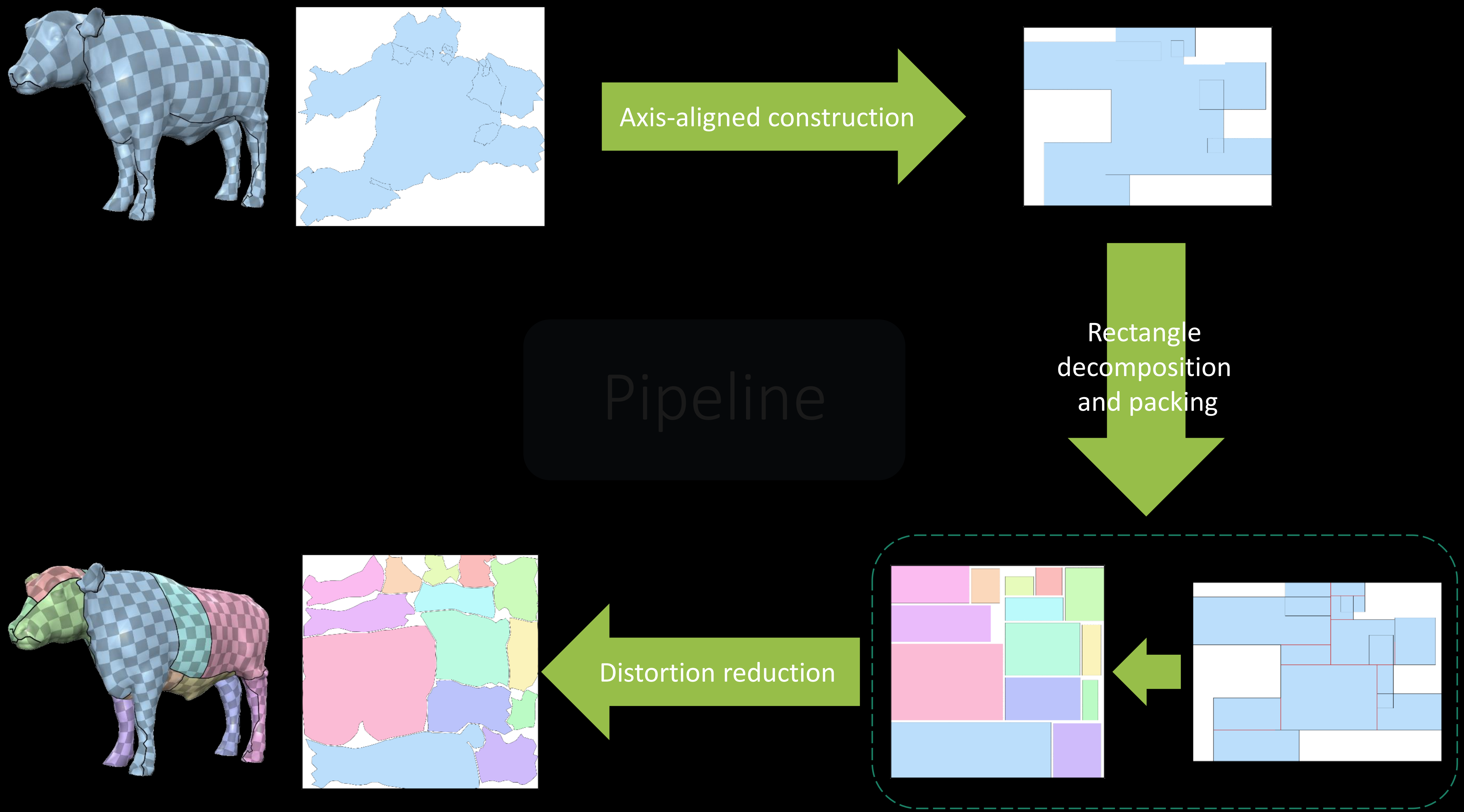

Axis-aligned construction




Candidate pool
Rectangle
decomposition
and packing

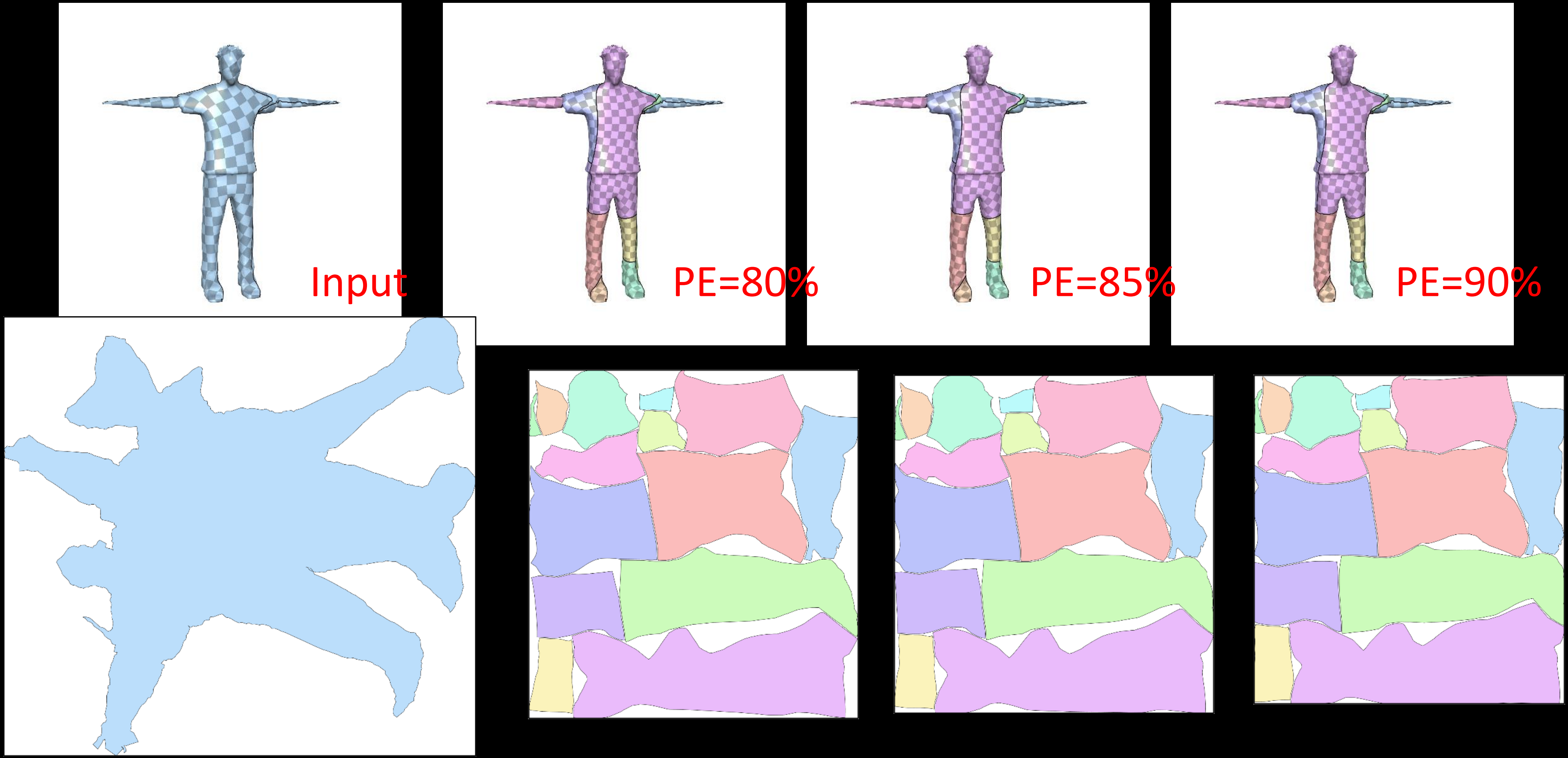

Candidate pool
Choose the one with the **highest score**
Rectangle decomposition and packing


Rectangle
decomposition
and packing
Distortion reduction

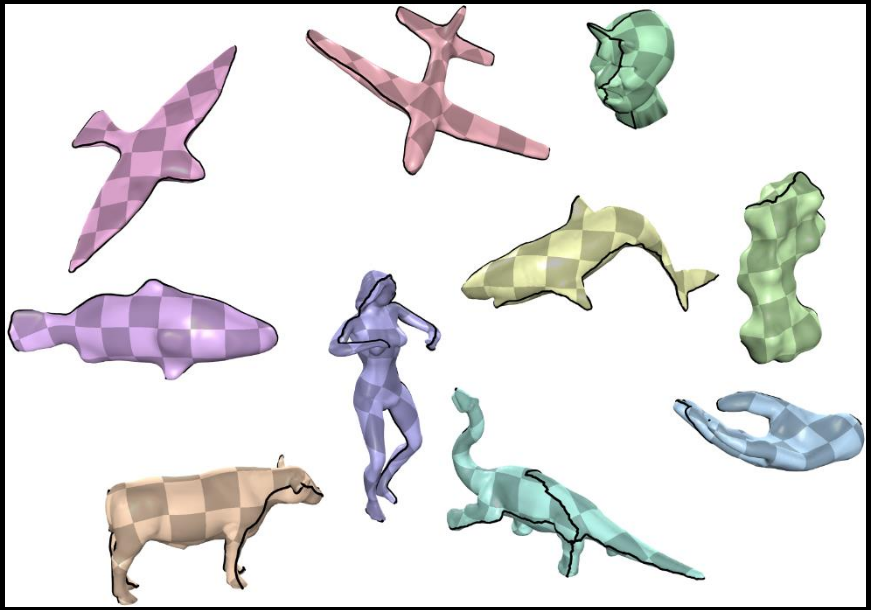

Pipeline
Axis-aligned construction
Rectangle decomposition and packing
Distortion reduction

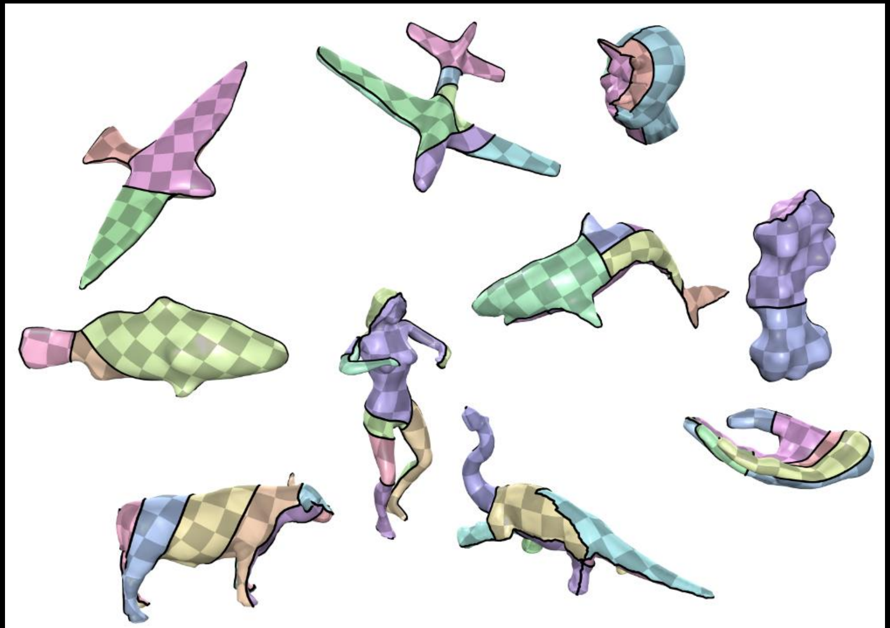
Experiments

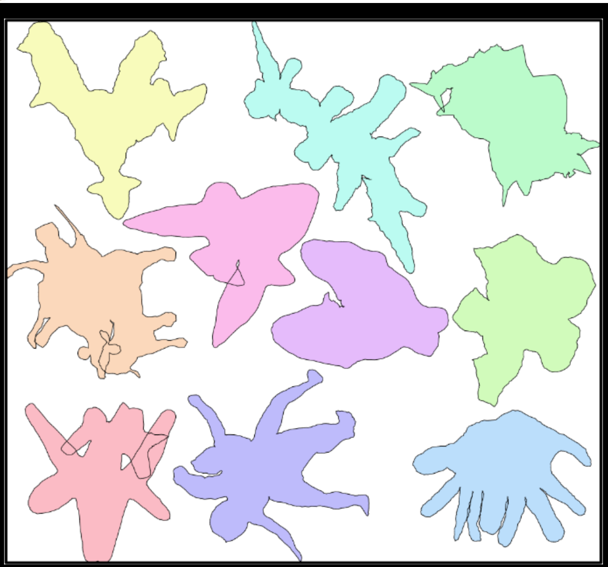
PE Bound

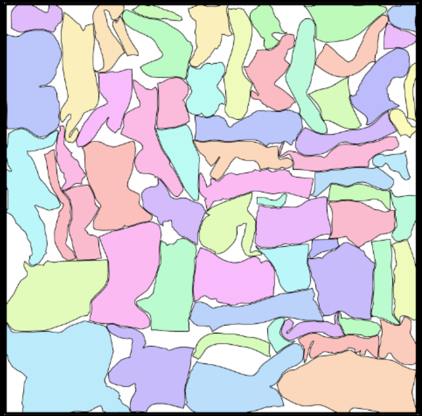


Collection of Models



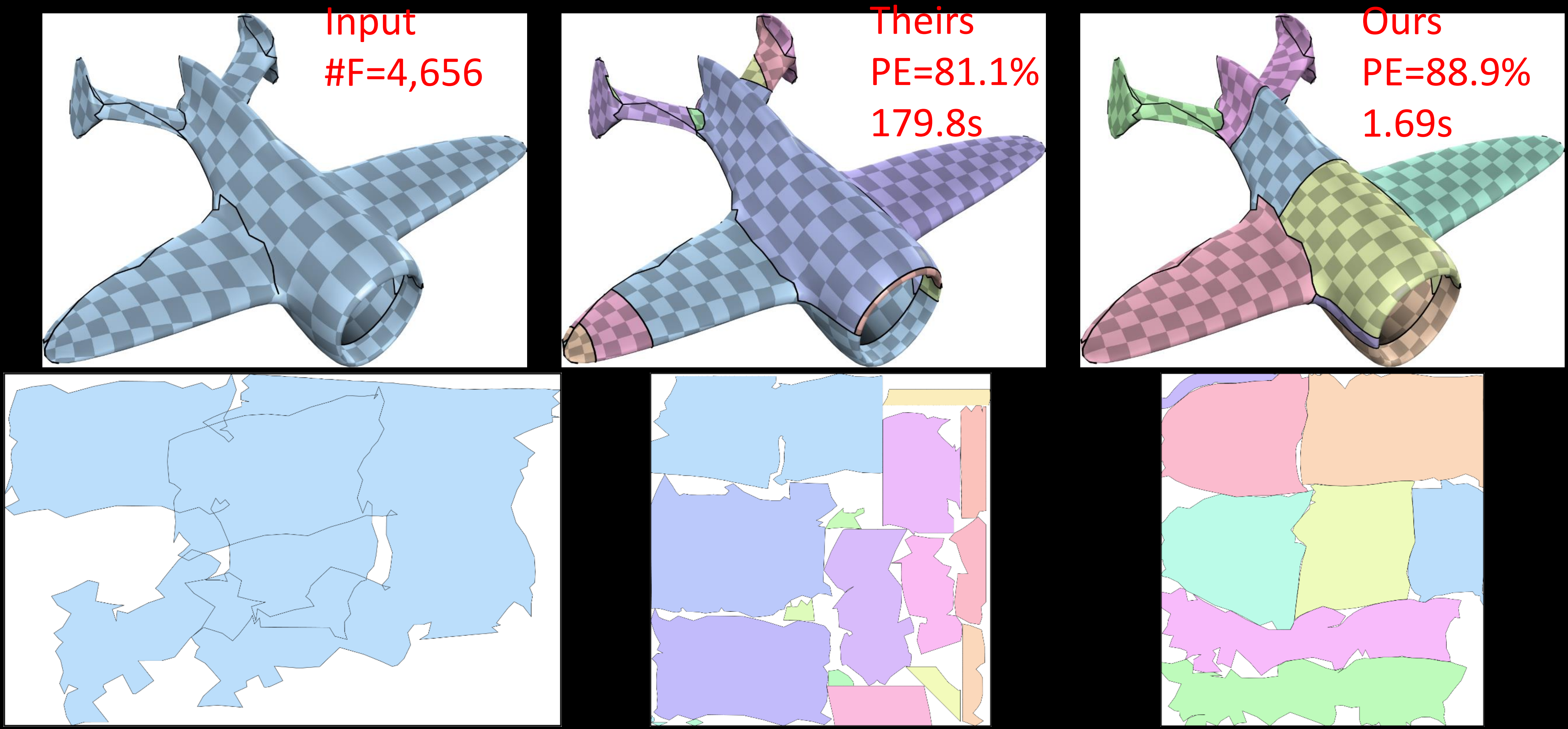




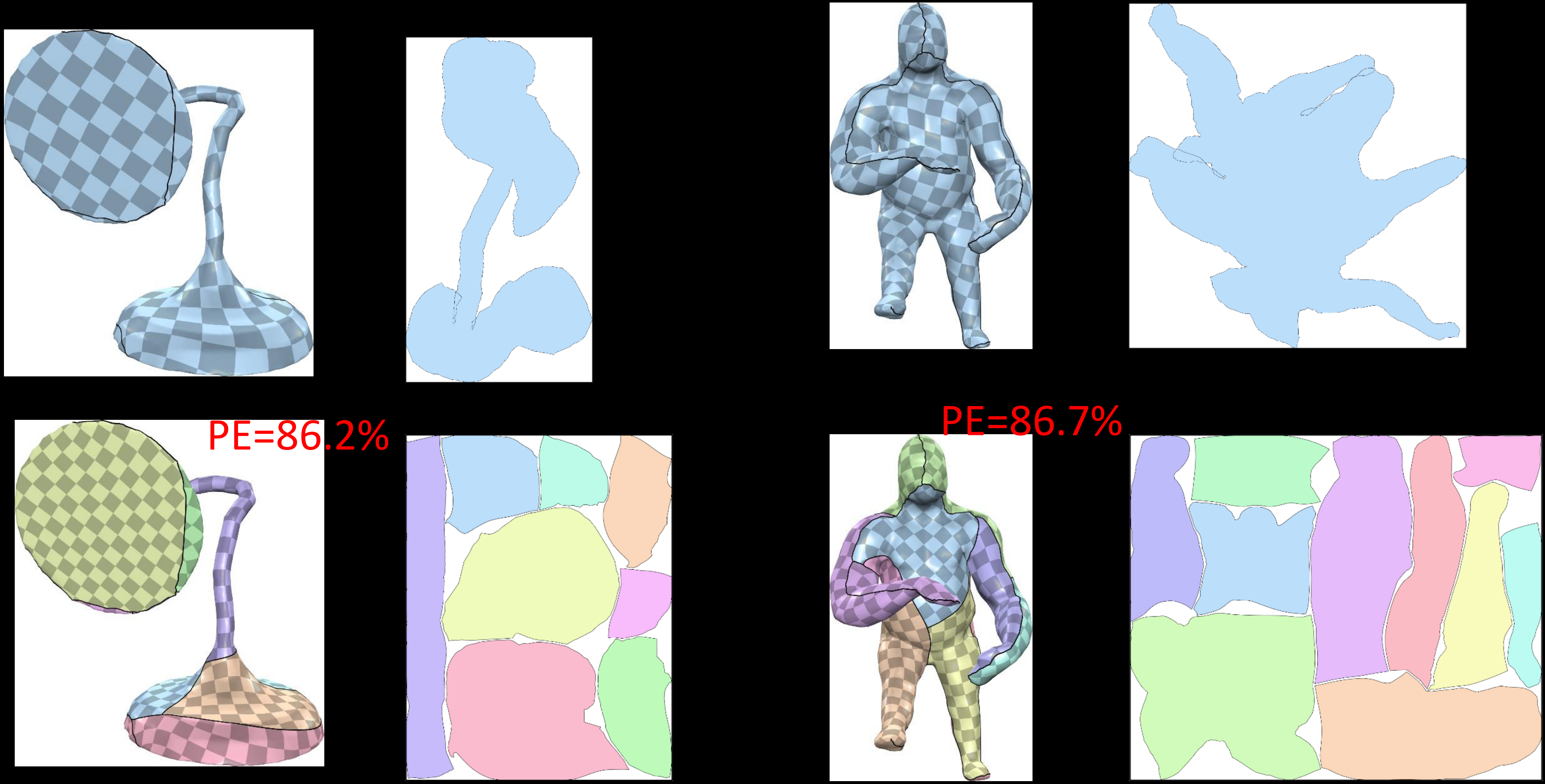


PE=80%

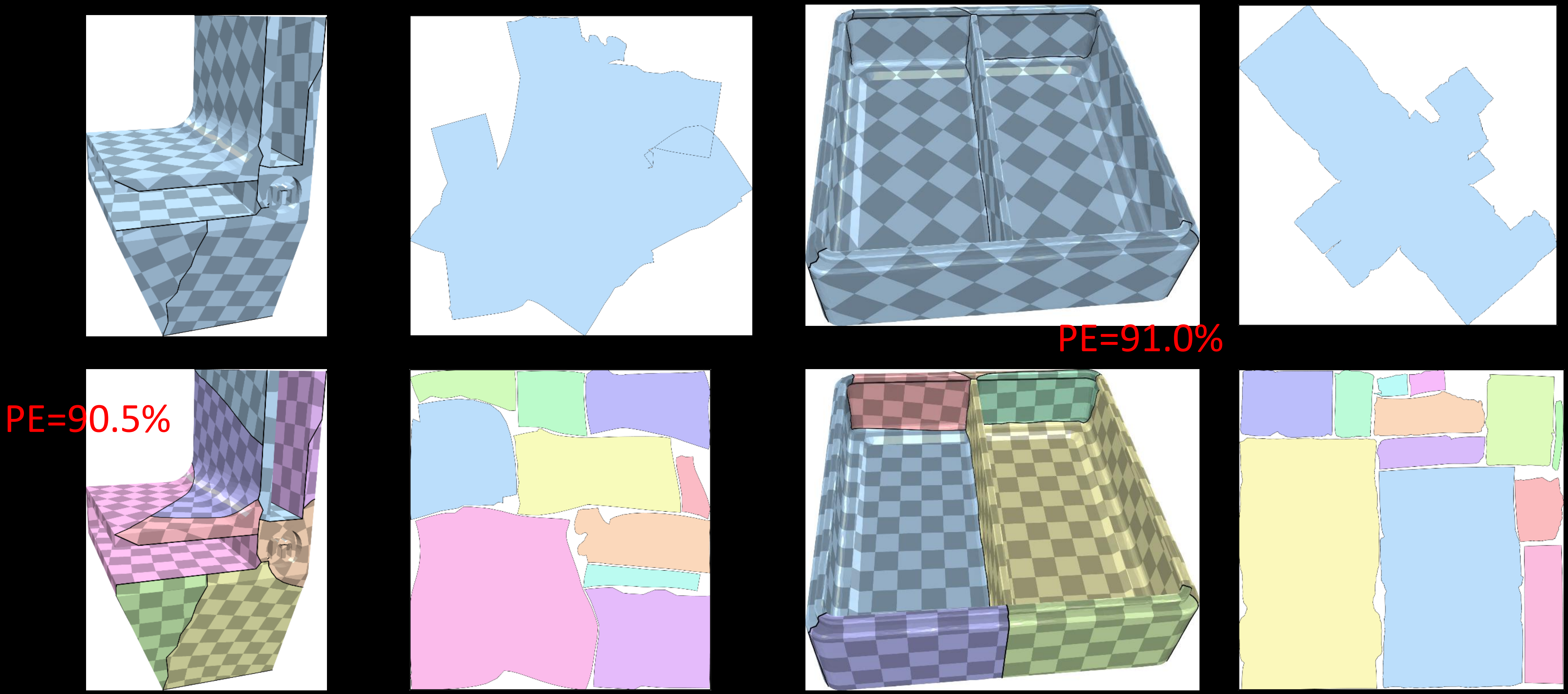
Comparison to [Limper et al. 2018]



Benchmark (5,588)



Benchmark (5,588)



Conclusion

Conclusions

- Our method provides a novel technique to refine input atlases with bounded packing efficiency.

- Key idea: converting polygon packing problems to a rectangle packing problems
  - High and bounded packing efficiency
  - Good performance and quality
  - Practical robustness

Limitation

- Modification of the input atlas may not meet the original intention.
- Boundary length elongation is not explicitly bounded.
- There is no theoretical guarantee, especially for the axis-aligned deformation process.

Thank you!

http://staff.ustc.edu.cn/~fuxm/