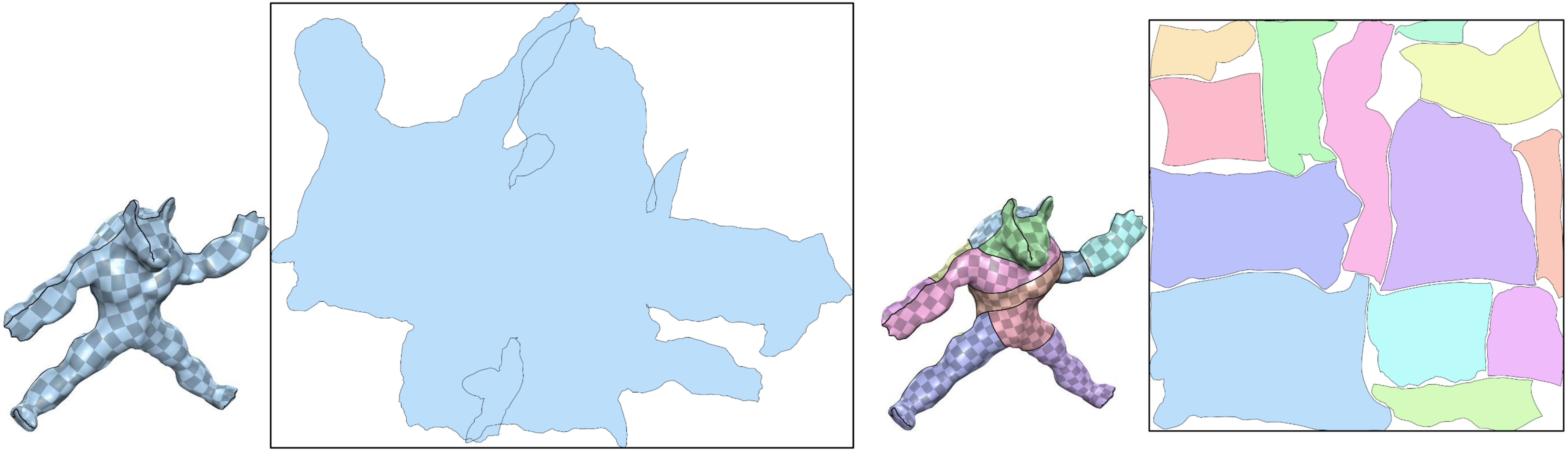
Atlas Refinement with Bounded Packing Efficiency



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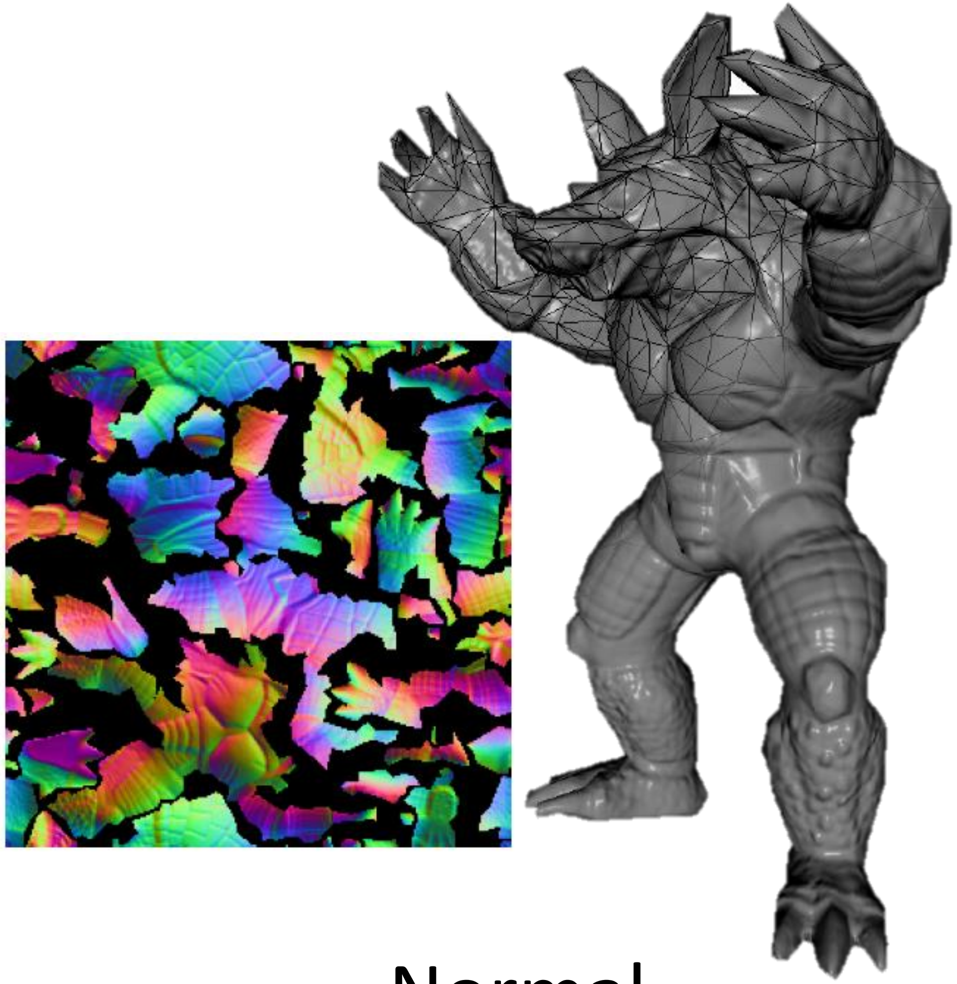
University of Science and Technology of China

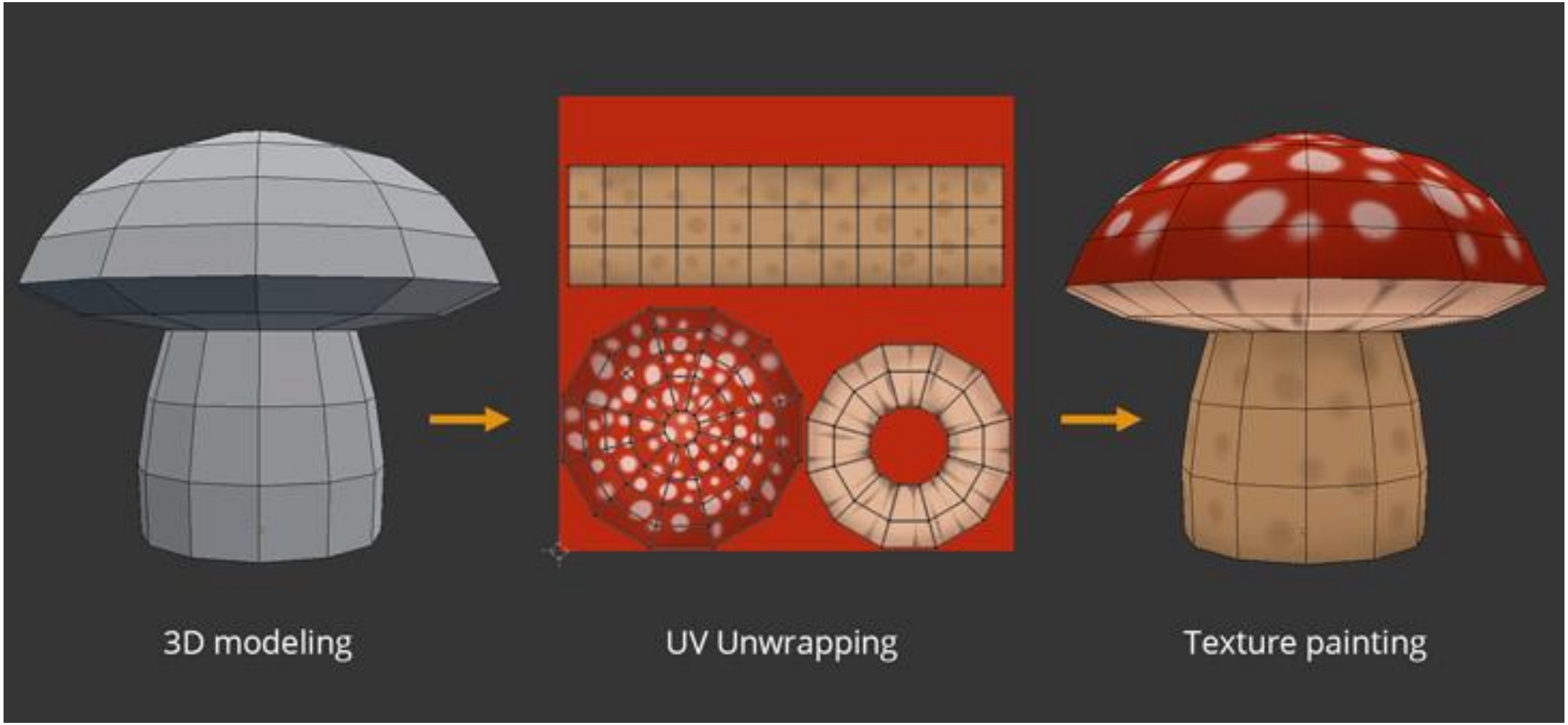
Atlas

Color

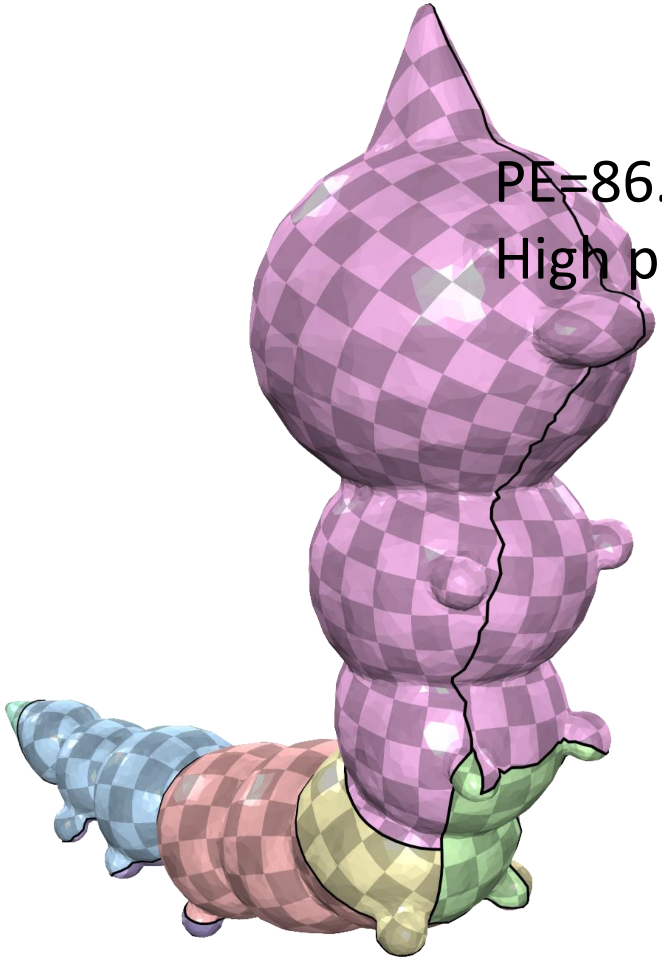


Normal

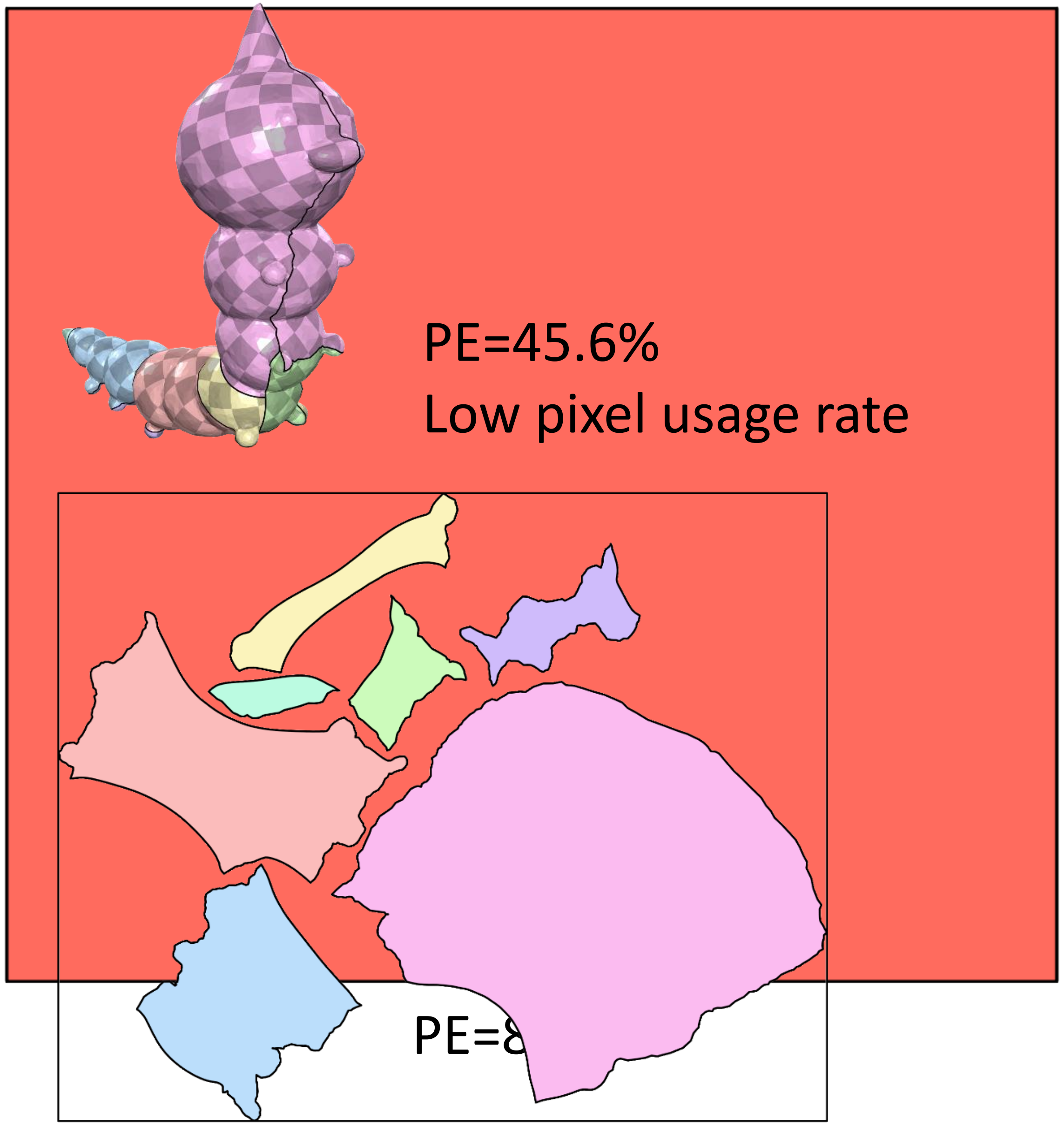
Texture



Packing Efficiency (PE)



PE=86.1%
High pixel usage rate



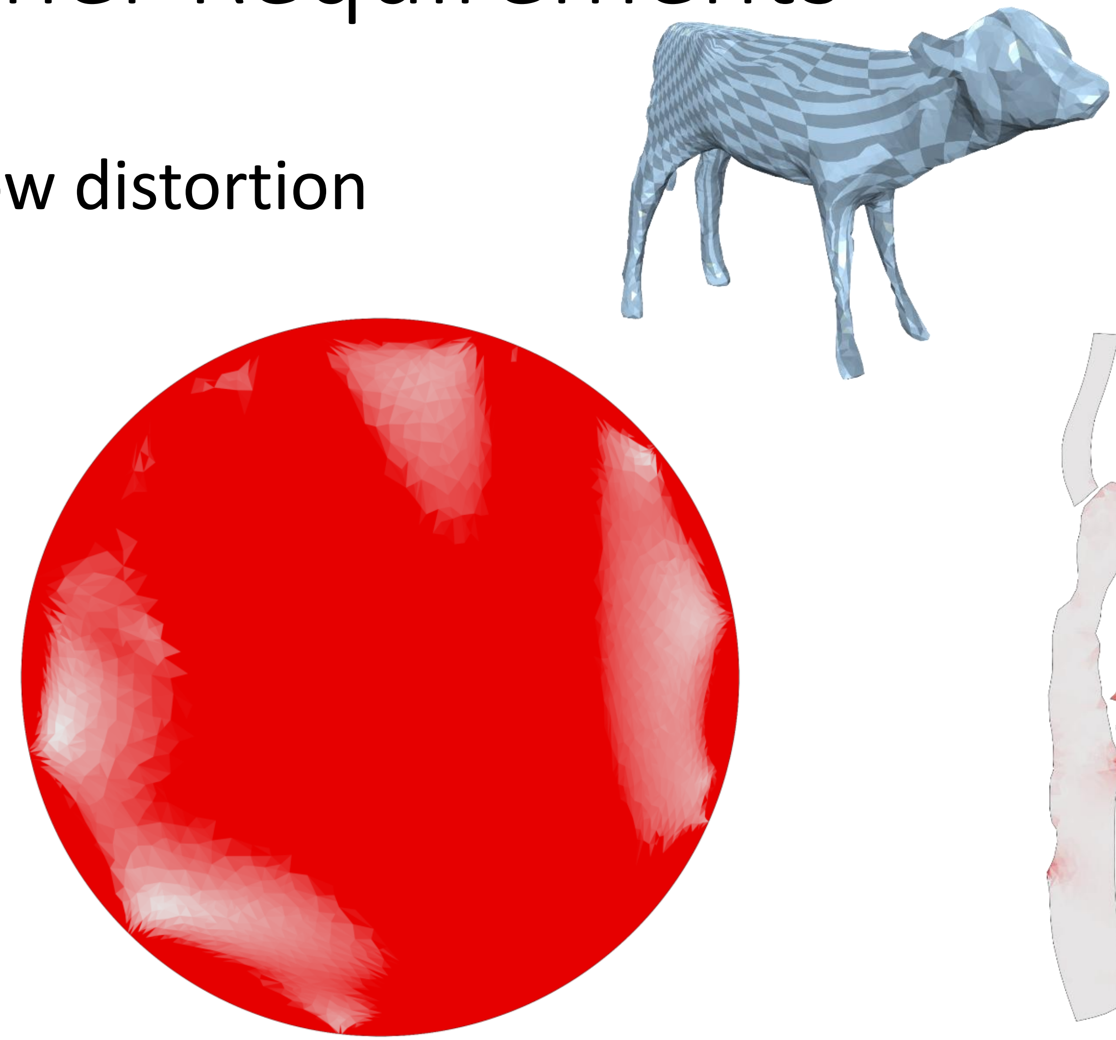
Packing Efficiency (PE)

Maximizing atlas packing efficiency is NP-hard!

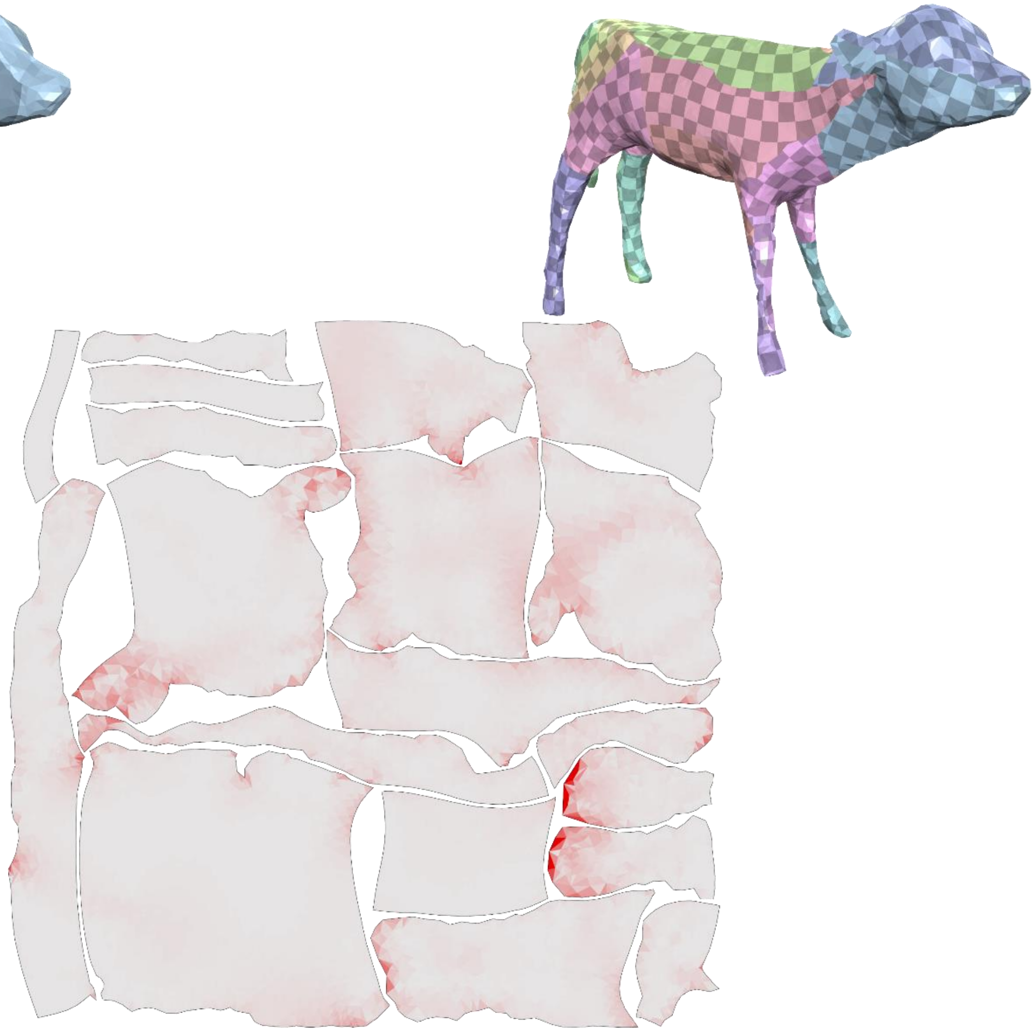
[Garey and Johnson 1979; Milenkovic 1999]

Other Requirements

- Low distortion



High Distortion



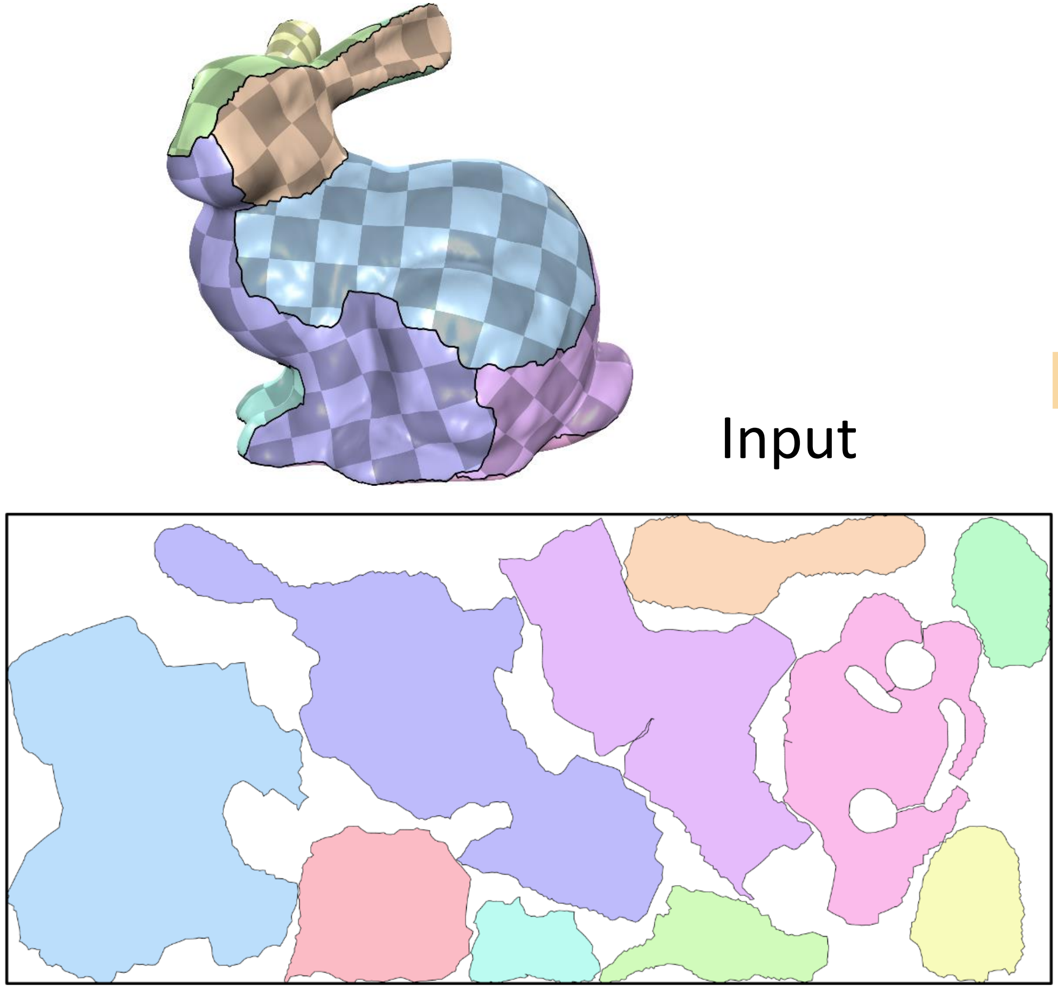
Low Distortion

Other Requirements

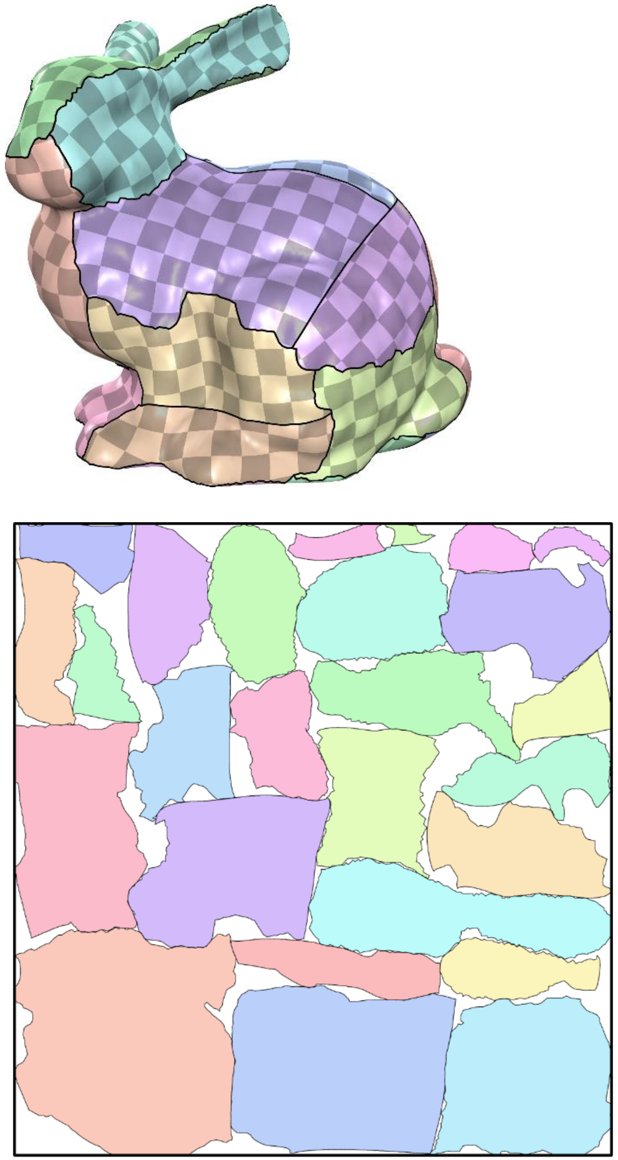
- Low distortion
  - [Golla et al. 2018; Liu et al. 2018; Shtengel et al. 2017; Zhu et al. 2018]
- Consistent orientation
  - [Floater 2003; Tutte 1963; Claici et al. 2017; Hormann and Greiner 2000; Rabinovich et al. 2017; Schüller et al. 2013]
- Bijection
  - [Jiang et al. 2017; Smith and Schaefer 2015]
- Low boundary length
  - [Li et al. 2018; Poranne et al. 2017; Sorkine et al. 2002]

These methods do not consider PE!

Atlas Refinement



Input

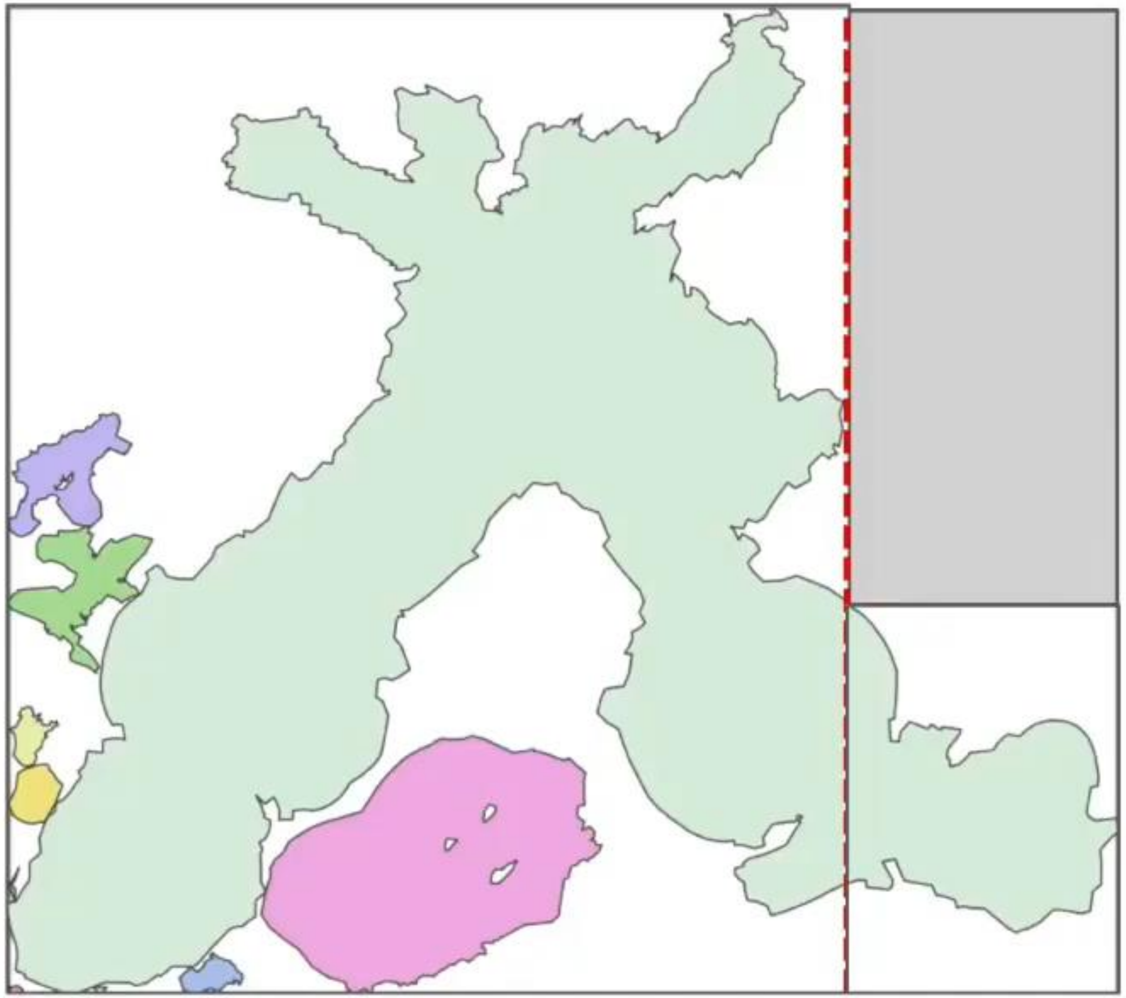


Bijective
High PE

Previous Work

Box Cutter [Limper et al. 2018]

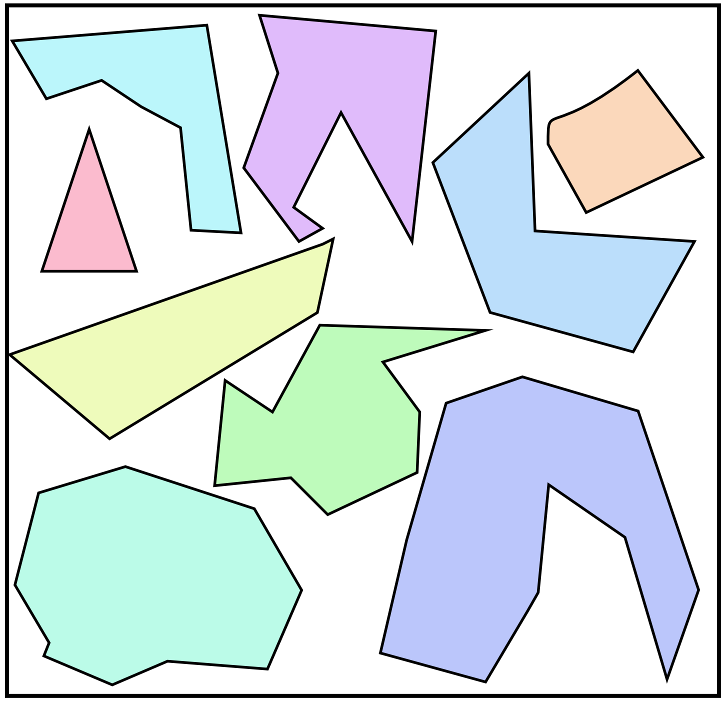
- Cut and repack



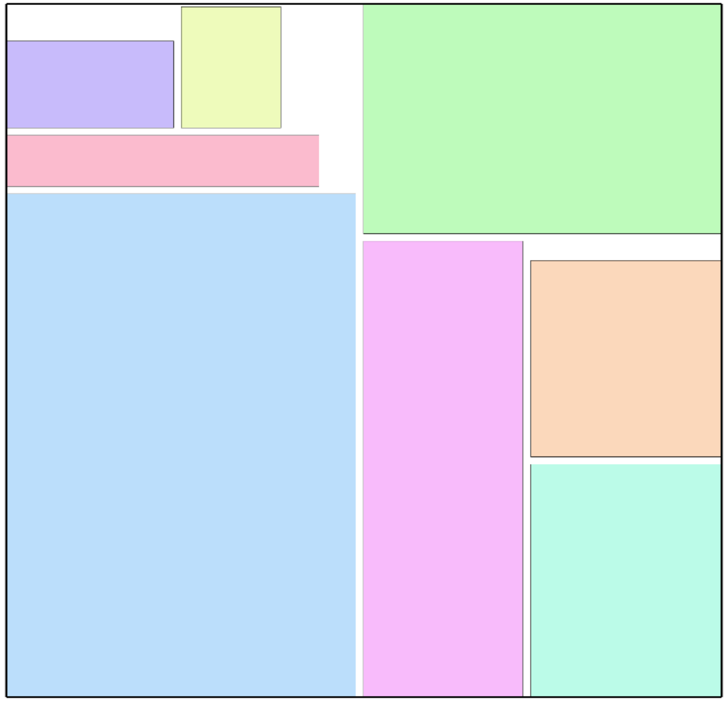
No guarantee for a high PE result!

Motivation

Packing Problems

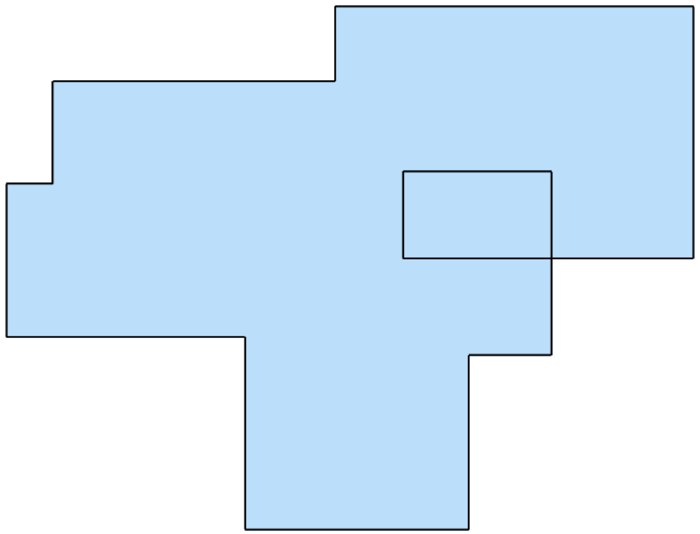


Irregular shapes
Hard to achieve high PE

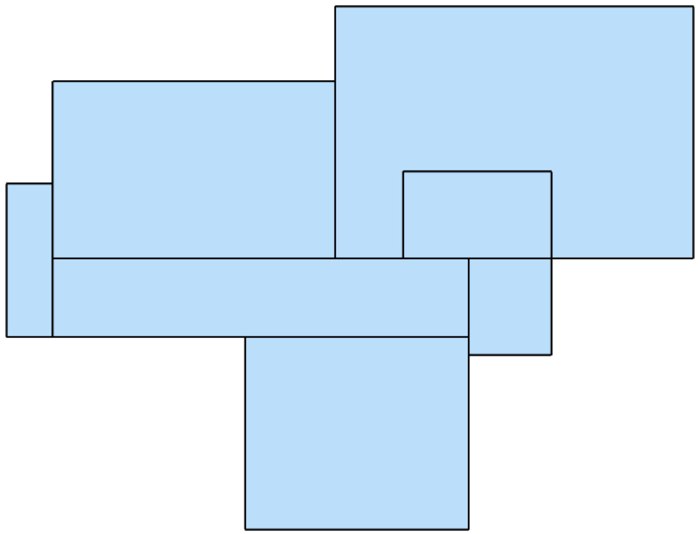


Rectangles
Simple to achieve high PE
Widely used in practice

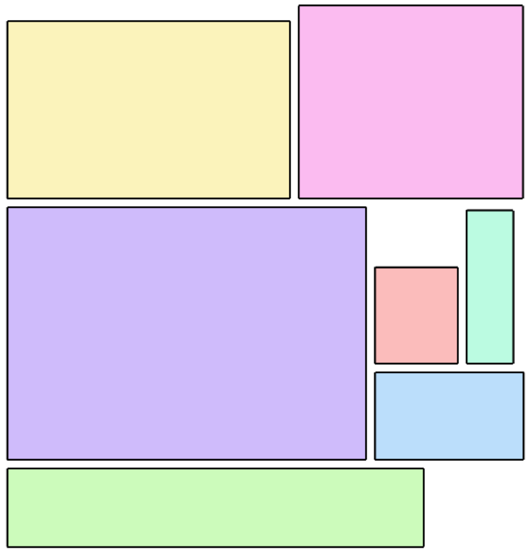
Axis-Aligned Structure



Axis-aligned structure

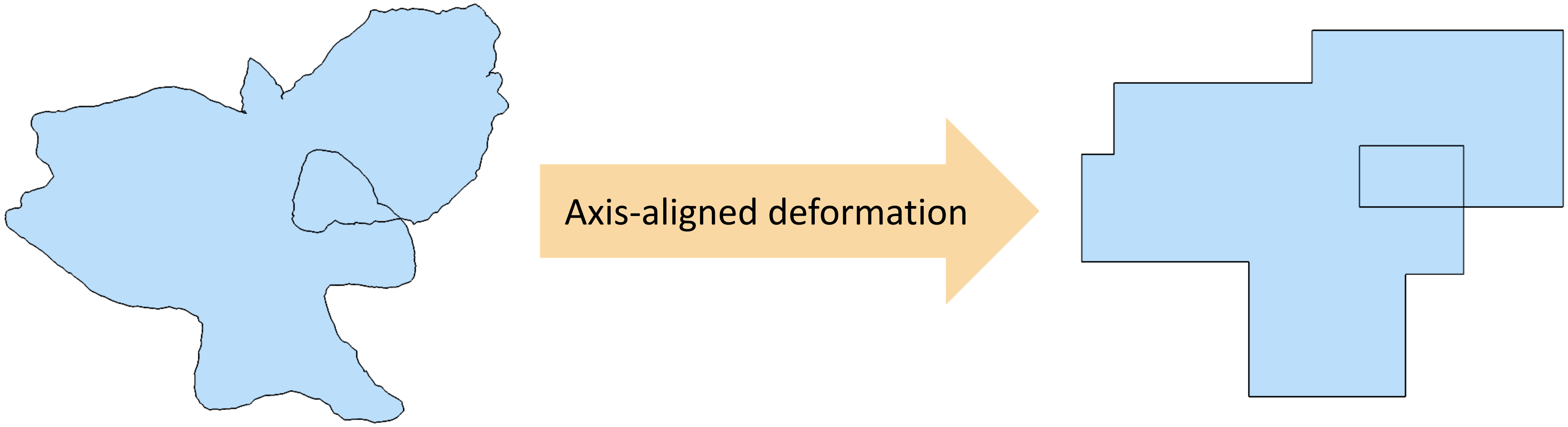


Rectangle decomposition



High PE (87.6%)!

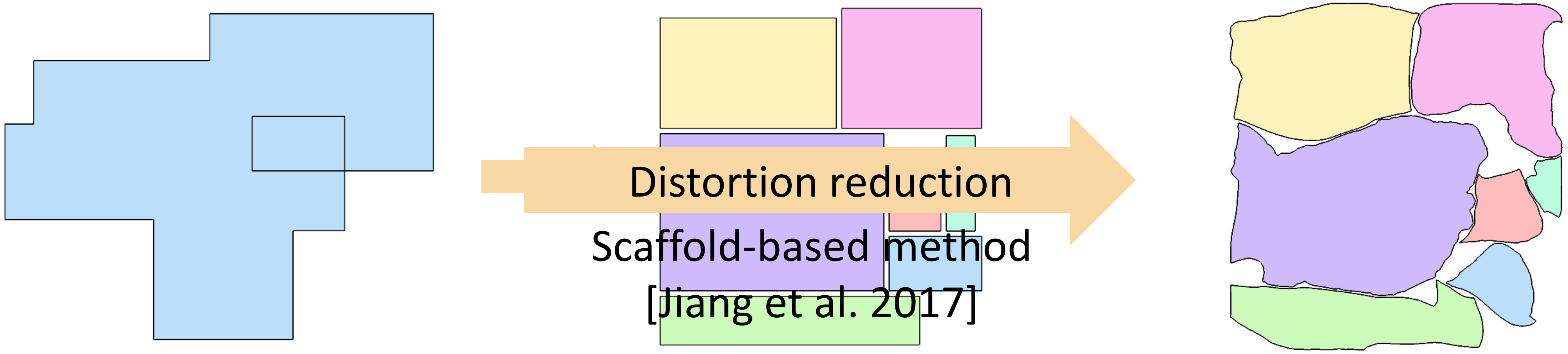
General Cases



Not axis-aligned

Axis-aligned
Higher distortion

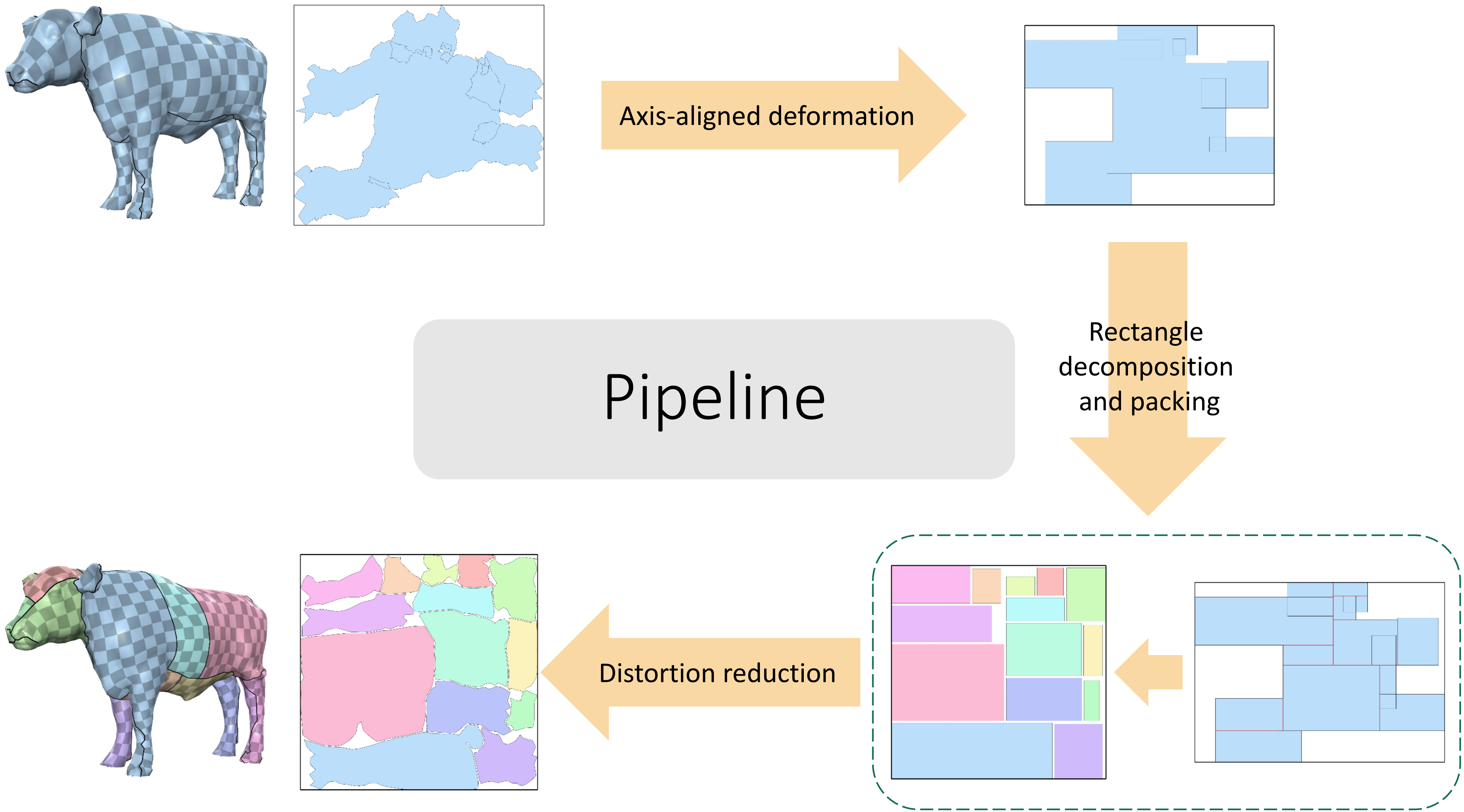
Distortion Reduction



Axis-aligned
High distortion

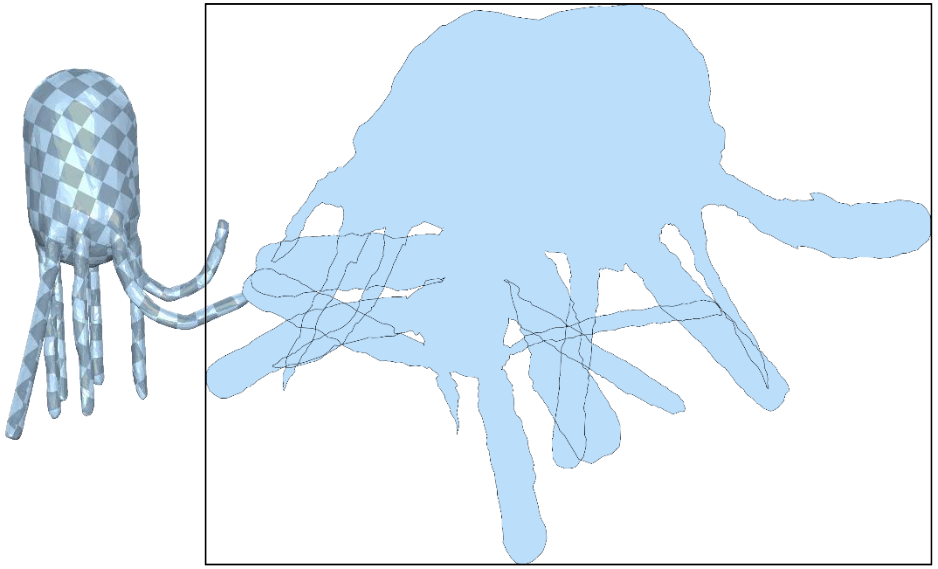
Bijective & High PE
High distortion

Bijective & High PE
Low distortion
Bounded PE

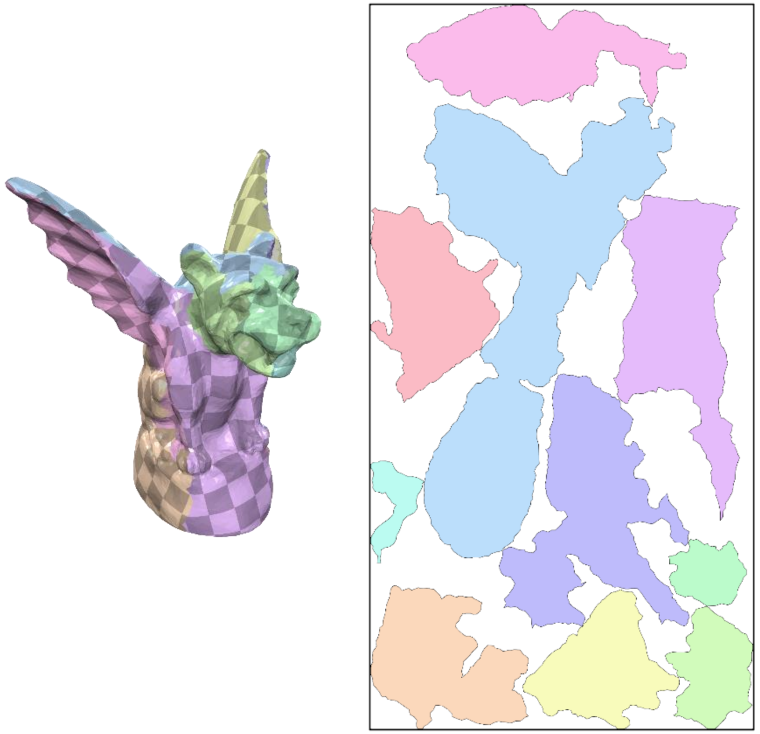

Axis-aligned deformation
Rectangle decomposition and packing
Pipeline
Distortion reduction

Axis-Aligned Deformation

- Input

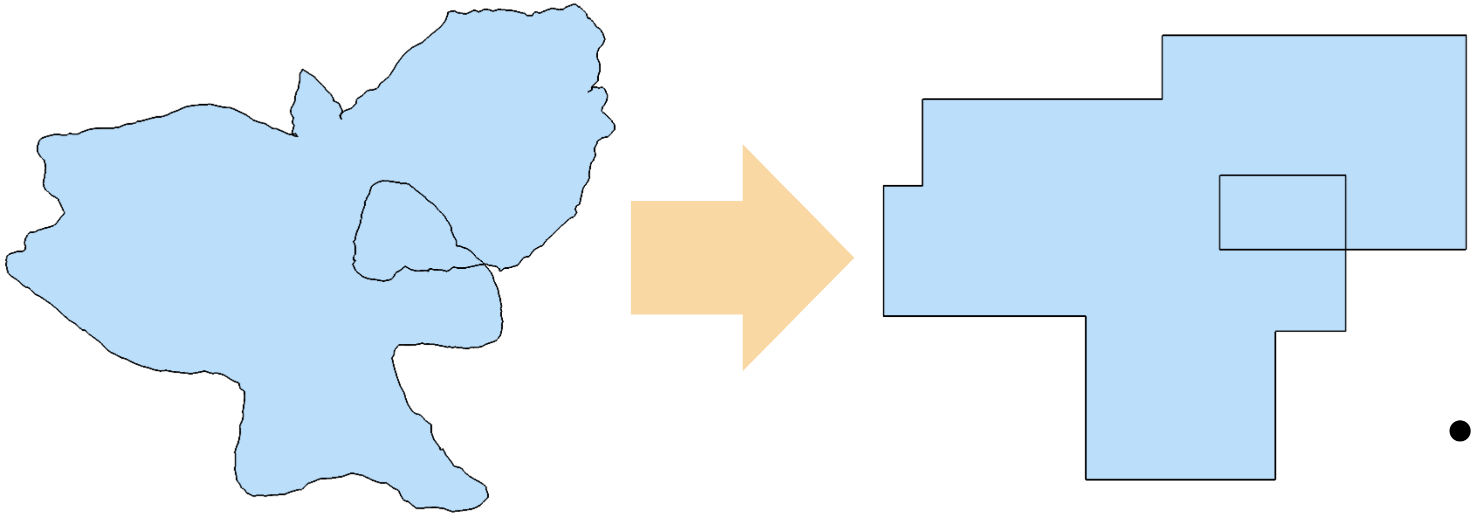


Single chart
Not bijective



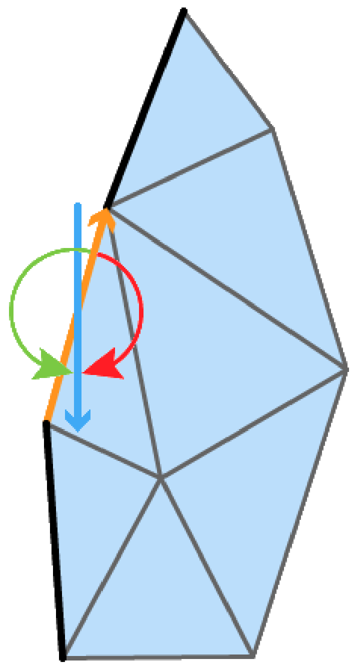
10 charts
Bijective

Axis-Aligned Deformation



- Targets of boundary edges
  - Smoothing
  - Labeling
- Deformation

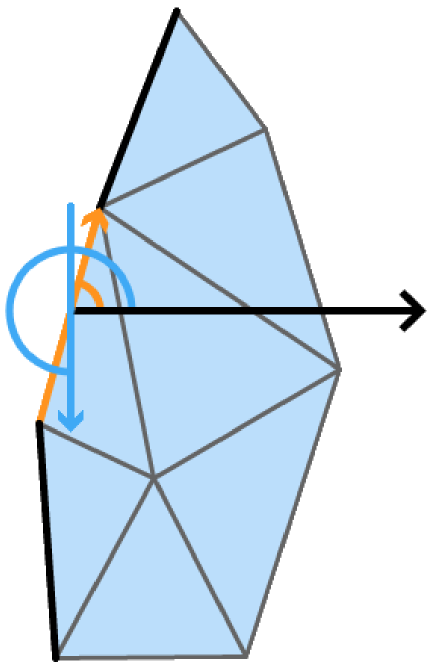
Axis-Aligned Deformation



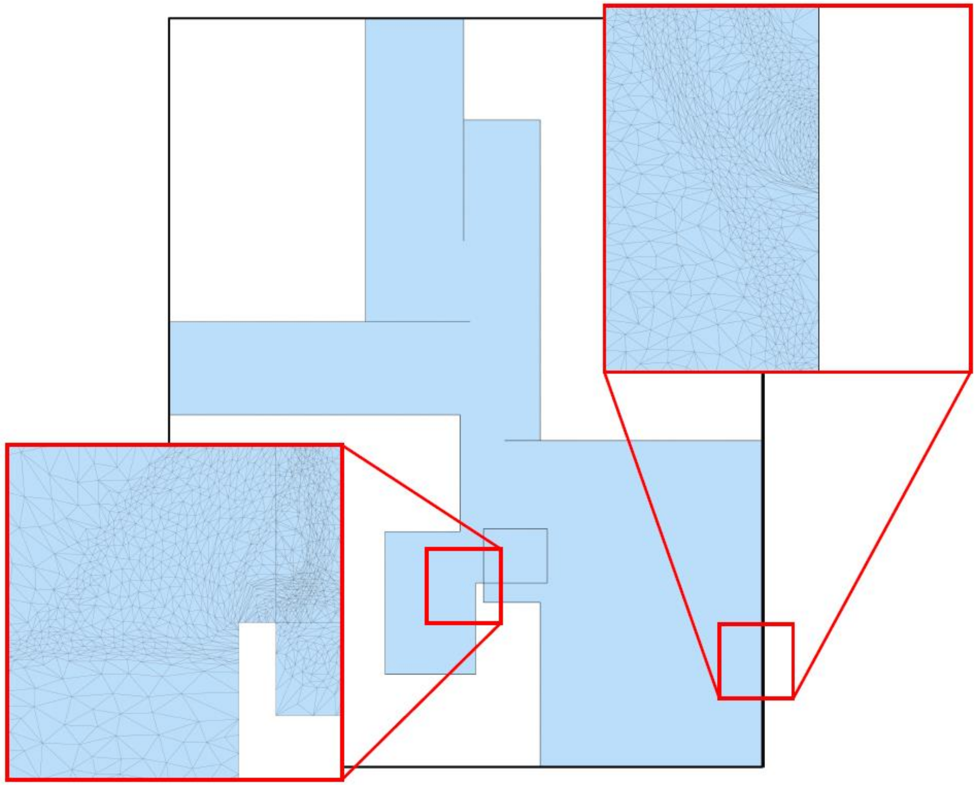
Direction vector
Ambiguous rotating directions

Fail!

Axis-Aligned Deformation

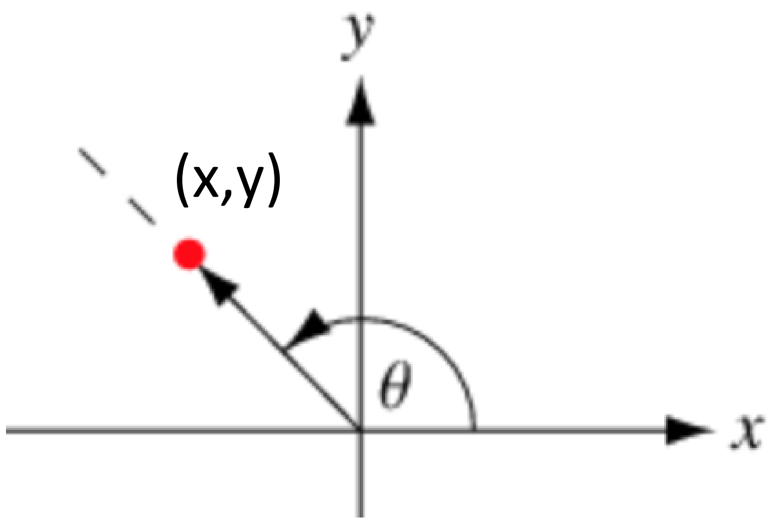


Polar angle
Clear rotating direction



Success!

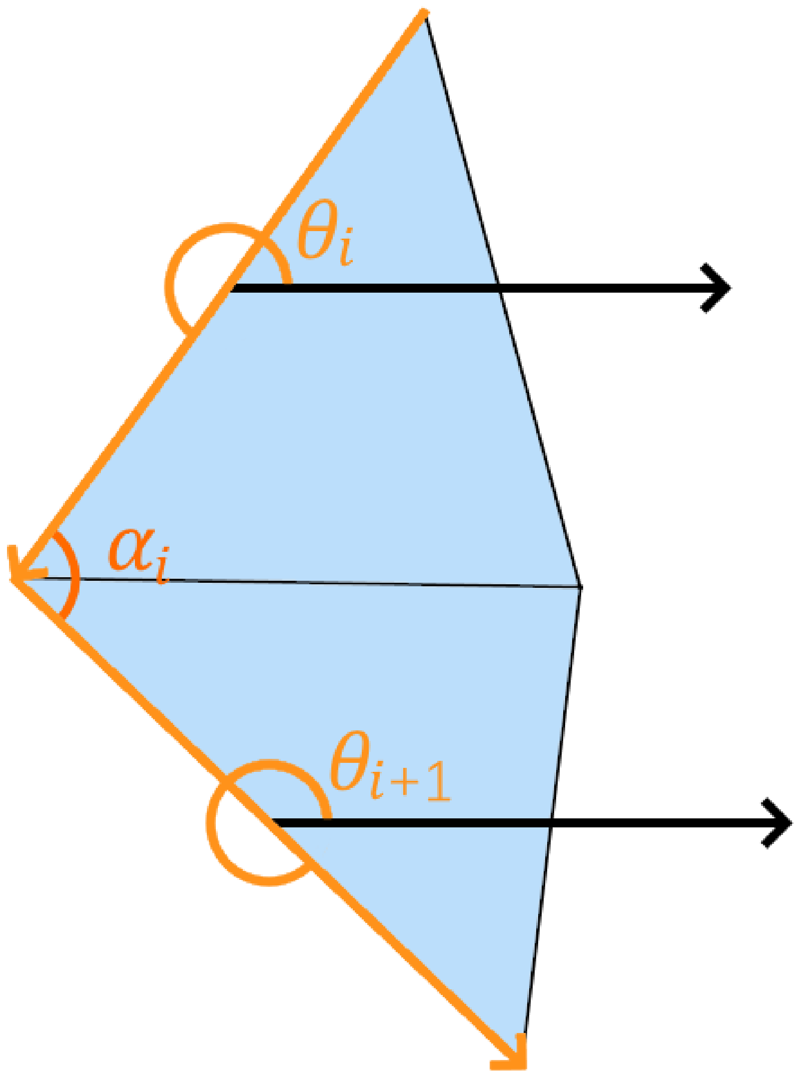
Polar Angle



$$\theta = \mathrm{atan2}(y, x) + 2k\pi$$

$$d\theta = \frac{xdy - ydx}{x^2 + y^2}$$

Polar Angle



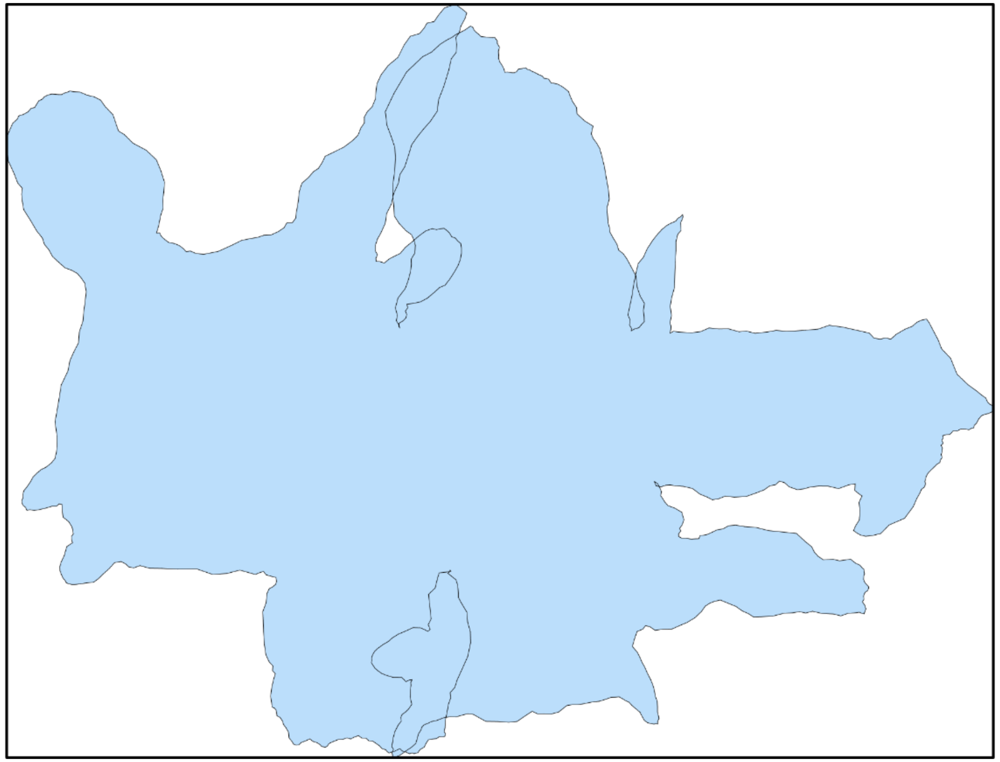
Discrete boundary curvature

$$\theta_{i+1} = \theta_i + \boxed{\pi - \alpha_i}$$

Gauss–Bonnet formula

$$\sum_i (\pi - \alpha_i) = 2\pi$$

Target Calculation



- Boundary smoothing
  - Gaussian smooth

$$G_\sigma(s_i^k) = \sum_{b_j} l_j \exp\left(-\frac{\mathrm{dist}(b_i, b_j)^2}{2\sigma^2}\right) s_j^k$$

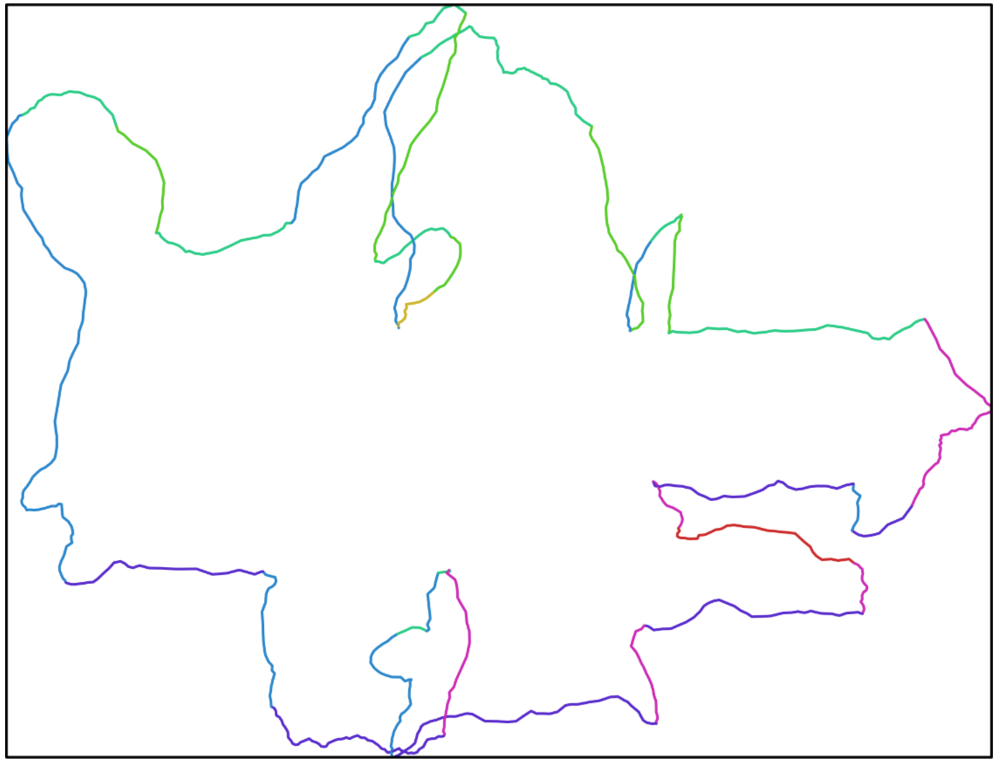
$$\hat{s}_i^k = G_\sigma(s_i^k)/\|G_\sigma(s_i^k)\|$$

  - Accept $\hat{s}_i^k$ if $\hat{s}_i^k \cdot s_i^k \geq 0$
  - Update interior angles

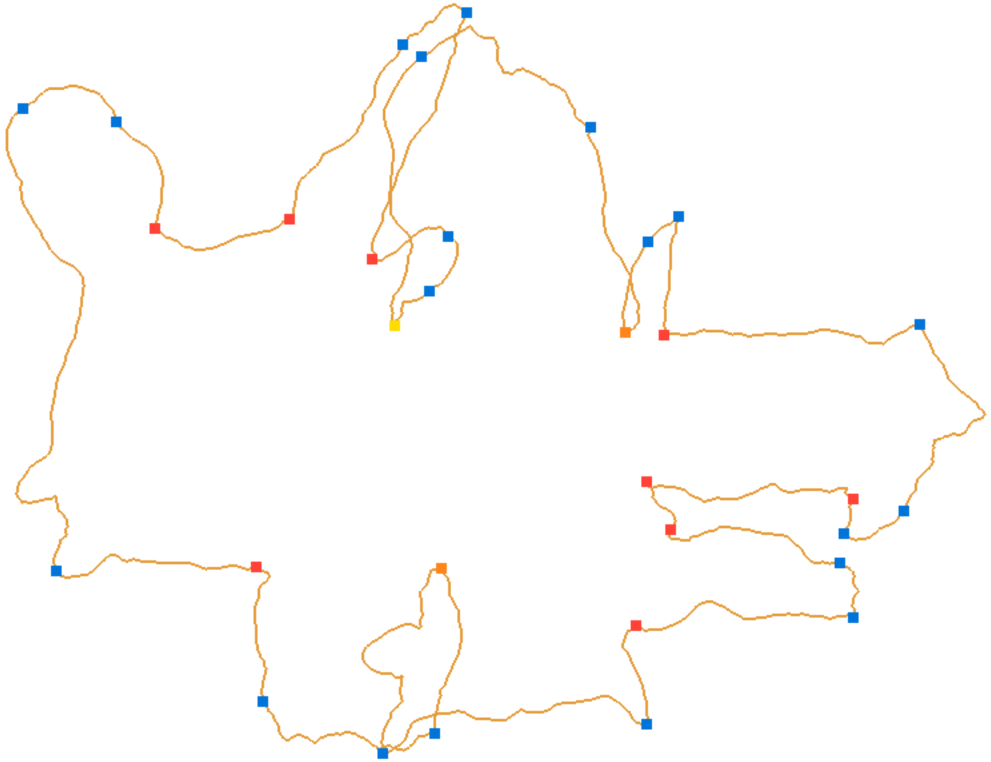
$$\hat{\alpha}_i^{k+1} = \hat{\alpha}_i^k + \angle(s_i^k, s_i^{k+1}) - \angle(s_{i+1}^k, s_{i+1}^{k+1})$$

- Global rotation
- Polar angle axis-alignment

Axis-Aligned Deformation



Target polar angle Θ_i



Corners

Axis-Aligned Deformation

- Energy of boundary alignment

$$E_{\text{edge}}(\mathbf{b}_i) = \overset{\text{Rotate polar angle}}{\boxed{\frac{1}{2}(1-\gamma)\left(\theta_i - \frac{\pi}{2}\Theta_i\right)^2}} + \overset{\text{Keep length}}{\boxed{\frac{1}{2}\gamma\left(\frac{l_i}{l_i^0} - 1\right)^2}}$$

$$E_{\text{align}}(\mathbf{c}) = \sum_{i=1}^{N_b} \frac{l_i^0}{l^0} E_{\text{edge}}(\mathbf{b}_i)$$

Axis-Aligned Deformation

- Energy of isometric distortion(symmetric Dirichlet)

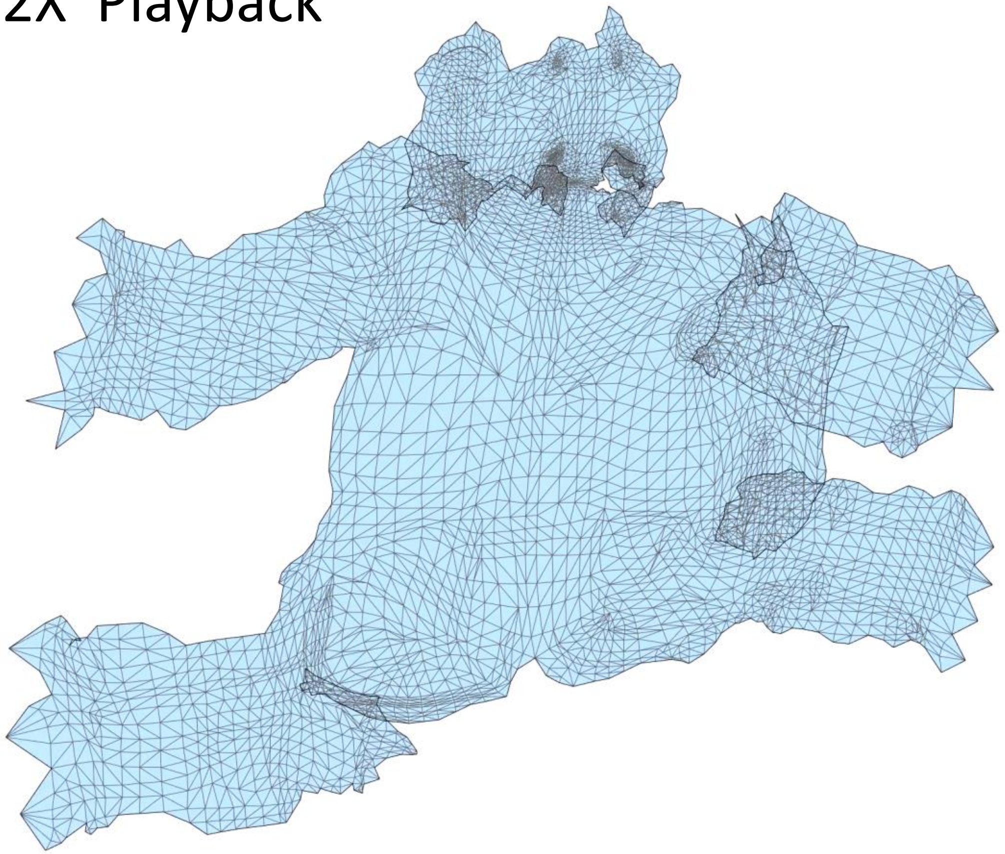
$$E_{\mathrm{d}}(\mathrm{c}) = \frac{1}{4} \sum_{\mathrm{f_i} \in \mathrm{F^C}} \frac{\mathrm{Area}(\mathrm{f}_i)}{\mathrm{Area}(\mathrm{M^C})} \left(\|J_i\|_F^2 + \|J_i^{-1}\|_F^2 \right)$$

Keep low distortion and orientation consistency.

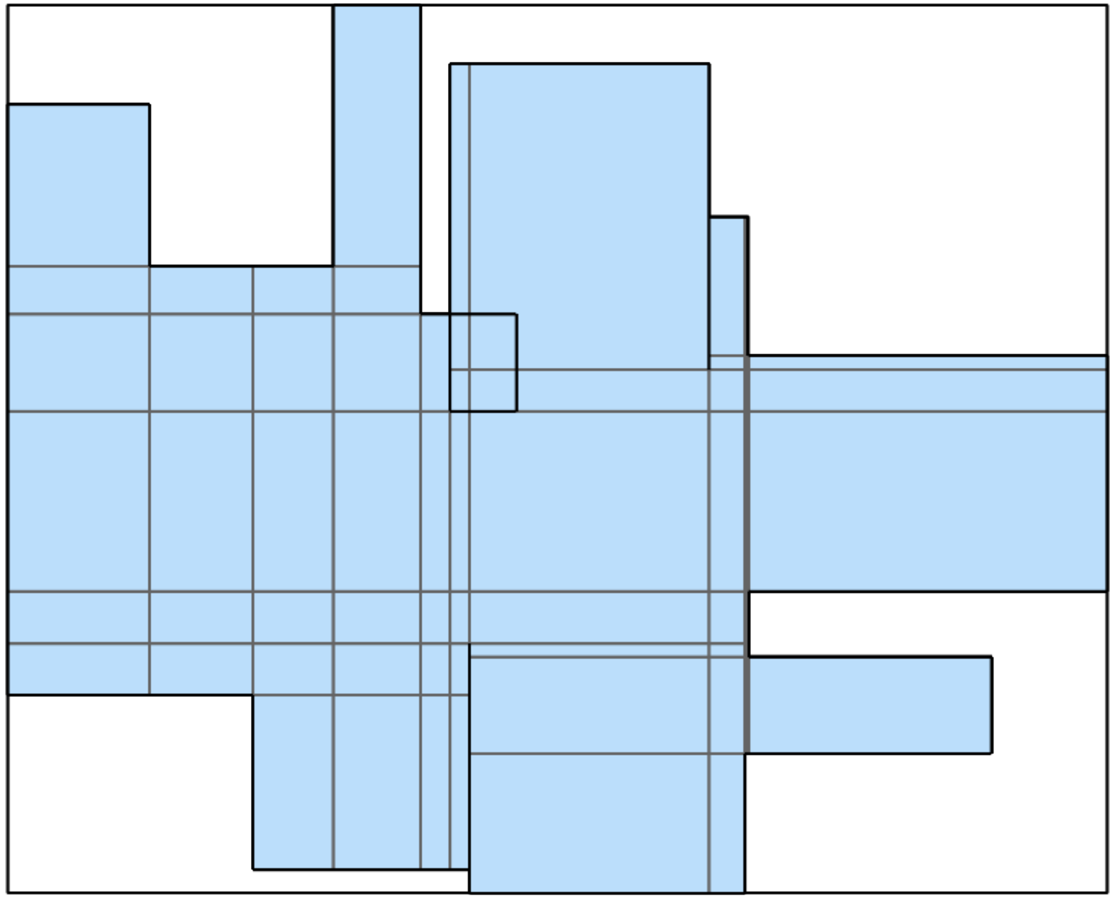
Axis-Aligned Deformation

$$\begin{array}{cc} \min_{\mathrm{c}} & E_{\mathrm{d}}(\mathrm{c}) + \lambda E_{\mathrm{align}}(\mathrm{c}) \\ \text{s.t.} & \det J_i > 0, \forall i \end{array}$$

0.2X Playback



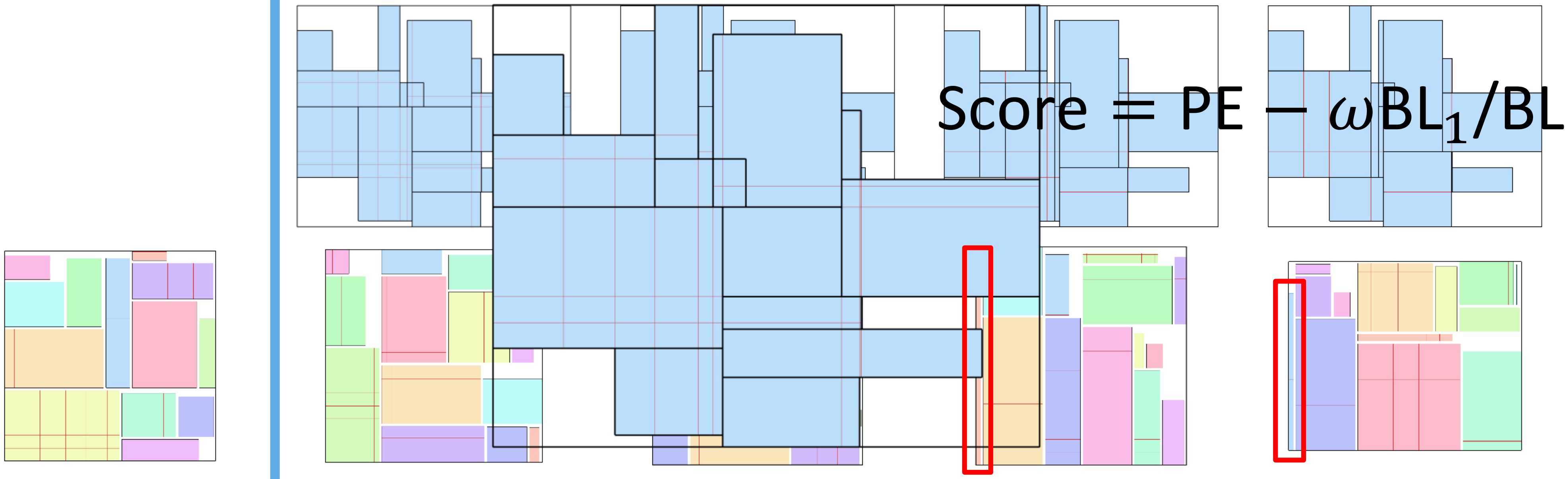
Rectangle Decomposition and Packing



The faces are all rectangles.
But the number is too many.

Rectangle Decomposition and Packing

- Motorcycle graph algorithm



$$\text{Score} = \text{PE} - \omega \text{BL}_1/\text{BL}_0$$

PE	87.0%	83.6%	84.4%
Score	0.688	0.659	0.658

Distortion Reduction

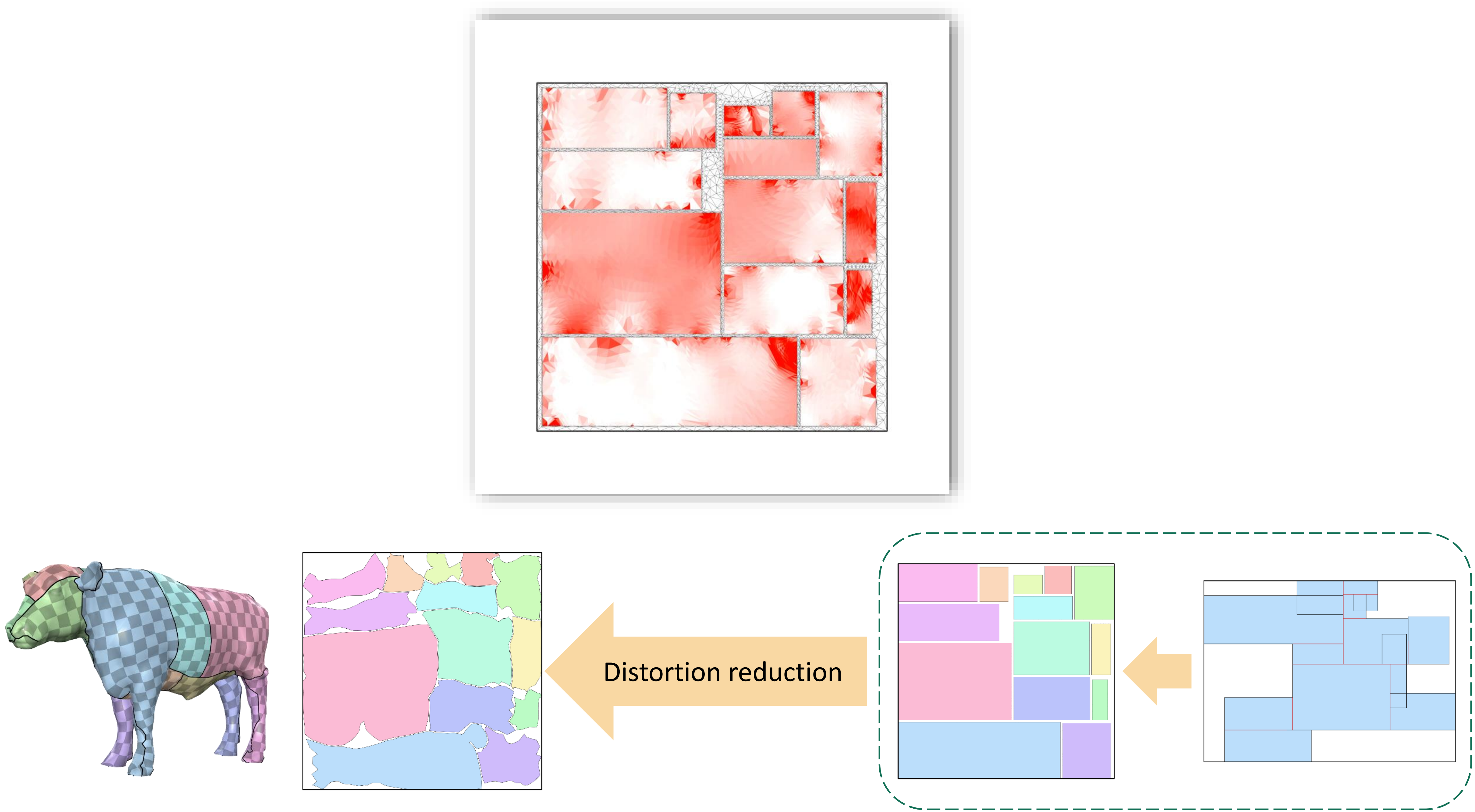
Isometric energy

$$\min_{\mathrm{C}} E_{\mathrm{reduction}} = \boxed{E_{\mathrm{d}}(\mathrm{C})} + \boxed{E_{\mathrm{PE}}(\mathrm{C})}$$

$$\text{s.t. } \Phi \text{ is } \boxed{\text{bijective}}$$

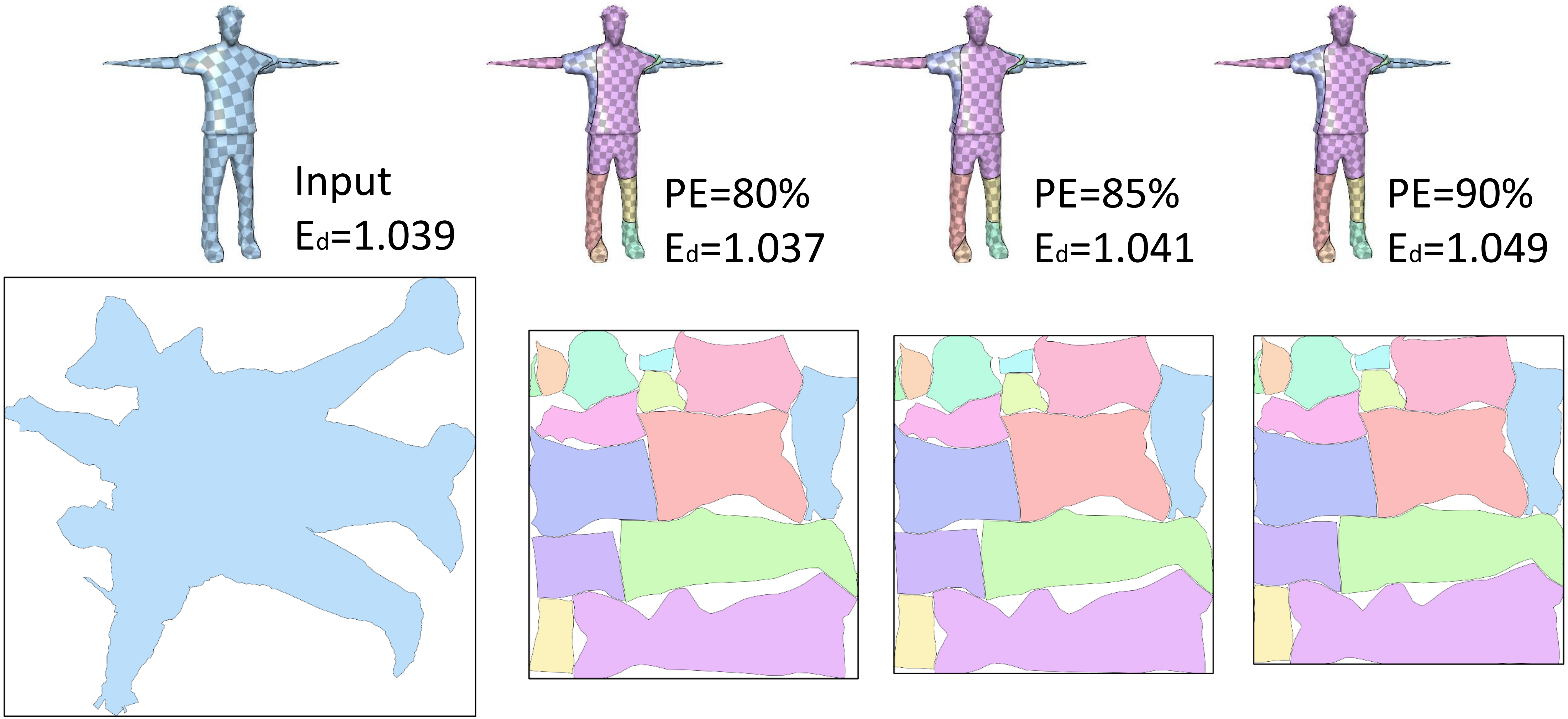
Barrier function of PE bound

Scaffold-based method [Jiang et al. 2017]

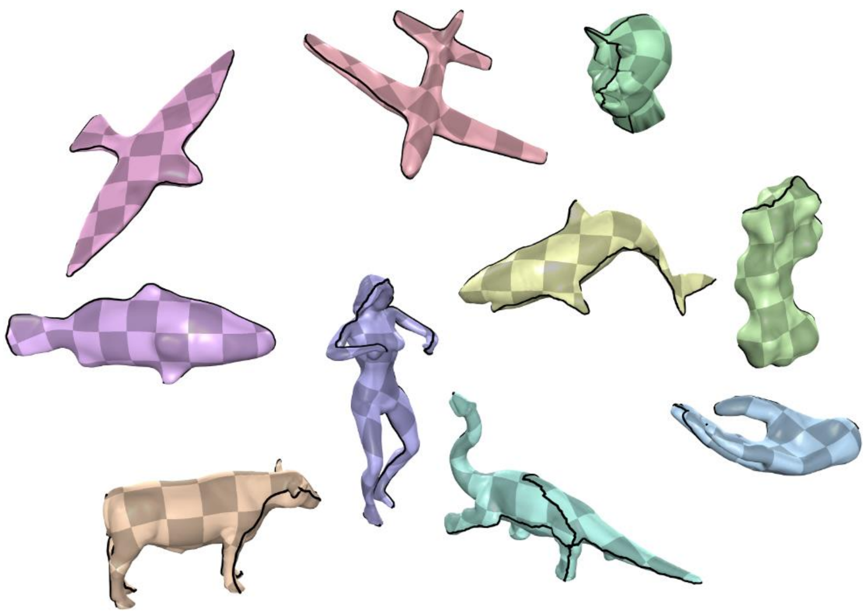

Distortion reduction

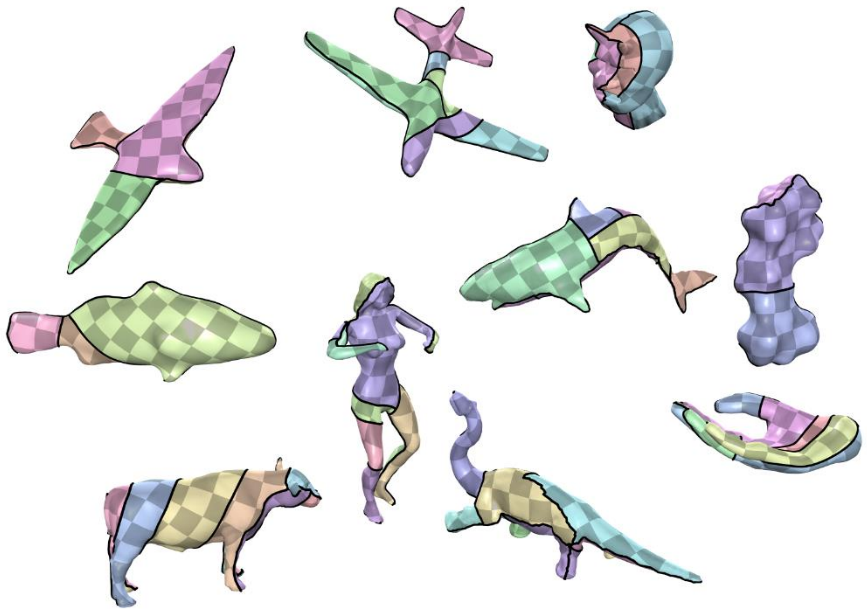
Experiments

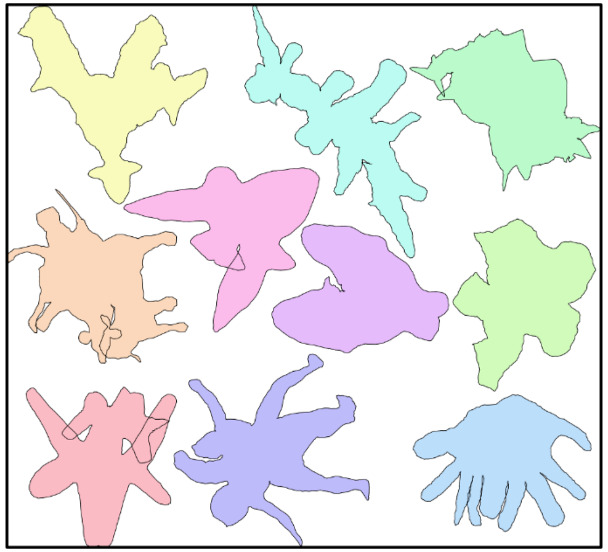
PE Bound



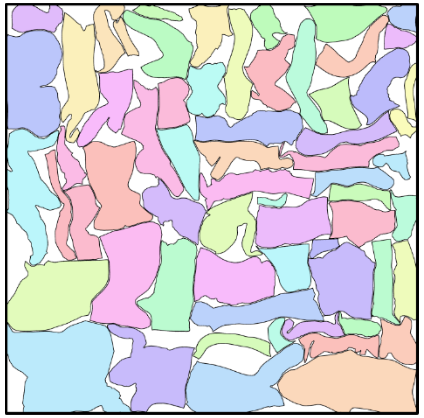
Collection of Models





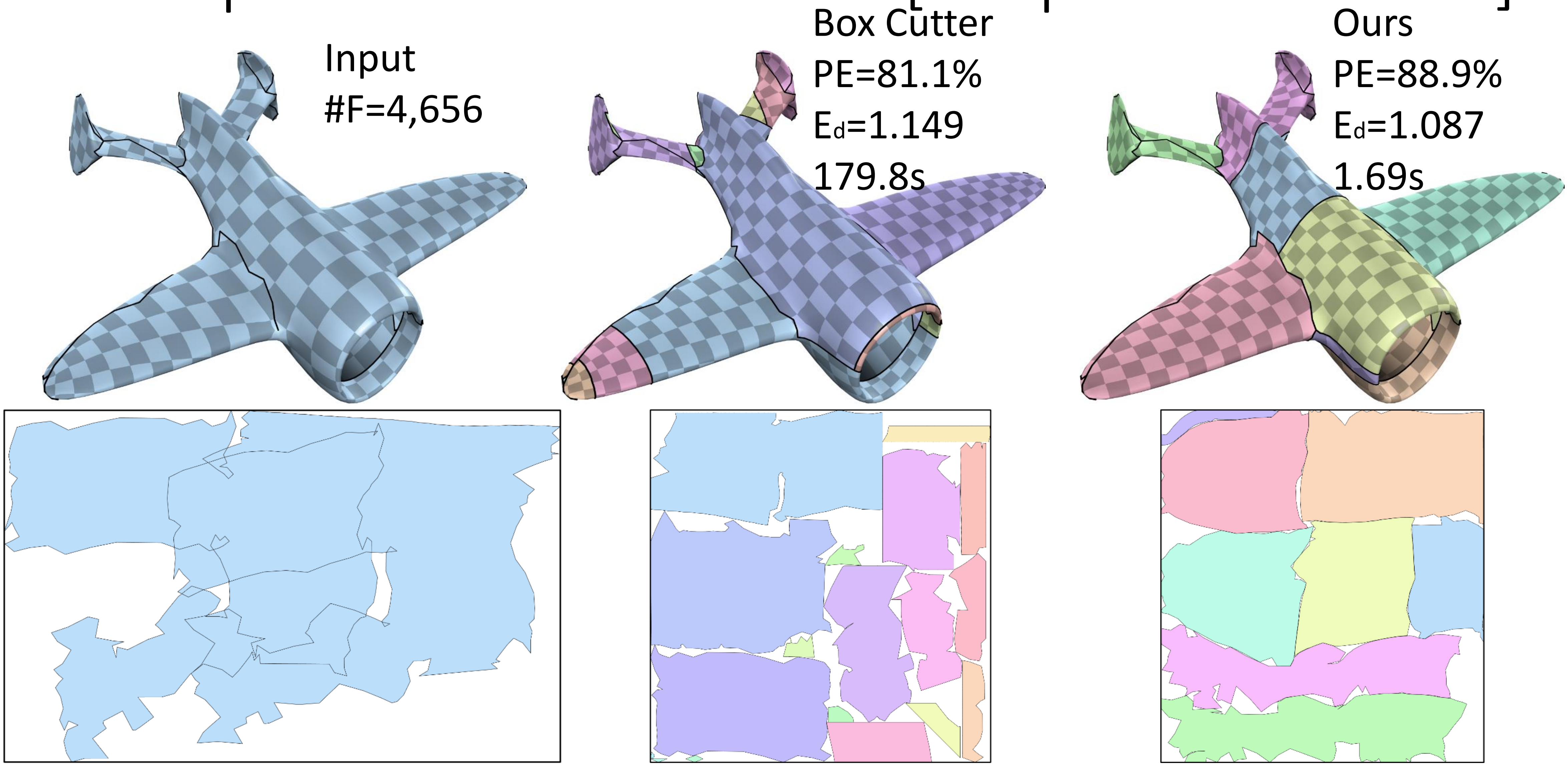


Input
E_d=1.022

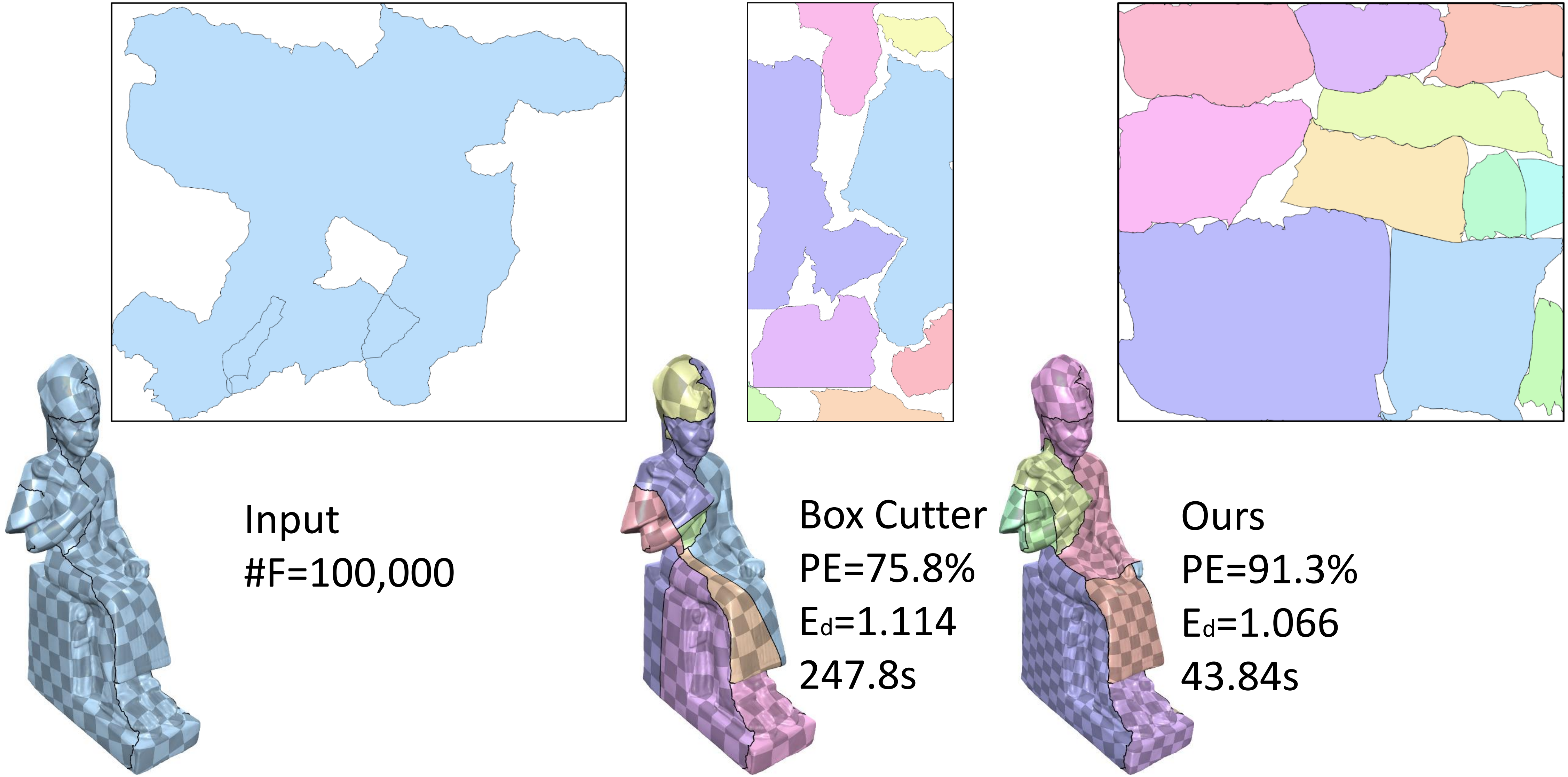


PE=80%
E_d=1.026

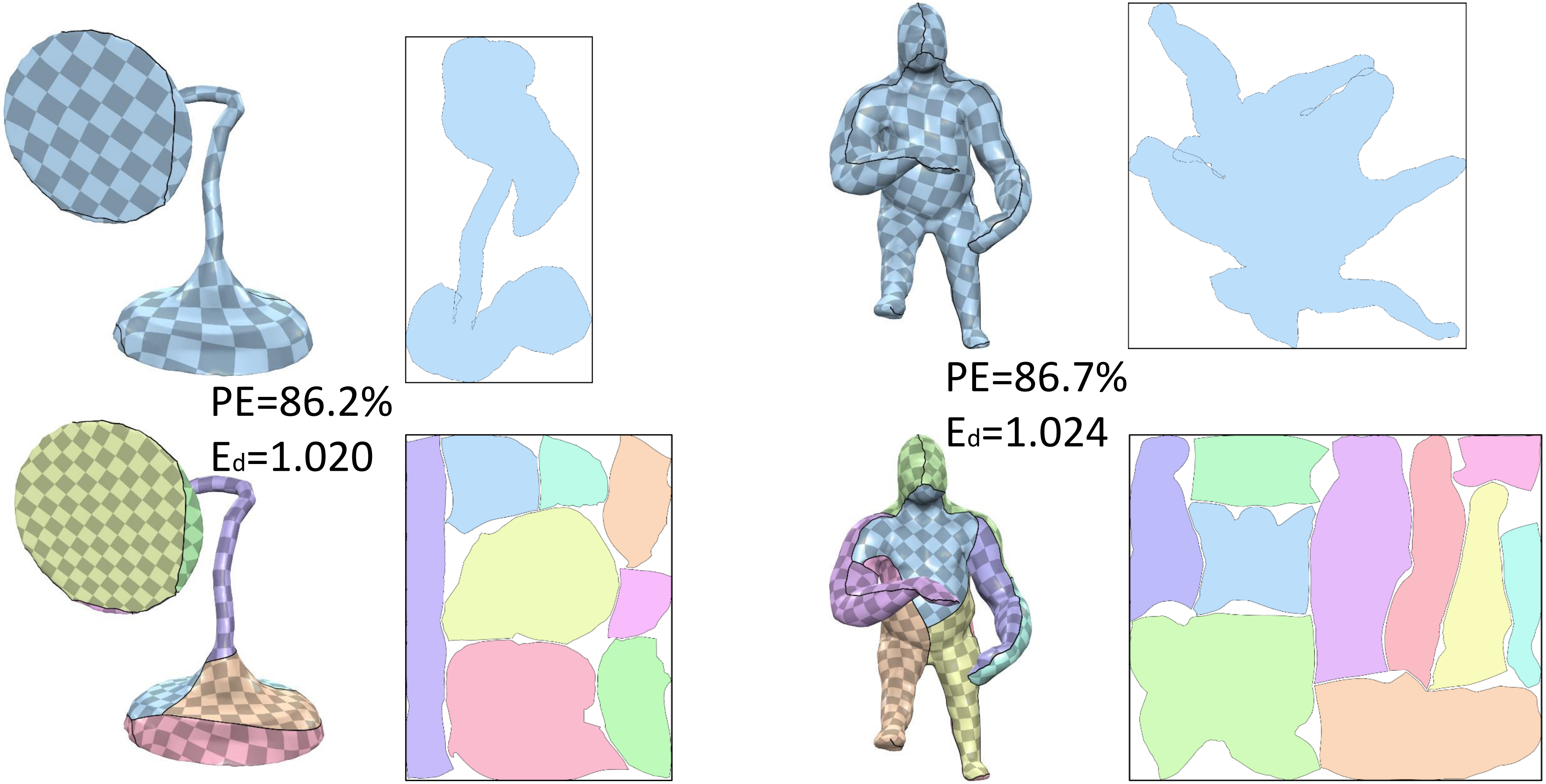
Comparison to Box Cutter [Limper et al. 2018]



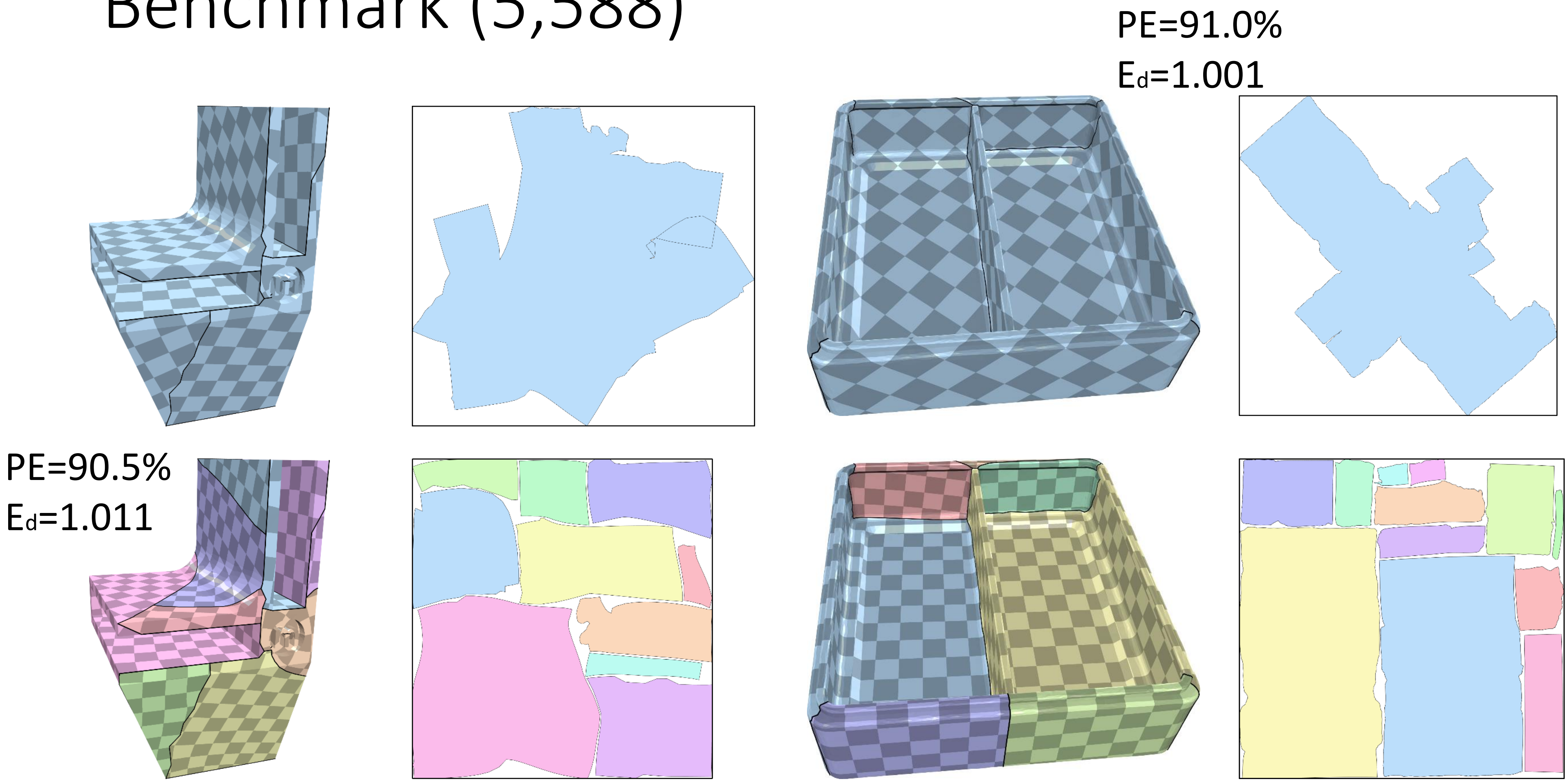
Comparison to Box Cutter [Limper et al. 2018]



Benchmark (5,588)



Benchmark (5,588)



Texture

PE=80.4%
E_d=1.119

PE=92.6%
E_d=1.018

Single-source Geodesics [Prada et al. 2018]

PE=89.1%
E_d=1.041

Conclusion

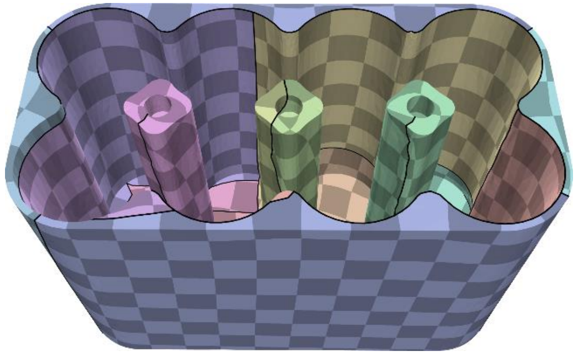
Conclusions

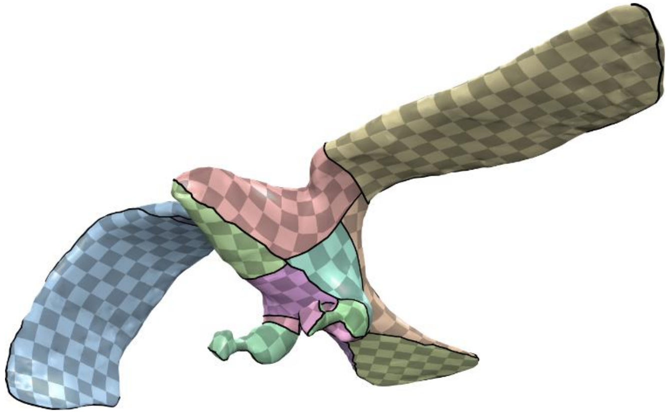
- Our method provides a novel technique to refine input atlases with bounded packing efficiency.

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

Limitation & Future Work

- 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!