Atlas generation

Xiao-Ming Fu

Outlines

- Definition

- Mesh cutting
- Chart parameterization
  - Bijective, low distortion
- Chart packing

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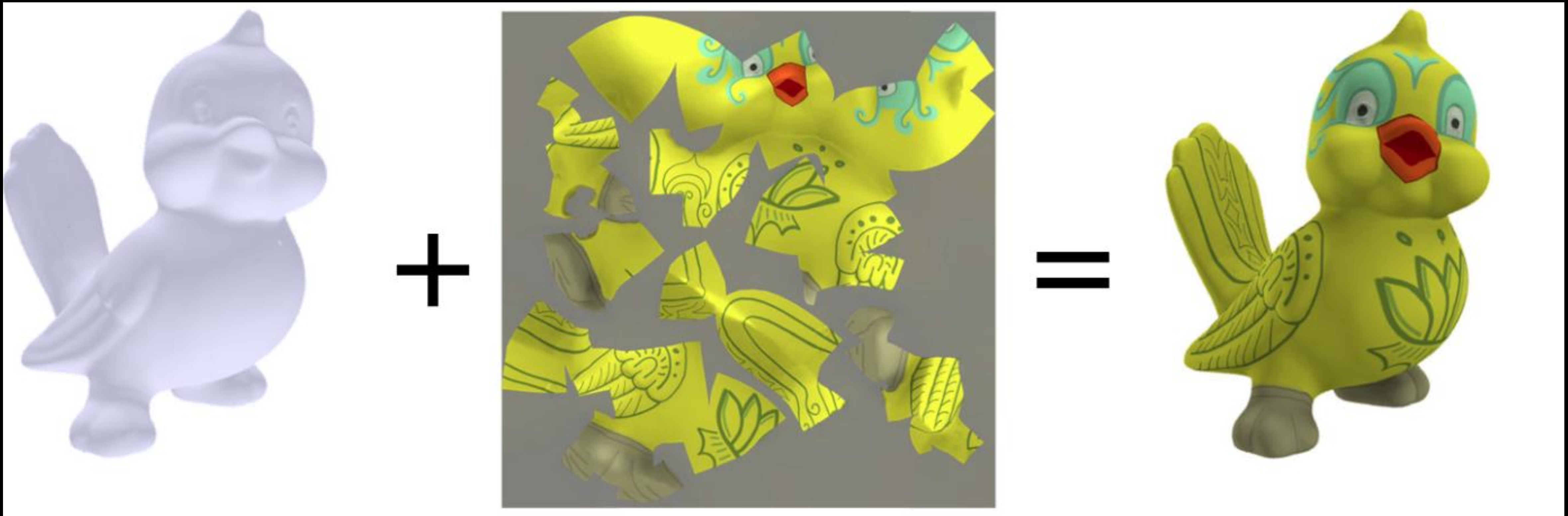
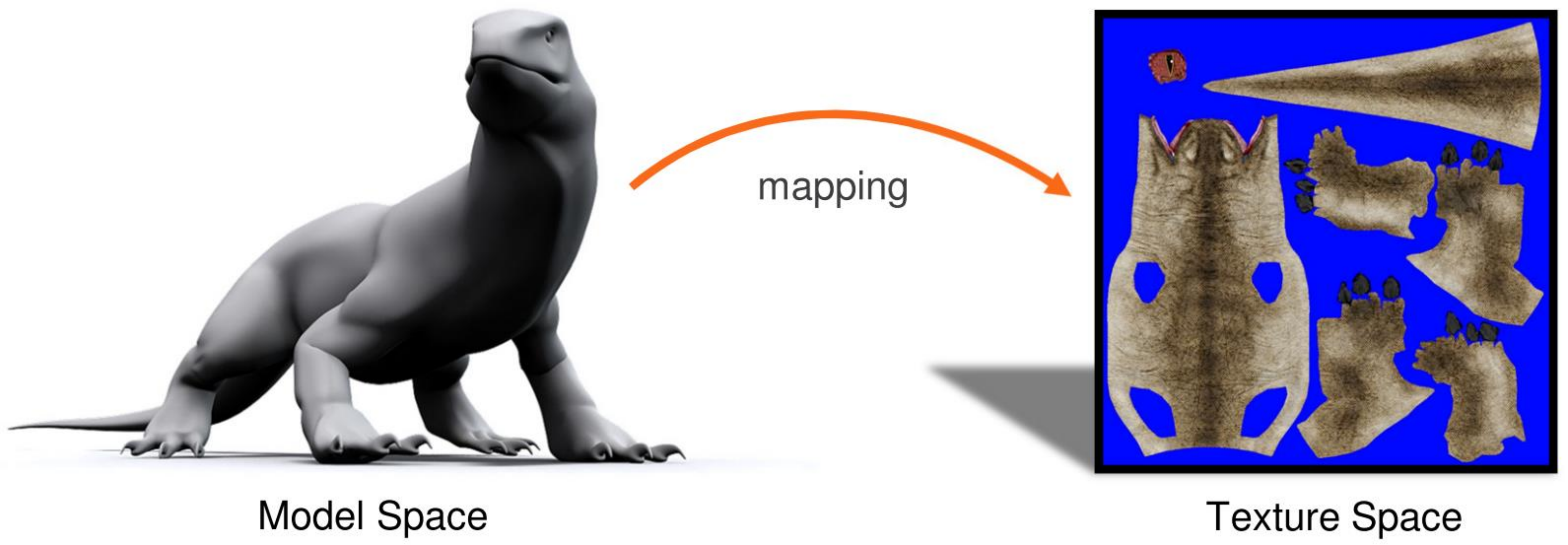
Texture Mapping

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



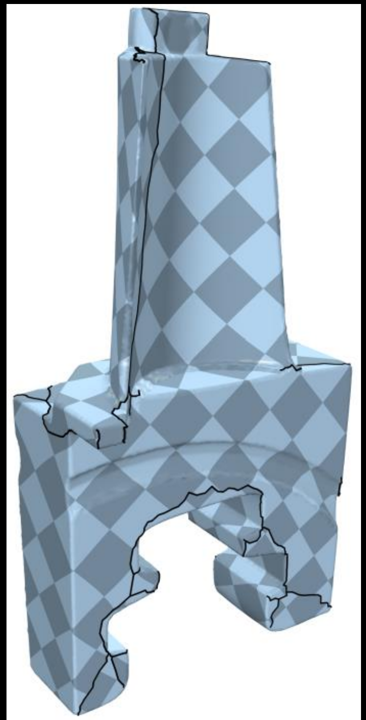
Atlas

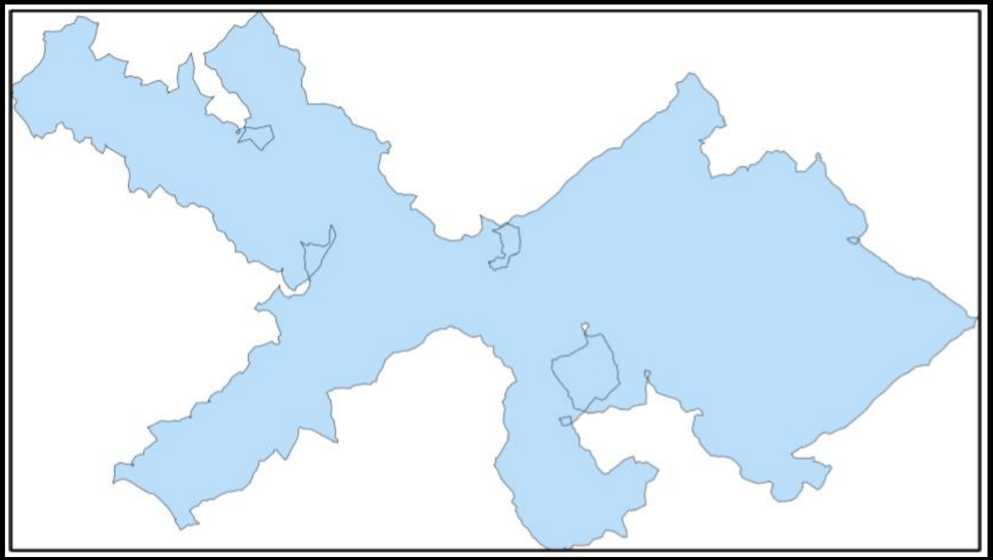
- Requires defining a **mapping** from the model space to the texture space.

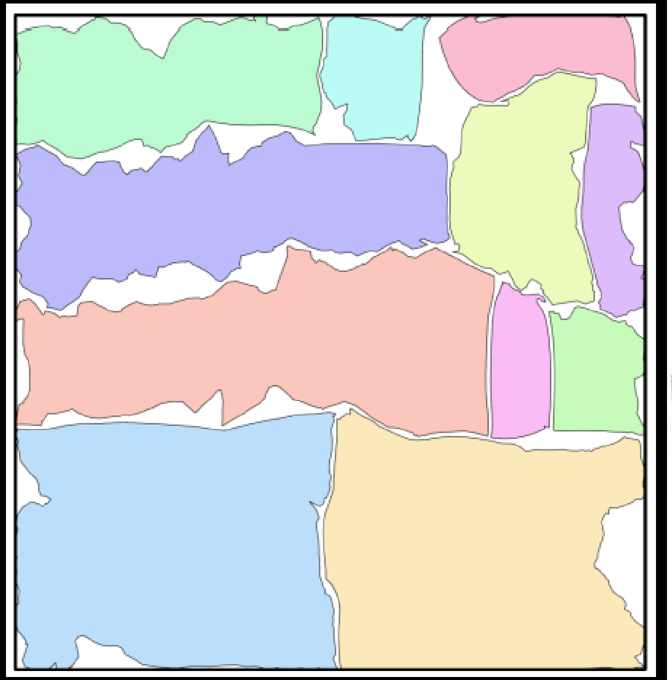


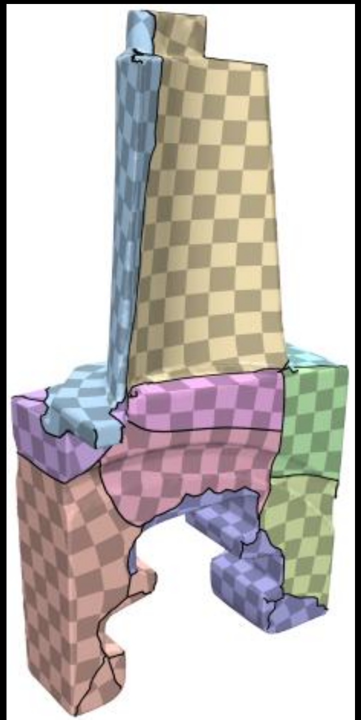
Generation process

Mesh Cutting → Parameterizations → Packing



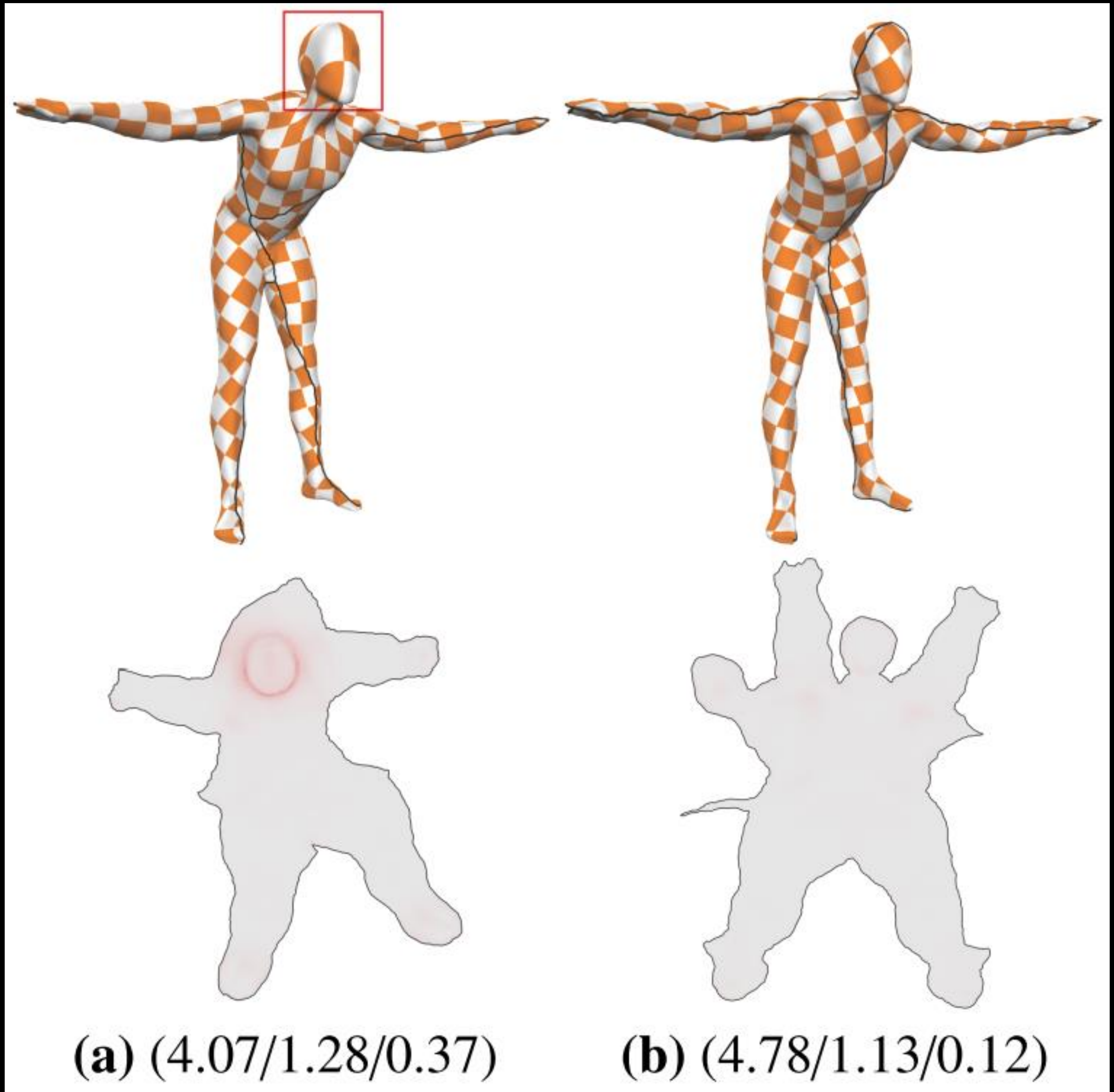




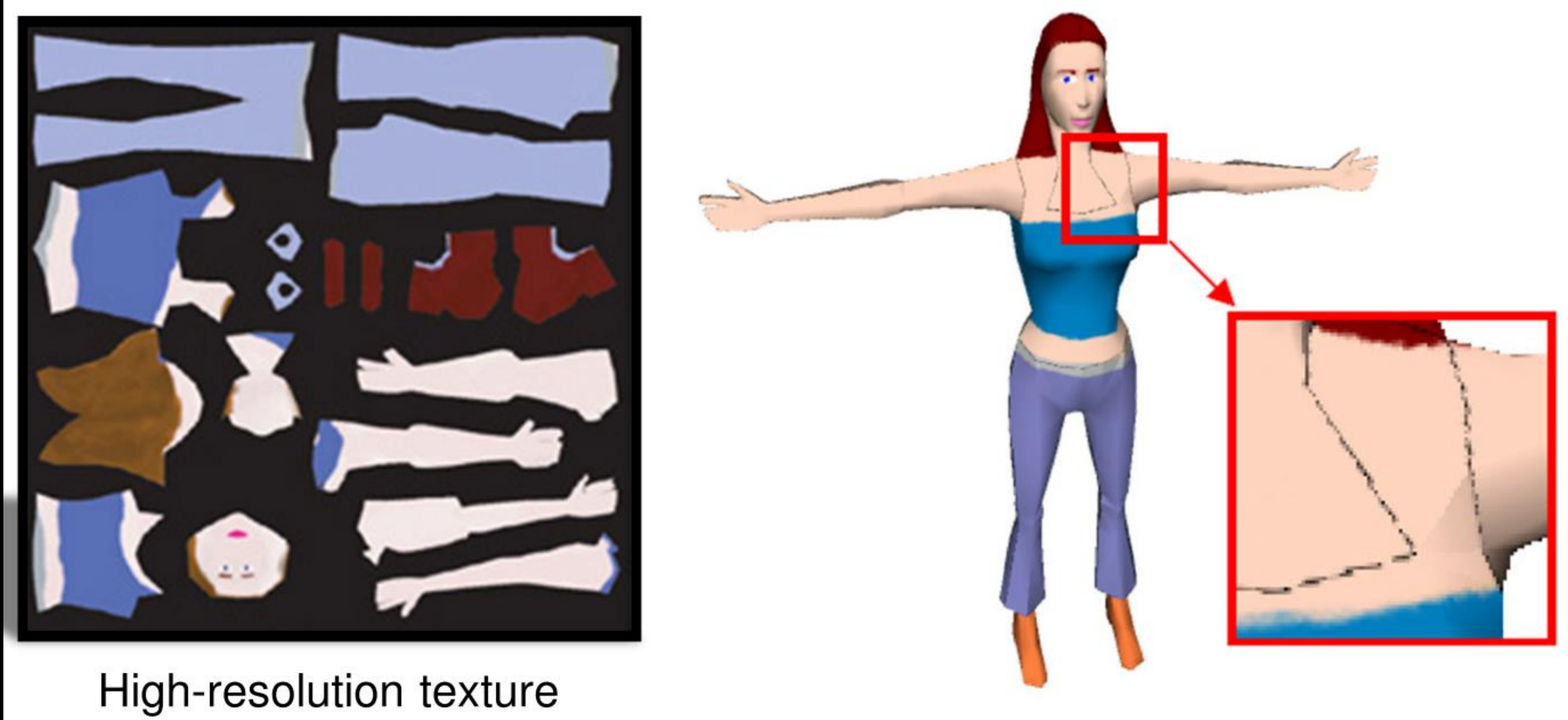


Mesh Cutting

- Low distortion
- As short as possible length

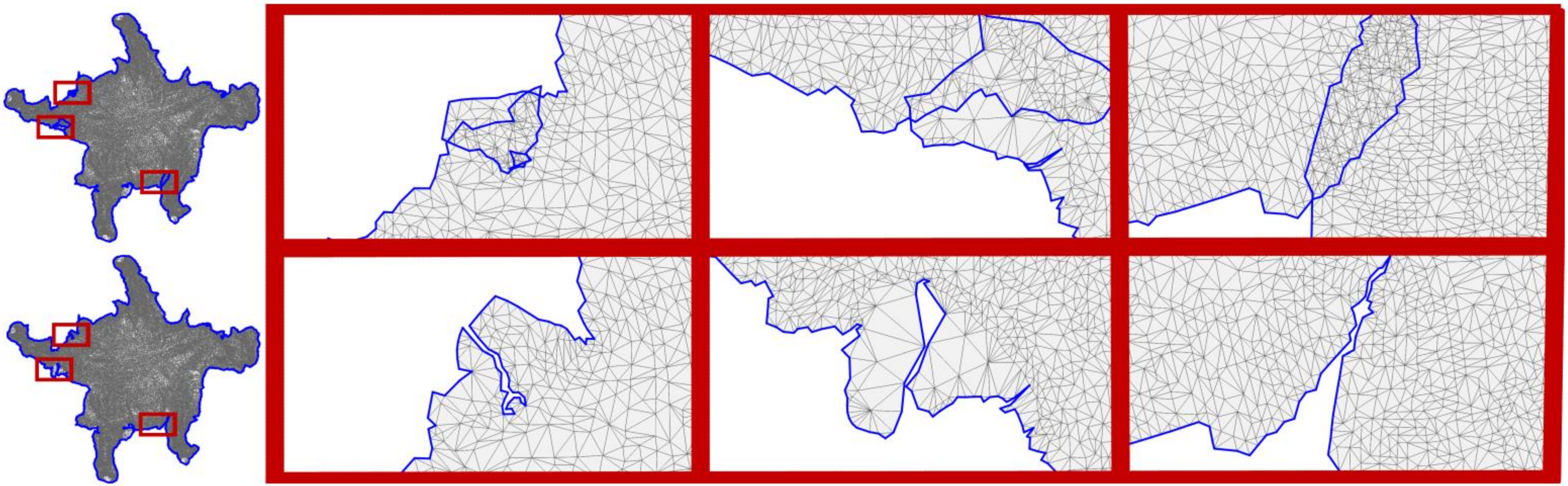


Seams introduce filtering artifacts



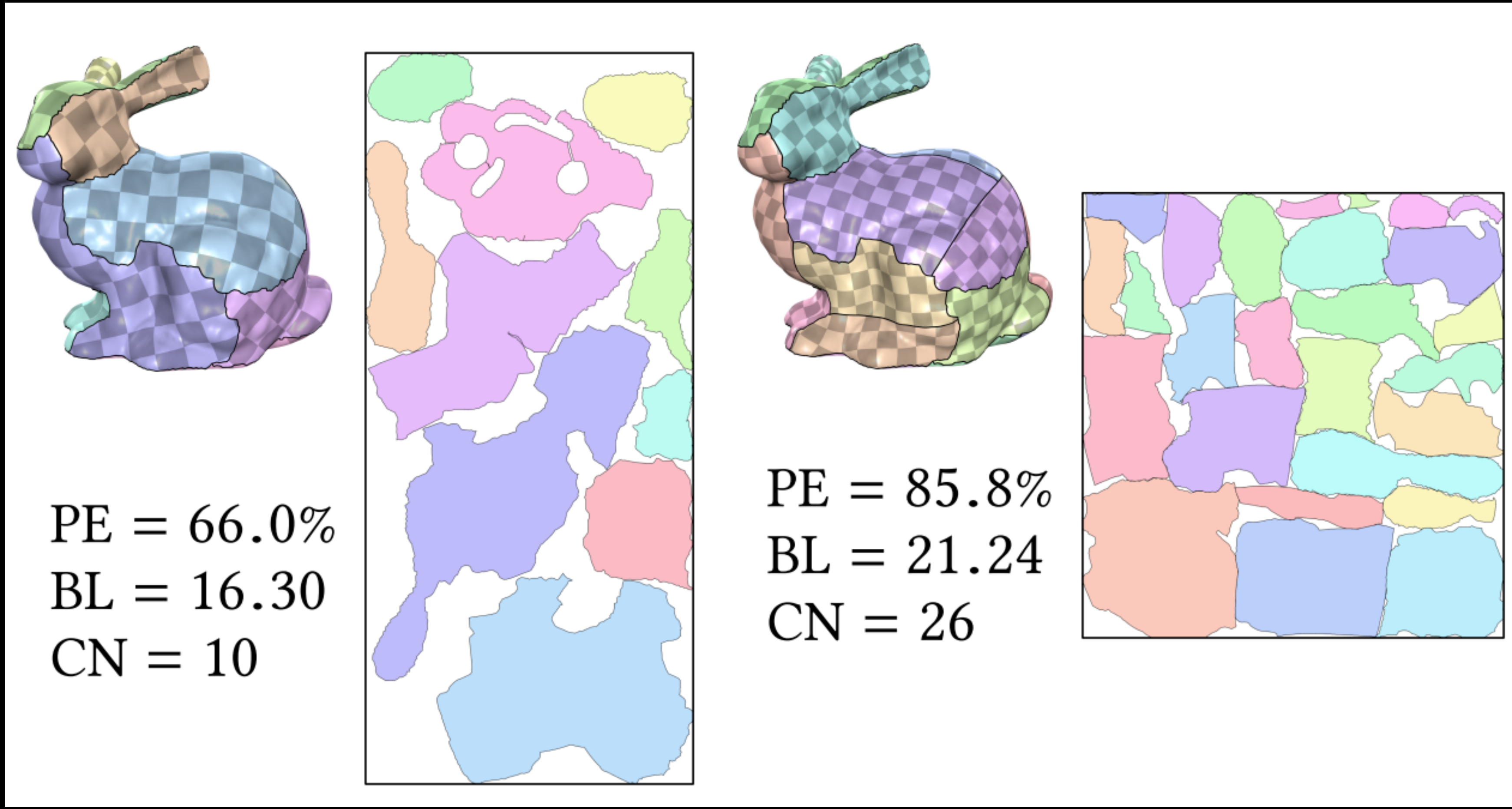
Parameterizations

- Bijective
- Low isometric distortion



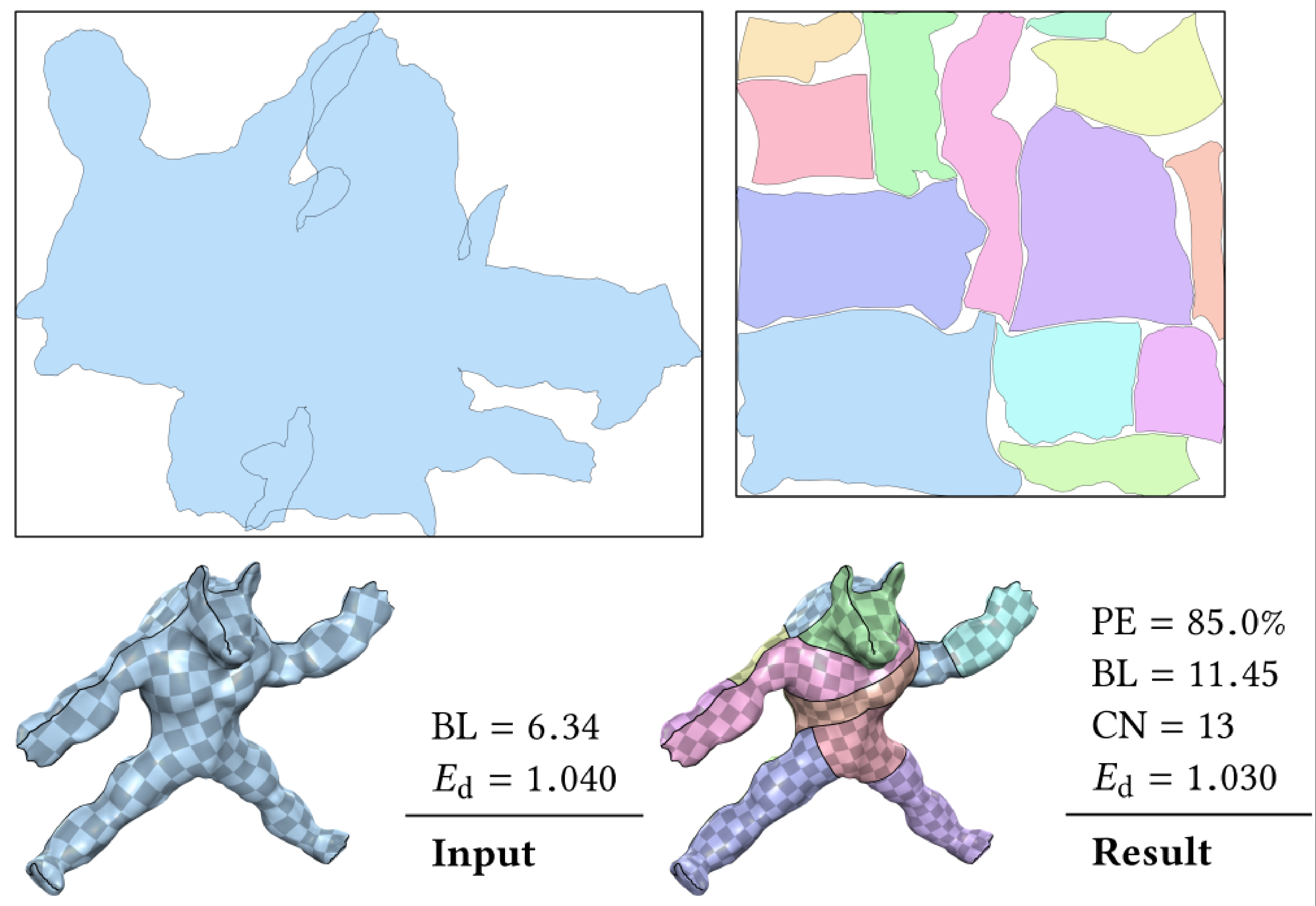
Packing

- High packing efficiency



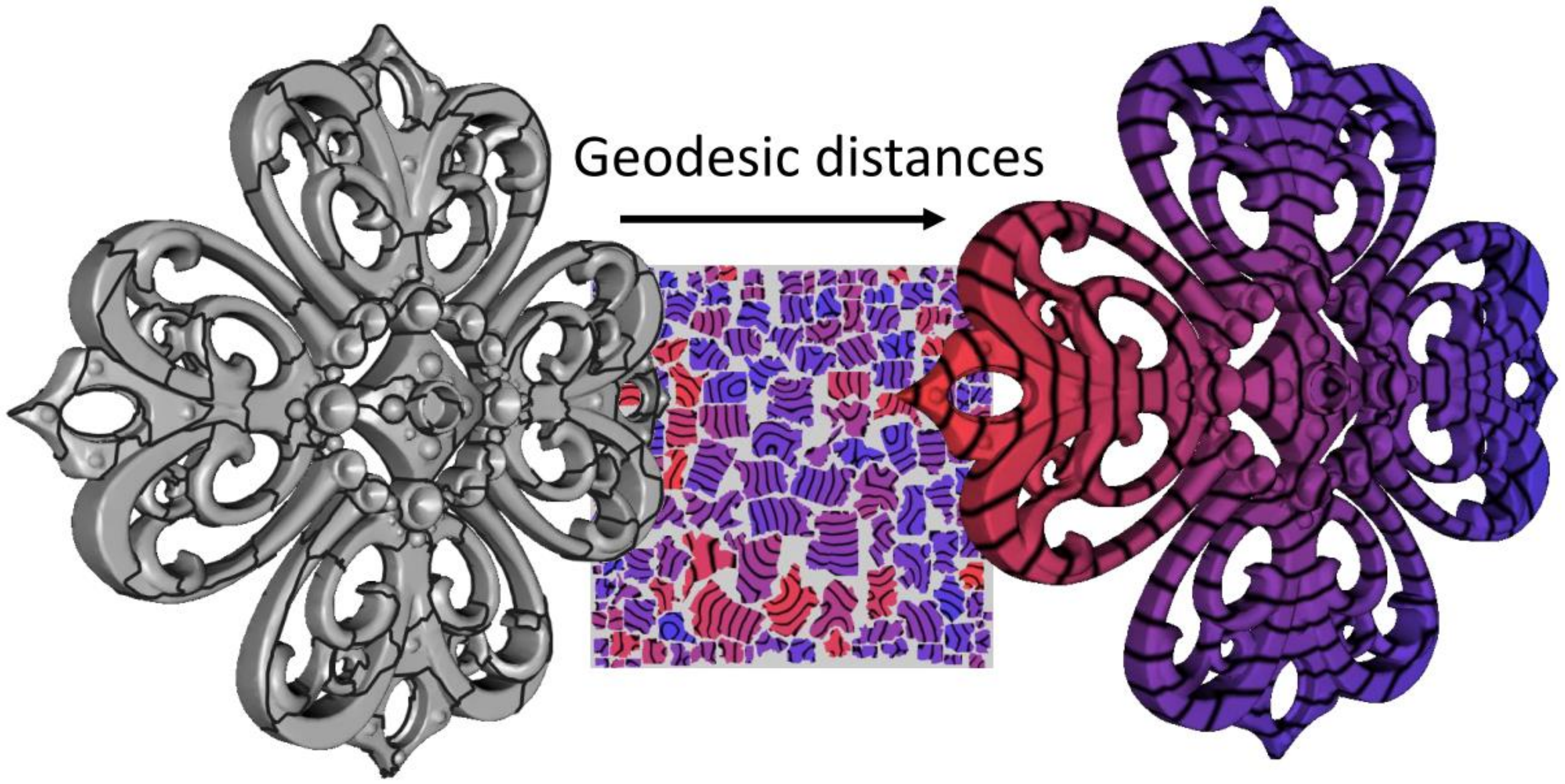
Packing

- High packing efficiency



Applications

- Signal storage
- Geometric processing



Gradient-Domain Processing within a Texture Atlas

Outlines

- Definition
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  - Bijective, low distortion
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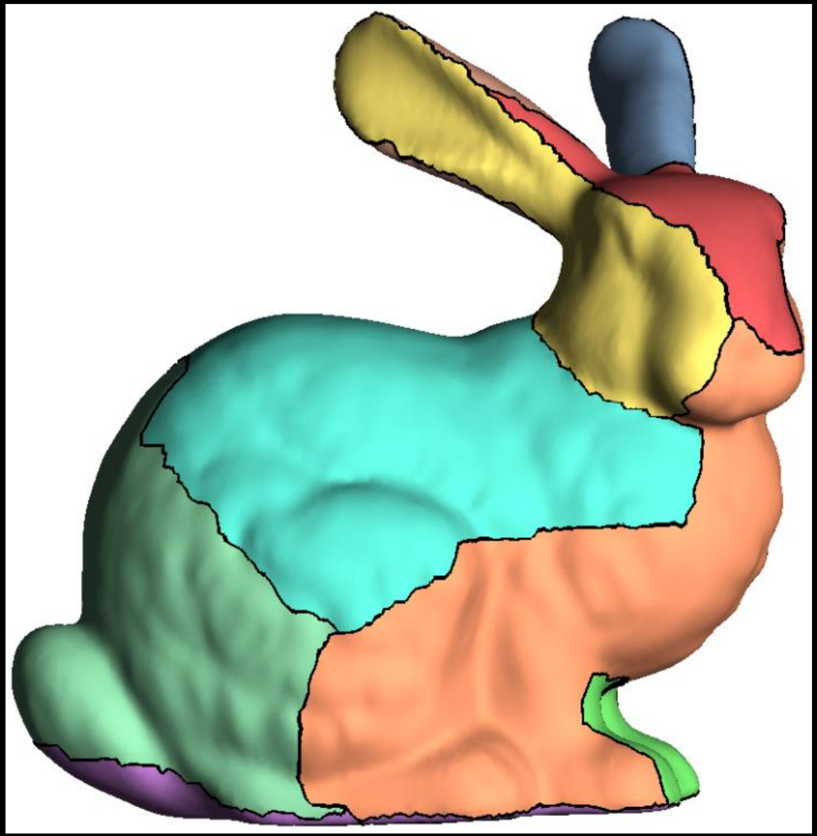
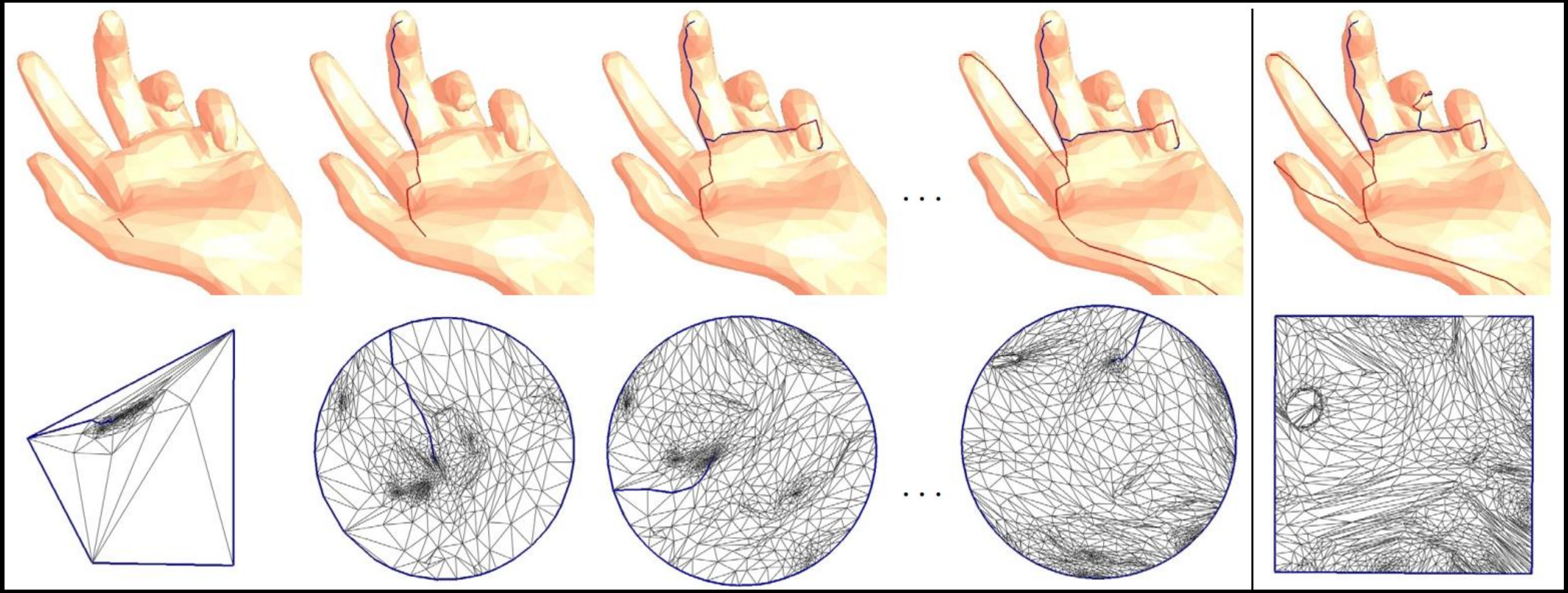
Mesh cutting

- Points → Paths
- Segmentation



Distortion points
Geometry Images, SIGGRAPH 2002

- Iterative method
  - Parameterize the mesh to the plane.
  - Add the point of greatest isometric distortion.



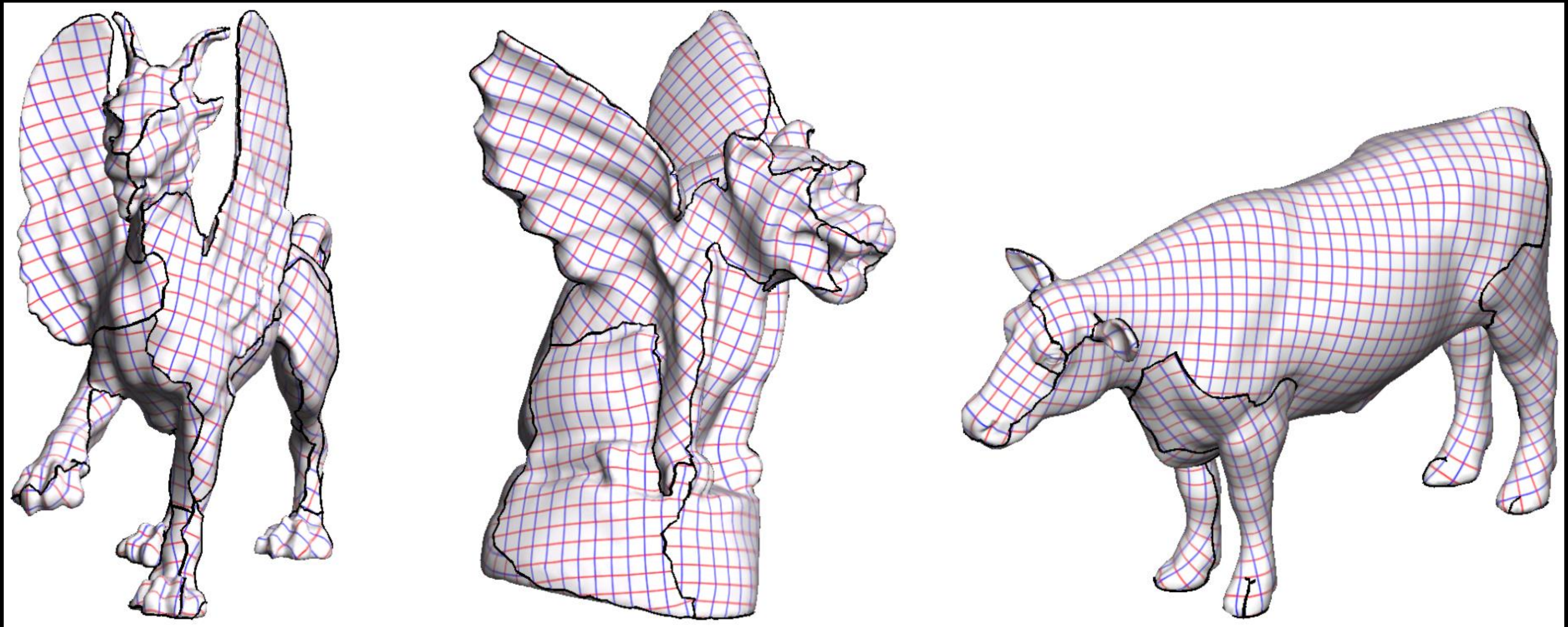
More methods

- Spanning tree seams for reducing parameterization distortion of triangulated surfaces, 2002
- Sphere-based cut construction for planar parameterizations, 2018

Segmentation

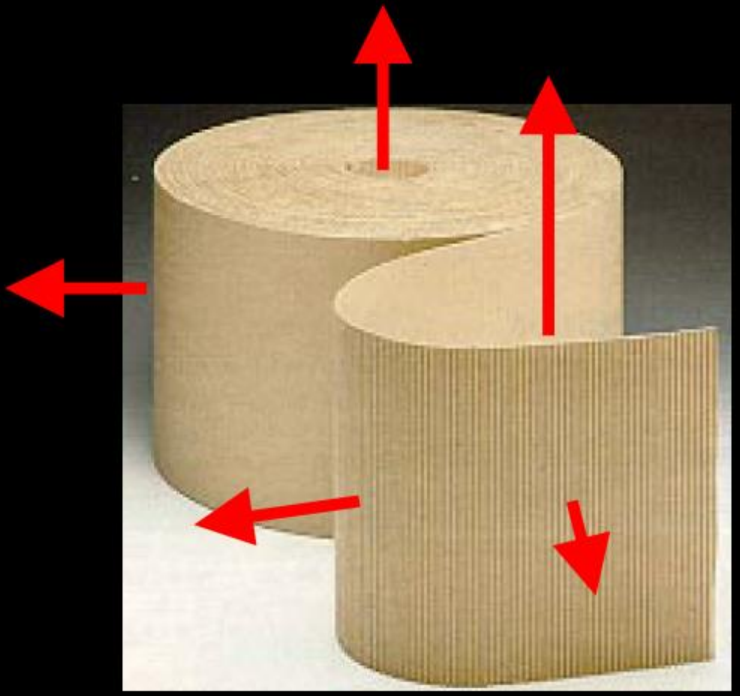
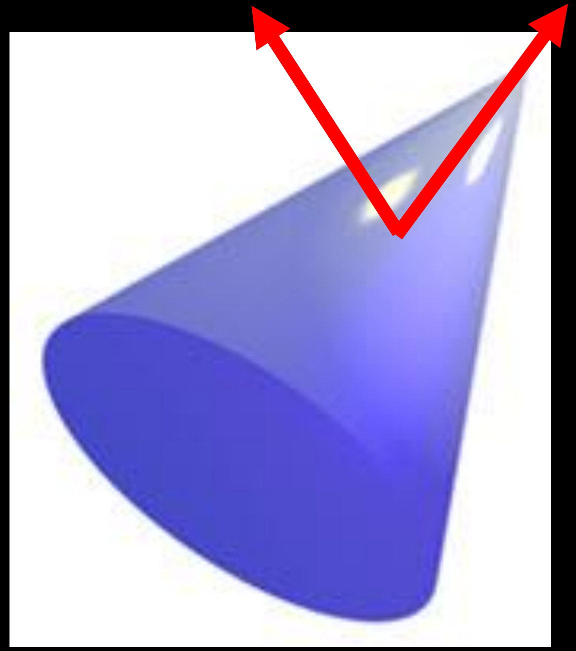
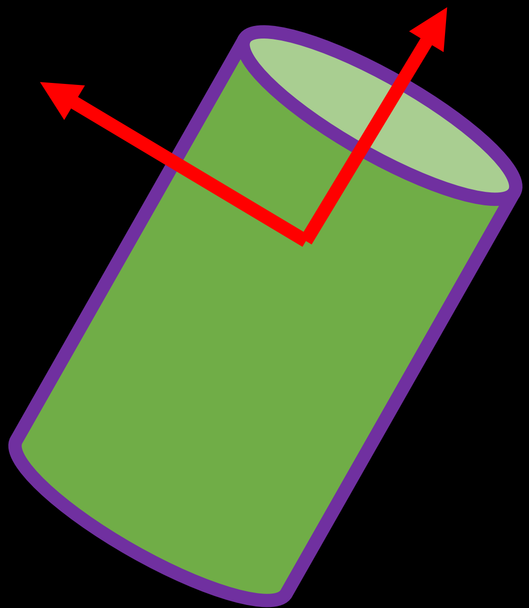
D-Charts: Quasi-Developable Mesh Segmentation, EG 2015

- Goal: mesh segmentation into compact charts that unfold with minimal distortion



Proxy

- Devlopable surfaces of constant slope
- Constant angle between surface normal and axis
- Proxy: $< axis, angle >, < N_c, \theta_c >$

Fitting error

- Measures how well triangle fits a chart

$$F(C,t) = (N_c \cdot n_t - cos\theta_c)^2$$

- Combine with compactness

$$C(C,t) = \frac{\pi D(S_c,t)^2}{A_c}$$

✓S_c is the seed triangle of the given chart

✓$D(S_c,t)$ is the length of the shortest path (inside the chart) between the two triangles

✓ A_c is the area of chart C

- Cost function

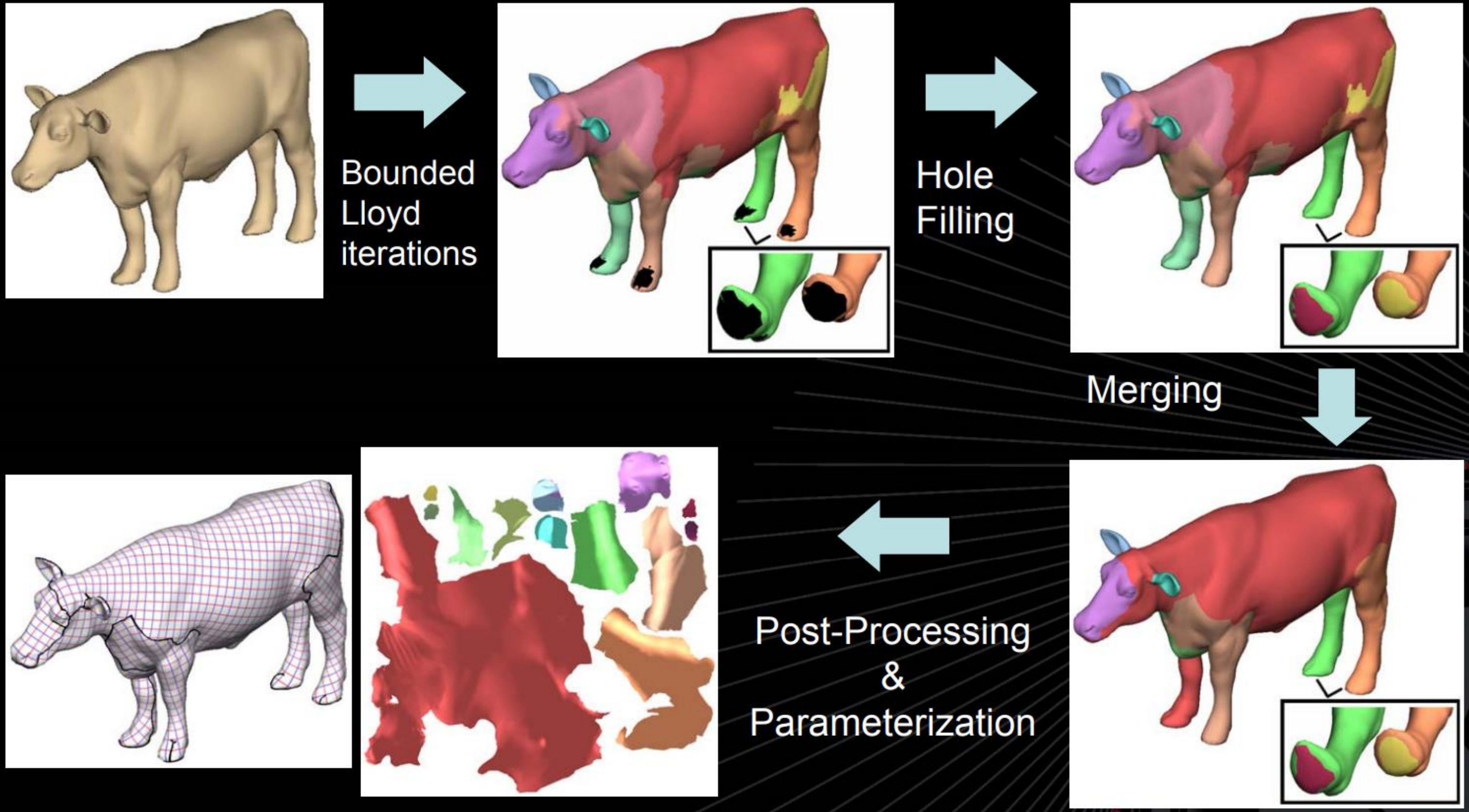
$$Cost(C,t) = A_t F(C,t)^{\alpha} C(C,t)^{\beta}$$

Segmentation method

- Lloyd algorithm
  - 1. Select random triangles to act as seeds
  - 2. Grow charts around seeds using a greedy approach
  - 3. Find new proxy for each chart
  - 4. Repeat from step 2 until convergence

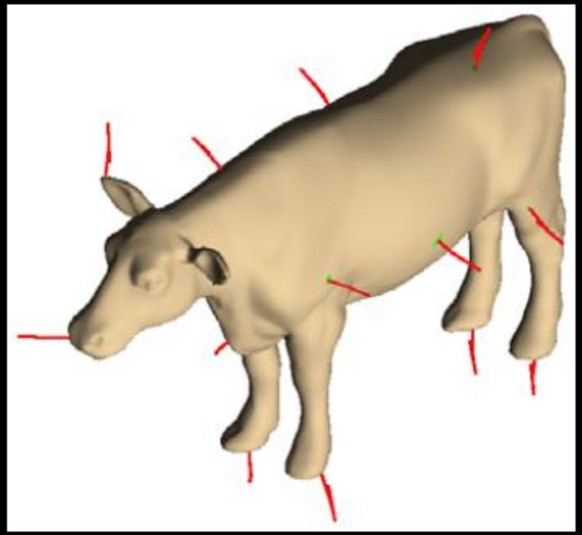
- K-means
- CVT

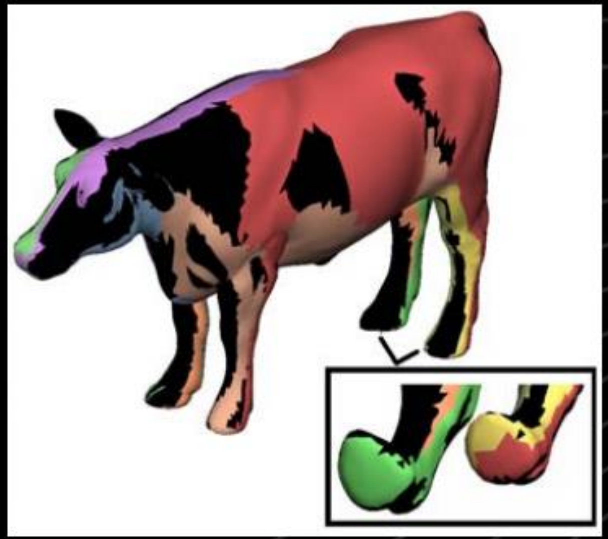
Algorithm overview

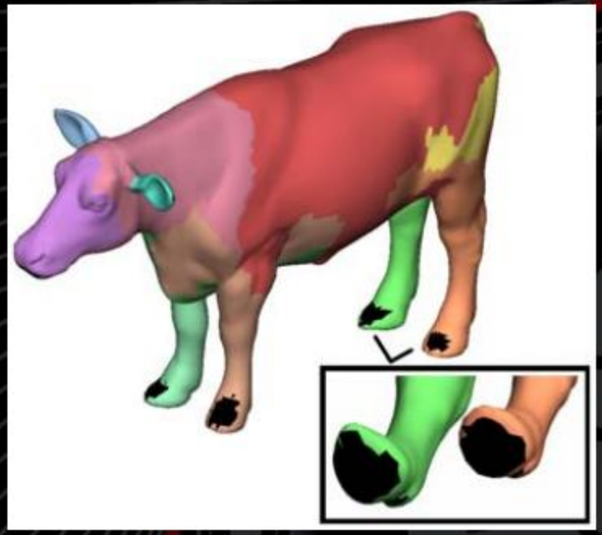


Bounded Lloyd iterations

- Initialization
  - Random / Furthest point seeds
  - Compute initial proxy
- Bounded Growing/Reseeding iterations
- Termination







Bounded Lloyd iterations – Growing

- Use greedy approach
  - Prioritize by $Cost(C, t)$
- Bound Fitting Error
  - Guarantee (nearly) developable charts
  - $F(C, t) < F_{max}$

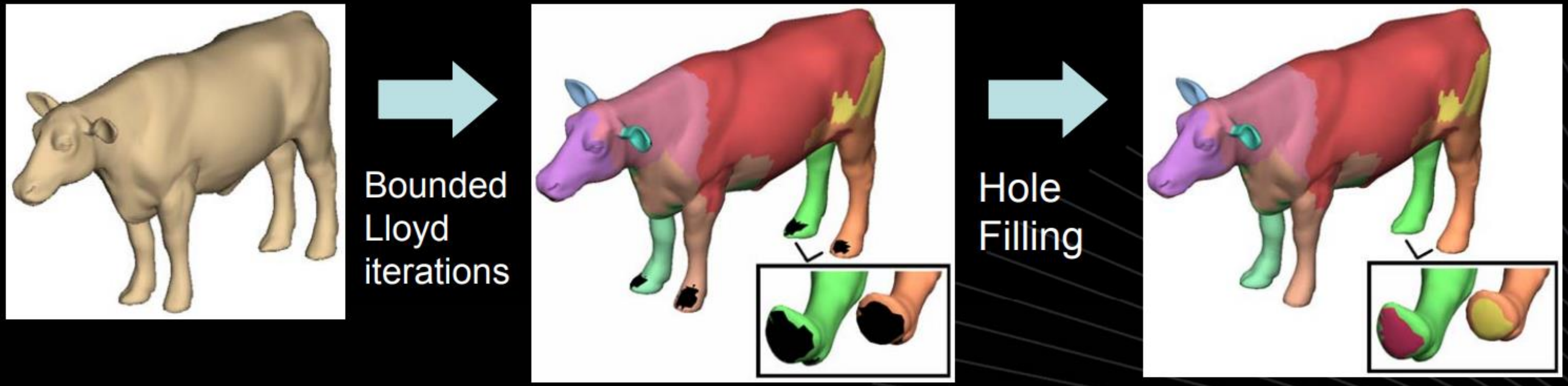
Bound Lloyd iterations – Reseeding

- Find new proxy

$$\min_{N_c,\theta_c} \frac{1}{A_c} \sum_{t \in C} A_t F(C,t) \;\; s.t. \left|\left|N_c\right|\right| = 1$$

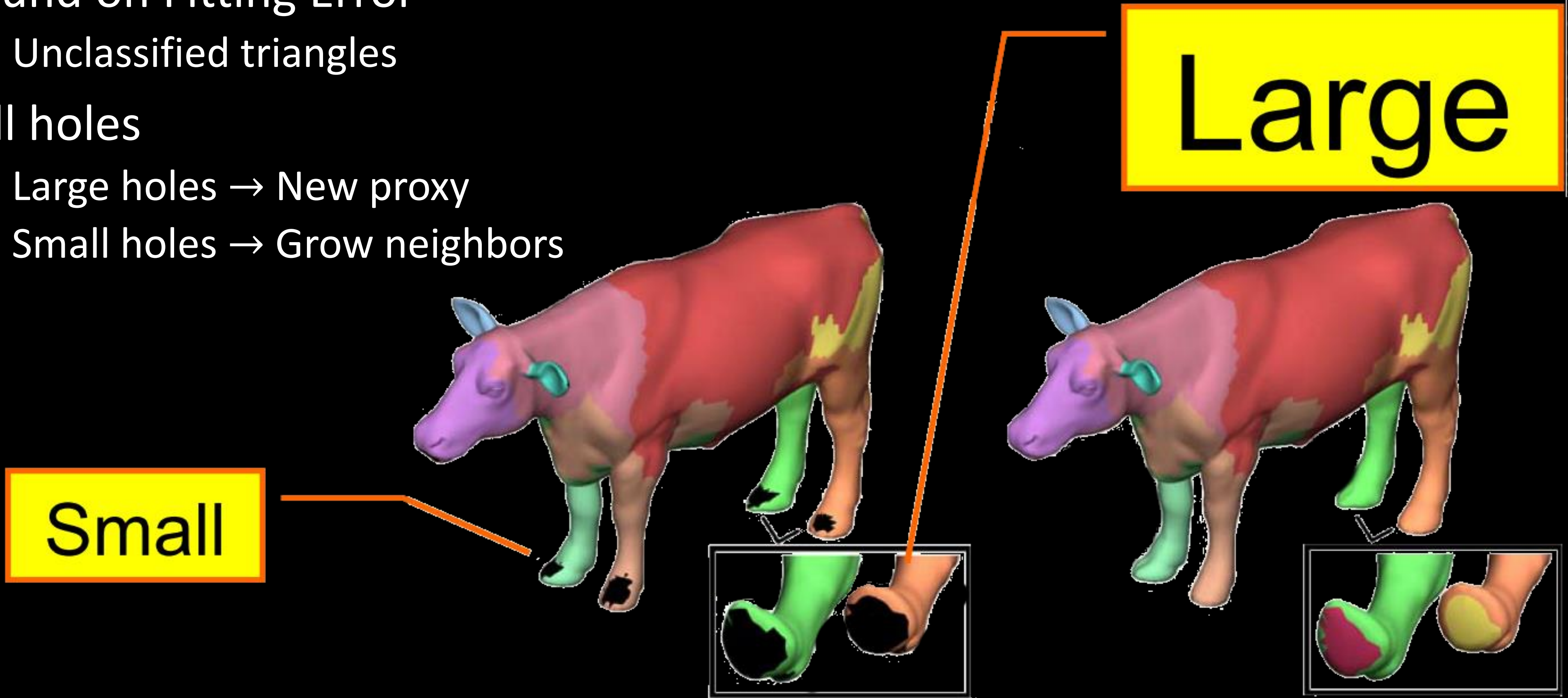
- Find new seed
  - Minimal Fitting Error
  - Close to center of chart
  - To find such seeds, we examine the first k triangles in the chart with minimal fitting error ($k = 10$ in all our examples), and then select the one closest to the center of the chart.

Algorithm overview

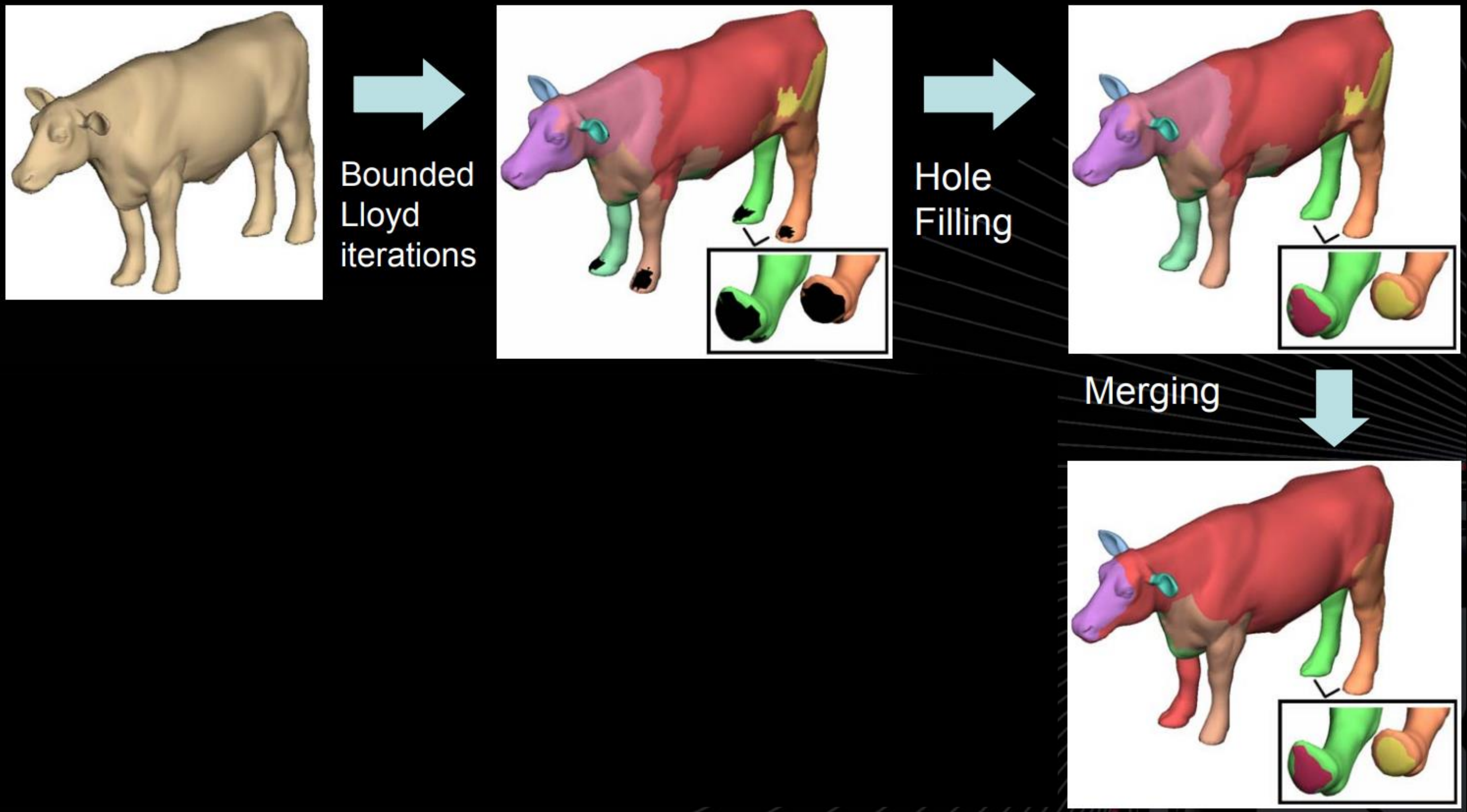


Hole filling

- Bound on Fitting Error
  - Unclassified triangles
- Fill holes
  - Large holes → New proxy
  - Small holes → Grow neighbors

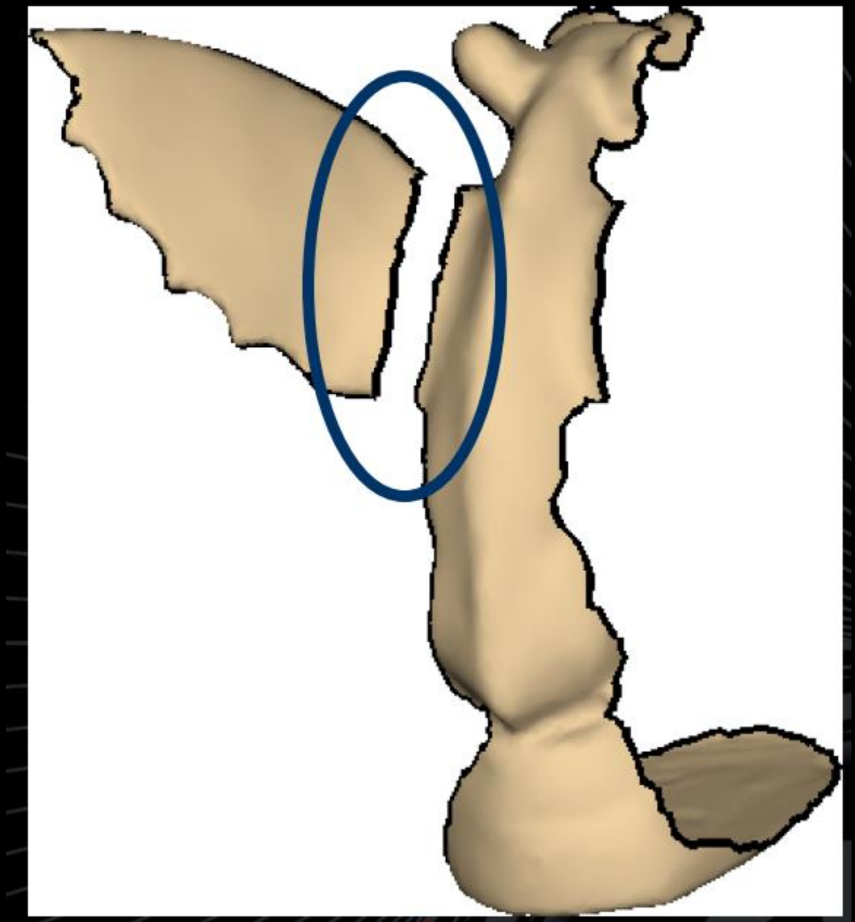


Algorithm overview

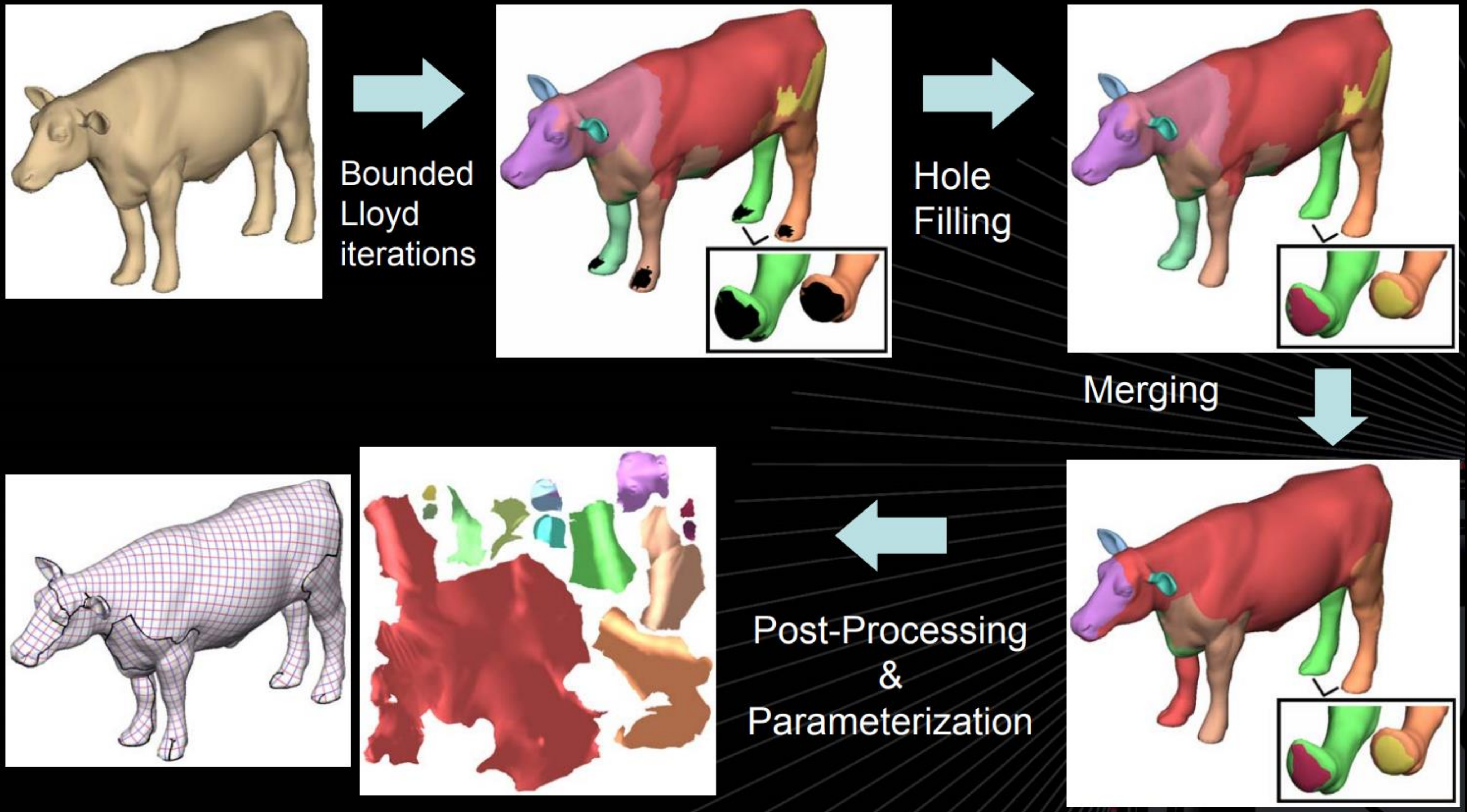


Merging

- Broaden set of captured developable surfaces
- Reduce number of charts



Algorithm overview



Post processing

- Straighten boundaries
- Darts/Gussets relax stress
  - Add seams toward high error regions
- Verify disc topology
- Parameterization

Outlines

- Definition

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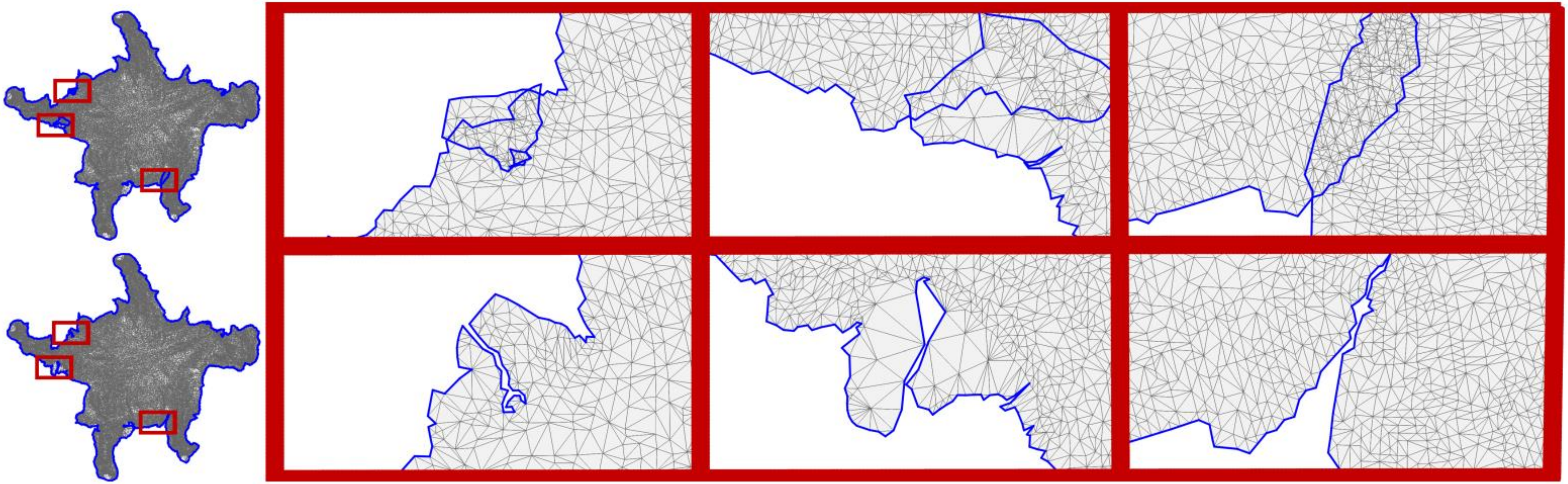
Bijection

- Preserving orientations
- No intersections of boundary



Barrier

Bijective Parameterization with Free Boundaries, SIGGRAPH 2015

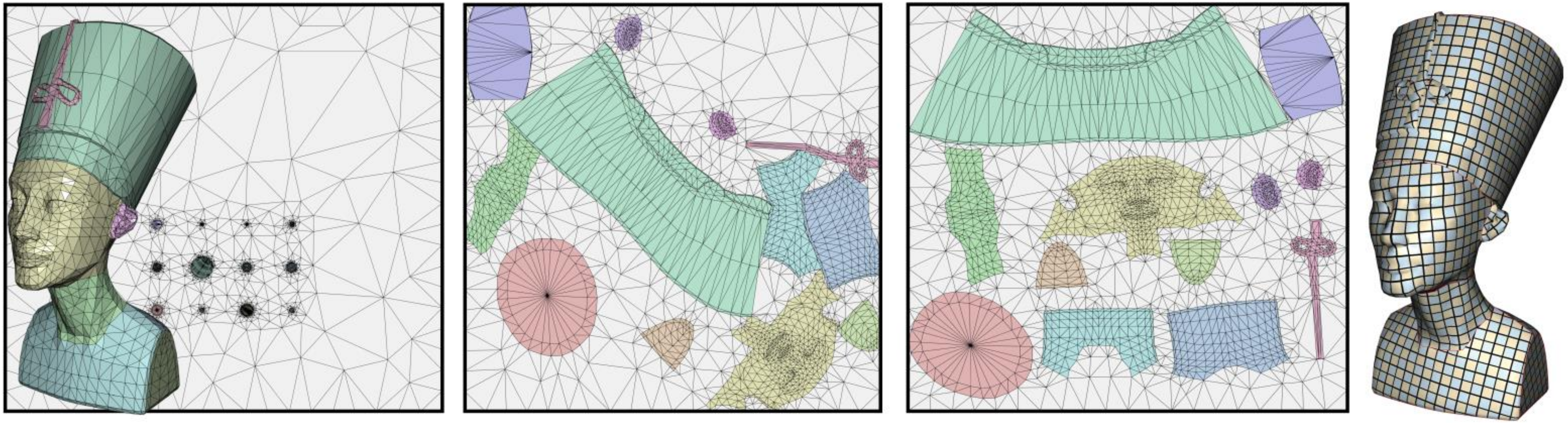
- For each boundary edge with vertices U1, U2, we associate a barrier function:

$$\max\left(0, \frac{\varepsilon}{dist(U_1, U_2, U_i)} - 1\right)^2$$

where, $dist(U_1, U_2, U_i)$ measures the distance from a boundary point $U_{i \neq 1,2}$ to the edge (U_1, U_2).

Scaffold

Simplicial Complex Augmentation Framework for Bijective Maps, SIGGRAPH Asia 2017



Outlines

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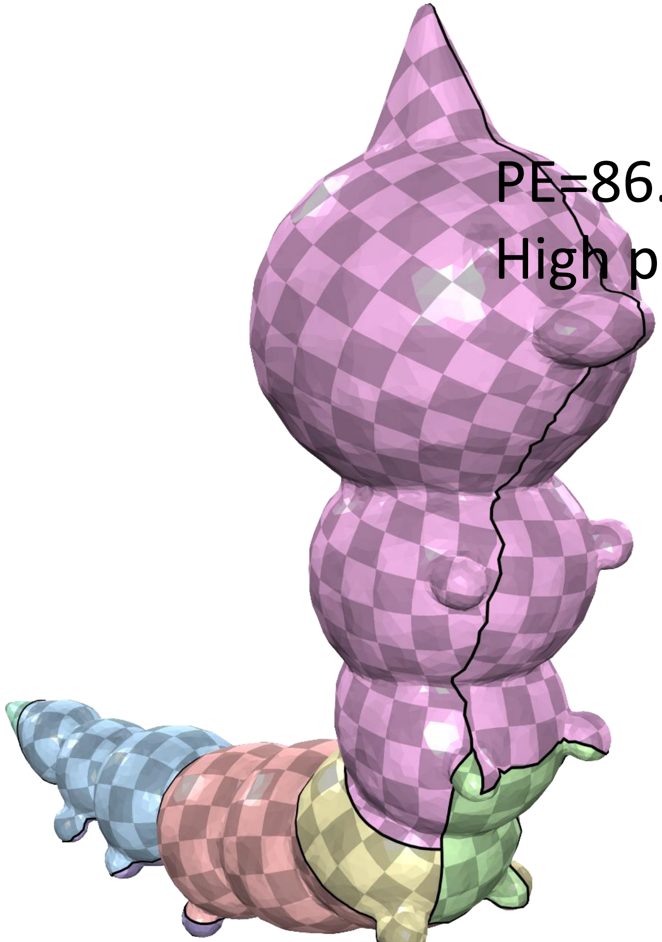
Atlas Refinement with Bounded Packing Efficiency

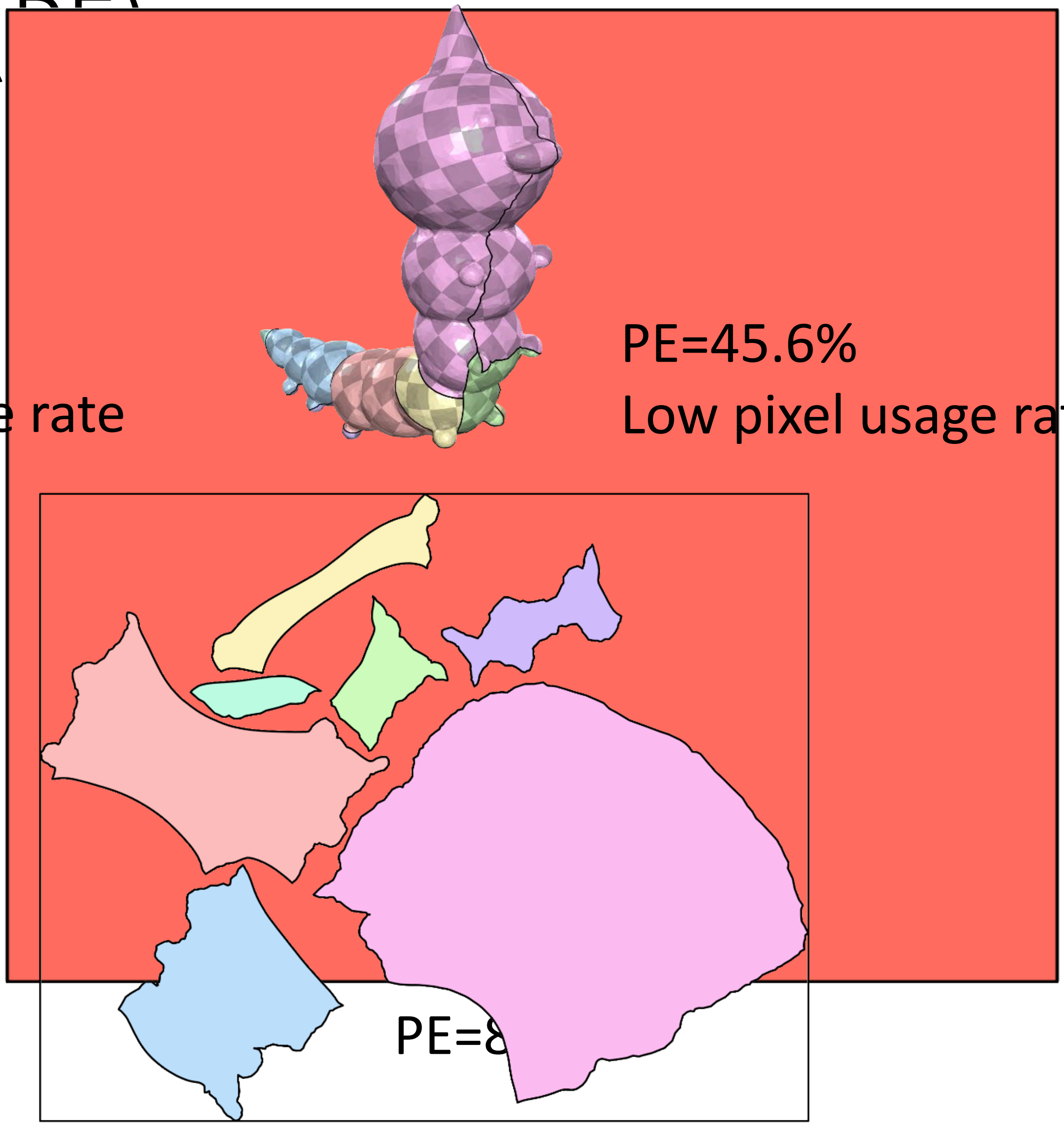
Hao-Yu Liu, Xiao-Ming Fu, Chunyang Ye, Shuangming Chai, Ligang Liu

ACM Transactions on Graphics (SIGGRAPH) 38(4), 2019.

Packing Efficiency (



PE=86.1%
High pixel usage rate



PE=45.6%
Low pixel usage rate

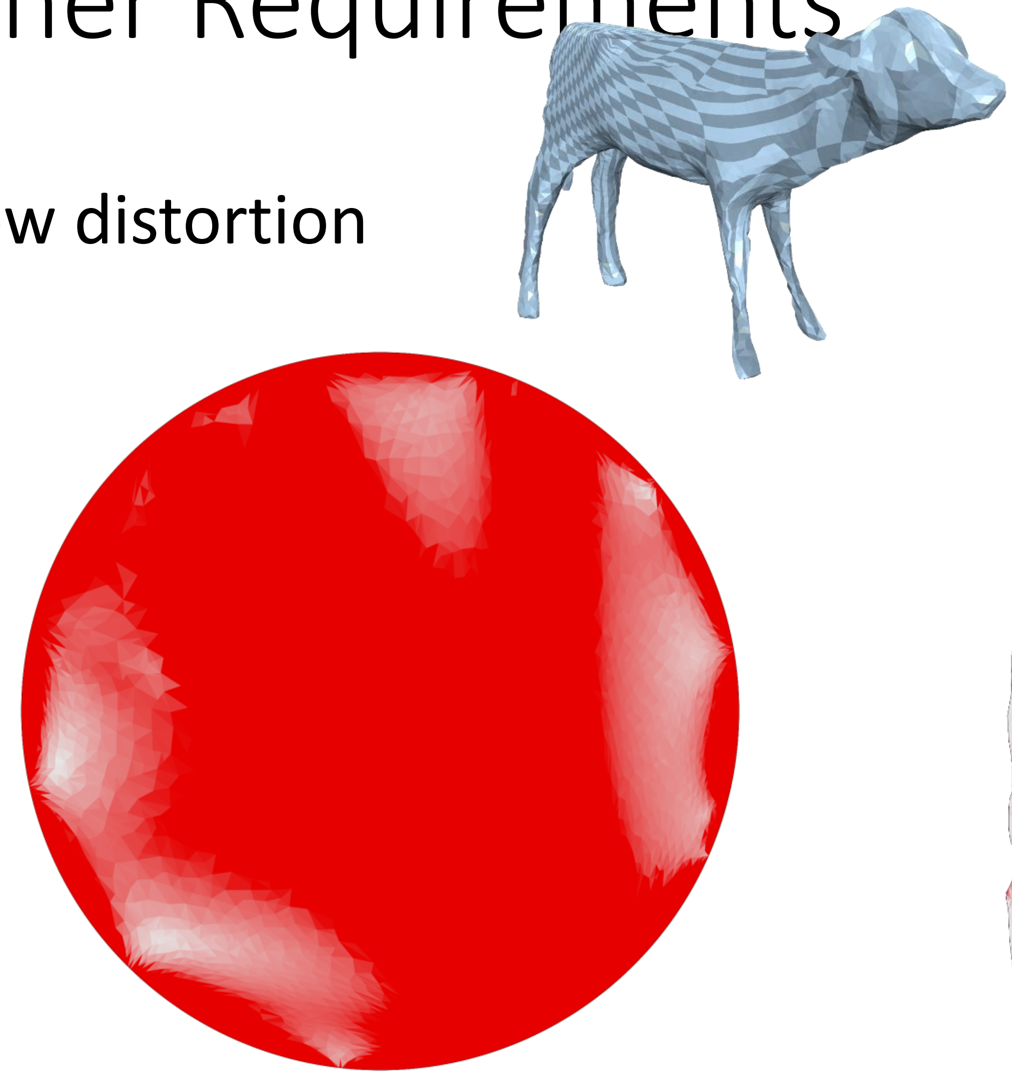
Packing Efficiency (PE)

Maximizing atlas packing efficiency is NP-hard!

[Garey and Johnson 1979; Milenkovic 1999]

Other Requirements

- Low distortion



High Distortion

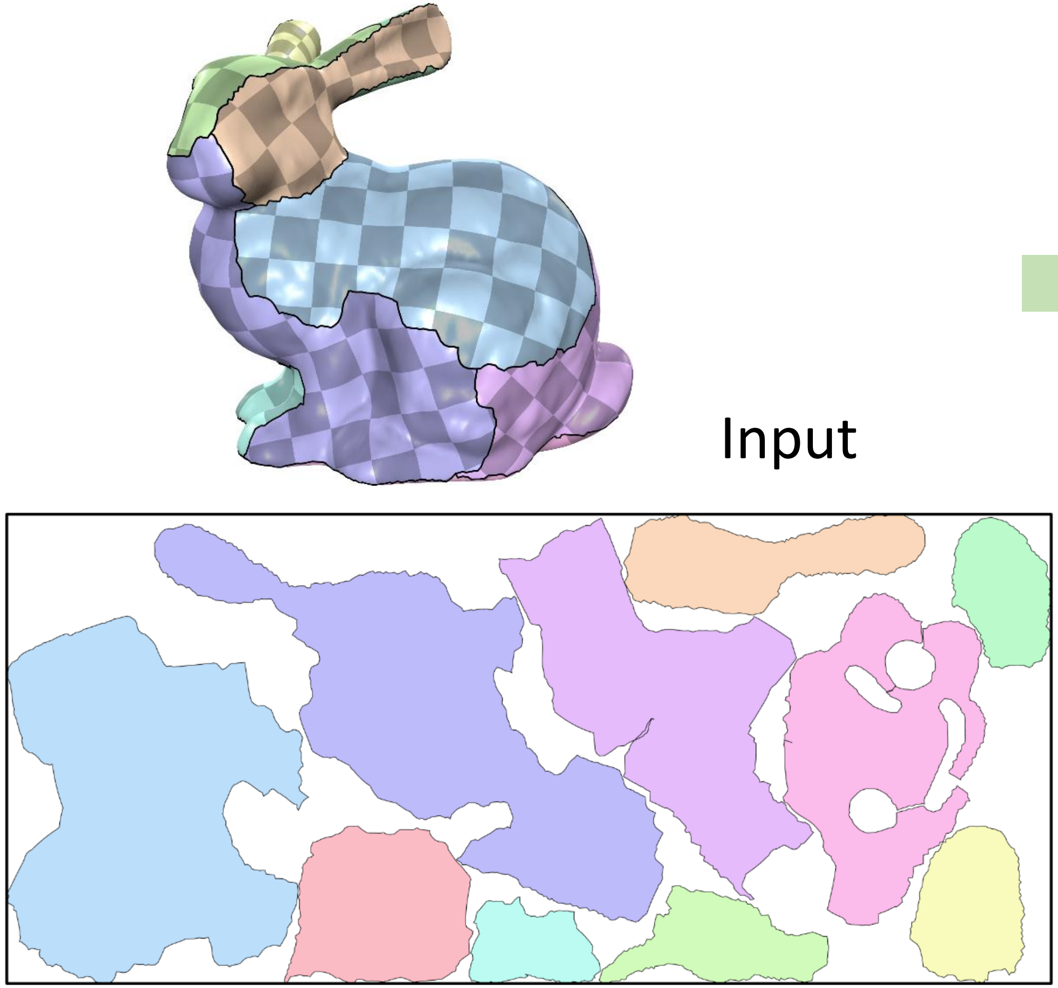
Low Distortion

Other Requirements

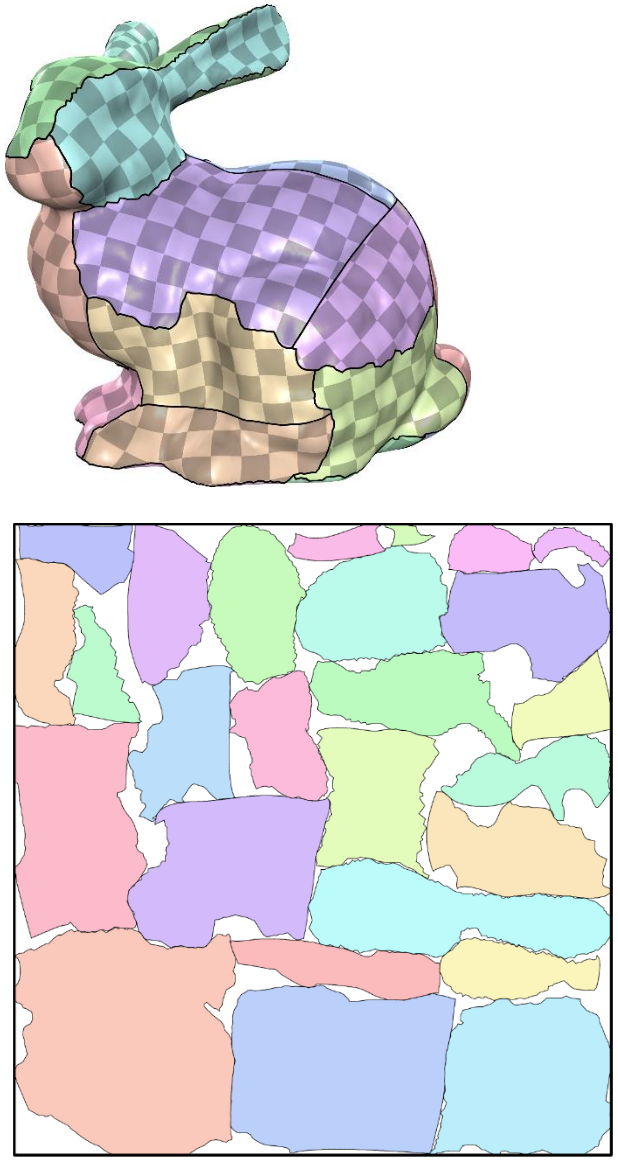
- Low distortion
  - [Golla et al. 2018; Liu et al. 2018; Shtengel et al. 2017; Zhu et al. 2018]
- Consistent orientation
  - [Floater 2003; Tutte 1963; Claici et al. 2017; Hormann and Greiner 2000; Rabinovich et al. 2017; Schüller et al. 2013]
- Overlap free
  - [Jiang et al. 2017; Smith and Schaefer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

These methods do not consider PE!

Atlas Refinement



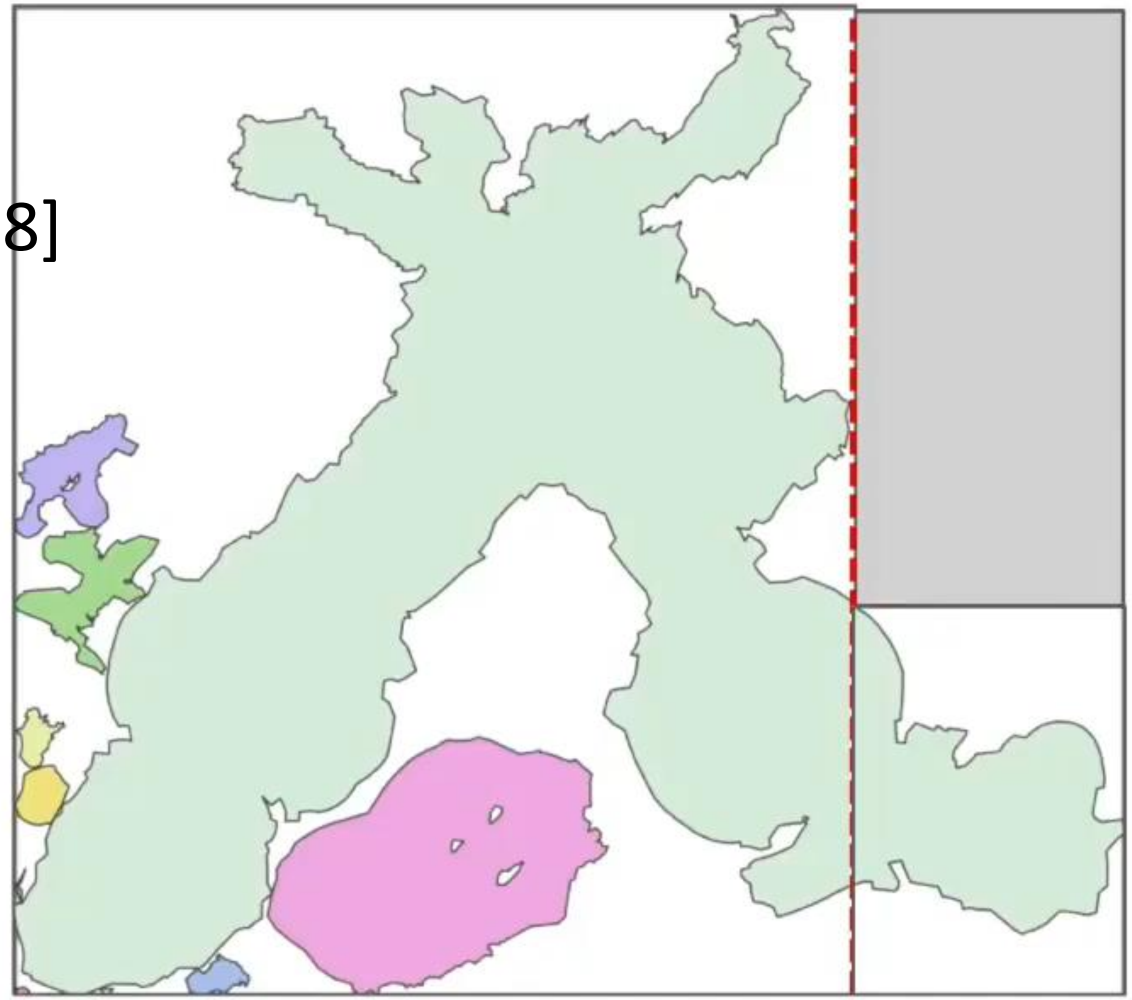
Input



No overlap
High PE

Previous Work

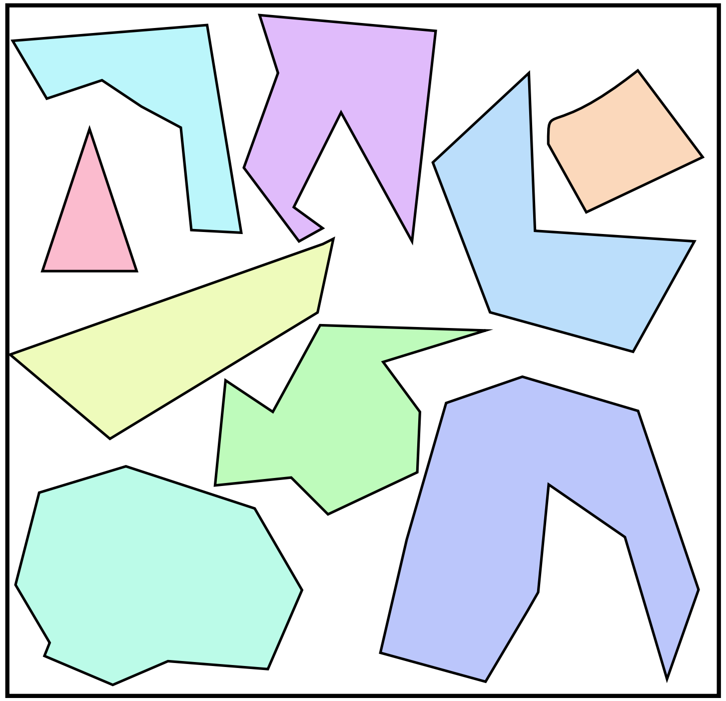
Box Cutter [Limper et al. 2018]



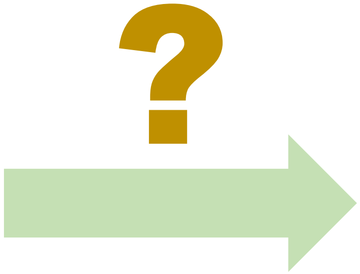
No guarantee for a high PE result!

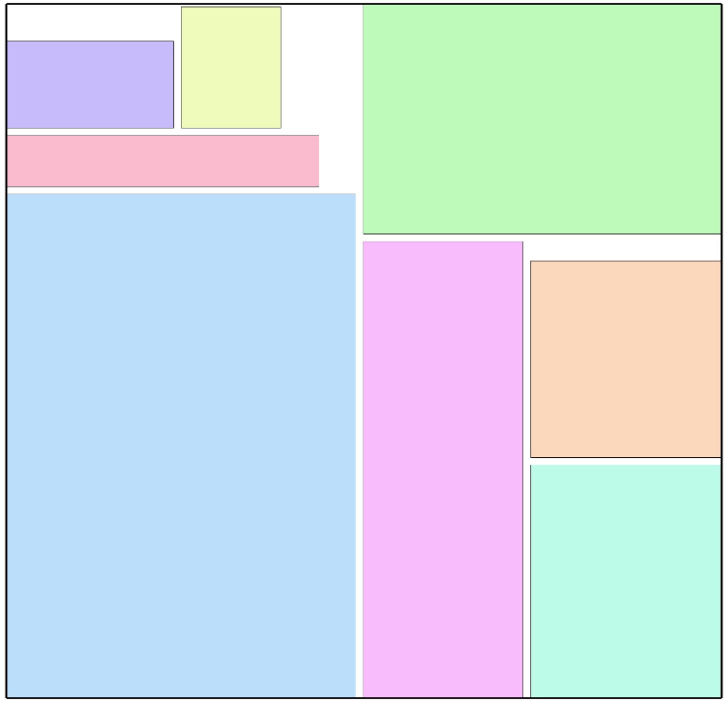
Motivation

Packing Problems



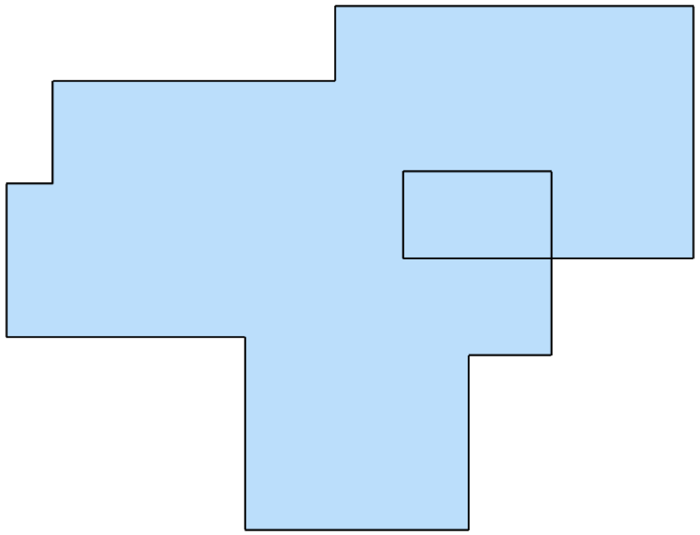
Irregular shapes
Hard to achieve high PE



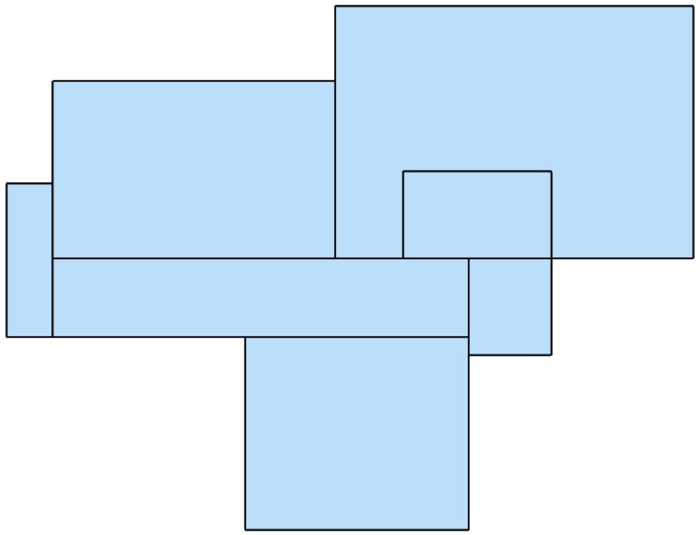


Rectangles
Simple to achieve high PE
Widely used in practice

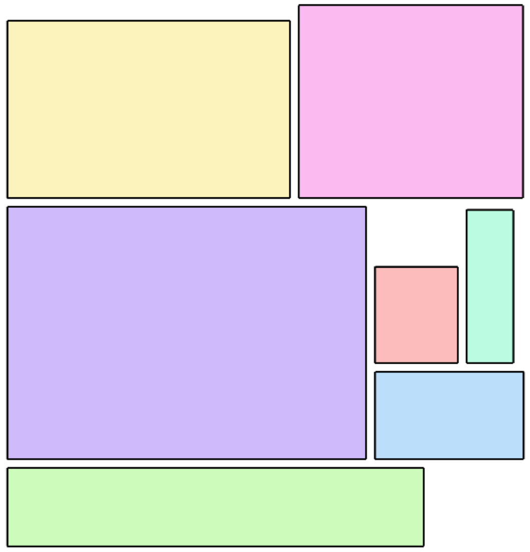
Axis-Aligned Structure



Axis-aligned structure

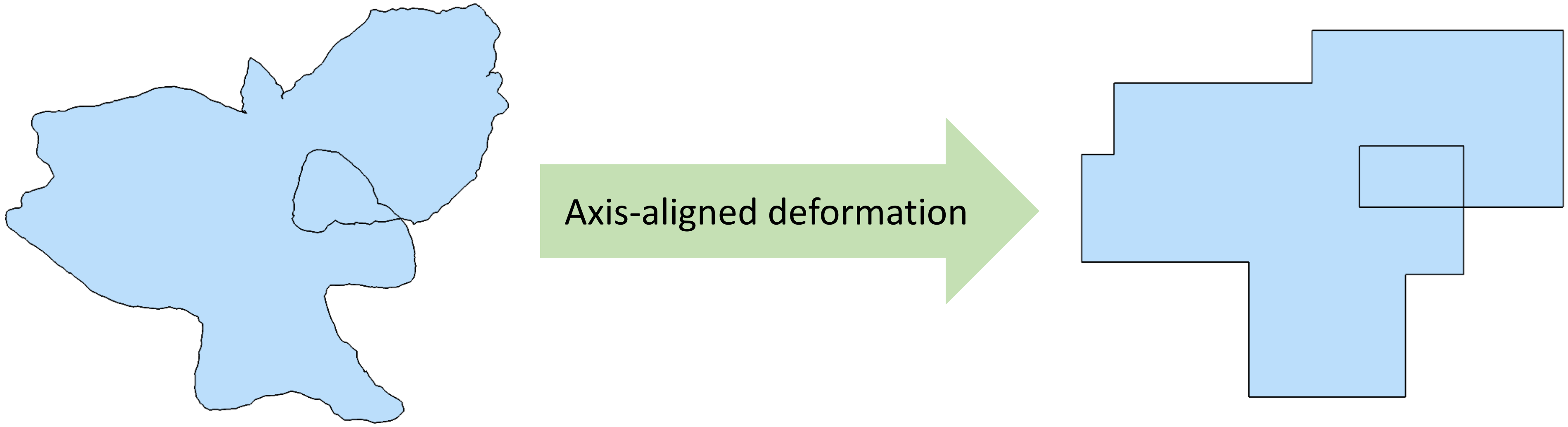


Rectangle decomposition



High PE (87.6%)!

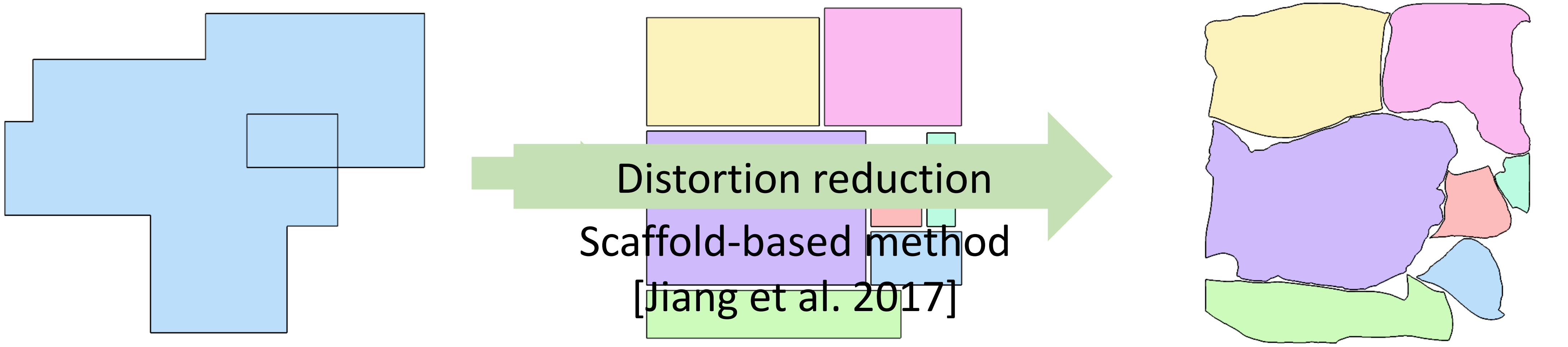
General Cases



Not axis-aligned

Axis-aligned
Higher distortion

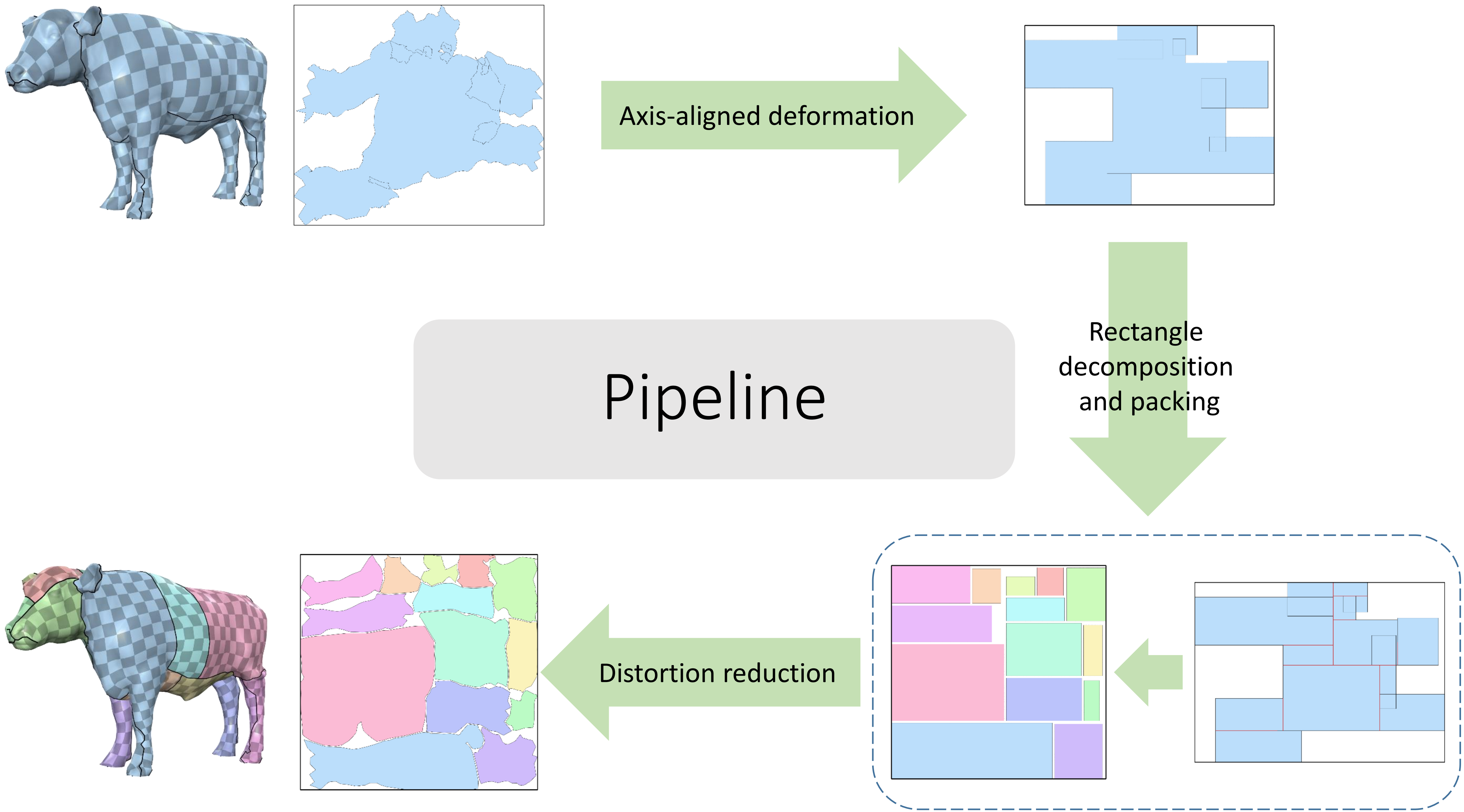
Distortion Reduction



Axis-aligned
High distortion

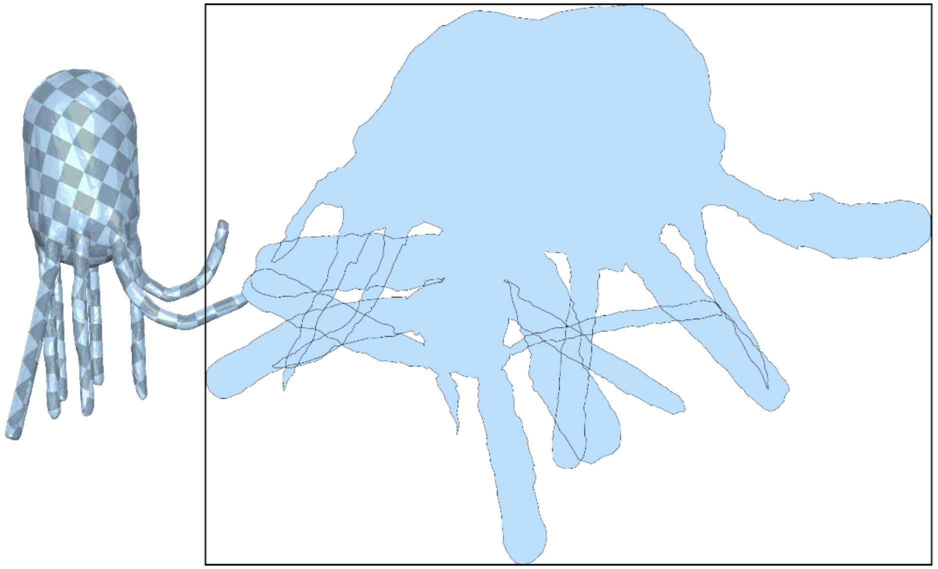
No overlap & High PE
High distortion

No overlap & High PE
Low distortion
Bounded PE

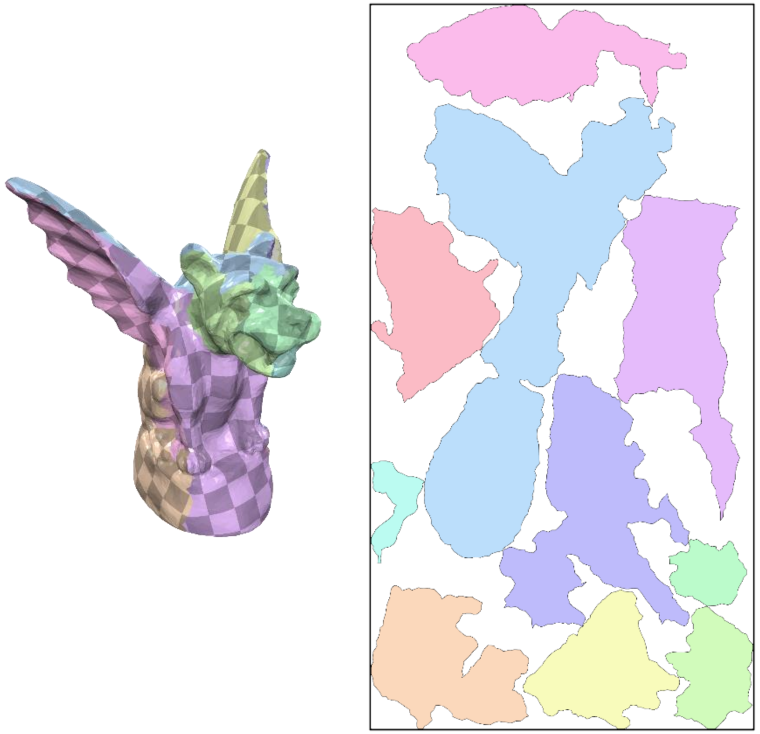

Axis-aligned deformation
Rectangle decomposition and packing
Pipeline
Distortion reduction

Axis-Aligned Deformation

- Input

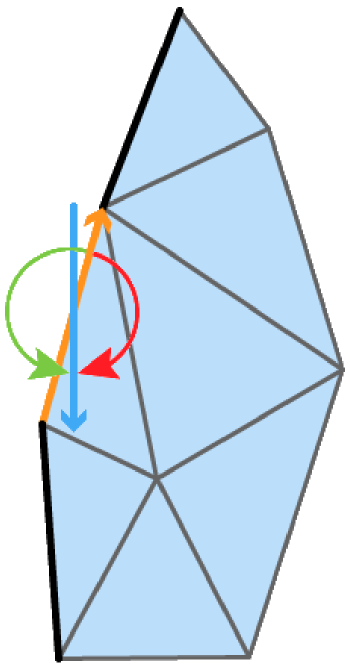


Single chart
With overlap

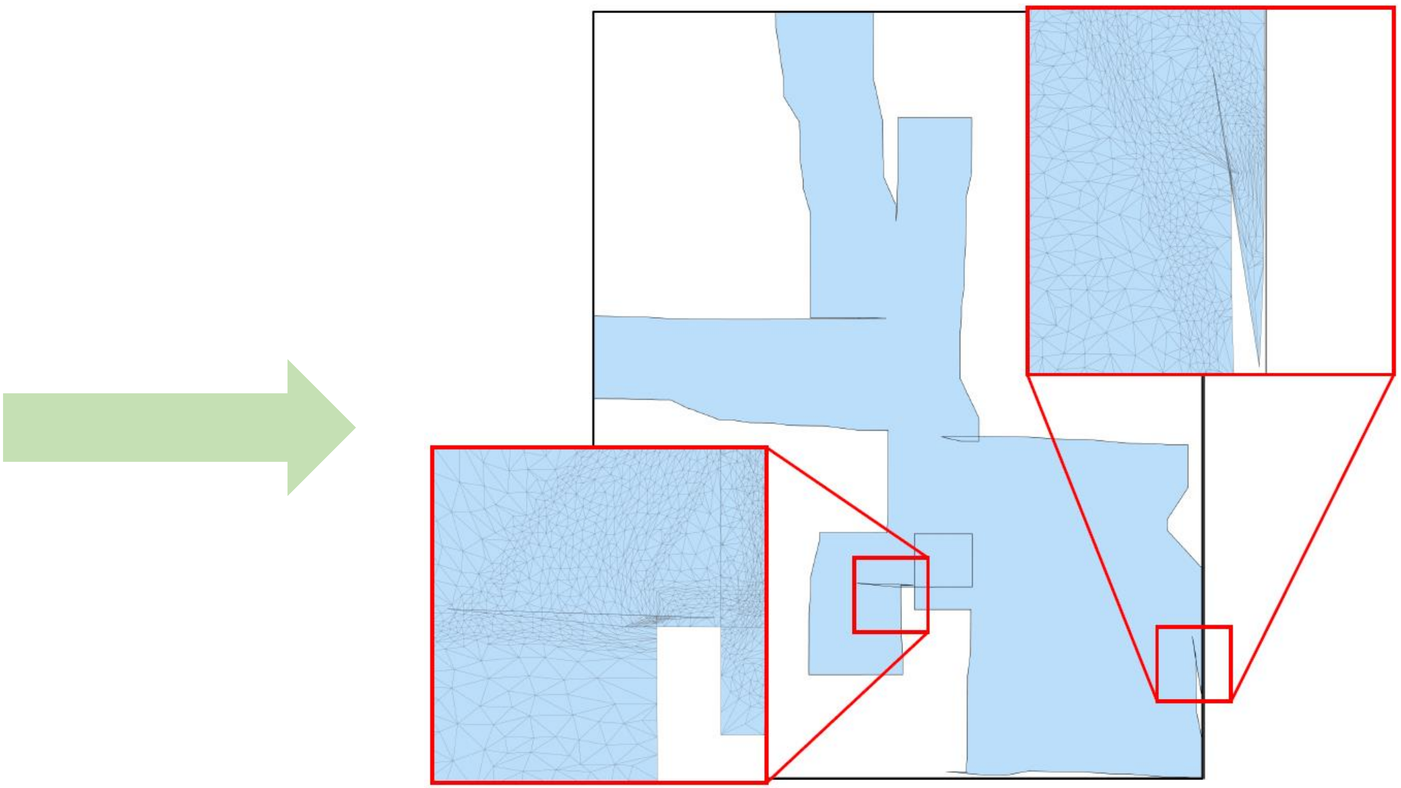


10 charts
Without overlap

Axis-Aligned Deformation

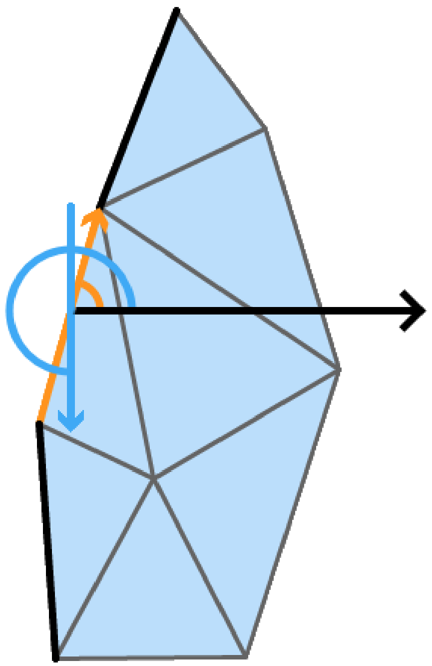


Direction vector
Ambiguous rotating directions

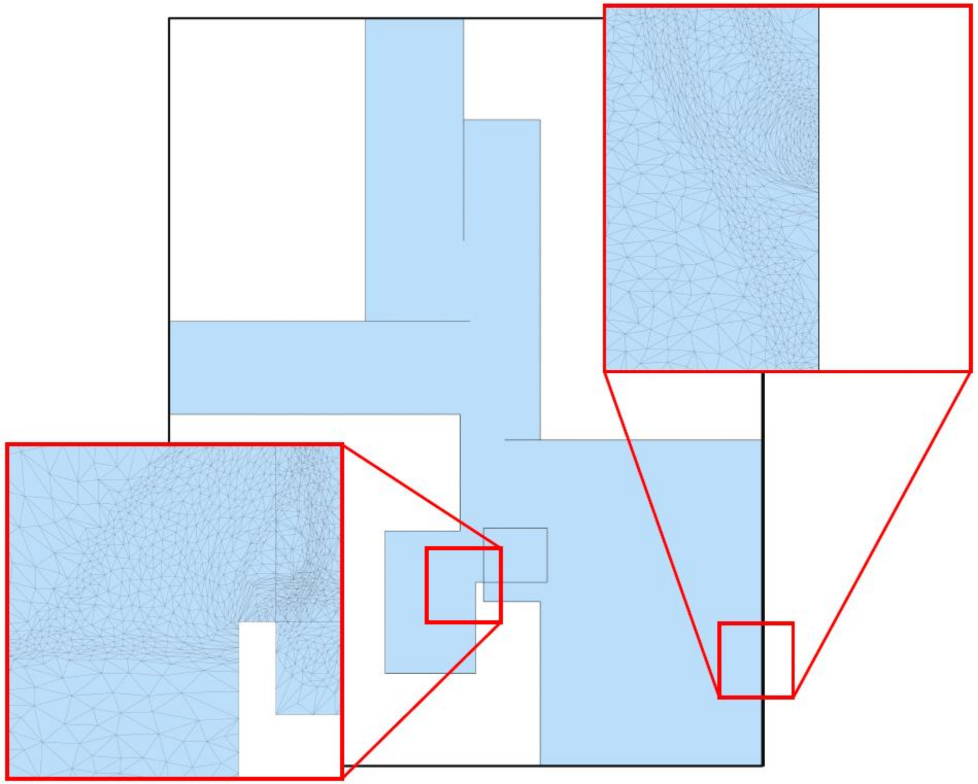


Fail!

Axis-Aligned Deformation

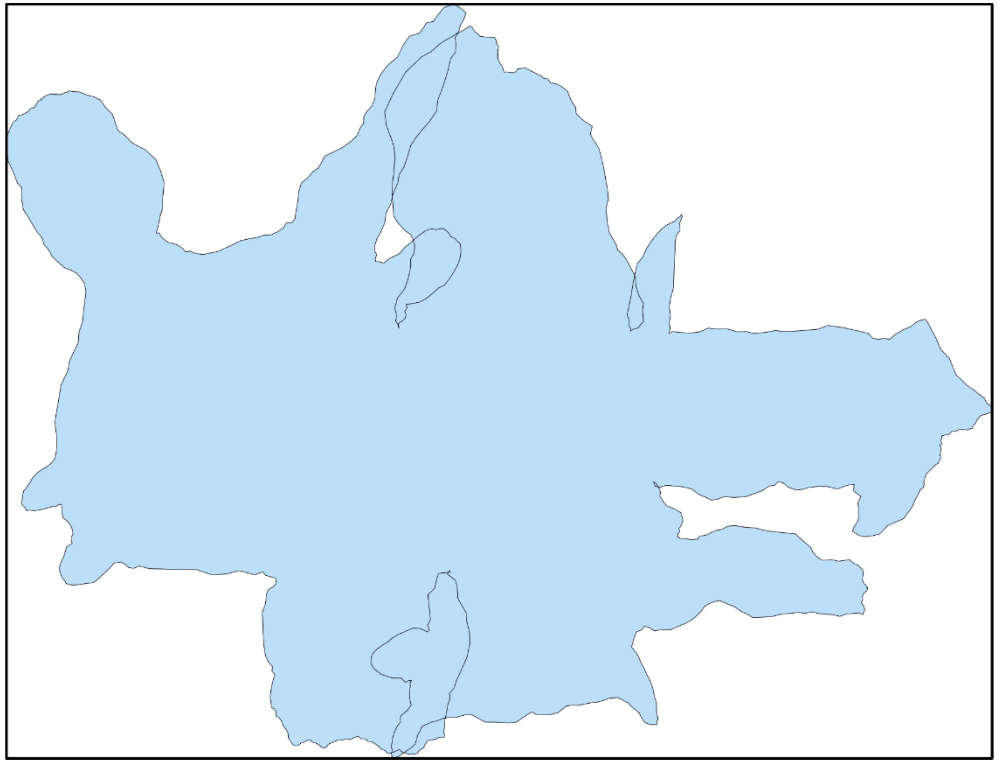


Polar angle
Clear rotating direction

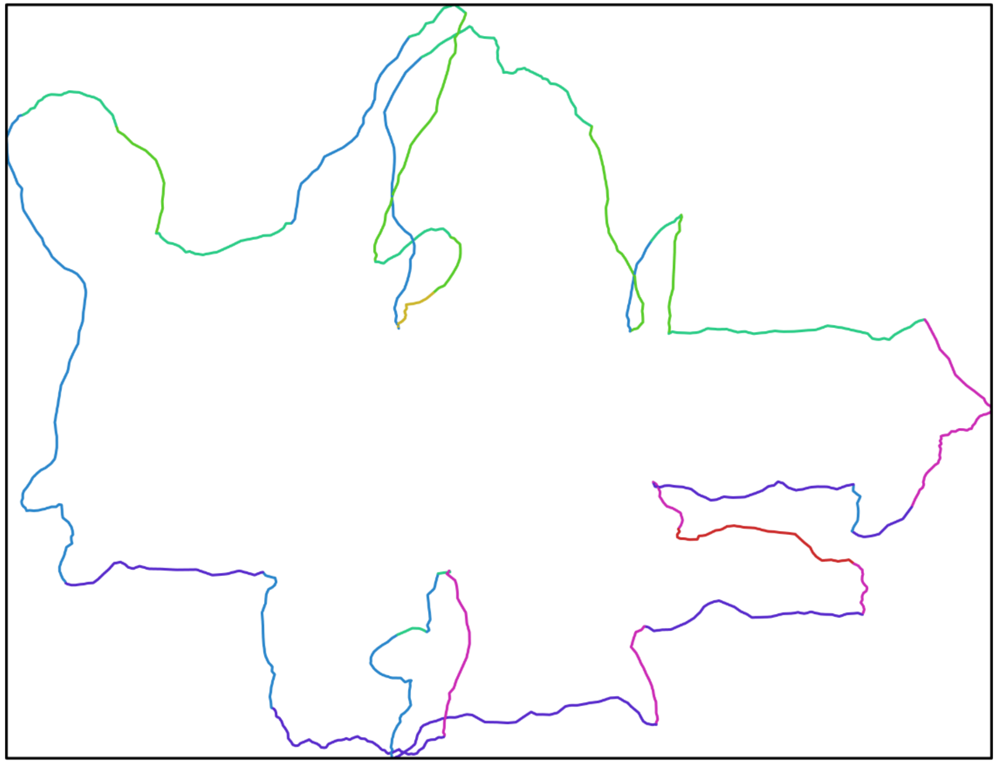


Success!

Axis-Aligned Deformation



Input



Target polar angle

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)

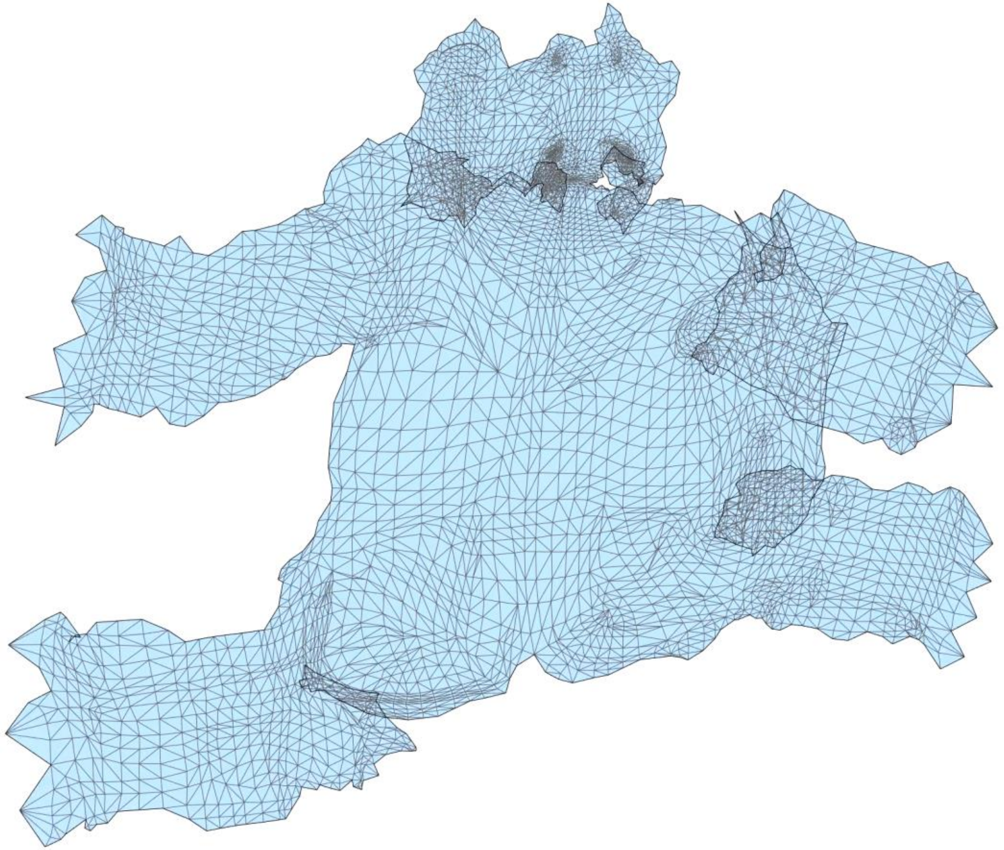
$$E_{\mathrm{d}}(\mathrm{c}) = \frac{1}{4} \sum_{\mathrm{f_i \in F^C}} \frac{\mathrm{Area}(\mathrm{f}_i)}{\mathrm{Area}(\mathrm{M^C})} \left(\| J_i \|_F^2 + \| J_i^{-1} \|_F^2 \right)$$

Keep low distortion and orientation consistency.

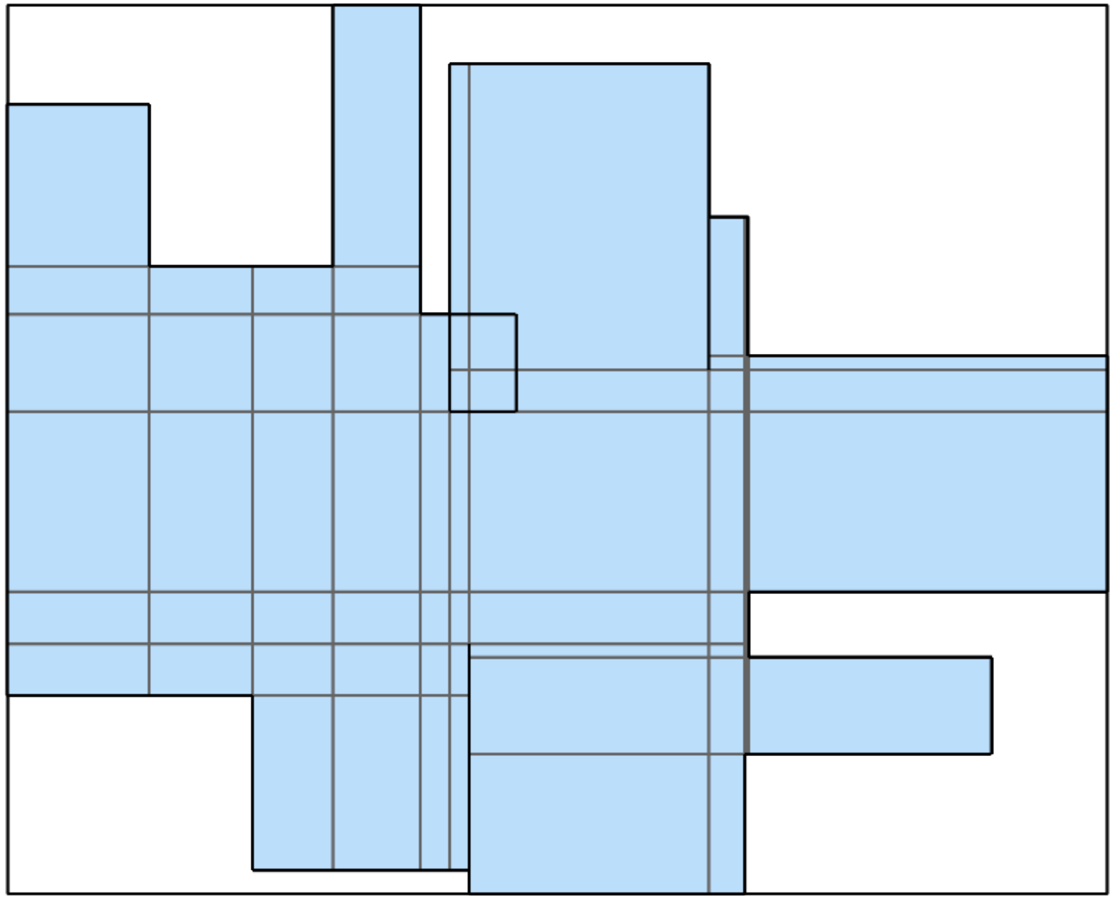
Axis-Aligned Deformation

0.2X Playback

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



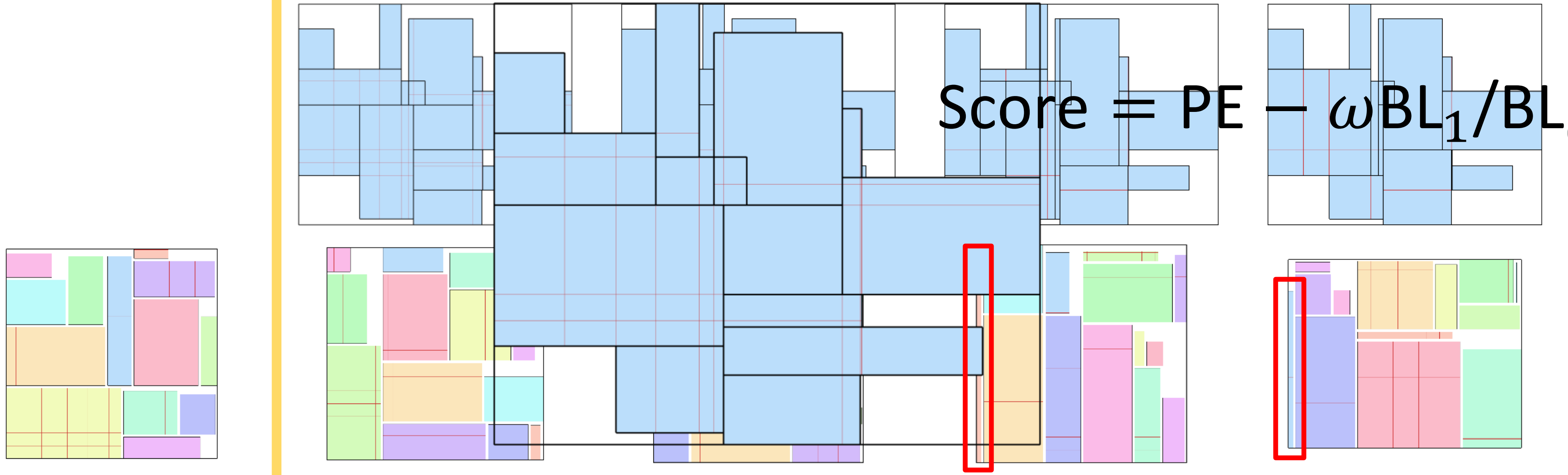
Rectangle Decomposition and Packing



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

Rectangle Decomposition and Packing

- Motorcycle graph algorithm



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

PE	87.0%	83.6%	84.4%
Score	0.688	0.659	0.658

Distortion Reduction

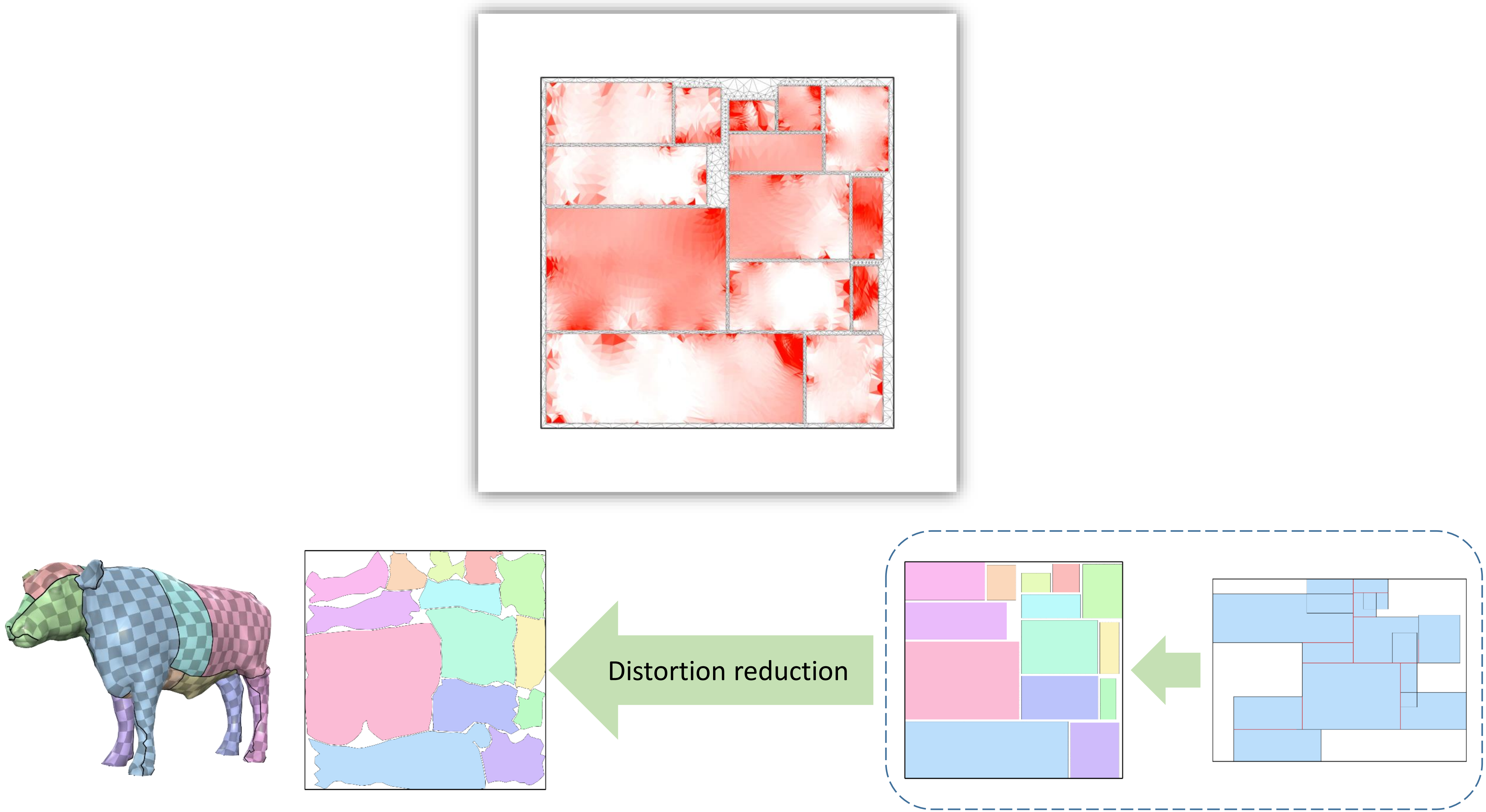
Isometric energy

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

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

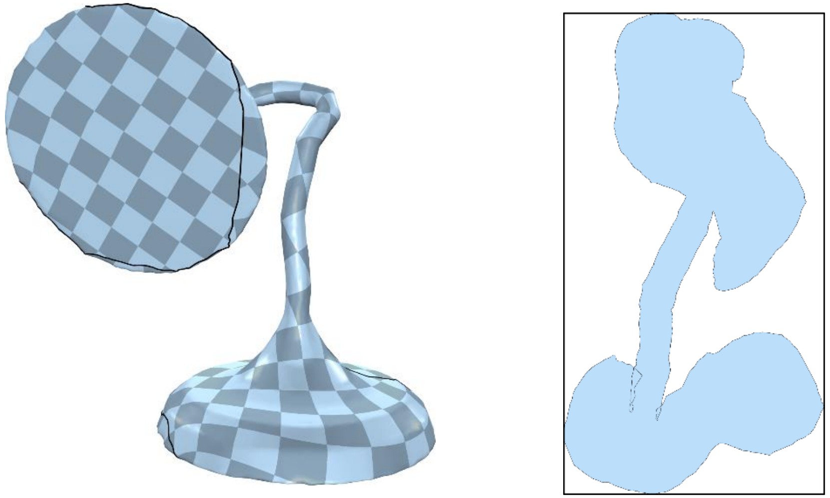
Barrier function of PE bound

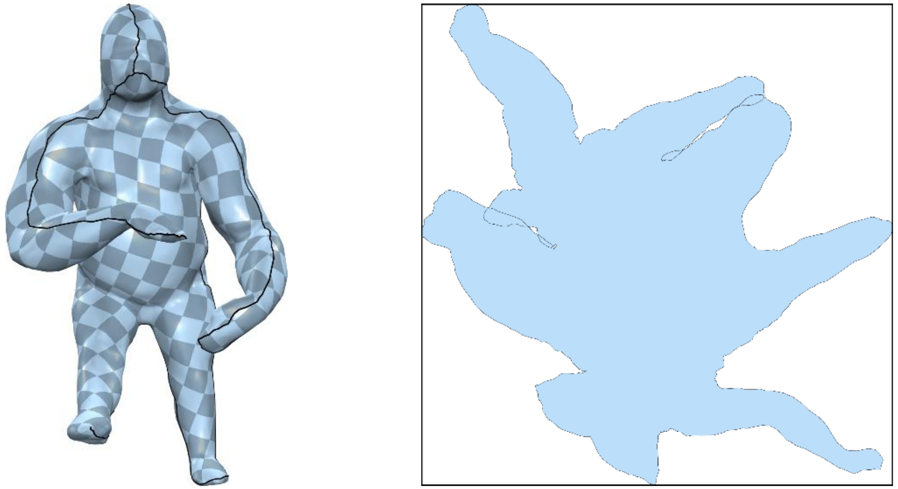
Scaffold-based method [Jiang et al. 2017]



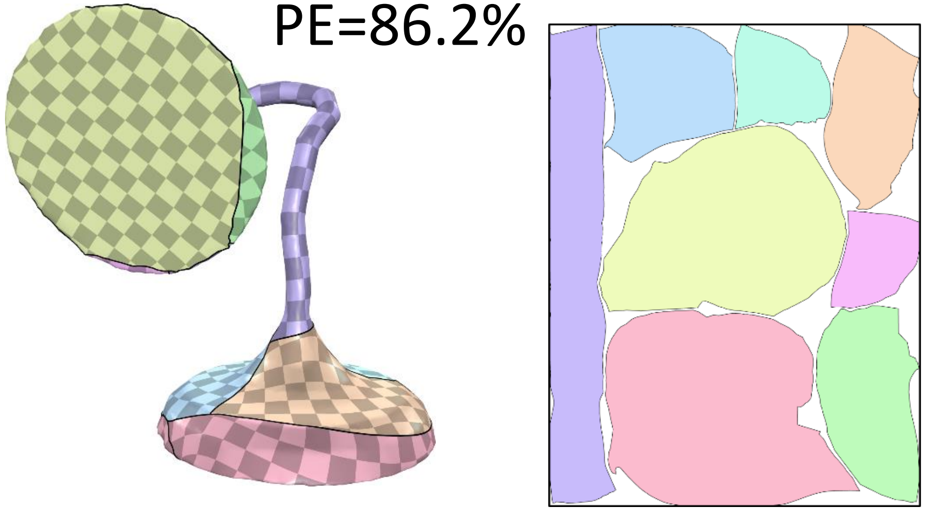
Distortion reduction

Benchmark (5,588)

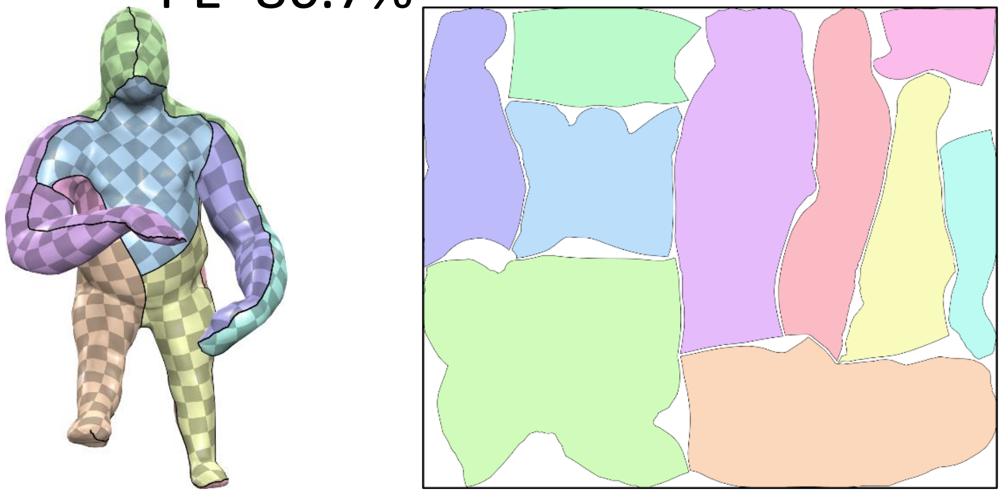




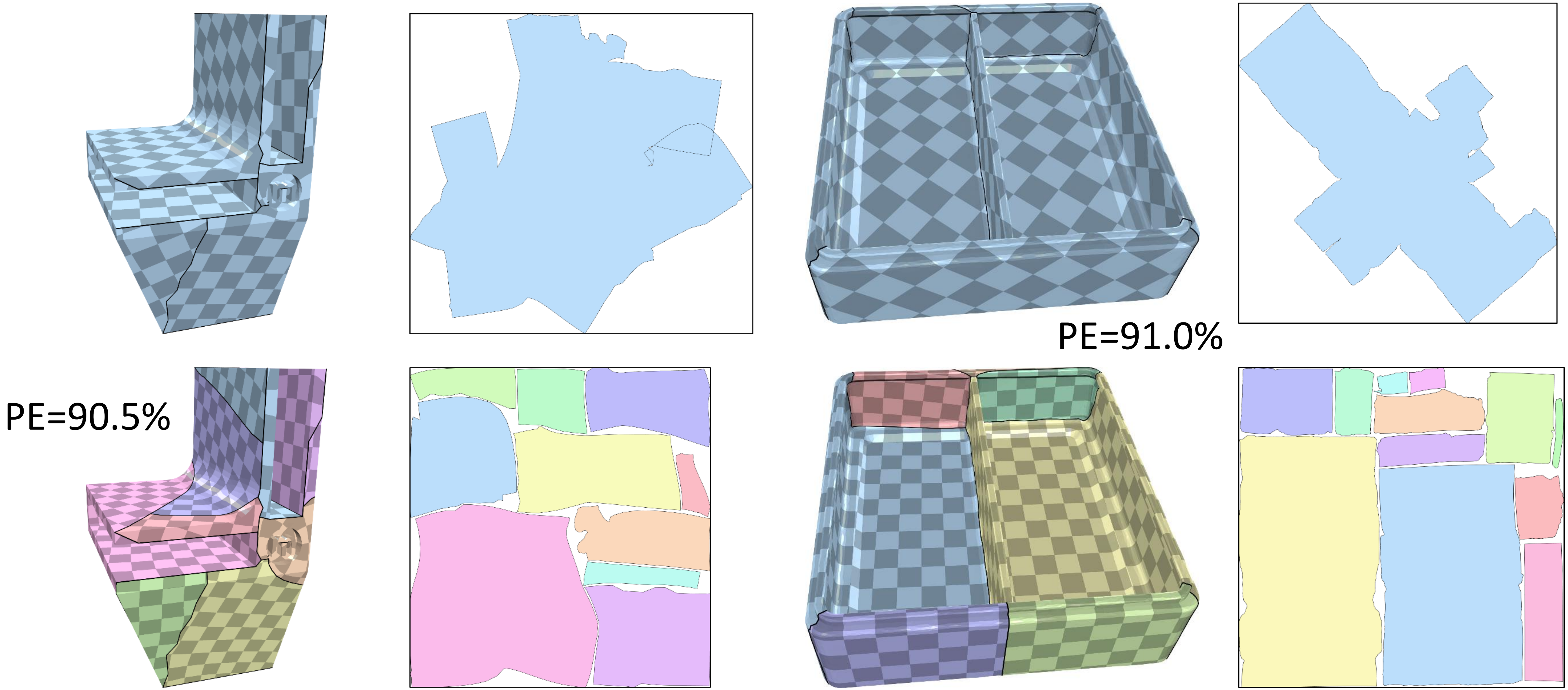
PE=86.2%



PE=86.7%



Benchmark (5,588)



PolyAtlas: Atlas Refinement with Bounded Packing Efficiency

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