Geometry Processing and Machine Learning for Modeling and Transmission of Complex 3D Scenes

Pierre Alliez

Project-team T I T A N E
Geometric Modeling of 3D Environments
https://team.inria.fr/titane/

Outline

CORESA topics

- Progressive compression
- Inter-surface mapping
- Higher-order meshes

Recent and outlook

- Cognitive 3D models
- Physics-informed modeling

CORESA Topics

Progressive Compression

Joint work with **Cédric Portaneri**, Michael Hemmer, Lukos Birklein and Elmar Schoemer

Google

DRACO
3D DATA COMPRESSION

Textured Mesh

Textured Mesh Components

Geometry

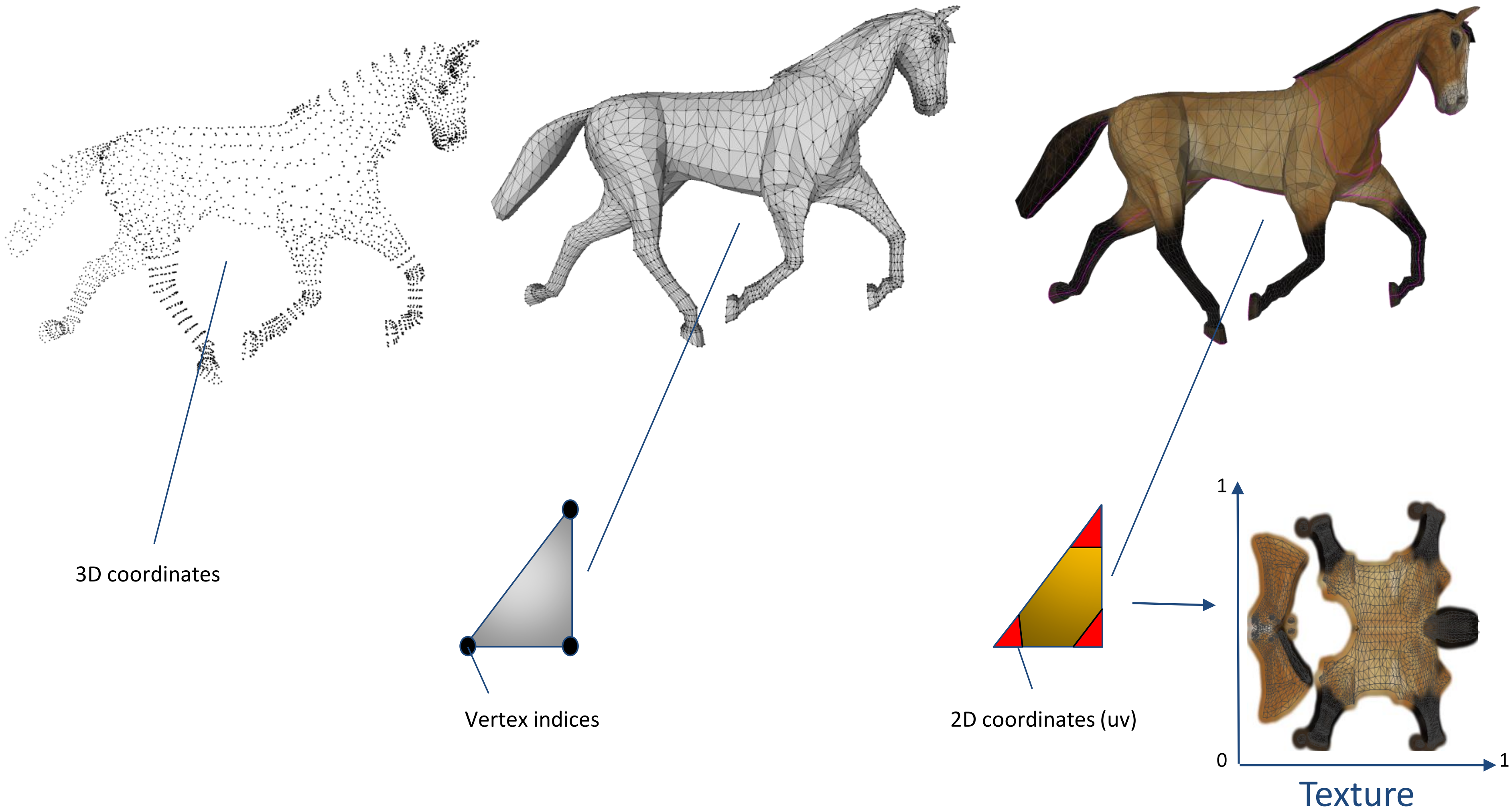
Location of vertices

Connectivity

How vertices are connected

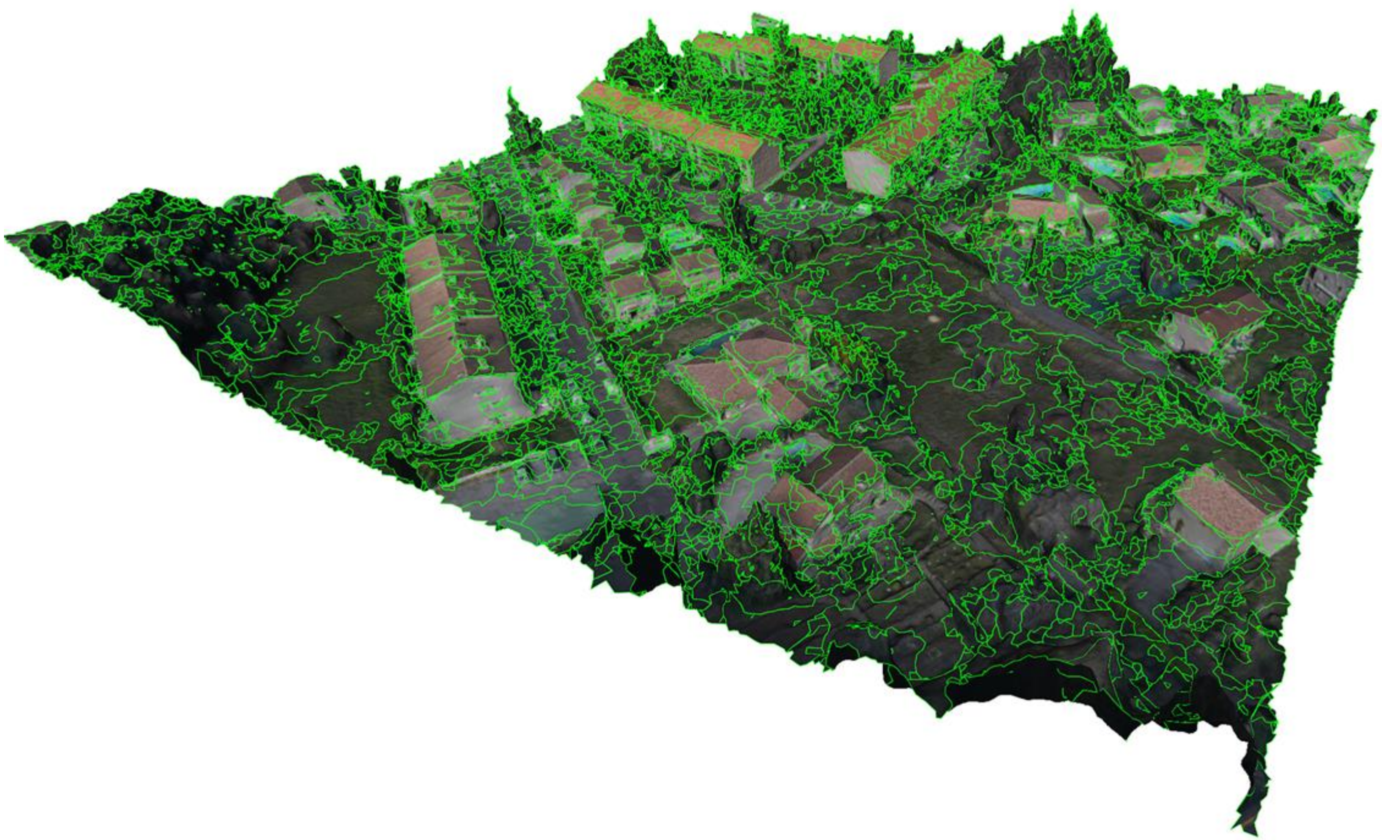
Texture Mapping

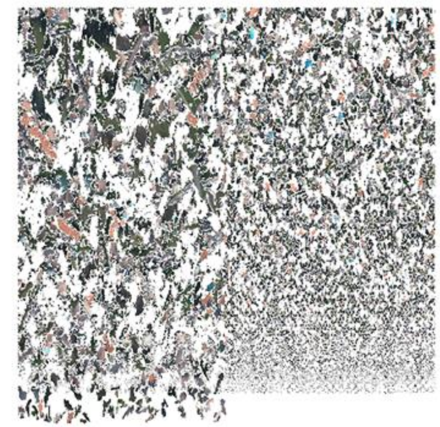
How the texture is applied



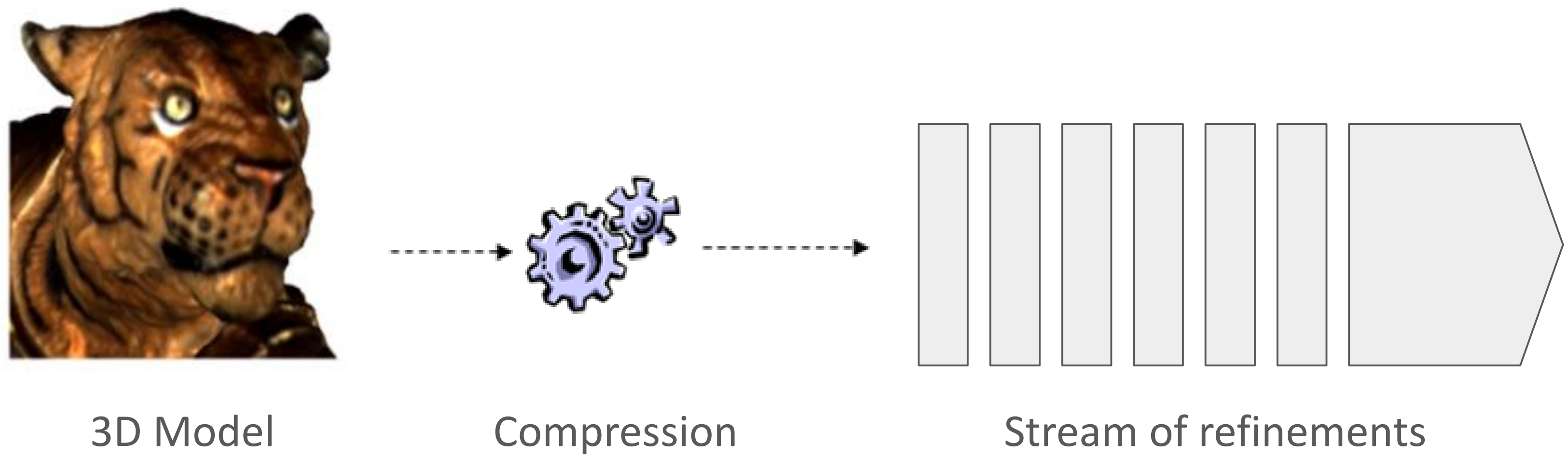
Context

Increasingly common: Automatically generated texture seams





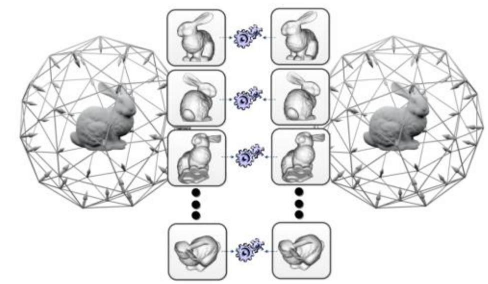
Progressive Compression

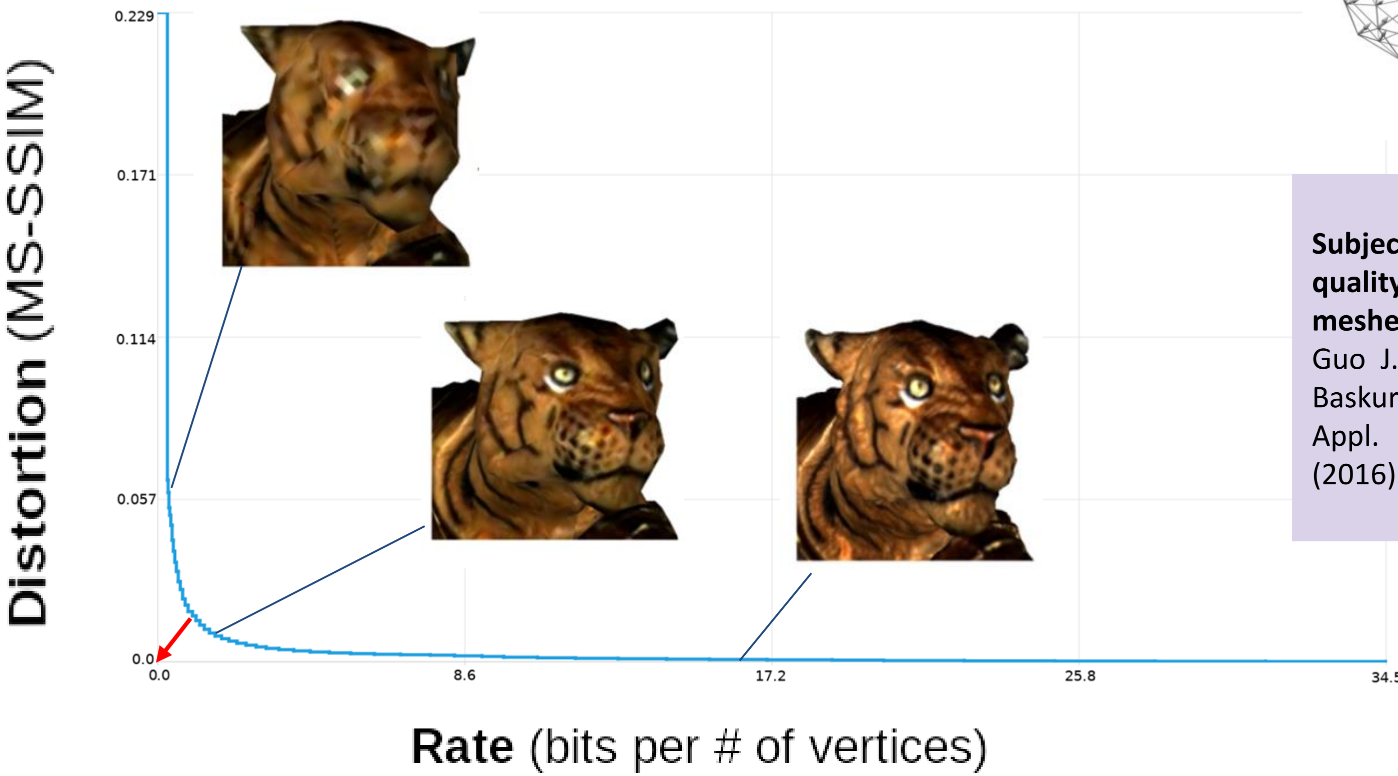


1st Level of Detail
(single-rate encoded)

Progressive Compression

Goal: optimize rate-distortion trade-off





Subjective and objective visual quality assessment of textured 3D meshes.
Guo J., Vidal V., Cheng I., Basu A., Baskurt A., Lavoué G. ACM Trans. Appl. Percept. 14(2), 11:1–11:20 (2016)

Previous Work

Progressive Streaming of Textured 3D Models in a Web Browser. Lavoué et al. In Proceedings of the 20th ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games, 2016

Progressive Compression of Arbitrary Textured Meshes. Caillaud, Vidal, Dupont, Lavoué. Computer Graphics Forum (Pacific Graphics), 2016.

Global Quantization

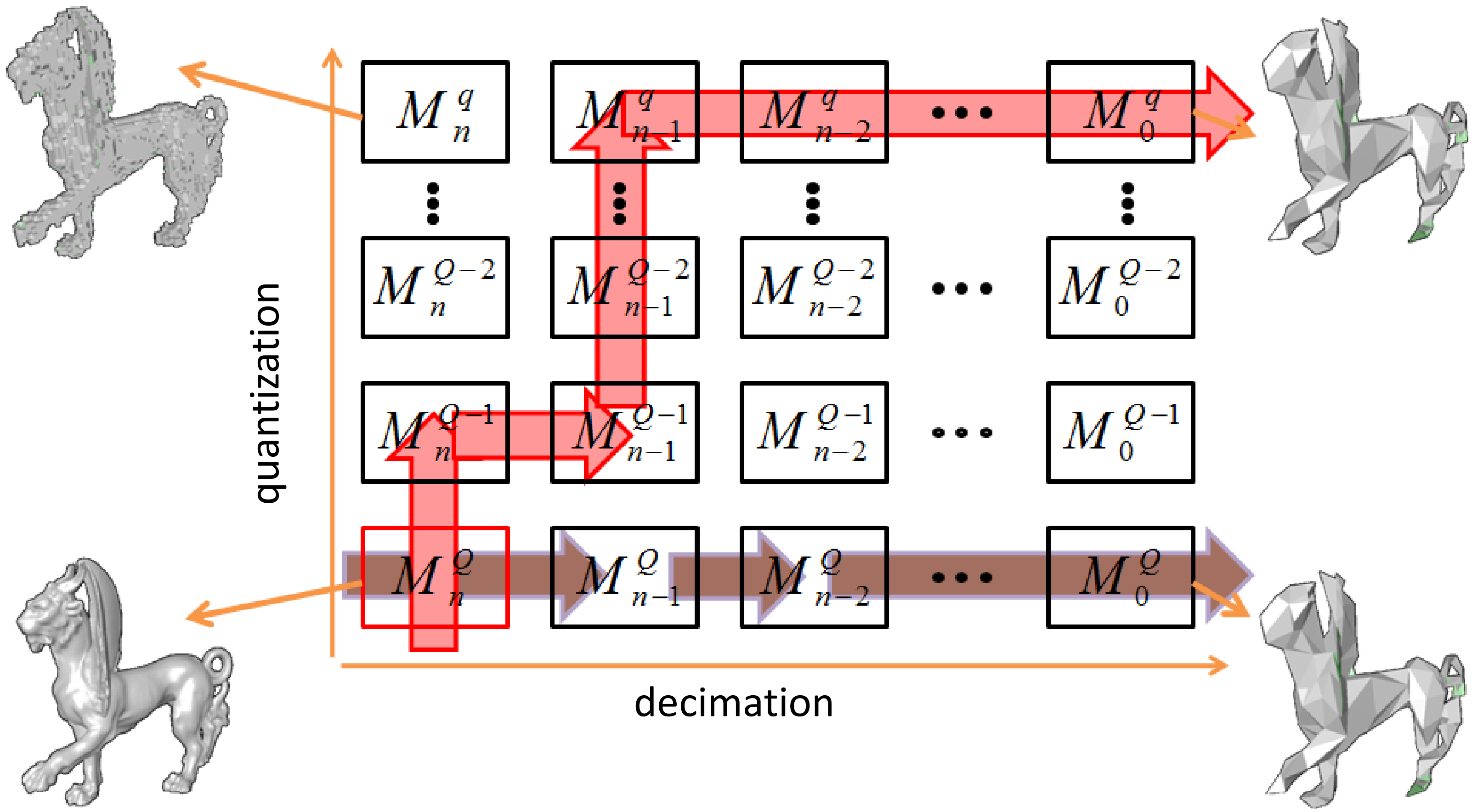
Input mesh

14 bits quantization on geometry

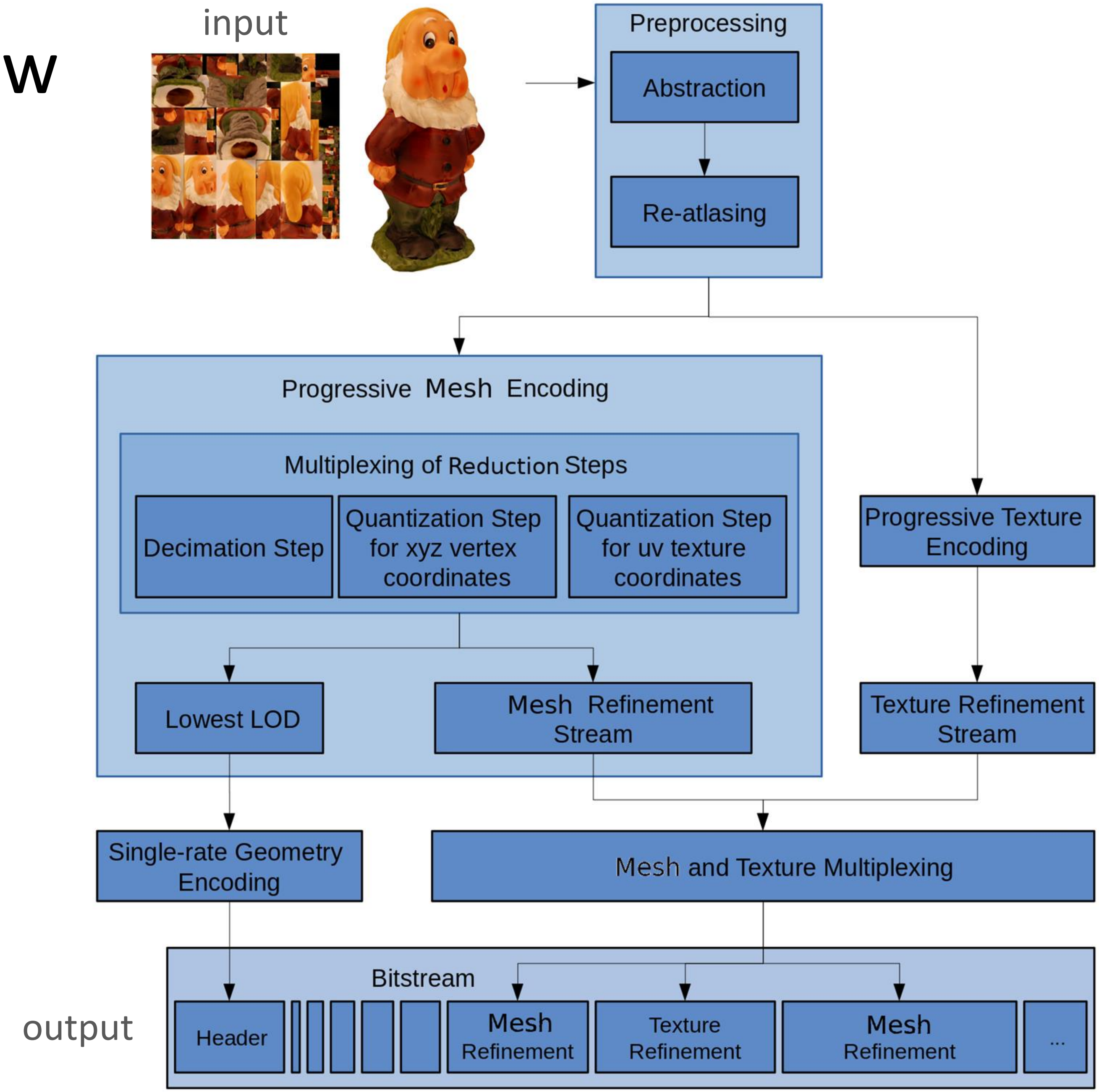
6 bits quantization on geometry

6 bits quantization on texture mapping

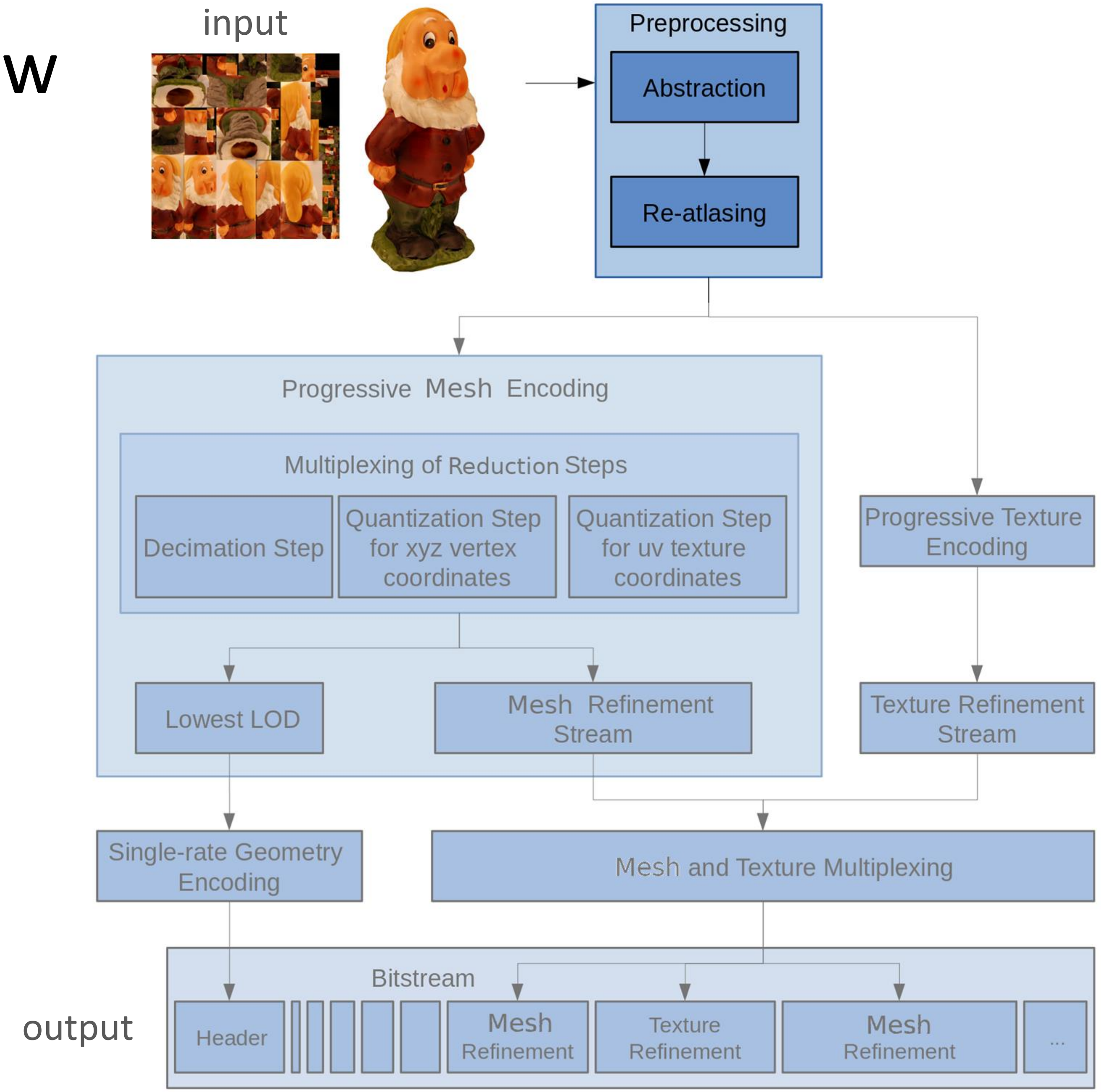
Adaptive Quantization [Lee, Lavoué, Dupont 09]



Overview


input
Preprocessing
Abstraction
Re-atlasing
Progressive Mesh Encoding
Multiplexing of Reduction Steps
Decimation Step
Quantization Step for xyz vertex coordinates
Quantization Step for uv texture coordinates
Lowest LOD
Mesh Refinement Stream
Progressive Texture Encoding
Texture Refinement Stream
Single-rate Geometry Encoding
Mesh and Texture Multiplexing
Bitstream
Header
Mesh Refinement
Texture Refinement
Mesh Refinement
...
output

Overview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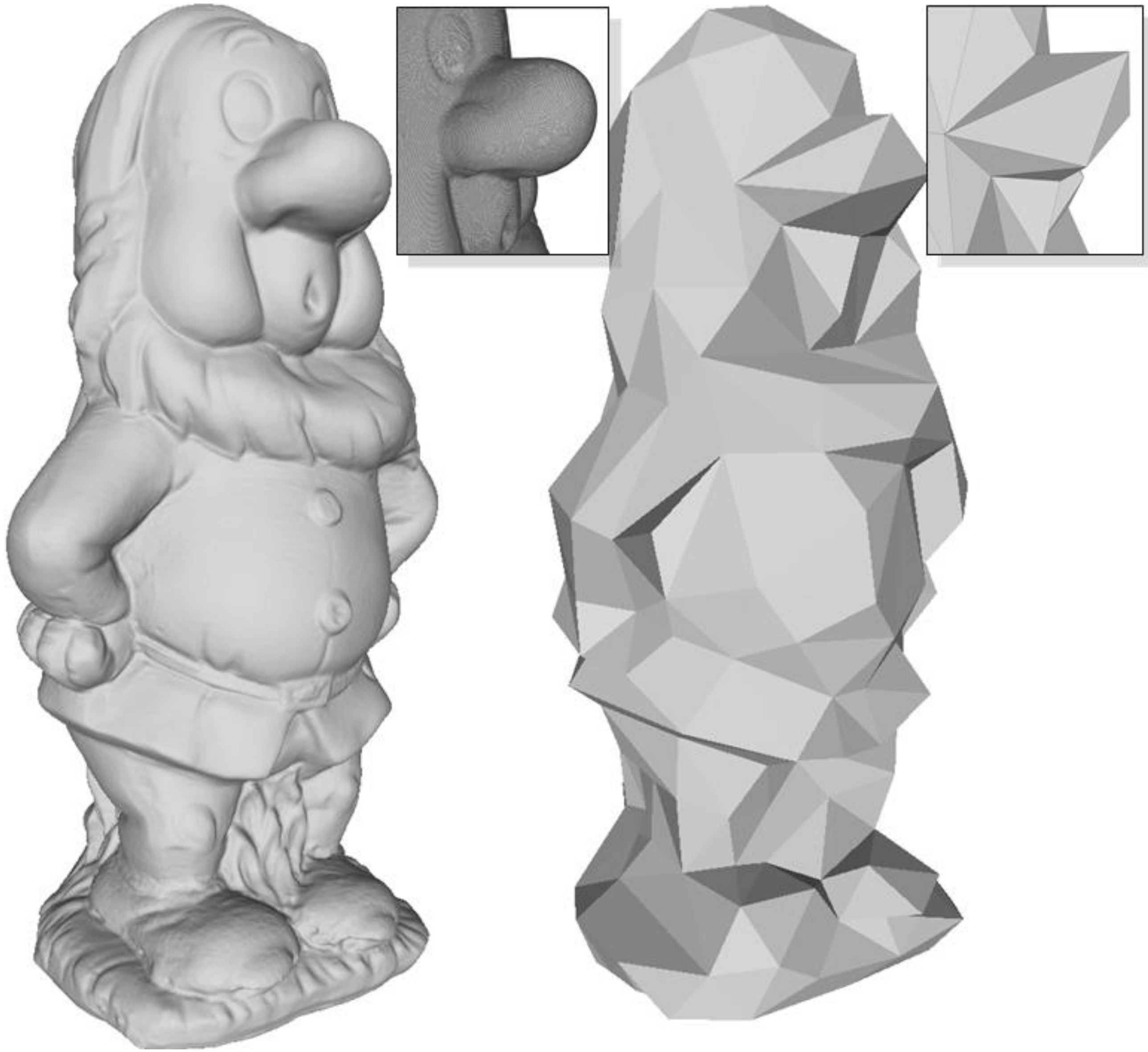
Preprocessing

Abstraction



Preprocessing

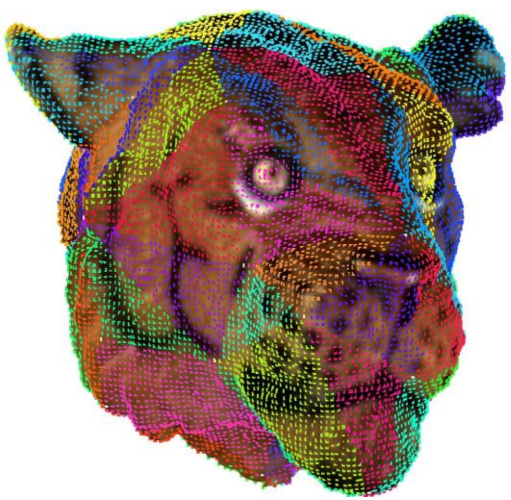
Re-atlasing

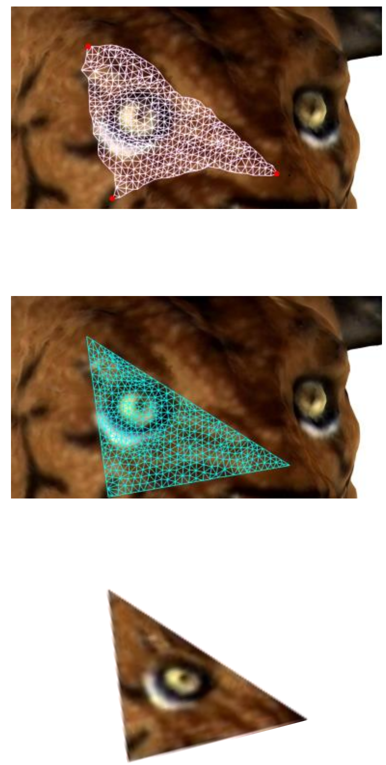
Decimation toward Abstraction

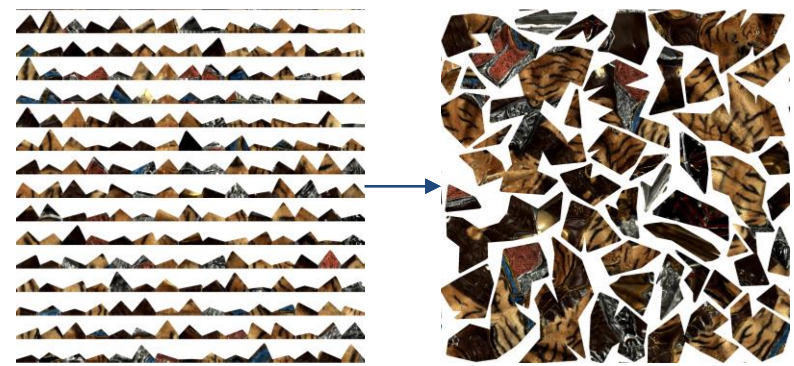
Seam-preserving simplification

Re-atlasing Steps

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ





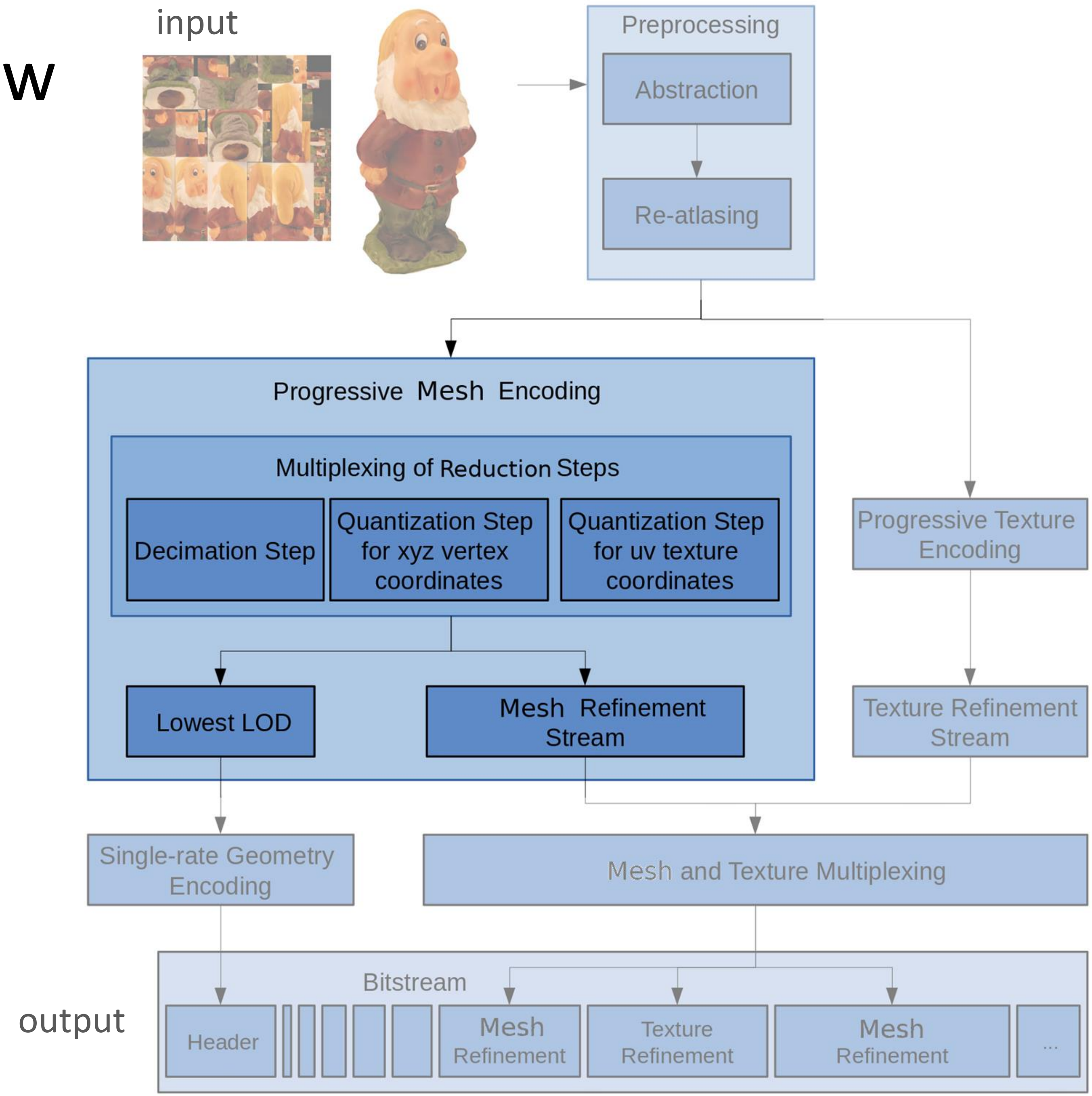


1. Cluster input triangles onto abstraction triangle

2. Form a texture patch by planar parameterization

3. Pack the texture patches. Glue texture seams and save them as virtual seams

Overview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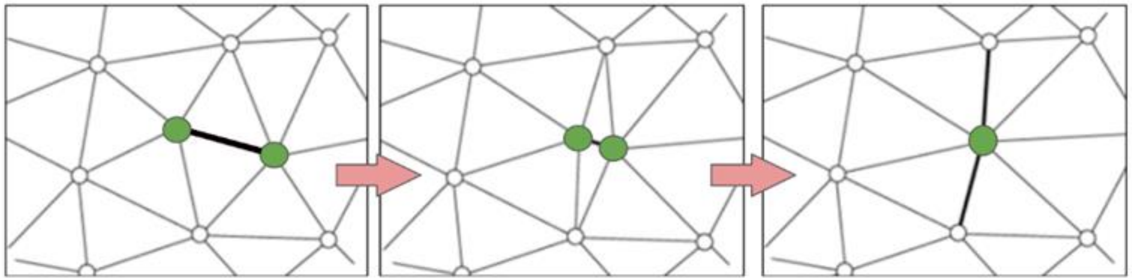
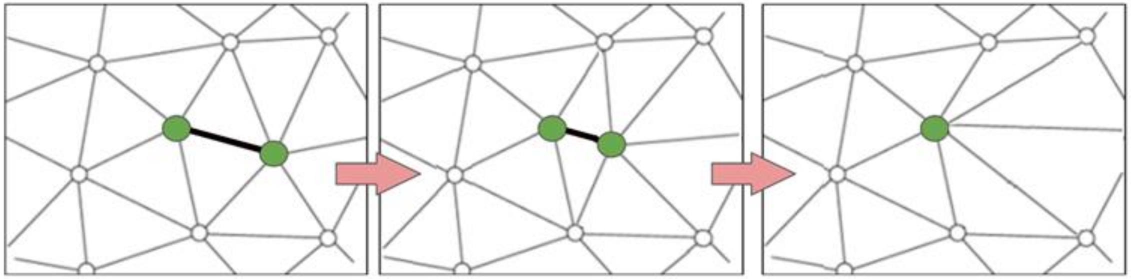
Decimation Operators

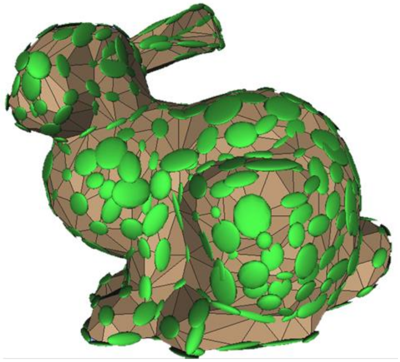
Full-edge collapse

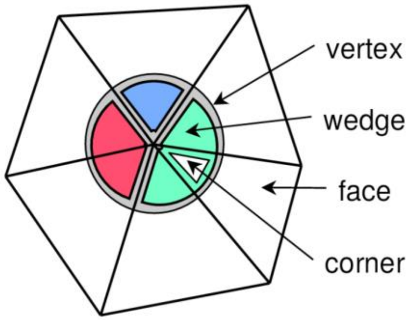


Half-edge collapse

(cheaper to encode)



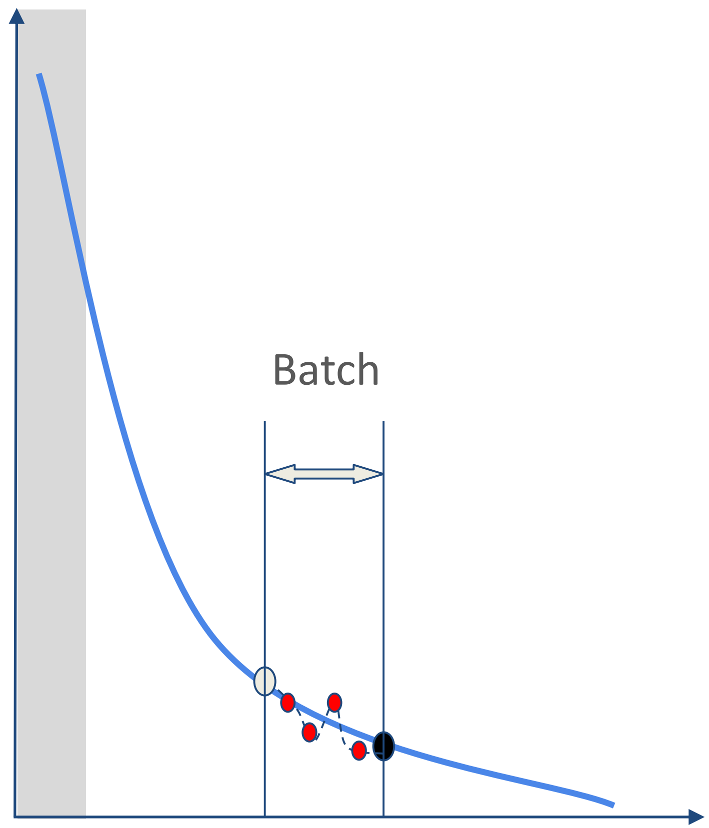


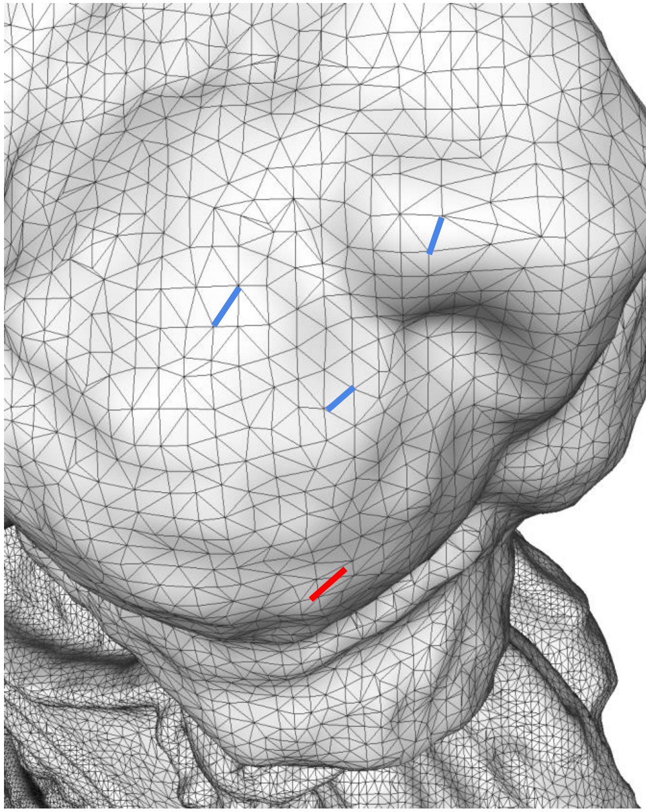


5D Quadric Error Metric

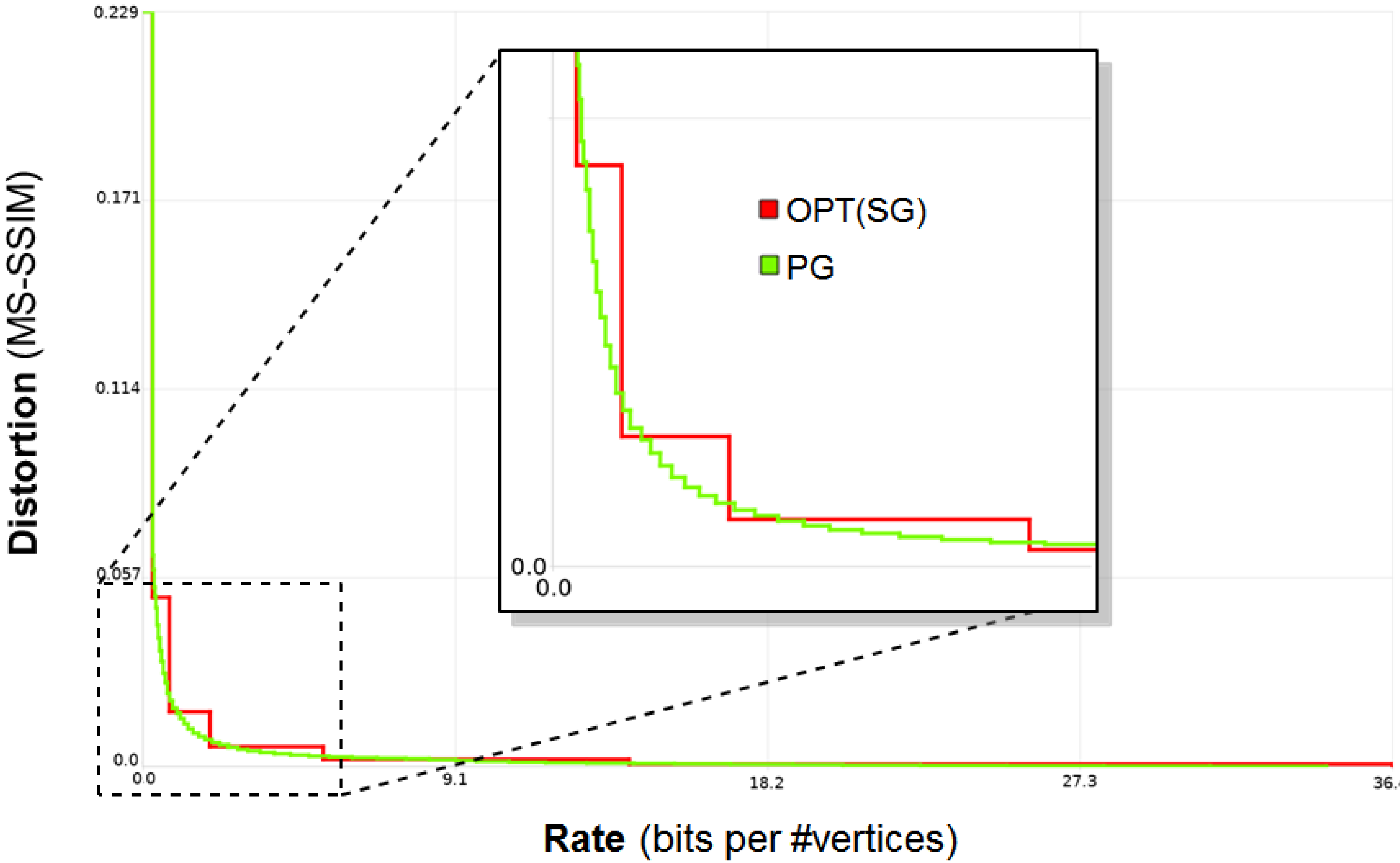
Decimation

Order of decimation operator



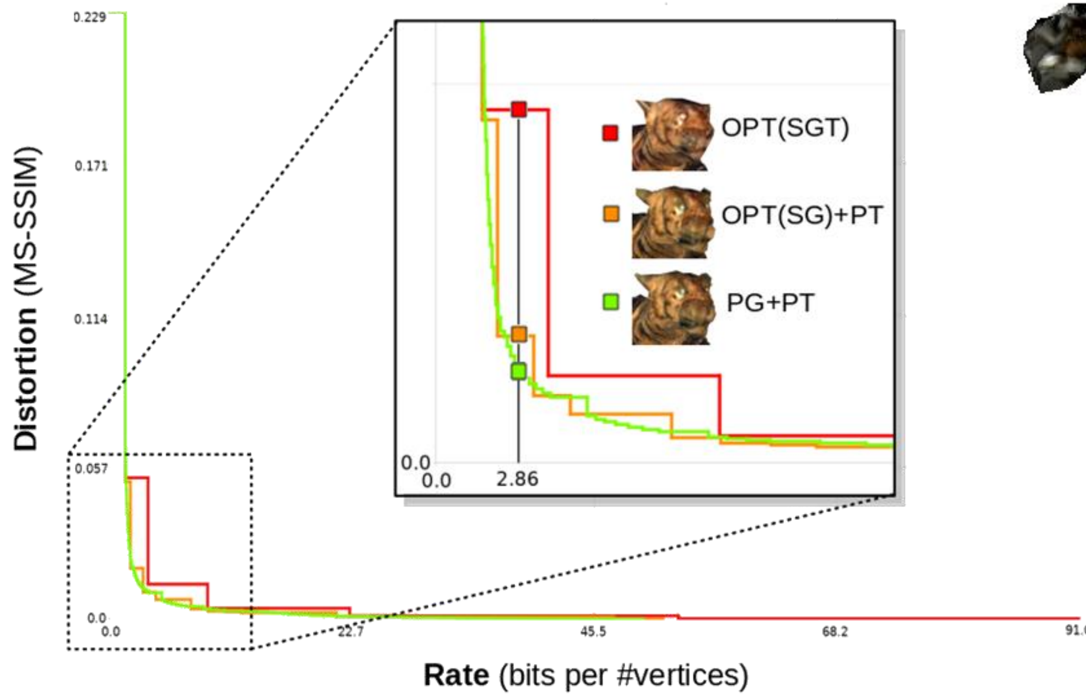


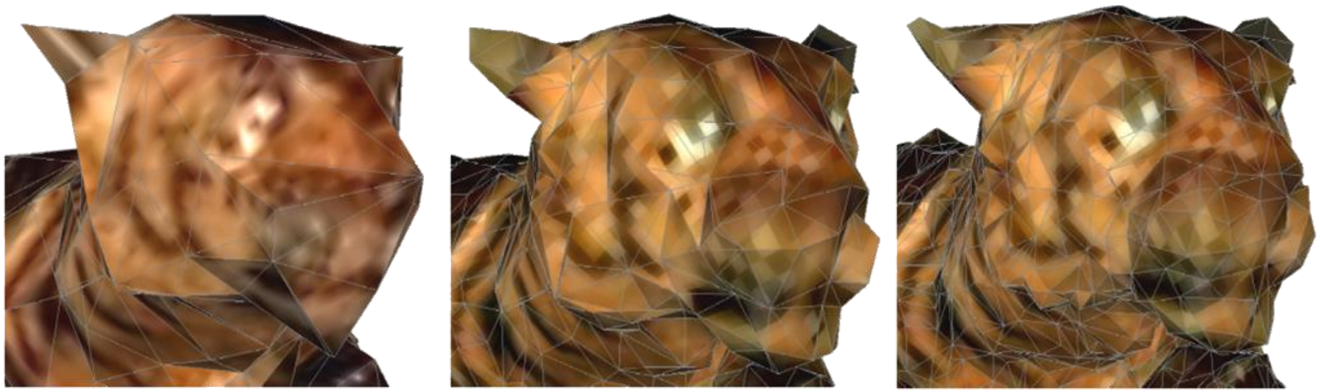
Results



Distortion (MS-SSIM)
0.229
0.171
0.114
0.057
0.0
0.0
9.1
18.2
27.3
36.4
Rate (bits per #vertices)
OPT(SG)
PG
0.0
0.0

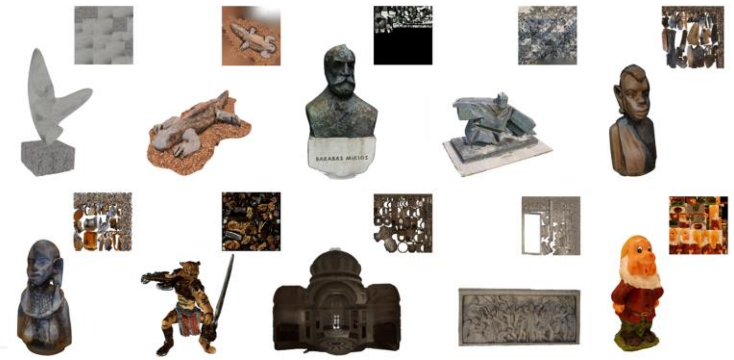
Results

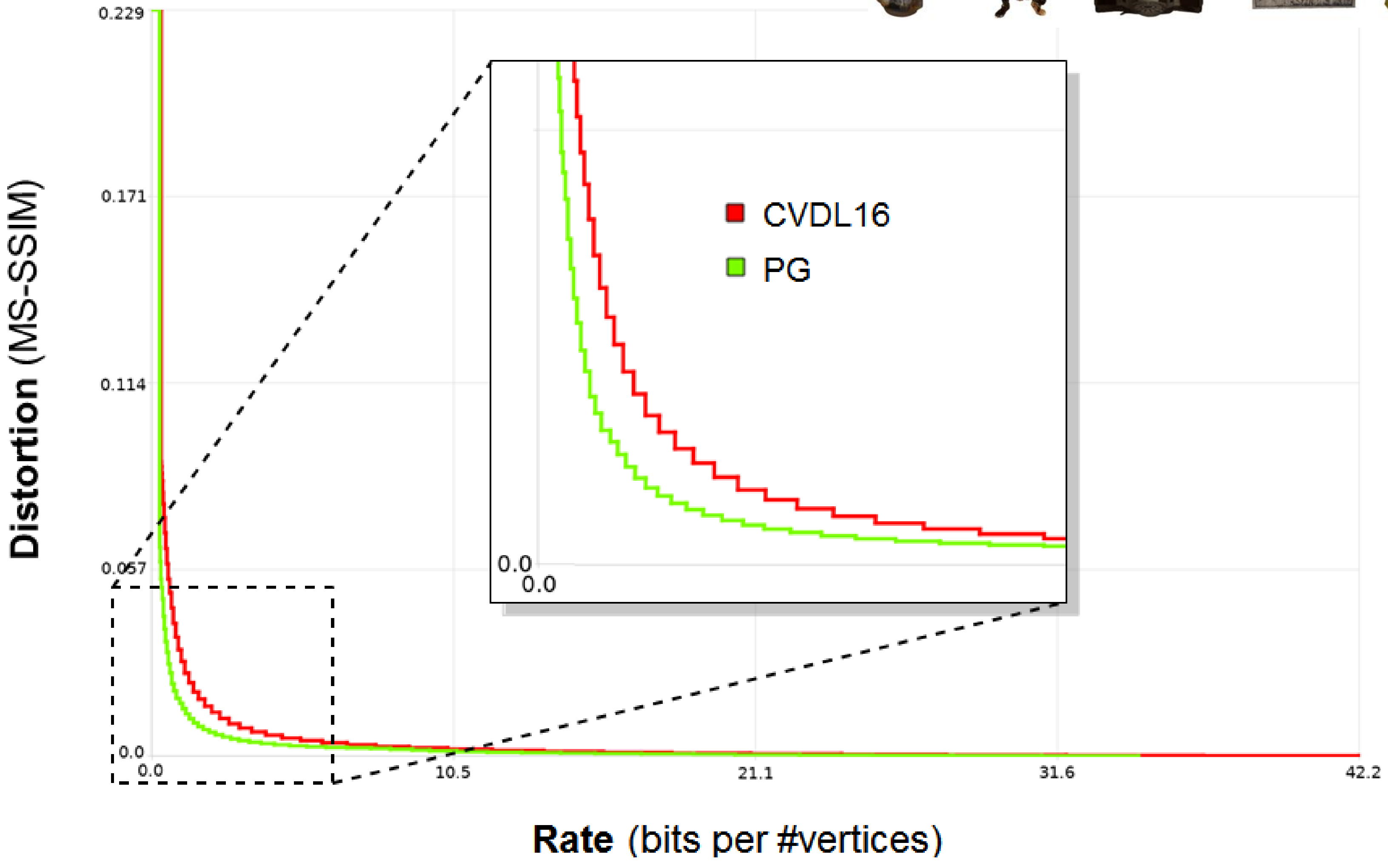




OPT(SGT) OPT(SG)+PT PG+PT

Results





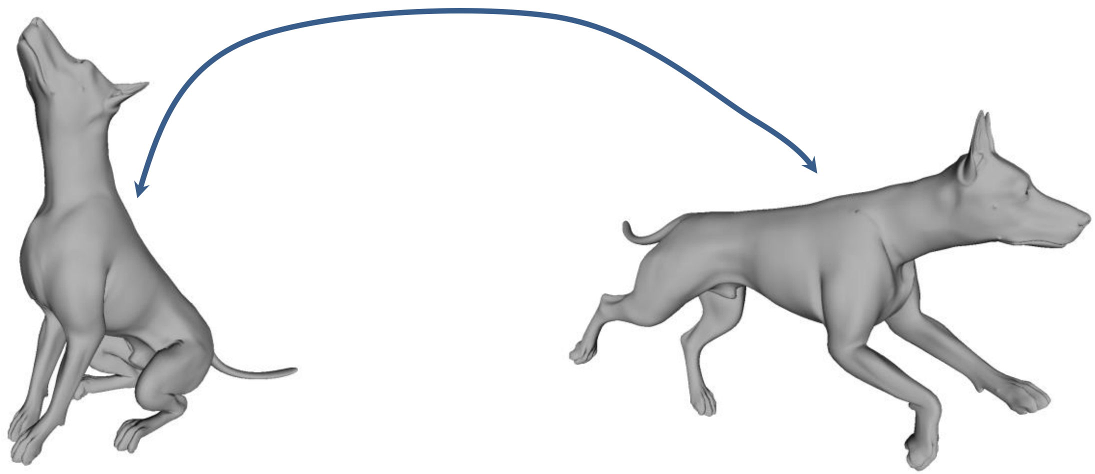
Distortion (MS-SSIM)
0.229
0.171
0.114
0.057
0.0
0.0
10.5
21.1
31.6
42.2
Rate (bits per #vertices)
CVDL16
PG
0.0
0.0

Inter-surface mapping

Joint work with **Manish Mandad**, David Cohen-Steiner, Leif Kobbelt, and Mathieu Desbrun

30 JULY–3 AUGUST Los Angeles SIGGRAPH2017

Problem Statement



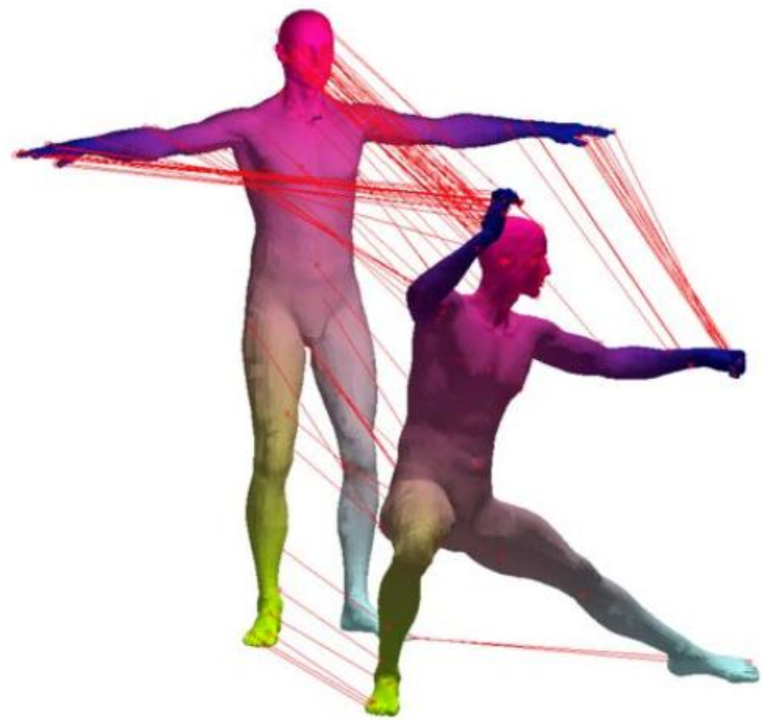
Find mapping between two surfaces

- Bijective
- Some degree of regularity
- Semantically meaningful

Inter-Surface Mapping

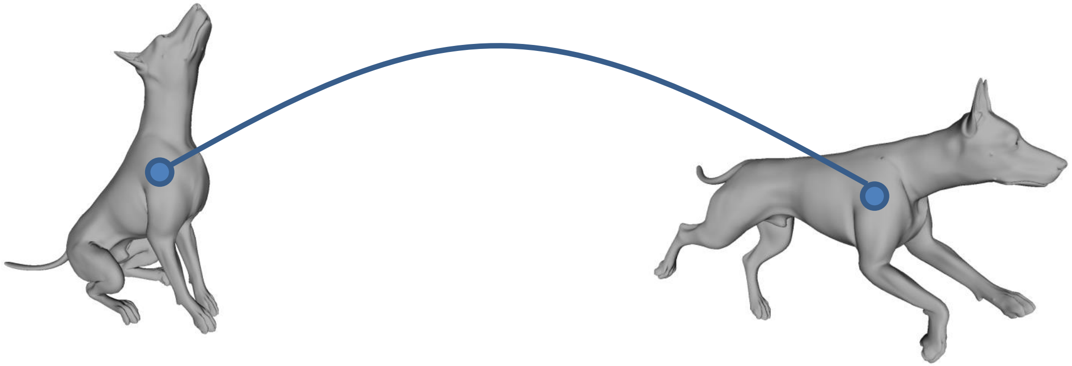
Used for:

- Template fitting
- Detail or attribute transfer
- Blending
- Morphing
- Surface reconstruction
- Remeshing
- …



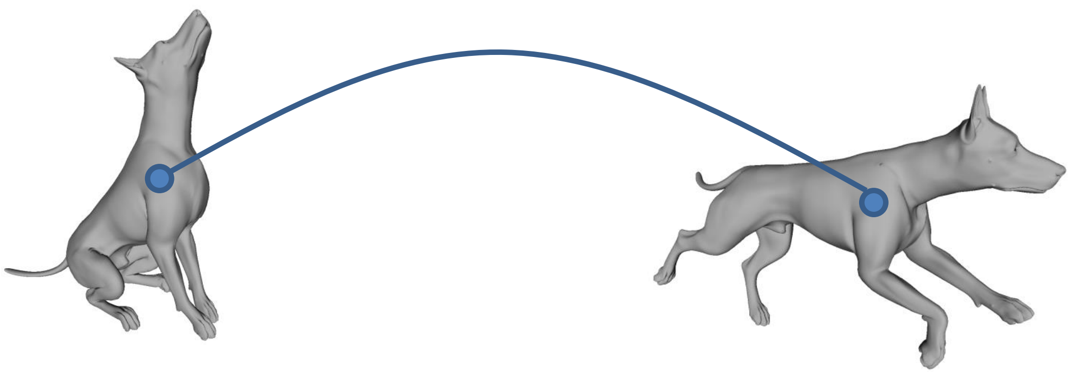
Homeomorphism?

- Bi-continuous function between topological spaces
- « continuous stretching and bending of the object into a new shape»
- …
- Neighborhoods map to neighborhoods



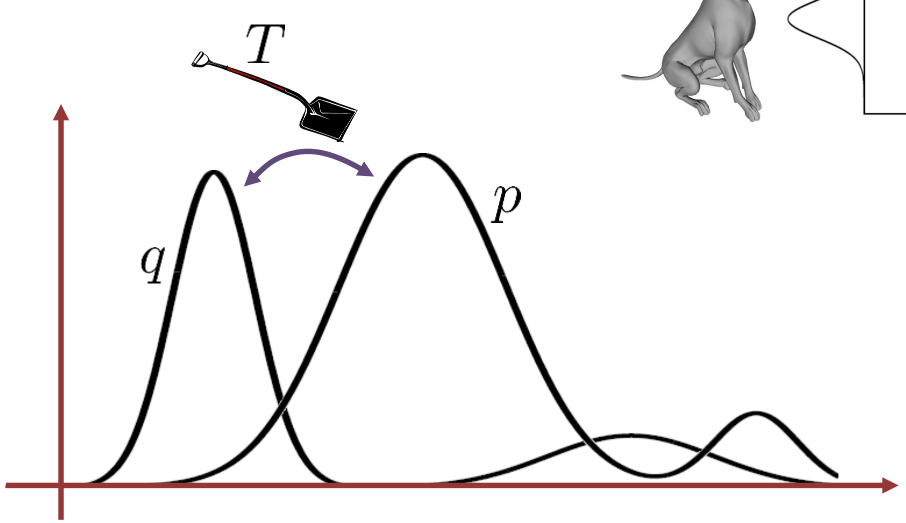
Homeomorphism?

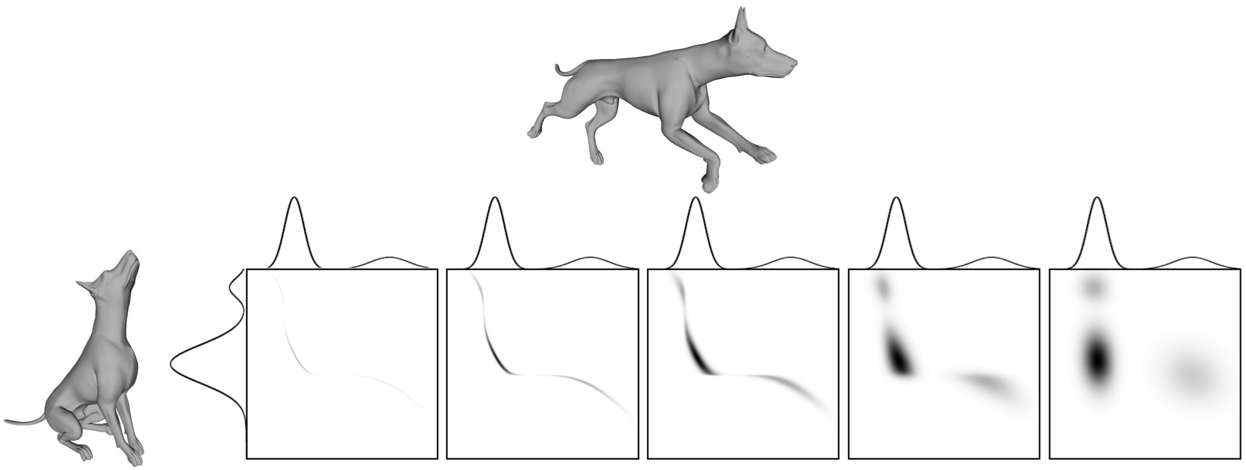
- *Geodesic neighbourhoods* map to *small geodesic neighbourhoods*



Proposal

Formulation based on **Optimal Transportation**





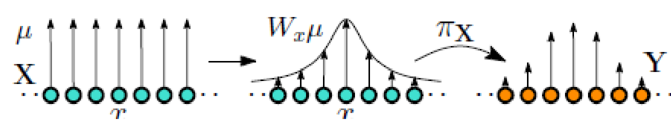
Figures from Solomon et al. 15

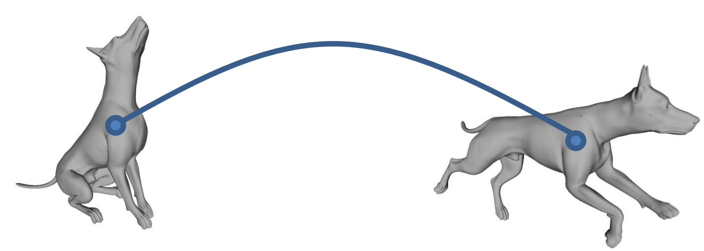
Formulation

- Minimize variances of images of neighborhoods by the transport plan.
- Penalizes stretching and favors point-to-point homeomorphisms.

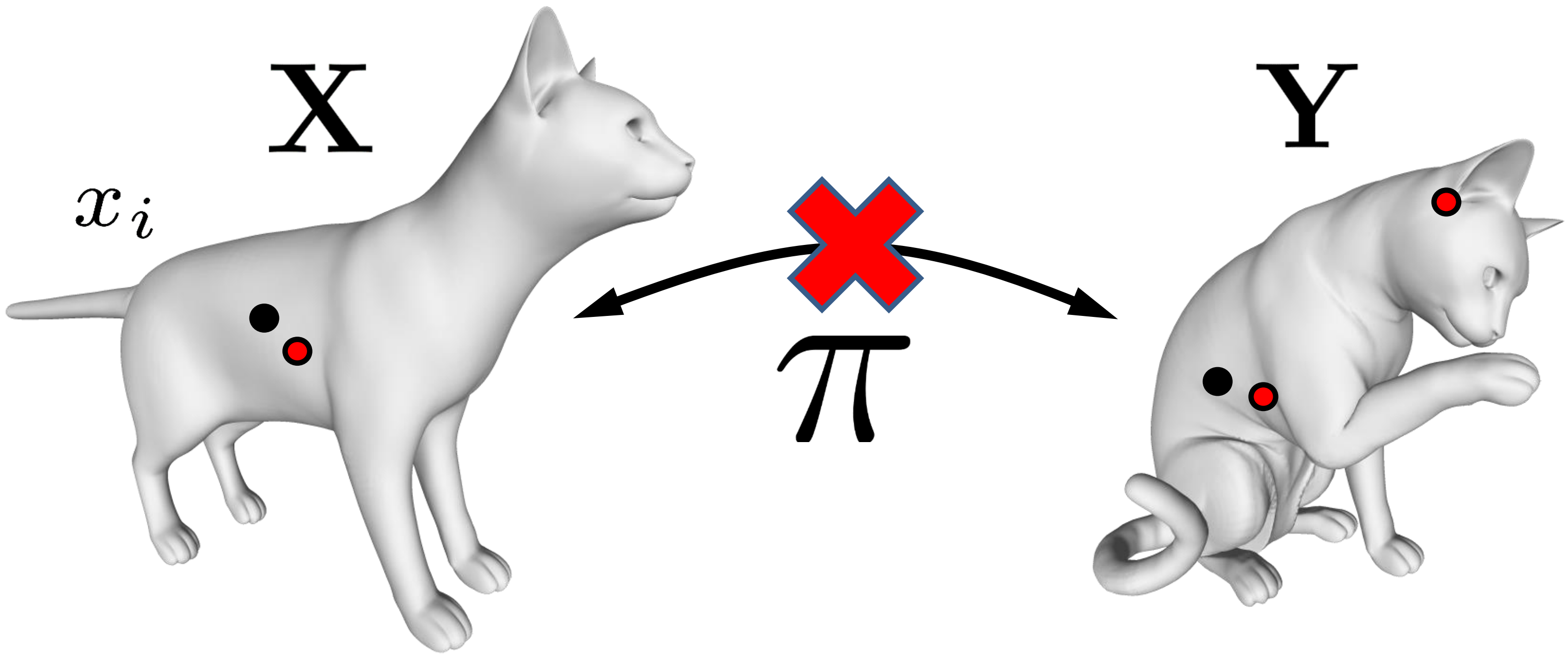
weighting function

$$E(\pi) = \int_{\mathbf{X}} \operatorname{var} \pi_{\mathbf{X}} \left(\frac{W_x \mu}{\operatorname{mass}(W_x \mu)} \right) d\mu(x) + \int_{\mathbf{Y}} \operatorname{var} \pi_{\mathbf{Y}} \left(\frac{W_y \nu}{\operatorname{mass}(W_y \nu)} \right) d\nu(y)$$



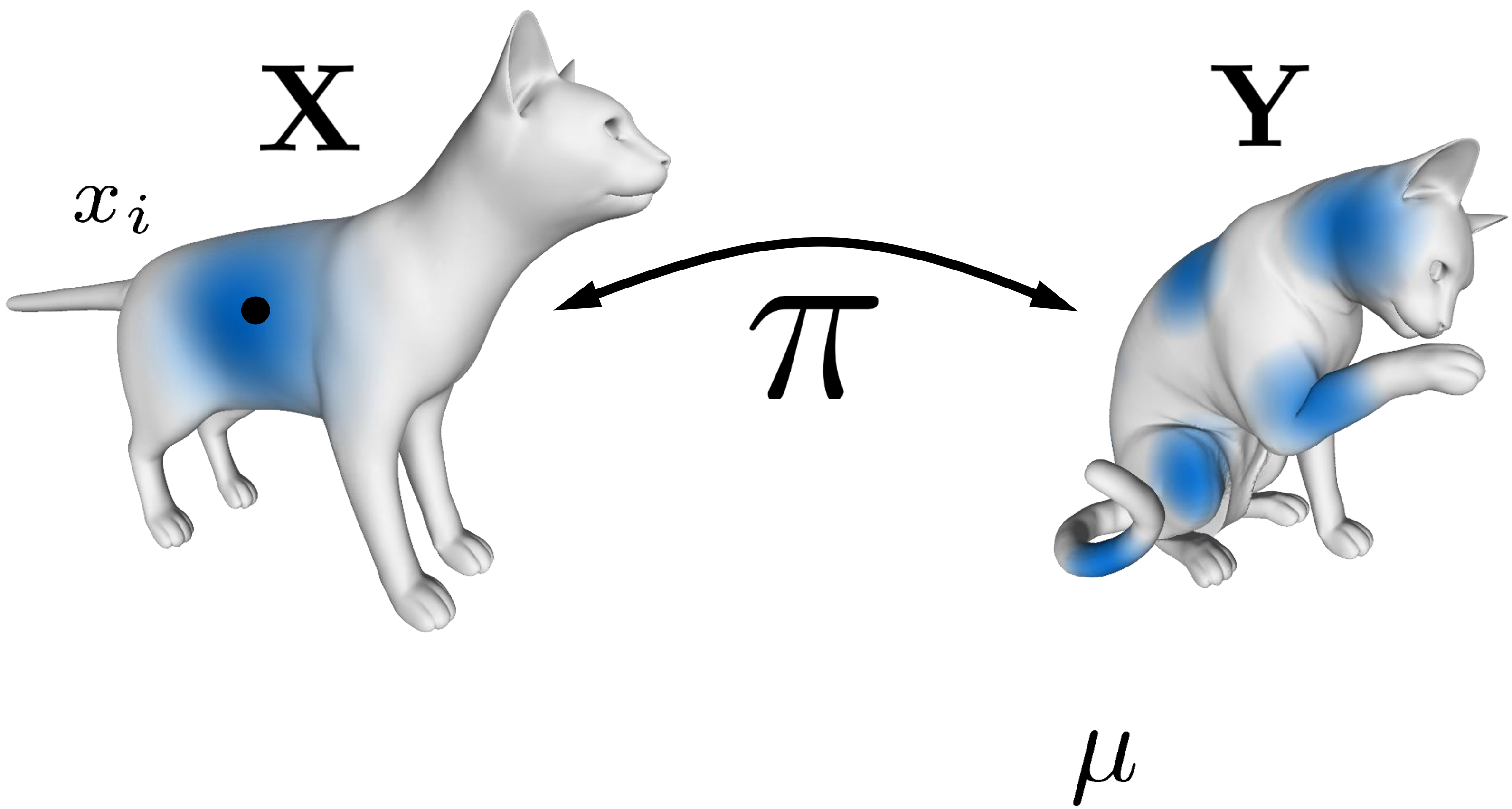


Continuity

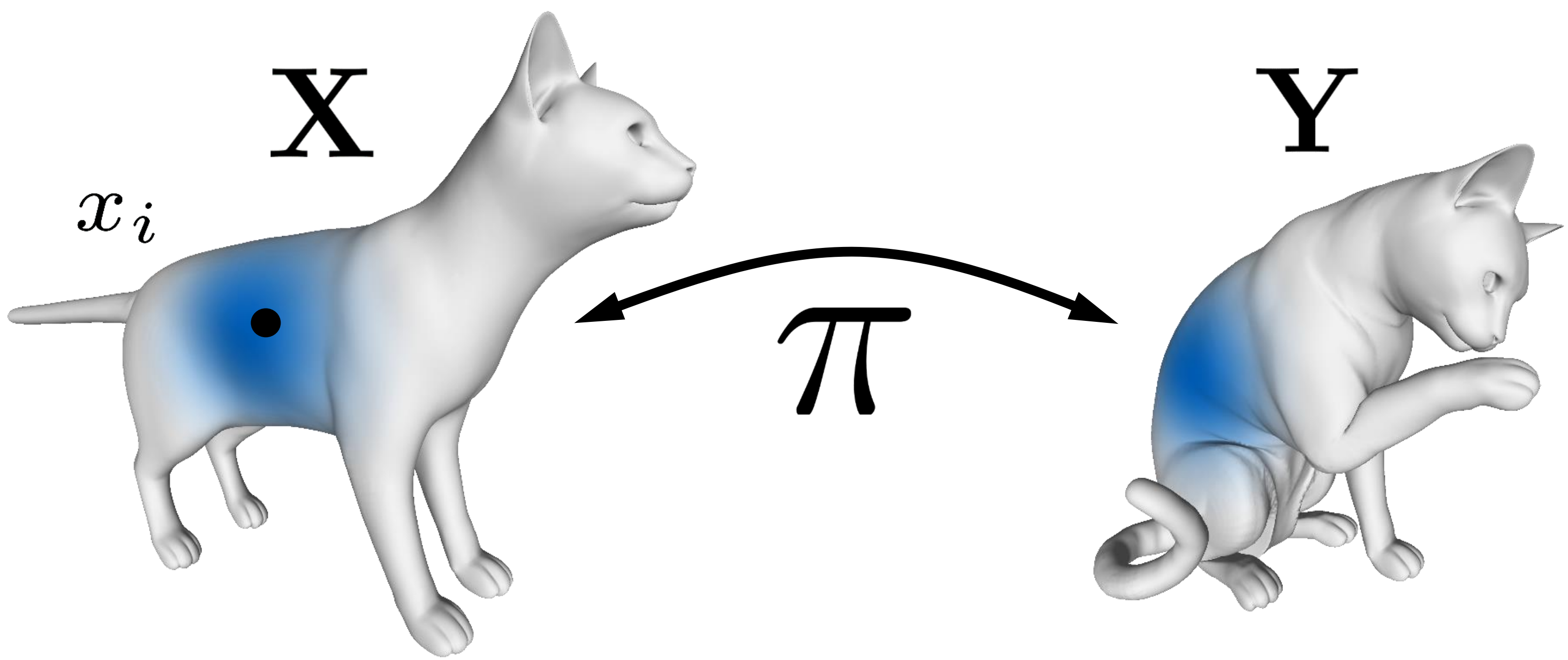


"Neighborhood maps to neighborhood"

Cost Function

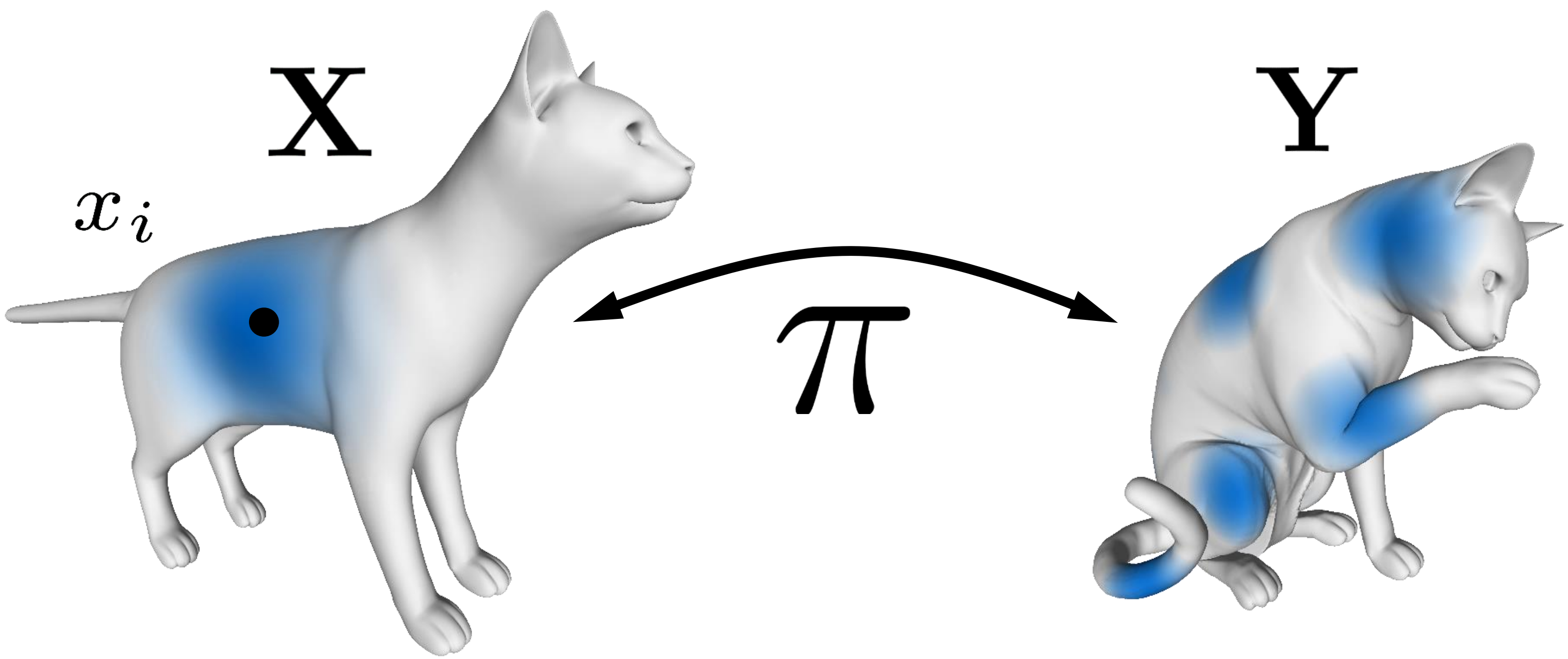


Cost Function



$$\mathcal{C}(\pi) = \sum\nolimits_{\mathbf{X}} \mathrm{var}\left(\pi\left(W_{x_i}\mu\right)\right)$$

Cost Function



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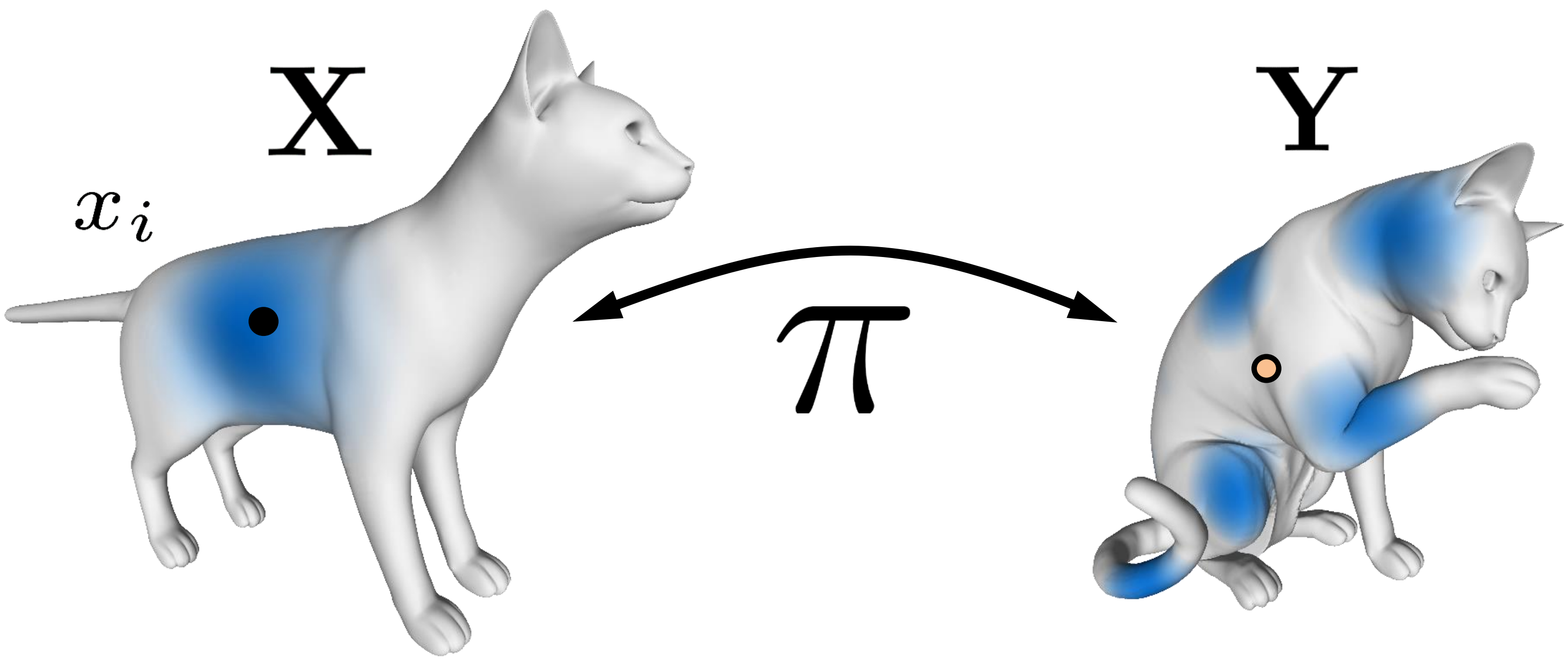
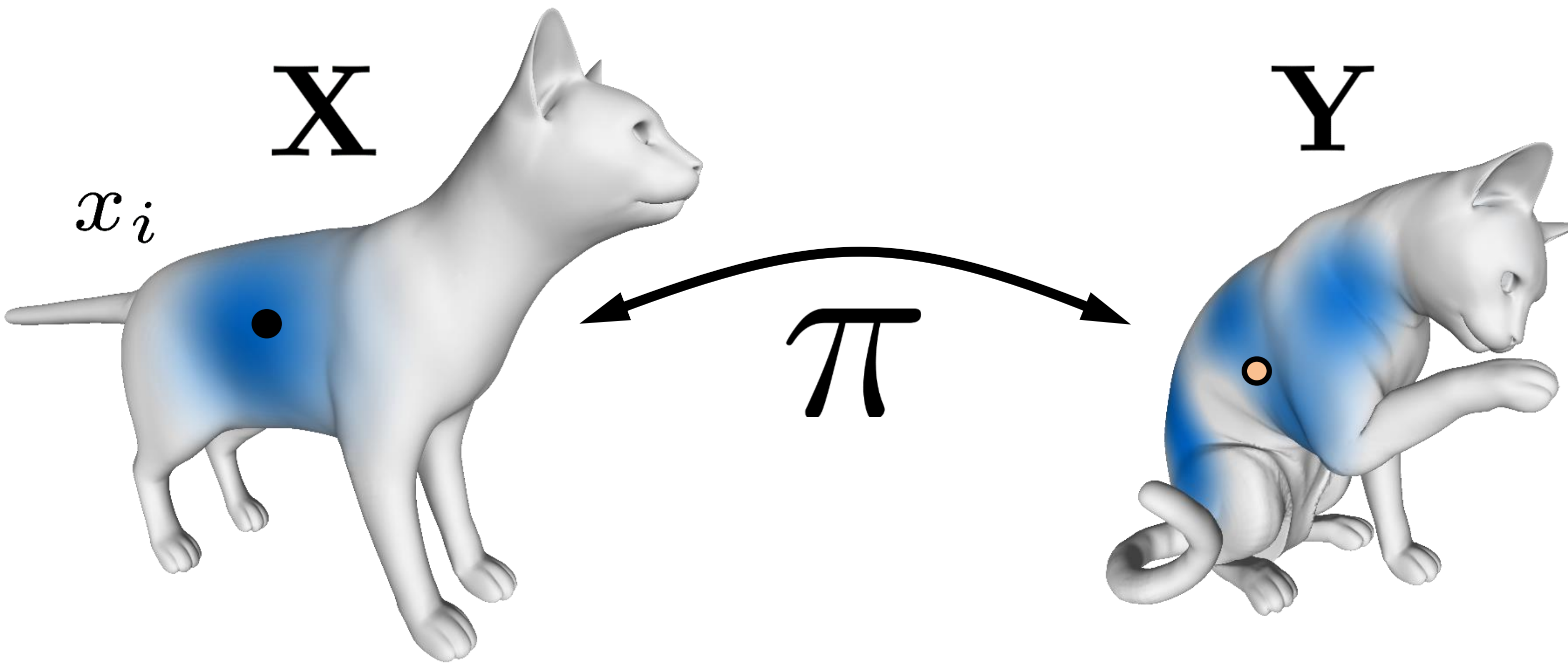


$$\mathcal{C}\left(\pi, \eta\right) = \sum\nolimits_{\mathbf{X}} \mathrm{var}\left(\pi\left(W_{x_i}\mu\right), \eta_{x_i}\right)$$

Cost Function



$$\mathcal{C}\left(\pi, \eta\right) = \sum_{\mathbf{X}} \mathrm{var}\left(\pi\left(W_{x_i}\mu\right), \eta_{x_i}\right)$$

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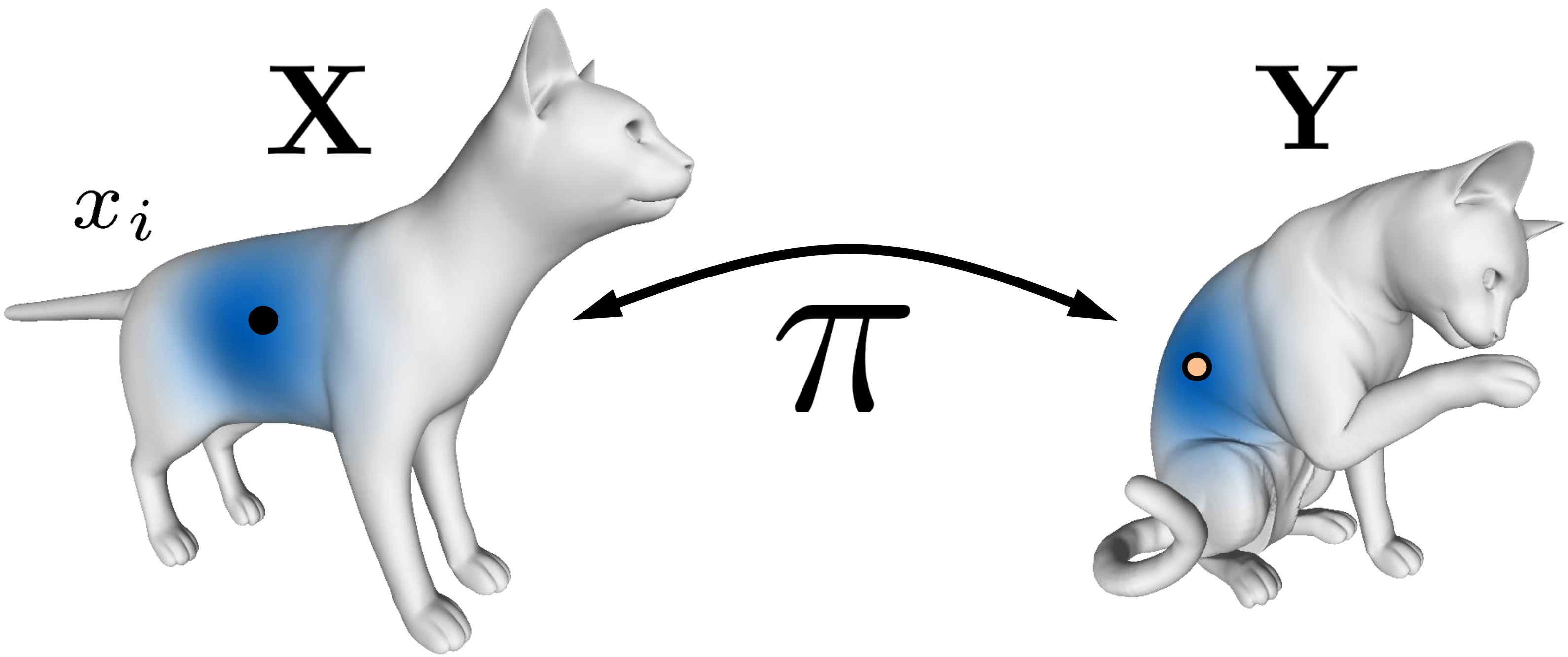

$$\mathcal{C}\left(\pi, \eta\right) = \sum_{\mathbf{X}} \mathrm{var}\left(\pi\left(W_{x_i}\mu\right), \eta_{x_i}\right)$$

Minimization

$$E(\pi) = \int_{\mathbf{X}} \text{var}\, \pi_{\mathbf{X}} \left(\frac{W_x \mu}{\text{mass}(W_x \mu)} \right) d\mu(x) + \int_{\mathbf{Y}} \text{var}\, \pi_{\mathbf{Y}} \left(\frac{W_y \nu}{\text{mass}(W_y \nu)} \right) d\nu(y)$$

Non-convex!

Reformulation with auxiliary variables. Given a measure $\mu = \sum \mu_i \delta_{x_i}$ and a point x, we denote by $\text{var}(\mu, x)$ its variance with respect to x:

$$\text{var}(\mu, x) = \sum \mu_i d(x_i, x)^2, \quad (2)$$

geodesic barycenter

Algorithm 1 Map optimization through alternating minimization

function ALTERNATING MINIMIZATION
  for $i = 1, 2, 3 \ldots$ **do**
    $\eta \leftarrow \min \mathcal{C}(\pi, \cdot)$ *// move centers to geodesic barycenters*
    $\pi \leftarrow \min \mathcal{C}(\cdot, \eta)$ *// solve optimal transport problem*
  return π ▷ variance-minimizing transport plan

Minimization

$$E(\pi) = \int_{\mathbf{X}} \operatorname{var} \pi_{\mathbf{X}} \left(\frac{W_x \mu}{\operatorname{mass}(W_x \mu)} \right) d\mu(x) + \int_{\mathbf{Y}} \operatorname{var} \pi_{\mathbf{Y}} \left(\frac{W_y \nu}{\operatorname{mass}(W_y \nu)} \right) d\nu(y)$$

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4: $\pi \leftarrow \min \mathcal{C}(\cdot, \eta)$ // *solve optimal transport problem*
5: **return** π ▷ variance-minimizing transport plan

in diffusion space

Sinkhorn iteration

[Cuturi et al.]

Minimization

$$E(\pi) = \int_{\mathbf{X}} \operatorname{var} \pi_{\mathbf{X}} \left(\frac{W_x \mu}{\operatorname{mass}(W_x \mu)} \right) d\mu(x) + \int_{\mathbf{Y}} \operatorname{var} \pi_{\mathbf{Y}} \left(\frac{W_y \nu}{\operatorname{mass}(W_y \nu)} \right) d\nu(y)$$

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$$\operatorname{var}(\mu, x) = \sum \mu_i d(x_i, x)^2, \qquad (2)$$

geodesic barycenter

Coarse to fine

Algorithm 1 Map optimization through alternating minimization

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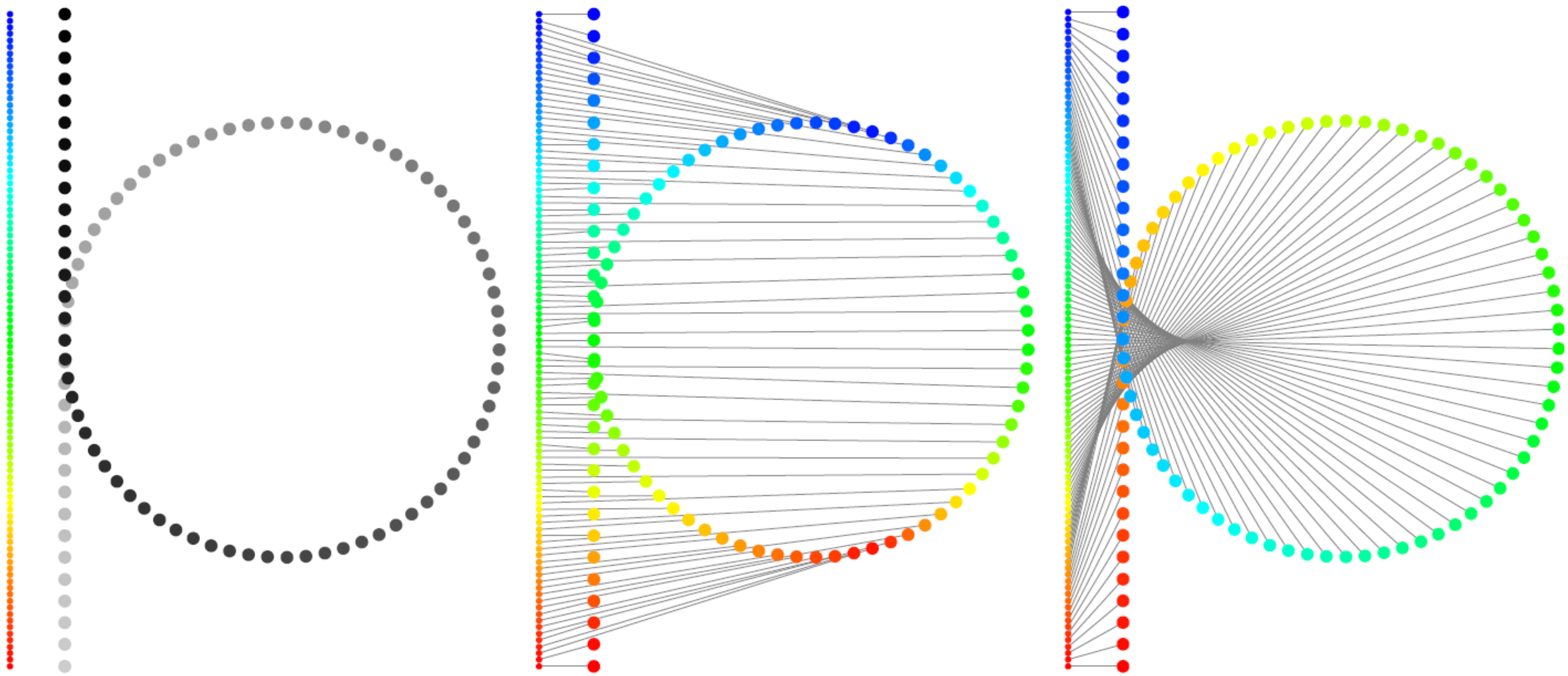
in diffusion space

Sinkhorn iteration

Minimization



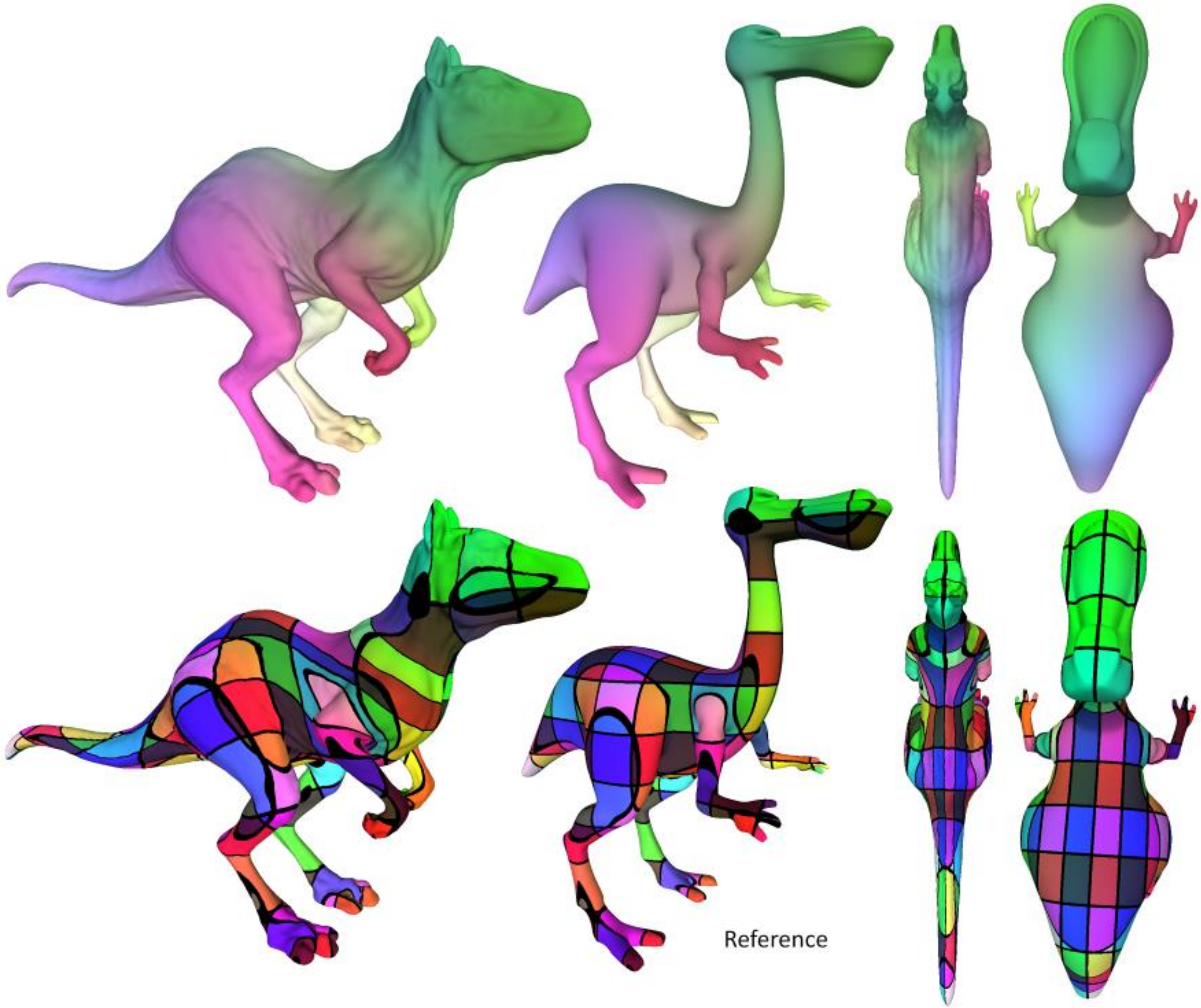
Input

Initial map
(nearest)

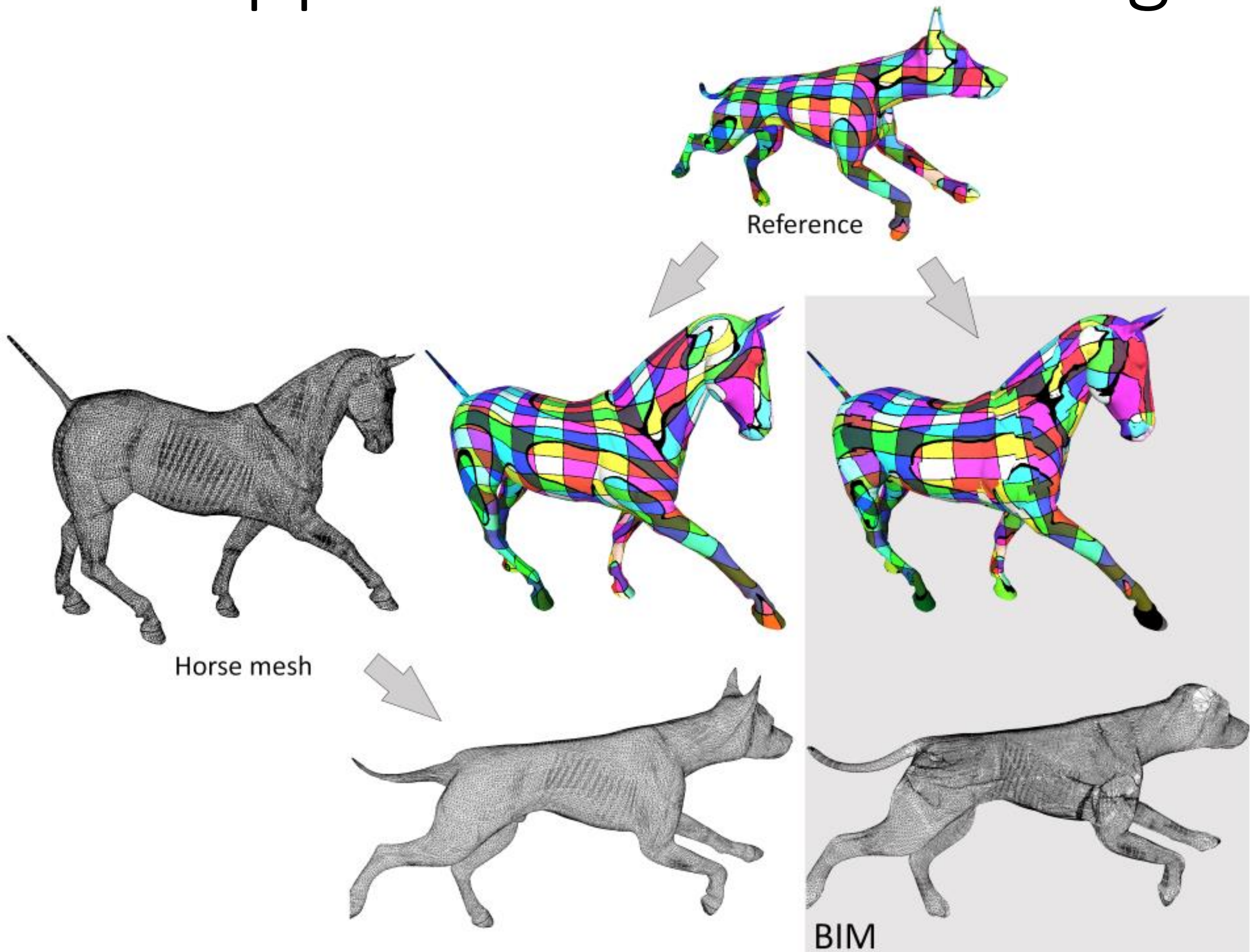
EM iterations

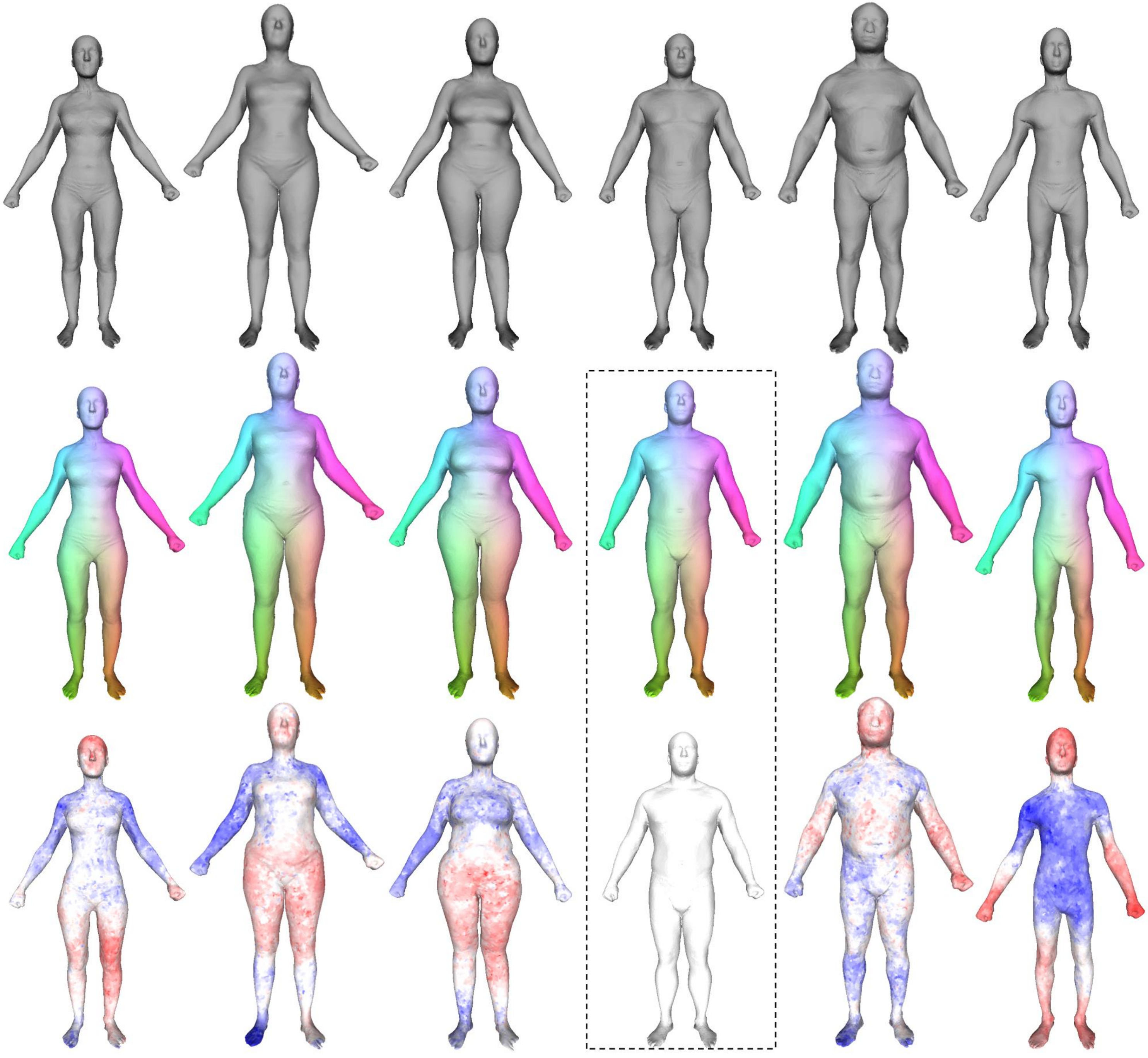
Isometric case

Non-isometric

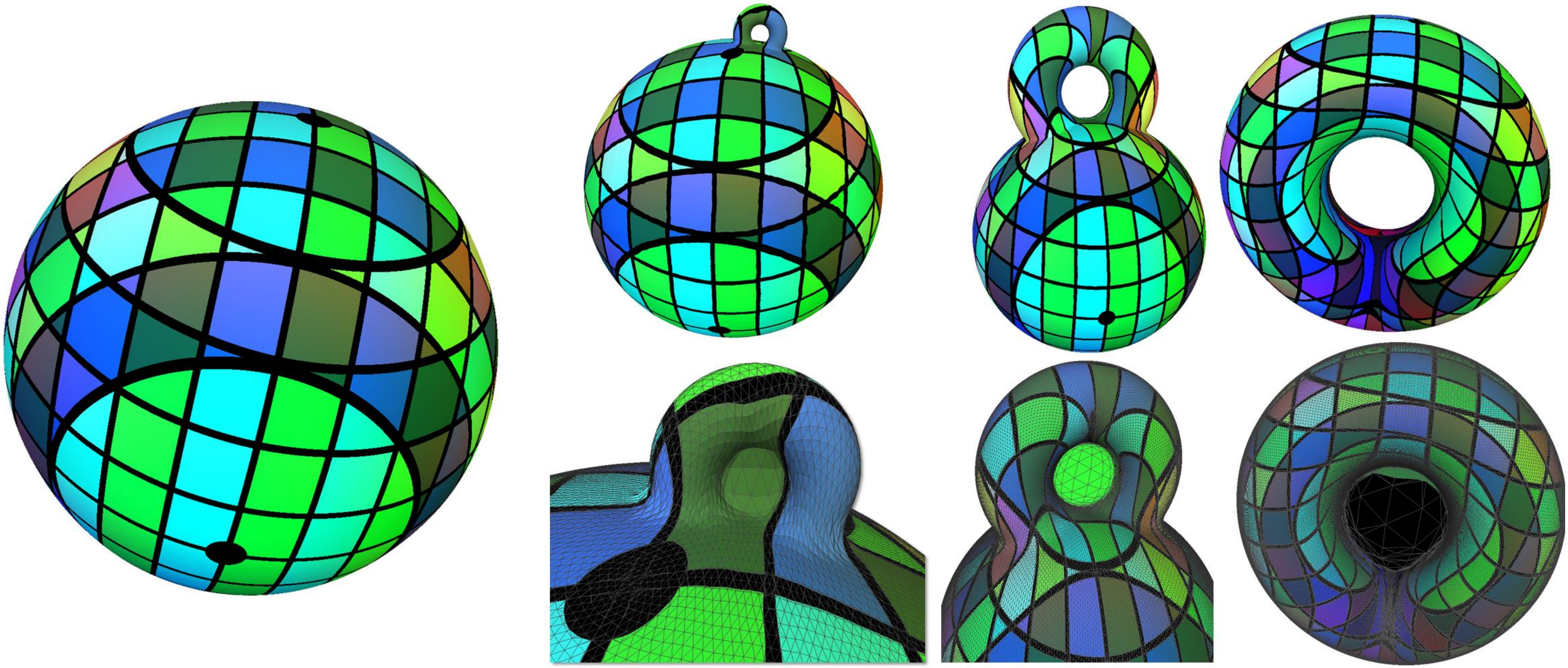


Application to Remeshing



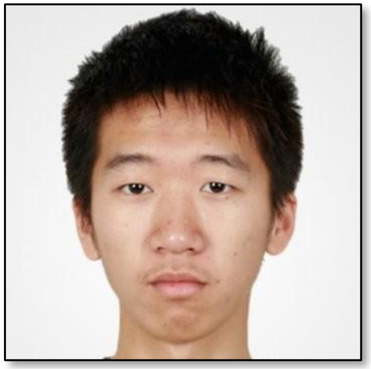


Resilience to Topological Noise



Higher-order Meshes

Joint work with **Leman Feng**, Laurent Busé,
Hervé Delingette and Mathieu Desbrun

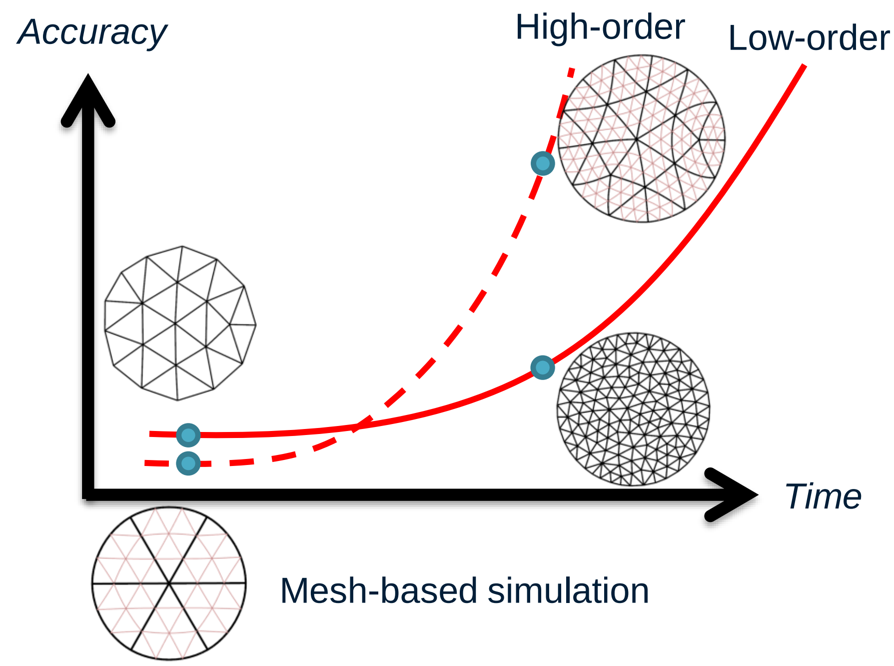


Motivations

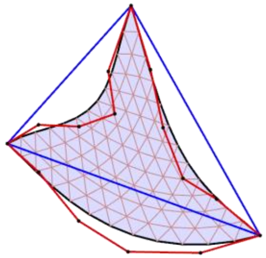
Simulation of laparoscopic liver surgery

Meshing = **essential preprocessing step**

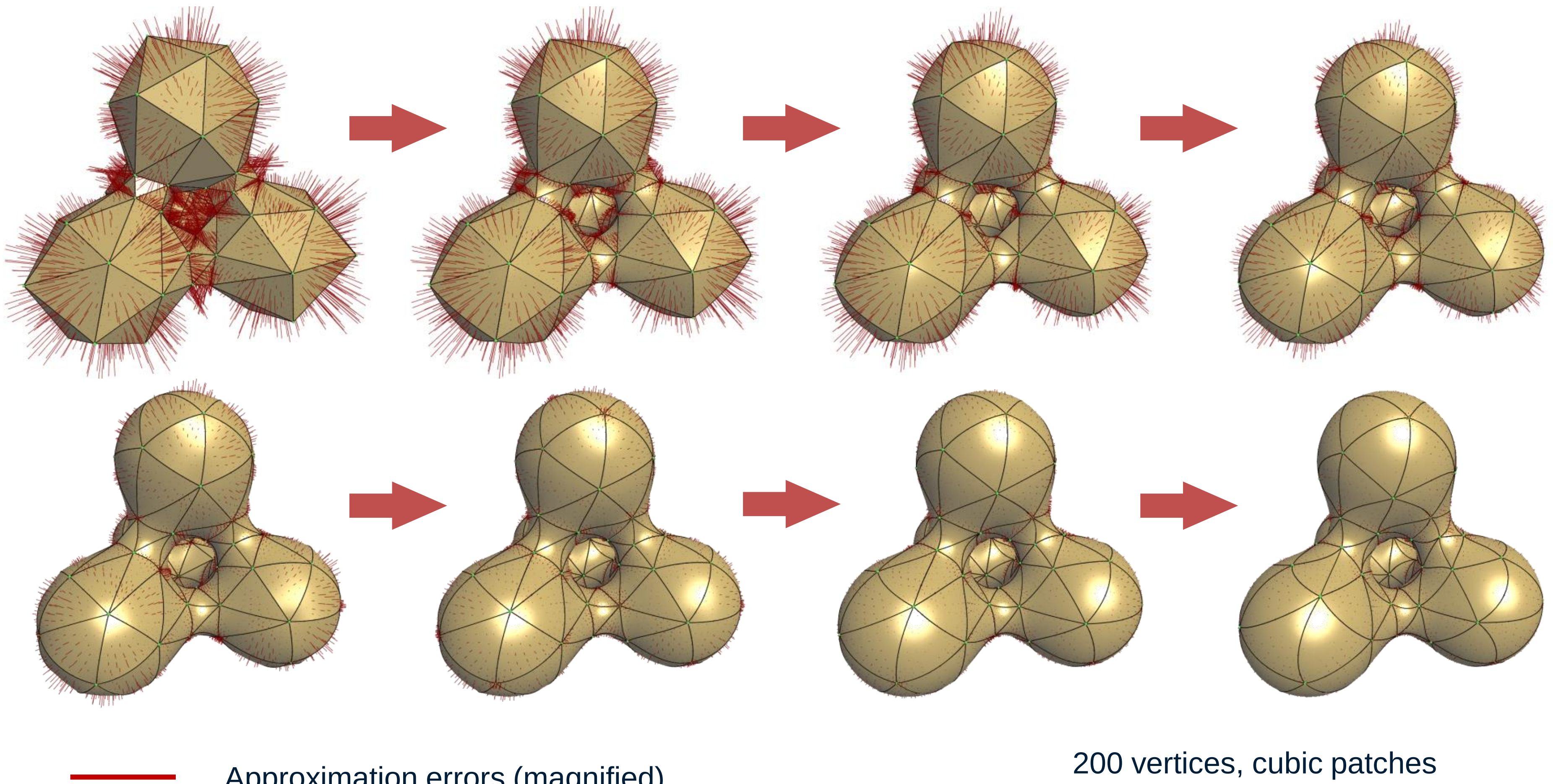
- Curved domains and complex phenomena motivate **higher-order elements** & basis functions [Roth '98, Weber '11, Suwelack '13, Geuzaine '15]
- Smaller element count.



Higher-order Meshing



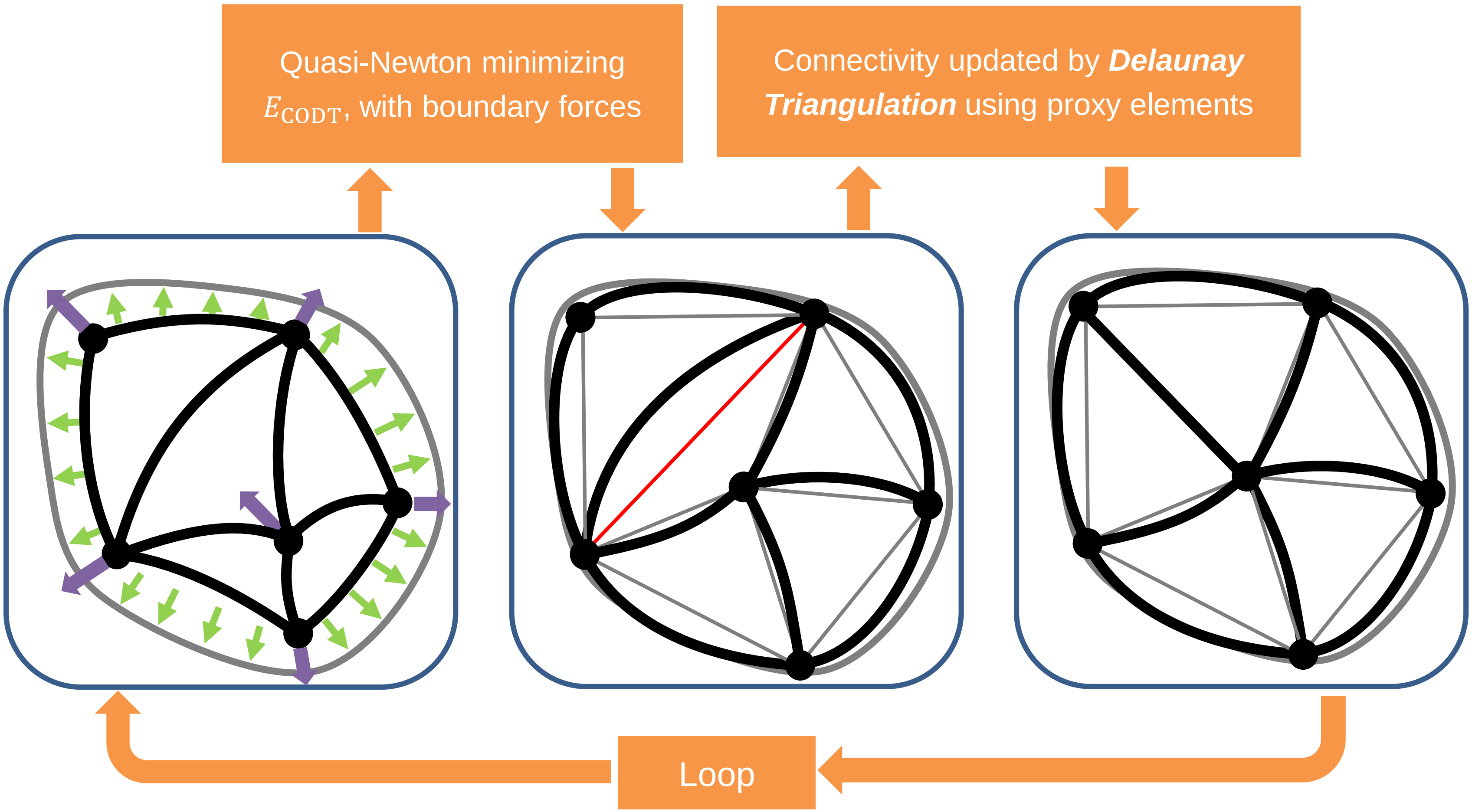
Bézier element



Approximation errors (magnified)

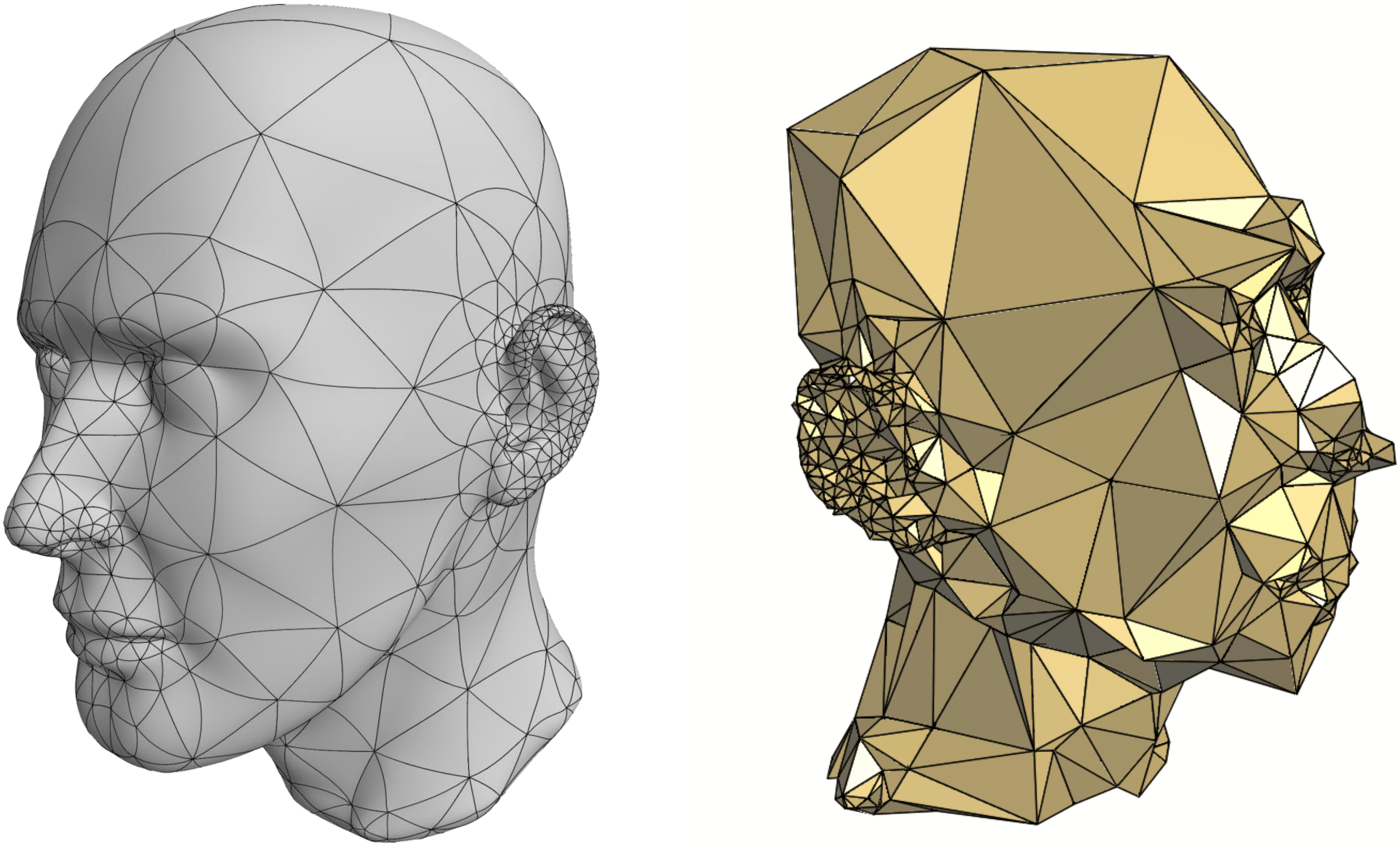
200 vertices, cubic patches

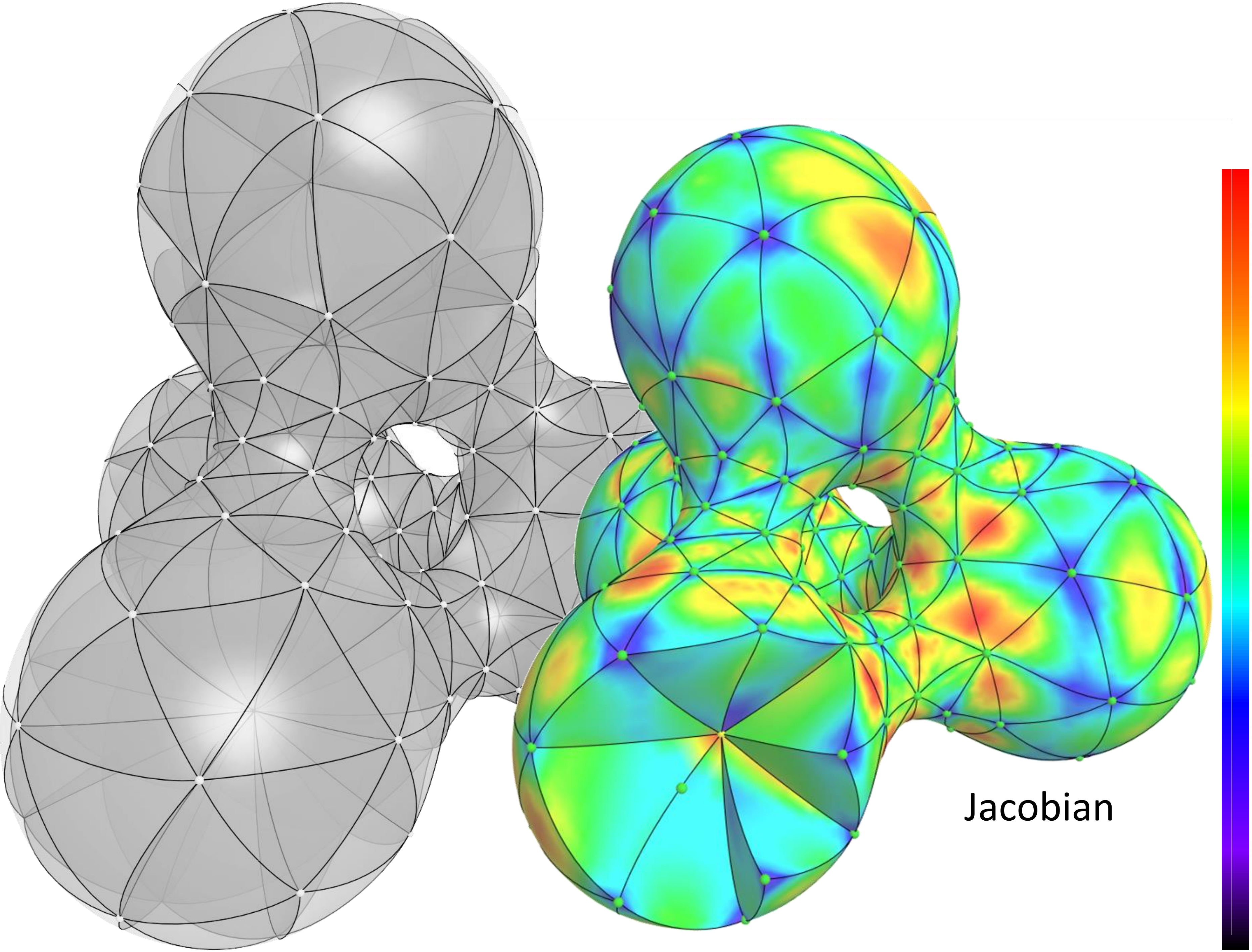
Algorithm



Quasi-Newton minimizing E_{CODT}, with boundary forces
Connectivity updated by ***Delaunay Triangulation*** using proxy elements
Loop

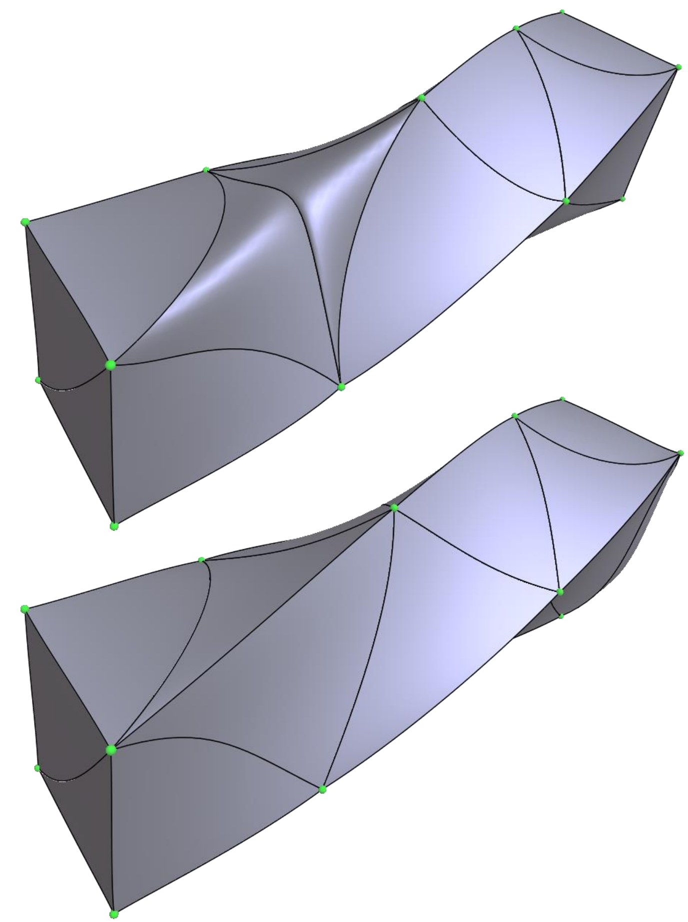
Algorithm




Jacobian

On-going Work

- **Sharp features & boundaries**
- **H/P dilemma**
  - Order vs element size
  - Learn prediction



Toolbox

Methodological Keywords

Computational geometry
- Delaunay-Voronoi
- Kinetic data structures

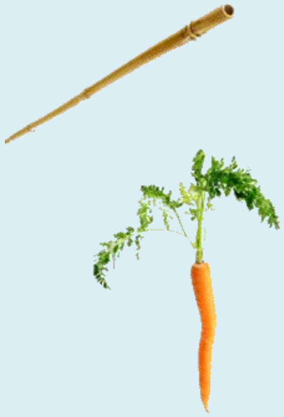
Geometric computing

CGAL

Applied mathematics
- Variational formulations
- Optimal transportation

Stochastic geometry
- Spatial point processes
- Monte Carlo sampling

Machine learning
- Support vector machines
- Random forests
- Deep neural networks
- …

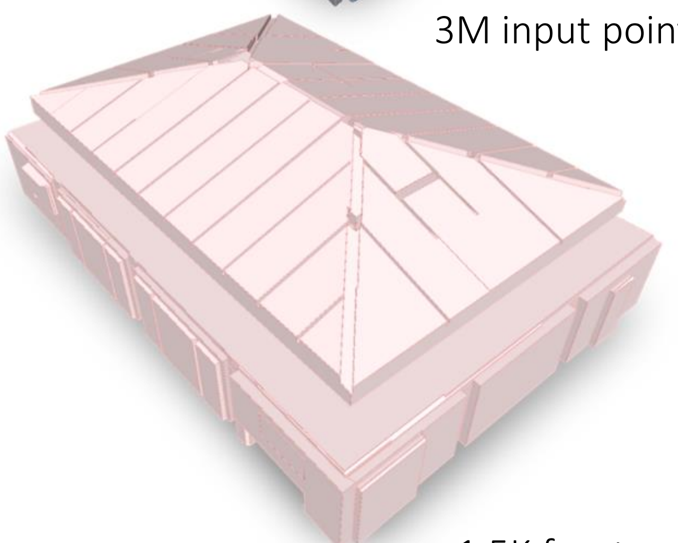


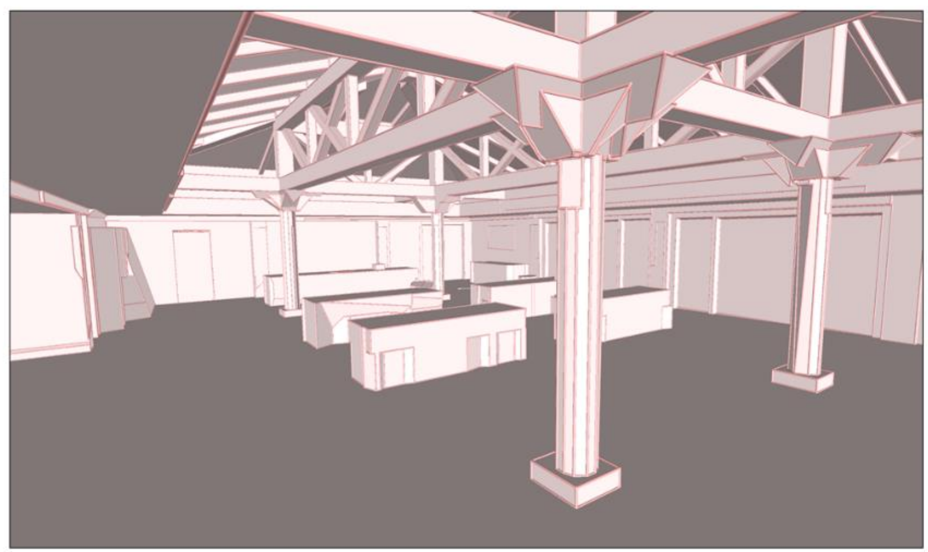
Recent and Outlook

Cognitive 3D models

3D Reconstruction…

3M input points

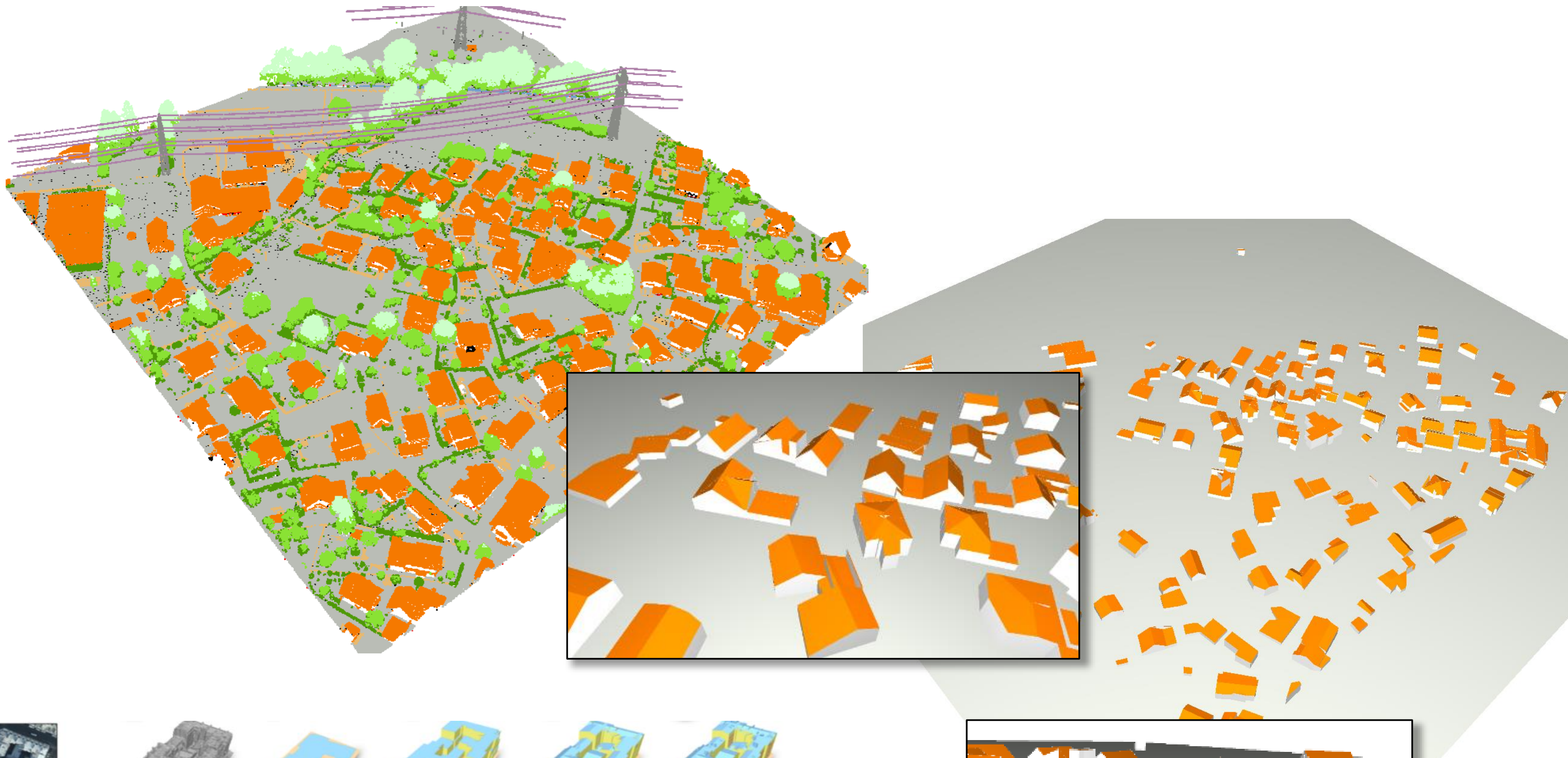


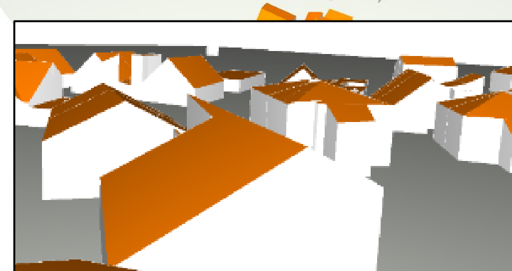


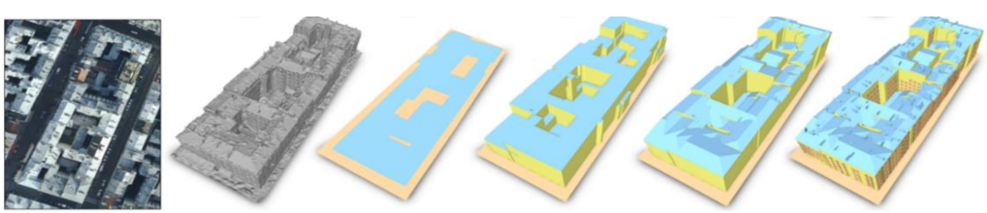
1.5K facets

[Bauchet-Lafarge 2020]

…and Support of Domain Knowledge

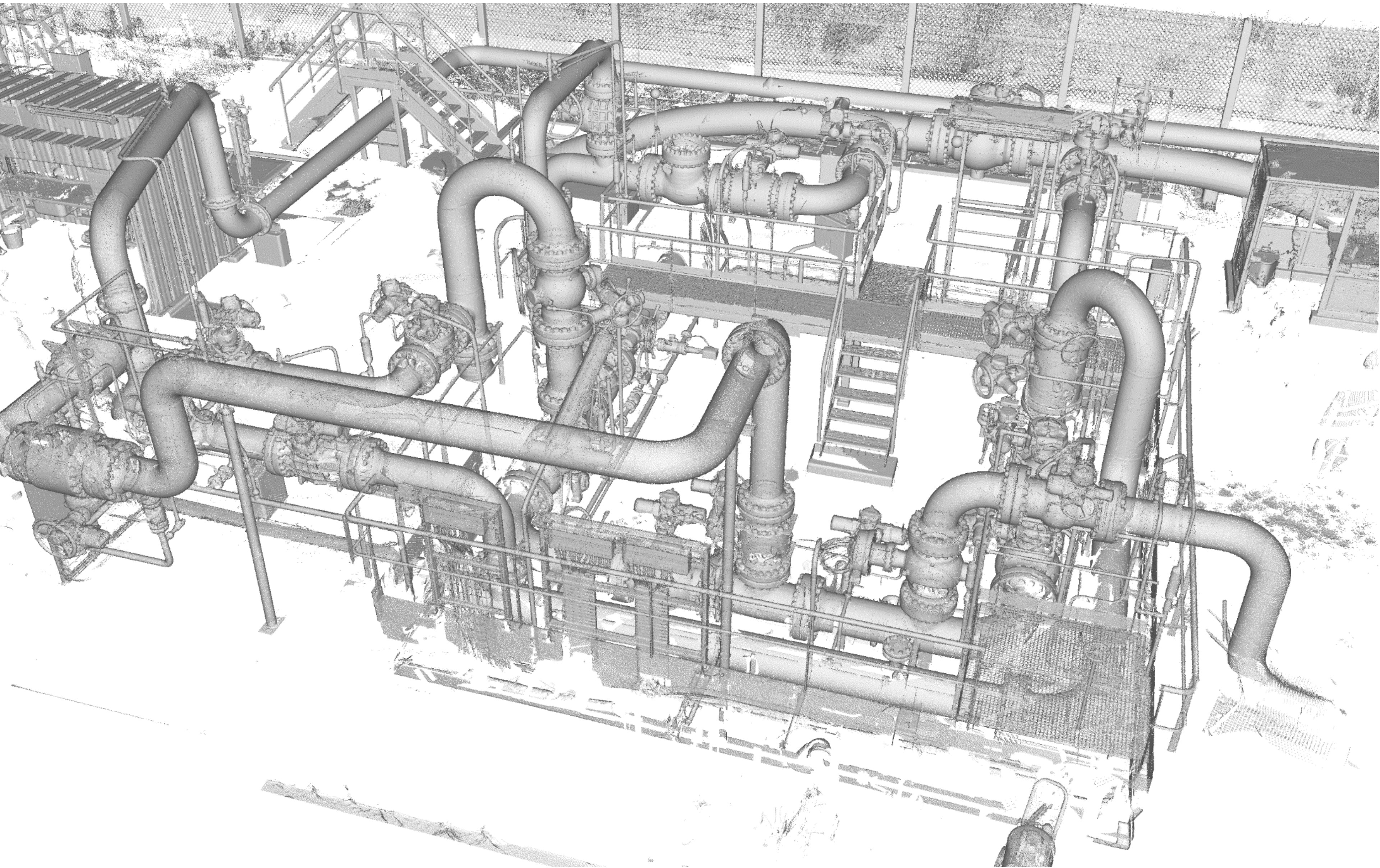






CityGML Level of detail 0 1 2 3

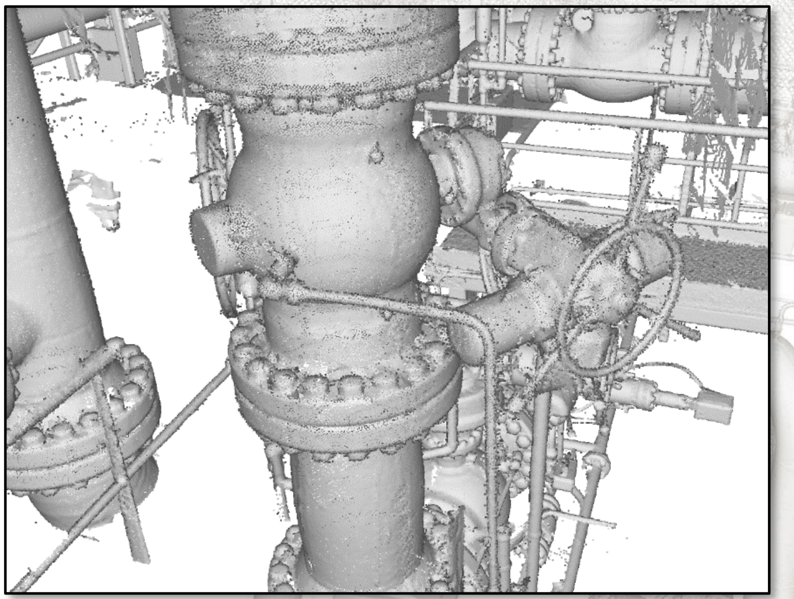
Raw Point Cloud…

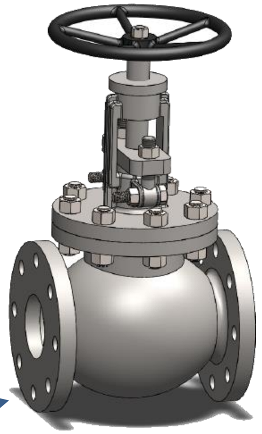


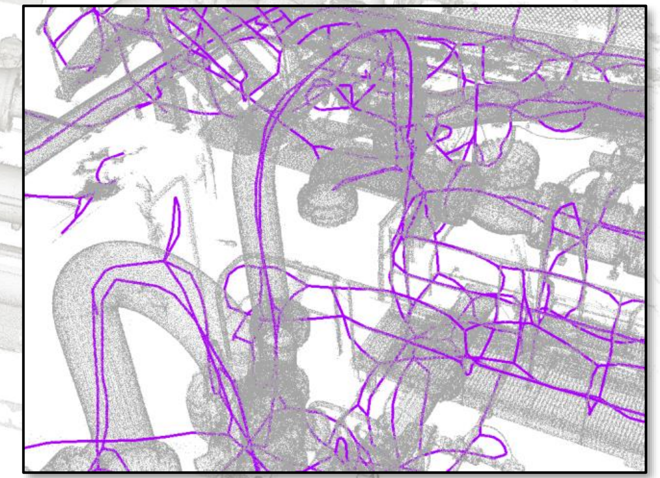
…and Cognitive 3D Model

Cognitive:

- Searchable
- Insights from digital realities
  - Abstraction
  - Detection
  - Segmentation
  - Domain-specific queries







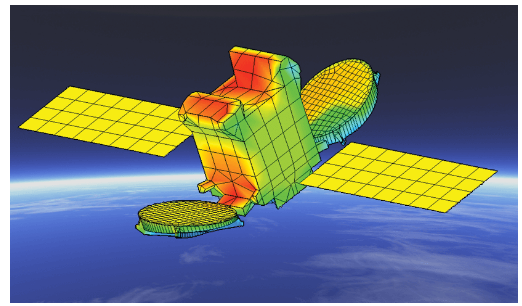
Pipe-run

Recent and Outlook

Physics-informed modeling

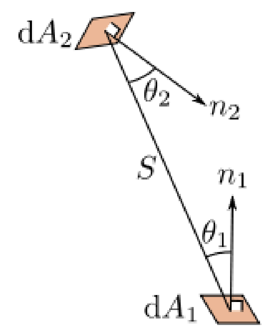
Radiative Thermal Simulation

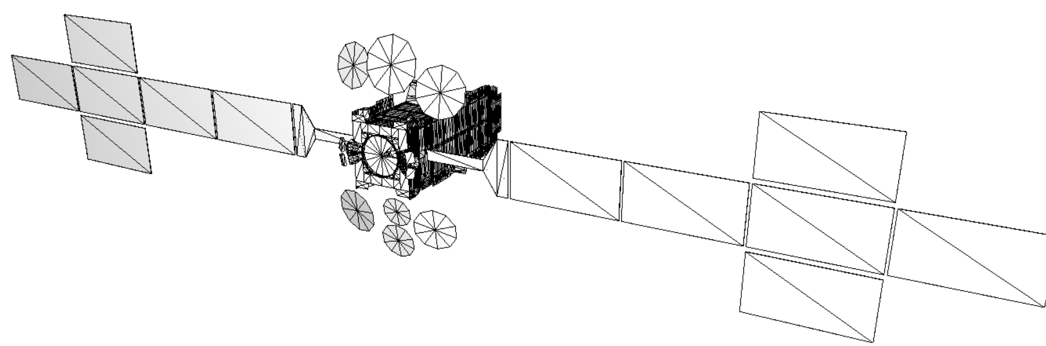
Vincent
Vadez



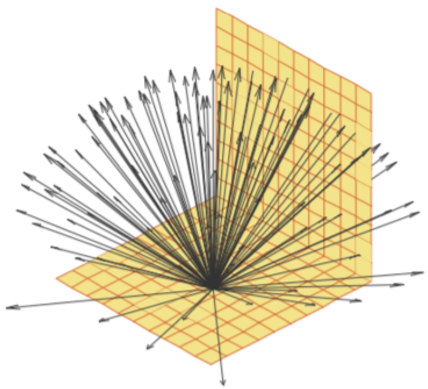
Goals

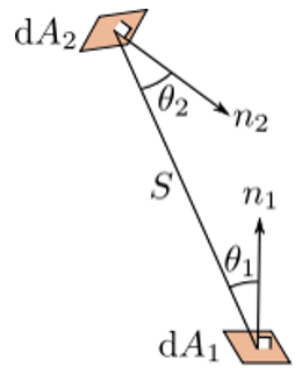
- View factors
- Thermal-aware geometric approximation
- Trade accuracy for time
- Guarantees: error bounds
  - under wide range of configurations and conditions

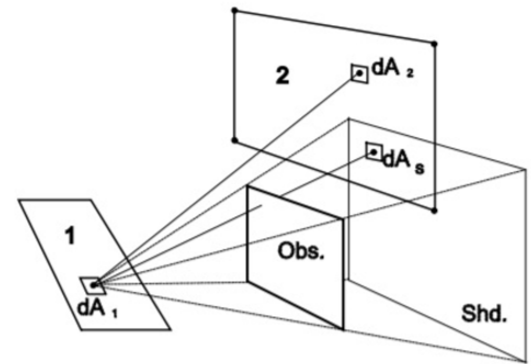


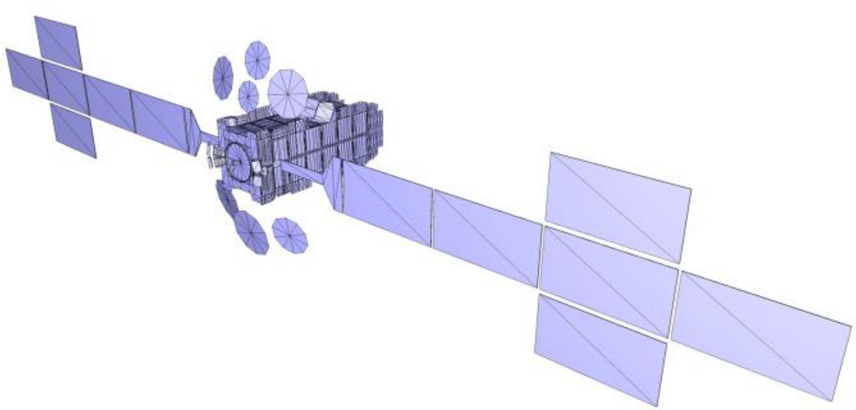


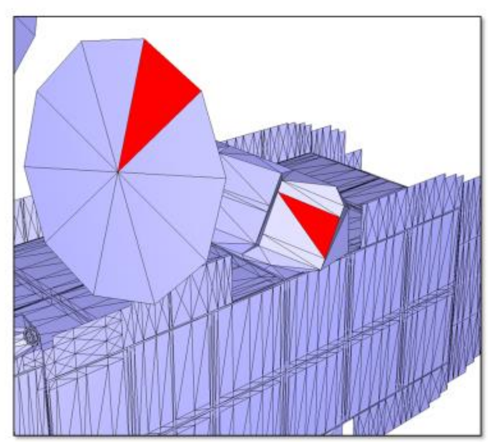
Geometric View Factors



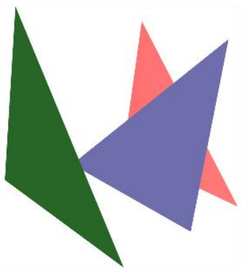


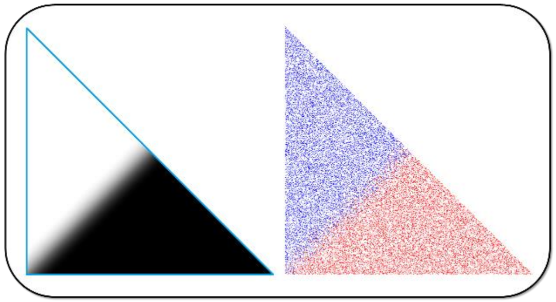


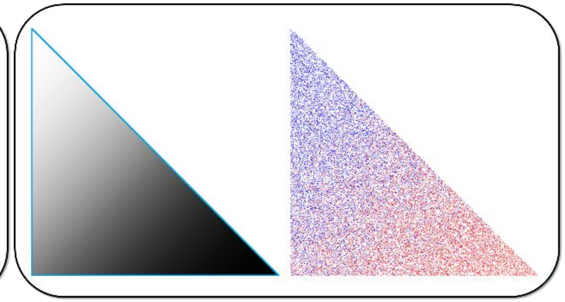


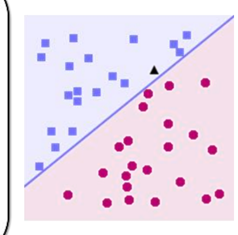


Progressive View Factors

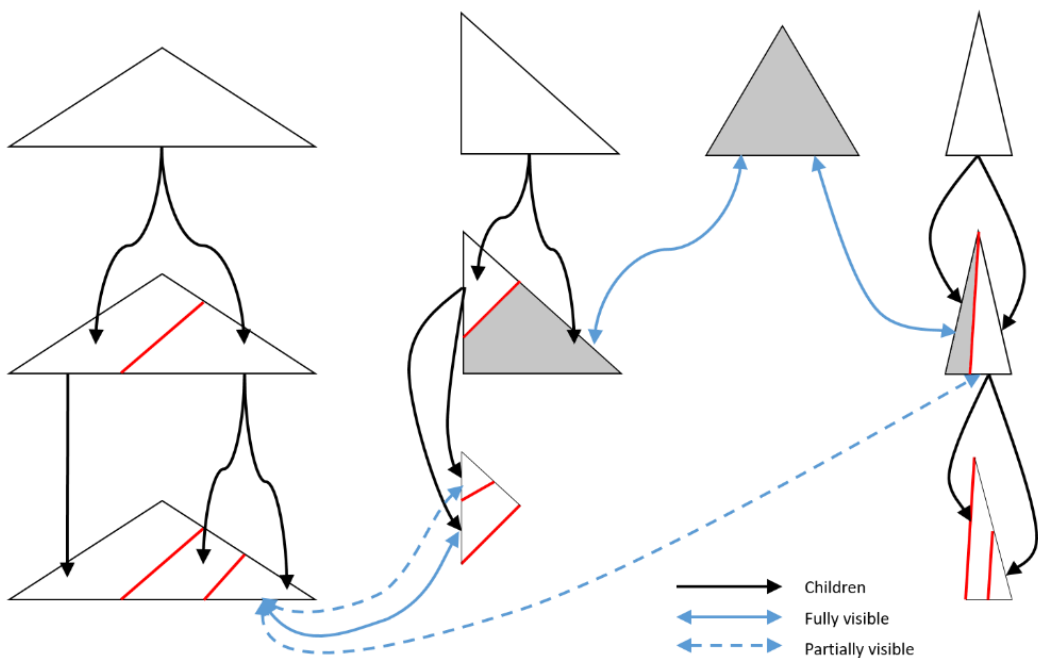




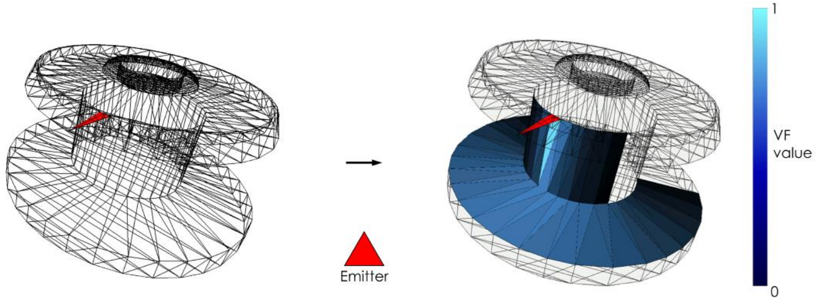


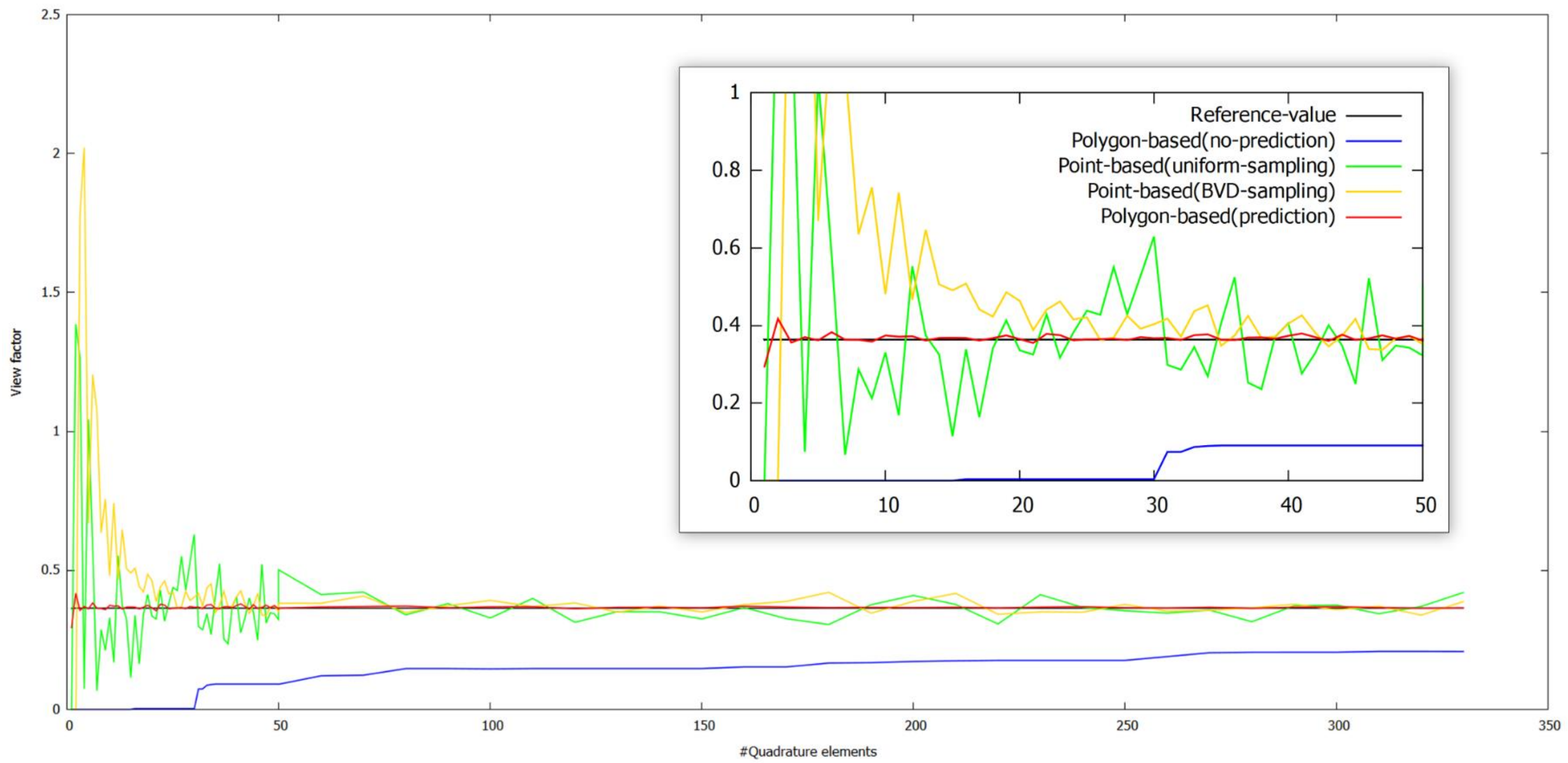


SVM

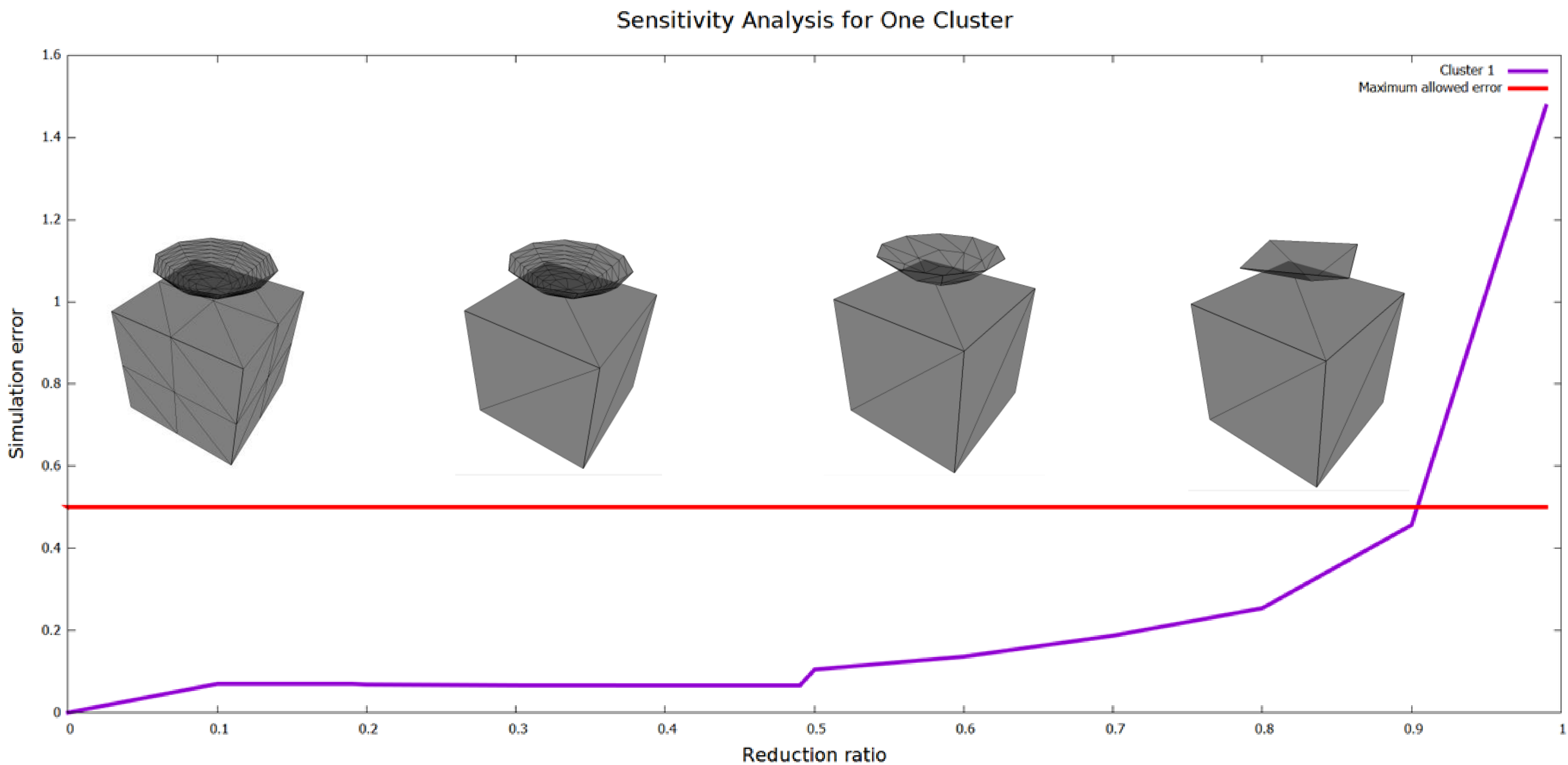


Predicting Geometric View Factors

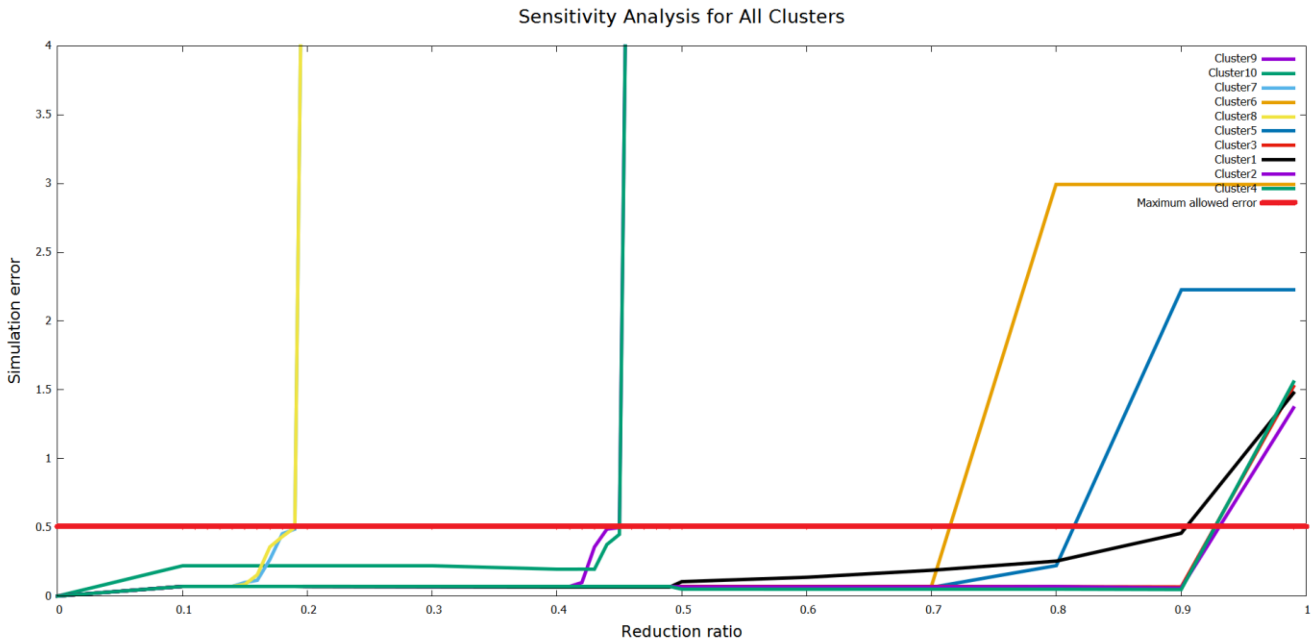


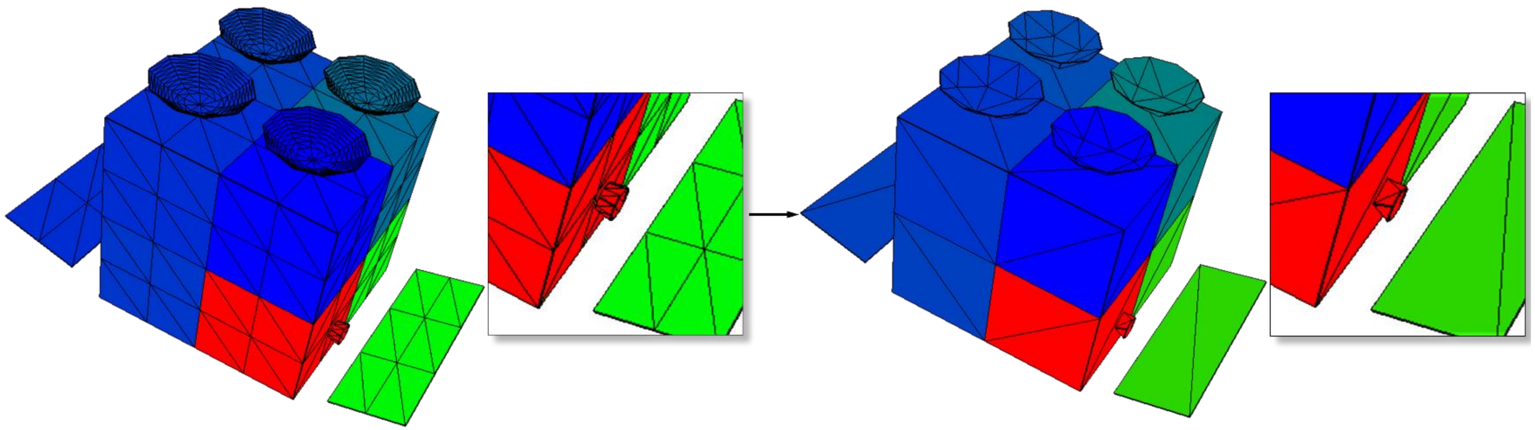


Physics-informed Mesh Reduction



Physics-informed Mesh Reduction



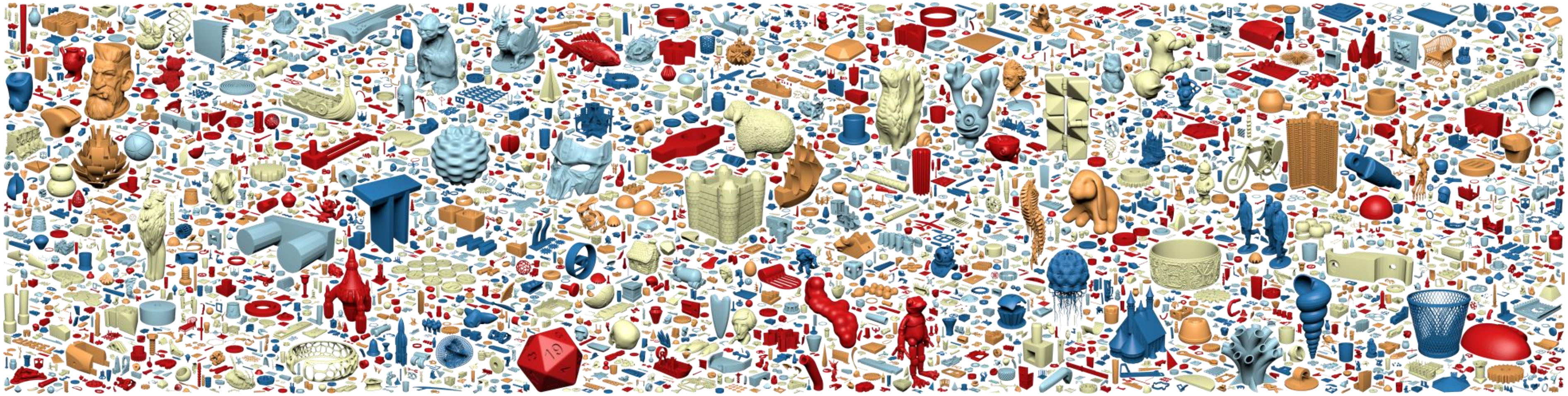


On-Going Work

- Learn physics-informed error metric
- Physics-informed 3D reconstruction

Physics-informed Modeling

- Improve discretizations
  - Simulation = discrete differential operators
  - Operator-specific mesh optimization



Training data

Thank you.

Funding

Consolidator Grant “IRON”
Robust Geometry Processing
Proof of Concept “TITANIUM”

3iA Côte d’Azur
Institut interdisciplinaire d’intelligence artificielle