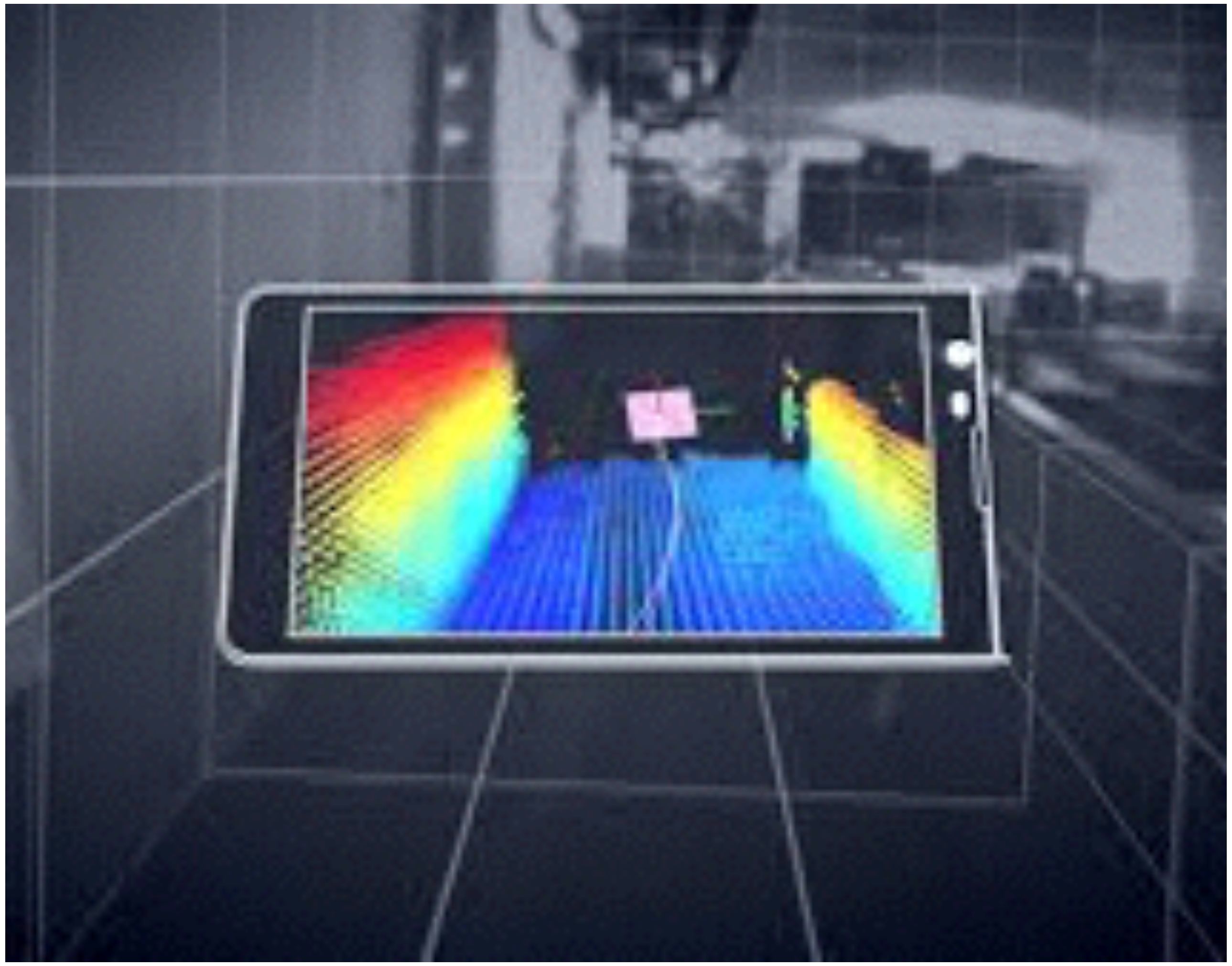
Finding Structure in Large Collections of 3D Models

Vladimir Kim

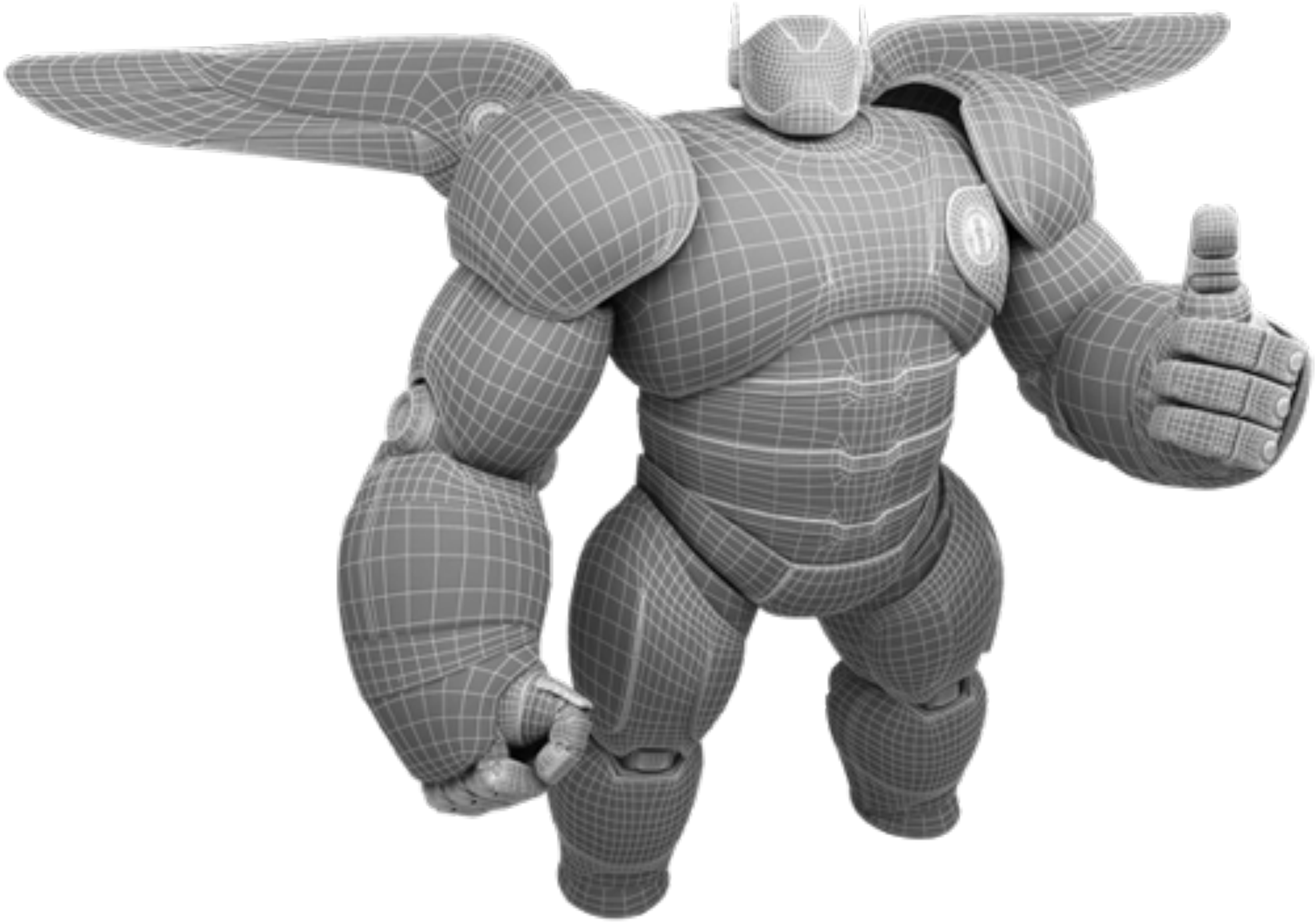
Adobe Research

Motivation

Explore, Analyze, and Create Geometric Data



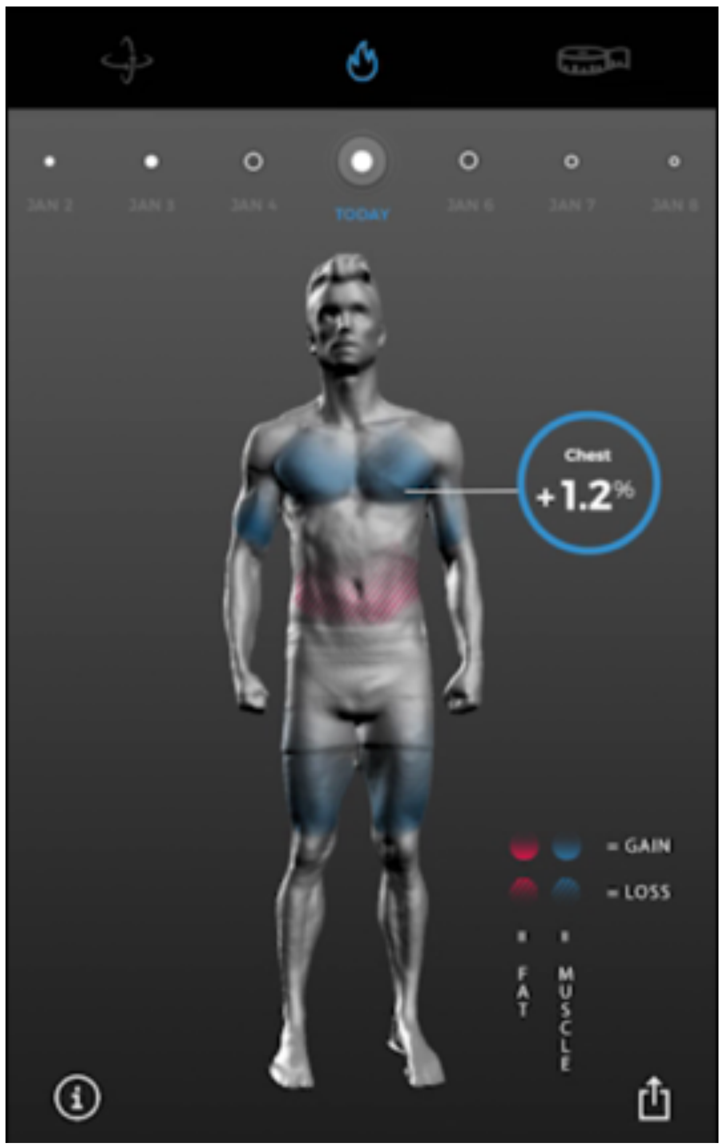
Real



Virtual

Motivation

Explore, Analyze, and Create Geometric Data

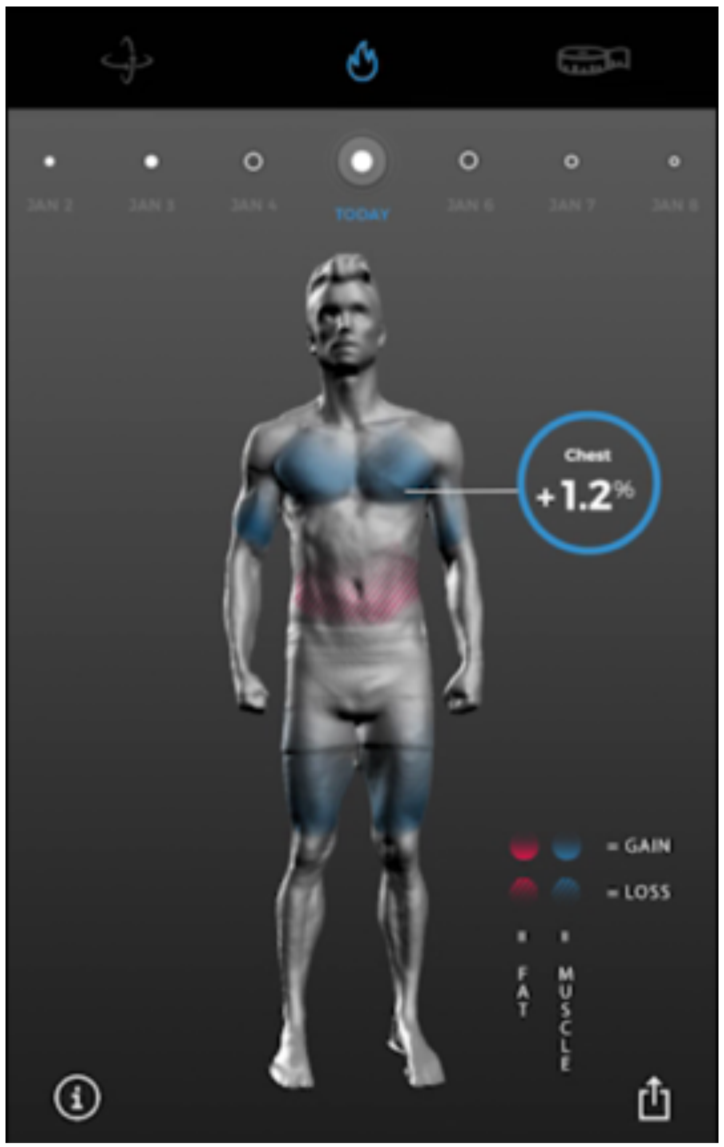


Personal data

(image from naked.fit)

Motivation

Explore, Analyze, and Create Geometric Data



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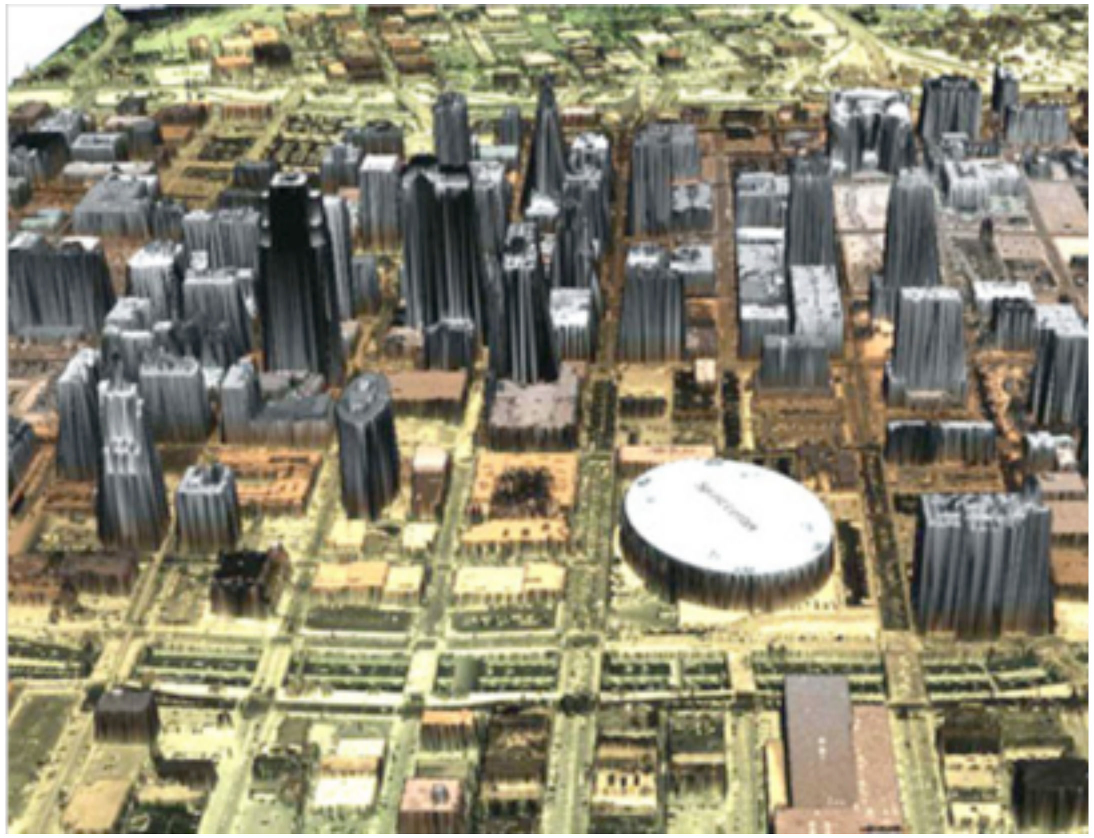
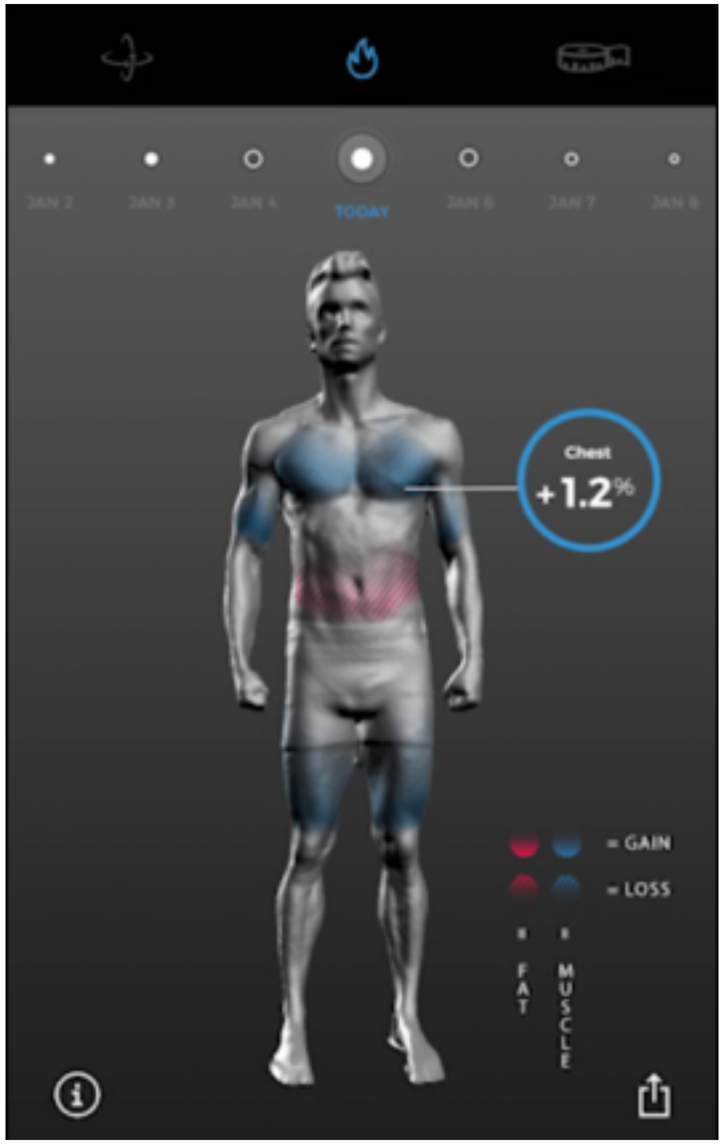


Scans of environments

Motivation

Explore, Analyze, and Create Geometric Data



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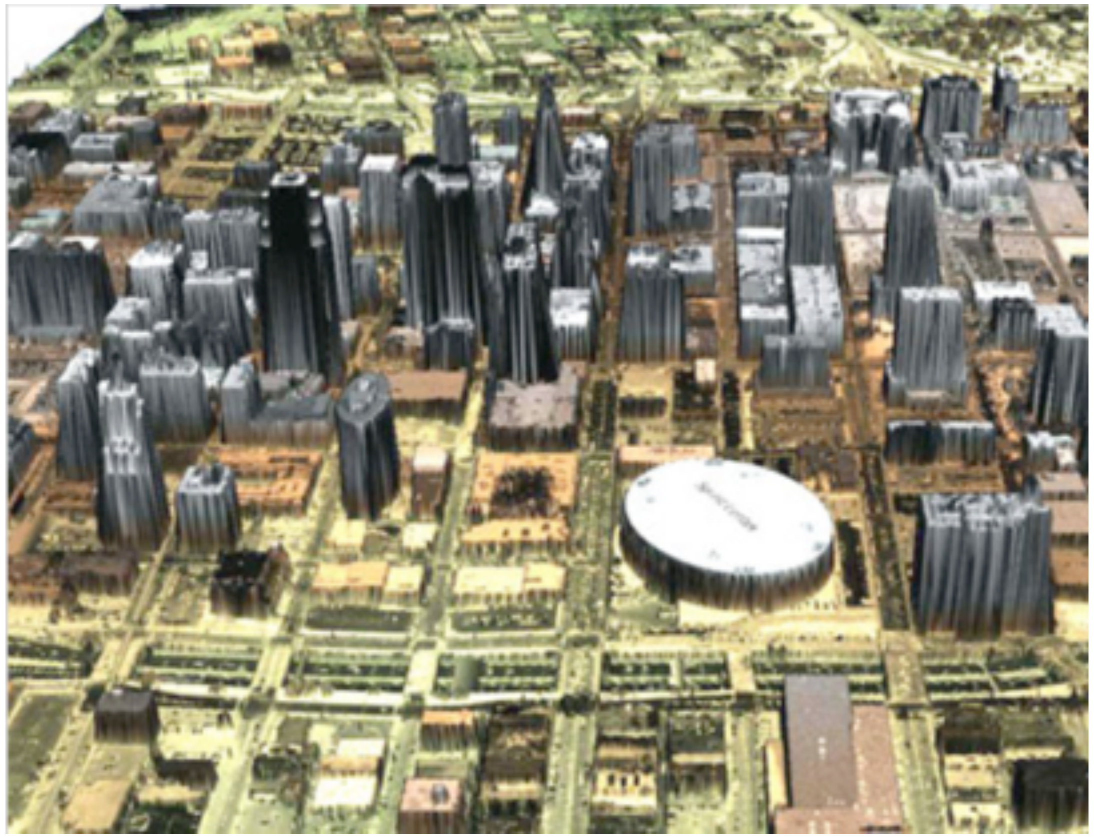

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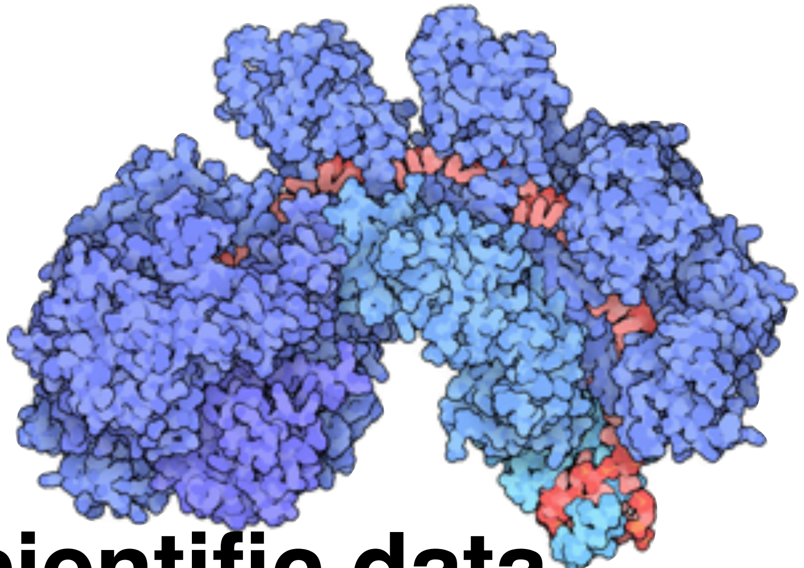
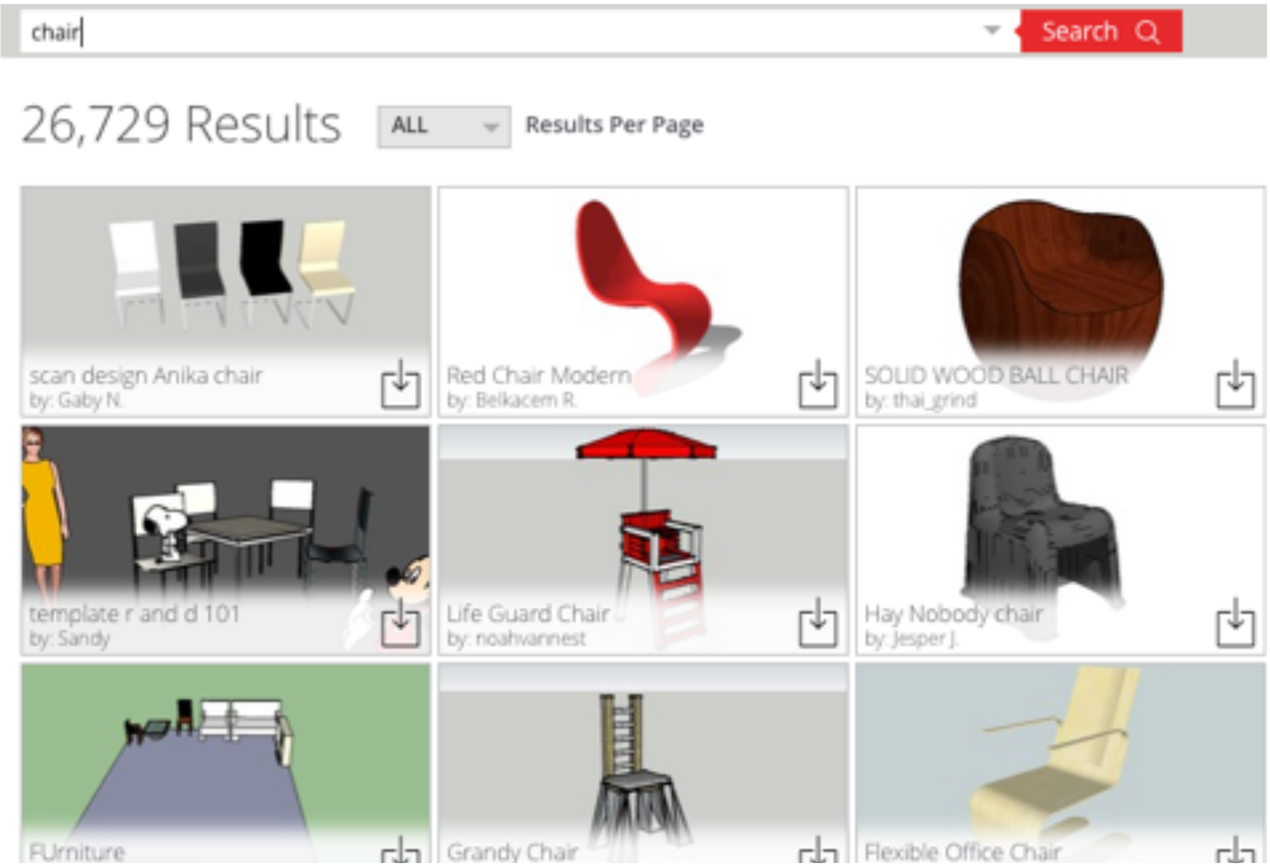


Scientific data

Medical Imaging

Motivation

Explore, Analyze, and Create Geometric Data

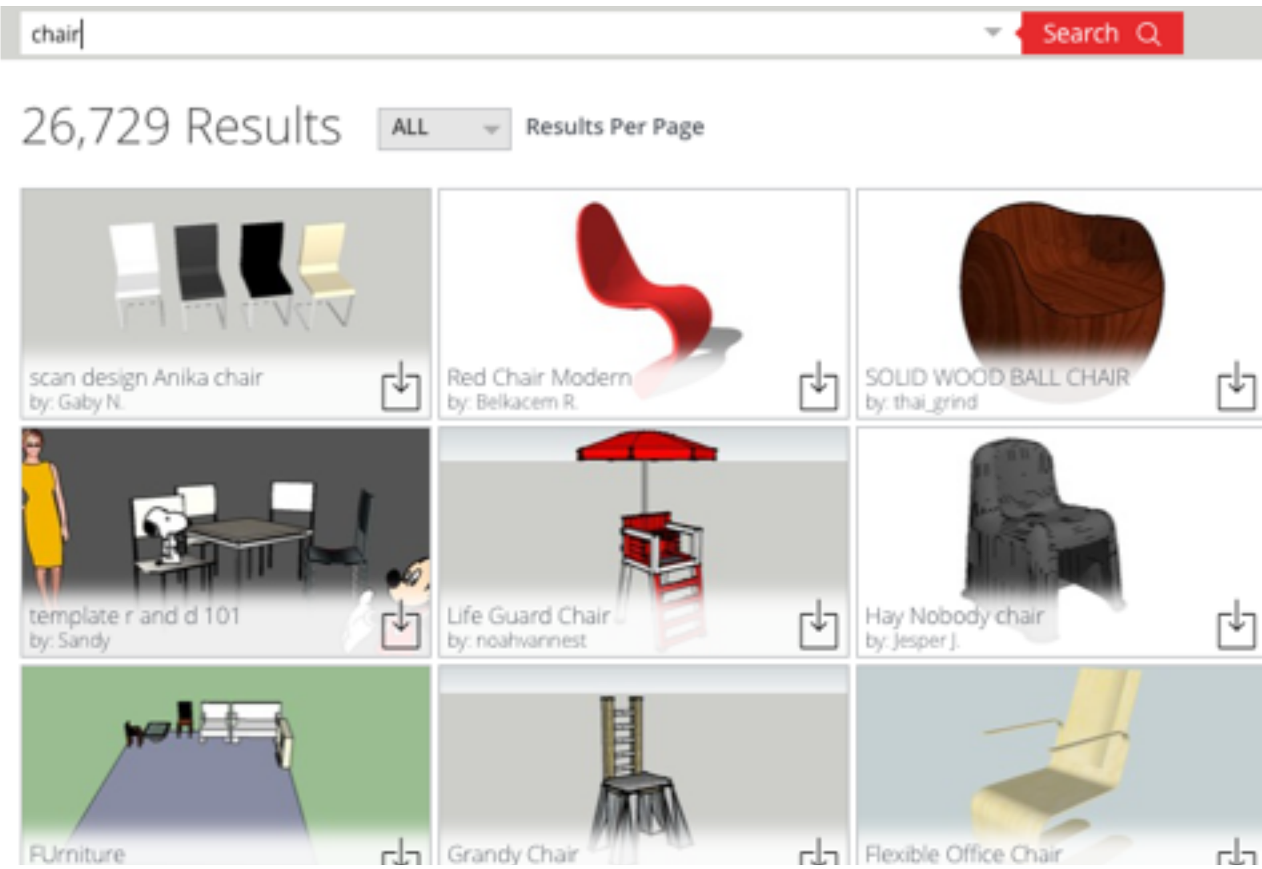


CG data

(image from 3dwarehouse.sketchup.com)

Motivation

Explore, Analyze, and Create Geometric Data



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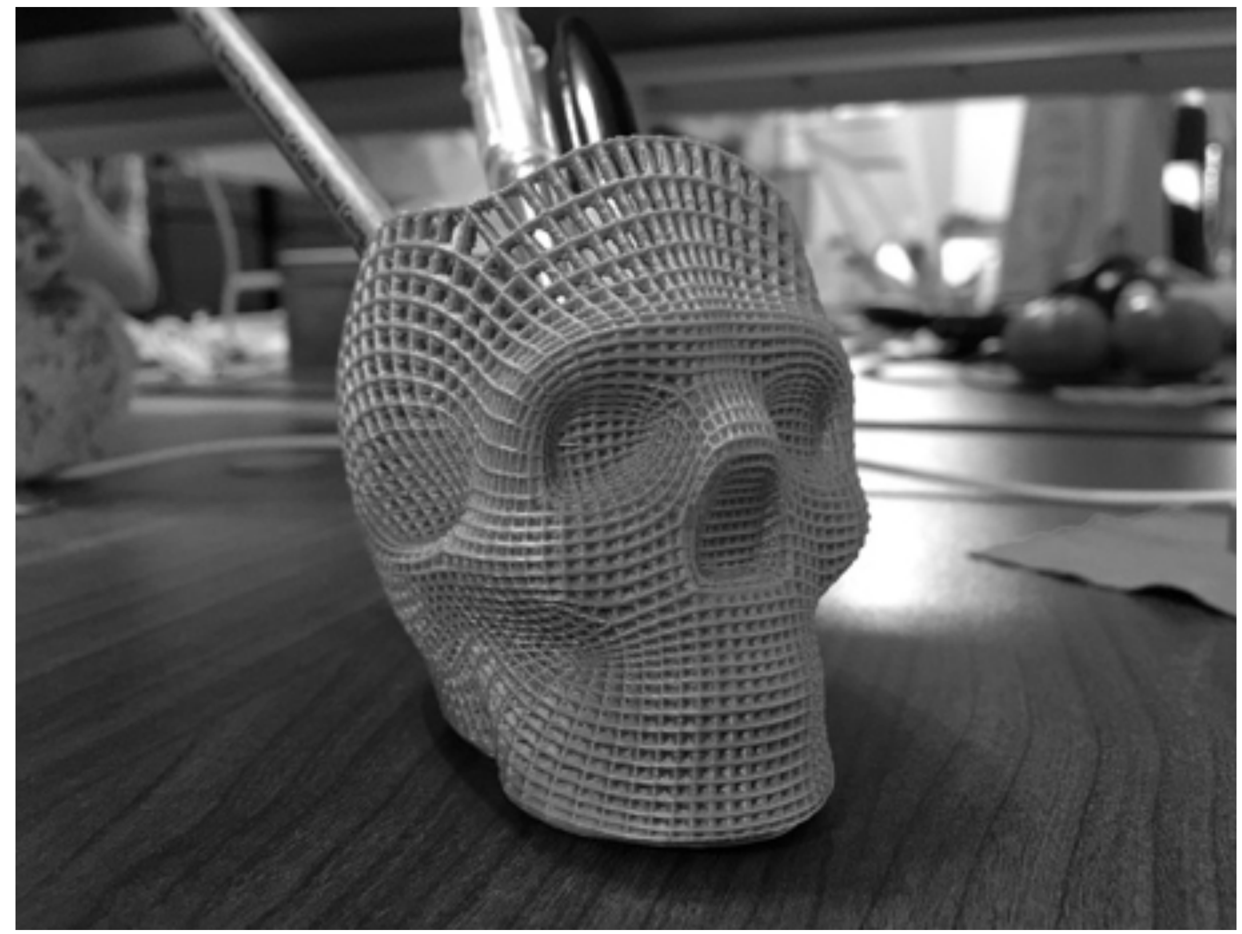
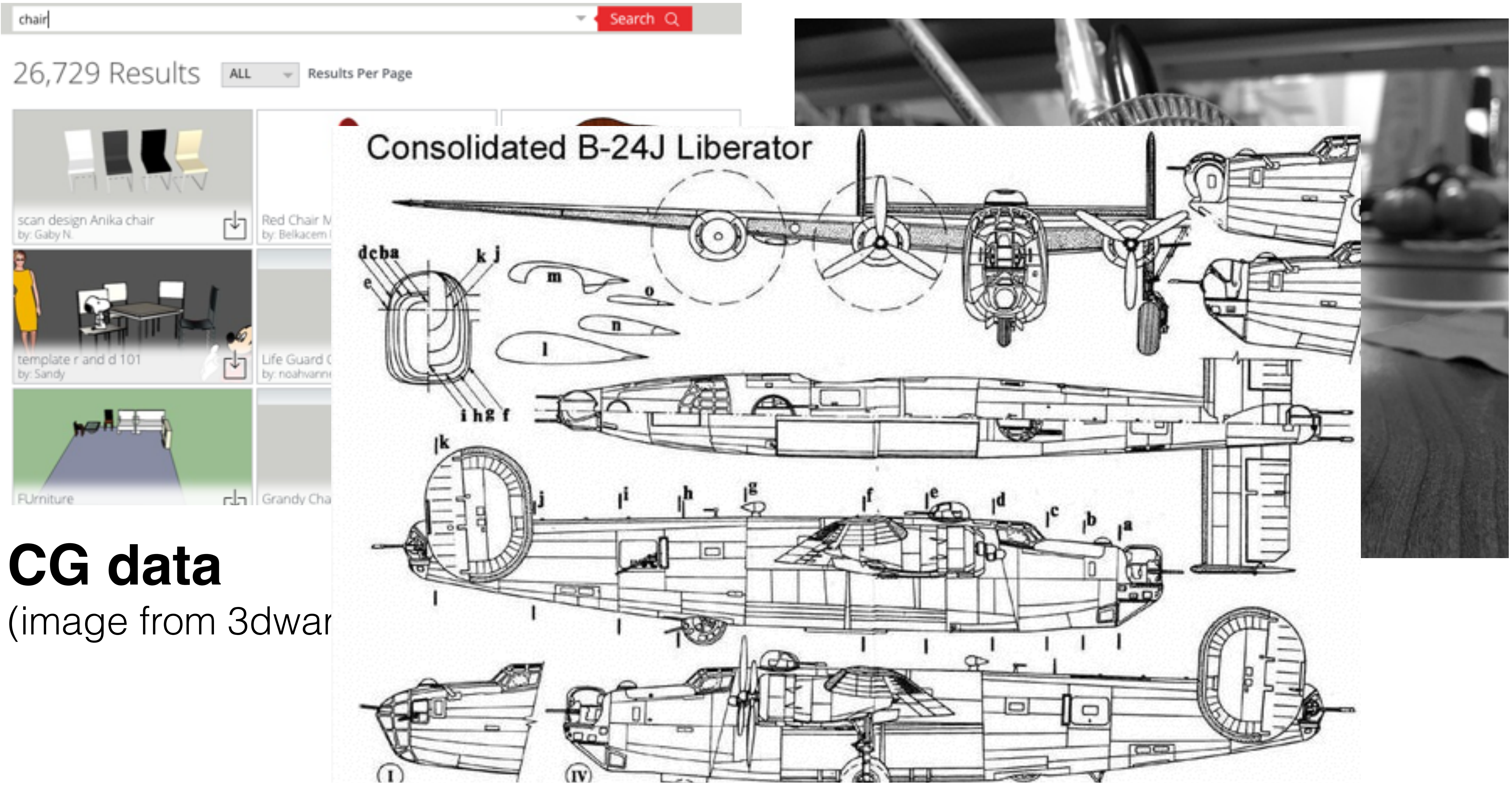


3D printing data
(image from thingiverse.com/)

Motivation

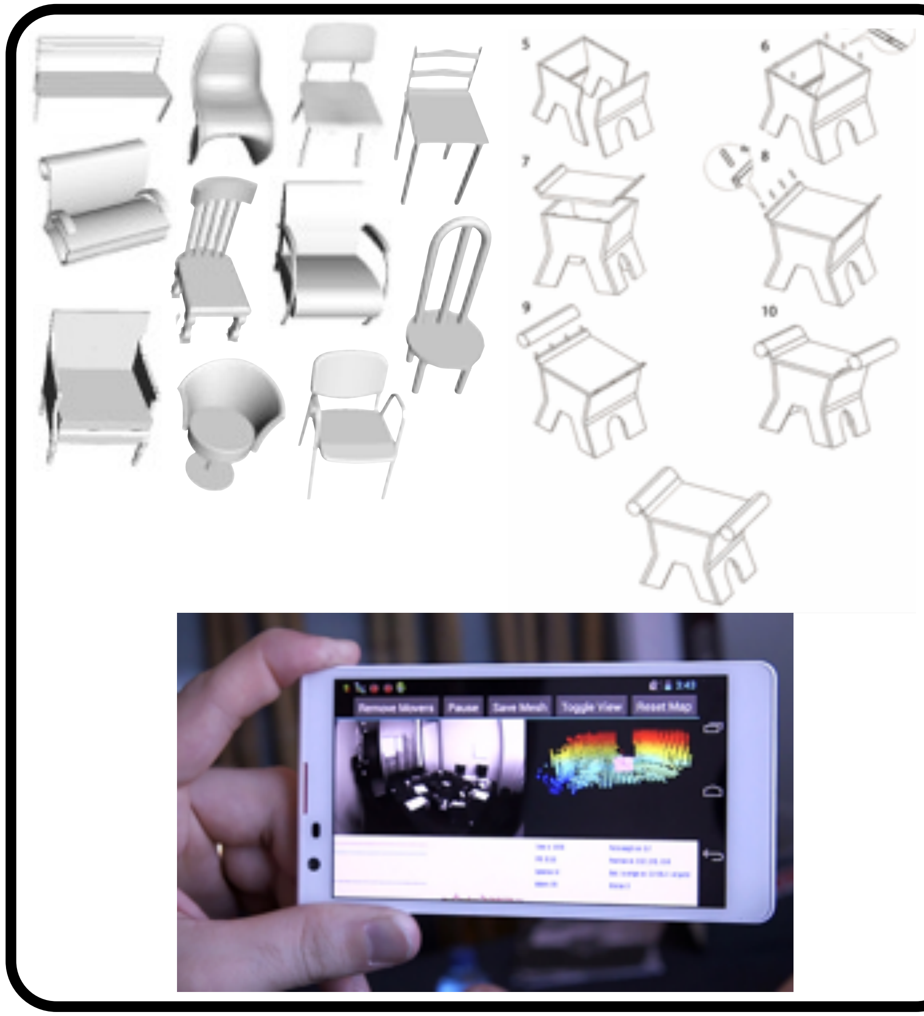
Explore, Analyze, and Create Geometric Data



CG data
(image from 3dwar

CAD models

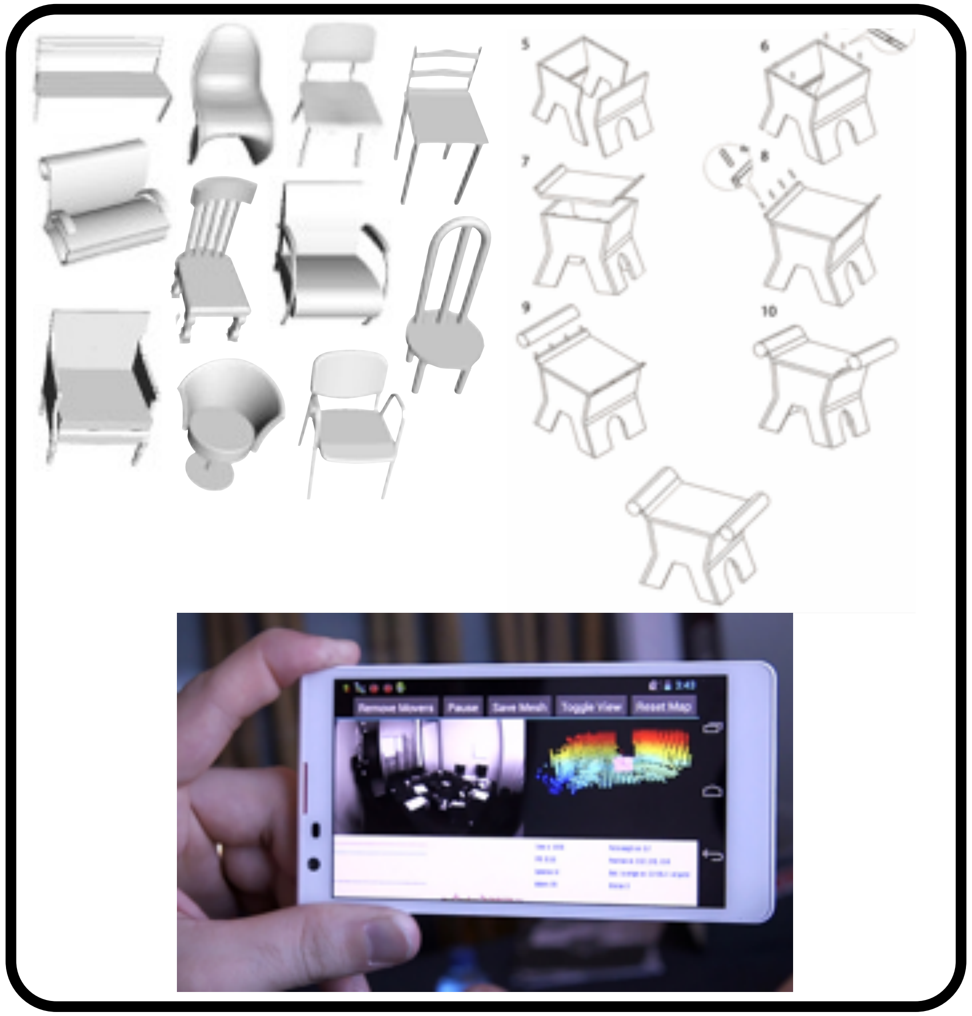
Goal



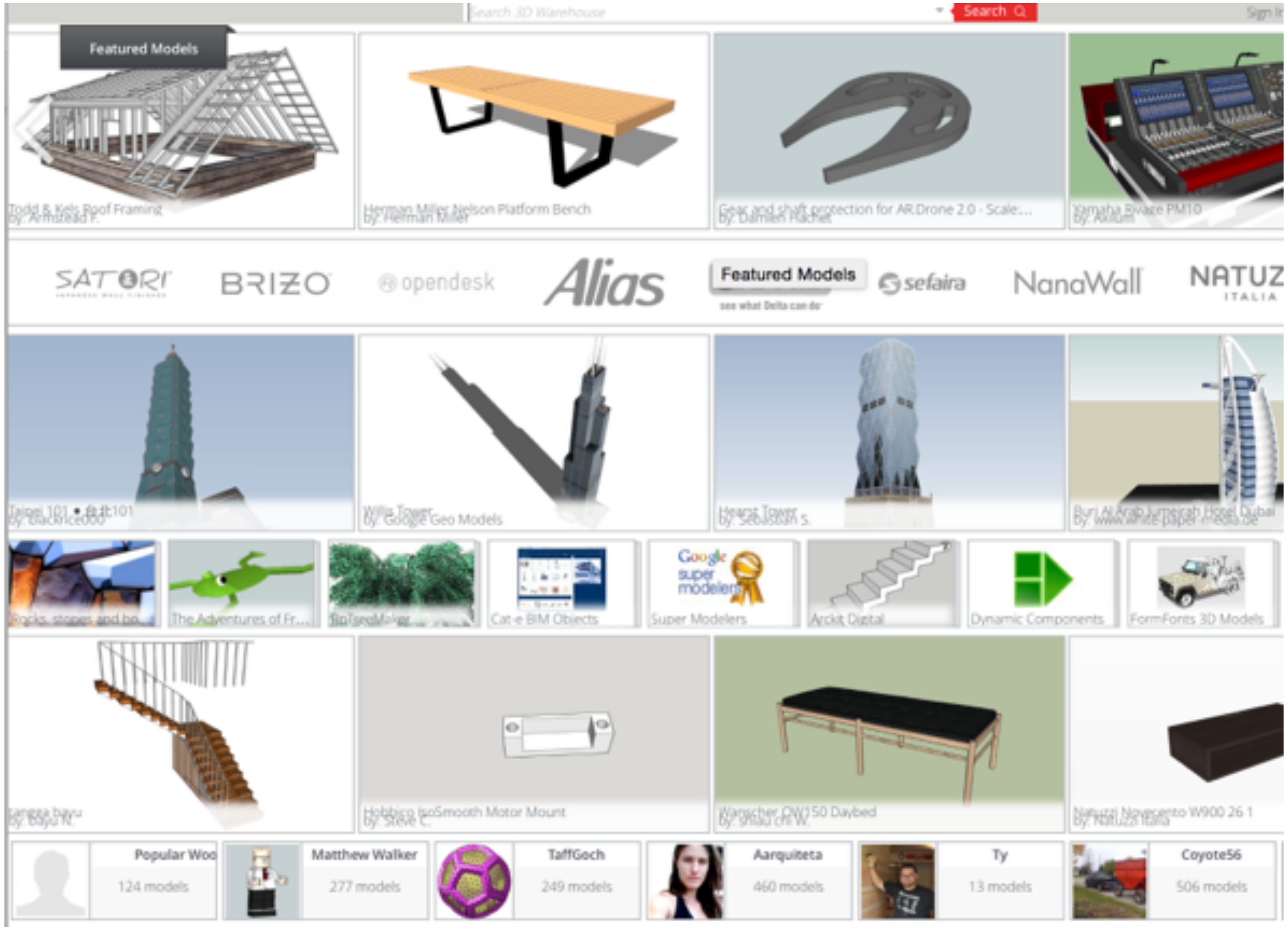
3D Data

→ **Structural Model** → **Applications**

Goal

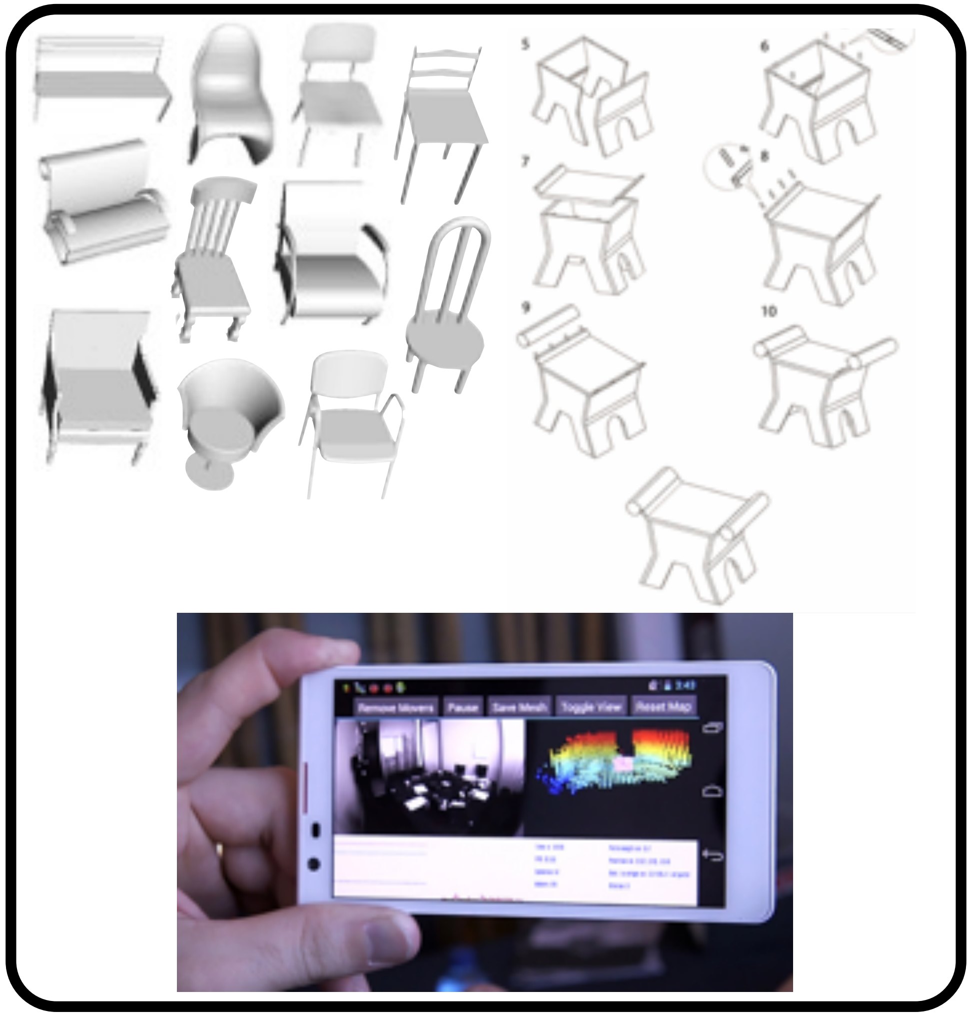


3D Data → **Structural Model** → **Explore**



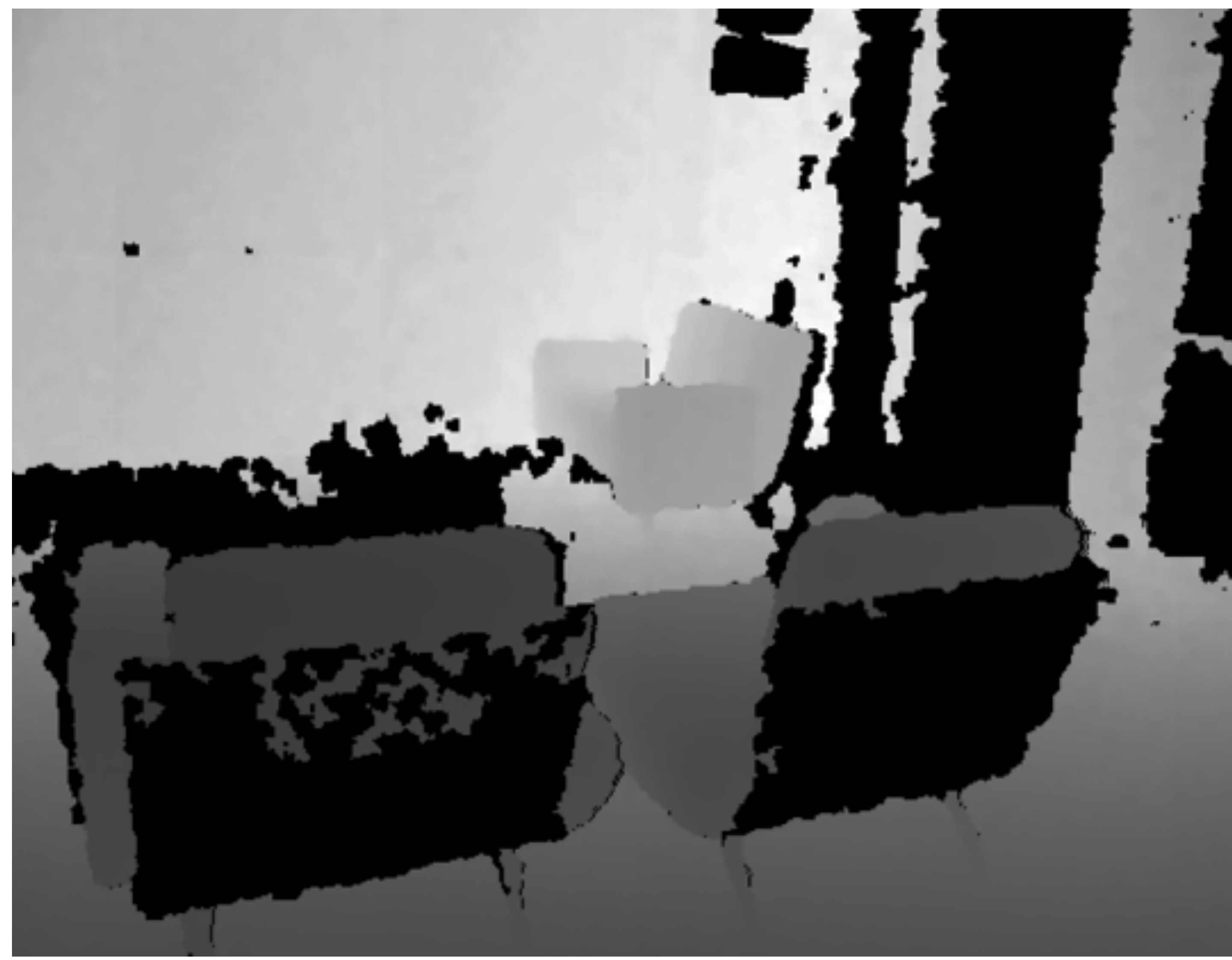
Organize and explore large collections of shapes

Goal



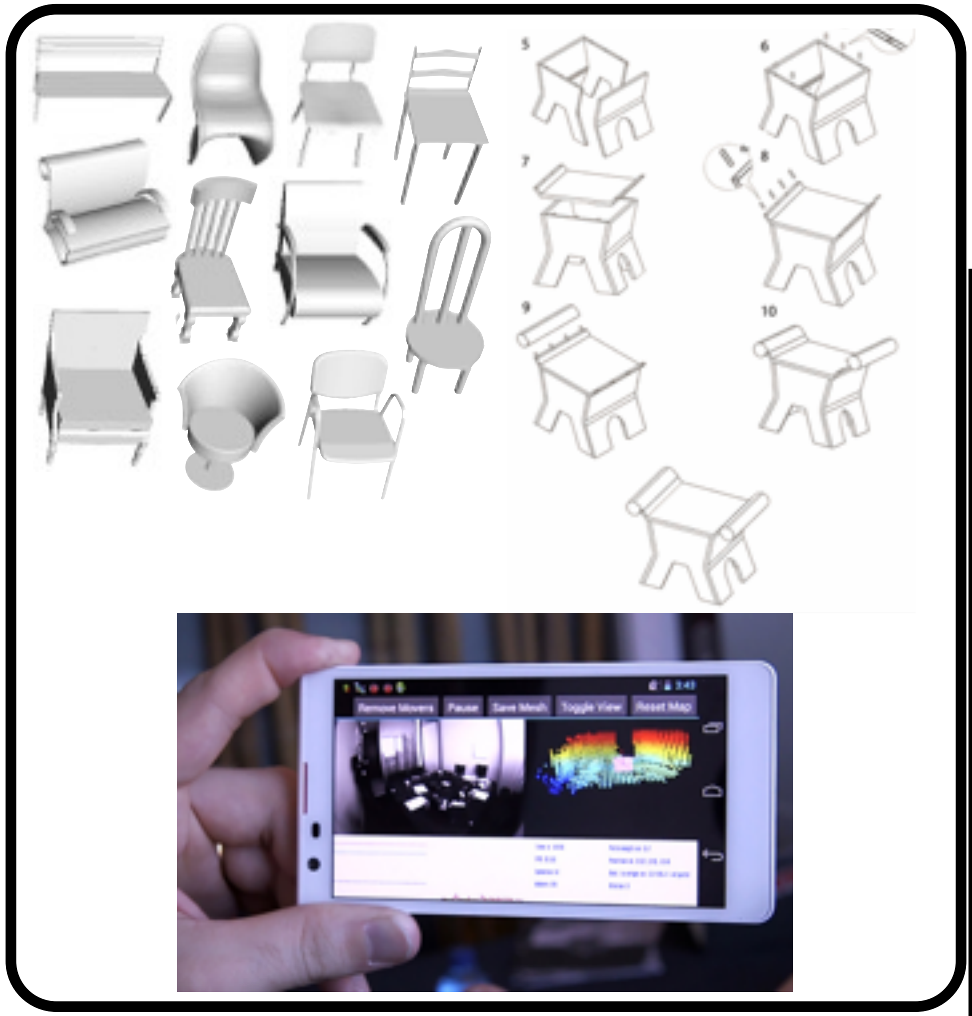
3D Data

→ **Structural Model** → **Analyze**



Understand and label novel geometric data

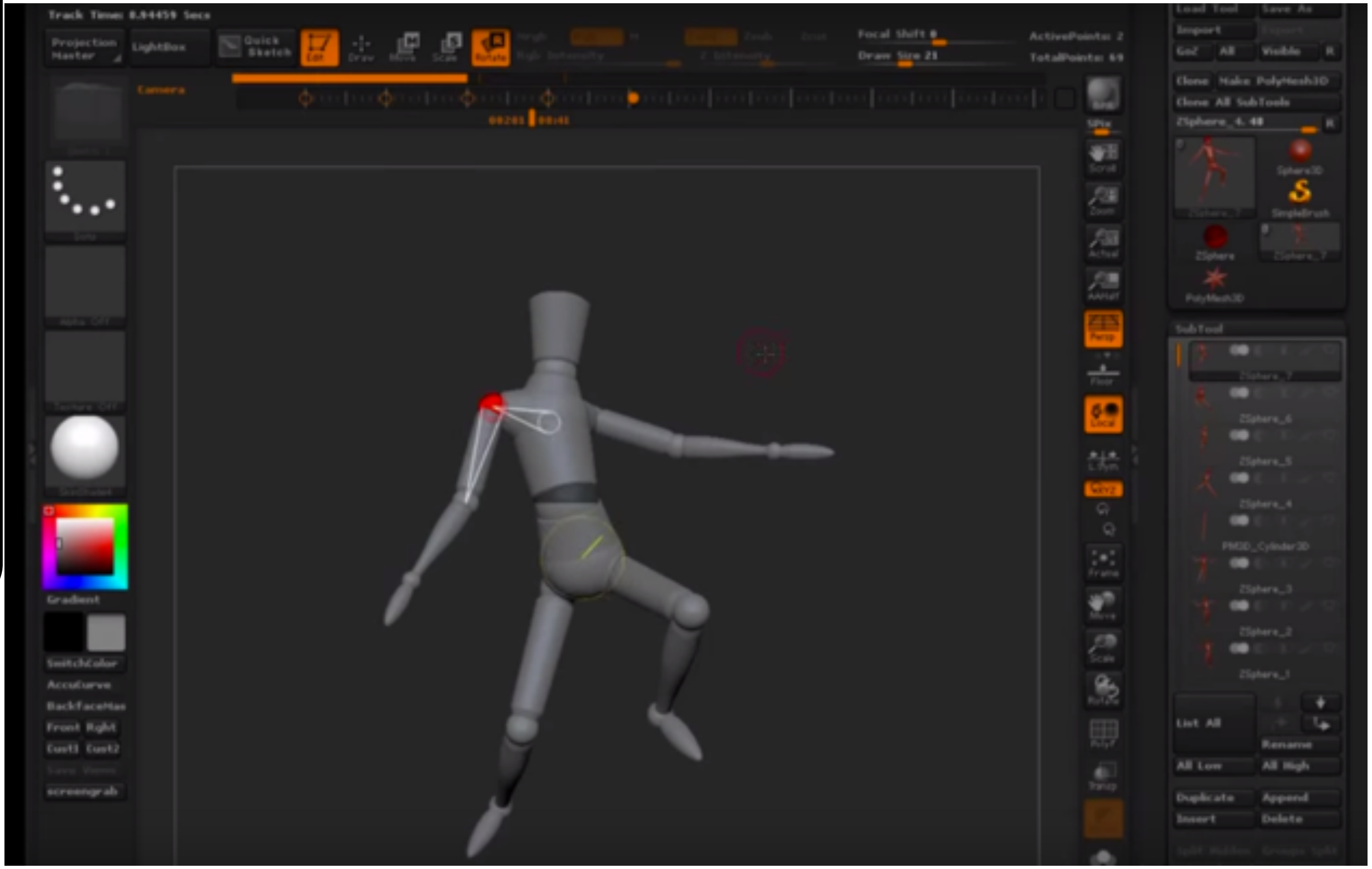
Goal



3D Data

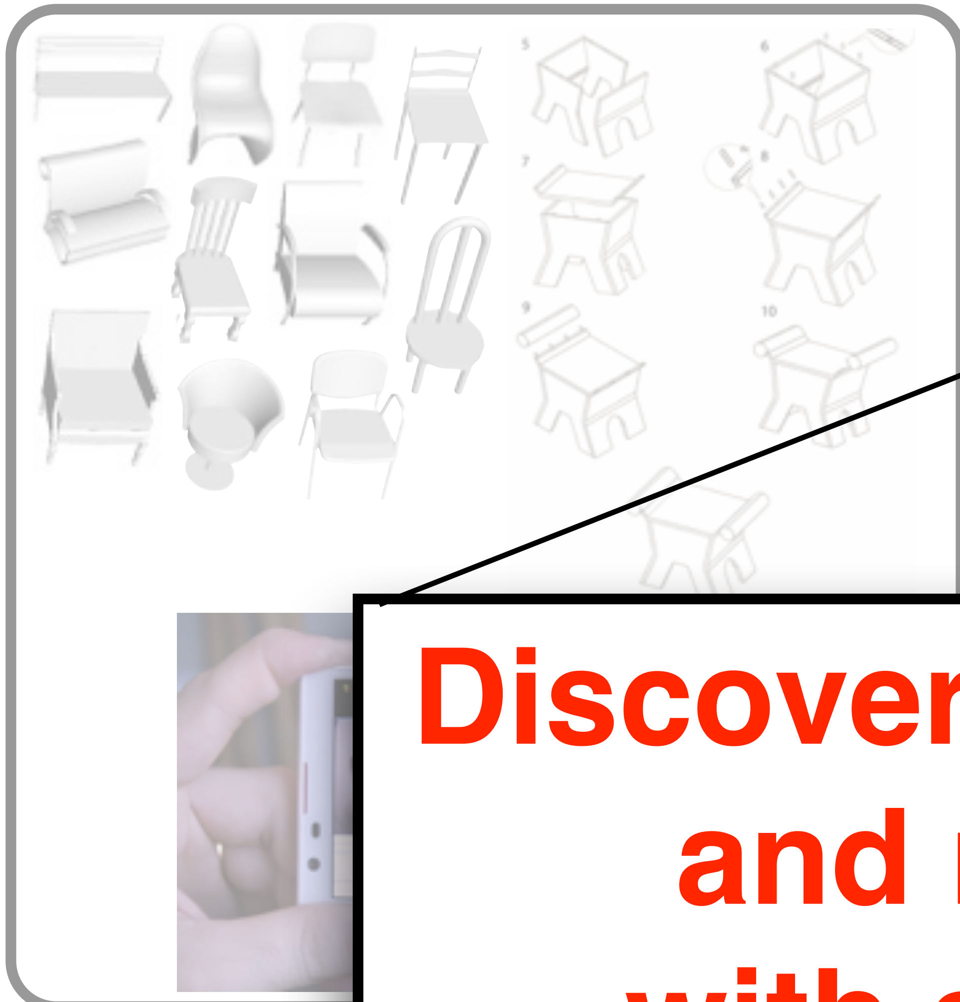
Structural Model

Create



Make 3D modeling more accessible to non-experts

Goal



Structural Model

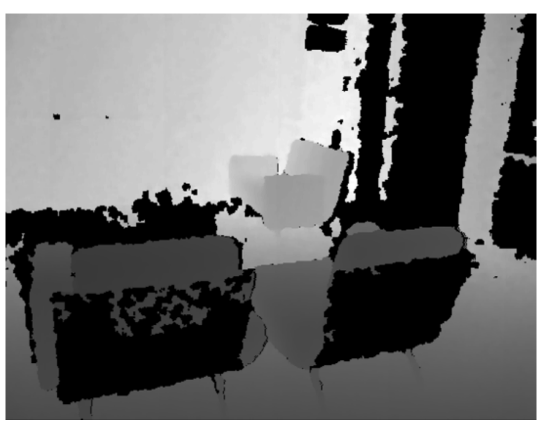
Create

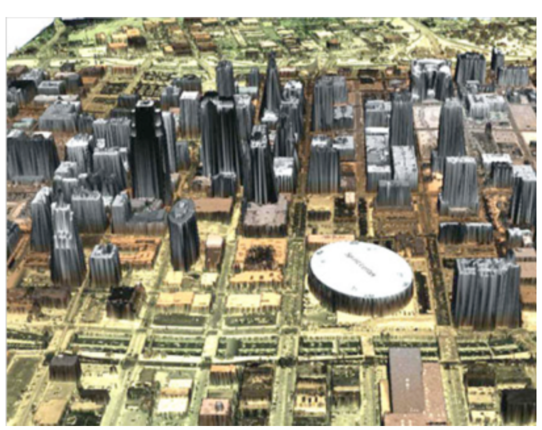
Discover repeating patterns and represent them with a concise model

Make 3D modeling more accessible to non-experts

Challenges

Discover similarities in unorganized geometry





Diversity

TurboSquid

3D Warehouse

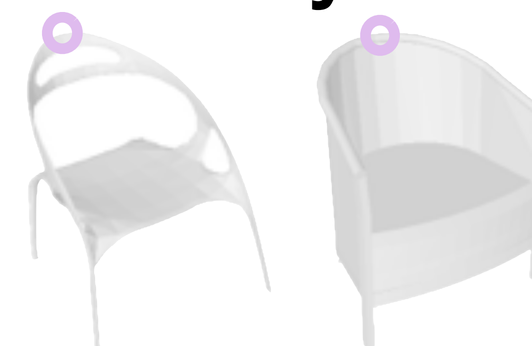
shapeways

Thingiverse

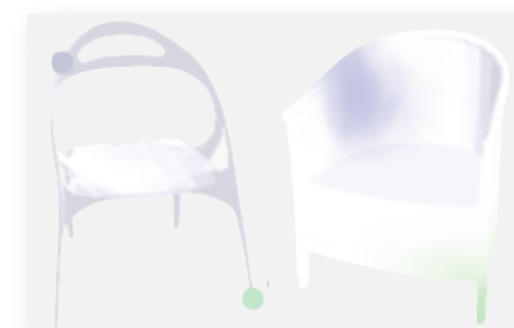
ShapeNet

Project Tango

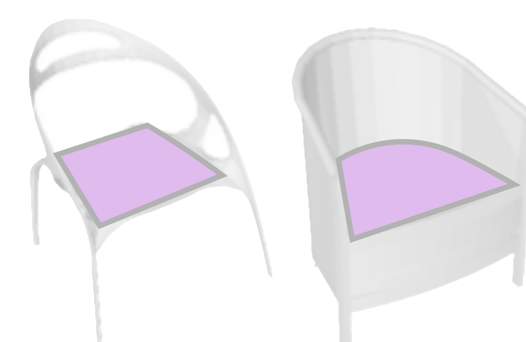
Scale



Point-to-point



Region-to-region

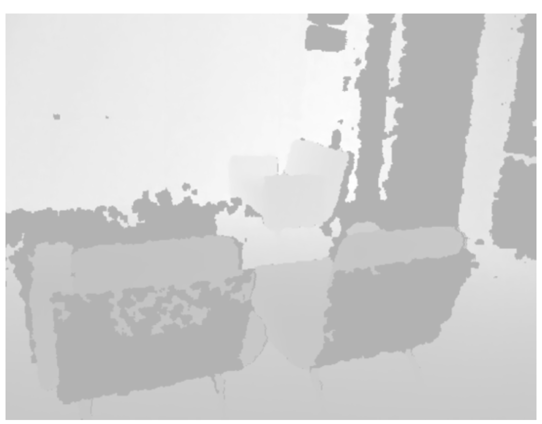


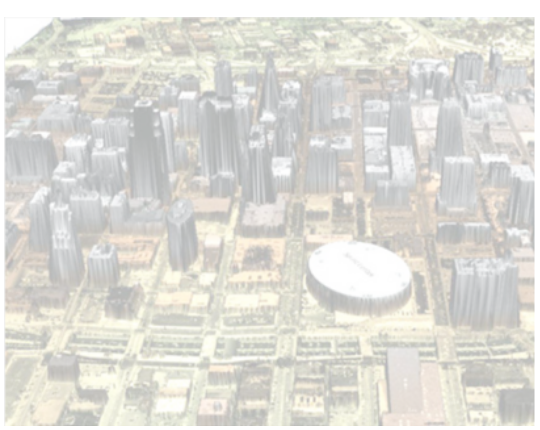
Part-to-part

Ambiguity

Challenges

Discover similarities in unorganized geometry





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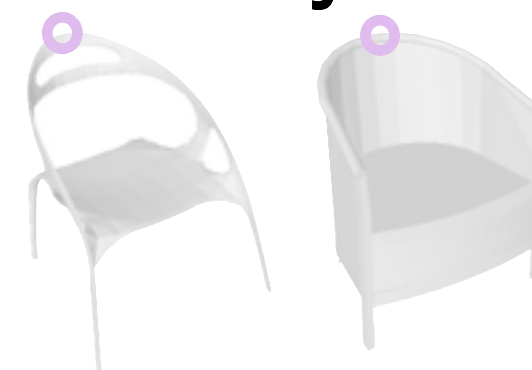

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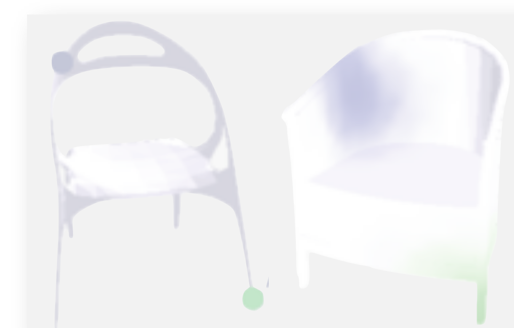

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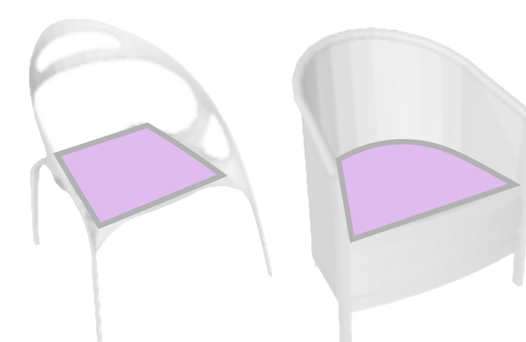

Part-to-part

Ambiguity

Challenges

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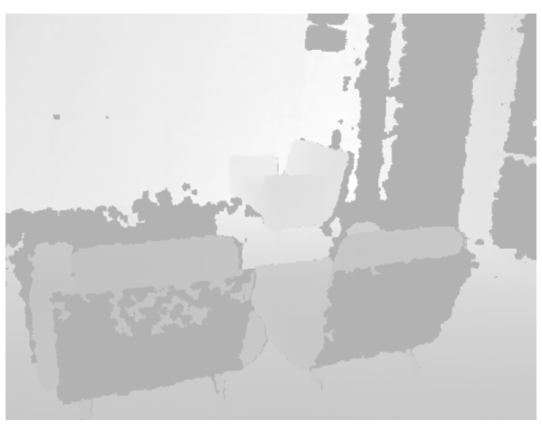

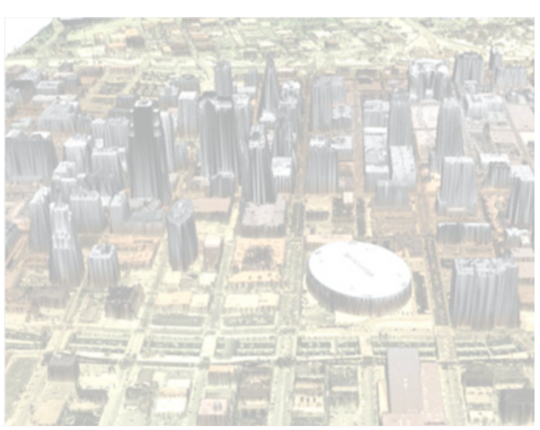

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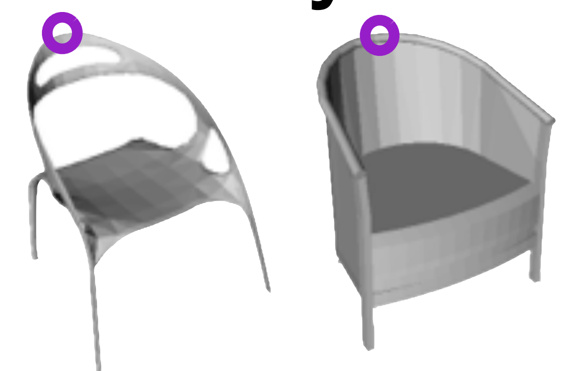

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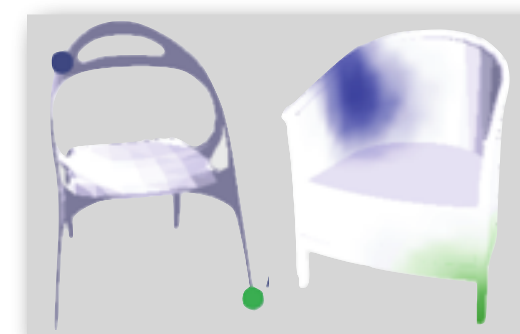

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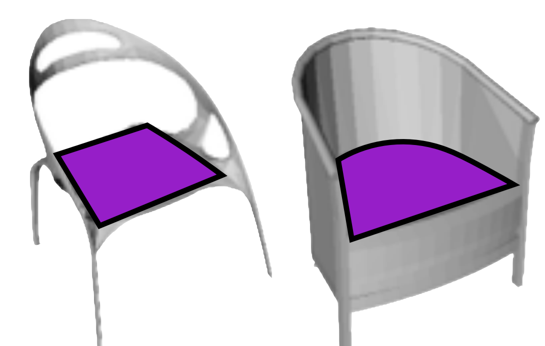


Part-to-part

Ambiguity

Talk Outline

Discover similarities to model structure

- Discover similarities
  - Blended intrinsic maps
  - Soft maps

- Model the structure
  - Learning deformable templates
  - Learning hierarchical templates

Talk Outline

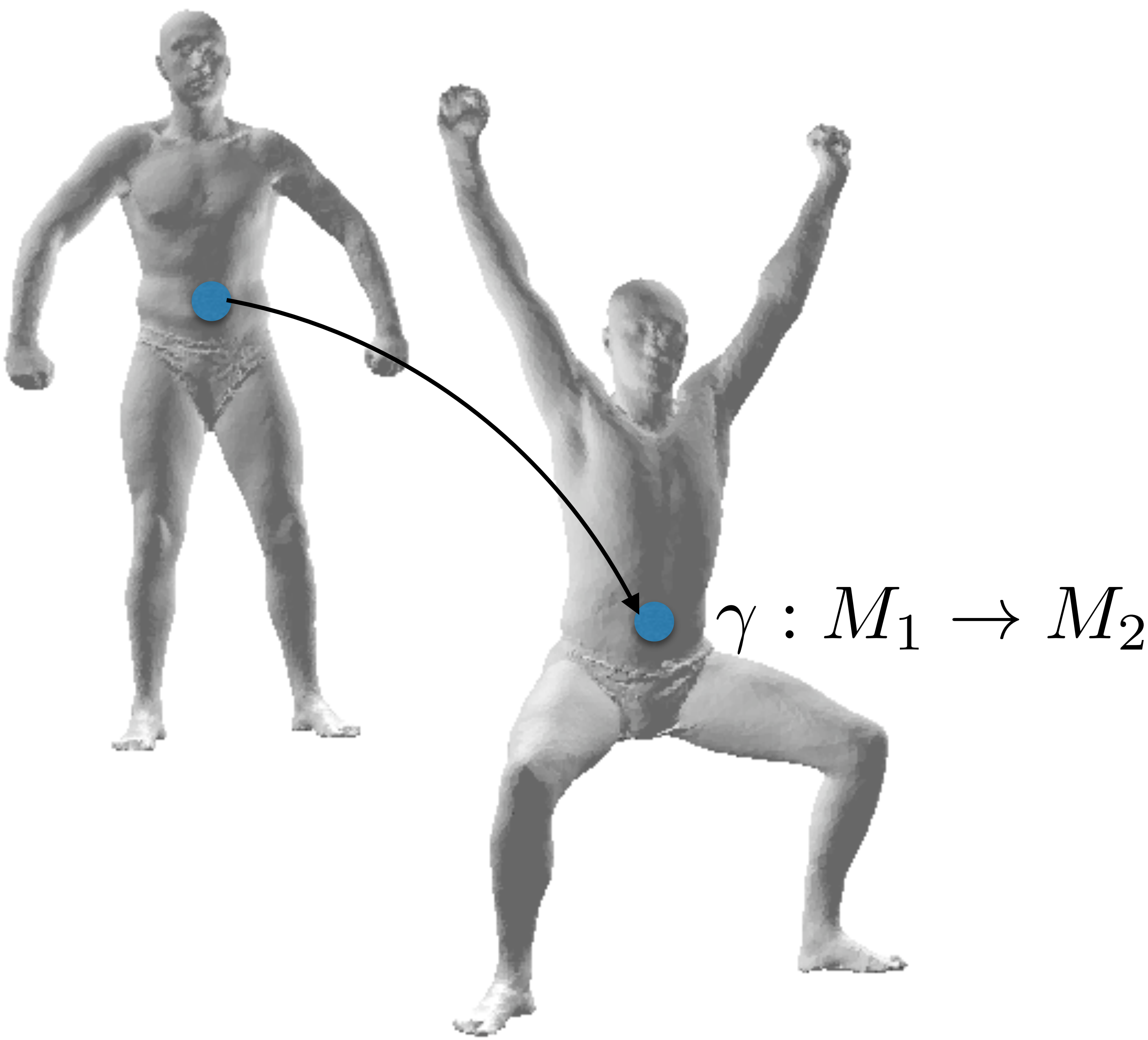
Discover similarities to model structure

➡ **Discover similarities**
  - Blended intrinsic maps
  - Soft maps

- Model the structure
  - Learning deformable templates
  - Learning hierarchical templates

Shape Correspondence

Correspondence as Metric Alignment



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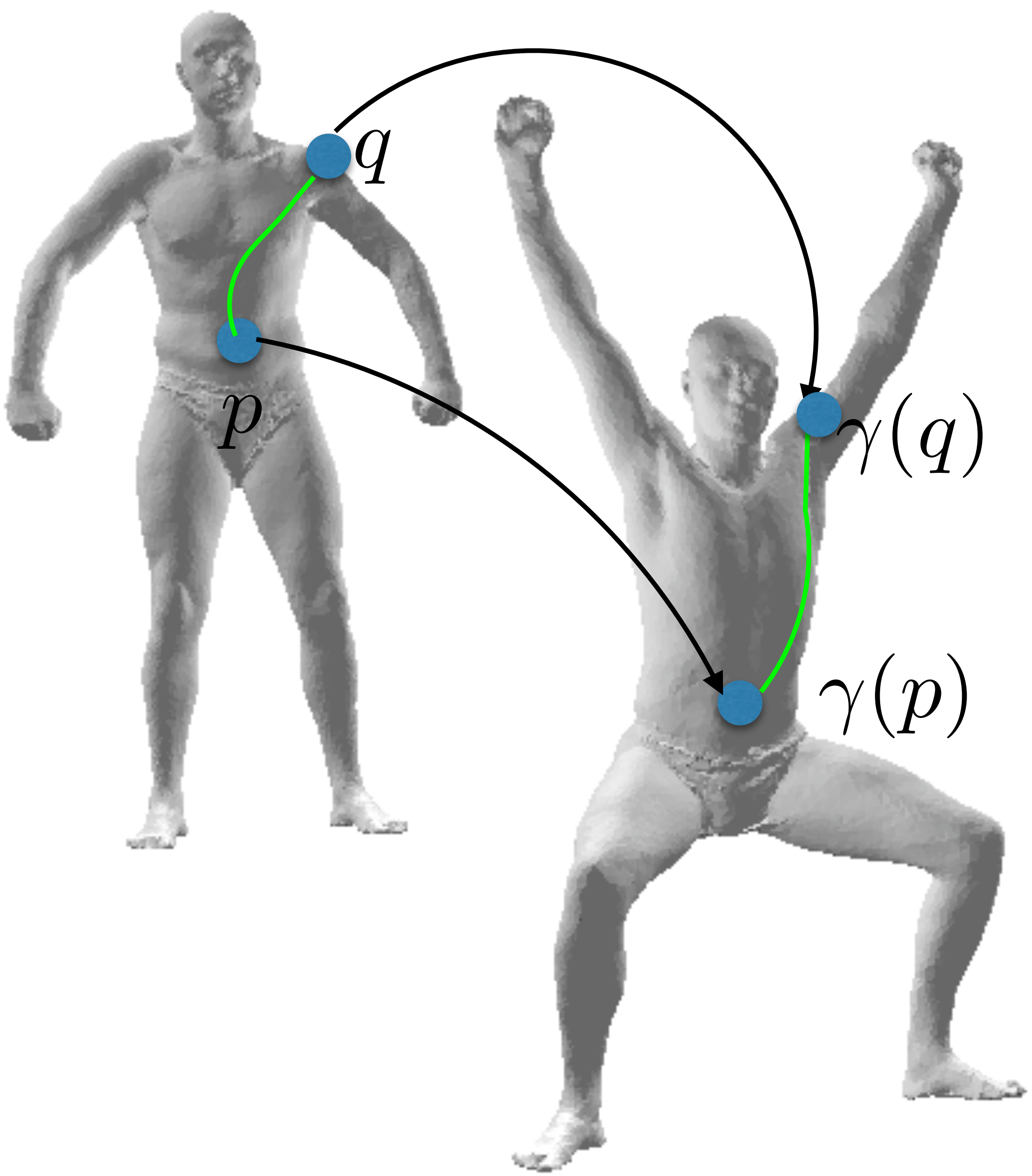
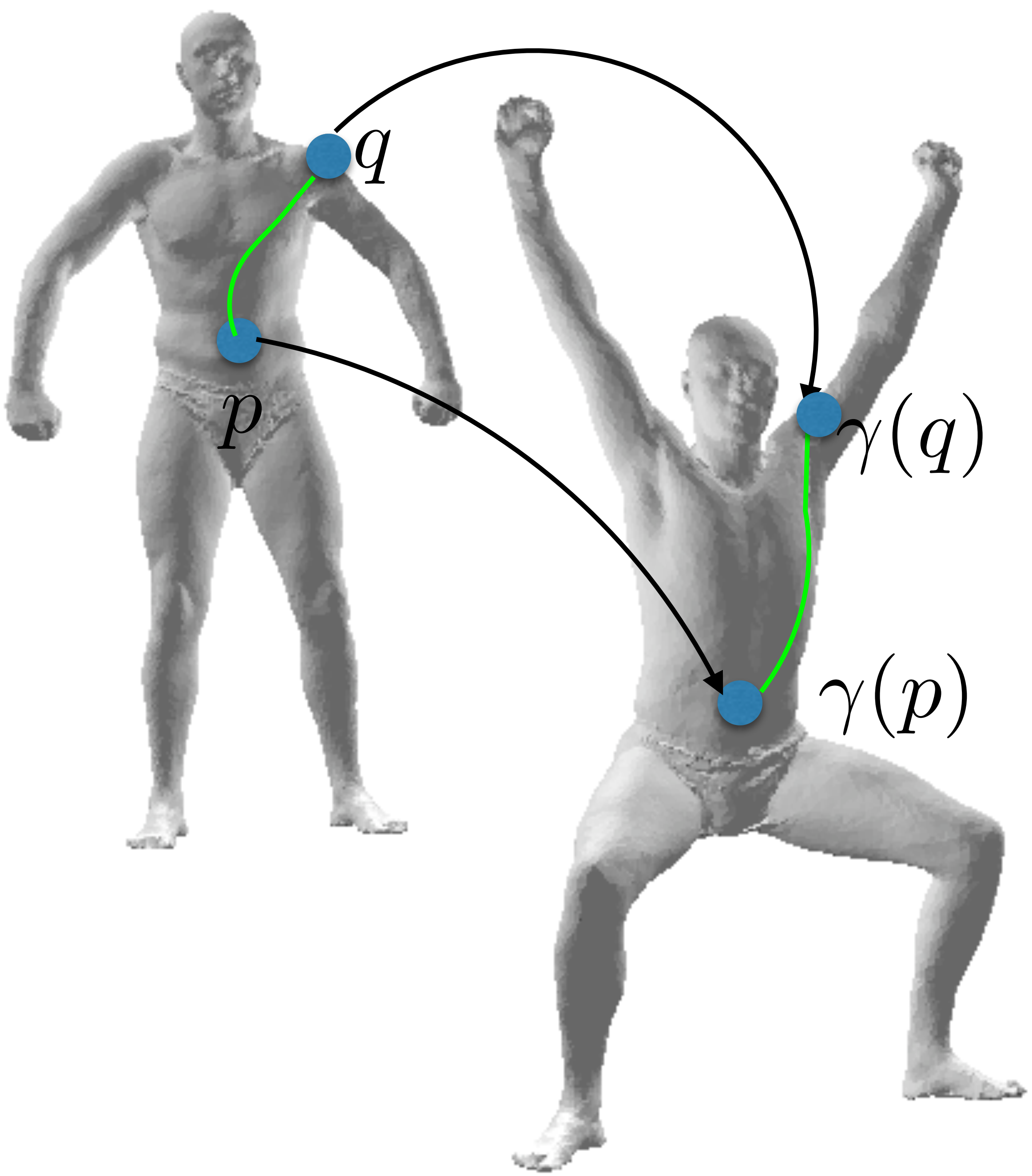


a good map: $\arg\min \|\overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))}\|$

Shape Correspondence

Correspondence as Metric Alignment

Sample γ >> Pick best



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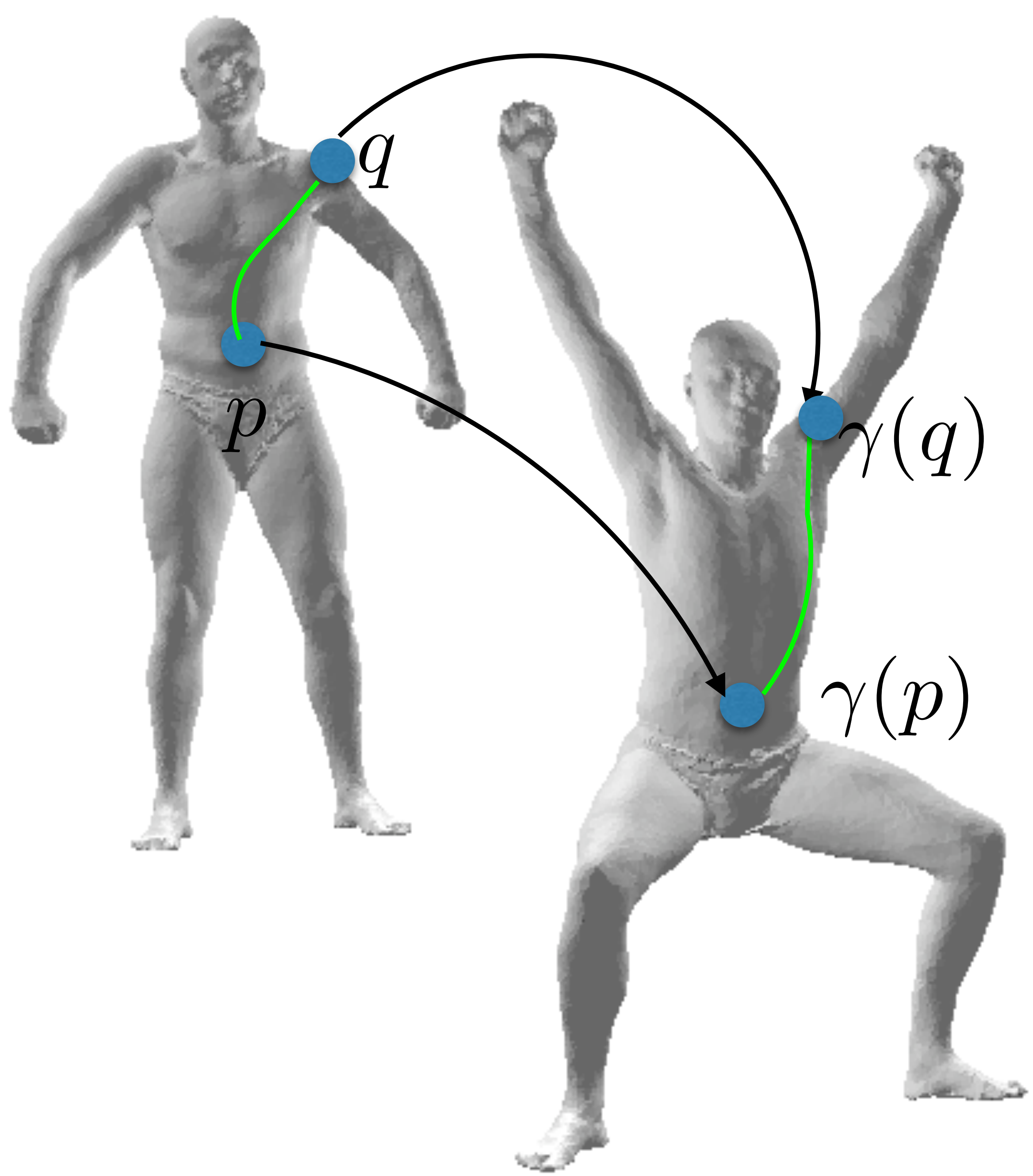


Observation:

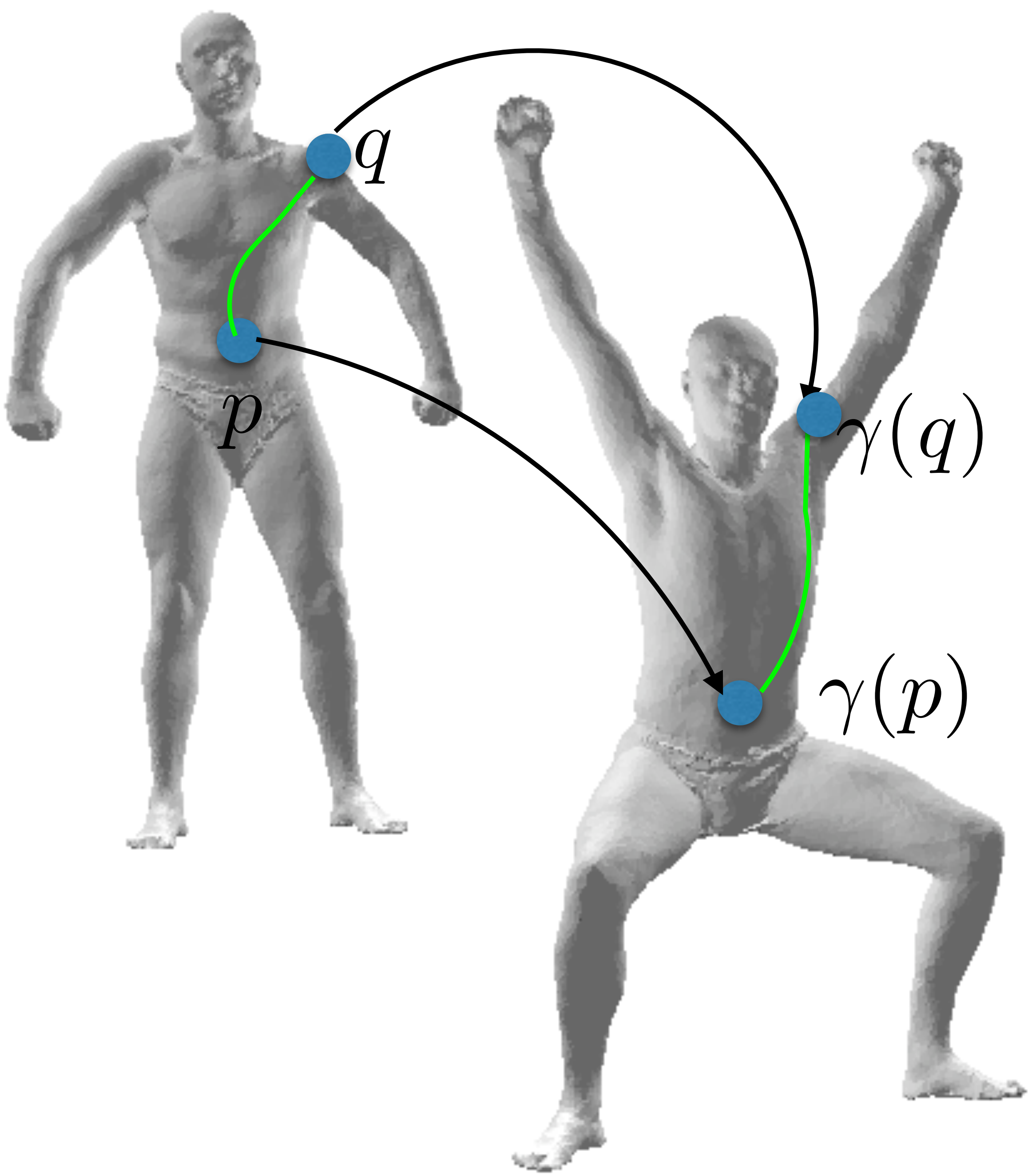
$$\text{isometric} = \text{area-preserving} + \text{conformal}$$

a good map: $\arg\min \| \overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))} \|$

Shape Correspondence

Correspondence as Metric Alignment

Sample γ >> Pick best



Observation: **combinatorial!**

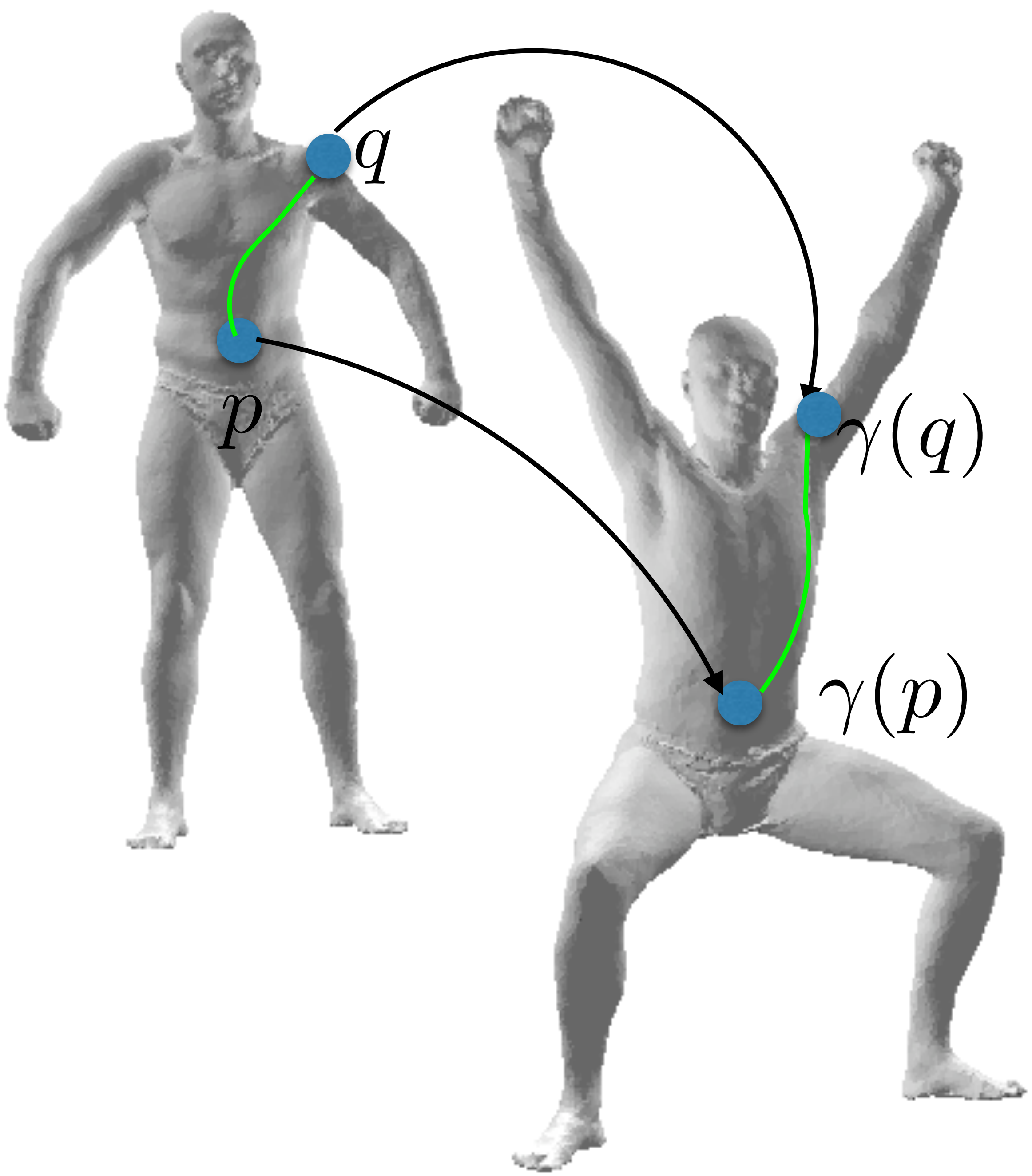
$$\text{isometric} = \boxed{\text{area-preserving}} + \text{conformal}$$

a good map: $$\arg\min \|\overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))}\|$$

Shape Correspondence

Correspondence as Metric Alignment

Sample γ >> Pick best



Observation:

$$\text{isometric} = \text{area-preserving}$$

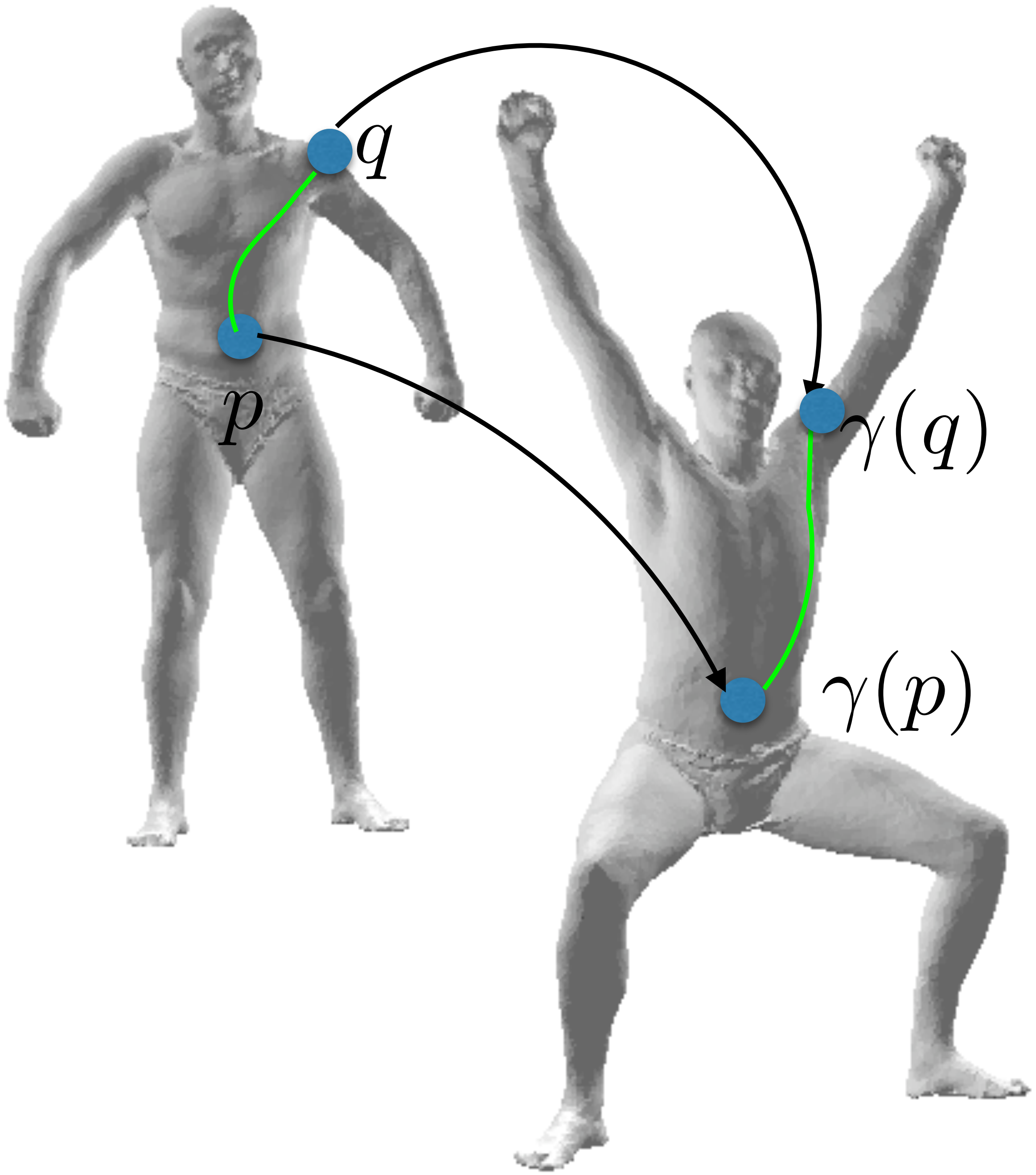
$$\boxed{+\ \text{conformal}}$$

polynomial!

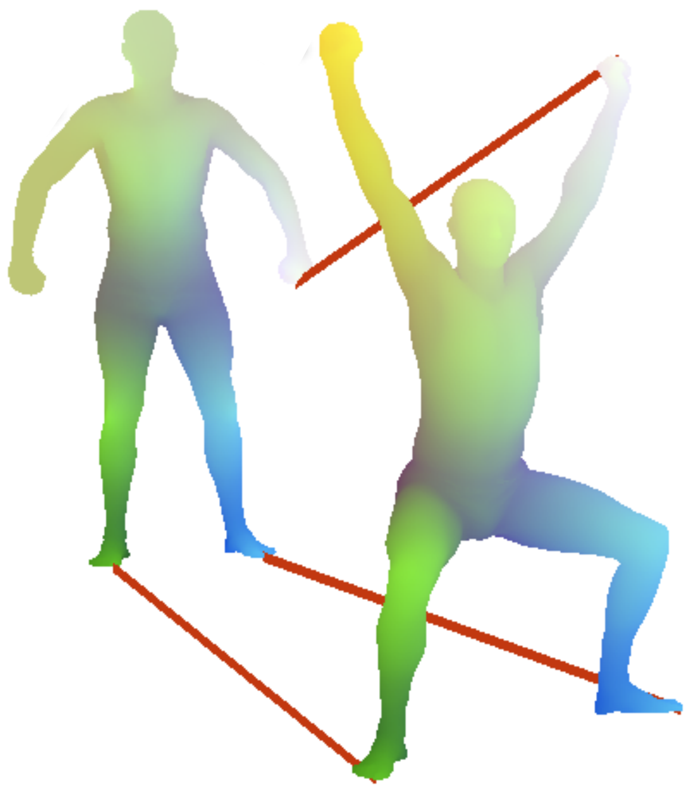
a good map: $\arg\min \|\overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))}\|$

Conformal Maps

Correspondence as Metric Alignment



Sample γ >> Pick best

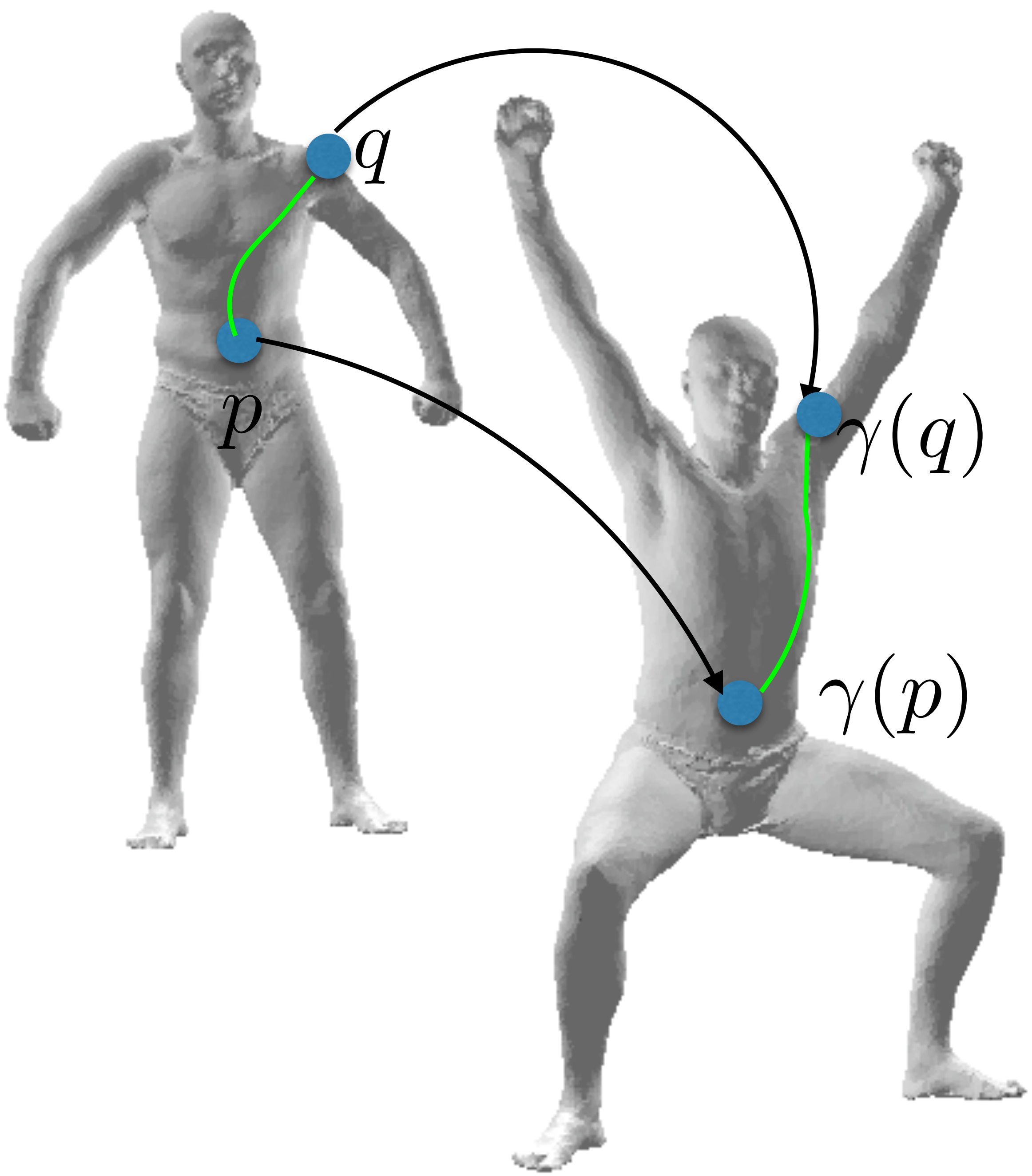


conformal map
defined by 3 points

a good map: $\arg\min \|\overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))}\|$

Conformal Maps

Correspondence as Metric Alignment



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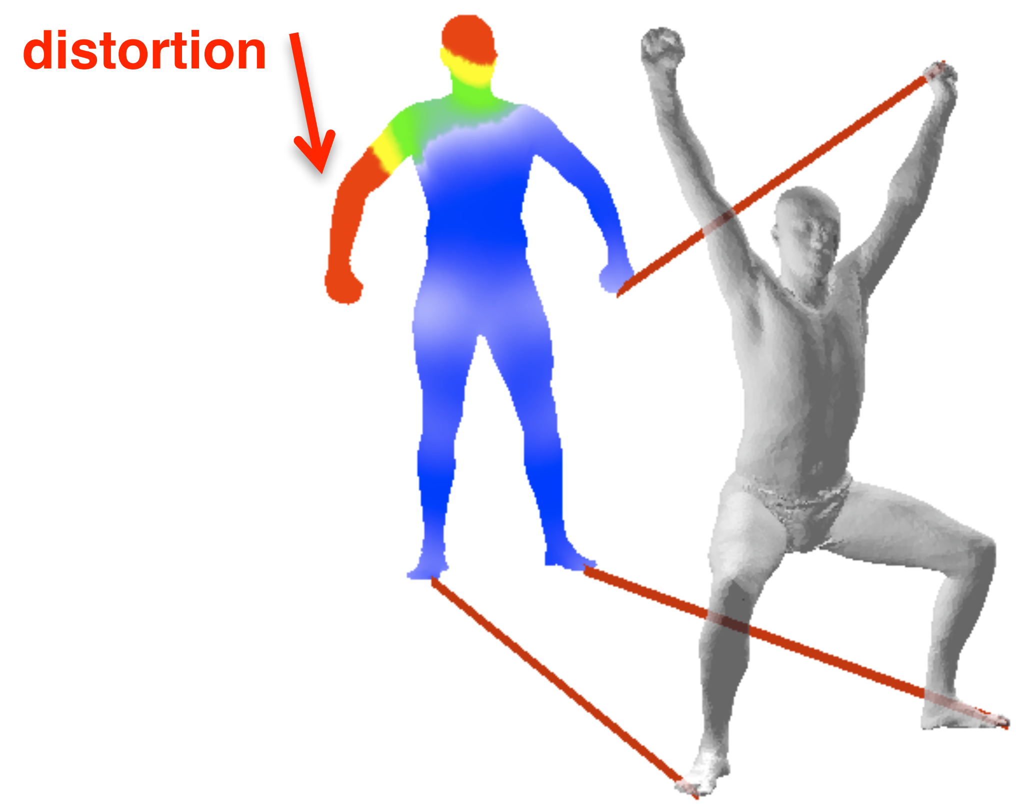

conformal map
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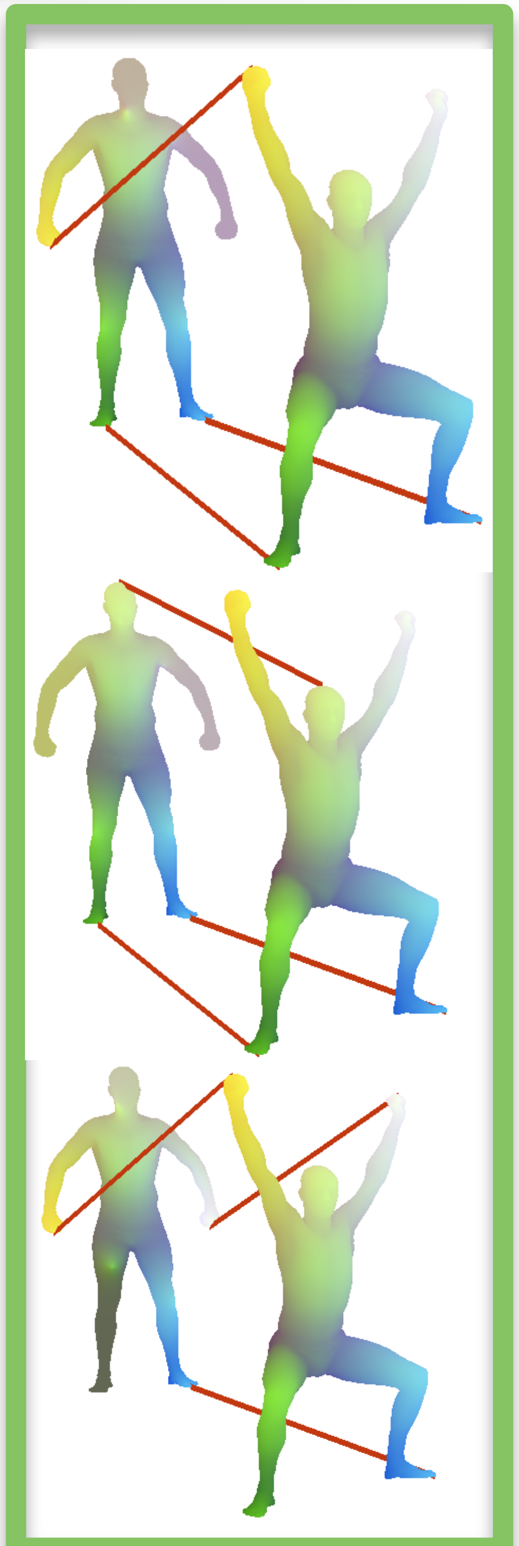
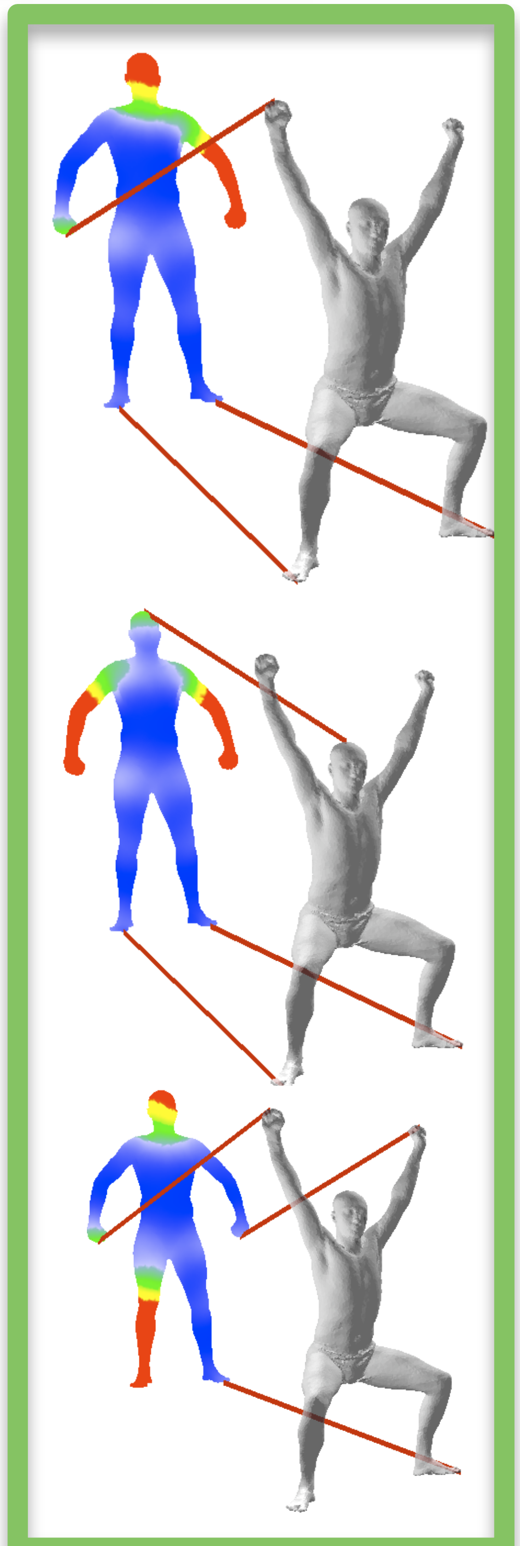
a good map: $\arg\min \|\overline{D(p,q)} - \overline{D(\gamma(p),\gamma(q))}\|$

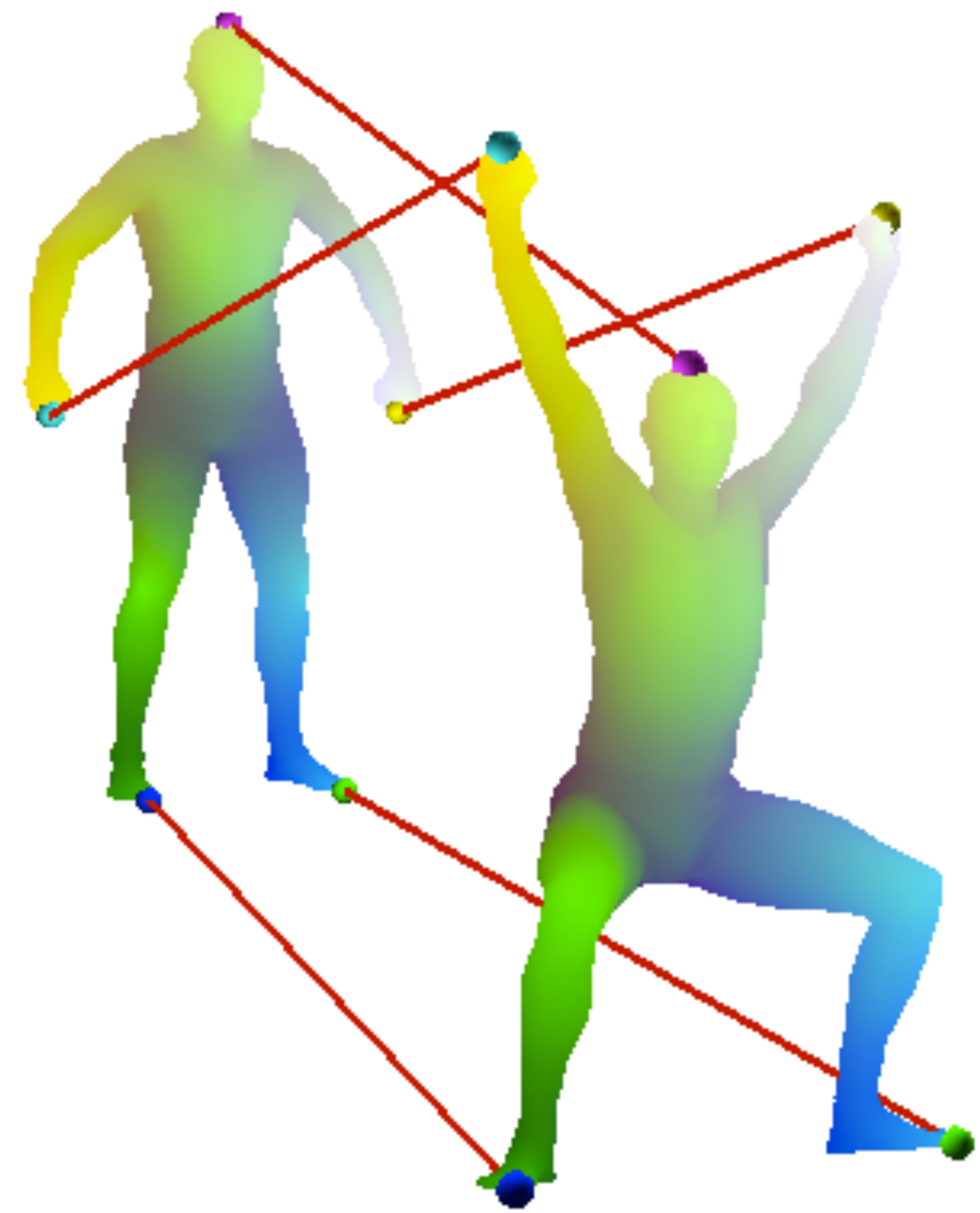
Blended Conformal Maps



Conformal Maps

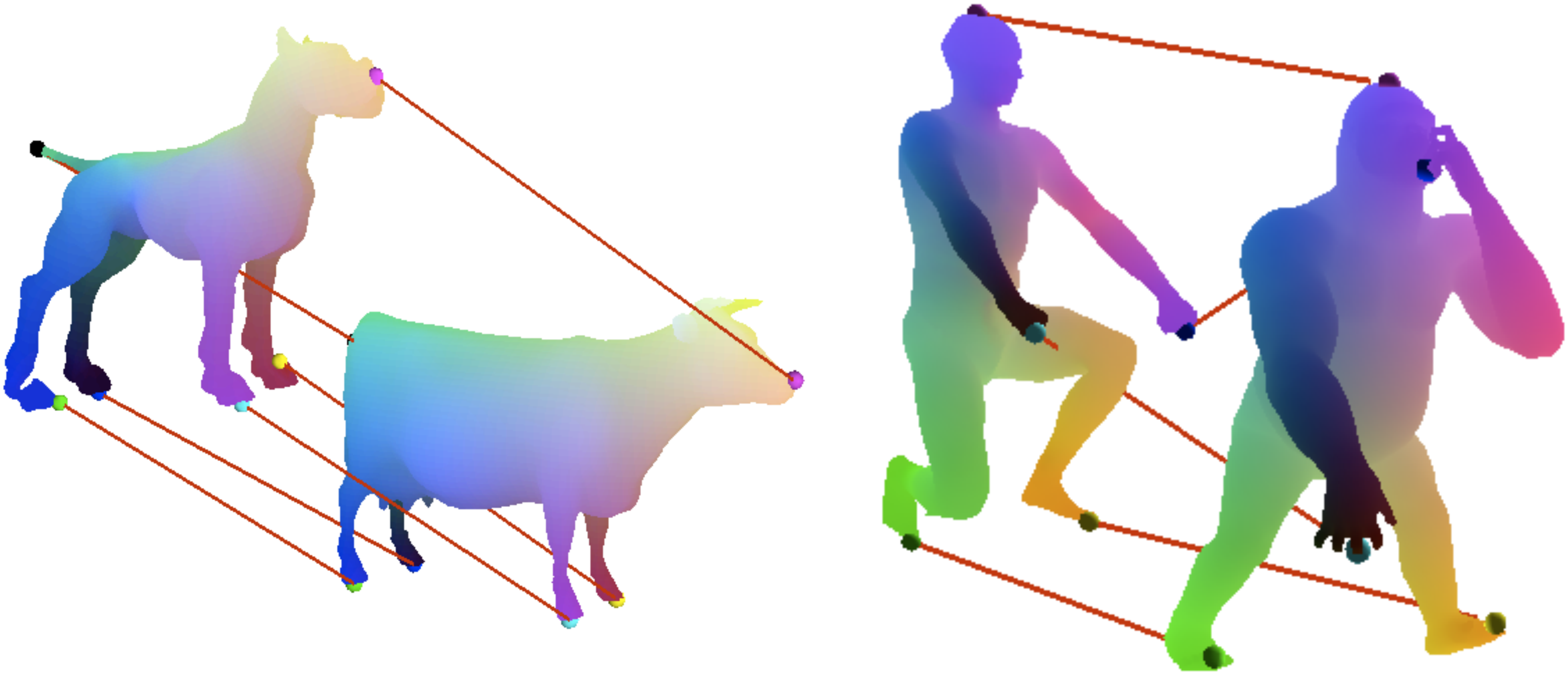


Weights



Blended Map

Blended Conformal Maps

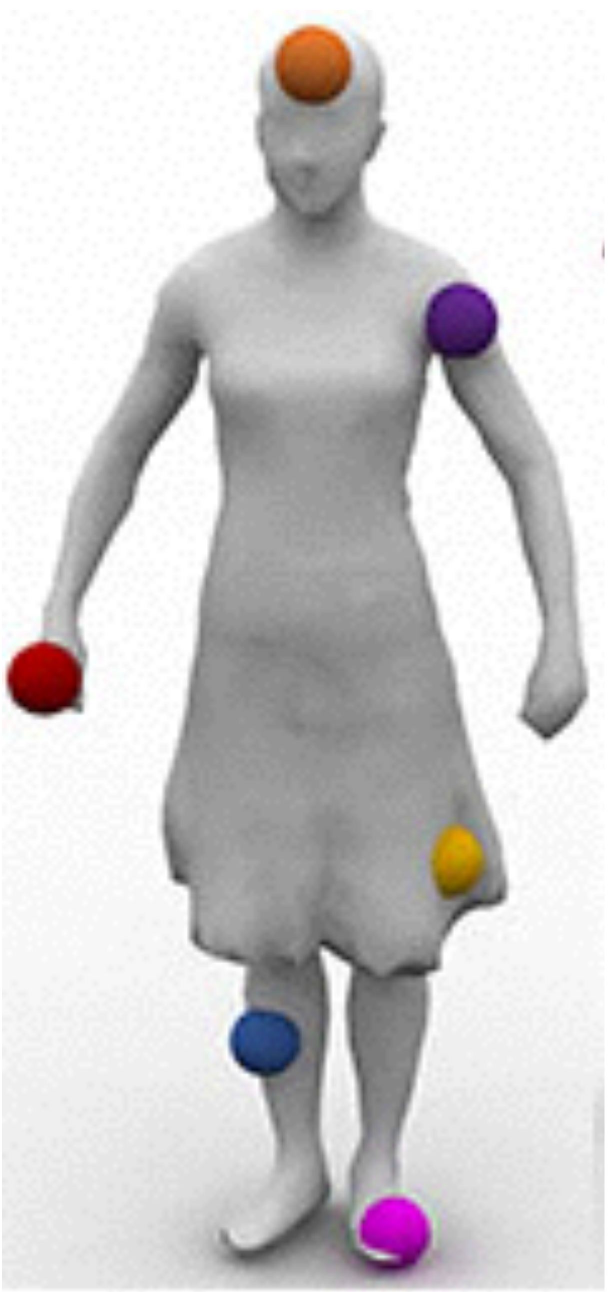


Non-isometric shapes

Limitations

What is the correct point-to-point map?

Limitations

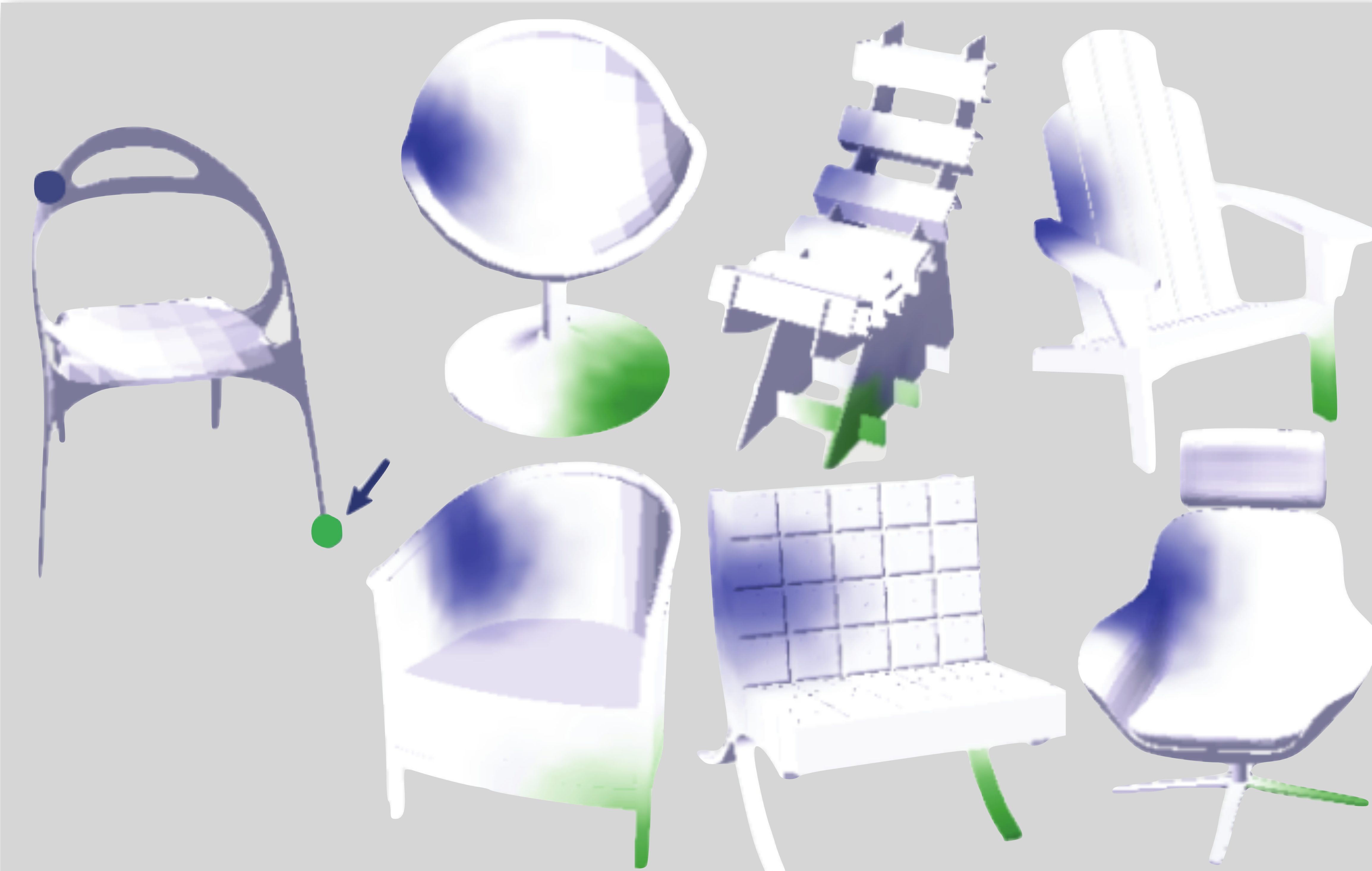


3D model

2D outline

What is the correct point-to-point map?

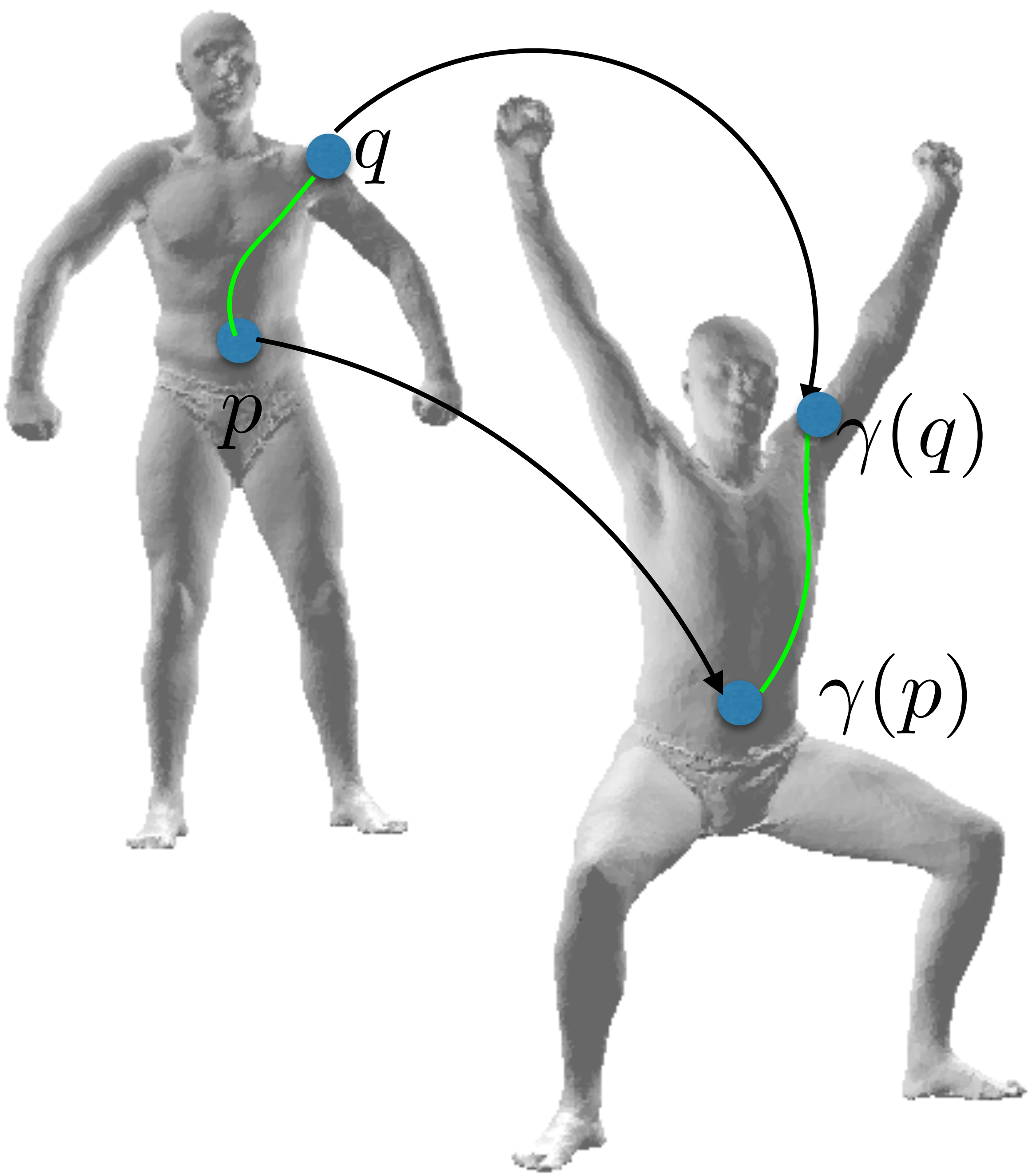
Soft Maps

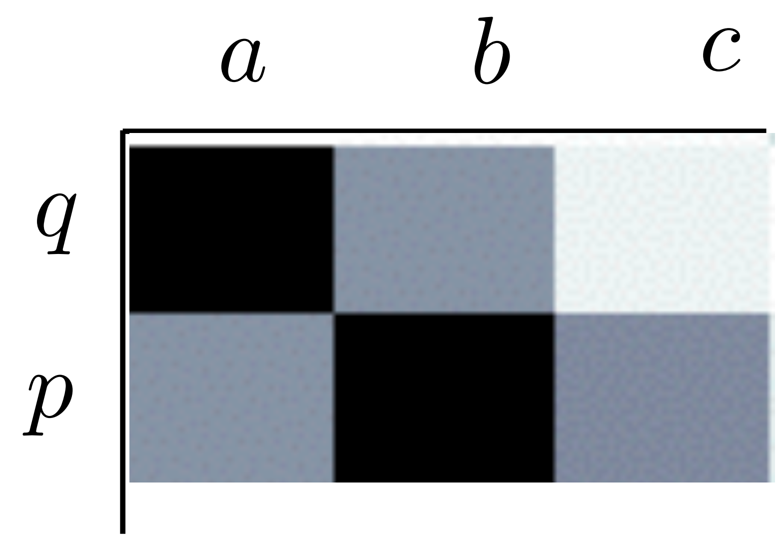


Soft Maps

Correspondence as Metric Alignment

Sample γ >> Pick best





mass transport

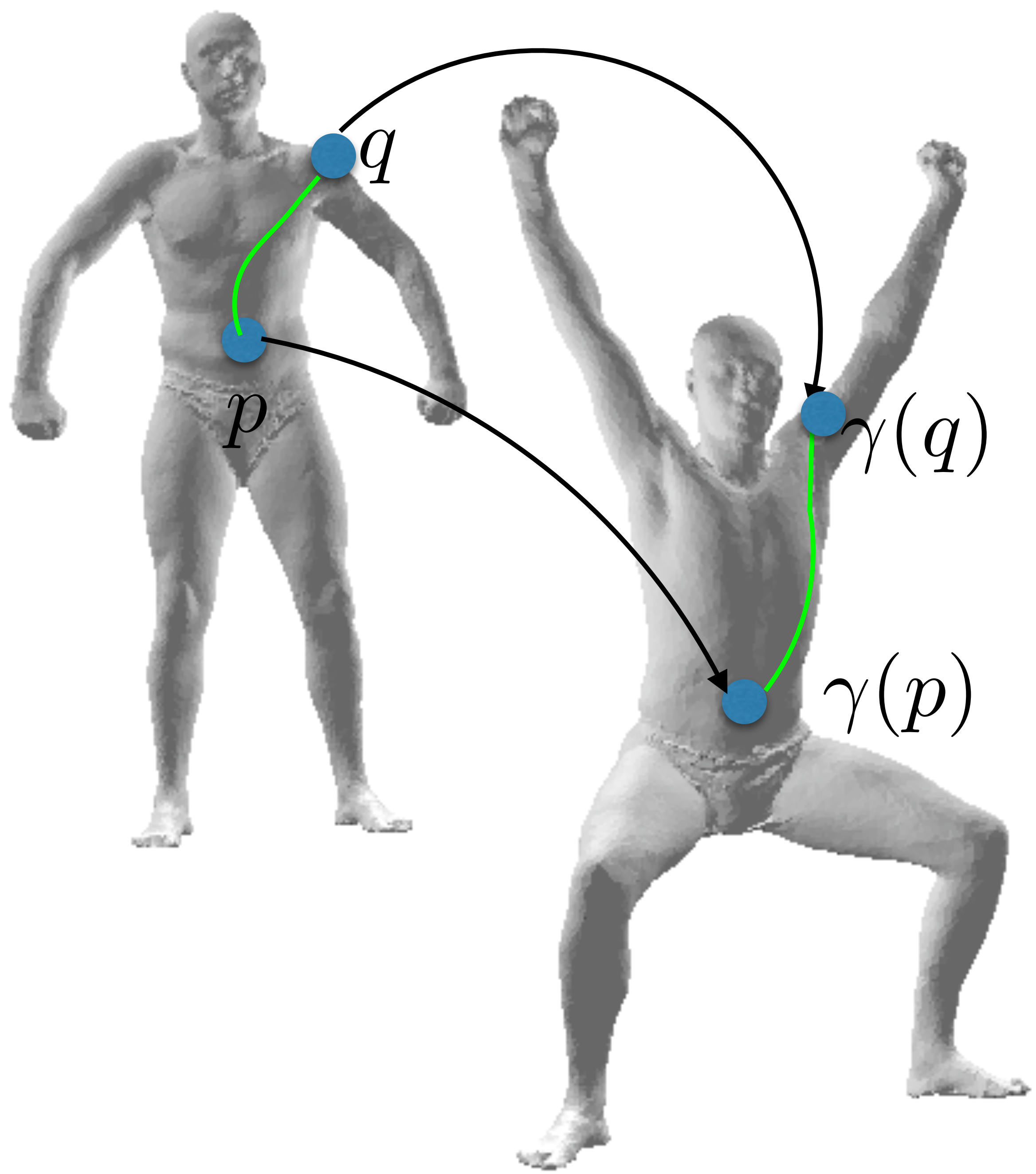
point-to-distribution

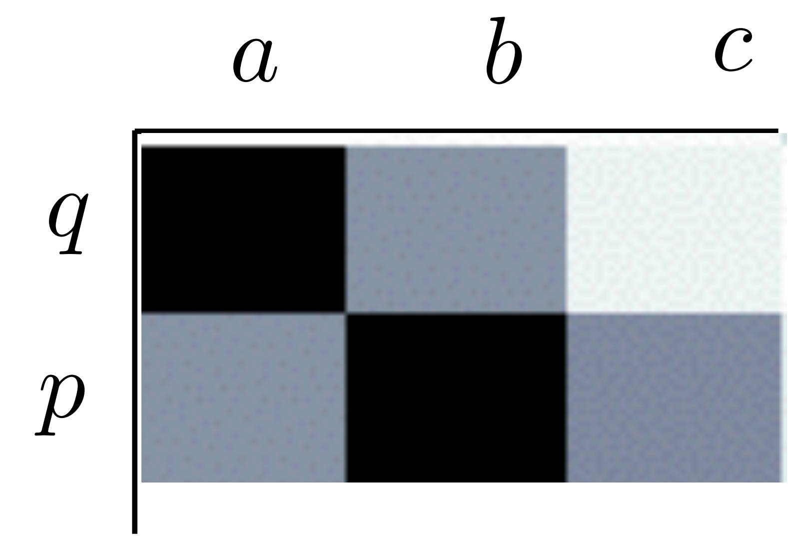
a good map:

Soft Maps

Correspondence as Metric Alignment

Sample γ >> Pick best





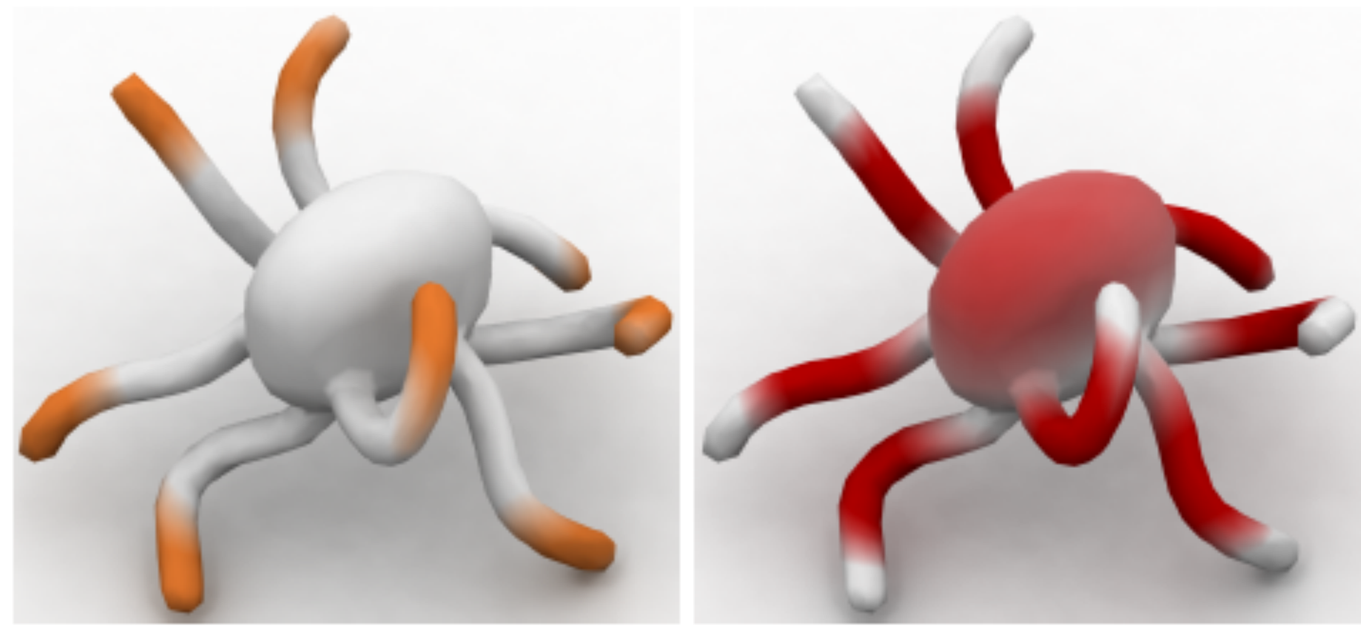
mass transport
point-to-distribution

a good map: $\arg\min \|D(p,q) - D(a,b)\|^2 \gamma(p,a)\gamma(q,b)$

Entropic Regularization

Make γ as sparse as possible: $H_\alpha(\gamma) = -\alpha < \gamma, \ln\gamma >$

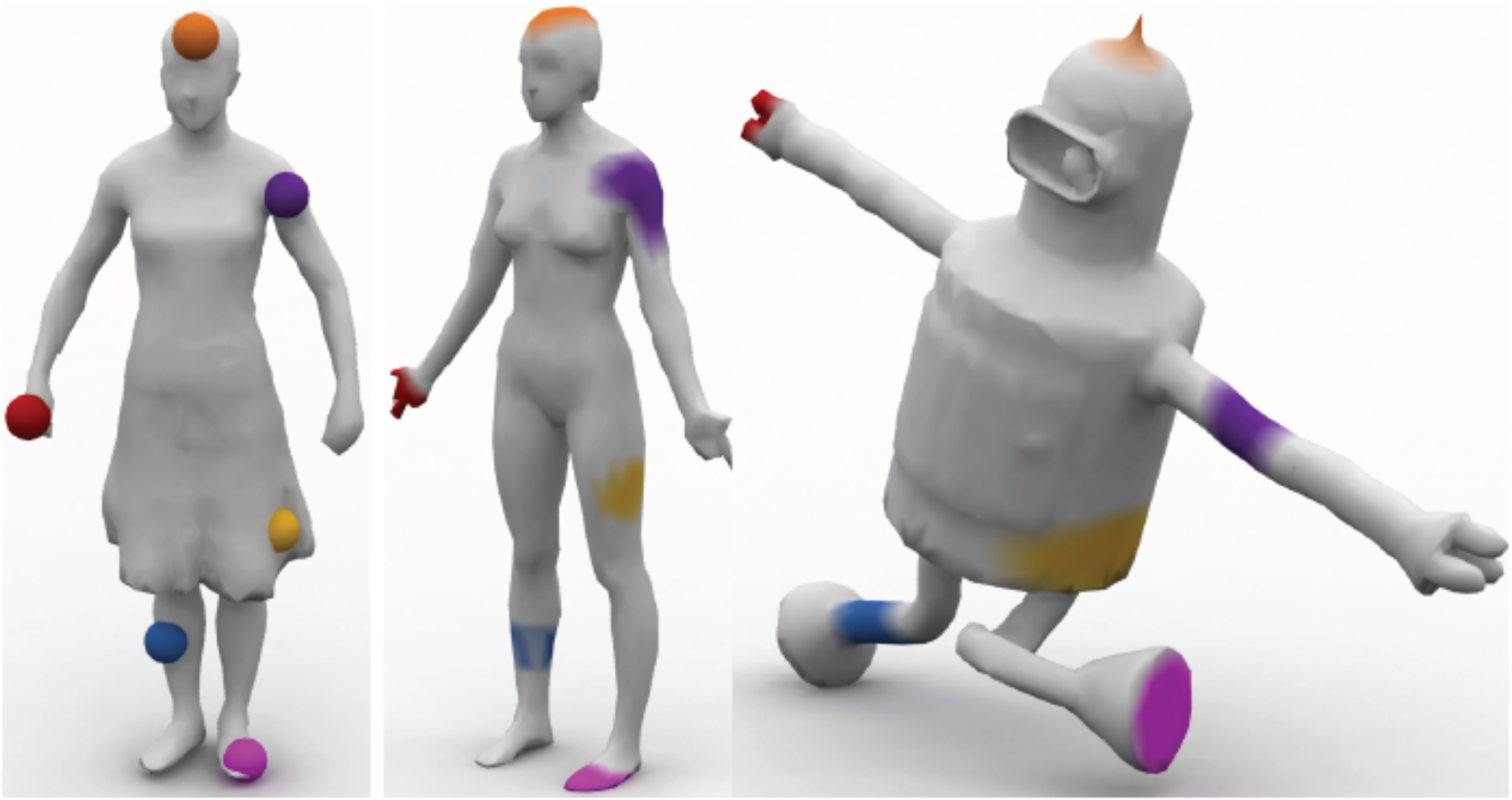
Source surface



Target surface ($\alpha = 8 \times 10^{-3}$)

Target surface ($\alpha = 7 \times 10^{-4}$)

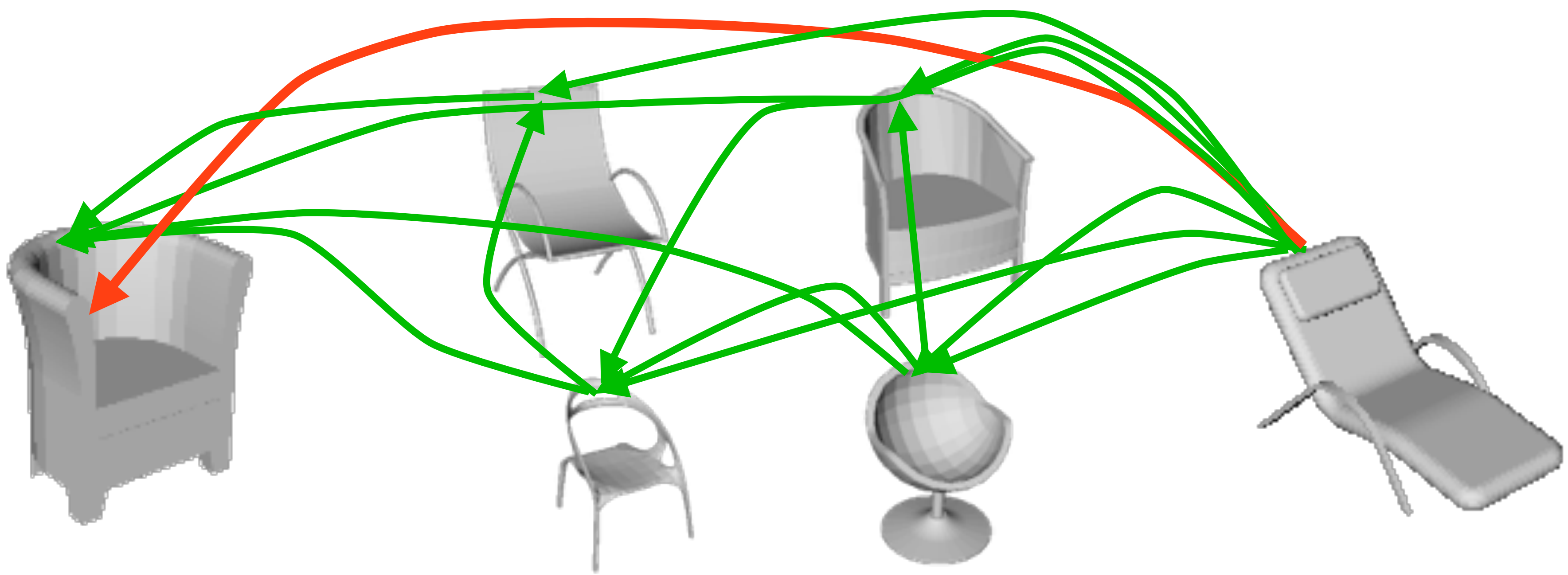
Soft Map Results



Soft Map Results

Consistency

Low-rank (cycle consistency) in collections of shapes

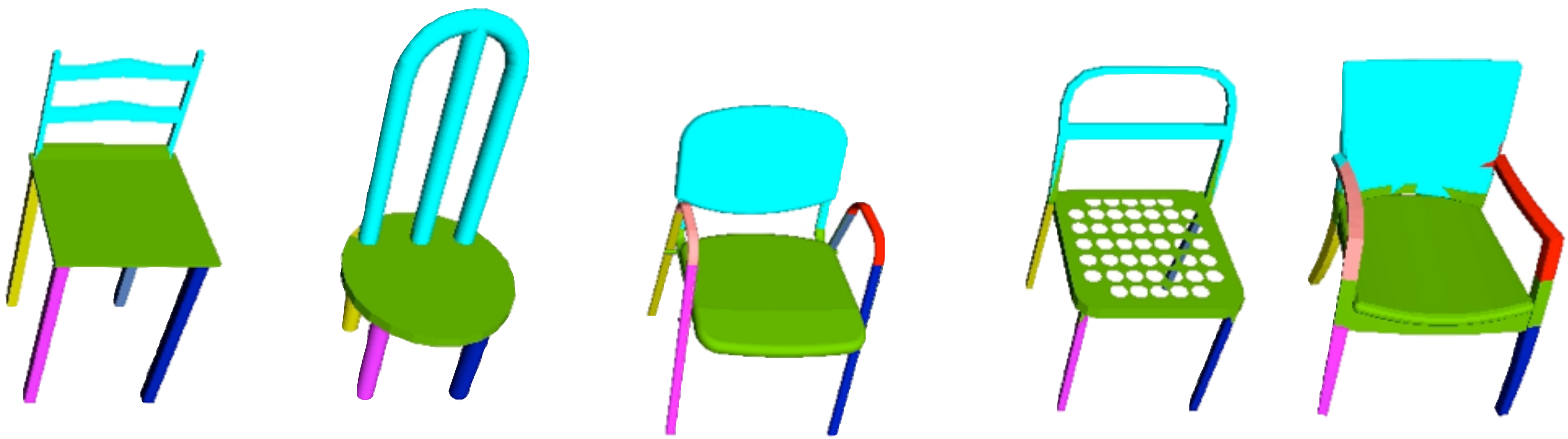


$$\underbrace{\begin{pmatrix} \mathbf{\Gamma}_{11} & \cdots & \mathbf{\Gamma}_{1p} \\ \vdots & \ddots & \vdots \\ \mathbf{\Gamma}_{p1} & \cdots & \mathbf{\Gamma}_{pp} \end{pmatrix}}_{\mathbf{G}} = \frac{1}{m} \underbrace{\begin{pmatrix} \mathbf{\Gamma}_{1} \\ \mathbf{\Gamma}_{2} \\ \vdots \\ \mathbf{\Gamma}_{p} \end{pmatrix}}_{\mathbf{A}} \underbrace{\begin{pmatrix} \mathbf{\Gamma}_{1} \\ \mathbf{\Gamma}_{2} \\ \vdots \\ \mathbf{\Gamma}_{p} \end{pmatrix}^{\top}}_{\mathbf{A}^{\top}}$$

Consistency

Low-rank assumption can help in discovering parts

- Additional terms: local shape cues for part boundaries



Talk Outline

Discover similarities to model structure

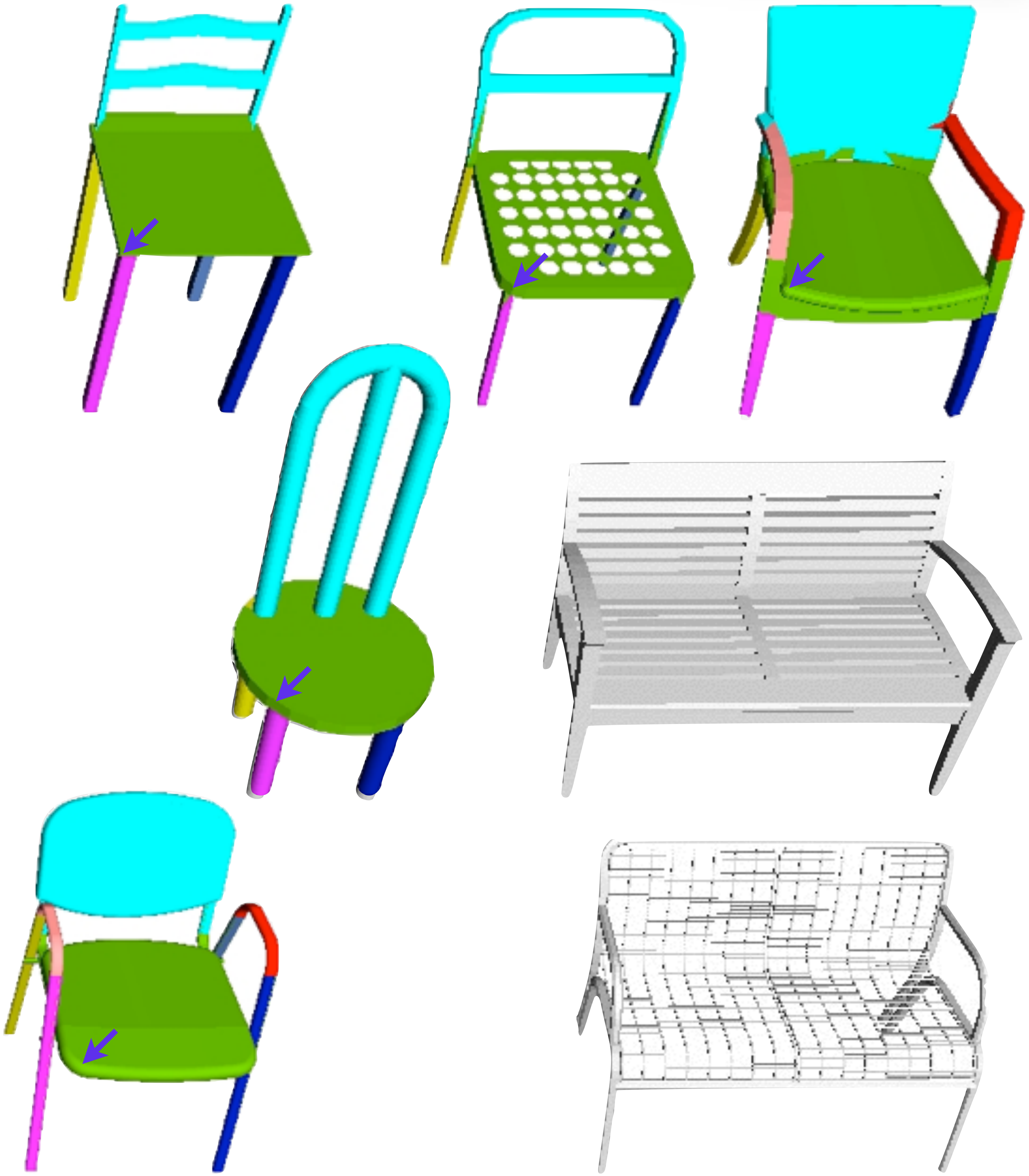
- Discover similarities
  - Blended intrinsic maps
  - Soft maps

➡ **Model the structure**
  - Learning deformable templates
  - Learning hierarchical templates

Learning Templates

Meta-algorithm

- ➡ **Shape-shape corrs.**
- Build templates
- Shape-template corrs.
- Update templates



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Meta-algorithm

- Shape-shape corrs.
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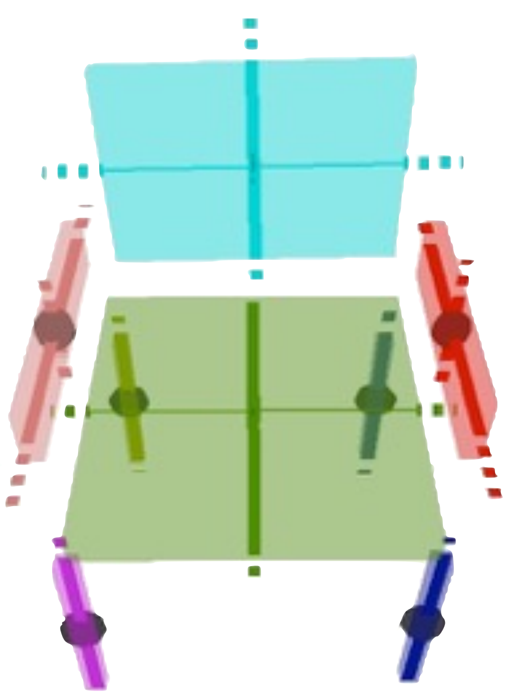
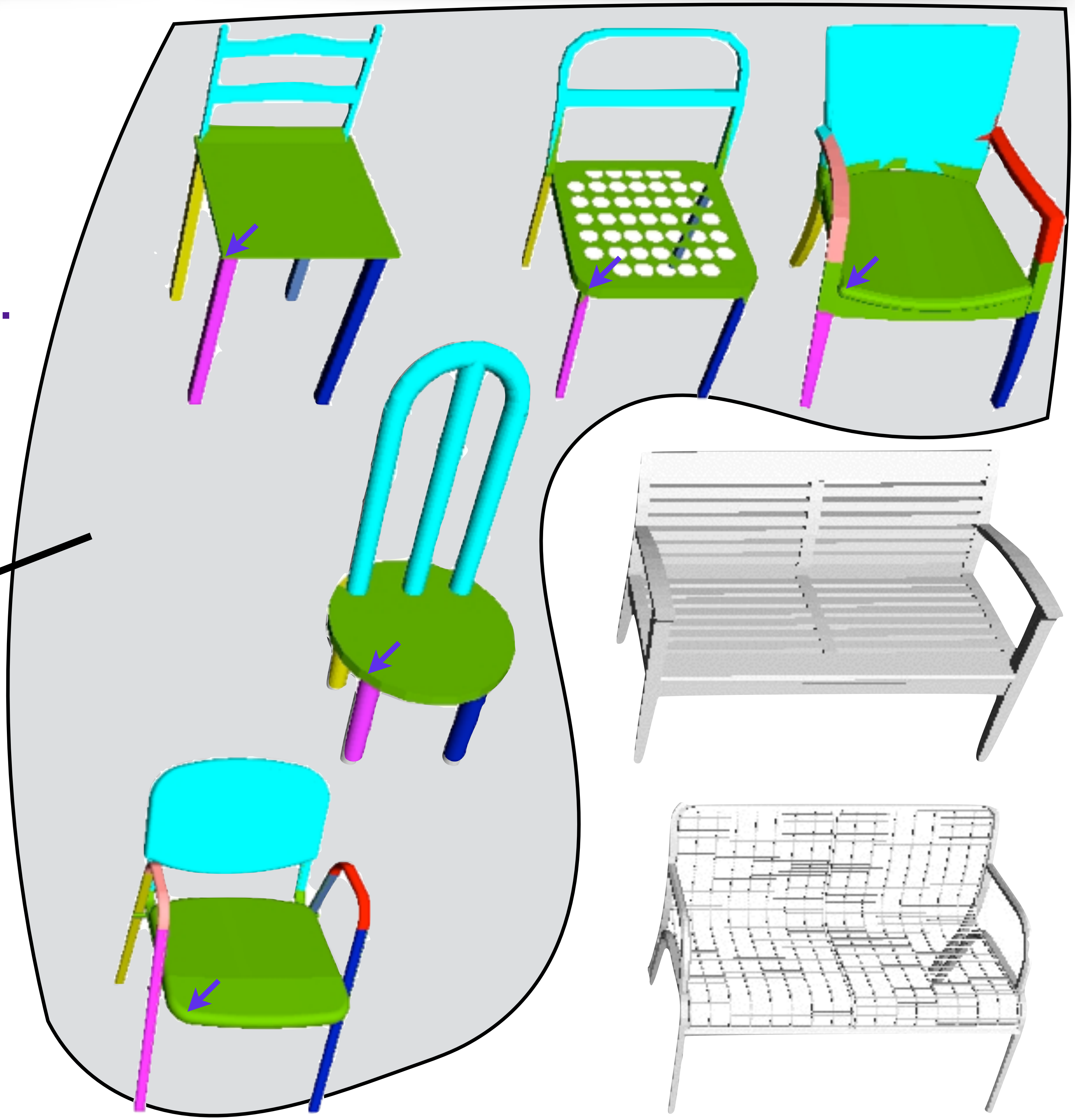
- Shape-template corrs.
- Update templates



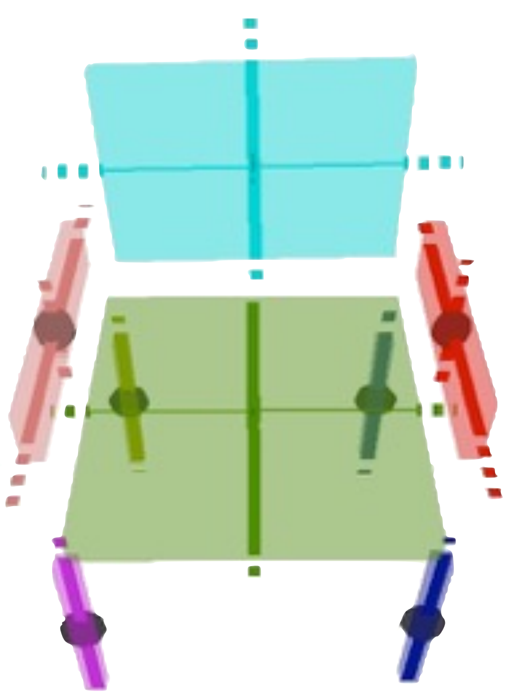
Deformable Template



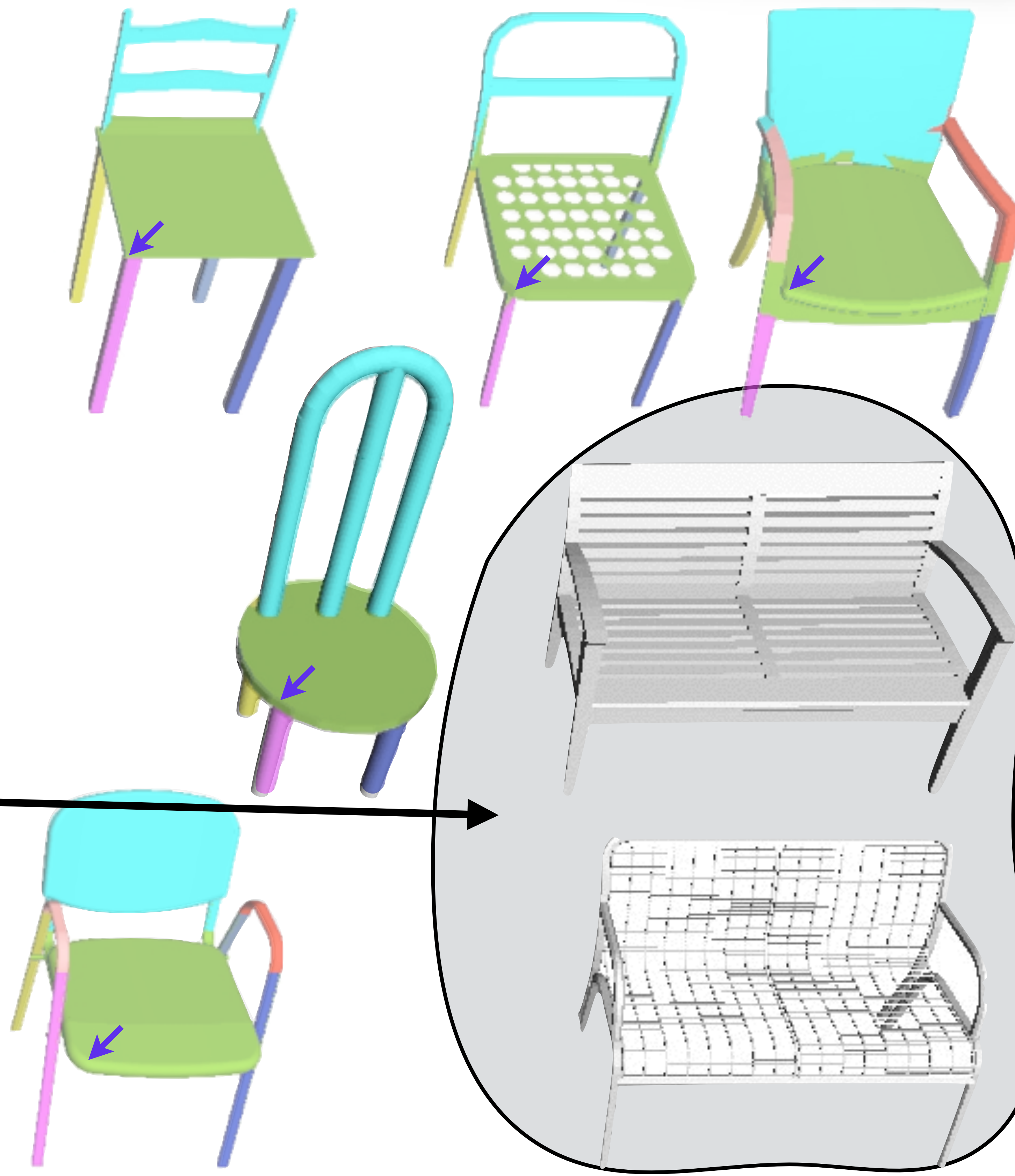
Learning Templates

Meta-algorithm

- Shape-shape corrs.
- Build templates
- ➡ **Shape-template corrs.**
- Update templates



Deformable Template



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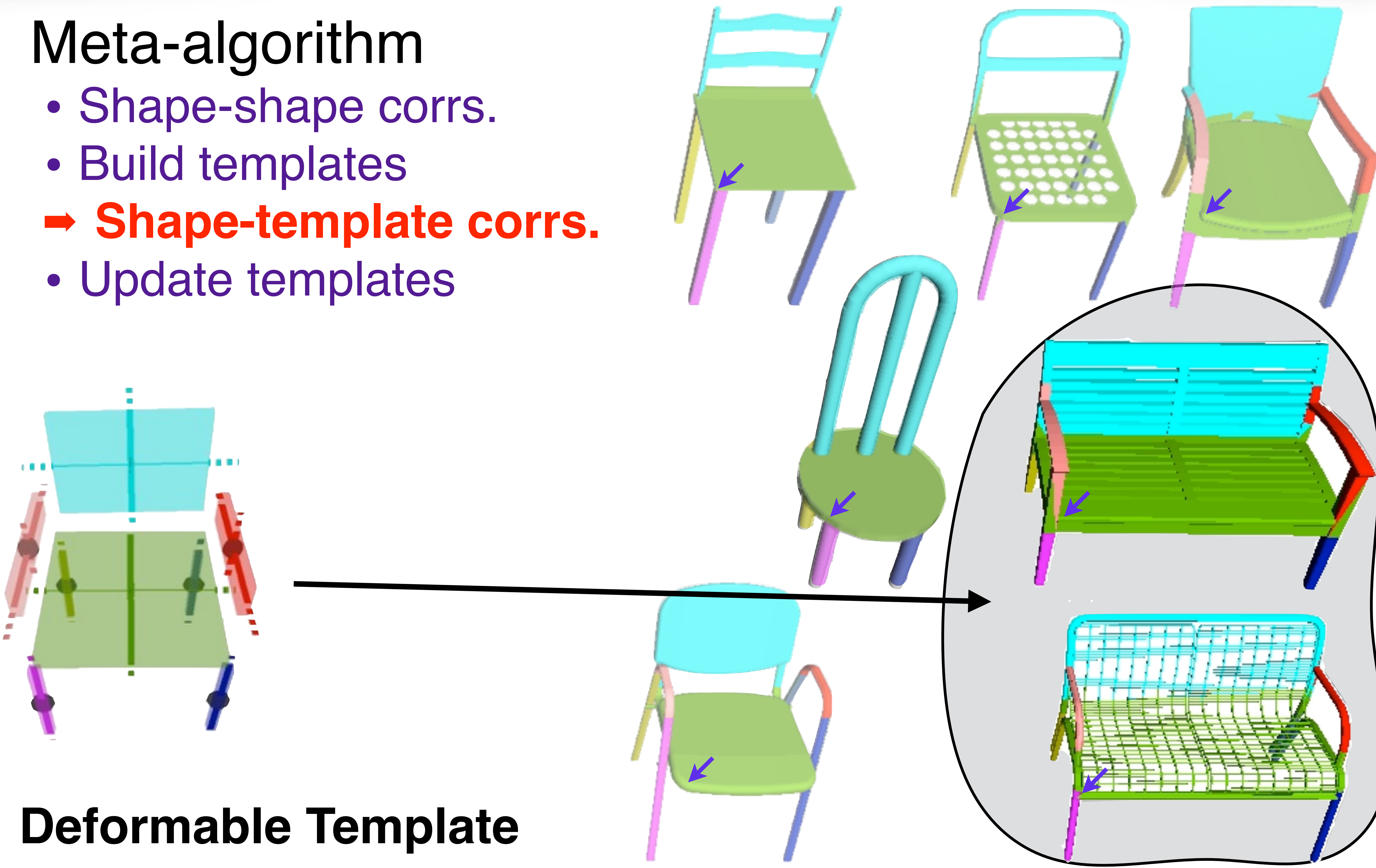


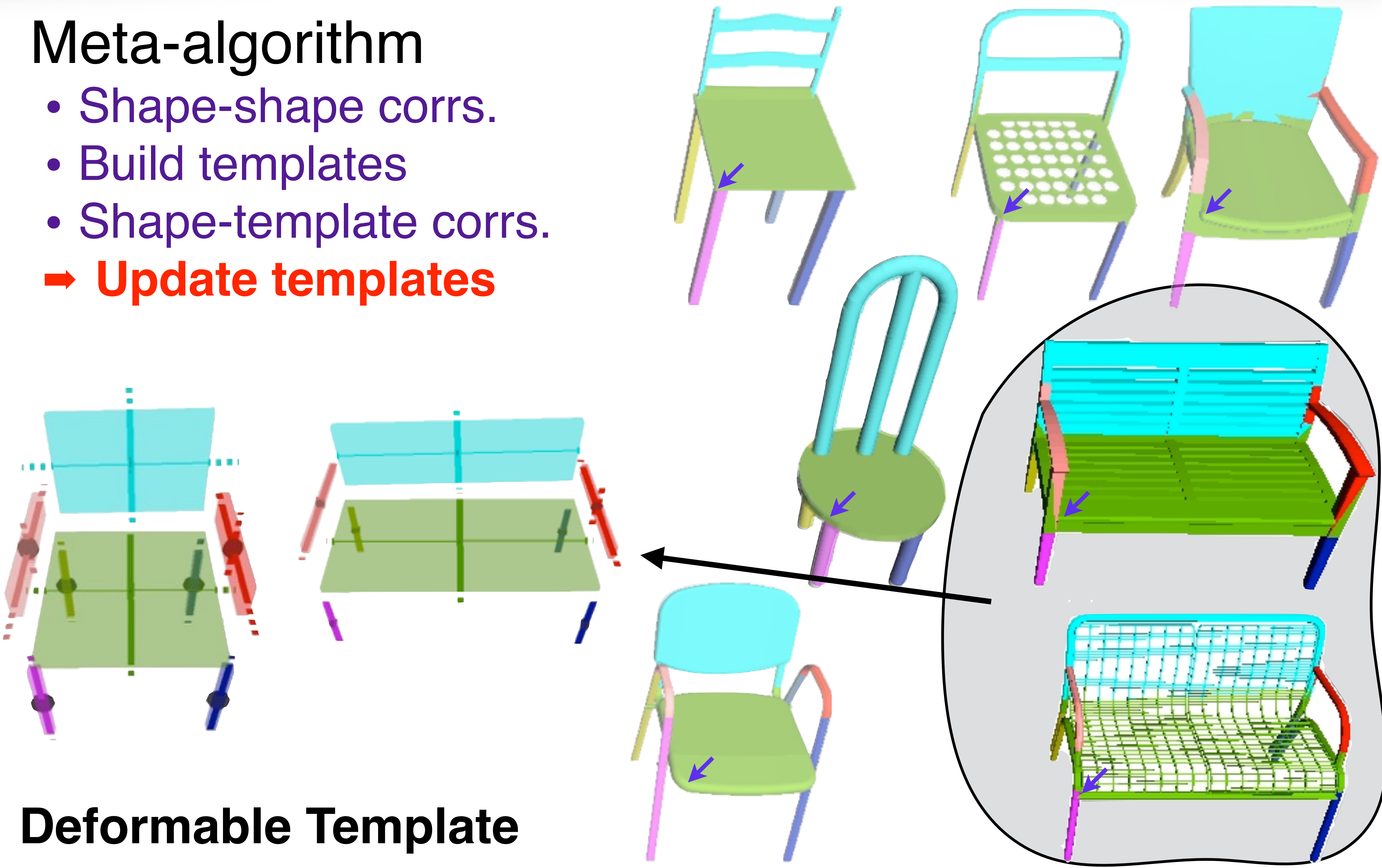
Deformable Template

Learning Templates

Meta-algorithm

- Shape-shape corrs.
- Build templates
- Shape-template corrs.

➡ **Update templates**

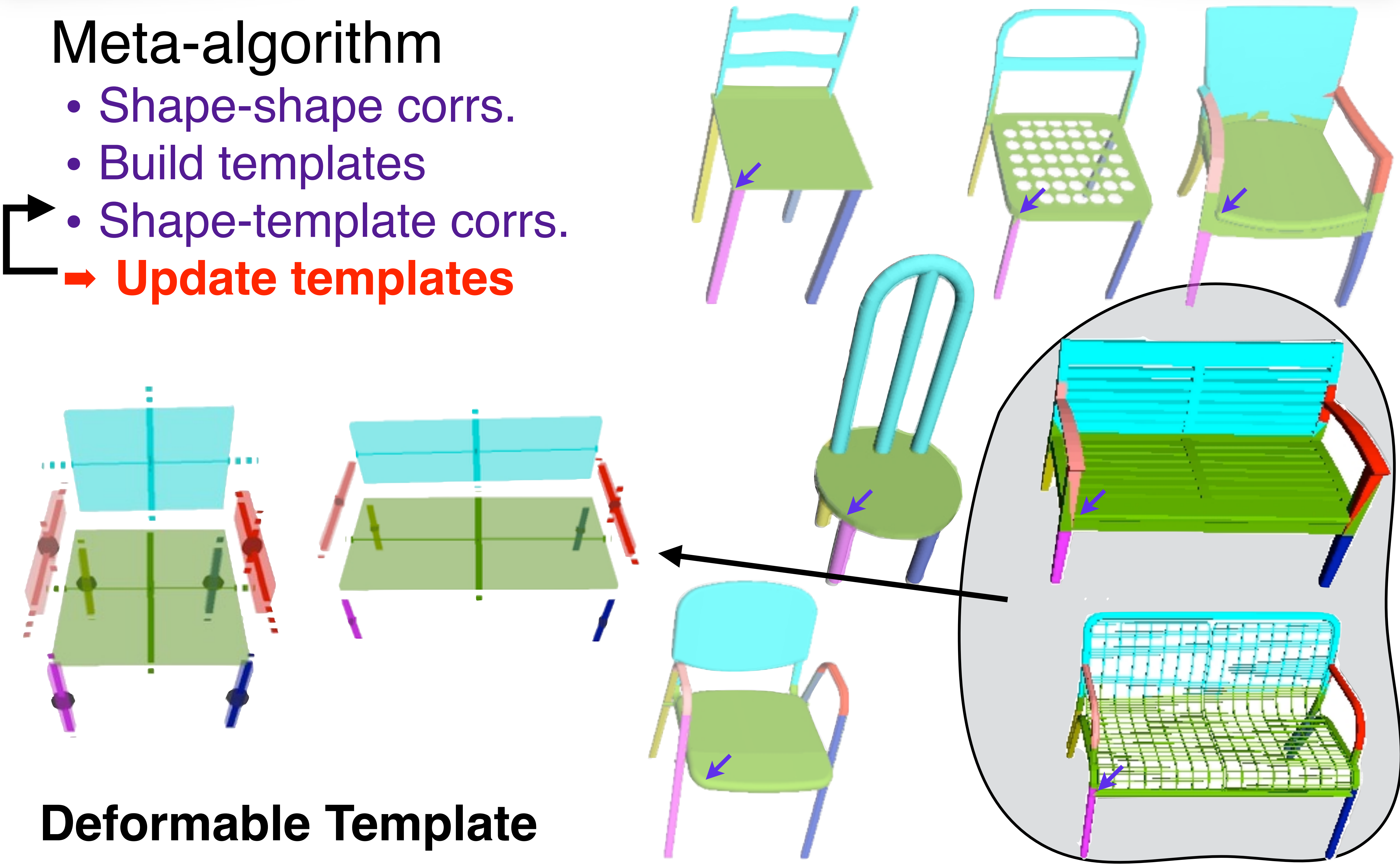


Deformable Template

Learning Templates

Meta-algorithm

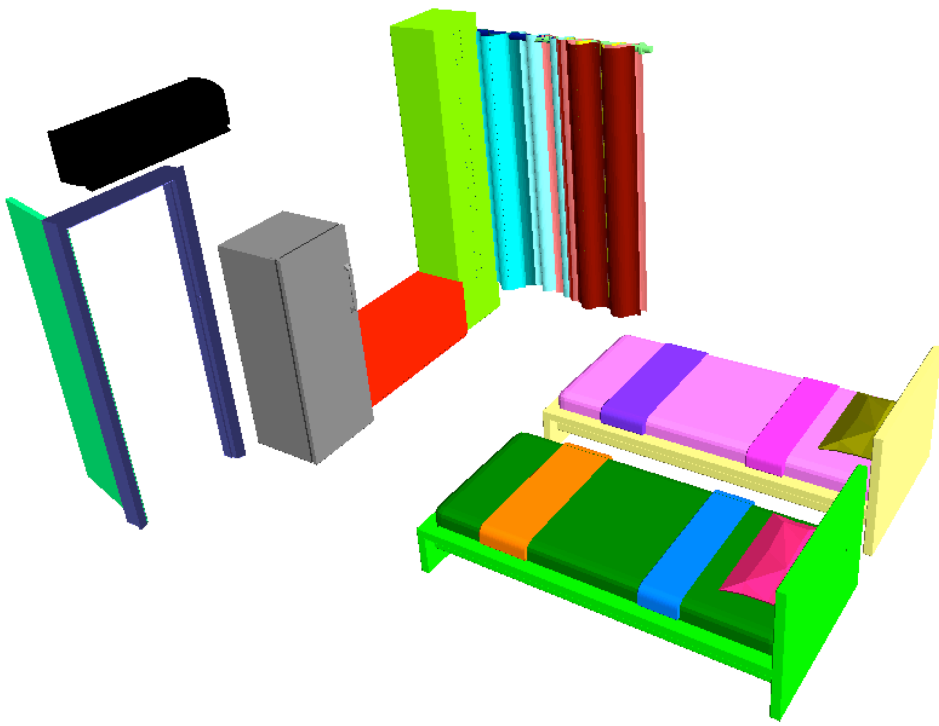
- Shape-shape corrs.
- Build templates
- Shape-template corrs.
- ➡ **Update templates**

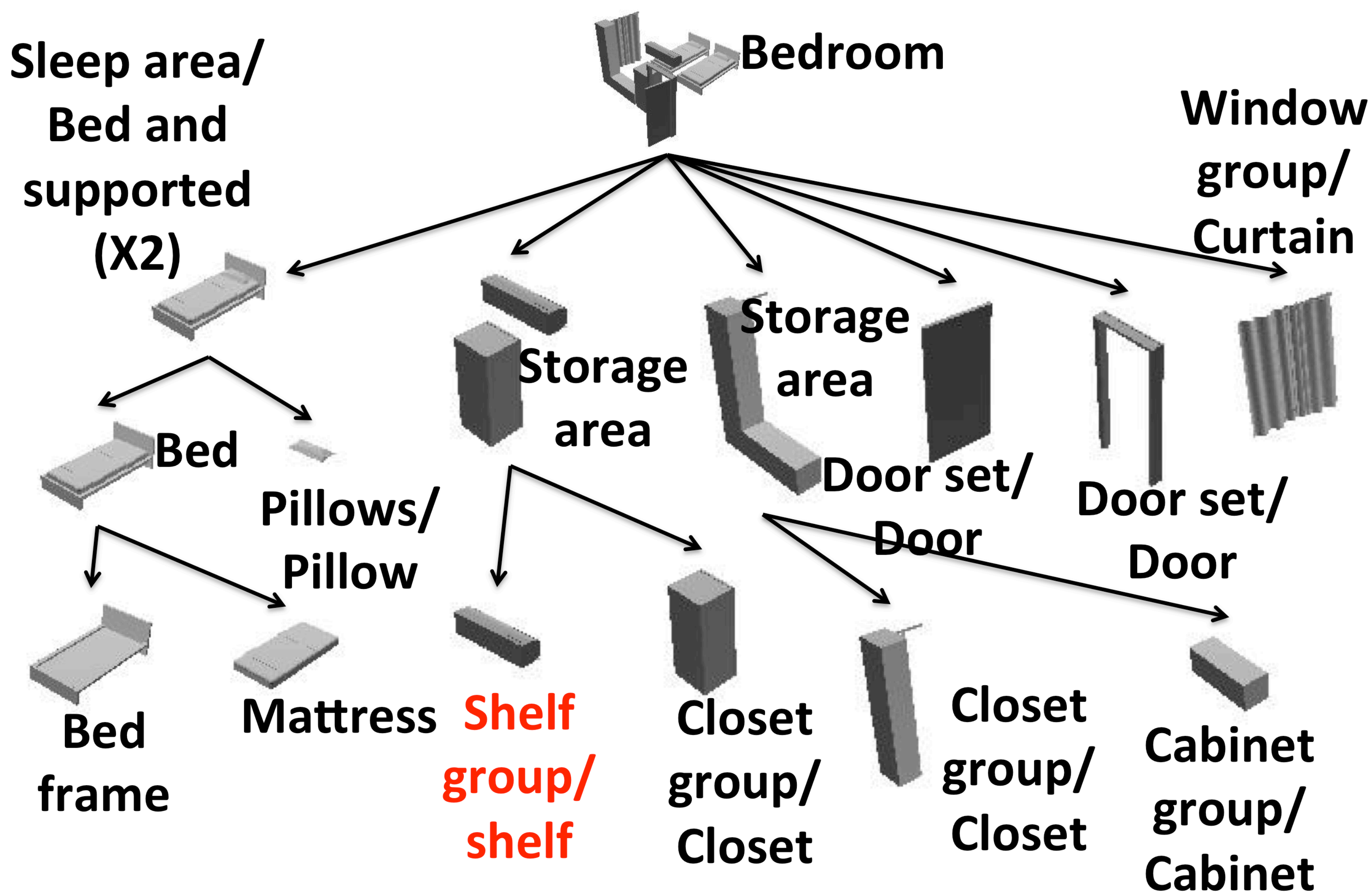


Deformable Template

Hierarchical Templates

Use hierarchical templates for scenes





Applications

Explore, Analyze, and Create Geometric Data

- Region-based exploration
- Scene completion
- 3D Modeling


3D Database Exploration: selecting(0), mode(2)


3D Database Exploration: selecting(0), mode(1)

Applications

Explore, Analyze, and Create Geometric Data

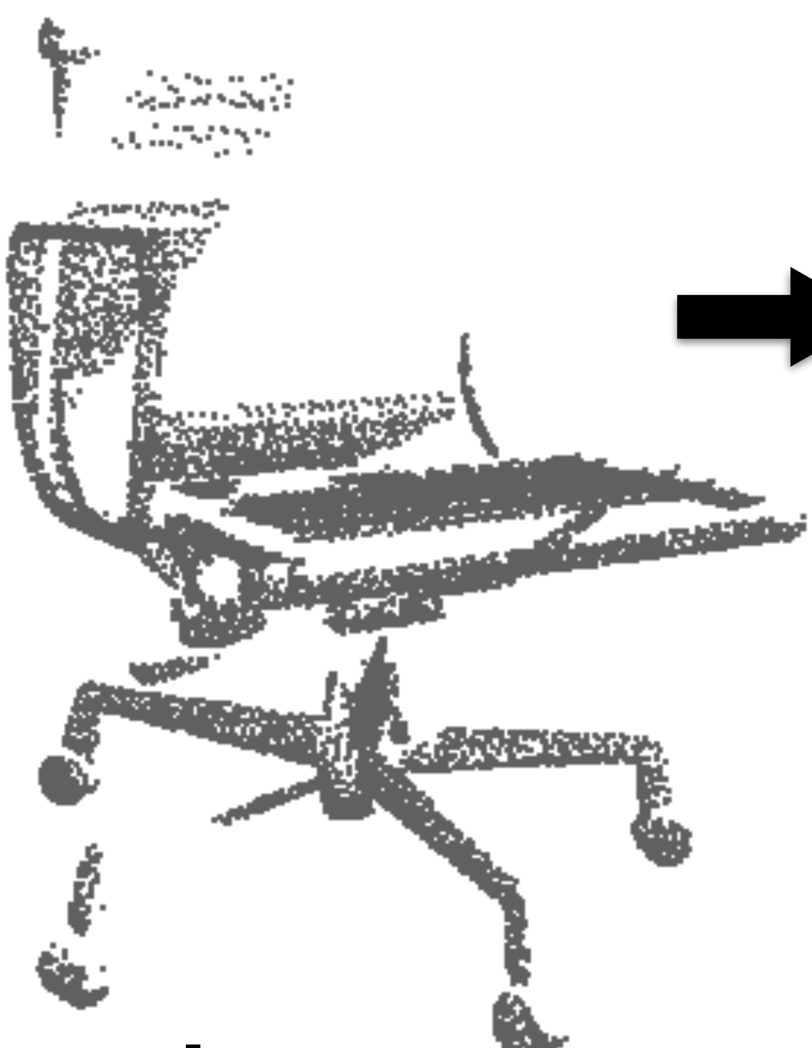
- Region-based exploration
- ➡ **Scene completion**
- 3D Modeling

Input

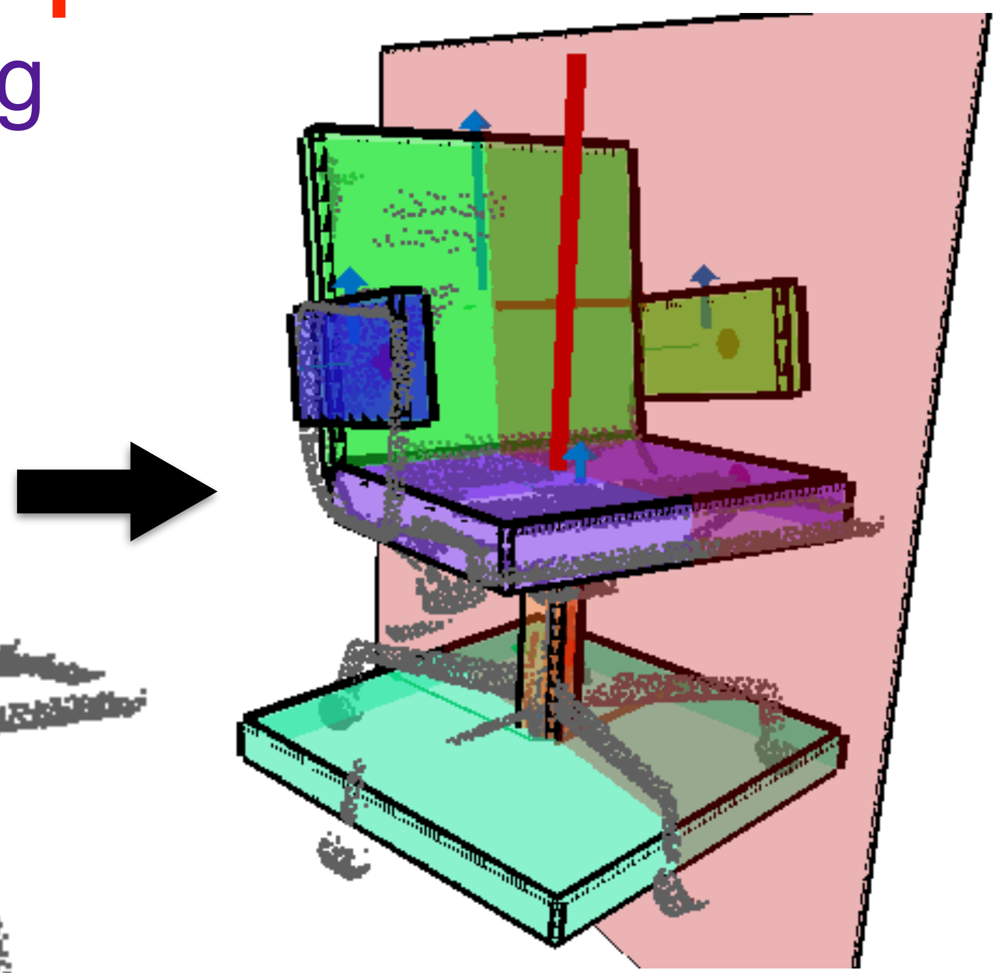
Applications

Explore, Analyze, and Create Geometric Data

- Region-based exploration
- ➡ **Scene completion**
- 3D Modeling



Input

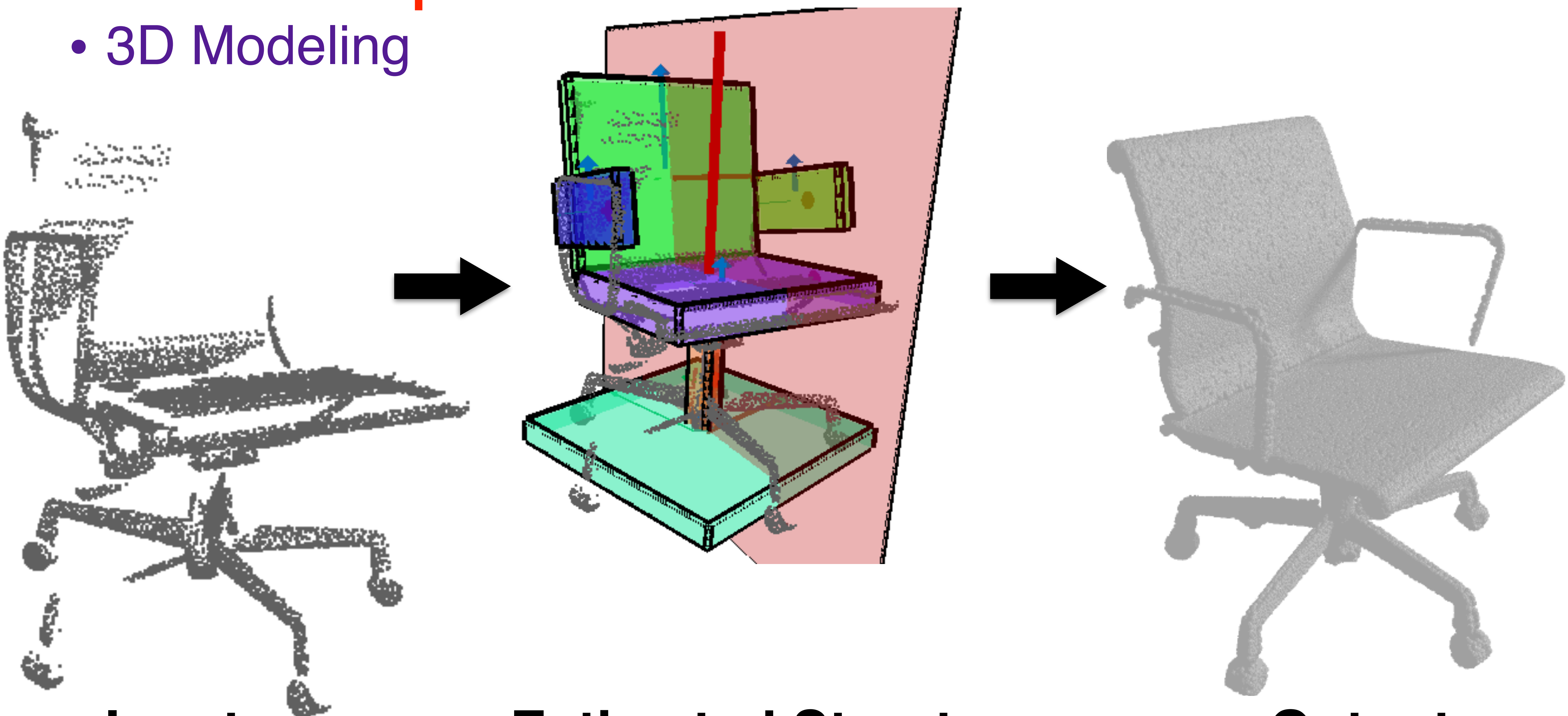


Estimated Structure

Applications

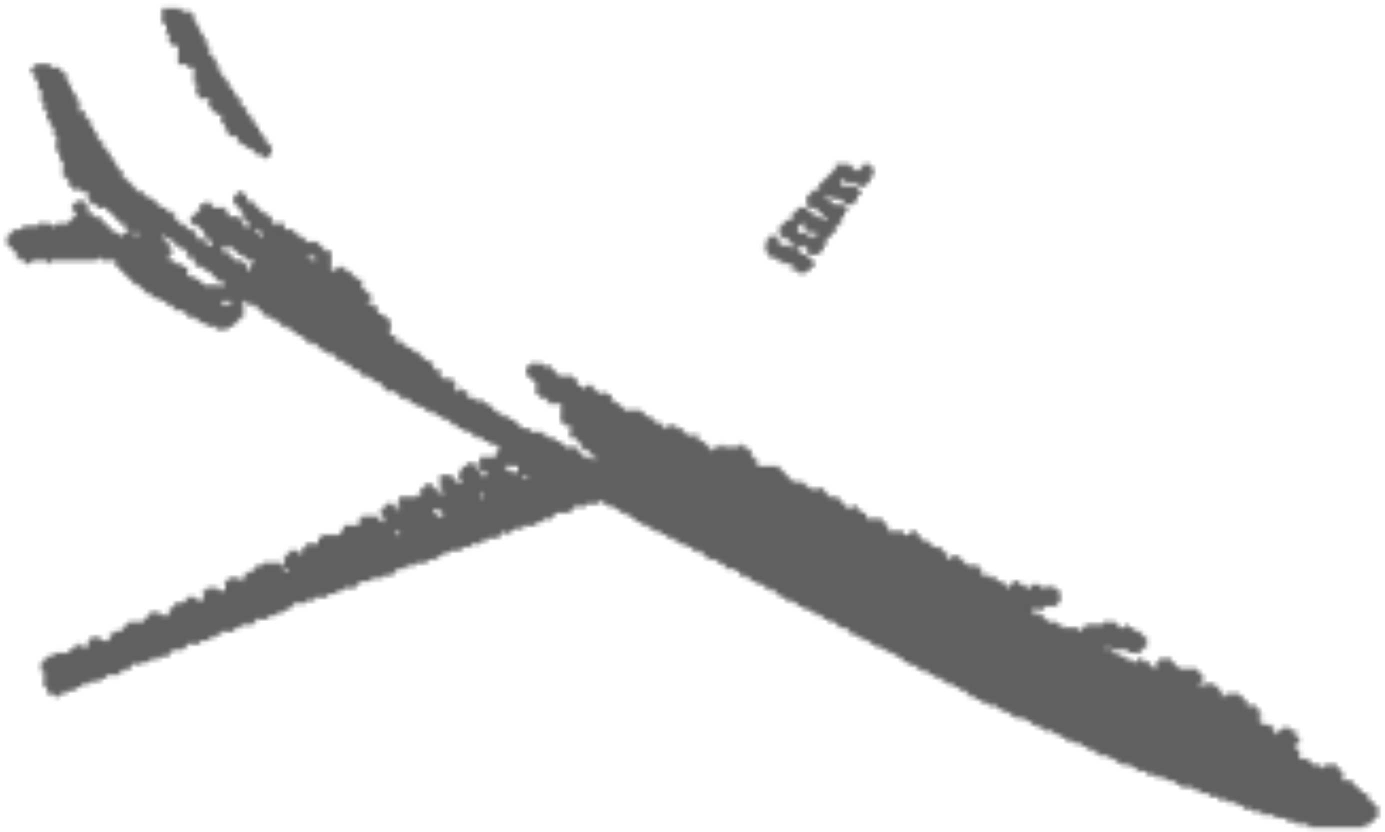
Explore, Analyze, and Create Geometric Data

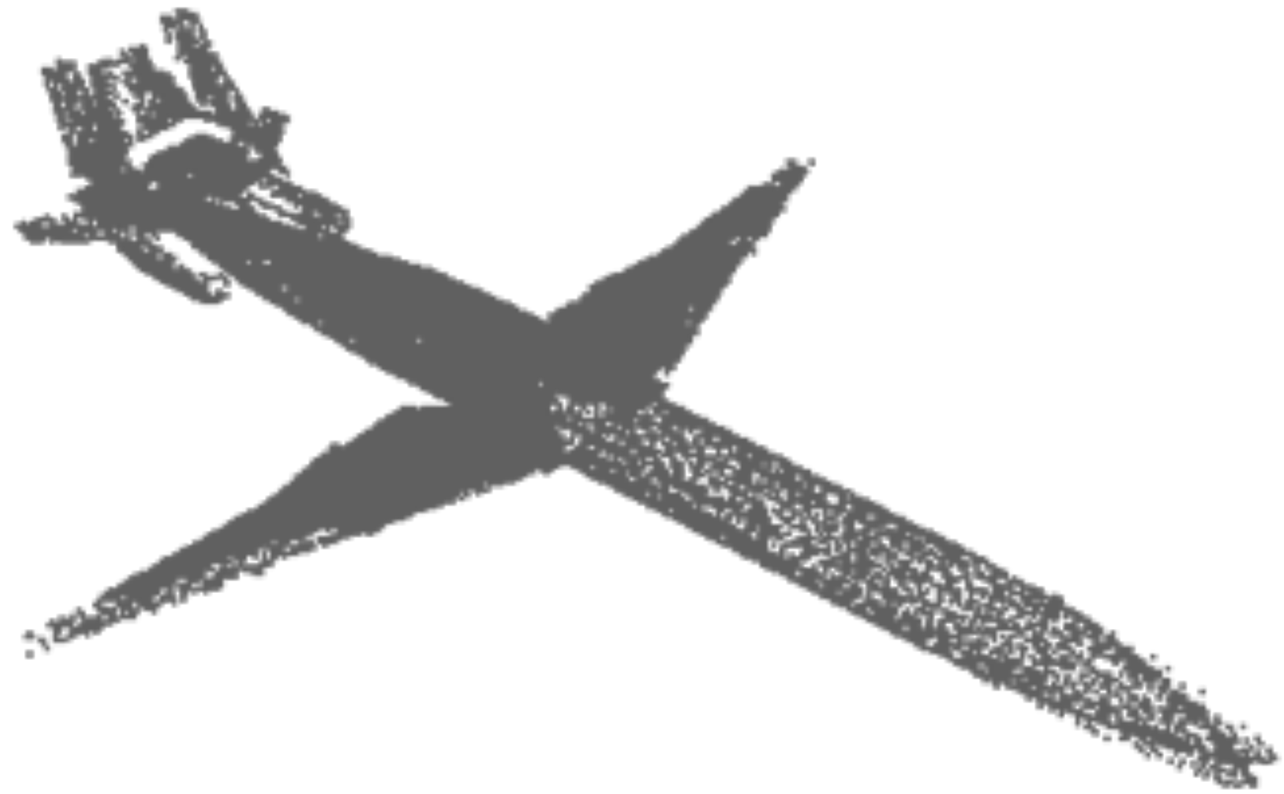
- Region-based exploration
- ➡ **Scene completion**
- 3D Modeling



Input **Estimated Structure** **Output**

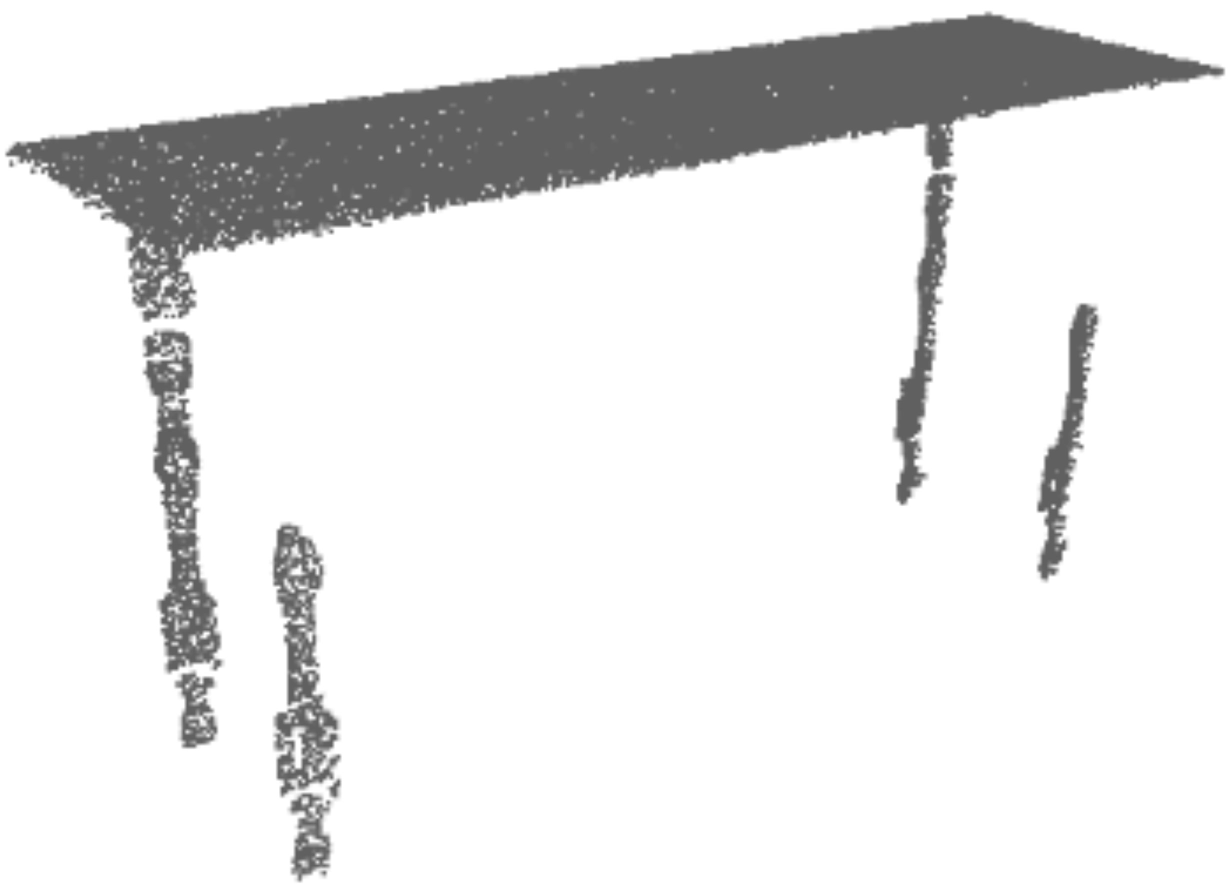
Applications



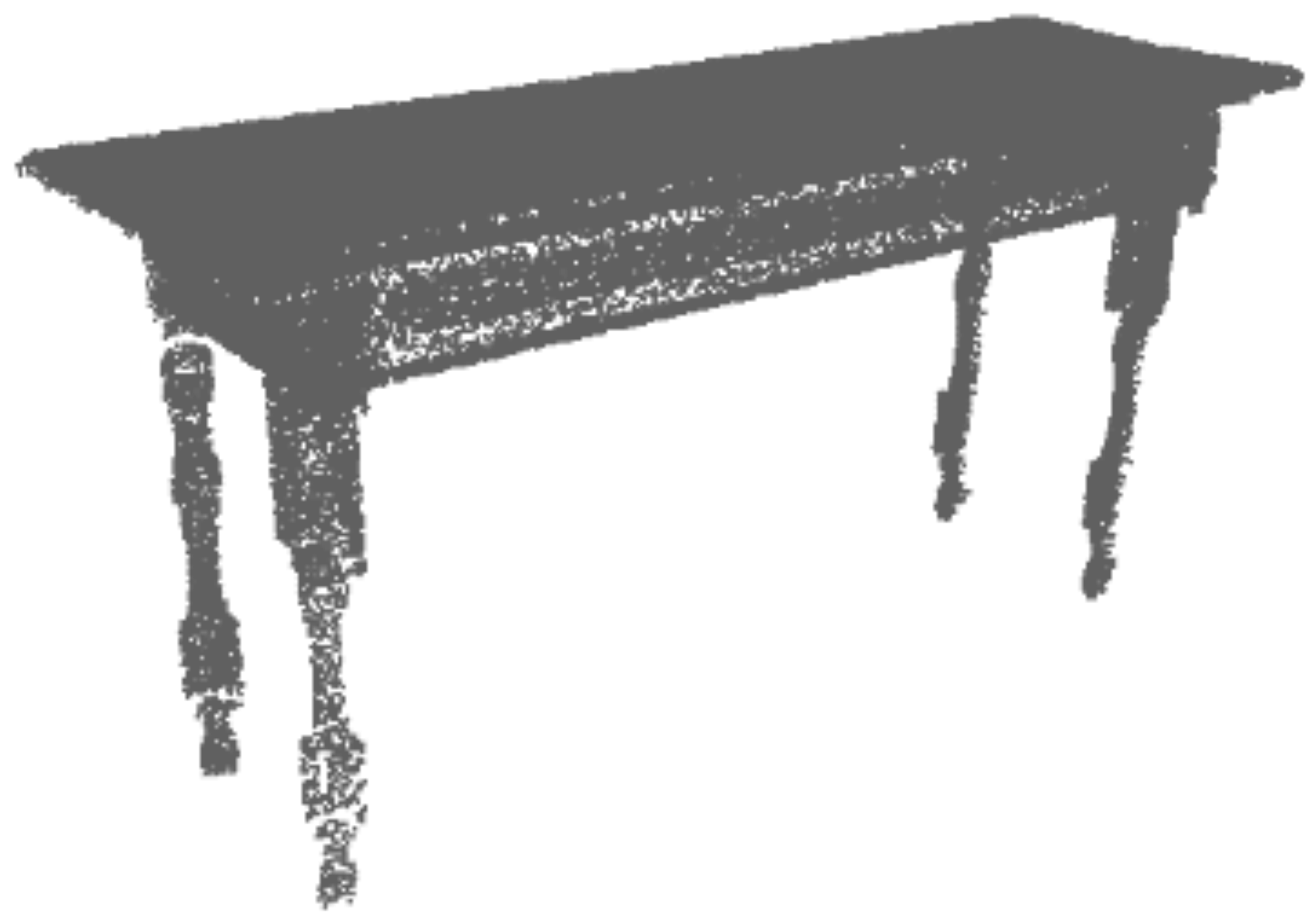


Input **Output**

Applications



Input



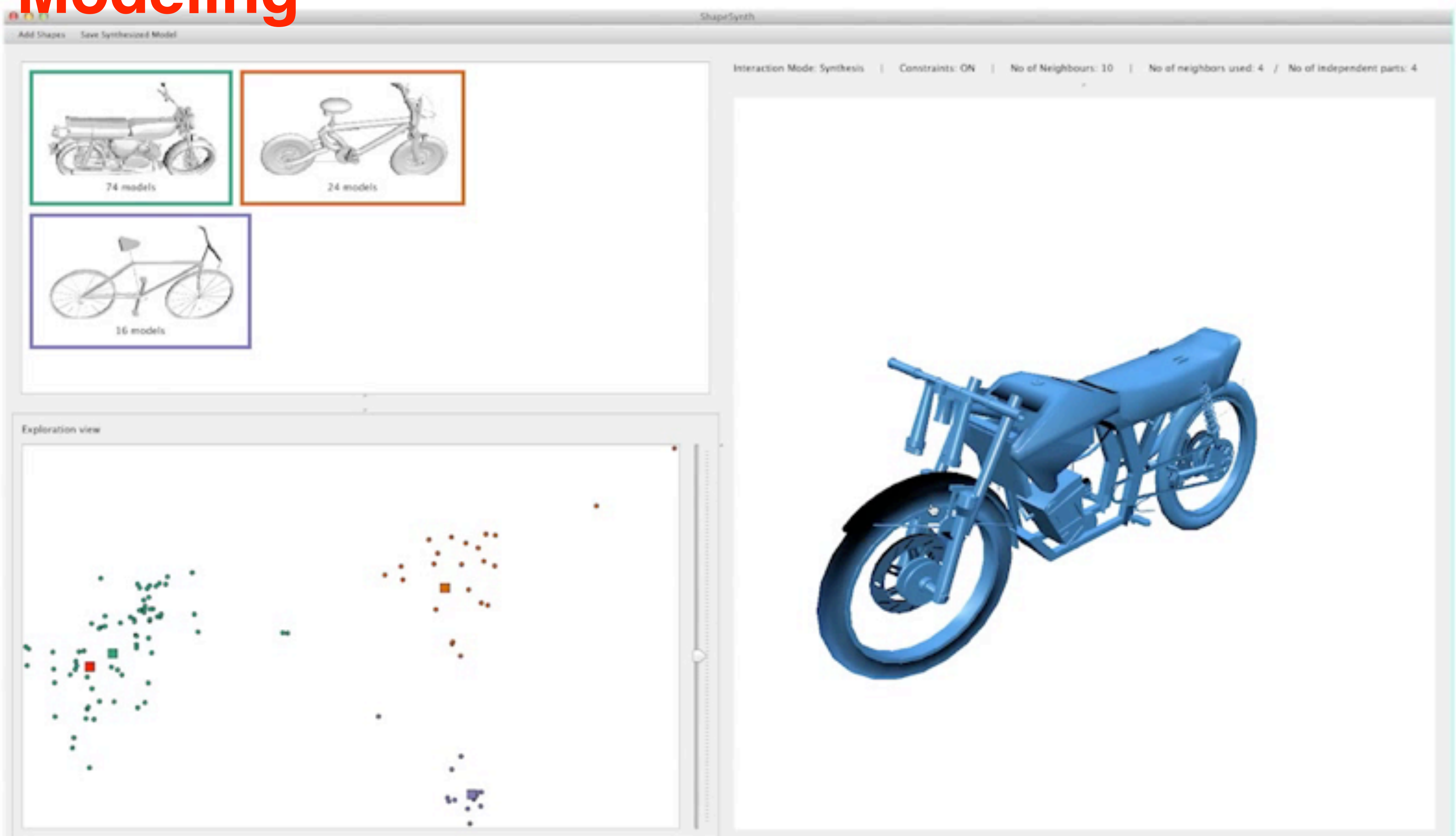
Output

Applications

Explore, Analyze, and Create Geometric Data

- Region-based exploration
- Scene completion

➡ **3D Modeling**



Summary

Large collections of 3D models are available (and more are coming!)

- 3D modeling repositories
- 3D printing datasets
- Kinect scans
- Laser scans of cities,
- Online shopping catalogues
- Medical imaging data
- Protein databases
- …

Summary

Large collections of 3D models are available (and more are coming!)

Discovering similarities is essential to find structure

- Need to handle: diversity, scale, and ambiguity in data

Summary

Large collections of 3D models are available
(and more are coming!)

Discovering similarities is essential to find structure

Finding structure can enable novel techniques for:

- Exploring and organizing the data
- Scene understanding
- Modeling

Future Work

Beyond geometry

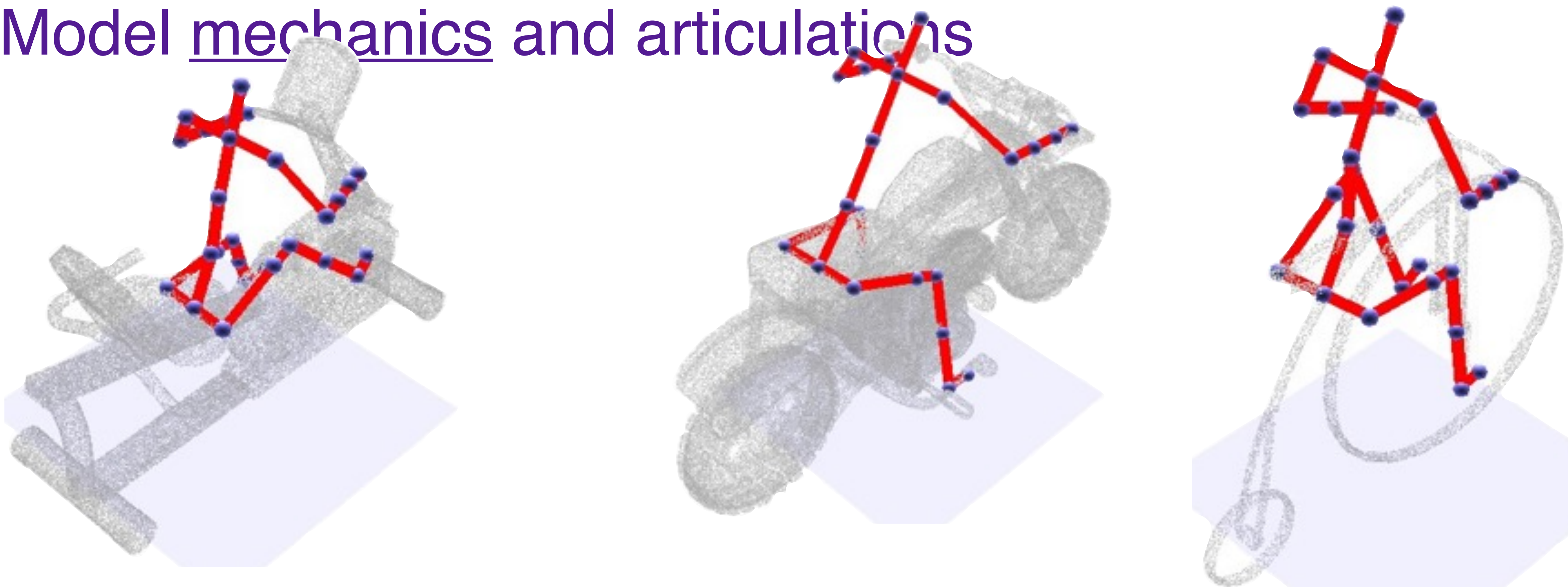
- Understand function
- Obtain human supervision to capture what is semantically salient
- Consider physical materials that make up objects
- Model mechanics and articulations

Future Work

Beyond geometry

➡ **Understand function**

- Obtain human supervision to capture what is semantically salient
- Consider physical materials that make up objects
- Model mechanics and articulations



Predict human-object interaction pose for shape analysis

Collaborators

R. Angst
Q. Huang
S. DiVerdi
L. Guibas
Y. Lipman
G. Peyre
S. Sra
Y. Zheng

M. Averkiou
S. Chaudhuri
T. Funkhouser
W. Li
N. Mitra
J. Solomon
M. Sung

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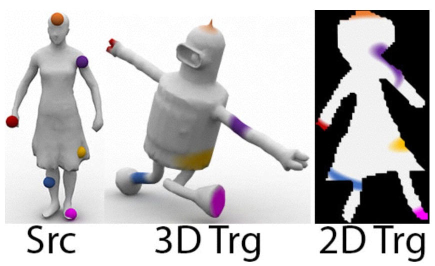

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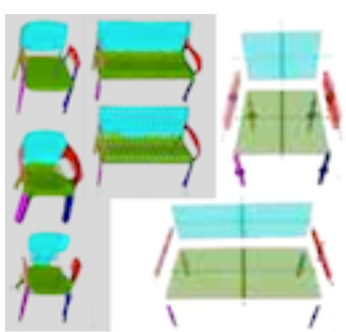
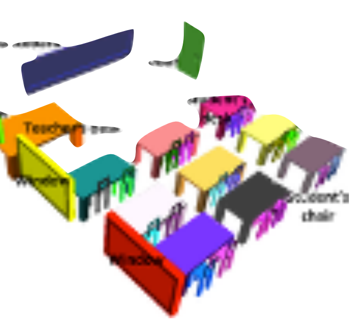
J. Solomon et al. SIGGRAPH 2016



Learning Part-based Templates from Large Collections of 3D Shapes
V. Kim et al., SIGGRAPH 2013



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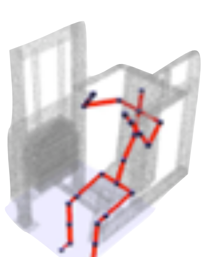

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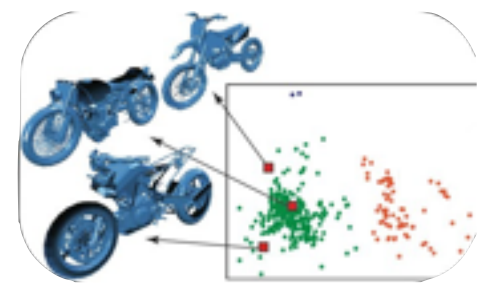

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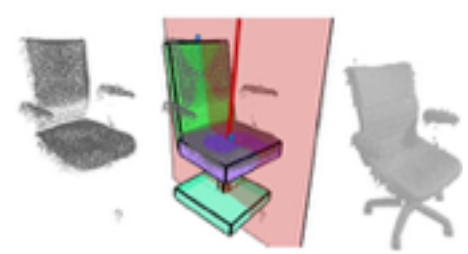

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