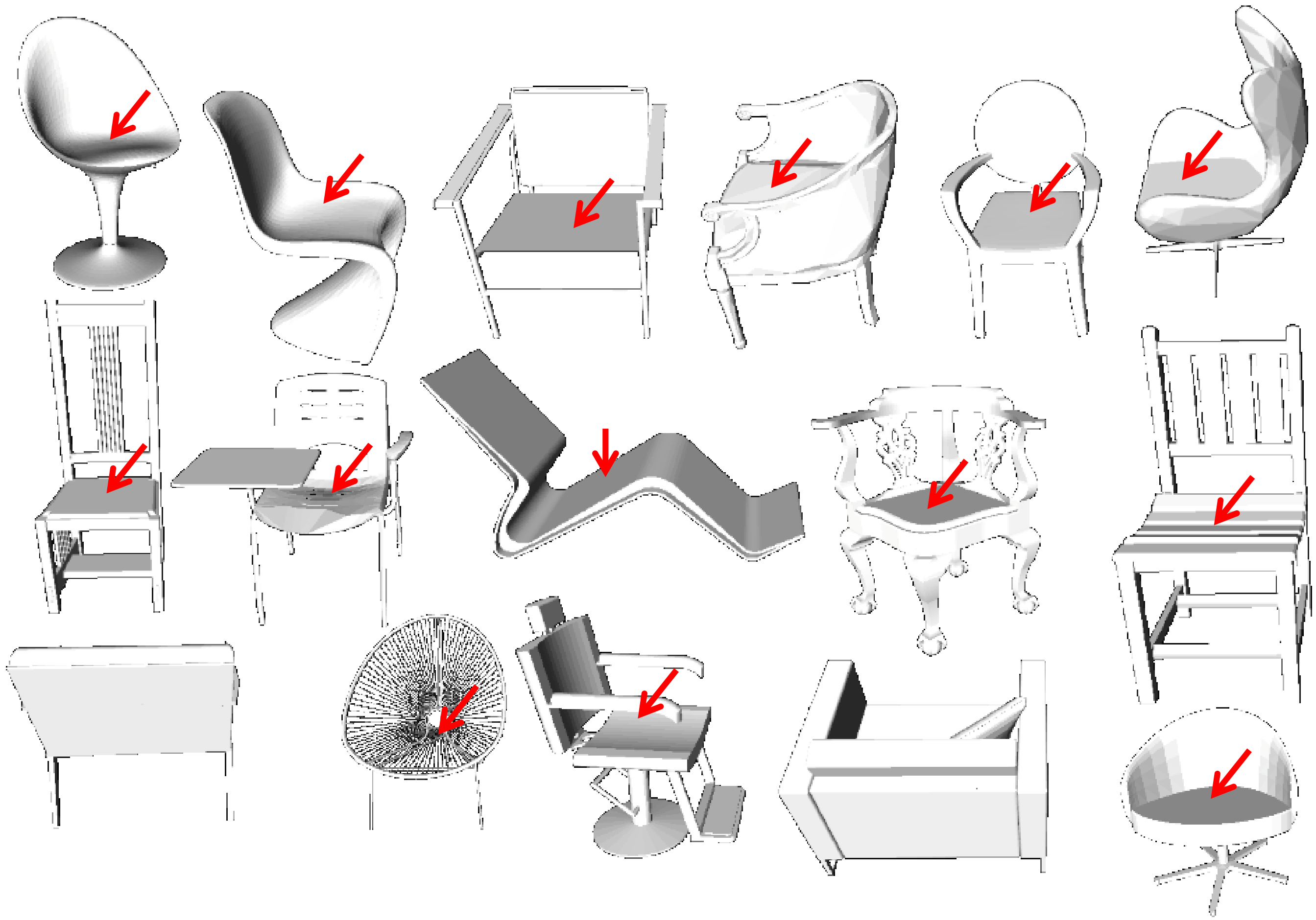
Finding Surface Correspondences With Shape Analysis

Thomas Funkhouser
COS 526, Fall 2016

Motivation

Finding surface correspondences is important for understanding relationships in 3D data



Motivation

Applications:

- Similarity measurement
- Collection exploration
- Surface interpolation
- Annotation transfer
- Surface registration
- Symmetry detection
- Saliency estimation
- Object recognition
- Visualization
- etc.

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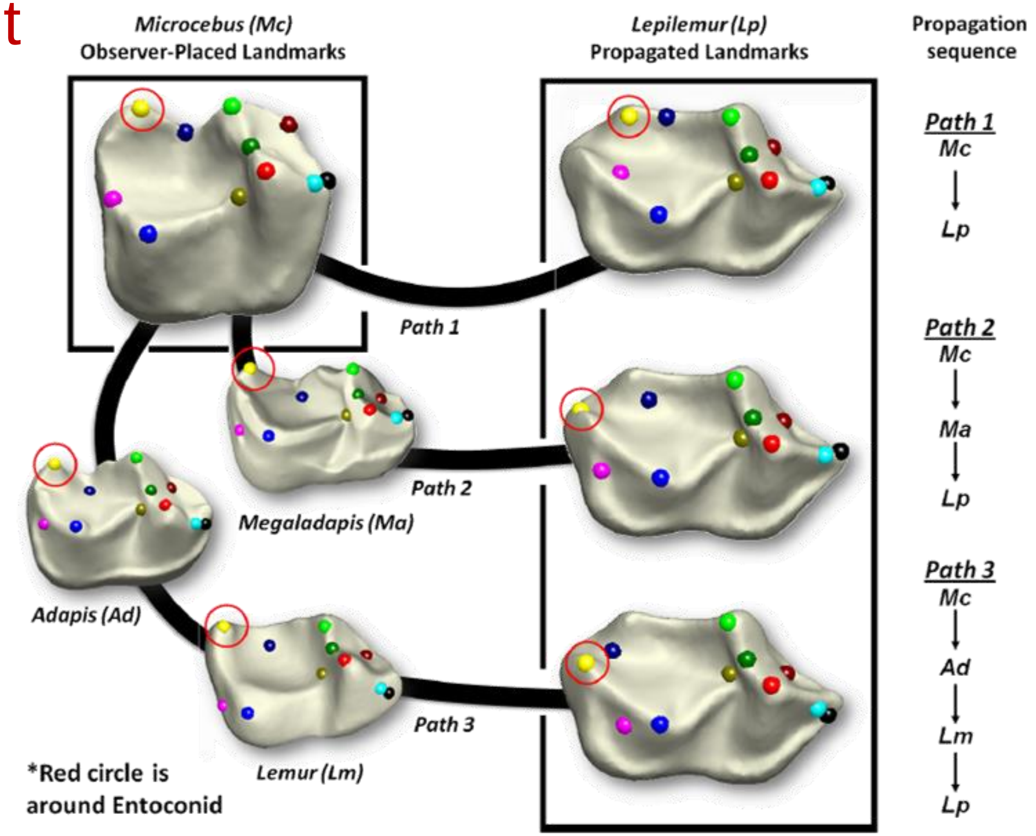
- ◦ etc.



[Boyer, Lipman, et al., 2011]

Motivation

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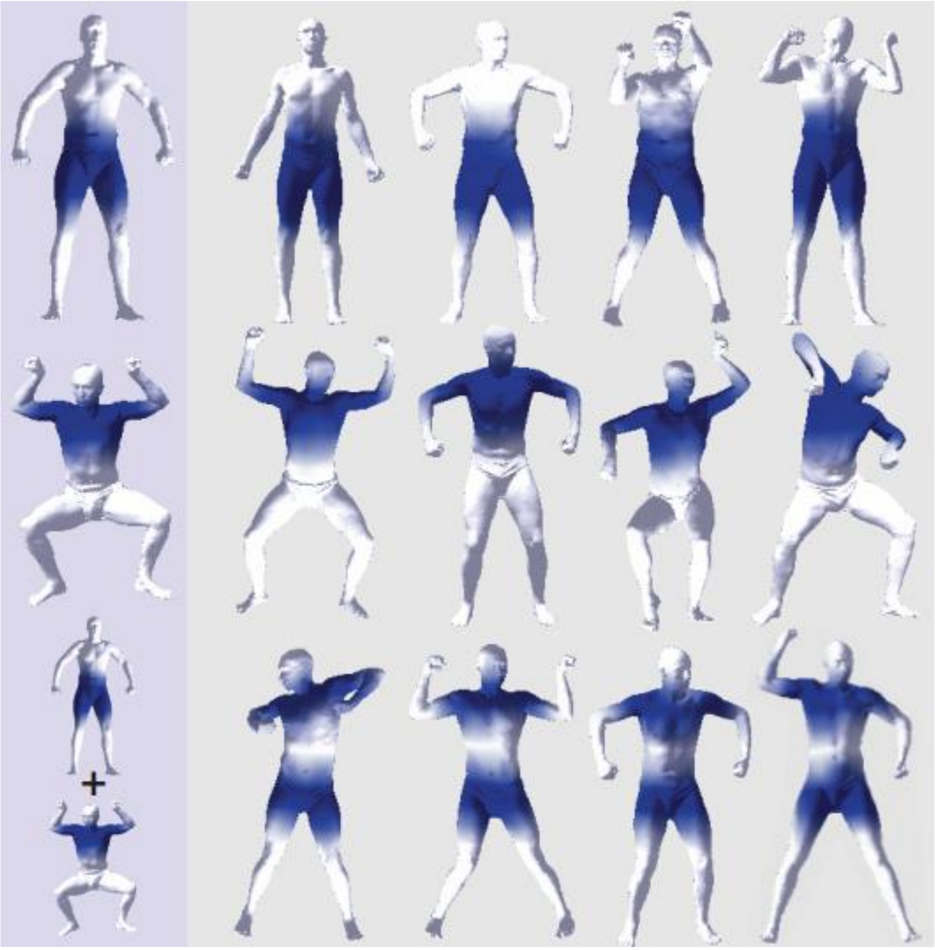
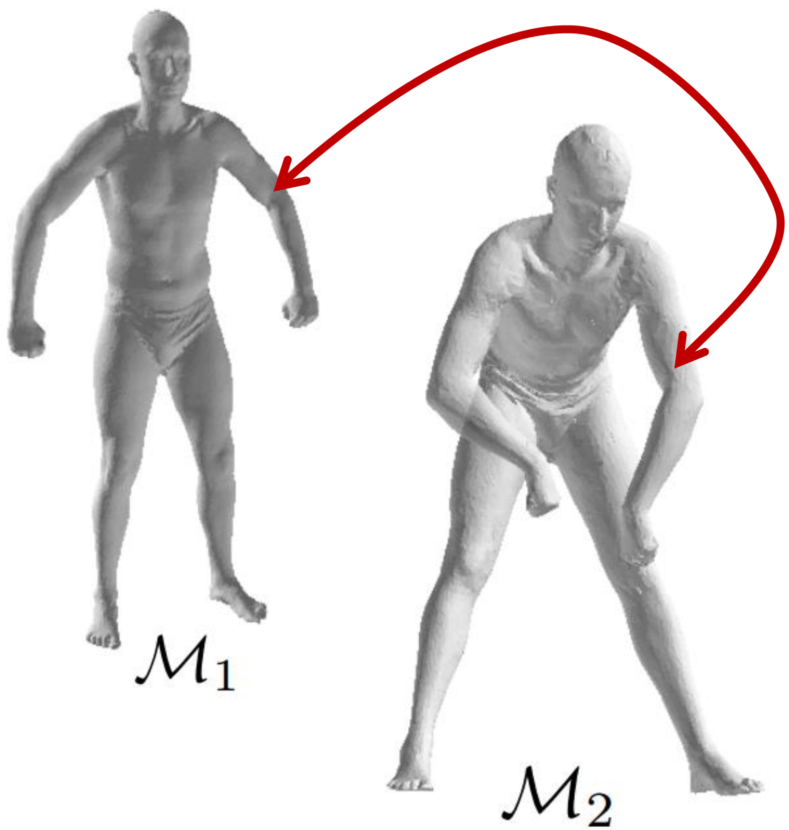


[Kim et al., 2012]

Goal

Develop algorithms to find point correspondences

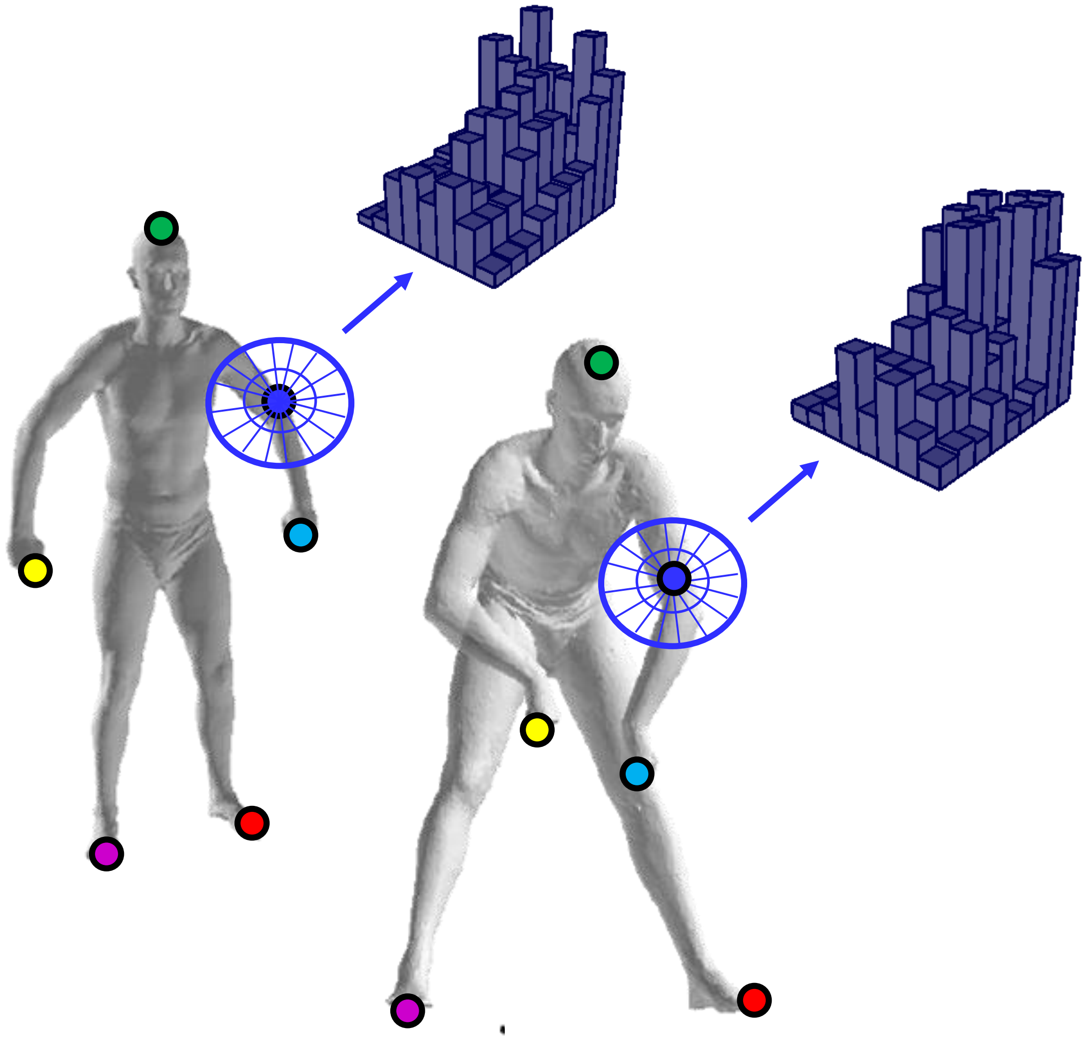
- Align “equivalent” features (semantic, functional, etc.)
- Consistent
- Robust
- Automatic
- Efficient



Previous Work

Classical methods:

- ➢ Local features
- ◦ Global maps



[Kazhdan et al., 2004]

Previous Work

Classical methods:

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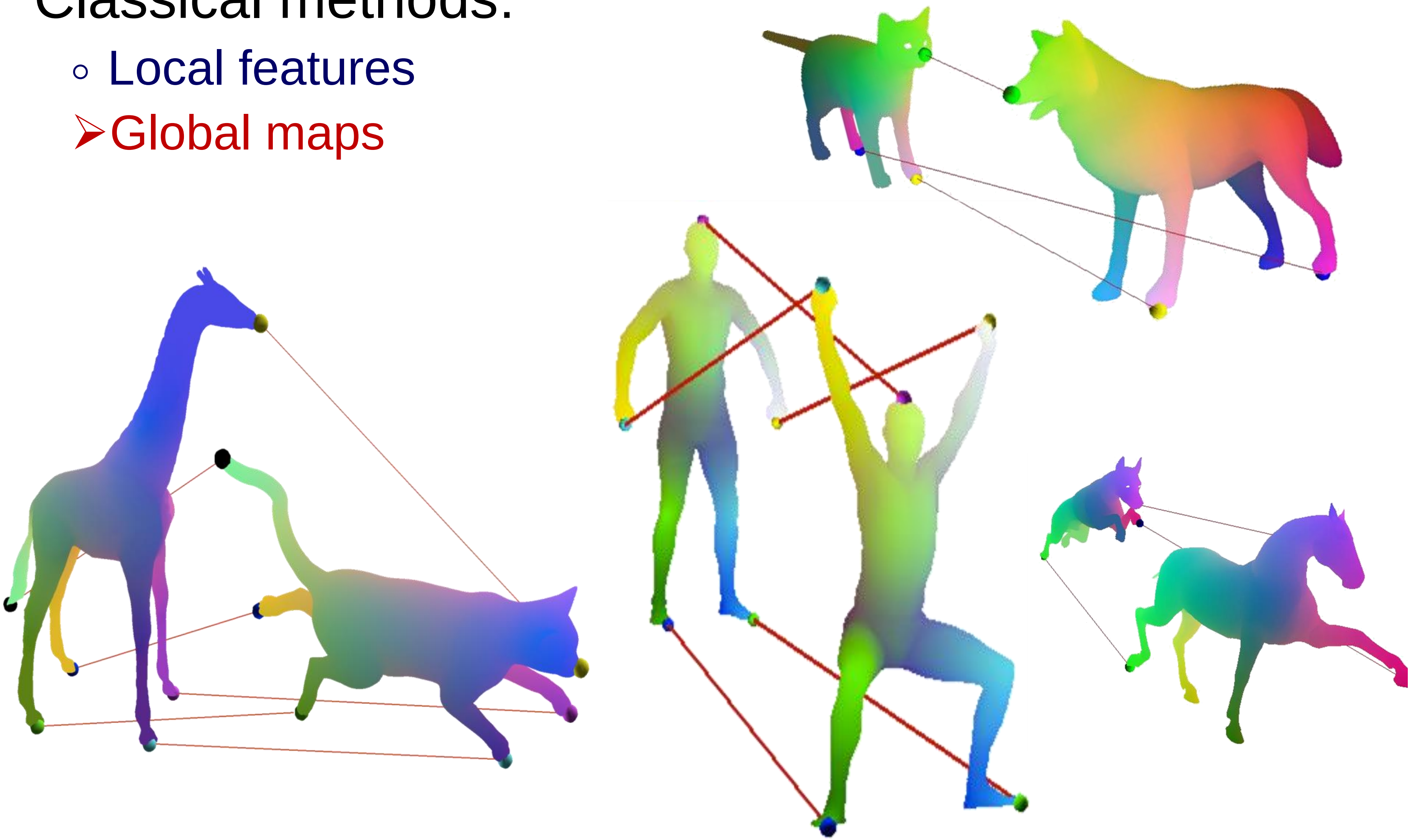
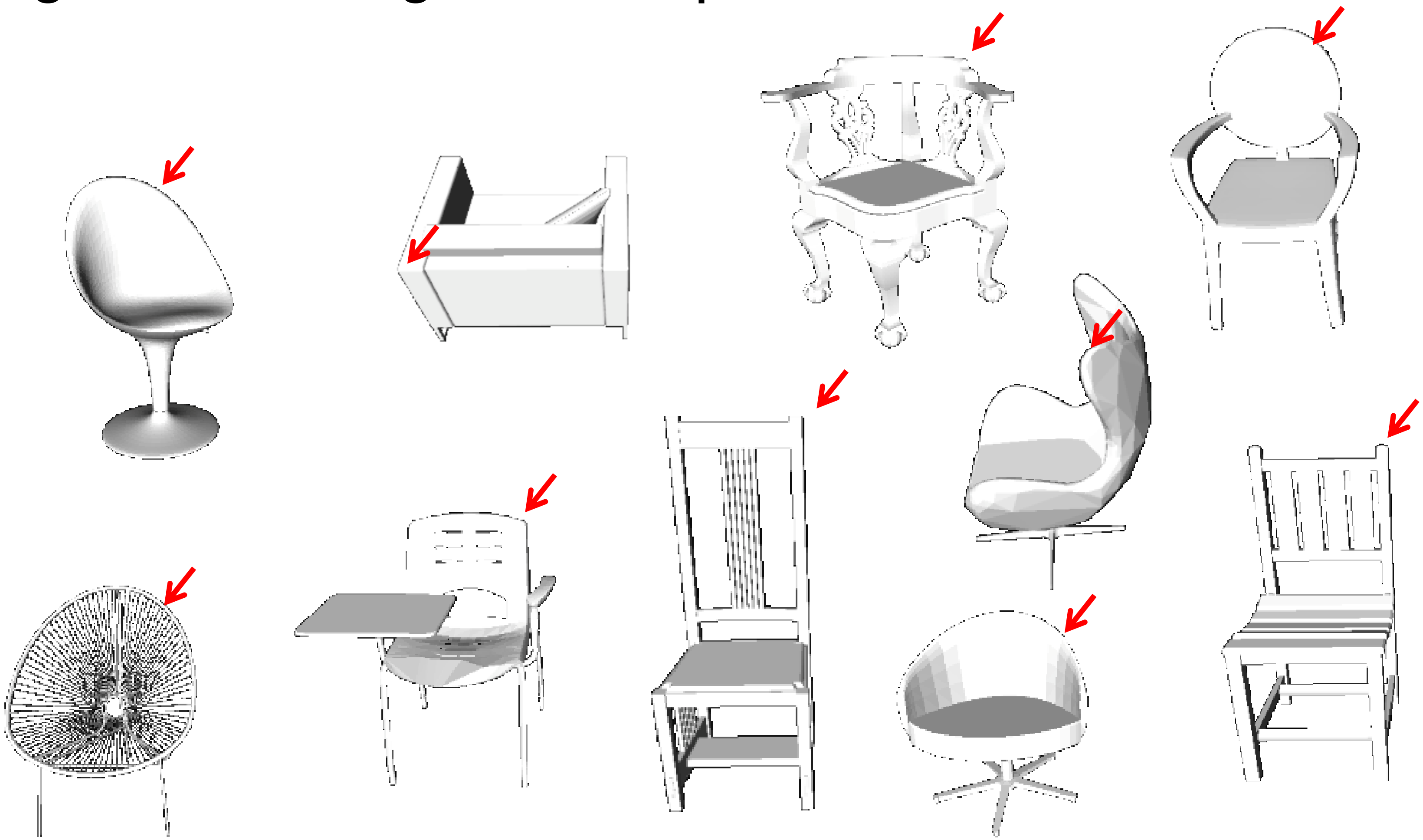
- ➢ Global maps



[Kim et al., 2011]

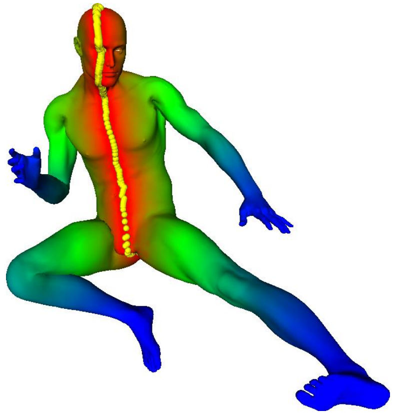
Challenge

Classical methods don’t work well for shapes with large local and global shape differences

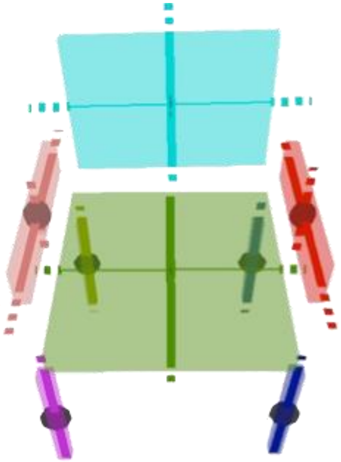


Hypothesis

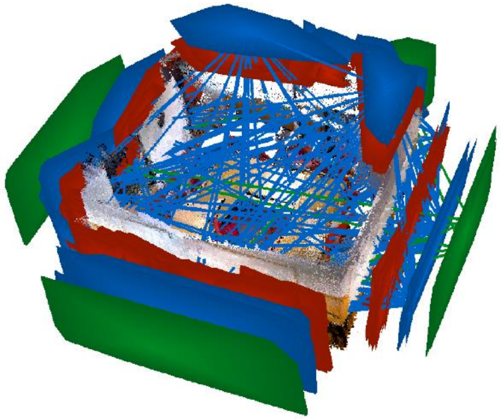
Discovering latent structure can be helpful for finding surface correspondences



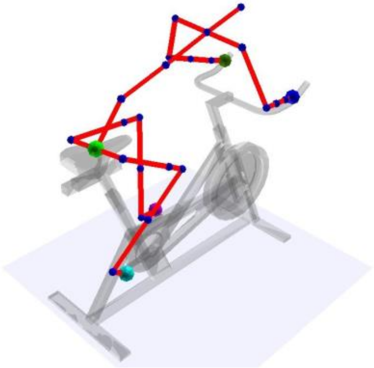
Symmetries



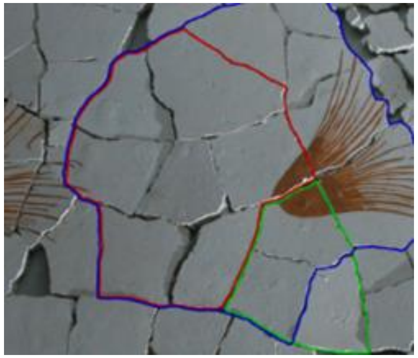
Parts



Constraints



Affordances



Assemblies

Outline of Talk

Introduction

Latent structures

- Symmetries
- Parts
- Affordances
- Constraints
- Assemblies

Conclusion

Outline of Talk

Introduction

Latent structures

- Symmetries
  - Parts
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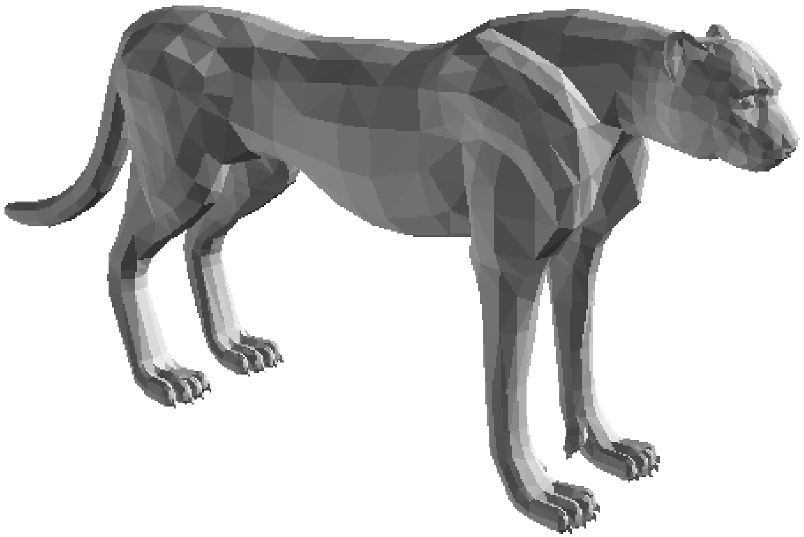
Conclusion

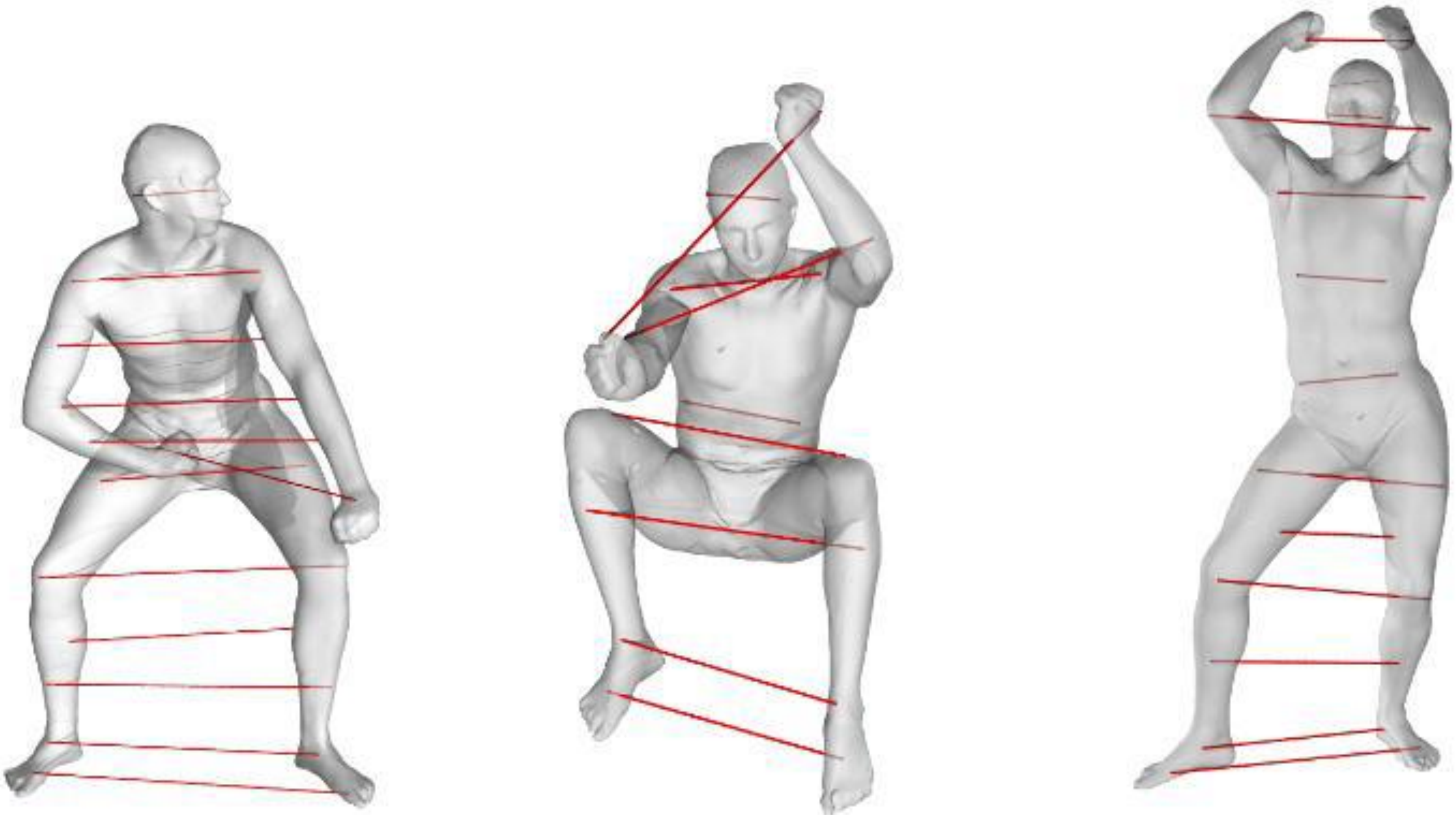
Symmetry-Aware Correspondences

Observation 1: symmetry is ubiquitous in natural shapes



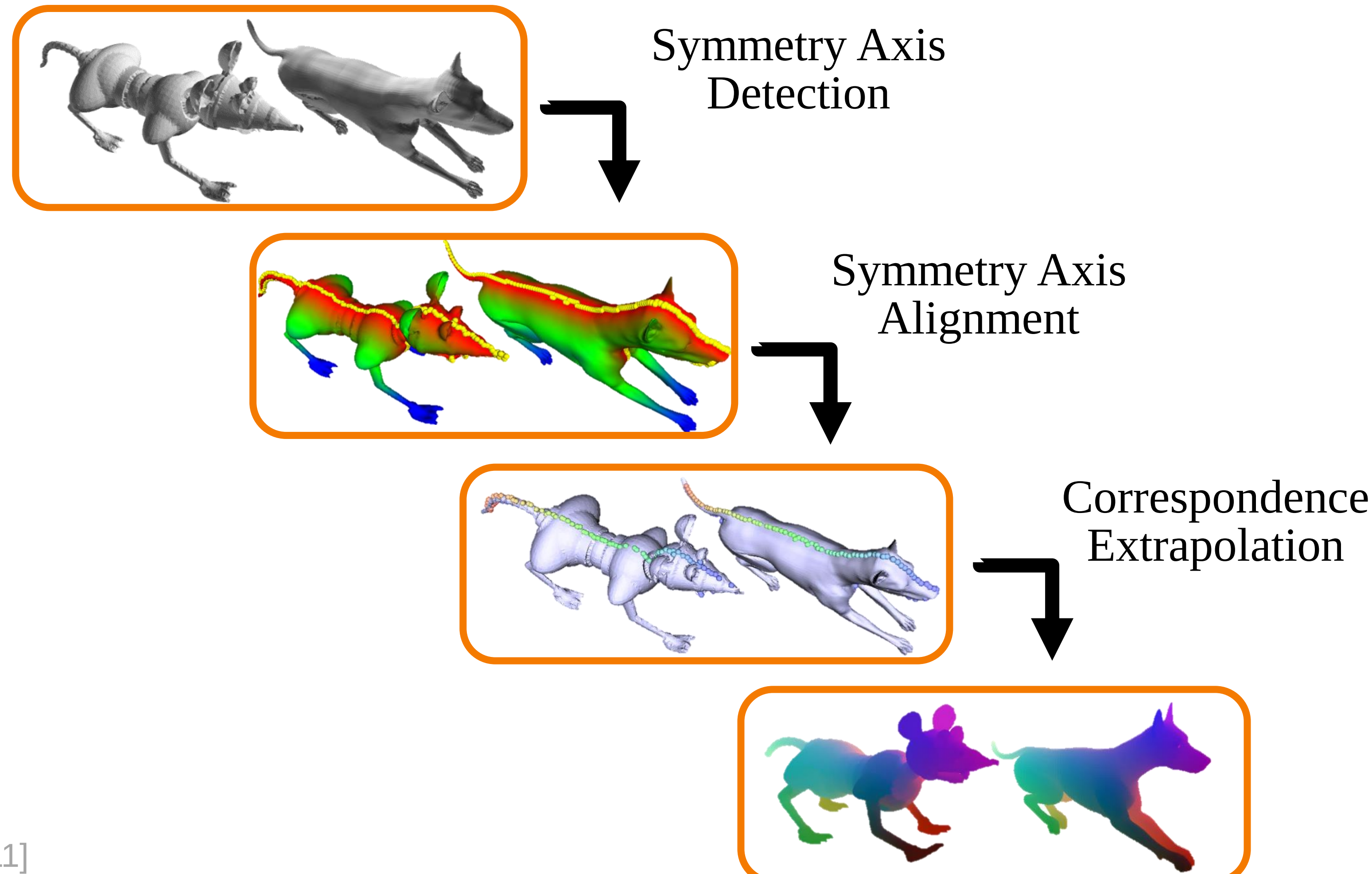
Symmetry-Aware Correspondences

Observation 2: detecting symmetries is easier than finding correspondences



Symmetry-Aware Correspondences

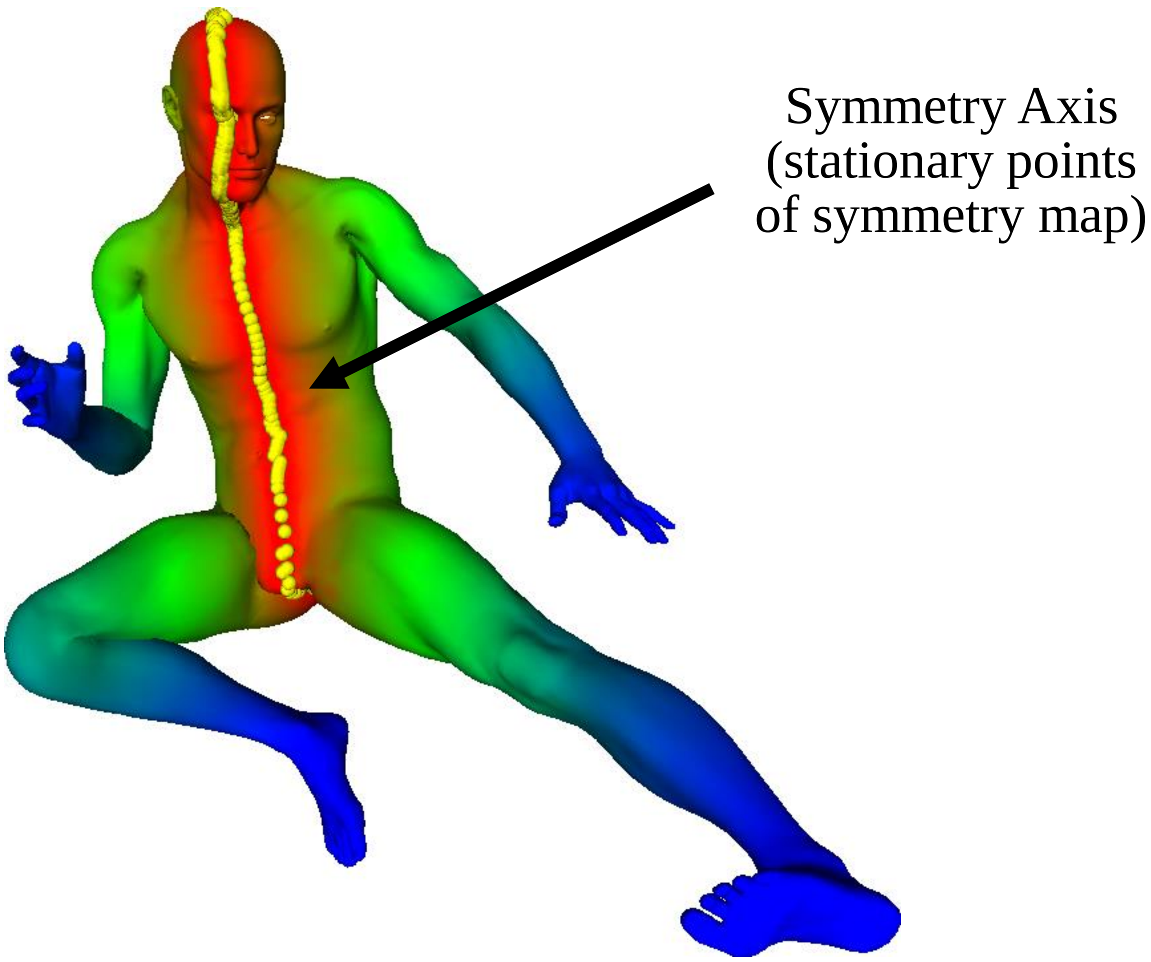
Approach: detect reflective symmetry axes and use them to find correspondences



[Liu et al., 2011]

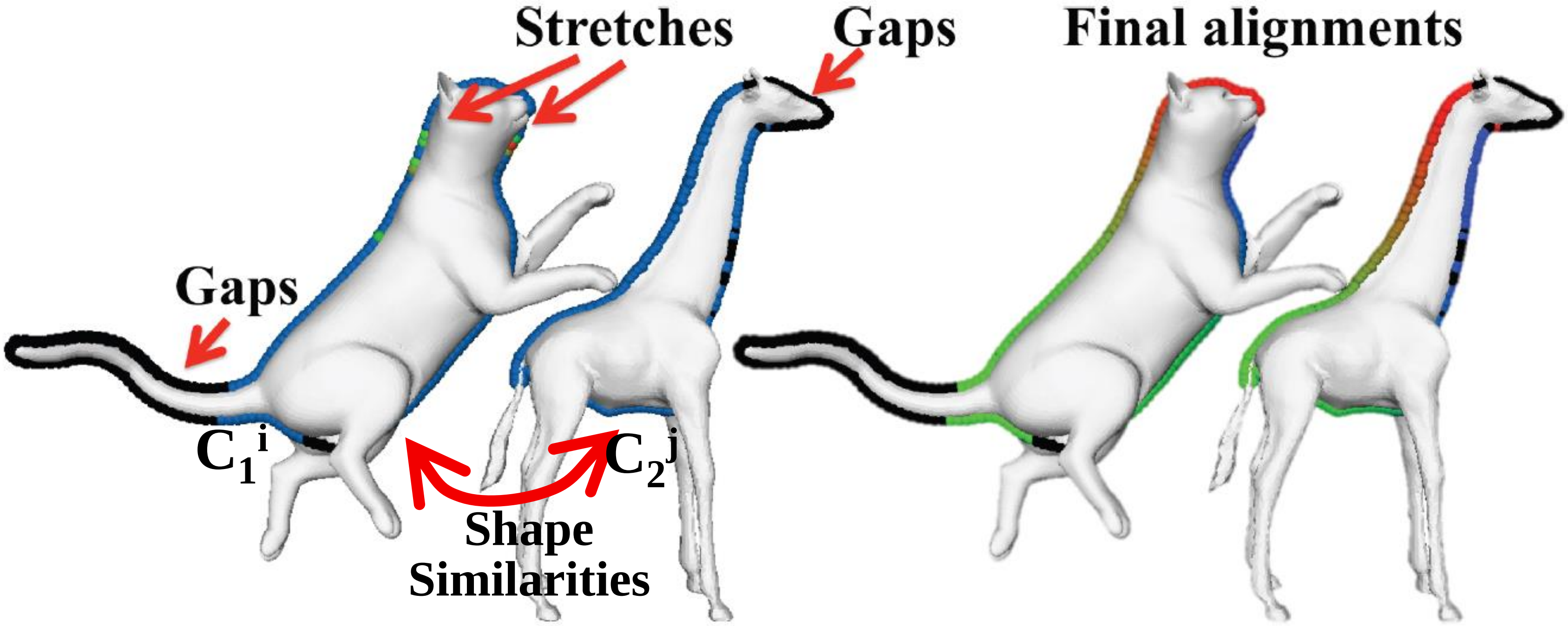
Symmetry Axis Detection

Given a mesh, extract potential symmetry axes



Symmetry Axis Alignment

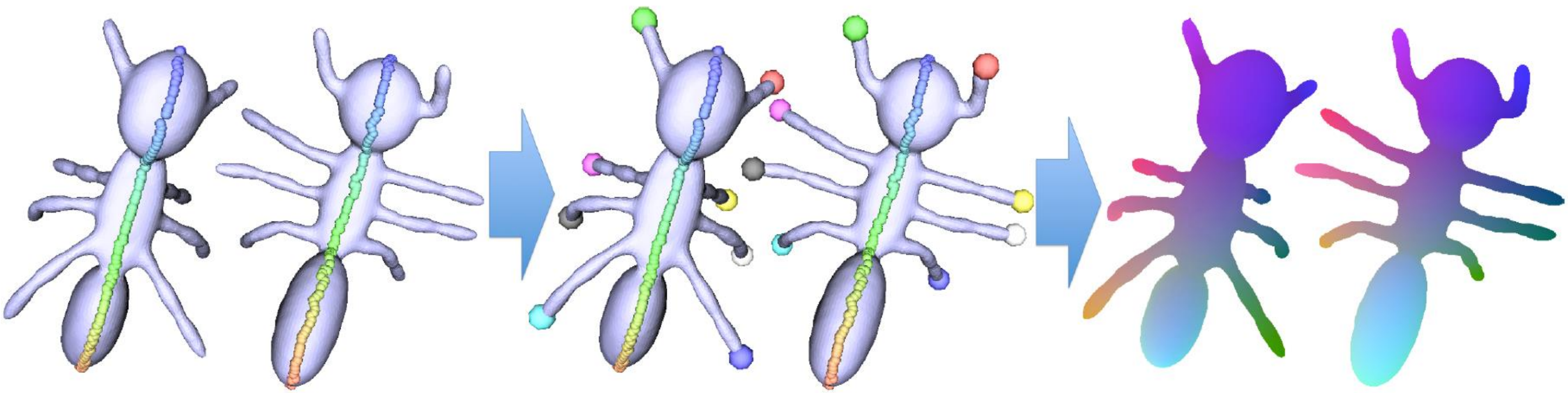
For every pair of symmetry axes, find optimal alignment for every pair of starting points



$$Q(C_1^i, C_2^j, c) = Q_{Axis}(C_1^i) \cdot Q_{Axis}(C_2^j) \cdot Q_{Align}(C_1^i, C_2^j, c)$$

Correspondence Extrapolation

Given an alignment between symmetry axes, extrapolate correspondences to rest of surfaces



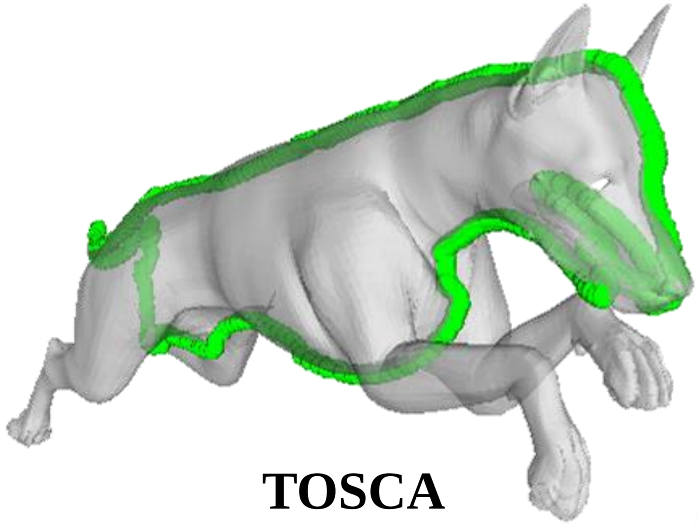
Aligned Symmetry Axes

Aligned Extremal Feature Points

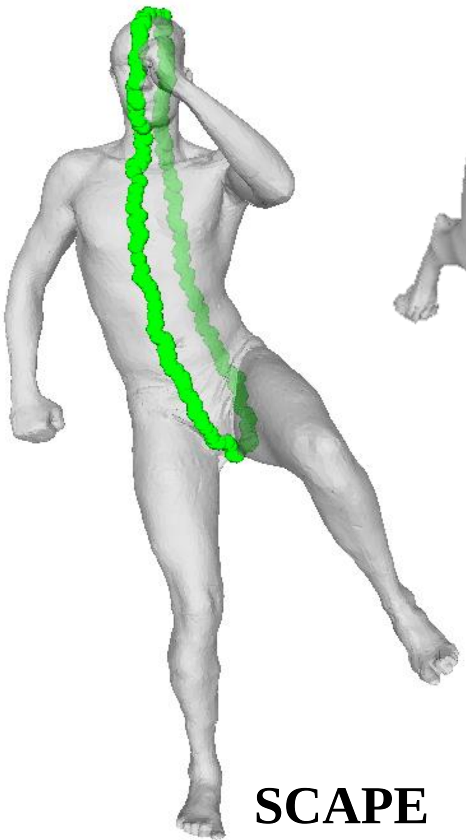
Full Surface Map

Symmetry-Aware Correspondence Evaluation

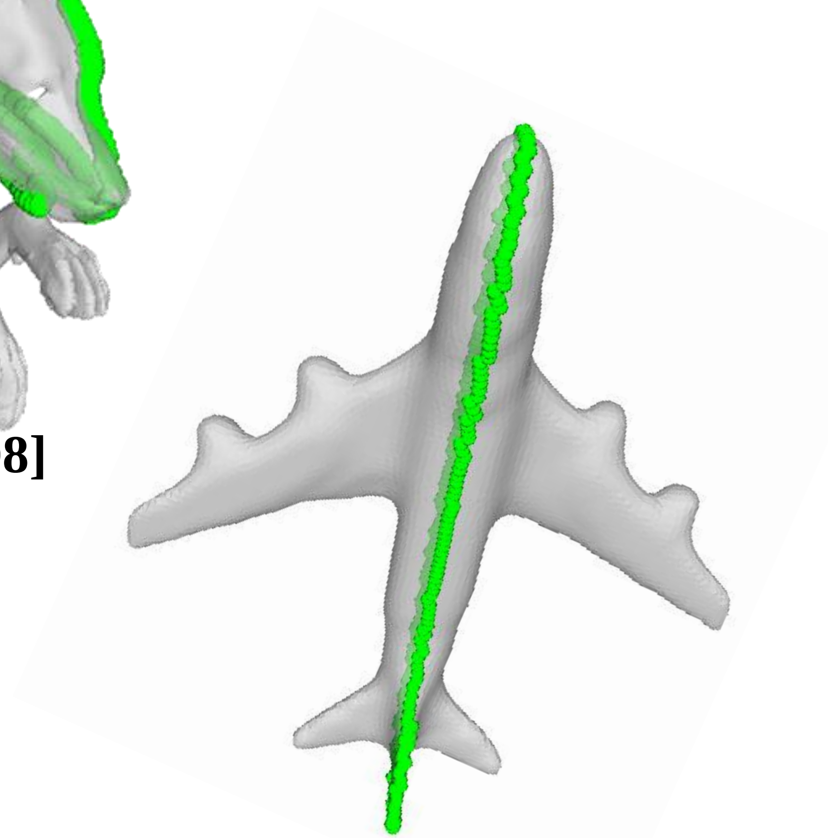
Surface Correspondence Benchmark [Kim 2011]



TOSCA
[Bronstein et al., 2008]



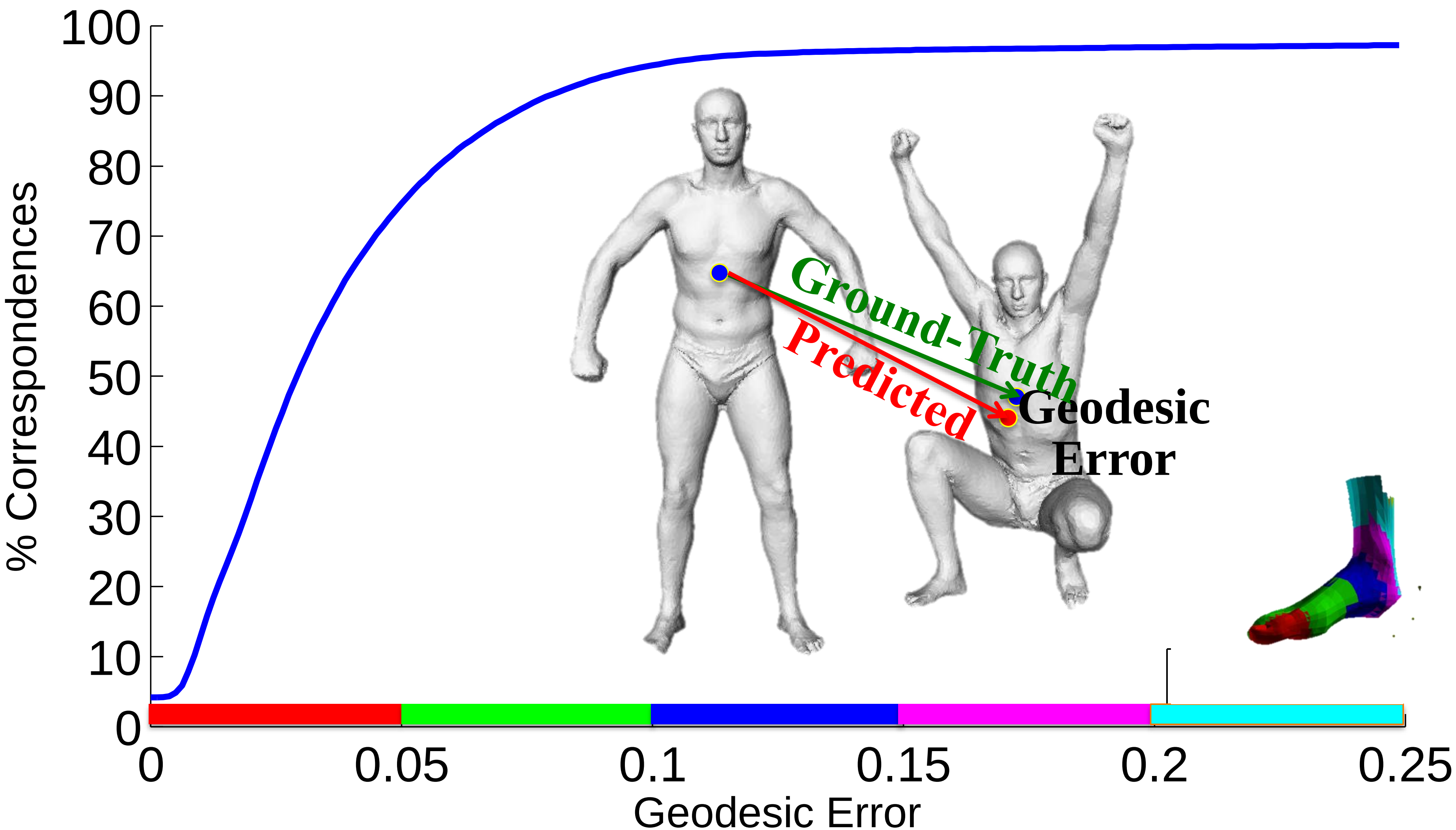
SCAPE
[Anguelov et al., 2004]



SHREC Watertight 2007
[Giorgi et al., 2007]

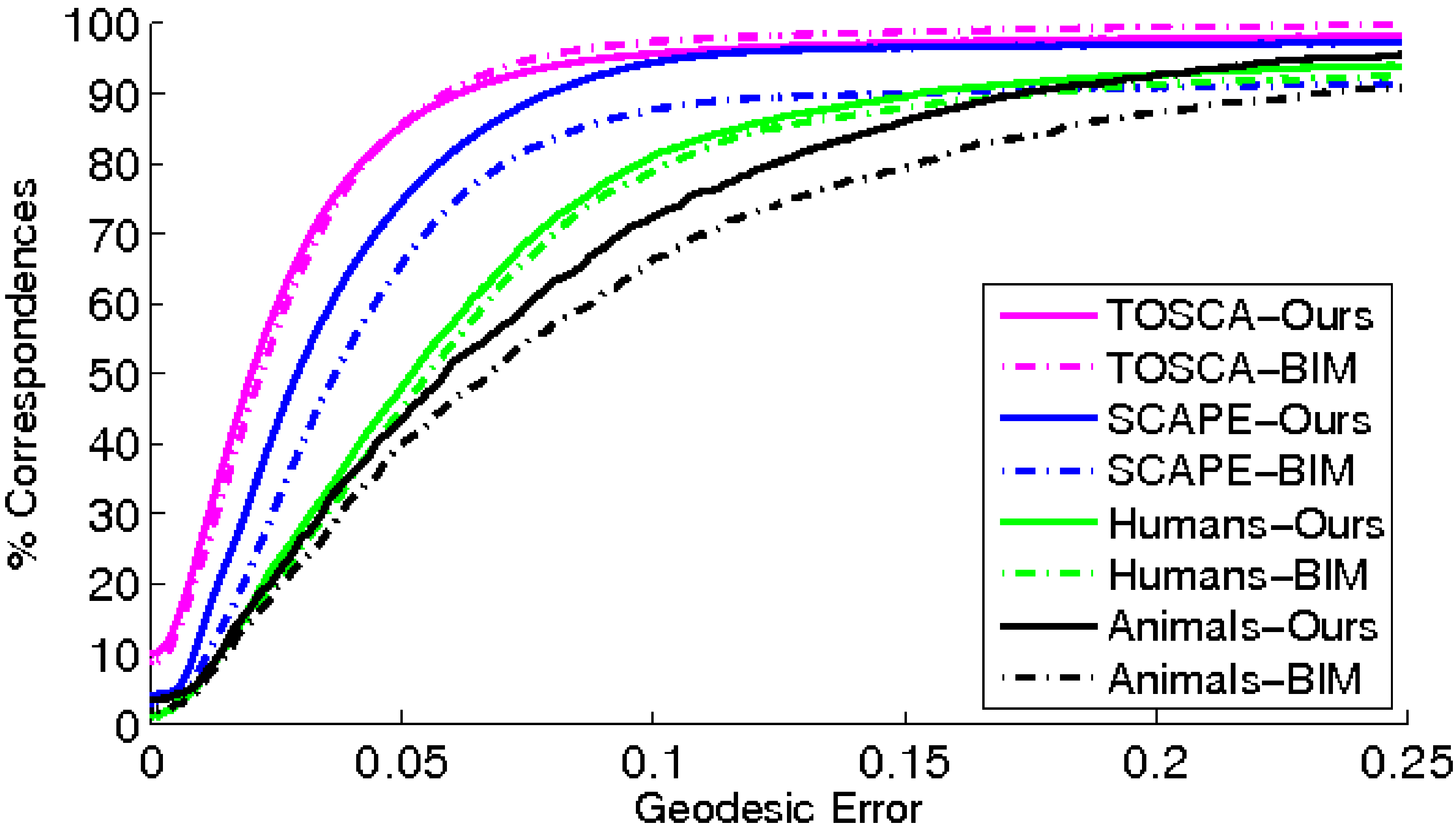
Symmetry-Aware Correspondence Results

Evaluation methodology



Symmetry-Aware Correspondence Results

Comparison to Blended Intrinsic Maps [Kim 2011]



Outline of Talk

Introduction

Latent structures

- Symmetries
- ➢ Parts
- Affordances
- Constraints
- Assemblies

Conclusion

Part-Aware Correspondences

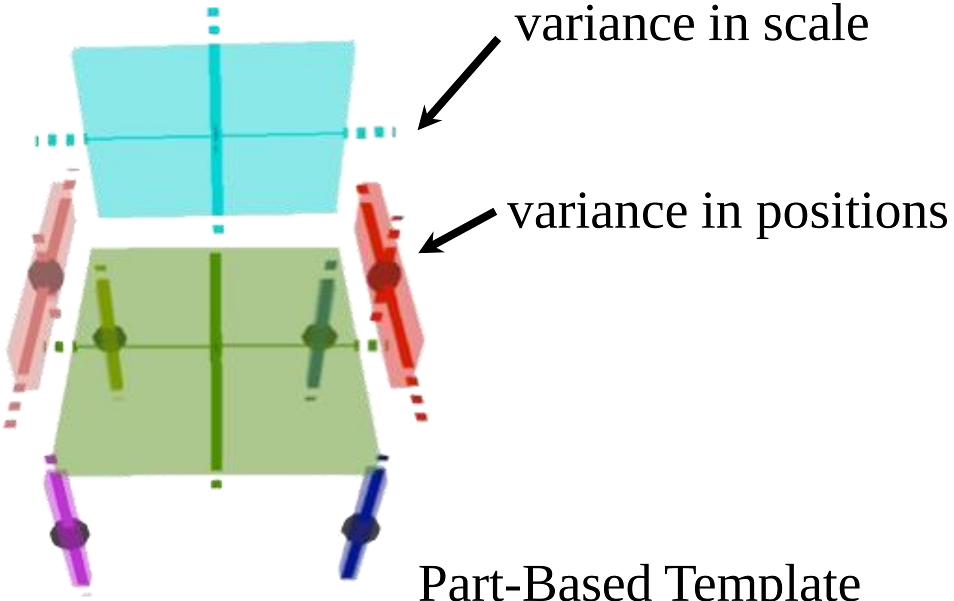
Observation: semantic correspondences are often based on parts

Consistent segmentation

[Golovinskiy et al., 2009]

Part-Aware Correspondences

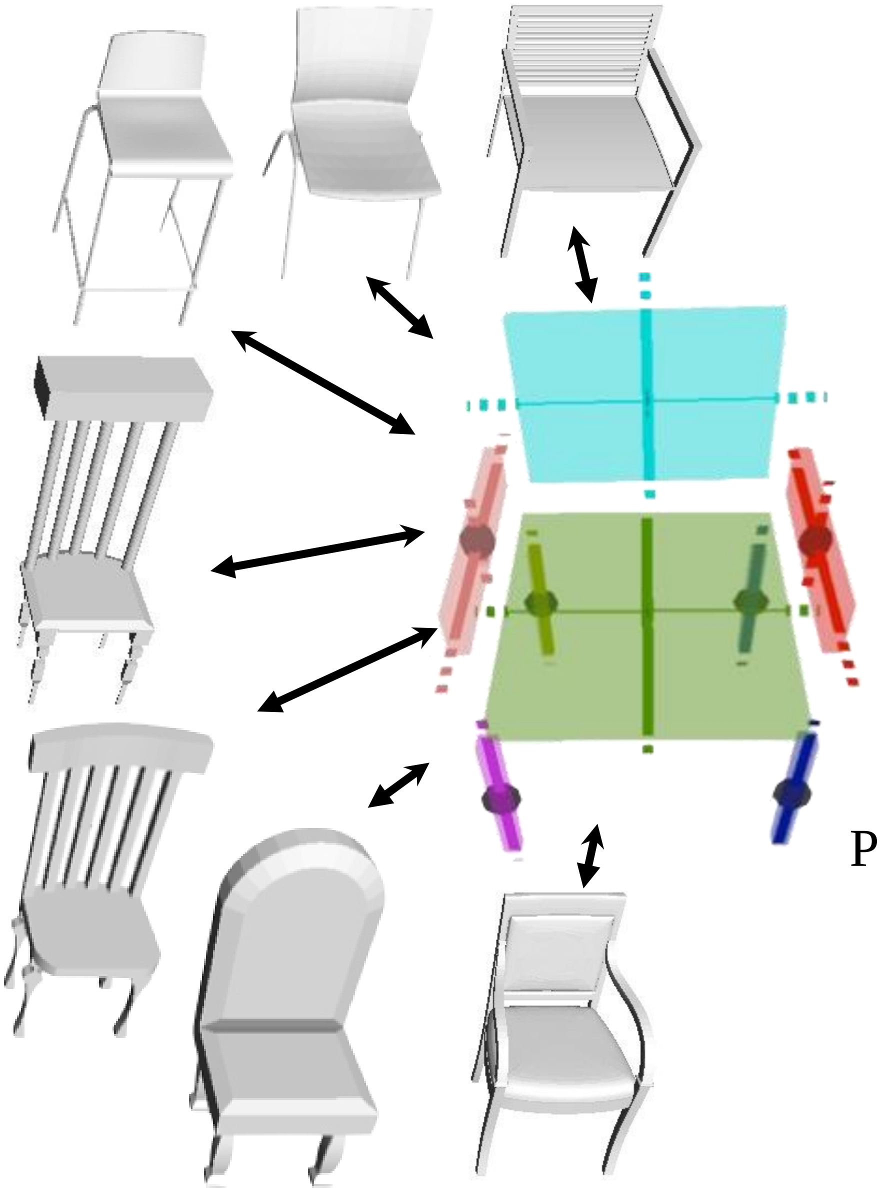
Approach: learn part-based templates for collection of models and use them to find correspondences



Part-Based Template

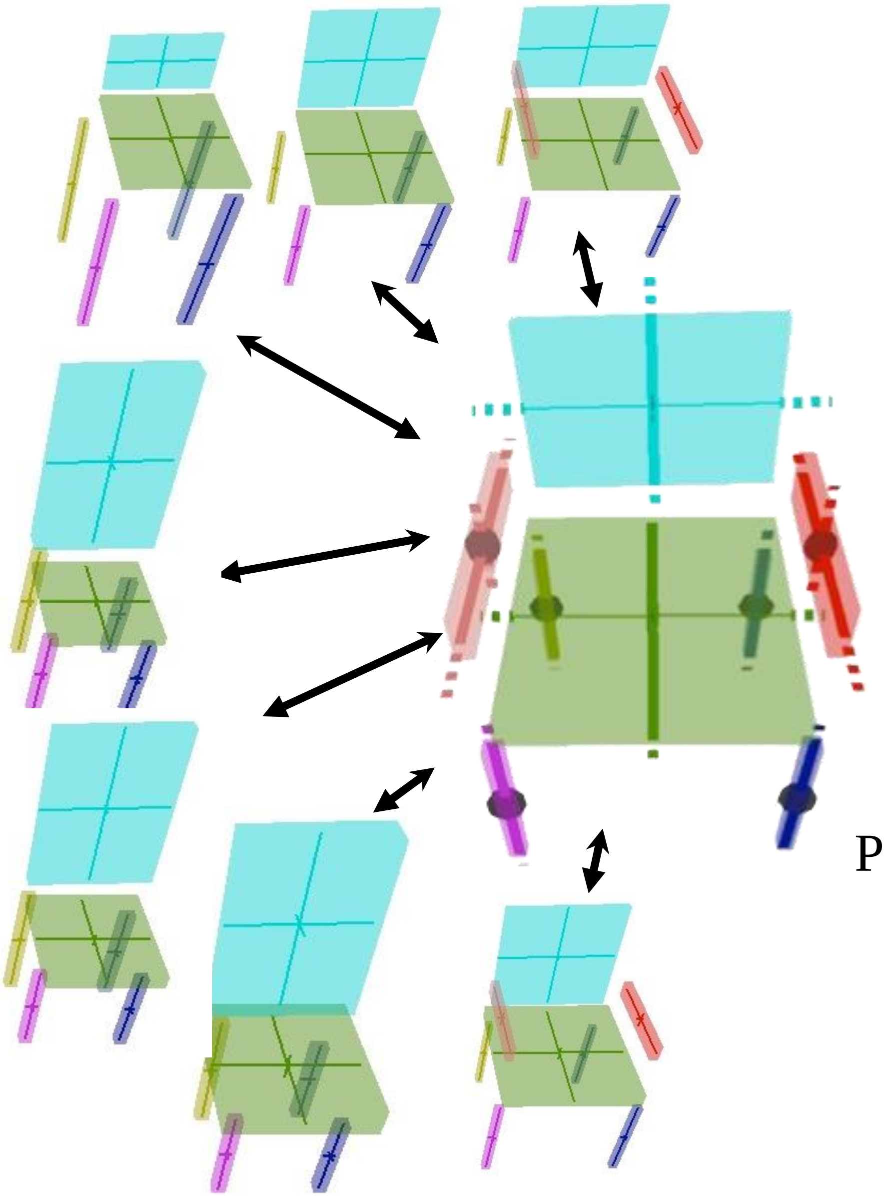
[Kim et al., 2013]

Part-Aware Correspondences



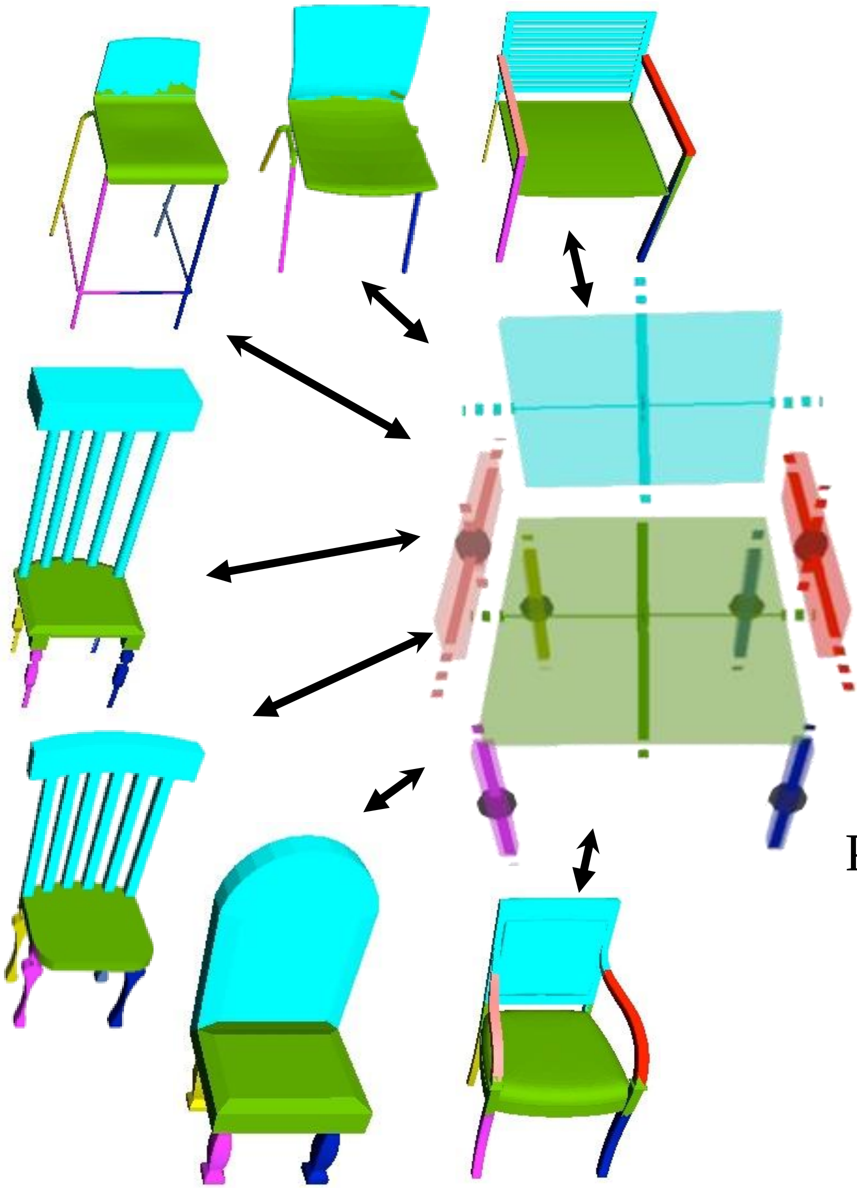
Part-Based Template

Part-Aware Correspondences



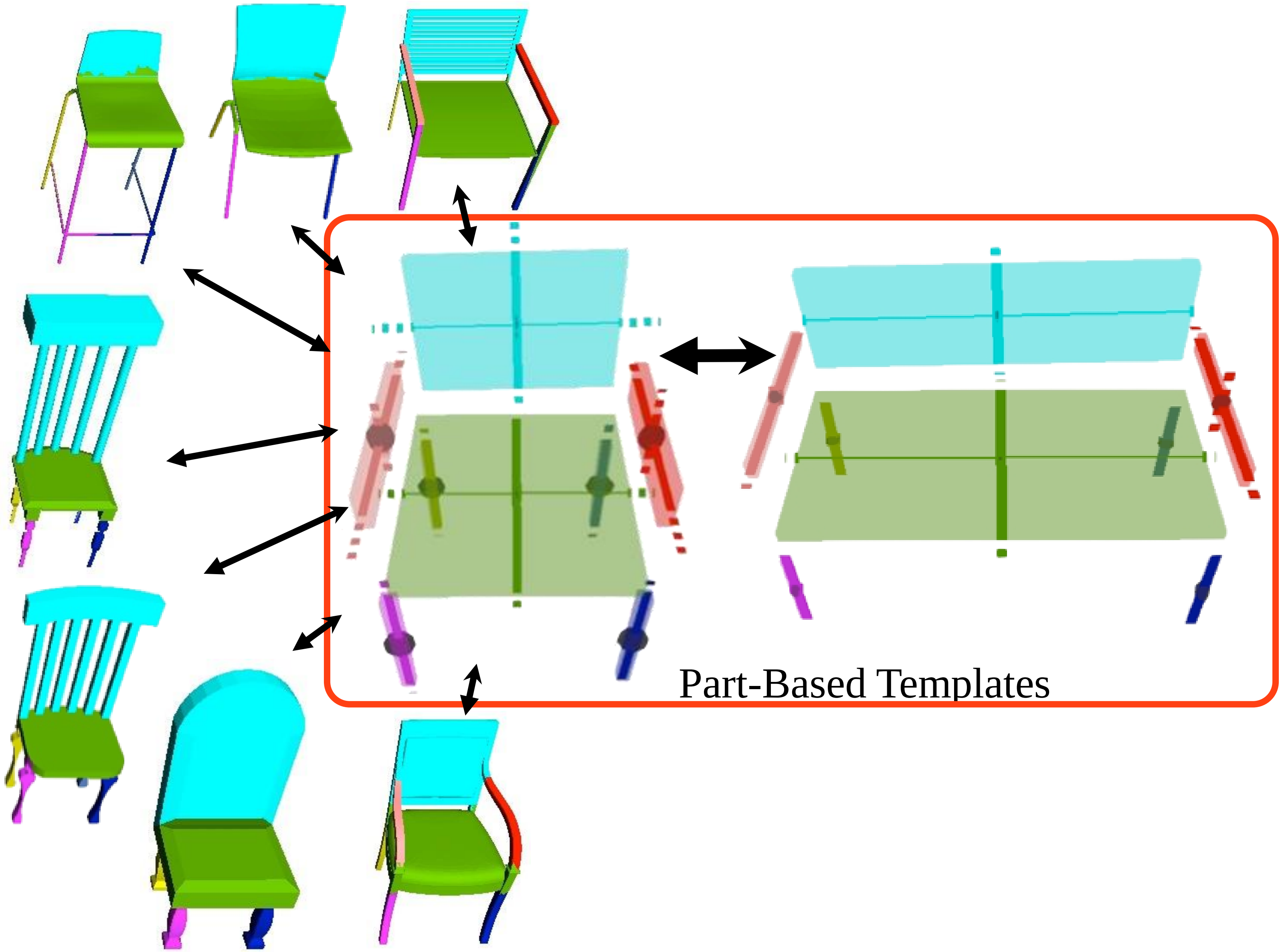
Part-Based Template

Part-Aware Correspondences

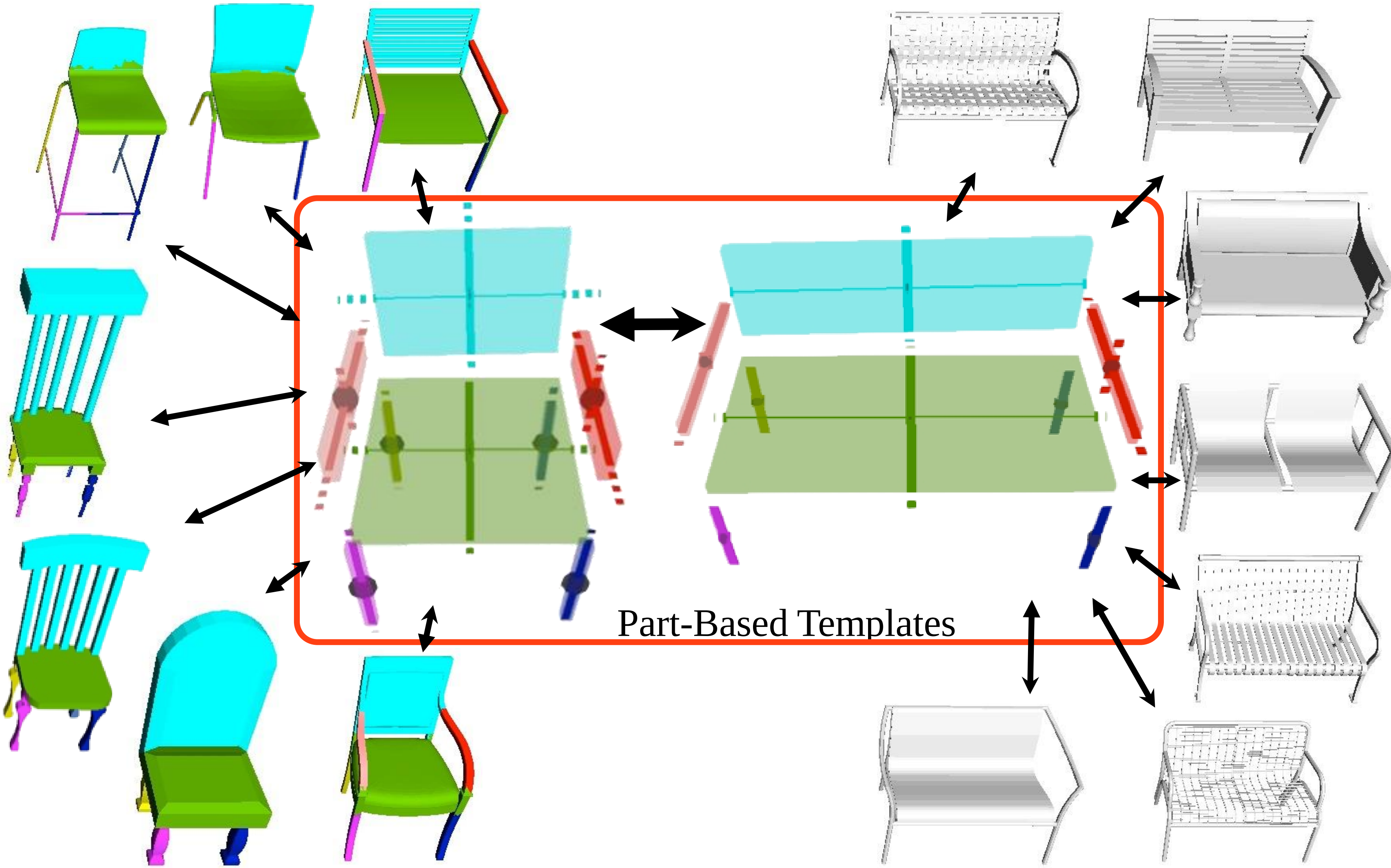


Part-Based Template

Part-Aware Correspondences



Part-Aware Correspondences



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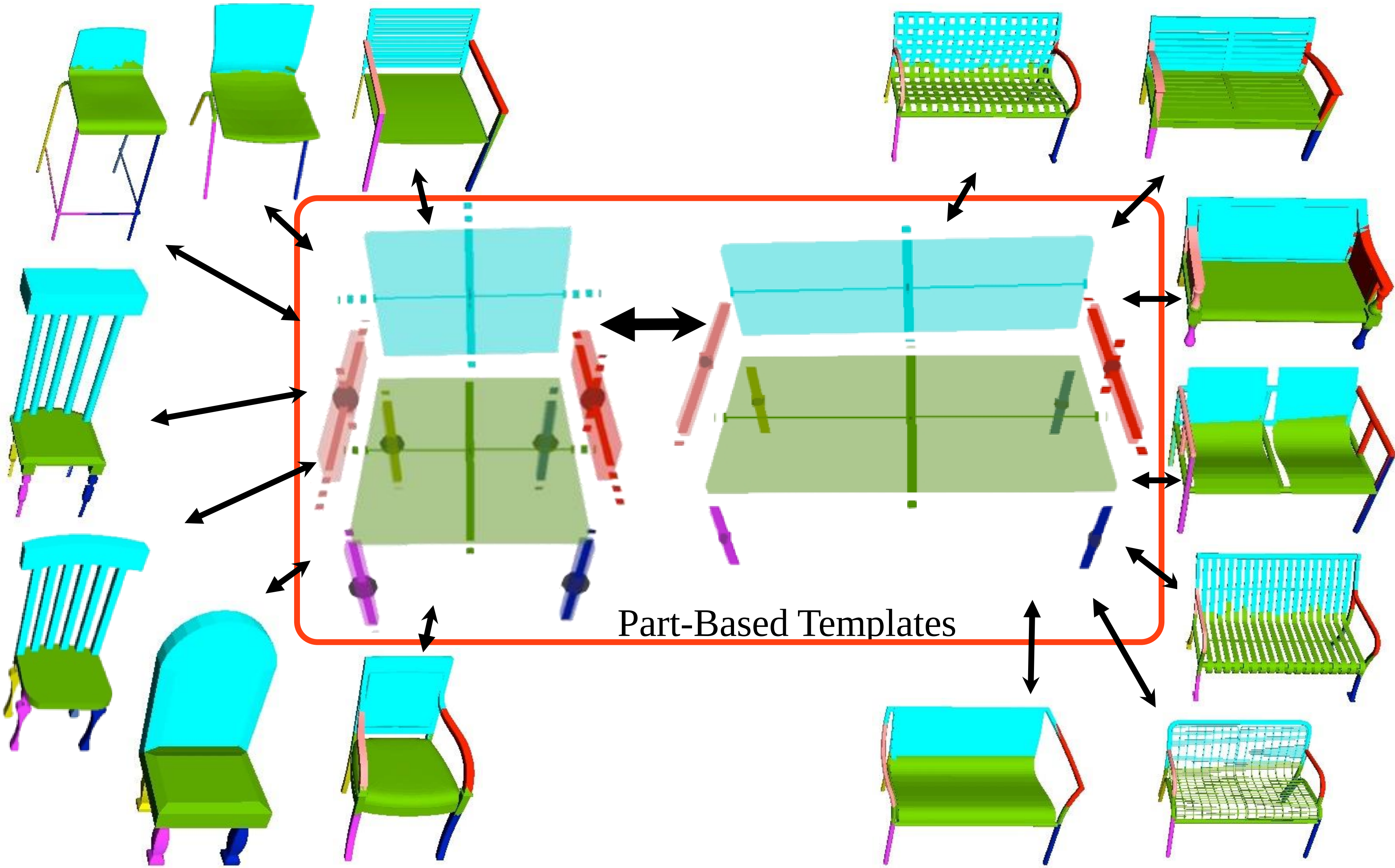
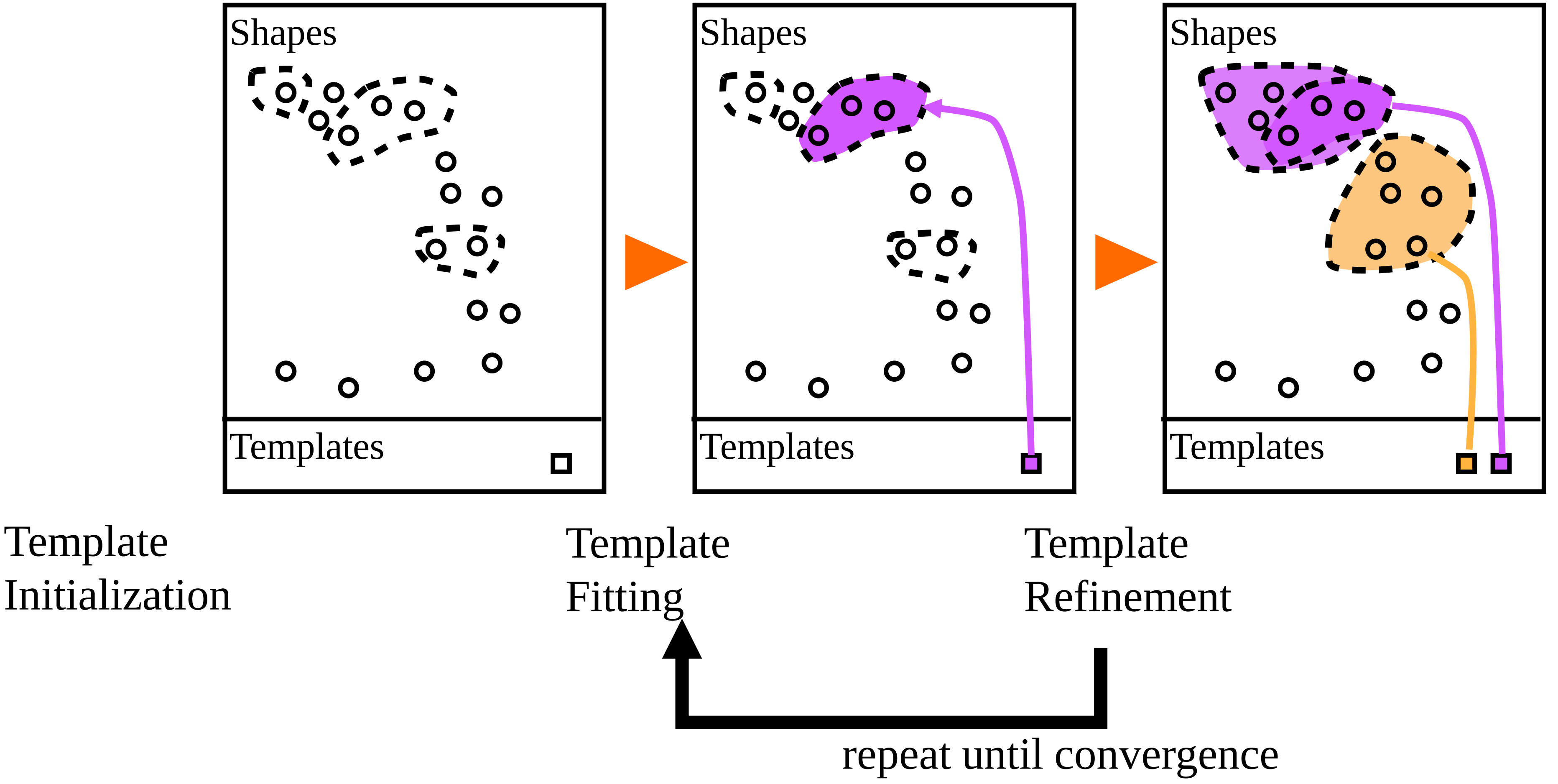


Part-Aware Correspondence Algorithm

Search for a set of templates that best explains a collection of models



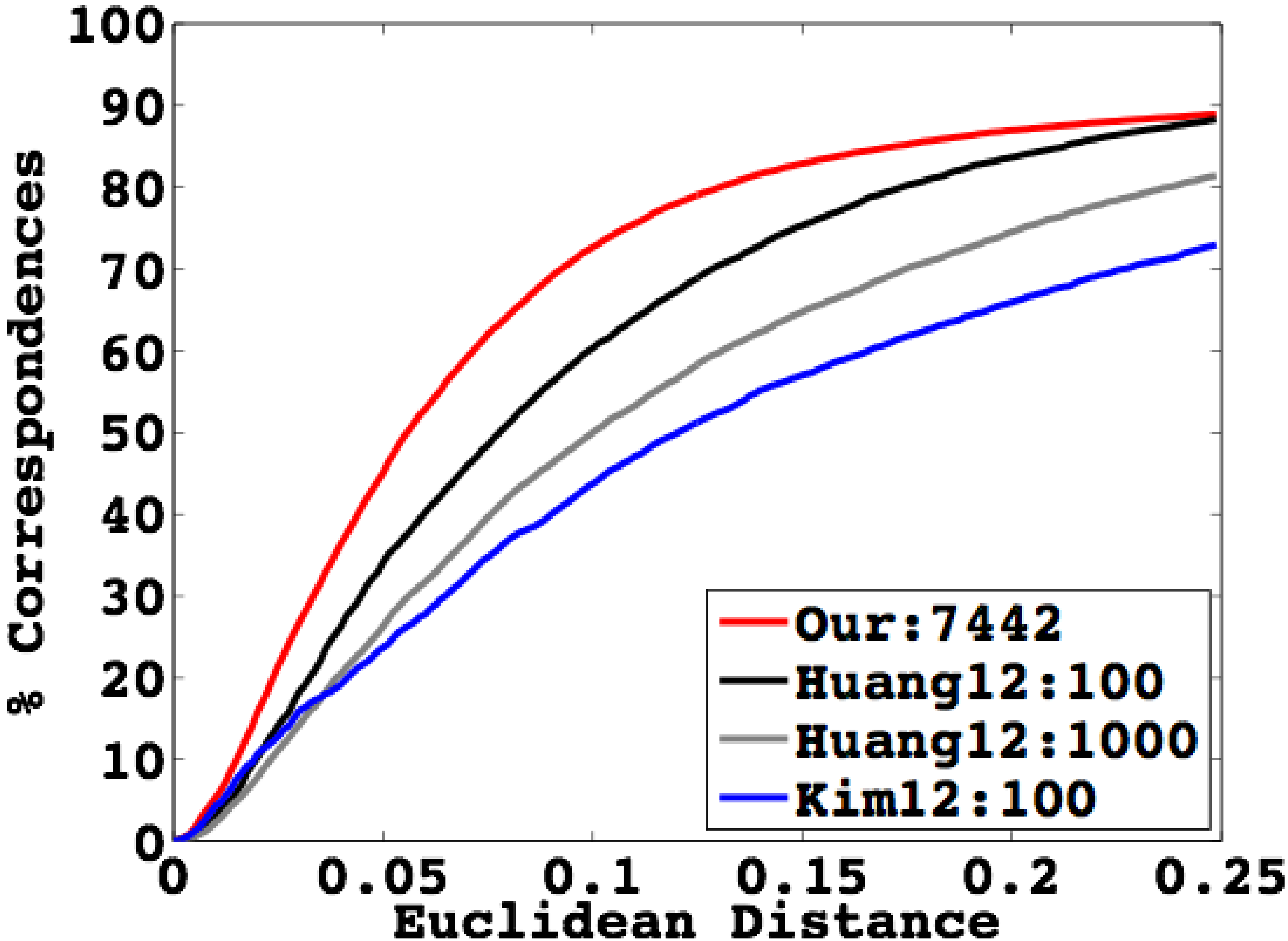
Part-Aware Correspondence Results

2 Templates

3113 Airplanes

Part-Aware Correspondence Results

Correspondence benchmark (7442 seats)



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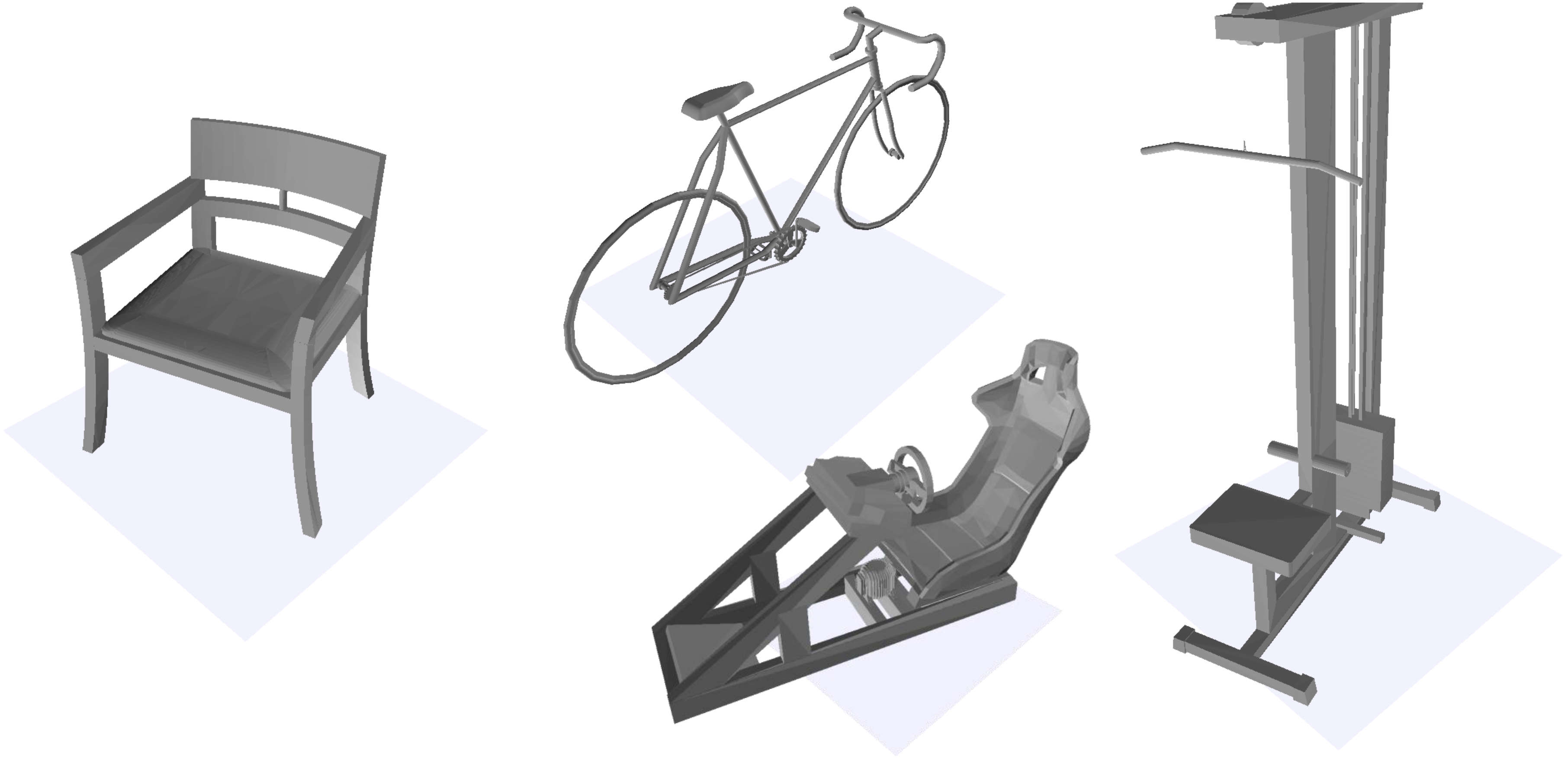
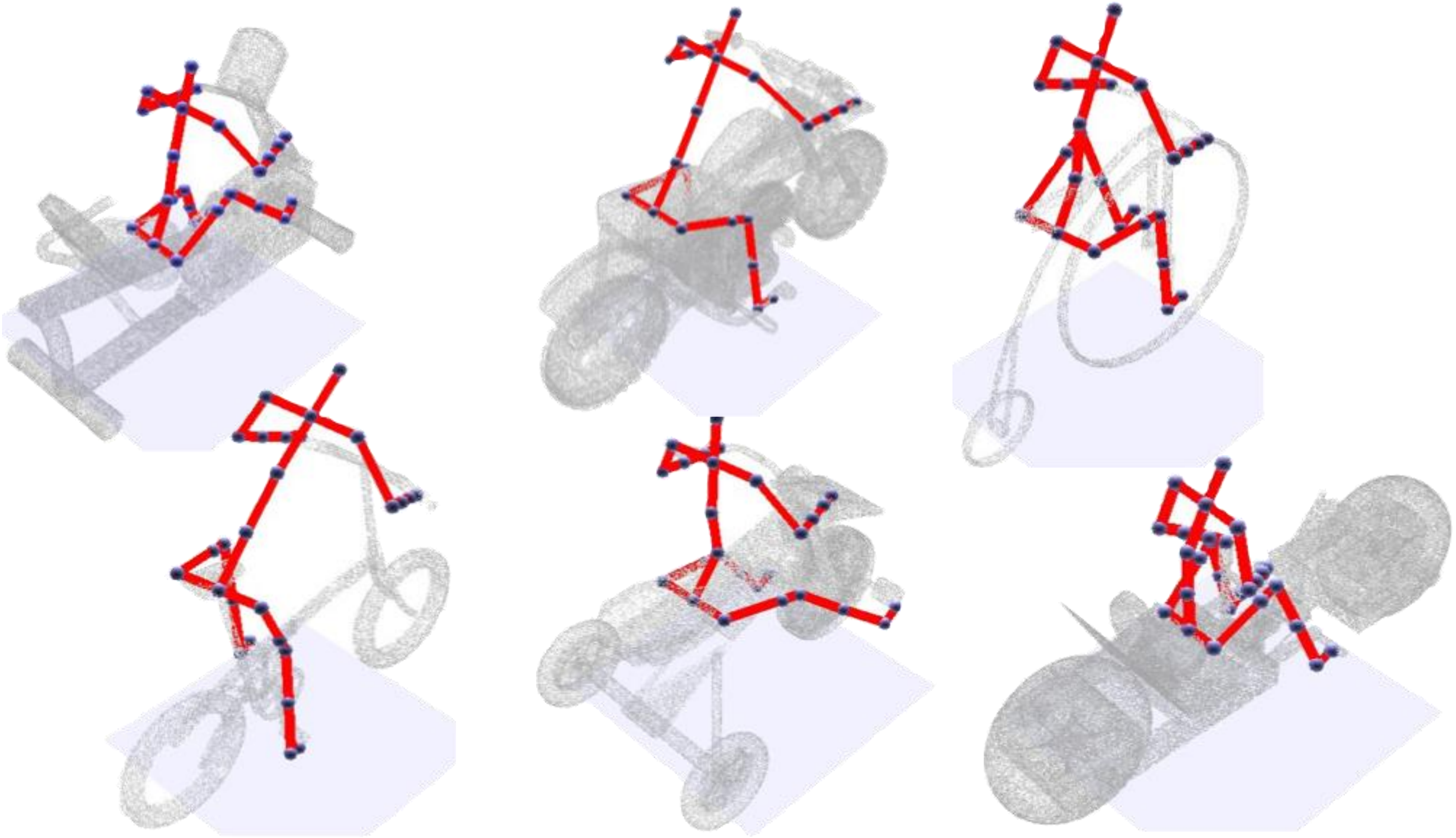
Affordance-Aware Correspondences

Observation 1: almost all man-made objects are used by people



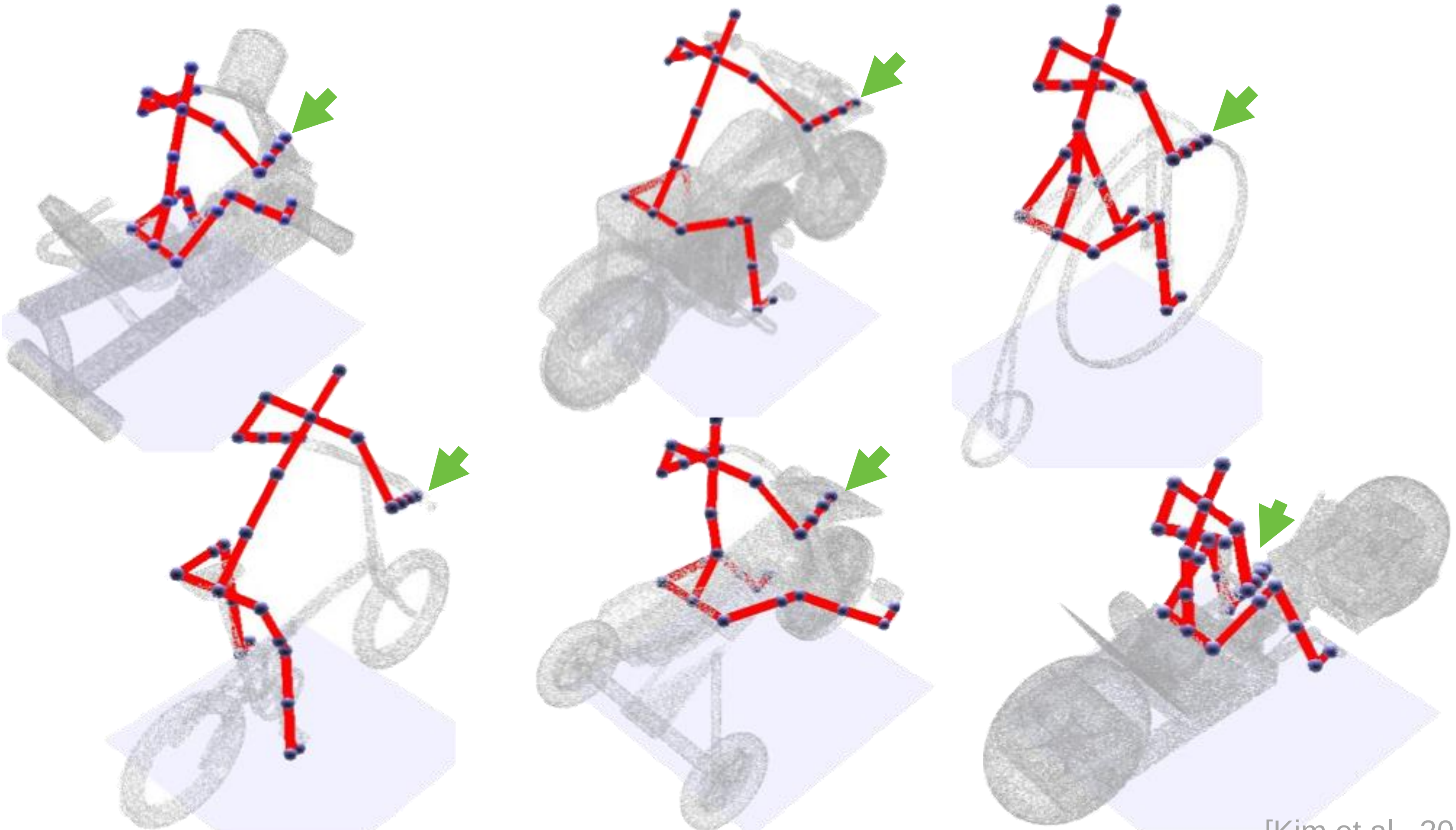
Affordance-Aware Correspondences

Observation 2: the poses people take when using objects reveal functional correspondences



Affordance-Aware Correspondences

Approach: predict poses of people and use them to find correspondences



[Kim et al., 2014]

Pose Prediction Algorithm

Pose Parameters

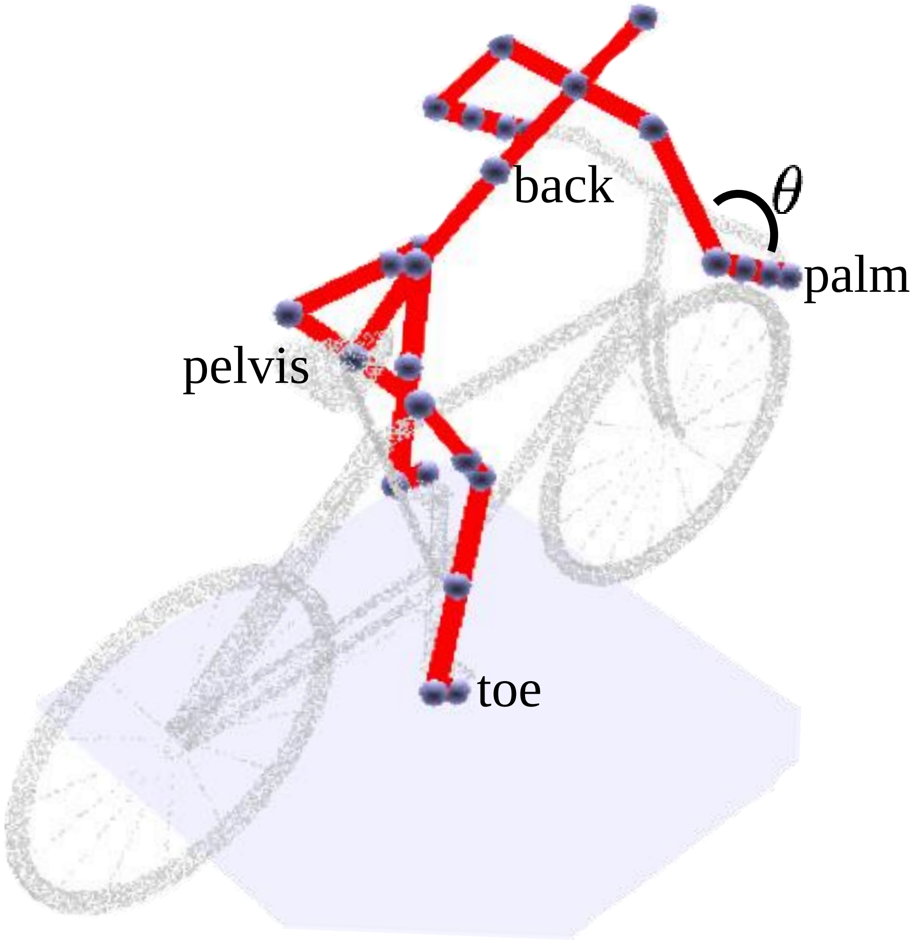
- Contact points
- Joint Angles

Energy Function

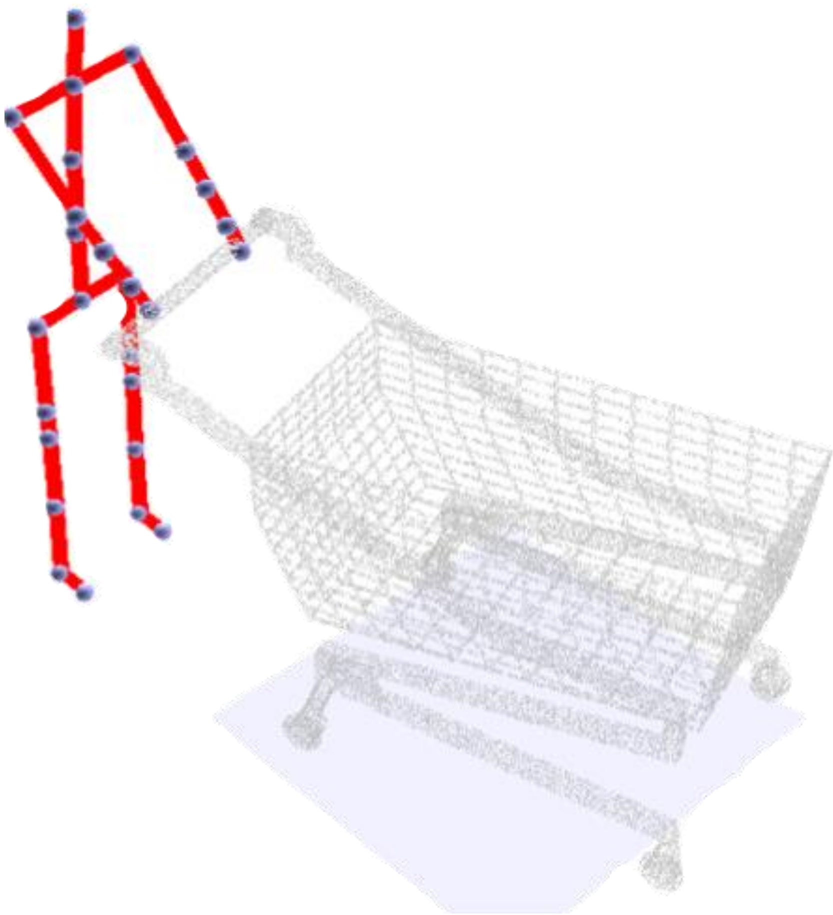
- Contact Distance
- Feature Compatibility
- Pose Prior
- Symmetry
- Surface intersections

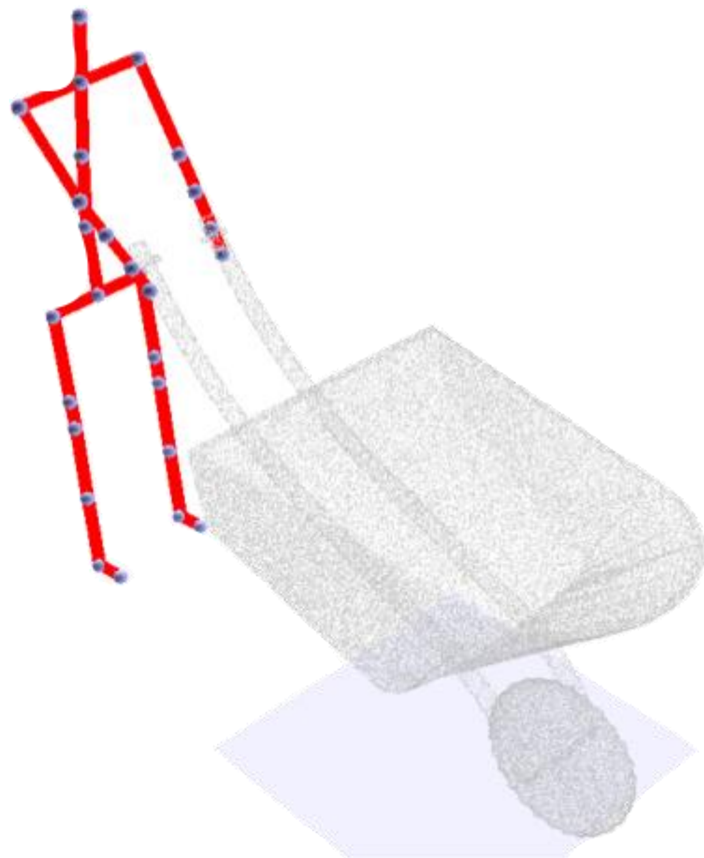
Search Procedure

- Sample pose parameters
- Solve contact points or joint angles (inverse kinematics)
- Evaluate energy function

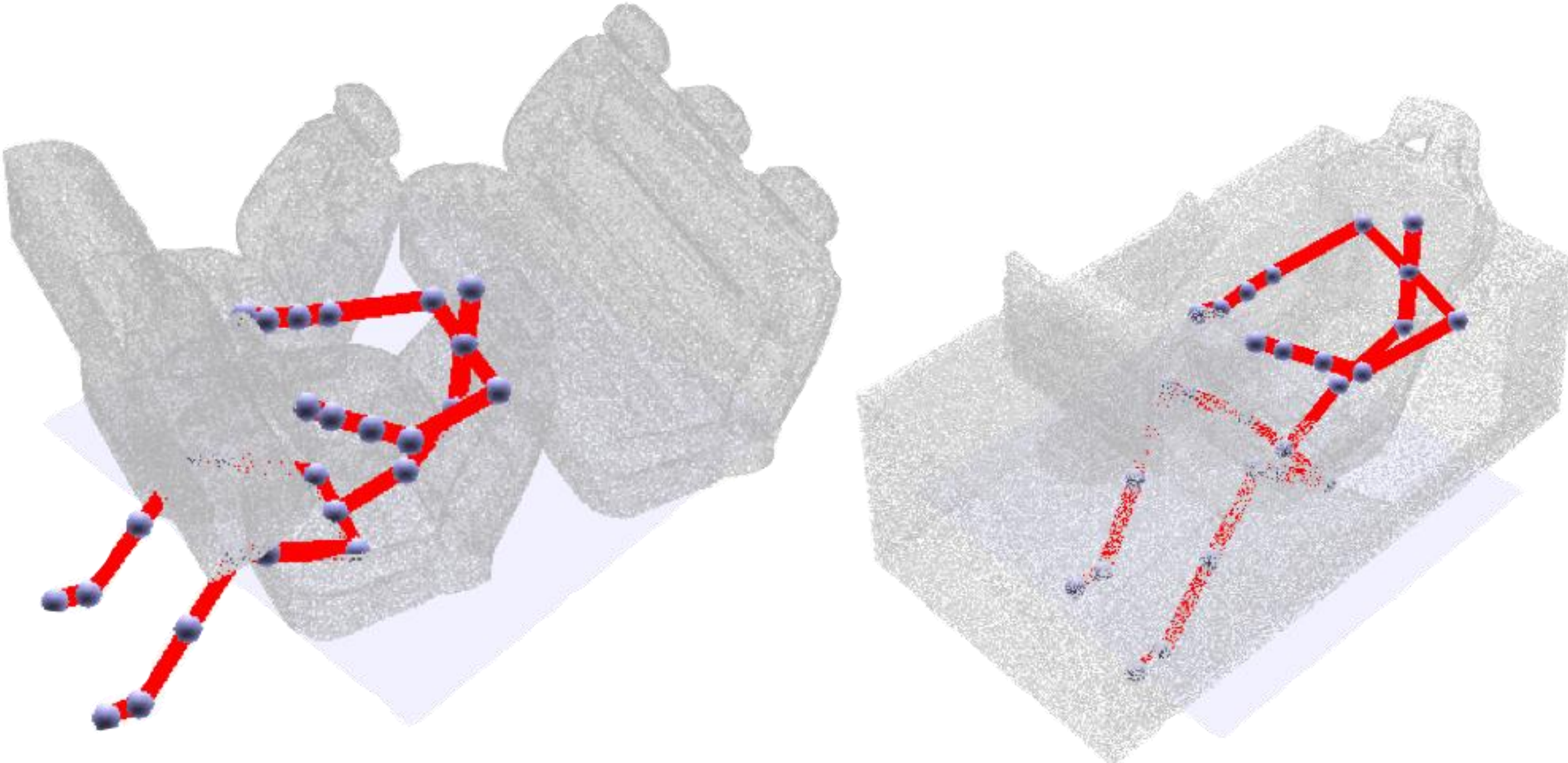


Pose Prediction Results

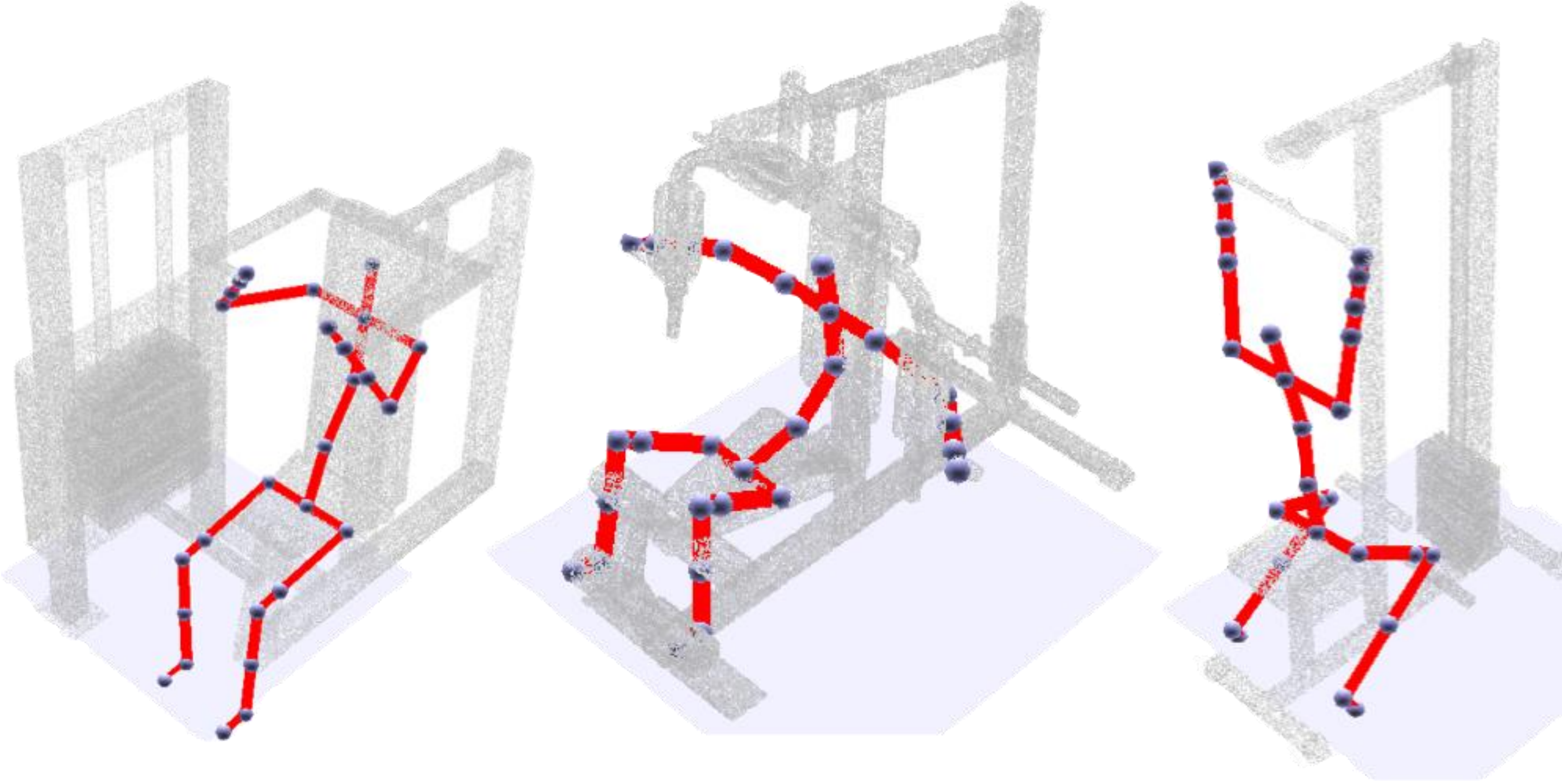




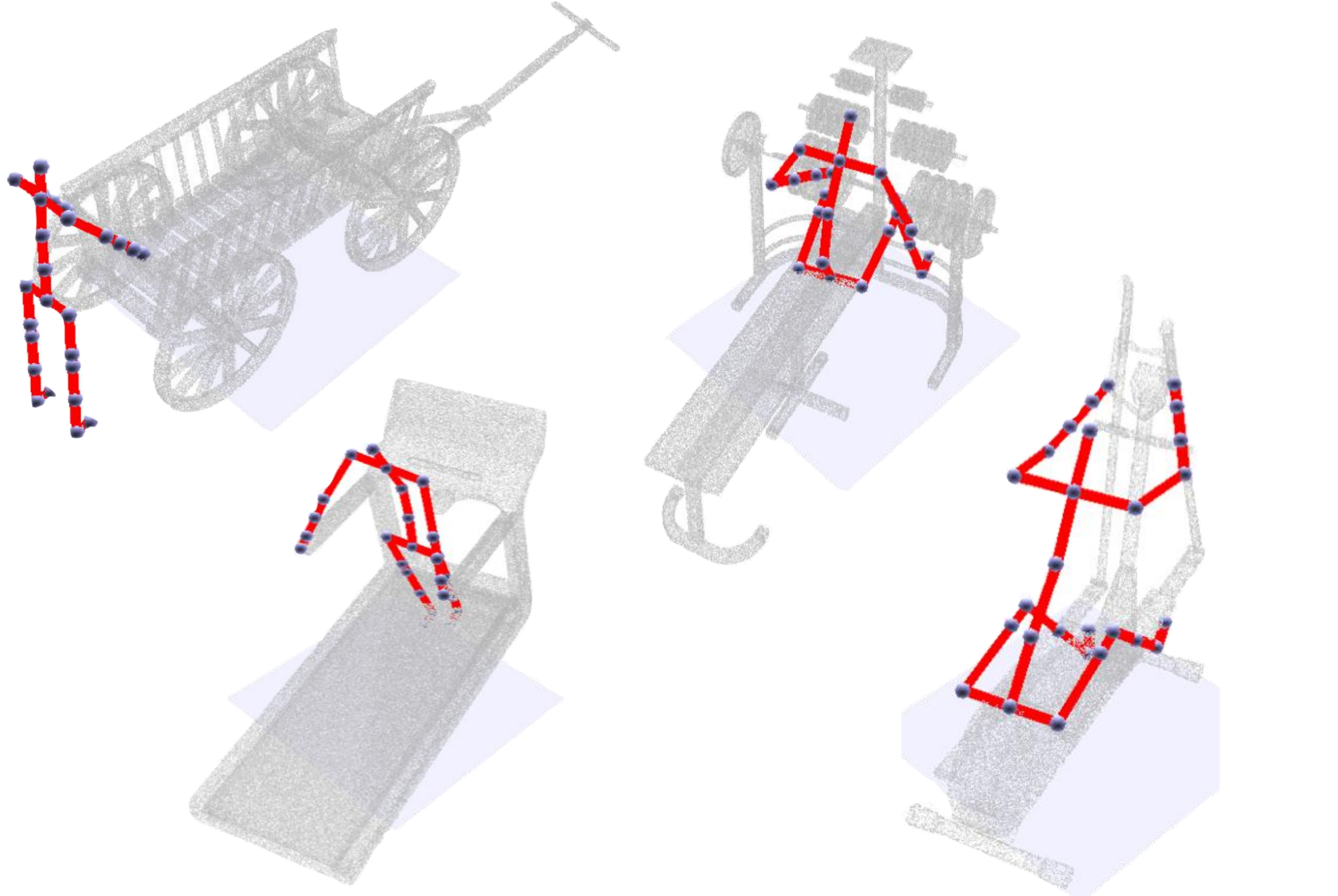
Pose Prediction Results



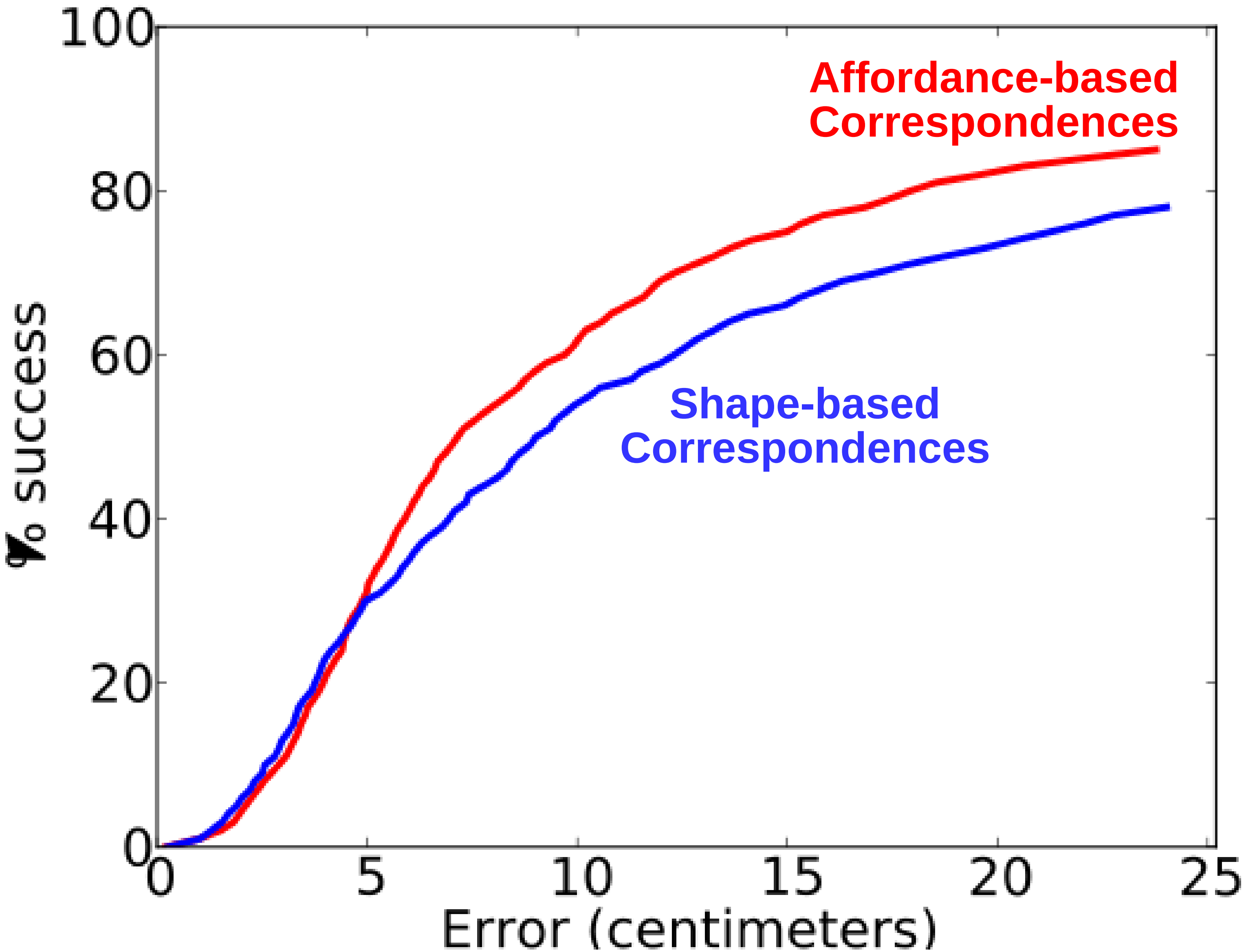
Pose Prediction Results



Pose Prediction Failures



Affordance Correspondence Results



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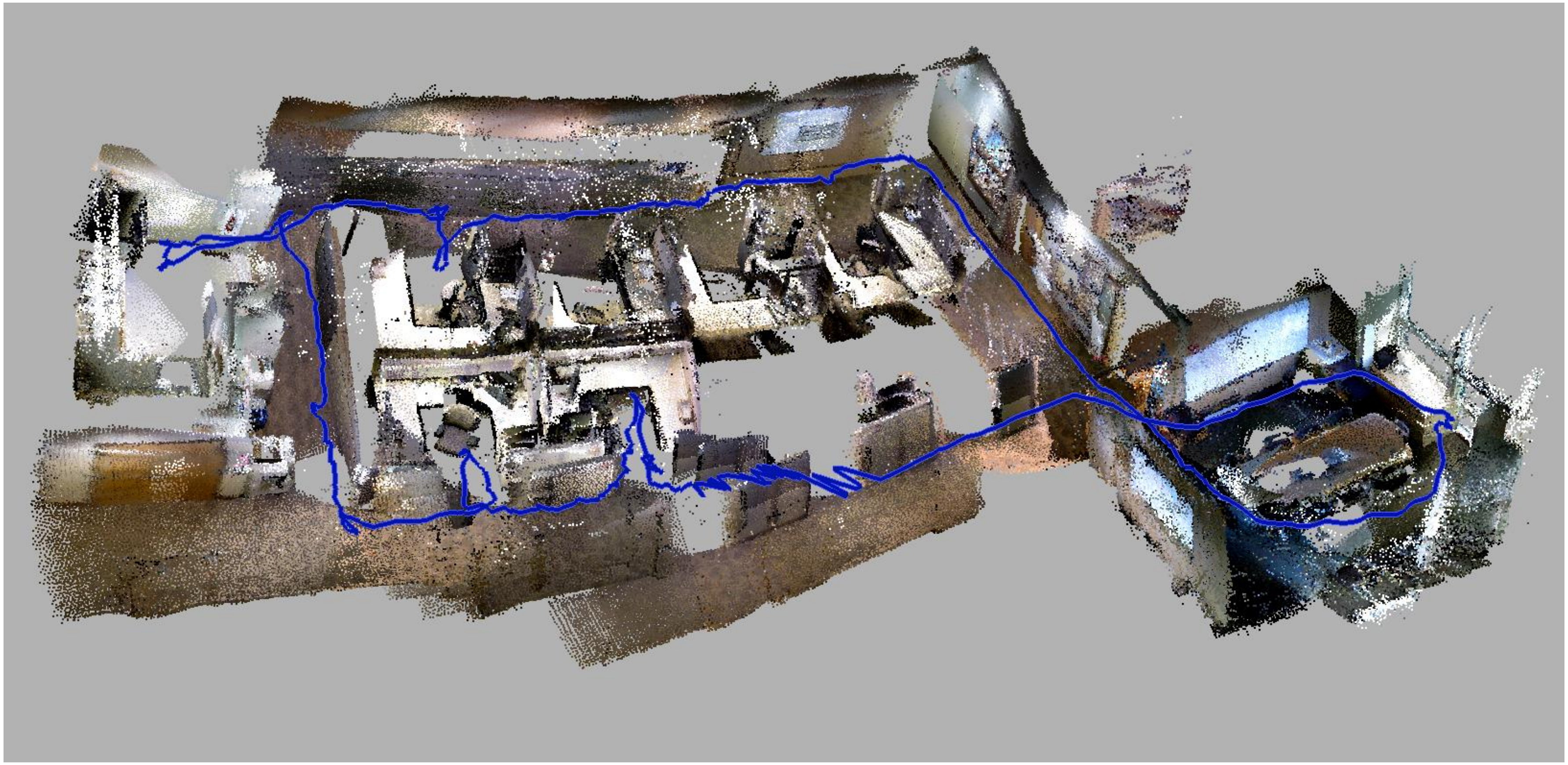
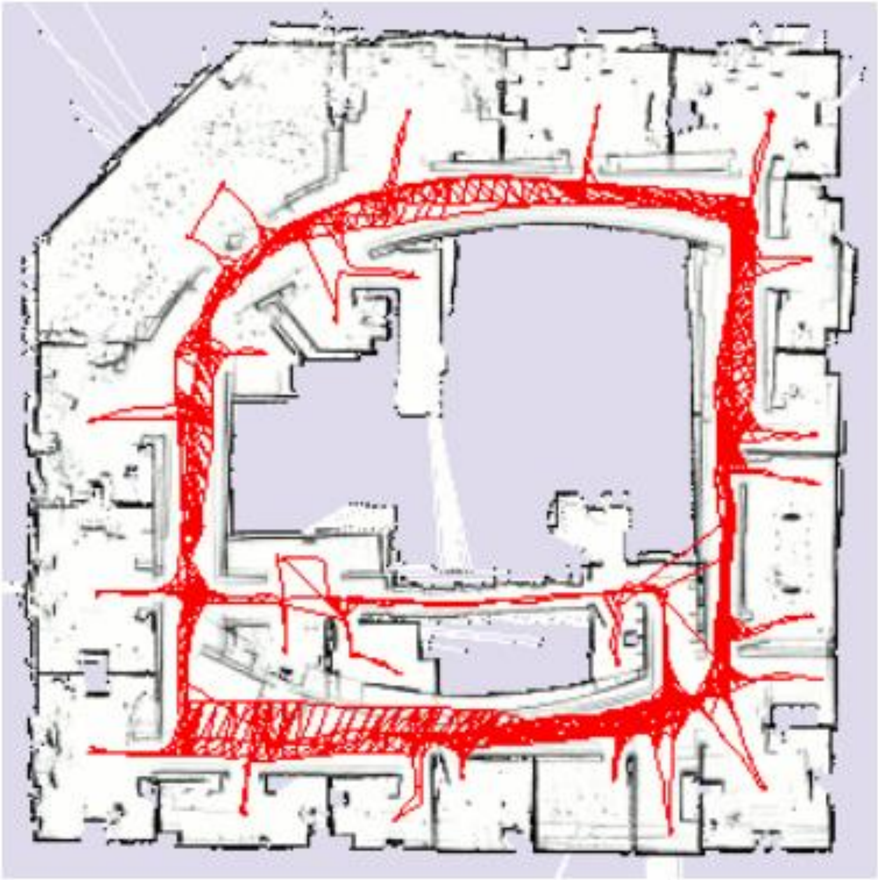
Constraint-Aware Correspondences

Observation 1: global registration of RGB-D scans requires finding “loop closure” correspondences



Constraint-Aware Correspondences

Observation 2: almost all indoor environments follow the Manhattan World assumption

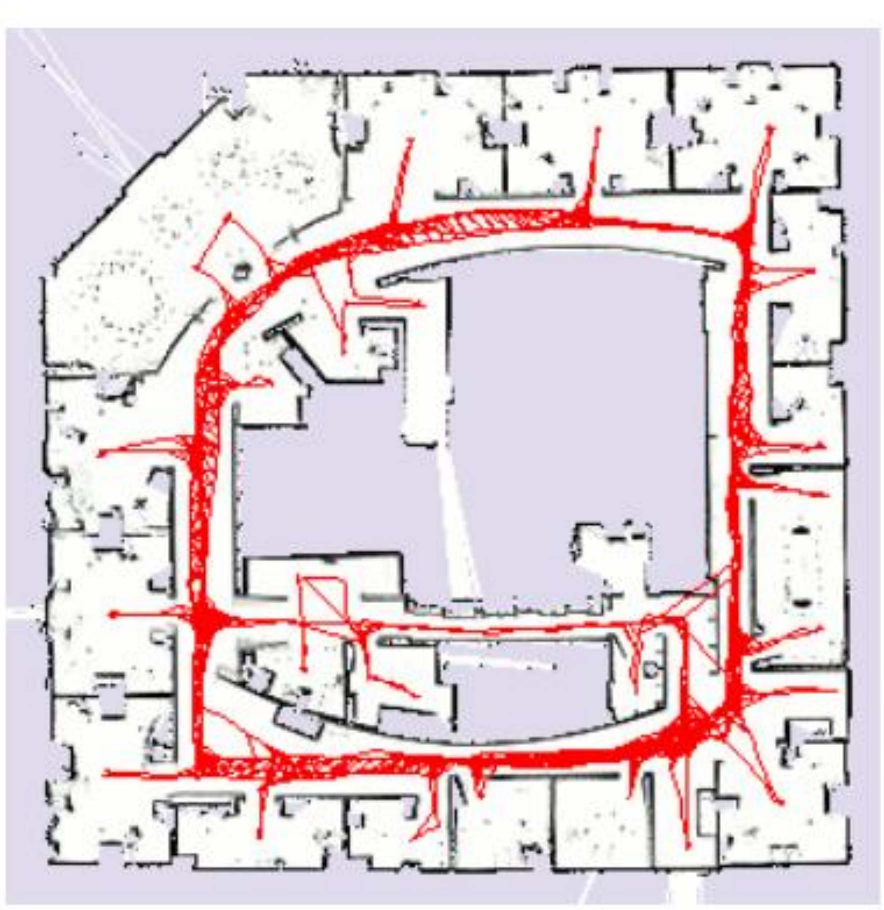


Intel Research Lab in Seattle

Constraint-Aware Correspondences

Observation 2: almost all indoor environments follow the Manhattan World assumption

- Orthogonal corners
- Parallel surfaces



Intel Research Lab in Seattle

Constraint-Aware Correspondences

Approach: detect and enforce Manhattan World constraints and use them to find correspondences

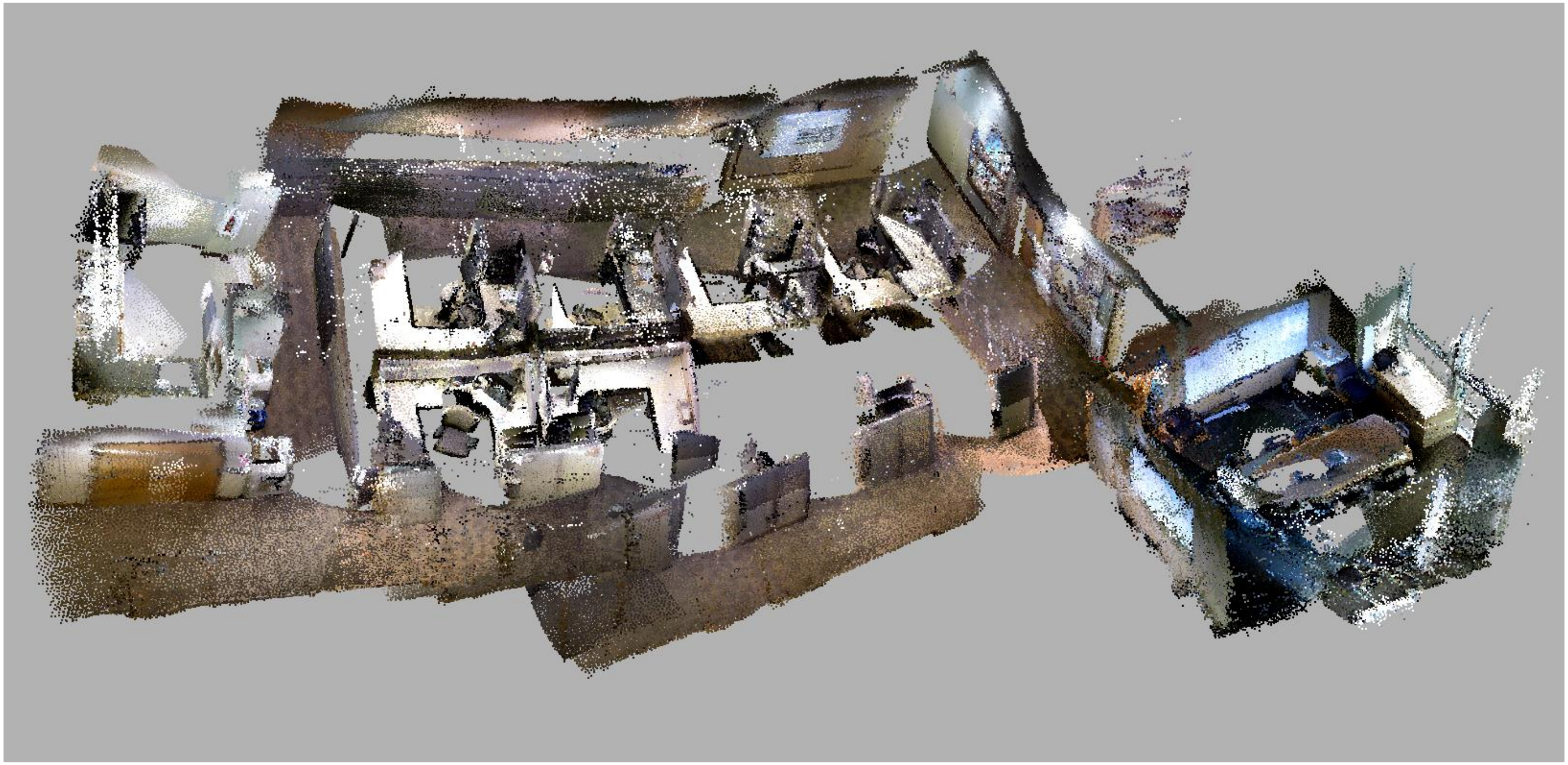
Camera Tracking without Constraints

Global Registration with Constraints

[Halber et al., submitted]

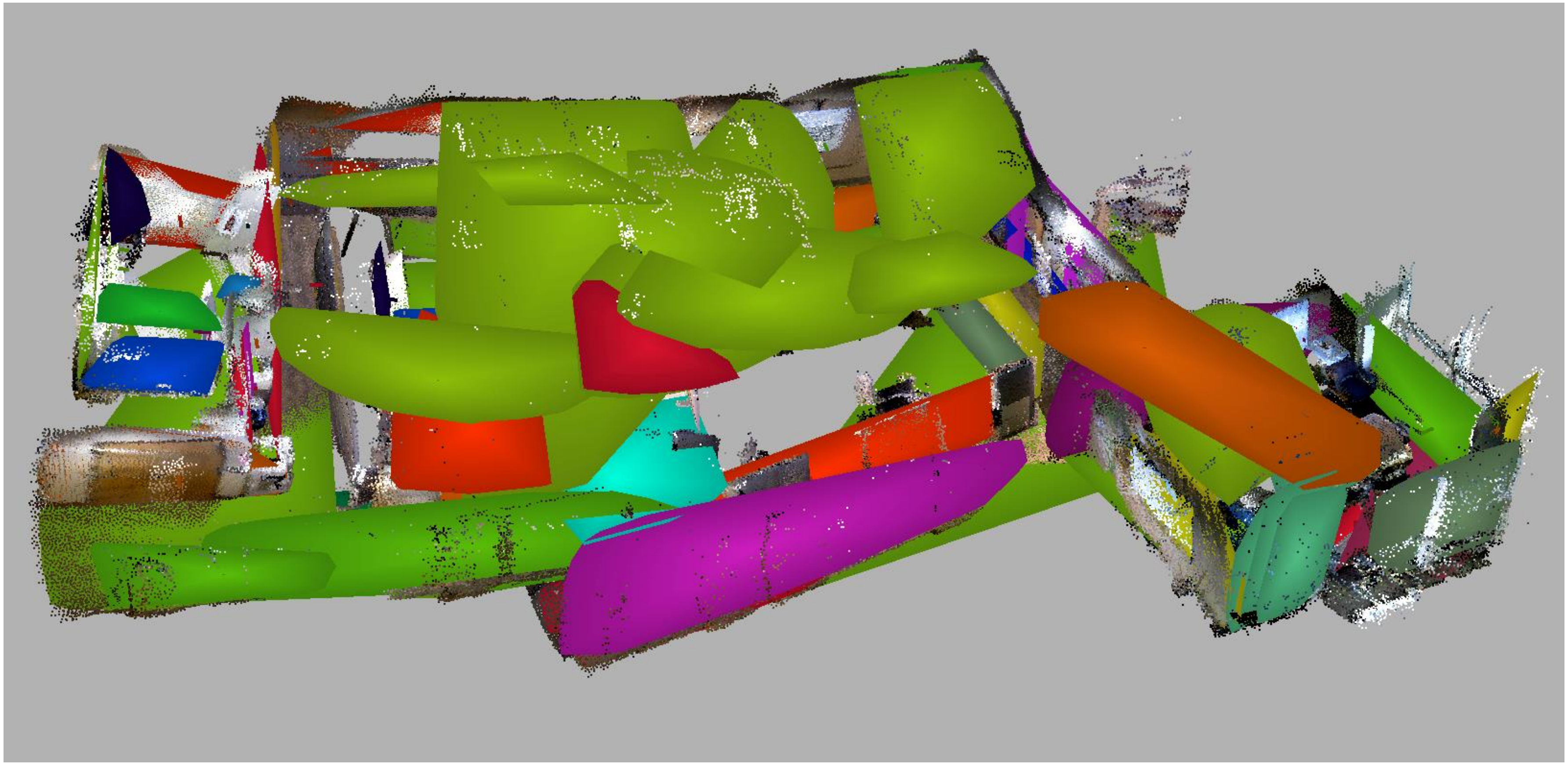
Constraint-Aware ICP Algorithm

Like a global ICP algorithm …



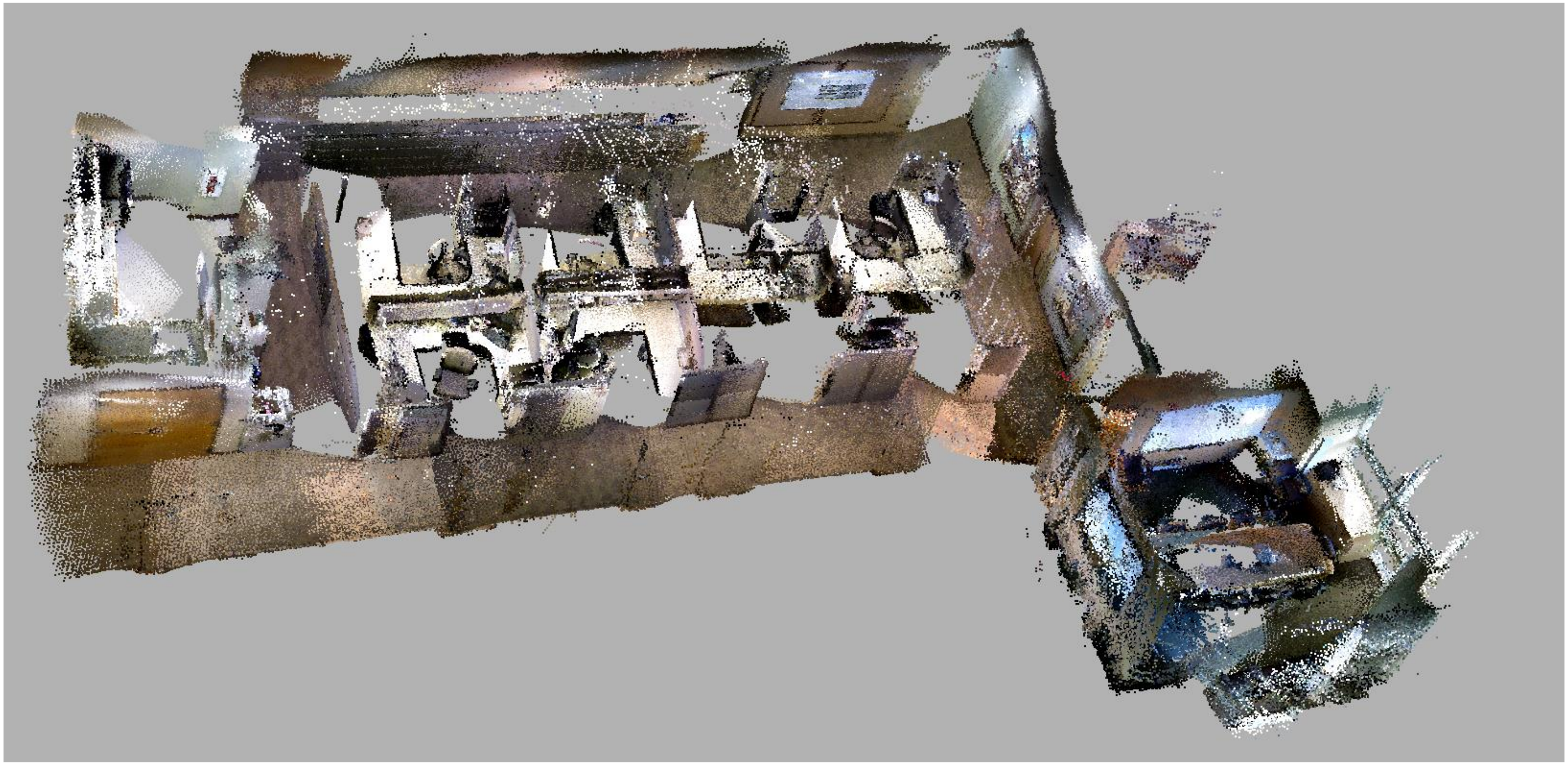
Constraint-Aware ICP Algorithm

… but detect constraint model in inner loop, and …



Constraint-Aware ICP Algorithm

… optimize correspondences and constraints jointly



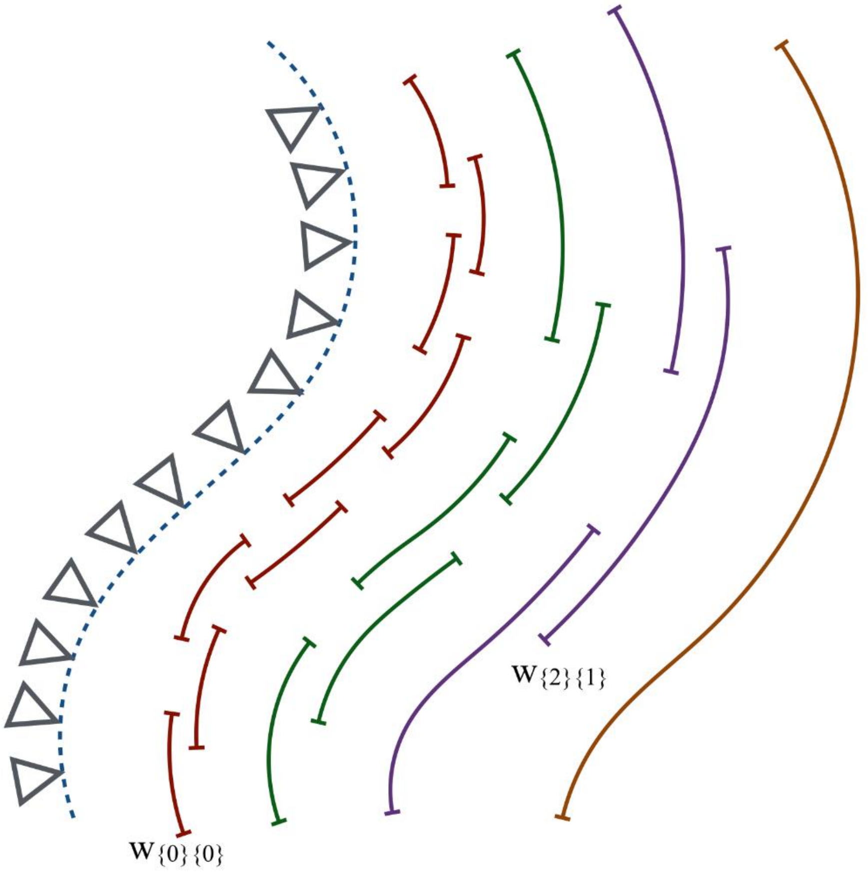
Constraint-Aware ICP Issue

How detect constraints in warped point clouds?

Fine-to-Coarse Registration

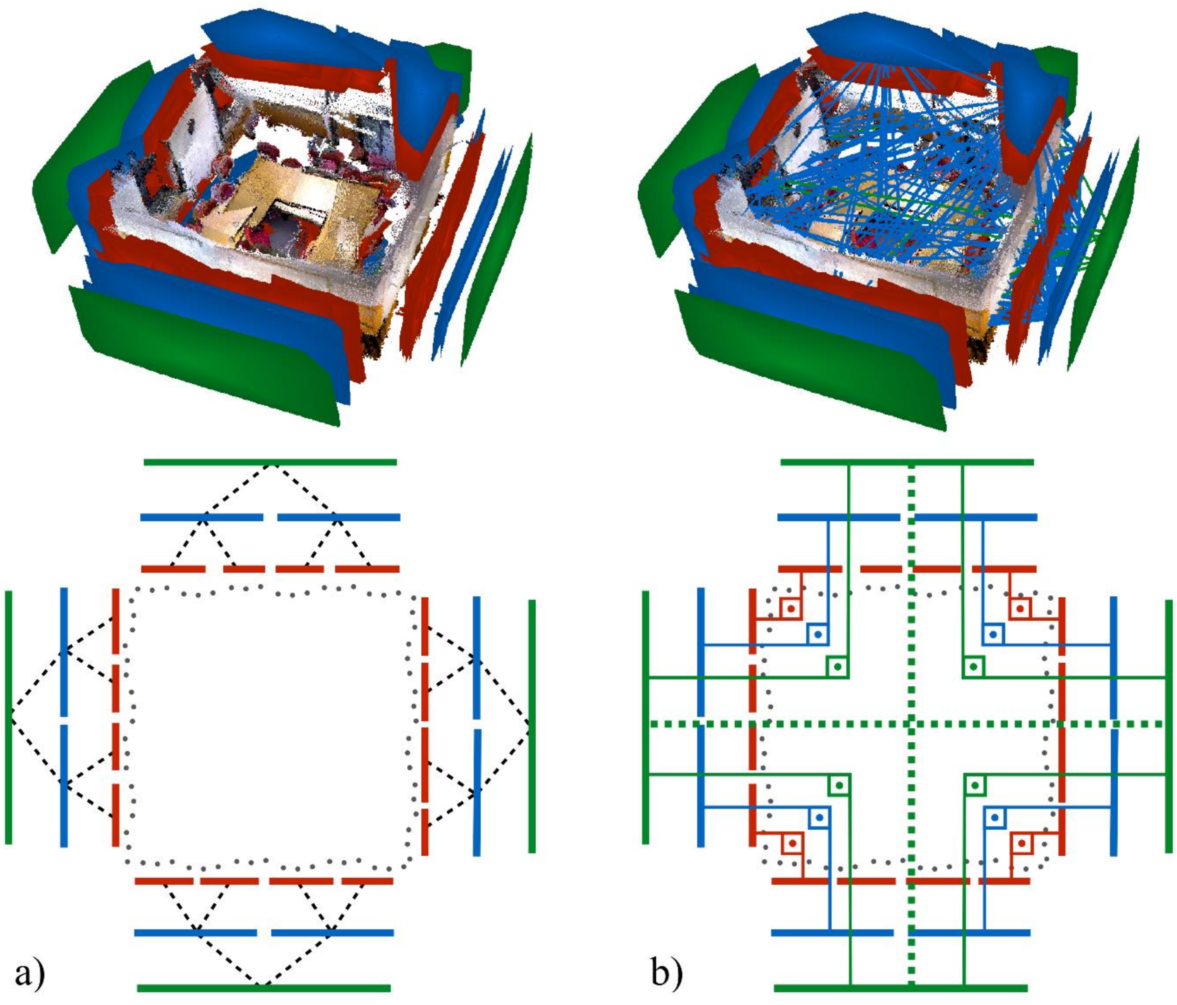
Iteratively:

1. Detect constraints within windows of size w
2. Optimize
3. Increase w

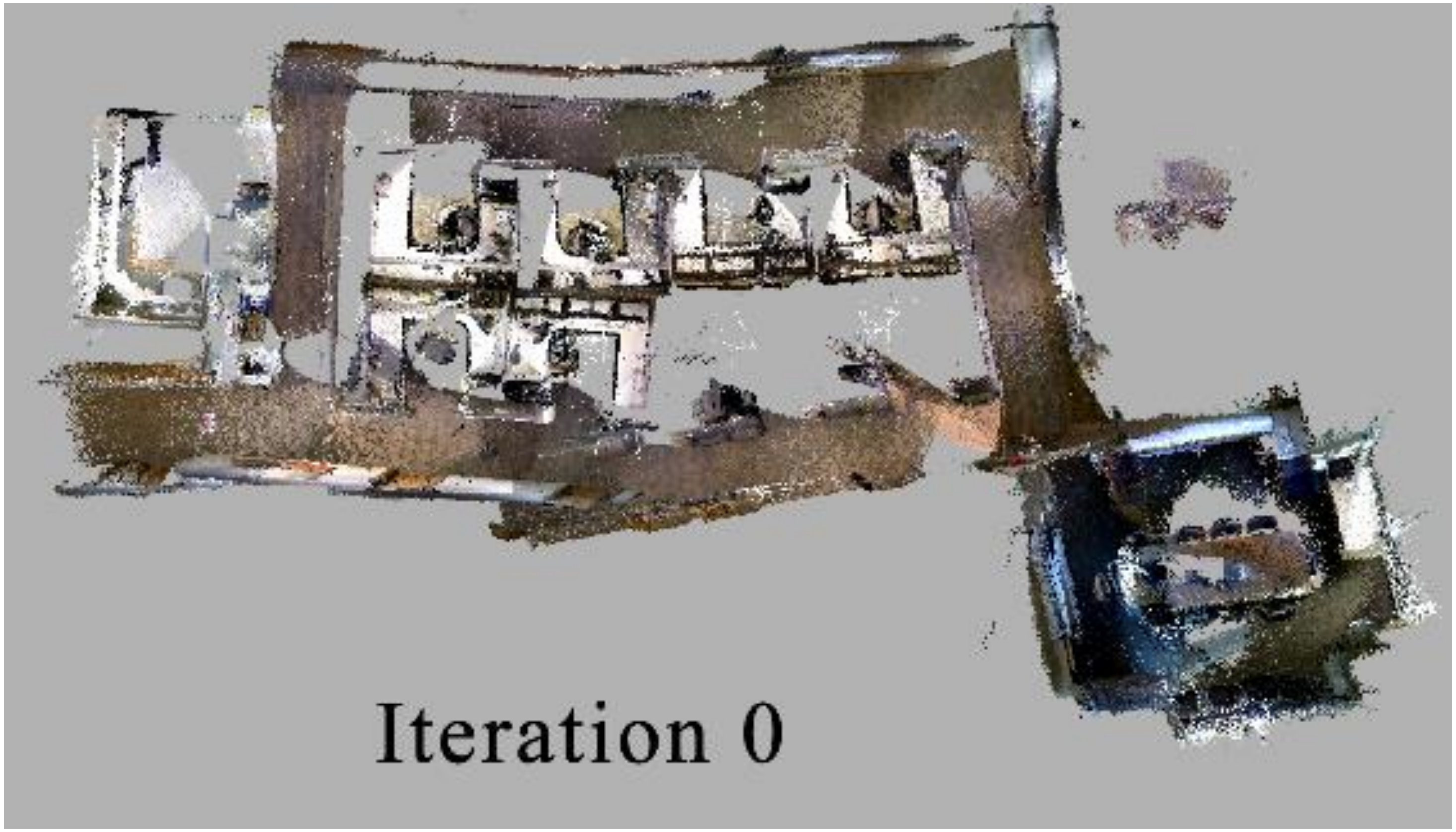


Fine-to-Coarse Registration

Creates hierarchy of structure and constraints

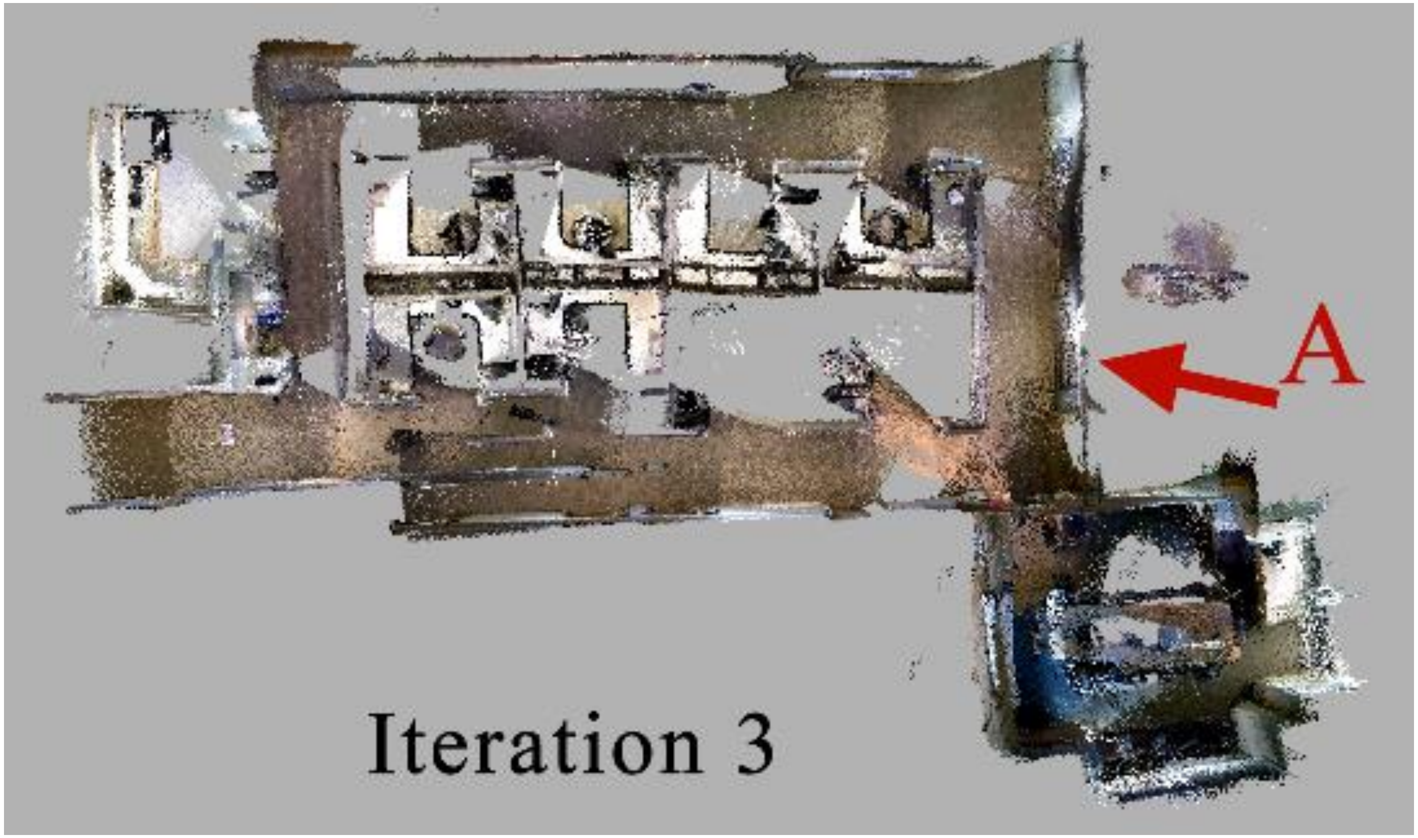


Fine-to-Coarse Registration



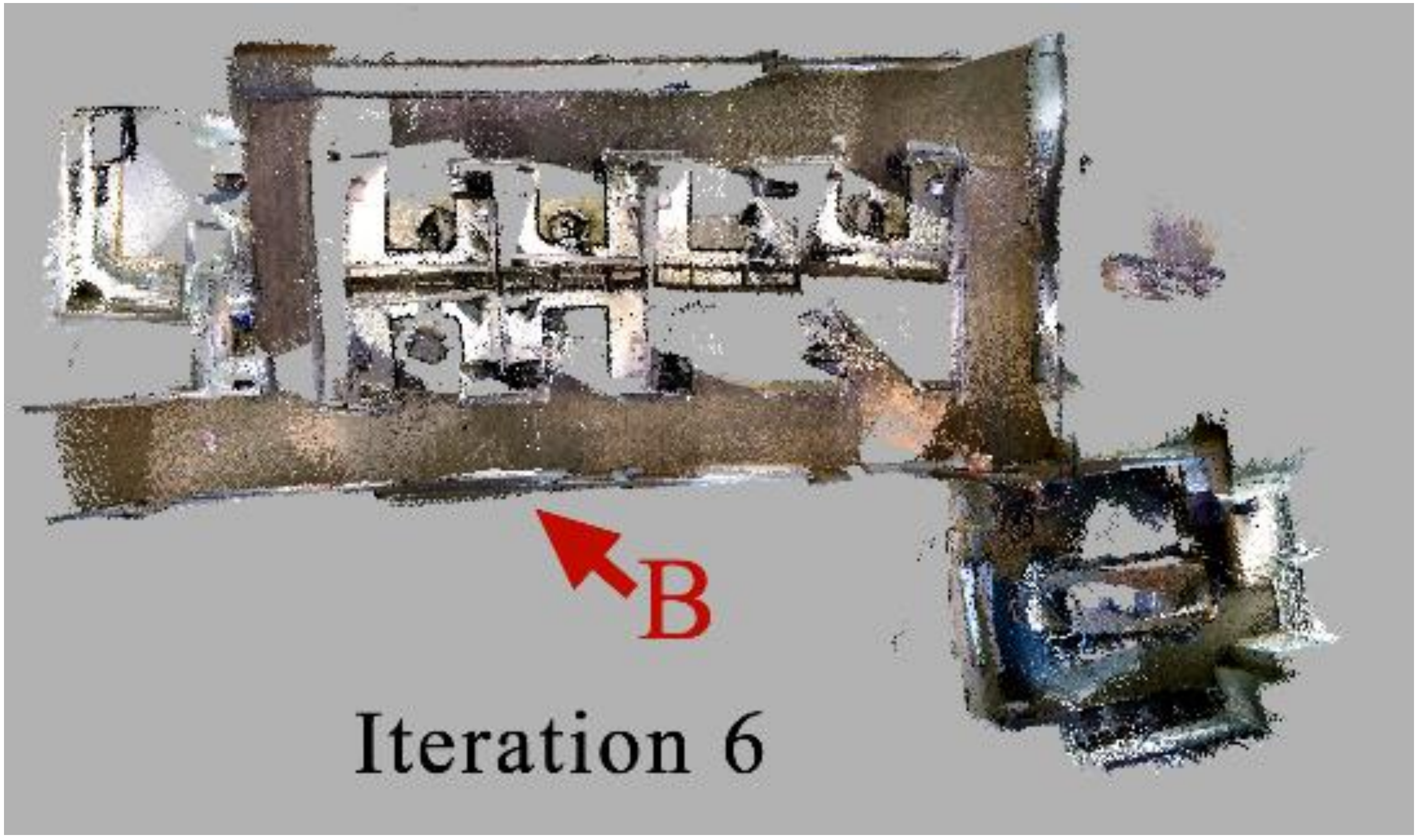
Fine-to-Coarse Registration

Fixes corners, straighten walls, …



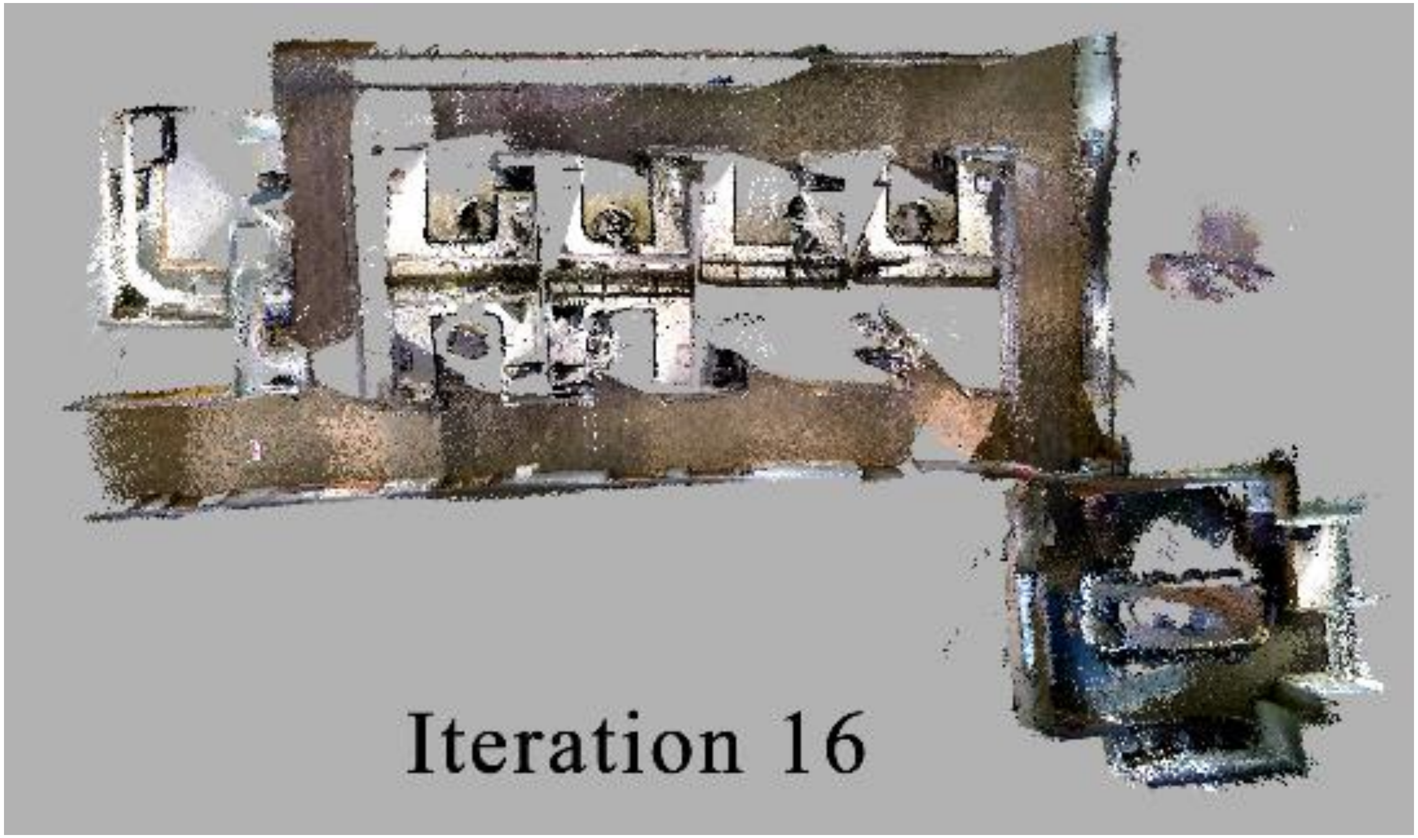
Fine-to-Coarse Registration

Fixes corners, straighten walls, closes loops, …

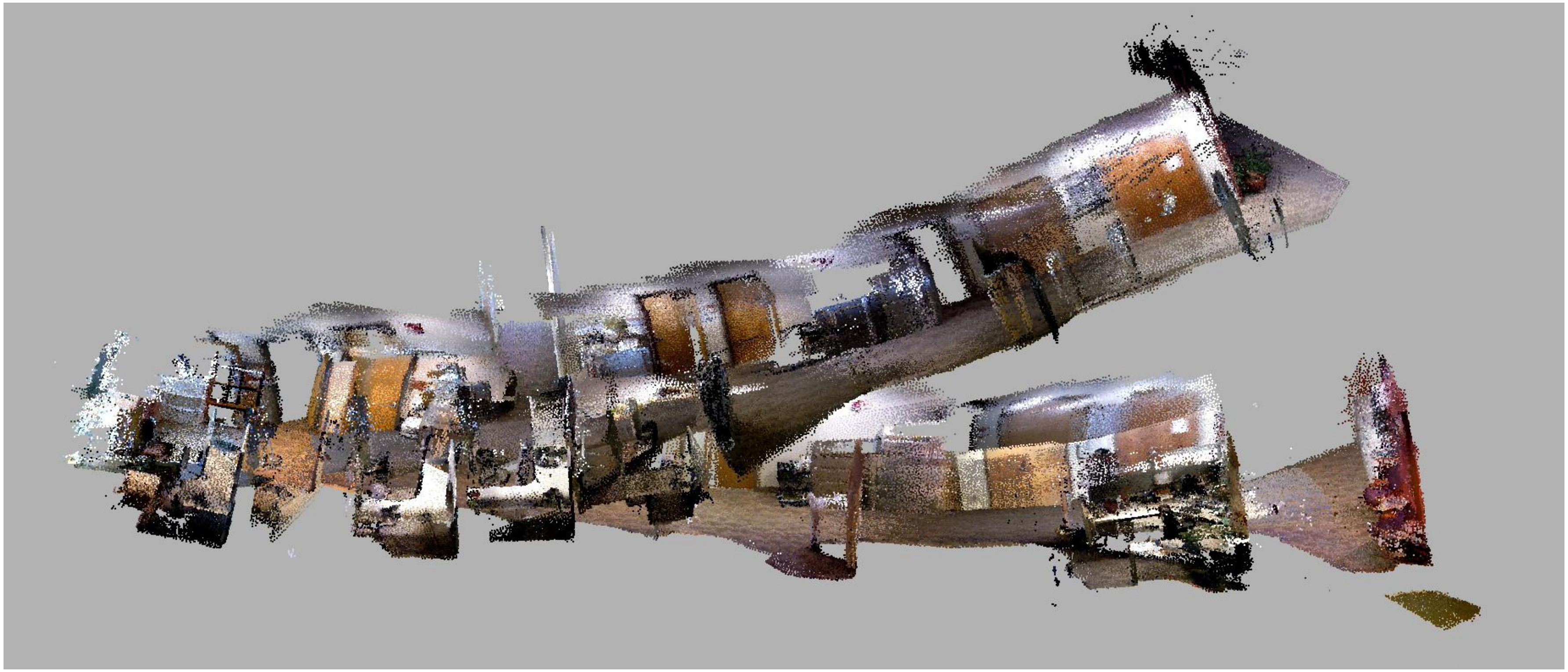


Fine-to-Coarse Registration

Fixes corners, straighten walls, closes loops, snaps



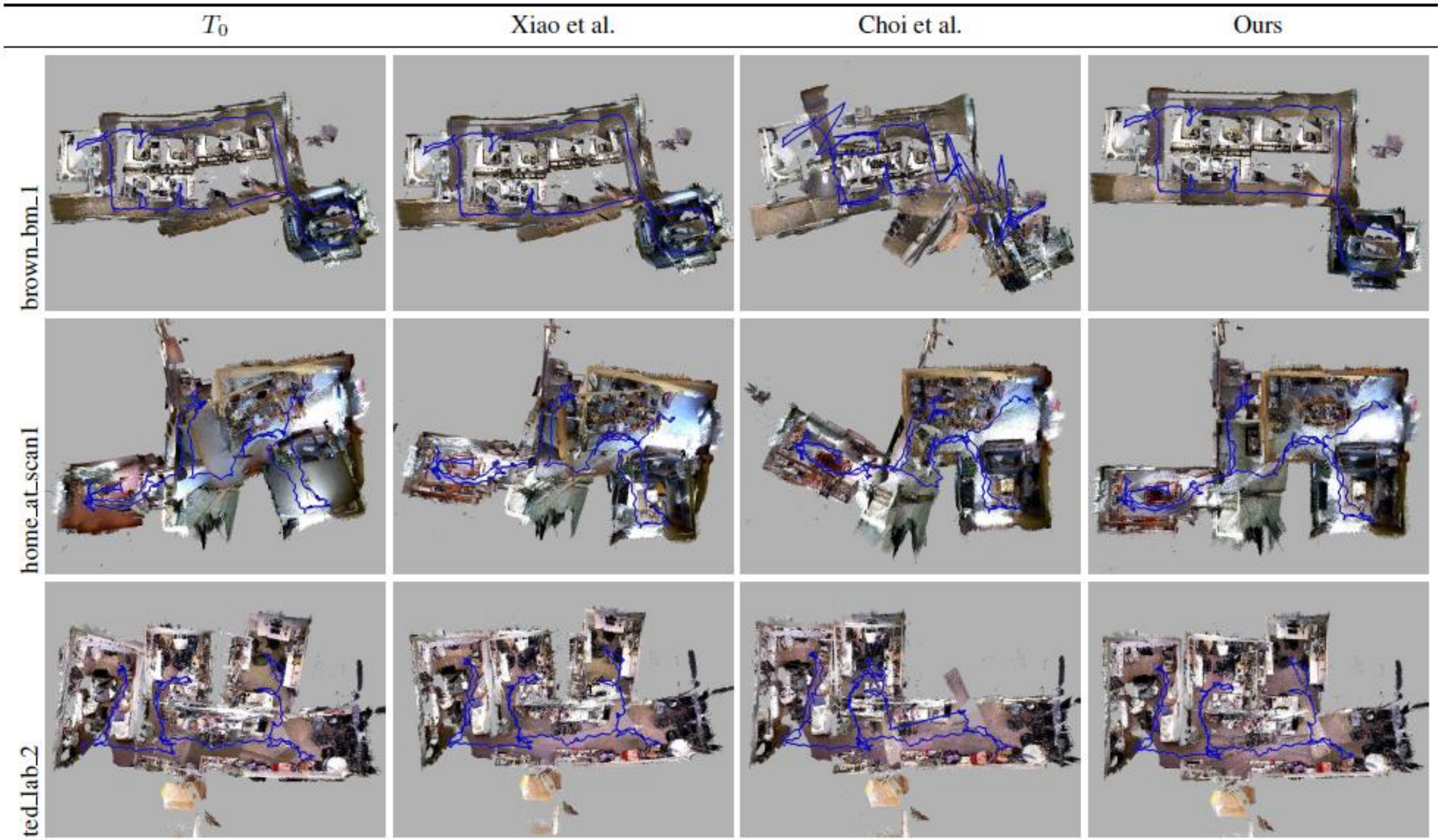
Fine-to-Coarse Registration Example



Constraint-Aware ICP Results

Comparison to previous methods:

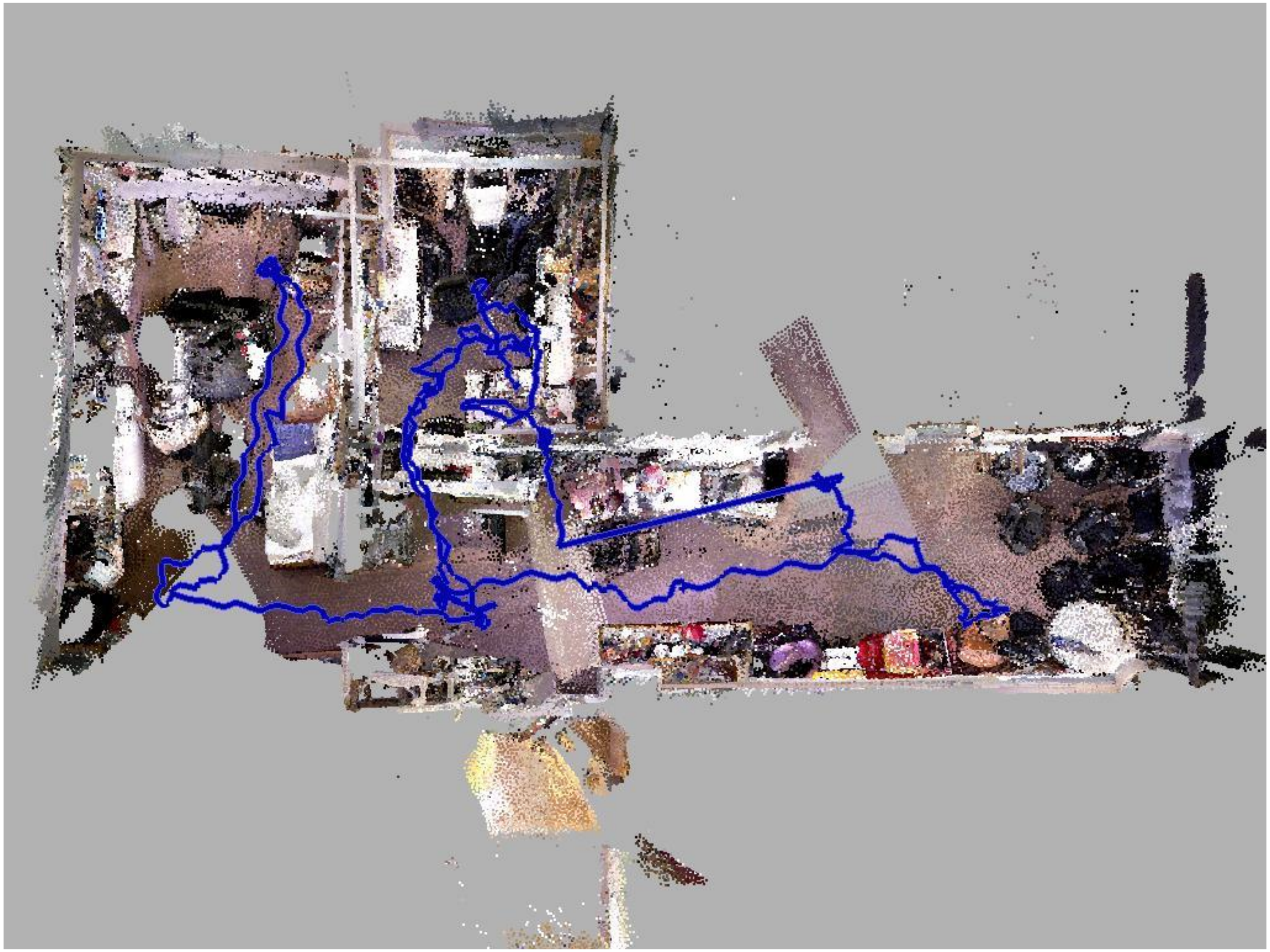
SUN3D



Constraint-Aware ICP Results

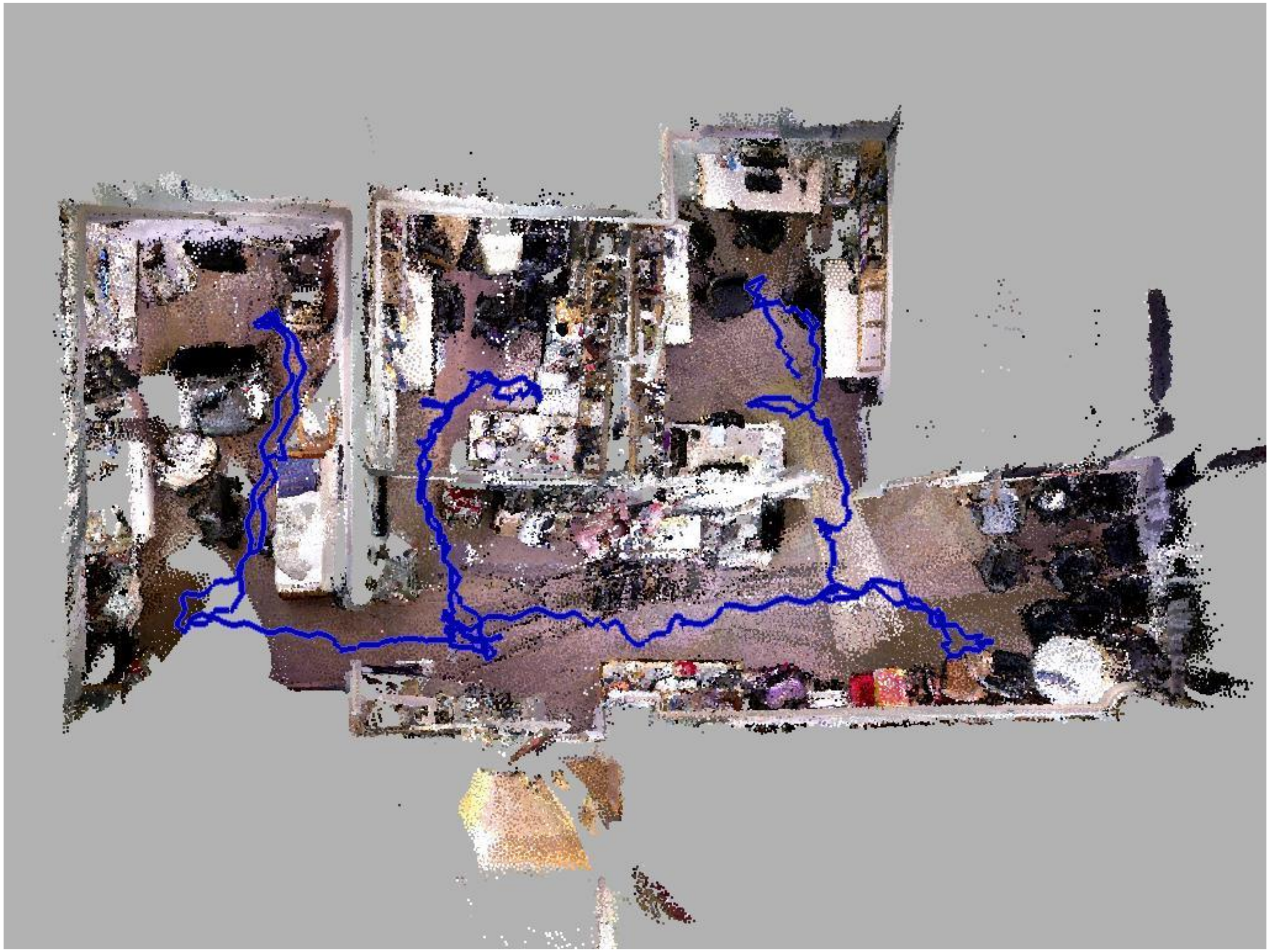
[Xiao et al., 2013]

Constraint-Aware ICP Results



[Choi et al., 2015]

Constraint-Aware ICP Results



Ours

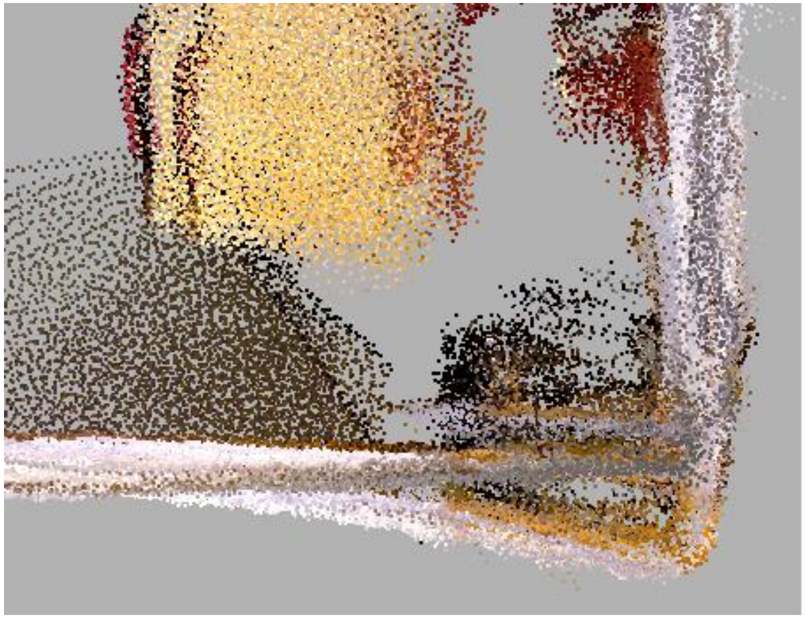
Constraint-Aware ICP Results

Comparison to previous methods:

[Xiao et al., 2013] Ours

Constraint-Aware ICP Results

Comparison to previous methods:



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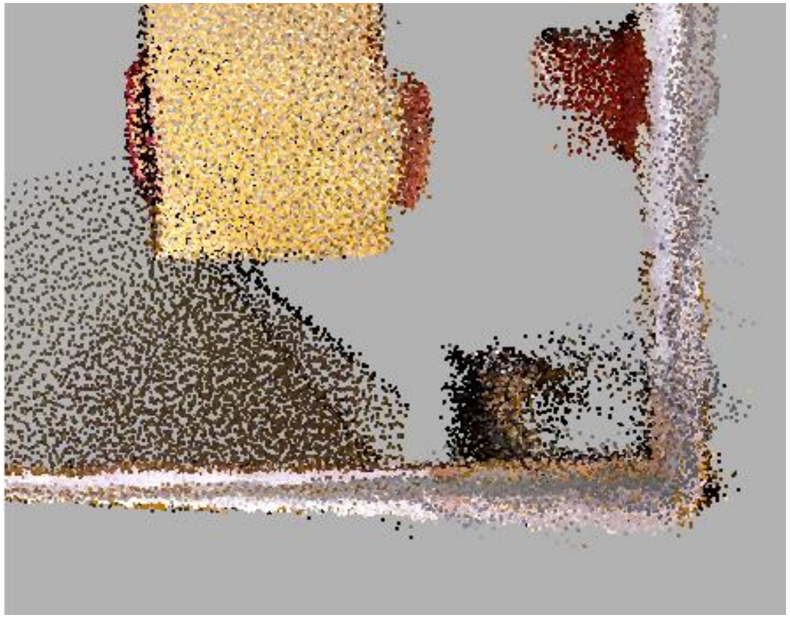
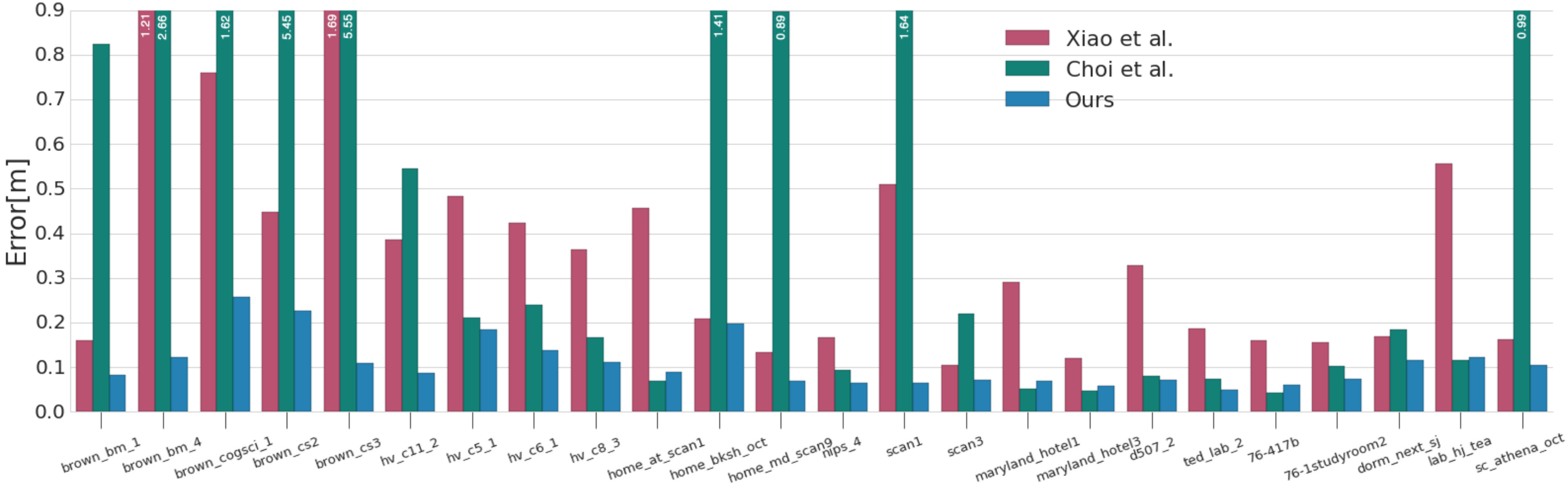


Ours

Constraint-Aware ICP Results

Comparison to previous methods:



Outline of Talk

Introduction

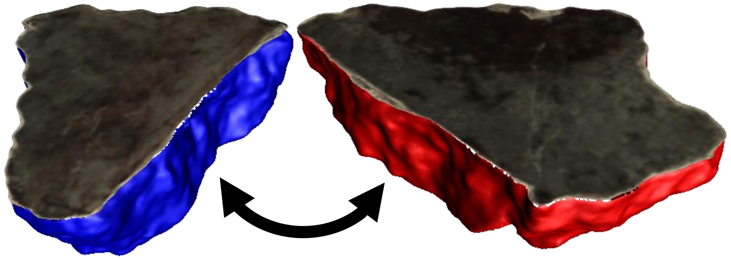
Latent structures

- Symmetries
- Parts
- Affordances
- Constraints
- Assemblies

Conclusion

Assembly-Aware Correspondences

Observation 1: assembling fractured objects requires finding complementary surface correspondences



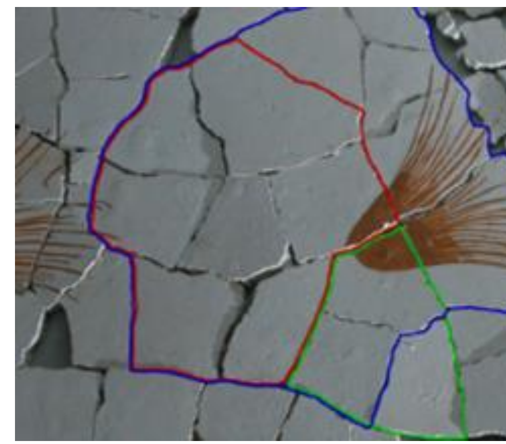
Fragments of fractured wall painting from Akrotiri [Doumas et al.]

Assembly-Aware Correspondences

Observation: fracture correspondences are constrained by latent structure of global assembly

Scanned Fragments

Candidate Correspondences

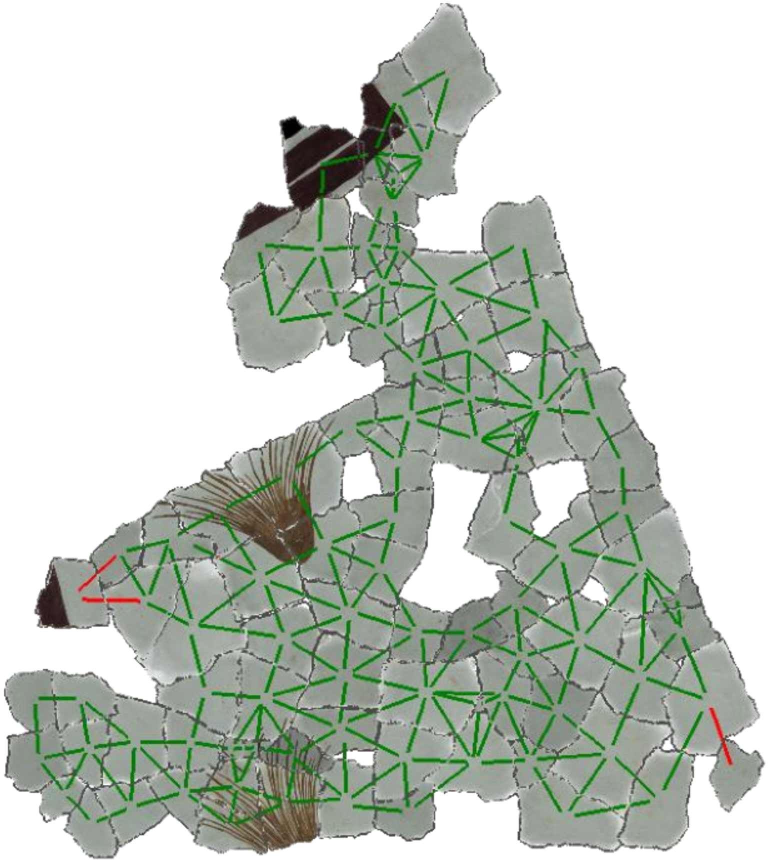


Assembly of Correspondences

Assembly-Aware Correspondences

Approach: search for global assembly directly

Scanned Fragments

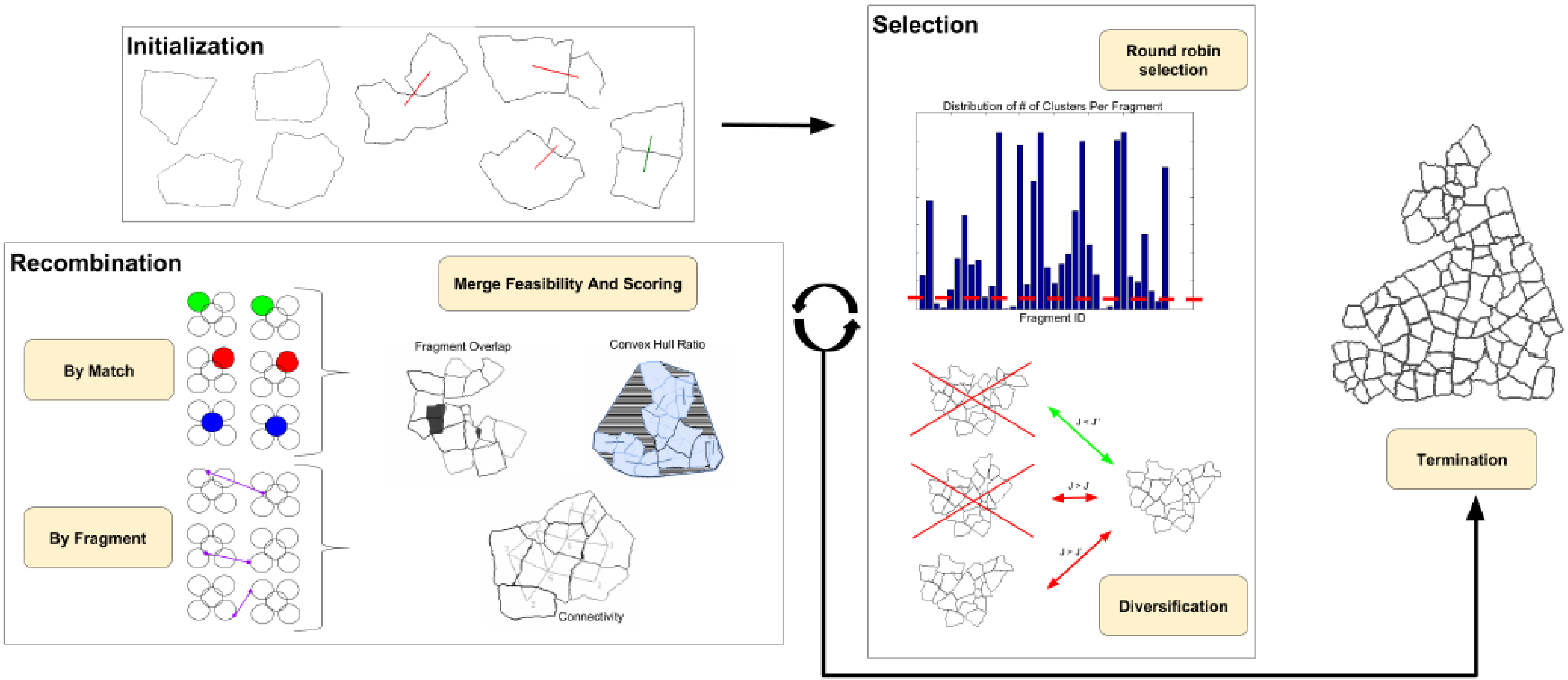


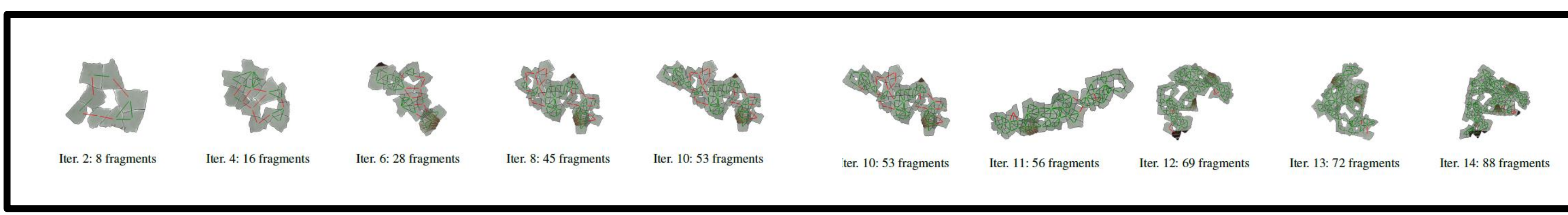
Global Assembly

[Sizikova et al., submitted]

Assembly Search Algorithm

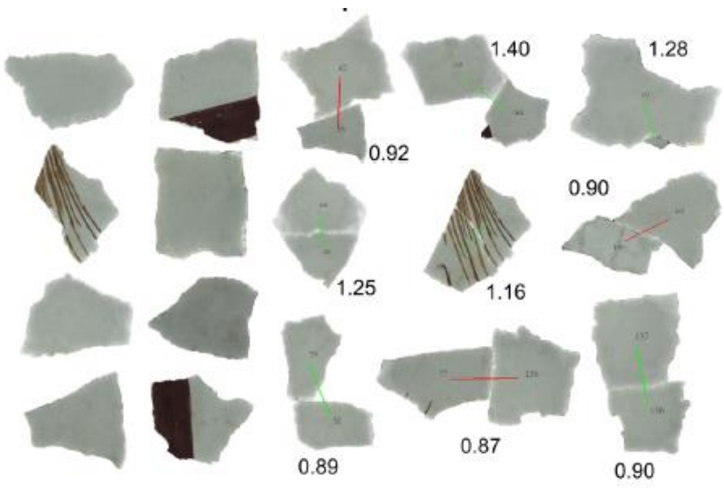
Genetic algorithm:



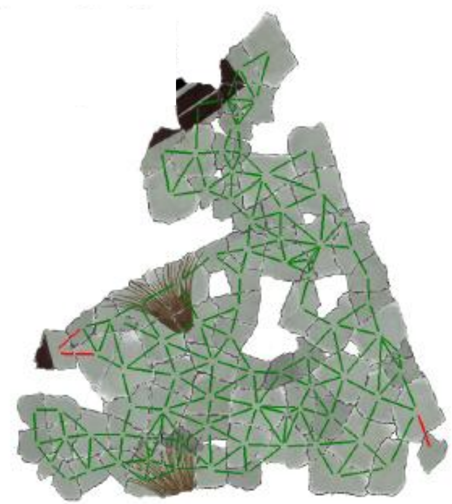


Assembly Search Result

Able to predict correspondences with higher precision and recall with our genetic algorithm



Pairwise Correspondences

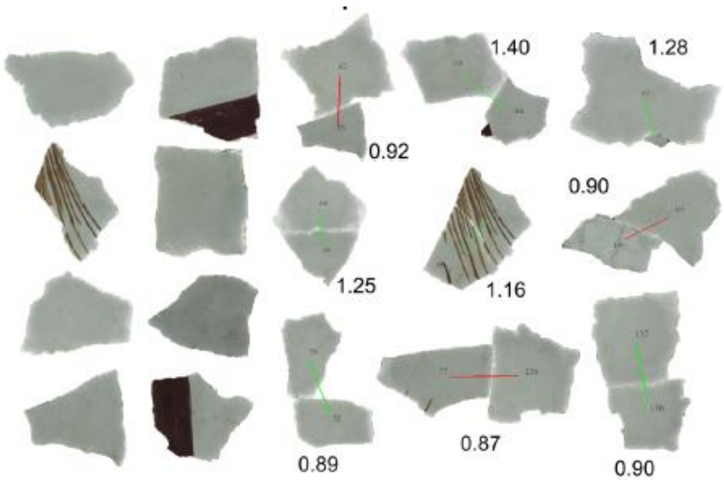


Our Result

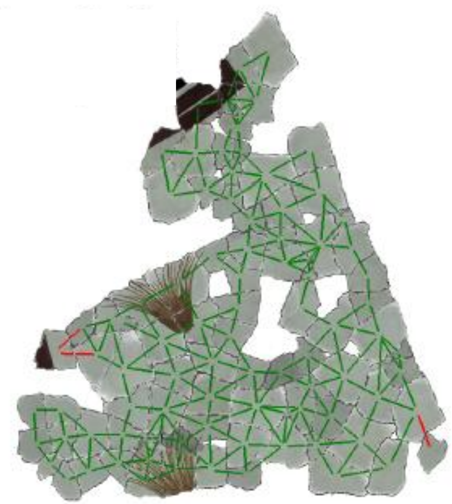
Ground Truth

Assembly Search Result

Able to predict correspondences with higher precision and recall with our genetic algorithm



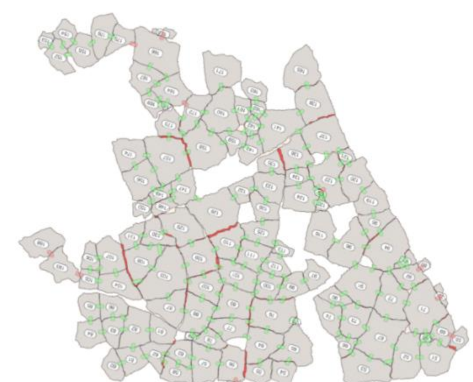
Pairwise Correspondences



Our Result

Ground Truth

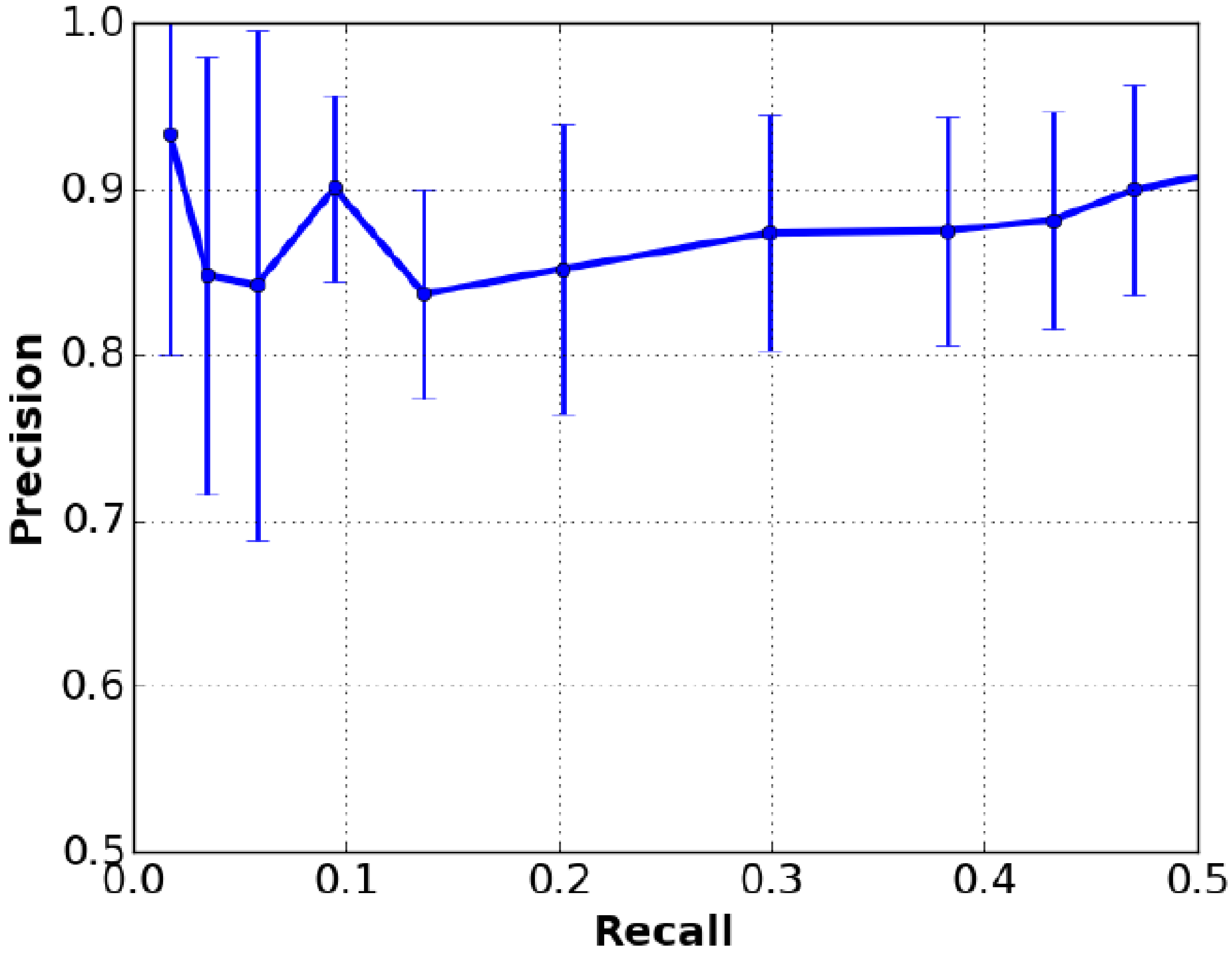
[Hierarchical Clustering]



[Casteneda et al., 2011]

Assembly Search Result

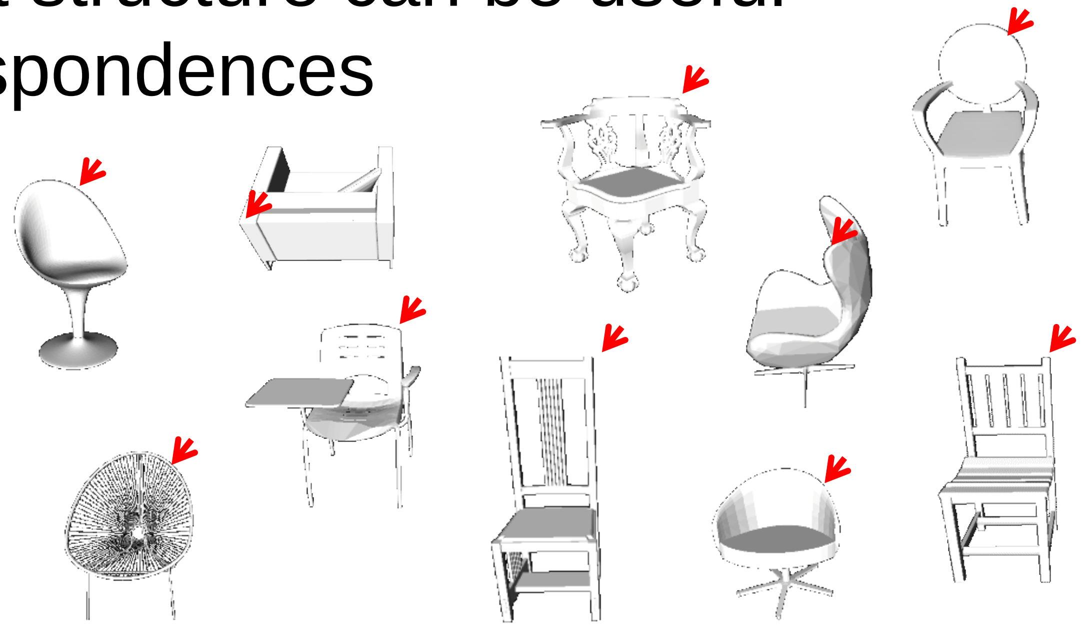
Precision of predicted correspondences gets better as recall increases during our genetic search



Conclusion

Discovering latent structure can be useful for finding correspondences

- Symmetries
- Parts
- Affordances
- Constraints
- Assemblies



Future work on surface correspondence should focus more on structure and semantics

- Hierarchies, supports, contexts, shape priors, physical properties, manufacturing methods, etc.

Acknowledgments

Collaborators:

- Sid Chaudhuri, Steve Diverdi, Leo Guibas, Maciej Halber, Vladimir Kim, Yaron Lipman, Tianqiang Liu, Wilmot Li, Niloy Mitra, Elena Sizikova

Data sets:

- Bronstein et al. (TOSCA), Brown et al. (3D Warehouse), Giorgi et al. (SHREC Watertight), Anguelov et al. (SCAPE), Xiao et al. (SUN3D), Weyrich et al. (Fresco)

Research funding:

- Intel, Adobe, Google, NSF

Thank You!