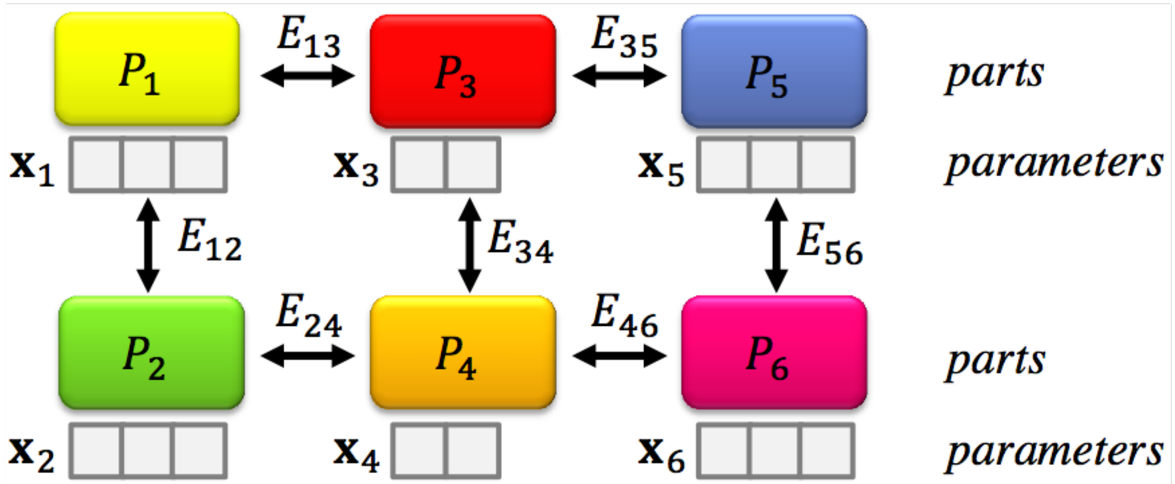
SPONSORED BY

Structure-Aware Shape Processing



vancouver SIGGRAPH2014 NATURALLY DIGITAL

Niloy J. Mitra — UCL

Michael Wand — Universiteit Utrecht

Hao Zhang — SFU

Daniel Cohen-Or — TEL AVIV UNIVERSITY

Vladimir Kim — Stanford University

Qi-Xing Huang — Stanford University

Course Structure

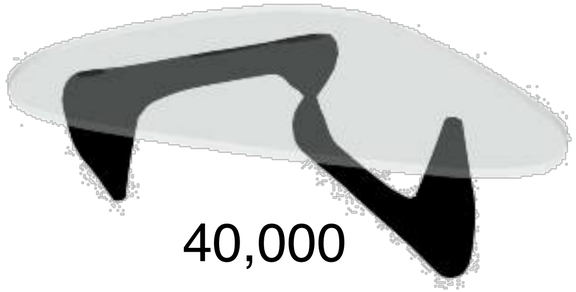
- **Introduction to Geometric ‘Structure’**
- **Extracting Structures**
  - analysis of Individual Models
  - analysis of Shape Collections (co-analysis)
  - encoding Structural Hierarchy
- **Manipulating Structures**
  - Modeling as Structural Variations
  - Structure-guided Design
  - **Organization + Exploration of Shape Collections**
- **Future Directions**

Organization & Exploration

Motivation

25,000

10,000



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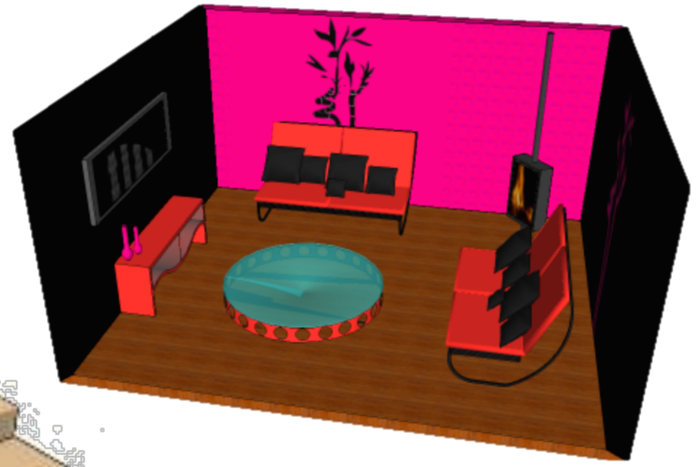
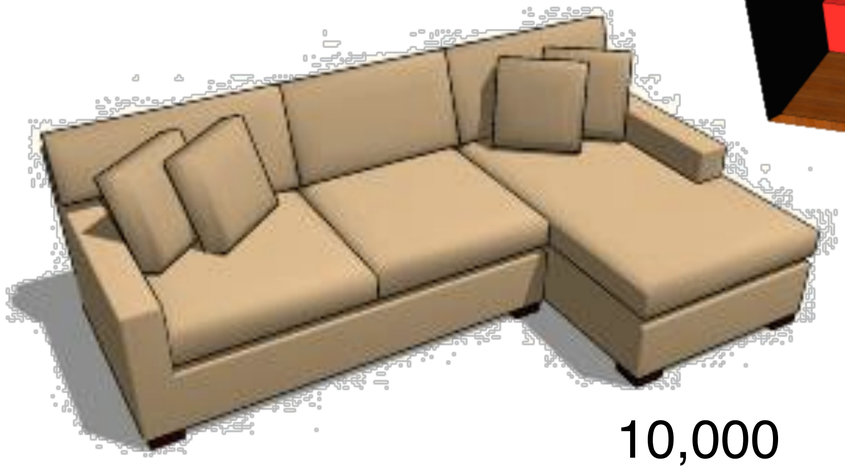


10,000

53,000

9,000



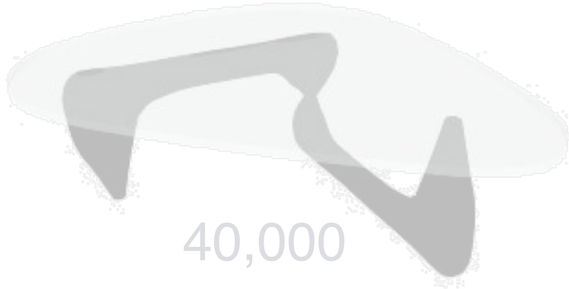
10,000

Sketchup 3D Warehouse

Motivation

25,000

10,000



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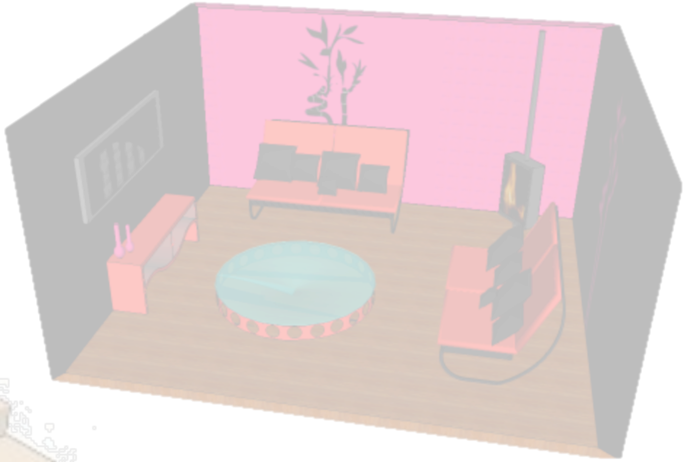

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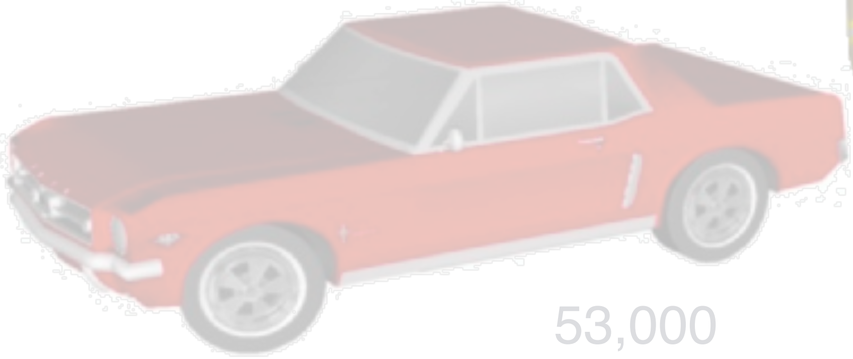
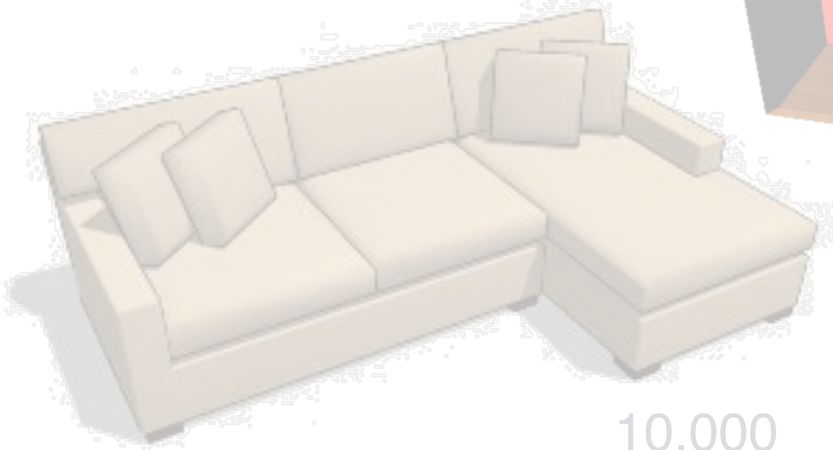


53,000

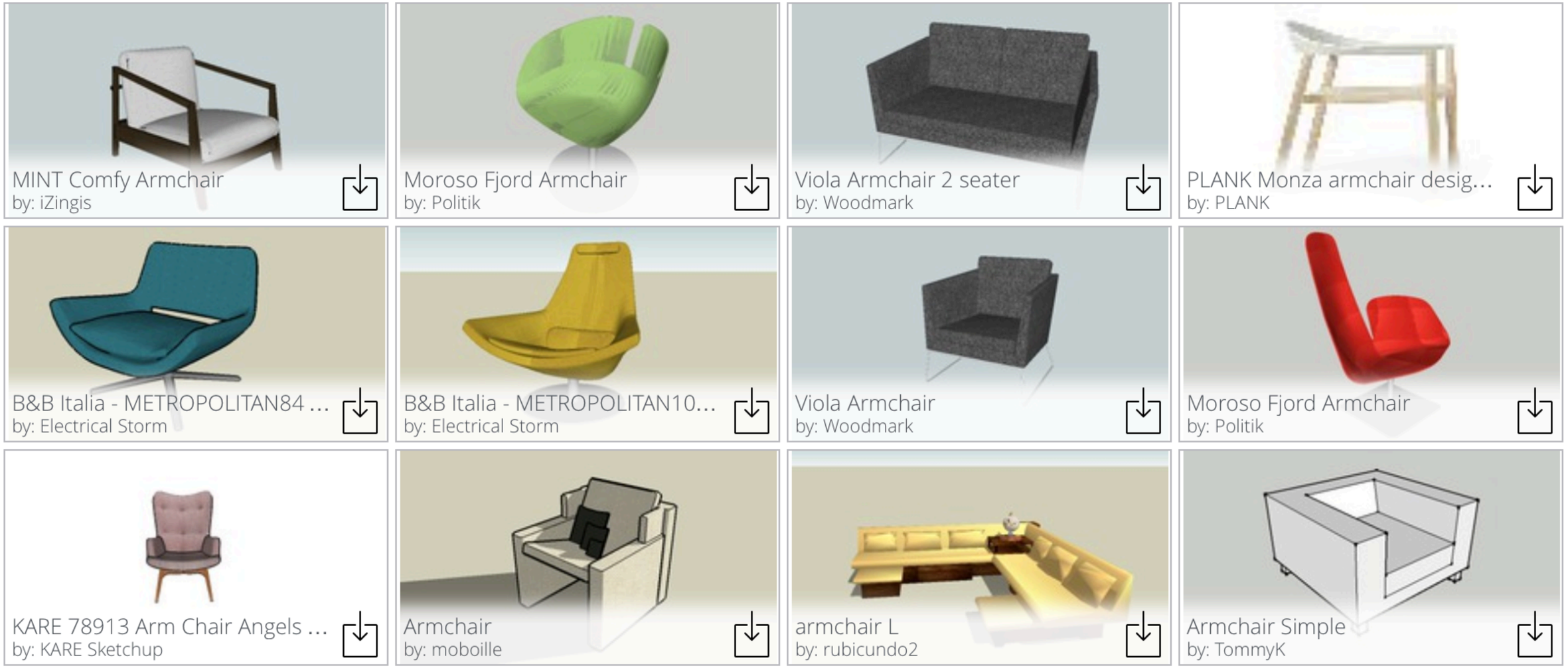
9,000



10,000

Sketchup 3D Warehouse

Motivation



Sketchup 3D Warehouse

Previous Work

- **Shape Retrieval**
  - User has a desired model in mind and specifies a query

Text-based

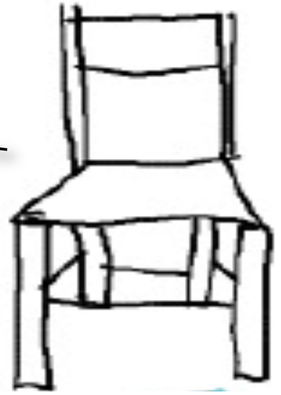
Shape-based

Moroso Fjord Armchair

[SketchUp Warehouse]

Shape Space

Sketch-based

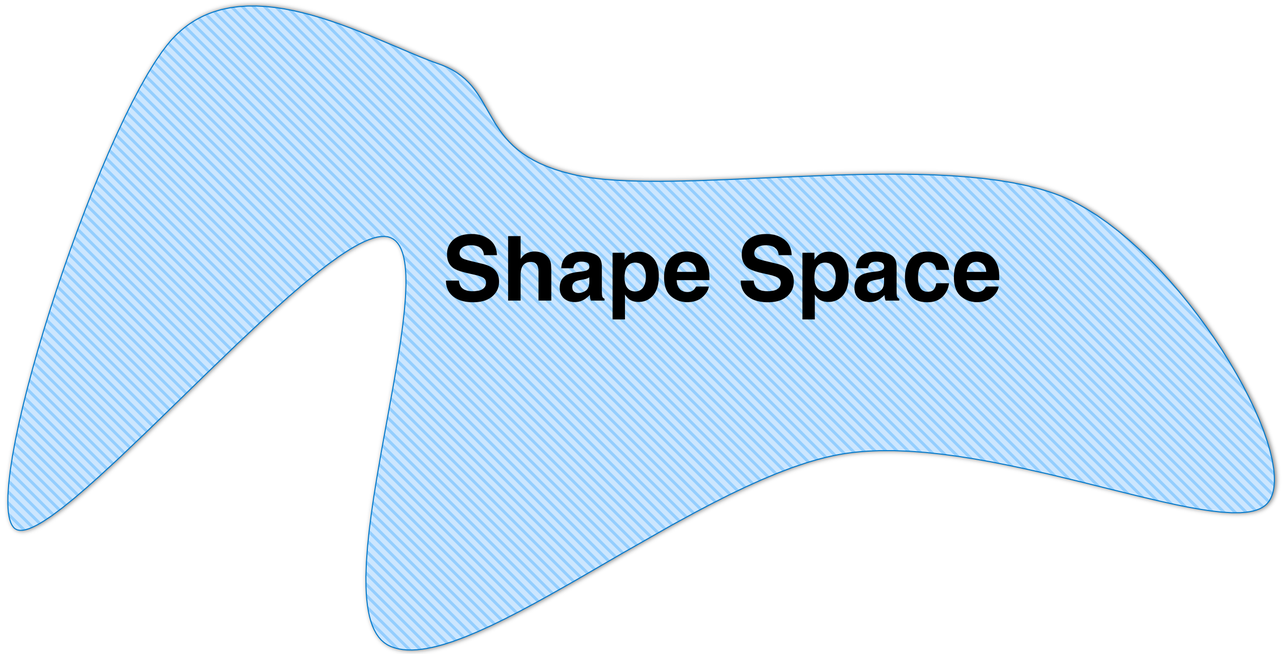


[A Search Engine for 3D Models, Funkhouser et al. 2003]

[Sketch-based Shape Retrieval, Eitz et al. 2012]

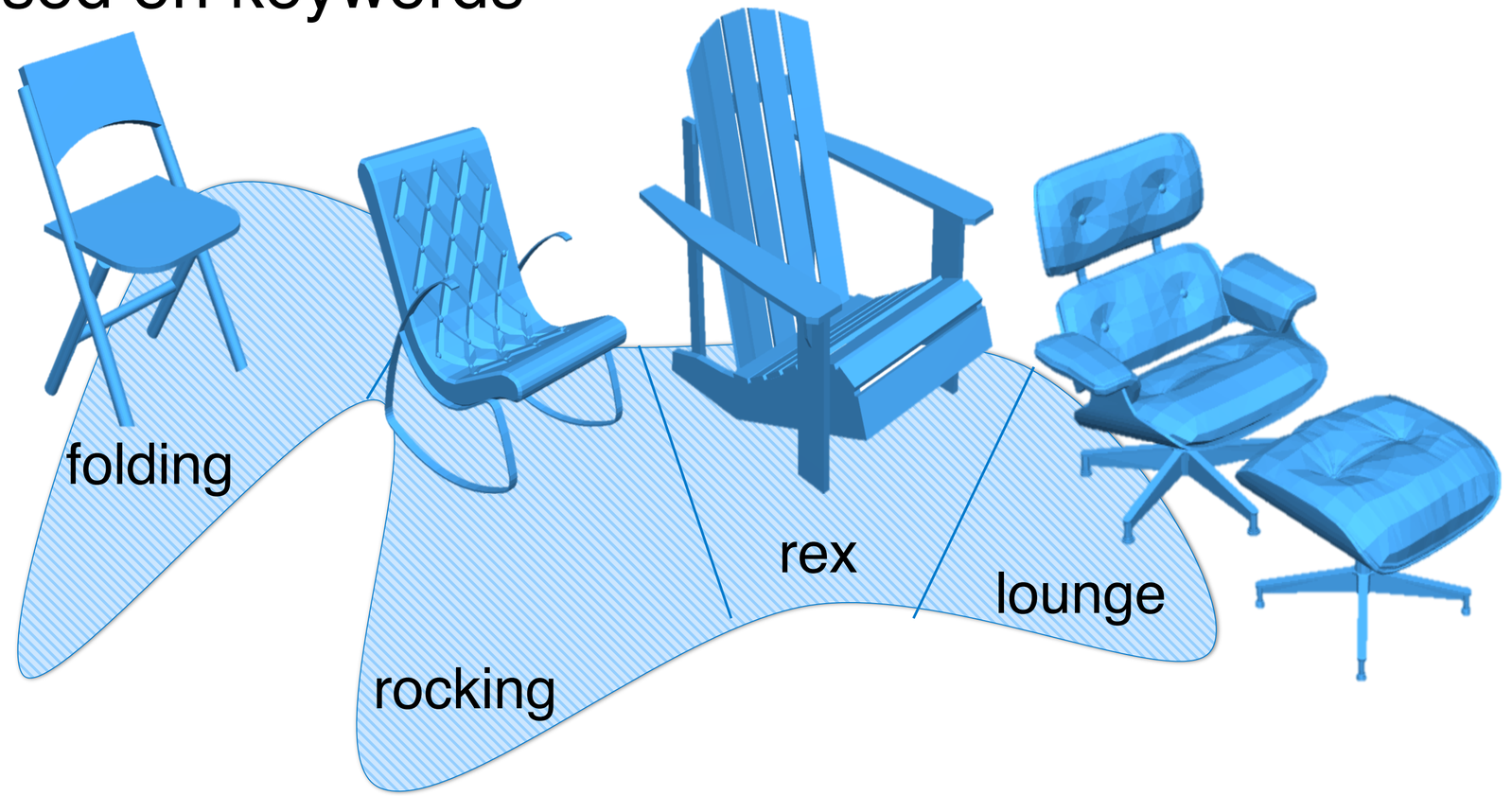
Exploration

- **Exploration Challenges**
  - User intent is not known a-priori
  - User needs to understand the shape space



Database Organization

- **Categorization**
  - Organize based on keywords



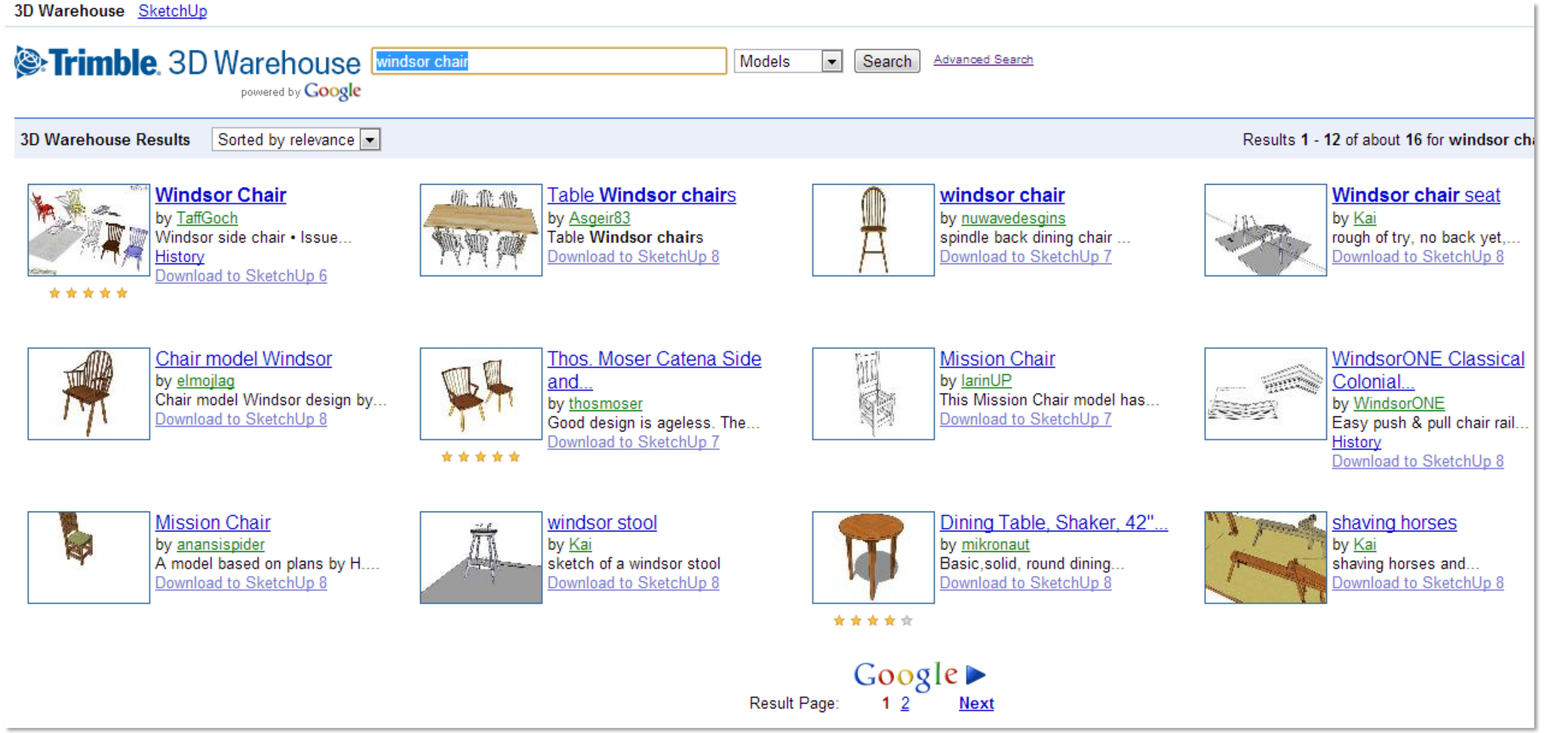
Fine-grained Classification

- **Propagating the tags from annotated shapes**

With-arms

Rocking

Windsor

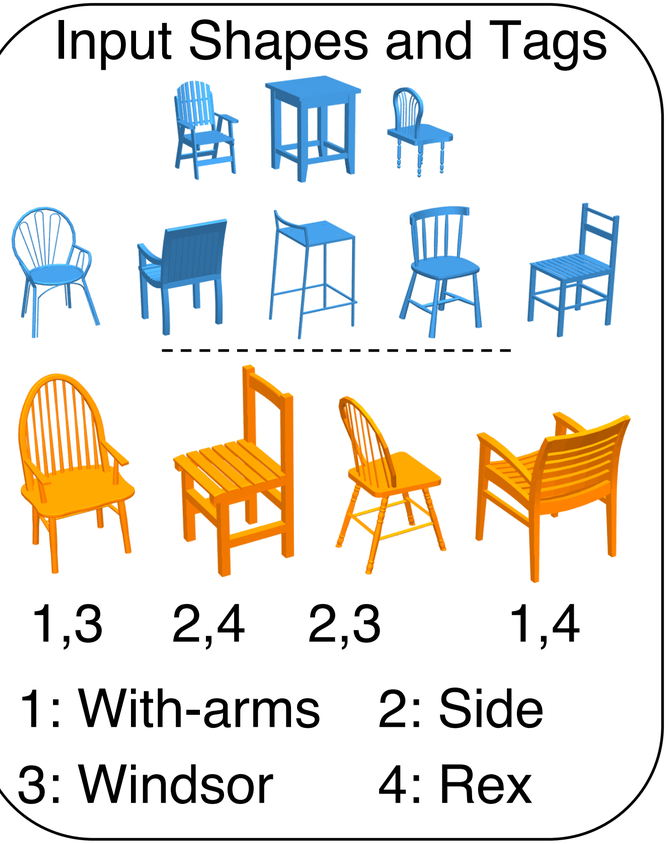


Sparse & noisy labels from uploaders

[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Fine-grained Classification

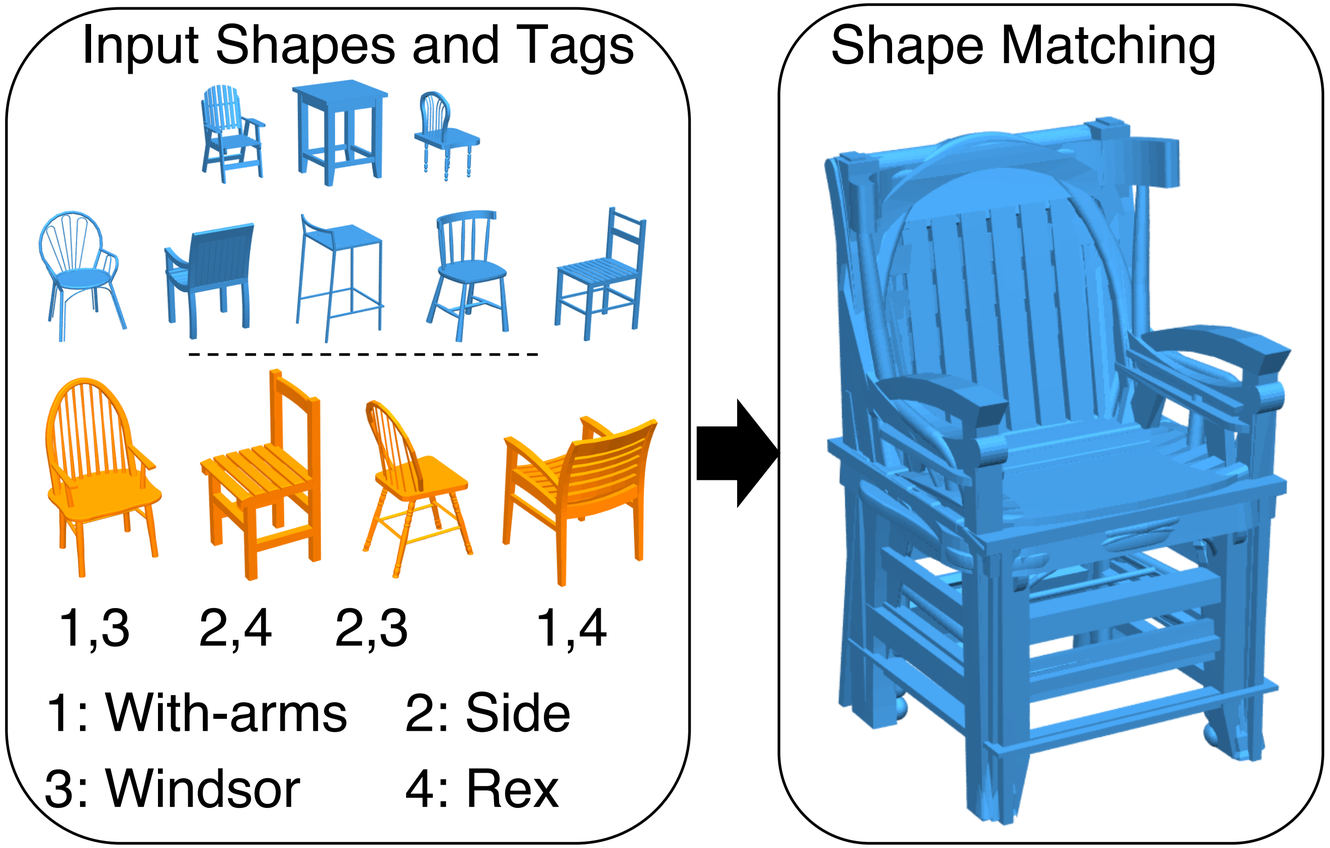
- **Analysis**



[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Fine-grained Classification

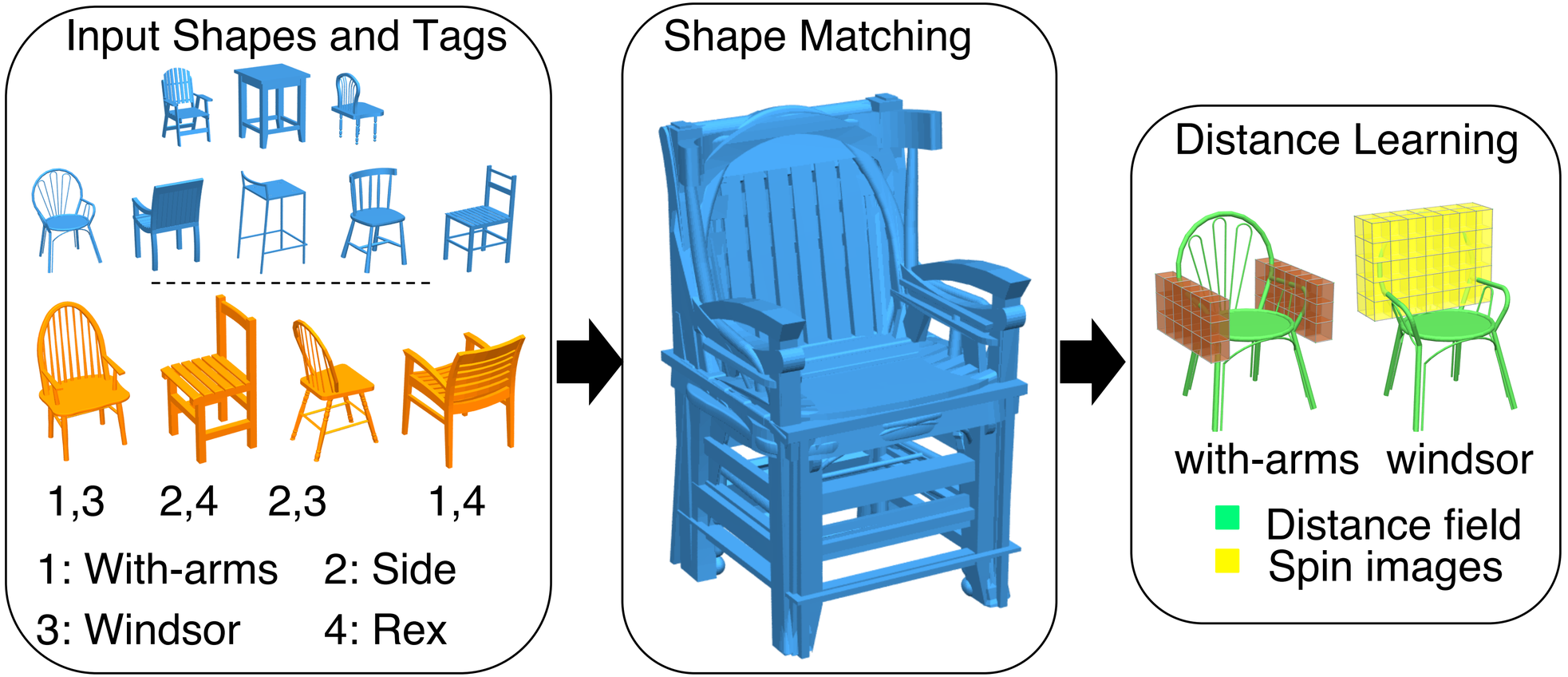
- **Analysis**



[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Fine-grained Classification

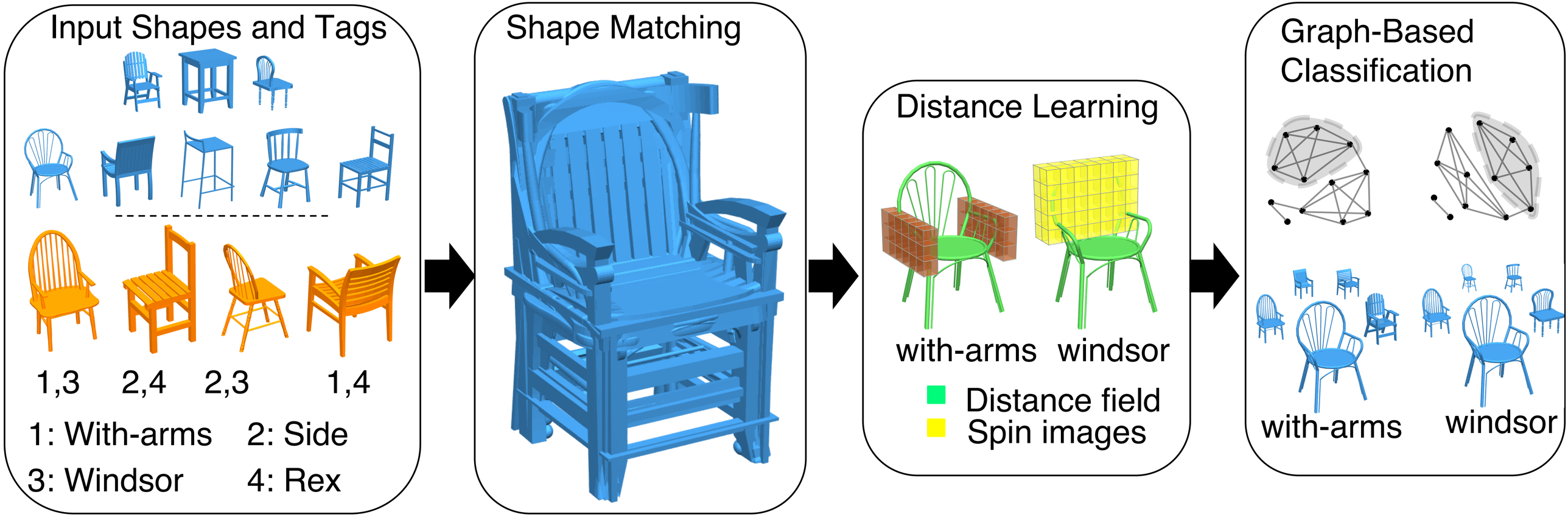
- **Analysis**



[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Fine-grained Classification

- **Analysis**

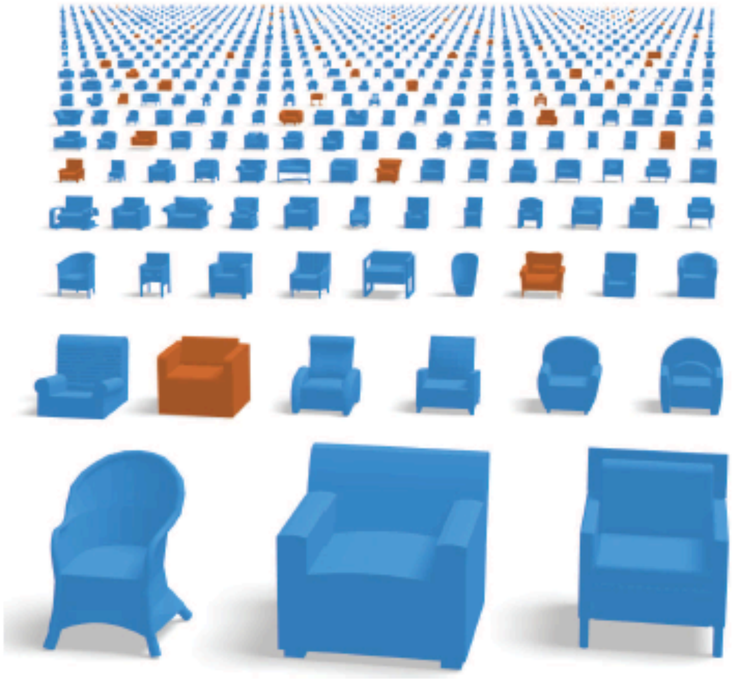


[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Fine-grained Classification

- **Result**

Chairs-with-arms



Club

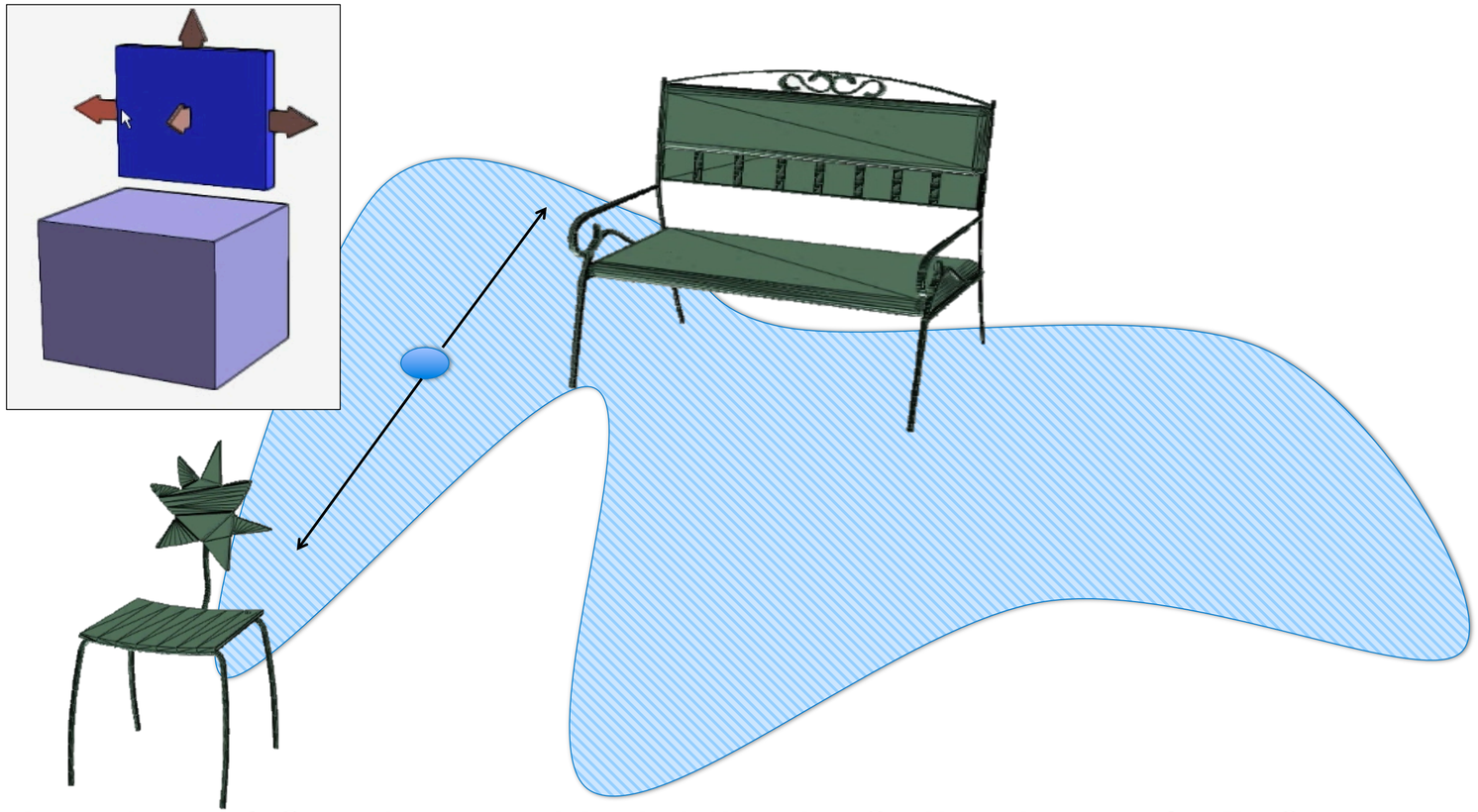
Swivel

Rex

[Fine-Grained Semi-Supervised Labeling of Large Shape Collections, Huang et al. 2013]

Data Organization

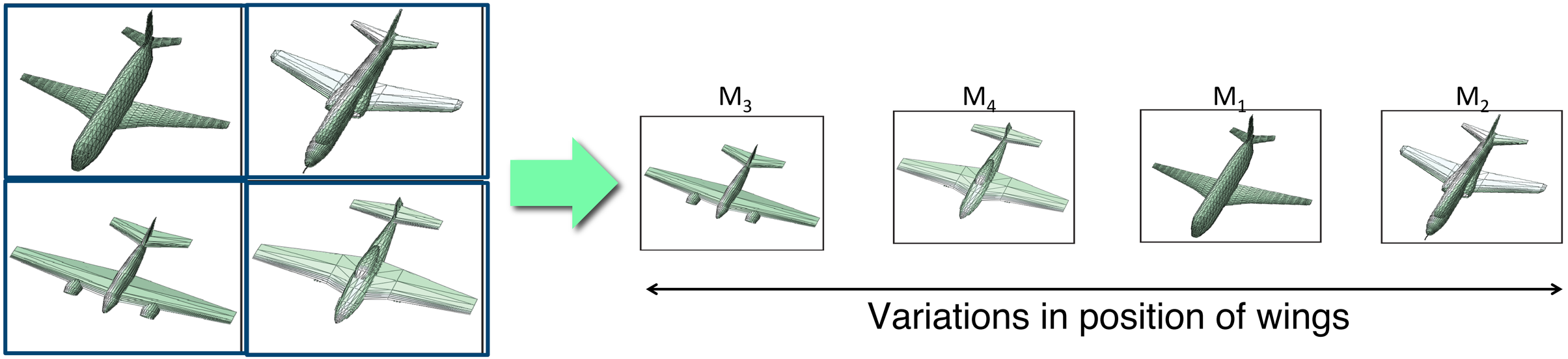
- **Part-based Exploration**
  - Navigate by deforming a template



[Exploration of Continuous Variability in Collections of 3D Shapes, Ovsjanikov et al. 2011]

Part-based Exploration

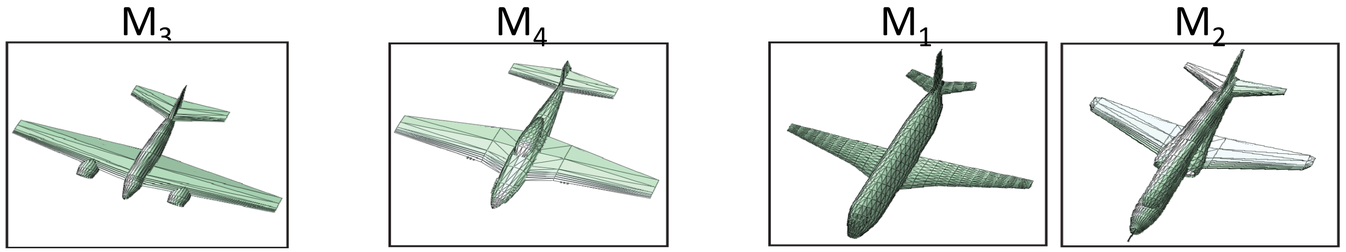
- **Key Idea**
  - Models are linked by low degree of freedom / variations



[Exploration of Continuous Variability in Collections of 3D Shapes, Ovsjanikov et al. 2011]

Part-based Exploration

- **Analysis**

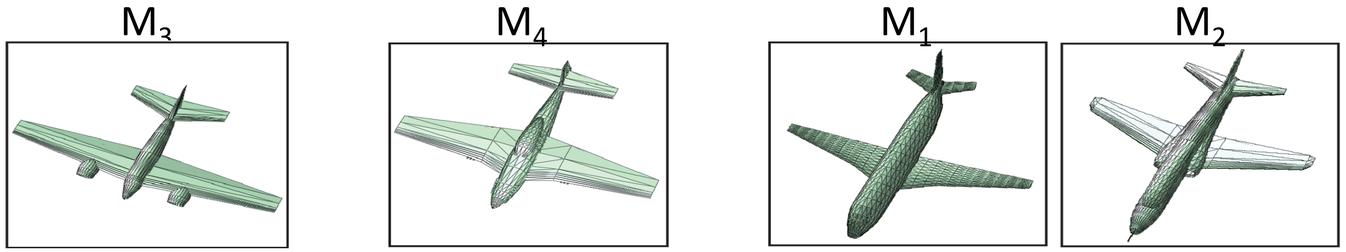


Descriptor space

1. **Convert to descriptor space**
2. Select Template
3. Deform template to fit curve
4. Generate morphable model

Part-based Exploration

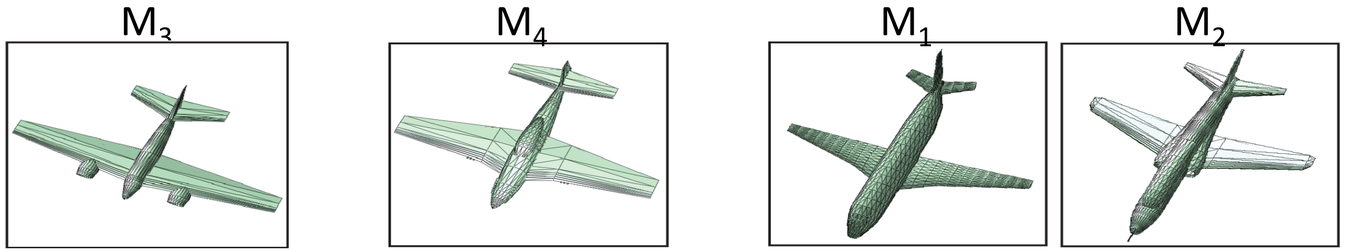
- **Analysis**



1. **Convert to descriptor space**
2. Select Template
3. Deform template to fit curve
4. Generate morphable model

Part-based Exploration

- **Analysis**



1. Convert to descriptor space

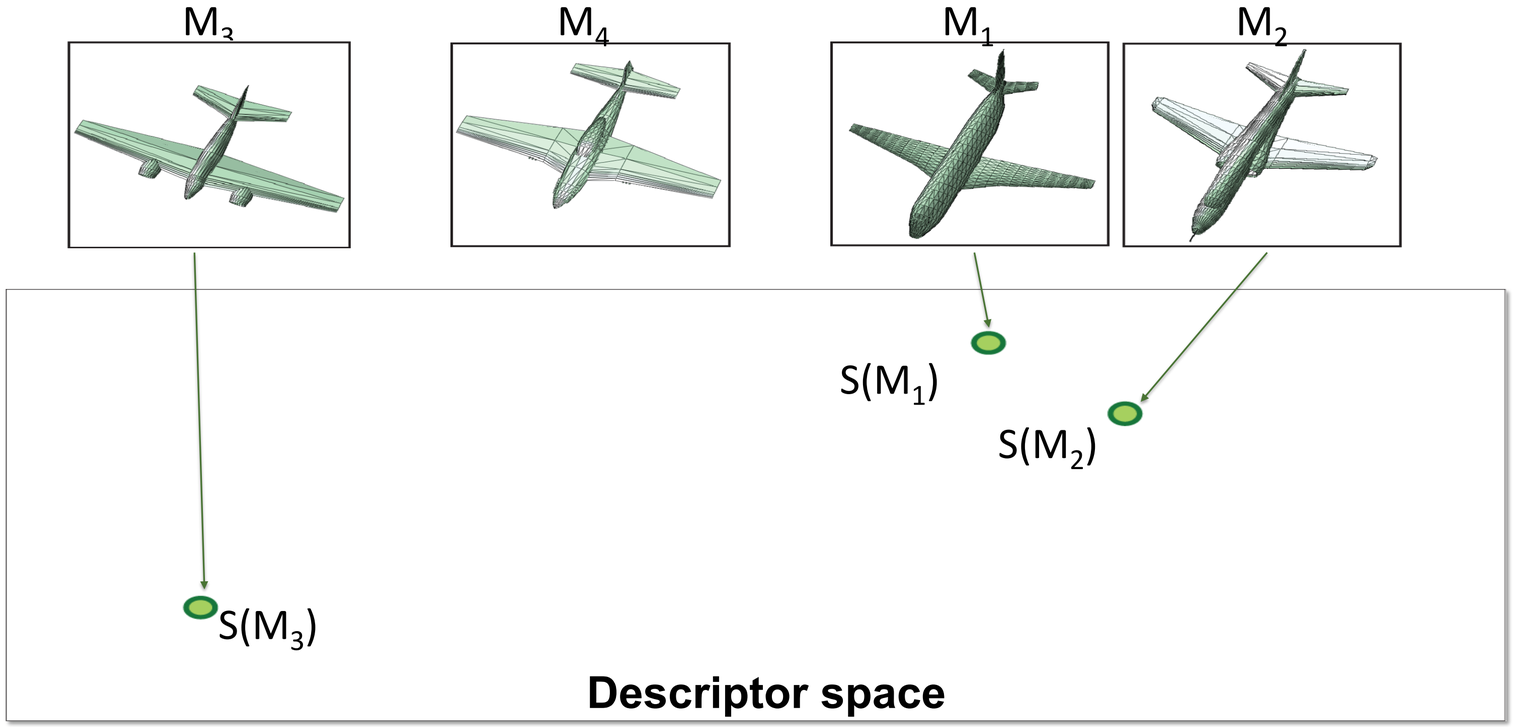
2. Select Template

3. Deform template to fit curve

4. Generate morphable model

Part-based Exploration

- **Analysis**



1. Convert to descriptor space

2. Select Template

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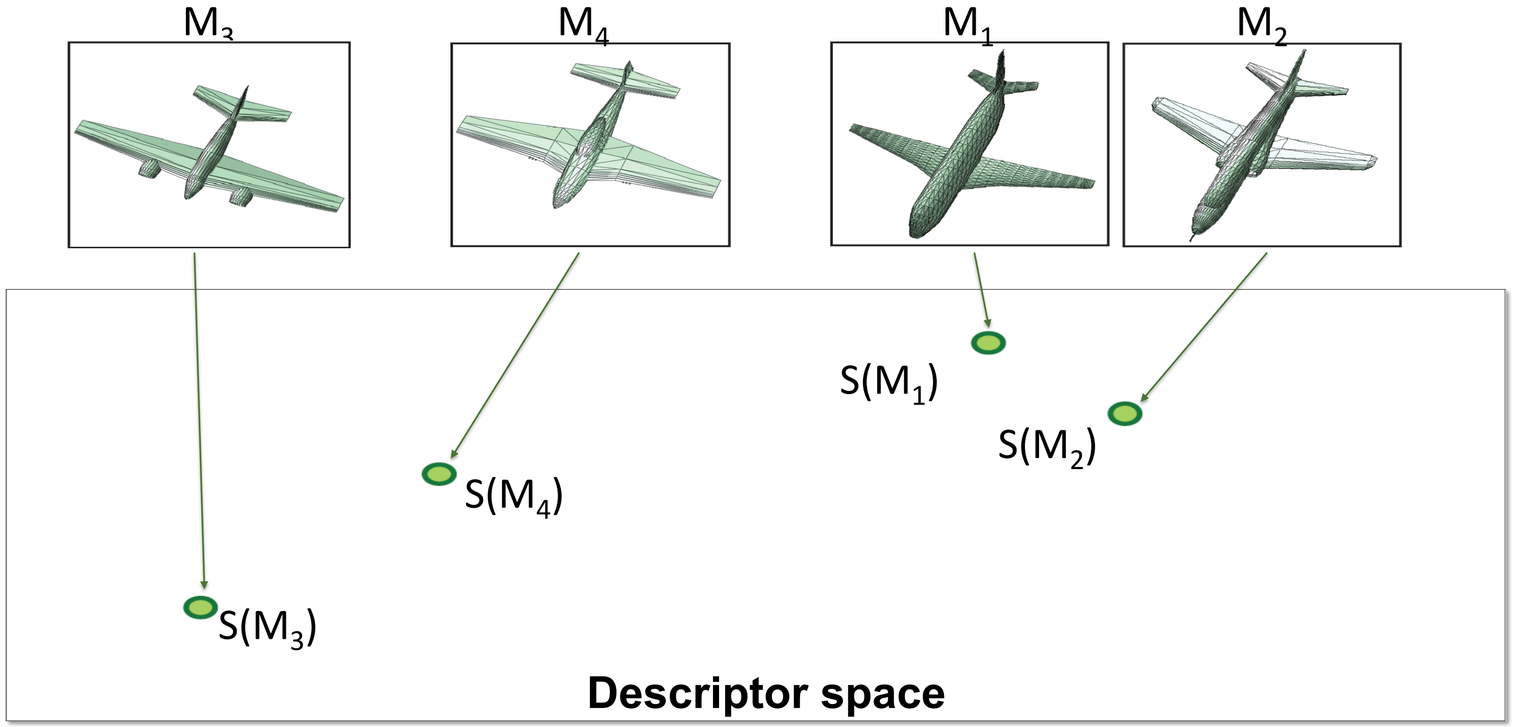
4. Generate morphable model

Part-based Exploration

- **Analysis**



1. Convert to descriptor space

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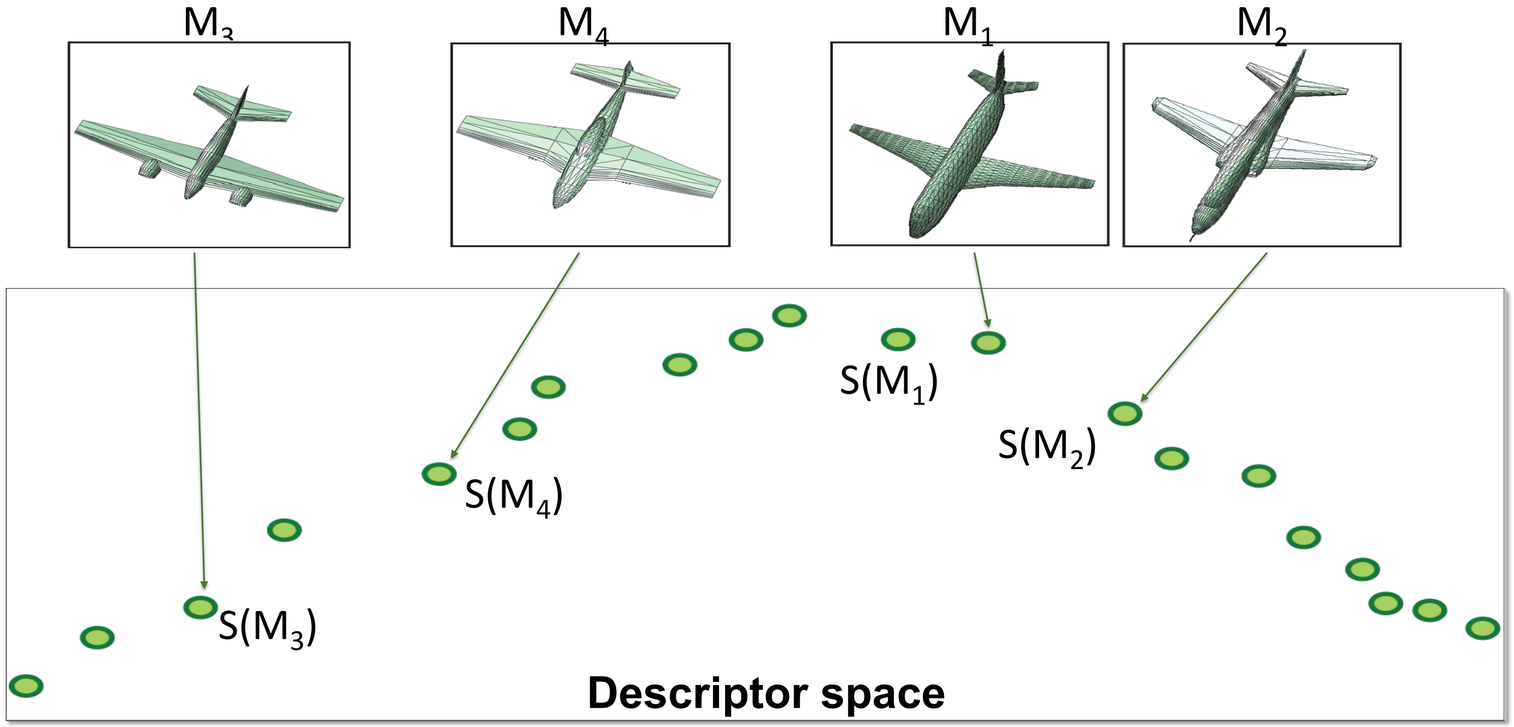
4. Generate morphable model

Part-based Exploration

- **Analysis**



1. Convert to descriptor space

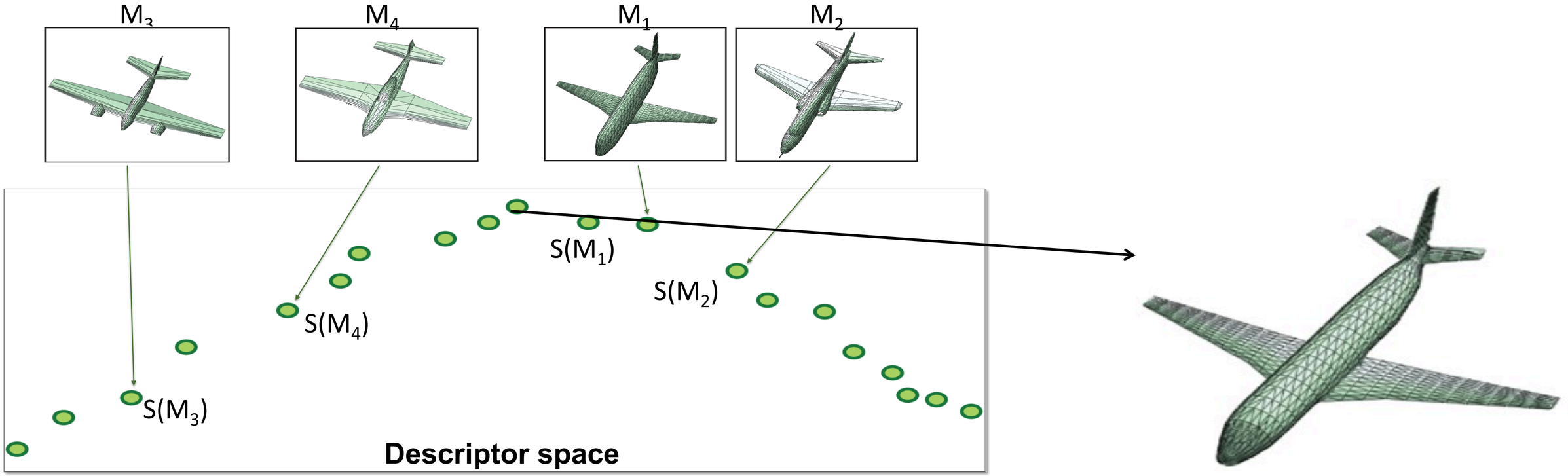
2. Select Template

3. Deform template to fit curve

4. Generate morphable model

Part-based Exploration

- **Analysis**



1. Convert to descriptor space

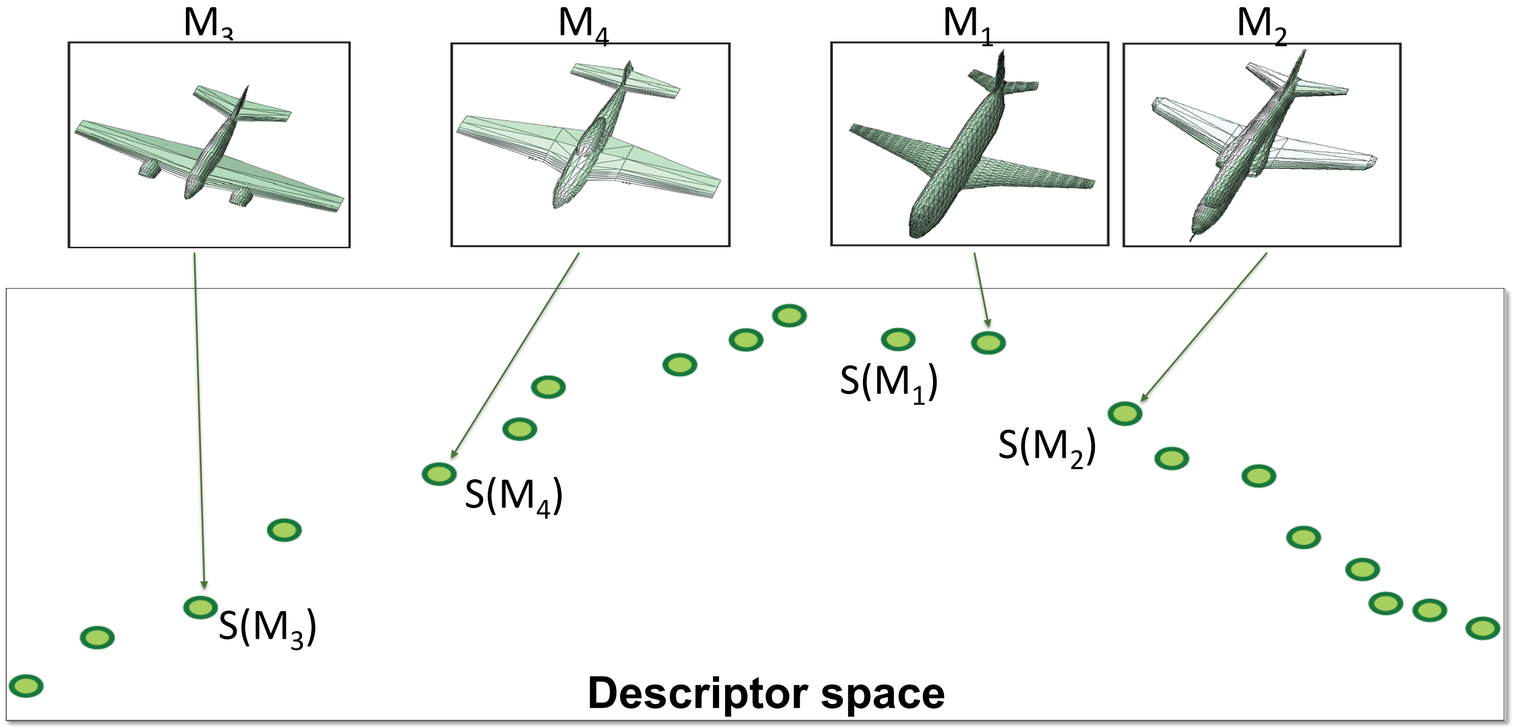
3. Deform template to fit curve

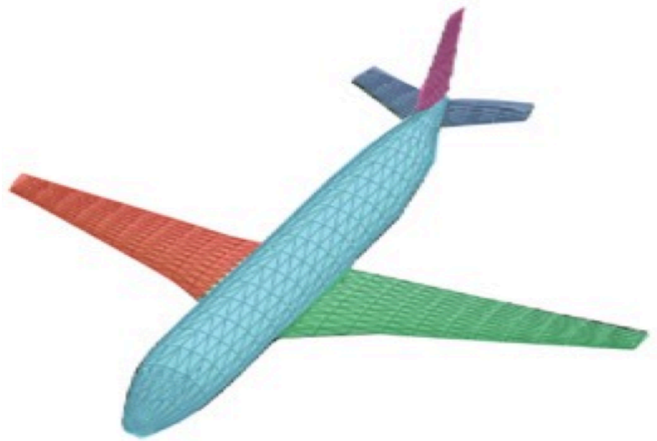
2. Select Template

4. Generate morphable model

Part-based Exploration

- **Analysis**





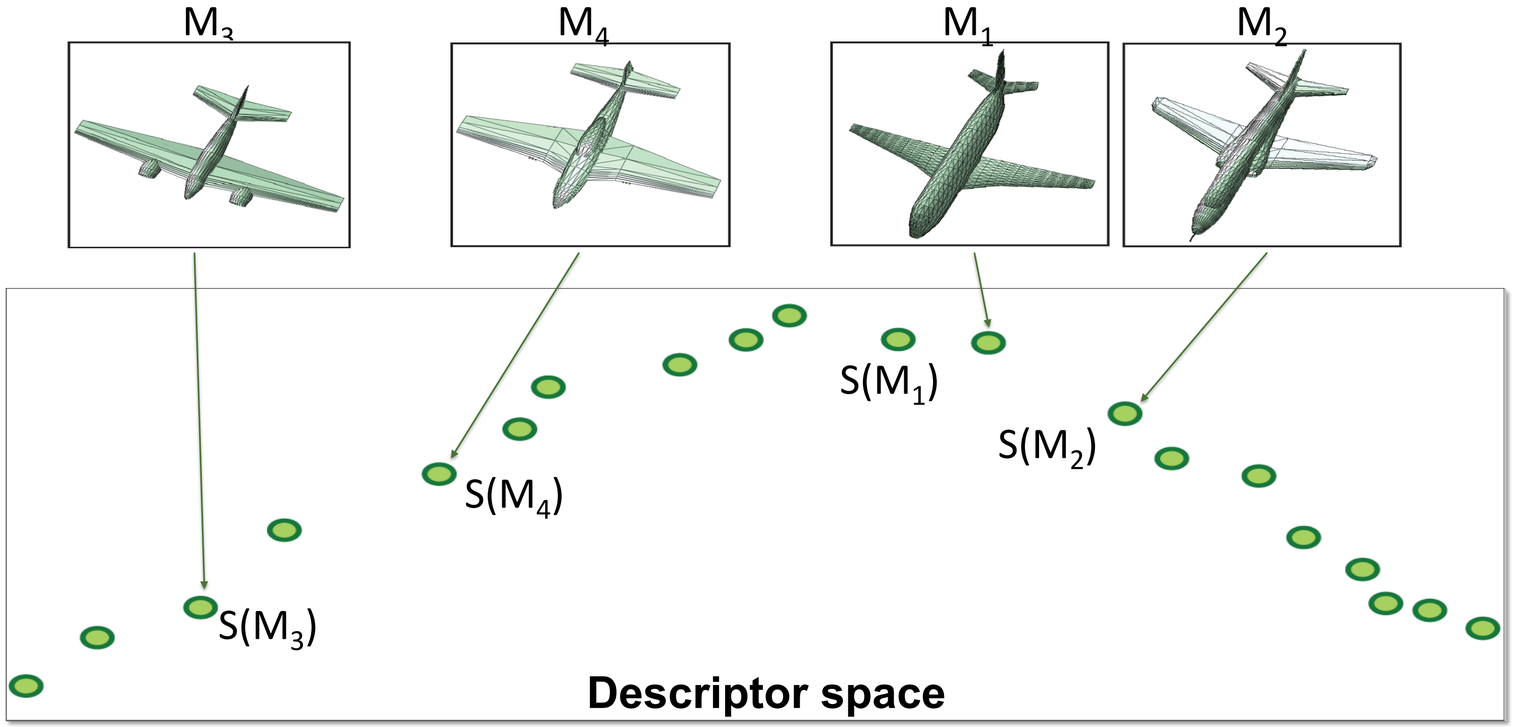
1. Convert to descriptor space
3. Deform template to fit curve

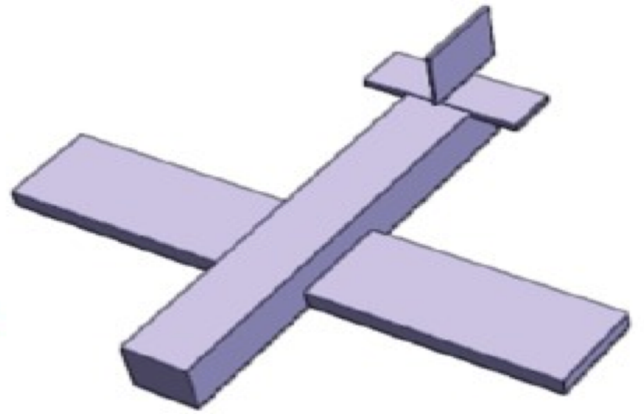
2. Select Template

4. Generate morphable model

Part-based Exploration

- **Analysis**





1. Convert to descriptor space

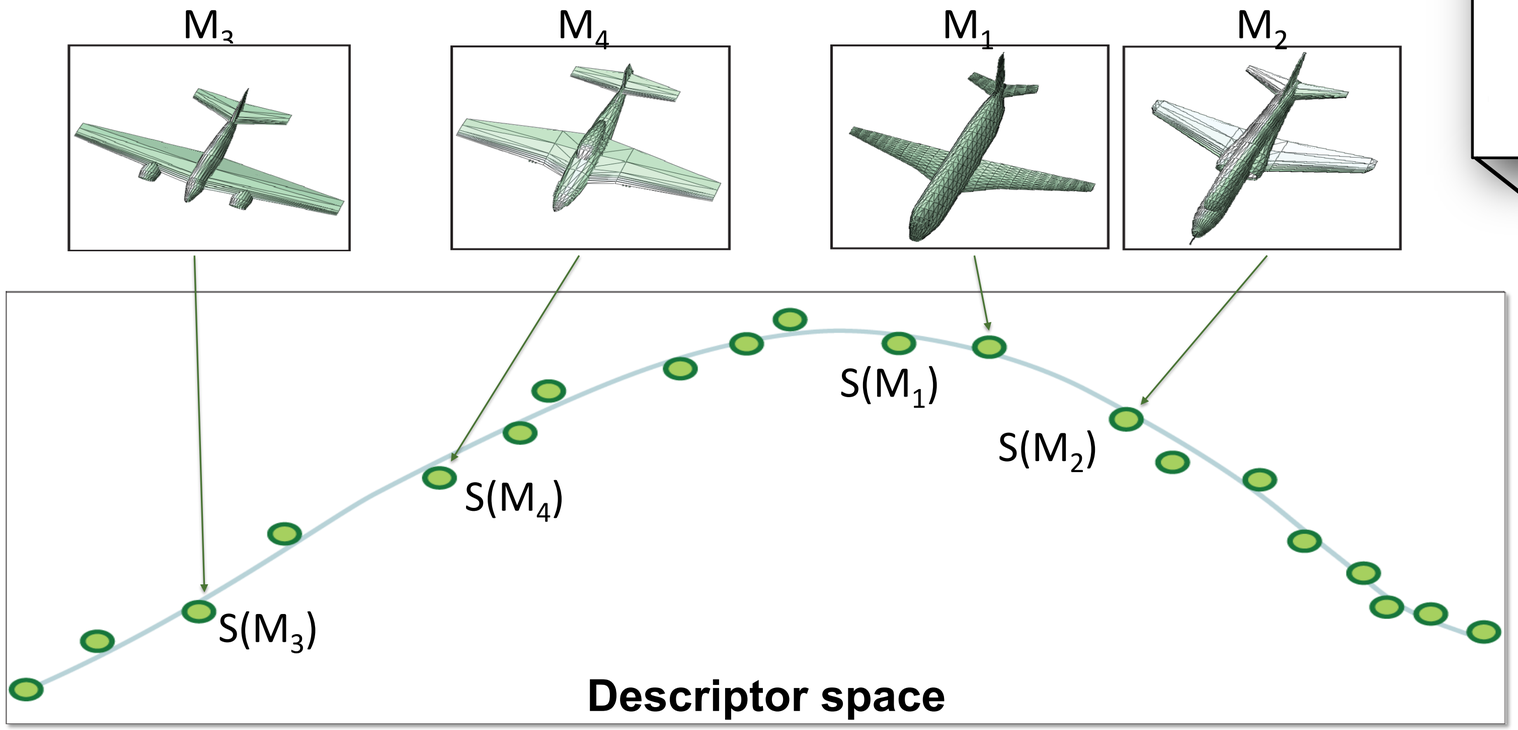
3. Deform template to fit curve

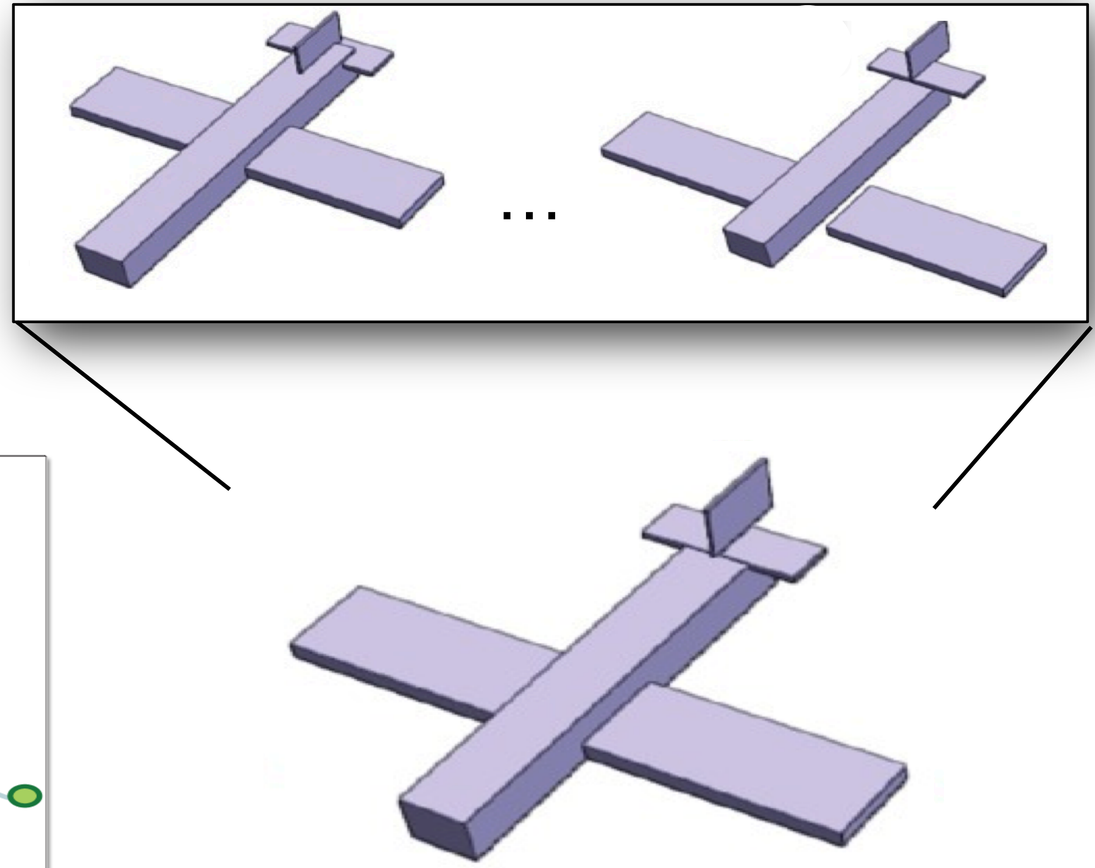
2. Select Template

4. Generate morphable model

Part-based Exploration

- **Analysis**





1. Convert to descriptor space

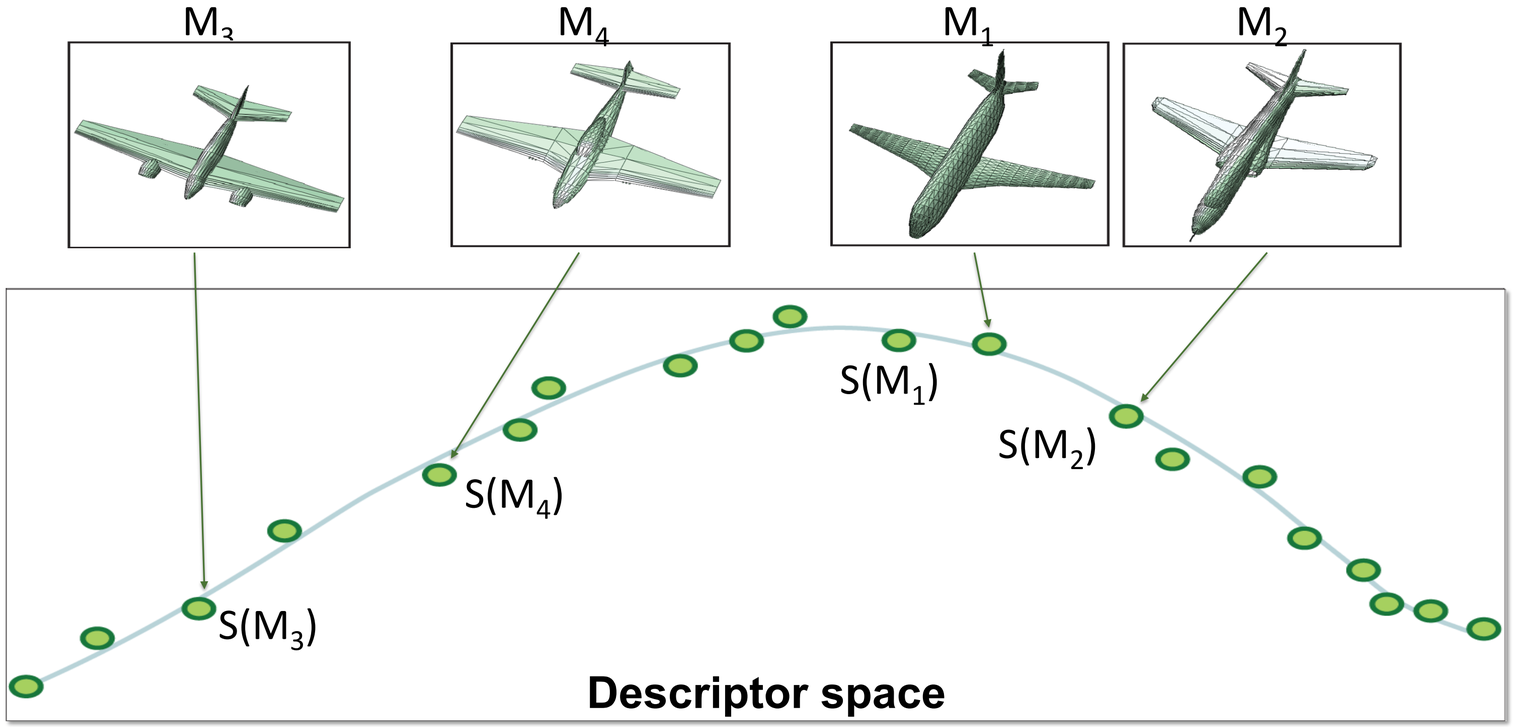
3. Deform template to fit curve

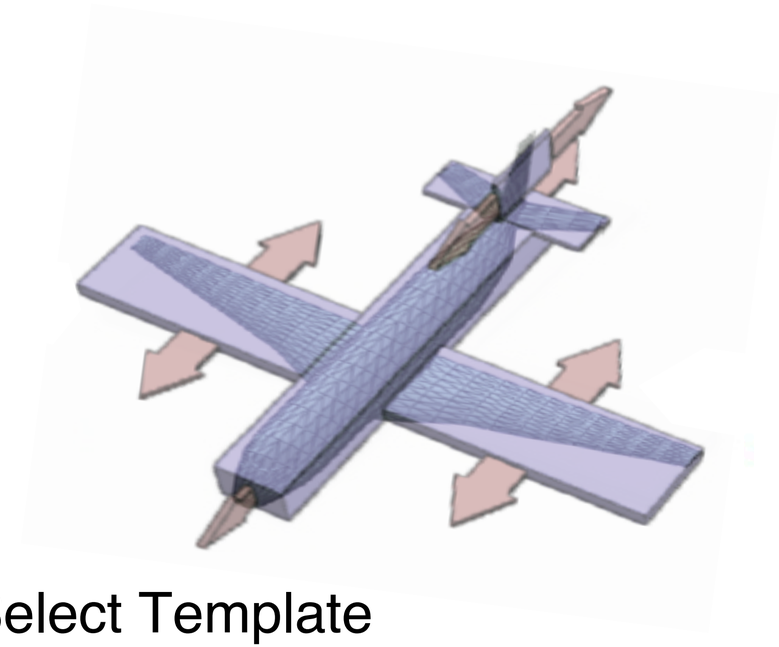
2. Select Template

4. Generate morphable model

Part-based Exploration

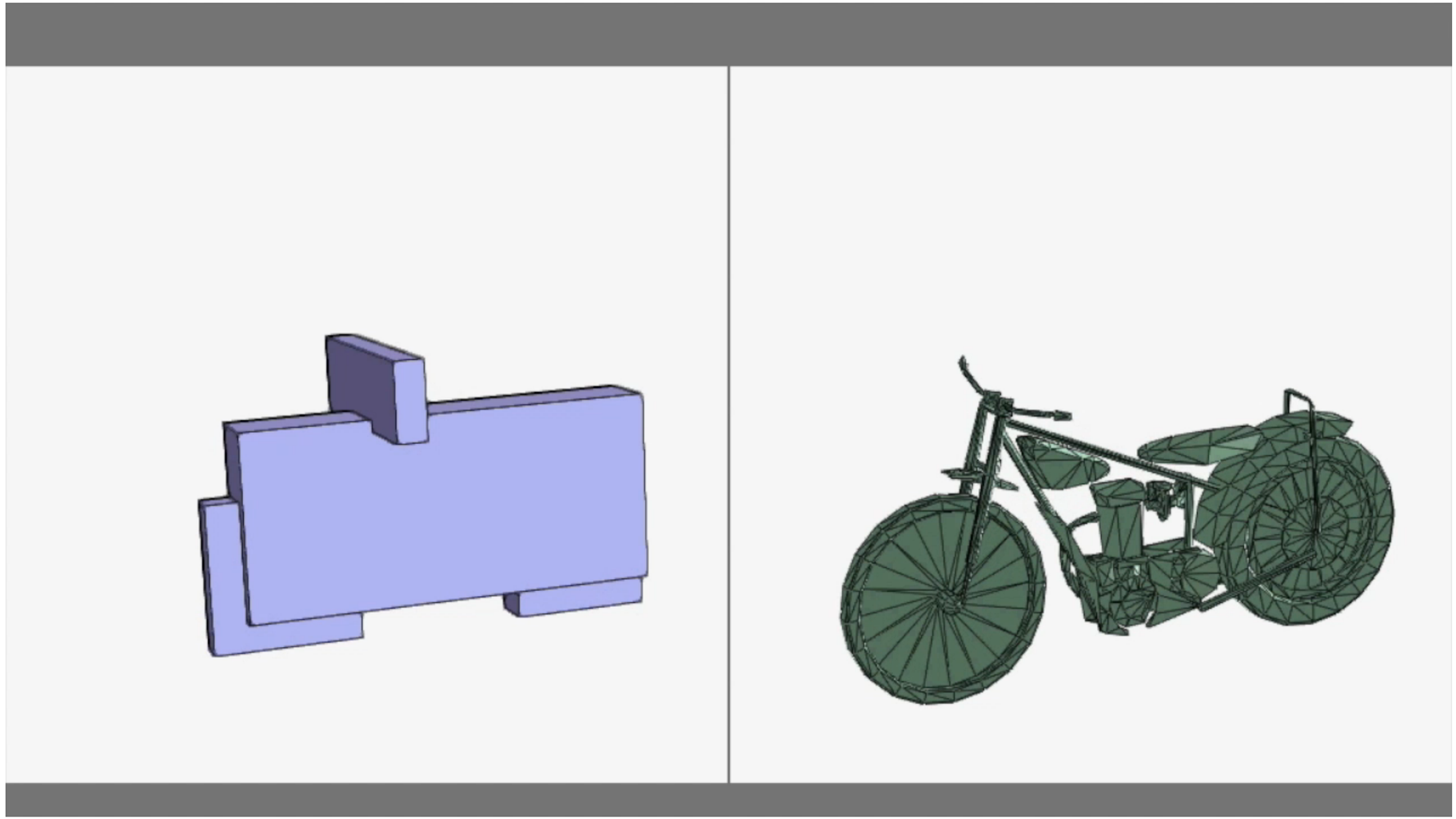
- **Analysis**





1. Convert to descriptor space
2. Select Template
3. Deform template to fit curve
4. **Generate morphable model**

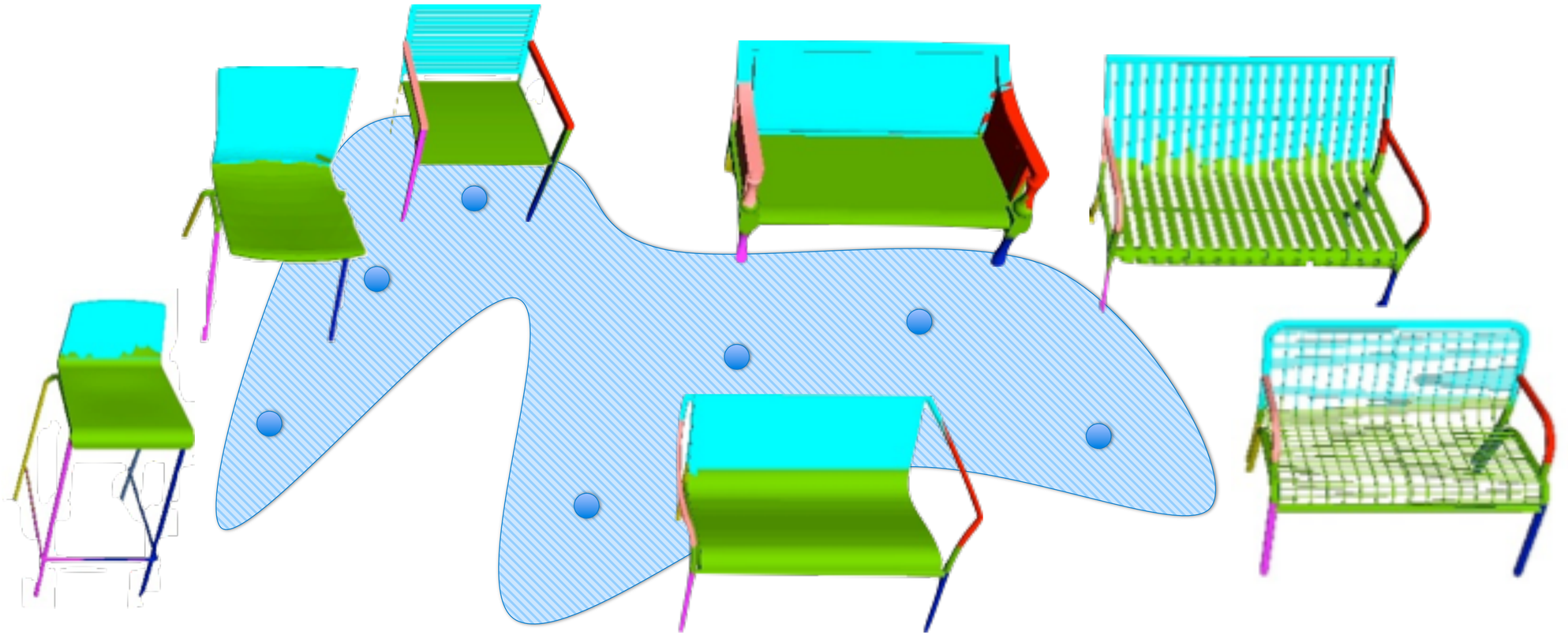
Part-based Exploration



[Exploration of Continuous Variability in Collections of 3D Shapes, Ovsjanikov et al. 2011]

Data Organization

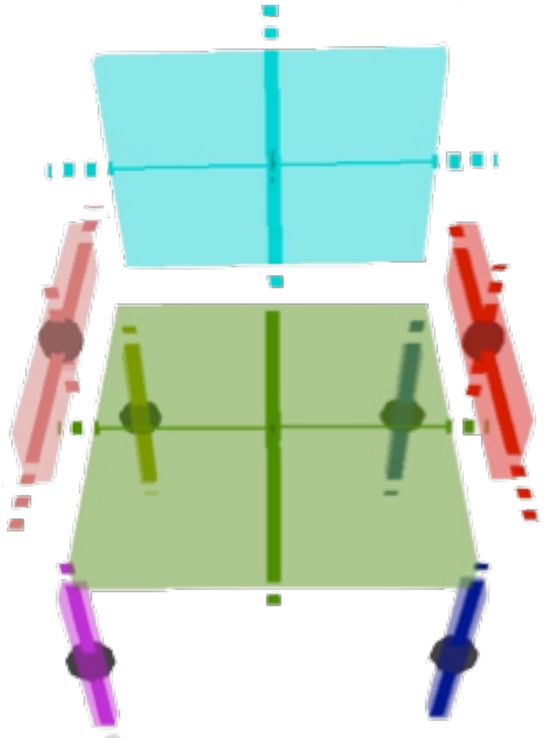
- **Part-based Exploration**
  - Navigate by selecting points in low-dimensional space

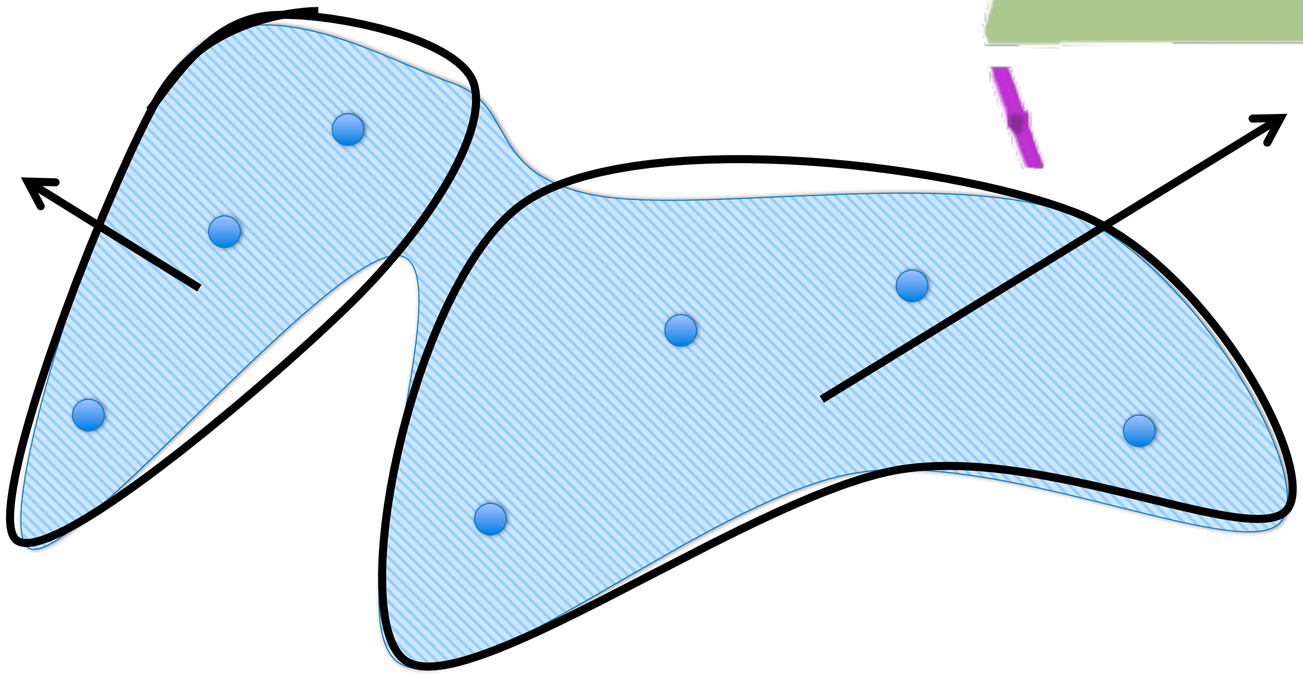


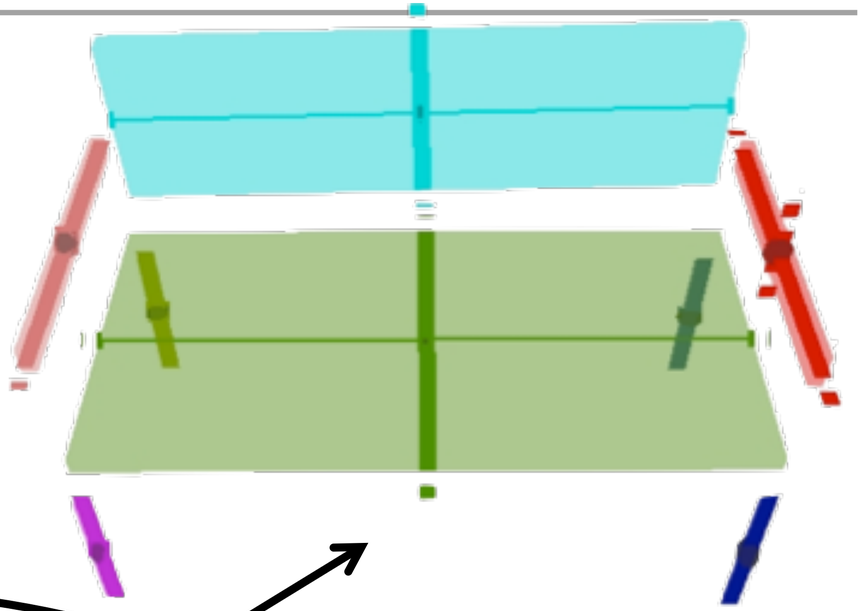
[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates





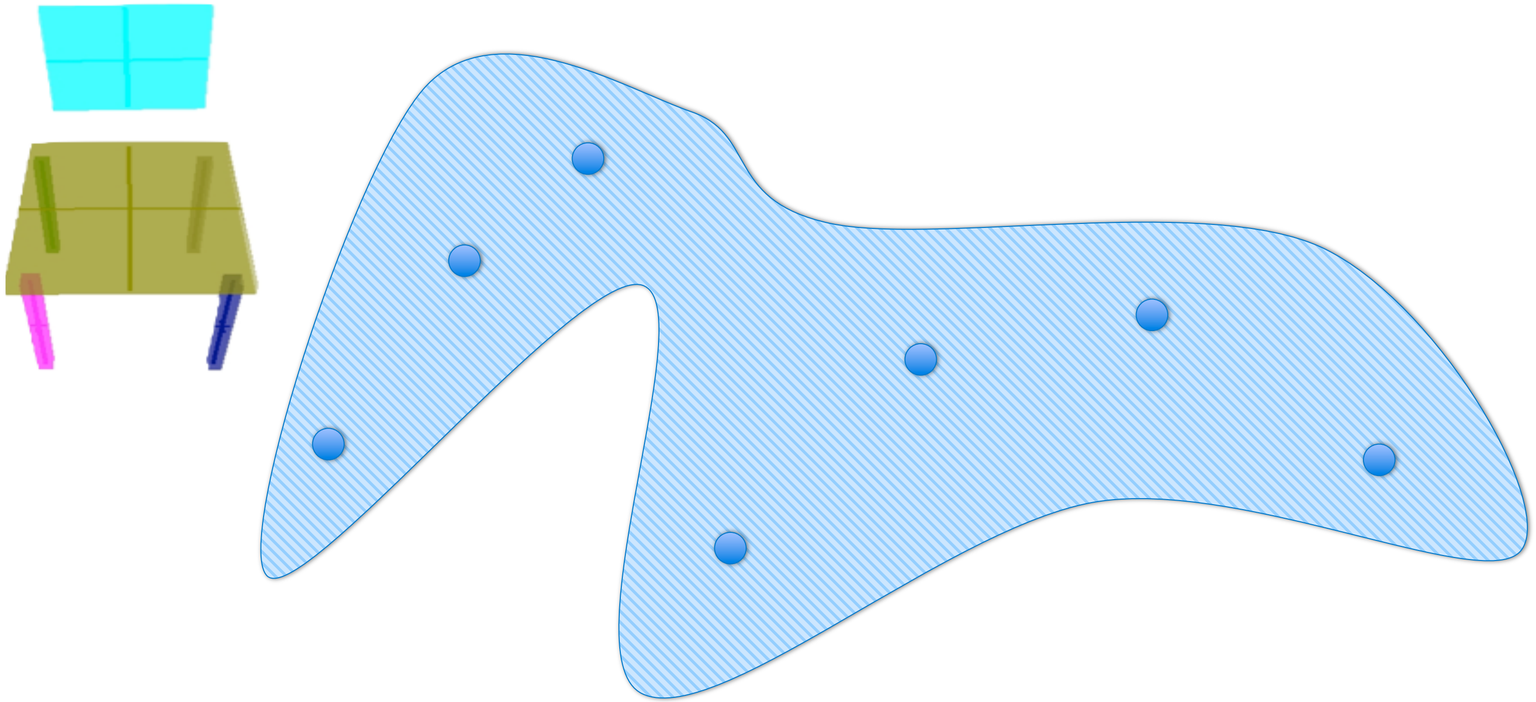


[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates

→ **Step I:**
Create initial template

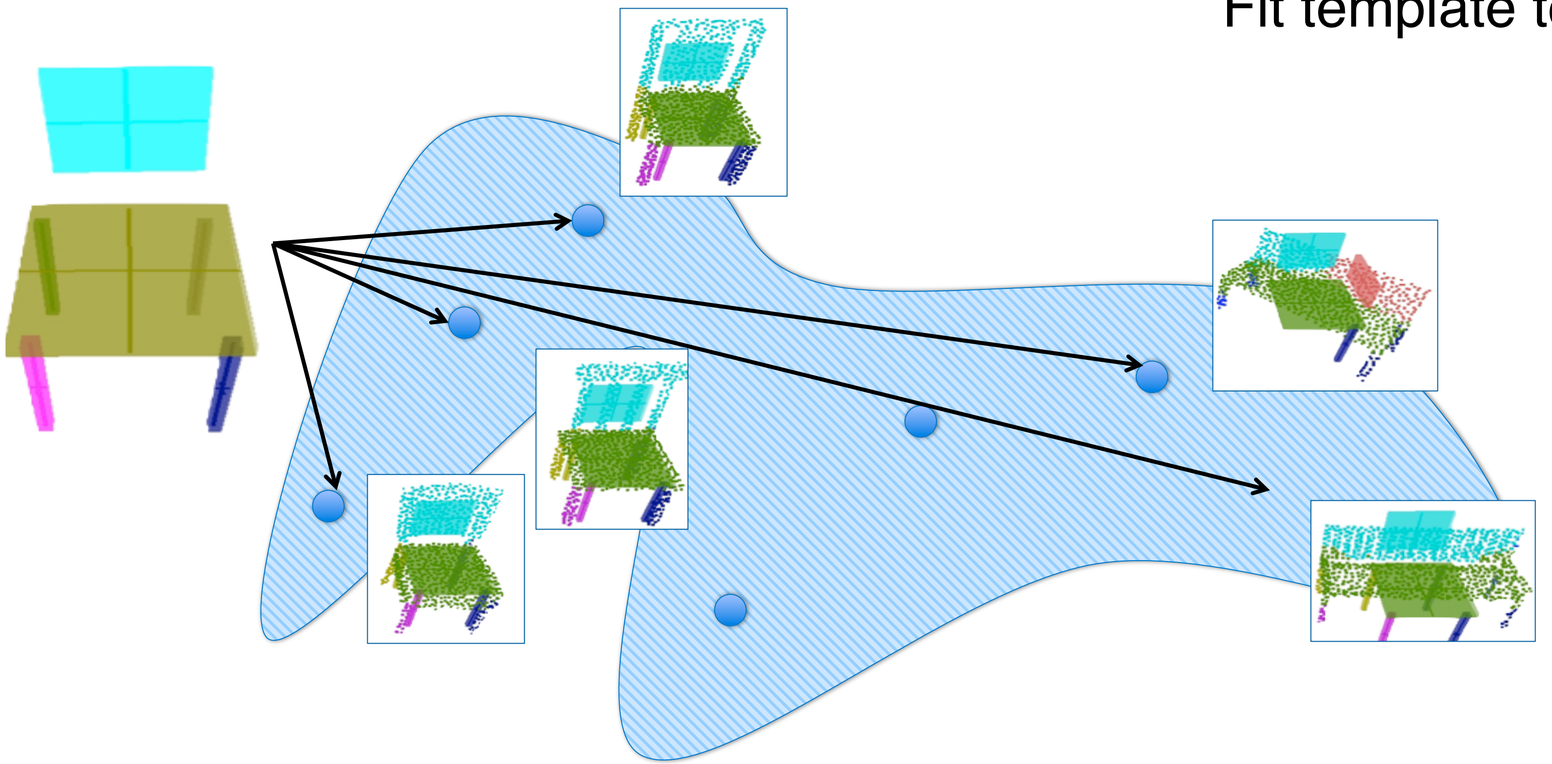


[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates

Step I:
Create initial template
Step II:
Fit template to some models

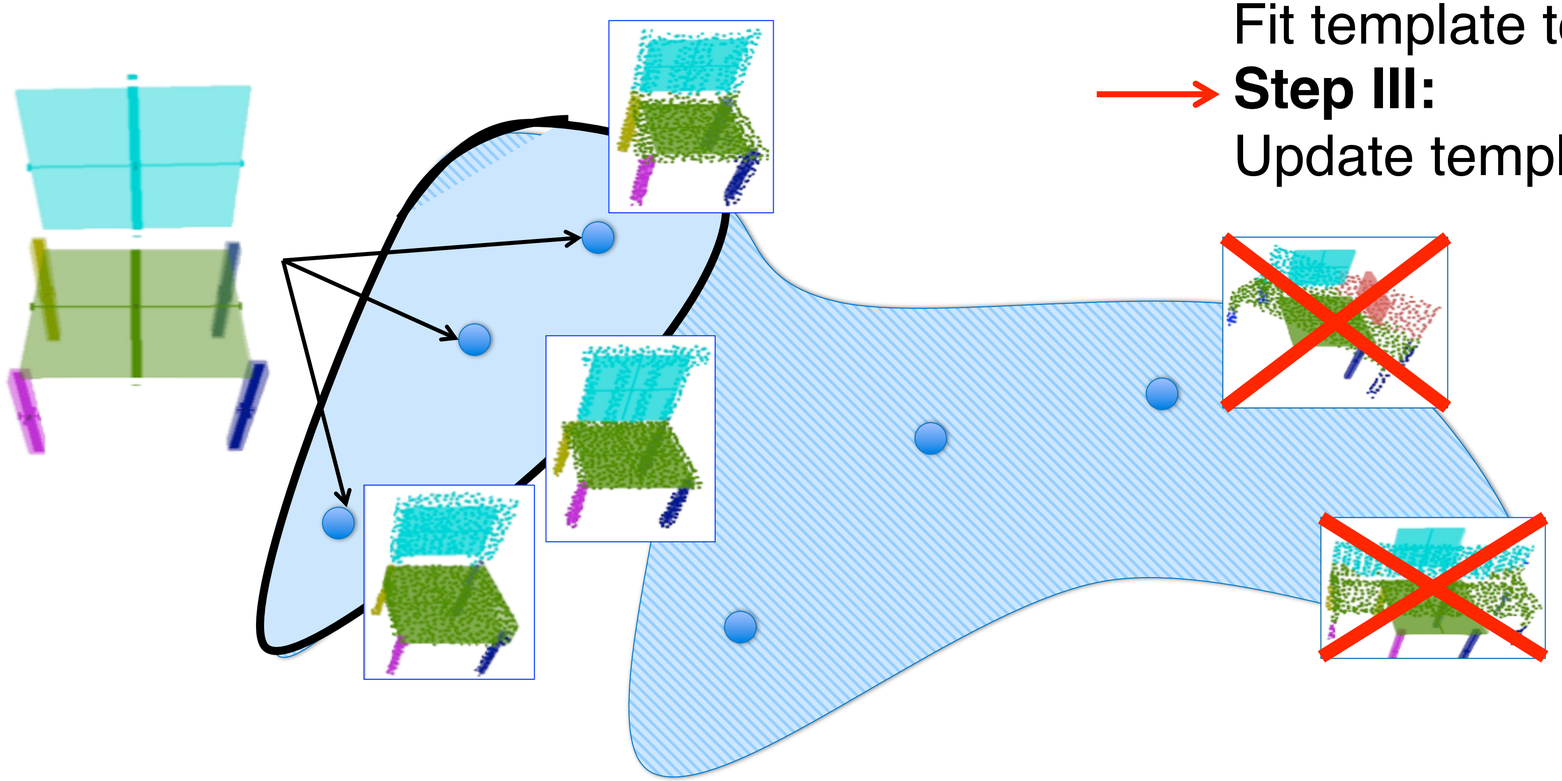


[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates

Step I:
Create initial template
Step II:
Fit template to some models
Step III:
Update template from good fits



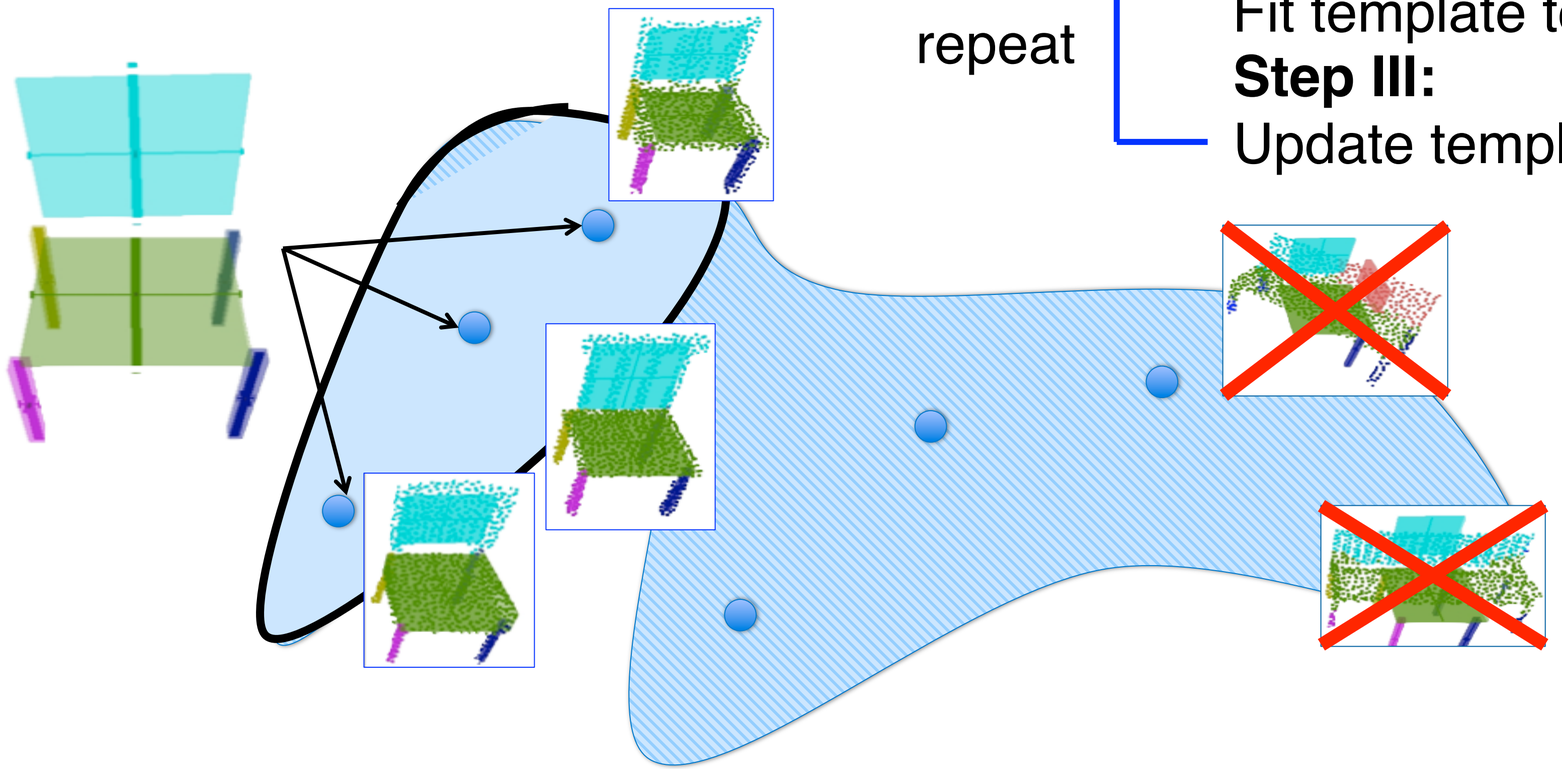
[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates

Step I:
Create initial template
Step II:
Fit template to some models
Step III:
Update template from good fits

repeat



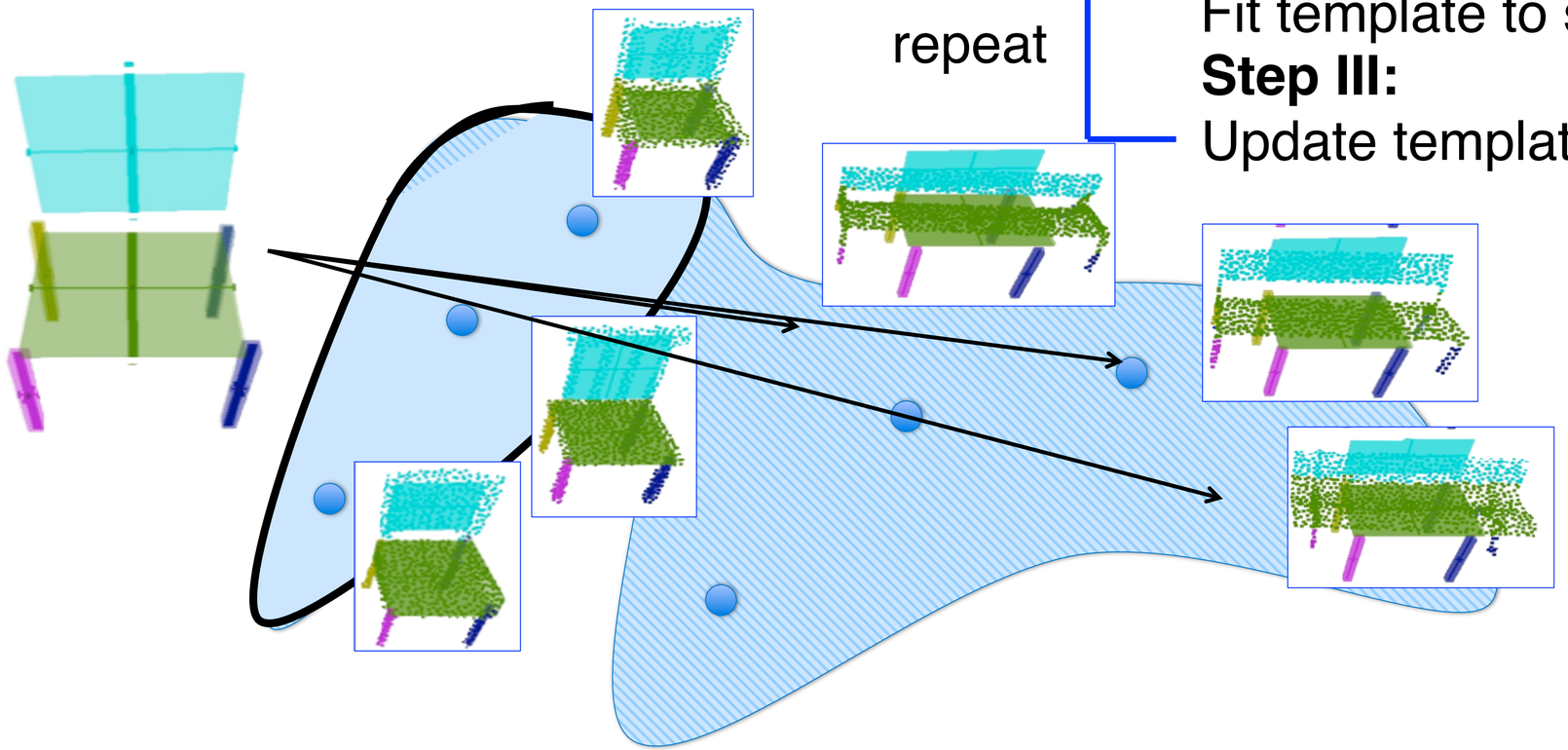
[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

- **Analysis**
  - Learn deformable templates

Step I:
Create initial template
Step II:
Fit template to some models
Step III:
Update template from good fits

repeat



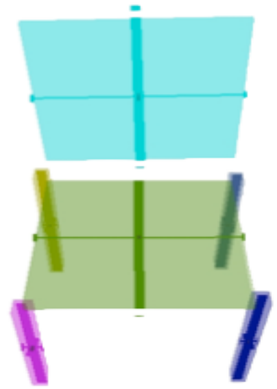
[Learning Part-based Templates from Large Collections of 3D Shapes, Kim et al. 2013]

Deformable Templates

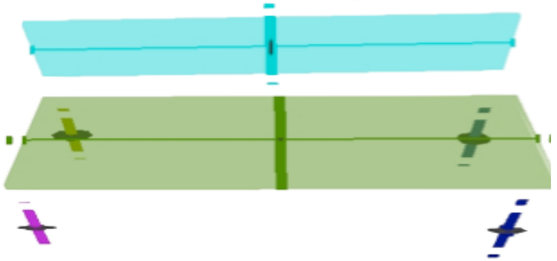
- **Analysis**
  - Learn deformable templates

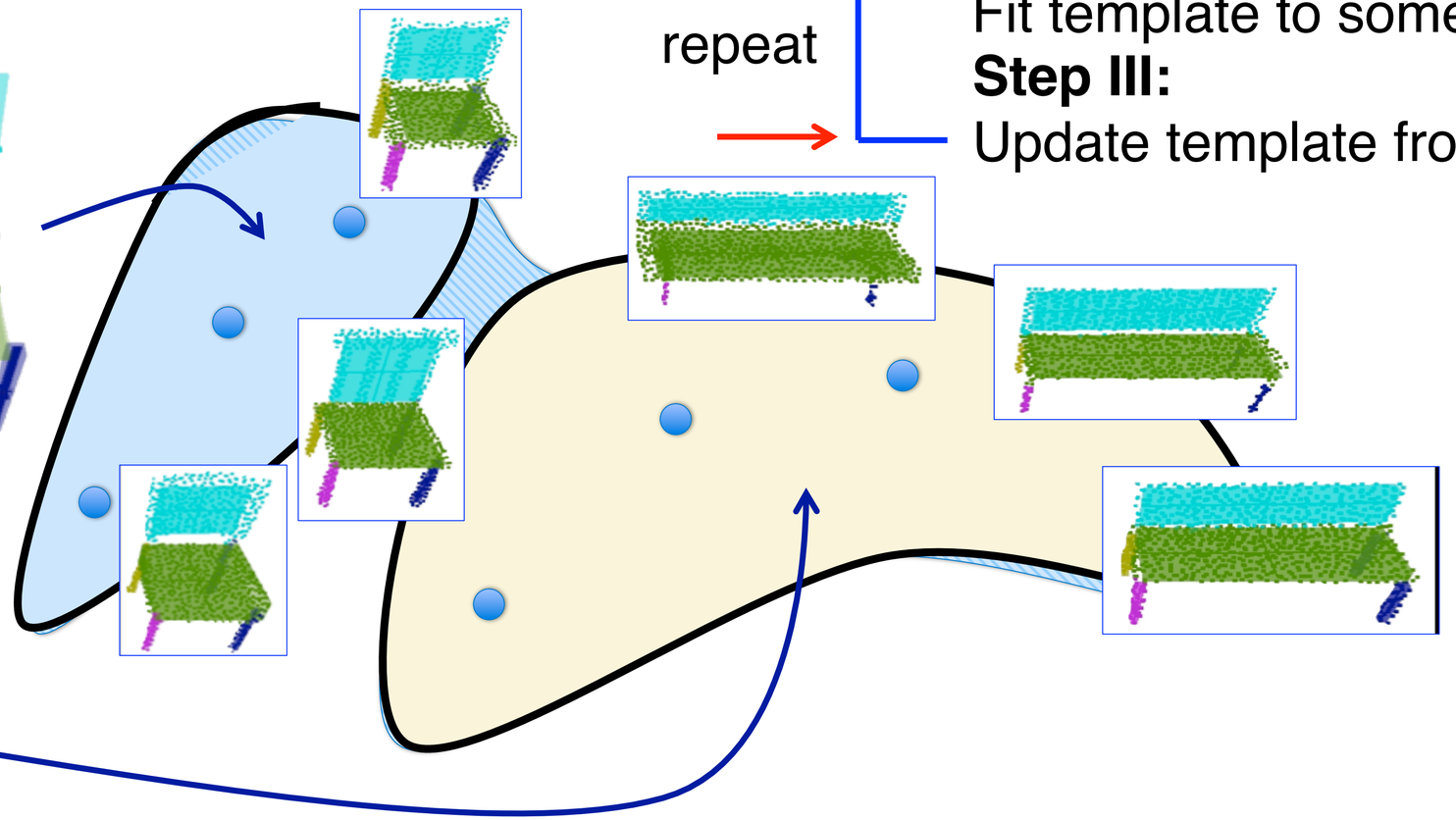
Step I:
Create initial template
Step II:
Fit template to some models
Step III:
Update template from good fits

repeat



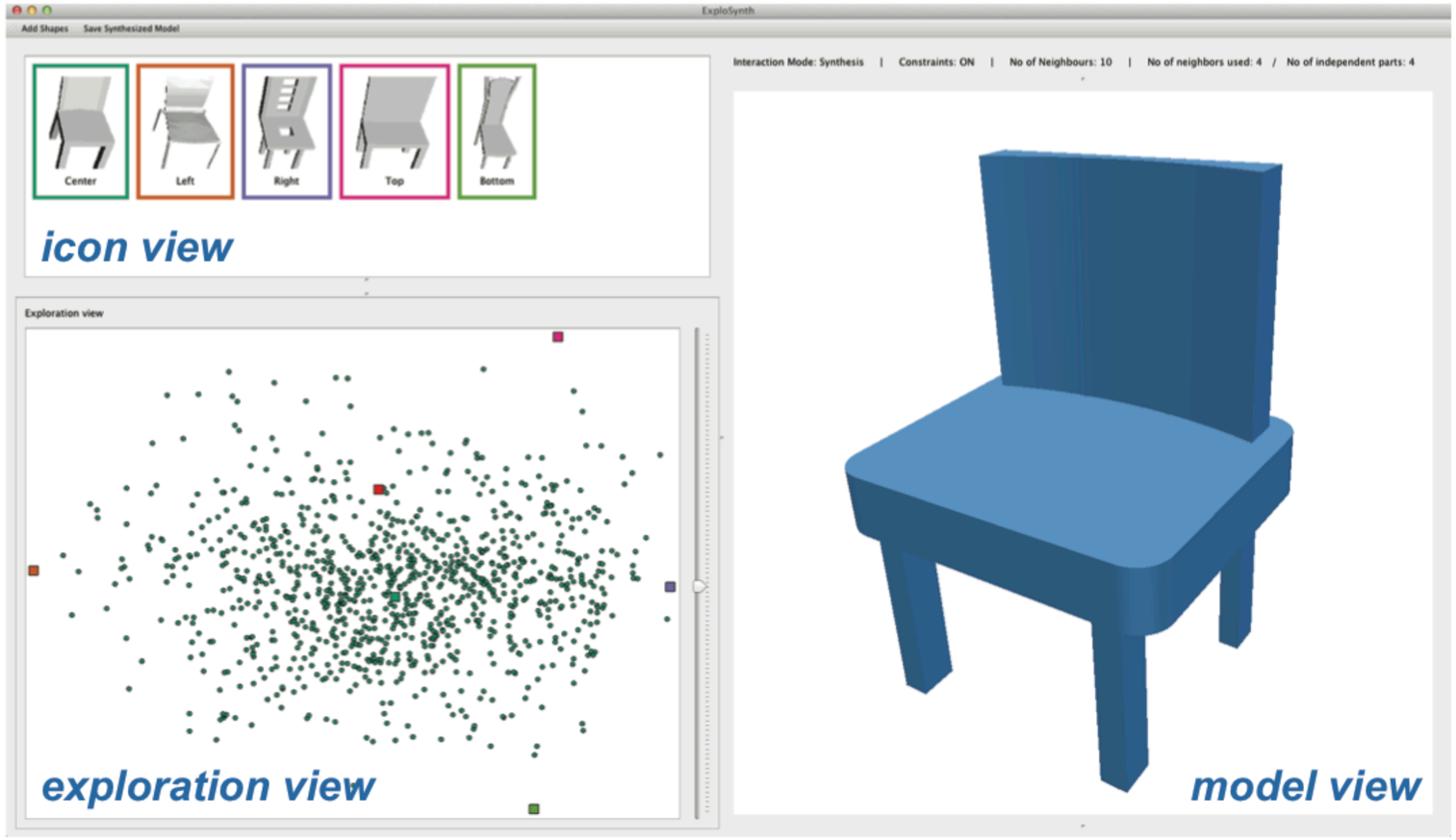
spawned template





Deformable Templates

- **Exploration Interface**



[ShapeSynth:
Parameterizing Model Collections for Coupled Shape Exploration and Synthesis , Averikou et al. 2013]

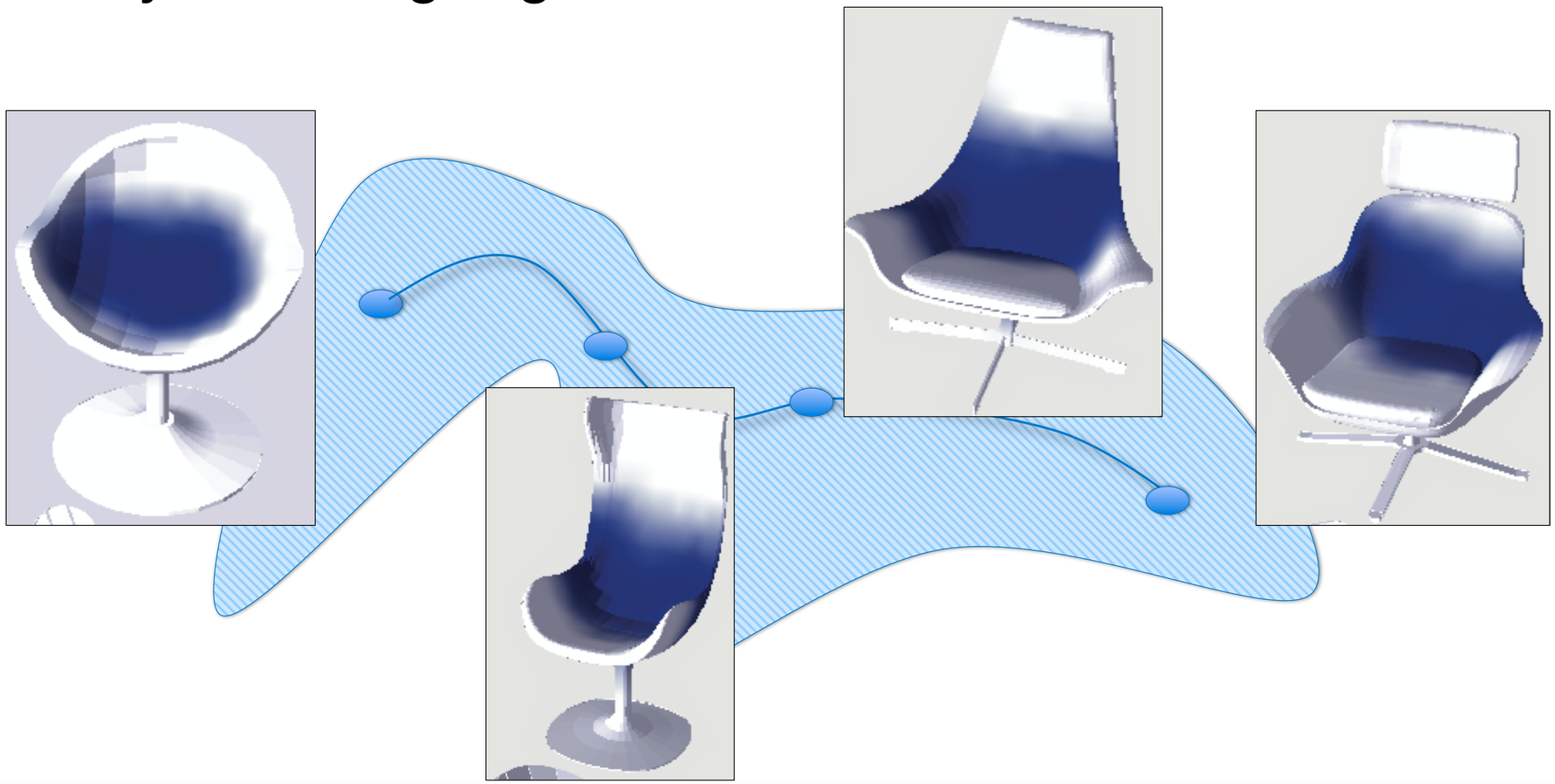
Deformable Templates

- **Exploration Interface**

[ShapeSynth:
Parameterizing Model Collections for Coupled Shape Exploration and Synthesis , Averikou et al. 2013]

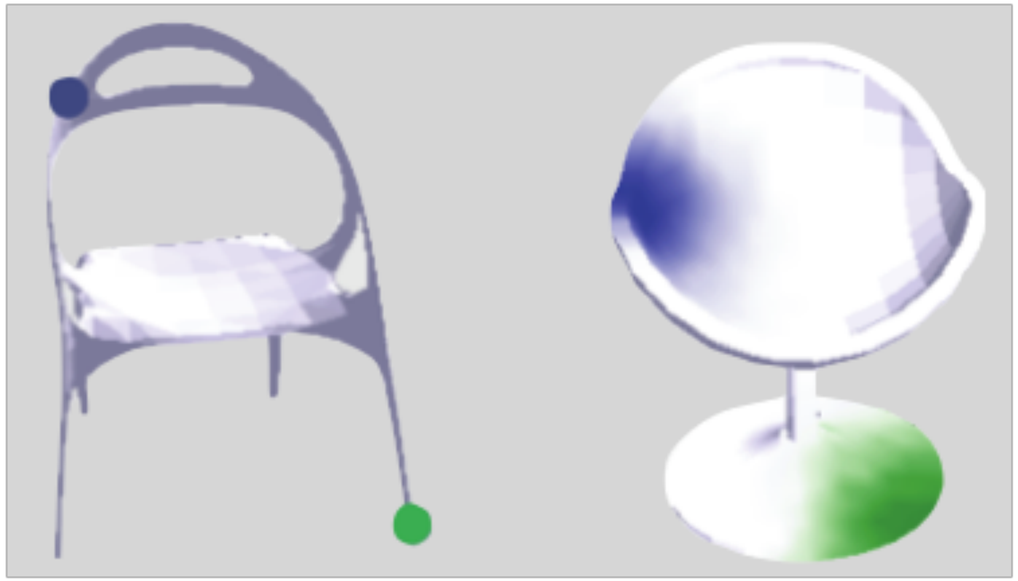
Organizing The Data

- **Region-based Exploration**
  - Navigate by selecting regions of interest

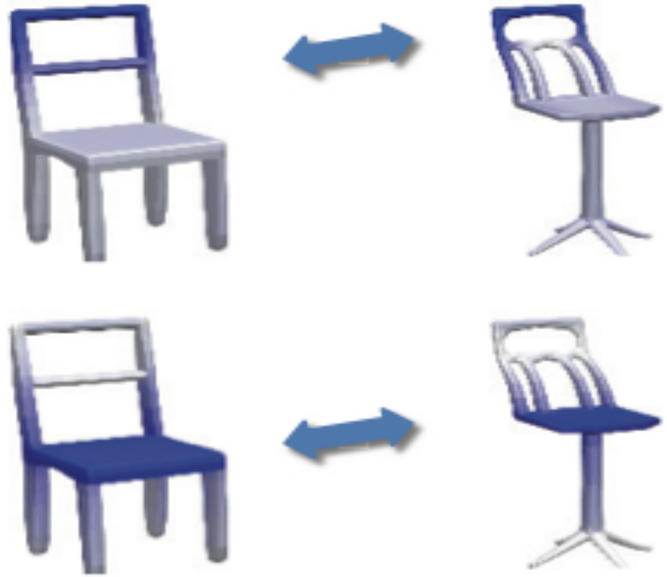


Region-based Exploration

- **Common Approach**
  - Detect correspondences
  - Find distances for ROI across the collection



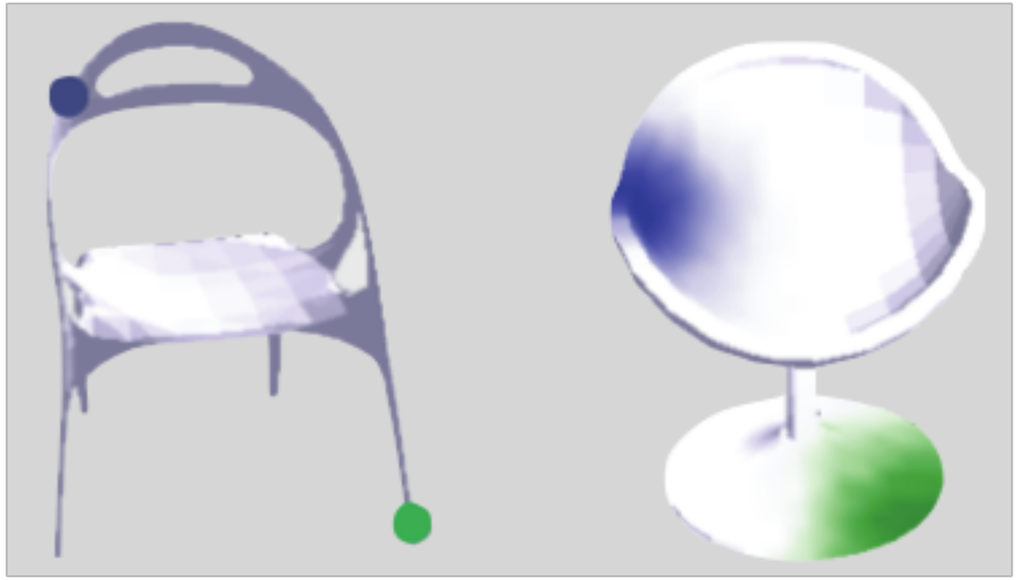
Fuzzy Correspondences, Soft Maps



Functional Maps, Shape Differences

Fuzzy Correspondences

- **Analysis**
  - Point-to-point correspondences do not handle ambiguity



Fuzzy Correspondences, Soft Maps

$$\mathbf{S} := \{S_1, S_2, \ldots, S_N\}$$

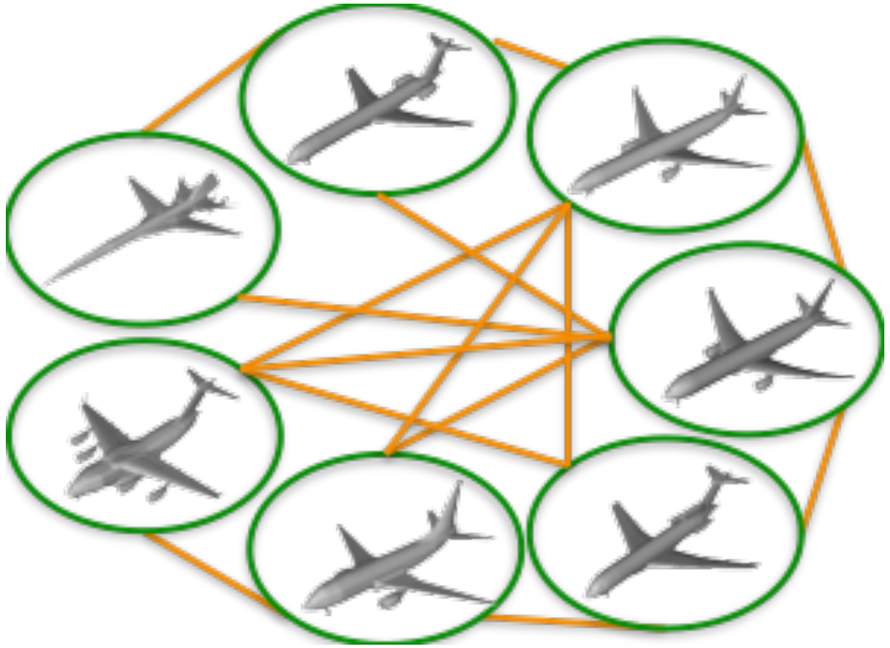
$$f(p_i, p_j) : \mathbf{S} \times \mathbf{S} \rightarrow \mathbb{R}$$

[Soft Maps Between Surfaces, Solomon 2012]

[Exploring Collections of 3D Models using Fuzzy Correspondences , Kim et al. 2012]

Fuzzy Correspondences

- **Analysis**
  - Point-to-point correspondences do not handle ambiguity
  - Diffuse correspondences to leverage transitivity



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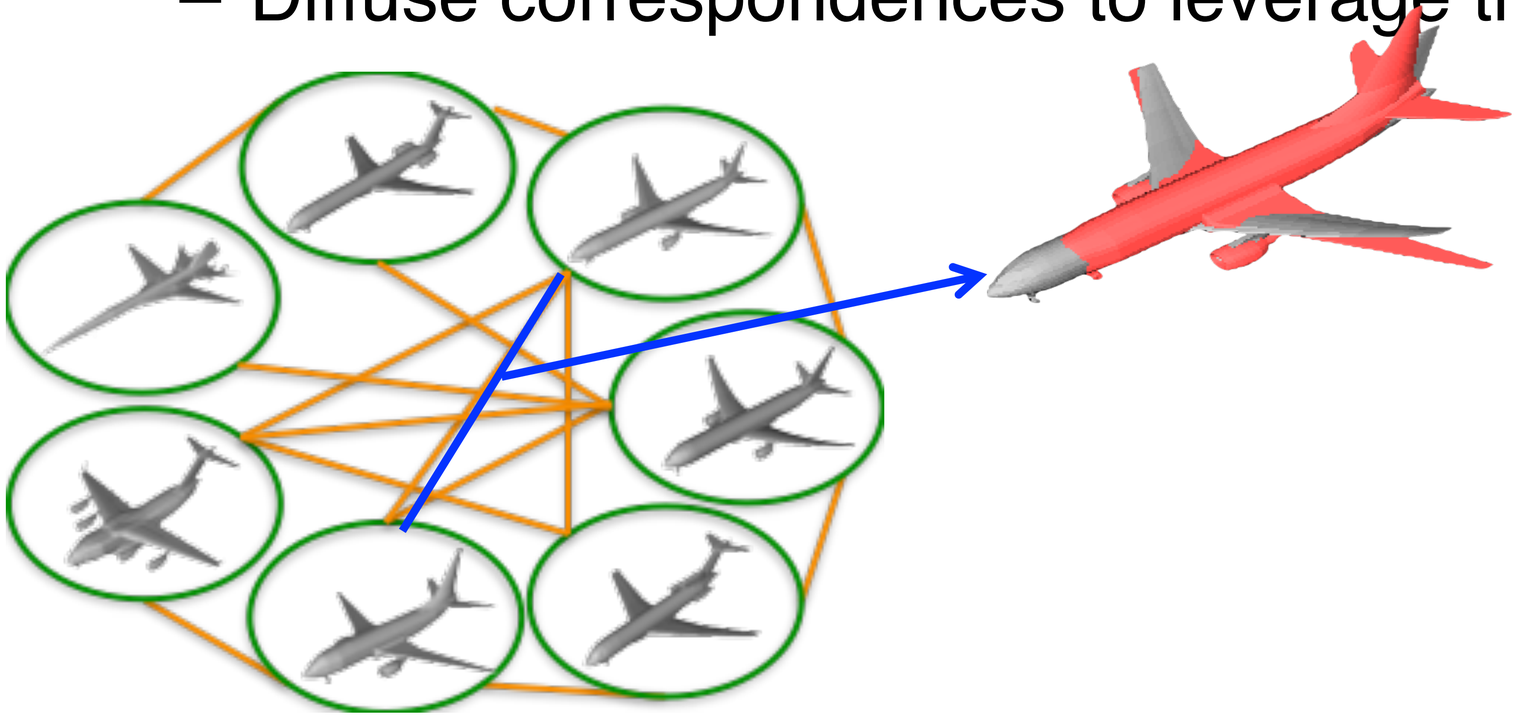

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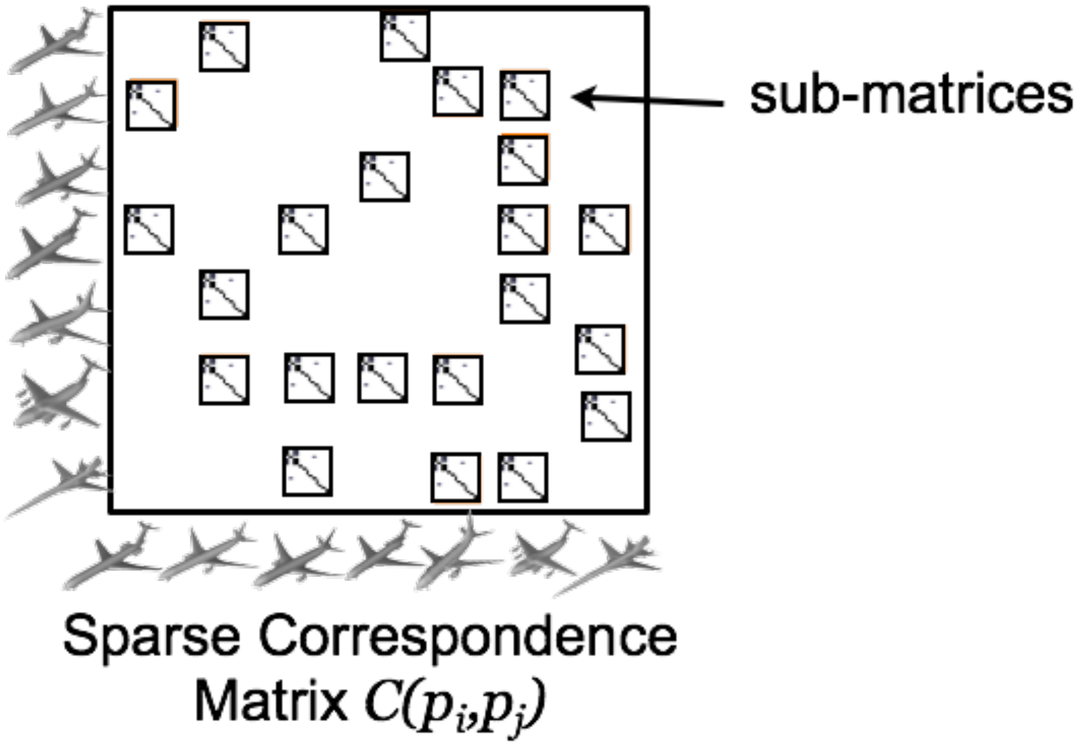

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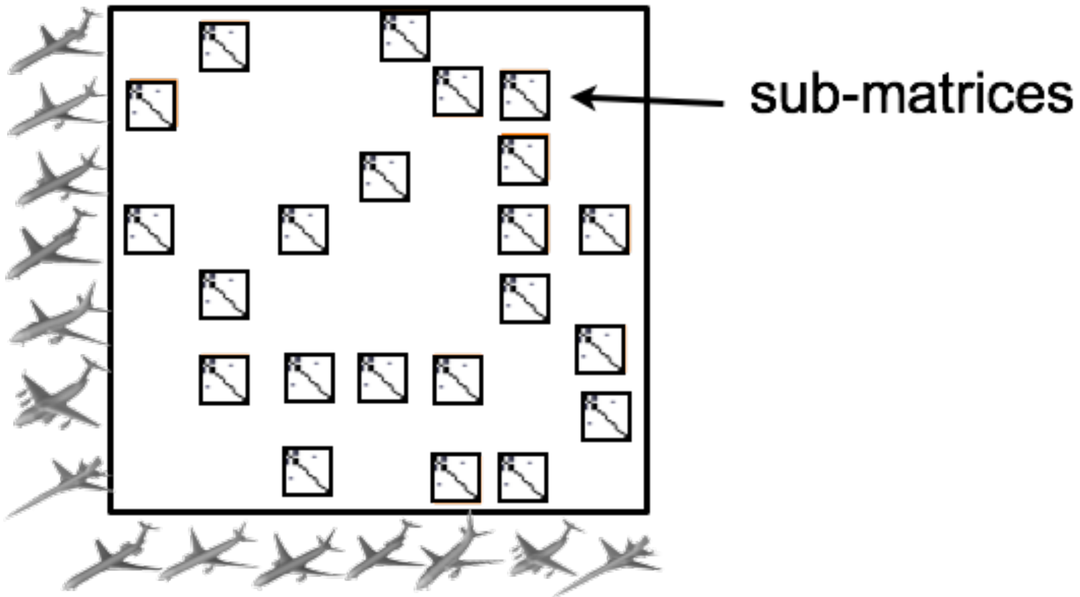
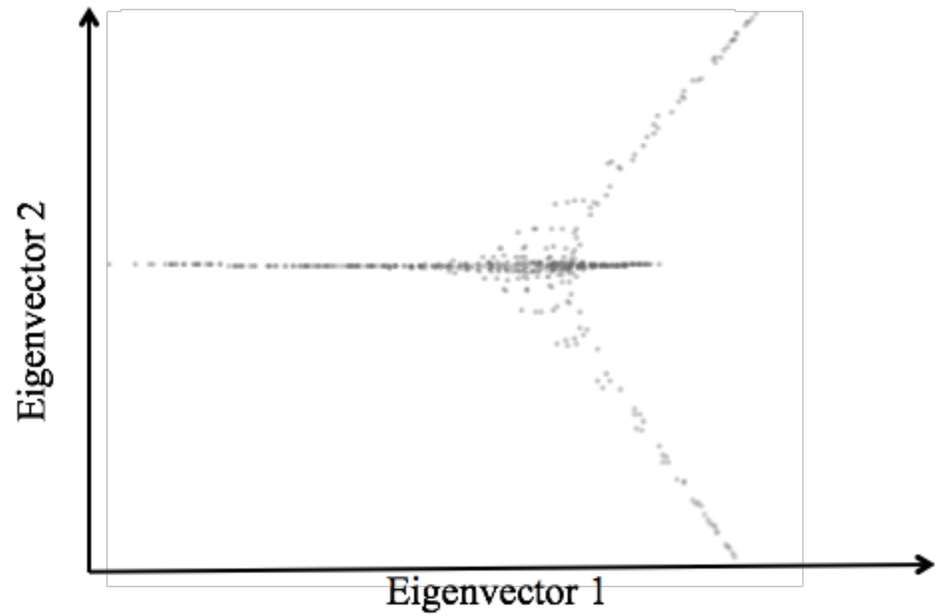


Sparse Correspondence Matrix $C(p_i,p_j)$



Spectral Embedding

Fuzzy Correspondences

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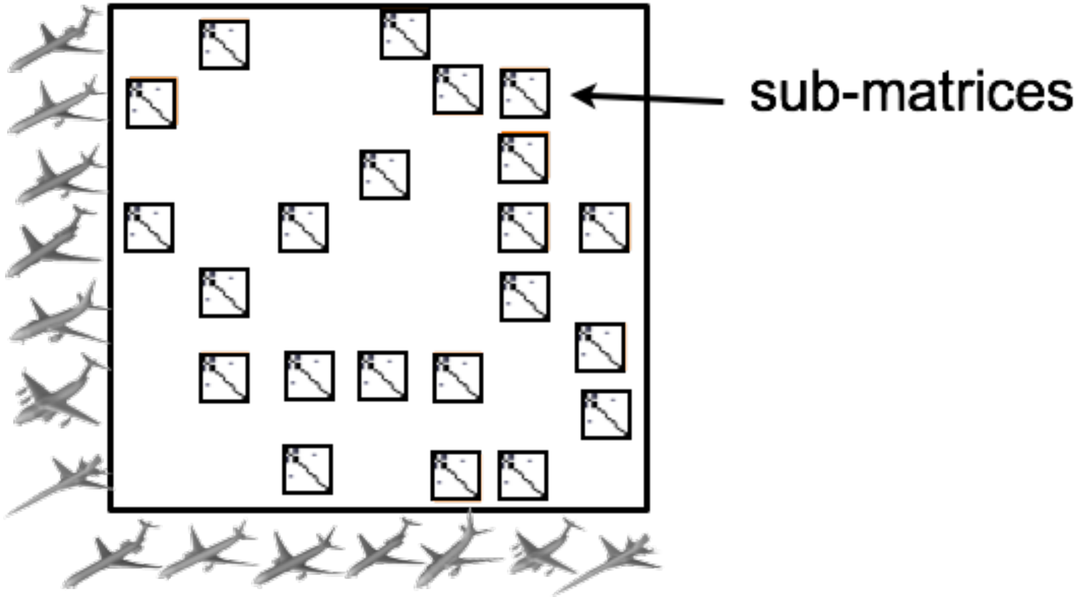

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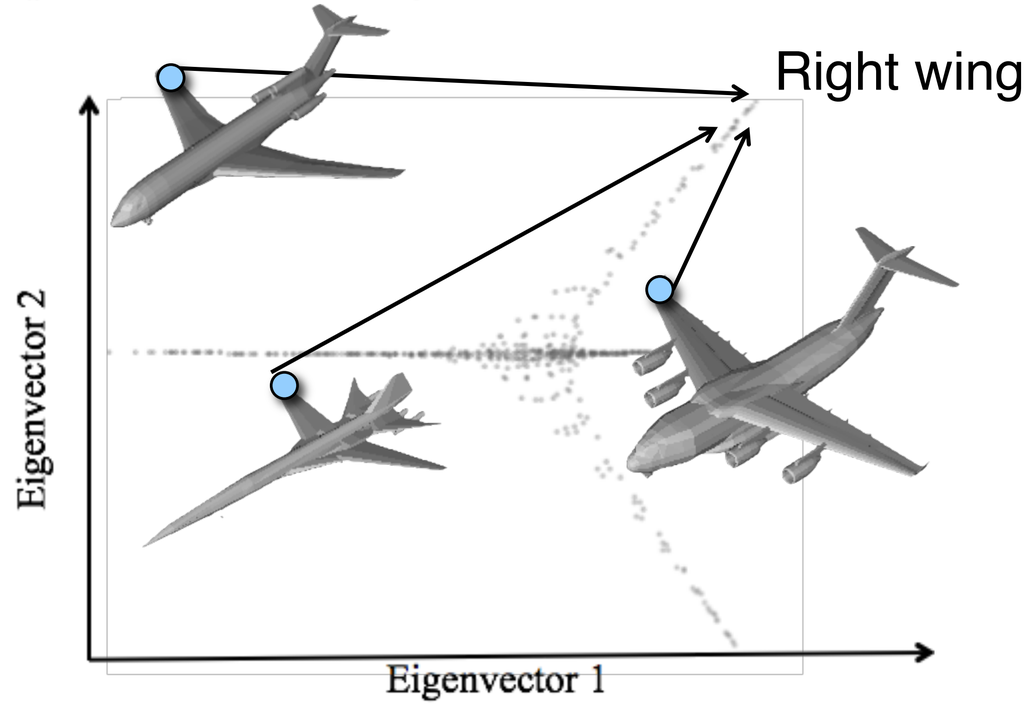

Spectral Embedding

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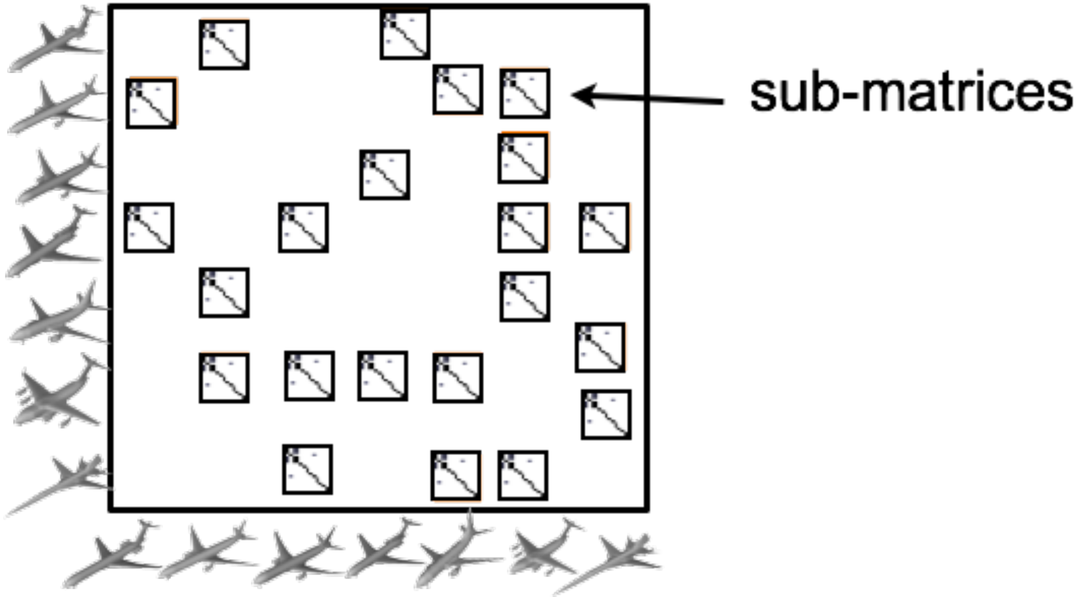

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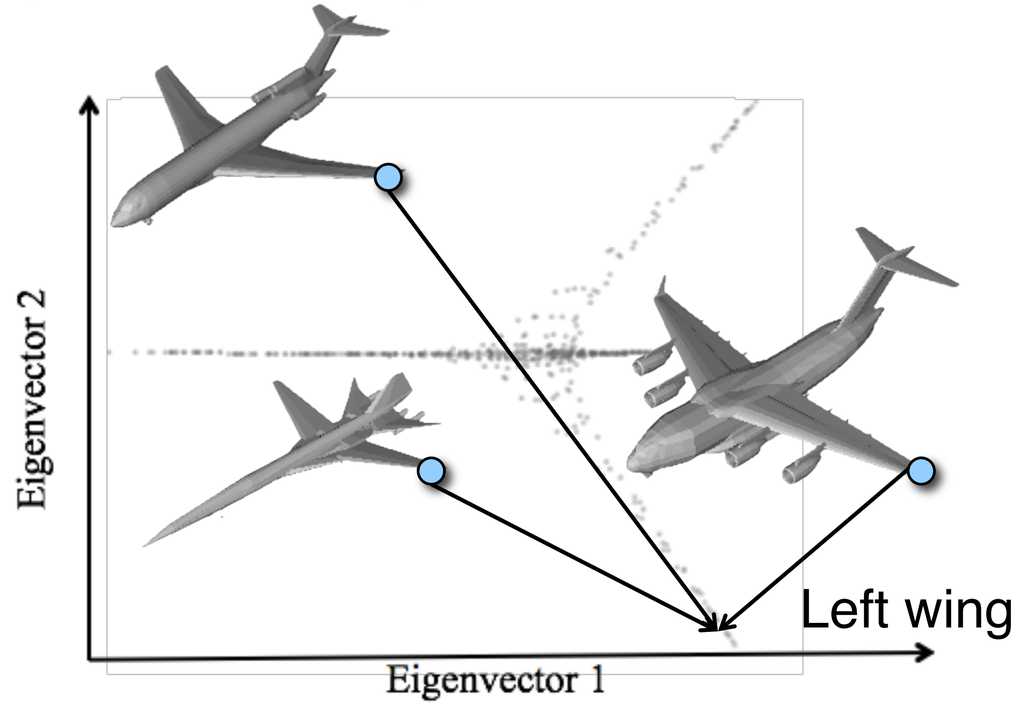
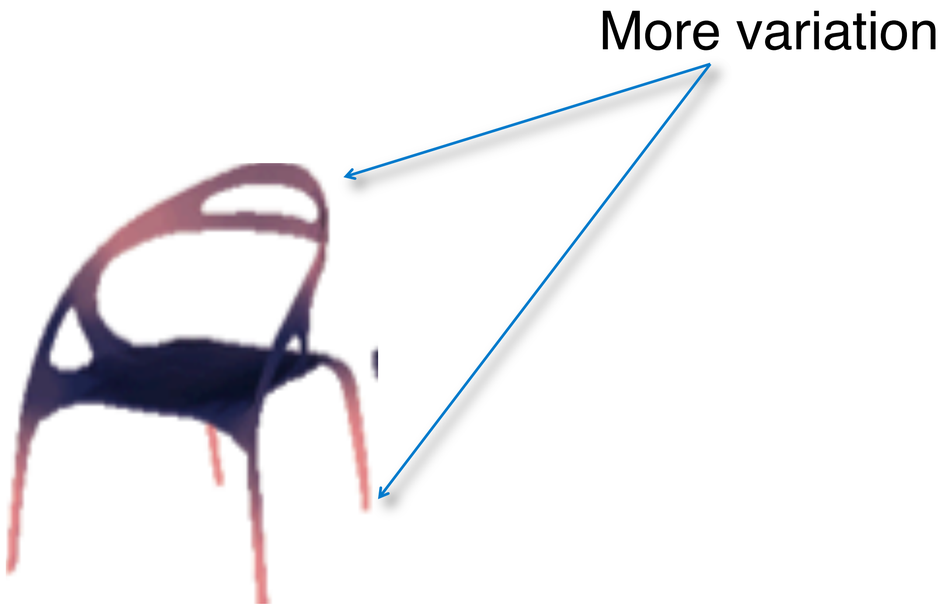


Spectral Embedding

Fuzzy Correspondences

- **Exploration Interface**
  - **Find Variations**
  - Align Viewpoints
  - Sort by Similarity



[Exploring Collections of 3D Models using Fuzzy Correspondences , Kim et al. 2012]

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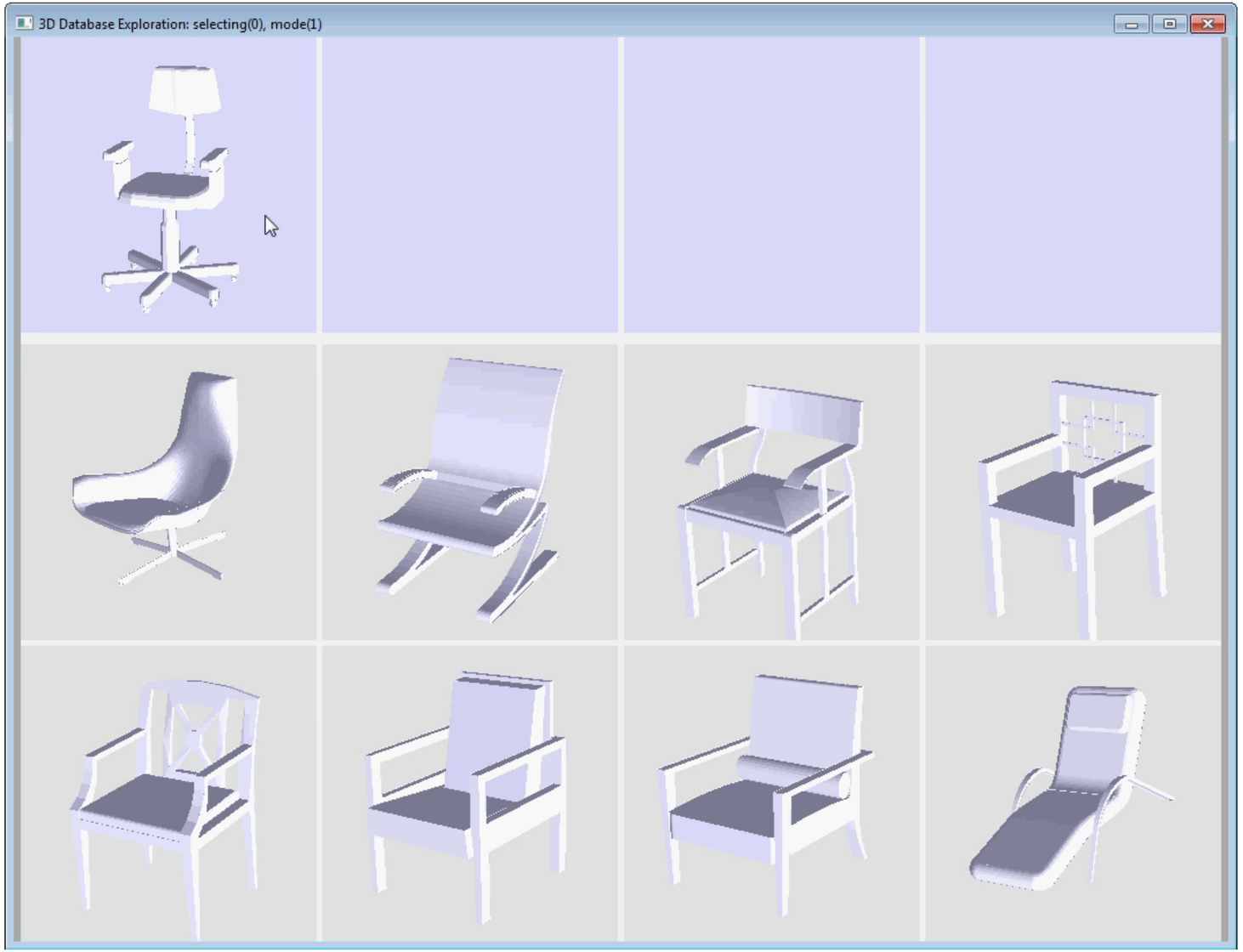

Region-Based Exploration

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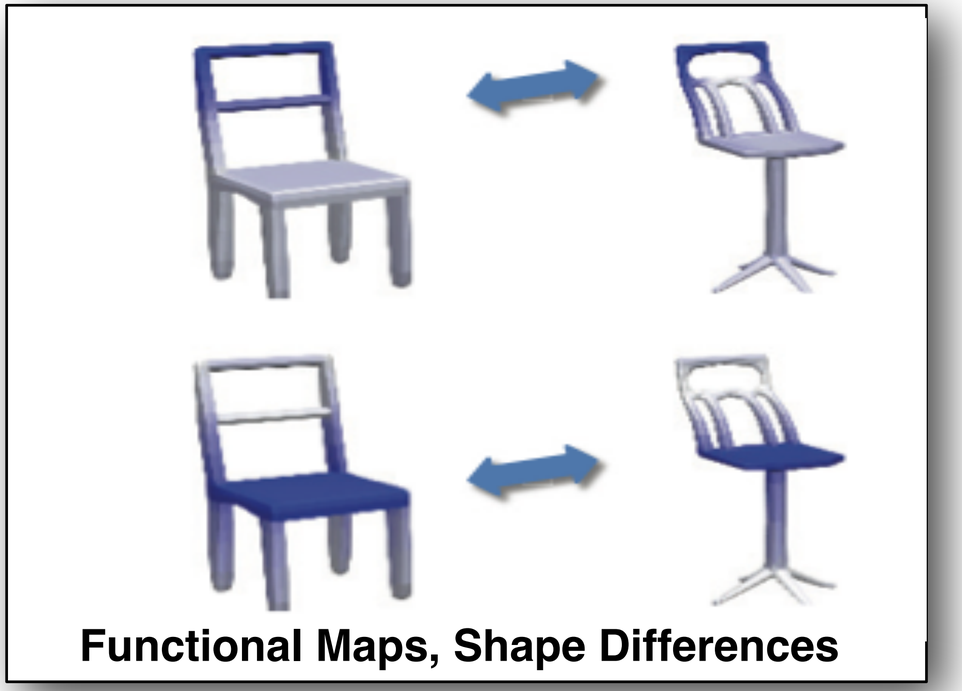
Fuzzy Correspondences, Soft Maps

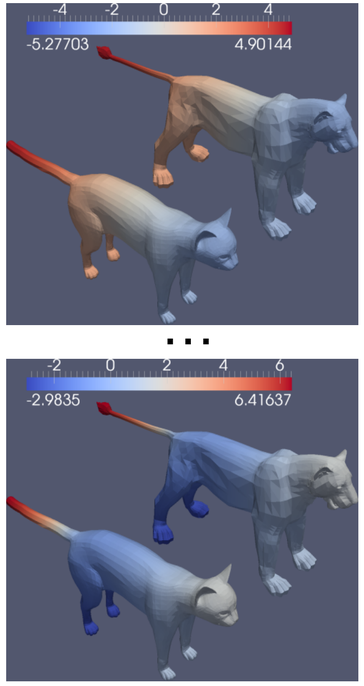


Functional Maps, Shape Differences

[Map-Based Exploration of Intrinsic Shape Differences and Variability, Rustamov et al. 2013]

Shape Differences

- **Analysis**
  - Functional maps approach



[Functional Maps: A Flexible Representation of Maps Between Shapes, Ovsjanikov et al. 2012]

Shape Differences

- **Analysis**
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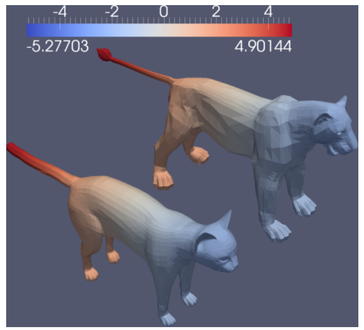

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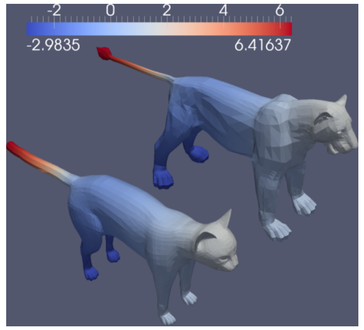
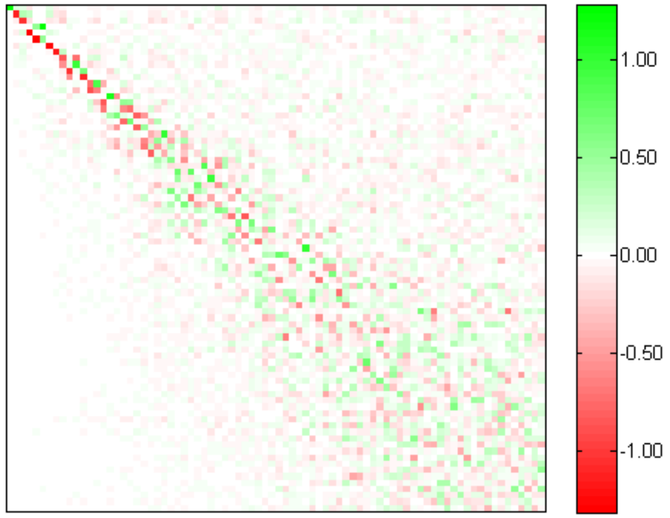




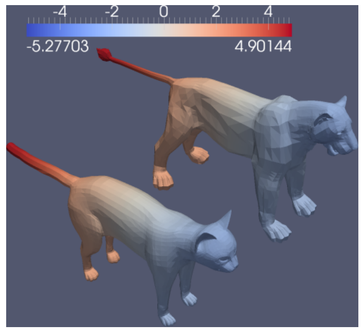
F is a linear operator (matrix)

$$F : L^2(cat) \rightarrow L^2(lion)$$

[Functional Maps: A Flexible Representation of Maps Between Shapes, Ovsjanikov et al. 2012]

Shape Differences

- **Analysis**
  - Functional maps approach
  - Measure distortions induced by a map



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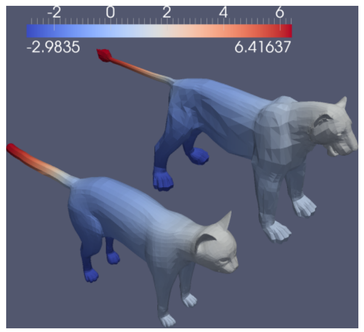
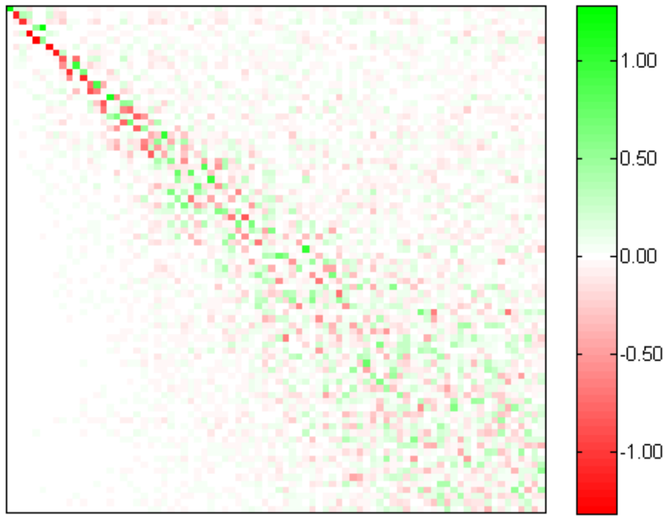
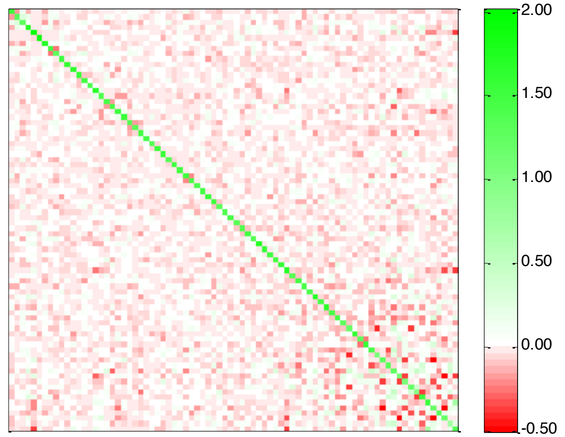
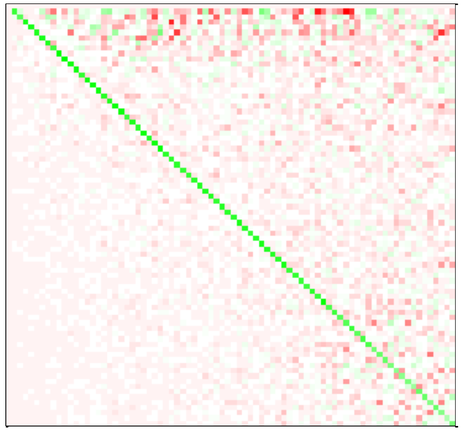




V – area-based shape diff

R – conformal shape diff





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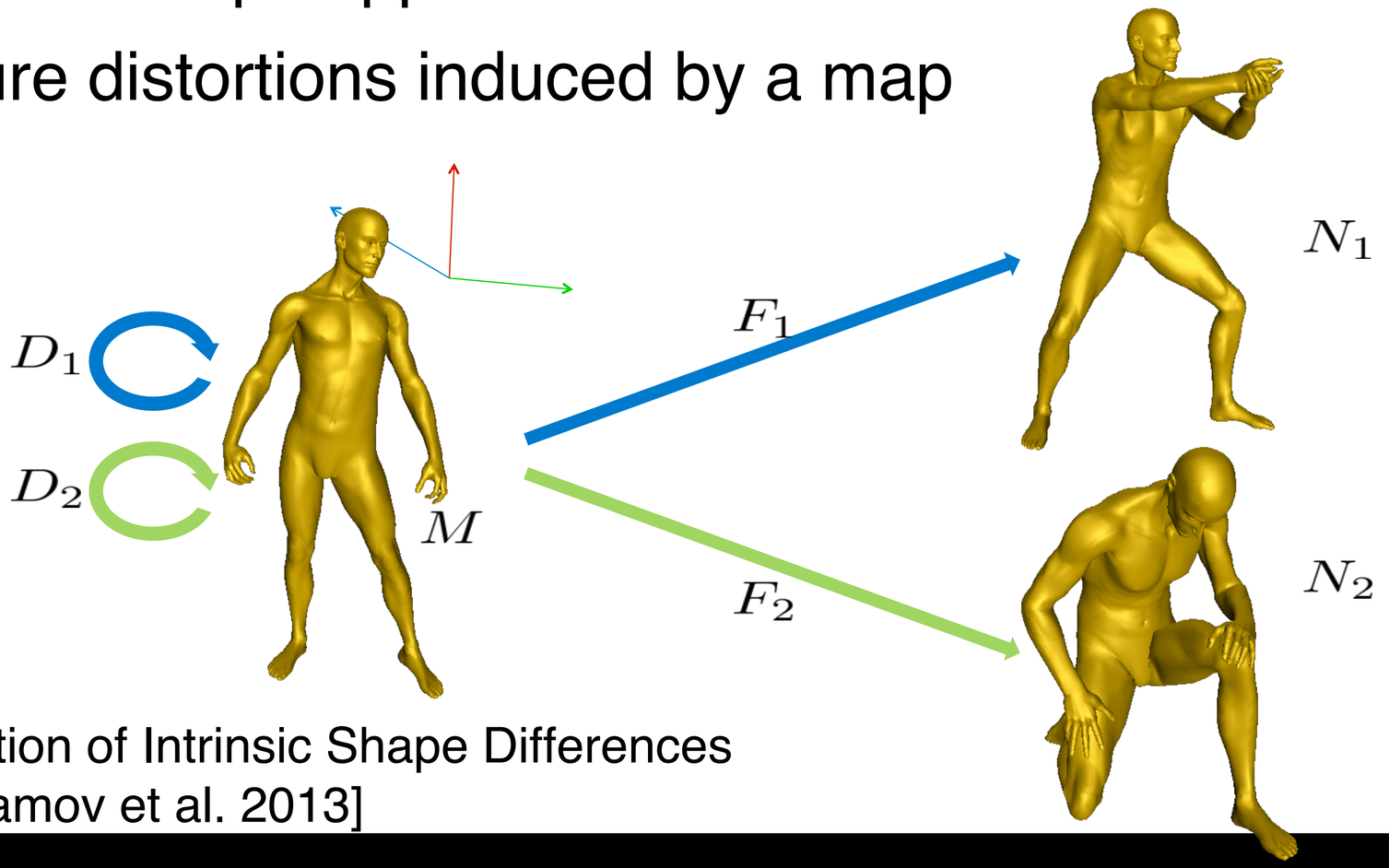

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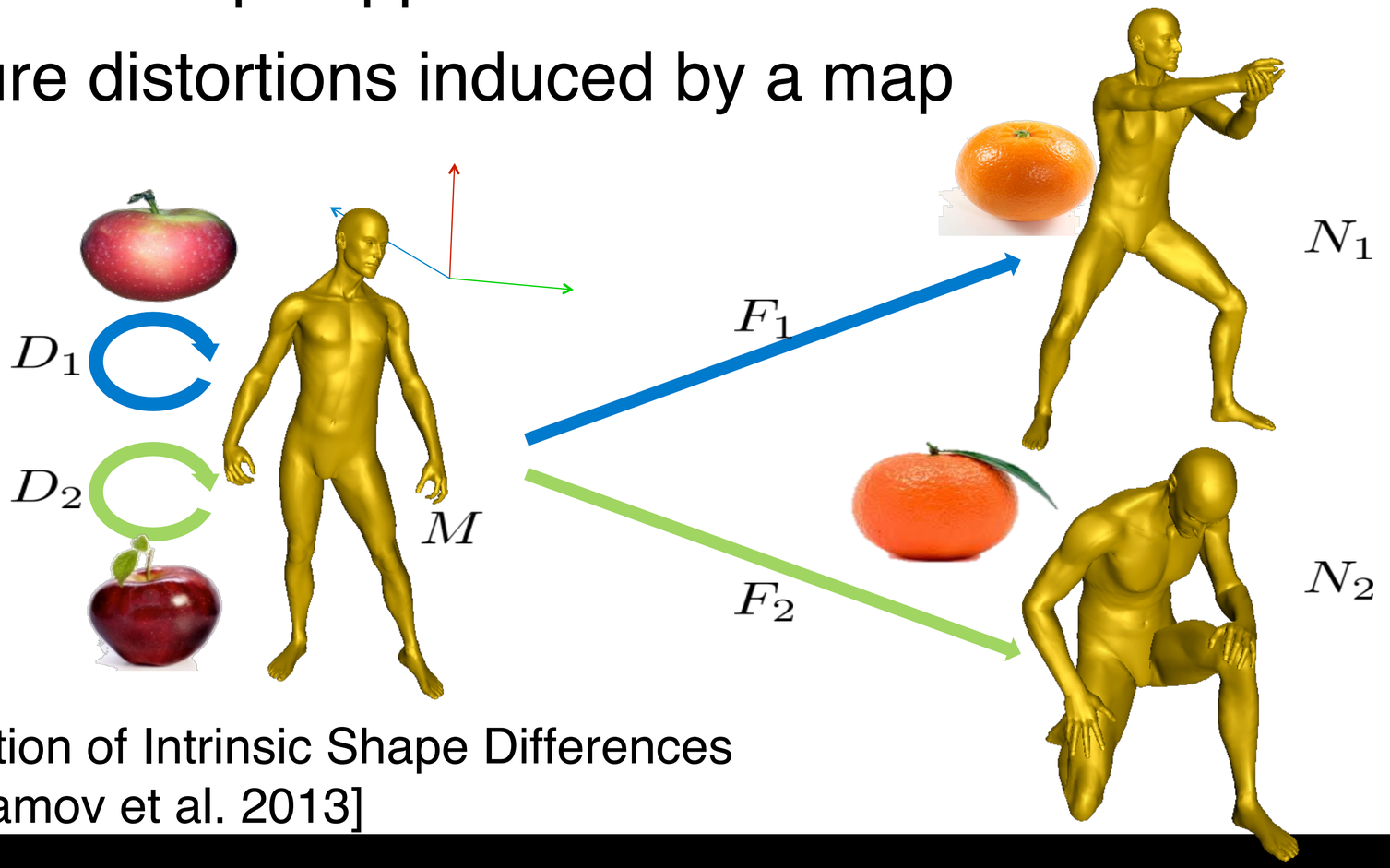

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Rustamov et al. 2013

Shape Differences

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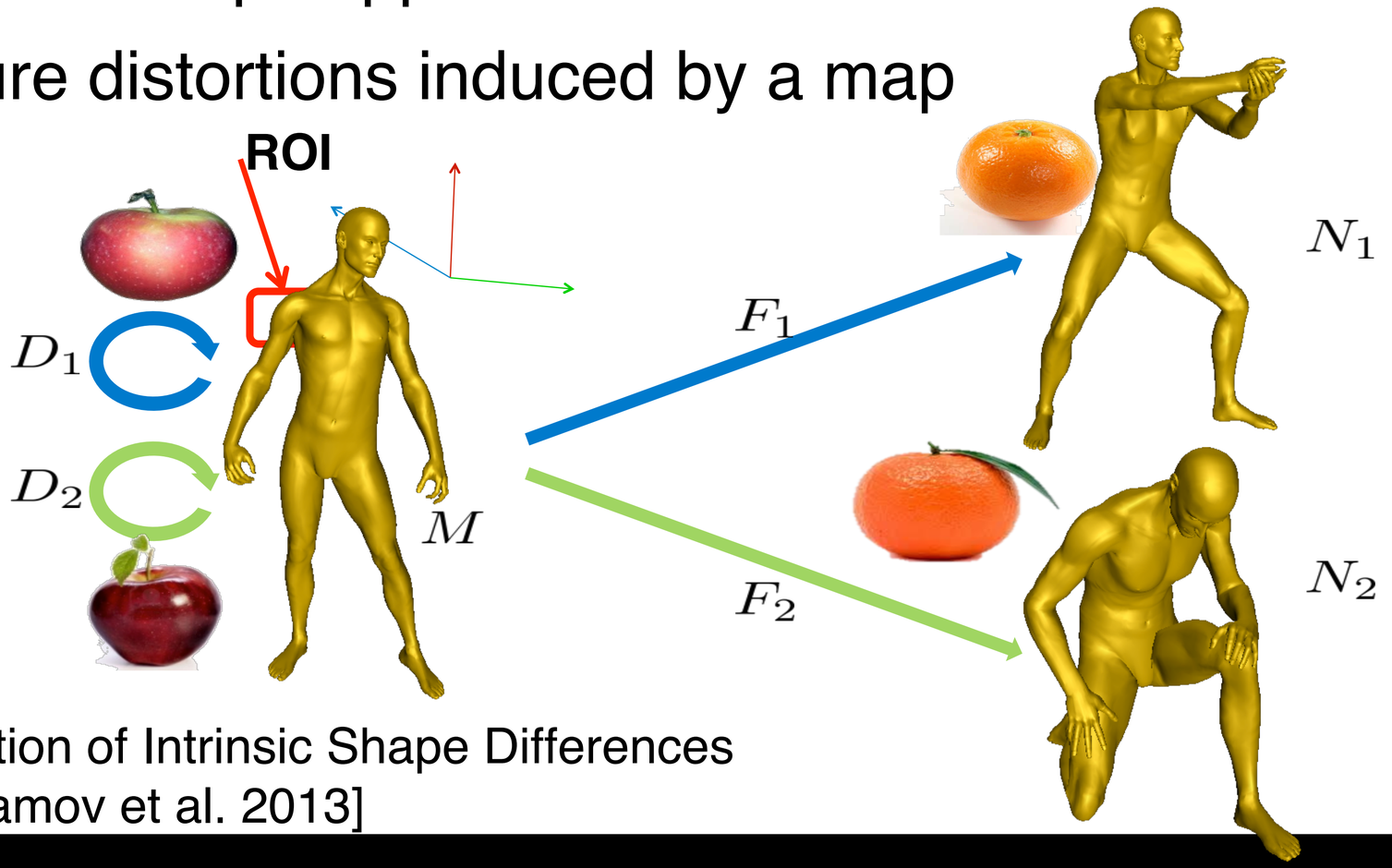
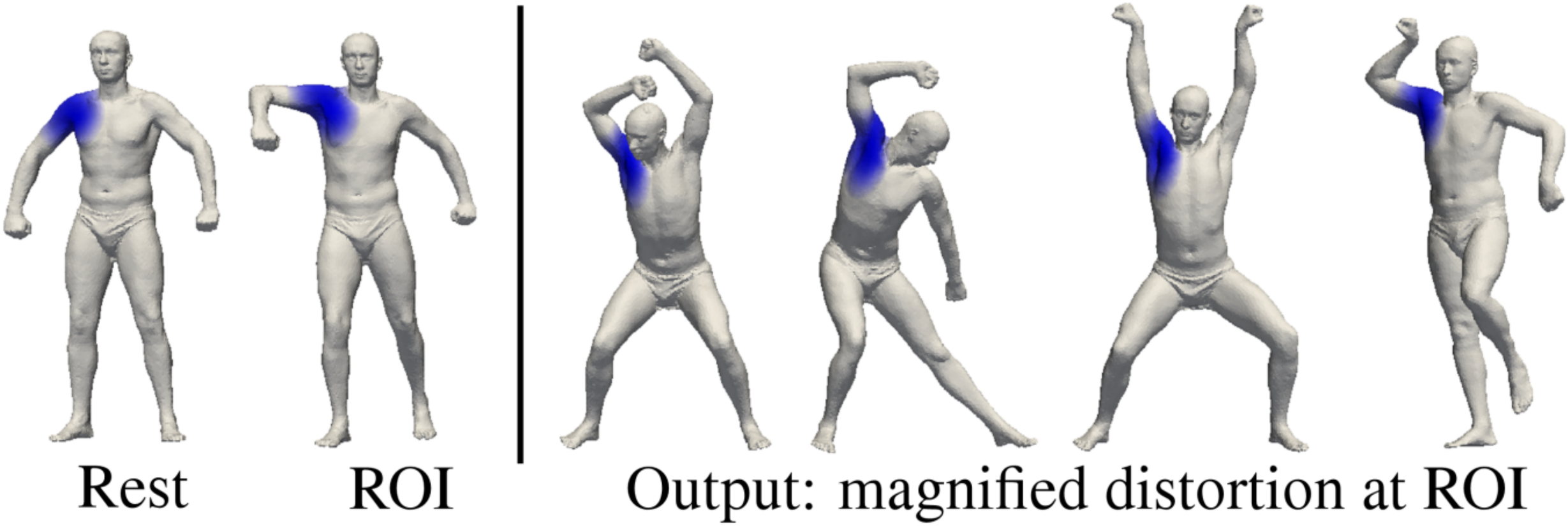


[Map-Based Exploration of Intrinsic Shape Differences and Variability, Rustamov et al. 2013]

Rustamov et al. 2013

Shape Differences

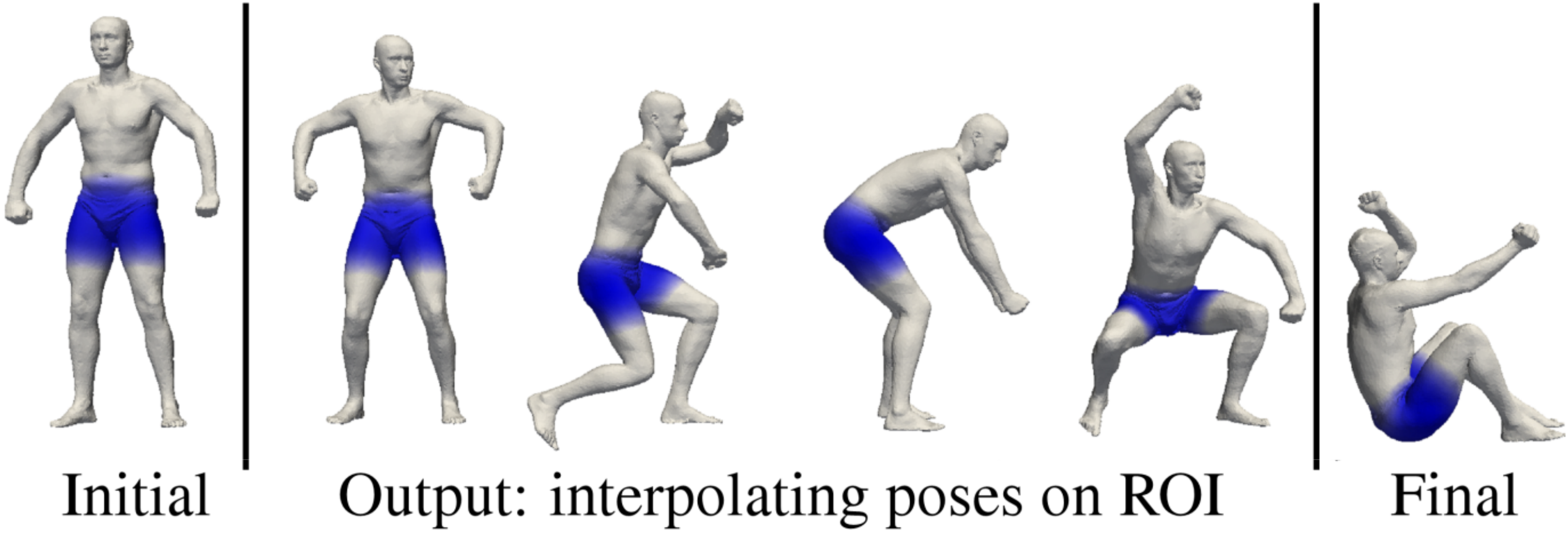
- **Exaggeration of difference in ROI**



[Map-Based Exploration of Intrinsic Shape Differences and Variability, Rustamov et al. 2013]

Shape Differences

- **Interpolation of difference in ROI**



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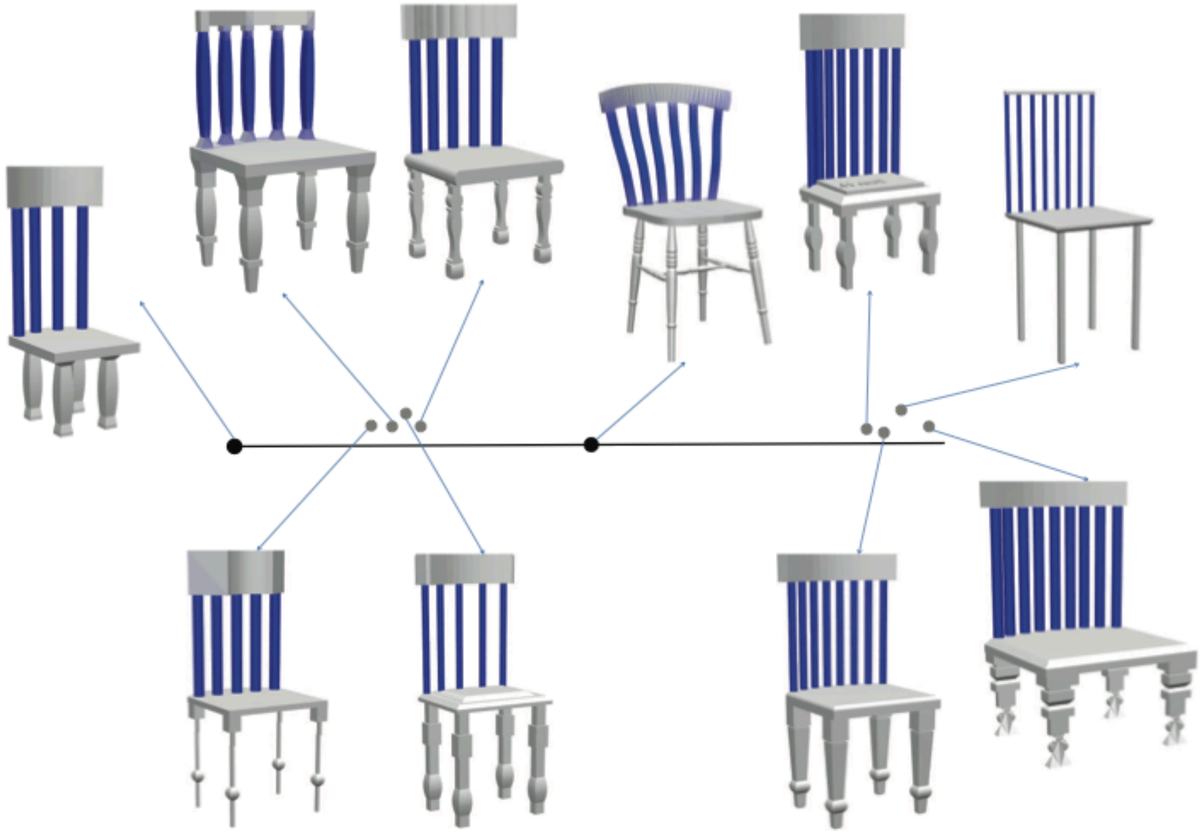
Shape Differences

- **Interpolation of difference in ROI**

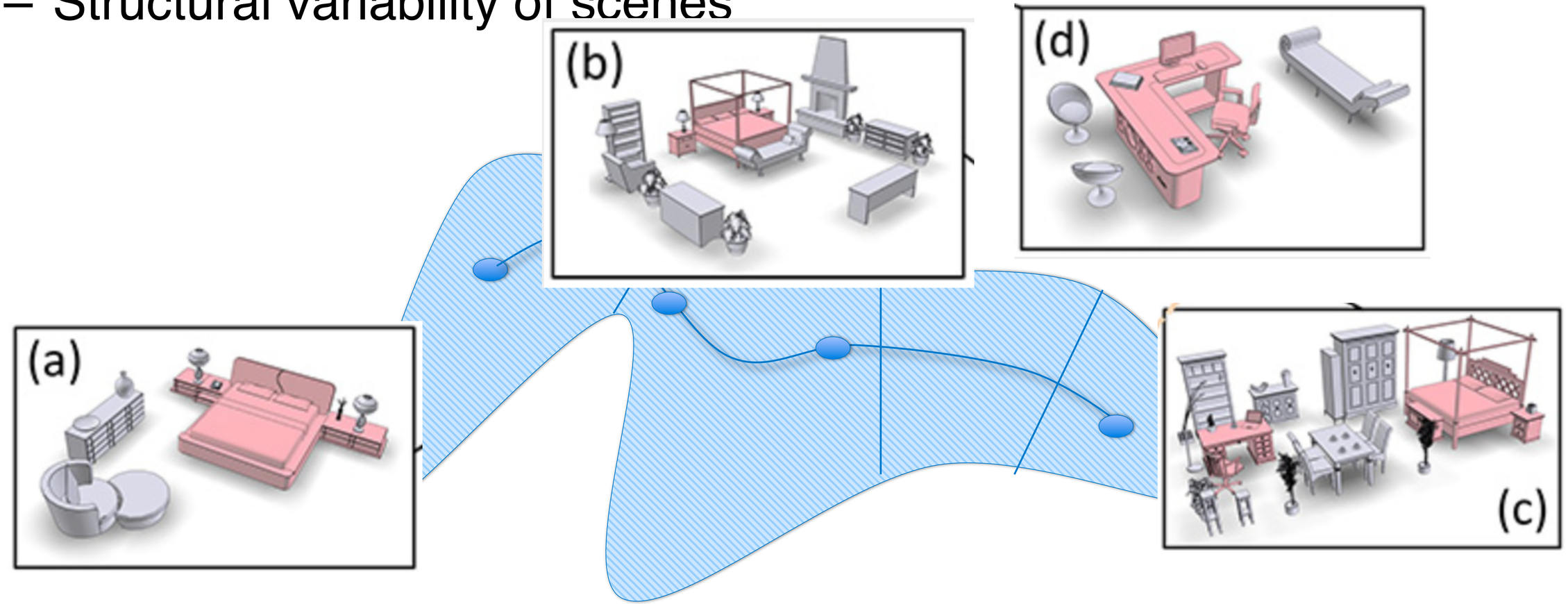
Also, Non-Isometric Case:



[Functional Map Networks for Analyzing and Browsing Large Shape Collections, Huang et al. 2014]

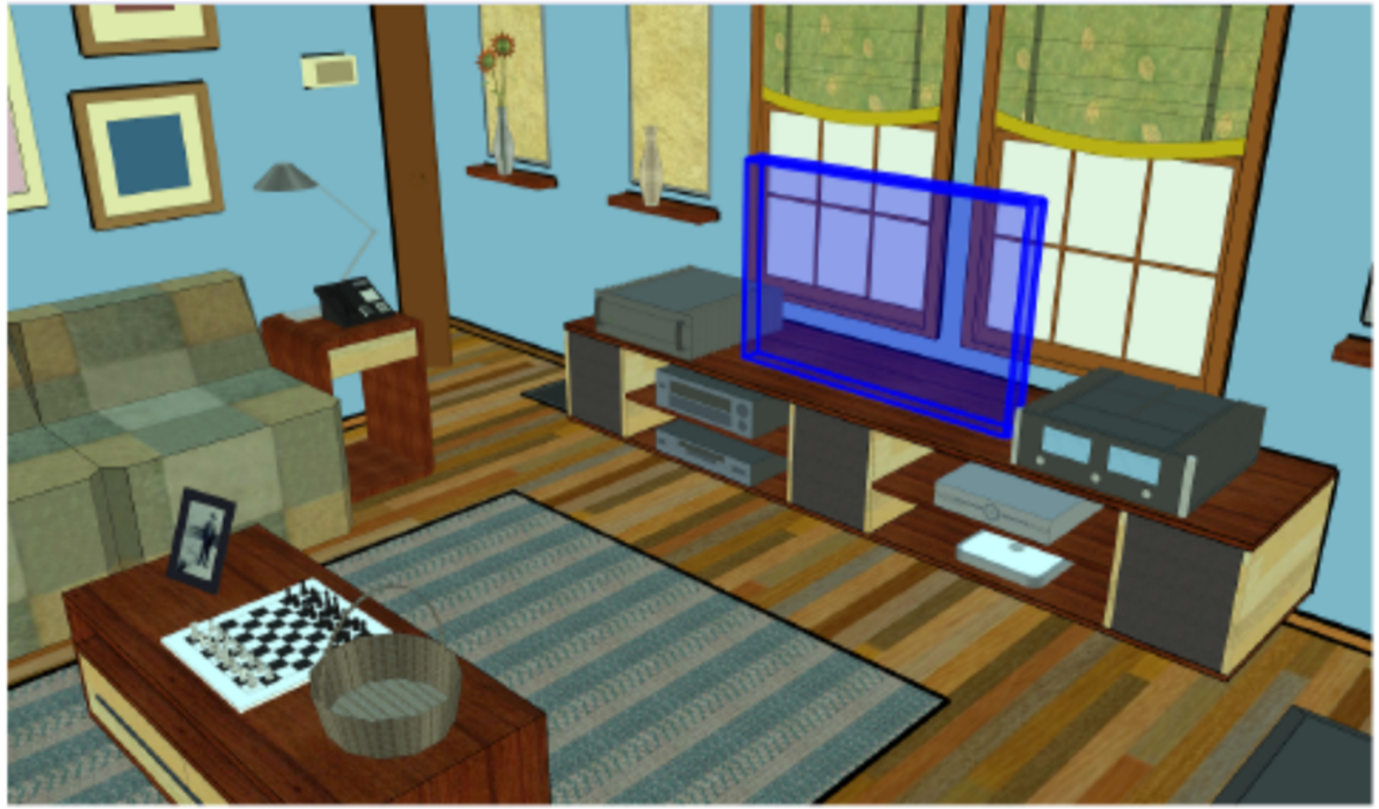
Data Organization

- **Exploration of 3D Scenes**
  - Structural variability of scenes



Scene Organization

- **Analysis**
  - Context provides a lot of information



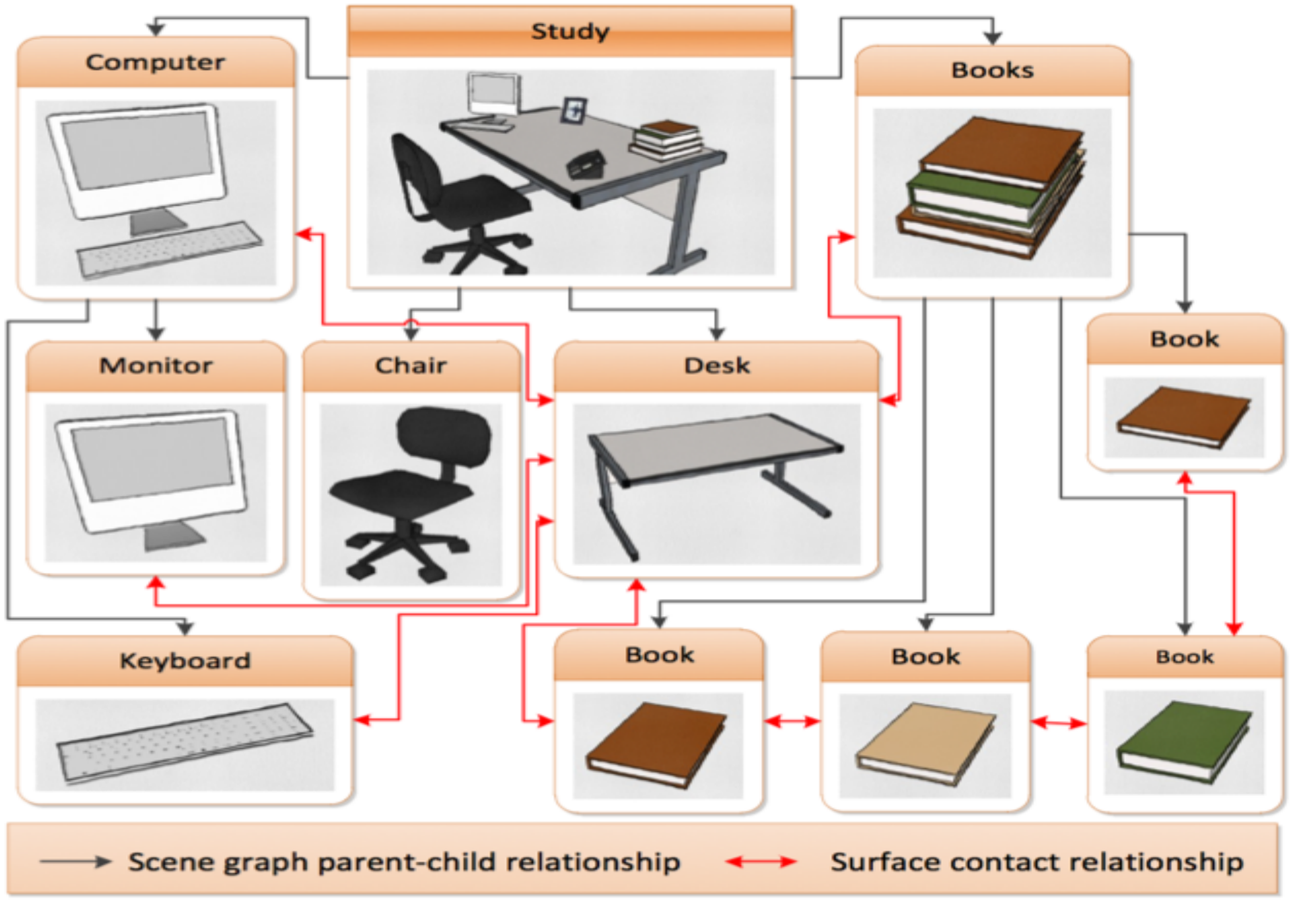
[Context-Based Search for 3D Models, Fisher and Hanrahan. 2010]

Scene Organization

- **Analysis**
  - Context provides a lot of information
  - Scenes as graphs

Relations:

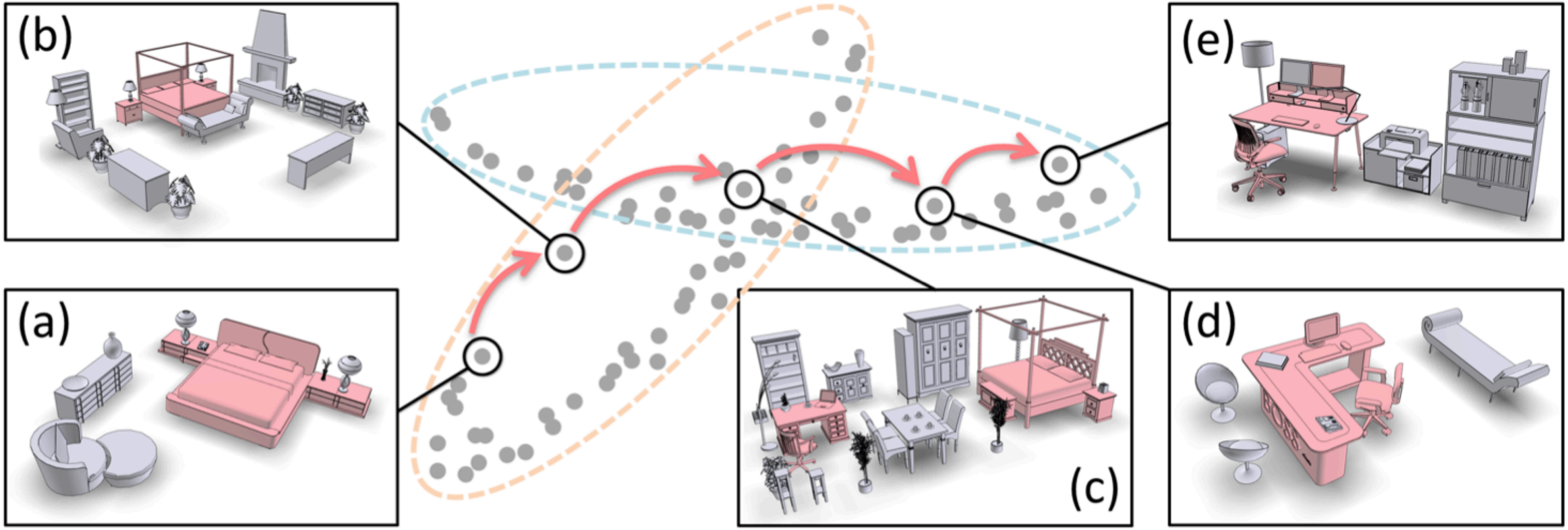
Containment
Horizontal support
Surface contact



[Characterizing Structural Relationships in Scenes Using Graph Kernels, Fisher et al.. 2011]

Contextual Focal Points

- **Scene Exploration via Focal Points**
  - Leverage salient subgraphs



[Organizing Heterogeneous Scene Collections through Contextual Focal Points, Xu et al. 2014]

Contextual Focal Points

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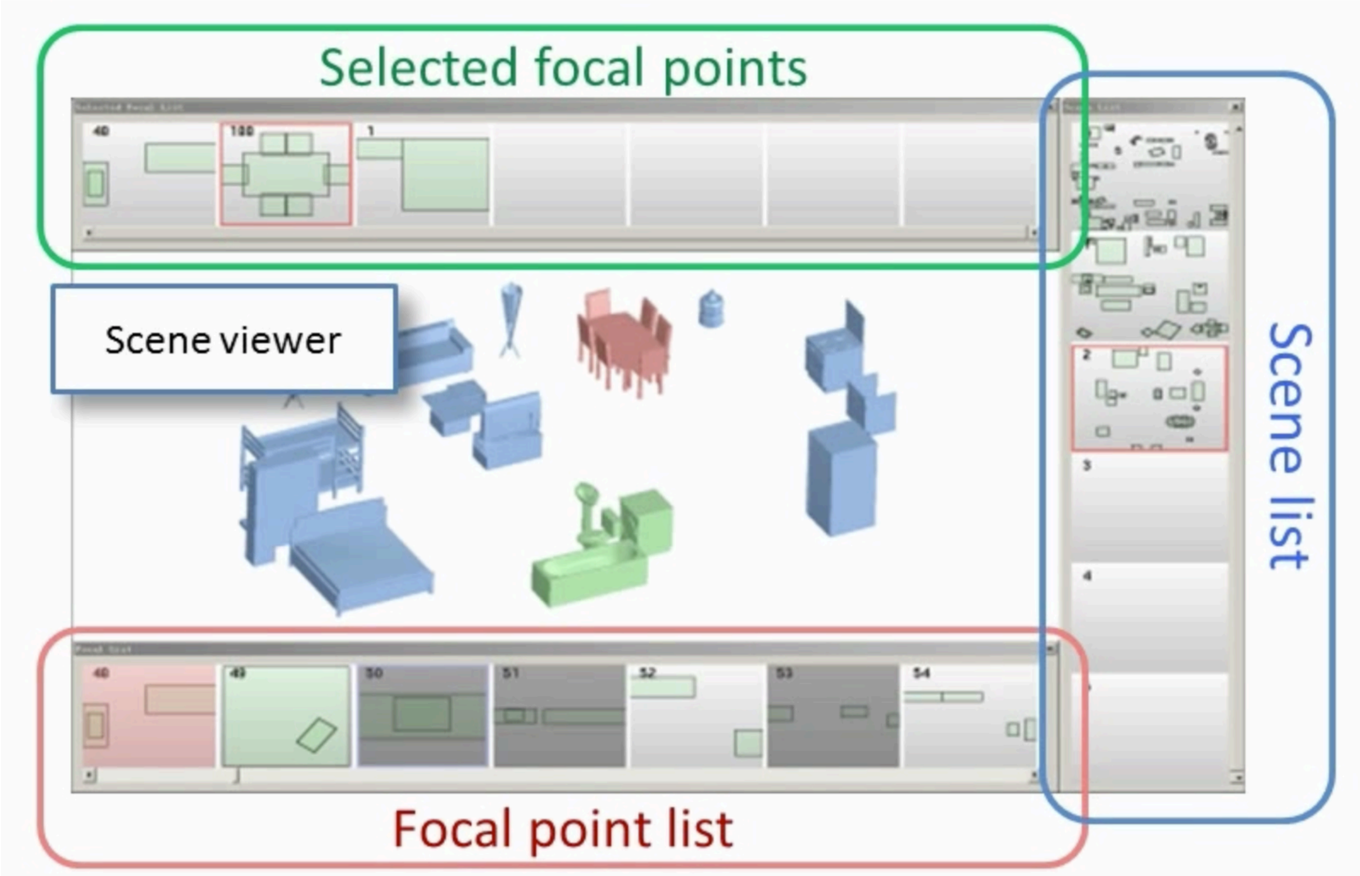

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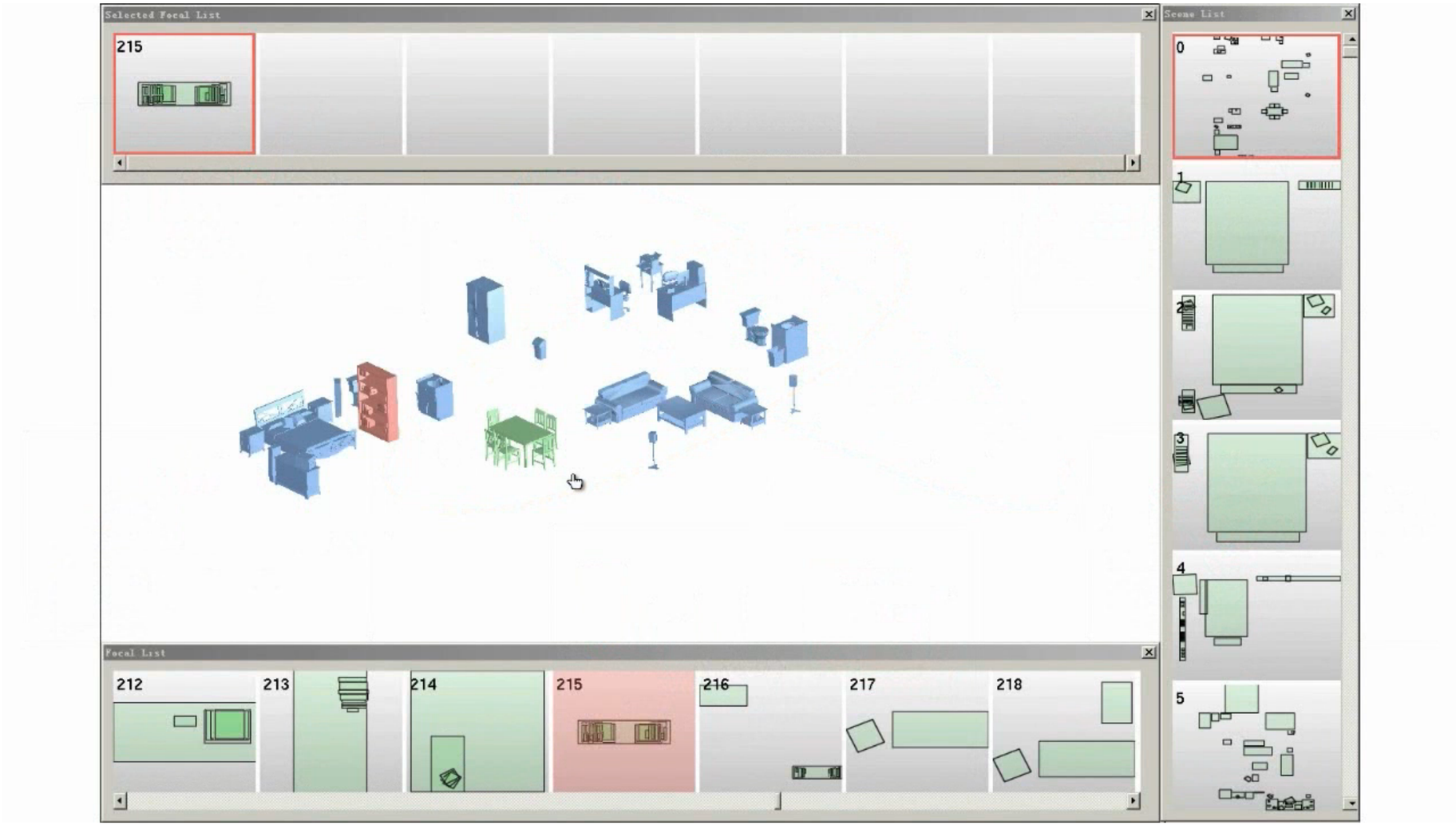
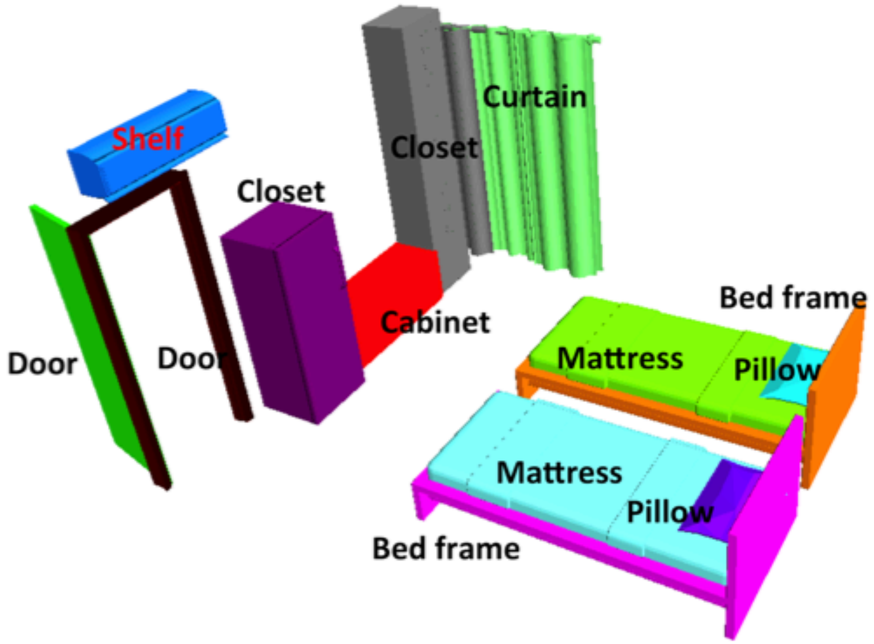
Contextual Focal Points

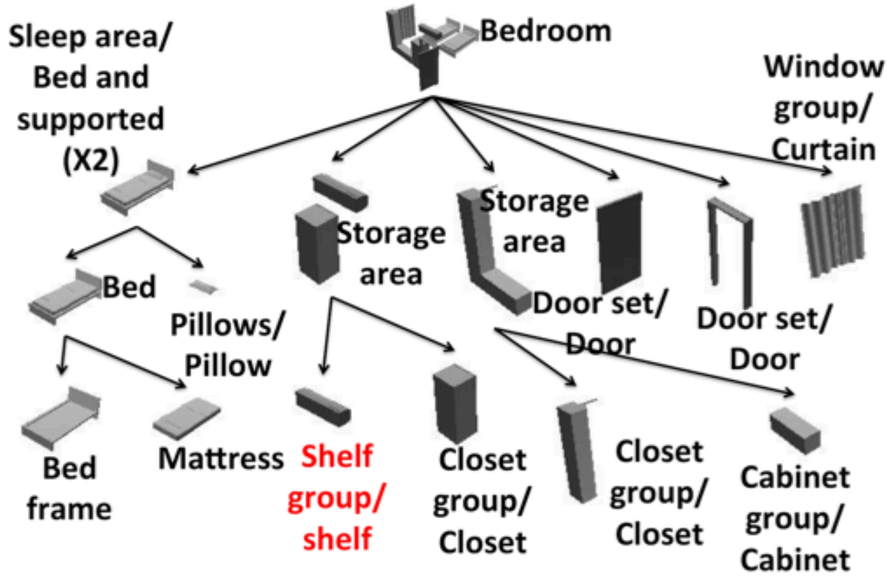


[Organizing Heterogeneous Scene Collections through Contextual Focal Points, Xu et al. 2014]

Scene Hierarchies

- **Hierarchical Analysis**
  - Learn interesting relations within groups of related objects
  - Visualize and explore at different levels of hierarchy

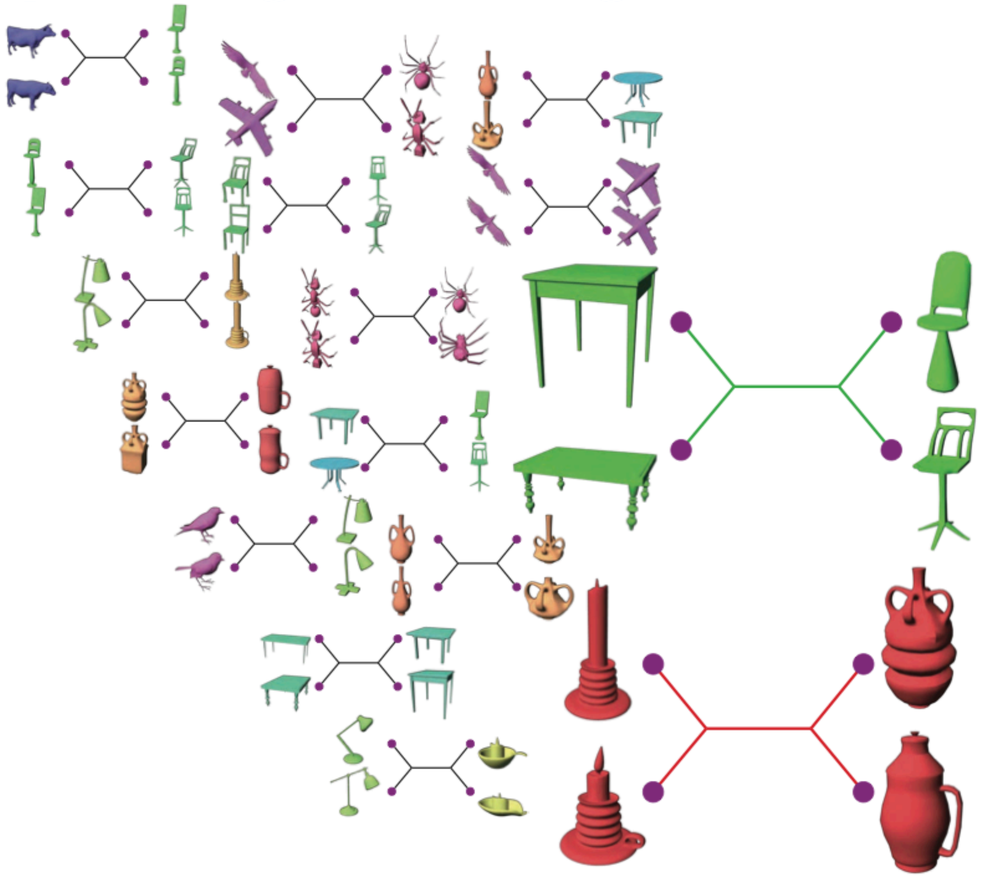


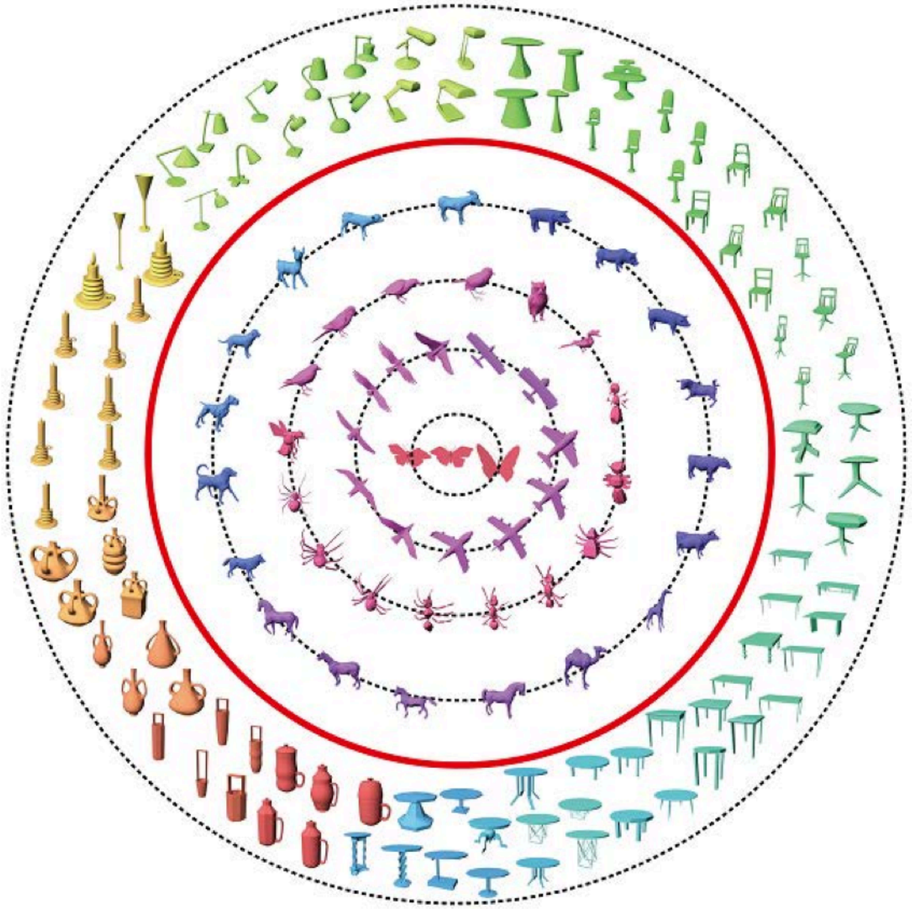


[Creating Consistent Scene Graphs Using a Probabilistic Grammar, Liu et al. 2014 (conditionally accepted)]

Other Interfaces

- **Exploring Heterogeneous Collections**

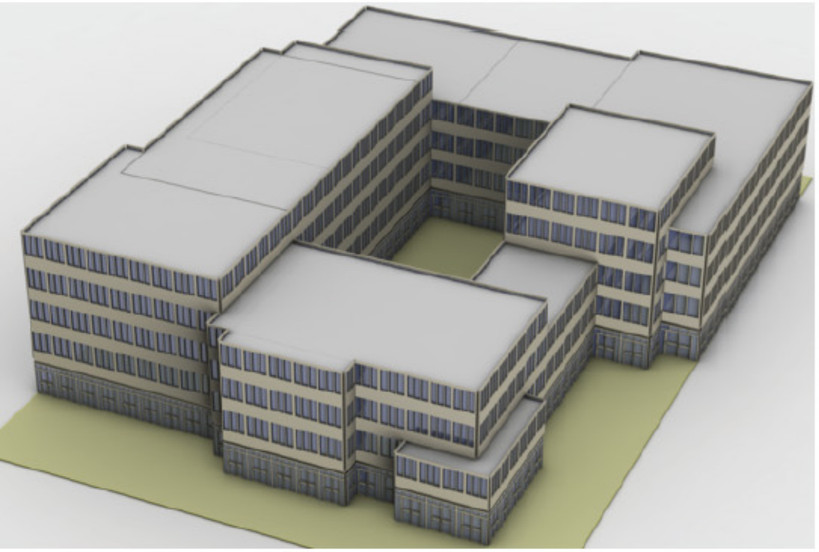




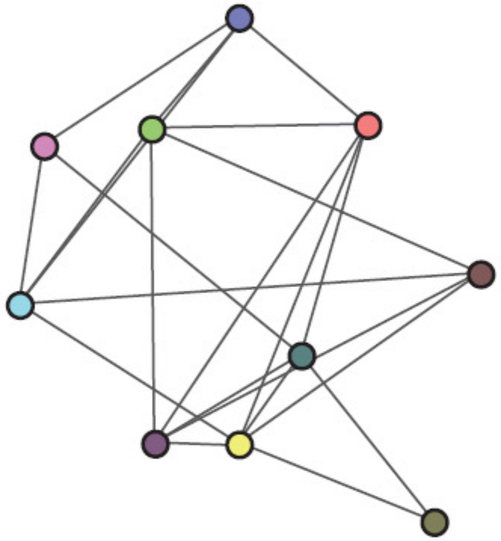
[Qualitative Organization of Collections of Shapes via Quartet Analysis, Huang et al. 2013]

Other Interfaces

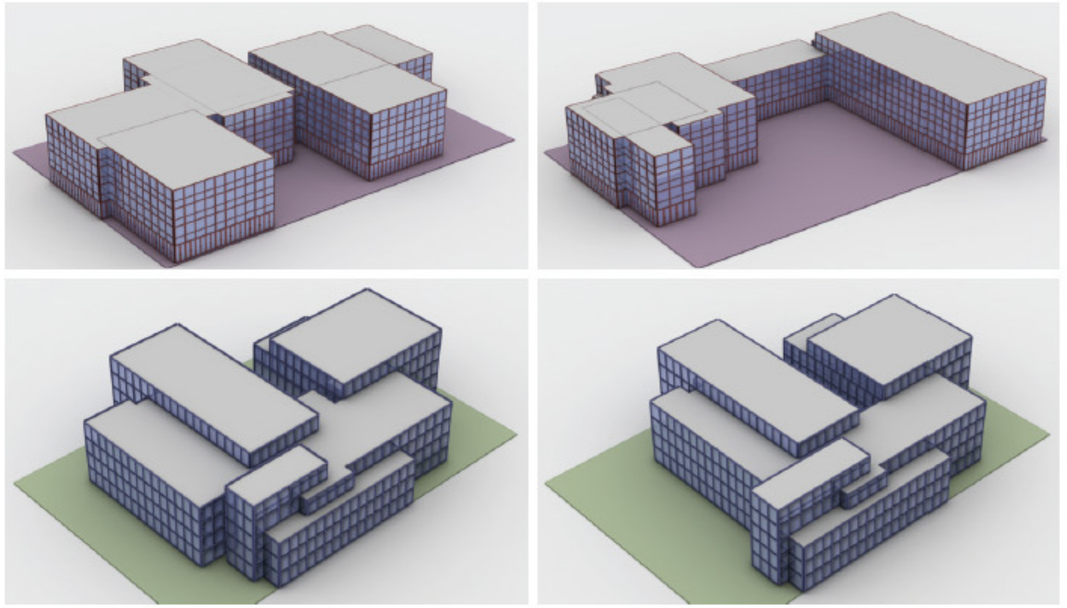
- **Exploring Building Layouts**



1 of 10 initial good layouts



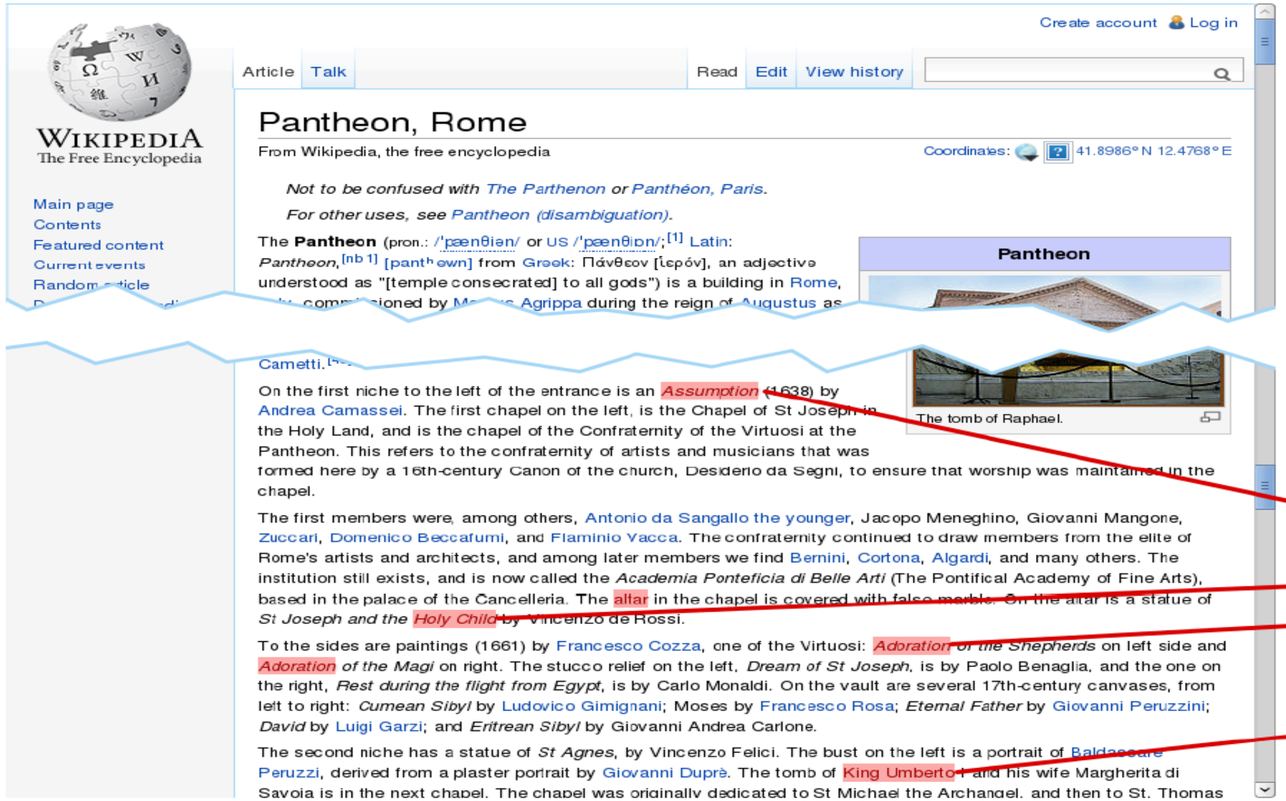
portal graph



[Generating and Exploring Good Building Layouts, Bao et al. 2013]

Other Interfaces

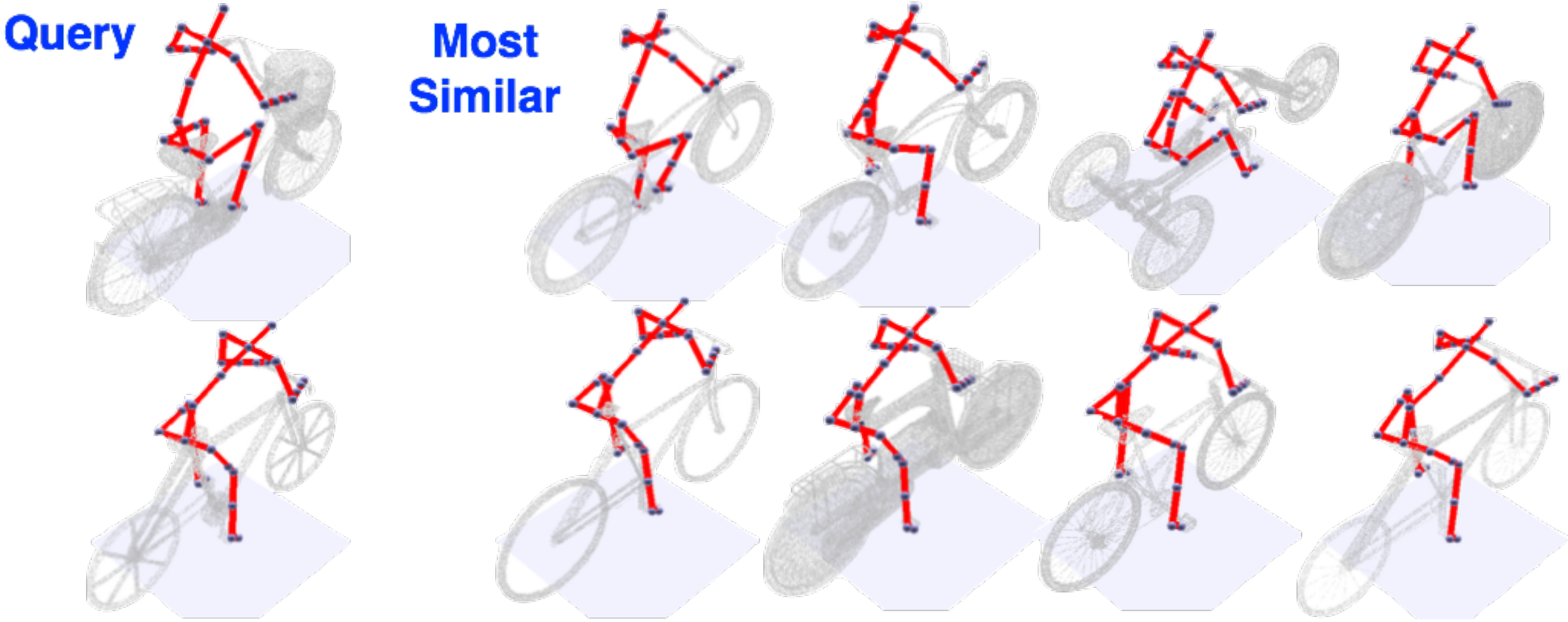
- **Exploring Cultural Heritage**



[3D Wikipedia: Using Online Text to Automatically Label and Navigate Reconstructed Geometry Russel et al. 2013]

Other Interfaces

- **Exploring Functional Shapes**



[Shape2Pose: Human-Centric Shape Analysis. Kim et al. 2014]

Thank you!