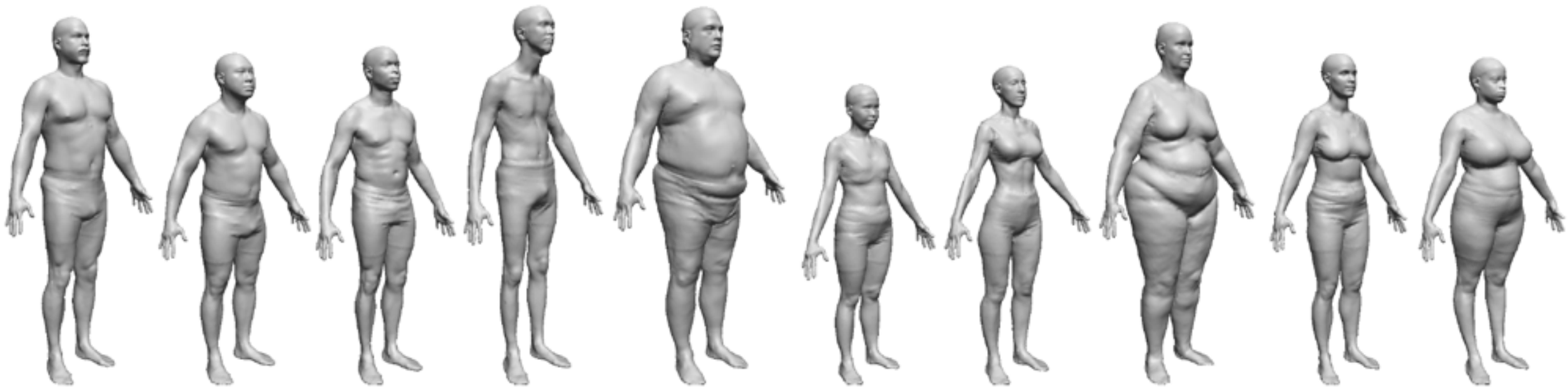
CS 468

Data-driven Shape Analysis

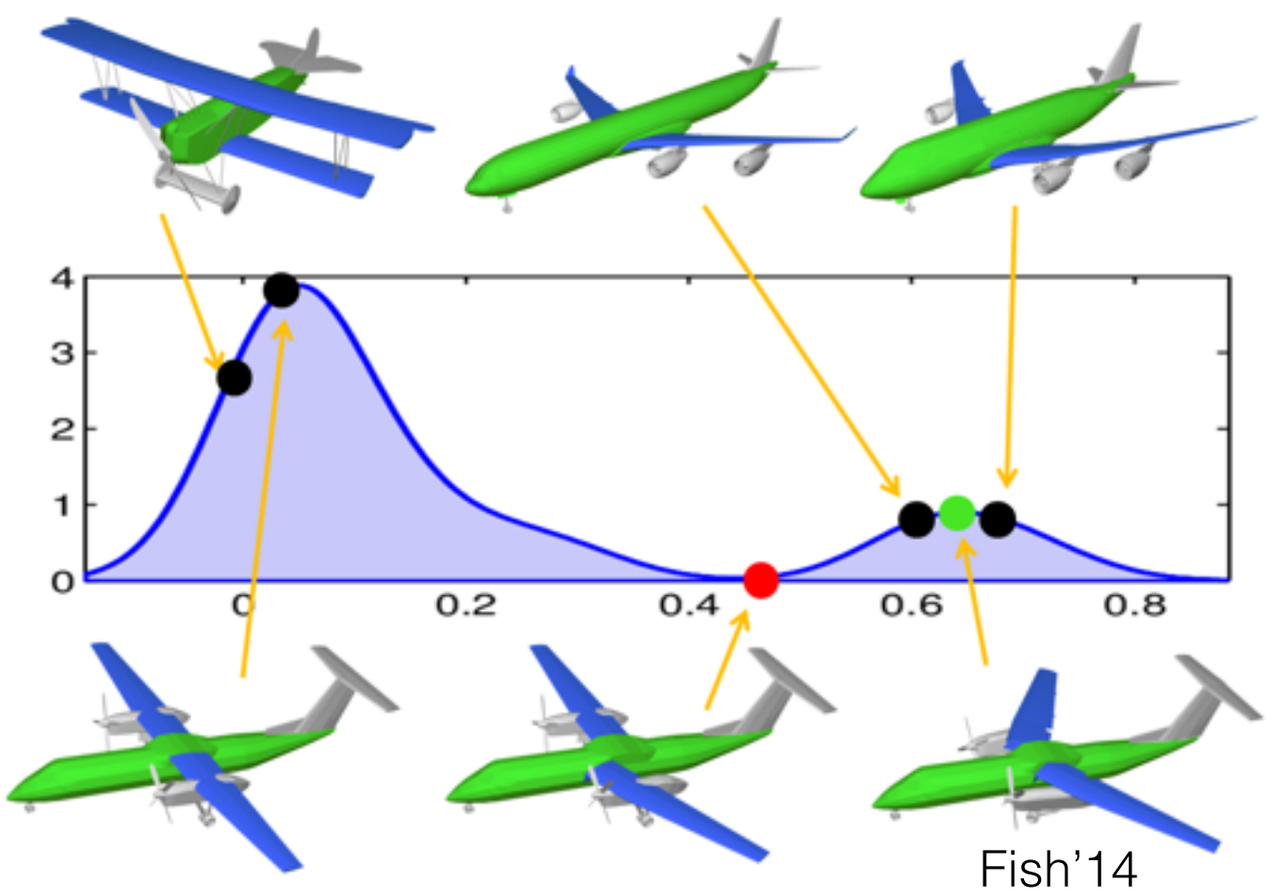
Parametric Models

May 13, 2014

Representing Shape Variations



Allen'03

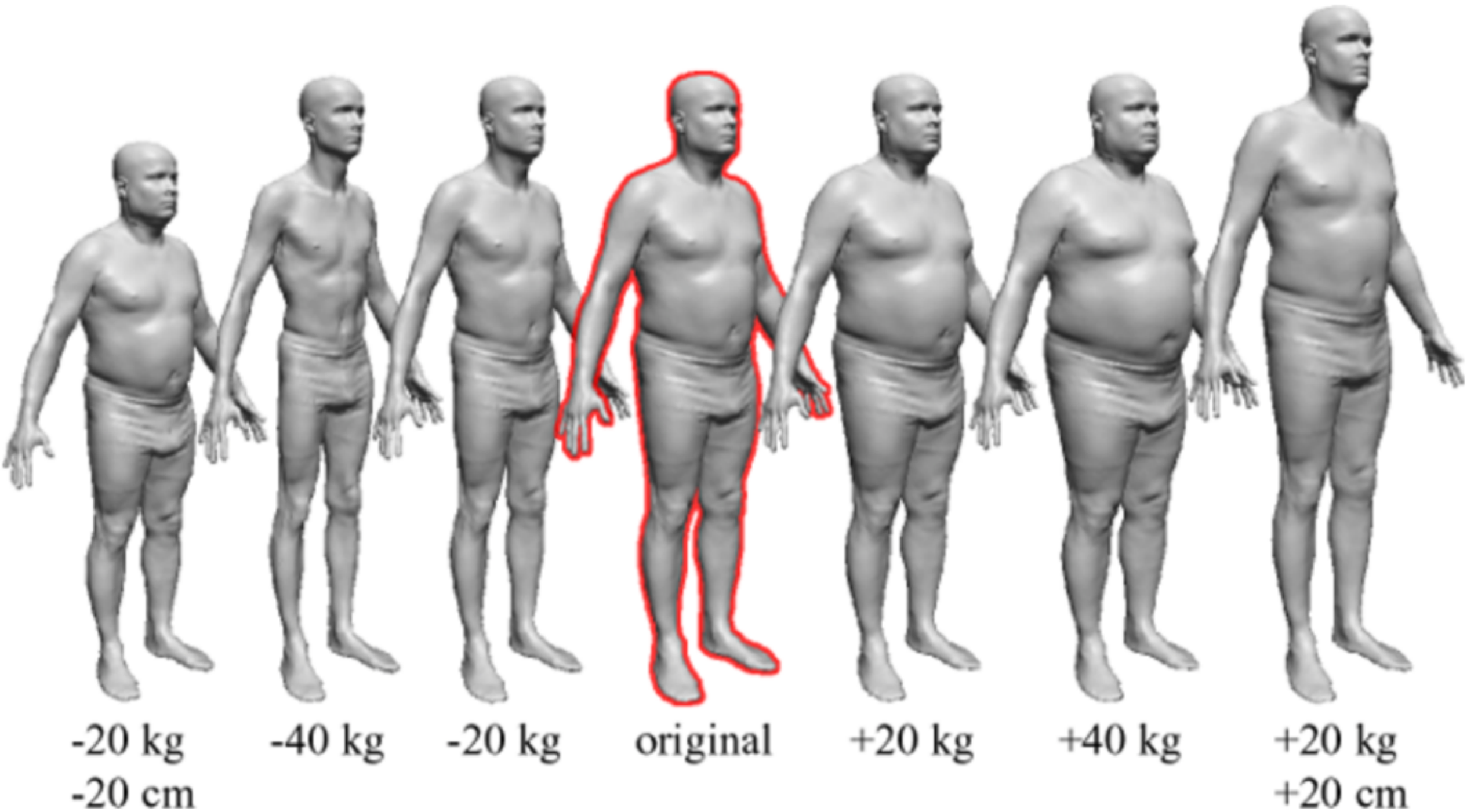


Fish'14

Wu'14

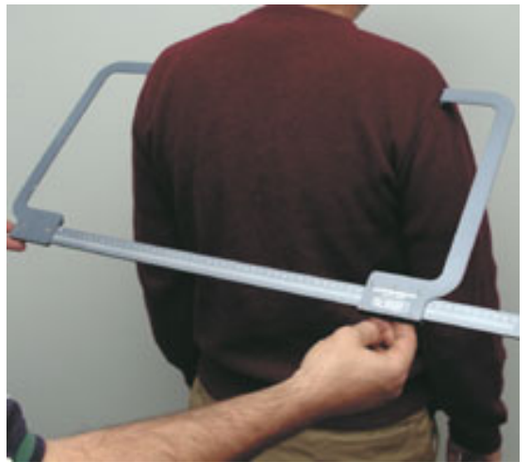
Space of Human Bodies

Variance in human bodies



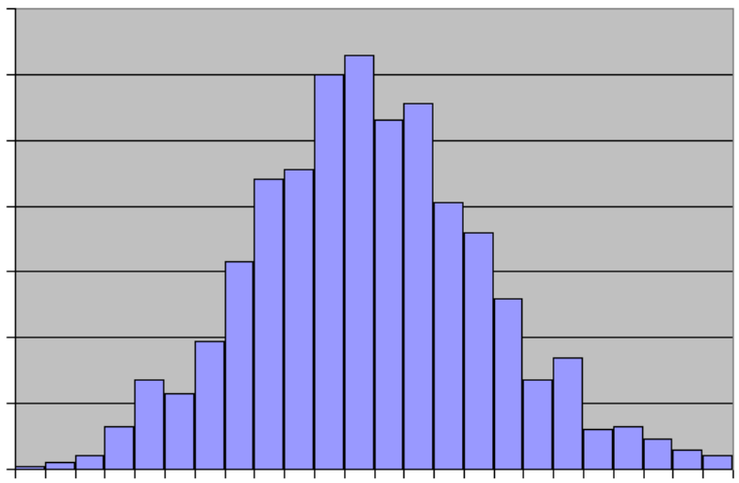
Allen'03

Variance in human bodies



Traditional anthropometry

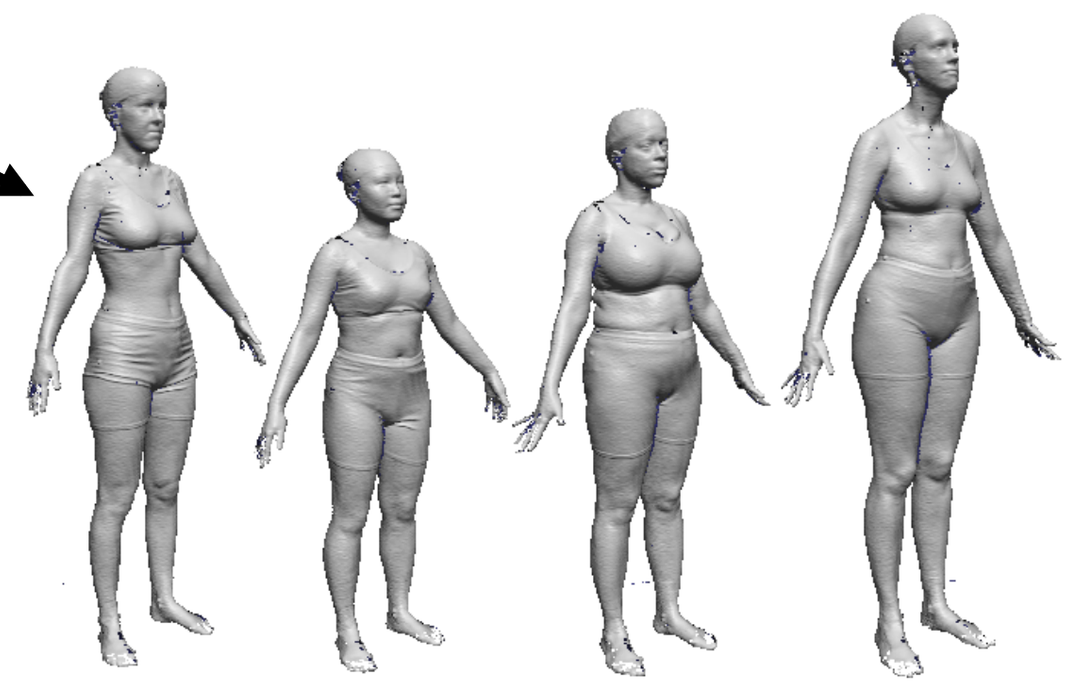
Subject Number	Neck Base Circumference (mm)	Shoulder Breadth (mm)	Sitting Height (mm)	Stature (mm)	Sul Ski (mr
1	537.00	647.00	971.00	1872.00	
2	496.00	529.00	962.00	1829.00	
7	475.00	547.00	936.00	1731.00	
8	456.00	477.00	935.00	1828.00	
9	481.00	512.00	926.00	1762.00	
10	486.00	519.00	950.00	1806.00	
12	465.00	495.00	924.00	1702.00	
13	443.00	452.00	866.00	1705.00	
16	459.00	493.00	936.00	1836.00	
24	480.00	519.00	940.00	1771.00	
25	481.00	539.00	941.00	1829.00	
26	484.00	539.00	894.00	1704.00	
27	450.00	489.00	884.00	1712.00	



Allen'03

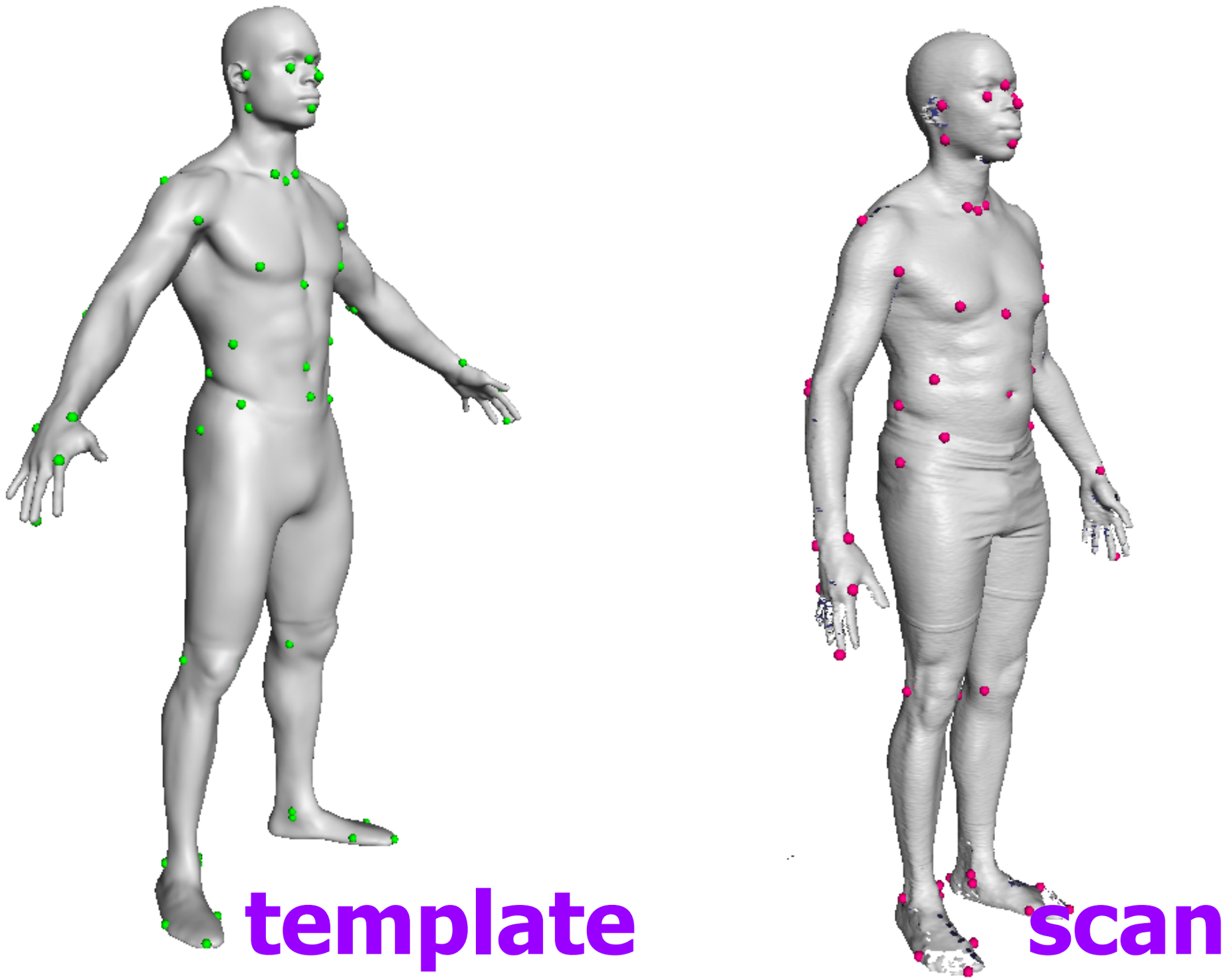
Variance in human bodies

Leverage new technology



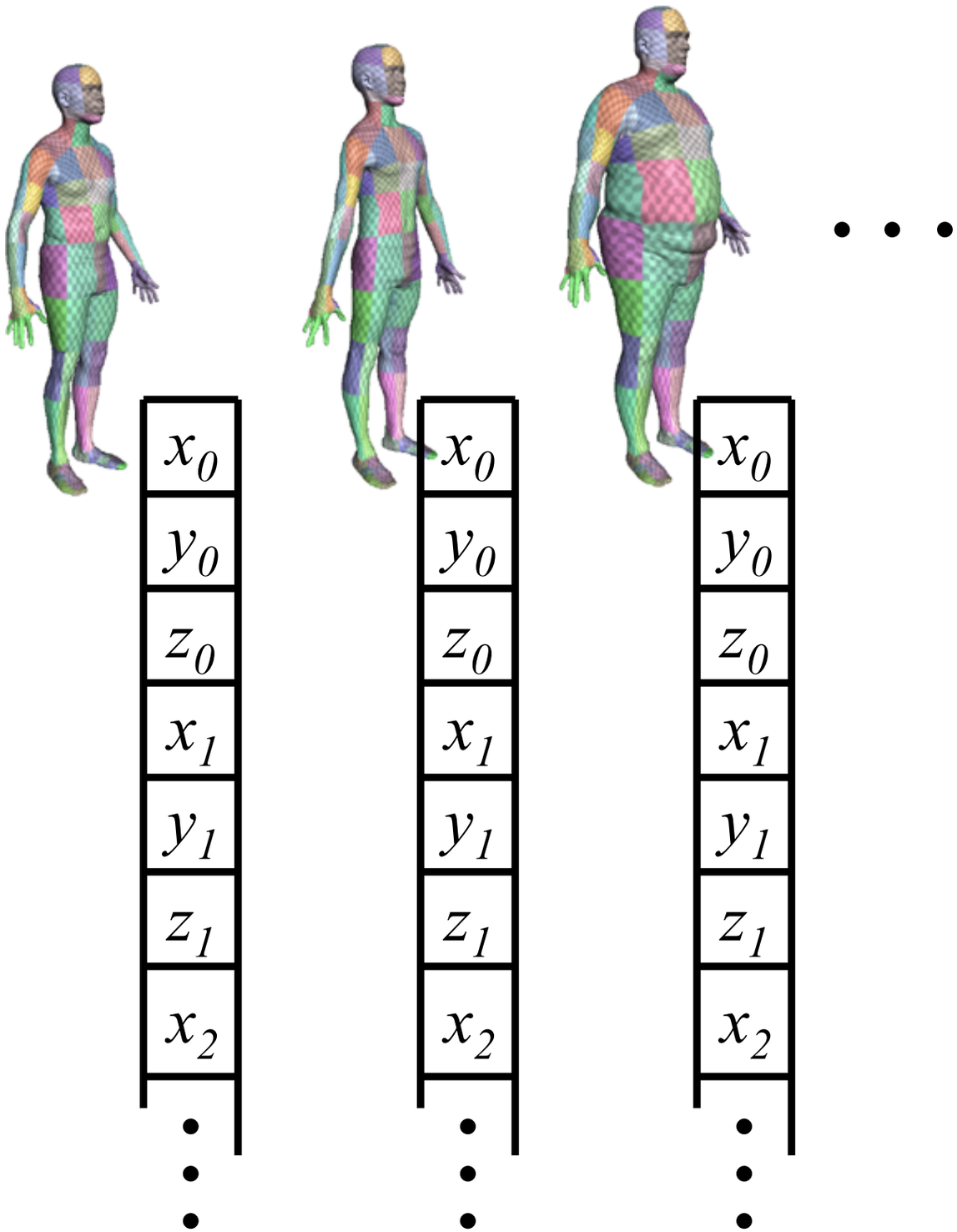
Allen'03

Variance in human bodies



Allen'03

Variance in human bodies



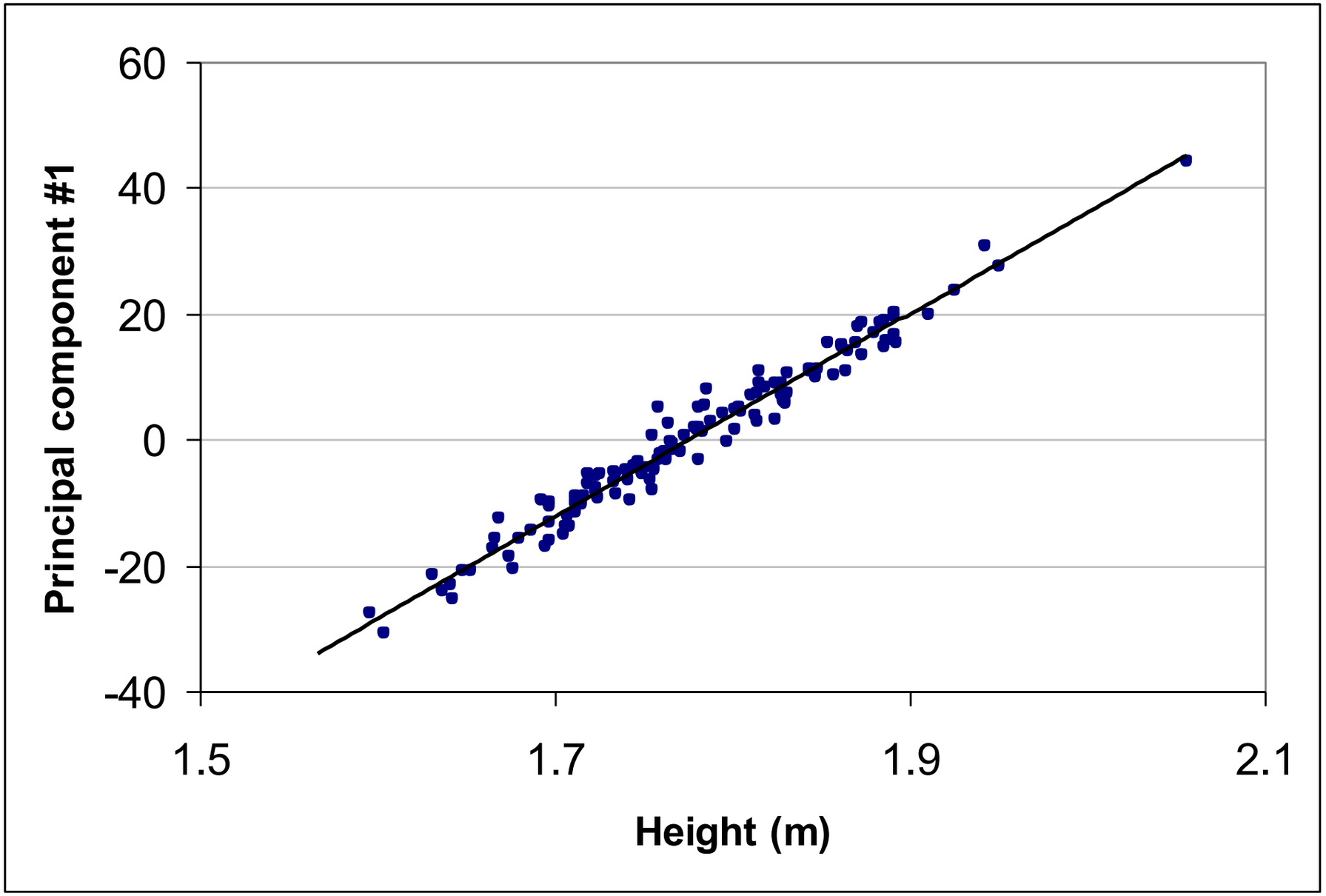
Statistical analysis (PCA) on vertex positions

average male

Allen'03

Variance in human bodies

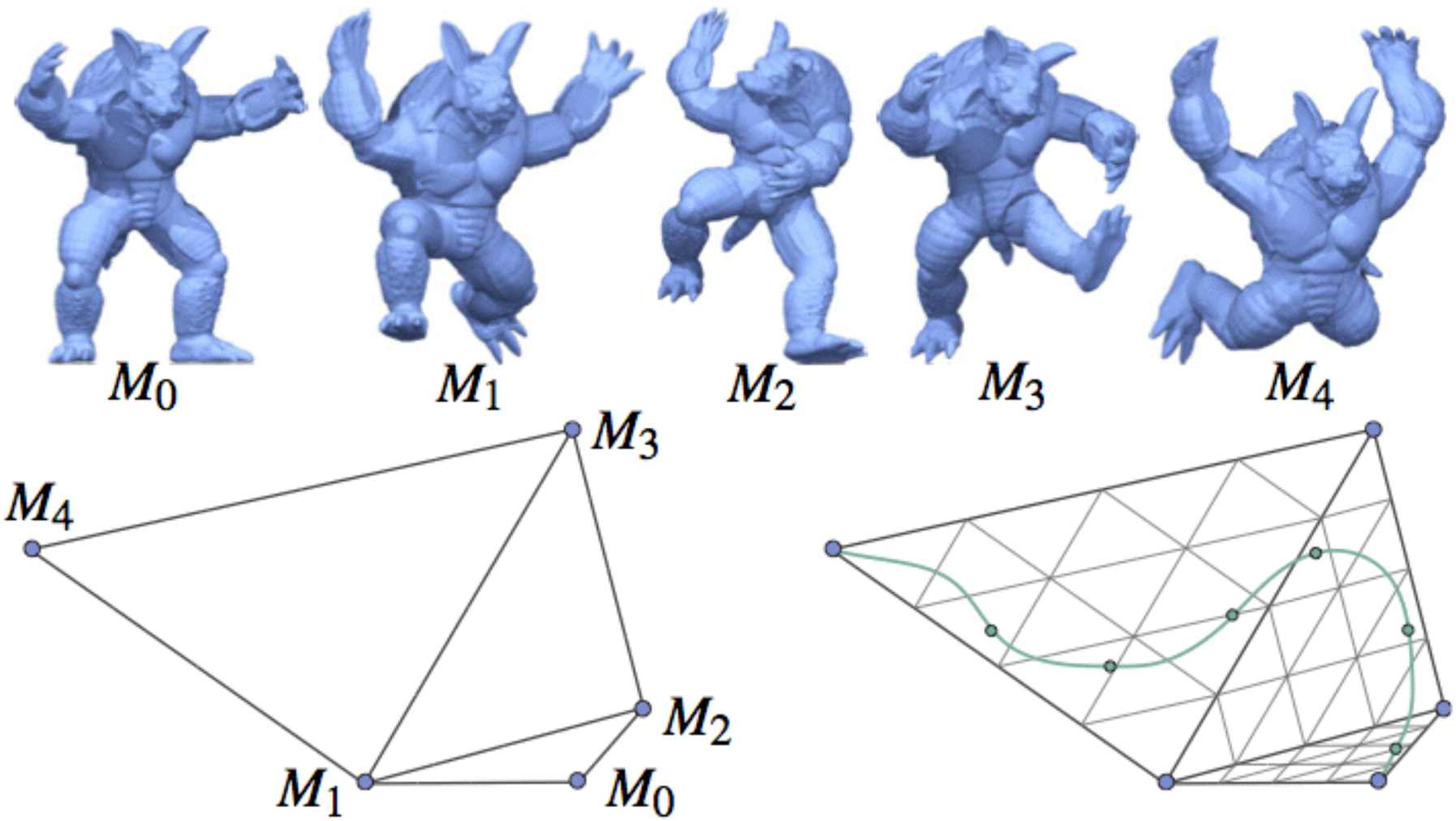
Correlate principal components with known attributes



Allen'03

Future Reads

Geodesics in shape space

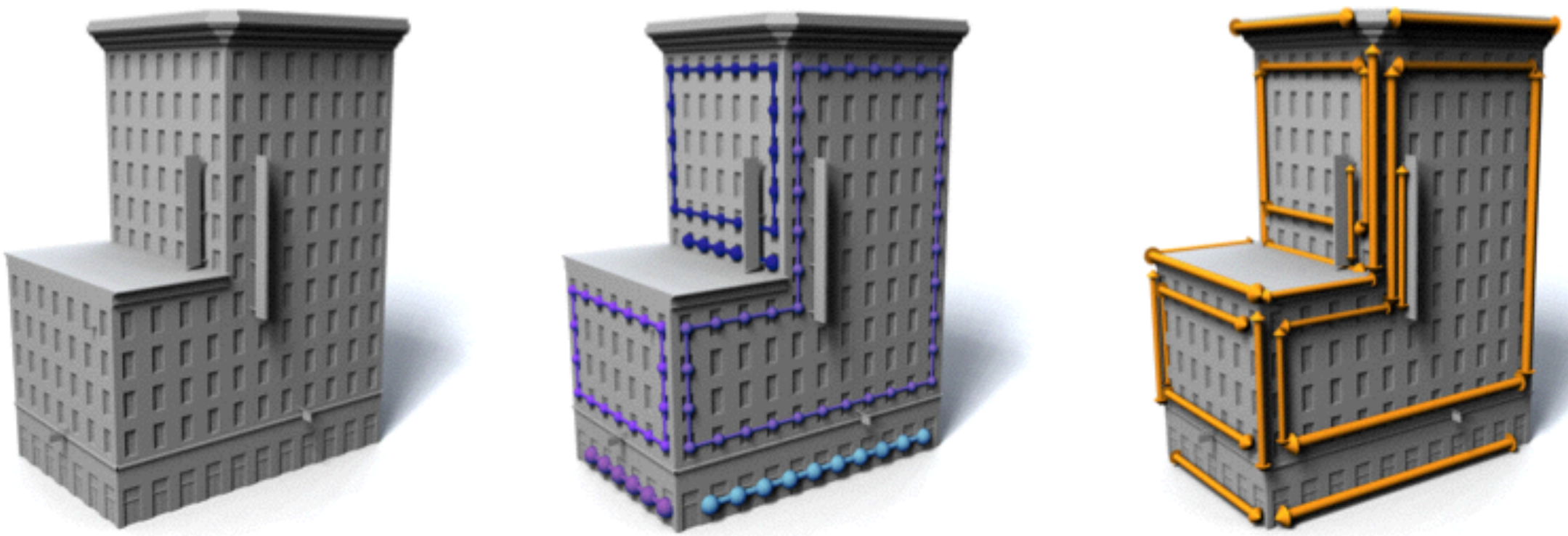


Kilian'07

Shape Grammars

Shape Grammar for a Building

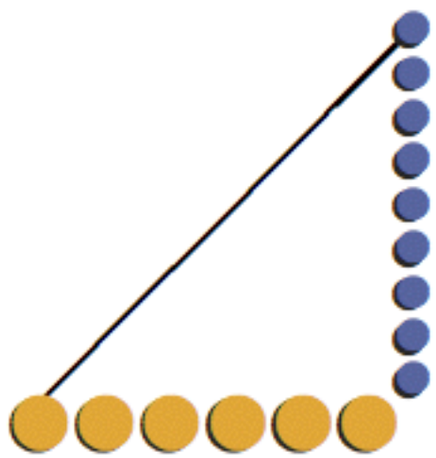
Extract a set of algebraic constraints



(a) input (b) regular patterns (c) degrees of freedom

Bokeloh'12

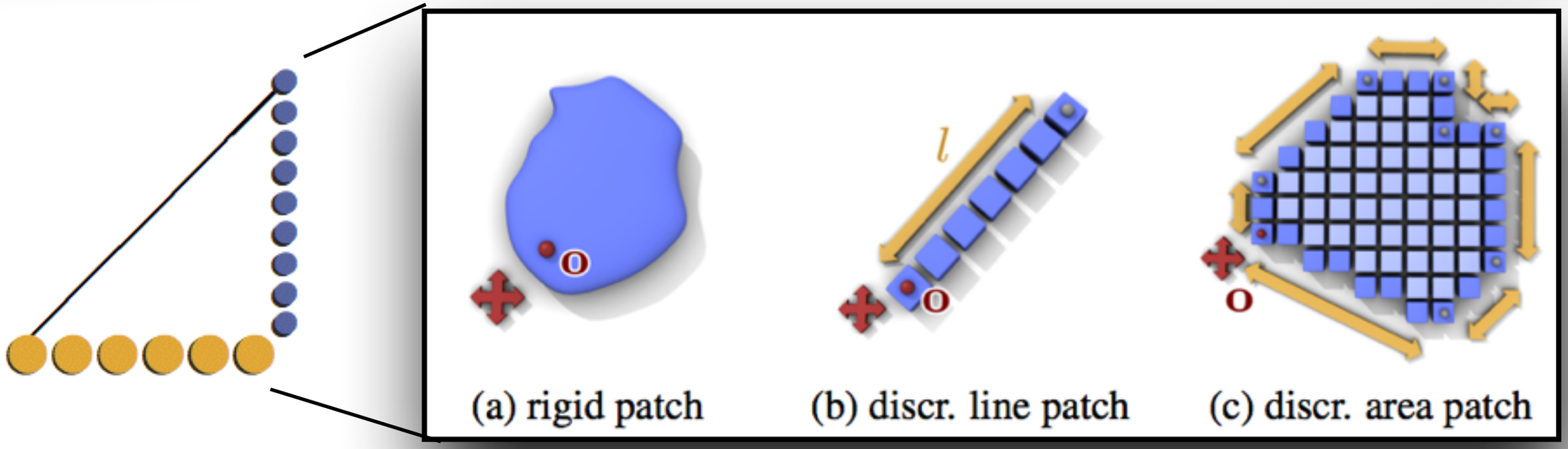
Shape Grammar for a Building



a) regular patterns

Bokeloh'12

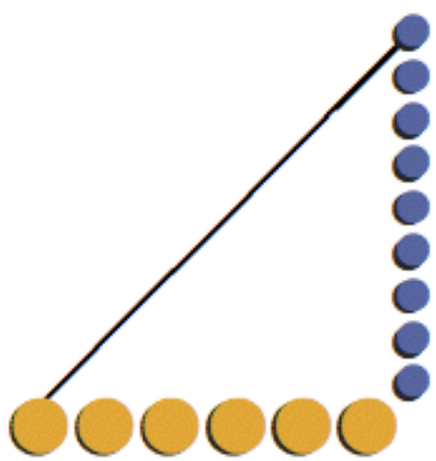
Shape Grammar for a Building



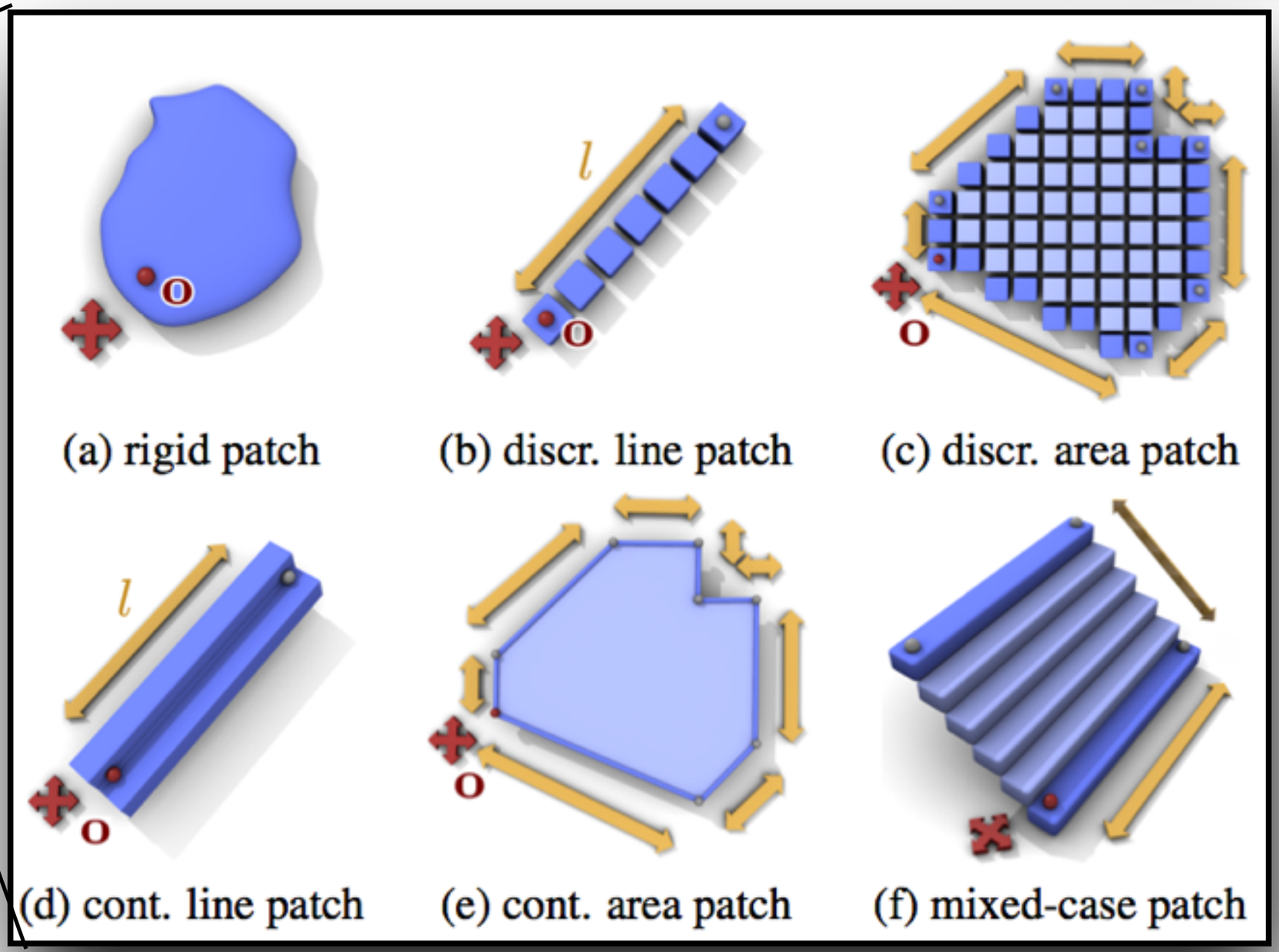
a) regular patterns

Bokeloh'12

Shape Grammar for a Building



a) regular patterns

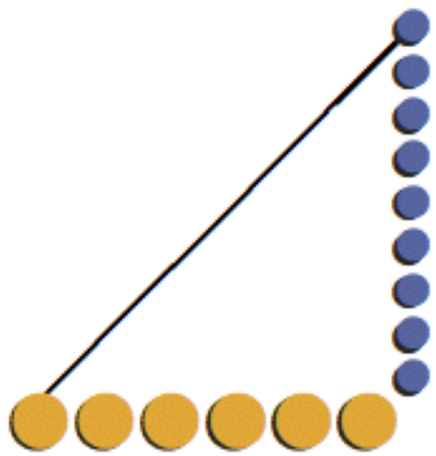


(a) rigid patch (b) discr. line patch (c) discr. area patch

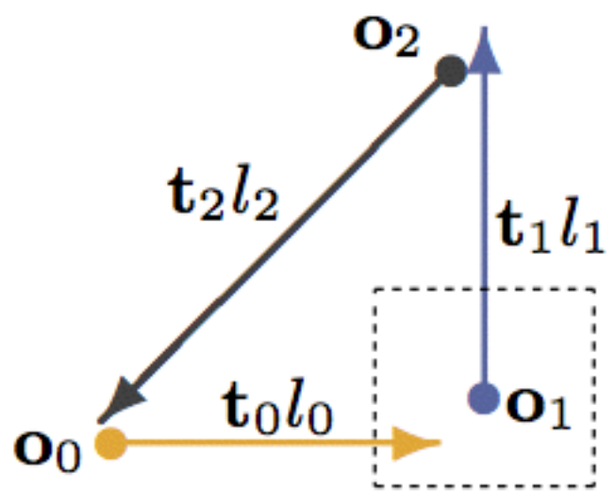
(d) cont. line patch (e) cont. area patch (f) mixed-case patch

Bokeloh'12

Shape Grammar for a Building



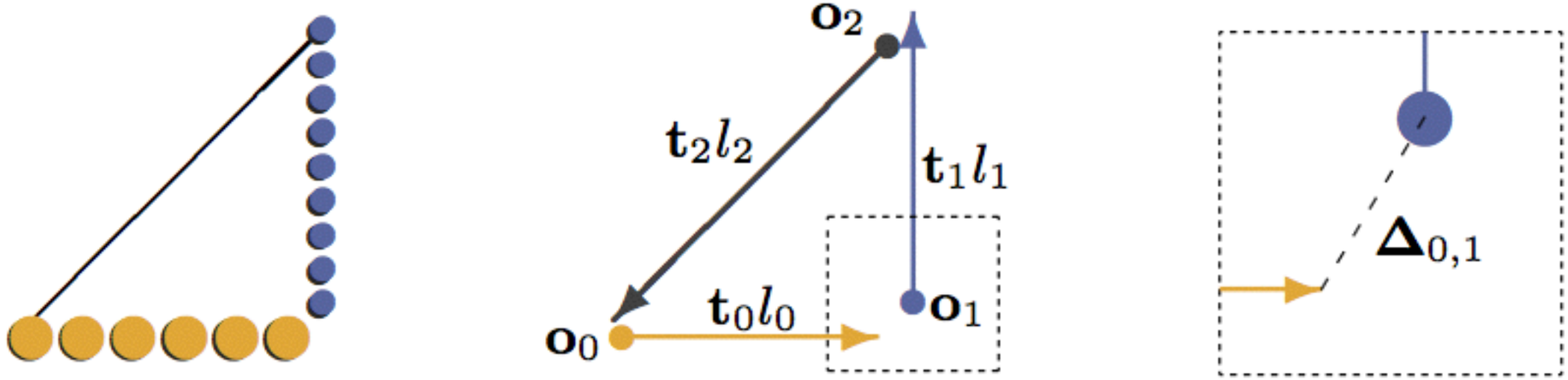
a) regular patterns



b) representation

Bokeloh'12

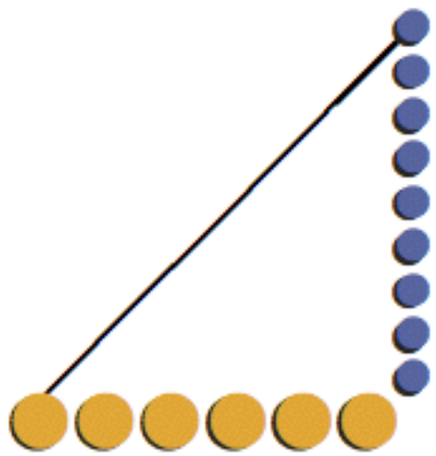
Shape Grammar for a Building



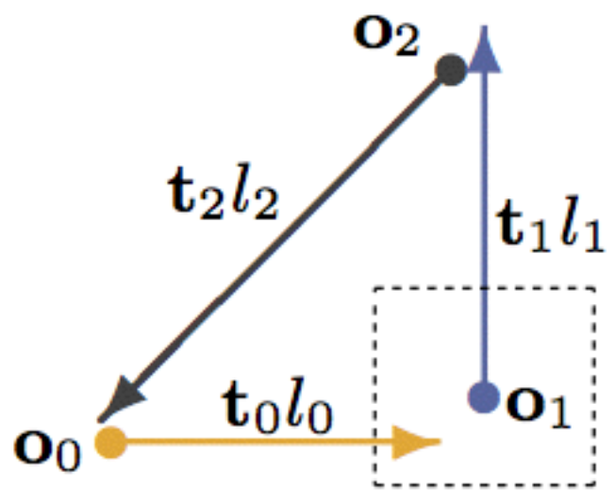
a) regular patterns b) representation c) links

Bokeloh'12

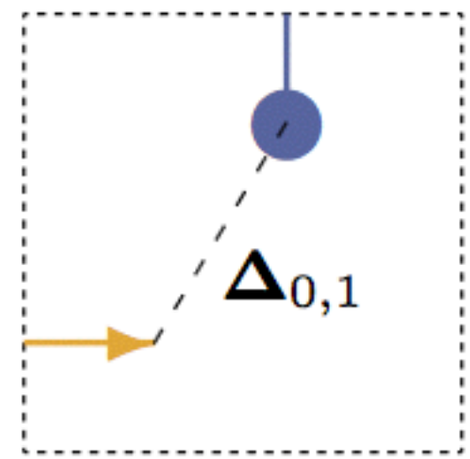
Shape Grammar for a Building



a) regular patterns



b) representation



c) links

$$\mathbf{o}_0 + \mathbf{t}_0 l_0 - \mathbf{o}_1 = \mathbf{\Delta}_{0,1}$$

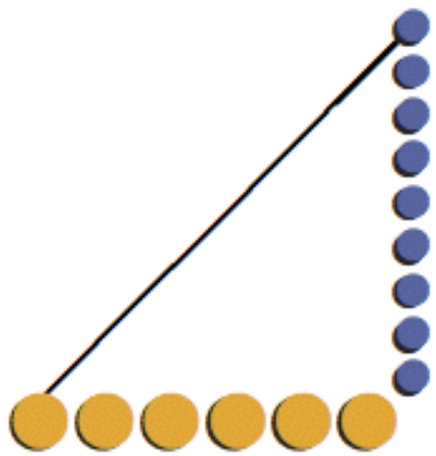
$$\mathbf{o}_1 + \mathbf{t}_1 l_1 - \mathbf{o}_2 = \mathbf{\Delta}_{1,2}$$

$$\mathbf{o}_2 + \mathbf{t}_2 l_2 - \mathbf{o}_0 = \mathbf{\Delta}_{2,0}$$

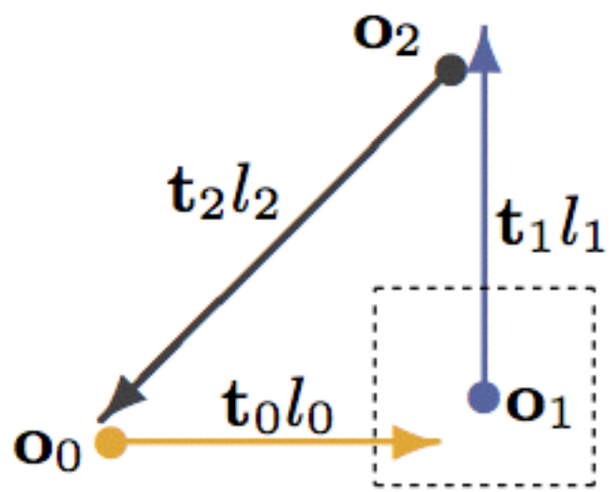
d) equations

Bokeloh'12

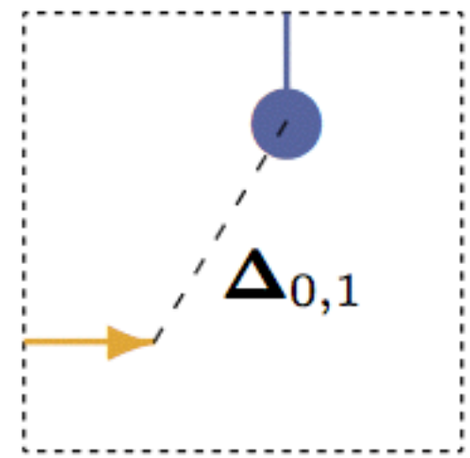
Shape Grammar for a Building



a) regular patterns



b) representation



c) links

$$\mathbf{o}_0 + \mathbf{t}_0 l_0 - \mathbf{o}_1 = \mathbf{\Delta}_{0,1}$$
$$\mathbf{o}_1 + \mathbf{t}_1 l_1 - \mathbf{o}_2 = \mathbf{\Delta}_{1,2}$$
$$\mathbf{o}_2 + \mathbf{t}_2 l_2 - \mathbf{o}_0 = \mathbf{\Delta}_{2,0}$$

d) equations

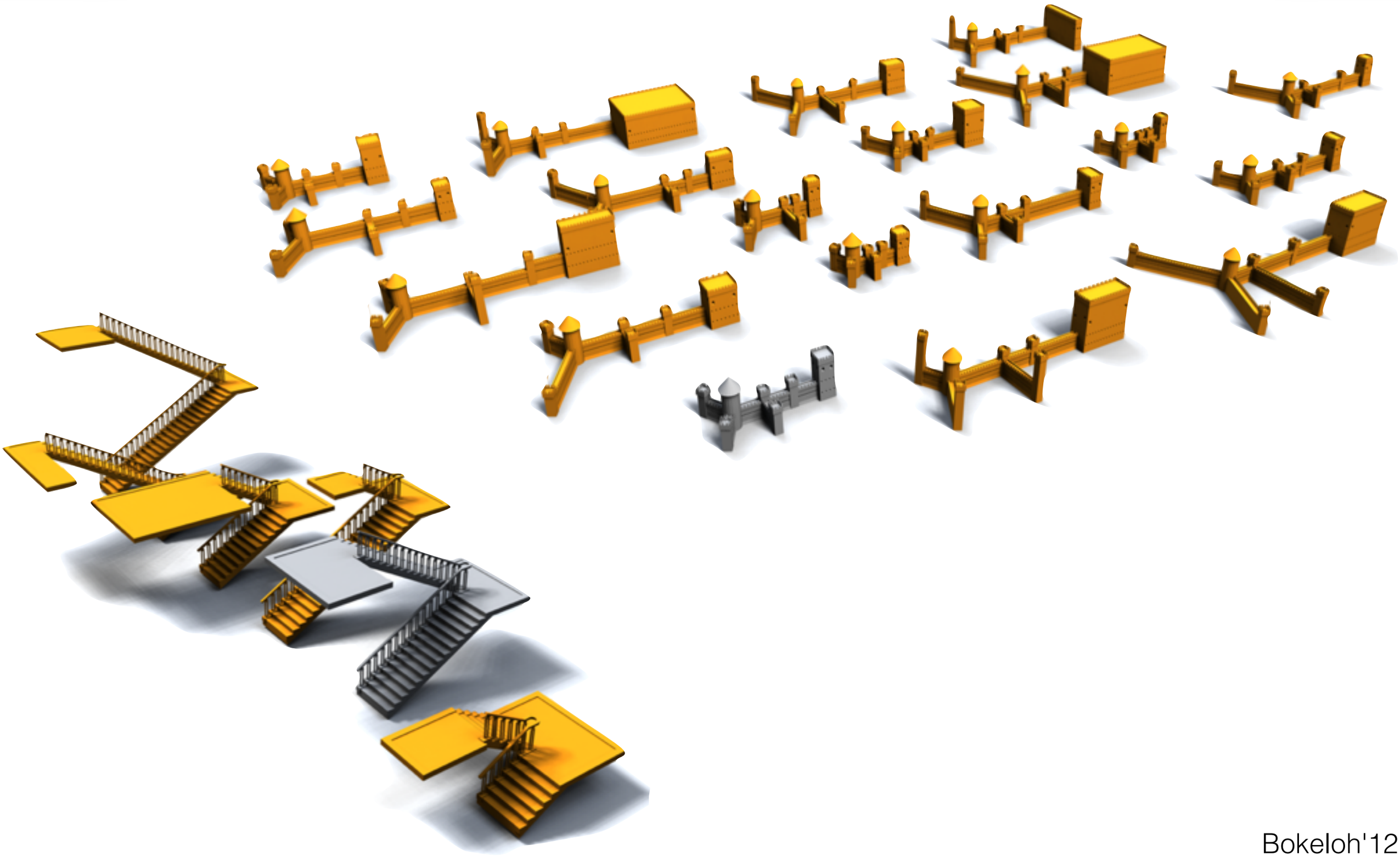
$$\begin{pmatrix} & & \\ & \mathbf{A} & \\ & & \end{pmatrix} \begin{pmatrix} \mathbf{o}_0 \\ \vdots \\ l_2 \end{pmatrix} = \begin{pmatrix} \mathbf{\Delta}_{0,1} \\ \mathbf{\Delta}_{1,2} \\ \mathbf{\Delta}_{2,0} \end{pmatrix}$$

$$\Longrightarrow \mathbf{x}(\lambda) = \mathbf{x}_0 + \mathrm{Ker}\,(\mathbf{A})\,\lambda$$

e) null space analysis

Bokeloh'12

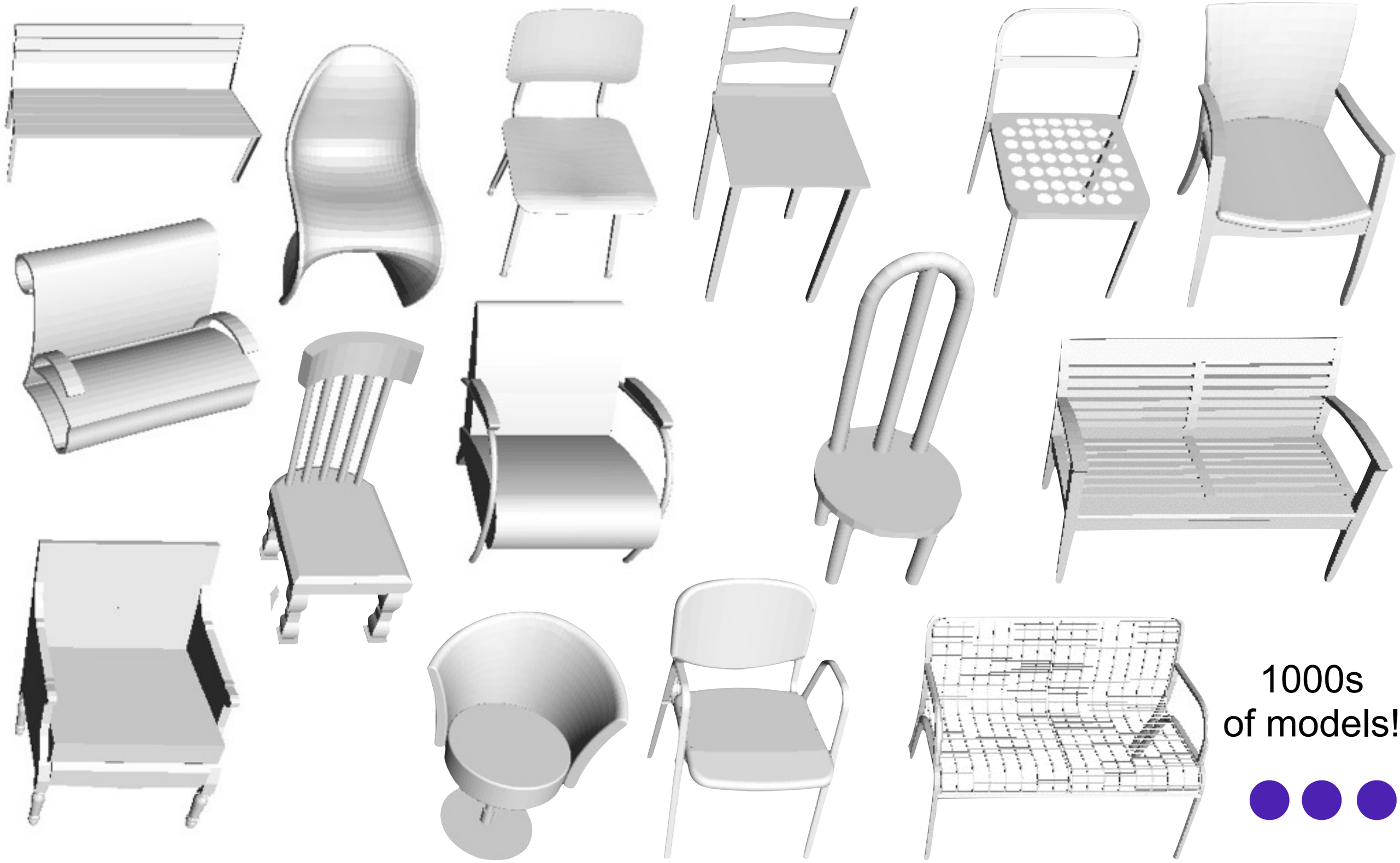
Shape Grammar for a Building



Bokeloh'12

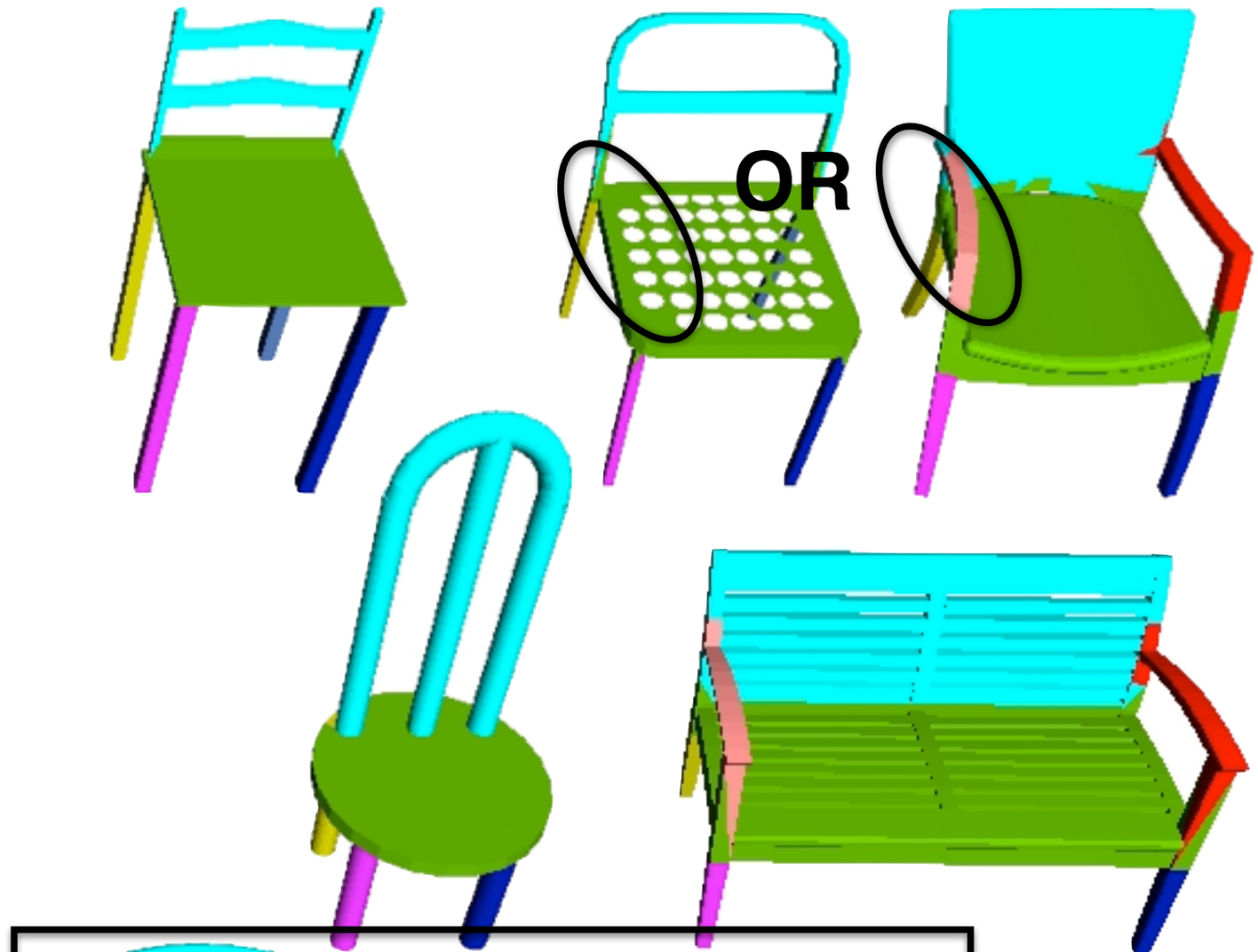
Part Arrangements

Collections of 3D shapes

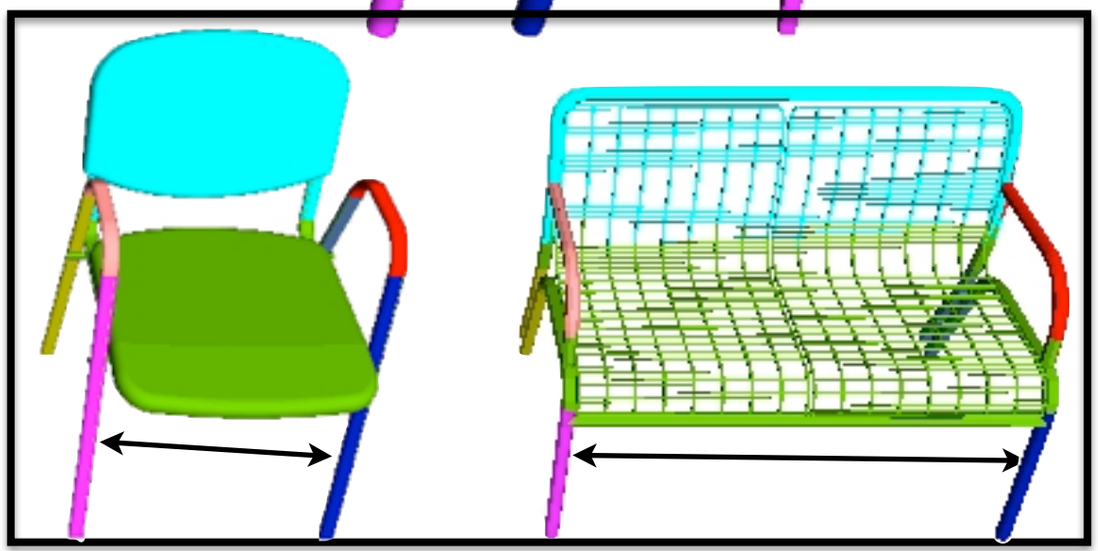


1000s
of models!

Understand Variations



Seats vary in width



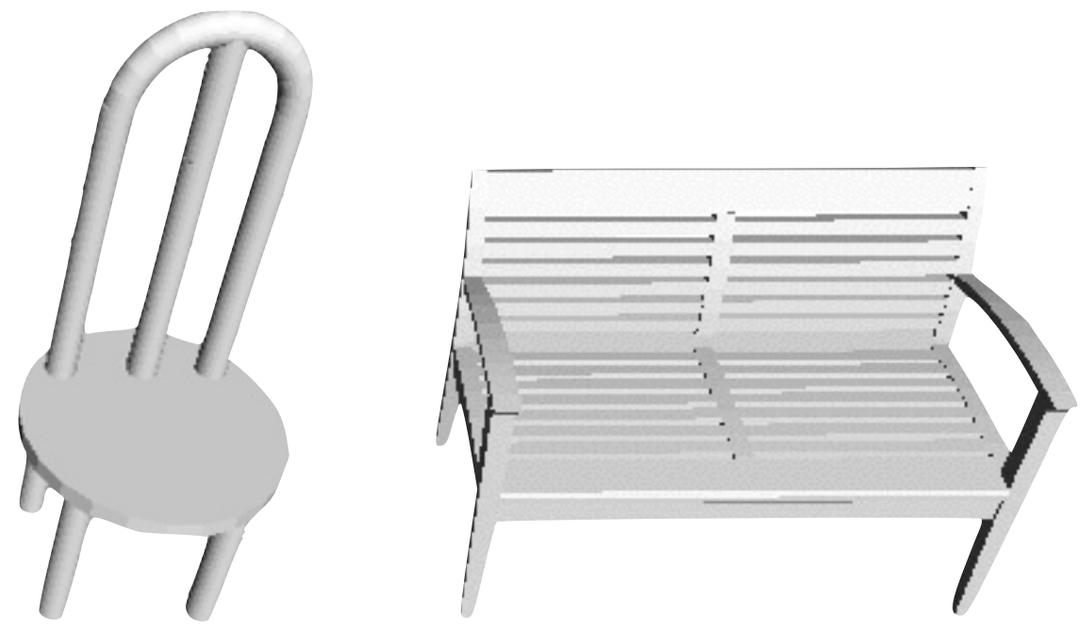
1000s of models!

Kim'13

Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations

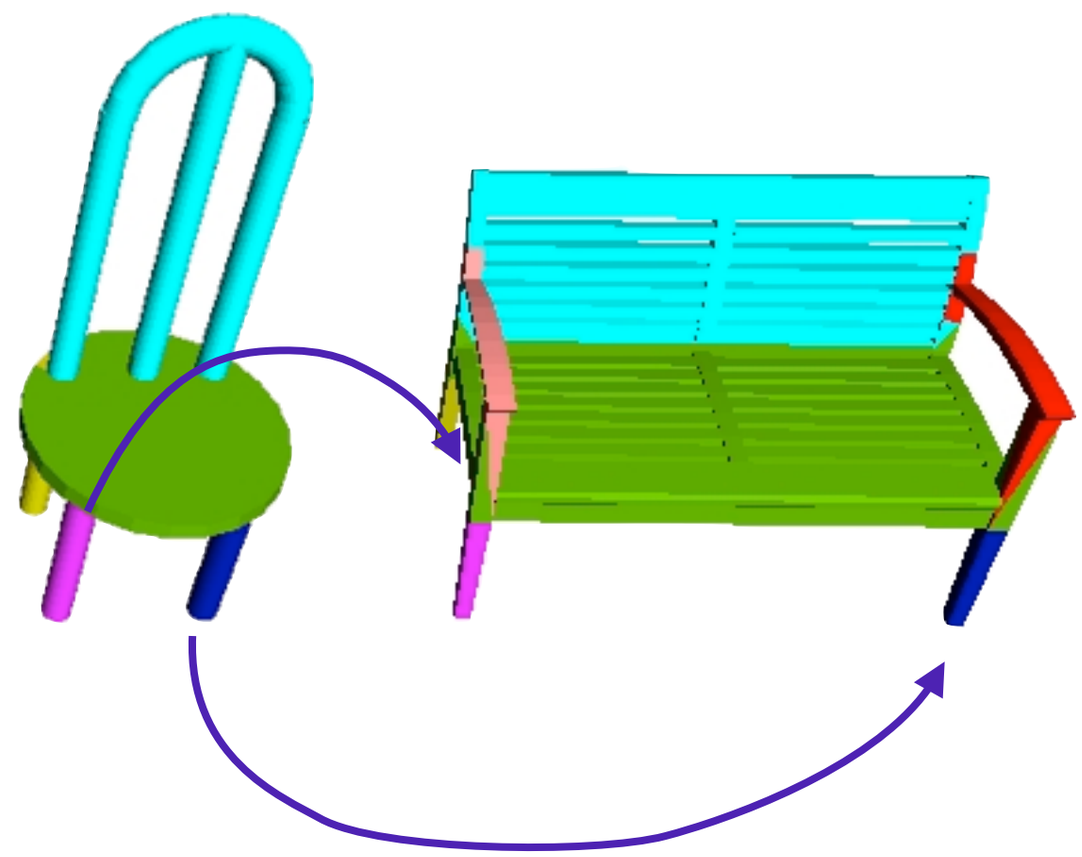


Kim'13

Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations



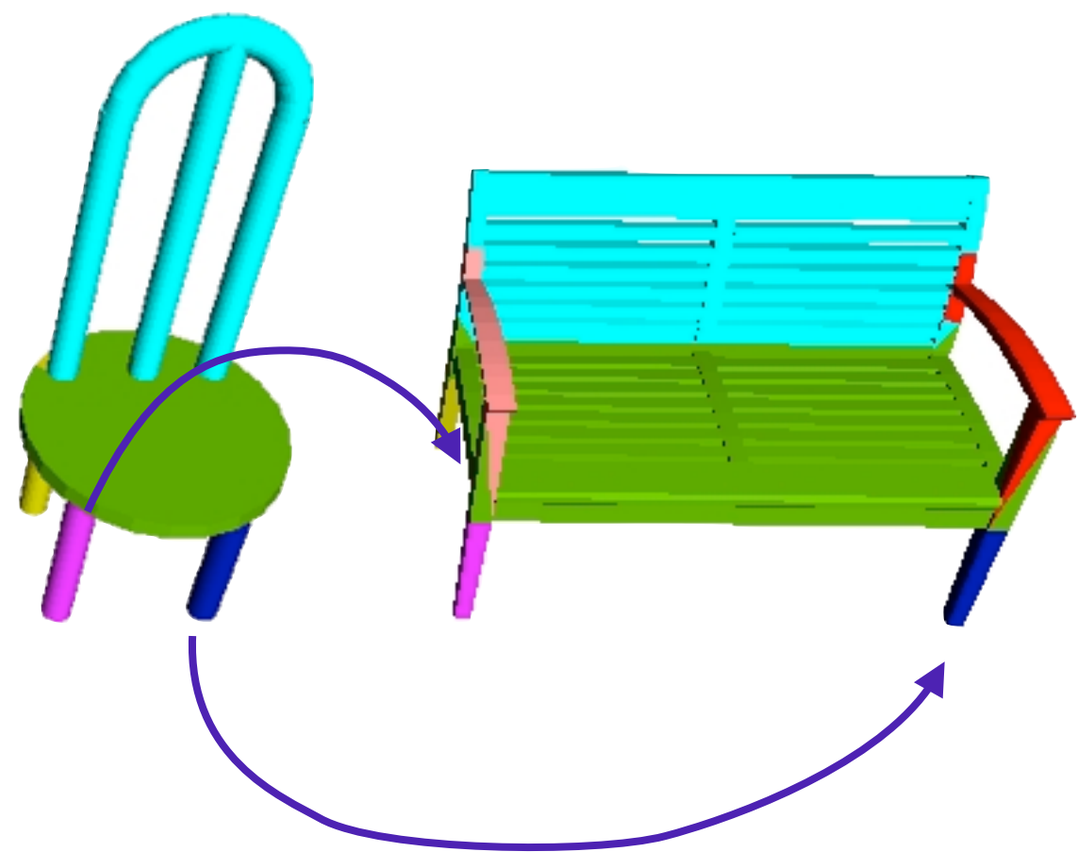
Smaller search space

Kim'13

Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations



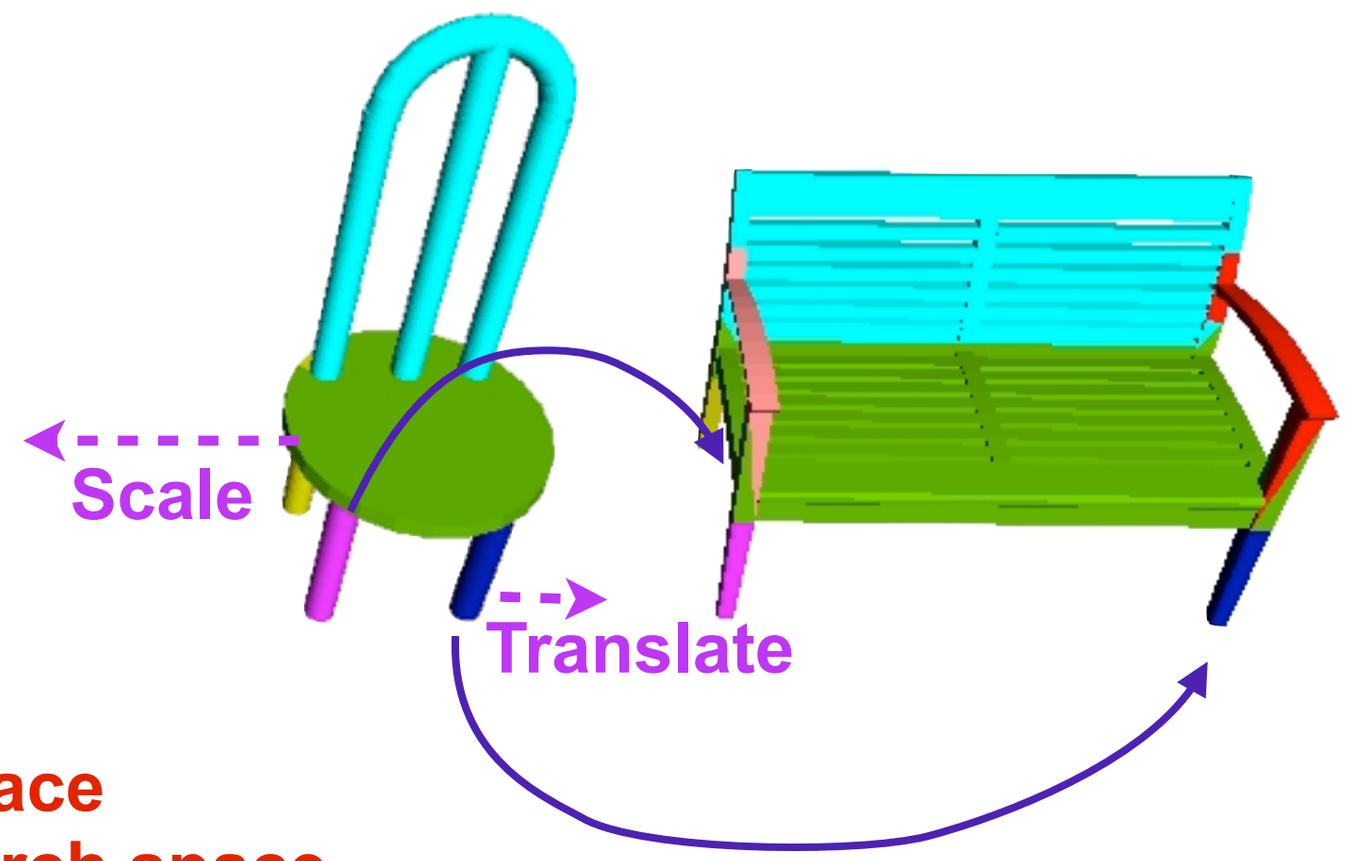
Smaller search space

Kim'13

Need Joint Analysis

The problems are inter-related:

- Correspondences
- Consistent Segmentations
- Shape Variations



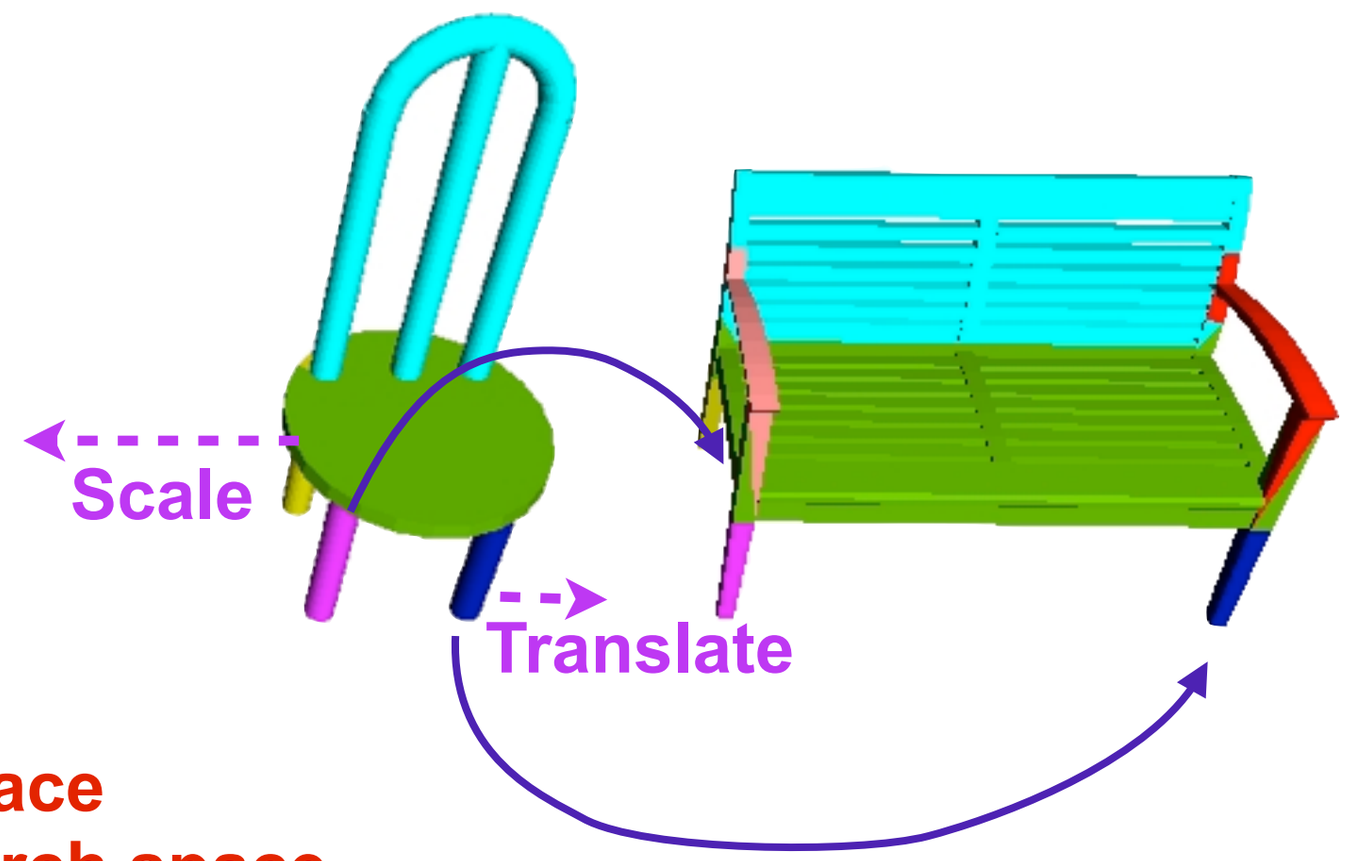
Smaller search space
More accurate search space

Kim'13

Need Joint Analysis

The problems are inter-related:

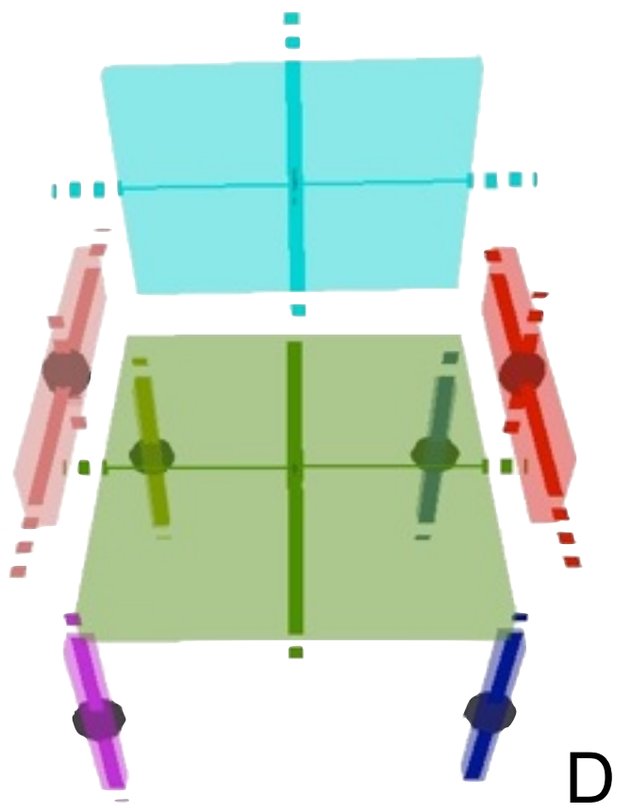
- Correspondences
- Consistent Segmentations
- Shape Variations



Smaller search space
More accurate search space
Man-made object vary w.r.t. parts

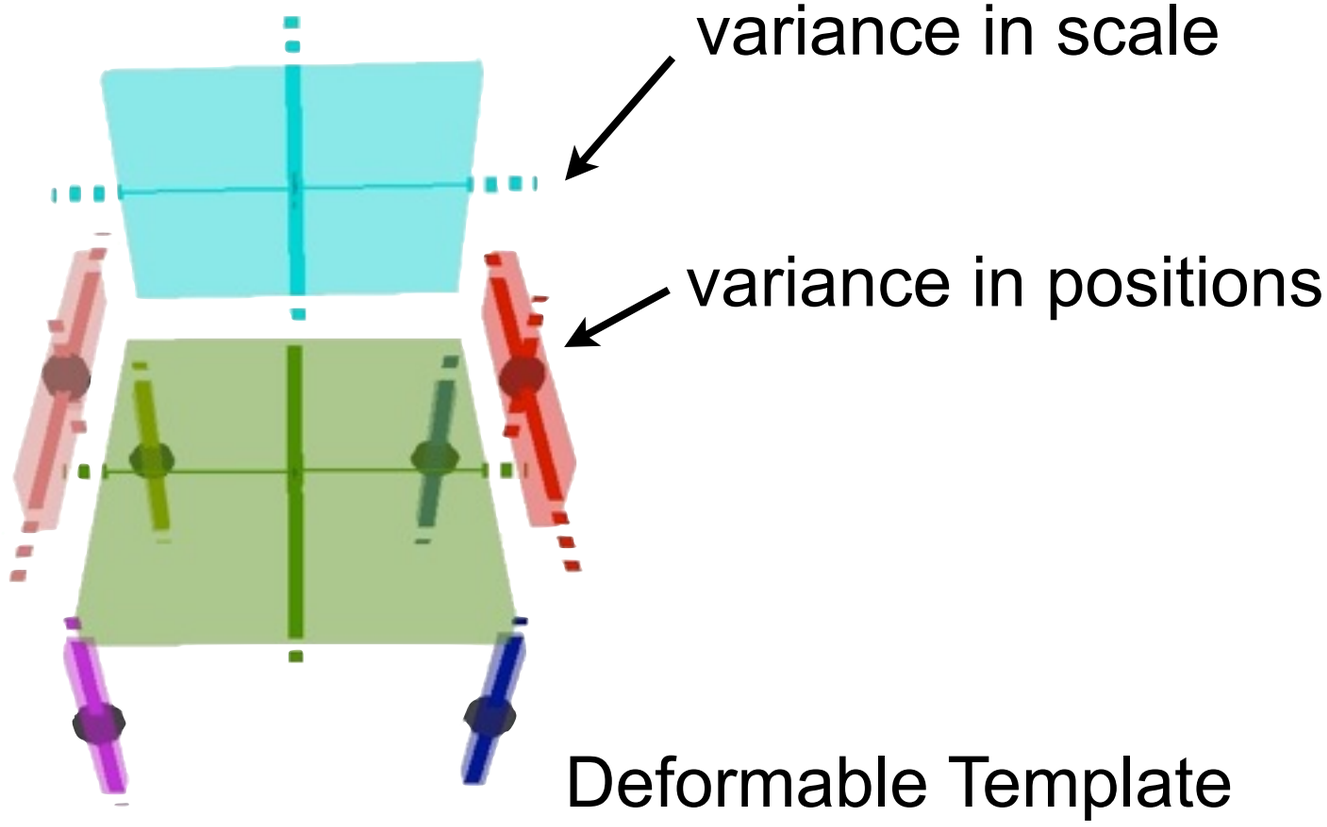
Kim'13

Box-like Templates

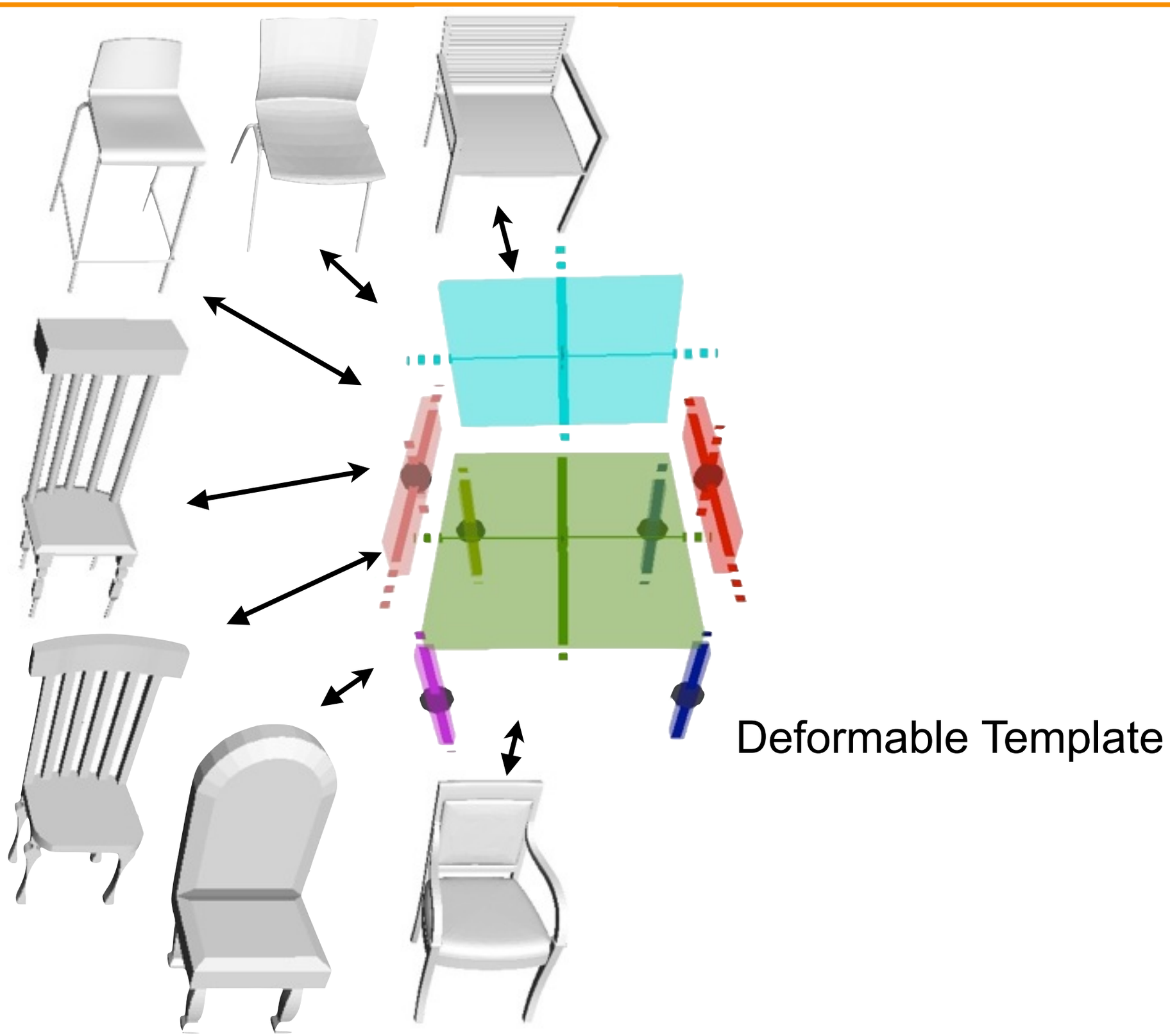


Deformable Template

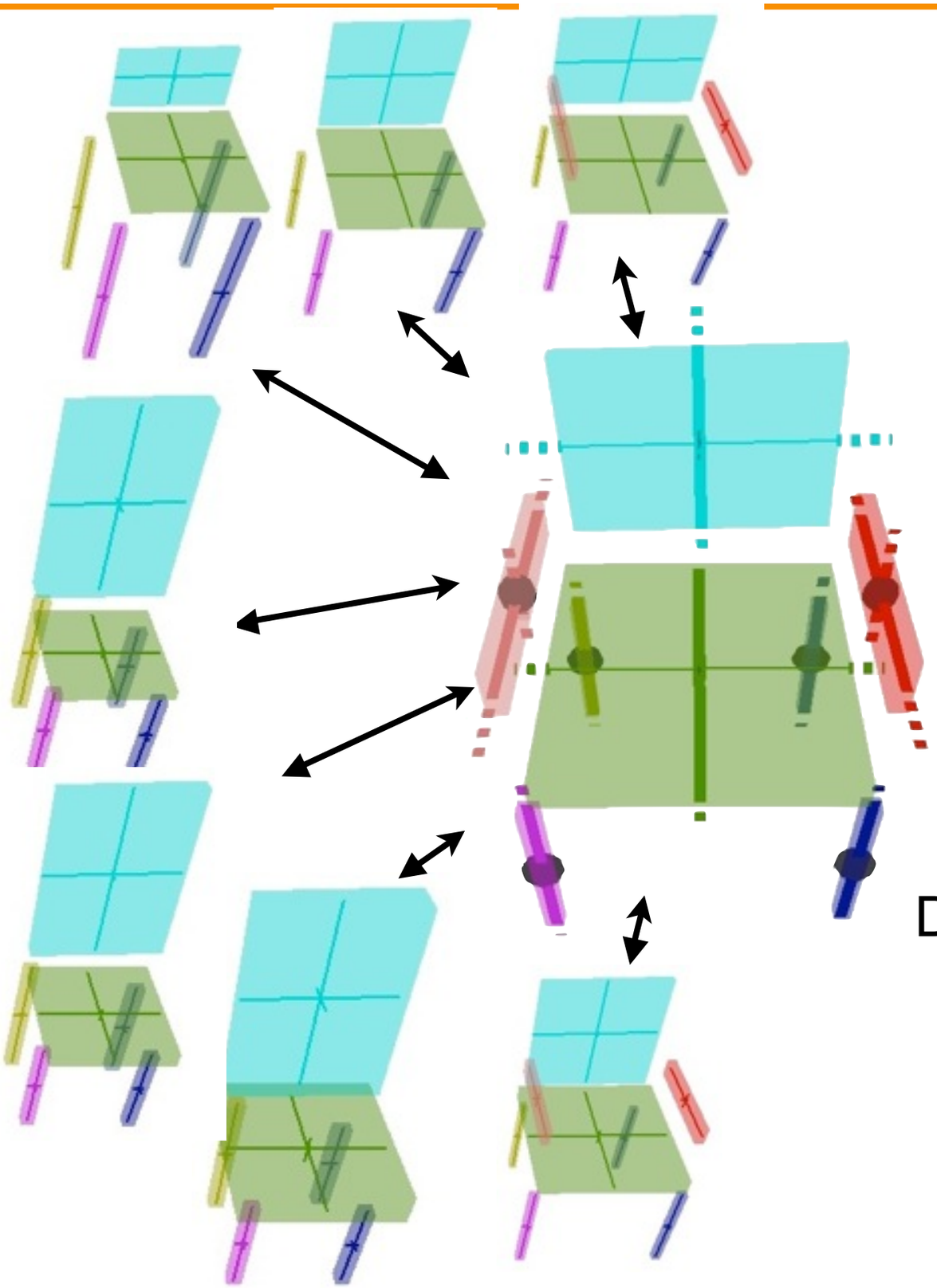
Box-like Templates



Box-like Templates

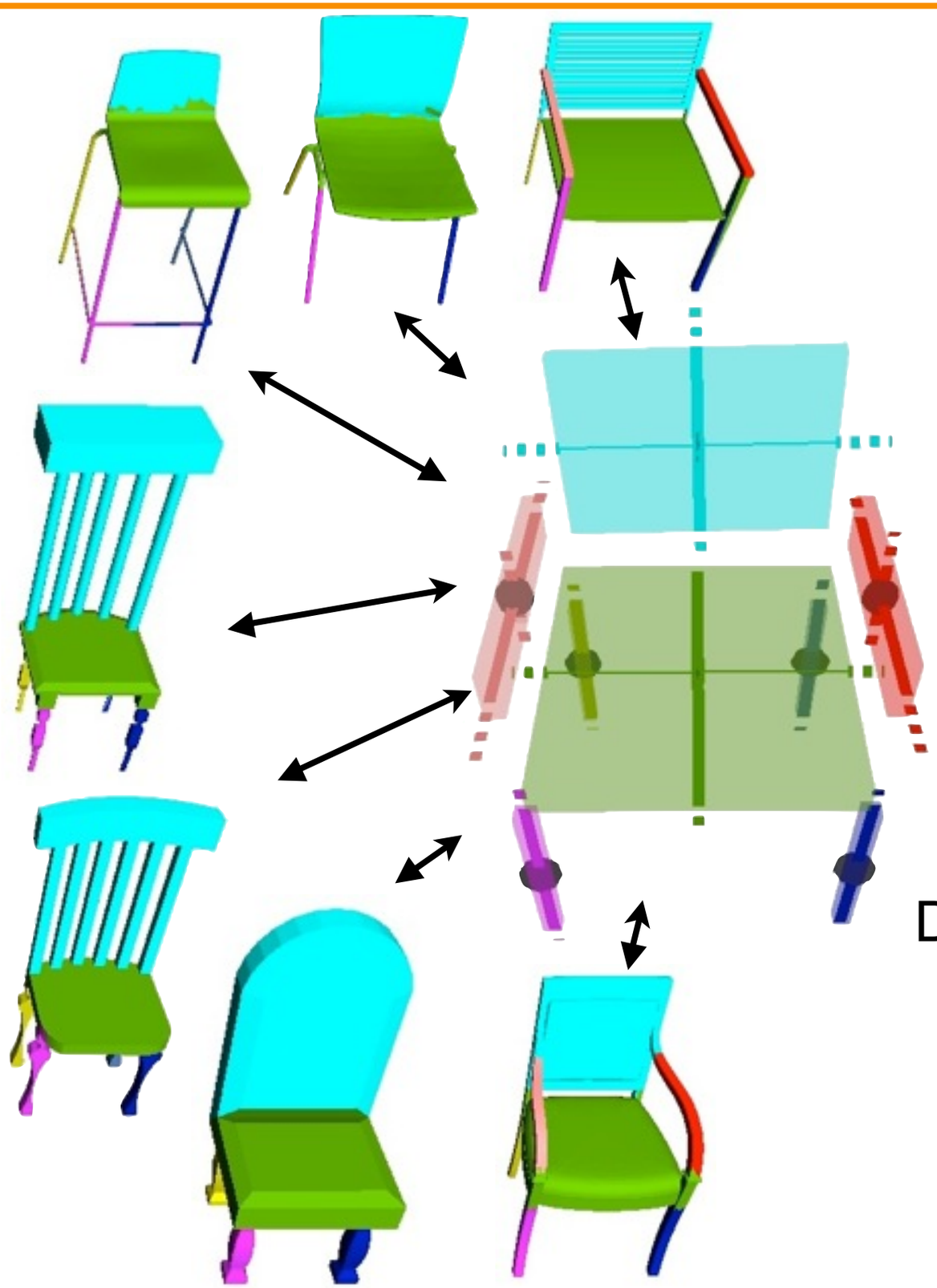


Box-like Templates



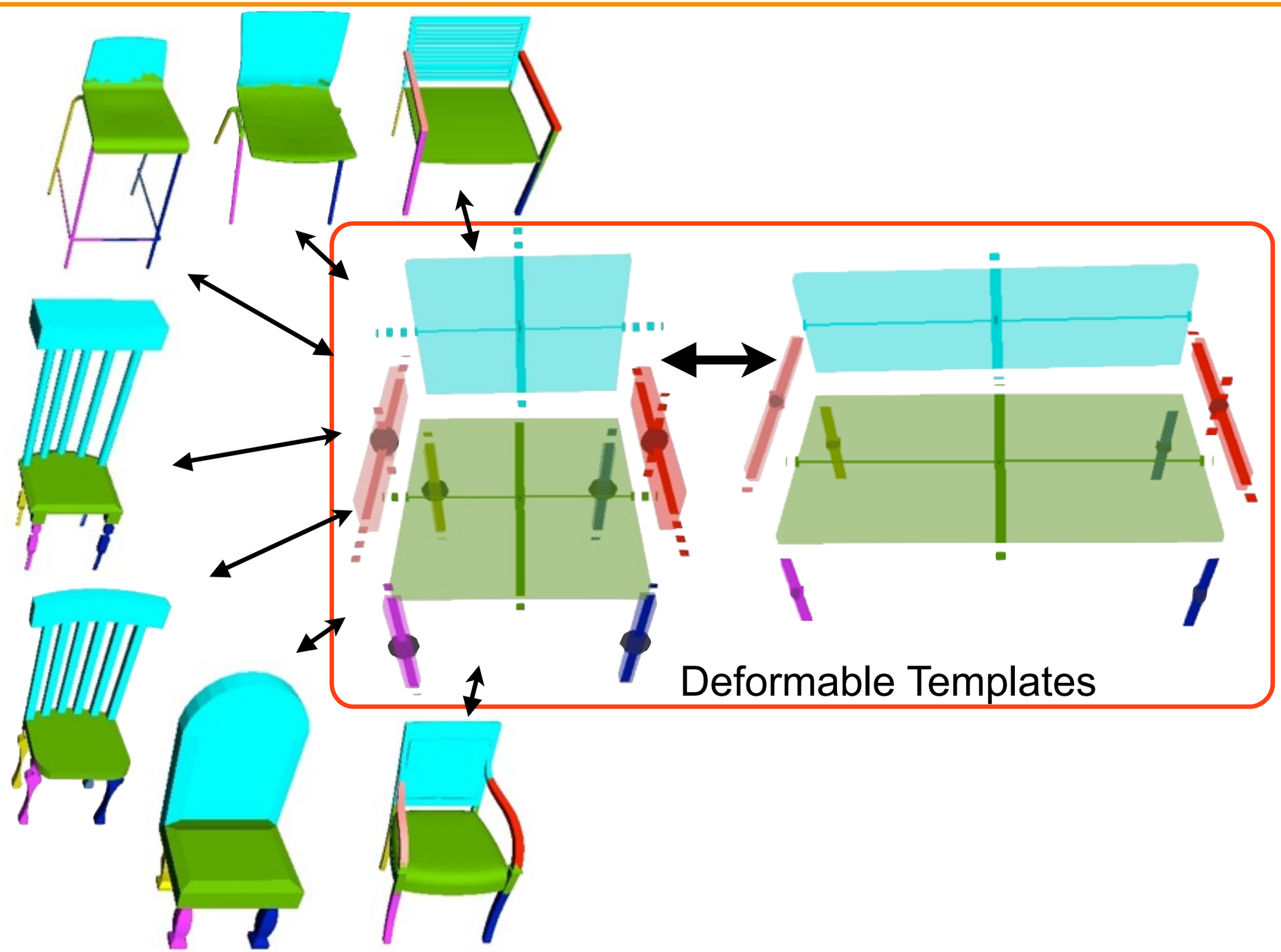
Deformable Template

Box-like Templates

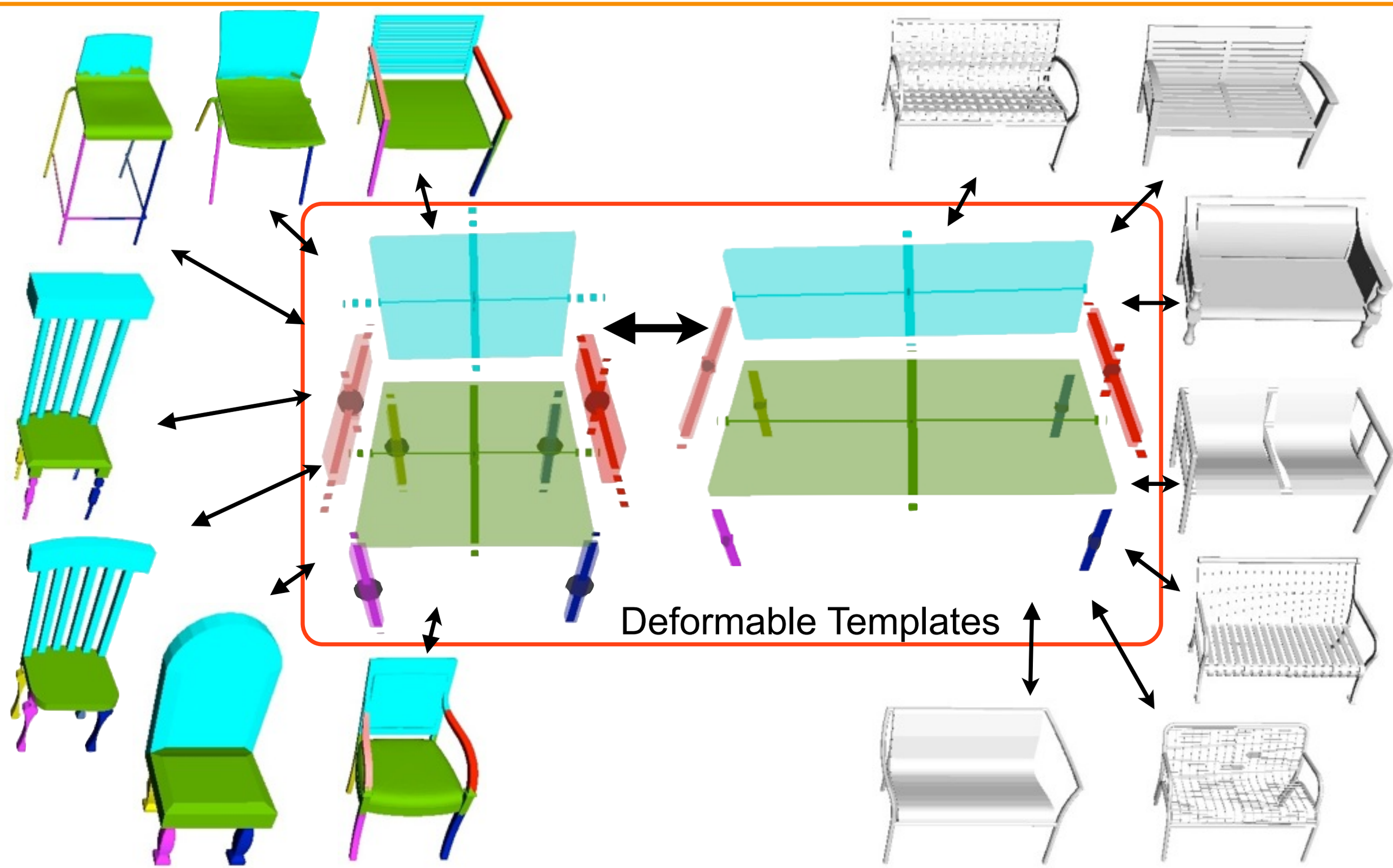


Deformable Template

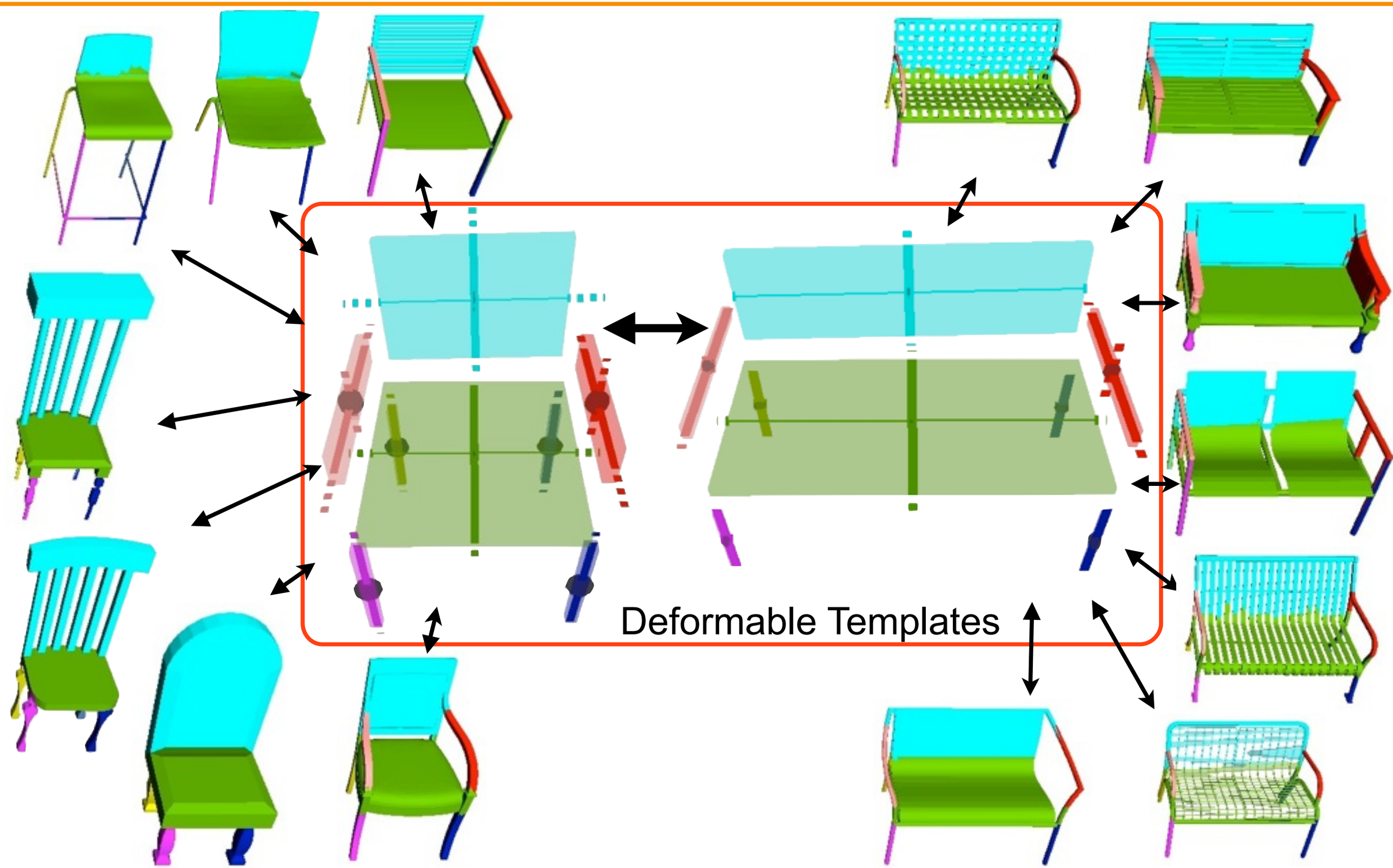
Box-like Templates



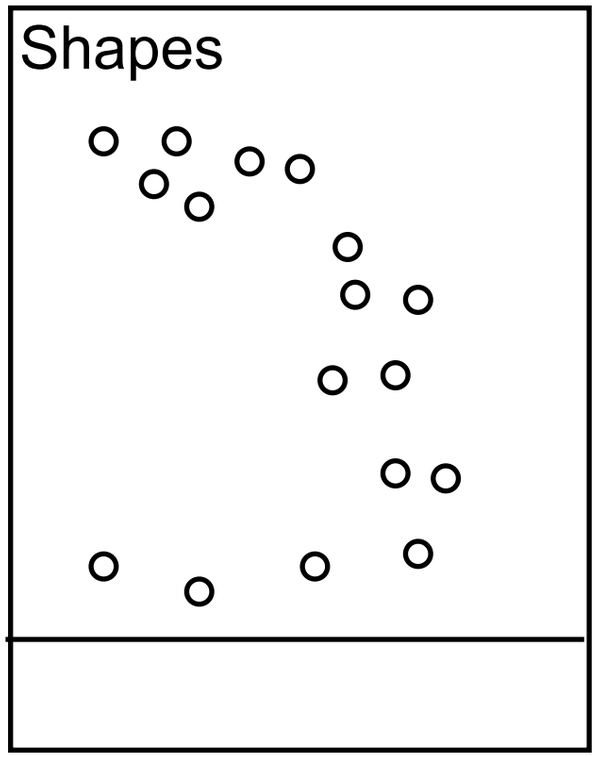
Box-like Templates



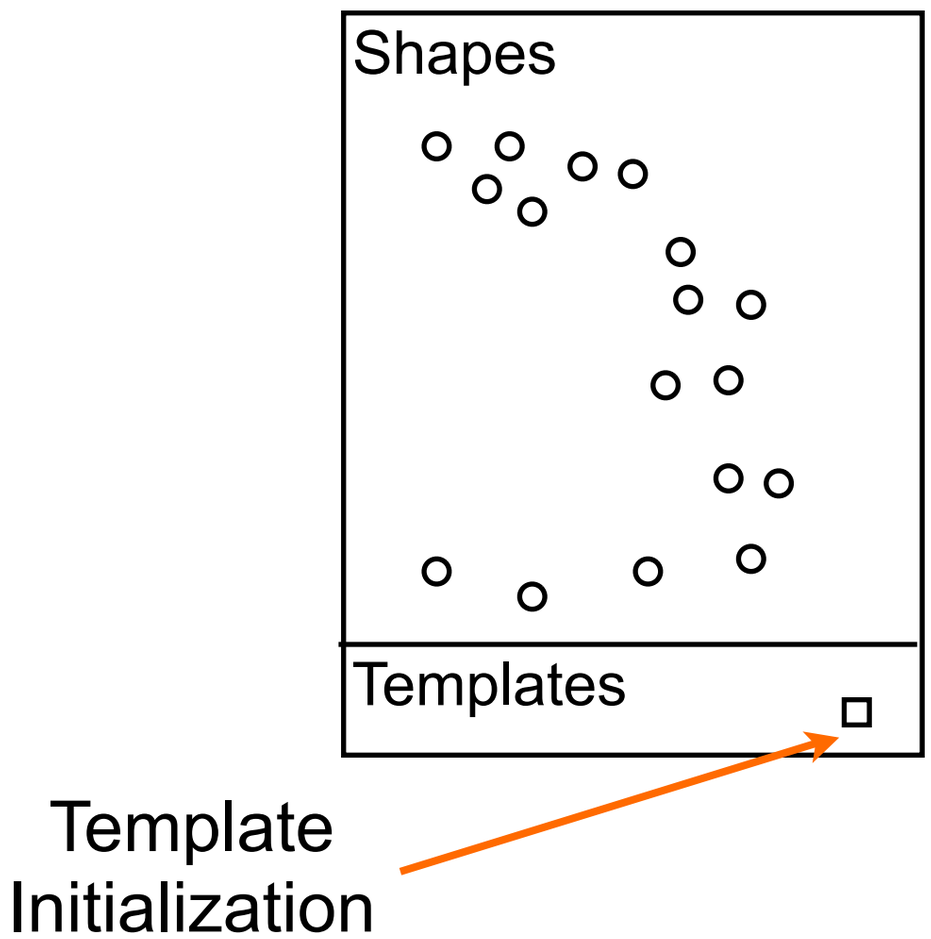
Box-like Templates



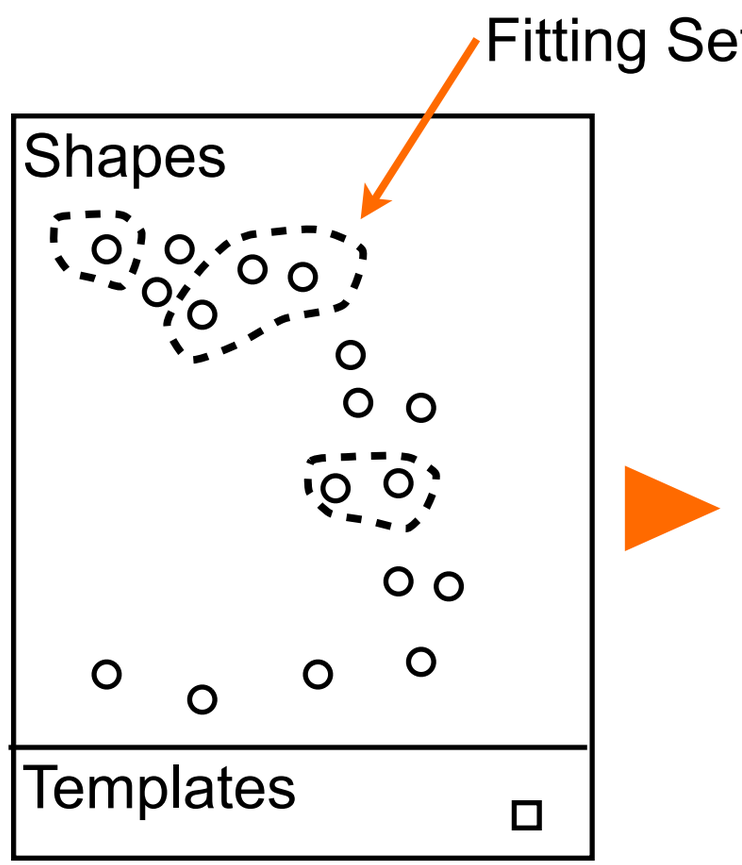
Algorithm Overview



Algorithm Overview



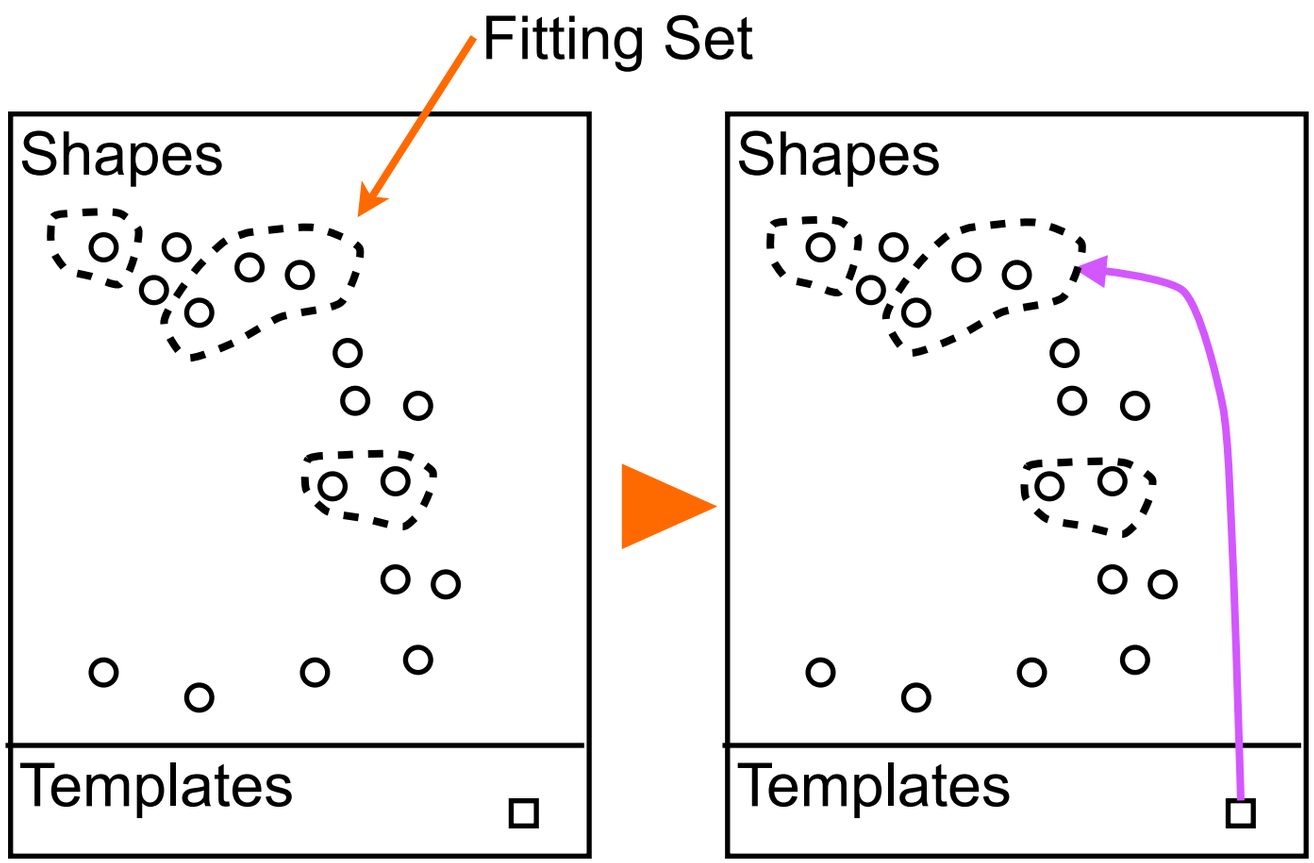
Algorithm Overview



Template Initialization

Template Fitting

Algorithm Overview



Template Initialization

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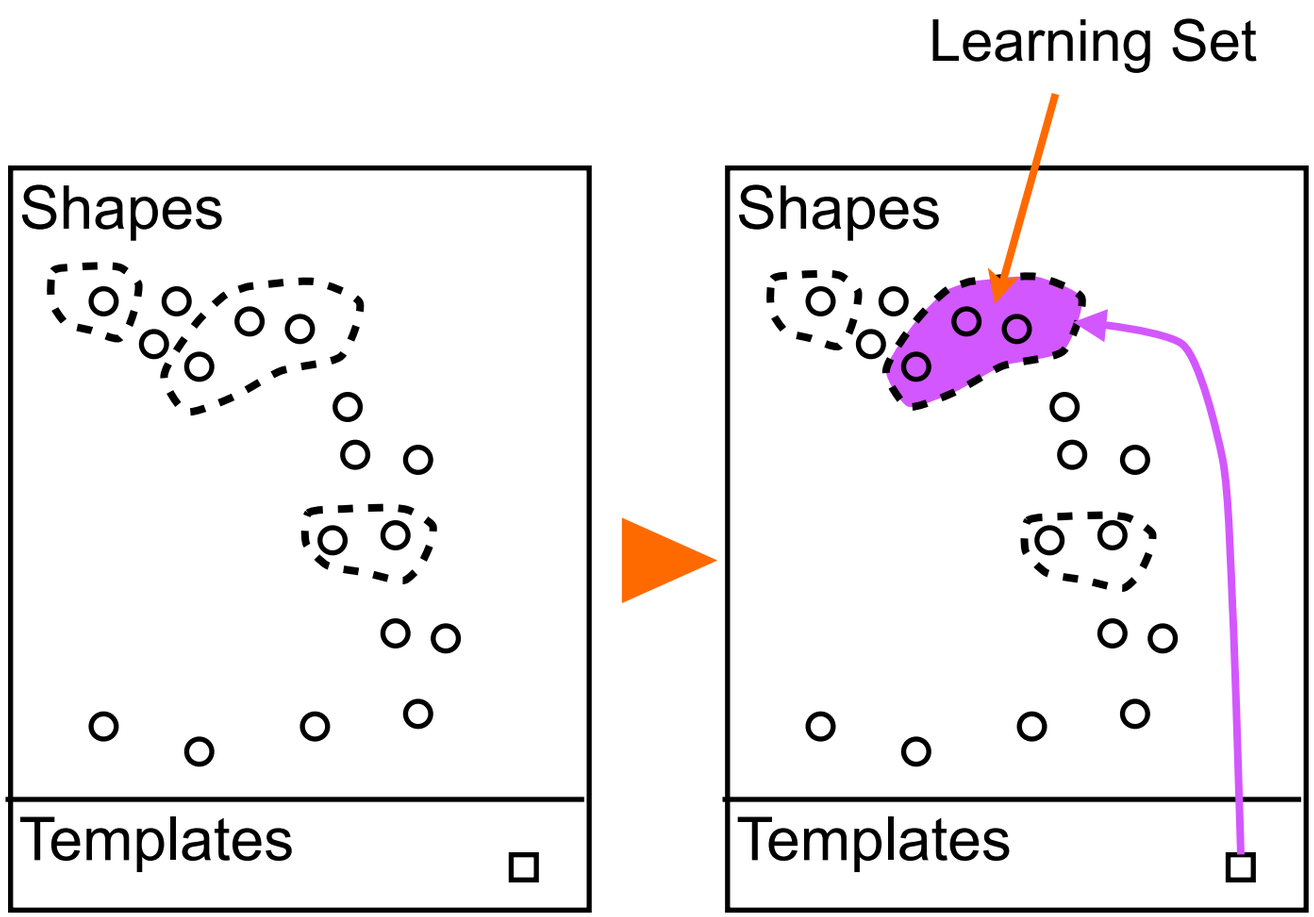
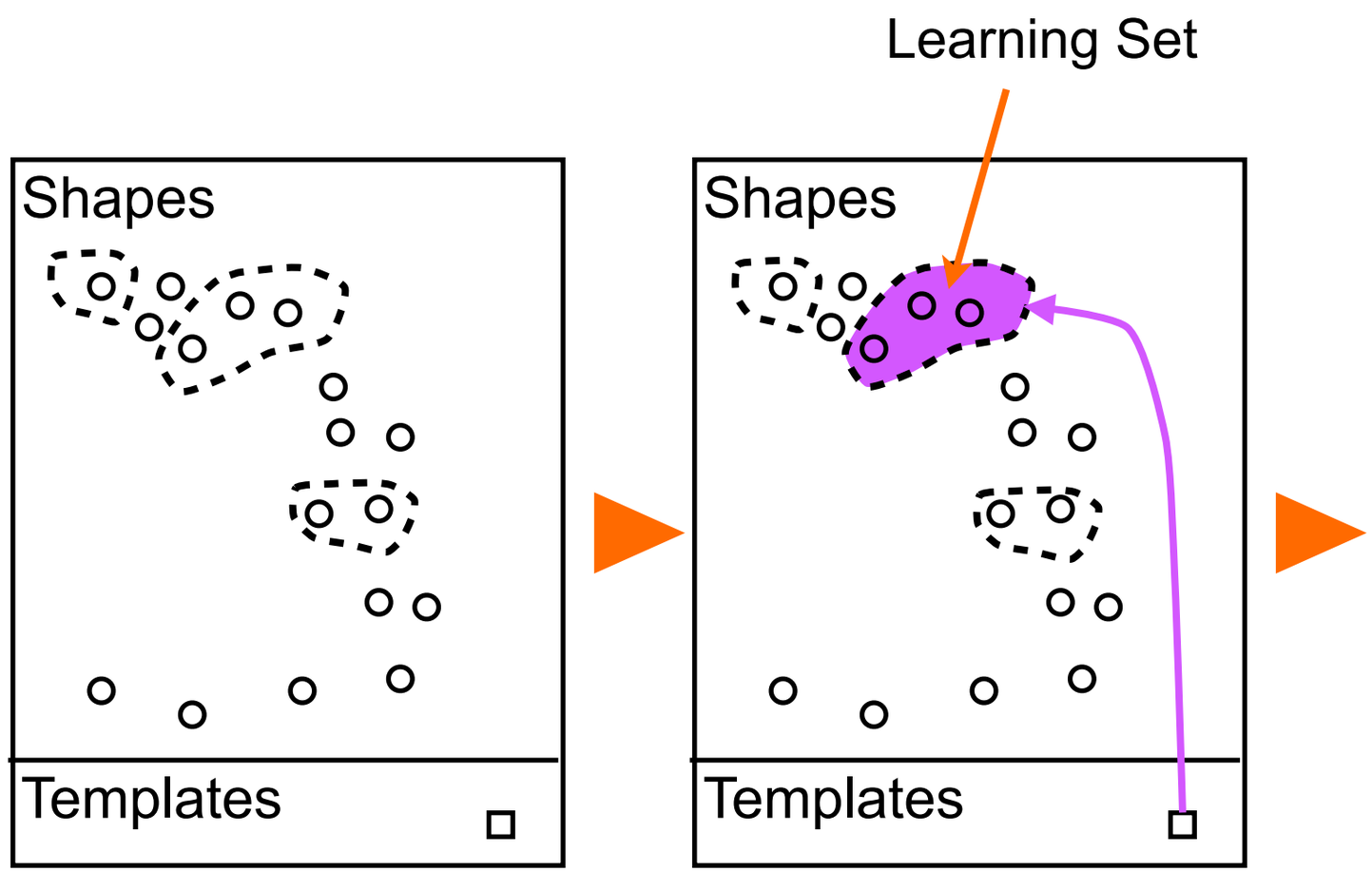


Template Initialization

Template Fitting

Algorithm Overview

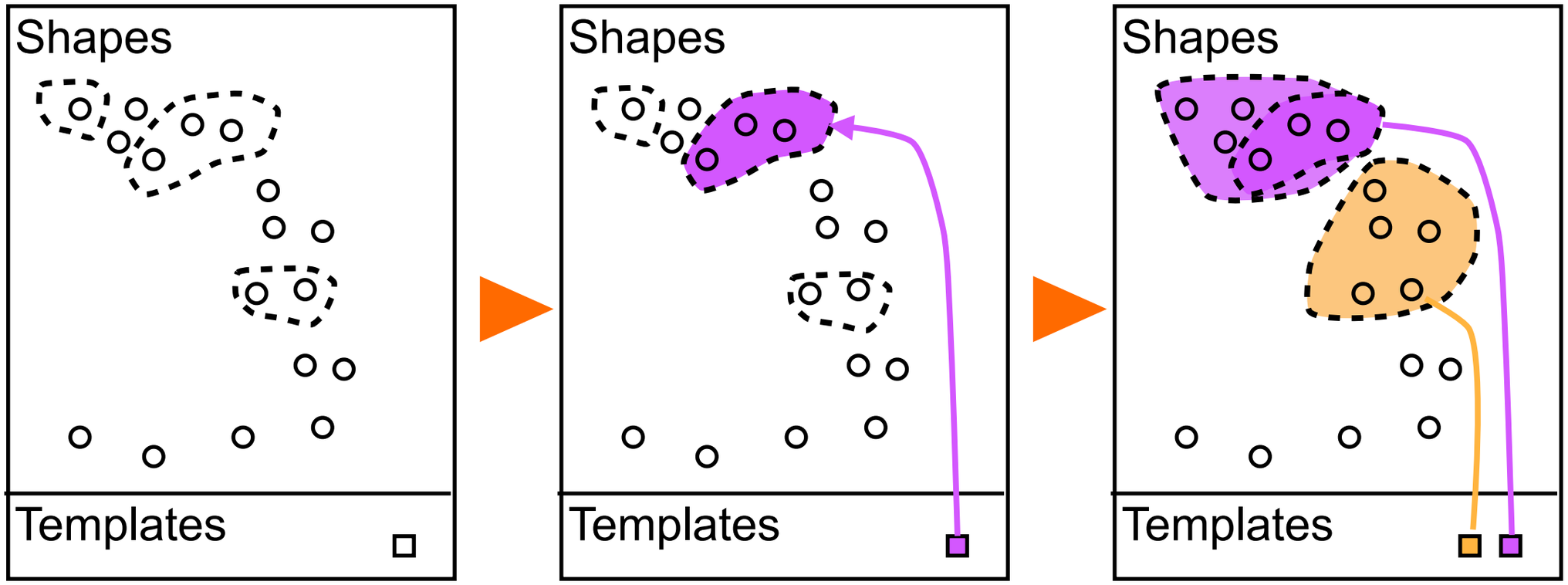


Template Initialization

Template Fitting

Template Refinement

Algorithm Overview

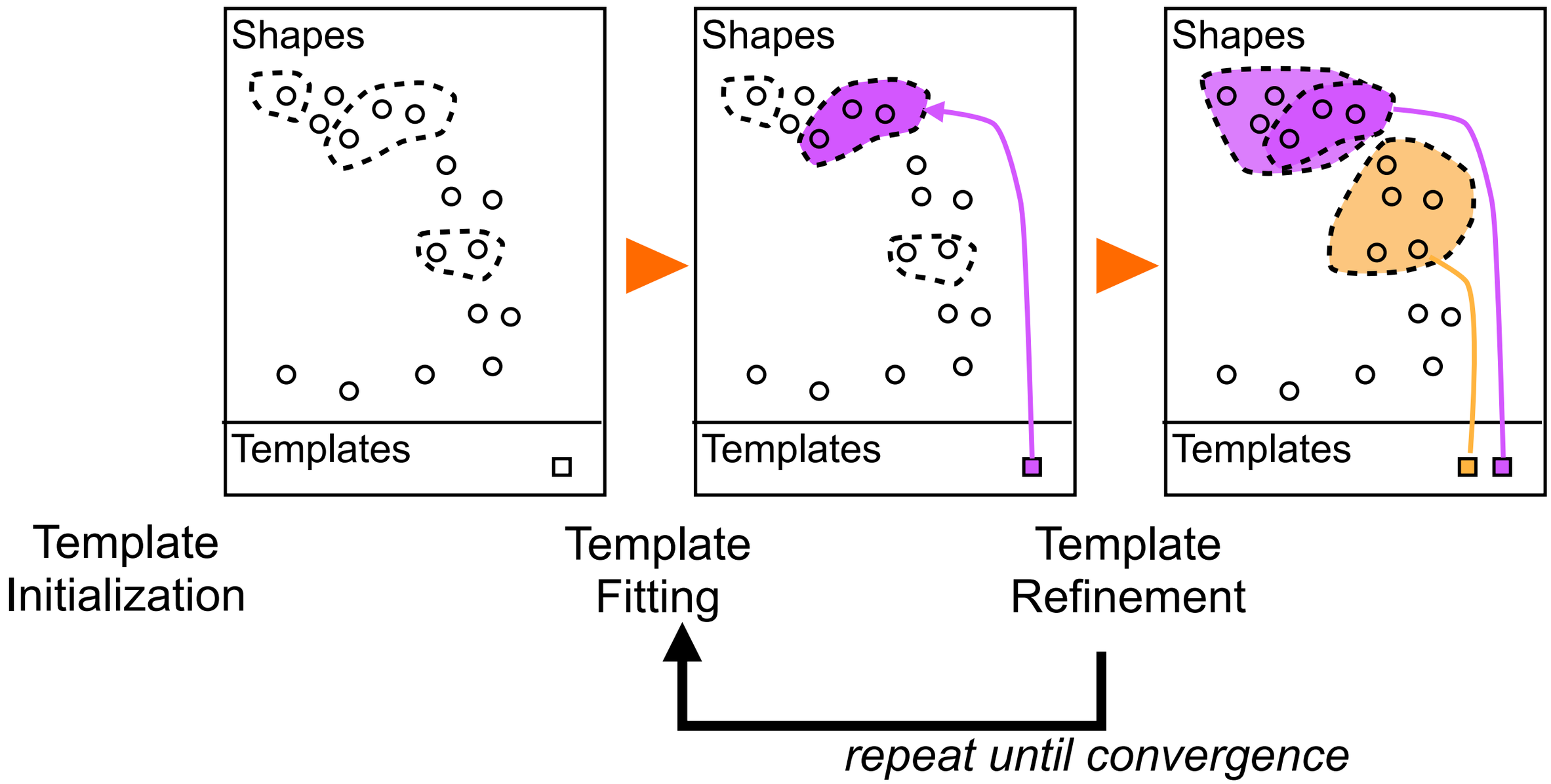


Template Initialization

Template Fitting

Template Refinement

Algorithm Overview



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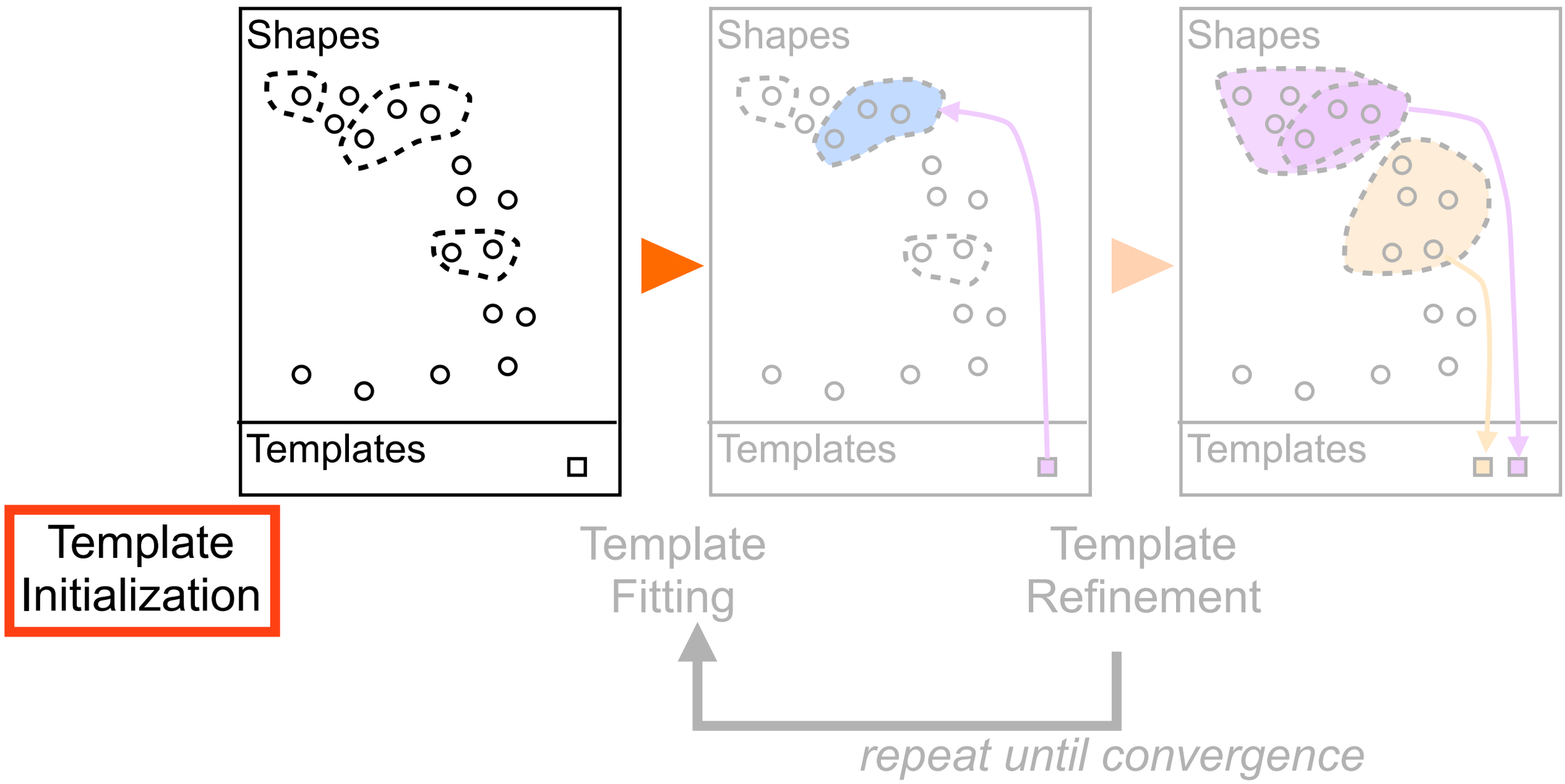
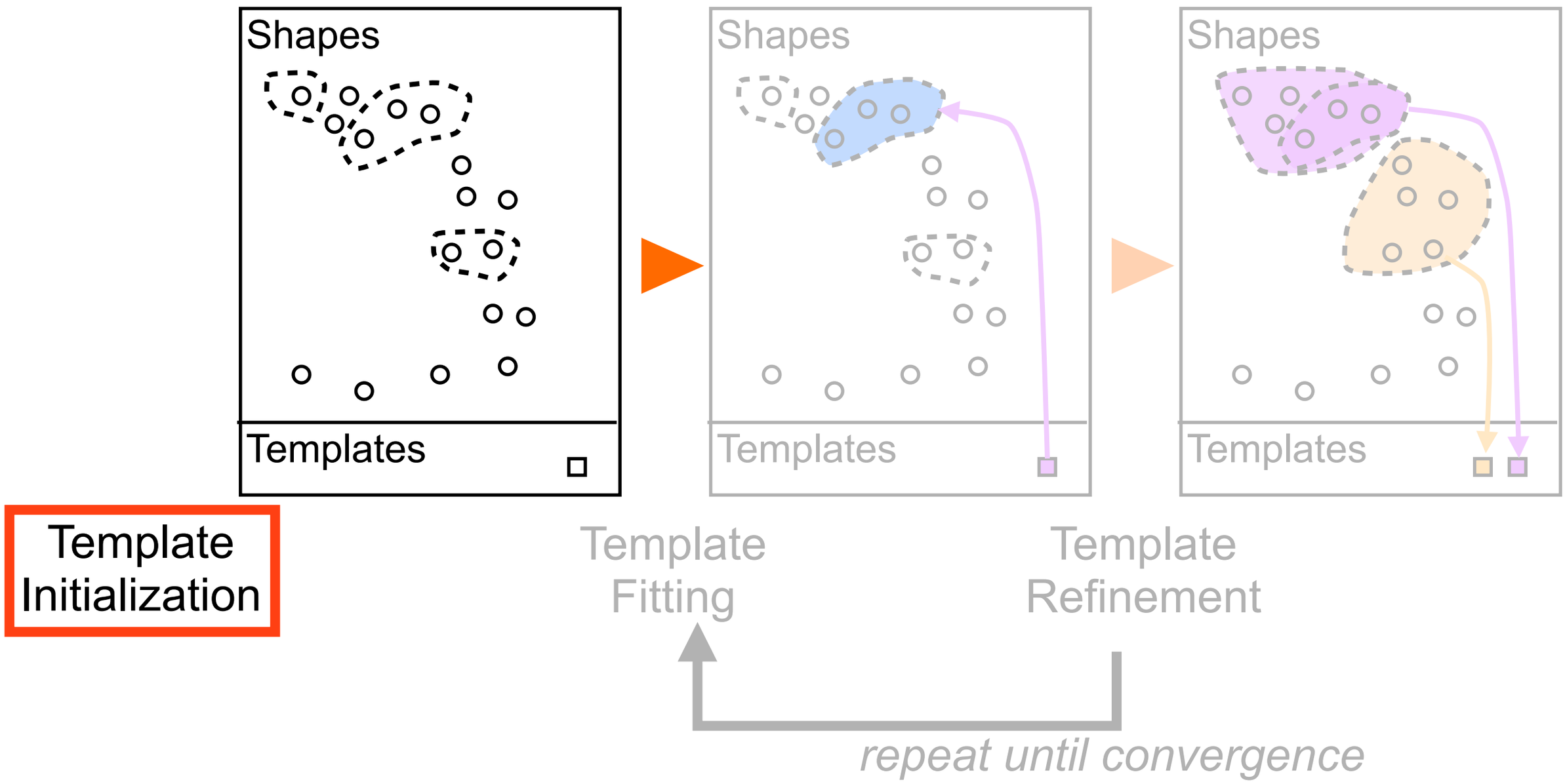


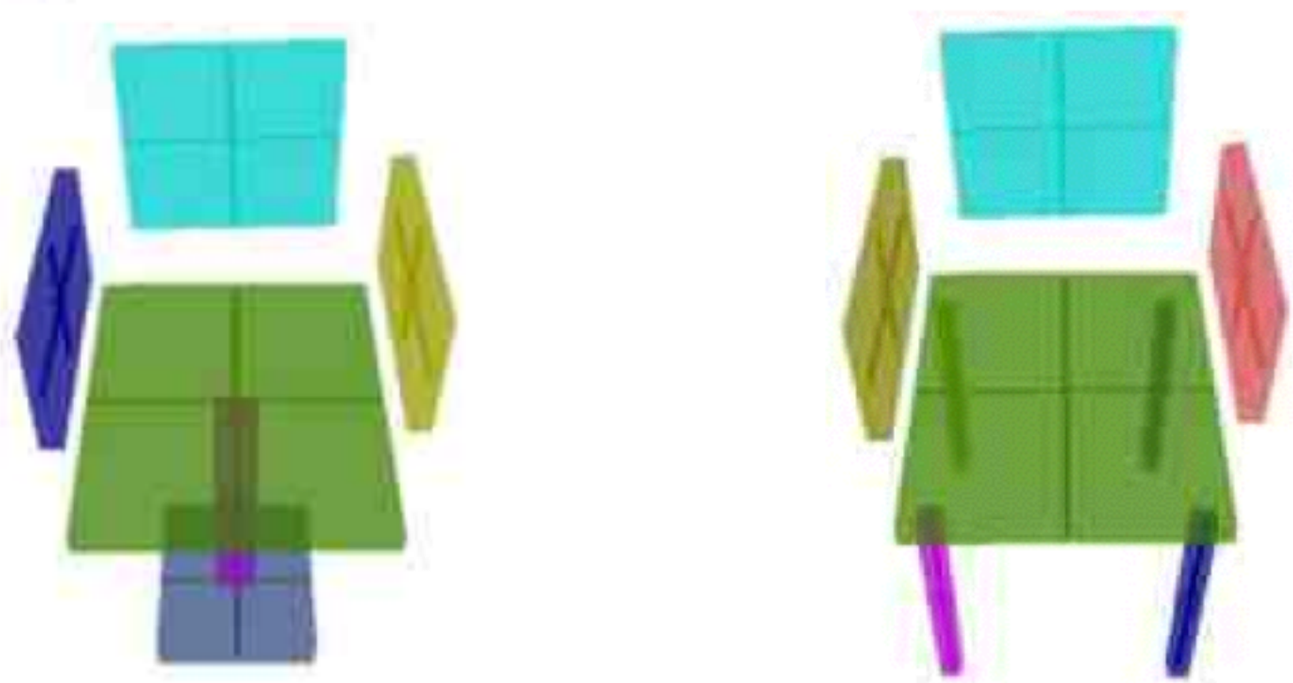
Algorithm Overview



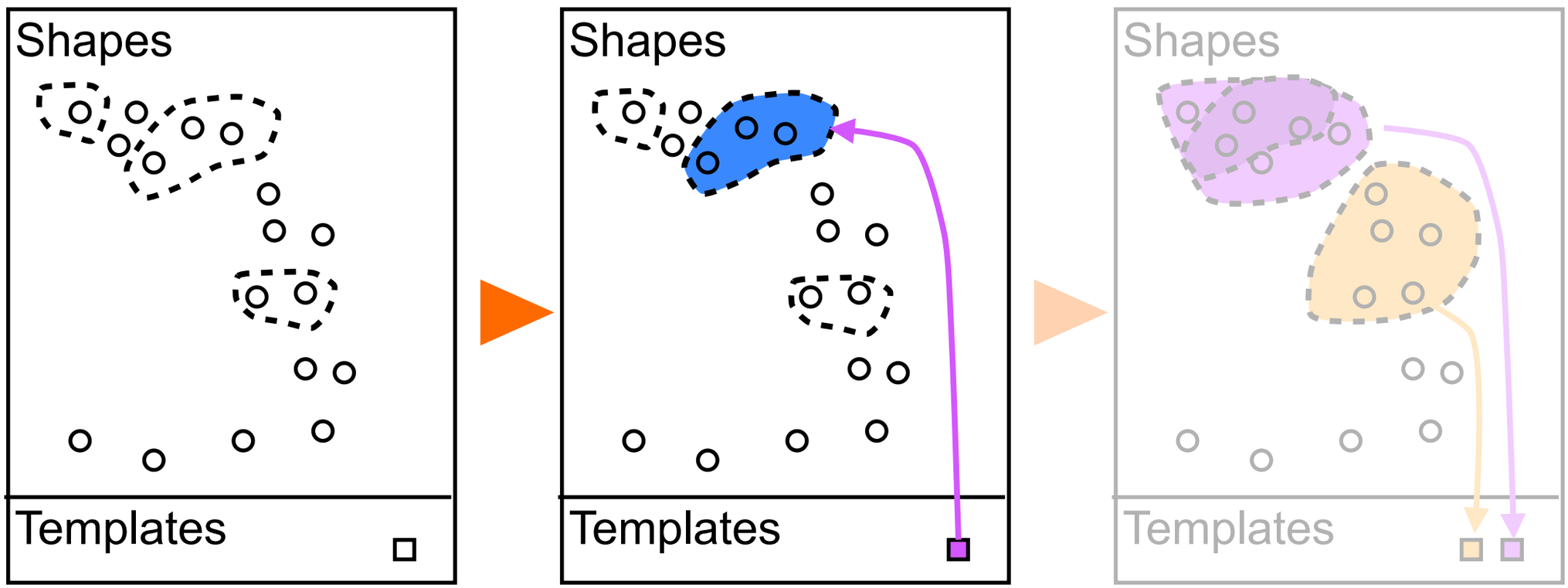
Template Initialization

Manual initialization

- The user aligns boxes to semantic parts (≈ 5 min)



Algorithm Overview



Template Initialization

Template Fitting

Template Refinement

Fitting Parameters

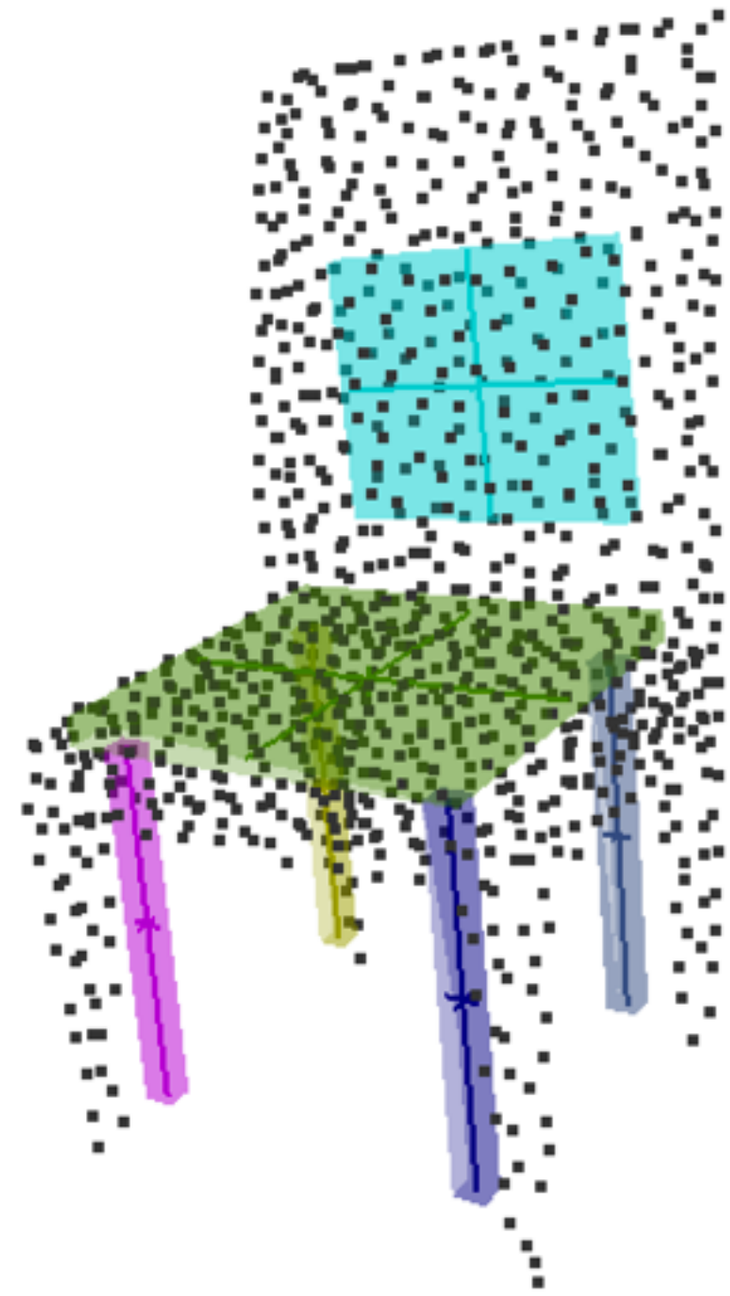
Rigid alignment

Per part deformations

- Existence
- Centroid position
- Anisotropic scale

Labeling of points in the shape

Shape ↔ template mapping



Fitting Energy

$$E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}}$$

- E_{data} (template $\leftrightarrow$ shape distance + local shape features)
- E_{deform} (plausibility of template deformation)
- E_{smooth} (close & similar regions should get the same label)

Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- Correspondences
- Deformation

Fitting Optimization

Alternate steps until shape segmentation converges:

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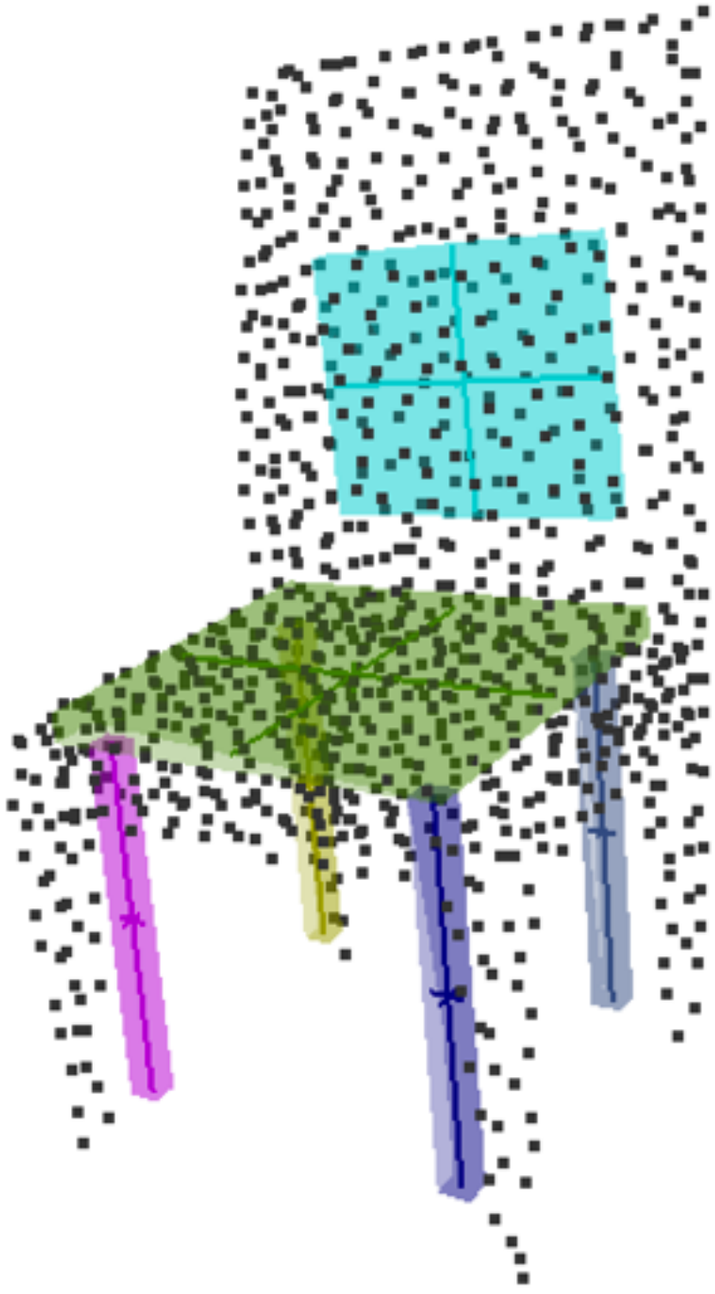


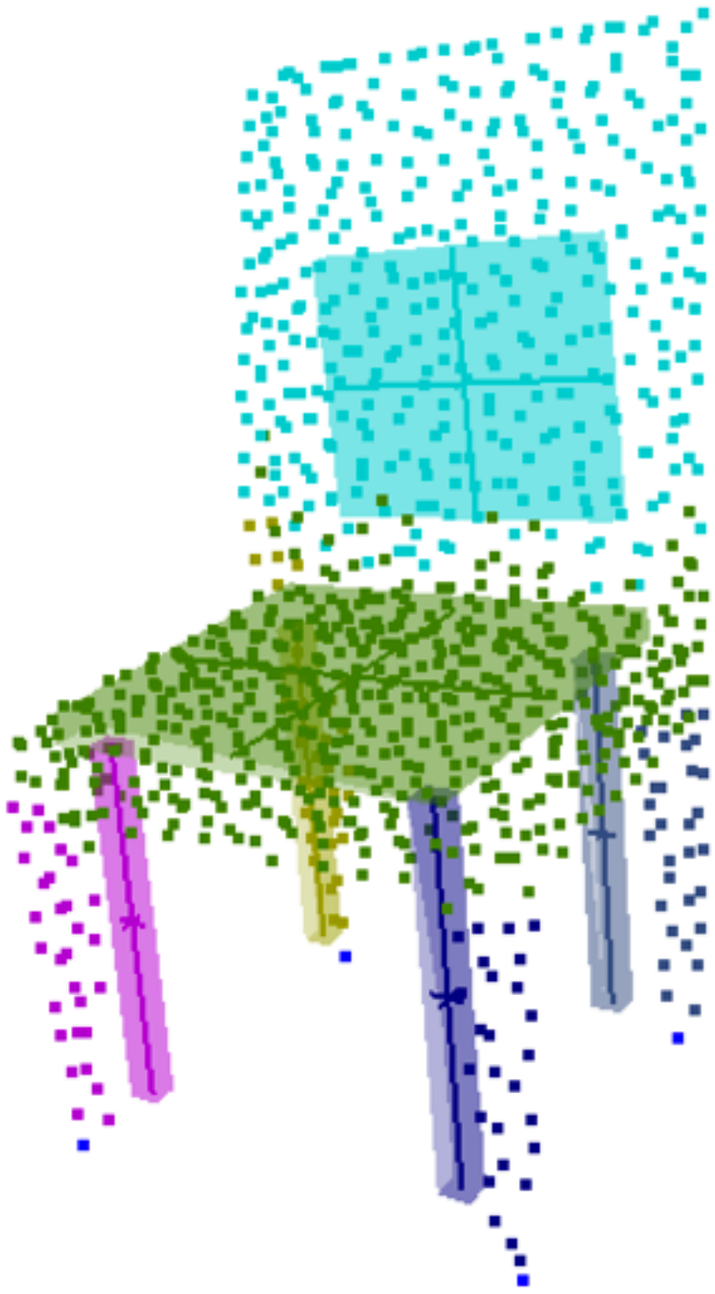
Fitting Optimization

Alternate steps until shape segmentation converges:

- ➡ Segmentation
- Correspondences
- Deformation

$$E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}}$$

Method: Graph cut [Boykov et al. 2001]



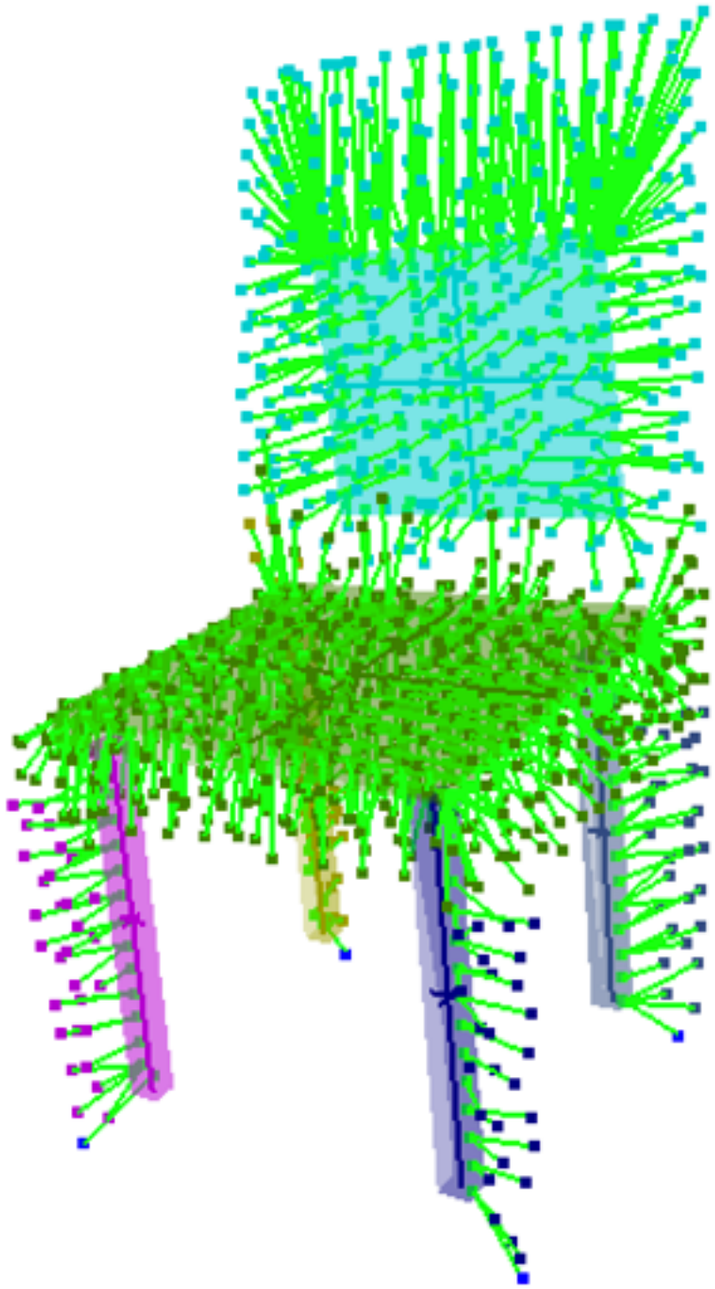
Fitting Optimization

Alternate steps until shape segmentation converges:

- Segmentation
- ➡ Correspondences
- Deformation

$$E = \underline{E_{\text{data}}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}}$$

Method: Part-aware closest points



Fitting Optimization

Alternate steps until shape segmentation converges:

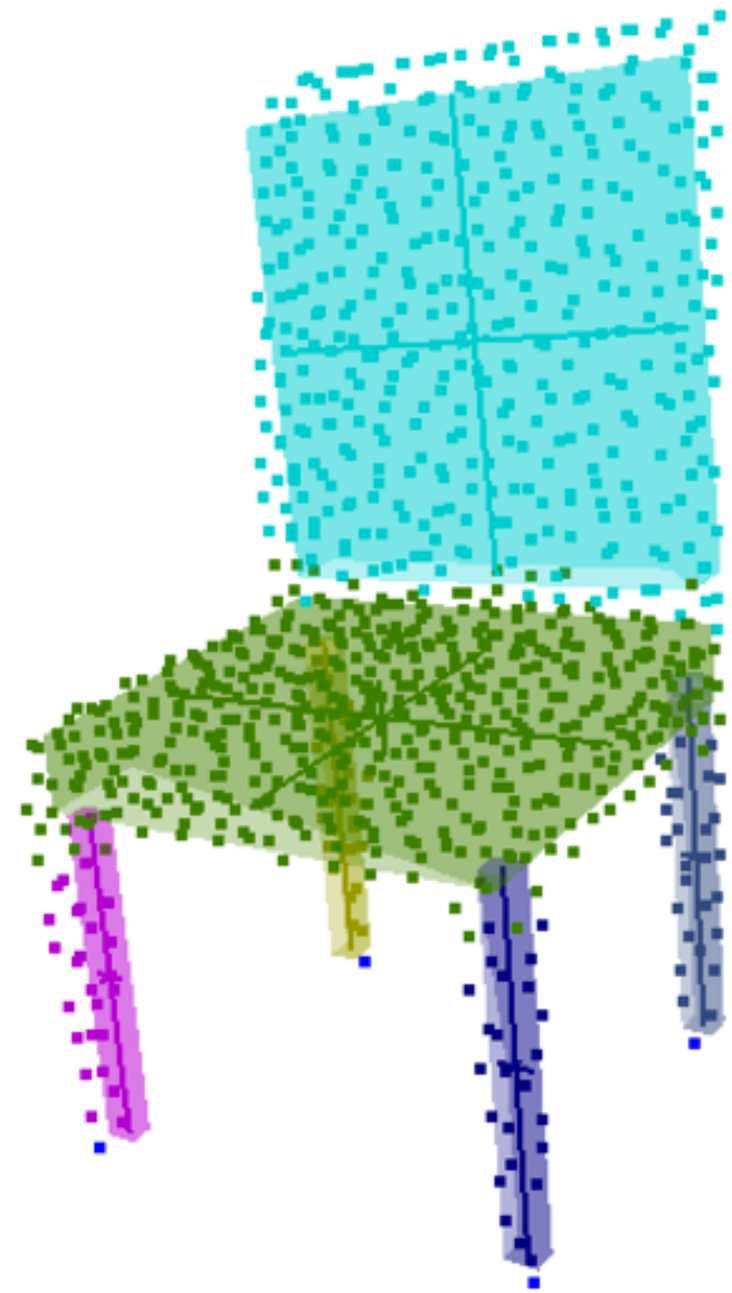
- Segmentation
- Correspondences
- ➡ Deformation

$$E = E_{\text{data}} + \gamma E_{\text{deform}} + \beta E_{\text{smooth}}$$

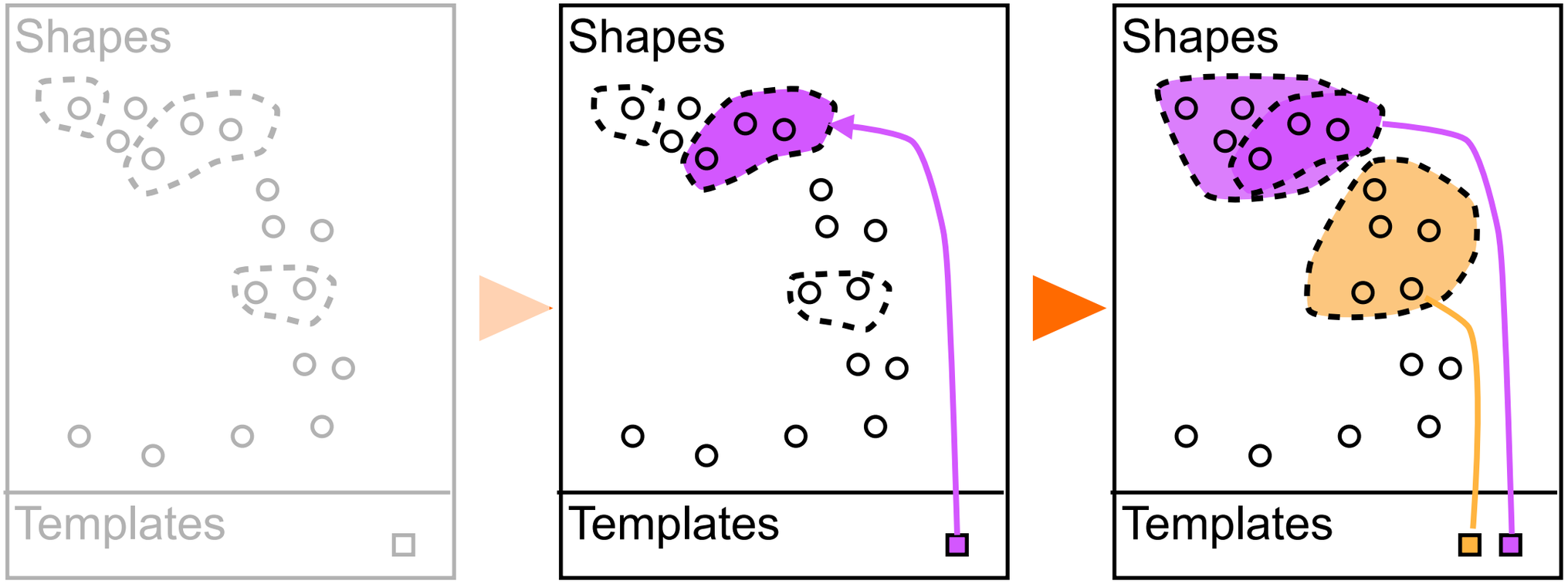
Method: Solve for critical points.

position: $$\frac{\partial(E_{\text{data}} + E_{\text{deform}})}{\partial b_p} = 0$$

scale: $$\frac{\partial(E_{\text{data}} + E_{\text{deform}})}{\partial b_s} = 0$$



Algorithm Overview



Template Initialization

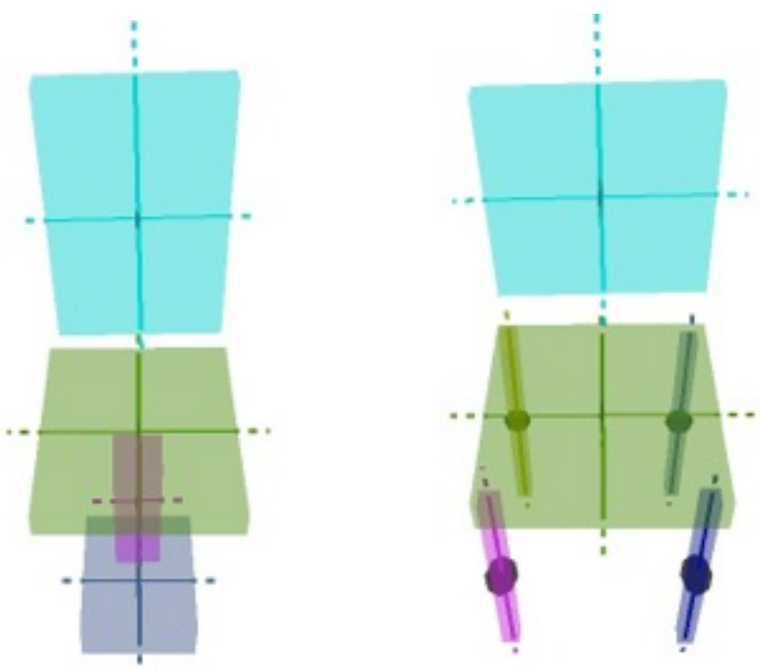
Template Fitting

Template Refinement

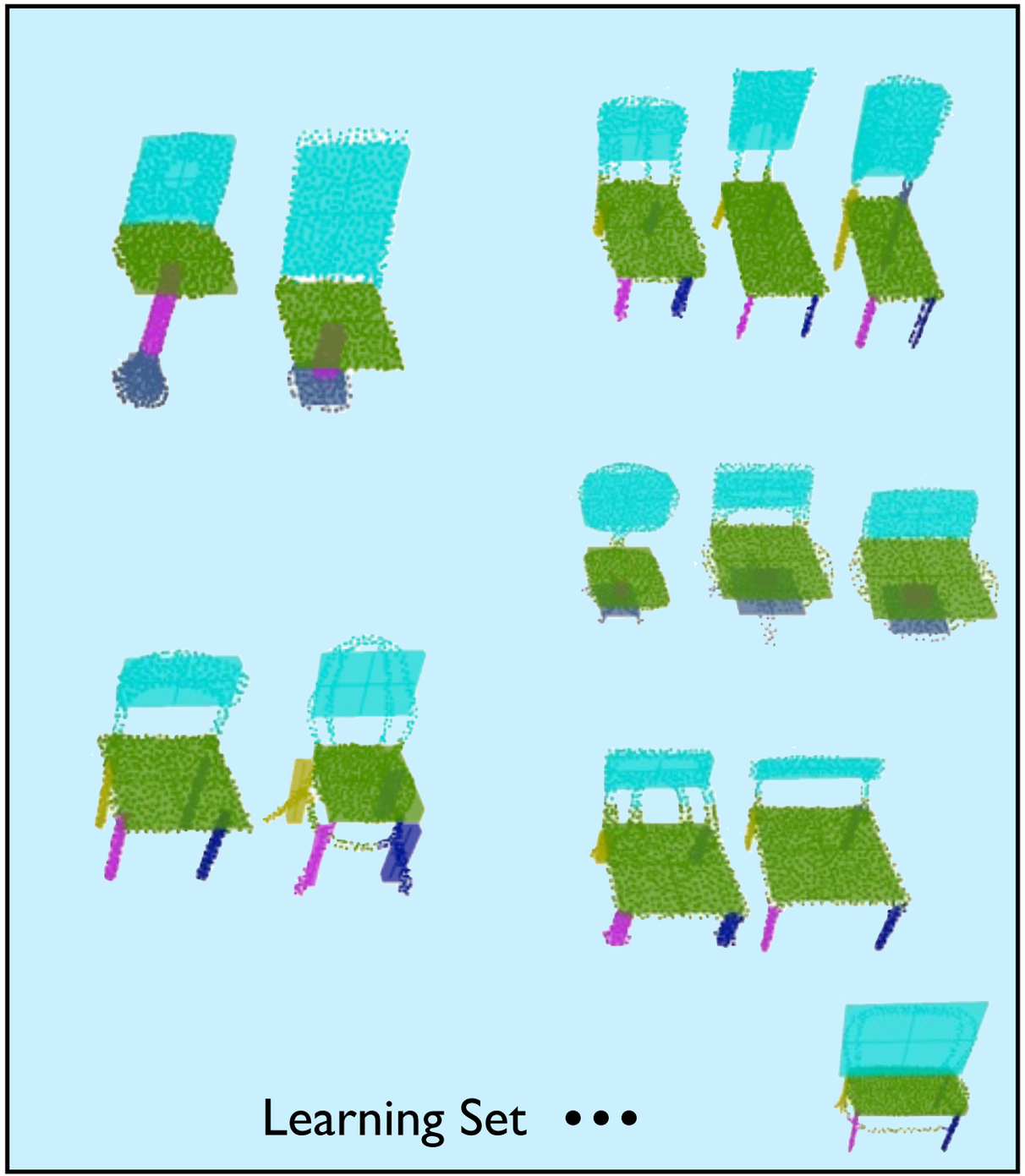
Template Refinement

Update template set from deformations in Learning Set

- Update current
- Spawn new
- Reject outliers



Current Template Set



Template Refinement

Update template set from deformations in Learning Set

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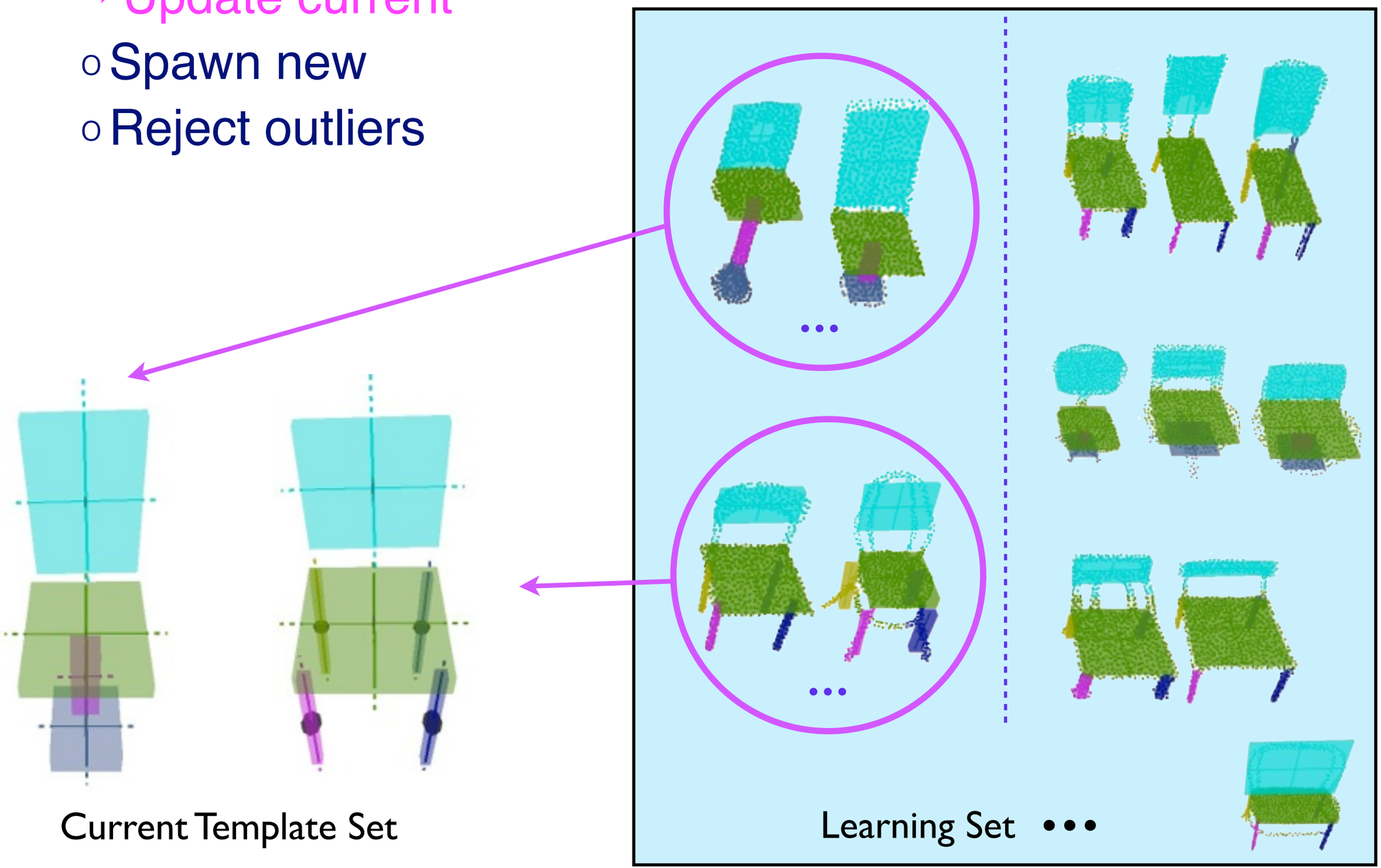

Template Refinement

Update template set from deformations in Learning Set

- ➡ Update current
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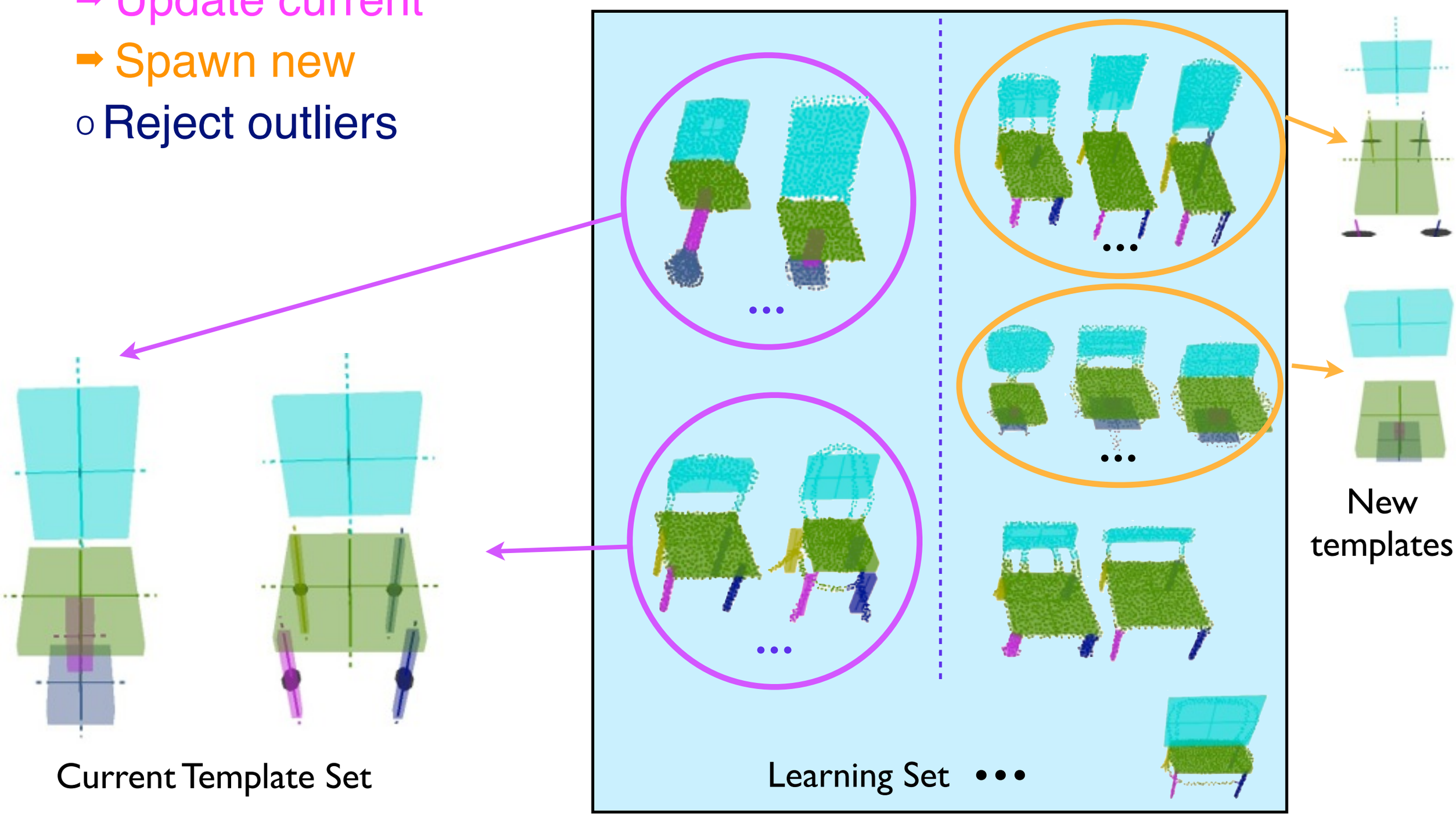

Template Refinement

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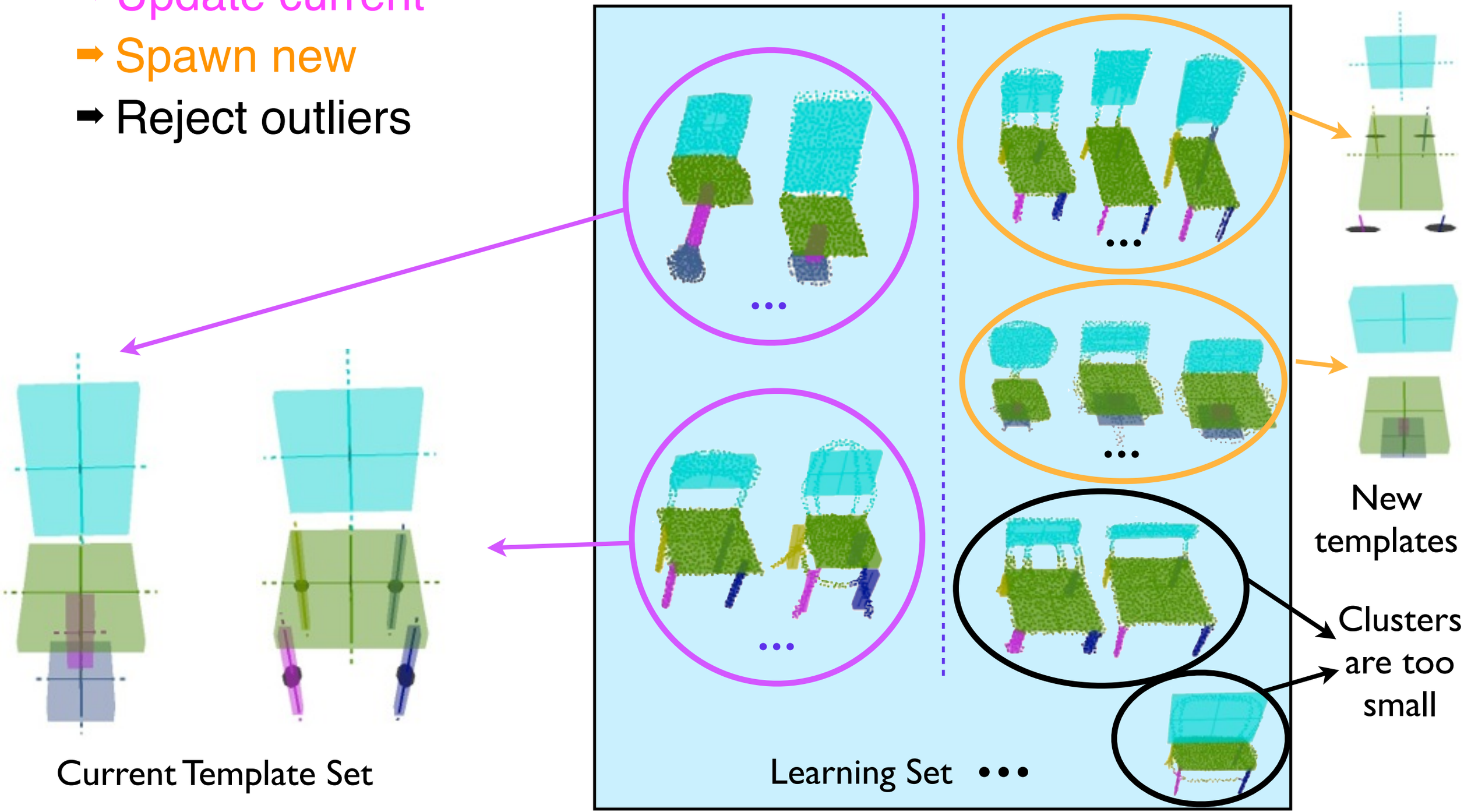
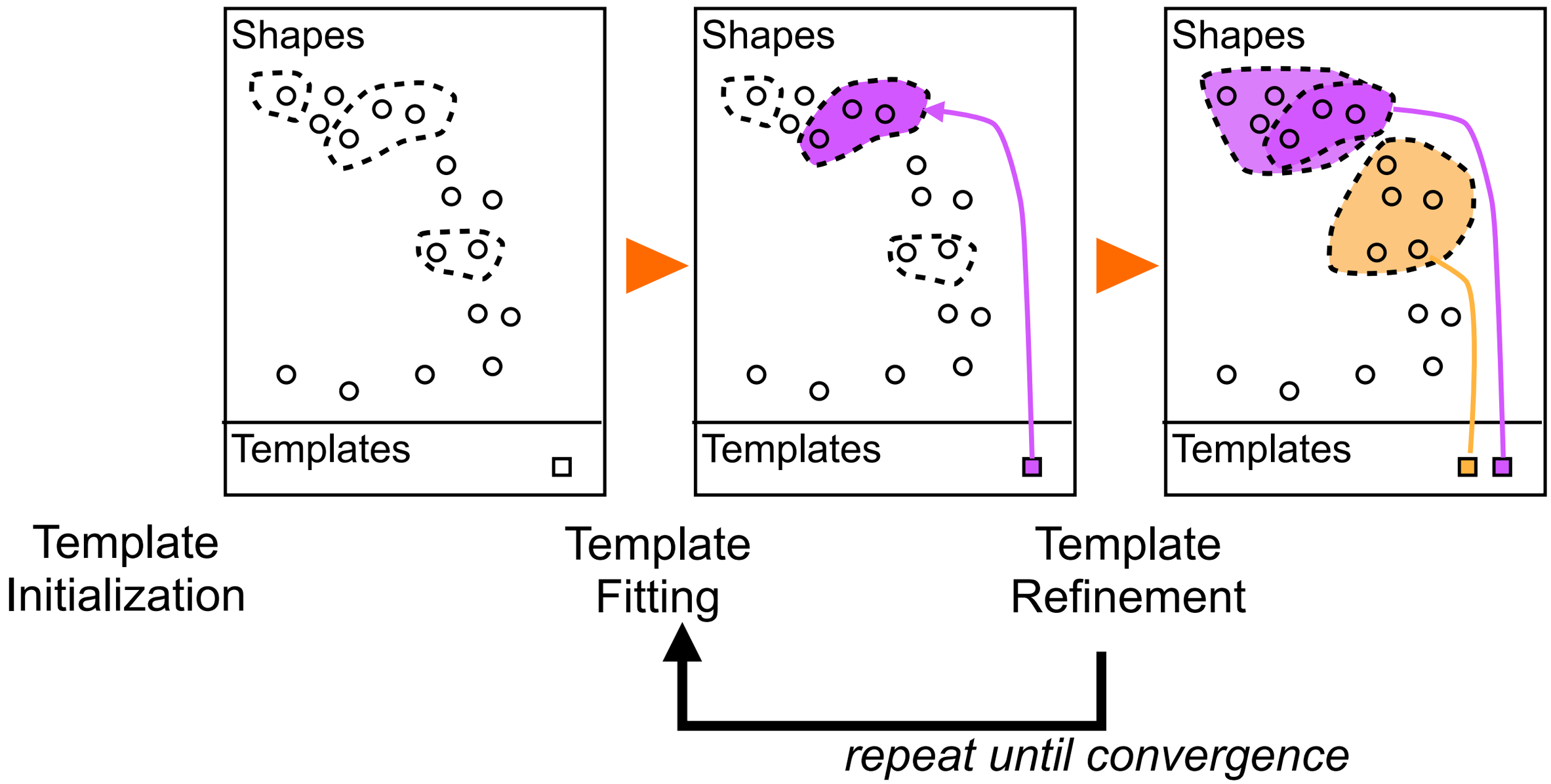
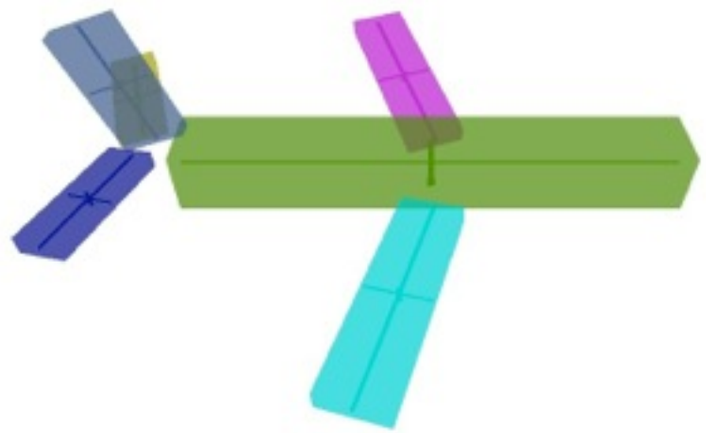


Algorithm Overview



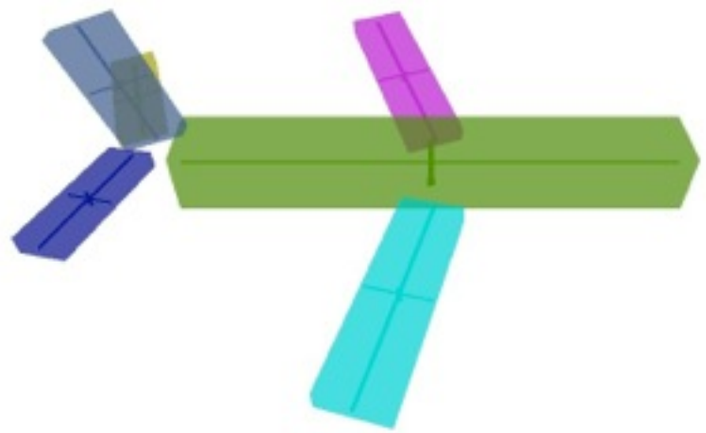
3D Warehouse: 3113 airplanes

Initial Template:

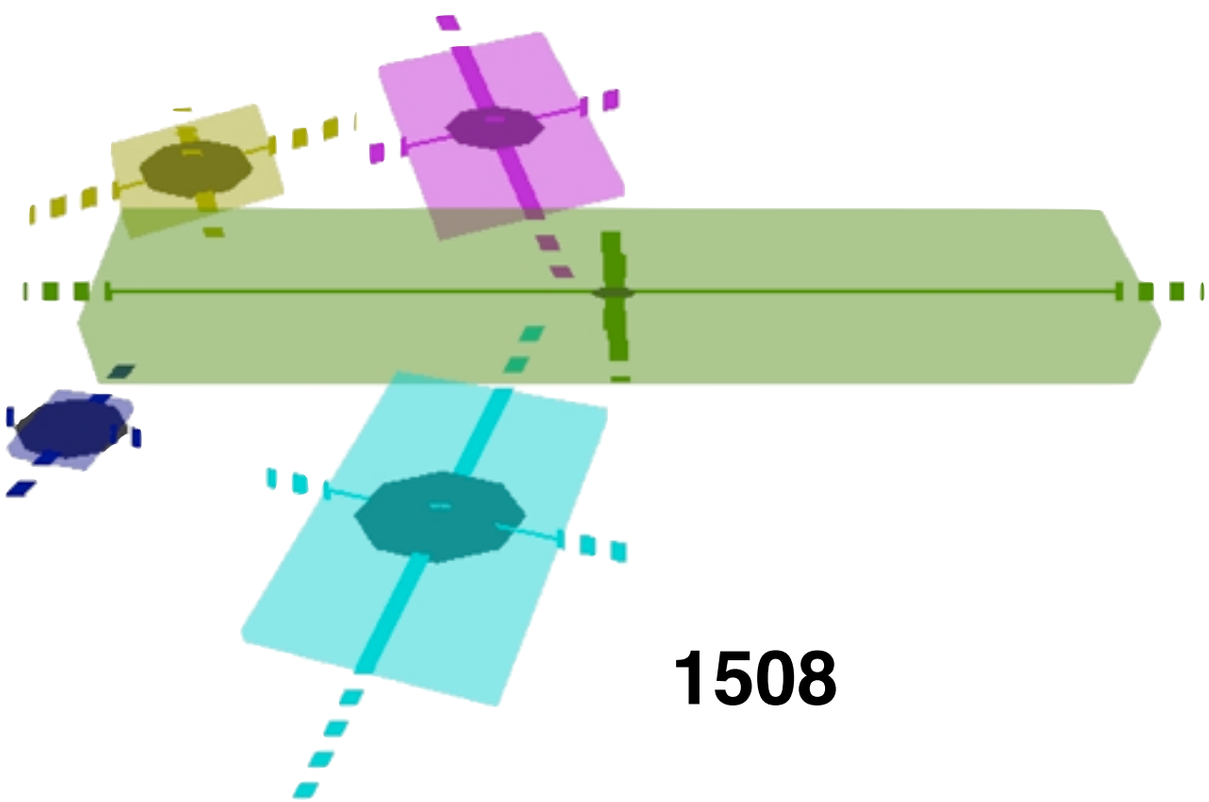


3D Warehouse: 3113 airplanes

Initial Template:



Final Templates:



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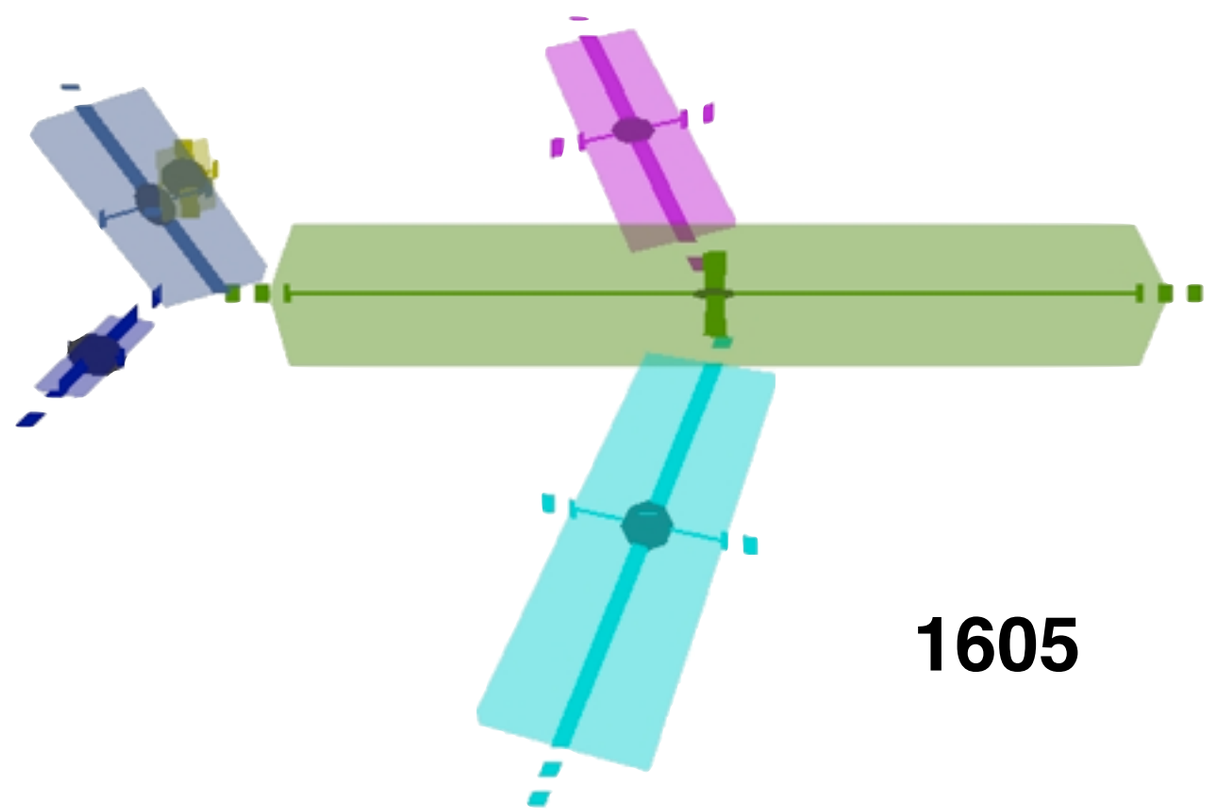
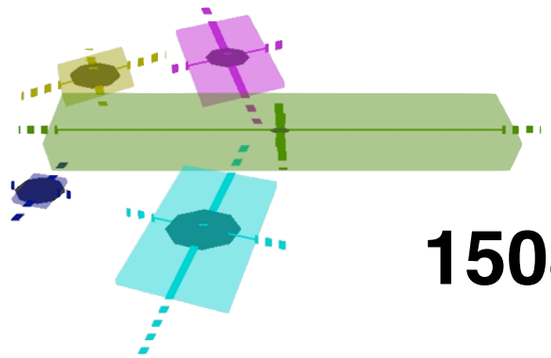


1605

3D Warehouse: 3113 airplanes



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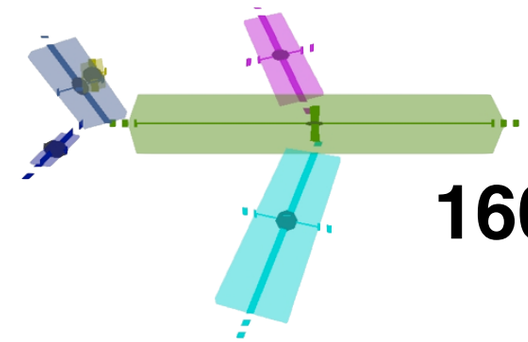

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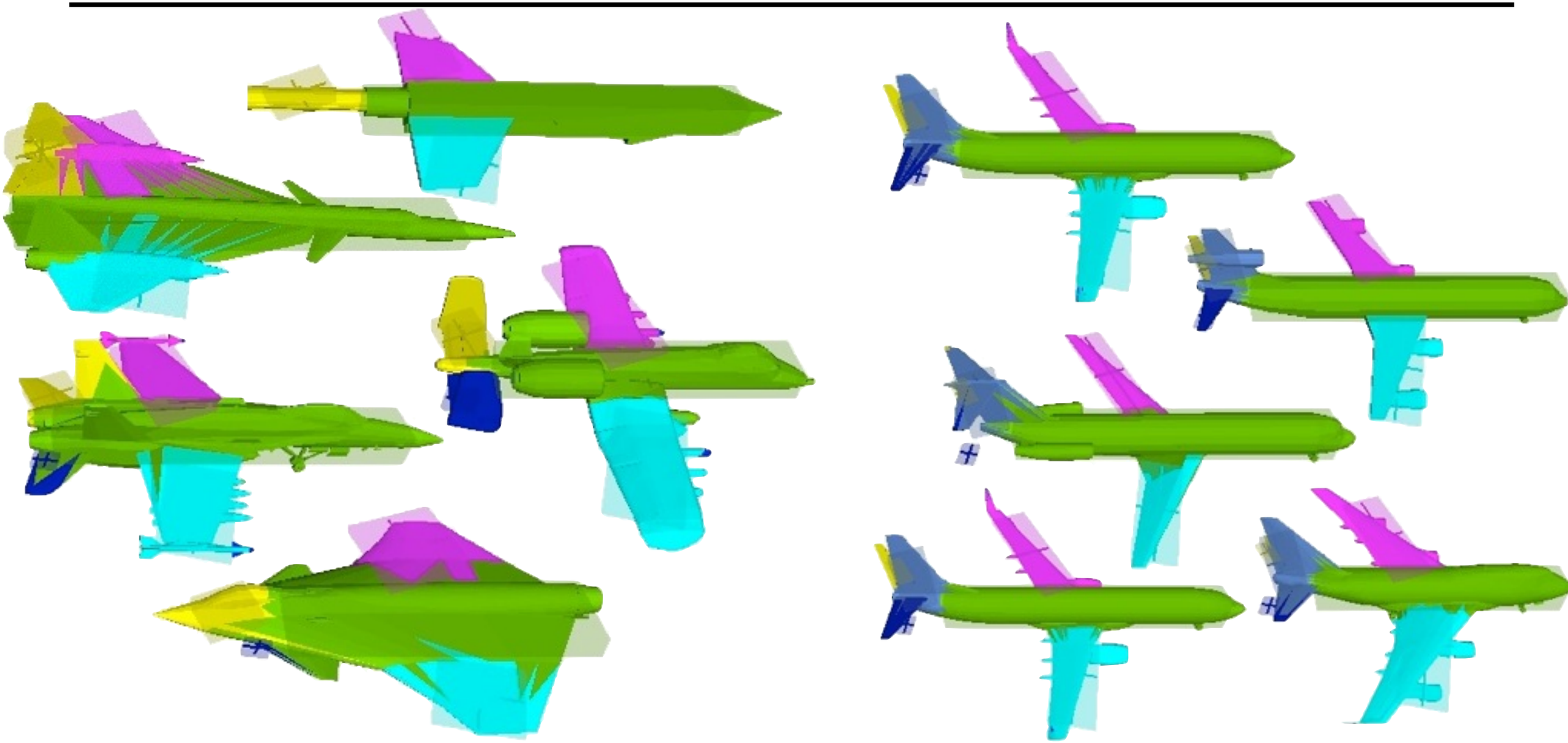
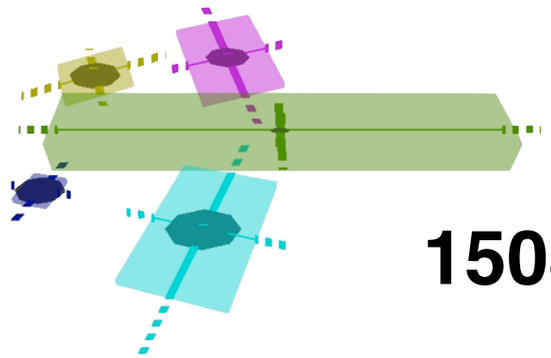


3D Warehouse: 3113 airplanes



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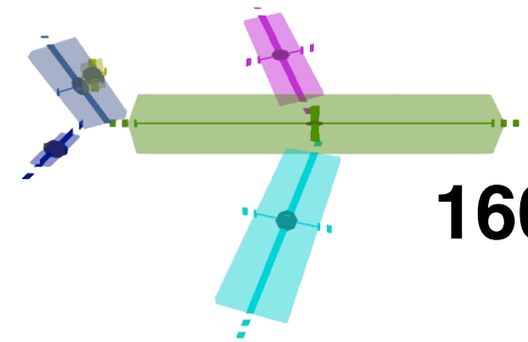

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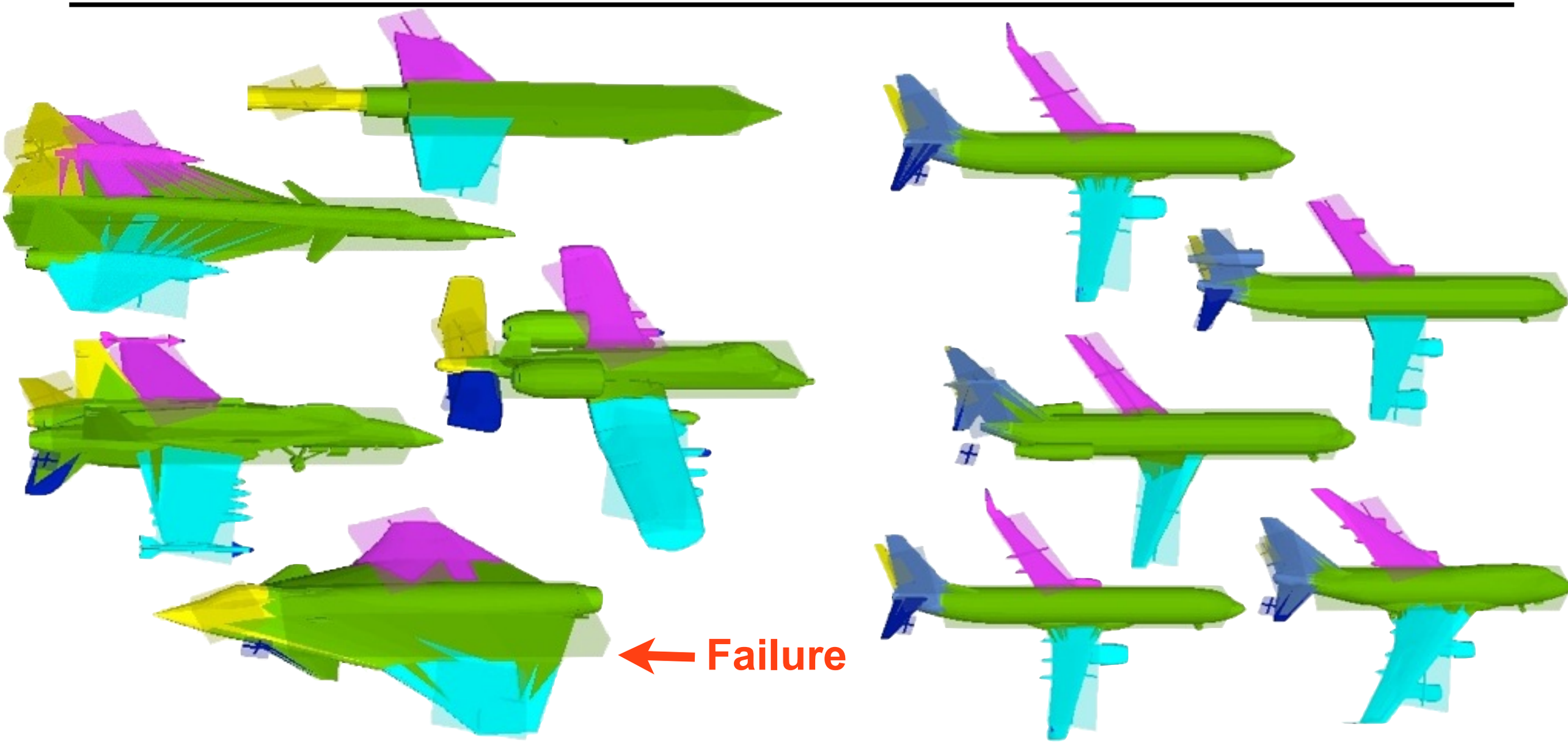
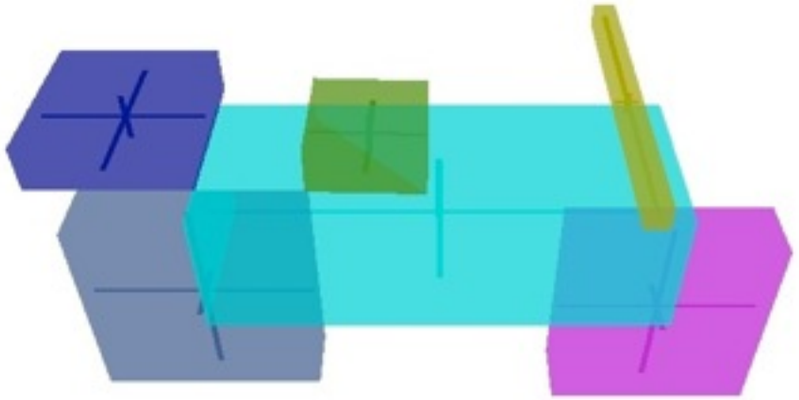


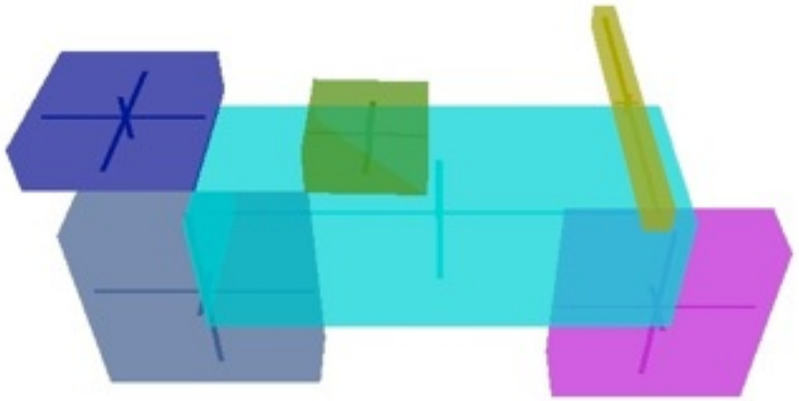
3D Warehouse: 471 bikes

Initial Template:

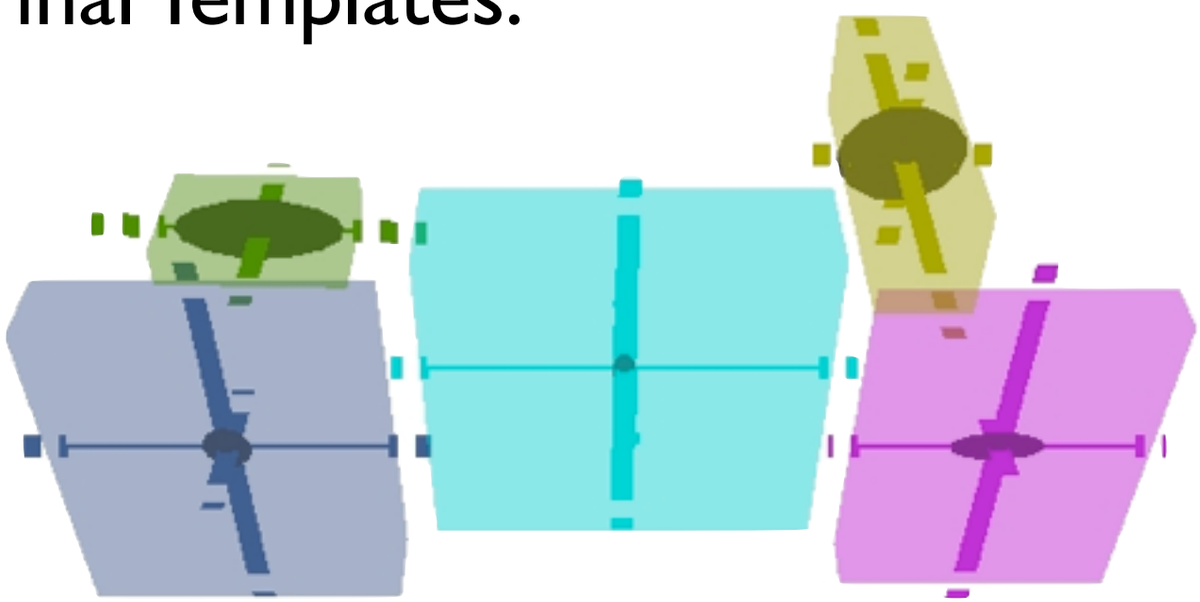


3D Warehouse: 471 bikes

Initial Template:



Final Templates:



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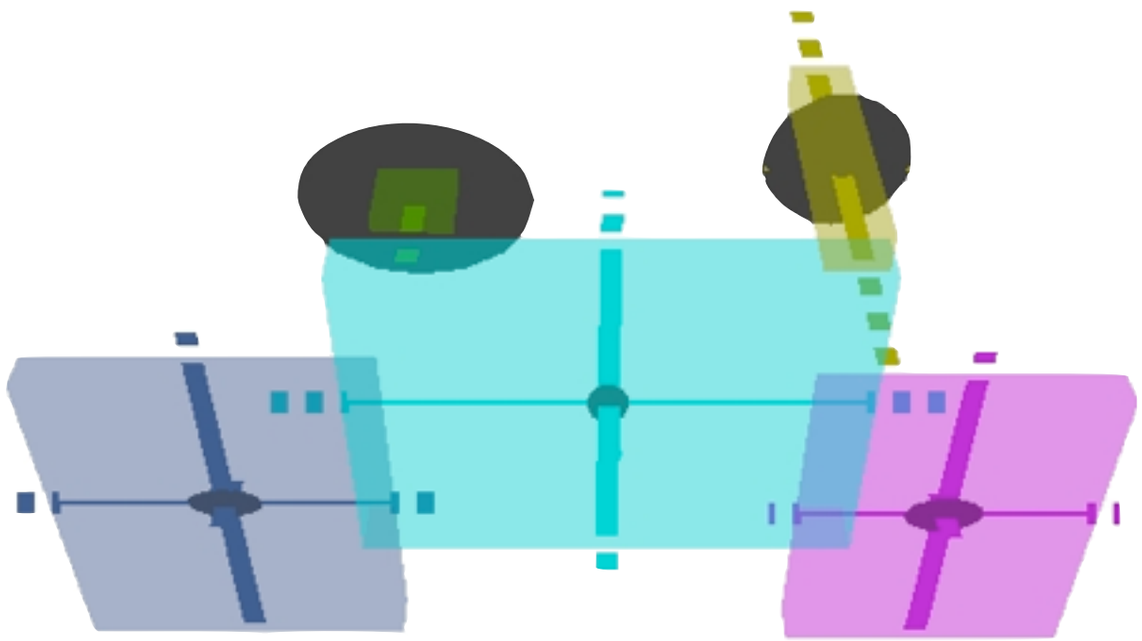
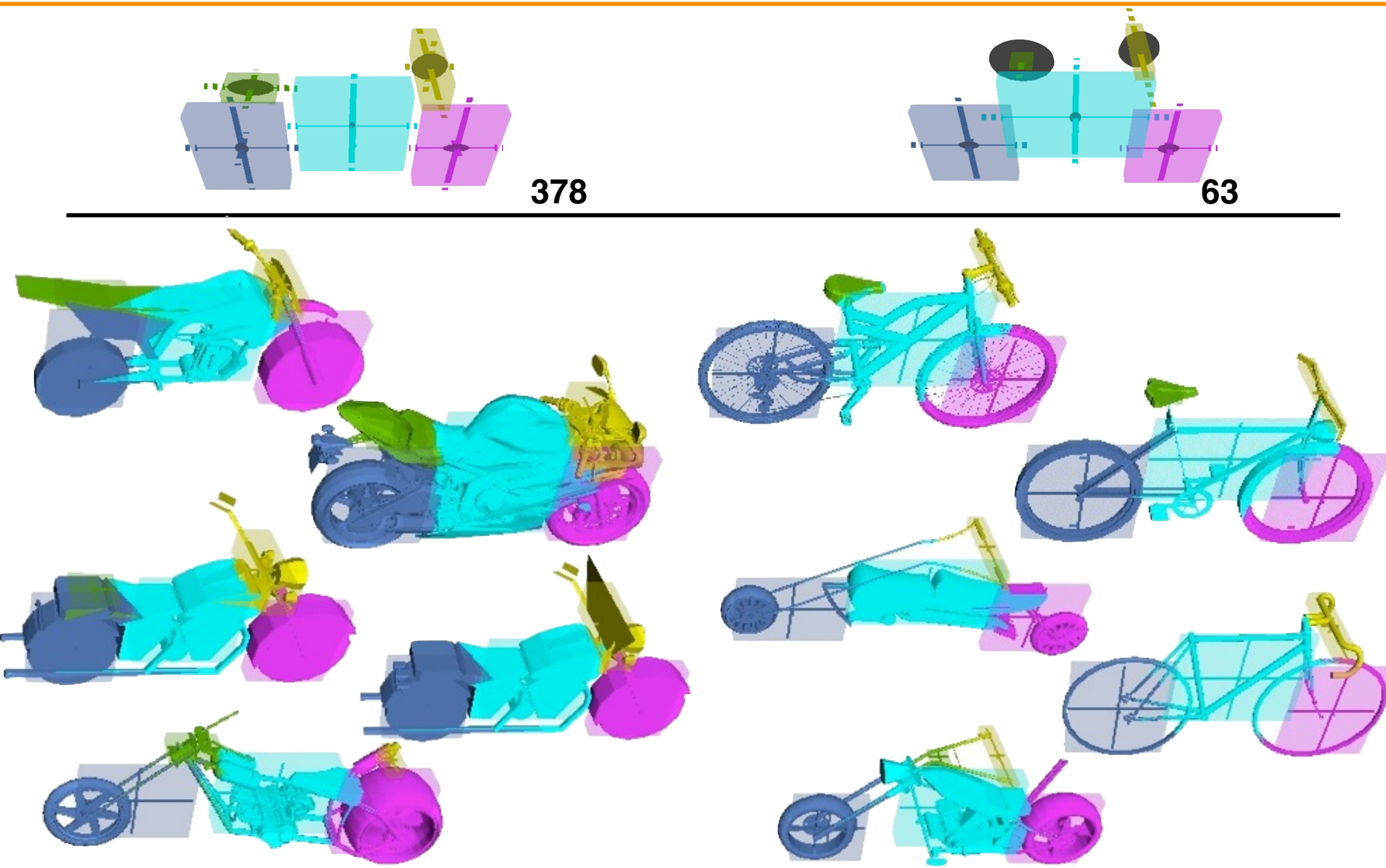


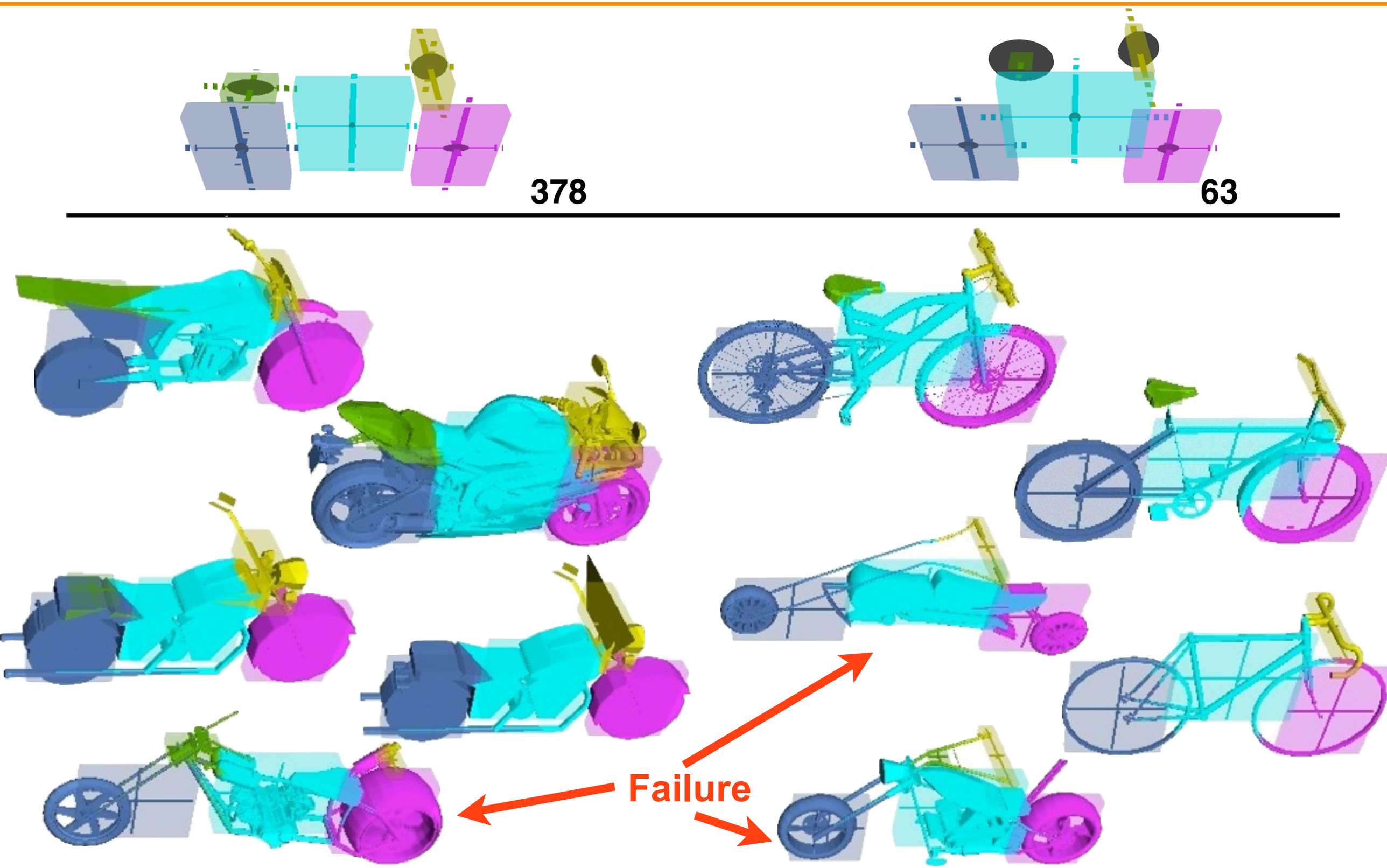
63

23 7 …

3D Warehouse: 471 bikes



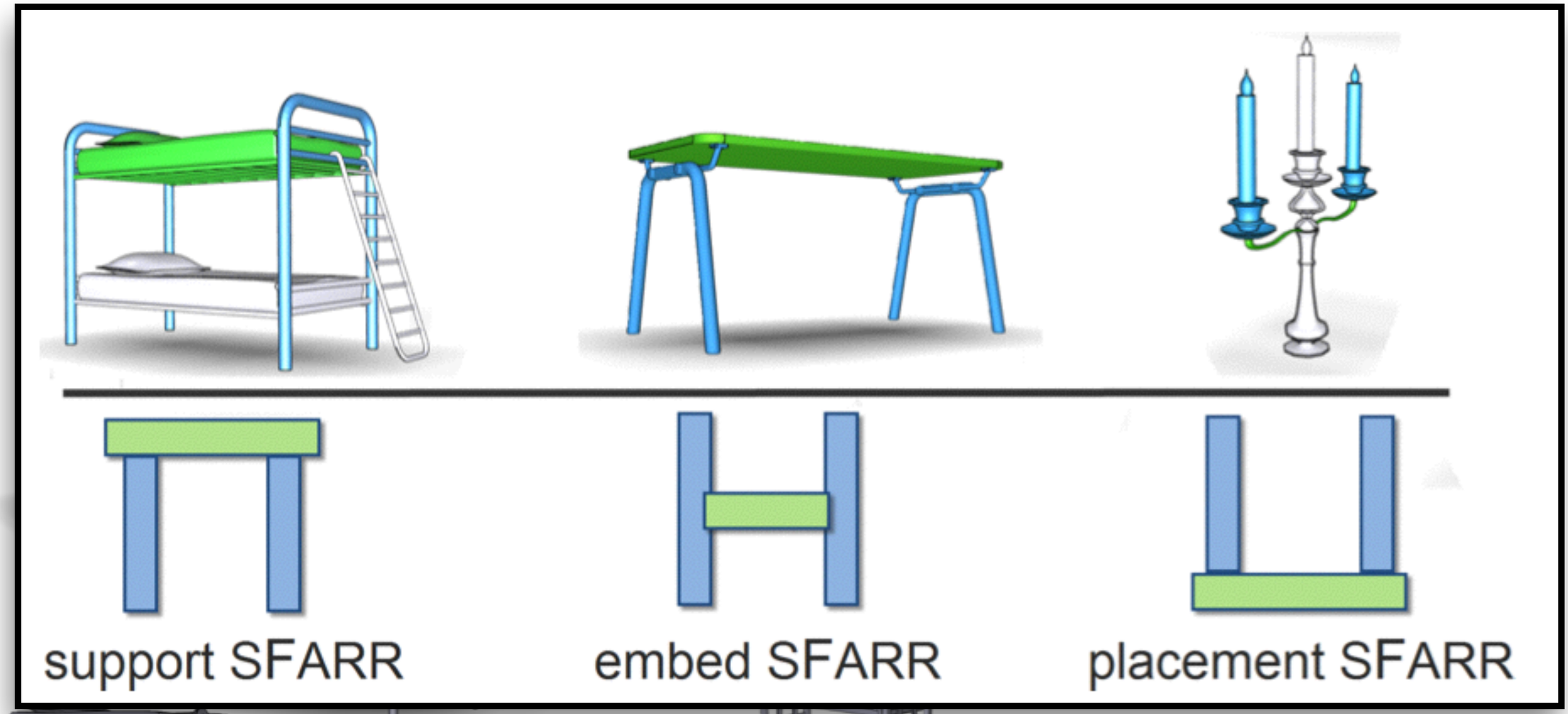
3D Warehouse: 471 bikes



Structural Part Relations

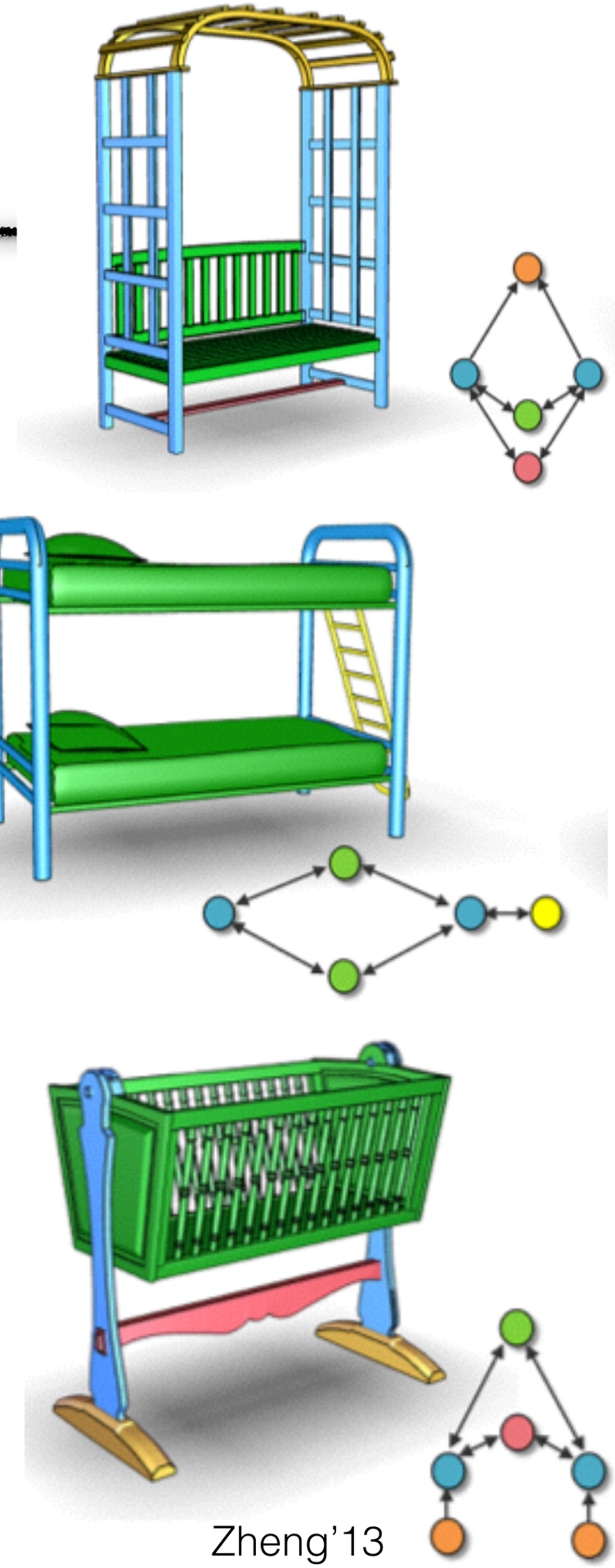
Zheng'13

Structural Part Relations



Zheng'13

Structural Part Relations



Zheng'13

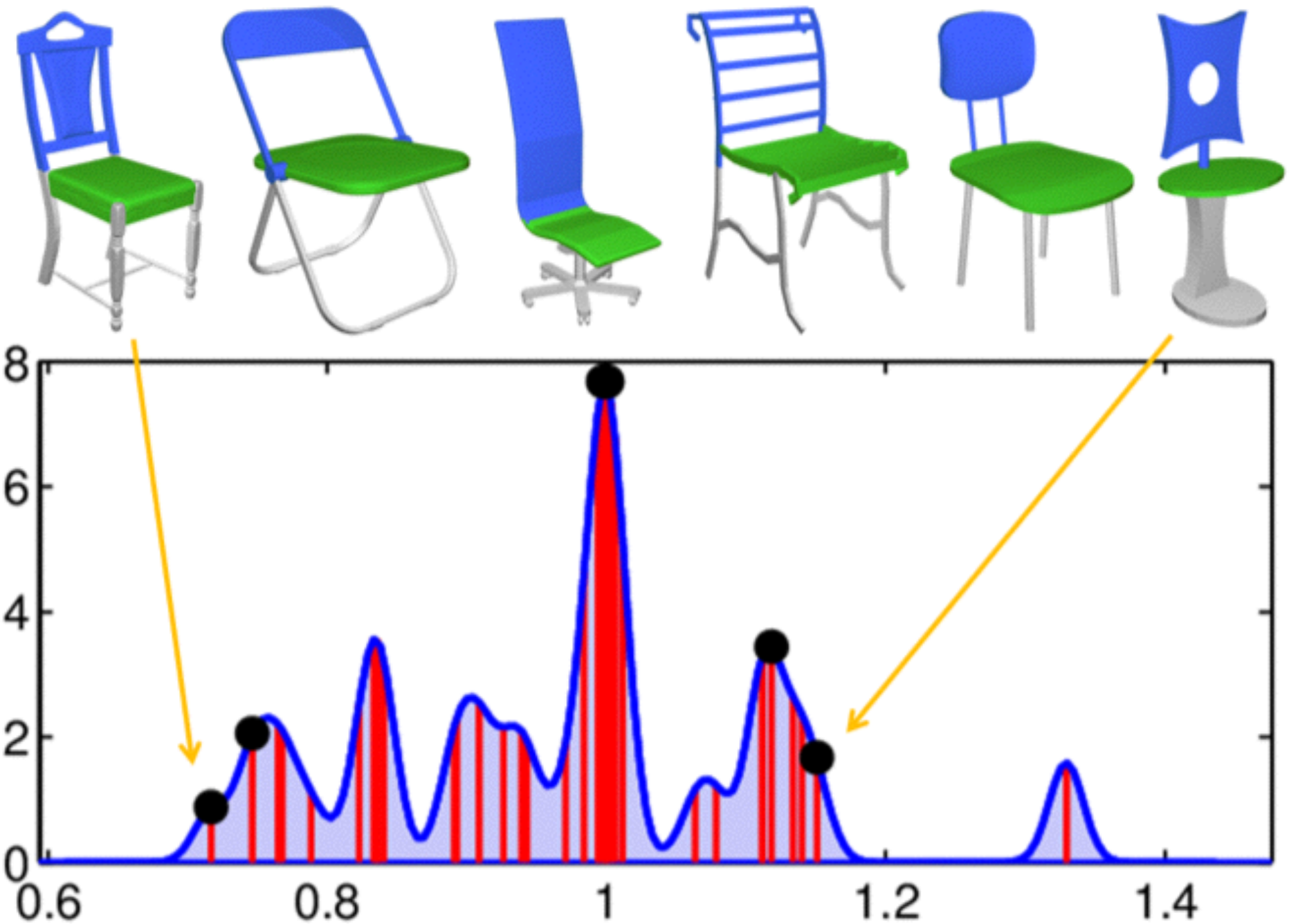
Structural Part Relations

Groups of structural arrangements

Zheng'13

Probabilistic Part Relations

Pairwise co-variability



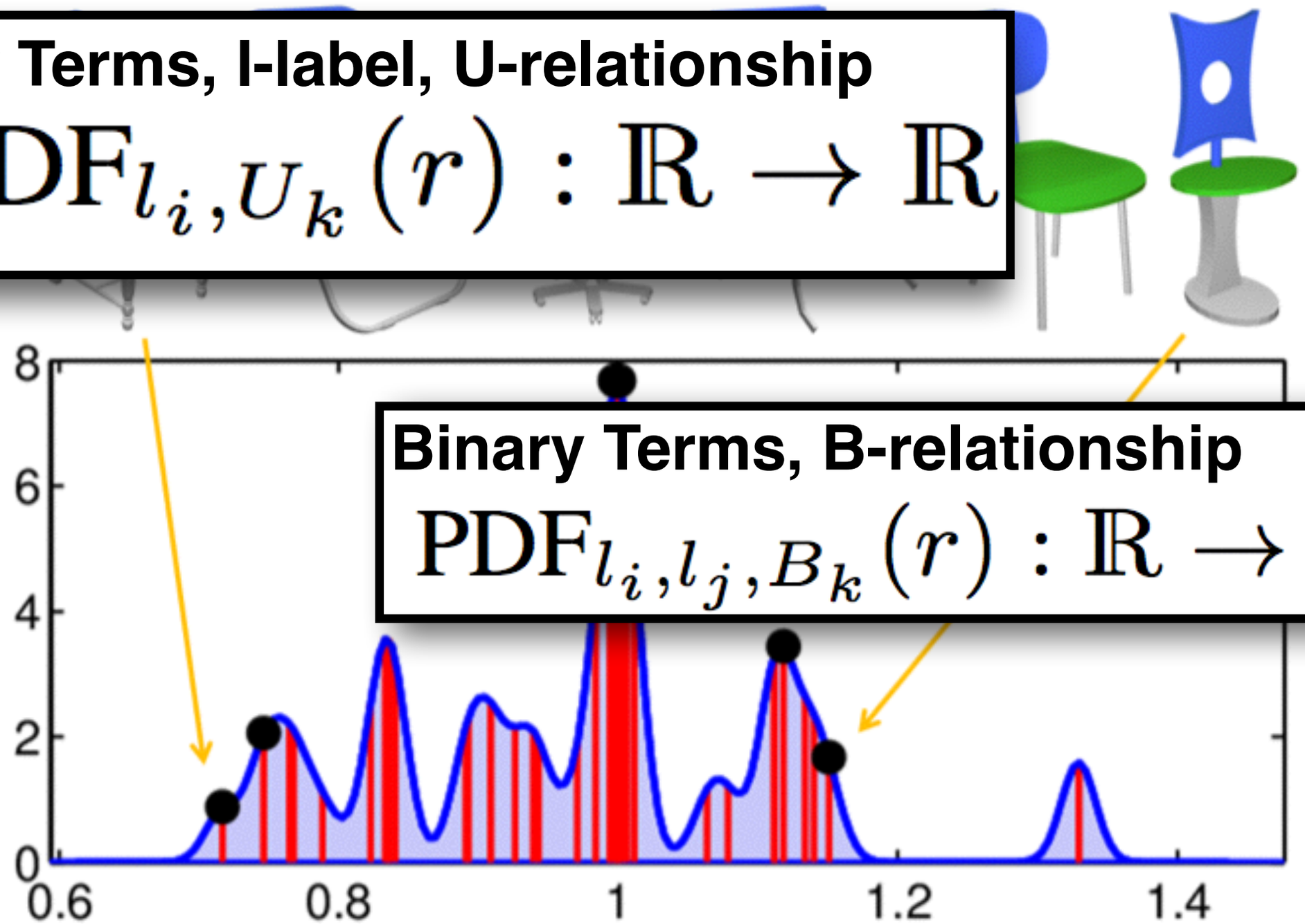
Fish'14

Probabilistic Part Relations

Pairwise co-variability

Unary Terms, l-label, U-relationship

$$\mathrm{PDF}_{l_i,U_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$

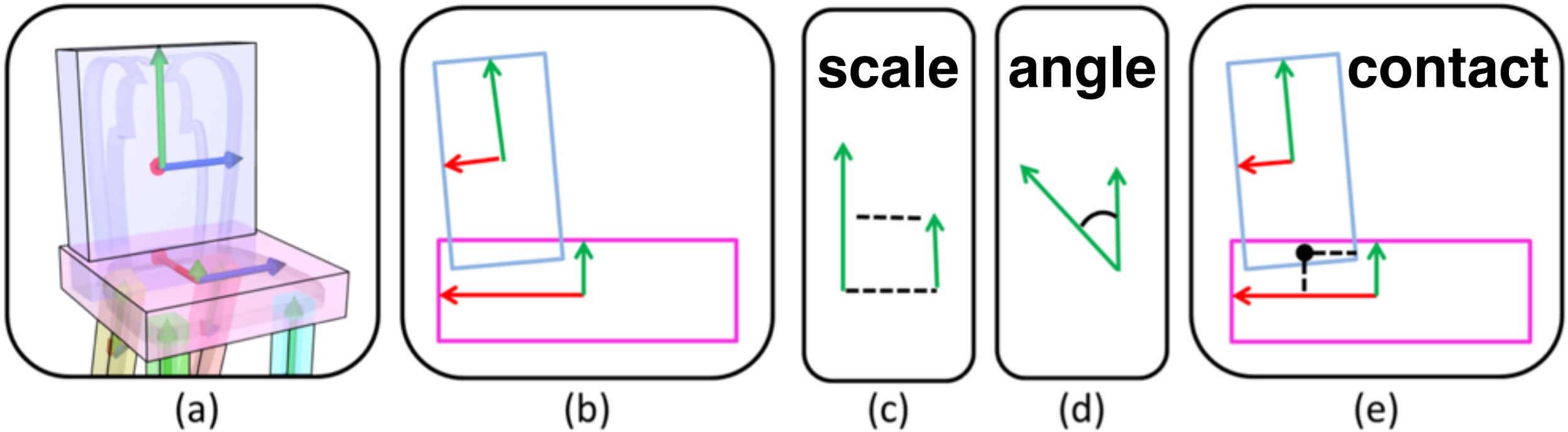


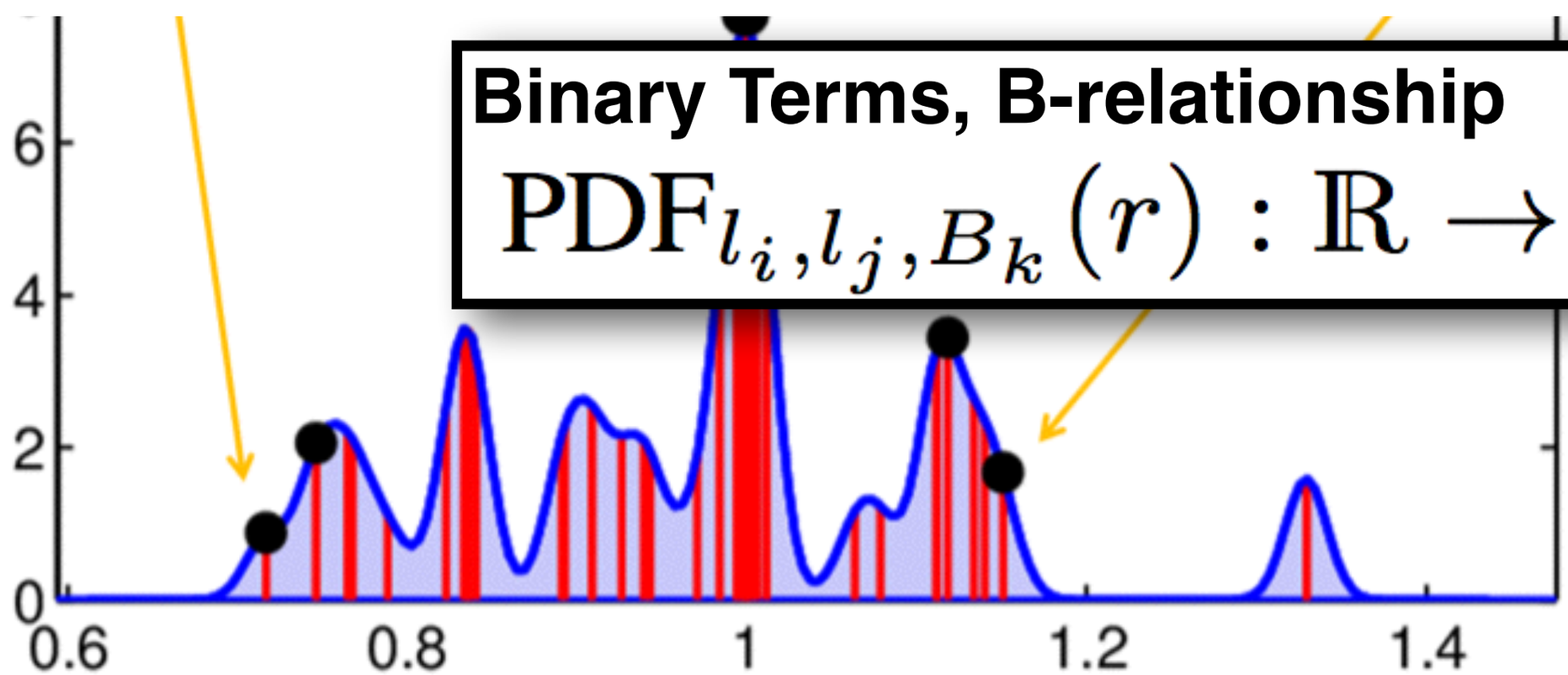
Binary Terms, B-relationship

$$\mathrm{PDF}_{l_i,l_j,B_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$

Fish'14

Probabilistic Part Relations





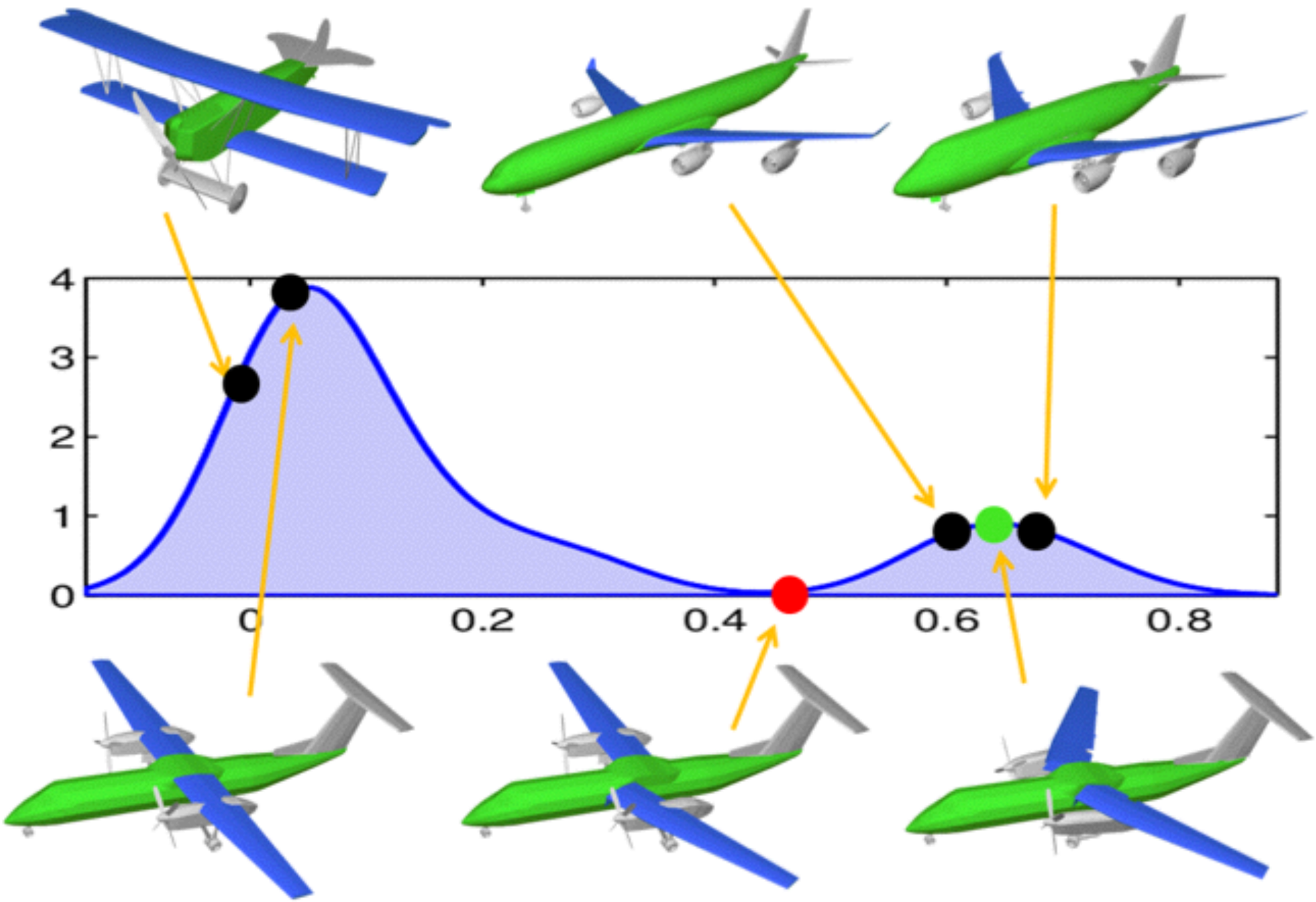
Binary Terms, B-relationship

$$\mathrm{PDF}_{l_i, l_j, B_k}(r) : \mathbb{R} \rightarrow \mathbb{R}$$

Fish'14

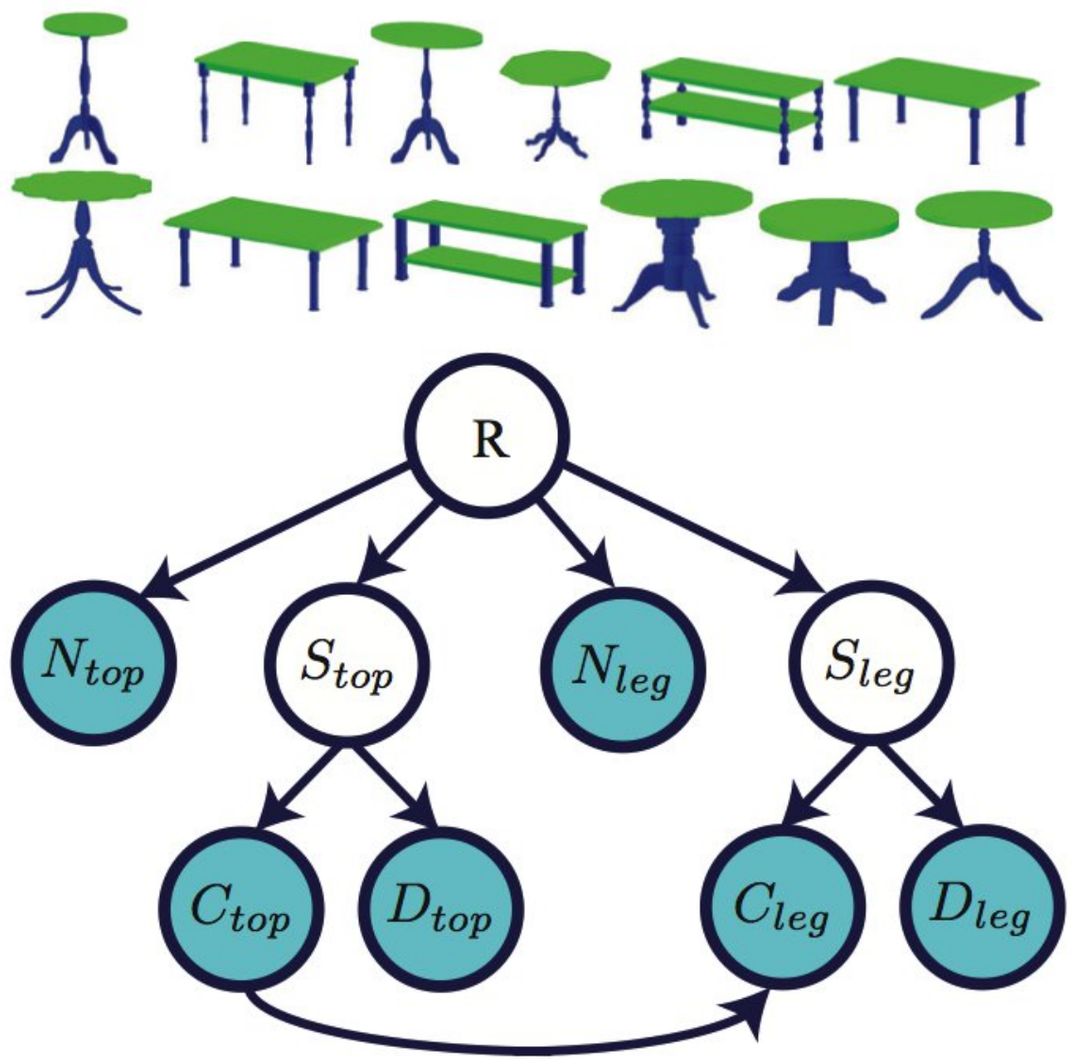
Probabilistic Part Relations

All pairwise & unary probabilities define joint probability



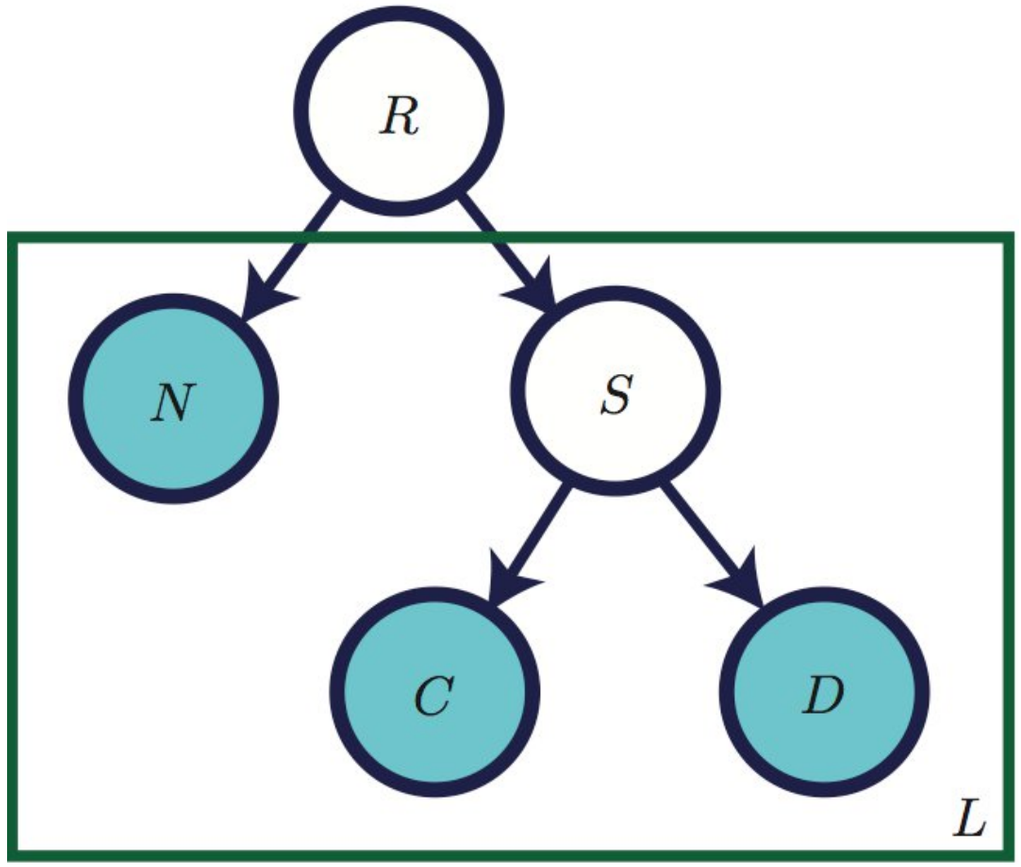
Fish'14

Discrete Probabilistic Part Relations



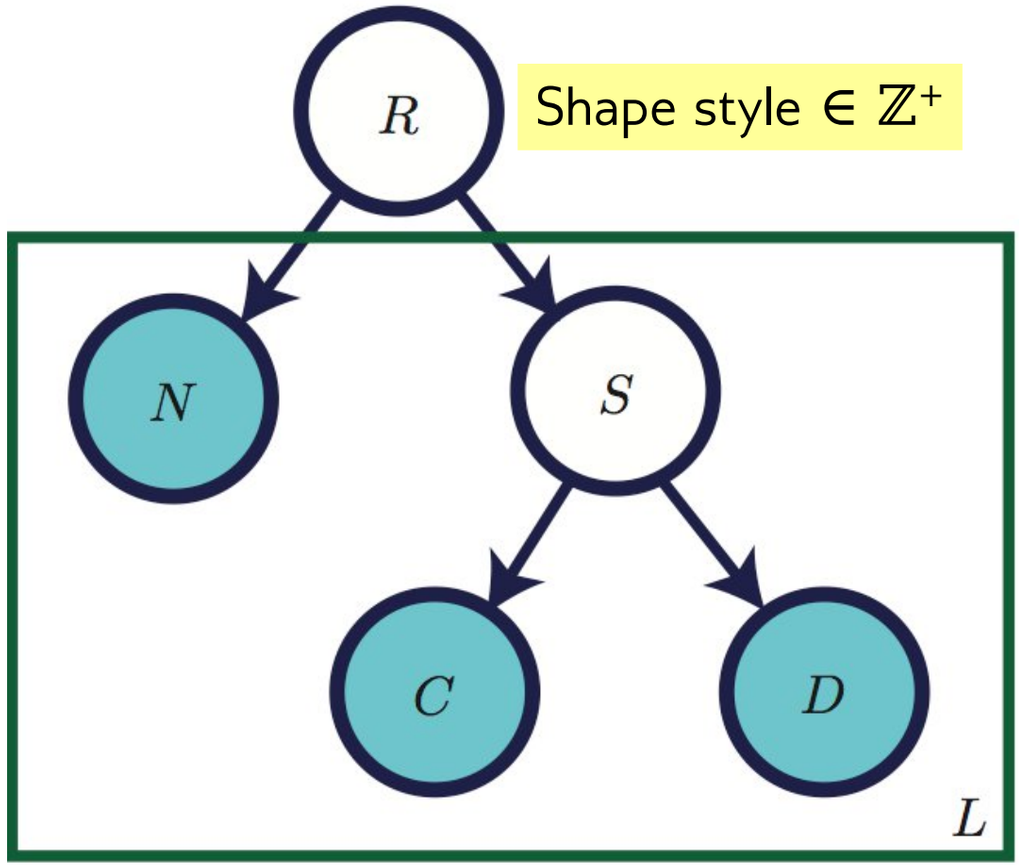
Kalogerakis'12

Discrete Probabilistic Part Relations



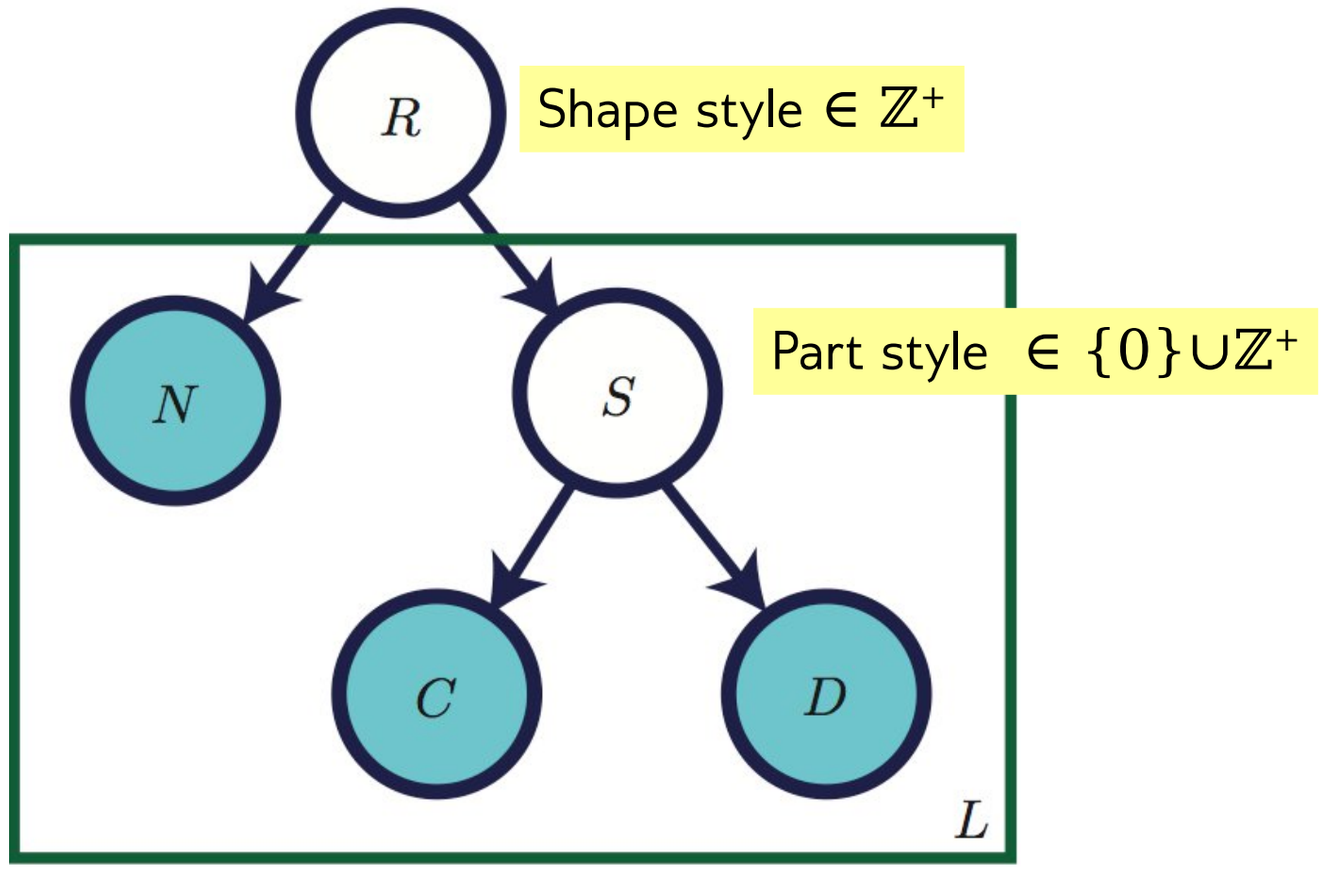
Kalogerakis'12

Discrete Probabilistic Part Relations



Kalogerakis'12

Discrete Probabilistic Part Relations



Kalogerakis'12

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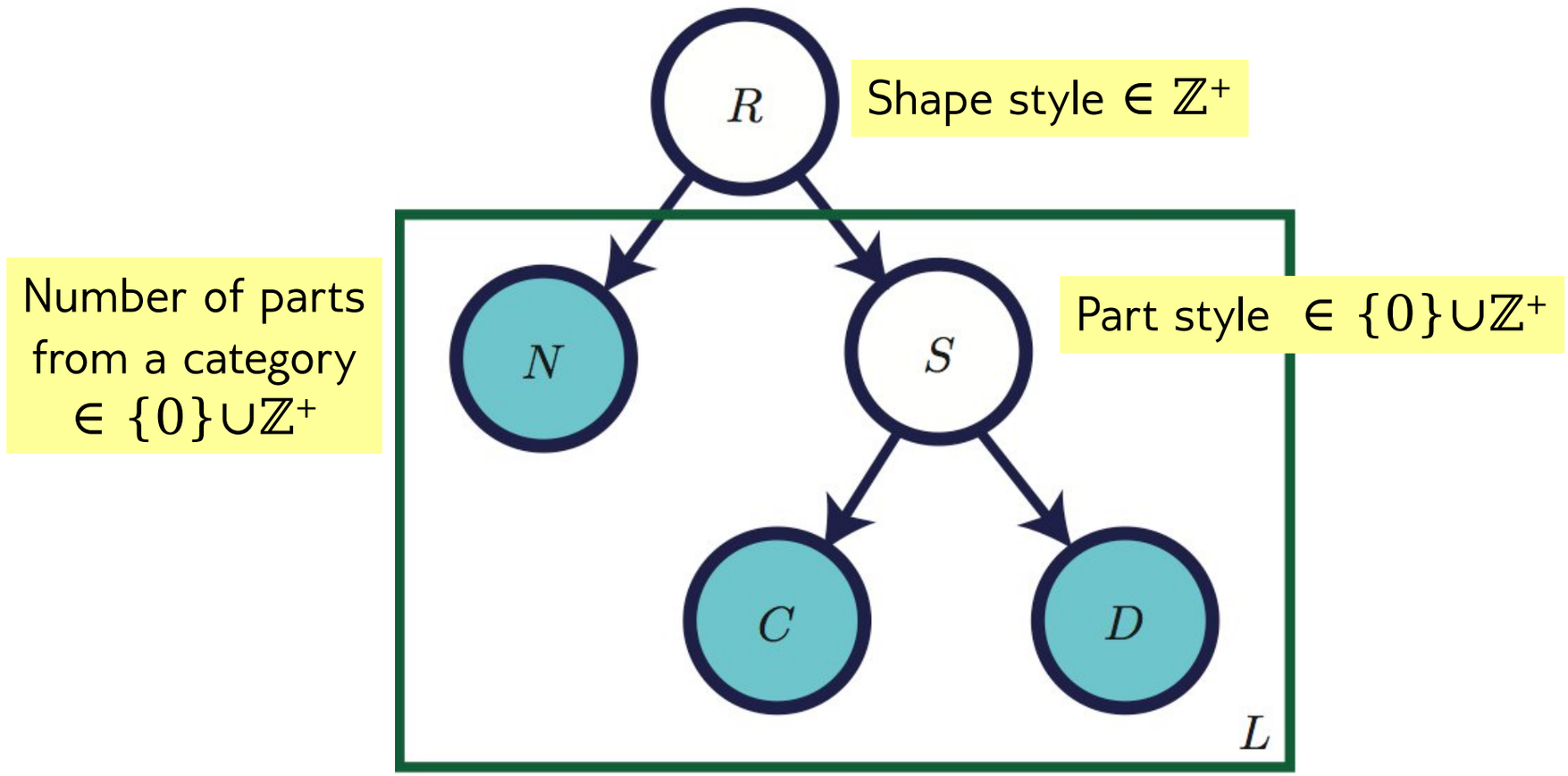
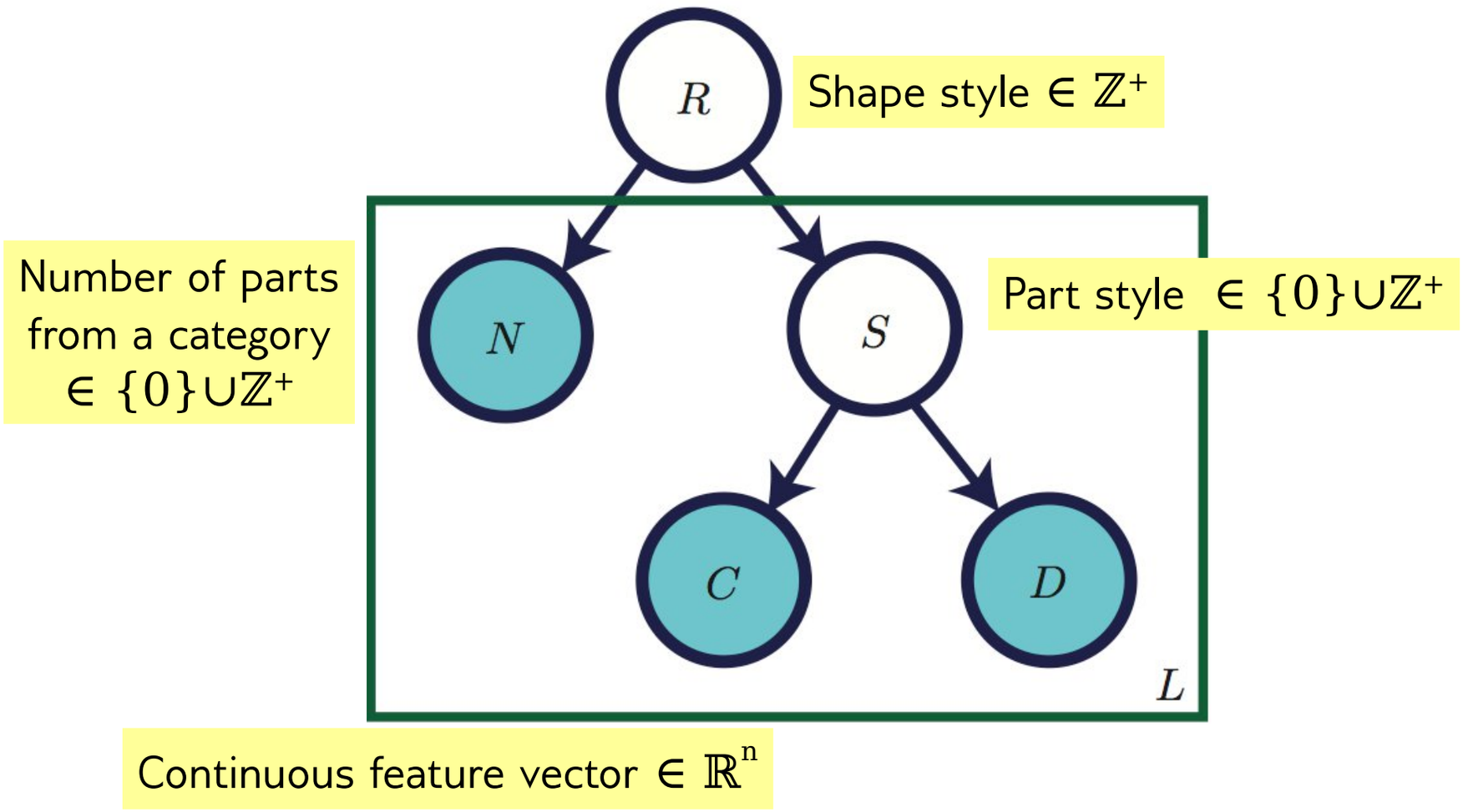


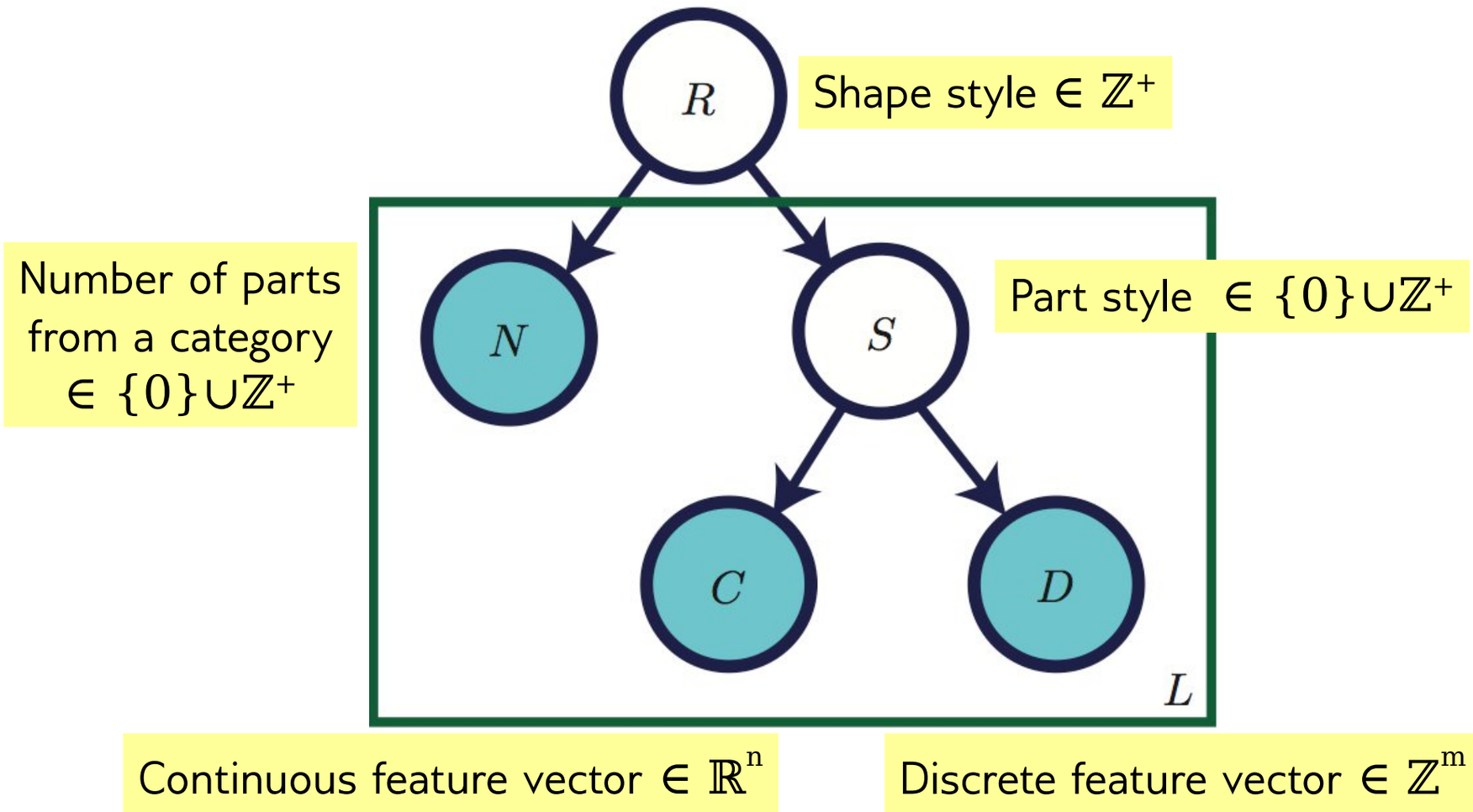
Kalogerakis'12

Discrete Probabilistic Part Relations



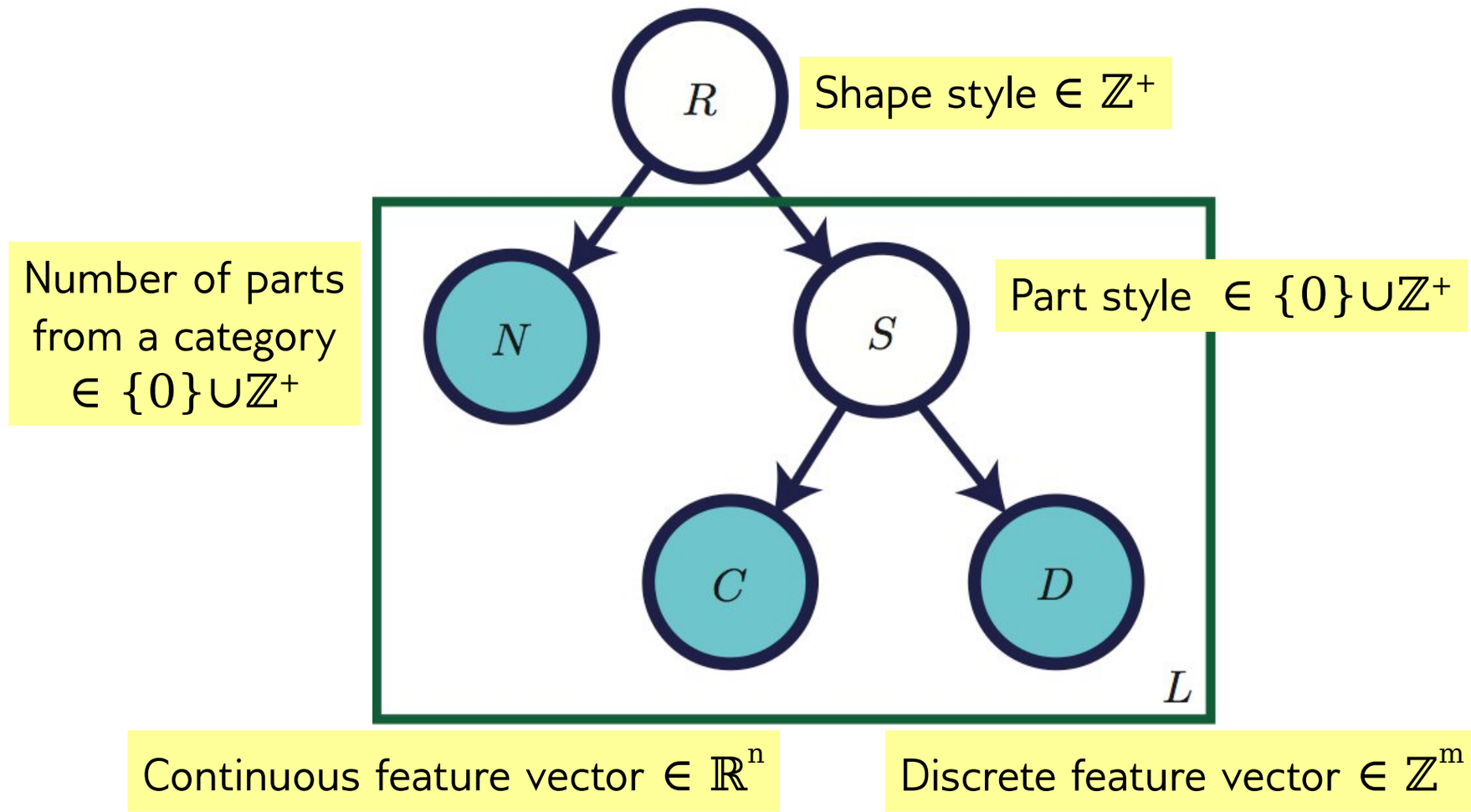
Kalogerakis'12

Discrete Probabilistic Part Relations



Kalogerakis'12

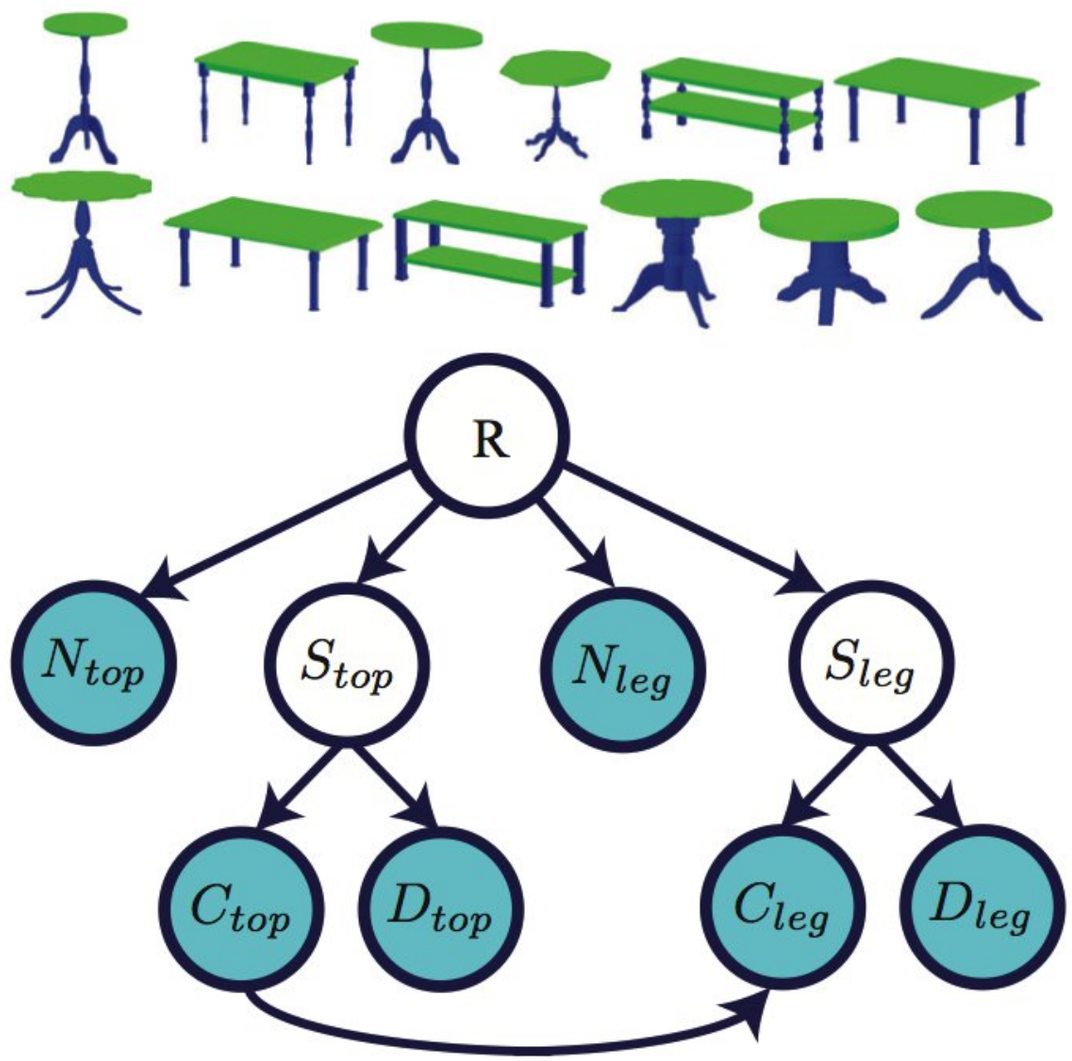
Discrete Probabilistic Part Relations



$$P(\mathbf{X}) = P(R) \prod_{l \in \mathcal{L}} \left[P(S_l \mid R) P(N_l \mid R, \pi(N_l)) P(\mathbf{C}_l \mid S_l, \pi(\mathbf{C}_l)) P(\mathbf{D}_l \mid S_l, \pi(\mathbf{D}_l)) \right]$$

Kalogerakis'12

Discrete Probabilistic Part Relations

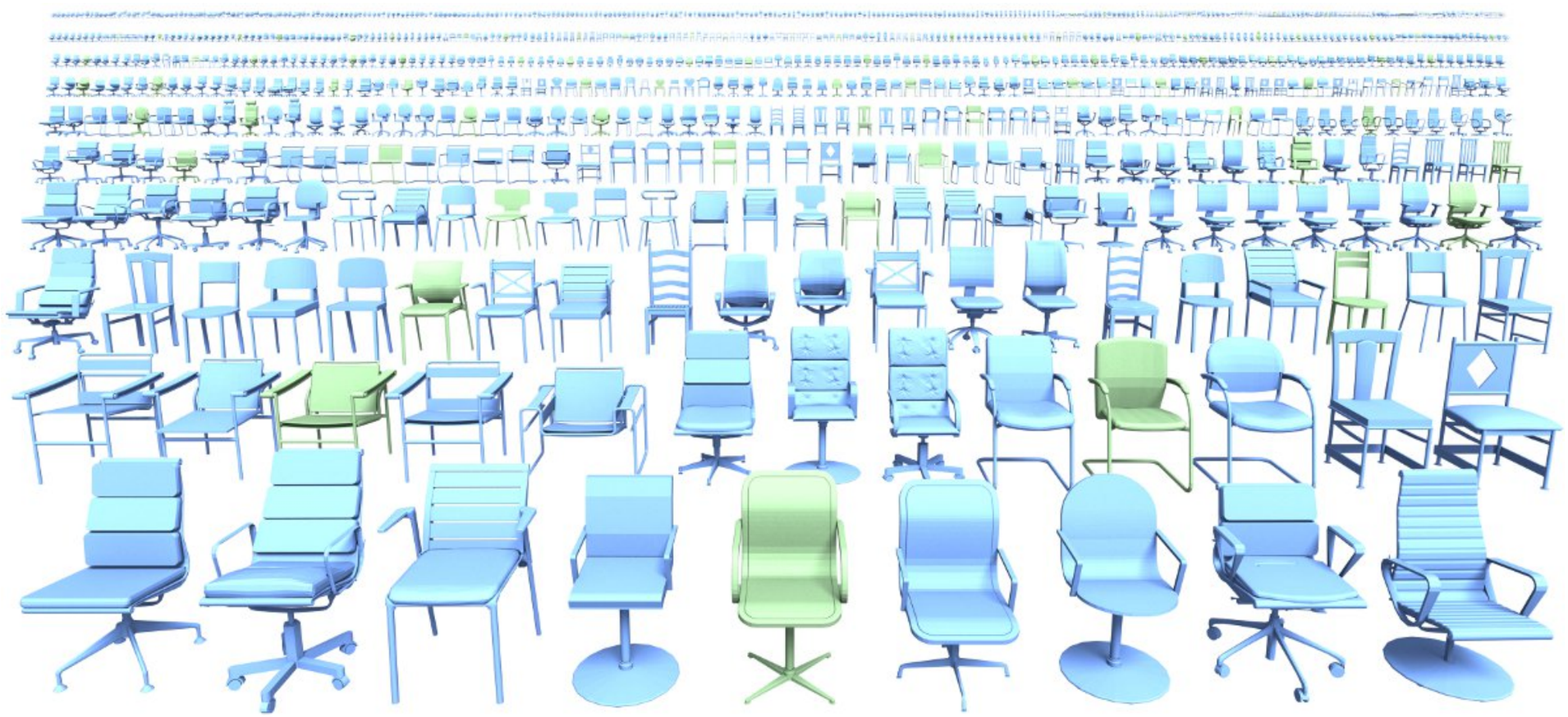


Kalogerakis'12

Shape Synthesis

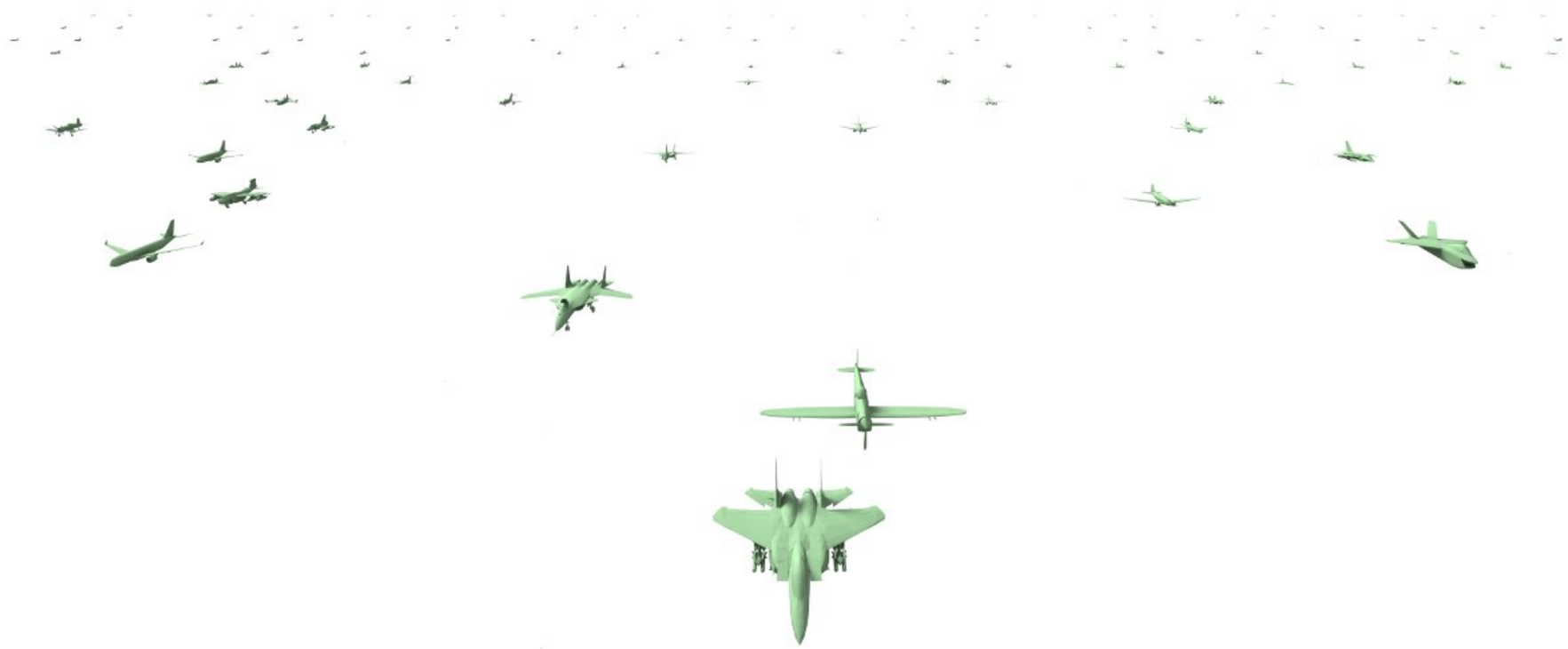
Kalogerakis'12

Shape Synthesis



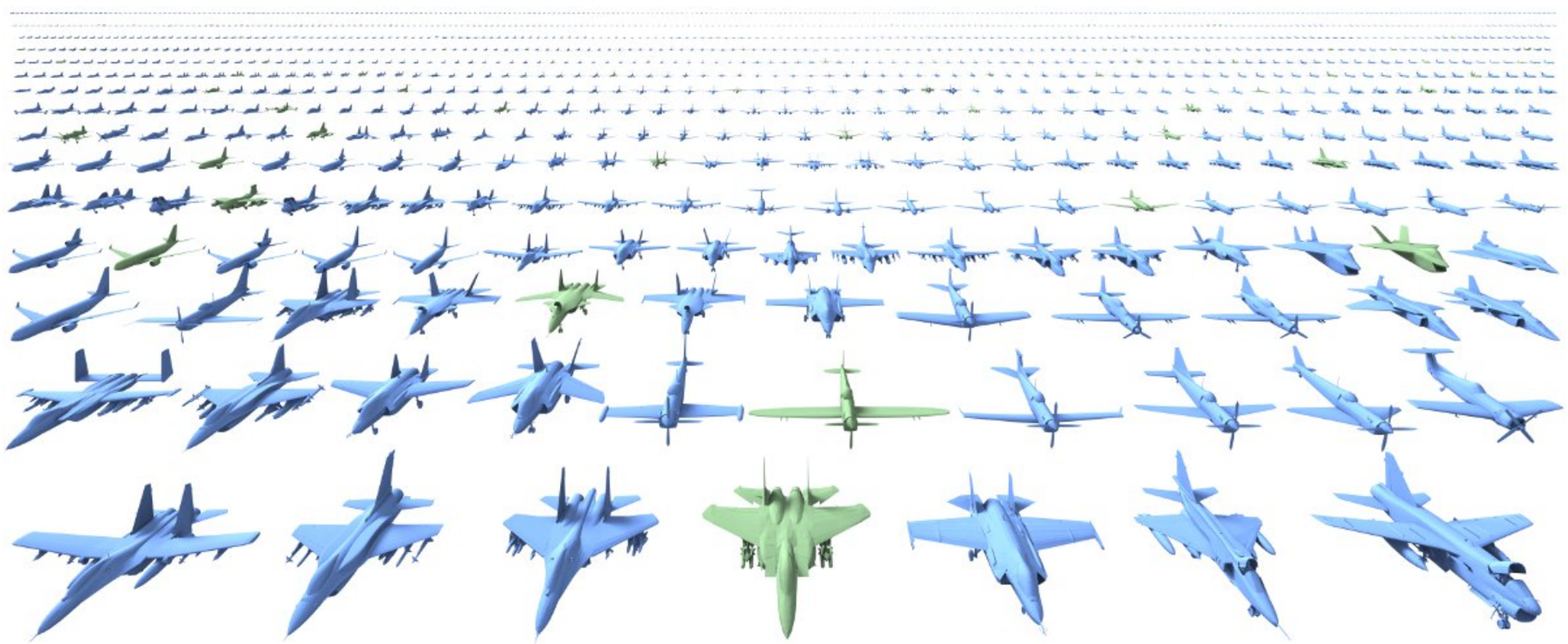
Kalogerakis'12

Shape Synthesis



Kalogerakis'12

Shape Synthesis

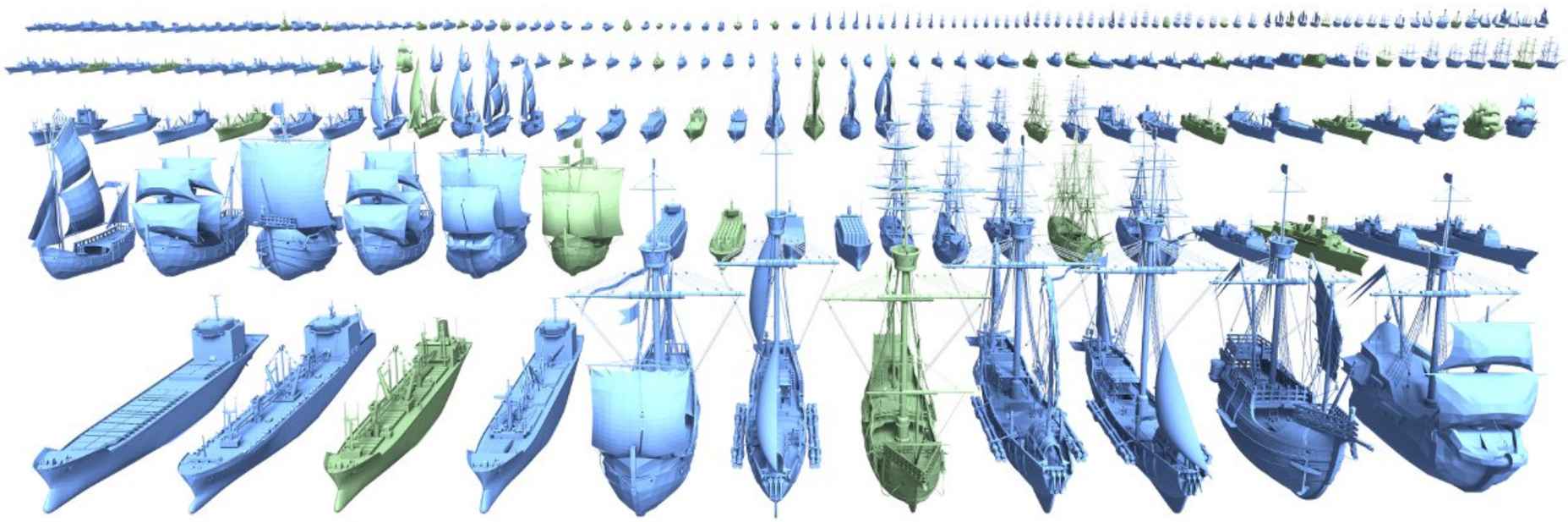


Kalogerakis'12

Shape Synthesis

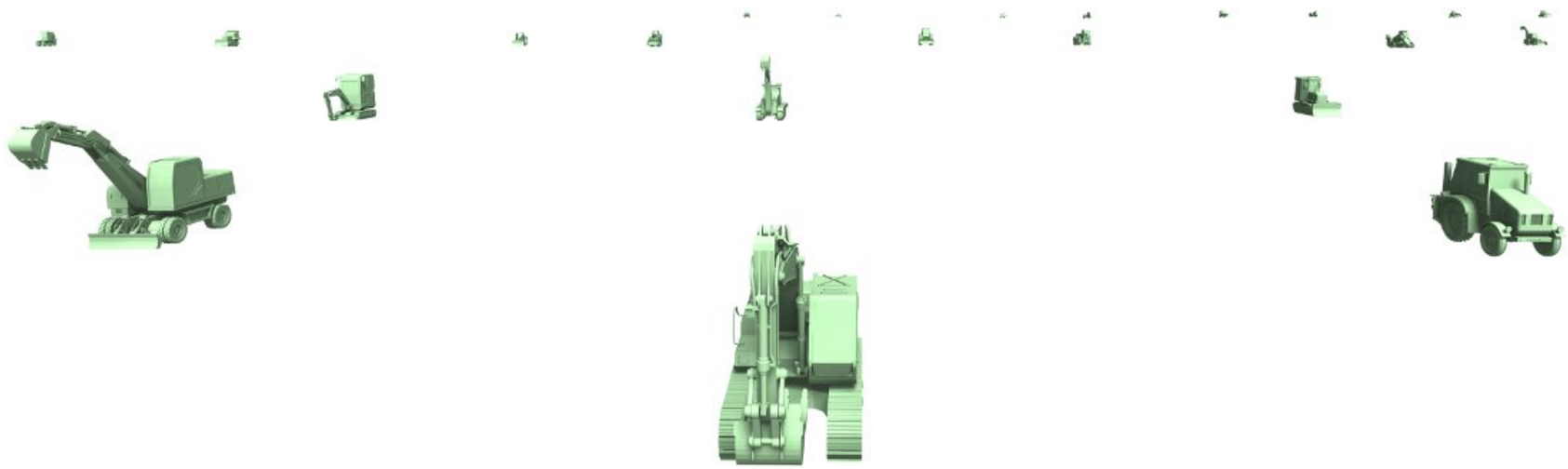
Kalogerakis'12

Shape Synthesis



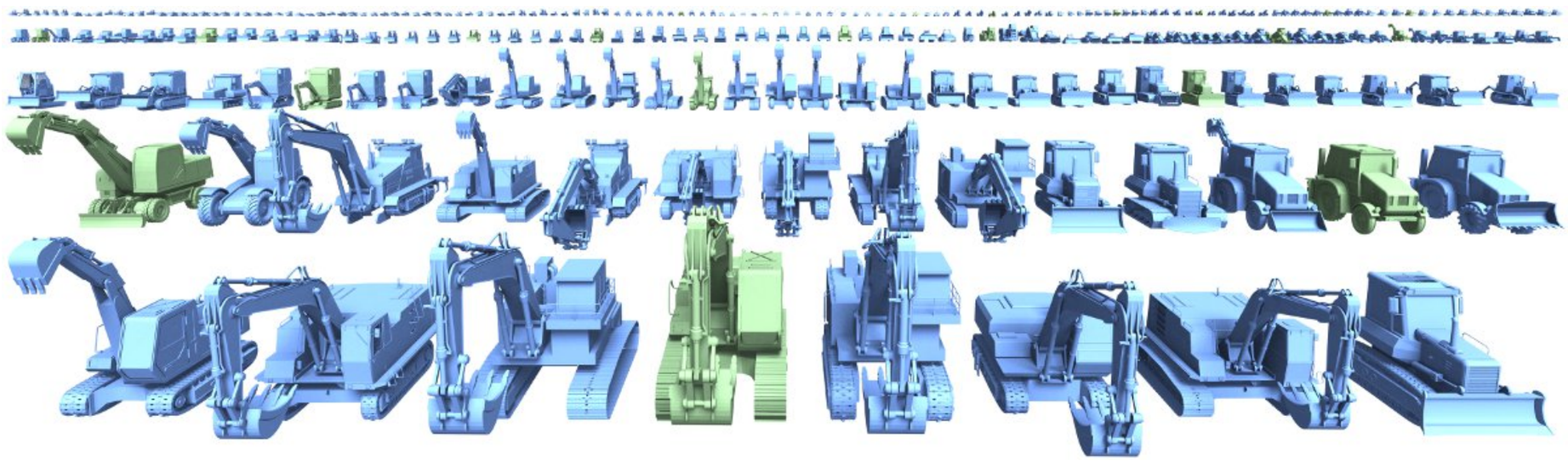
Kalogerakis'12

Shape Synthesis



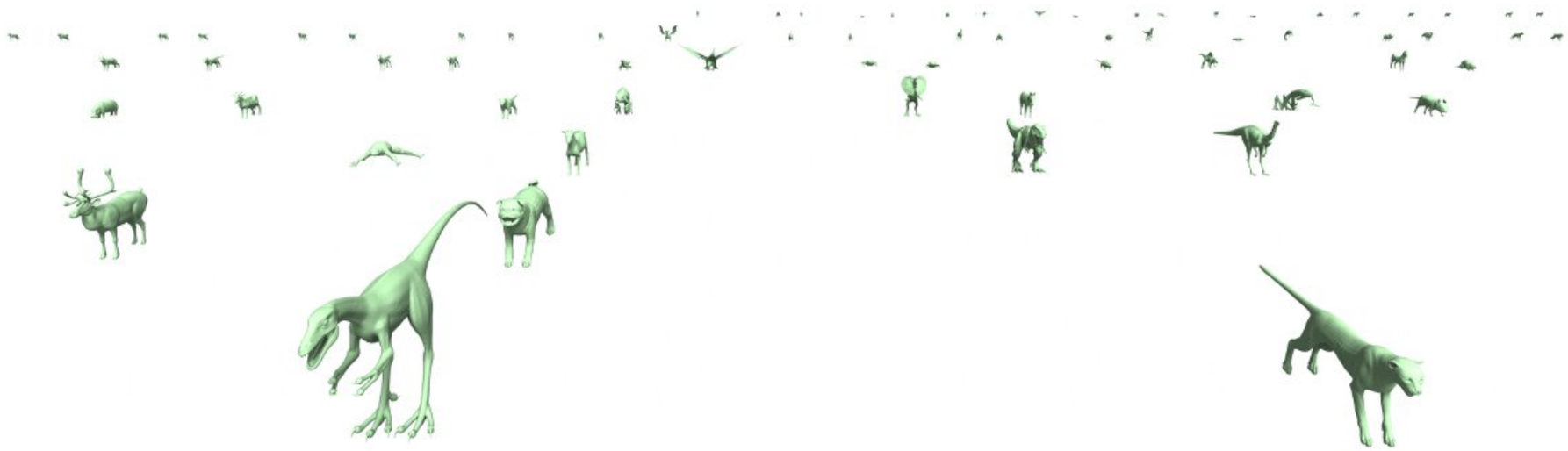
Kalogerakis'12

Shape Synthesis



Kalogerakis'12

Shape Synthesis



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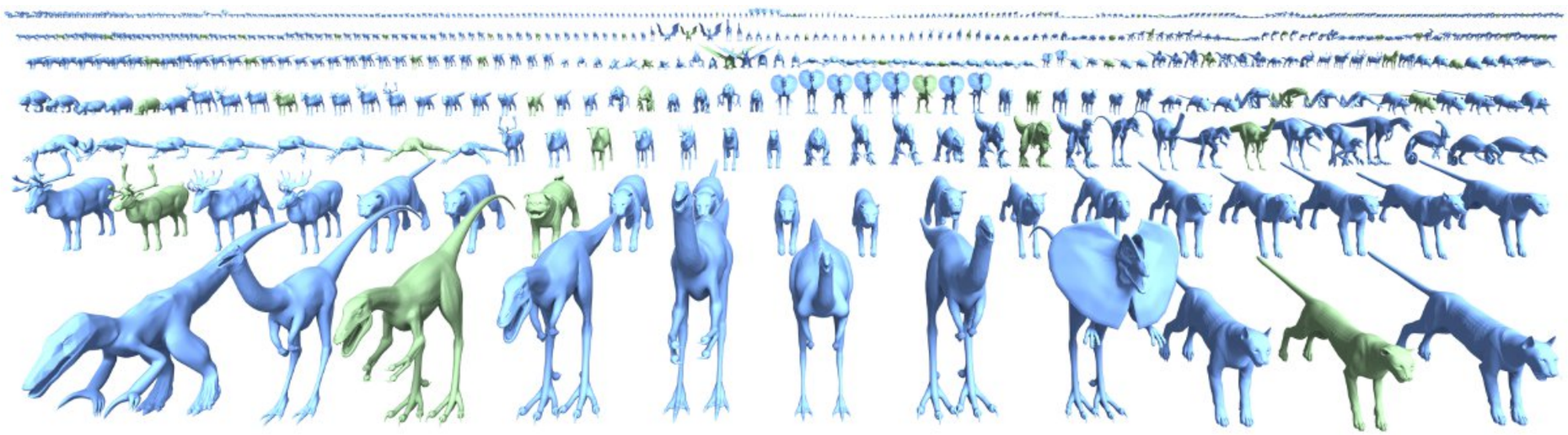
Shape Synthesis



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