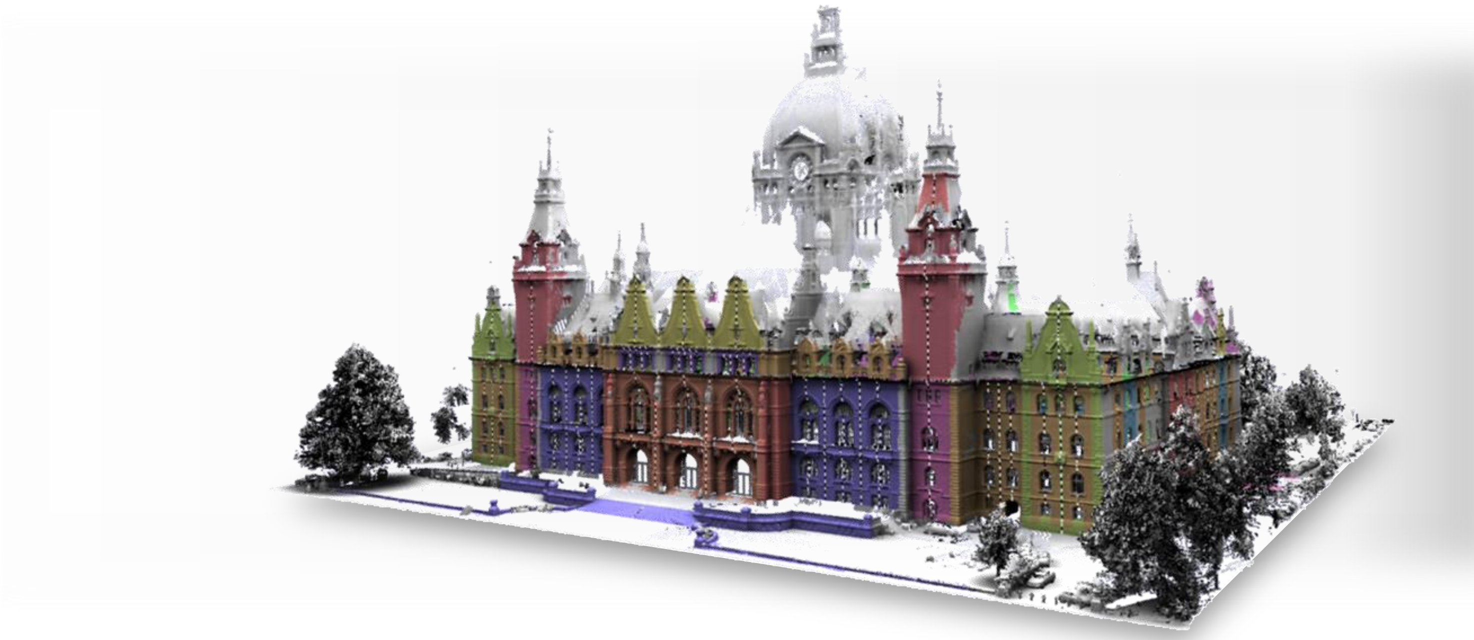
Structure-Aware Shape Processing

Analysis of Individual Models



Niloy J. Mitra — UCL
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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

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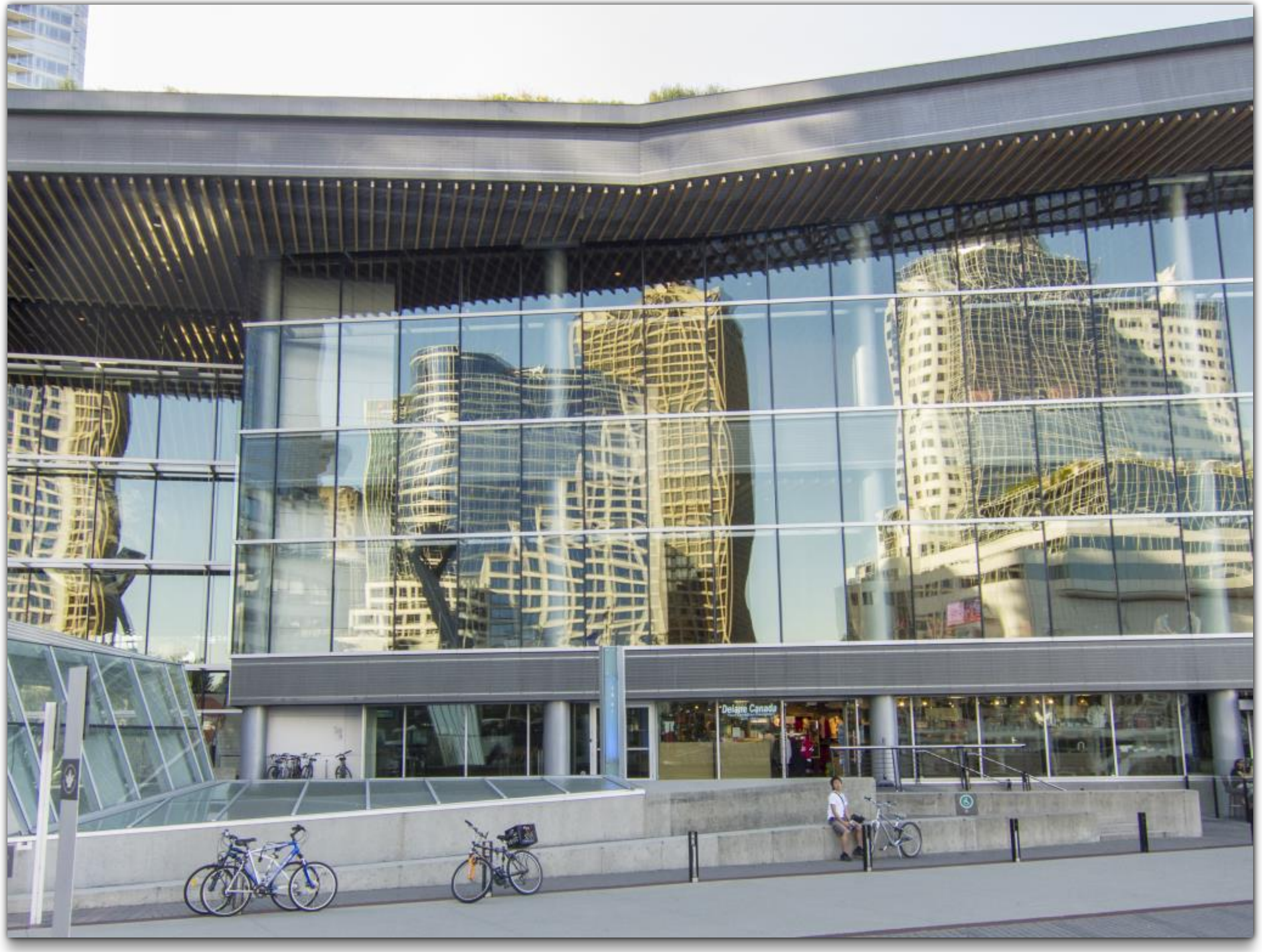
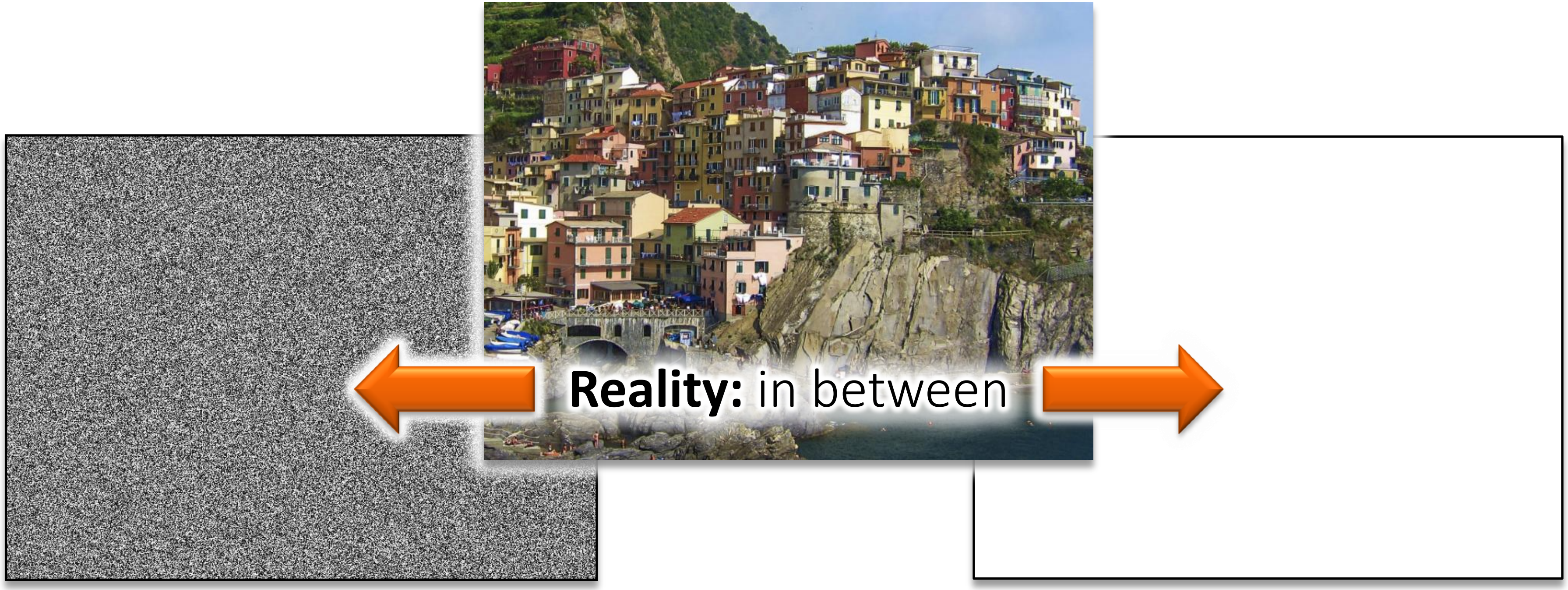


Structure

What is Structure?



No structure

Extremely structured

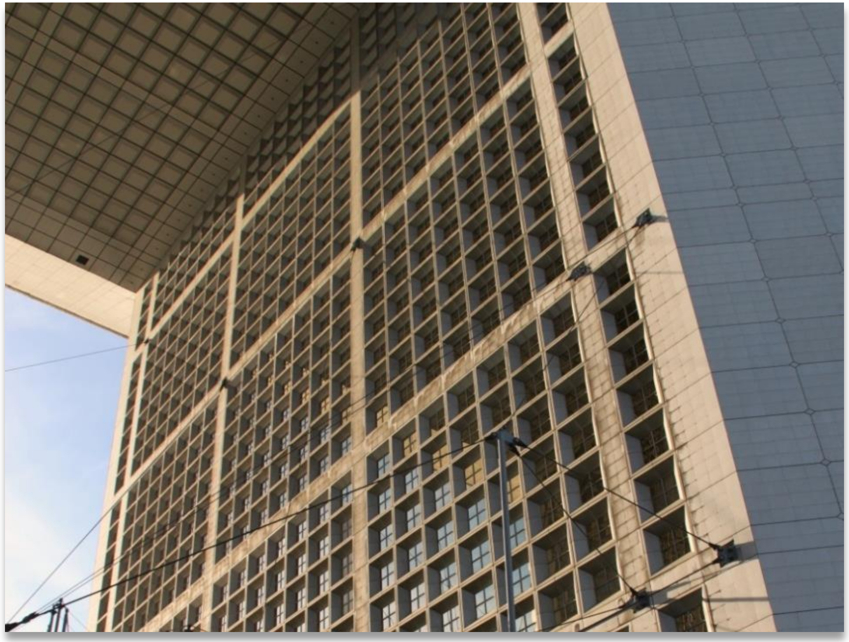
Structure = *redundancy*, *lack of Information*

How to Structure Shapes

Structure detection

- Express a lot of information with less
- More compact encoding
- Compression



Structure Examples

How to Structure Shapes

Structure detection

- Express a lot of information with less

Avoiding overfitting

- “Hard to vary”
- “Significance / generalization”: Enough data to justify model
- (Many) fewer parameters than data

Challenge: Single Models

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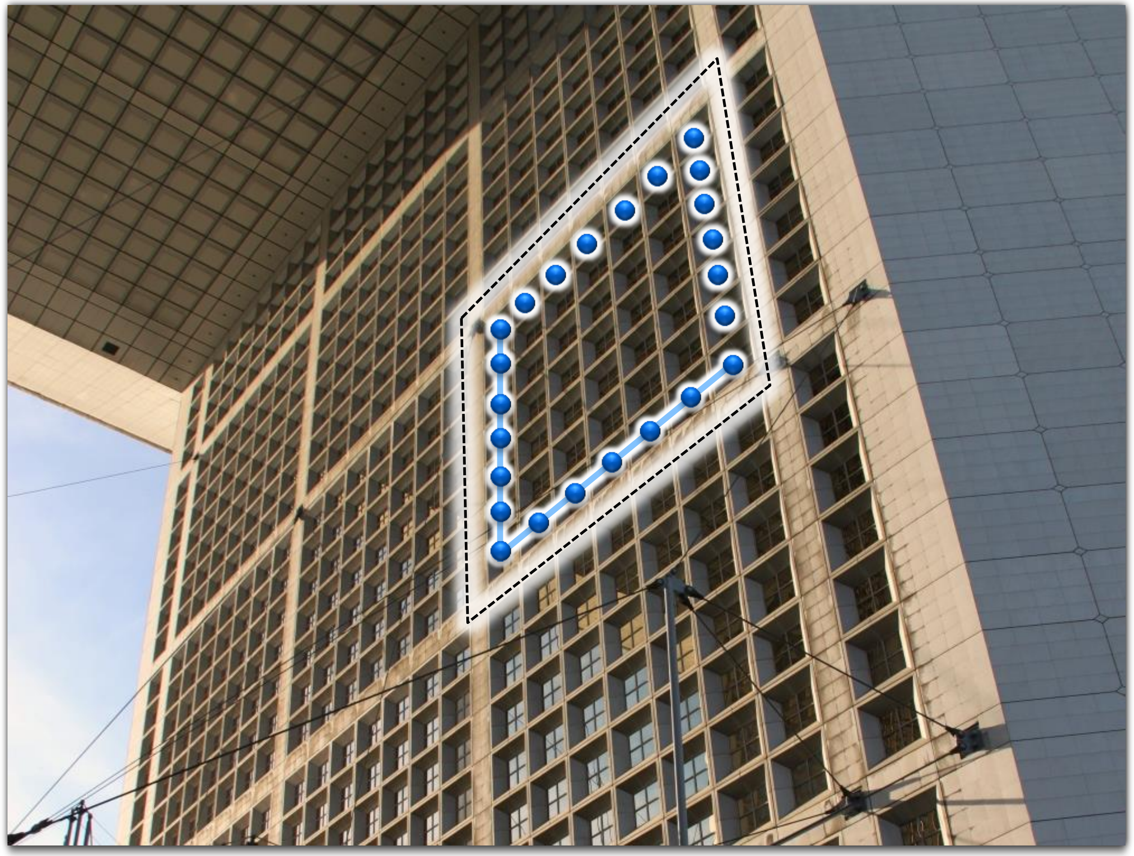
Single model analysis

Challenge

- Limited ability for data-driven learning
- More a priori assumptions



Structure Models

Model Variants

Many different models

- Correspondences & symmetry
- Hierarchy
- Geometric primitives
- Segmentation
- Physical constraints
- Deformation / modal analysis
- …

Model Variants

Many different models

- **Correspondences & symmetry** ← **Focus**
- Hierarchy
- Geometric primitives
- Segmentation
- Physical constraints
- Deformation / modal analysis
- ...

Model Variants

Many different models

- Correspondences & symmetry
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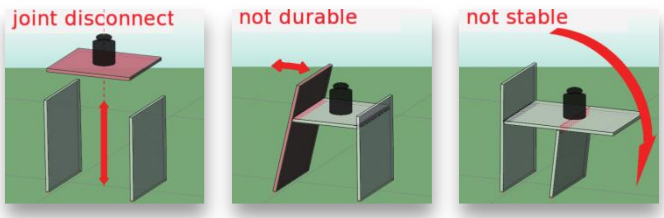
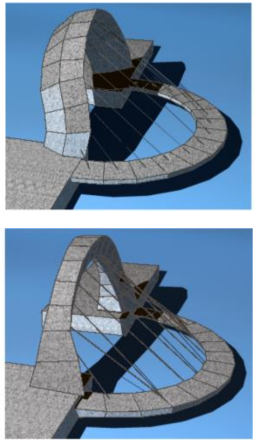
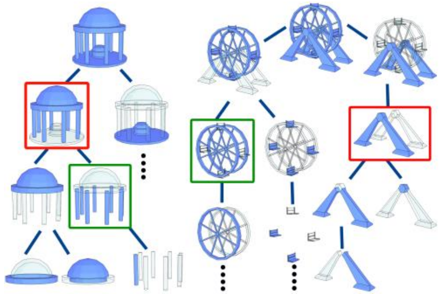
- ...



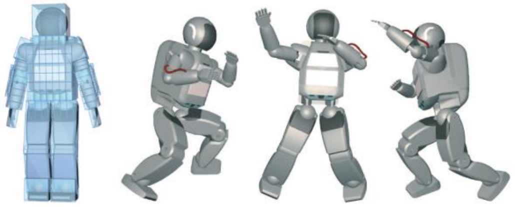
[Umetani et al. 2011]



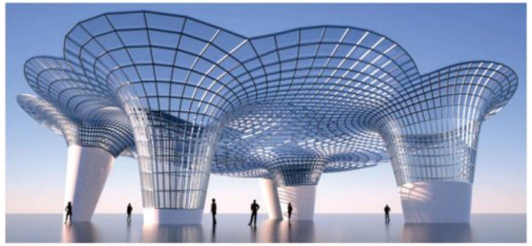
[Whiting et al. 2011]



[Wang et al. 2011]



[Xu et al. 2009]



[Yang et al. 2011]

more later...

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Correspondences & Symmetry

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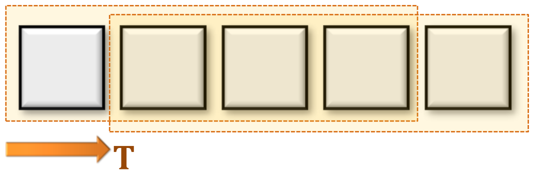
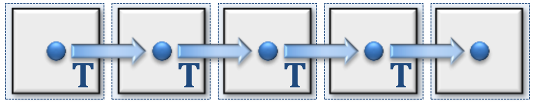
Compositional Models

Agenda

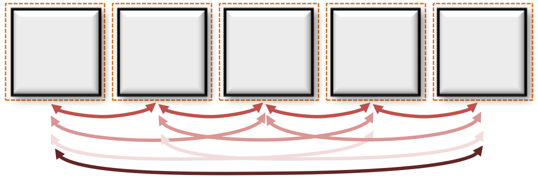
- Correspondences



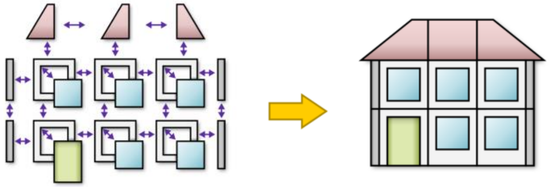
- Symmetry & regularity



- Partial symmetry & building blocks



- Inverse procedural modeling



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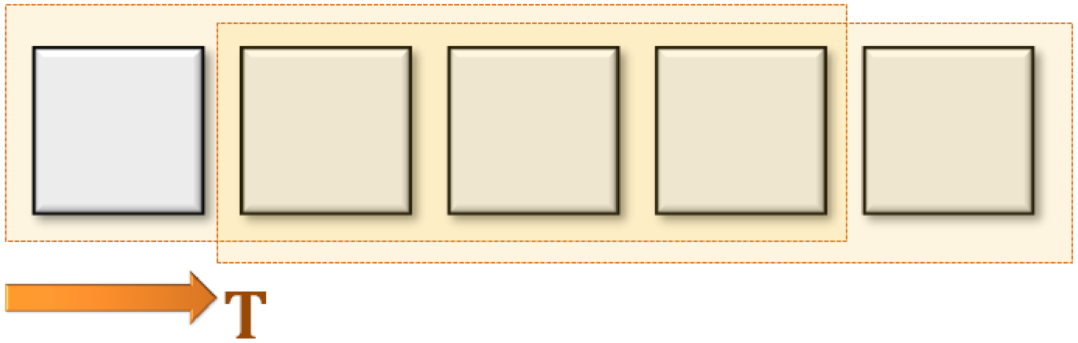
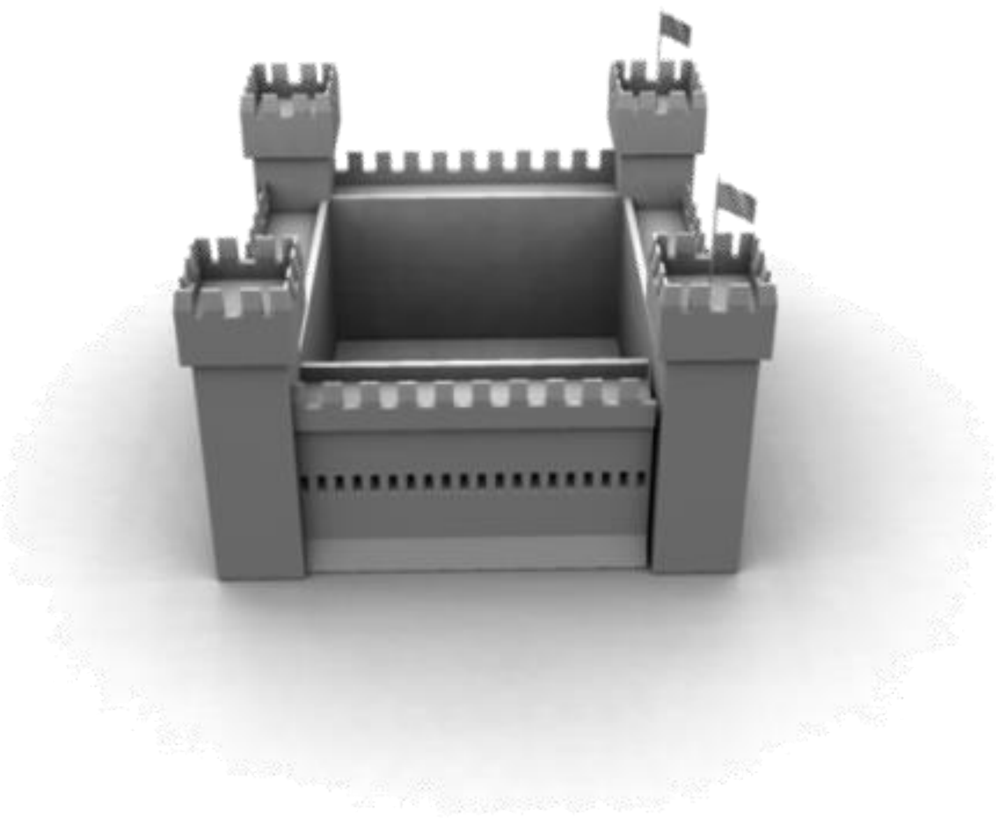
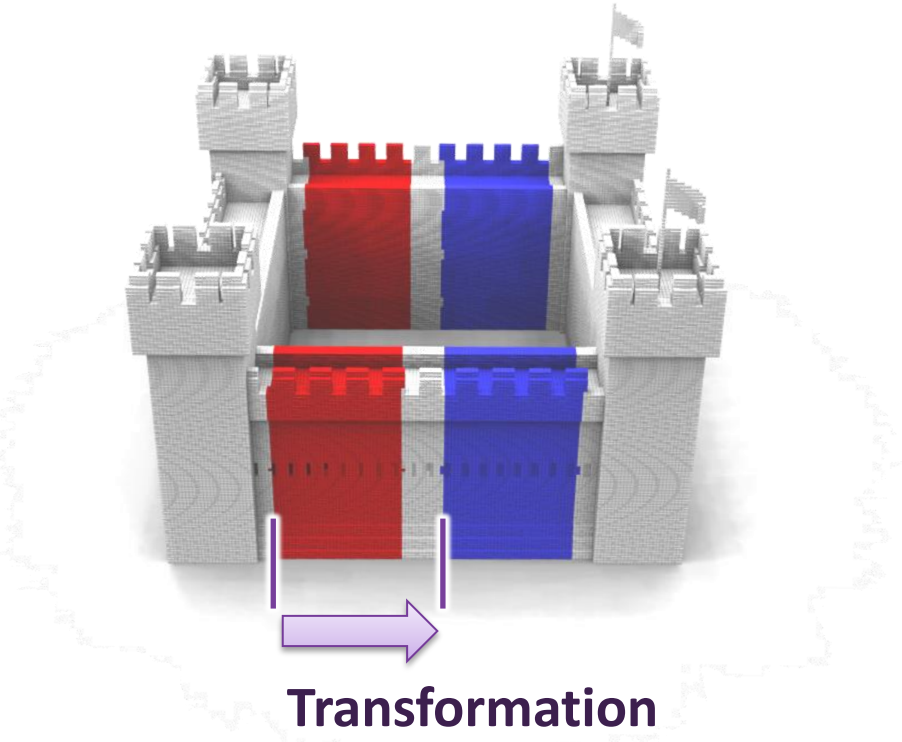


Correspondences

Correspondences



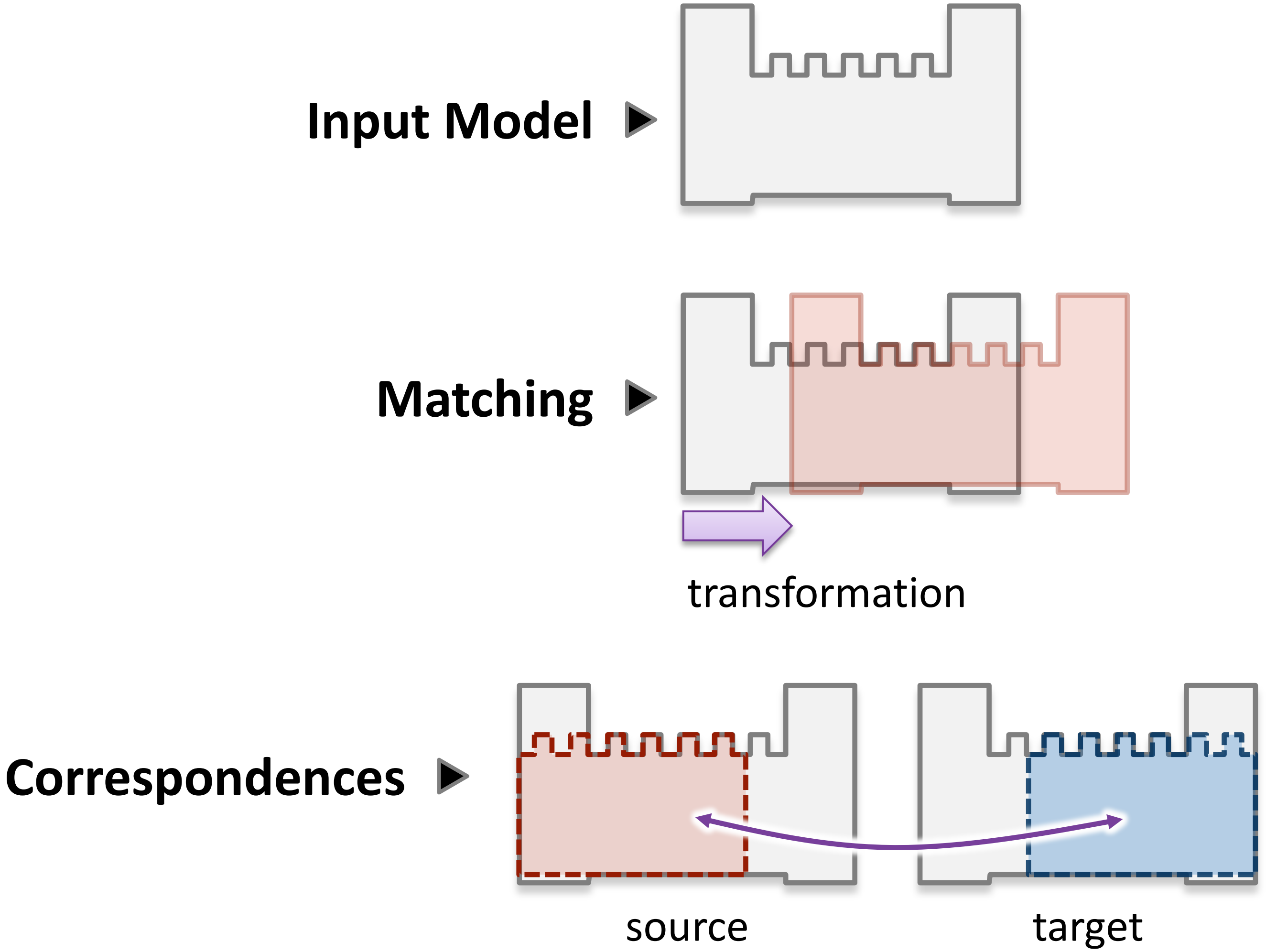


How to Compute?

Correspondences

- Apply transformation
- Report matching area

Links model subsets via transformation



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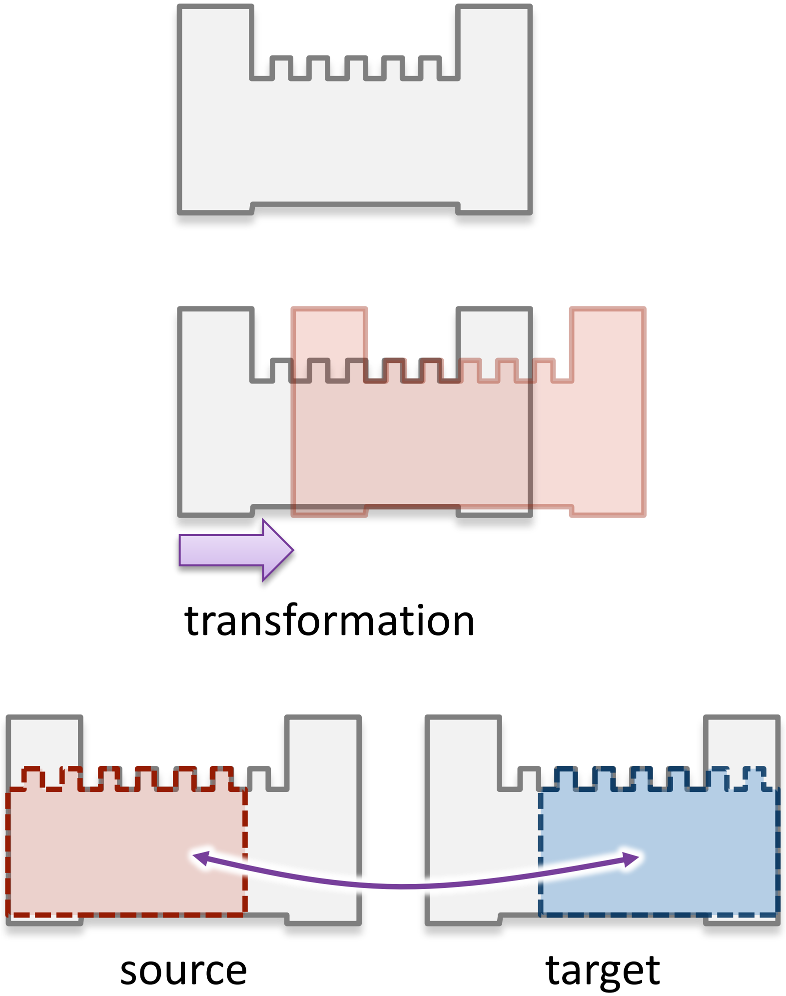
How to Compute?

Which transformations?

- Fix group of transformations
  - Rigid mappings (6/3 DOF)
  - Similarity transforms (7/4 DOF)
  - Isometries (6/3 DOF)
- Restricitive prior assumptions
  - Single model: few parameters
  - Shape collections will permit learning



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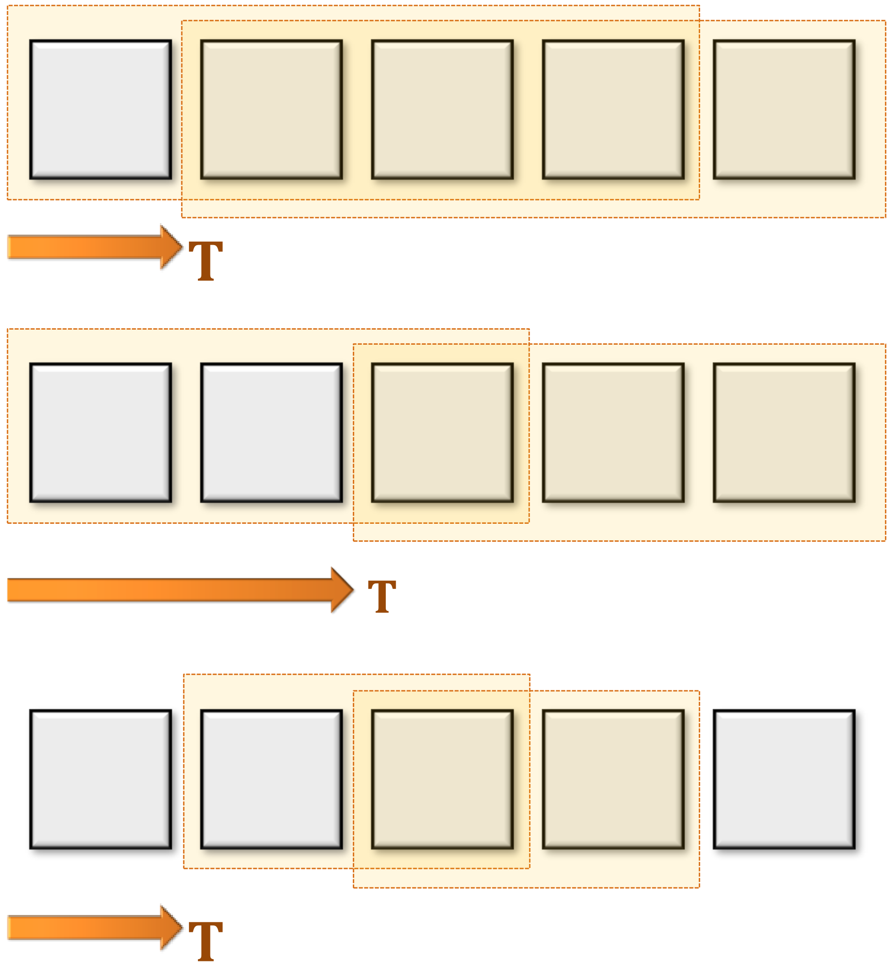
Structure?

Pairwise Correspondences



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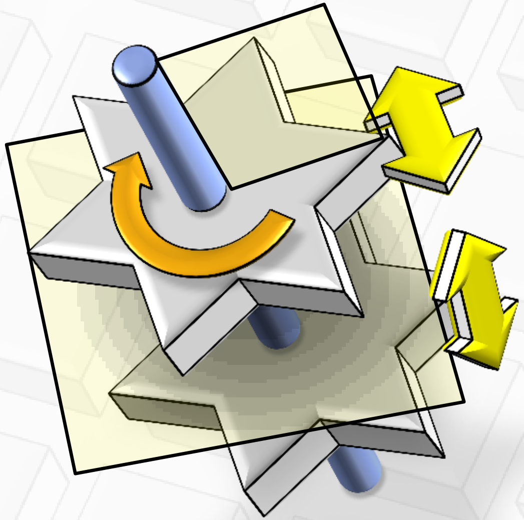

Symmetry

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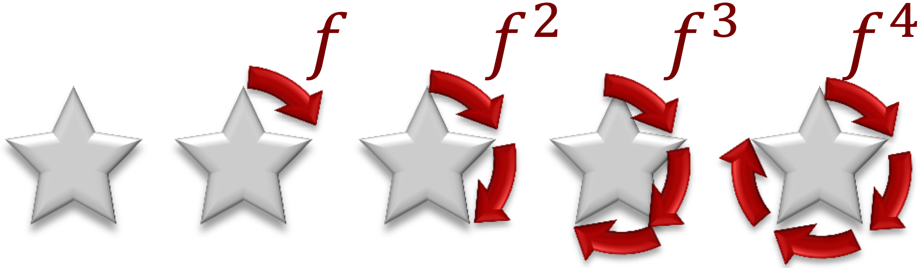
Symmetry

What is symmetry?

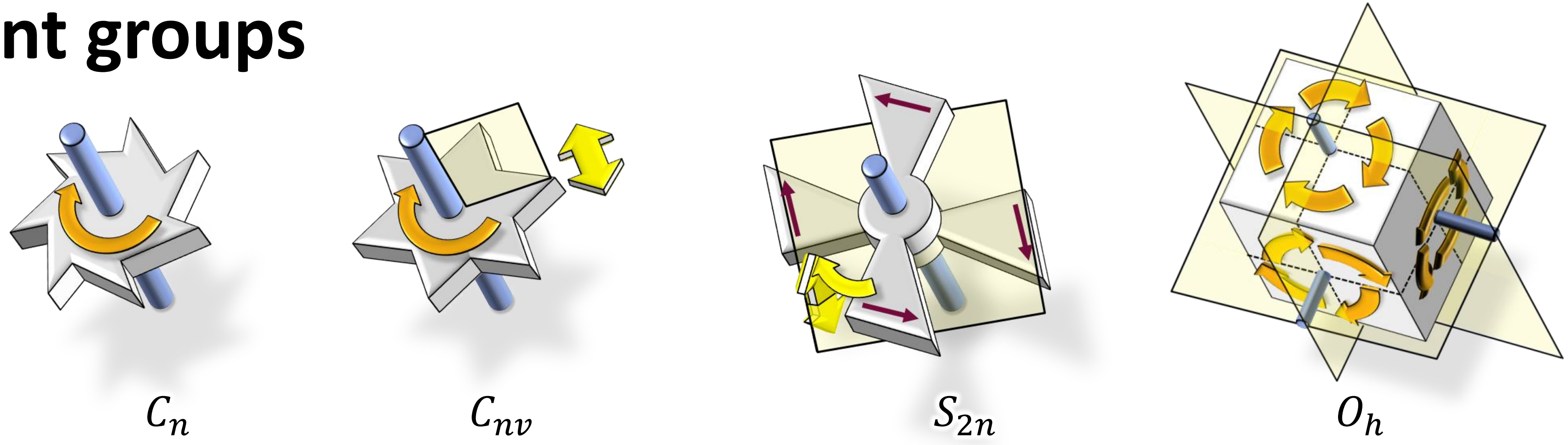
- Operations leave shape X intact
  - $f(X) = X$
- *Set of all such* operations forms a group



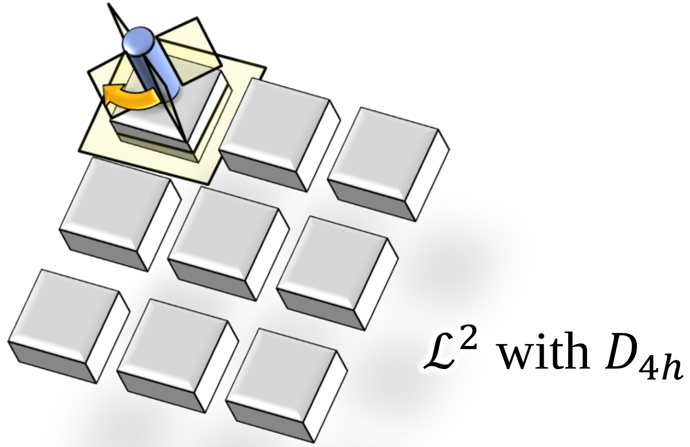
- Encodes absence of information

Euclidean Symmetry Groups

Point groups

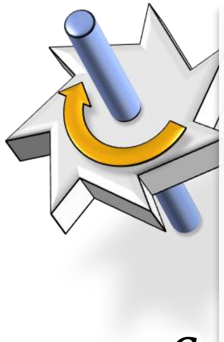


(Crystallographic) lattices

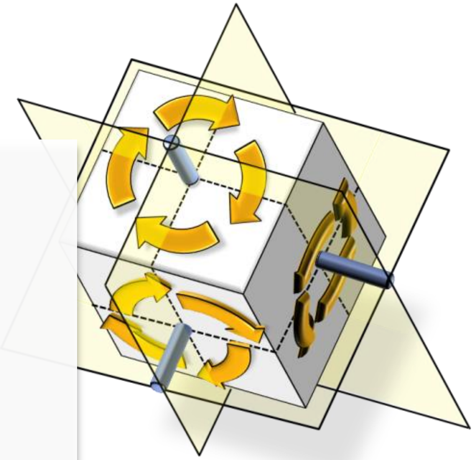


Euclidean Symmetry Groups

Point groups



C_n



O_h

(Crystallo

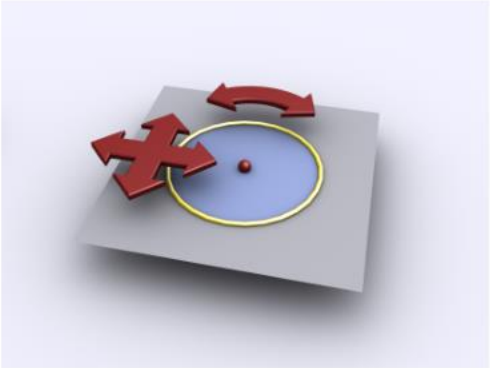
Transformation:
Set of all products of few generator transformations

Rigid symmetry groups:
Structure classification known

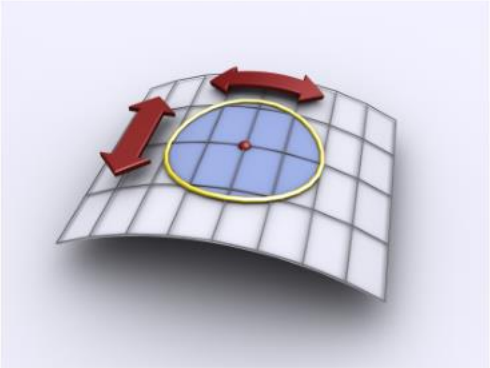
$\mathcal{L}^2$ with D_{4h}

Continuous Symmetry

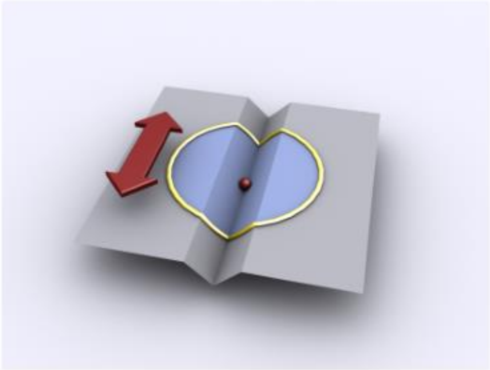
spherical



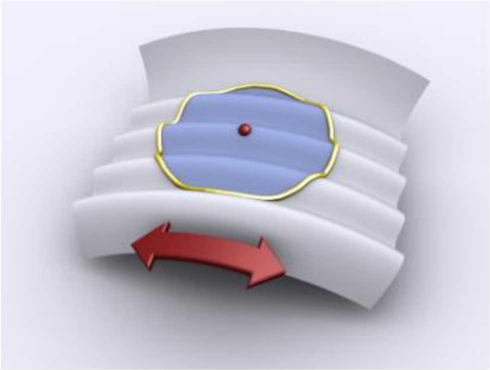
planar



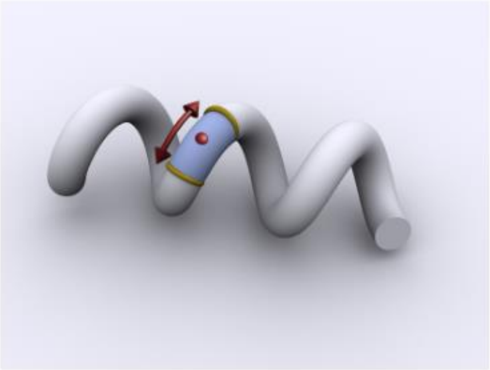
cylindrical



linear extrusion



surface of revolution



helical

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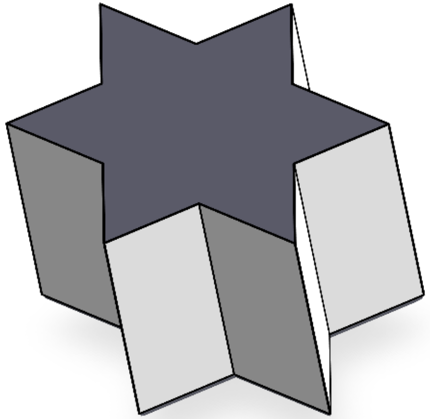
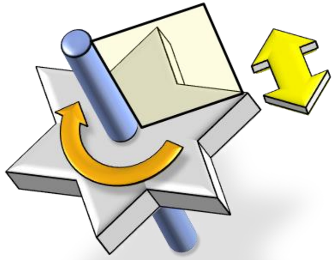
Combinations



C_{nv} + **extrusion**

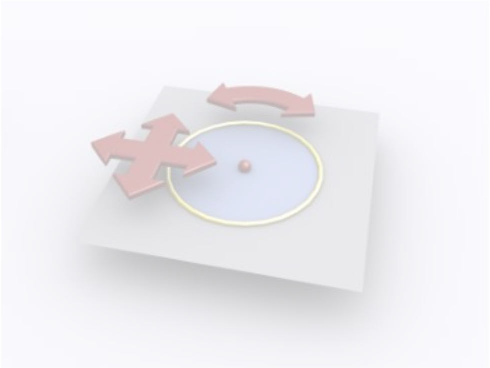
=



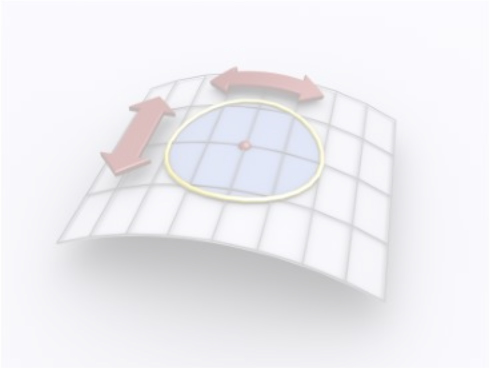
C_{nv}

+

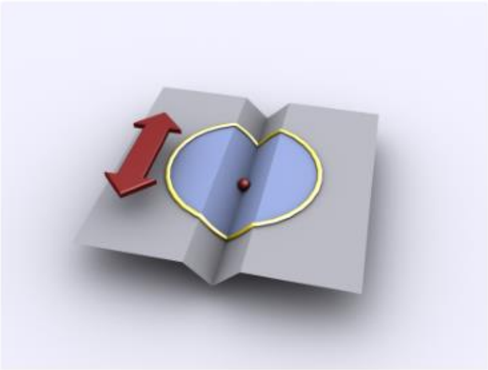
spherical



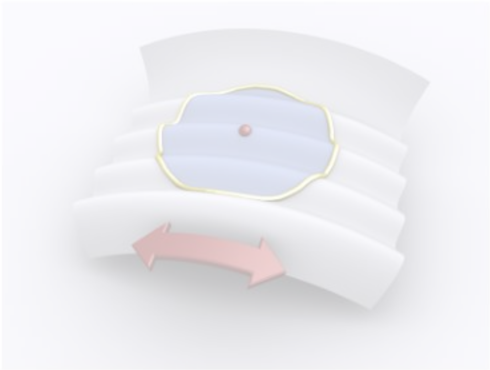
planar



cylindrical



linear extrusion



surface of revolution

helical

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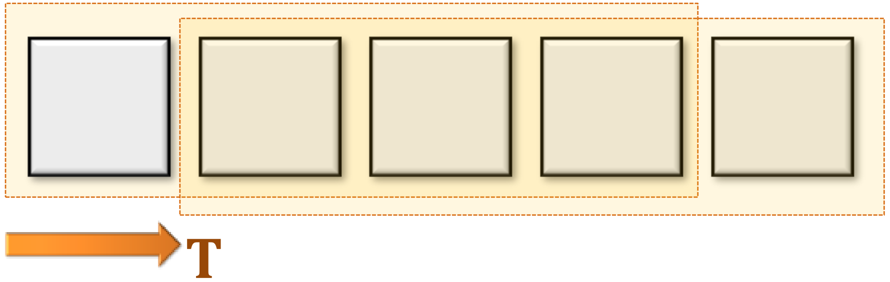
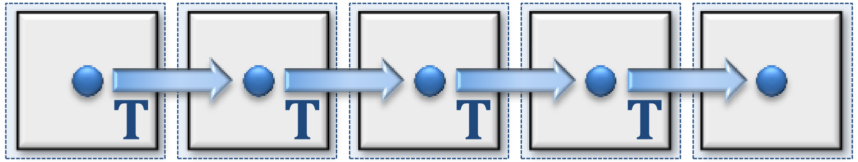
Symmetry structure

Pairwise correspondences



Pairwise matches

Global symmetry: Transformation groups



Regular transformations

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Symmetry Groups

Classic notion of symmetry

- Group of *transformations*
- Acting globally on the *complete shape*
- Global property

More complex structure?

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Solution #1: (Partial) Regularity Graphs

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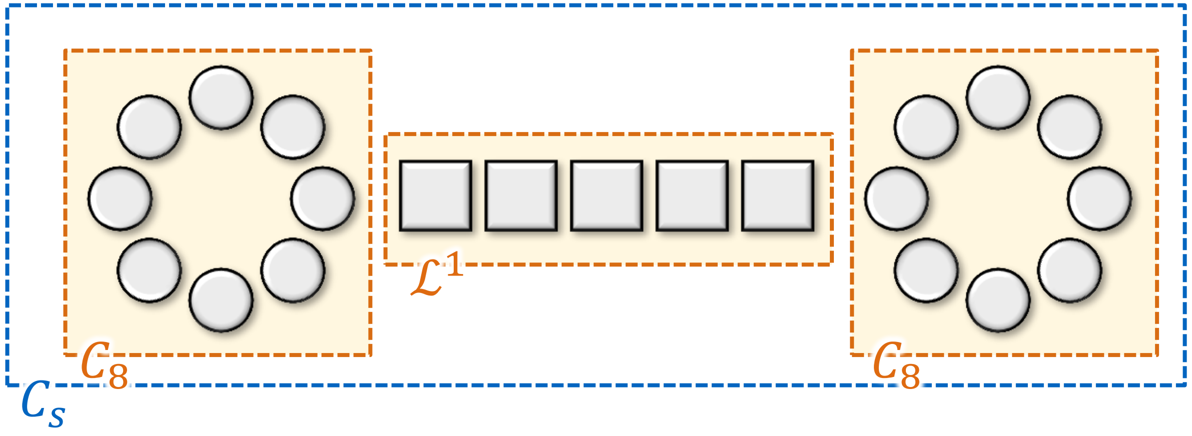
Regularity Graphs

Partial regularity

- Regular subset
- Allow excerpts of groups

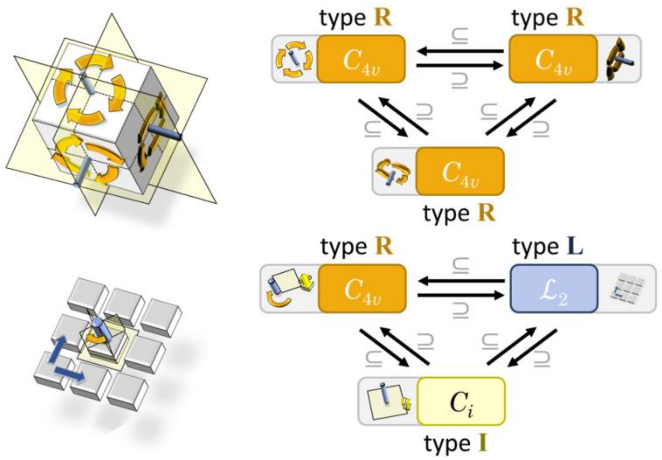


Encoding

- Regularity graphs

Limitation

- Still requires regular placement
- No natural hierarchy



[Tevs et al. 2014]

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Solution #2: Building Blocks

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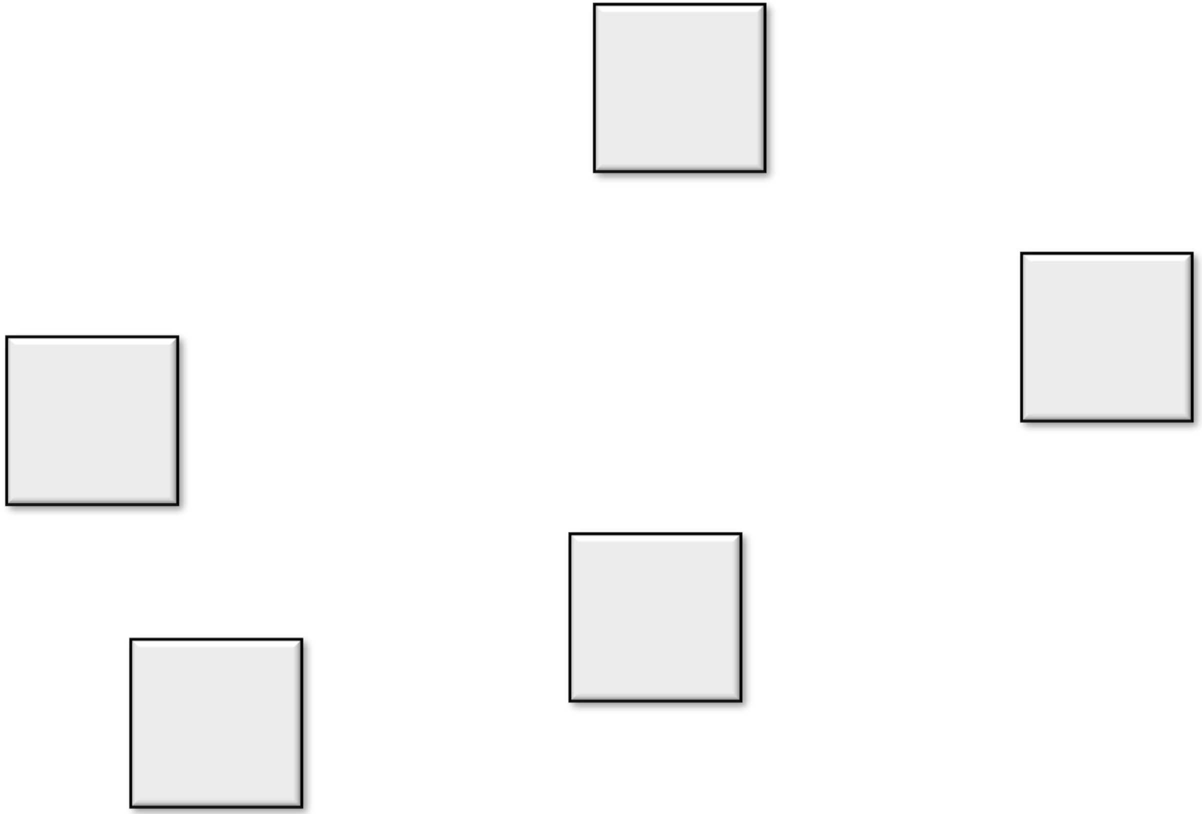
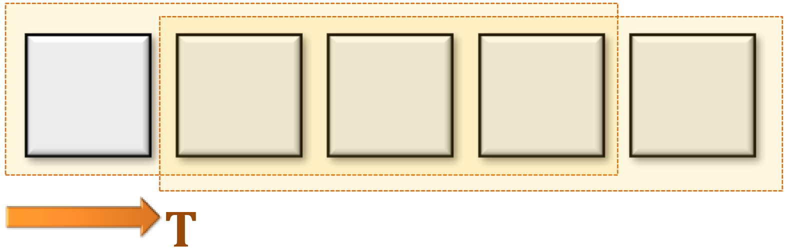
Structure?

Structure?



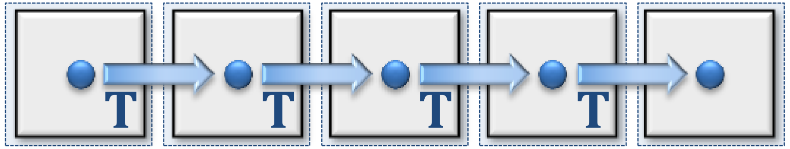
Symmetry Structure

Pairwise correspondences



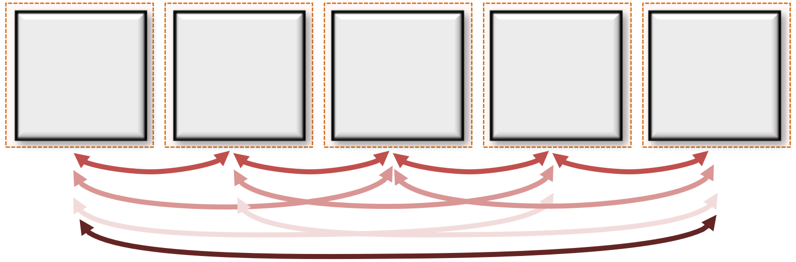
Pairwise matches

Global symmetry: Transformation groups



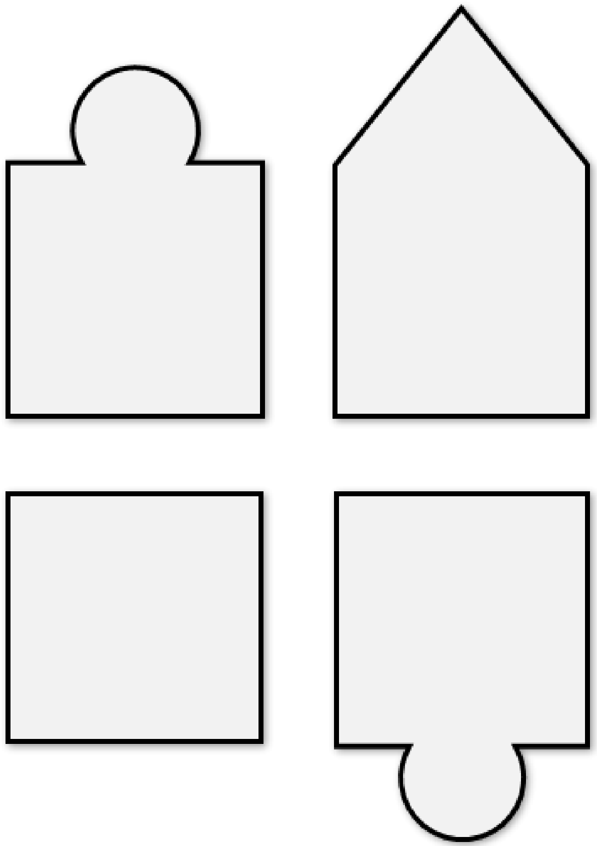
Regular transformations

Partial symmetry: Permutation groups



Building blocks

Example scene



“input”

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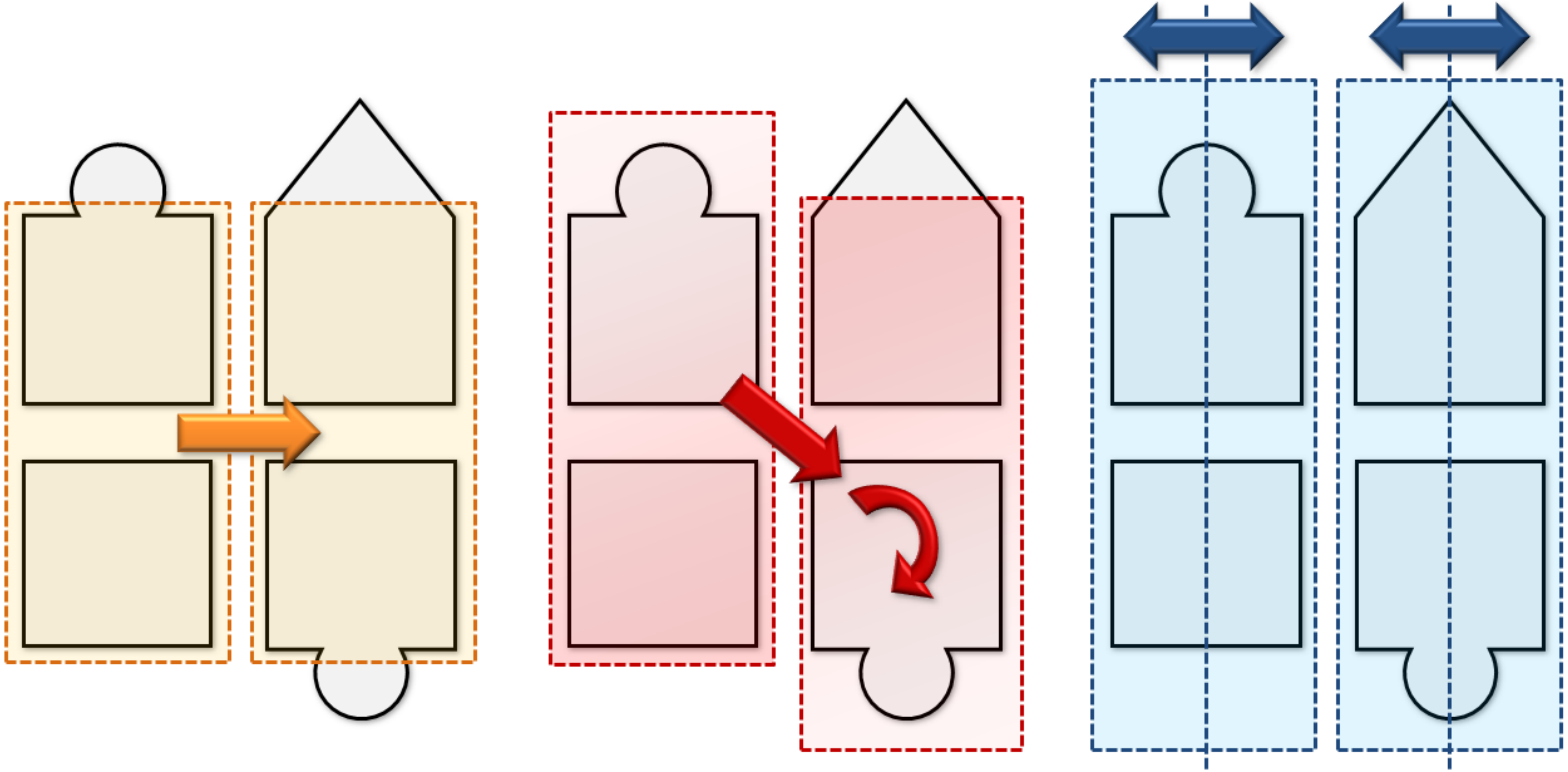
Pairwise correspondences



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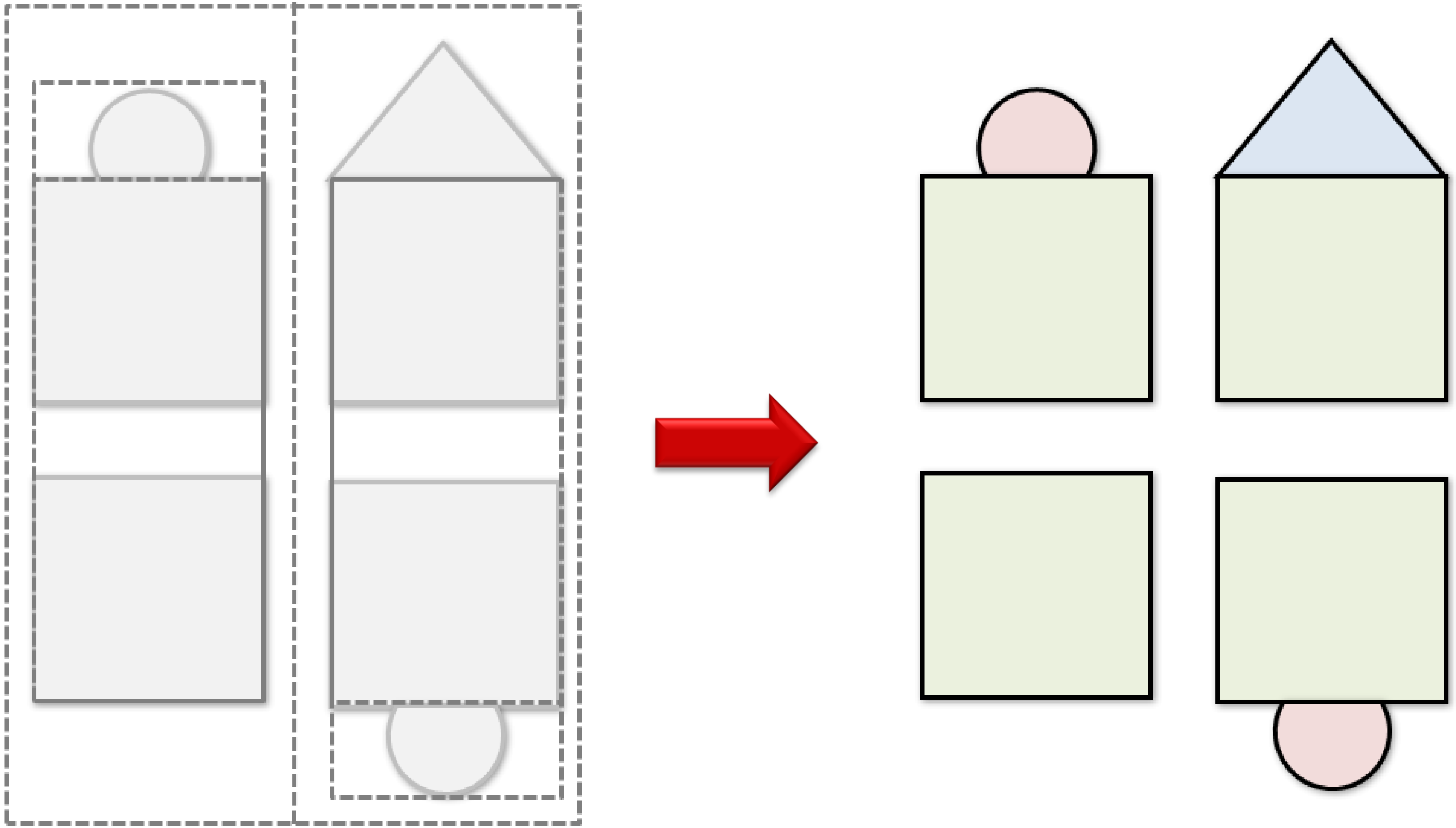
Cut at boundaries



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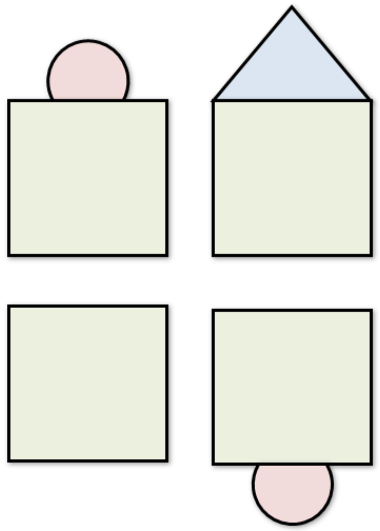
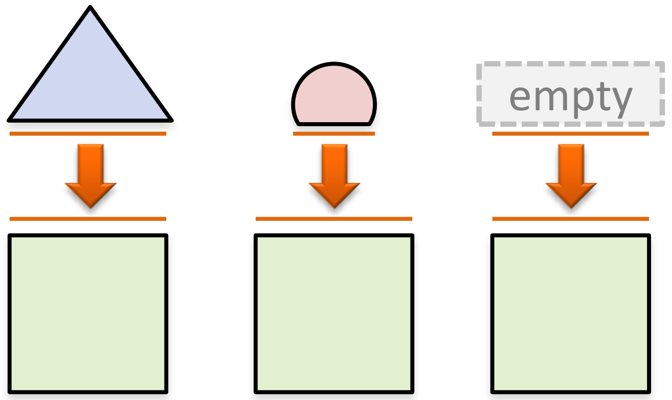
Building Blocks

Two pieces of information

- Detection of building blocks
  - Cutting along all boundaries
- Assembly rules
  - Along boundaries of tiles
  - Permit pairwise docking as seen in examples



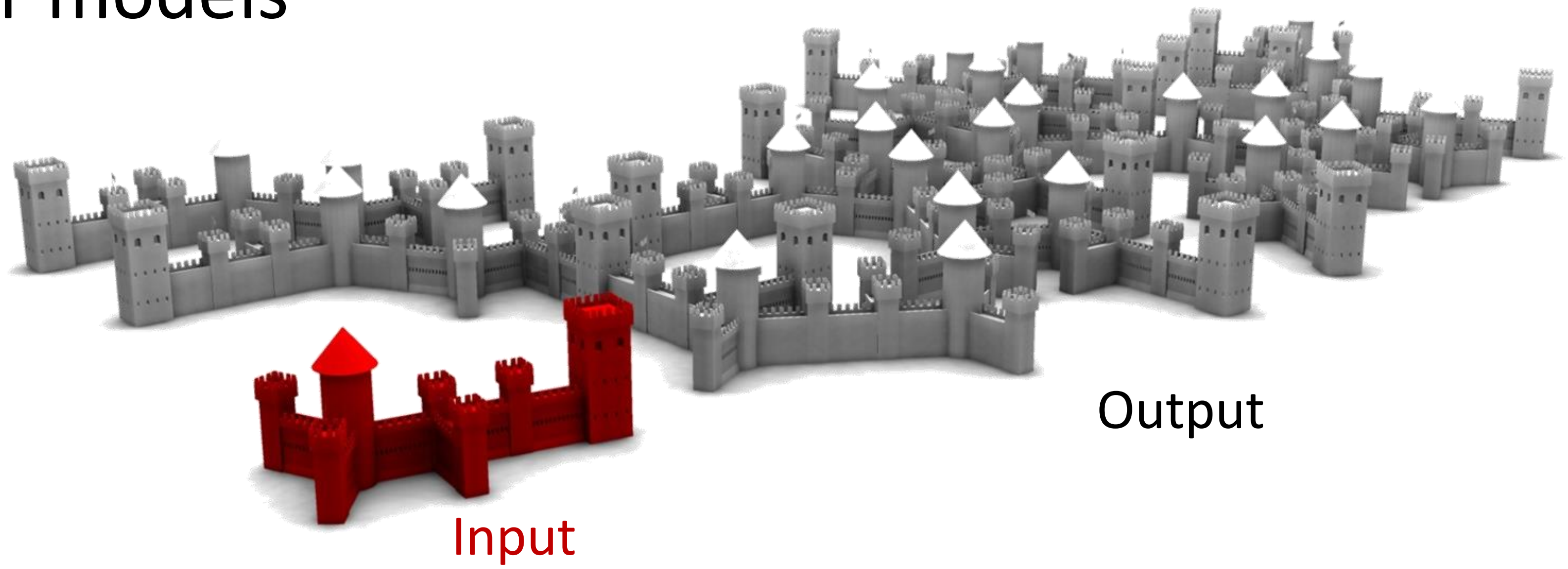


Inverse Procedural Modeling

Overview

Rules from example geometry

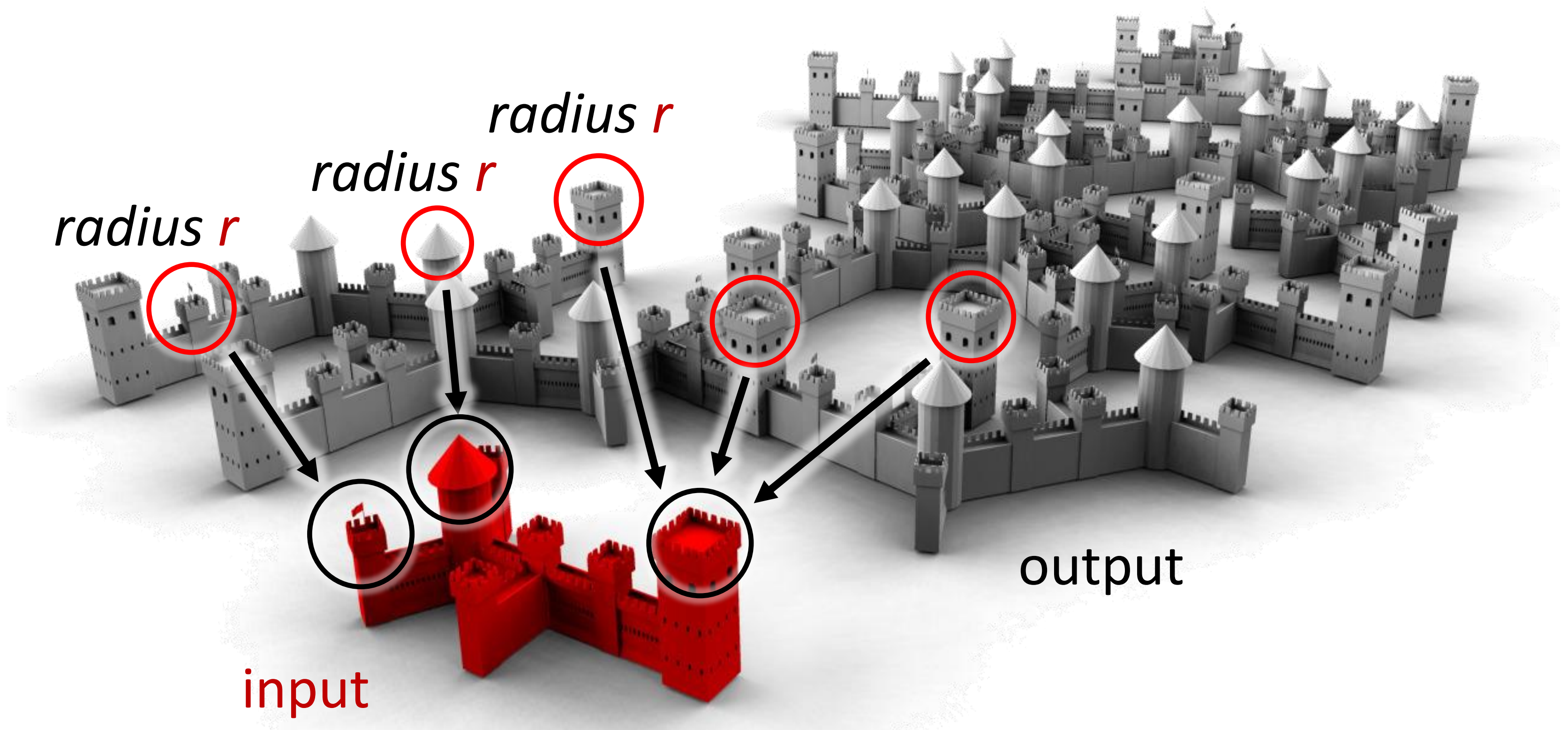
- Example model
- Compute rules describing a class of similar models



What are similar models?

r-Similarity

- Local neighborhoods match exemplar



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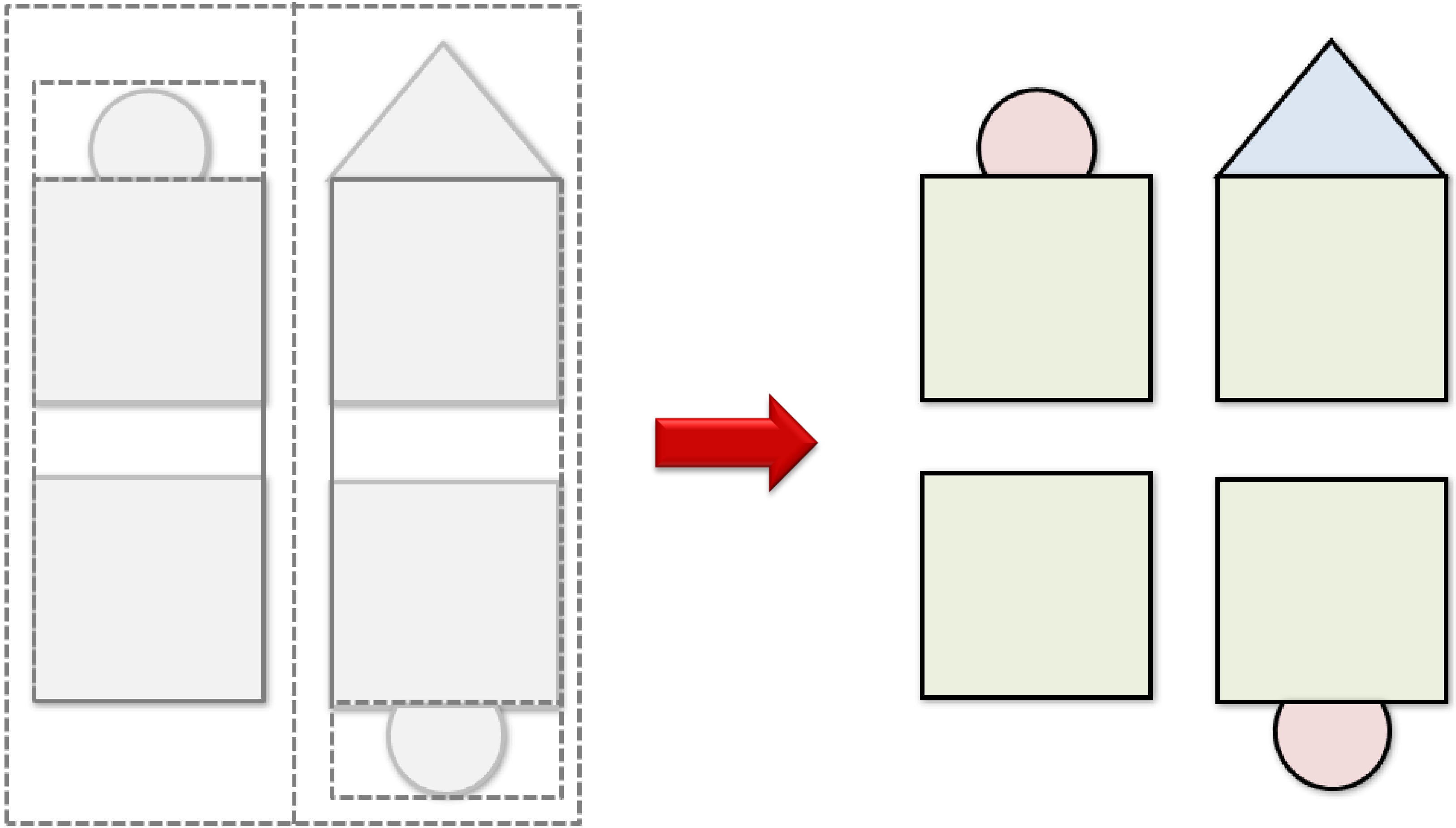
Cut at boundaries



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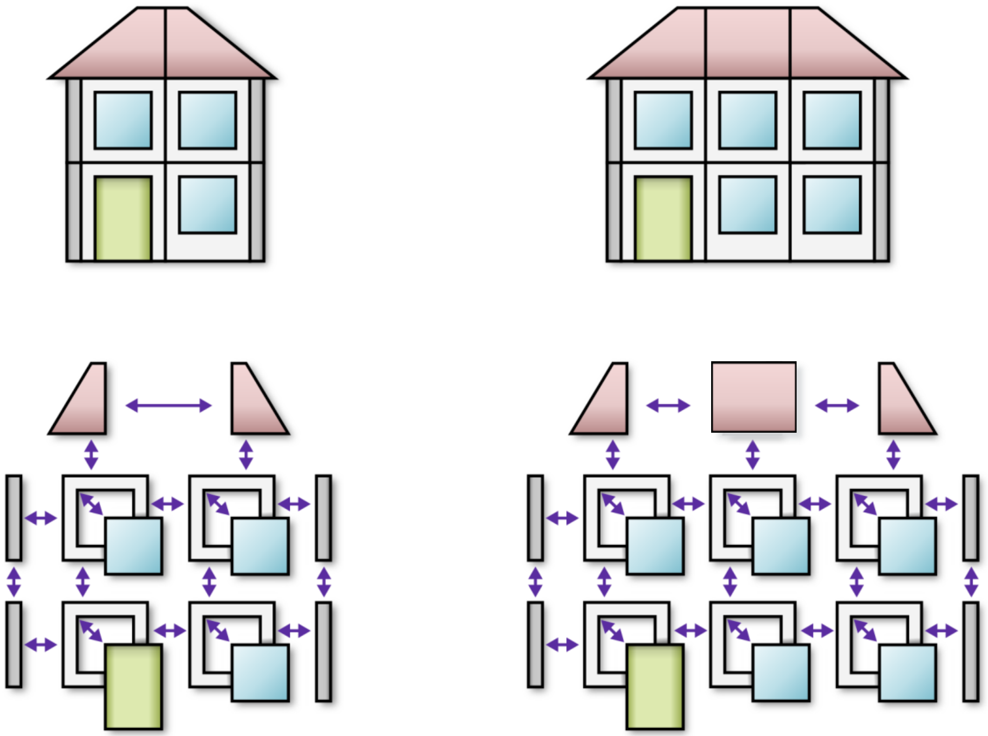
Building Blocks



Results:

- Build *all r-similar* models
- Construction is unique

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Assembly Rules

Tiling Grammar

- Assemble tiles along boundaries
- As seen in exemplar input

Problem

- Hard problem
- Undecidable – tiling grammars are Turing complete!

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Context-Free Shape Grammars

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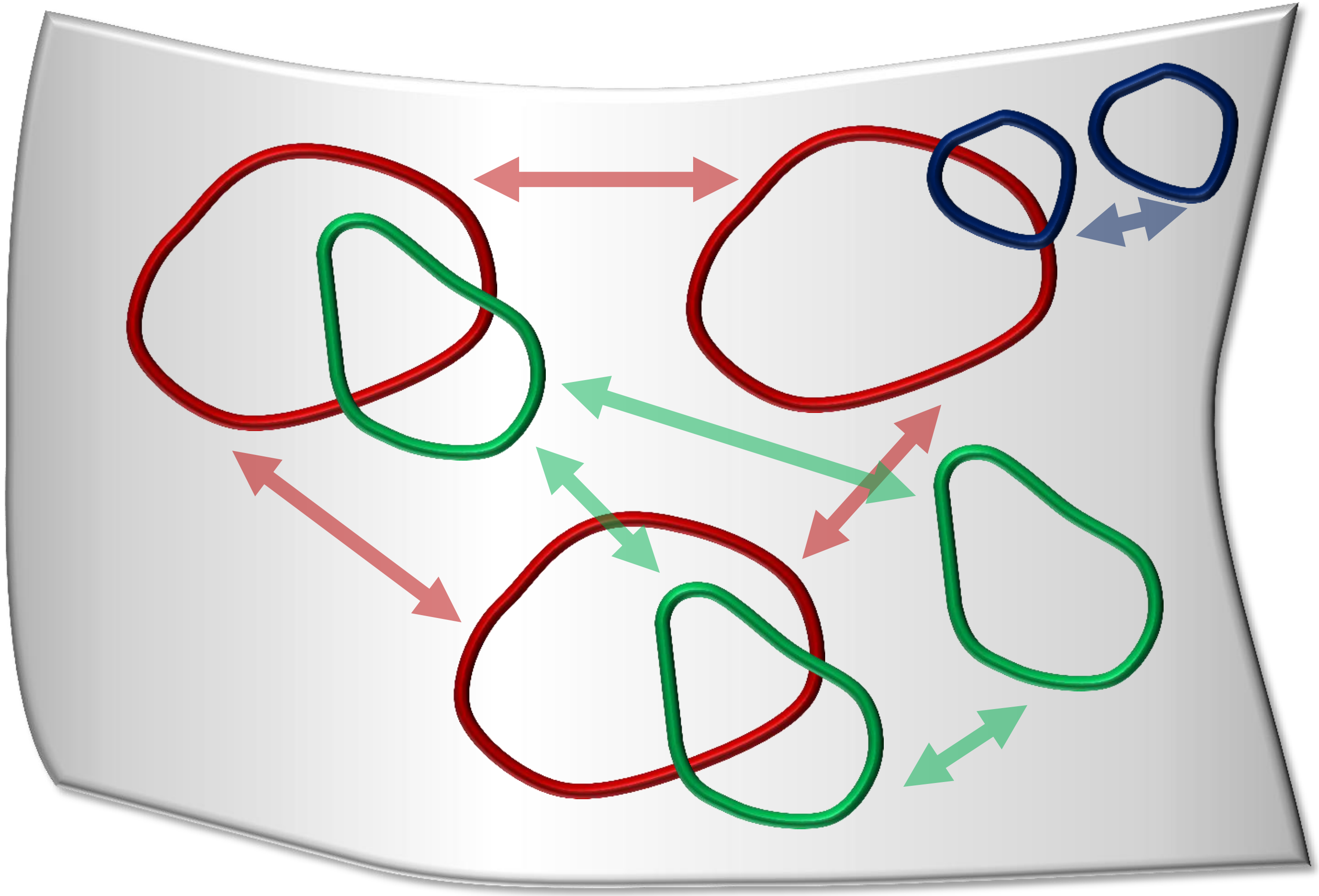
Symmetry Boundaries



Shape Grammar

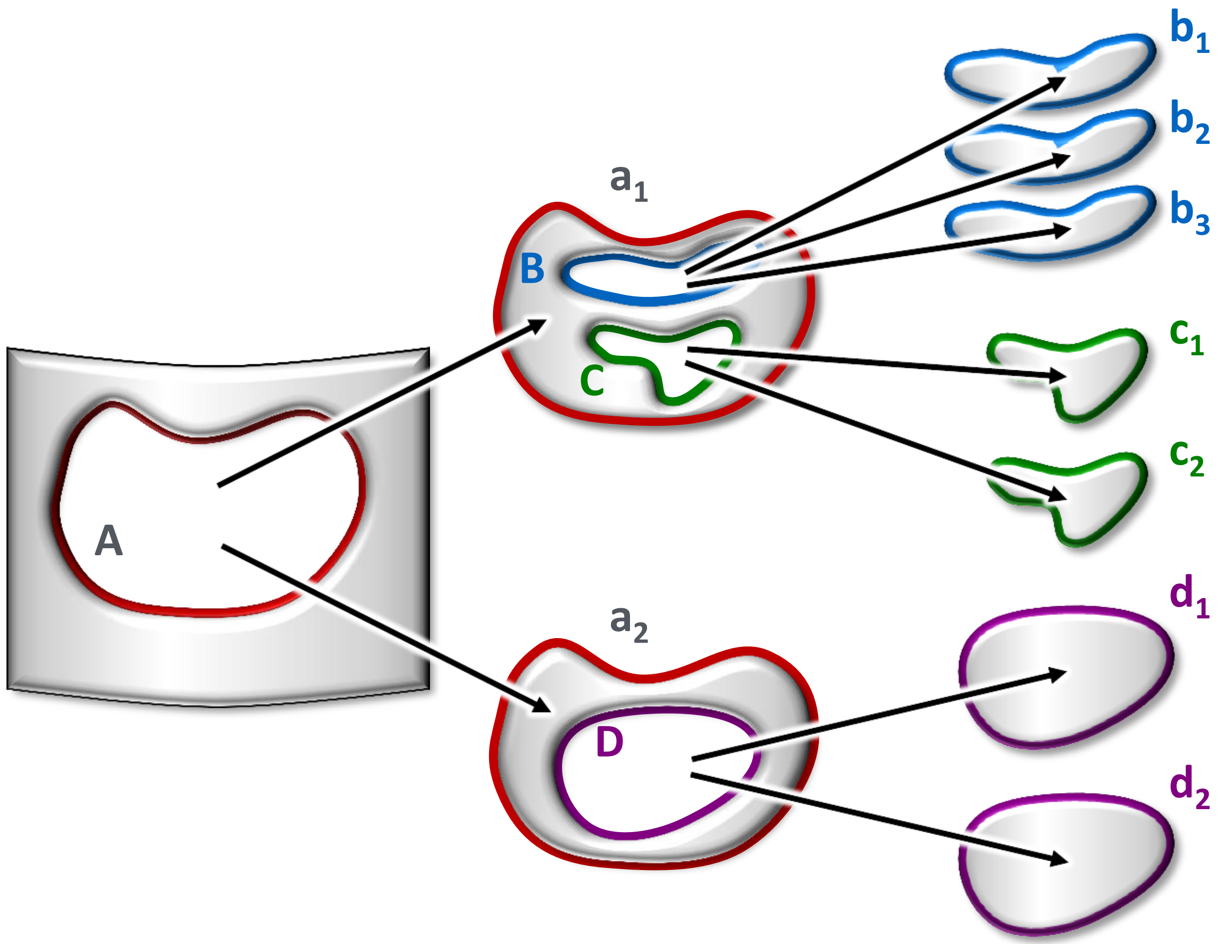
Grammar:

$A \rightarrow a_1\ B\ C \mid a_2\ D$

$B \rightarrow b_1 \mid b_2 \mid b_3$

$C \rightarrow c_1 \mid c_2$

$D \rightarrow d_1 \mid d_2$



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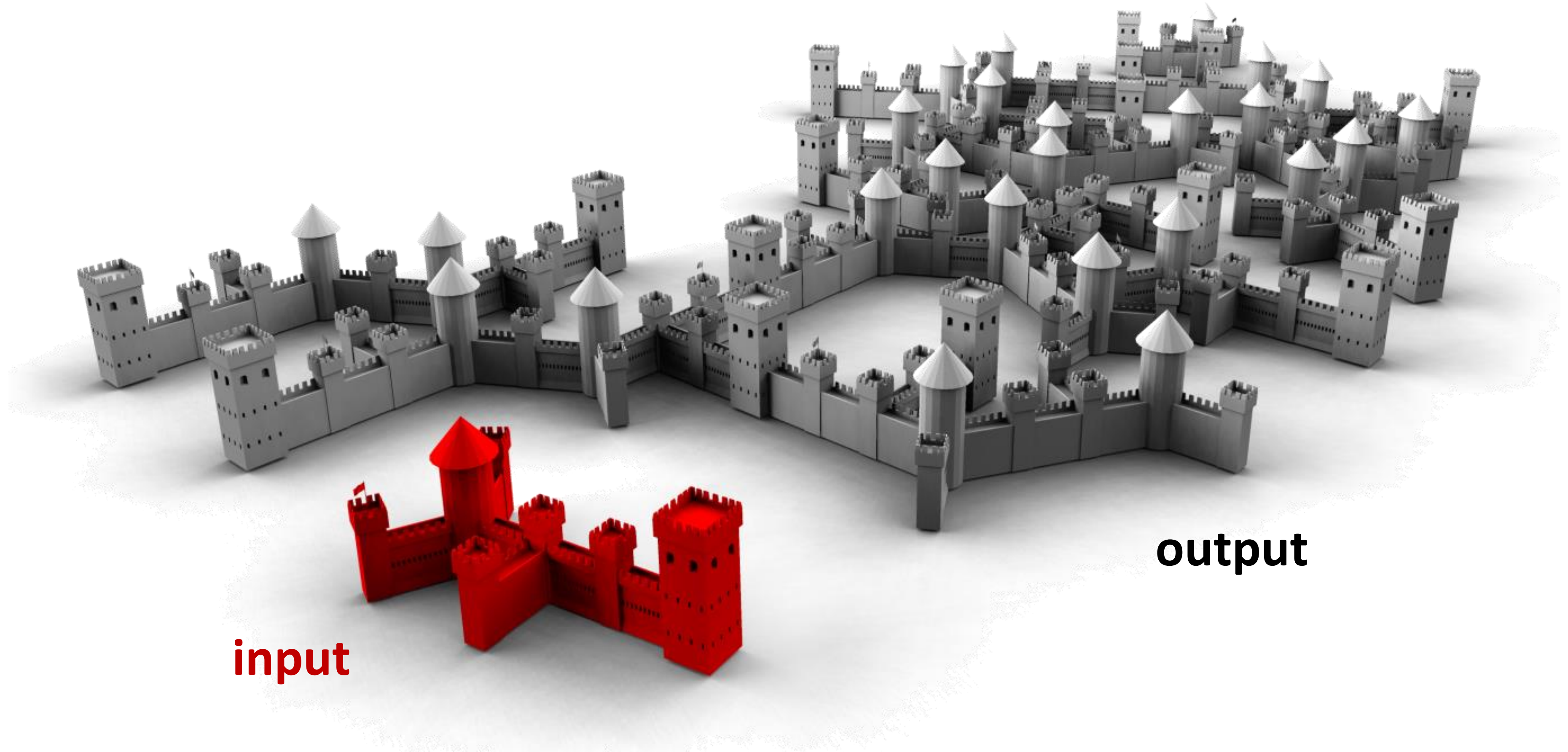
Results



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Results

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Regularly Placed Building Blocks

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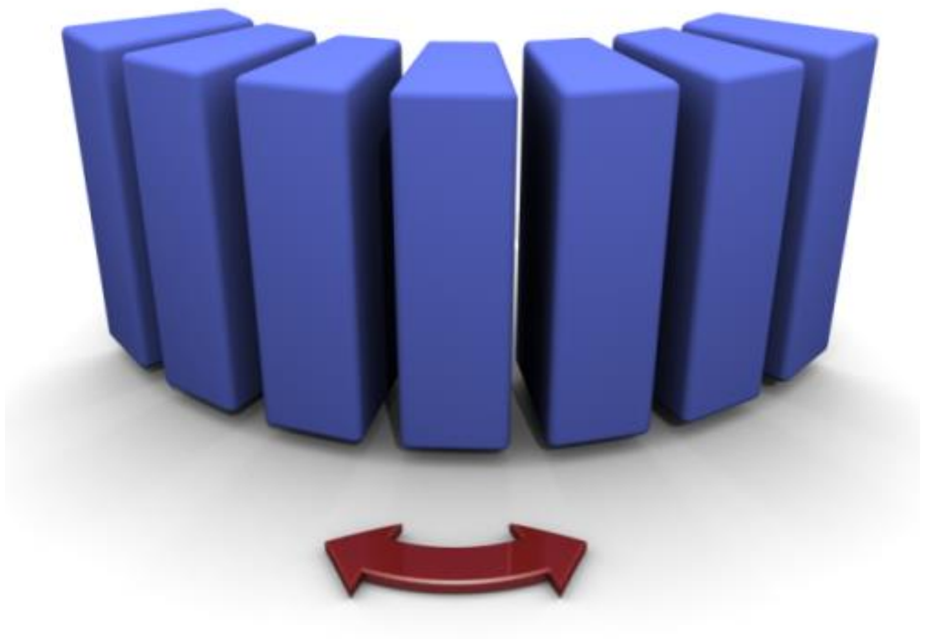
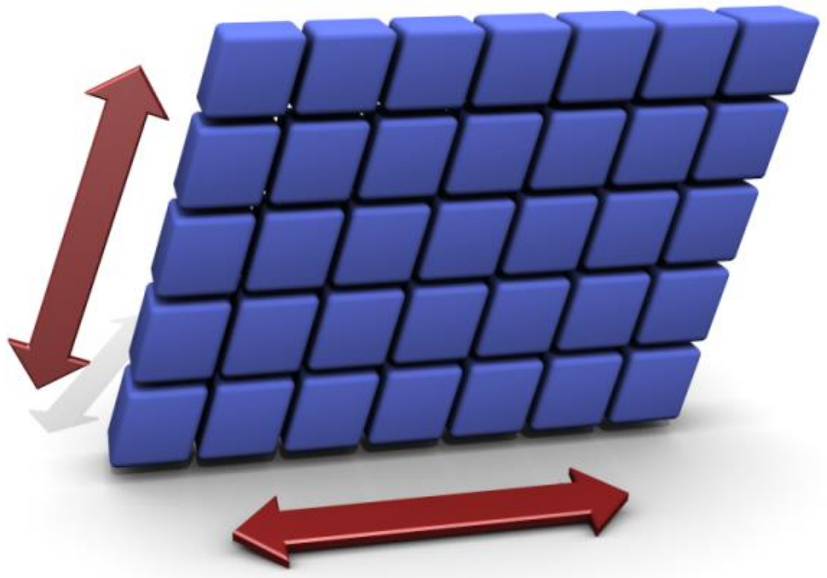
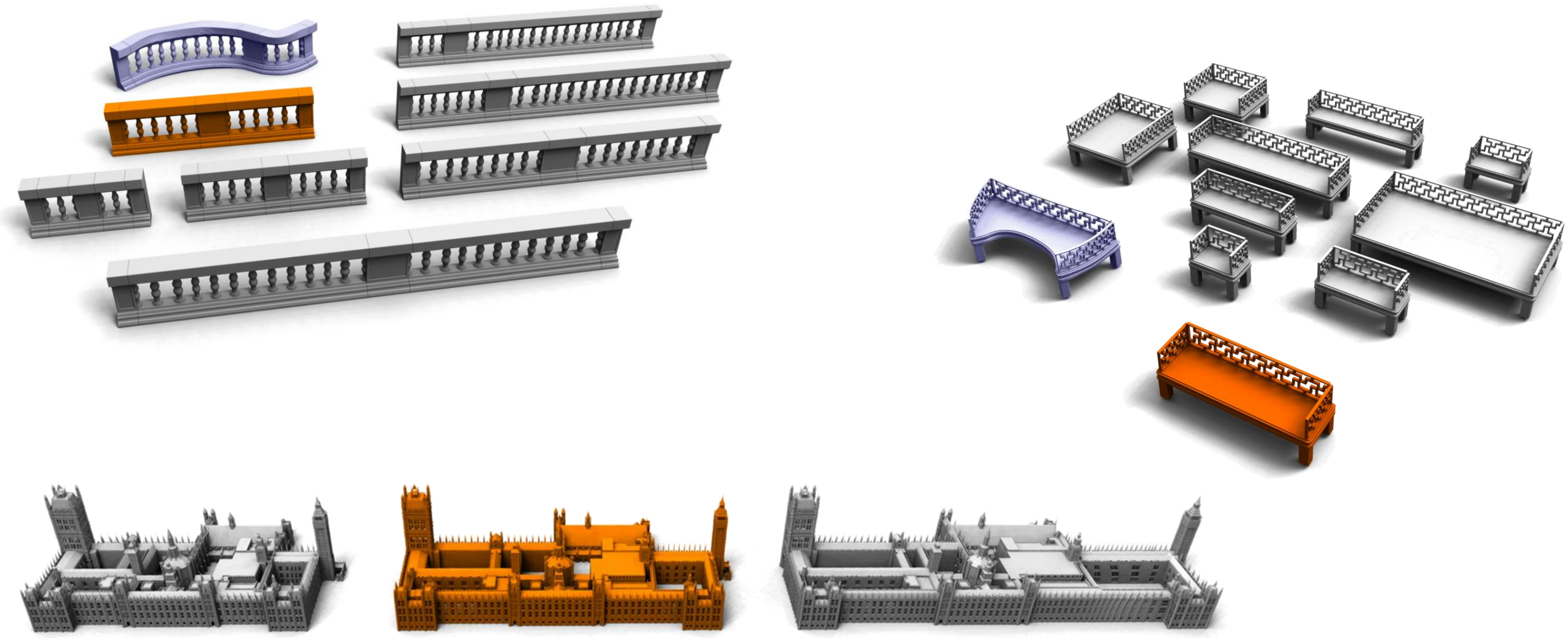
Preserve Grid Structures

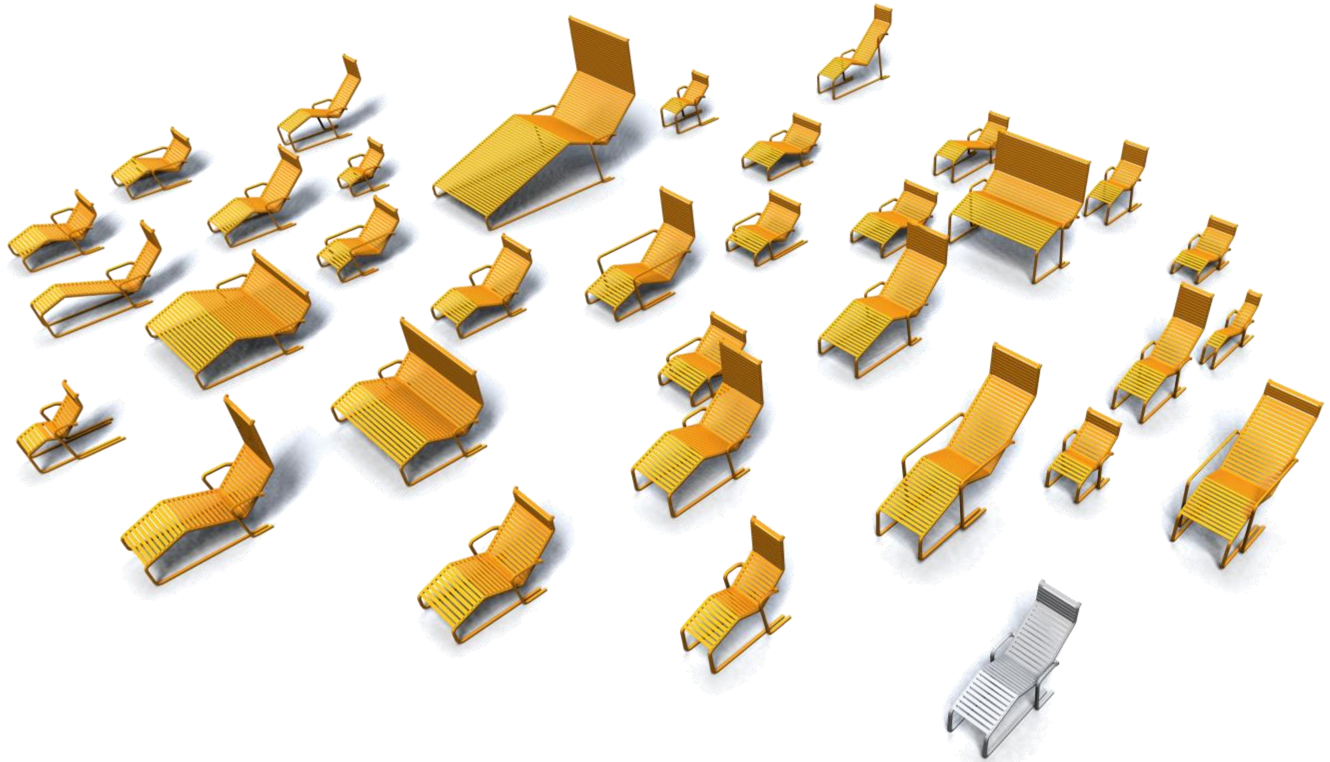




Regularity Aware Deformation



Regularity Preservation



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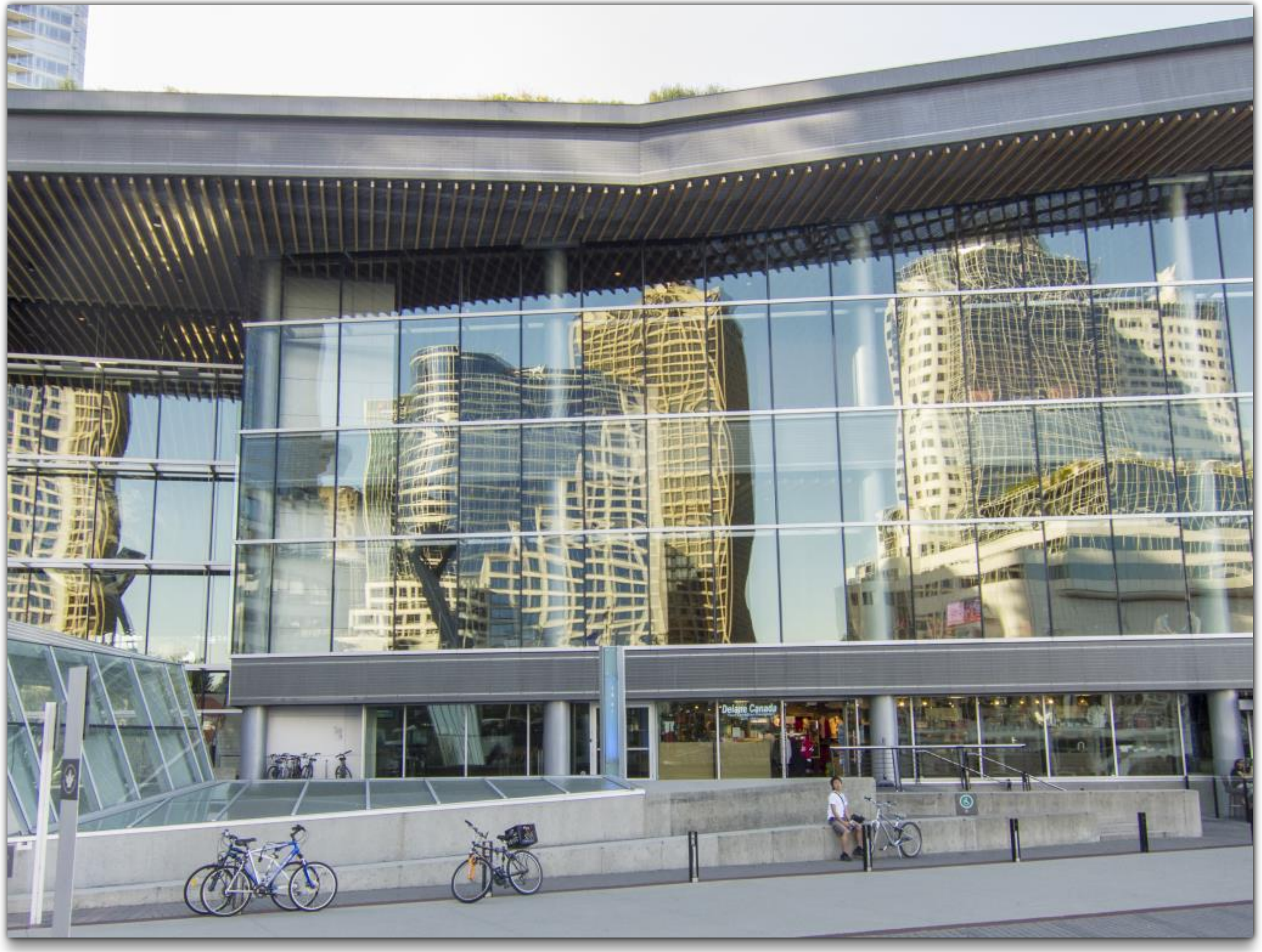

Summary

Summary

Structure

- Concise / compressive data explanation

Structure models for single shapes

- Elementary geometric assumptions
- A lot of data fits low-parameter models

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Summary

Correspondences

- Shape matching

Symmetry

- Regularity in transformations

Building Blocks

- Regular building blocks

Inverse procedural modeling

- Learn how building blocks connect

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