

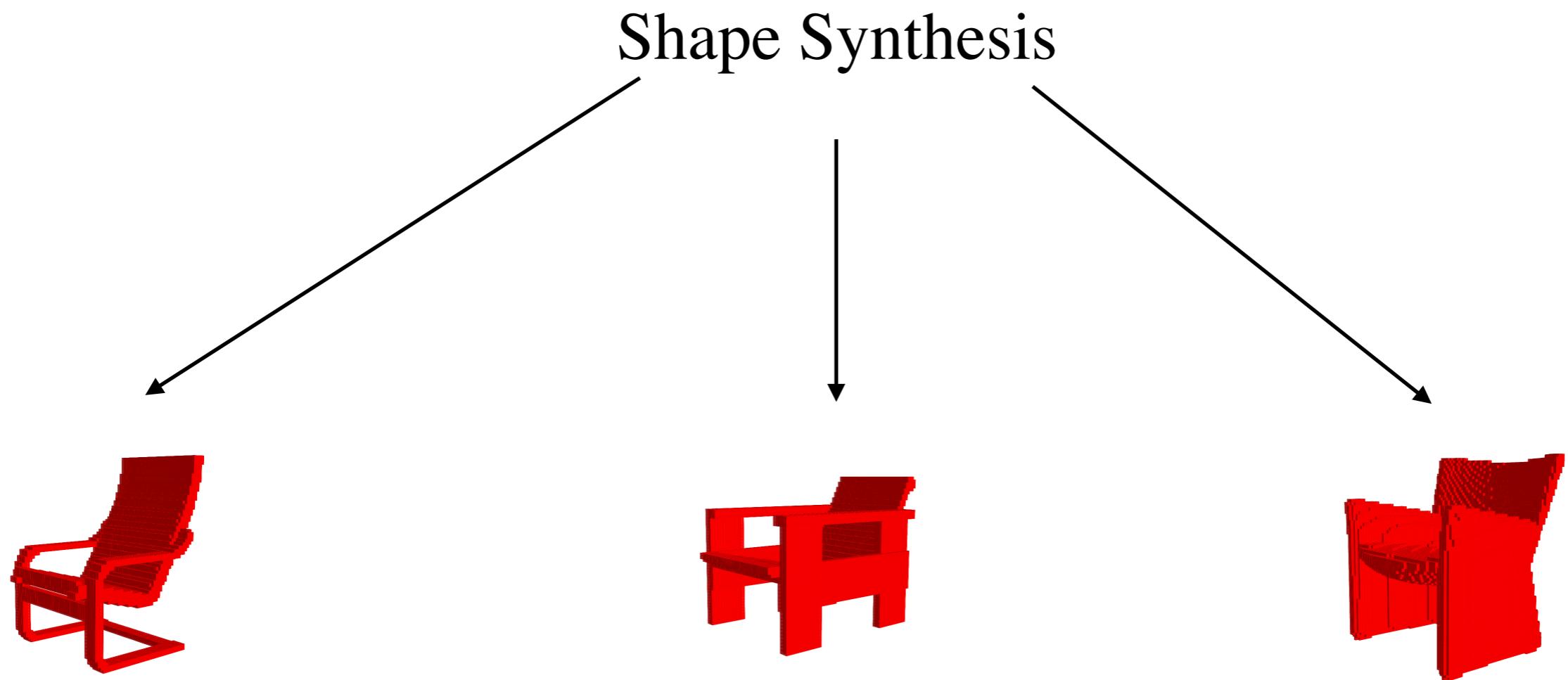
Shape Synthesis Using Structure-Aware Reasoning

Elena Sizikova (Balashova)
CILVR Seminar

September 9, 2019

Introduction

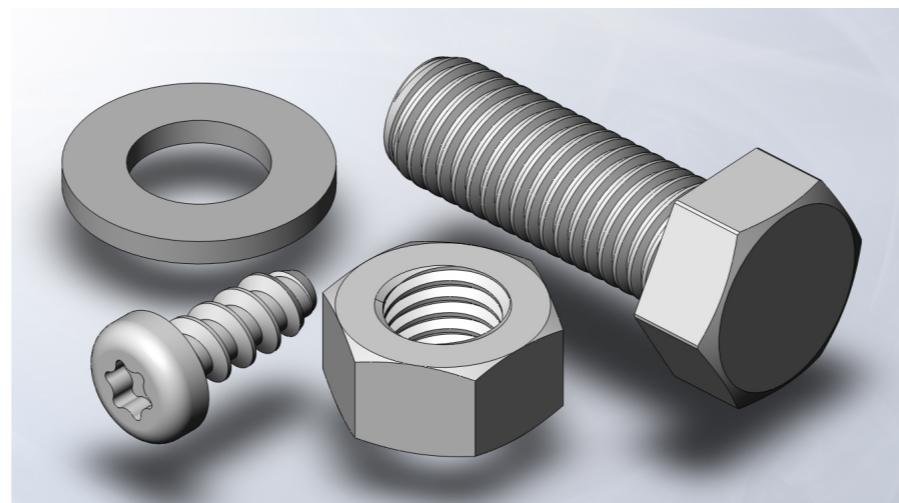
Introduction



Introduction



[\[http://nwn.blogs.com\]](http://nwn.blogs.com)



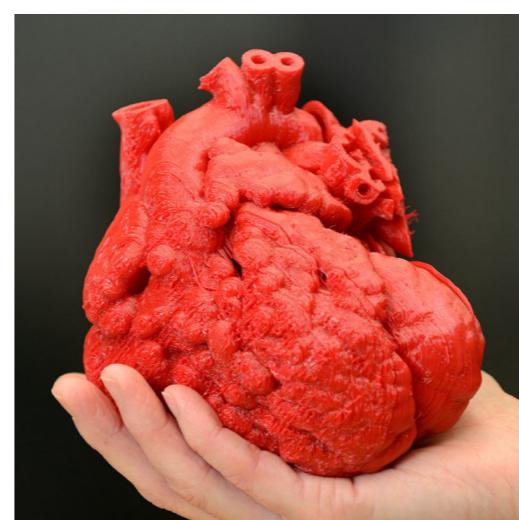
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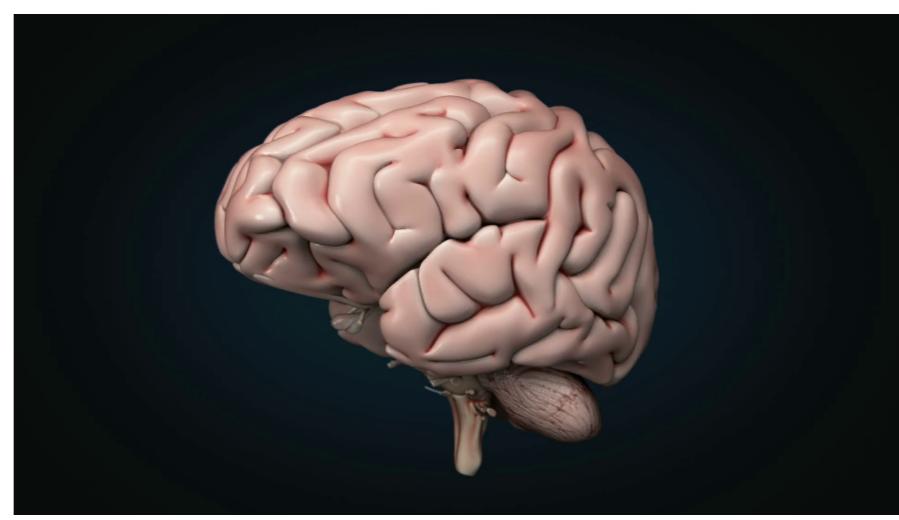
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[\[http://au.educationhq.com\]](http://au.educationhq.com)



[\[https://blog.zmorph3d.com\]](https://blog.zmorph3d.com)



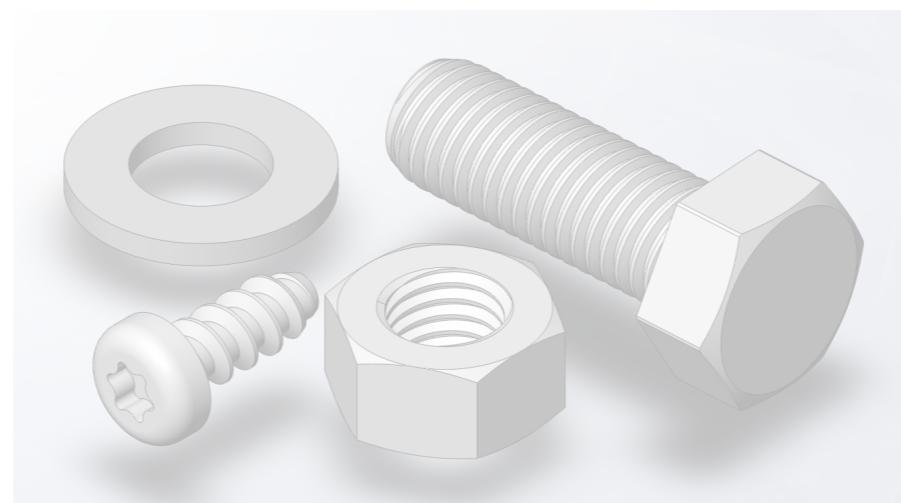
[\[VideoBlocks\]](#)

Introduction

Virtual Reality



[\[http://nwn.blogs.com\]](http://nwn.blogs.com)



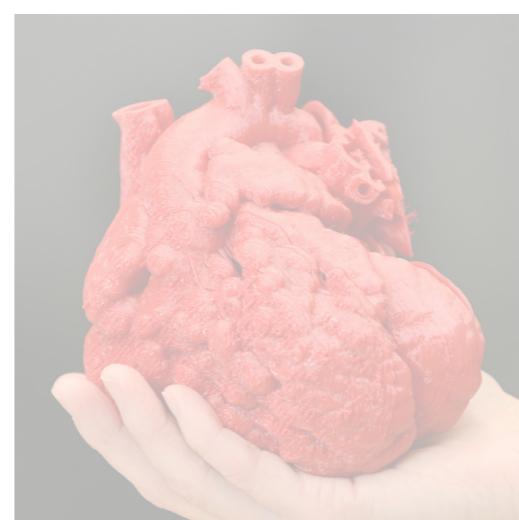
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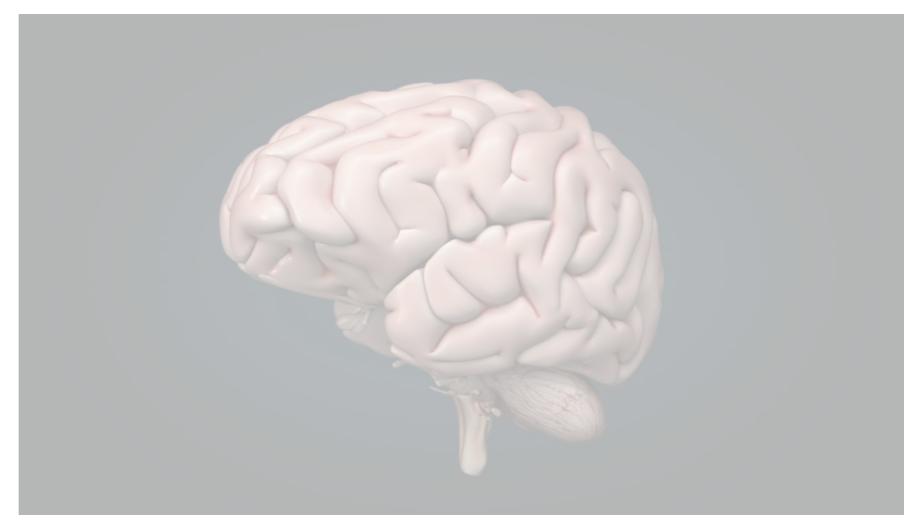
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[\[http://au.educationhq.com\]](http://au.educationhq.com)



[\[https://blog.zmorph3d.com\]](https://blog.zmorph3d.com)



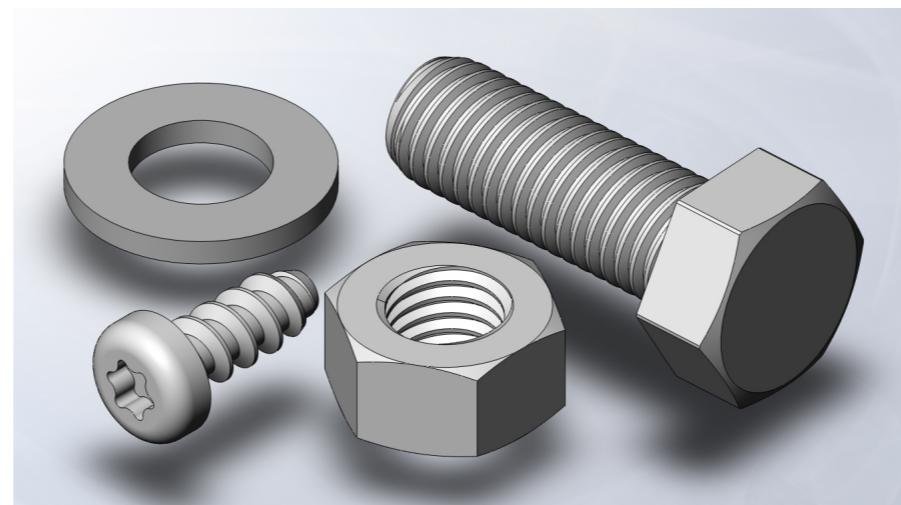
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Introduction

CAD Modelling



[<http://nwn.blogs.com>]



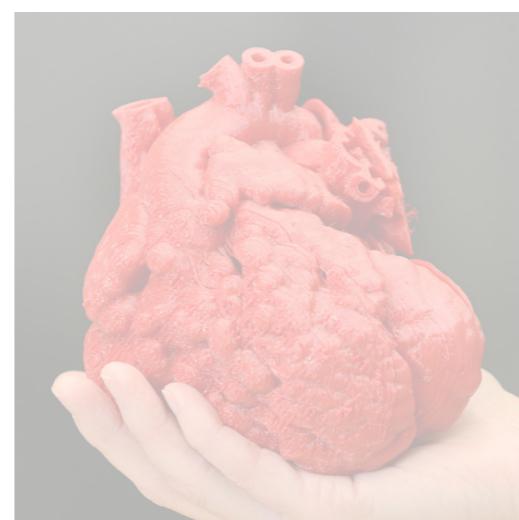
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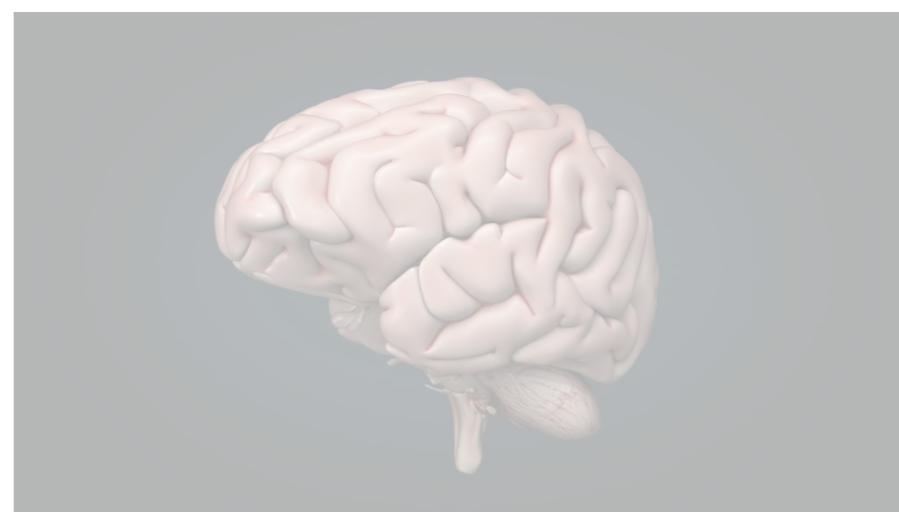
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[<http://au.educationhq.com>]



[<https://blog.zmorph3d.com>]



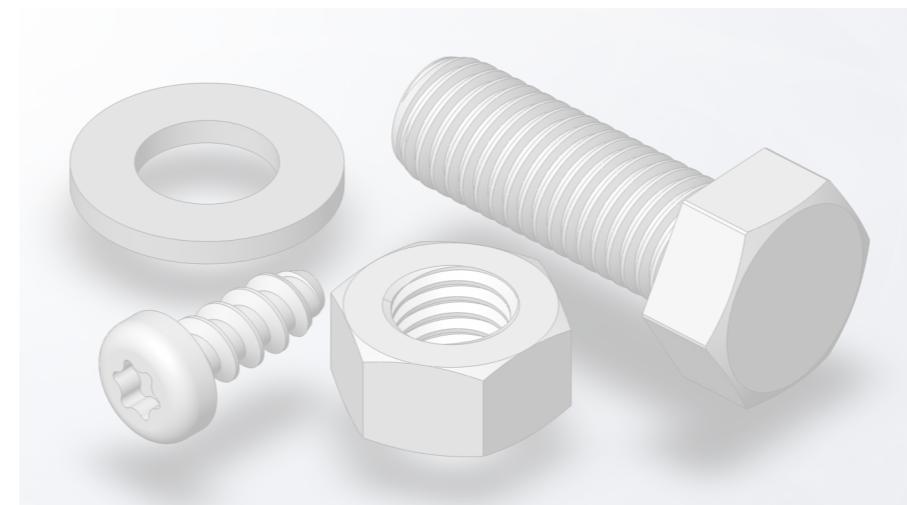
[[VideoBlocks](#)]

Introduction

Artistic Design



[<http://nwn.blogs.com>]



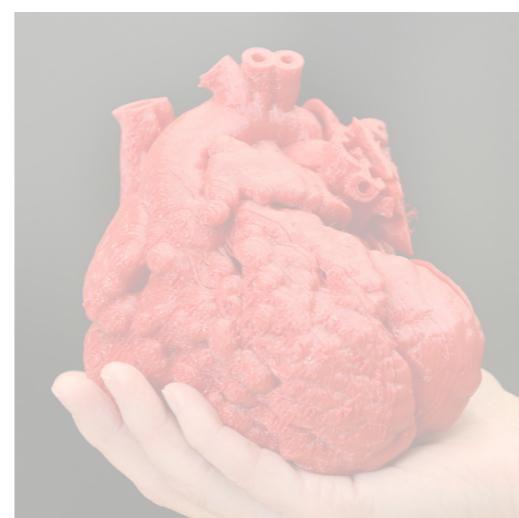
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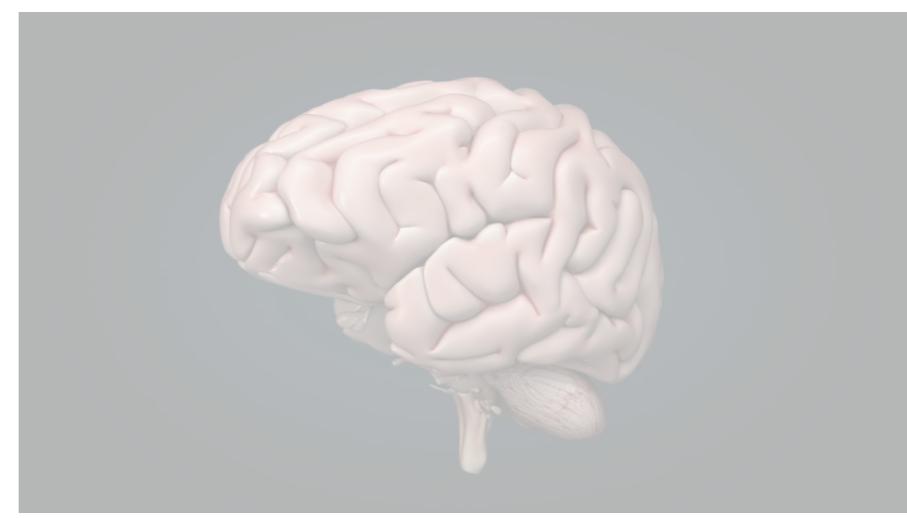
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[<https://blog.zmorph3d.com>]

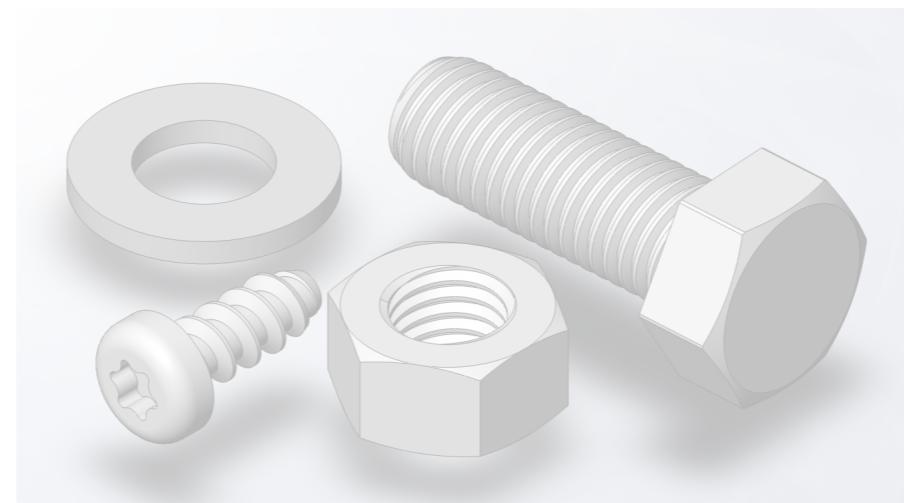


[[VideoBlocks](#)]

Introduction



[<http://nwn.blogs.com>]



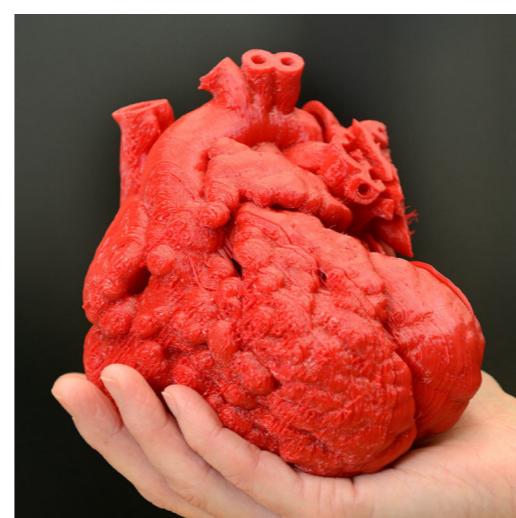
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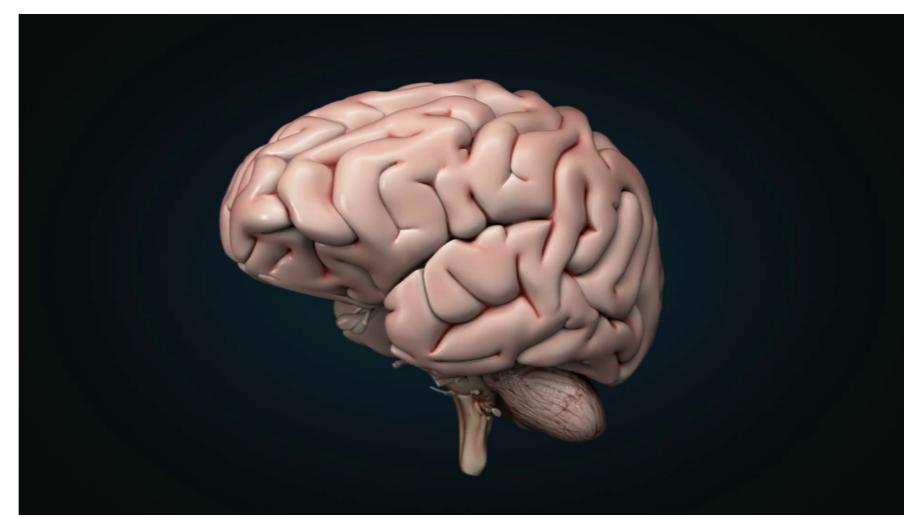
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[<https://blog.zmorph3d.com>]



[[VideoBlocks](#)]

Medicine

Background

User-Assisted

Automatic

Background

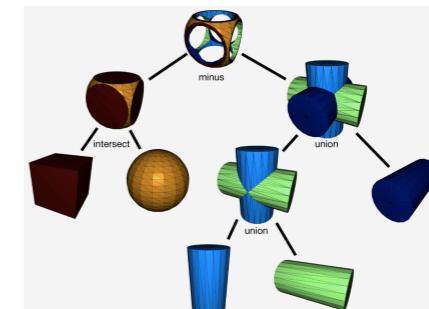
User-Assisted

Computer-Aided Design
(CAD) Modelling



[www.autodesk.com]

Constructive Solid Geometry (CSG)

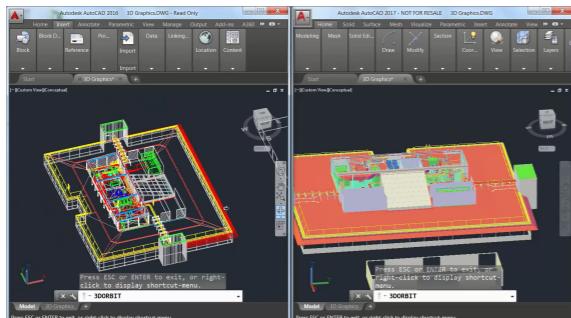


[www.alecjacobson.com]

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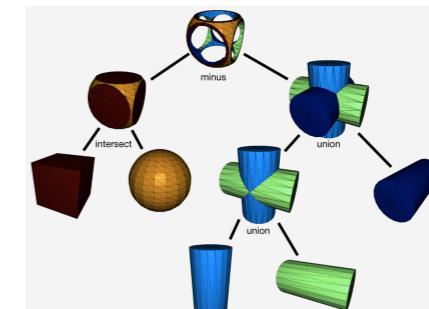
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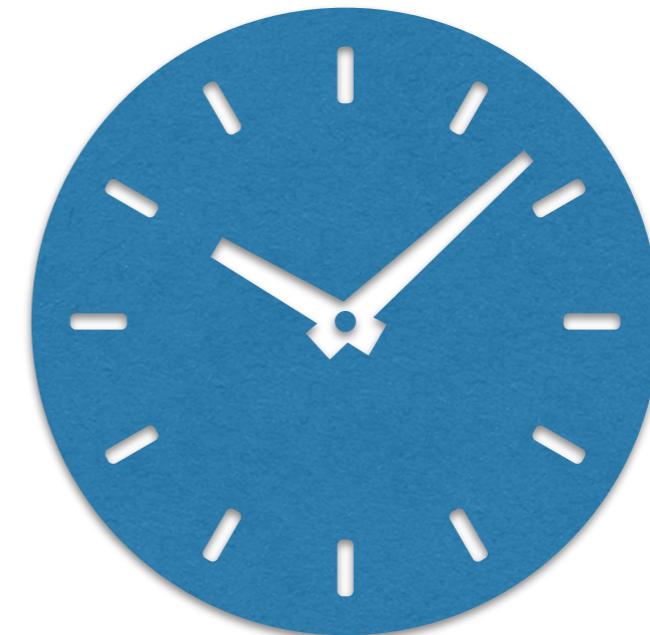
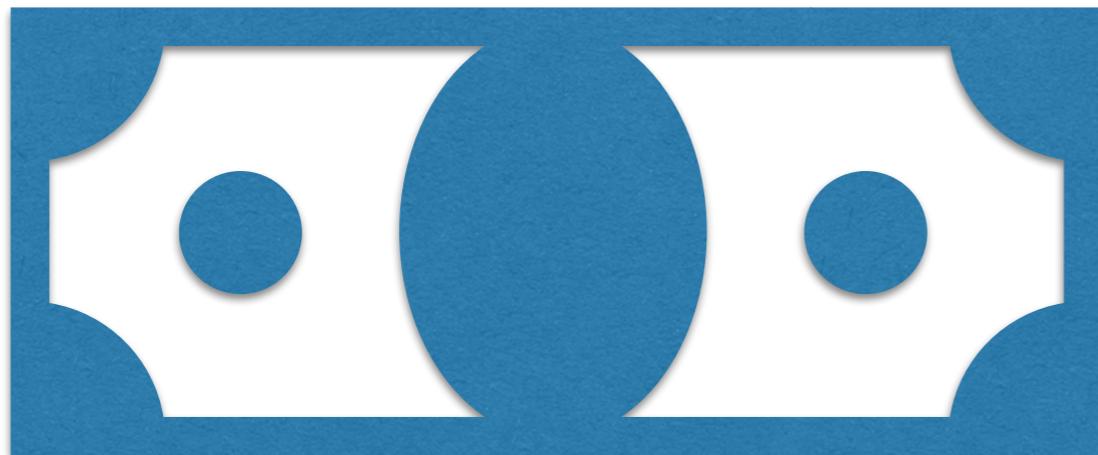


[www.autodesk.com]

Constructive Solid Geometry (CSG)



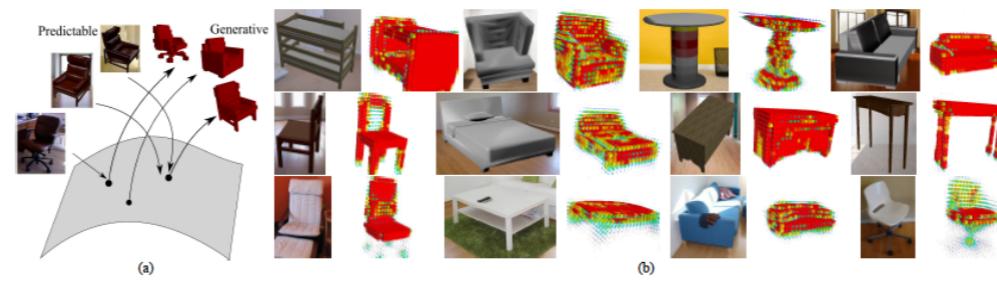
[www.alecjacobson.com]



Background

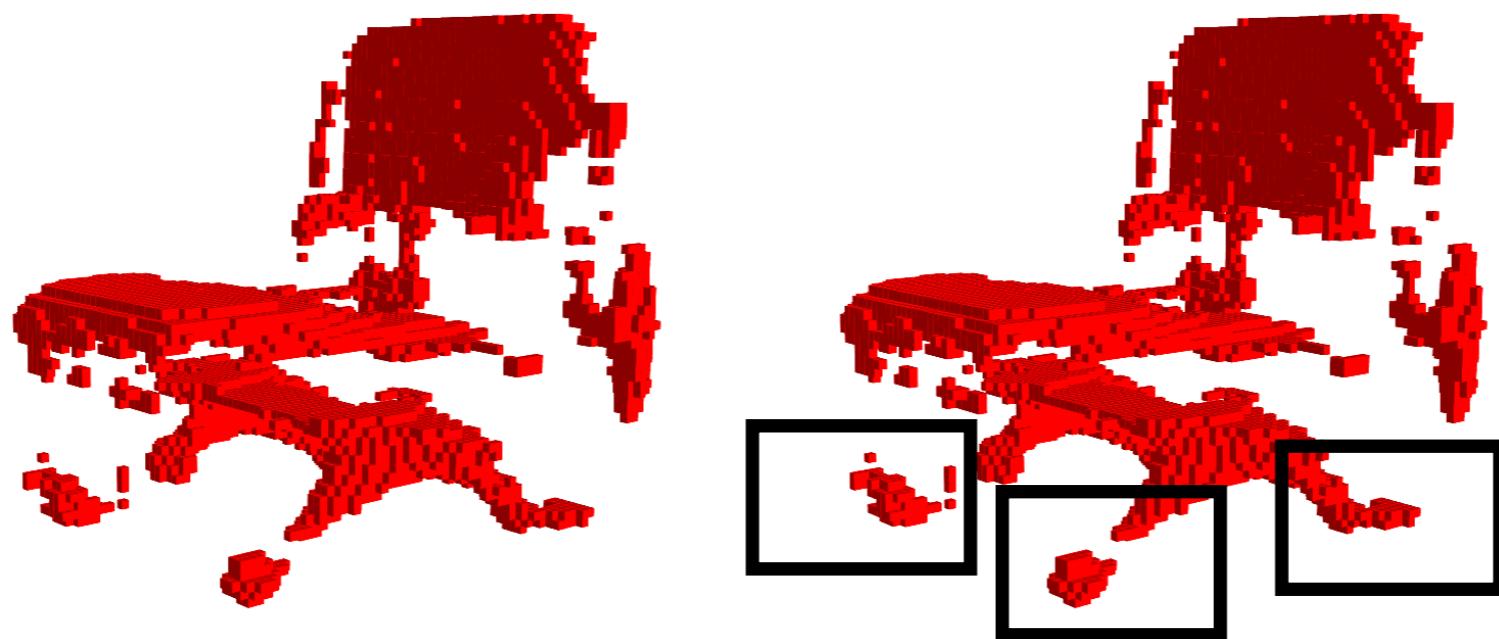
Automatic

Deep Generative Models



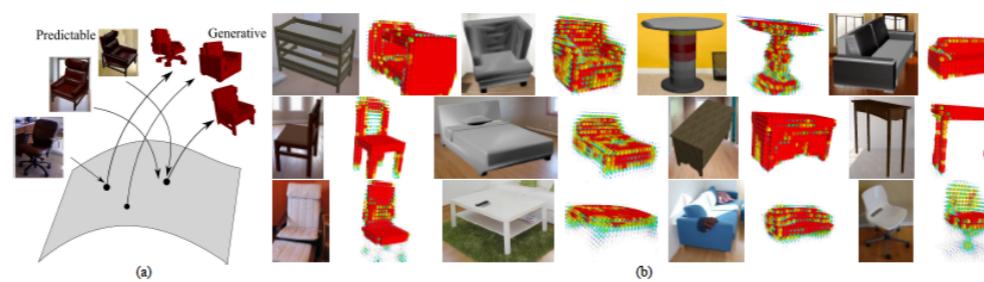
[Girdhar '16] aka TL Network

Background



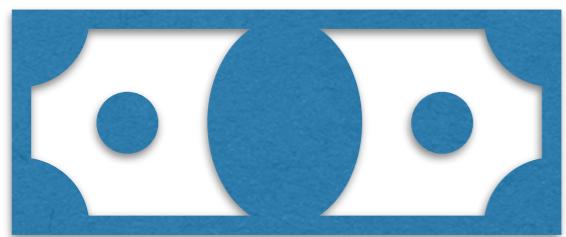
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Deep Generative Models

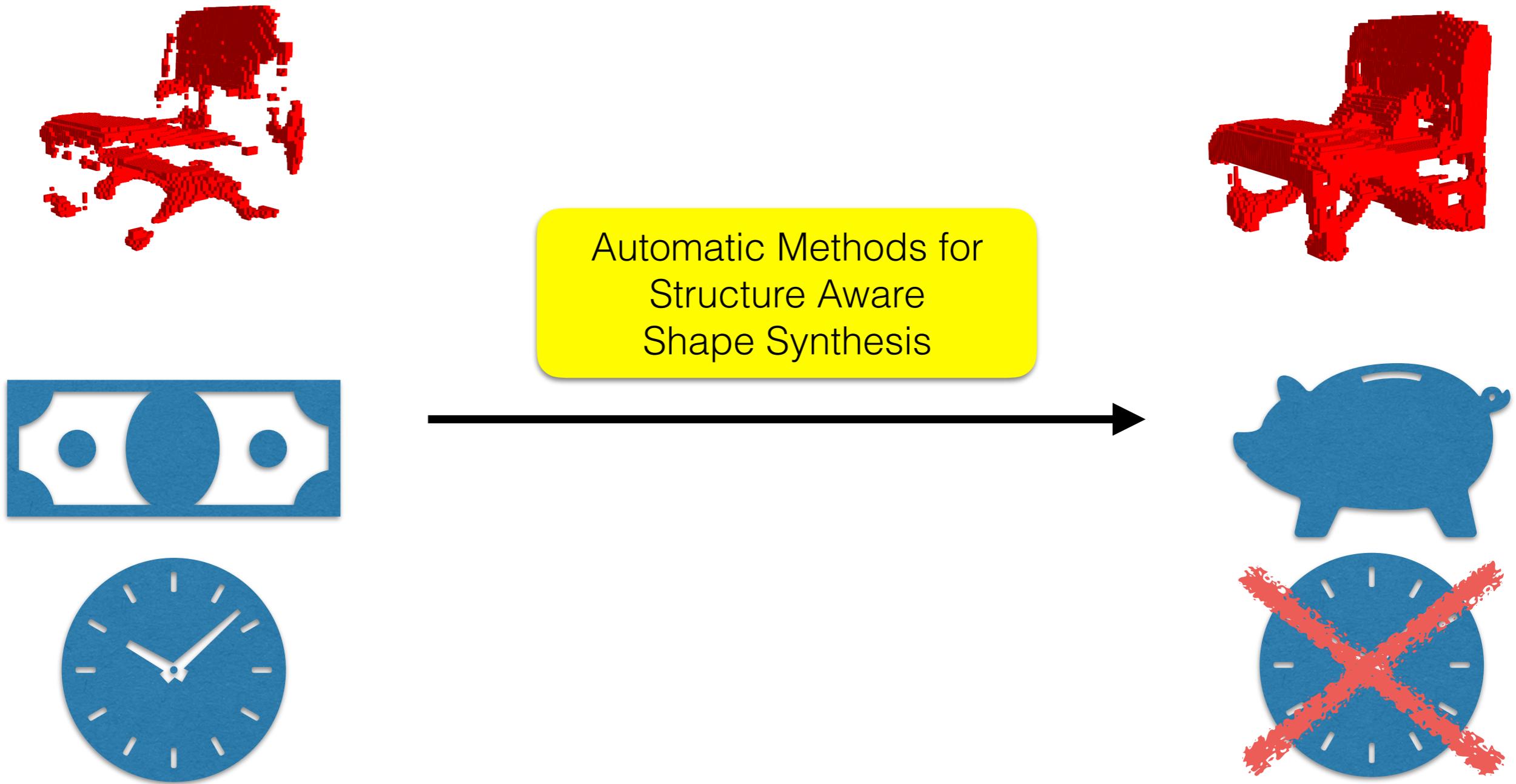


[Girdhar '16] aka TL Network

Background



Background

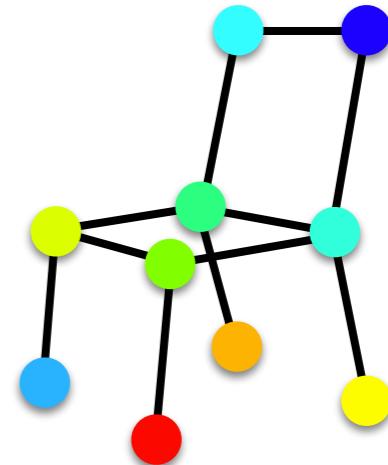


Structure Overview

Types of Structure

Landmark

- 3D shapes with complex topology



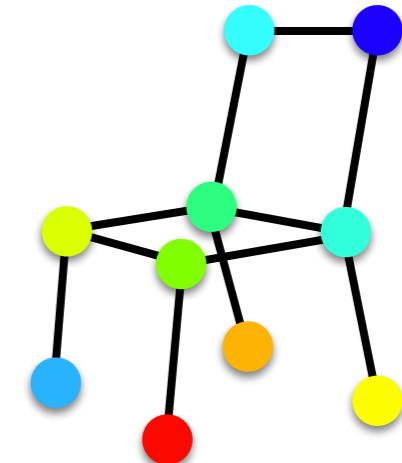
[3DV 18]

Structure Overview

Types of Structure

Landmark

- 3D shapes with complex topology



[3DV 18]

[E. Balashova](#), V. Singh, B. Teixeira, J. Wang, T. Chen, T. Funkhouser.
Structure-Aware Shape Synthesis.
International Conference on 3D Vision (3DV) 2018.
Spotlight Presentation.

Goal: Realistic Shape Synthesis

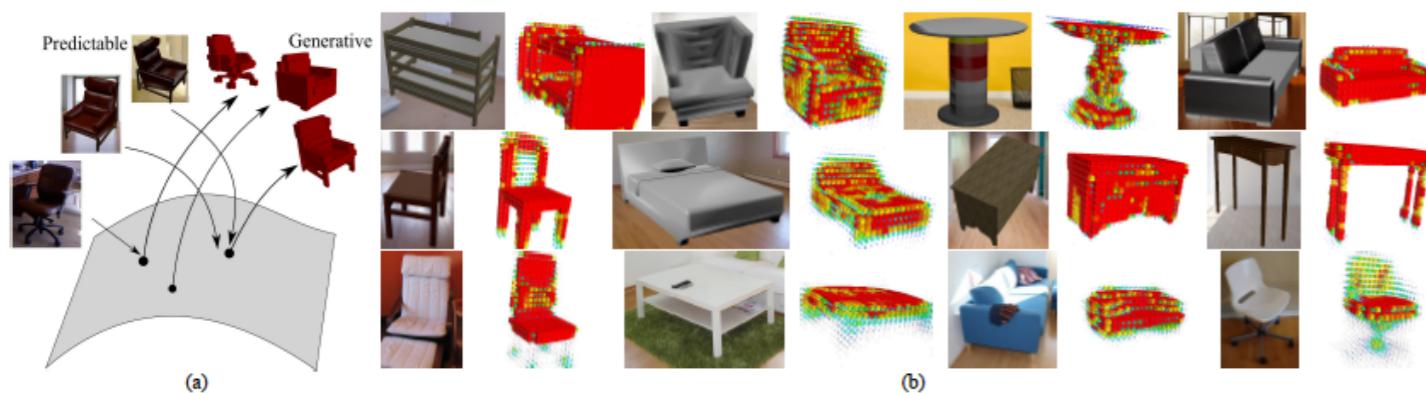


“Realistic” requires:
correct semantic structure

Data-Driven Methods

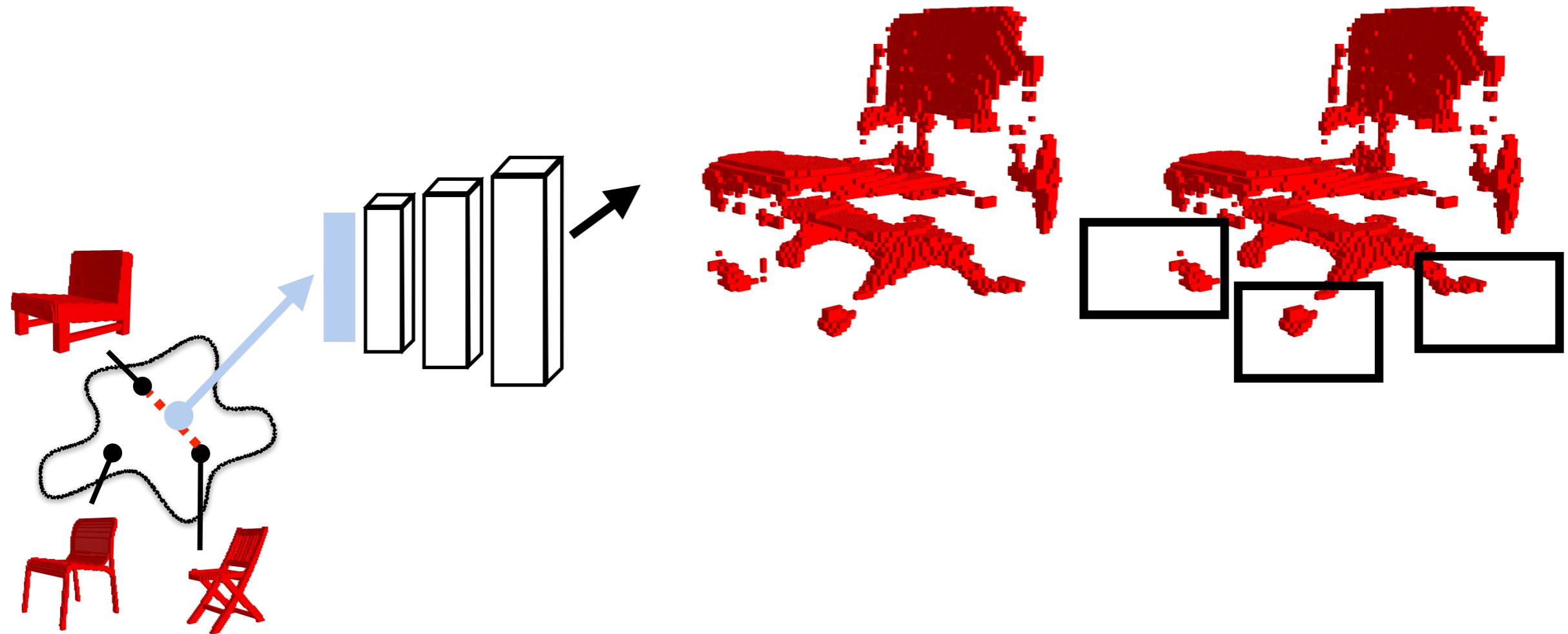


[Wu '16] aka 3D-GAN

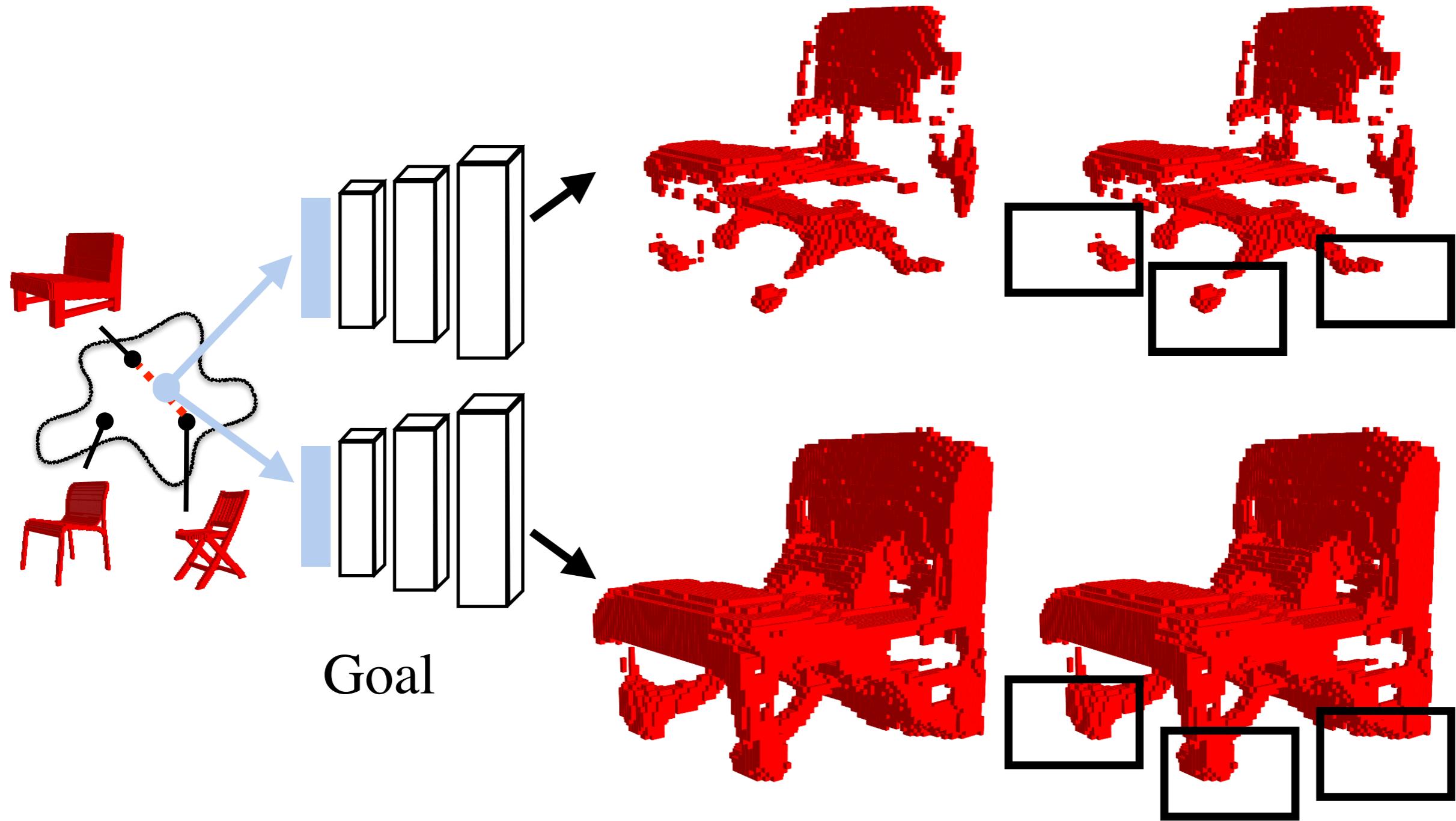


[Girdhar '16] aka TL Network

Challenge

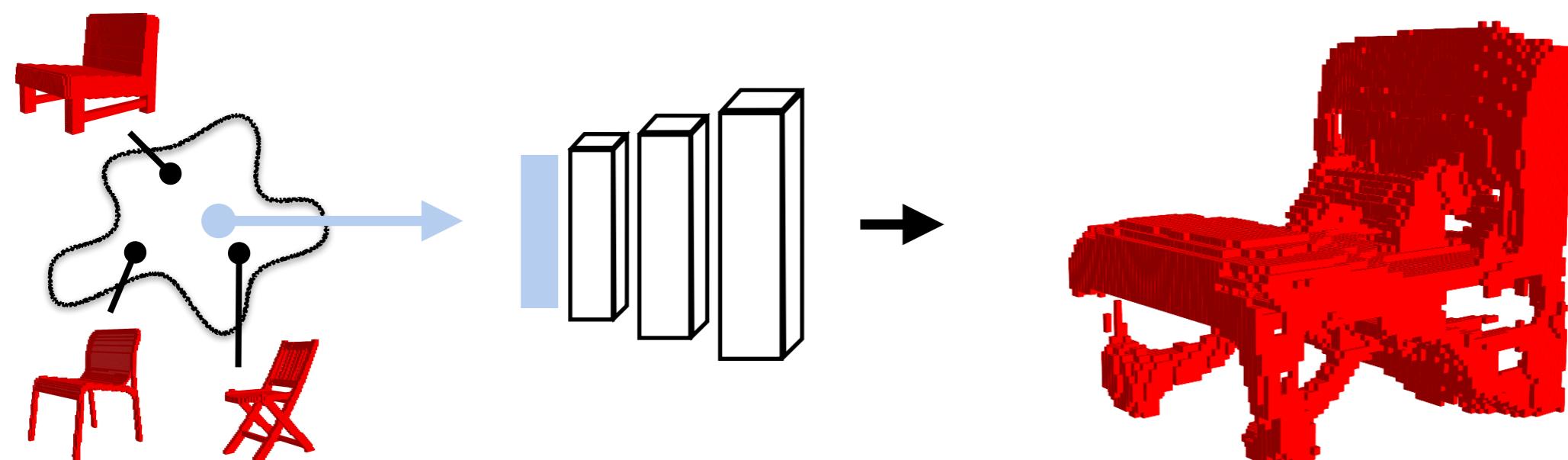


Structure-Aware Synthesis



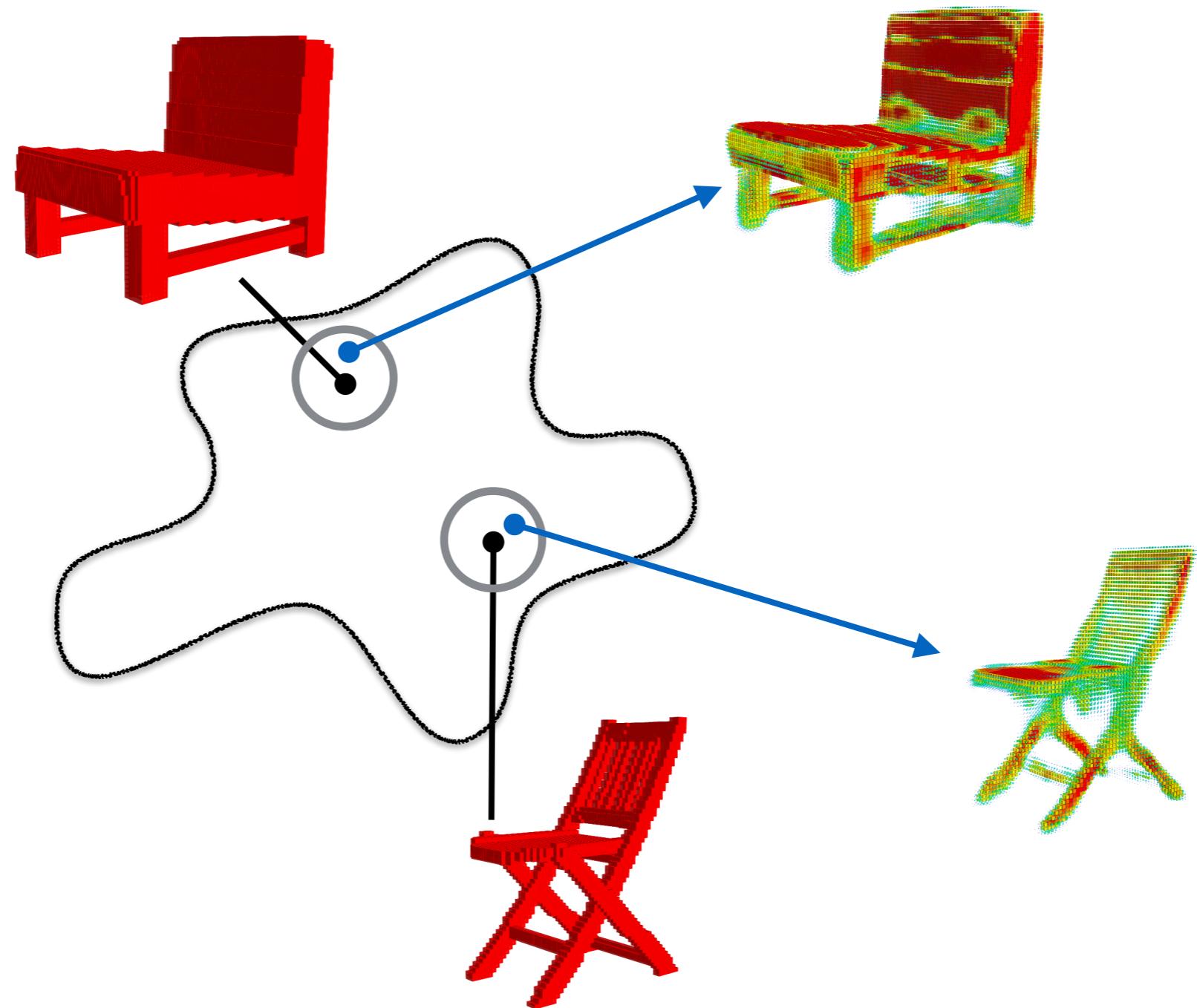
Goal

Any Manifold Point

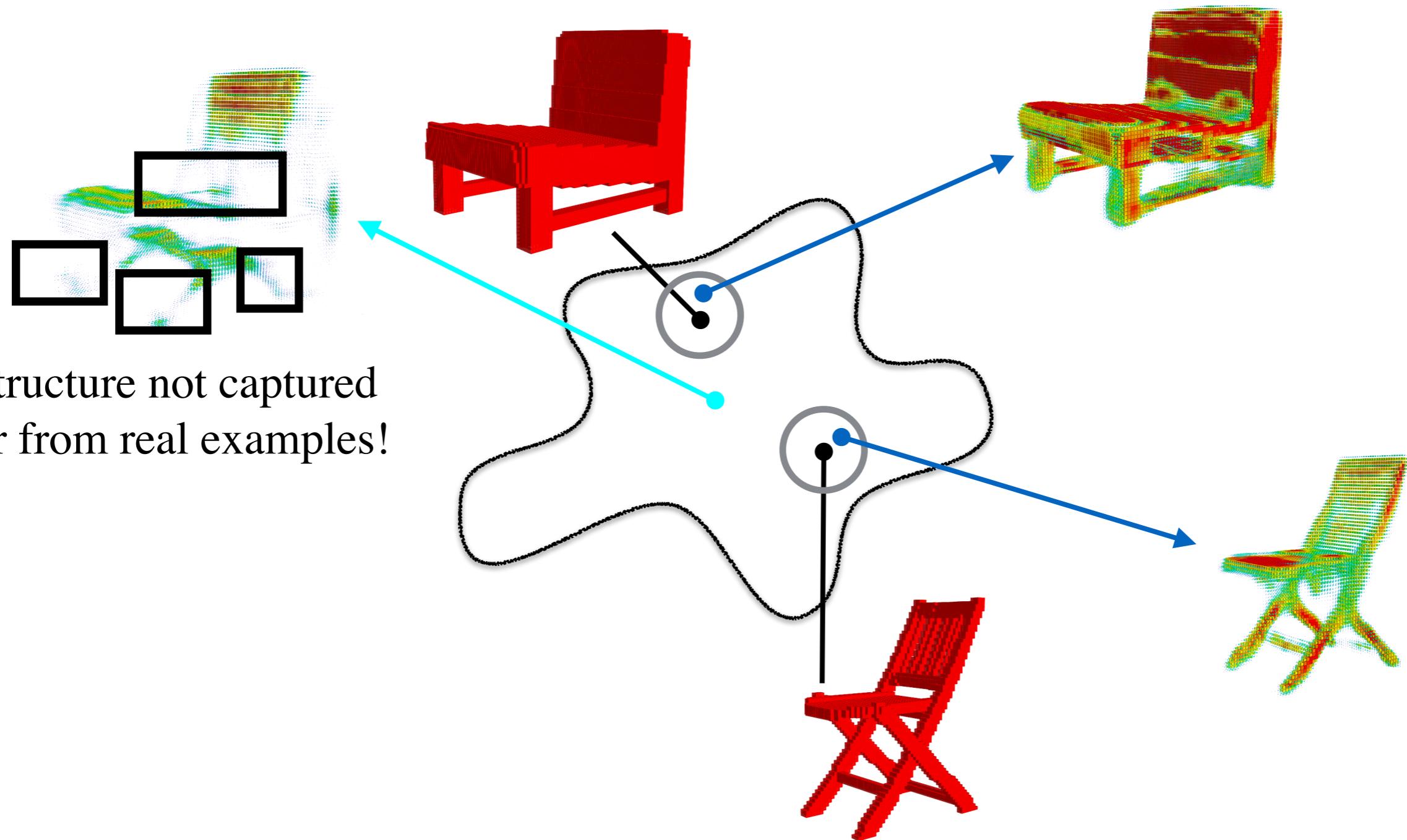


Structurally Correct Example

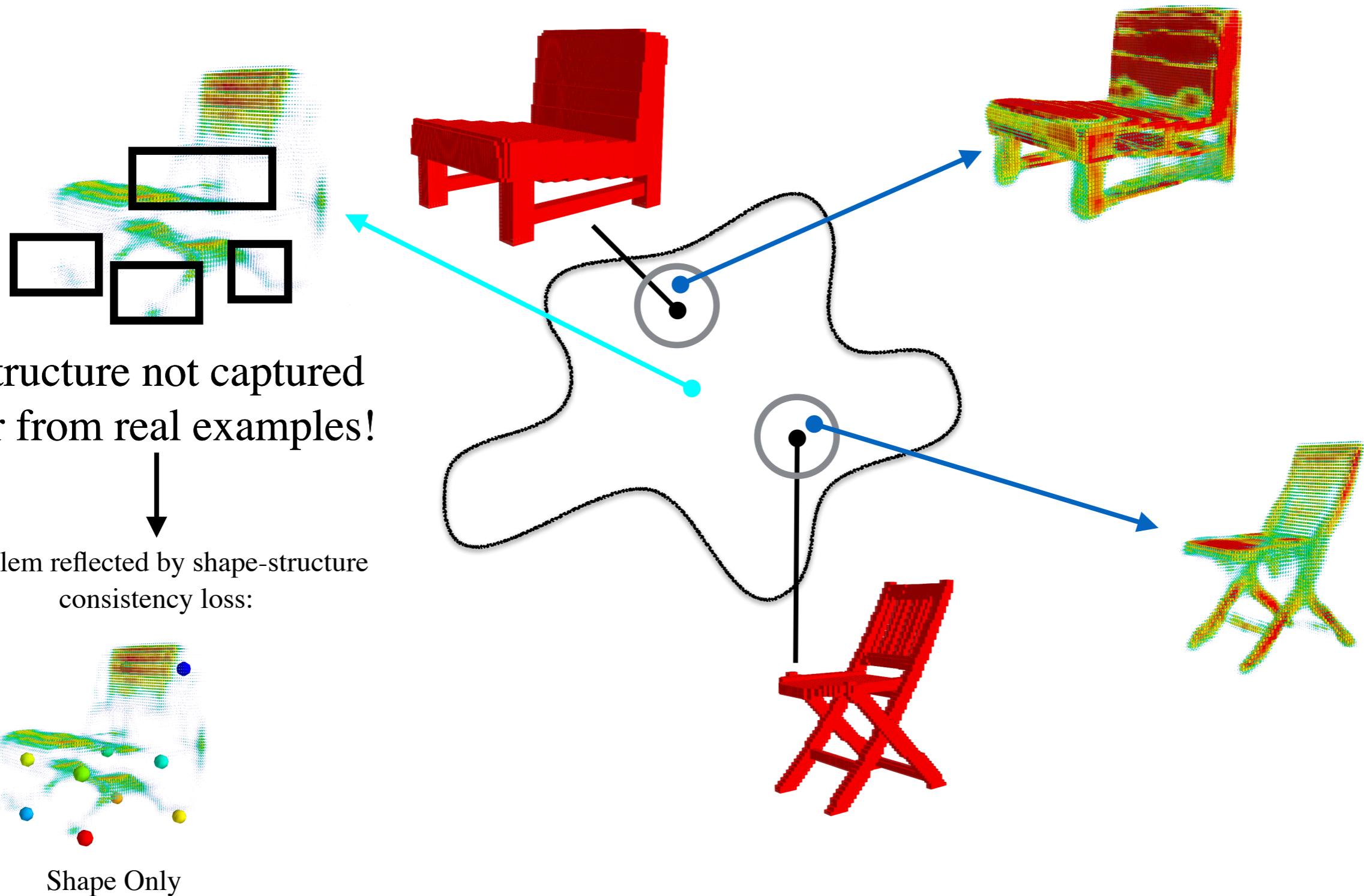
Manifold Learning



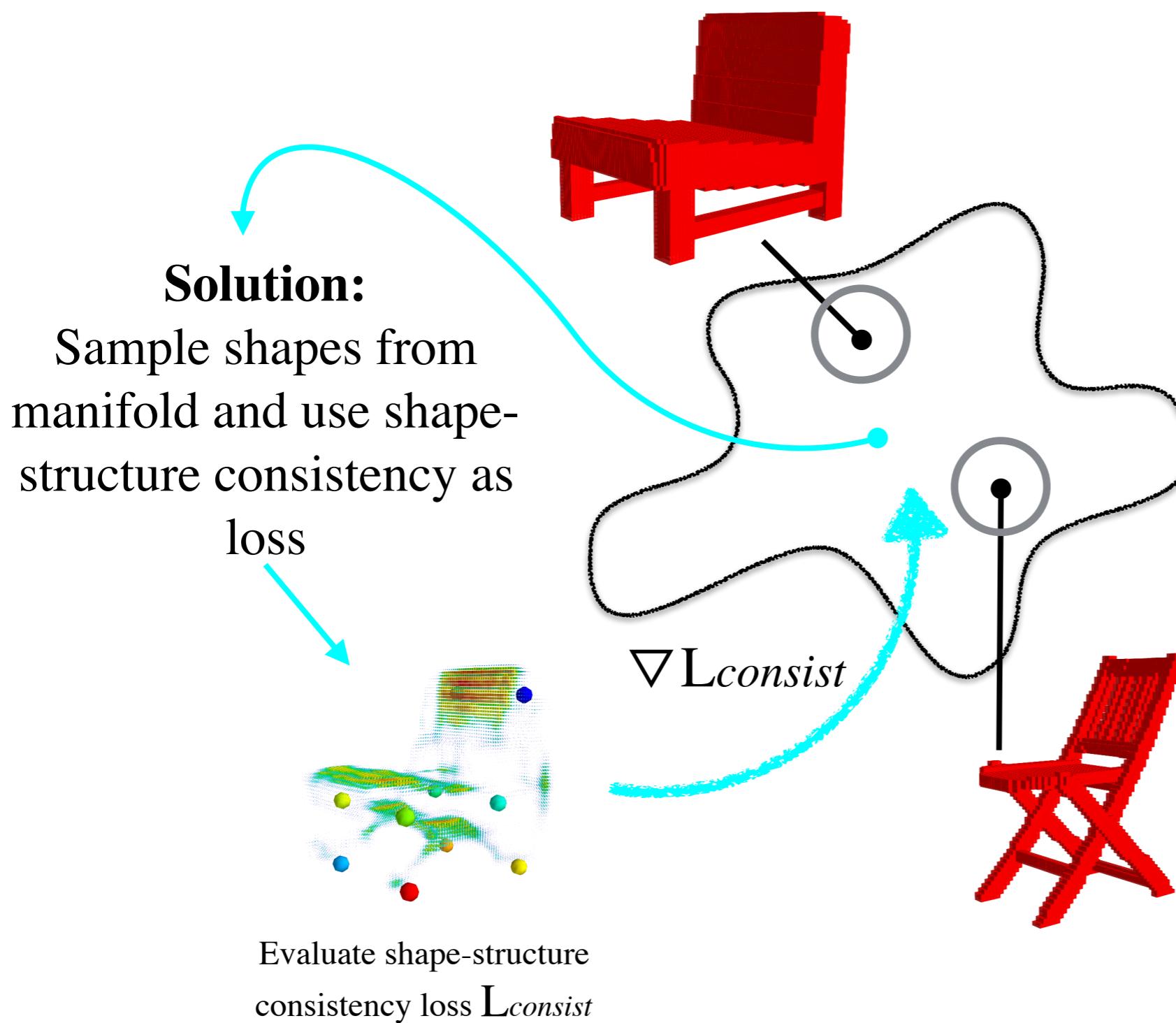
Manifold Learning



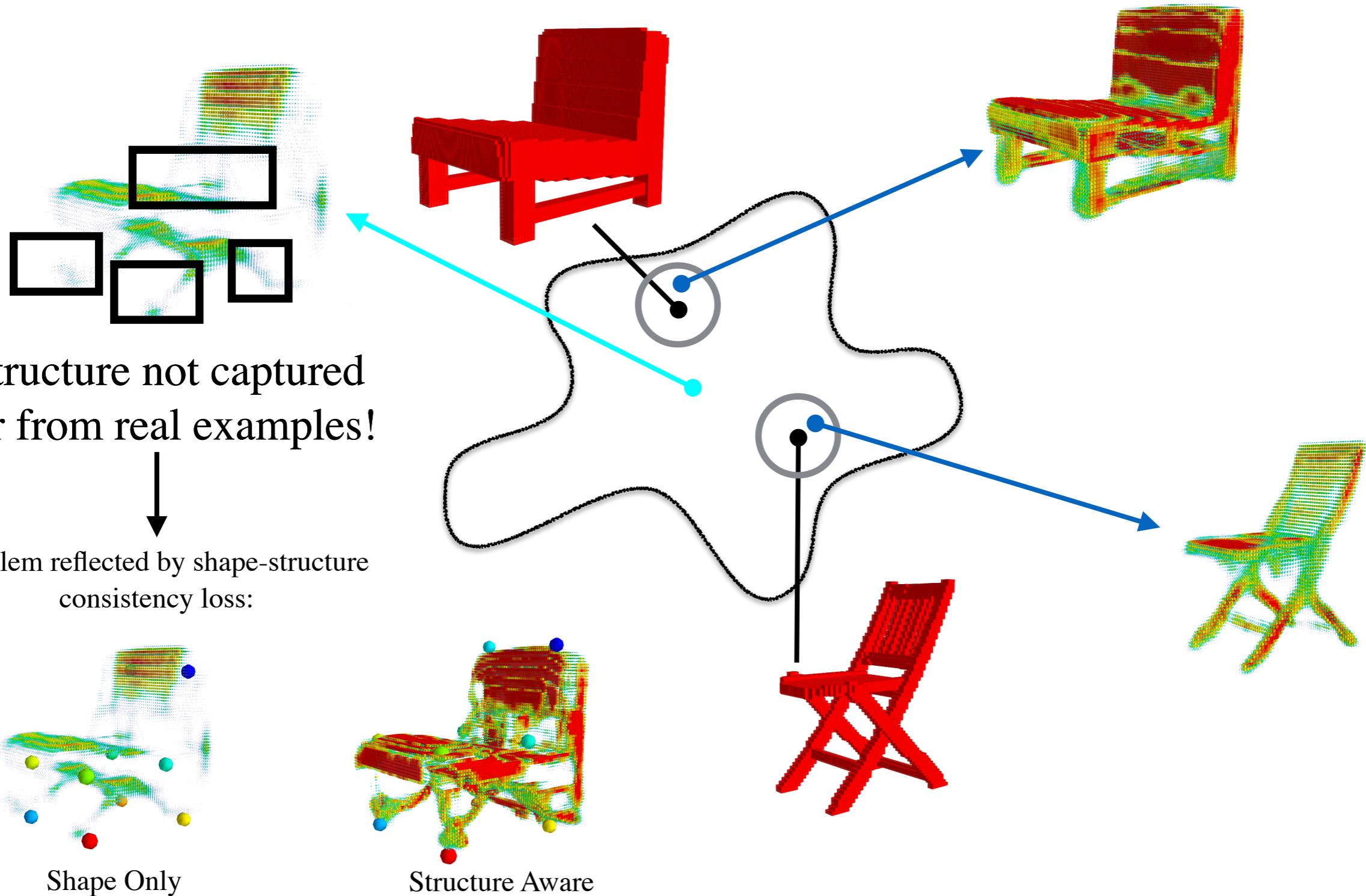
Manifold Learning



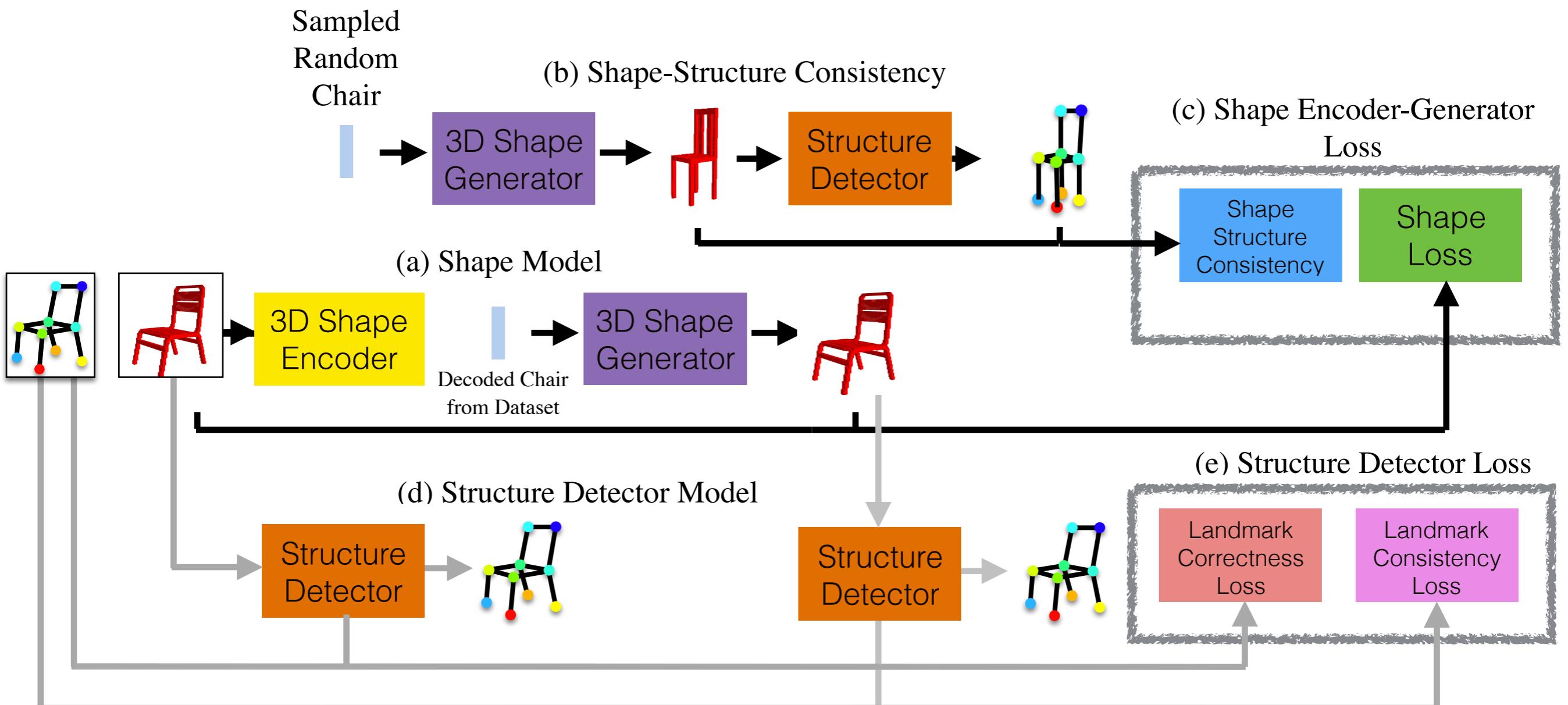
Manifold Learning



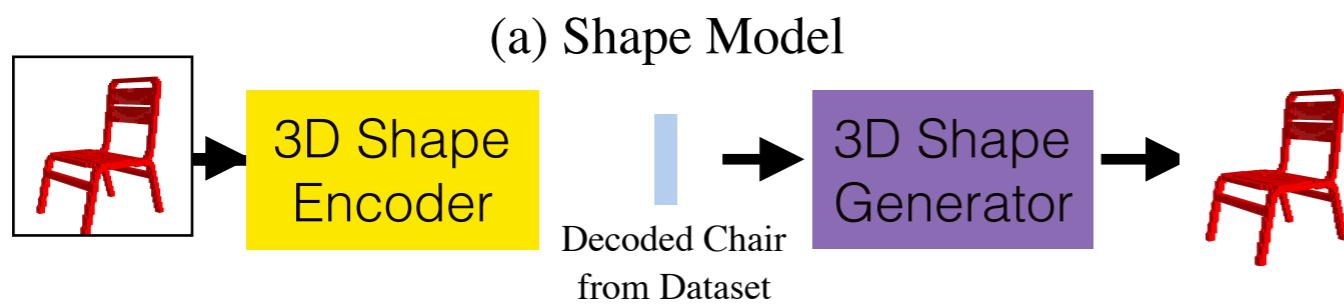
Manifold Learning



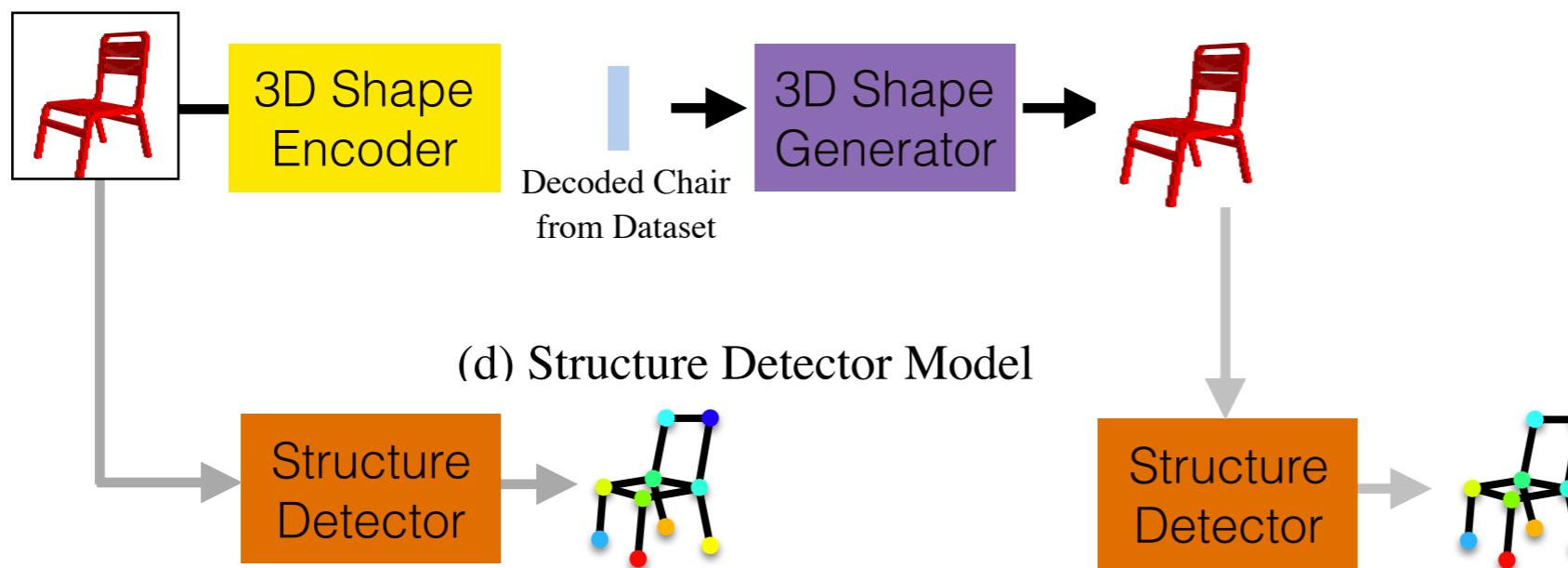
Overview: Structure-Aware Approach



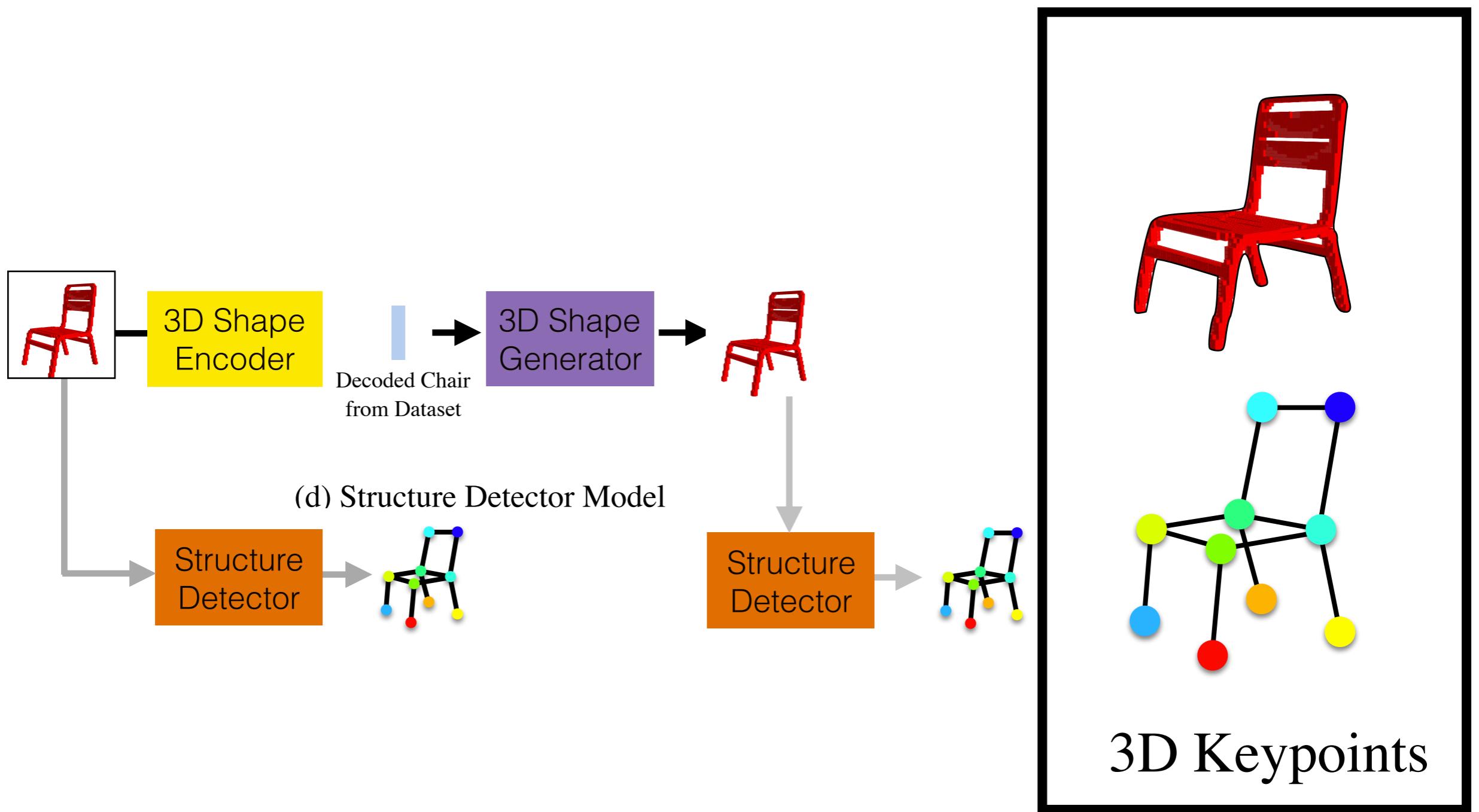
Overview: Structure-Aware Approach



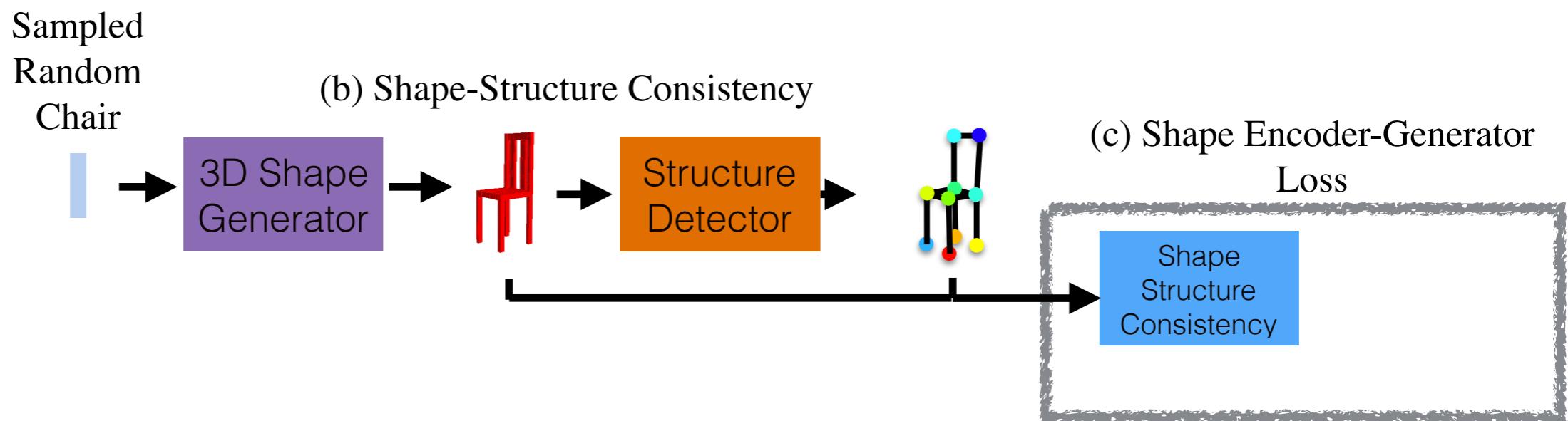
Overview: Structure-Aware Approach



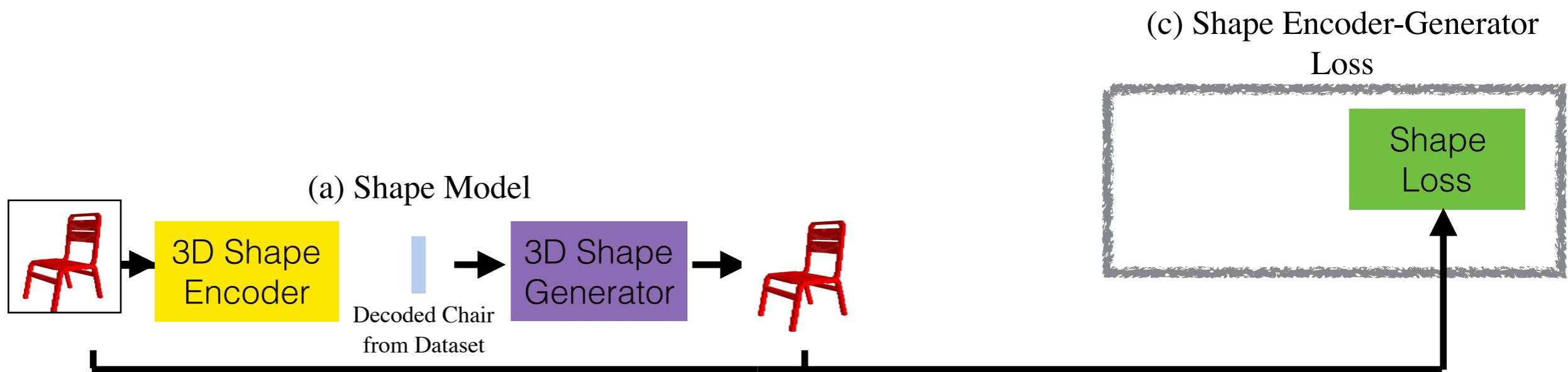
Overview: Structure-Aware Approach



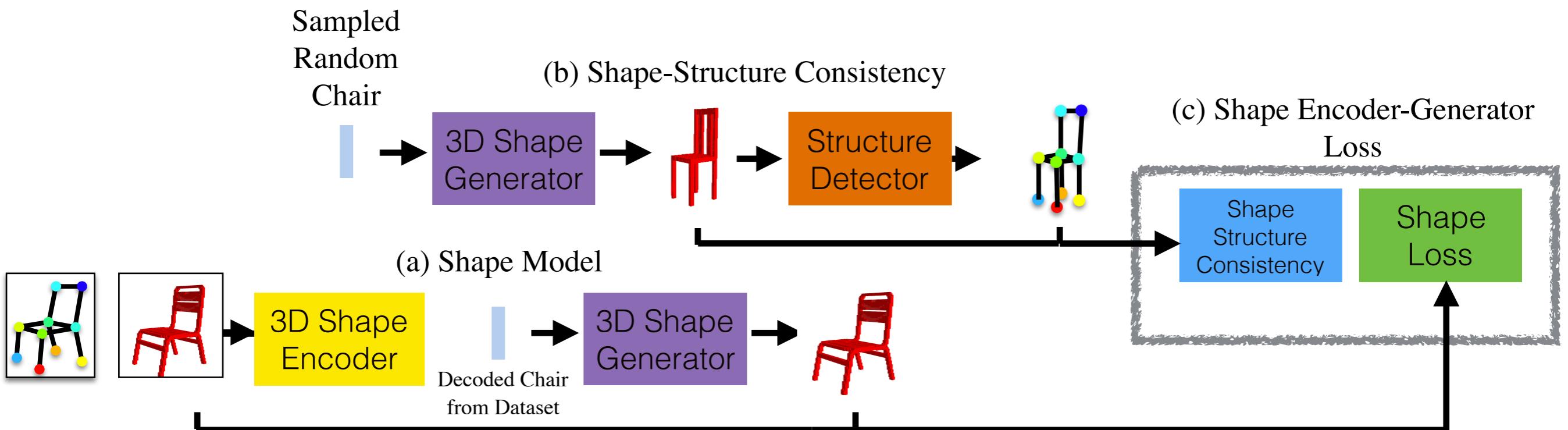
Overview: Structure-Aware Approach



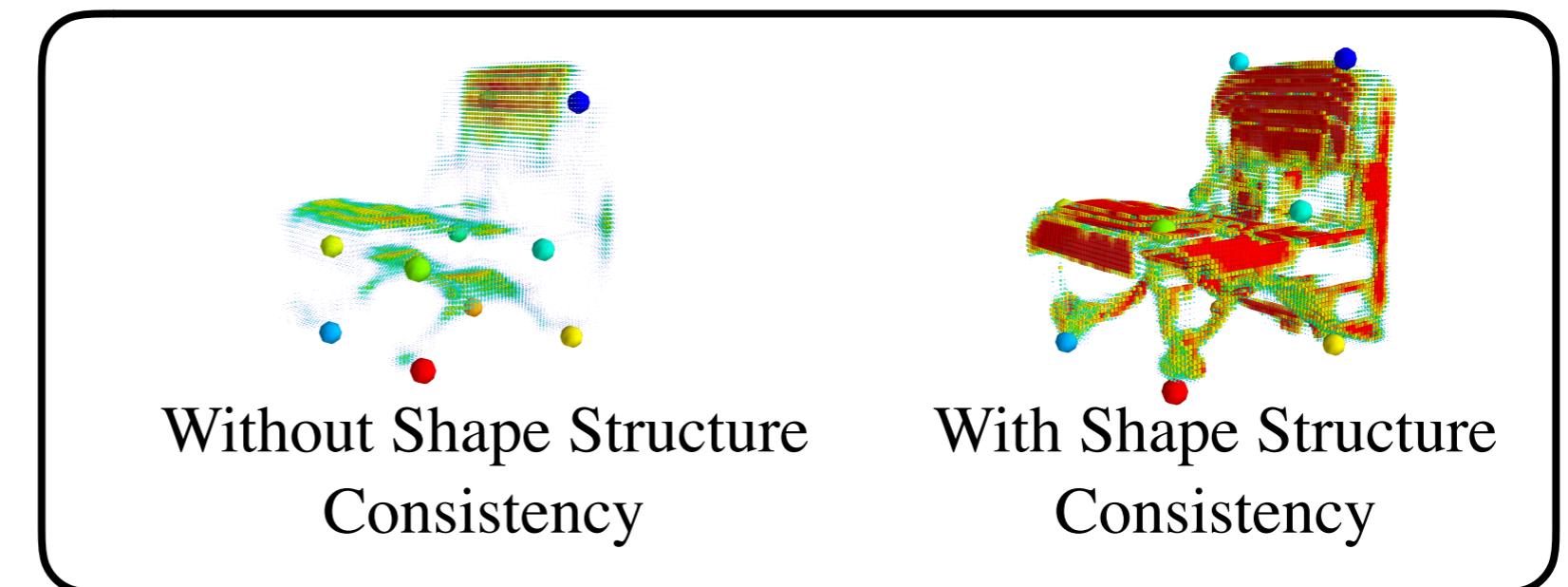
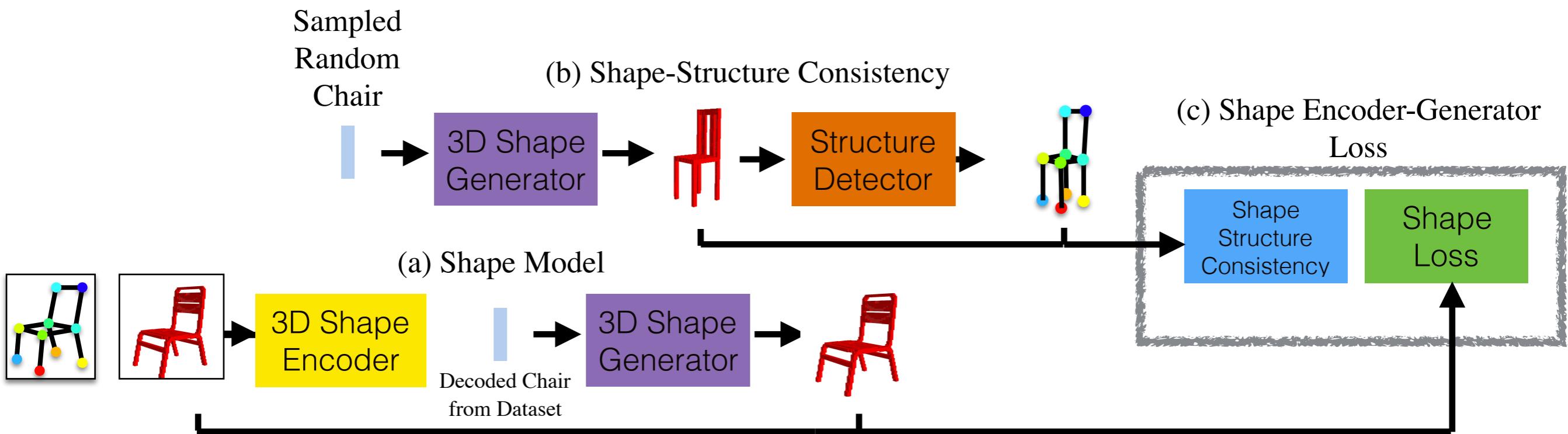
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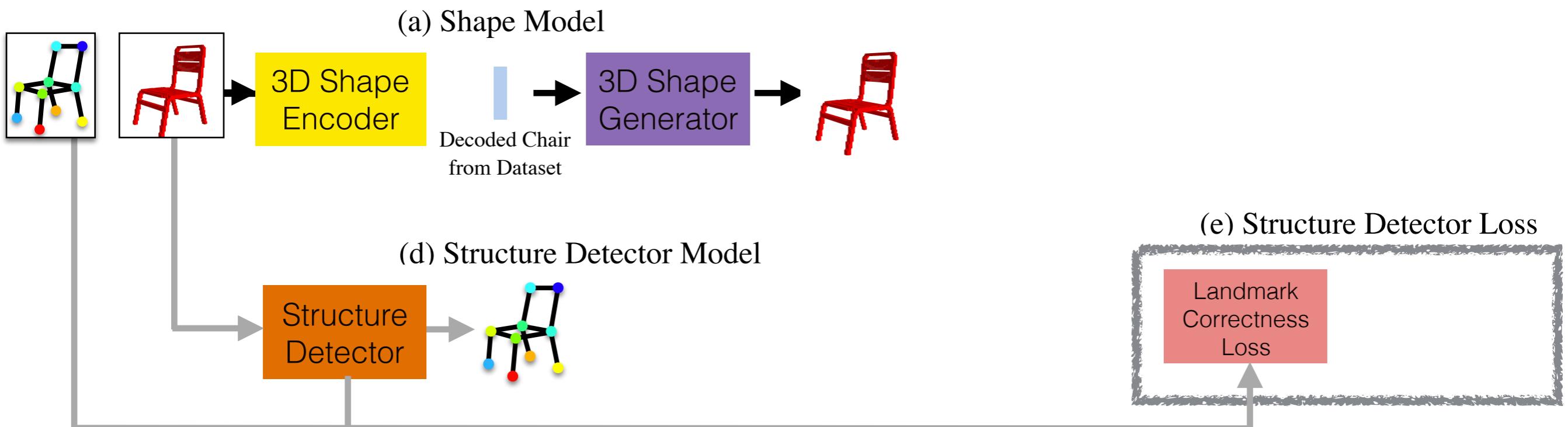
Overview: Structure-Aware Approach



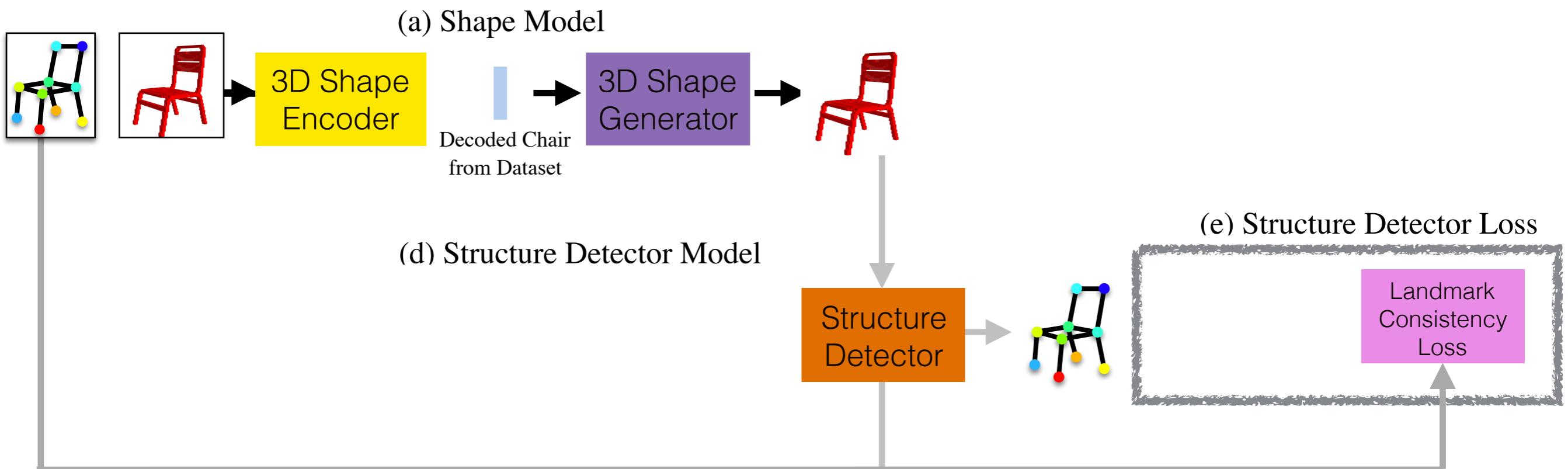
Overview: Structure-Aware Approach



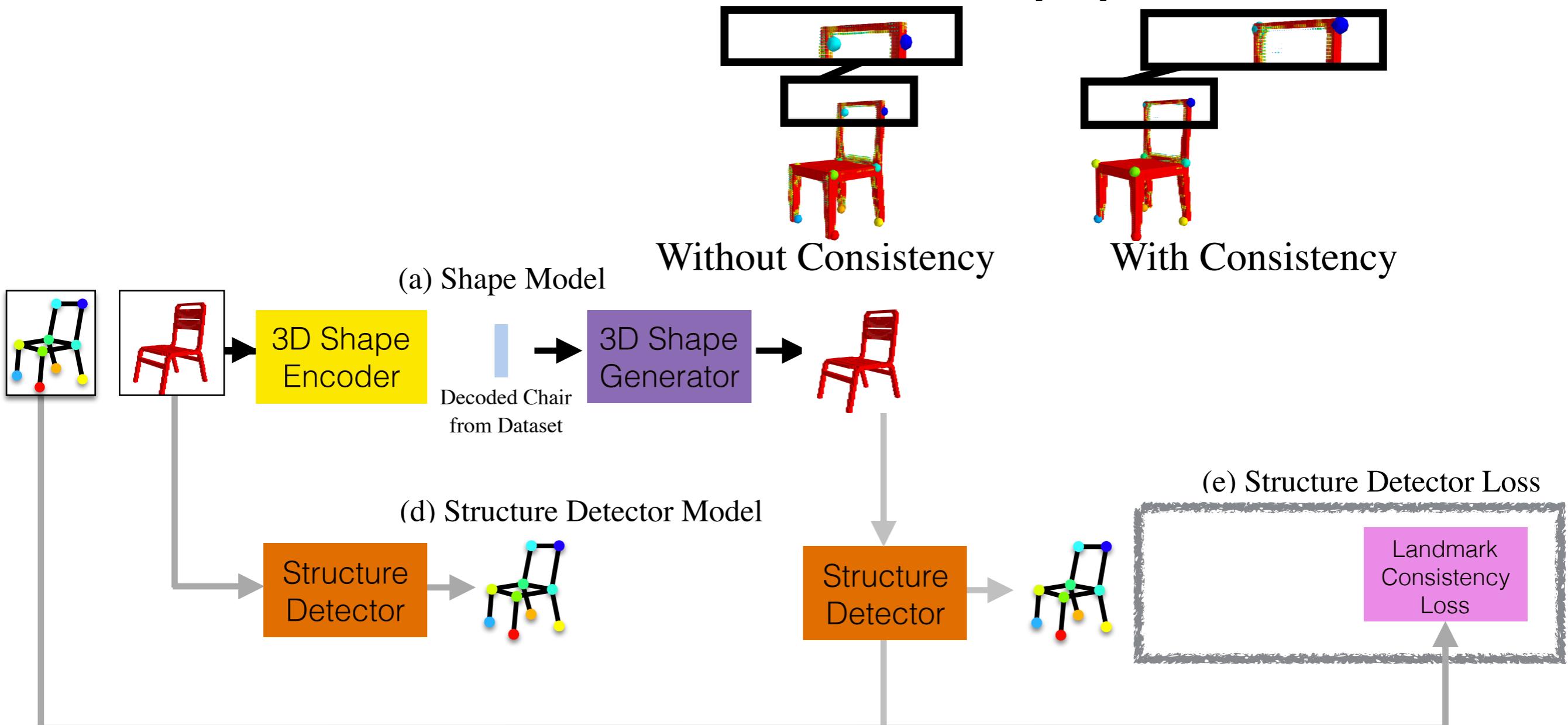
Overview: Structure-Aware Approach



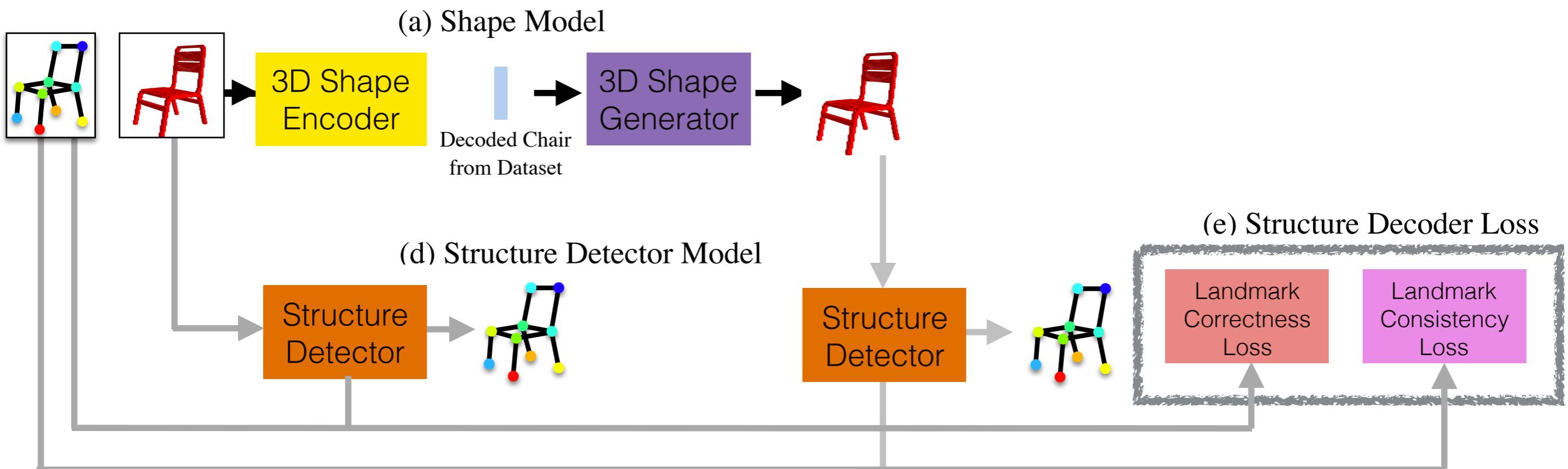
Overview: Structure-Aware Approach



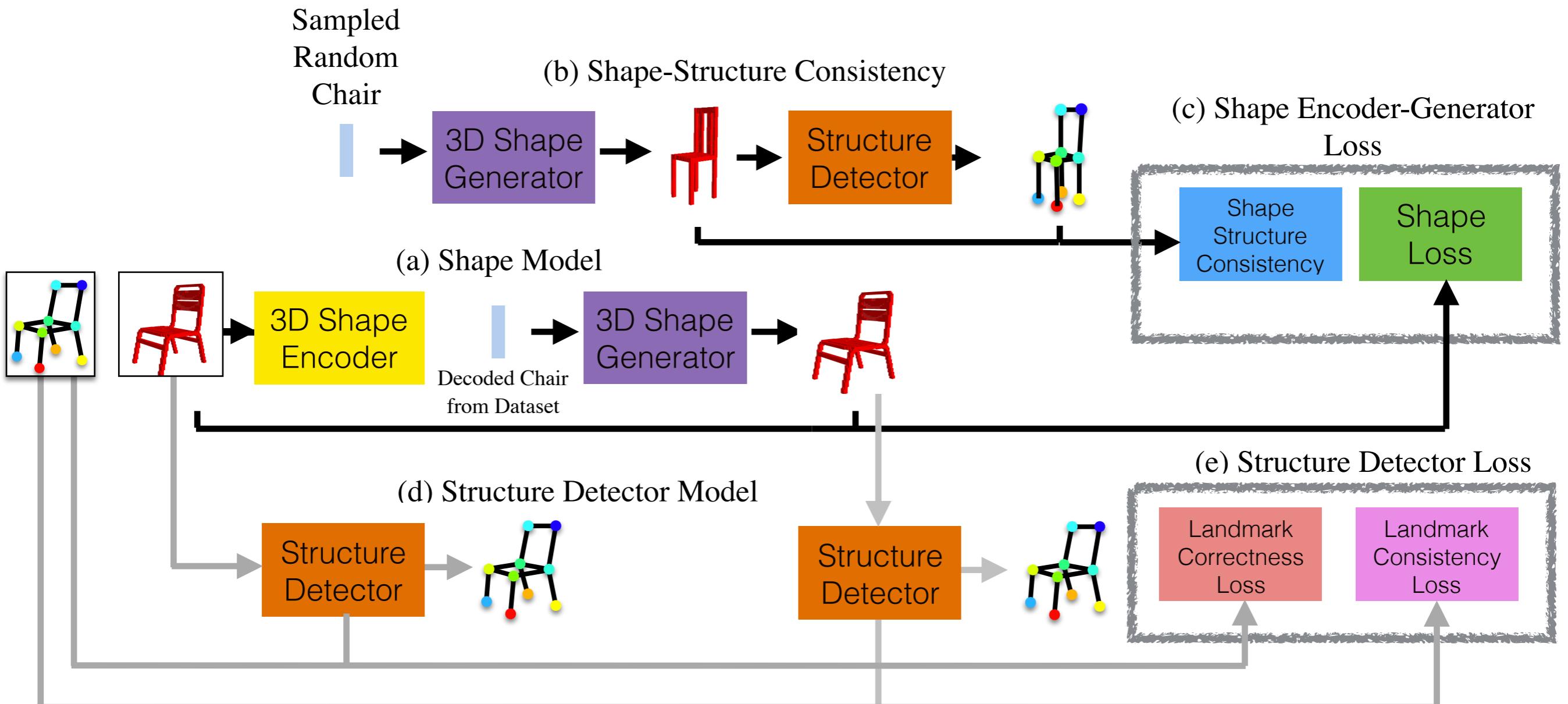
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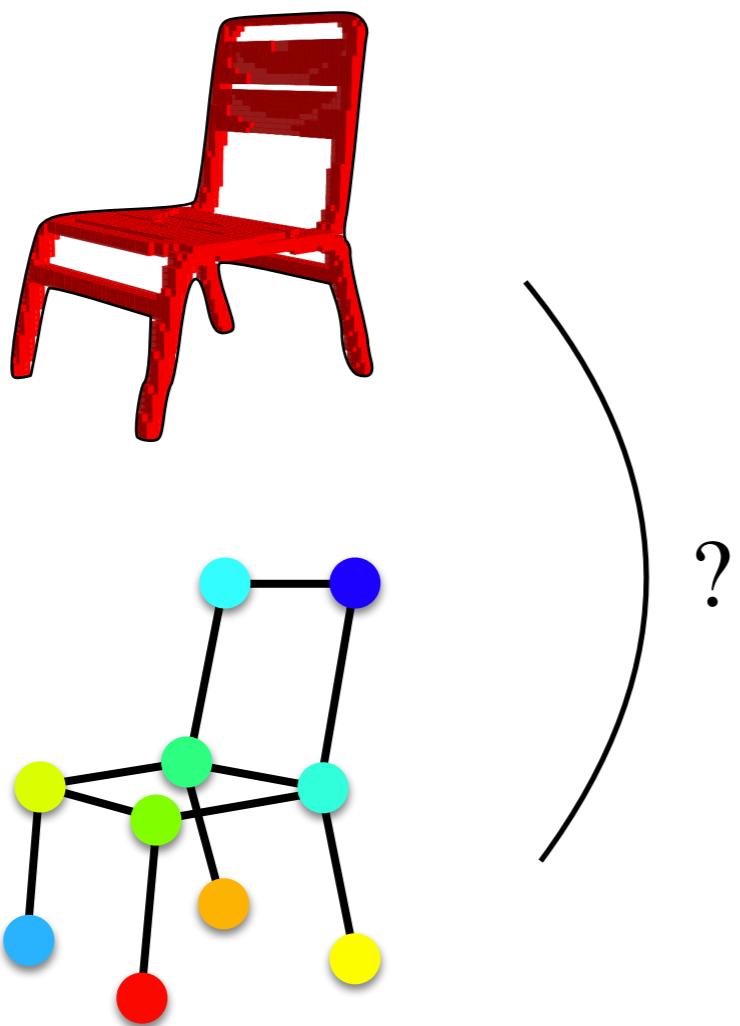
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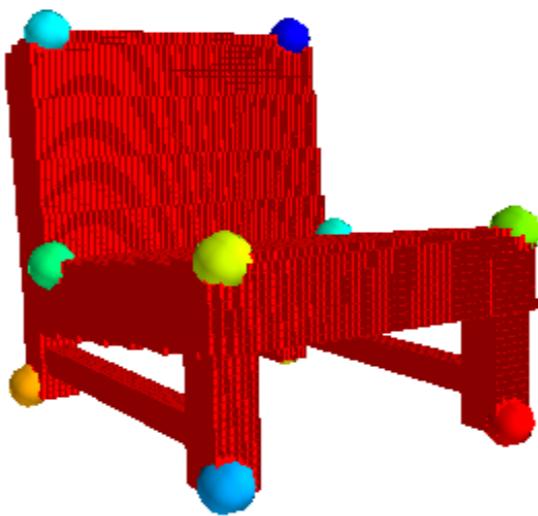


Shape Structure Consistency

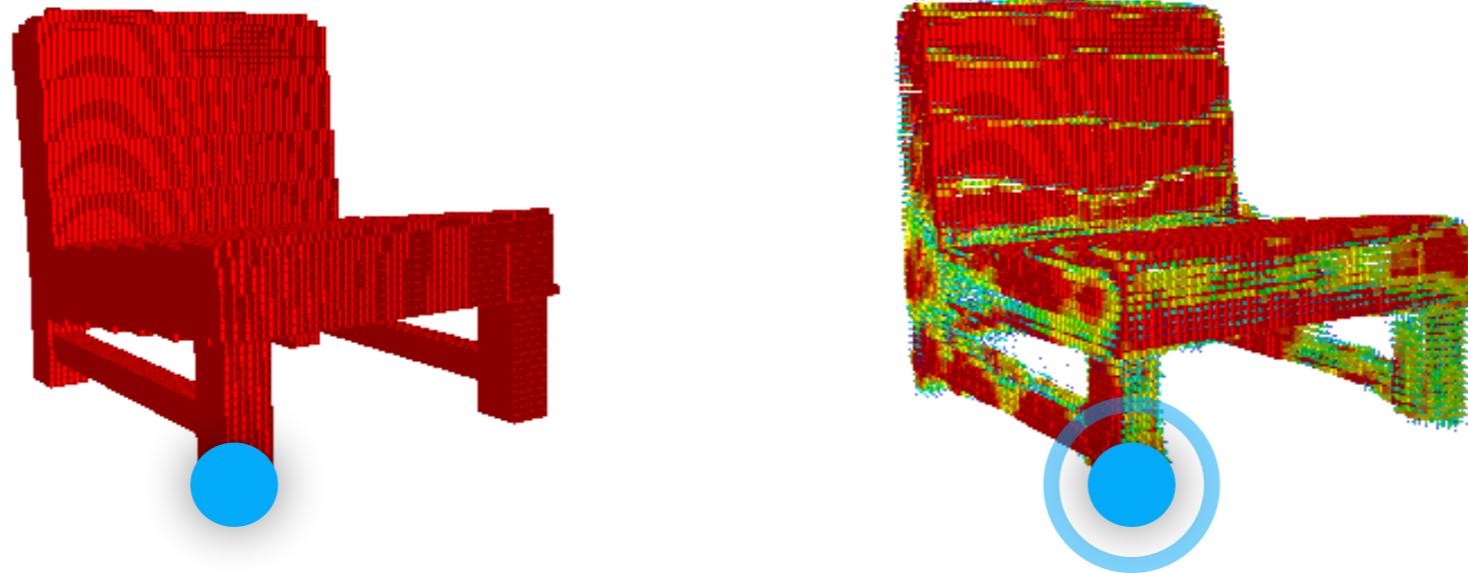


Set of 3D Keypoints

Shape Structure Consistency



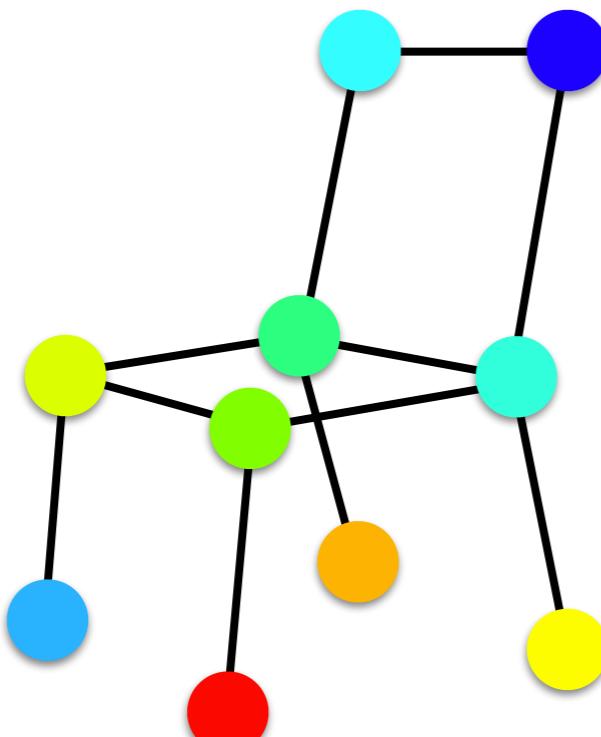
(a) Landmark Structure



(b) Shape - Structure Consistency

Dataset

	# 3D Models	# of Landmarks	# of Landmark Annotated Models (Yi [CVPR '17])
Chair Shapenet [Chang '15]	Train: 5422 Test: 1356	10	Train: 1296 Test: 374

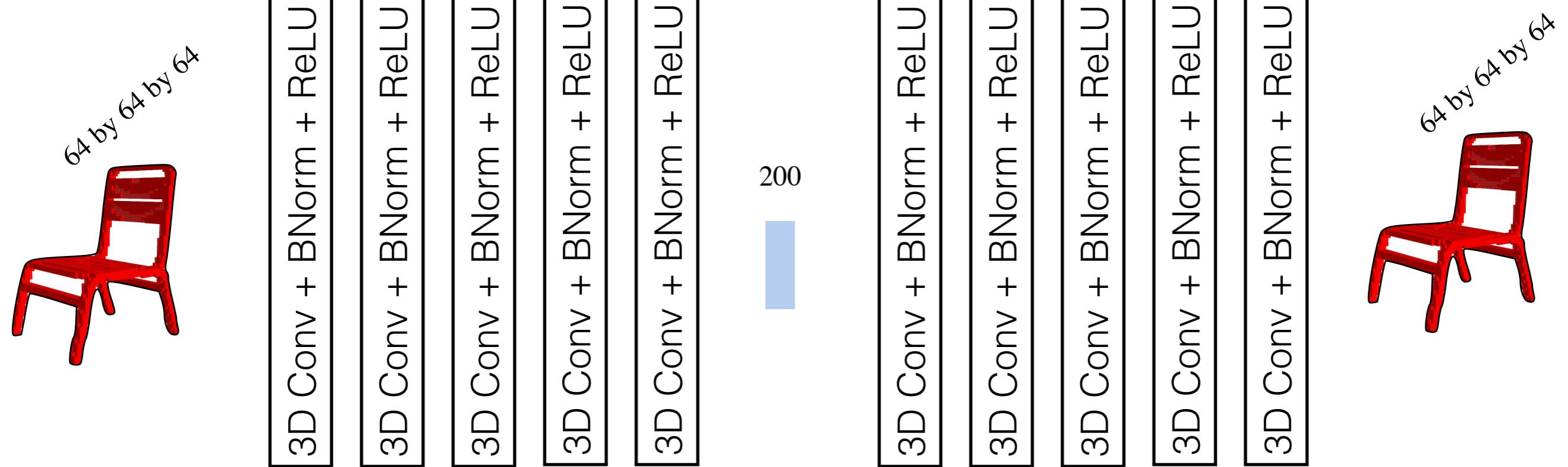




Architecture

3D Encoder and Generator

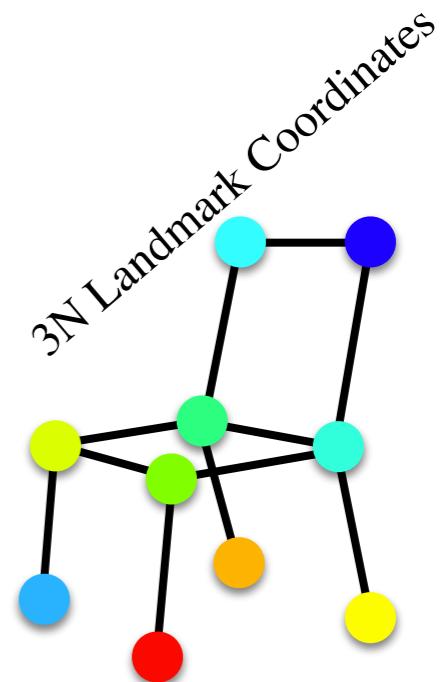
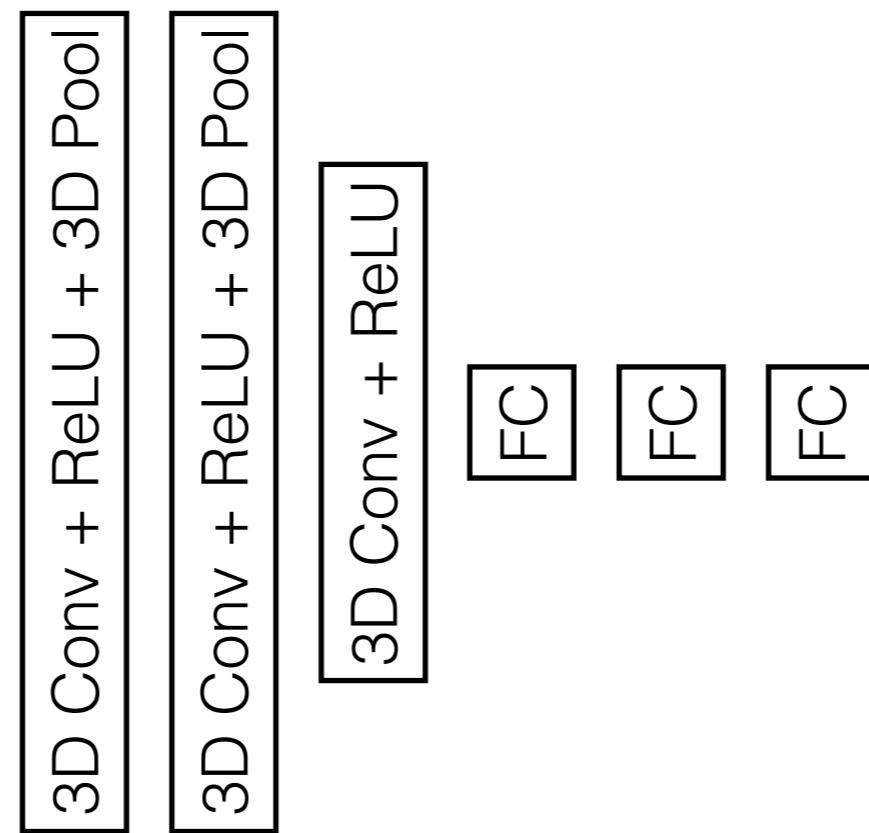
Based on Wu [NIPS'16]



Architecture

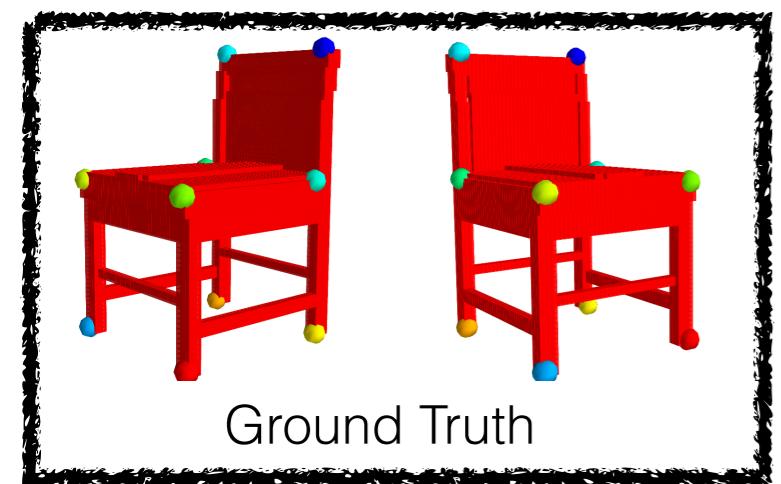
Structure Detector

Based on Ge [CVPR '17]

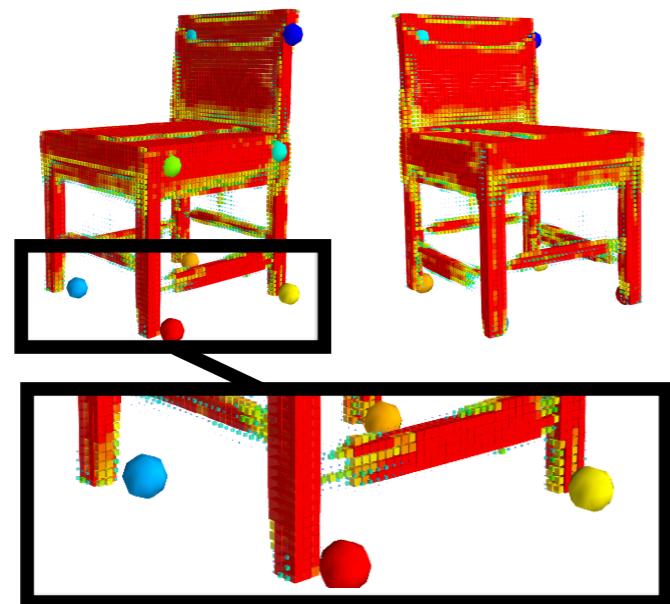


Experimental Results

Joint Learning



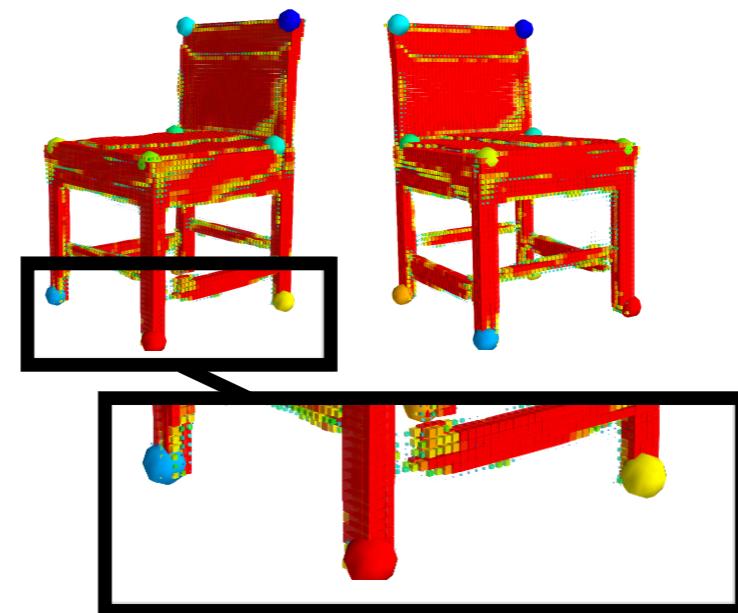
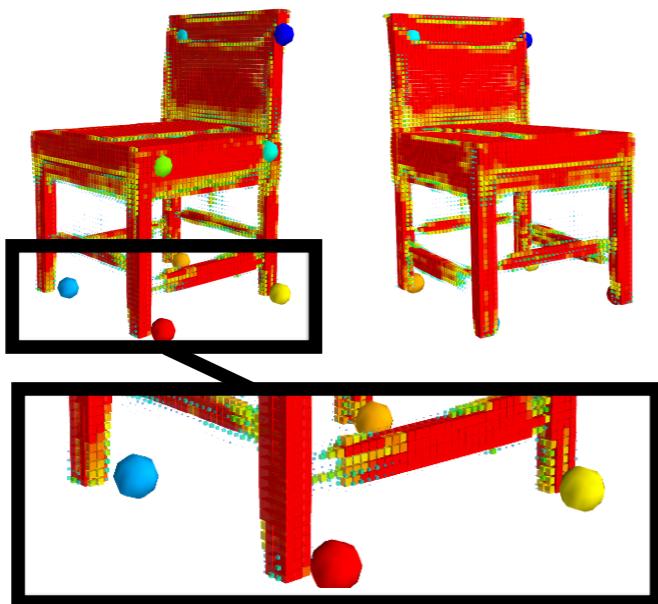
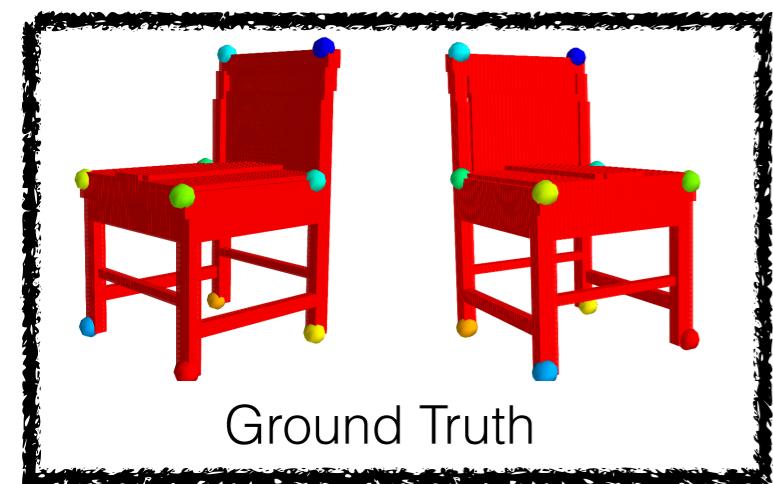
Ground Truth



Before Joint Training

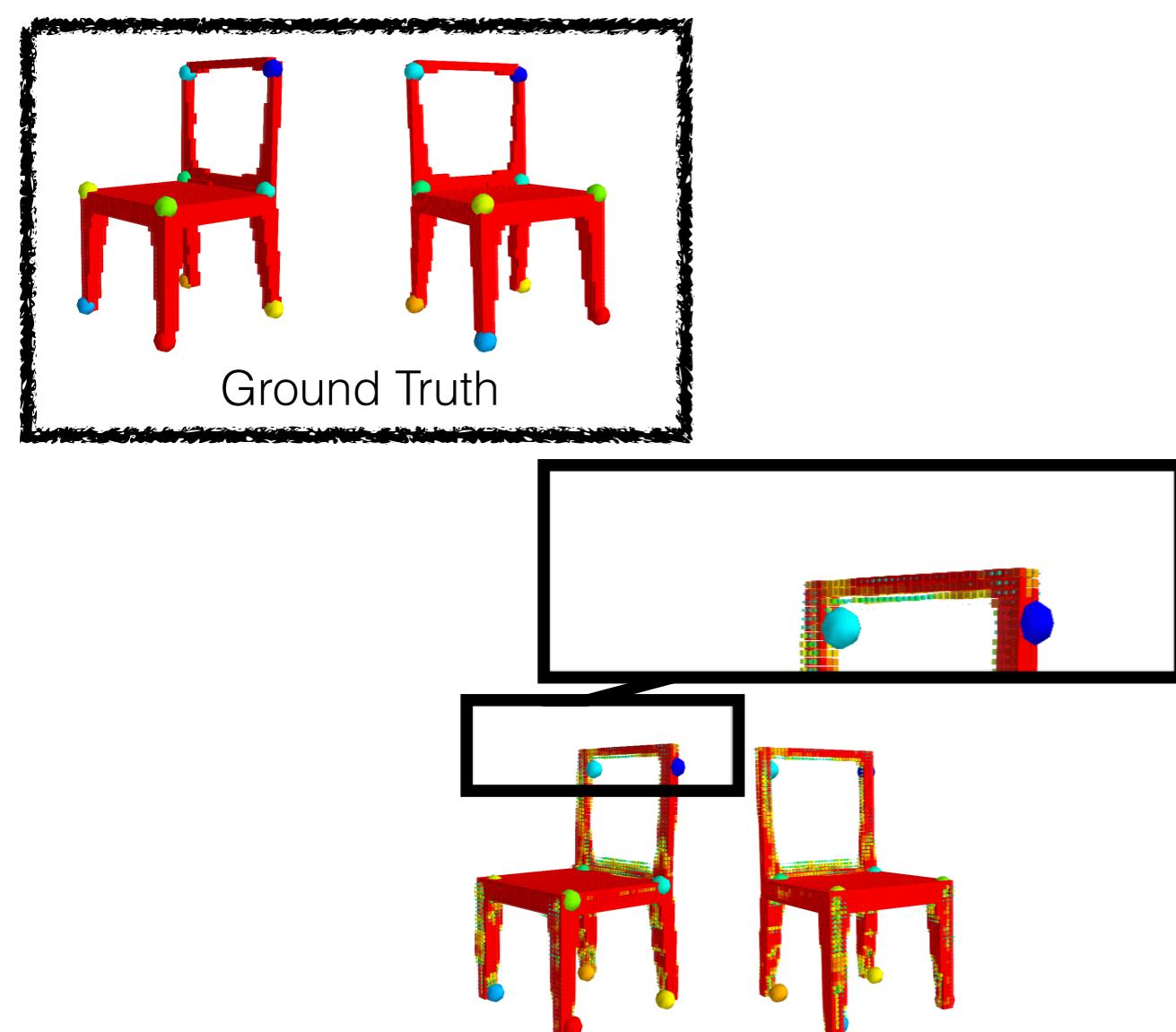
Structure detector learns to predict landmarks on
noisy shapes

Joint Learning



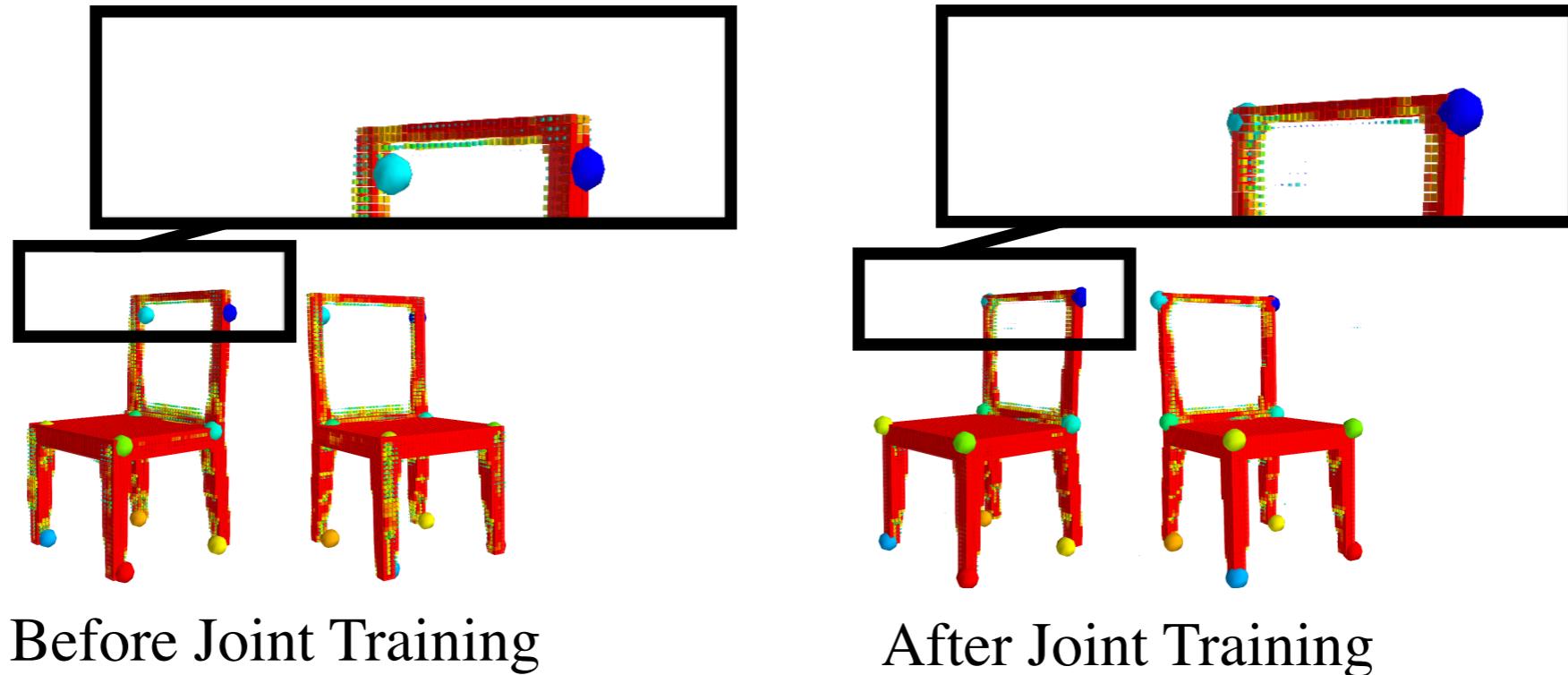
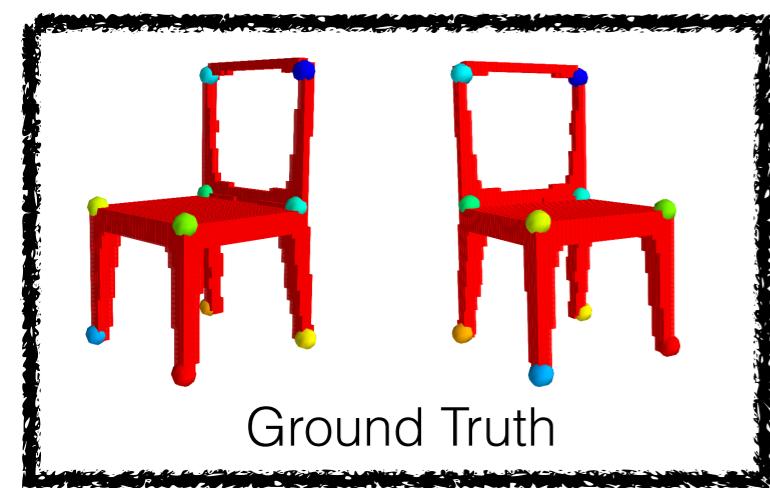
Structure detector learns to predict landmarks on
noisy shapes

Joint Learning



Structure decoder learns to predict landmarks on
noisy shapes

Joint Learning



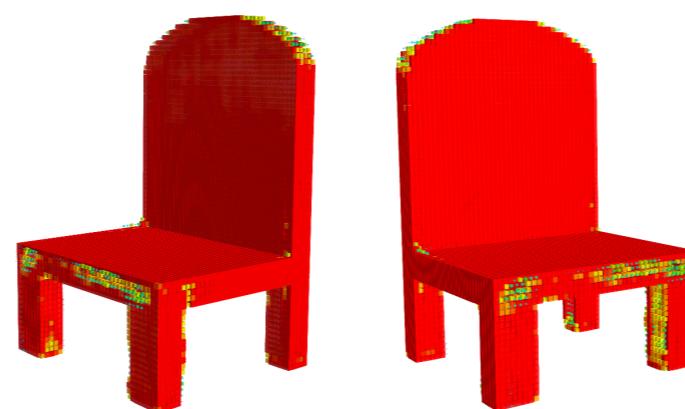
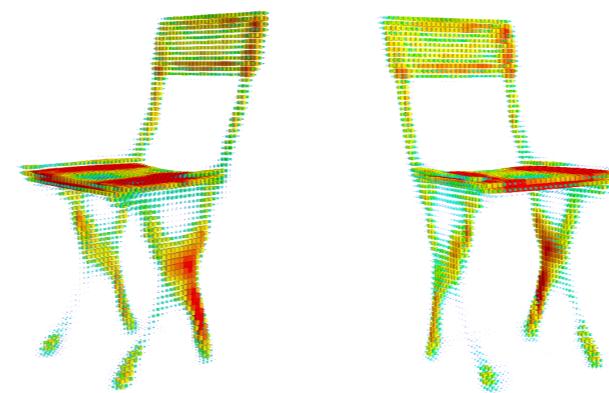
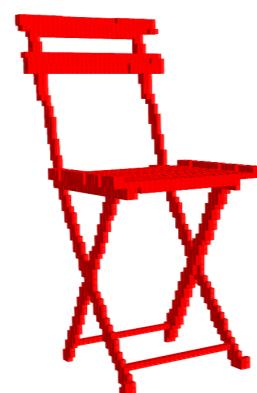
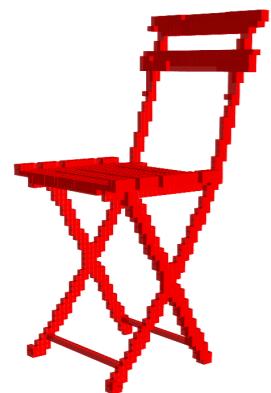
Structure decoder learns to predict landmarks on
noisy shapes

Joint Learning



Input Shape

Joint Learning



Input Shape

Shape Only

Joint Learning



Input Shape

Shape Only

Structure Aware

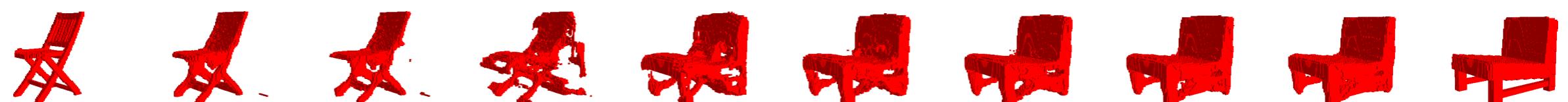
Interpolation

Interpolation

Shape
Only



Structure
Aware



Shape
Only



Structure
Aware



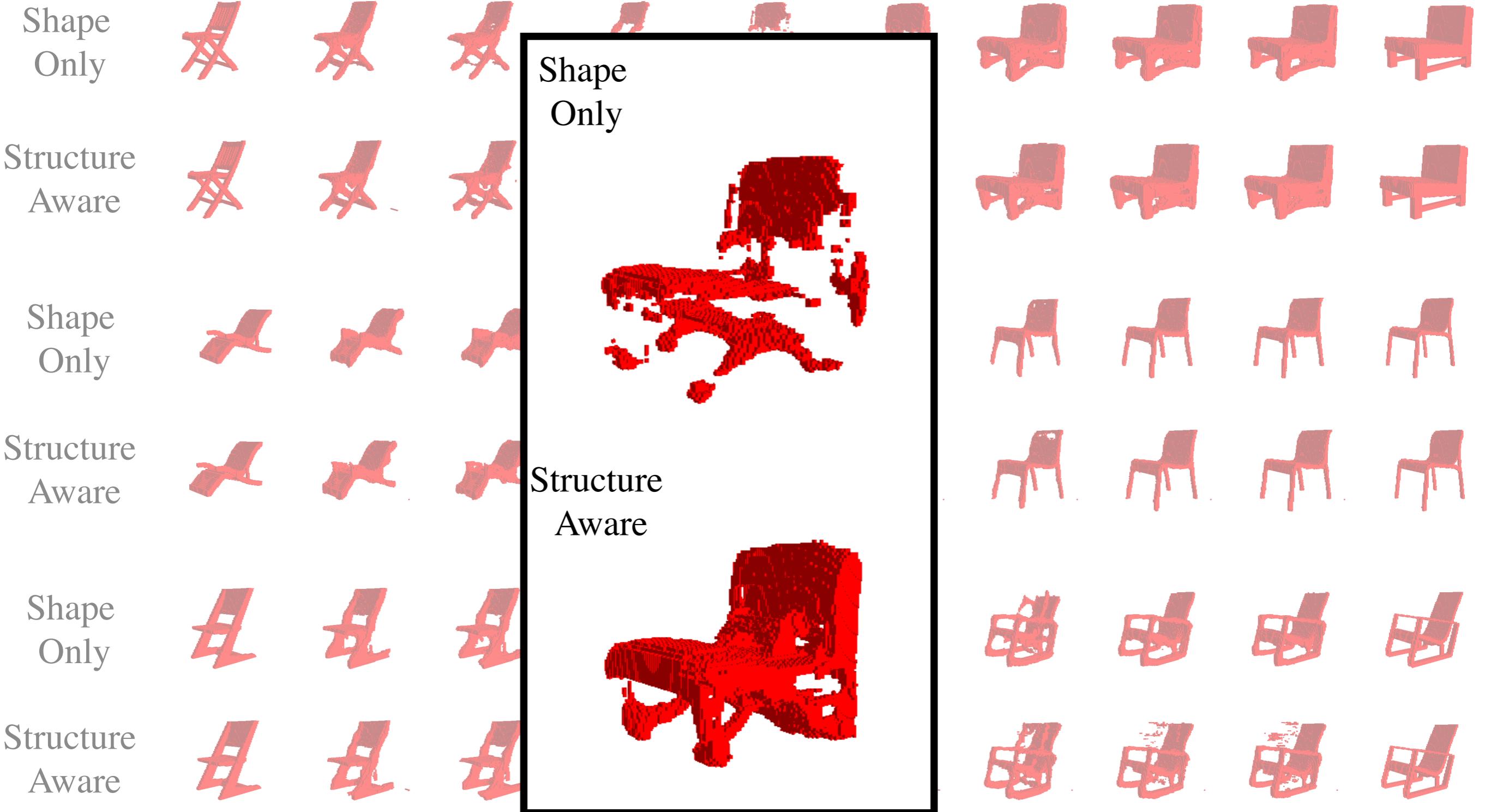
Shape
Only



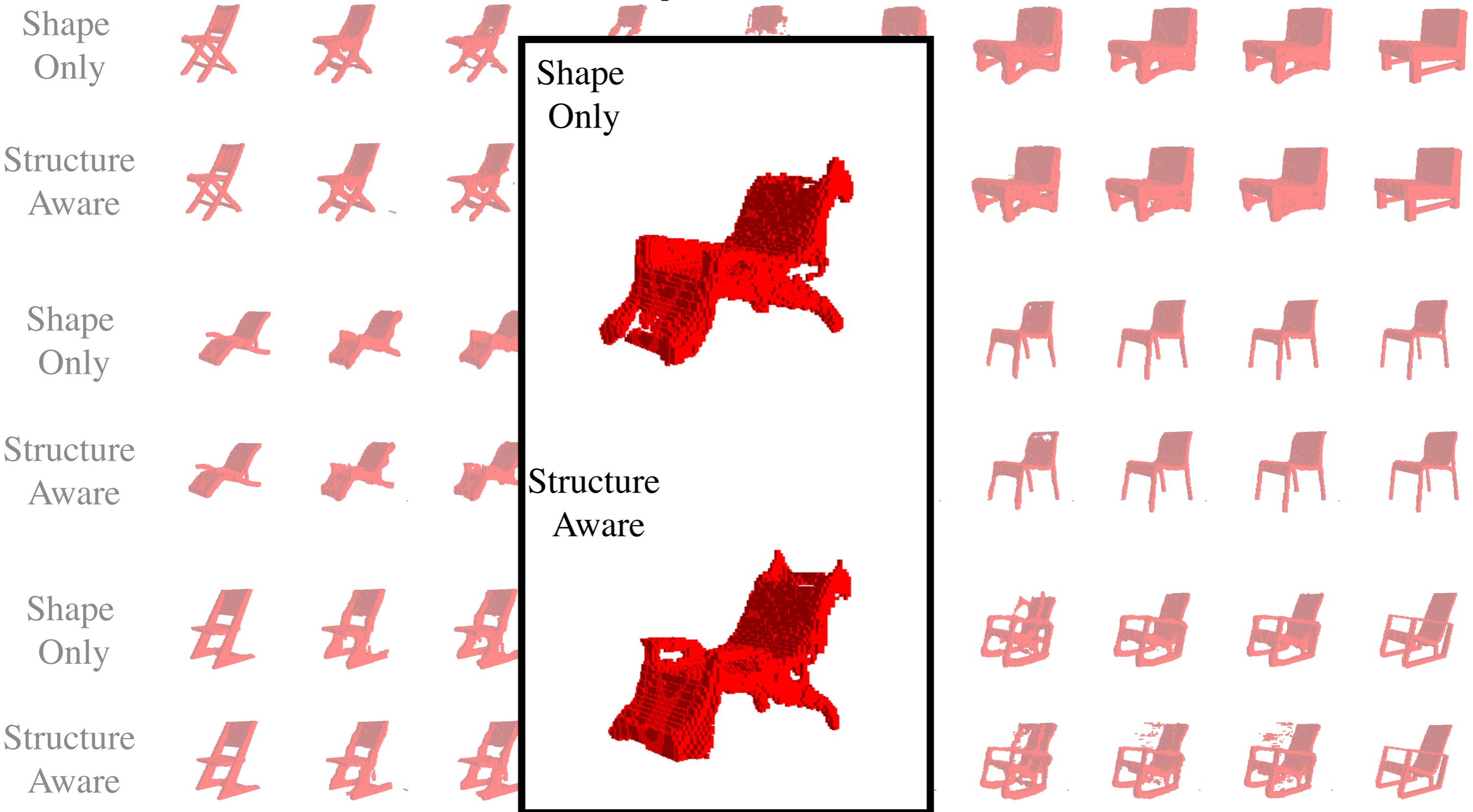
Structure
Aware



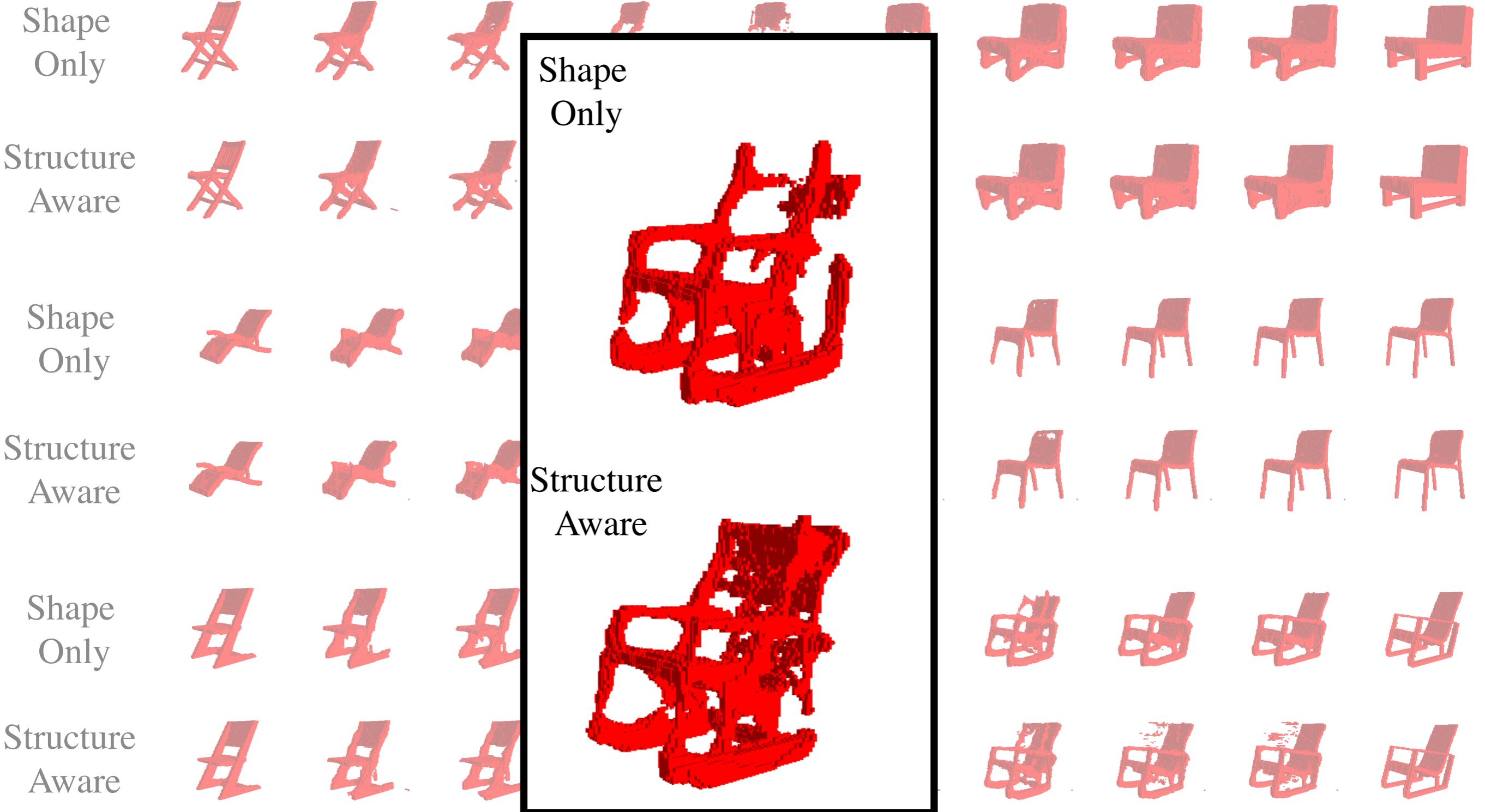
Interpolation



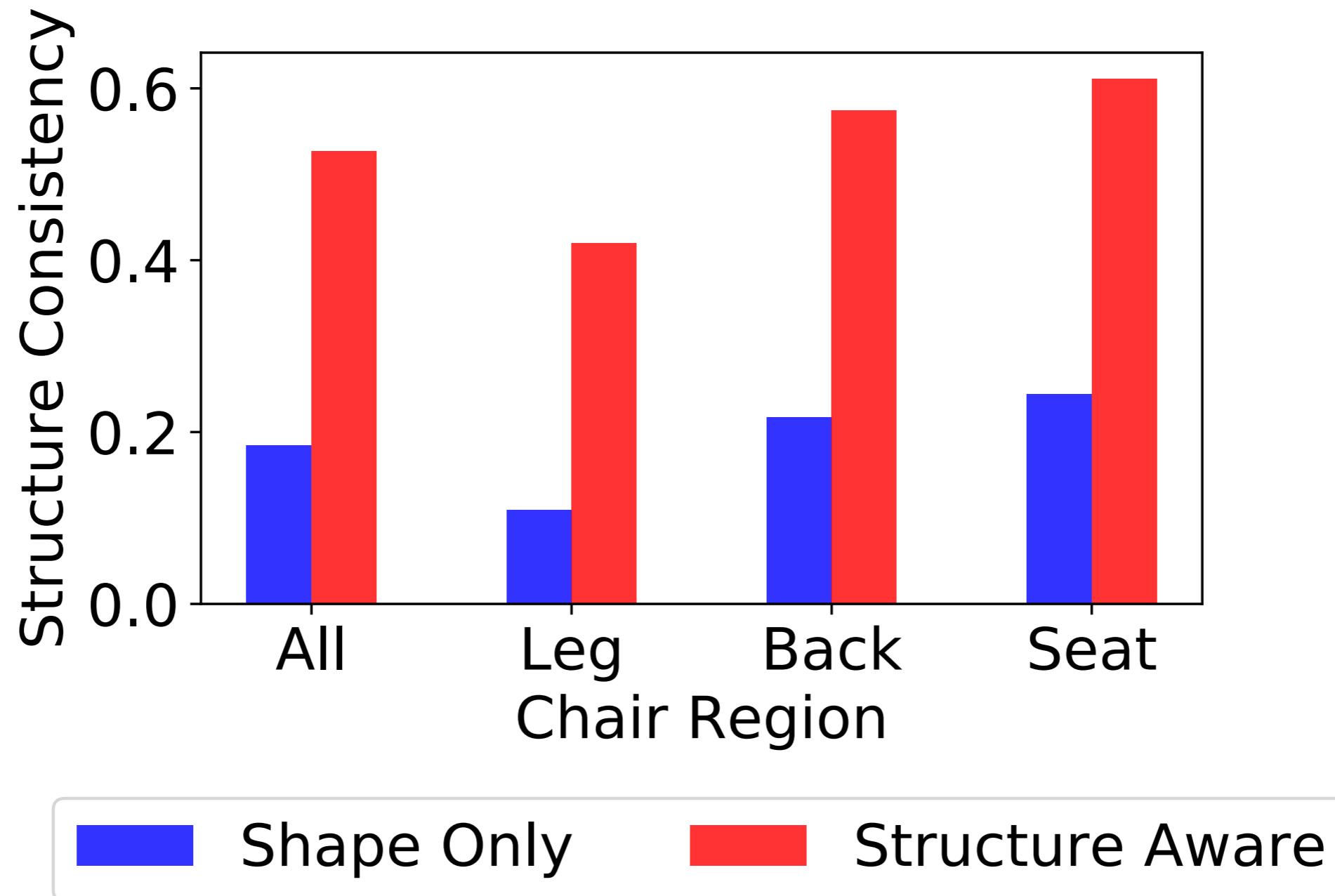
Interpolation



Interpolation



Landmark Consistency

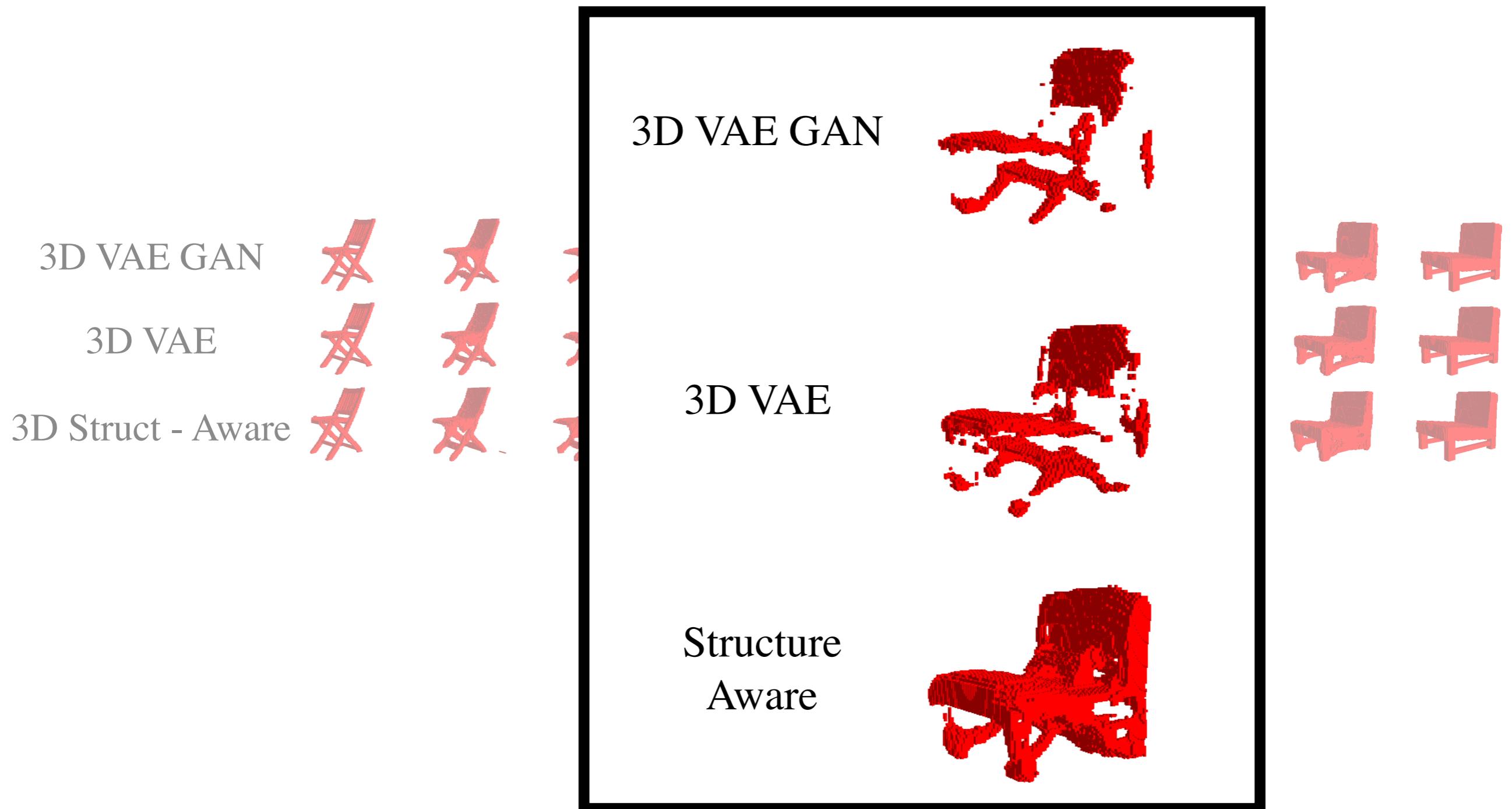


Comparison to 3D GAN

Comparison to 3D GAN

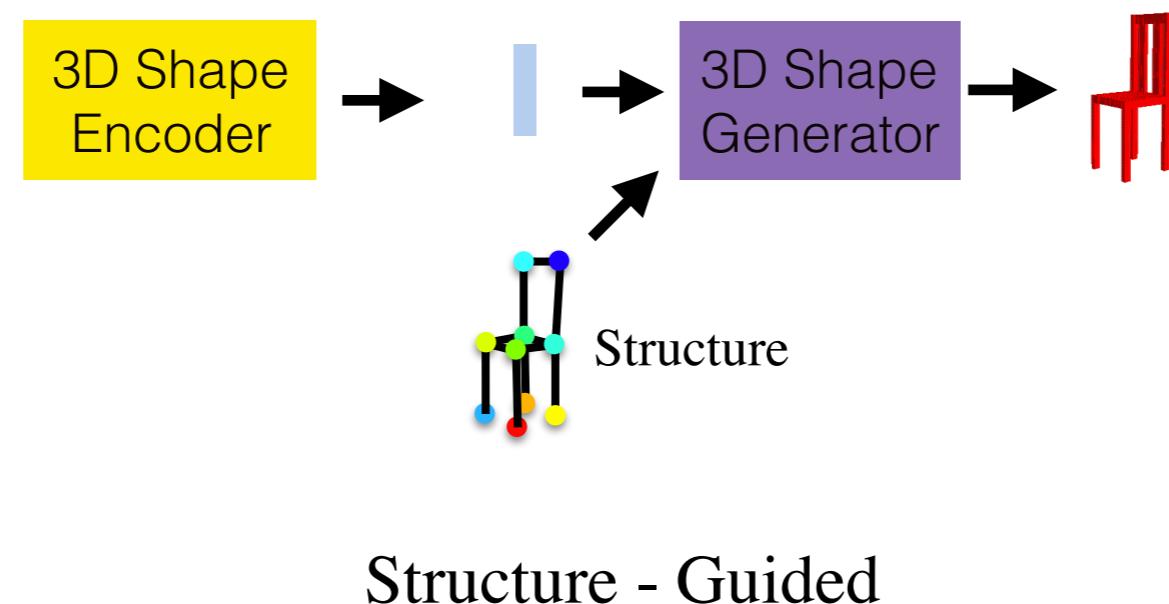
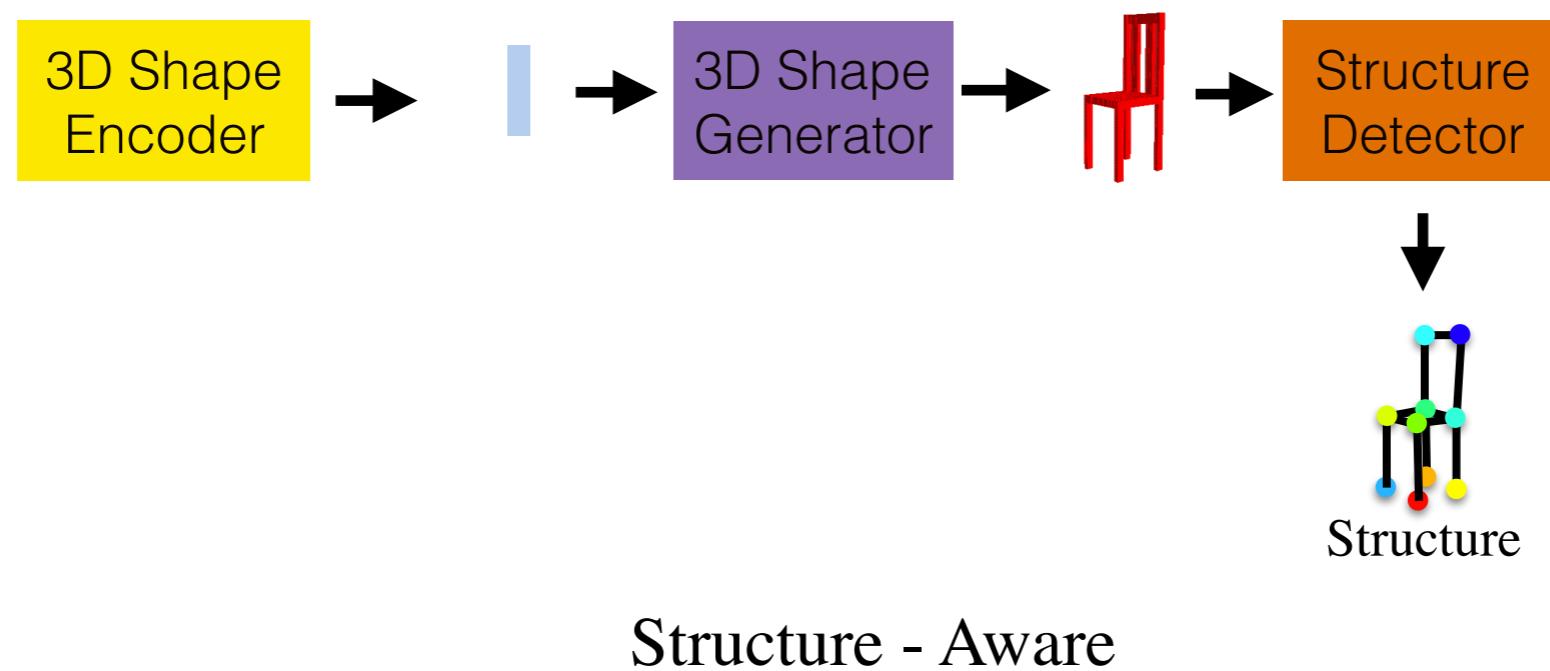


Comparison to 3D GAN

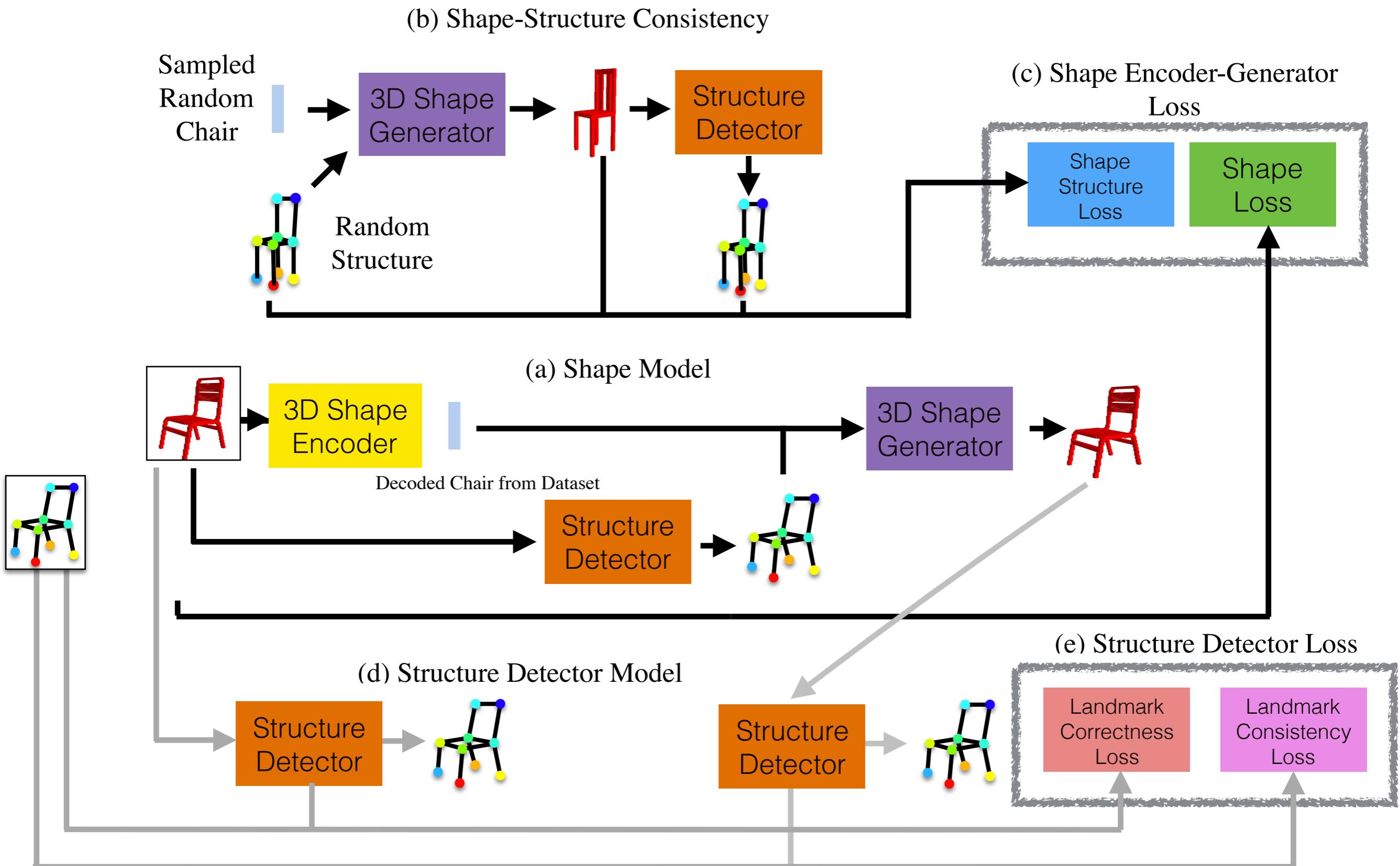


Overview: Structure-Guided Approach

Overview: Structure-Guided Approach



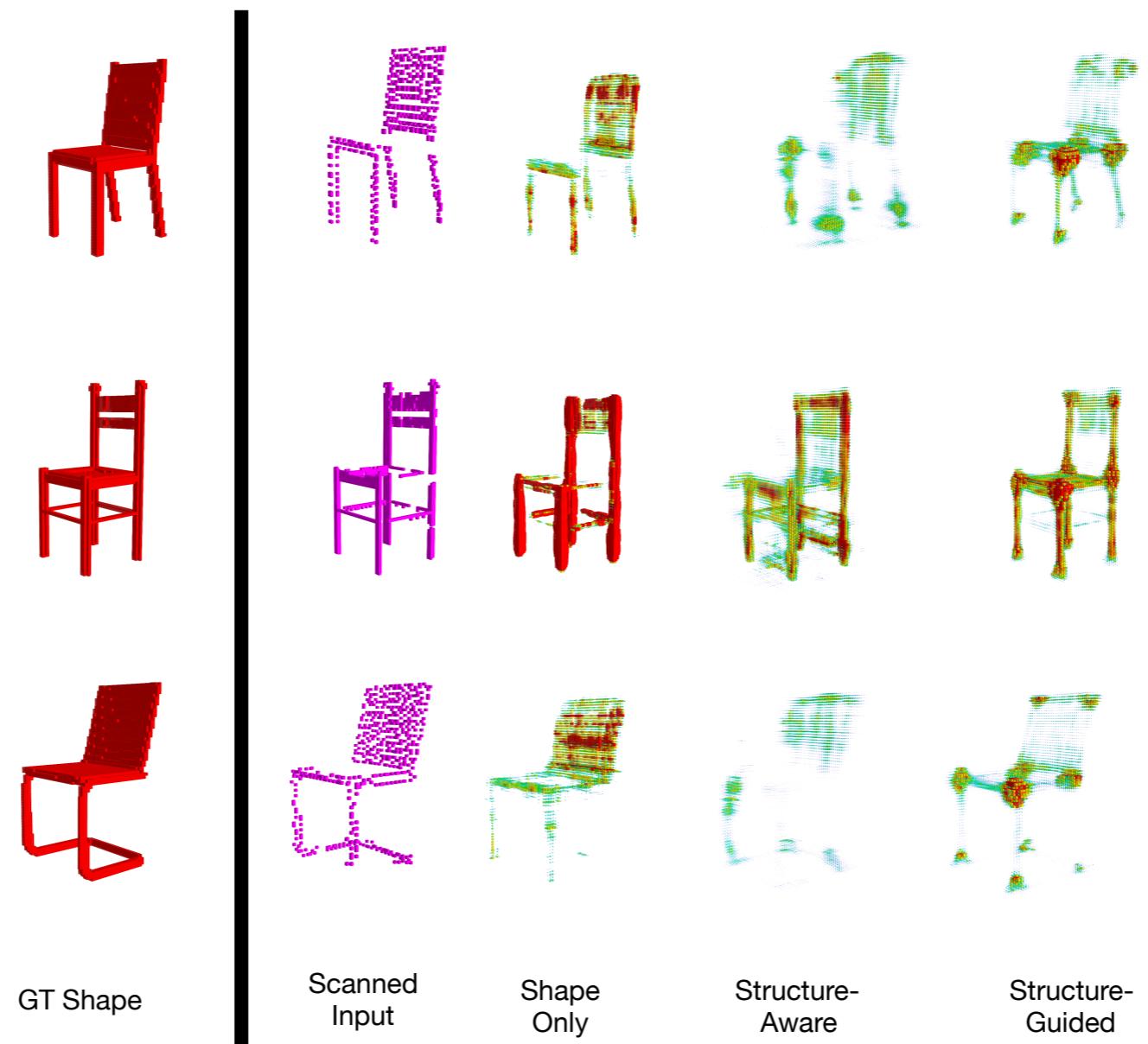
Overview: Structure-Guided Approach



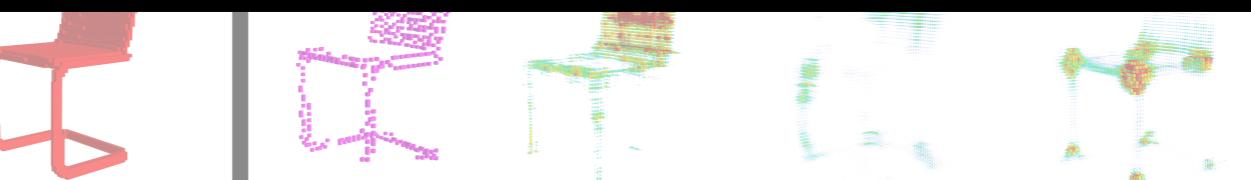
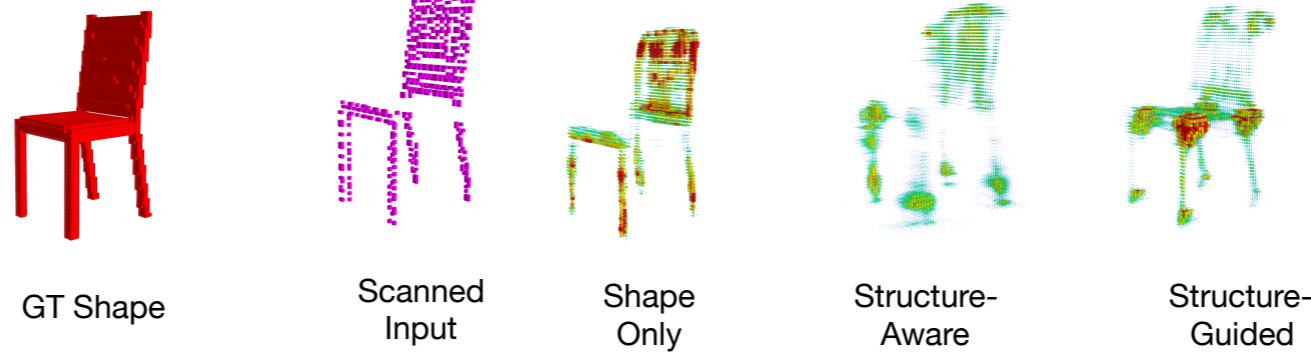
Shape Completion

Virtually scanned 3D shapes from SHAPENET [Chang '15],
Dai et al. [CVPR '17]

Shape Completion

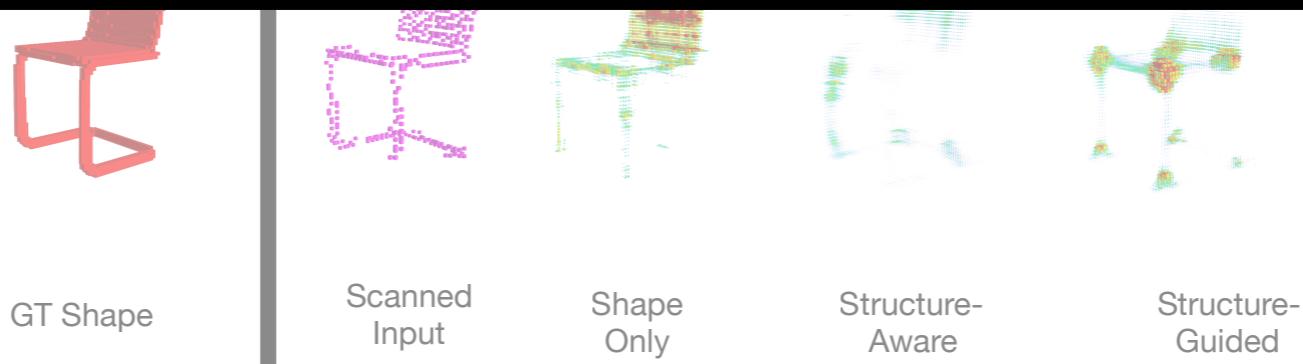
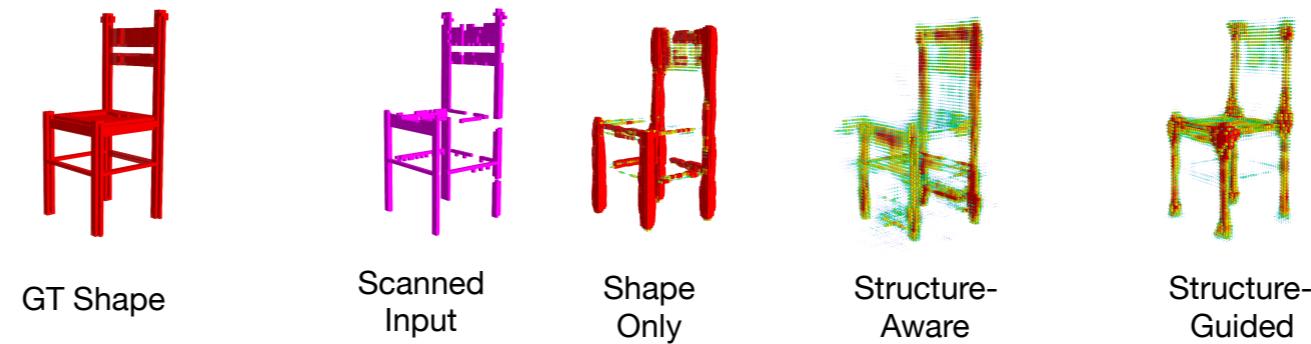
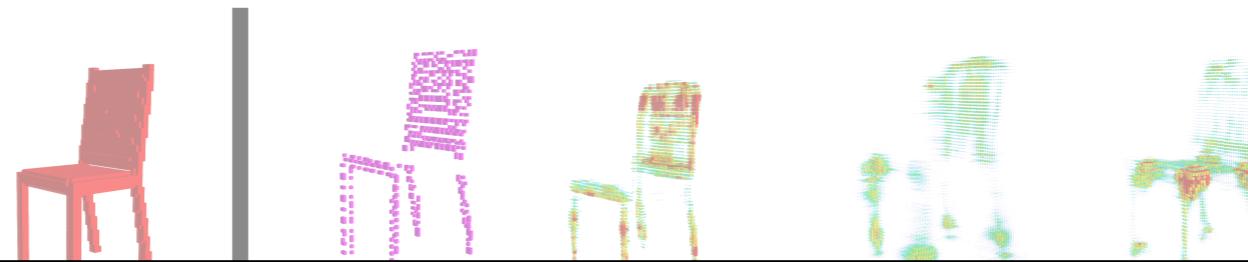


Shape Completion

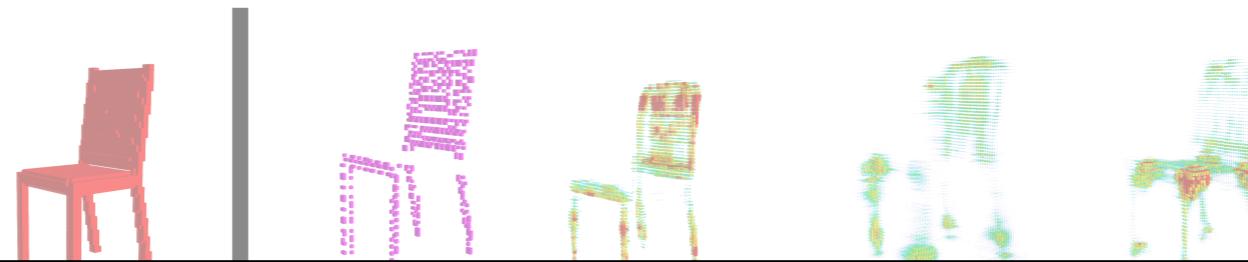


GT Shape Scanned Input Shape Only Structure-Aware Structure-Guided

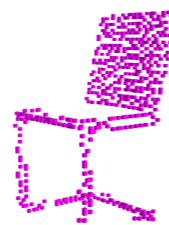
Shape Completion



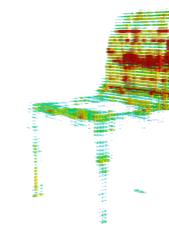
Shape Completion



GT Shape



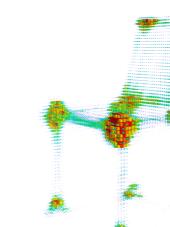
Scanned Input



Shape Only



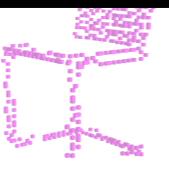
Structure-Aware



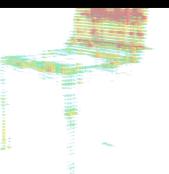
Structure-Guided



GT Shape



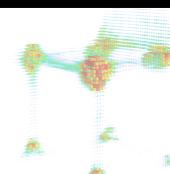
Scanned Input



Shape Only

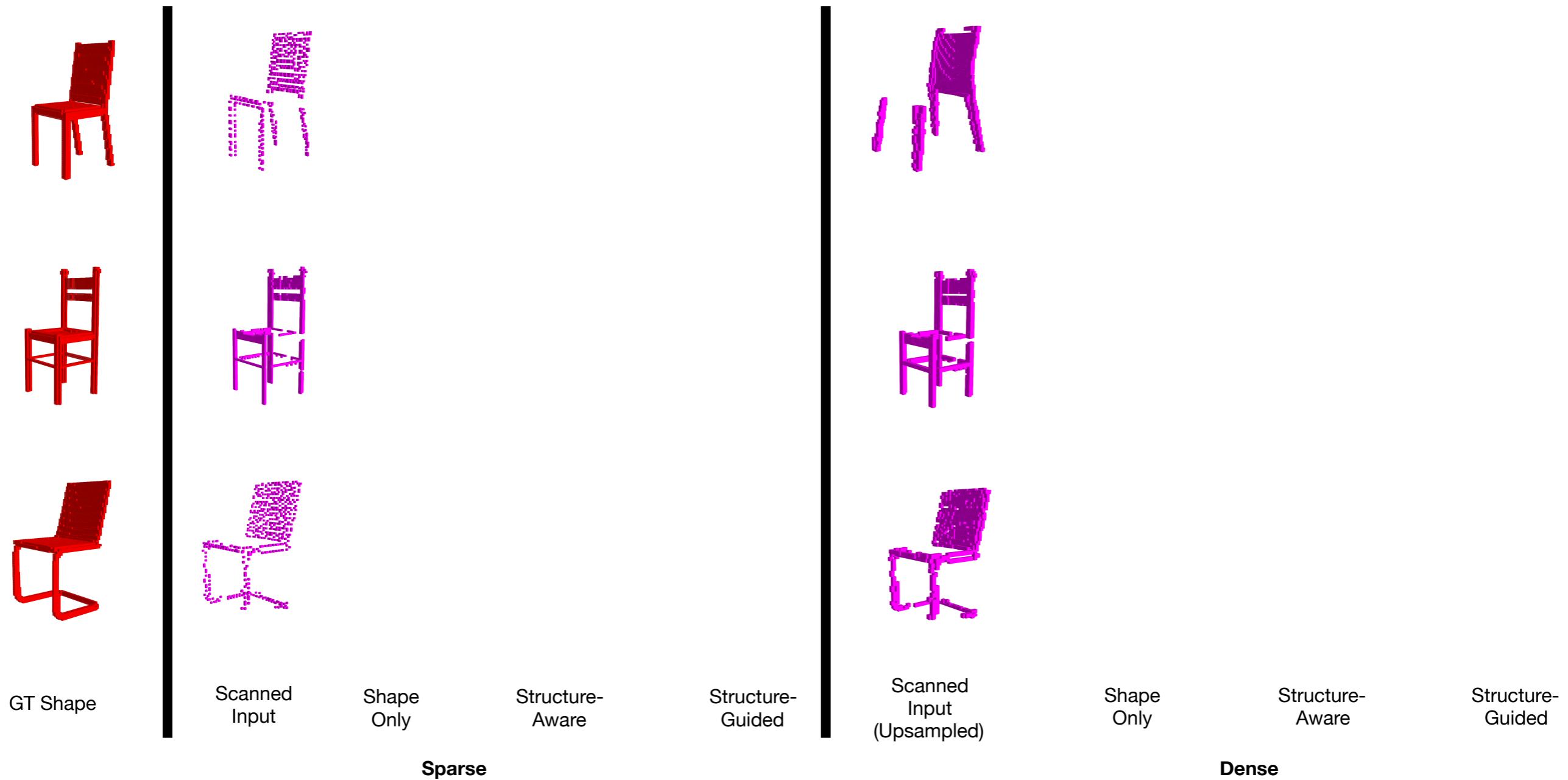


Structure-Aware

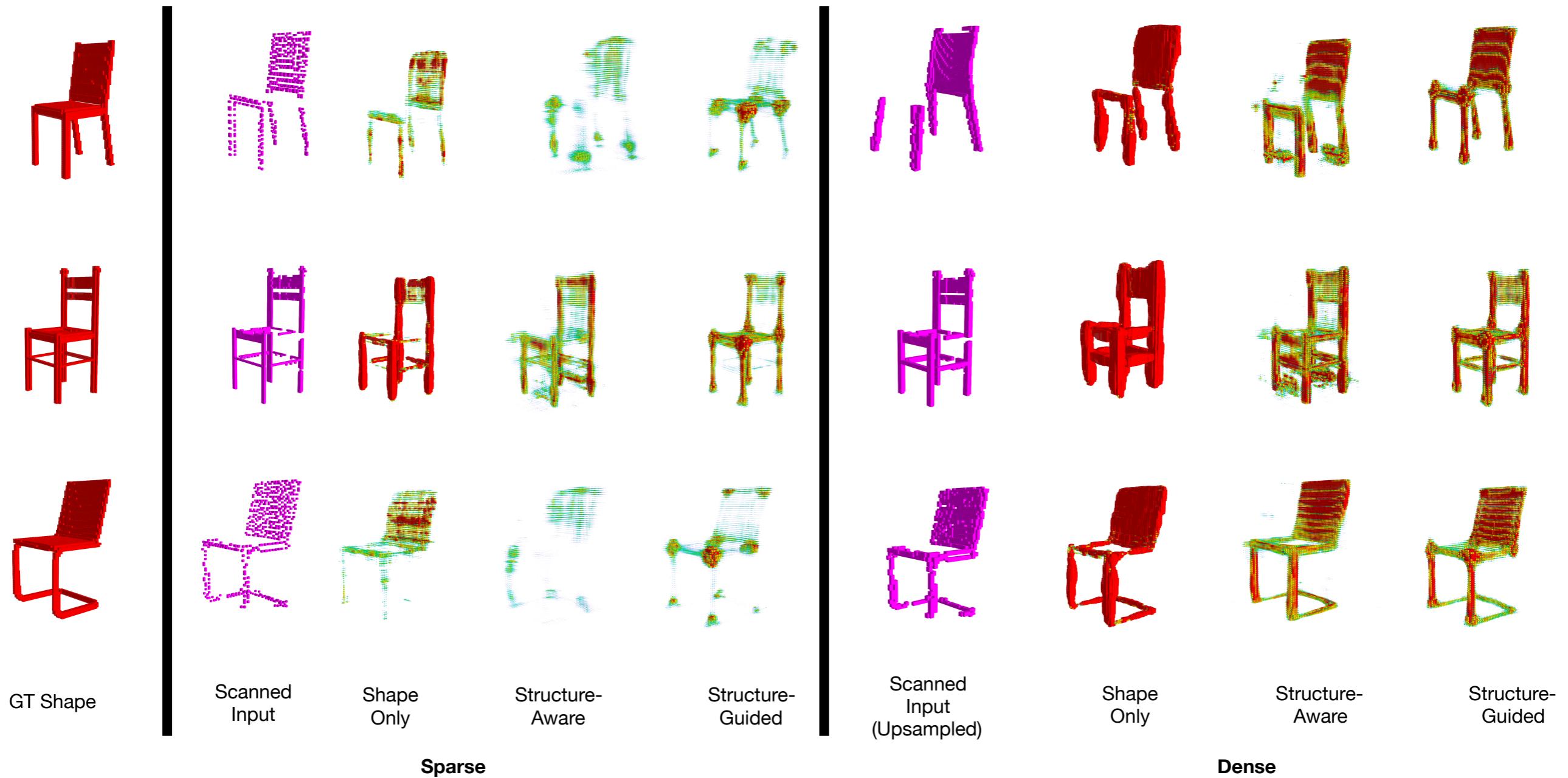


Structure-Guided

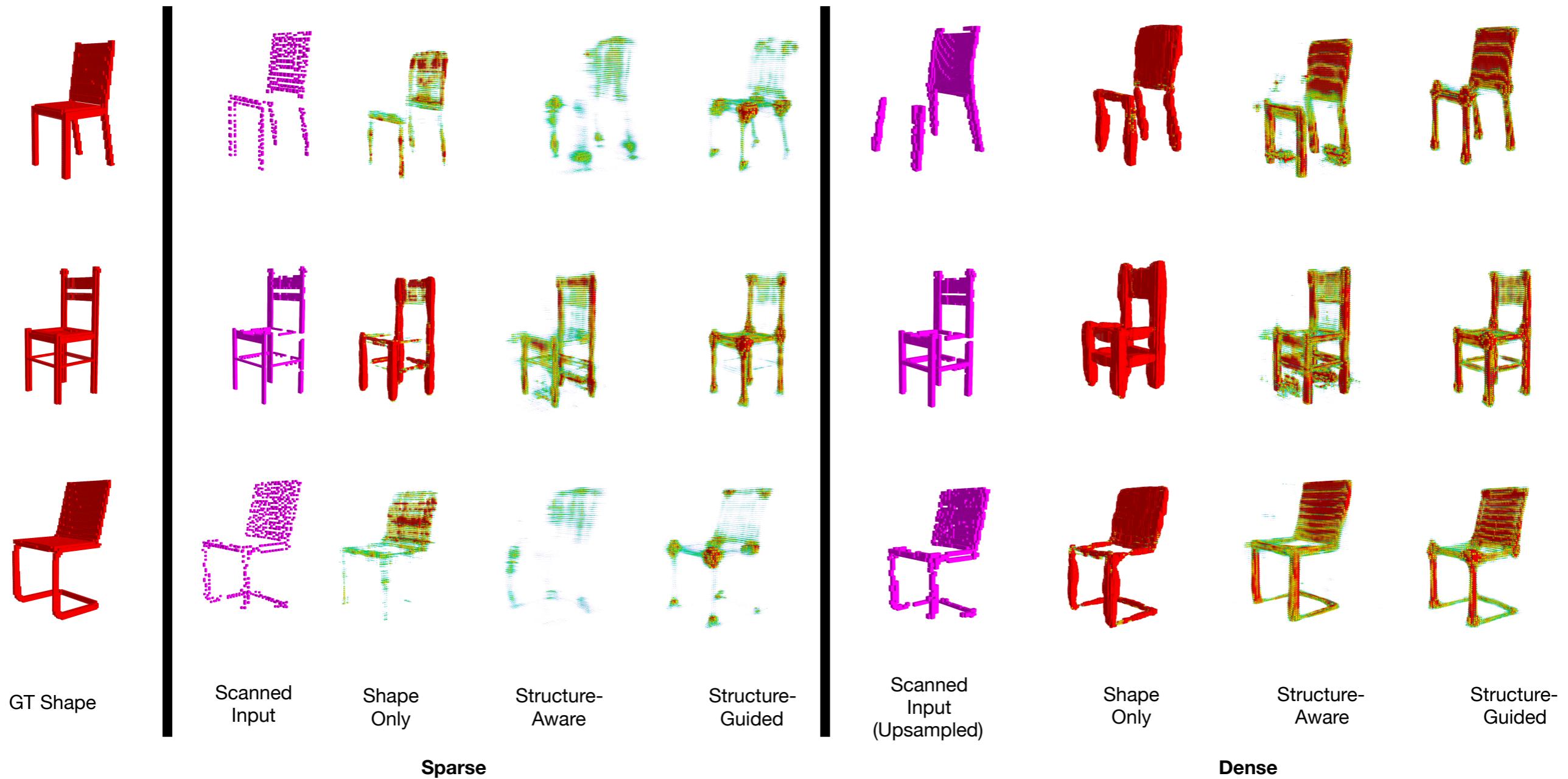
Sparse vs. Dense Completion



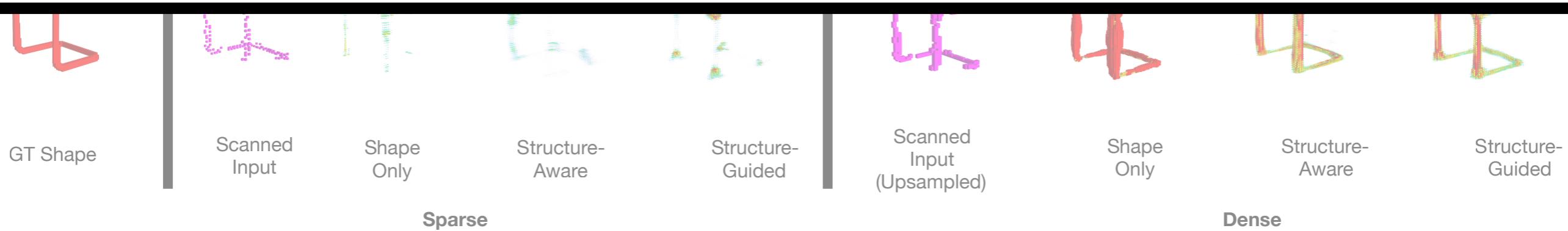
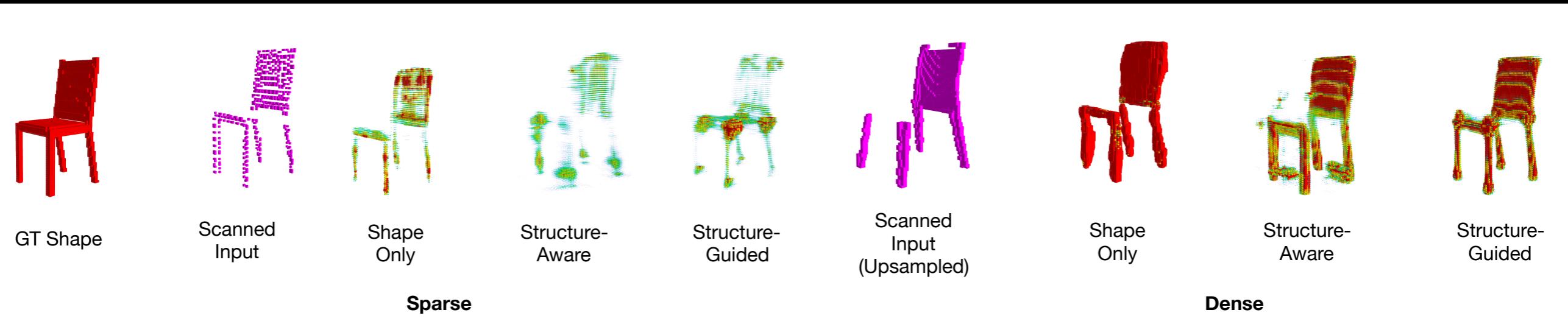
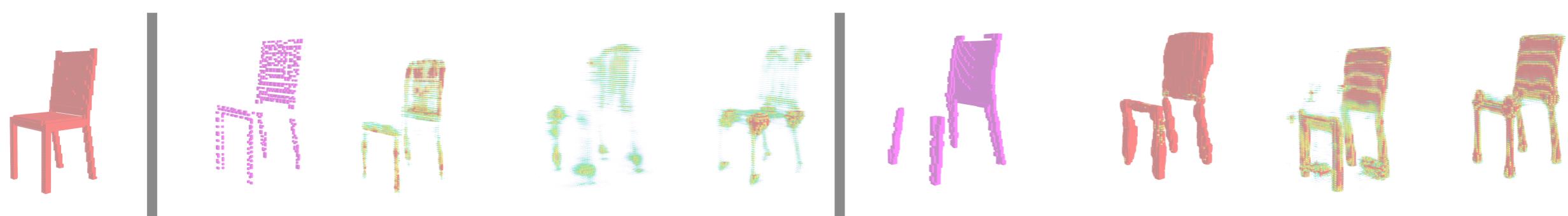
Sparse vs. Dense Completion



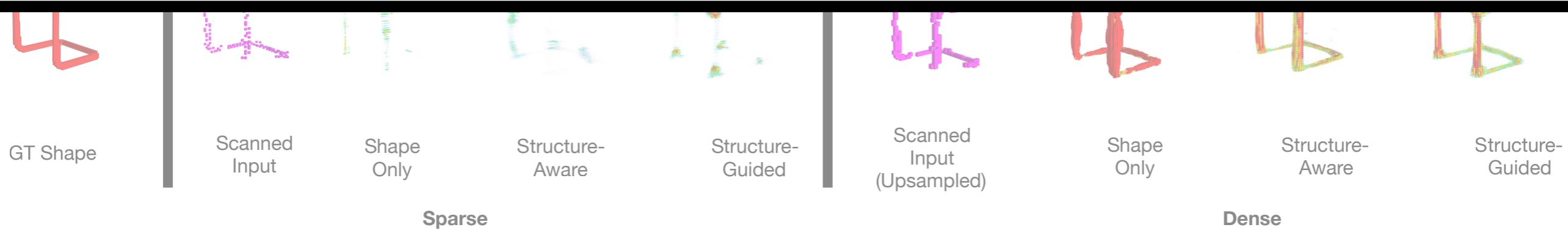
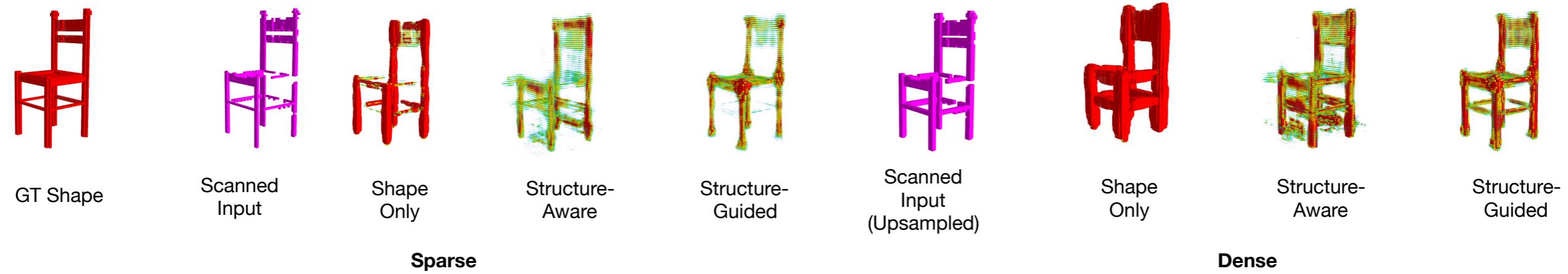
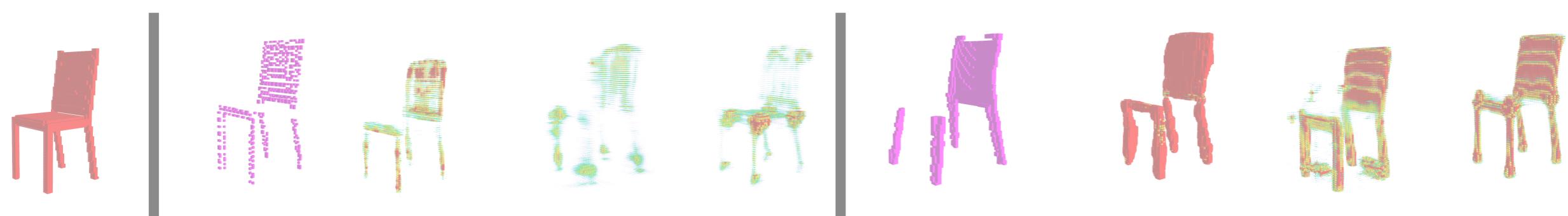
Sparse vs. Dense Completion



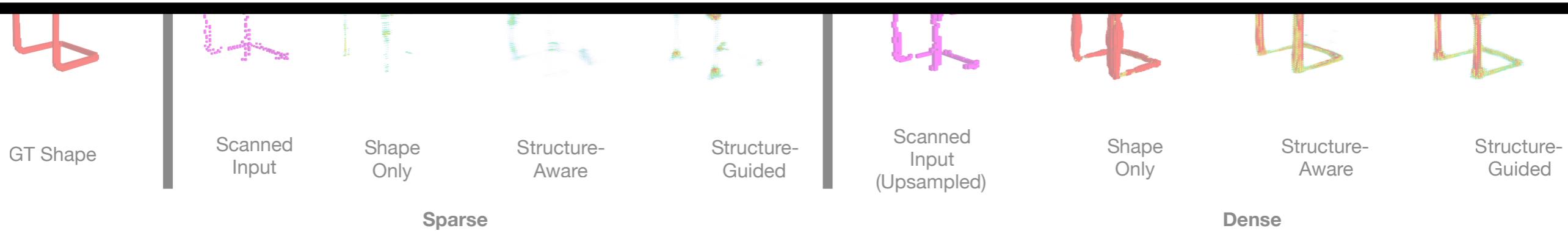
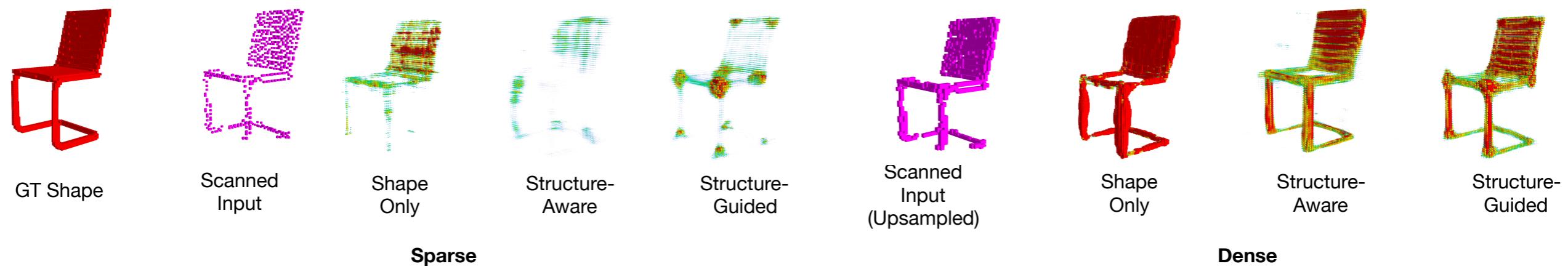
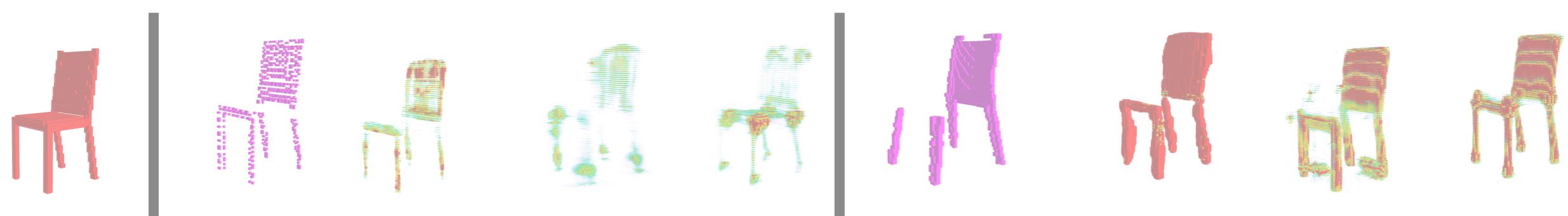
Sparse vs. Dense Completion



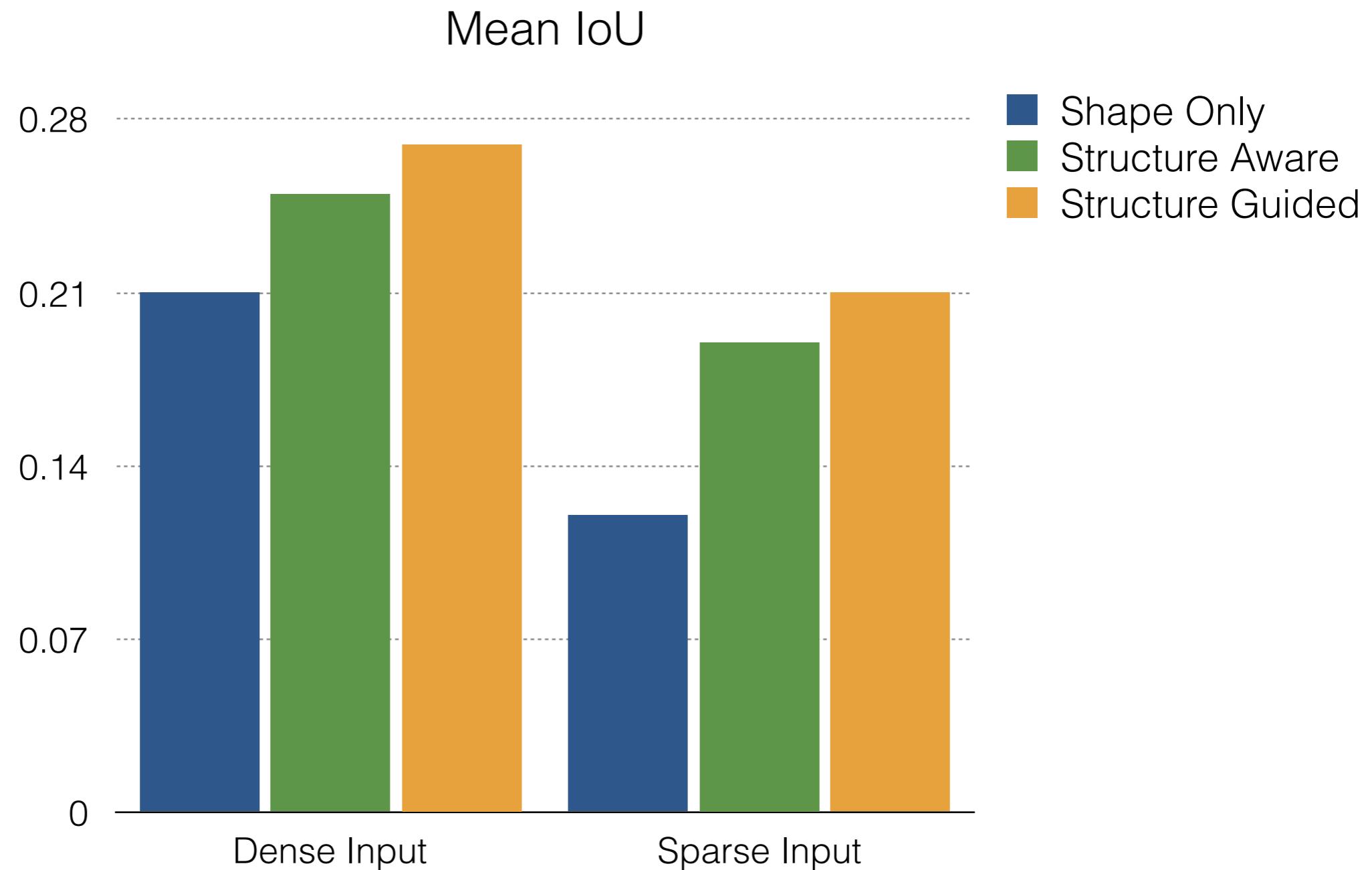
Sparse vs. Dense Completion



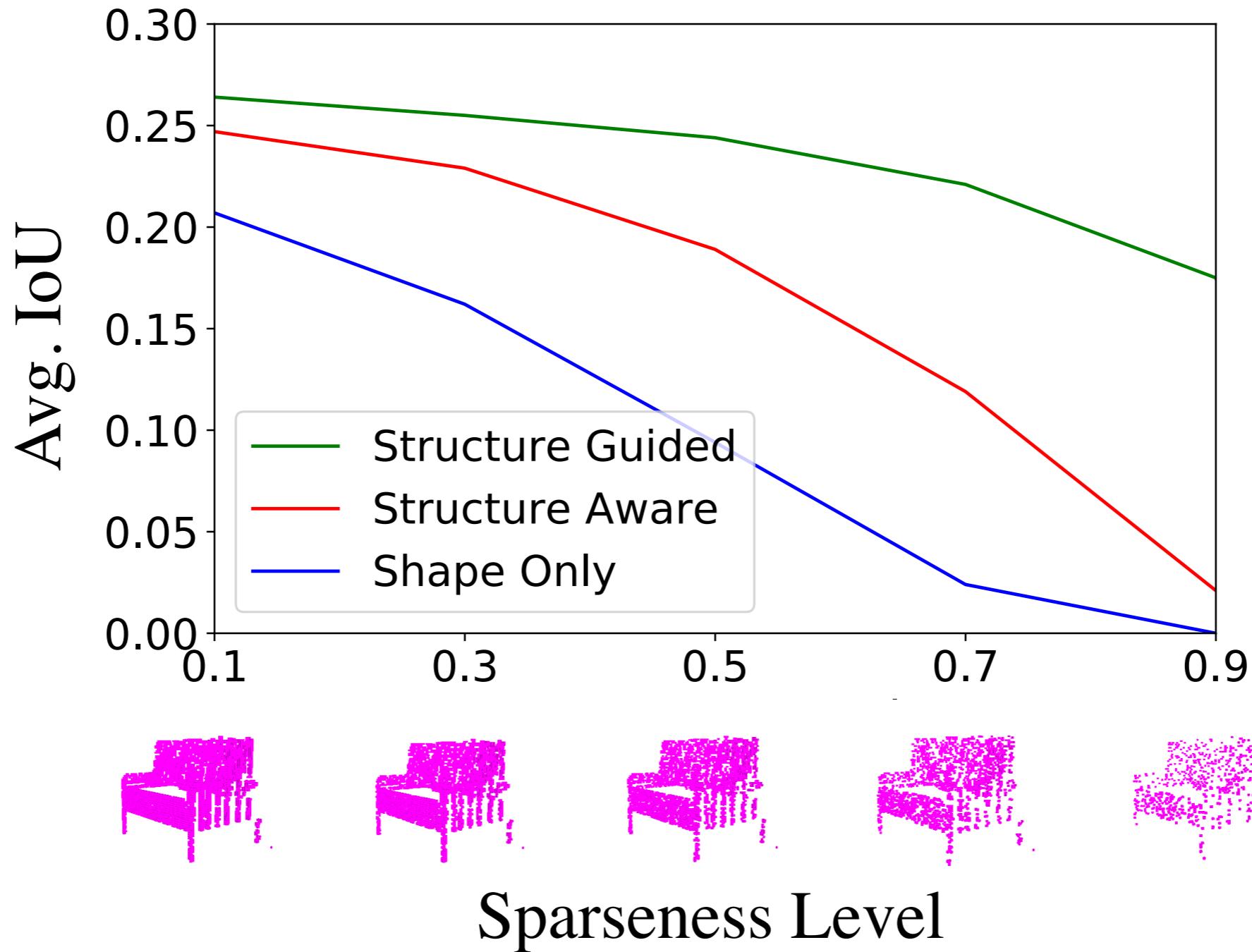
Sparse vs. Dense Completion



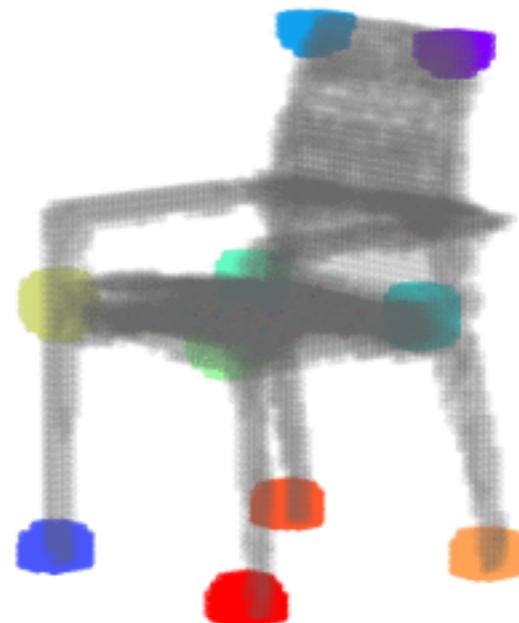
Sparse vs. Dense Completion



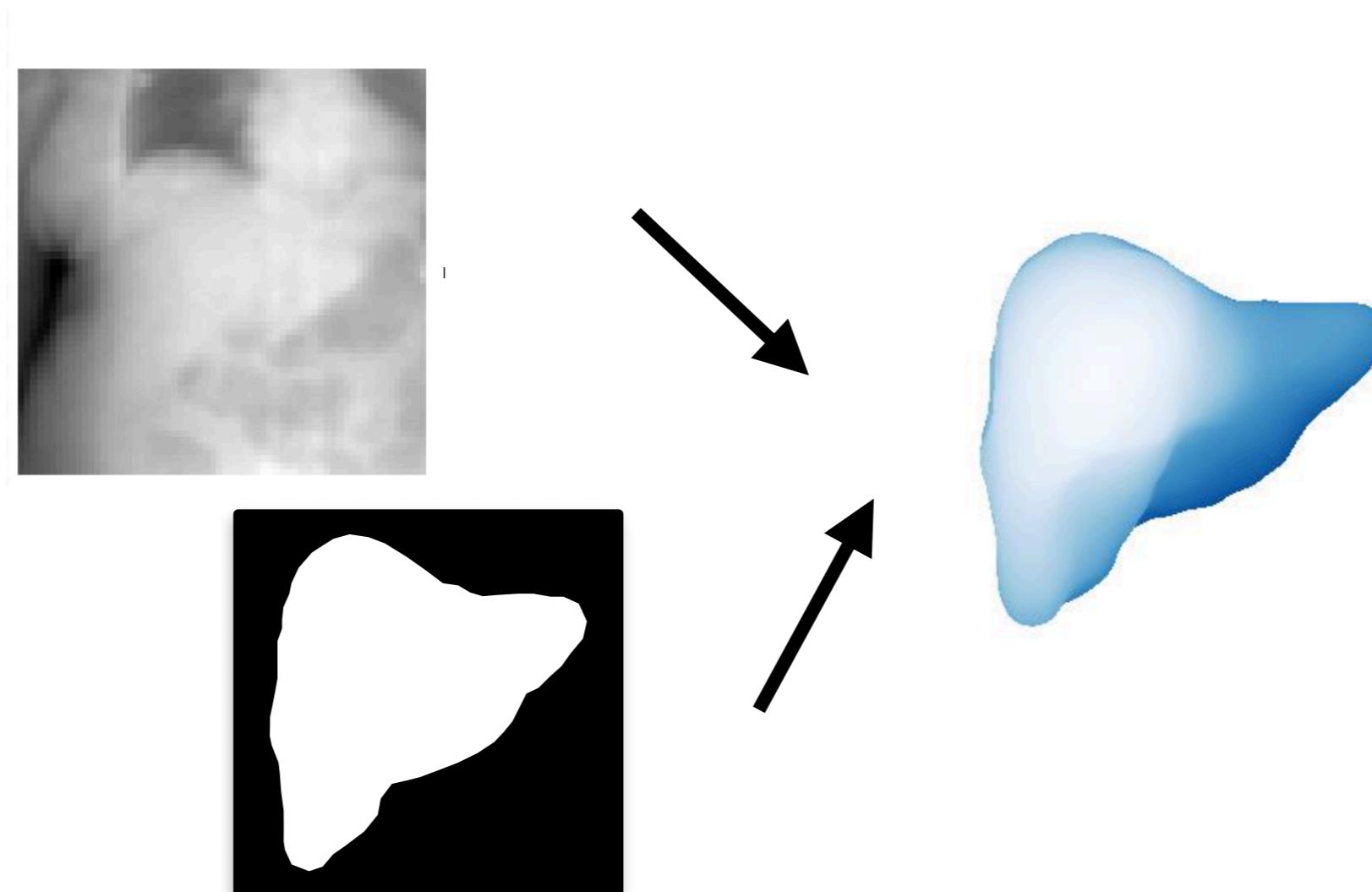
Sparse vs. Dense Completion



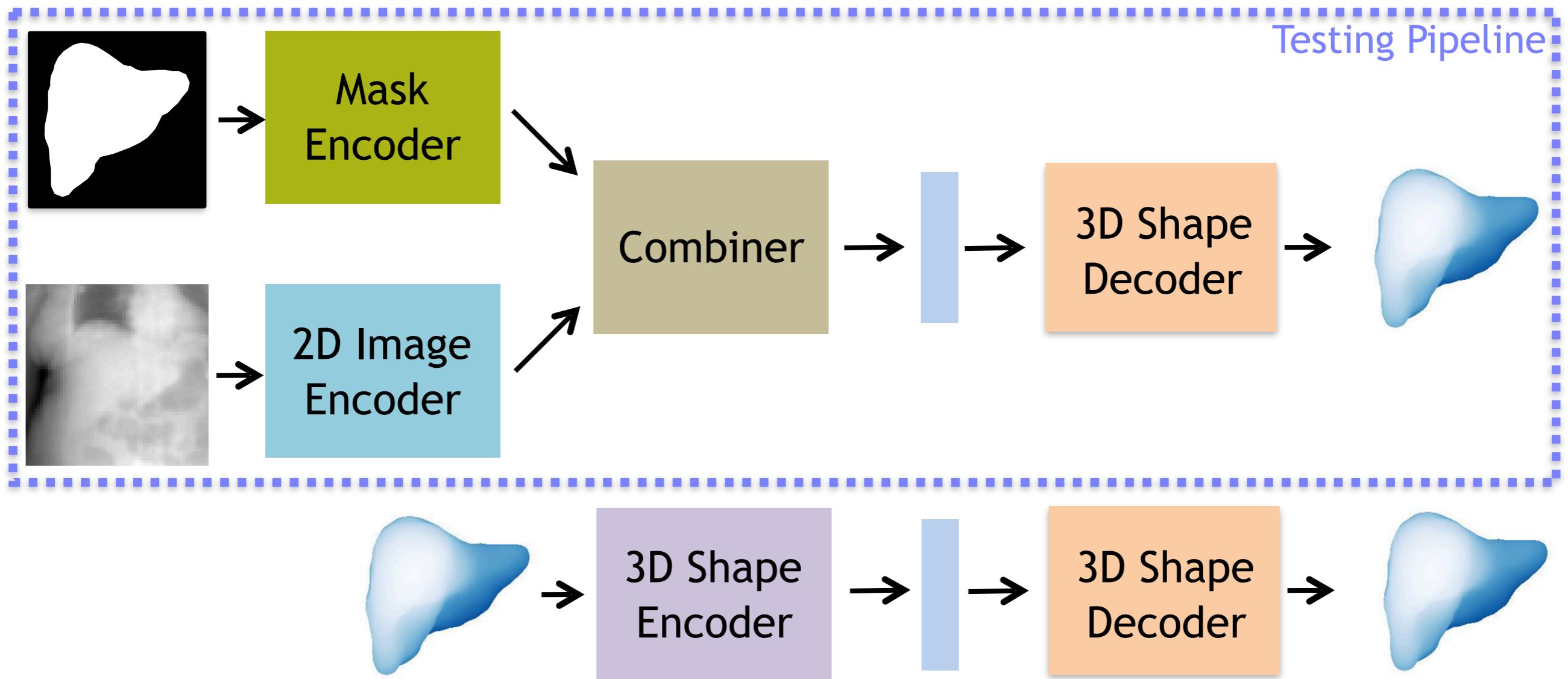
Structure-Guided Interactive Editing



Structure-Aware Liver Reconstruction



Structure-Aware Liver Reconstruction



Objective

We optimize the networks using a combination loss function L :

$$L = \alpha_1 L_{rec}(s, s') + \alpha_2 L_{KL} + \alpha_3 L_{rec}(s, G(\bar{z})) + \alpha_4 L_{mask}(k, \tilde{k}),$$

Kullback
Leibler divergence Encoder Output

$$L_{mask}(k, \tilde{k}) = - \sum_{n=1}^N k_n \log \tilde{k}_n + (1 - k_n) \log (1 - \tilde{k}_n).$$

Mask Loss BCE Loss
GT Mask Pred. Mask

$$L_{rec}(s, s') = - \frac{1}{N} \sum_{n=1}^N s_n \log s'_n + (1 - s_n) \log (1 - s'_n)$$

BCE Loss
Reconstruction Loss

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ - Sub-Component weights

Results

Input Topogram

Ground Truth Shape

Topogram Only
Shape Prediction

Topogram + Mask
Shape Prediction

Example 1

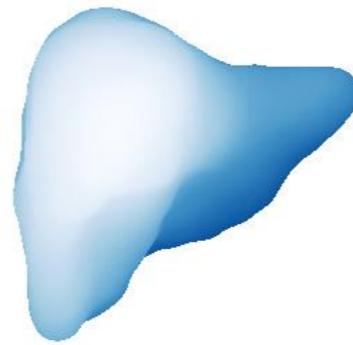
Example 2

Results

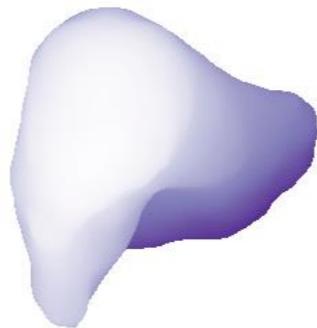
Example 1



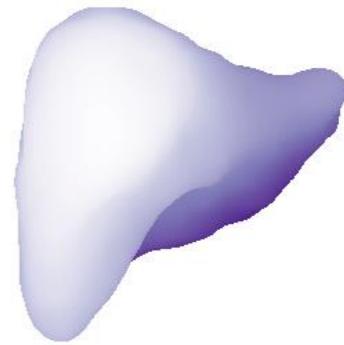
Ground Truth Shape



Topogram Only
Shape Prediction

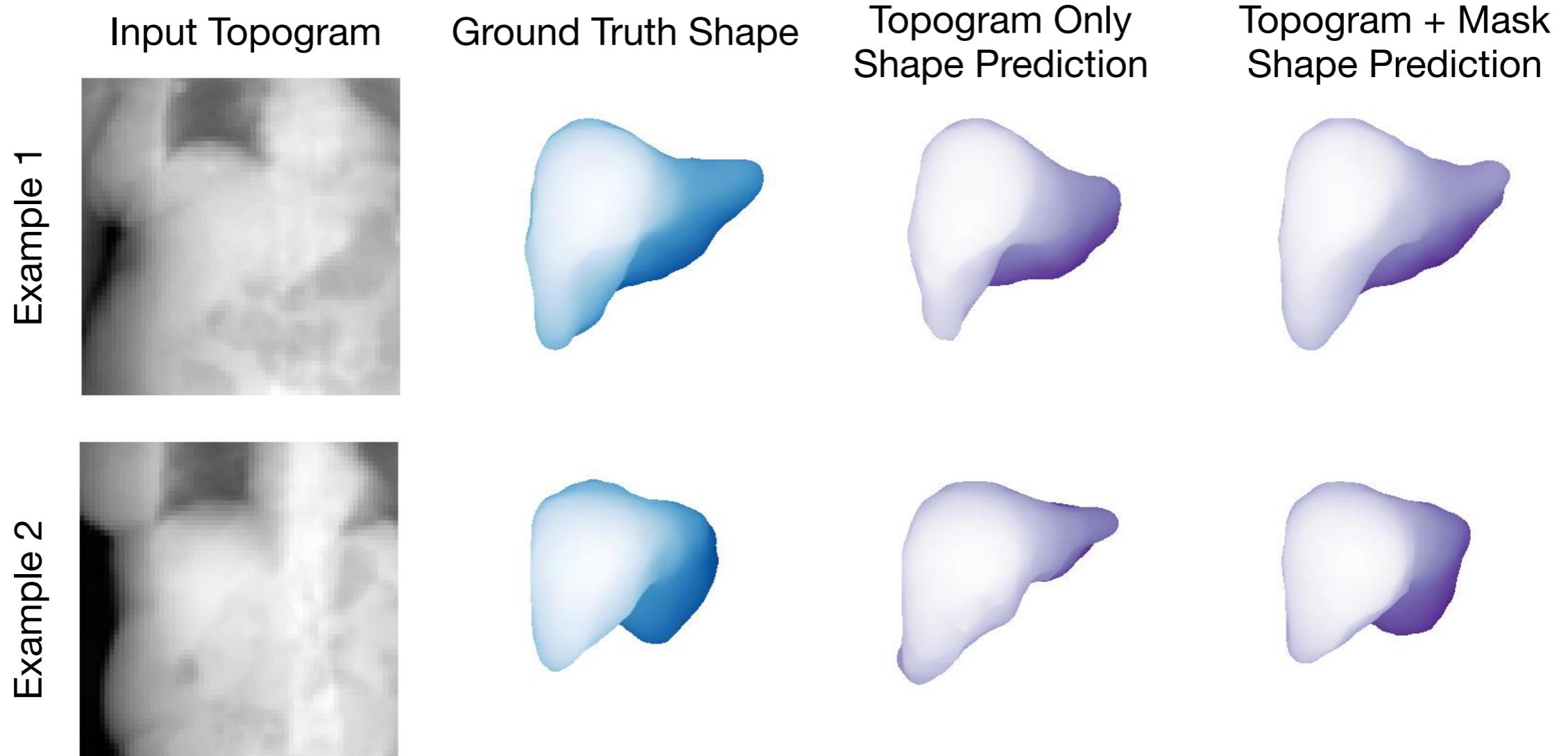


Topogram + Mask
Shape Prediction



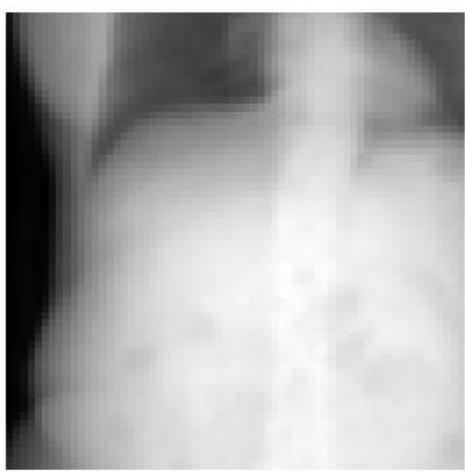
Example 2

Results



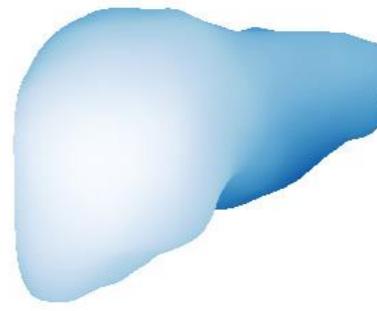
Results

Example 3

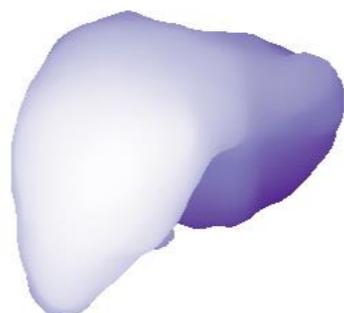


Input Topogram

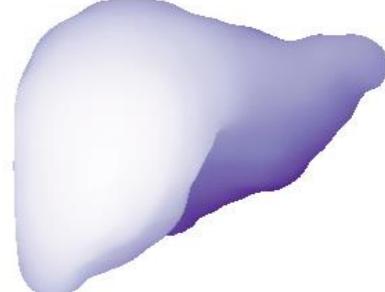
Ground Truth Shape



Topogram Only
Shape Prediction

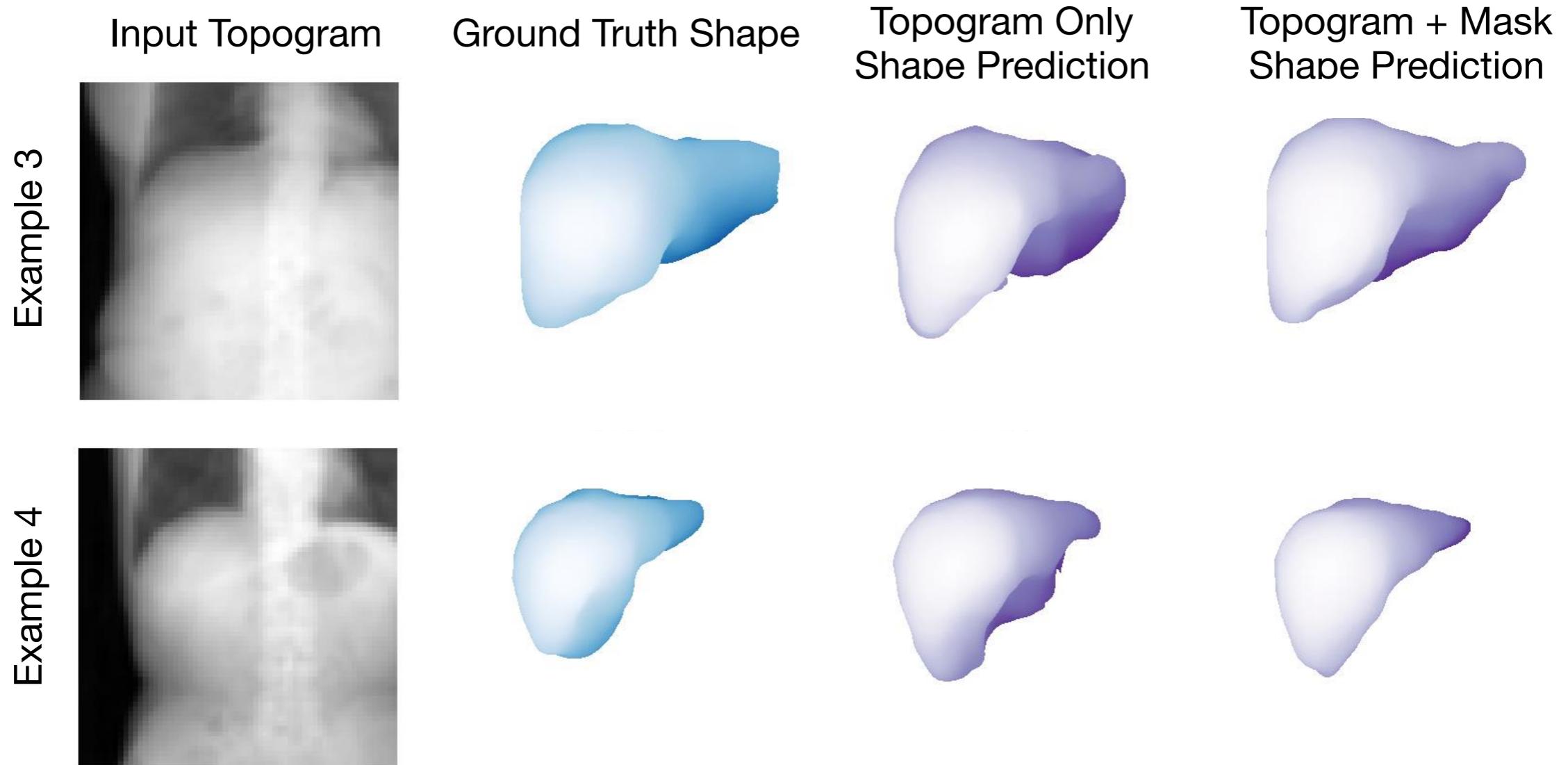


Topogram + Mask
Shape Prediction



Example 4

Results



Results

Example (1)

Example (2)

Example (3)

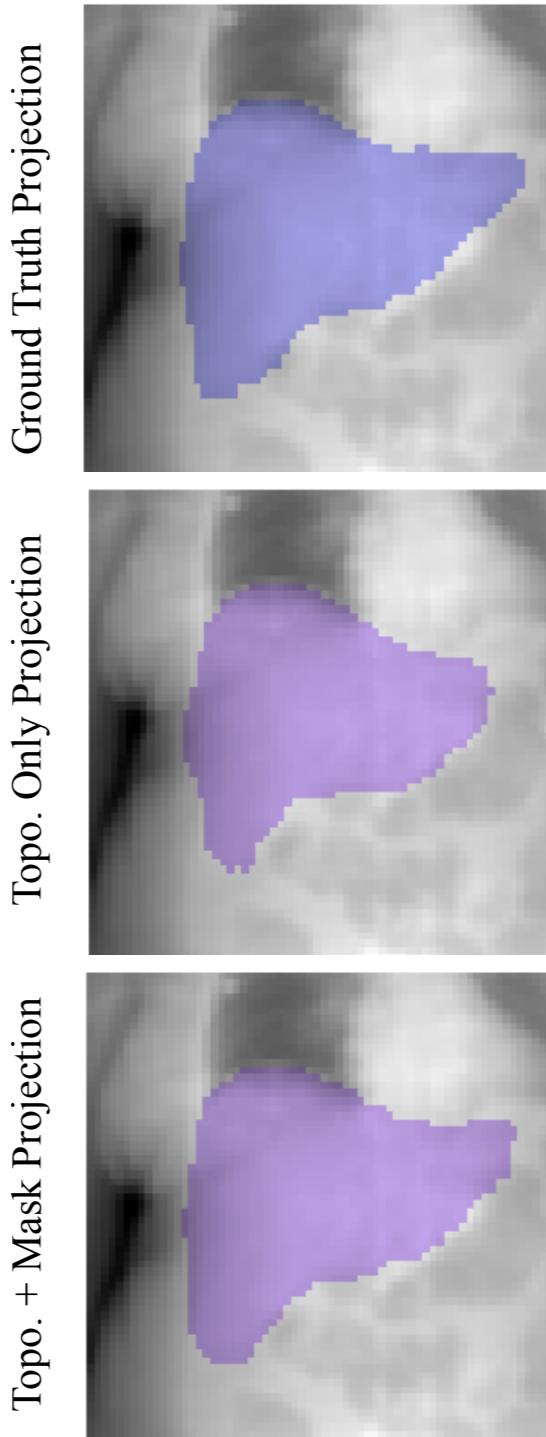
Topo. Only Projection

Topo. + Mask Projection

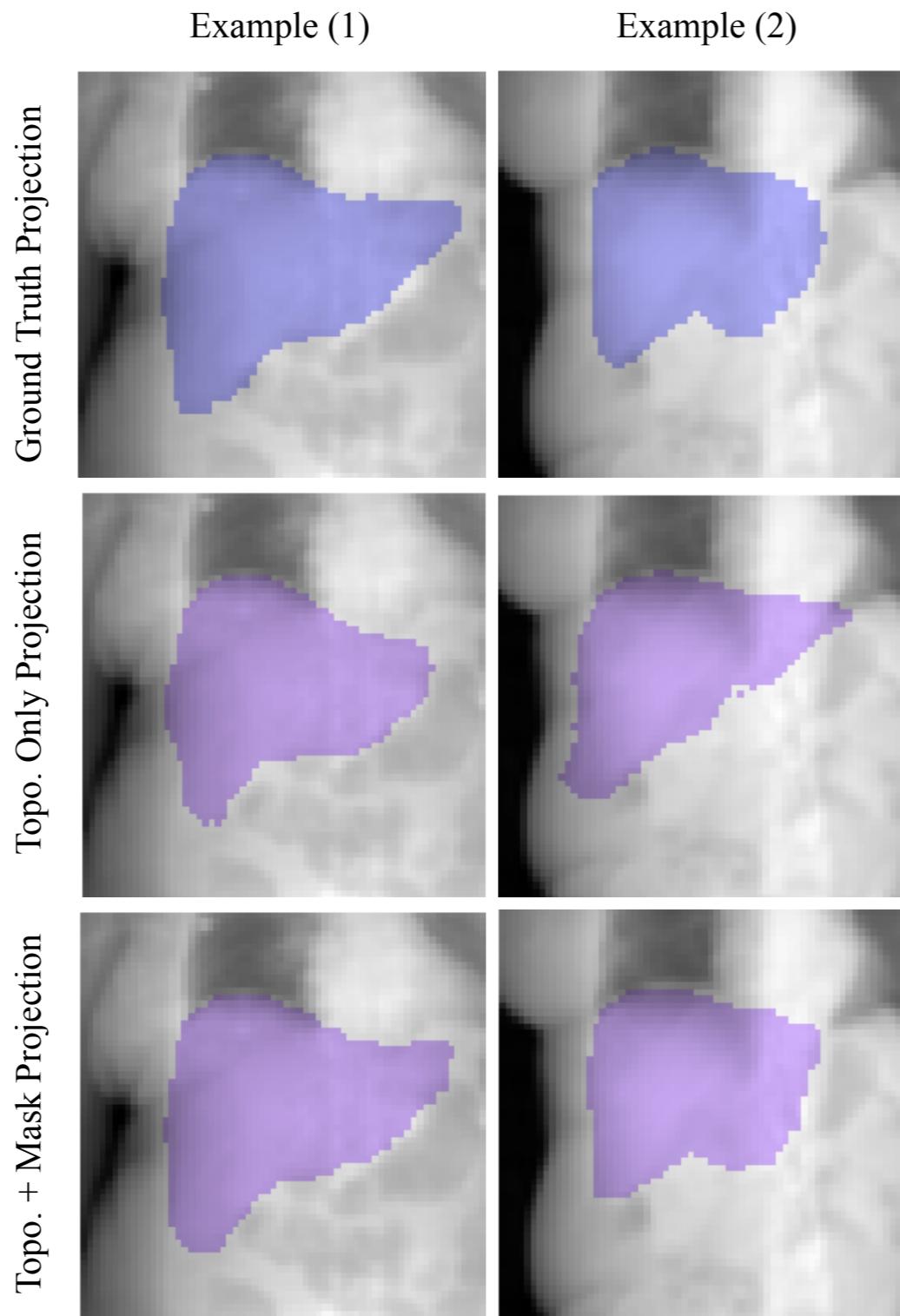
Ground Truth Projection

Results

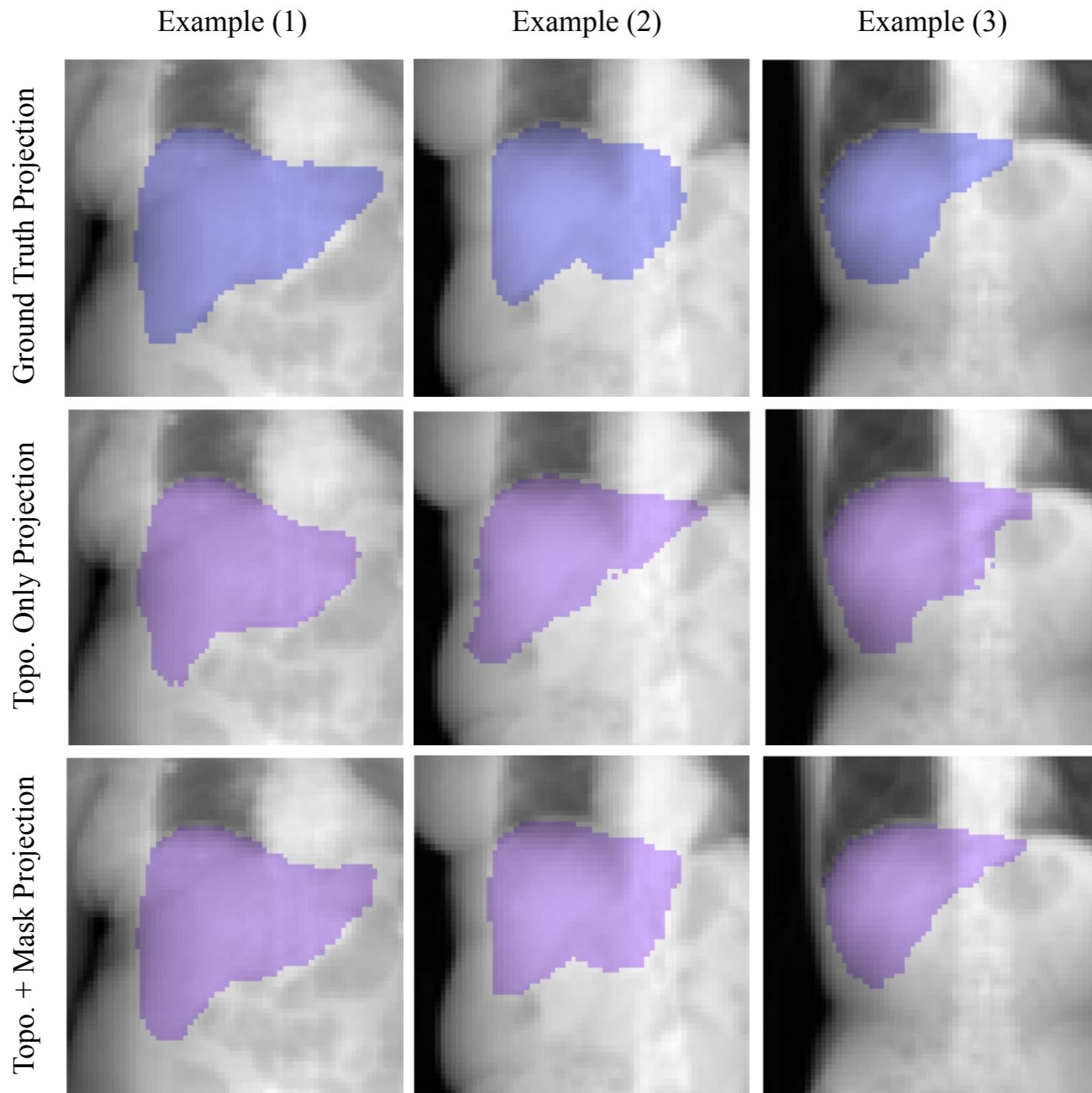
Example (1)



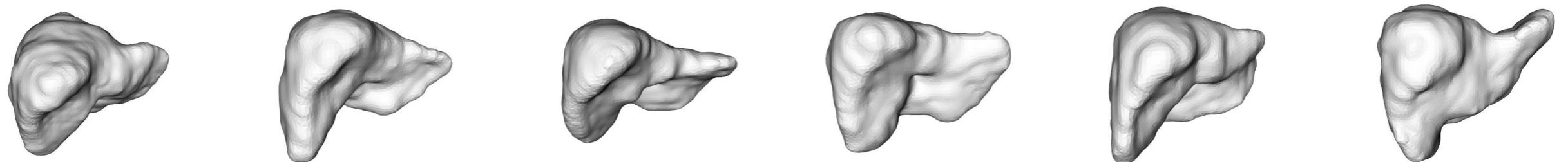
Results



Results



Volume Prediction

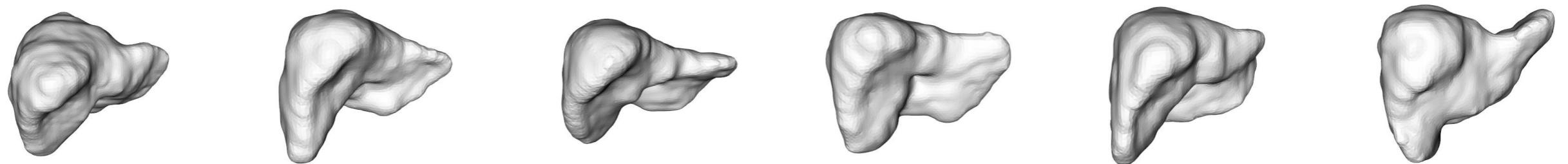


V_{gt} - ground truth volume

V_{pred} - predicted volume

$$V_f = \|V_{pred} - V_{gt}\|/V_{gt}$$

Volume Prediction



Metric	Topogram Only	Topogram + Mask
Volume Error (V_f)	0.10	0.06

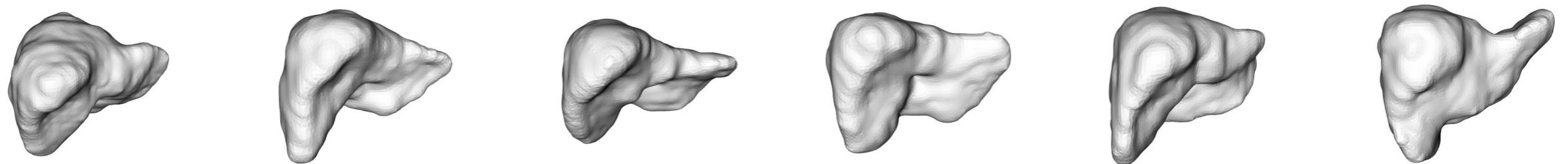
Mean Volume Error evaluation and comparison.

V_{gt} - ground truth volume

V_{pred} - predicted volume

$$V_f = \|V_{pred} - V_{gt}\| / V_{gt}$$

Volume Prediction



Metric	Mask Only	Topogram Only	Topogram + Mask
Volume Error (V_f)	0.34	0.10	0.06

Mean Volume Error evaluation and comparison.

V_{gt} - ground truth volume

V_{pred} - predicted volume

$$V_f = \|V_{pred} - V_{gt}\| / V_{gt}$$

Quantitative Evaluation

	Volume Prediction	Shape Reconstruction		
	Volume Error (V_f)	IoU	Dice	Hausdorff
Variational Autoencoder (VAE) (without/with mask)	0.10/ 0.06	0.78/ 0.82	0.87/ 0.90	7.10/ 5.00

Comparison of the variational auto-encoder (VAE) (with and without mask).

Quantitative Evaluation

	Volume Prediction	Shape Reconstruction		
	Volume Error (V_f)	IoU	Dice	Hausdorff
Variational Autoencoder (VAE) (without/with mask)	0.10/ 0.06	0.78/ 0.82	0.87/ 0.90	7.10/ 5.00
Adversarial (3D-GAN) [29]	0.21	0.61	0.75	10.50

Comparison of the variational auto-encoder (VAE) (with and without mask), and generative adversarial network (GAN) -based approaches on volume prediction and shape reconstruction tasks.

Quantitative Evaluation

	Volume Prediction	Shape Reconstruction		
	Volume Error (V_f)	IoU	Dice	Hausdorff
Variational Autoencoder (VAE) (without/with mask)	0.10/0.06	0.78/0.82	0.87/0.90	7.10/5.00
Adversarial (3D-GAN) [29]	0.21	0.61	0.75	10.50
Performance Difference	109% / 250%	22% / 26%	14% / 17%	48% / 110%

Comparison of the variational auto-encoder (VAE) (with and without mask), and generative adversarial network (GAN) -based approaches on volume prediction and shape reconstruction tasks.

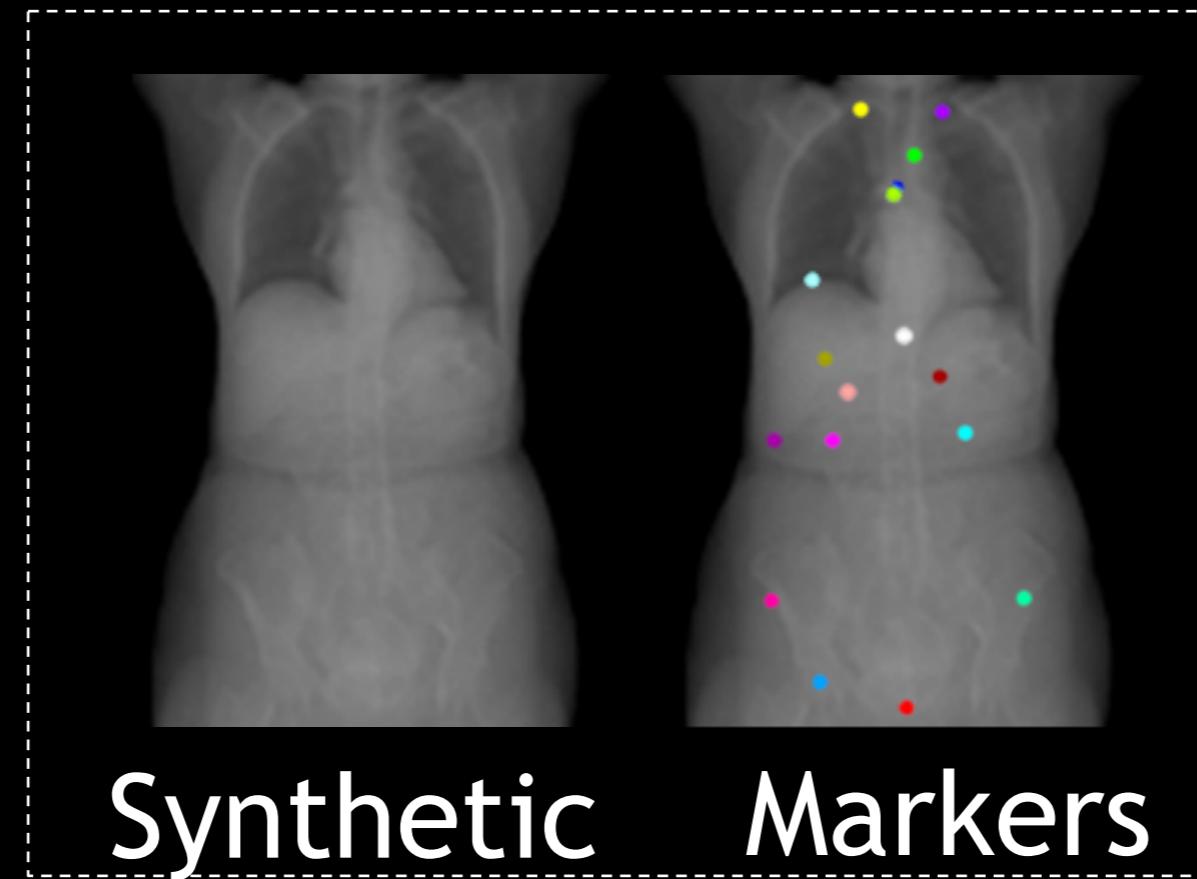
Interactive Techniques

[B Teixeira, V. Singh, K. Ma, B. Tumeroy, T. Chen, Y. Wu, E. Balashova, D. Comaniciu](#)
Generating Synthetic X-Ray Images of a Person from Surface Geometry
Conference on Computer Vision and Pattern Recognition (CVPR) 2018.

Parametrized Synthetic X-ray



3D Surface
Mesh

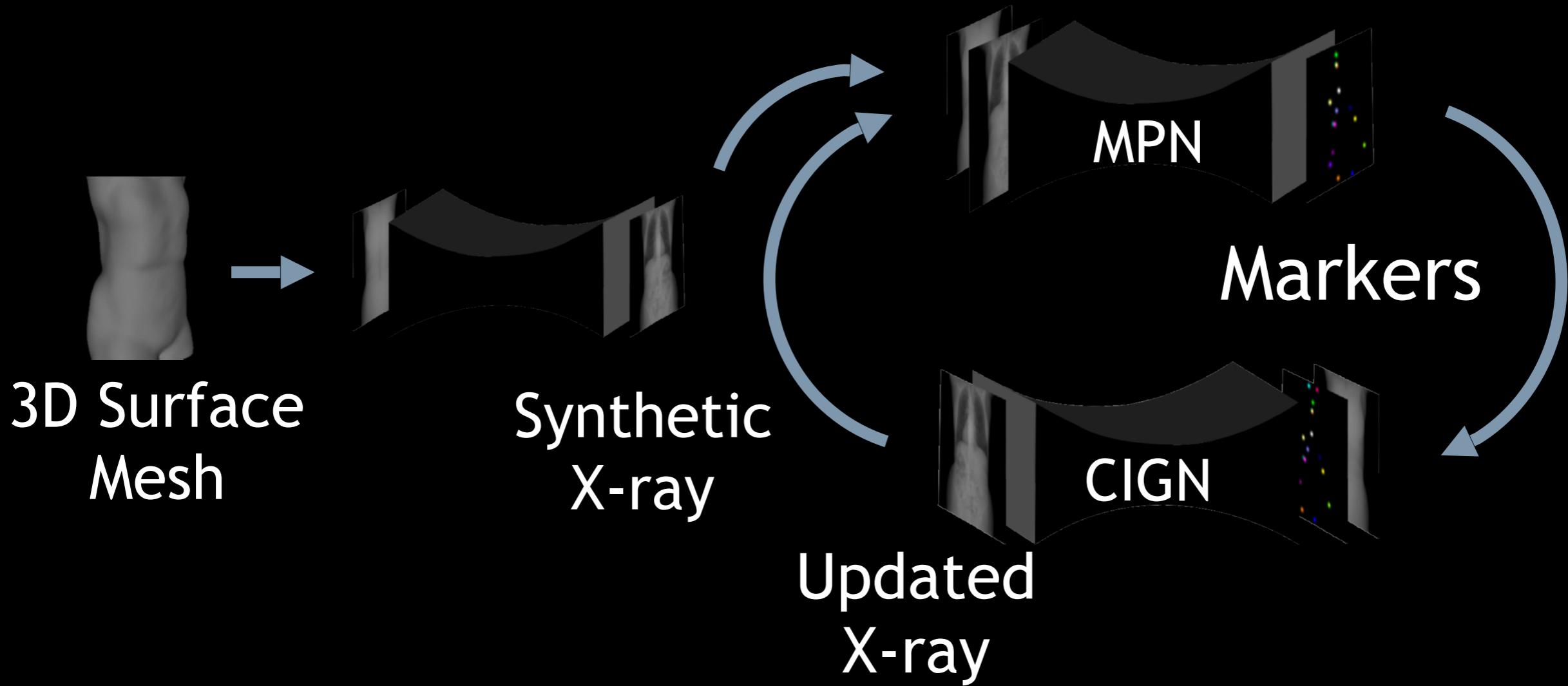


Synthetic
X-ray

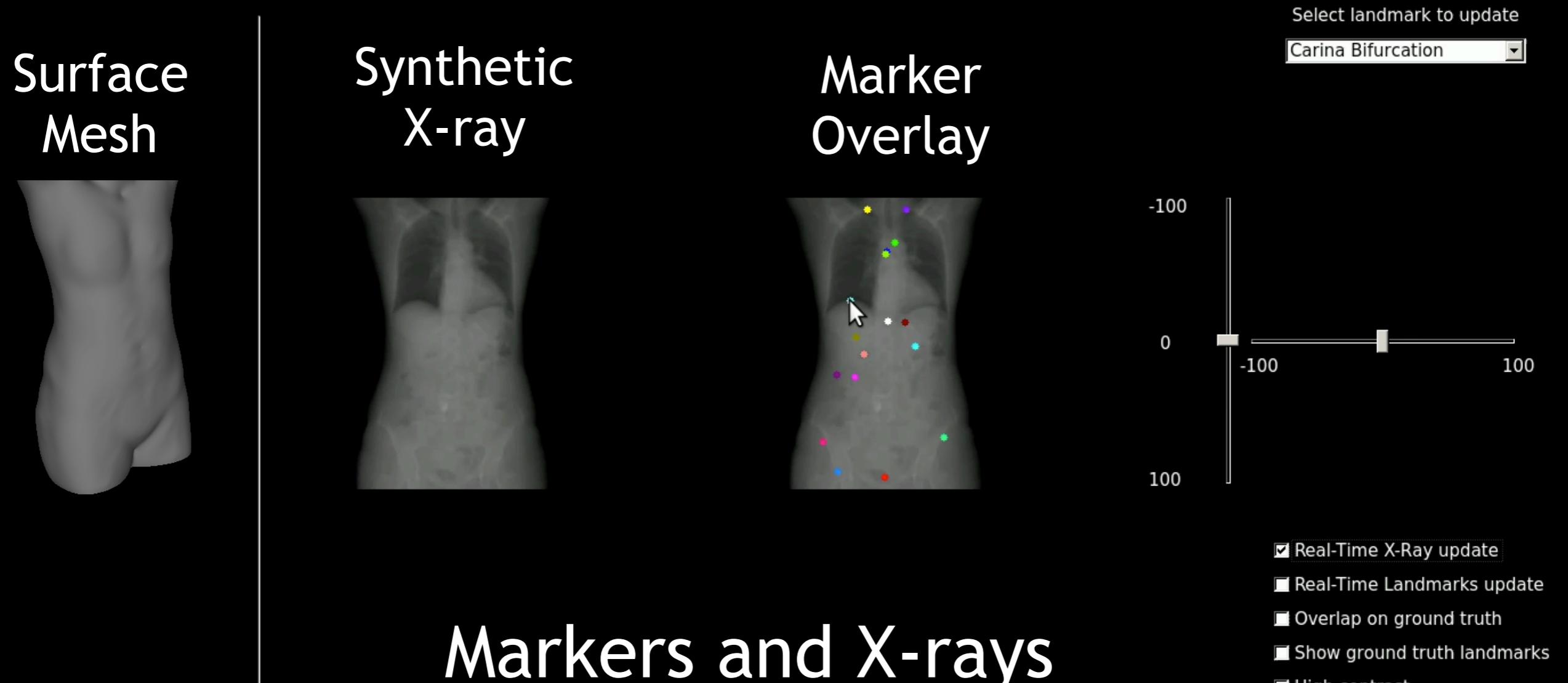


Real X-ray
(For
comparison)

Approach Overview



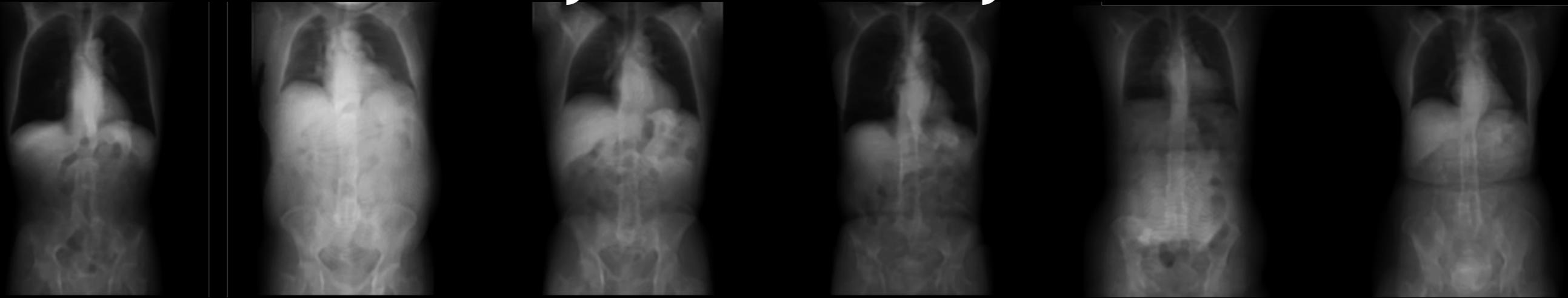
Markers as Parametrization for Synthetic X-ray



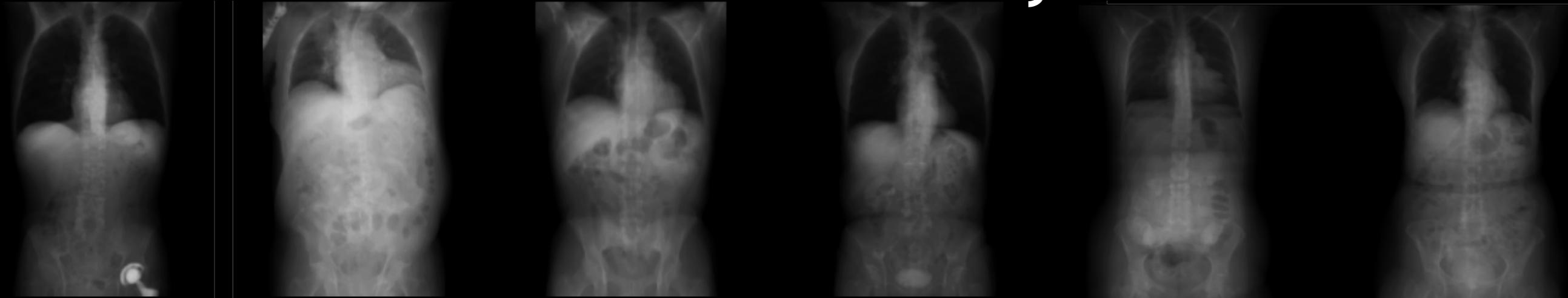
Markers and X-rays converge to a steady state where both are consistent

Results on Testing Set

Synthetic X-rays

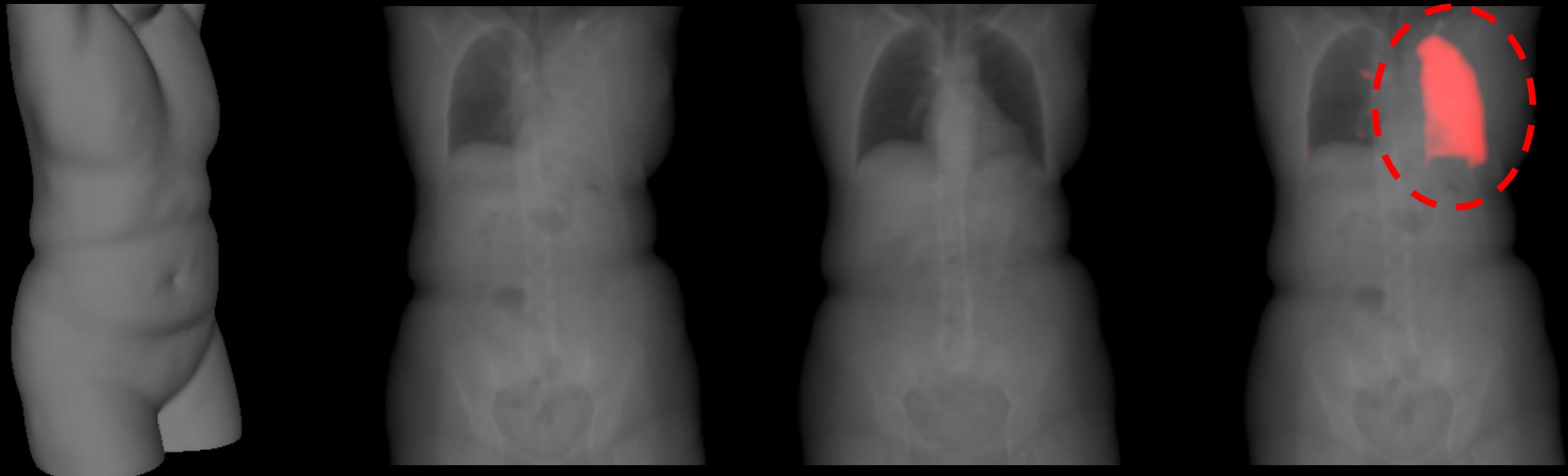


Ground Truth X-rays



Synthetic X-ray to Detect Pathologies

Trauma Patient Data with no Left Lung



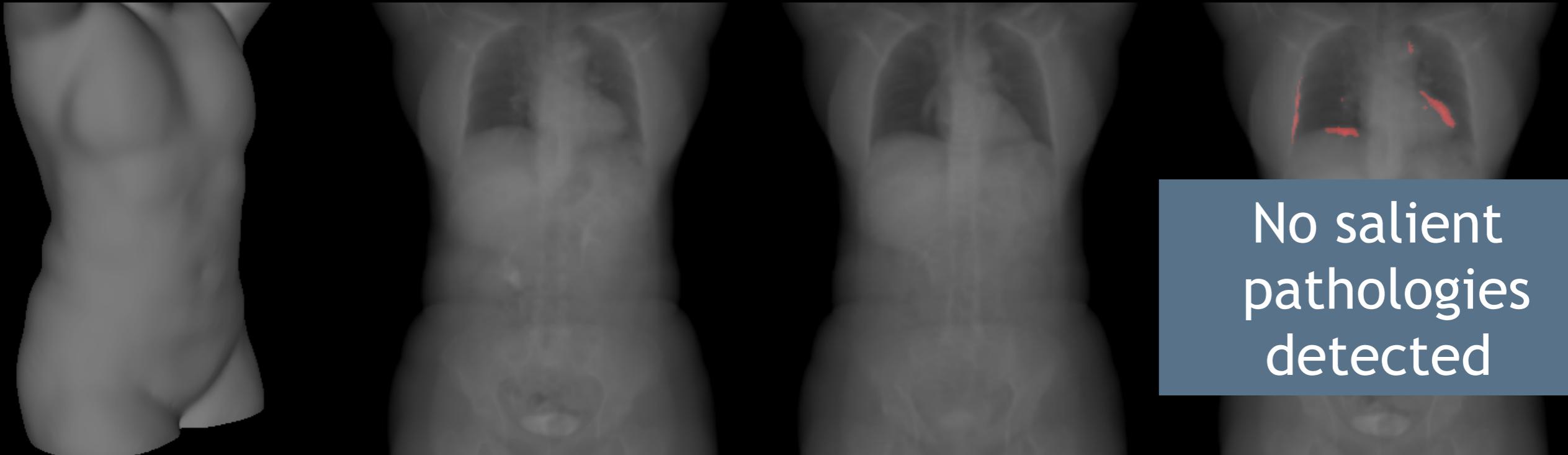
3D Surface Mesh

Real X-ray

Synthetic X-ray Difference Overlay

Synthetic X-ray to Detect Pathologies

Patient with no visual salient pathologies



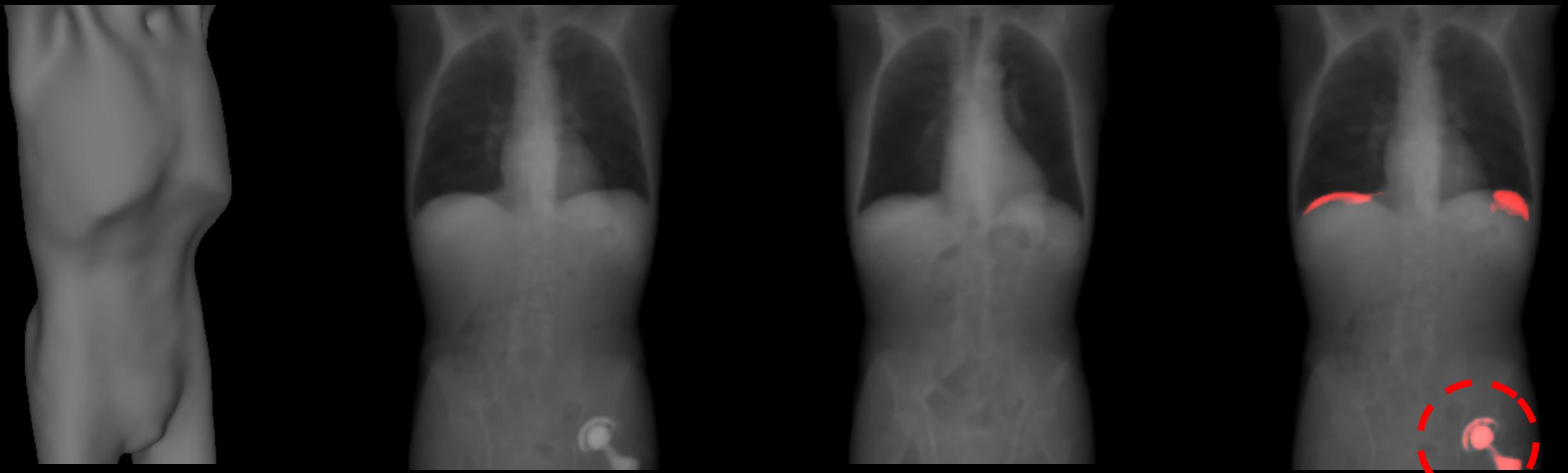
3D Surface Mesh

Real X-ray

Synthetic X-ray Difference Overlay

Synthetic X-ray to Detect Implants

Patient with metallic implant in the left leg



3D Surface Mesh

Real X-ray

Synthetic X-ray Difference Overlay

Acknowledgements

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- **Funding:** NSF-GRFP, Siemens Healthcare, Adobe, Princeton

Please see esizikova.github.io for more info.

Thank you for listening!