Structure-Aware Shape Analysis in Medical Imaging

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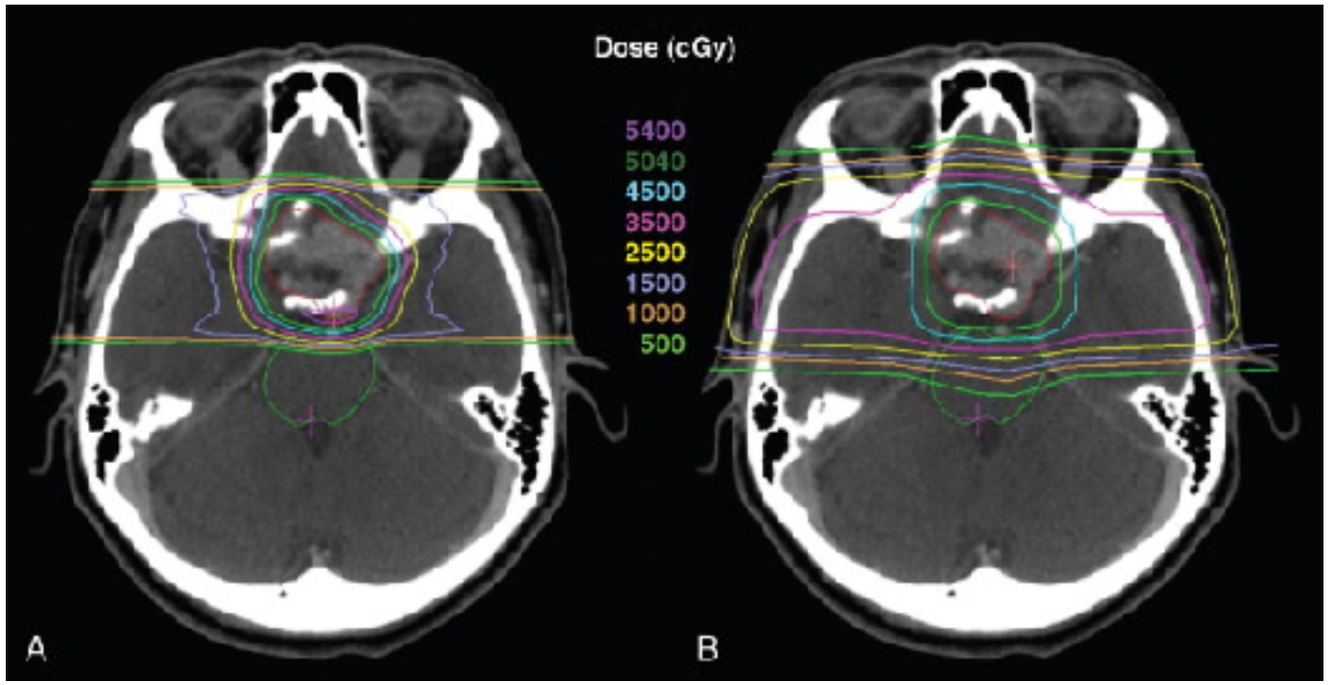
Introduction

Treatment Planning

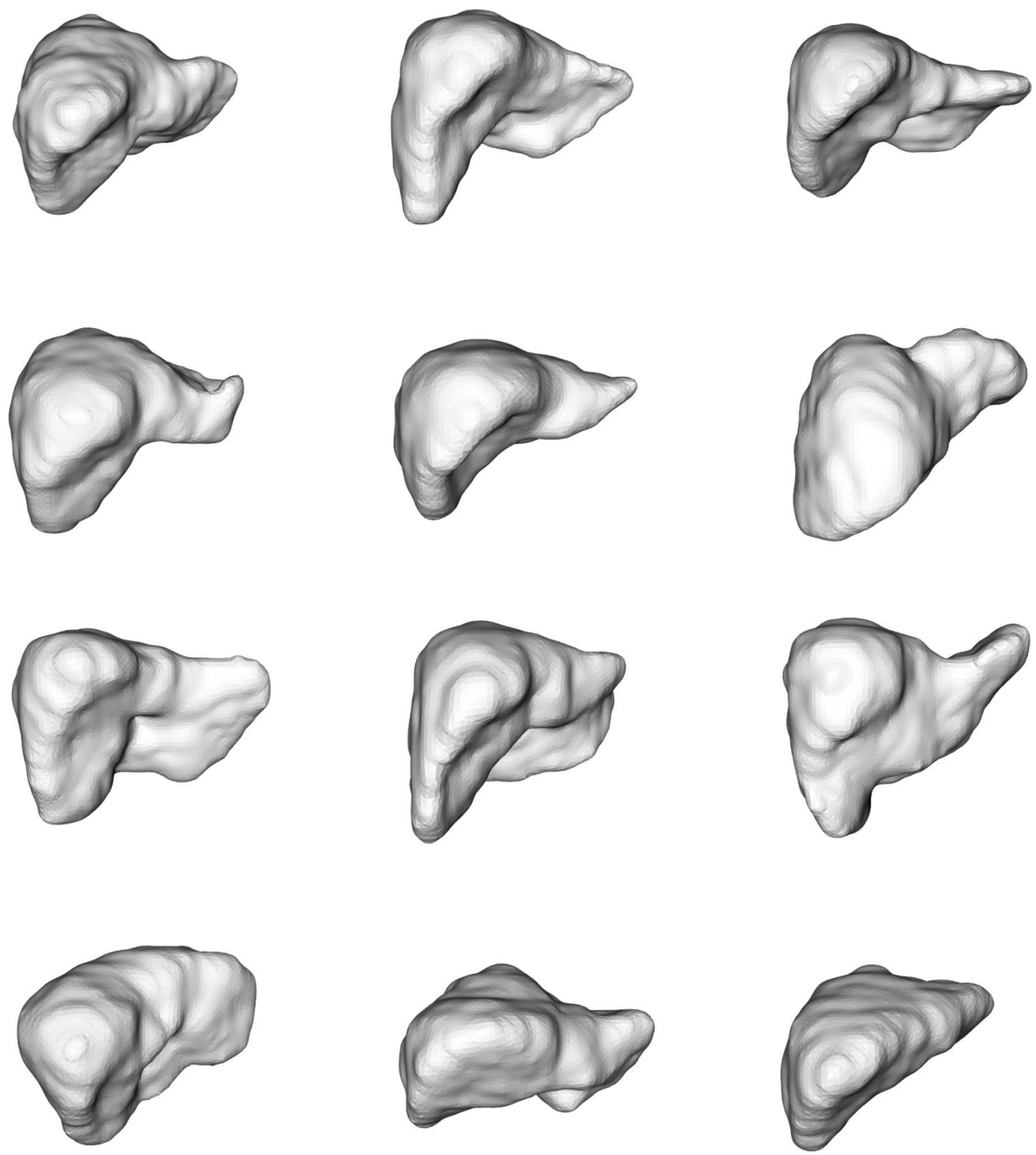


[Shih '10]

Post Operative Followup

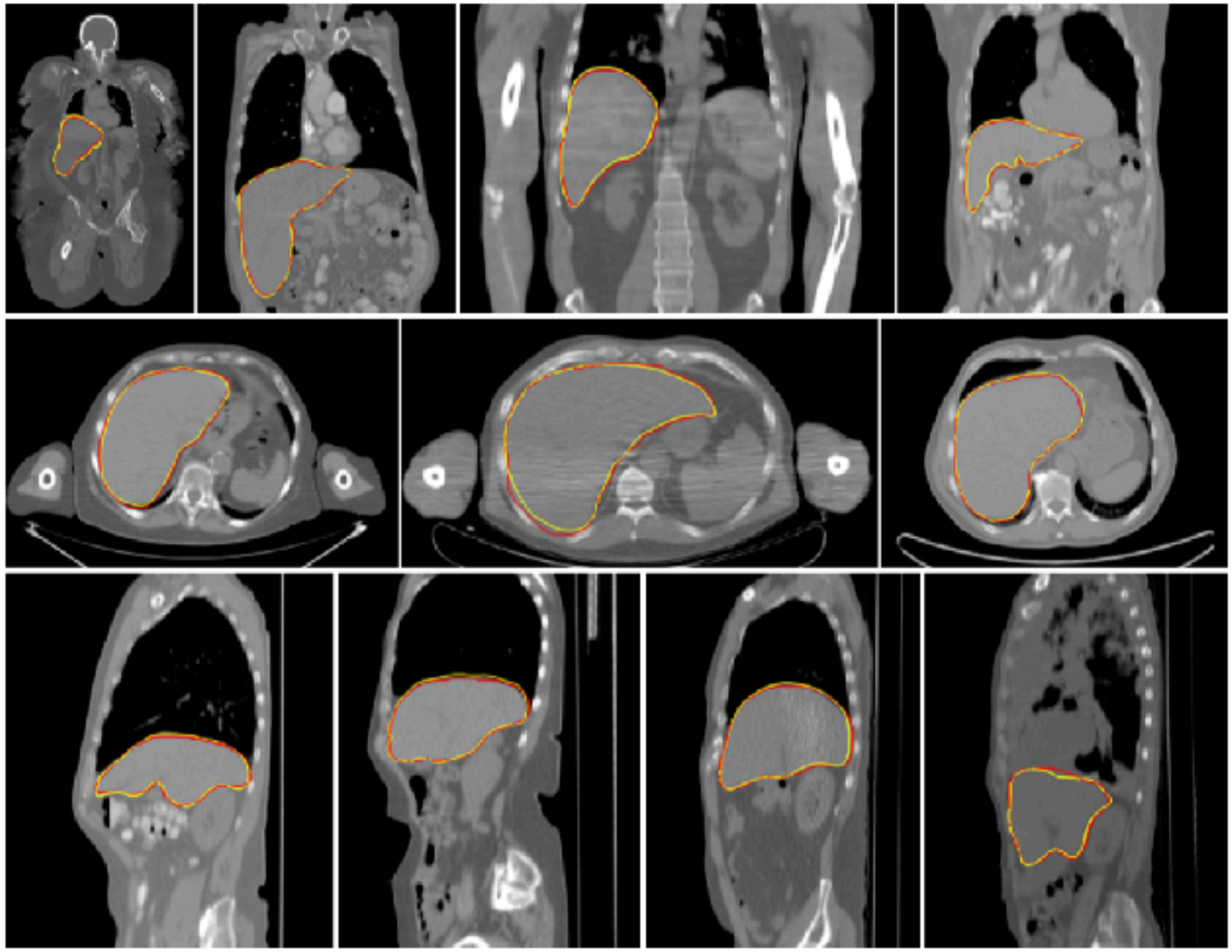
[Cincinnati Children's]

Introduction



High Degree of Shape Variation

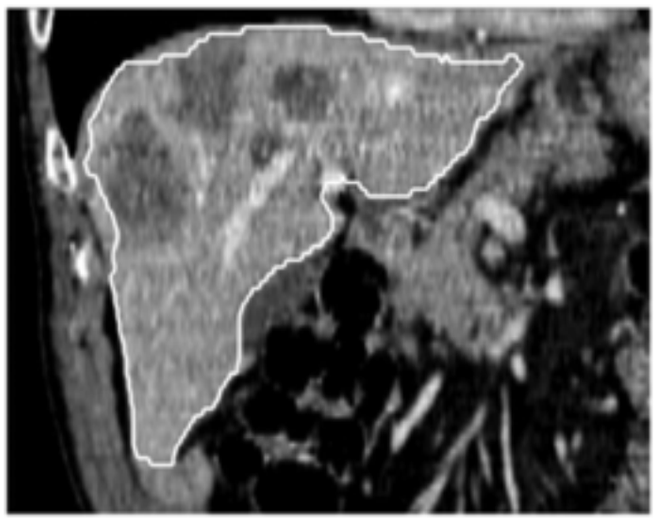
Background



[Yang '17]

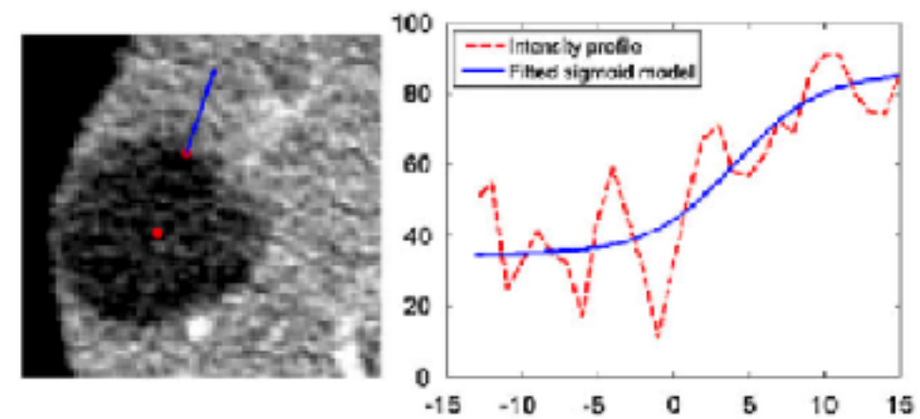
Background

Statistical Shape Model



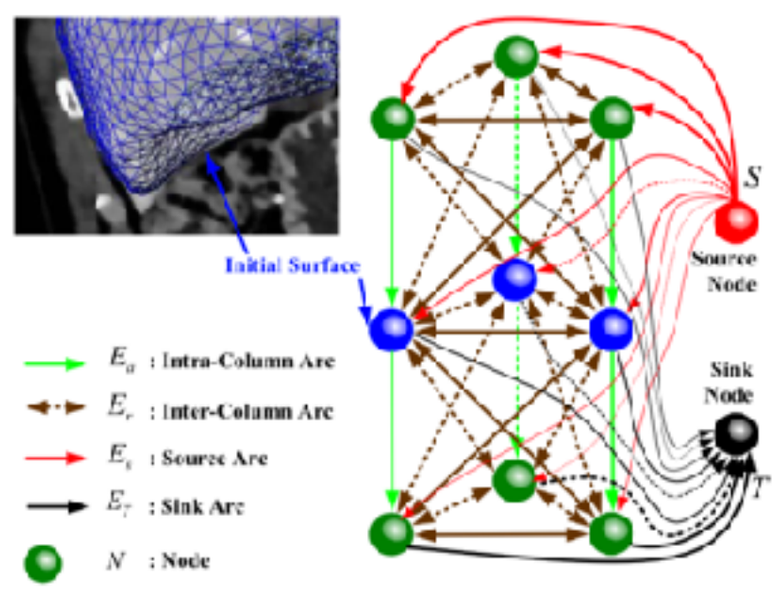
[Heimann '09]

Sigmoid Edge Model



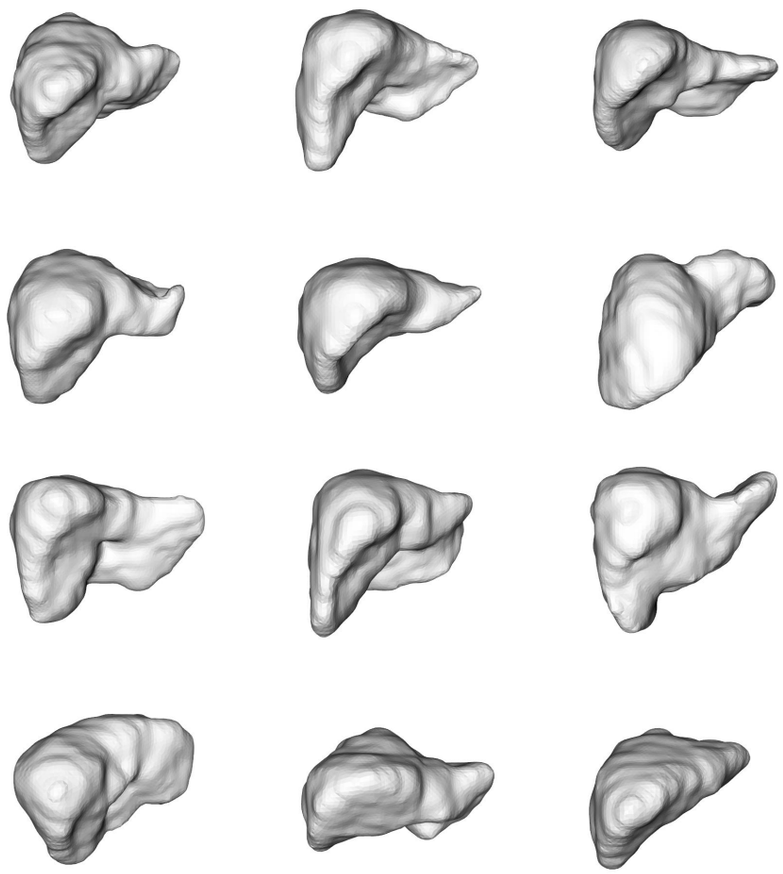
[Foruzan '15]

Graph Cut



[Li '15]

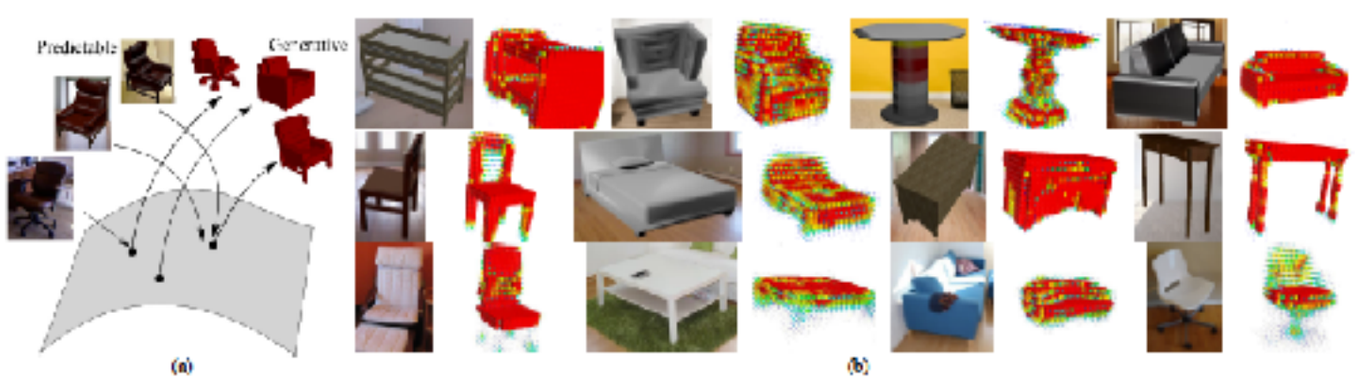
Challenge



Model

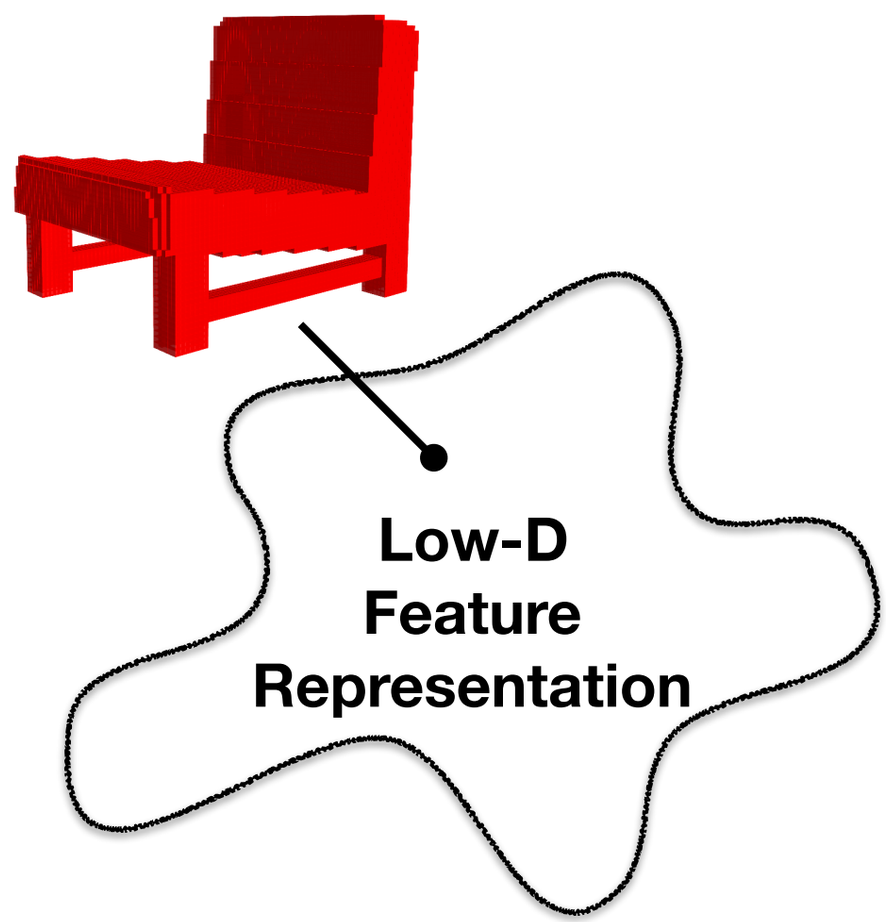
Neural Manifolds

[Wu ‘16] aka 3D-GAN

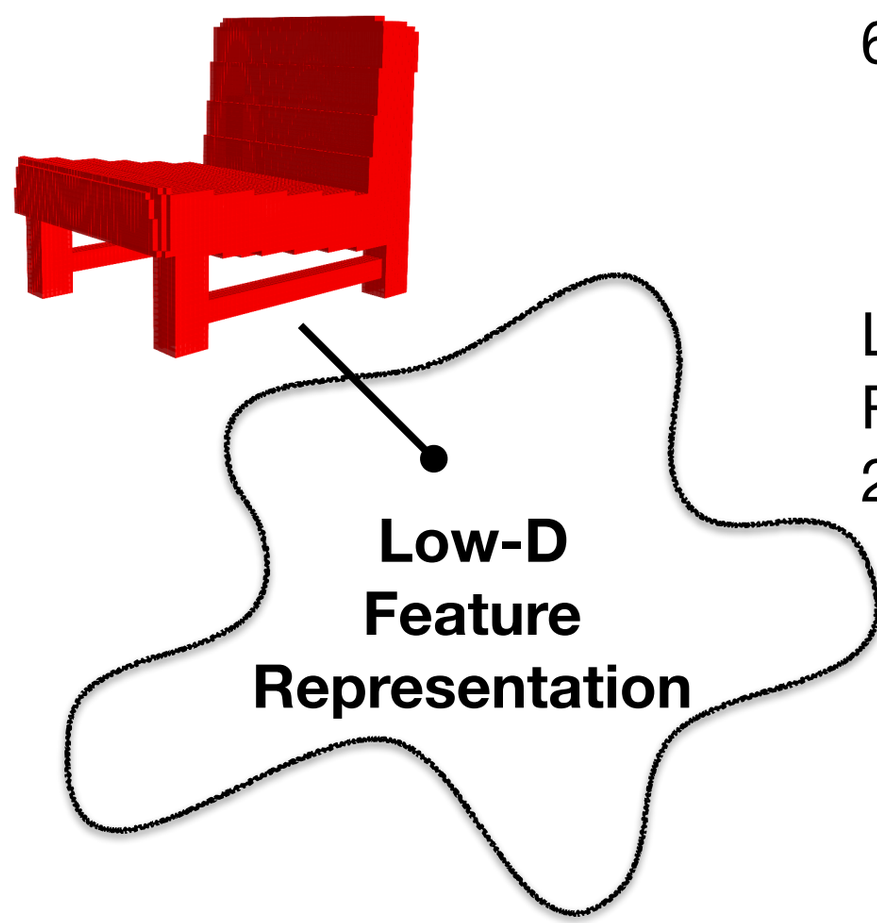


[Girdhar ‘16] aka TL Network

Neural Manifolds



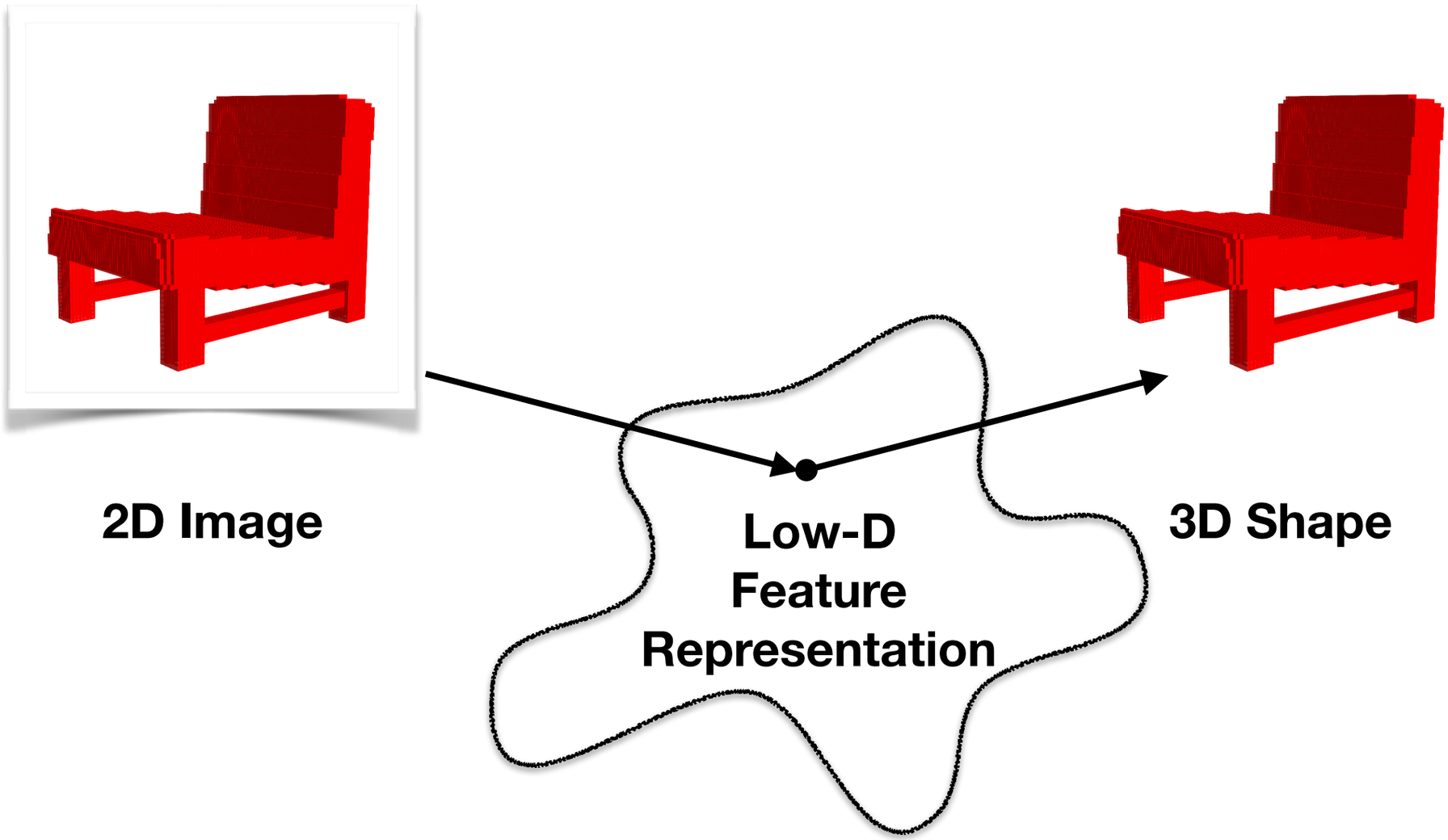
Neural Manifolds



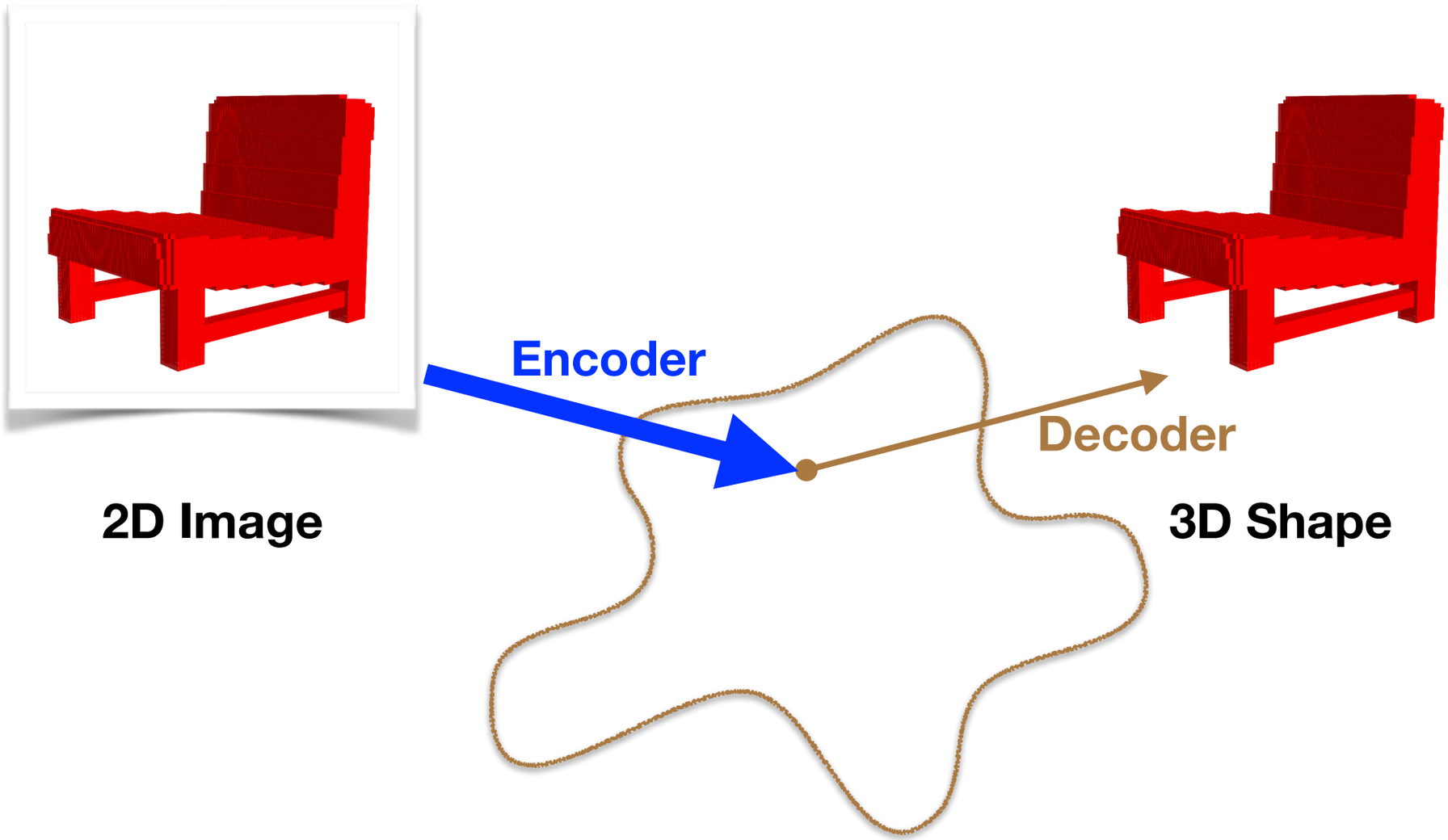
Voxel Grid Shape Representation:
64x64x64 = 262,144 parameters

Low-Dimensional Feature
Representation:
200 parameters

3D Reconstruction

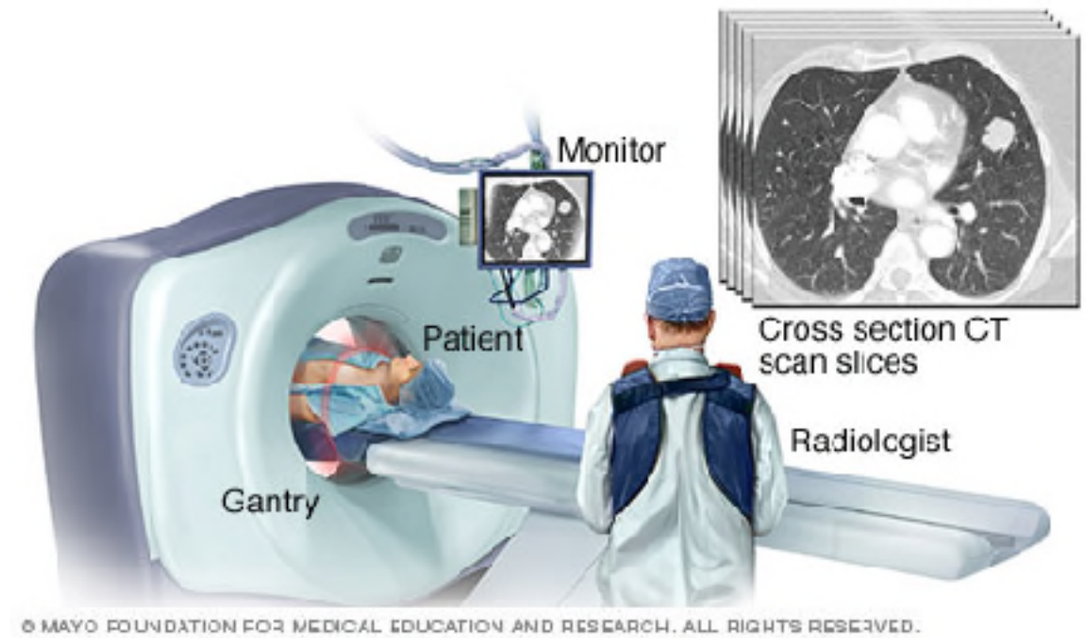


3D Reconstruction



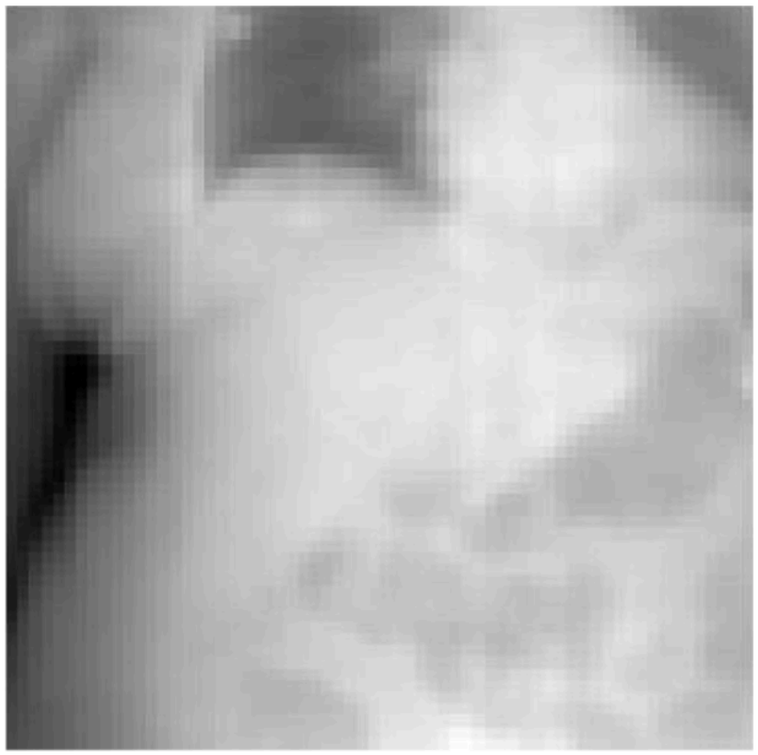
Application:
3D Liver Reconstruction

Application:
3D Liver Reconstruction

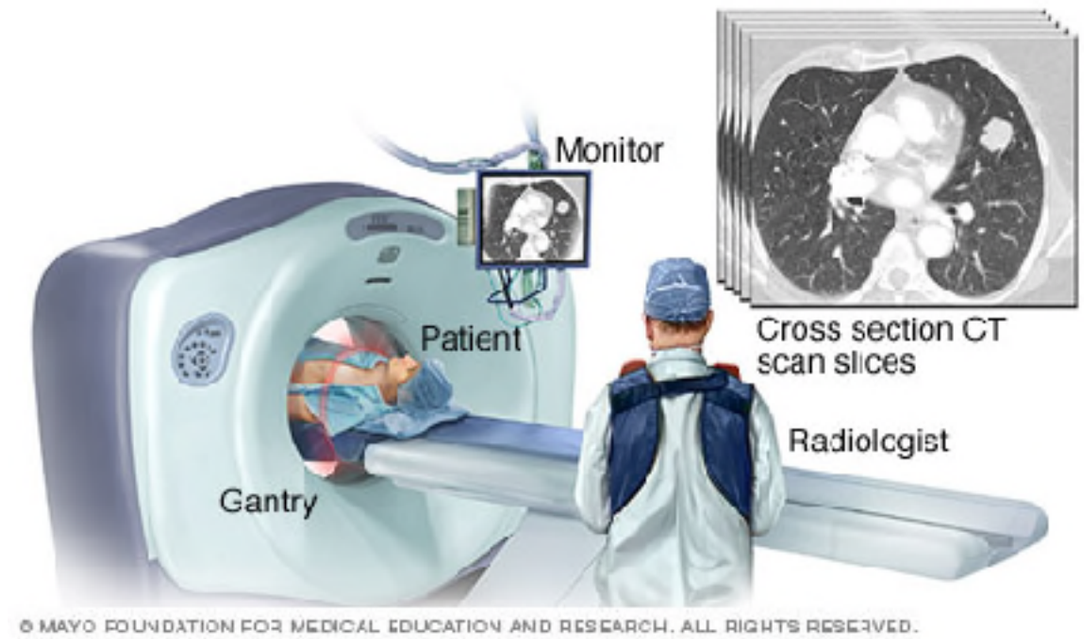


CT Scan

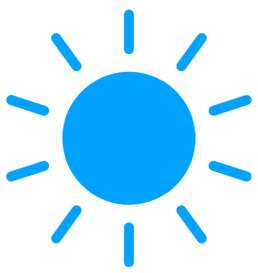
Application:
3D Liver Reconstruction



Topogram Scan



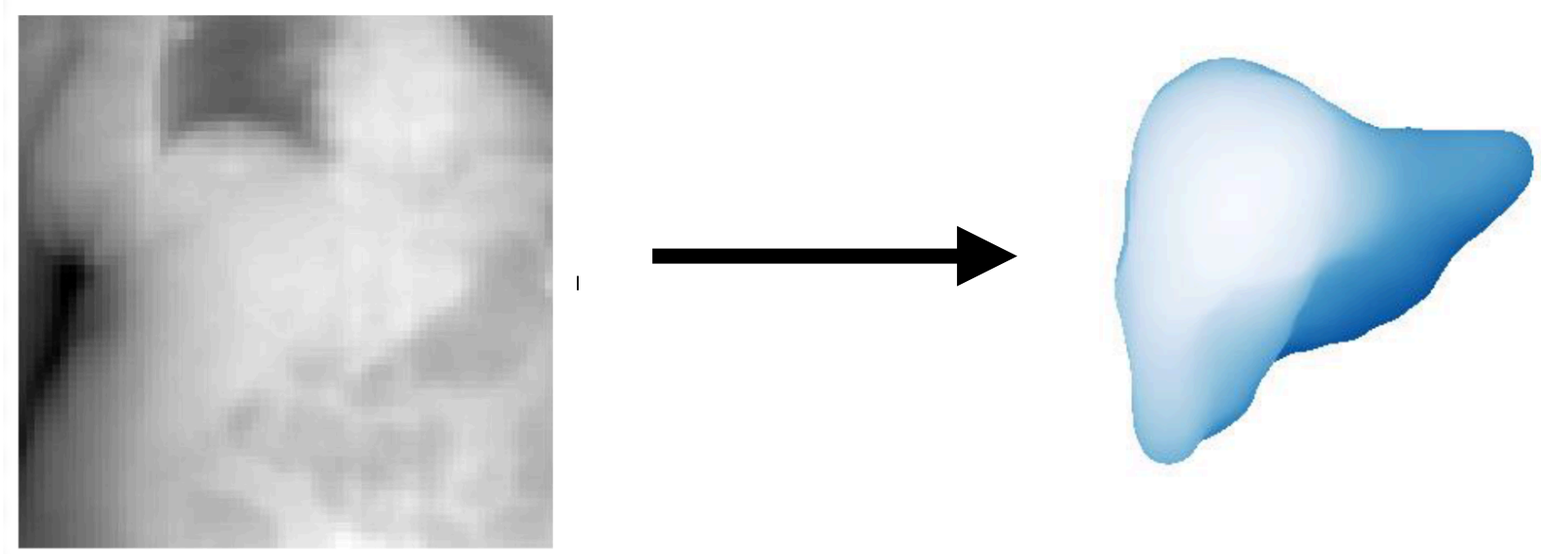
CT Scan



Higher radiation exposure!

More Expensive!

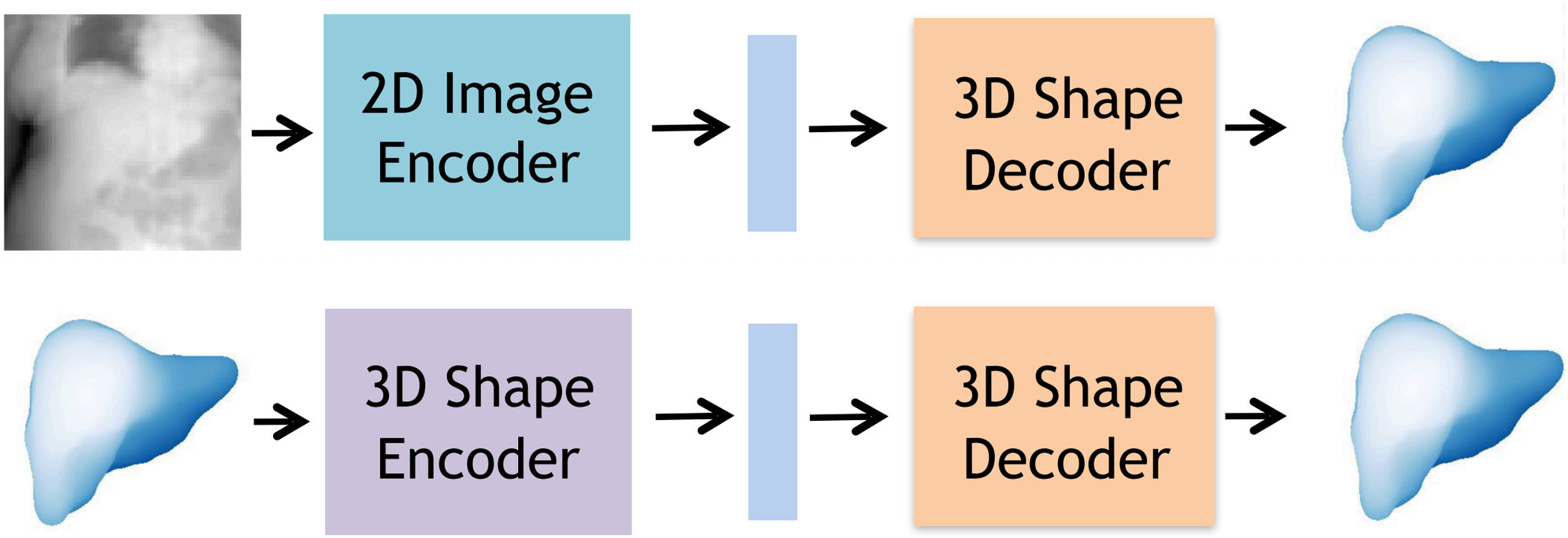
Application:
3D Liver Reconstruction



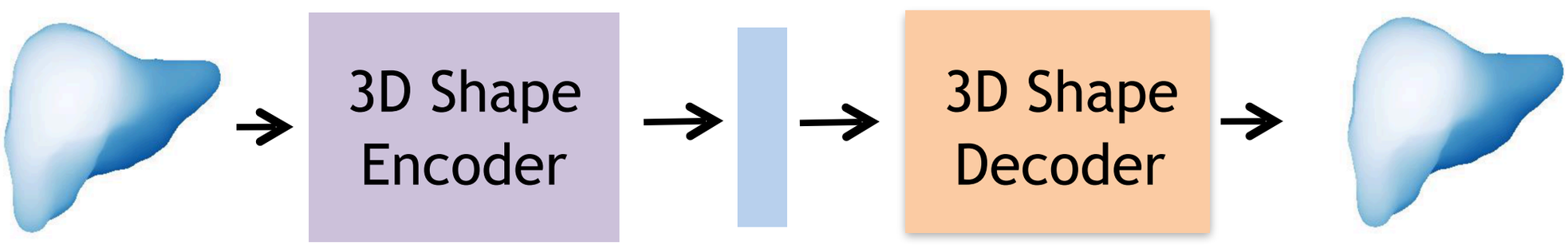
Topogram **3D Shape**

E. Balashova, J. Wang, V. Singh, B. Georgescu, B. Teixeira, A. Kapoor
3D Organ Shape Reconstruction from Topogram Images
Information Processing in Medical Imaging (IPMI) 2019.

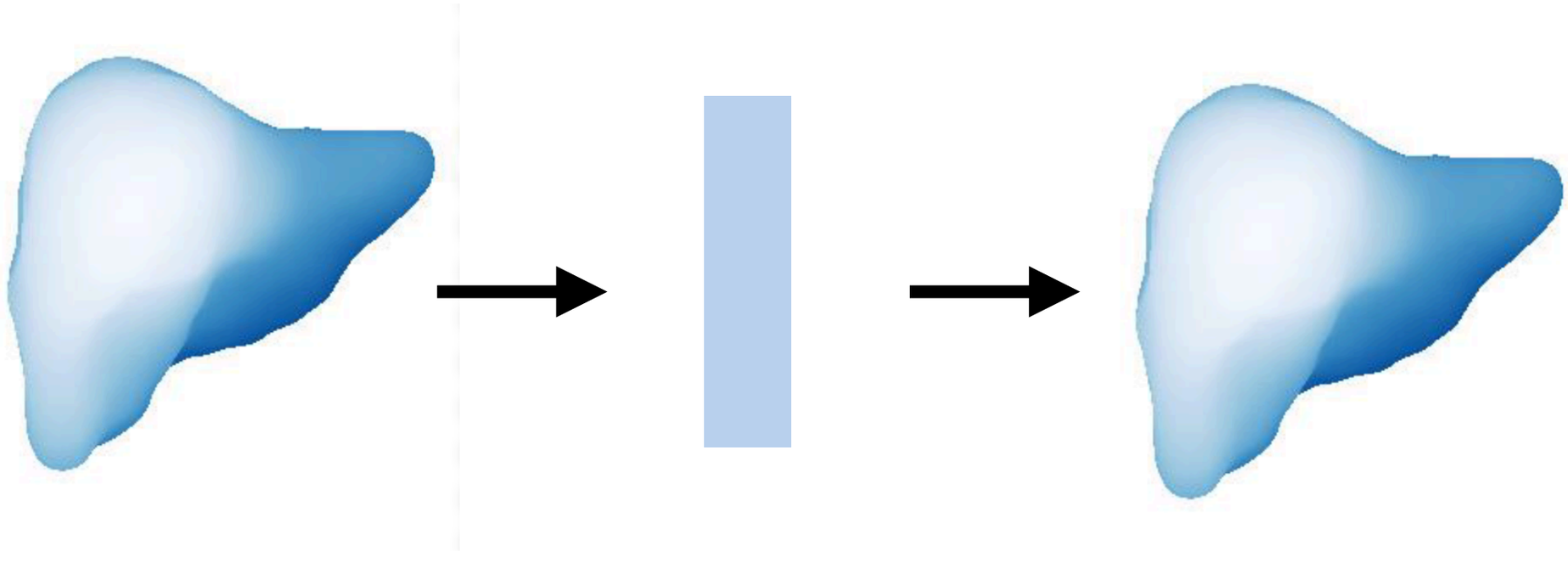
Model


2D Image Encoder
3D Shape Decoder
3D Shape Encoder
3D Shape Decoder

Model

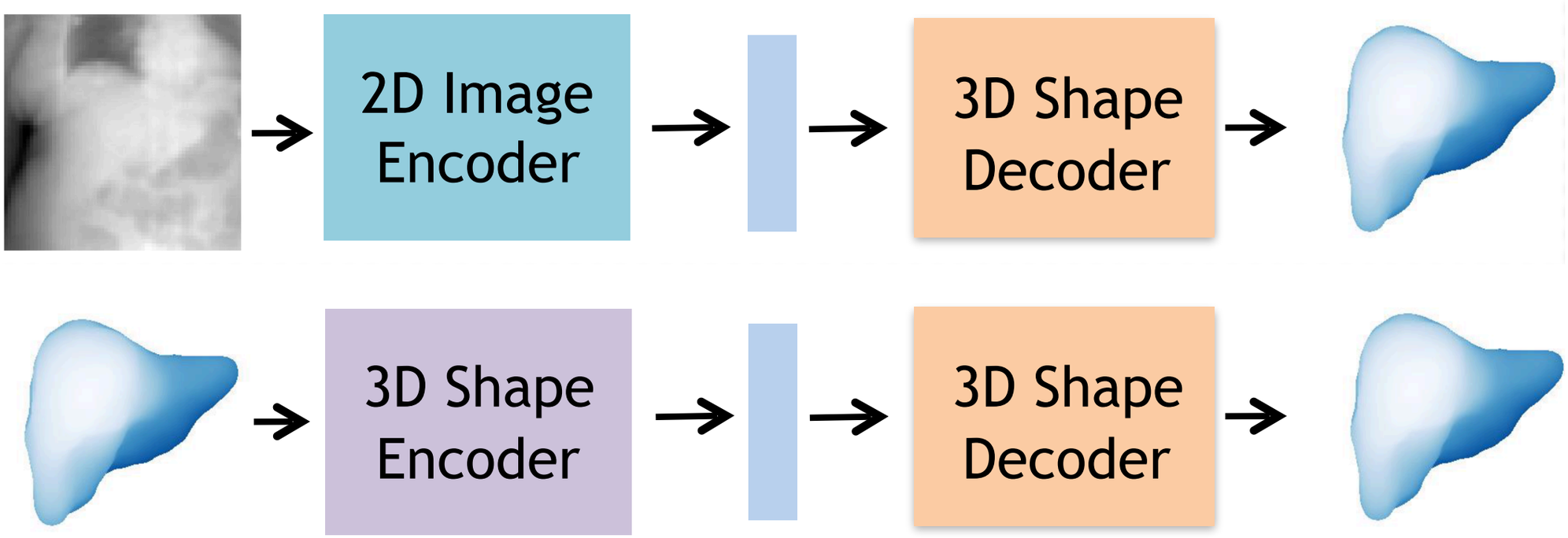


3D Shape Model



Learn a neural shape model based on [Girdhar ’16]

Model


2D Image Encoder
3D Shape Decoder
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Objective

We optimize the networks using a combination loss function L:

Kullback Leibler divergence

Encoder Output

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

Shape Model Loss **Image Loss**

GT Shape Pred. Shape

BCE Loss

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

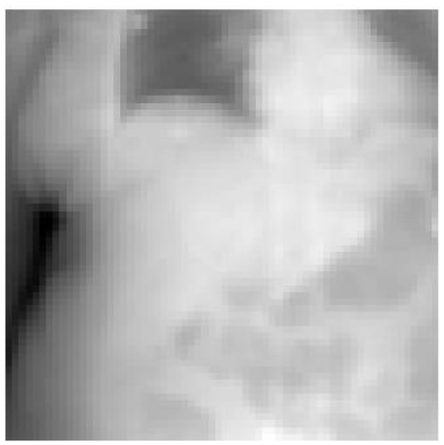
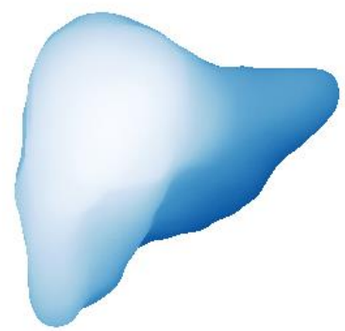
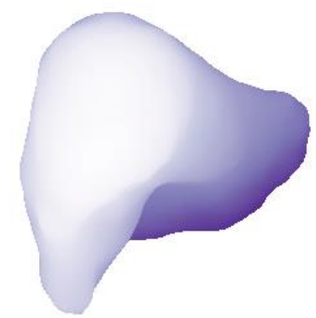
Reconstruction Loss

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

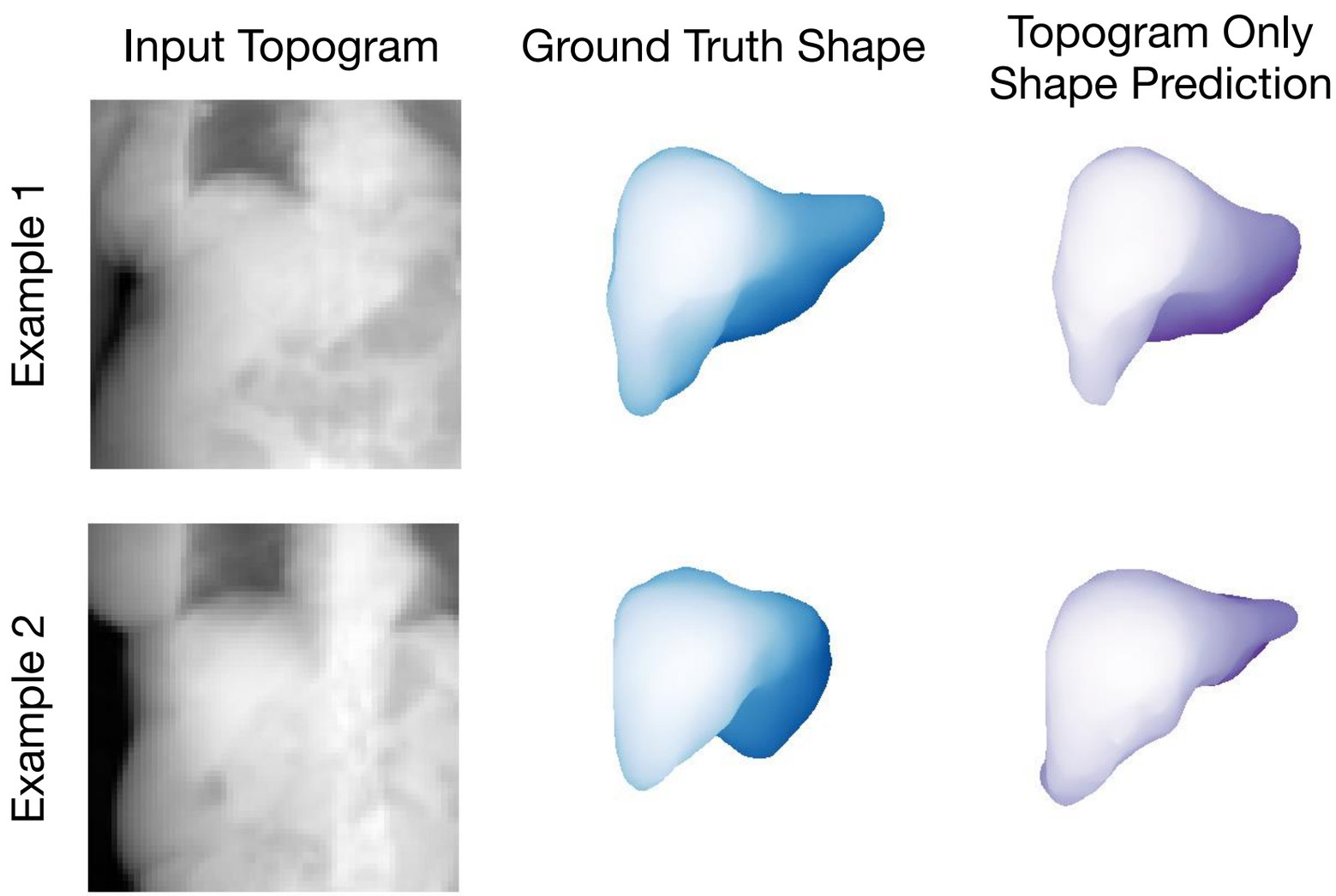
Results

	Input Topogram	Ground Truth Shape	Topogram Only Shape Prediction
Example 1			
Example 2			

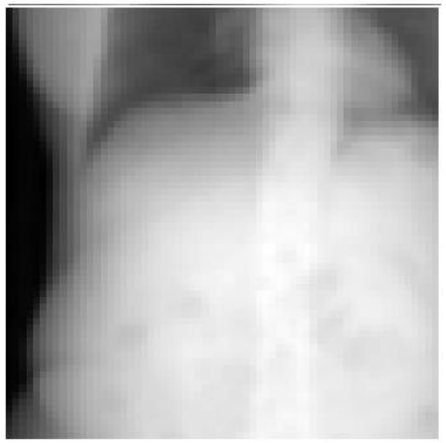
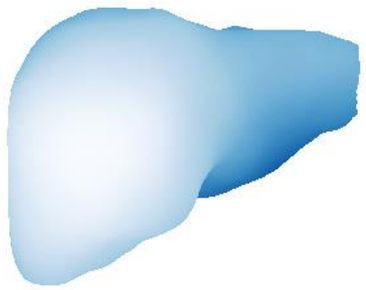
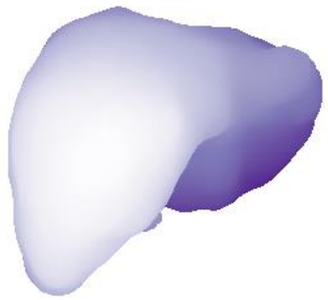
Results

	Input Topogram	Ground Truth Shape	Topogram Only Shape Prediction
Example 1			
Example 2			

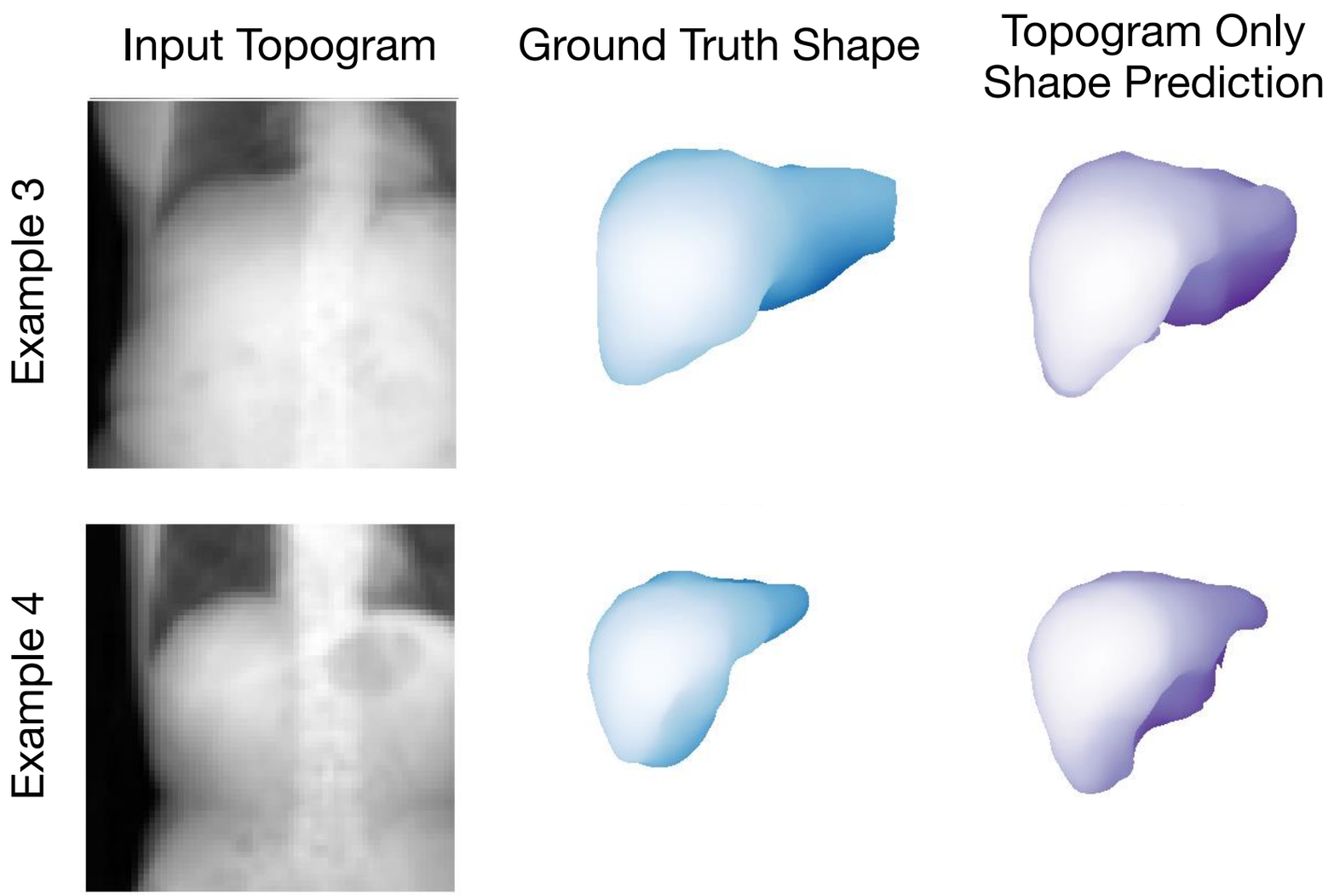
Results


Input Topogram
Ground Truth Shape
Topogram Only
Shape Prediction
Example 1
Example 2

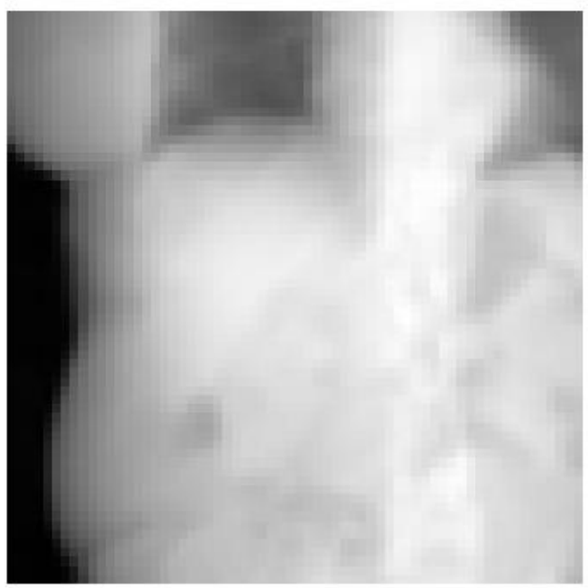
Results

	Input Topogram	Ground Truth Shape	Topogram Only Shape Prediction
Example 3			
Example 4			

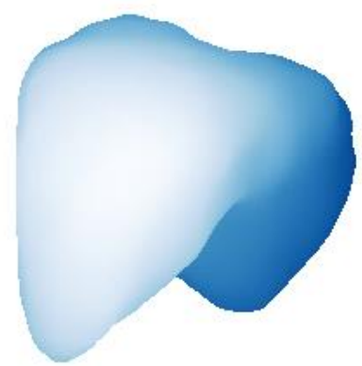
Results


Input Topogram
Ground Truth Shape
Topogram Only
Shape Prediction
Example 3
Example 4

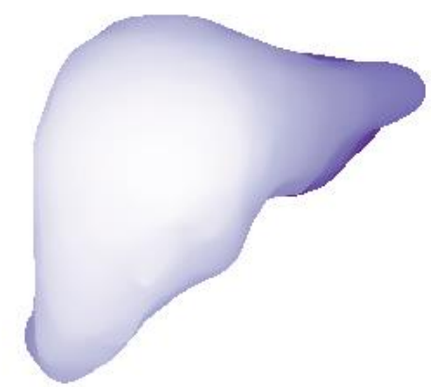
Improve Accuracy?



Ground Truth Shape



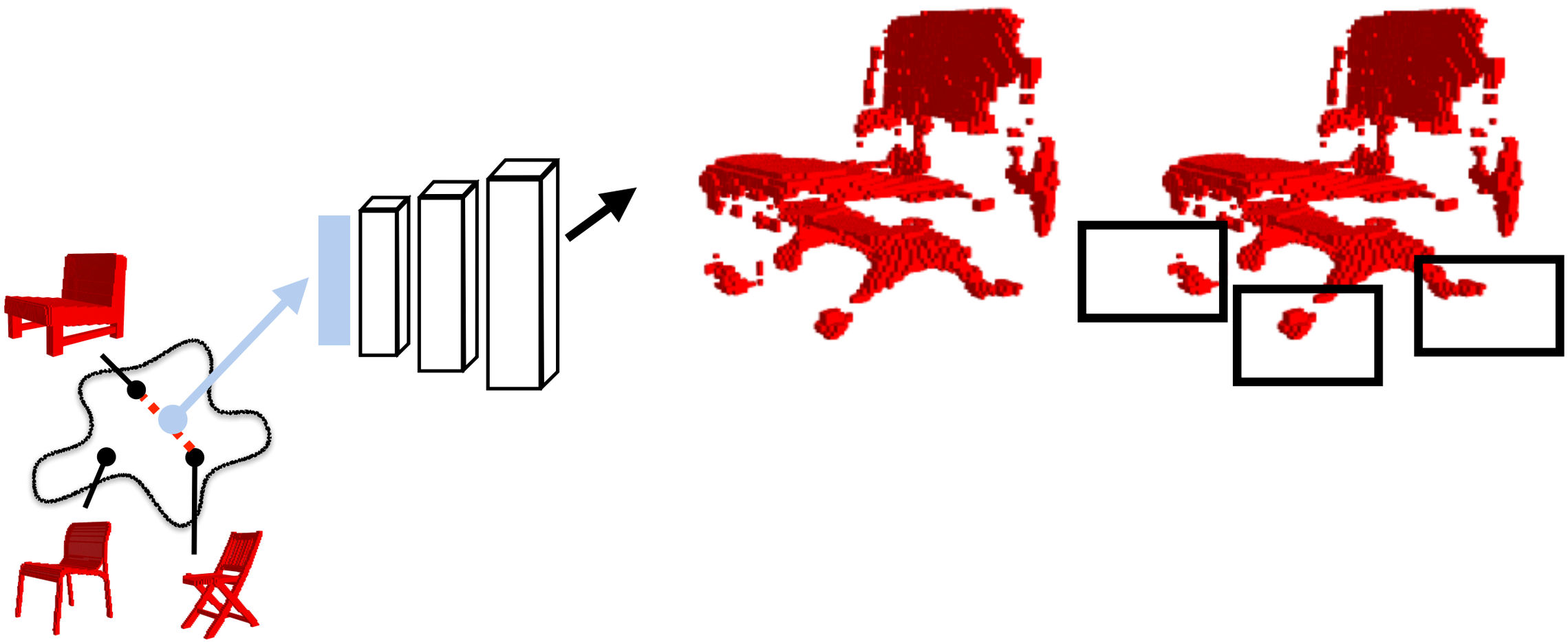
Shape Prediction



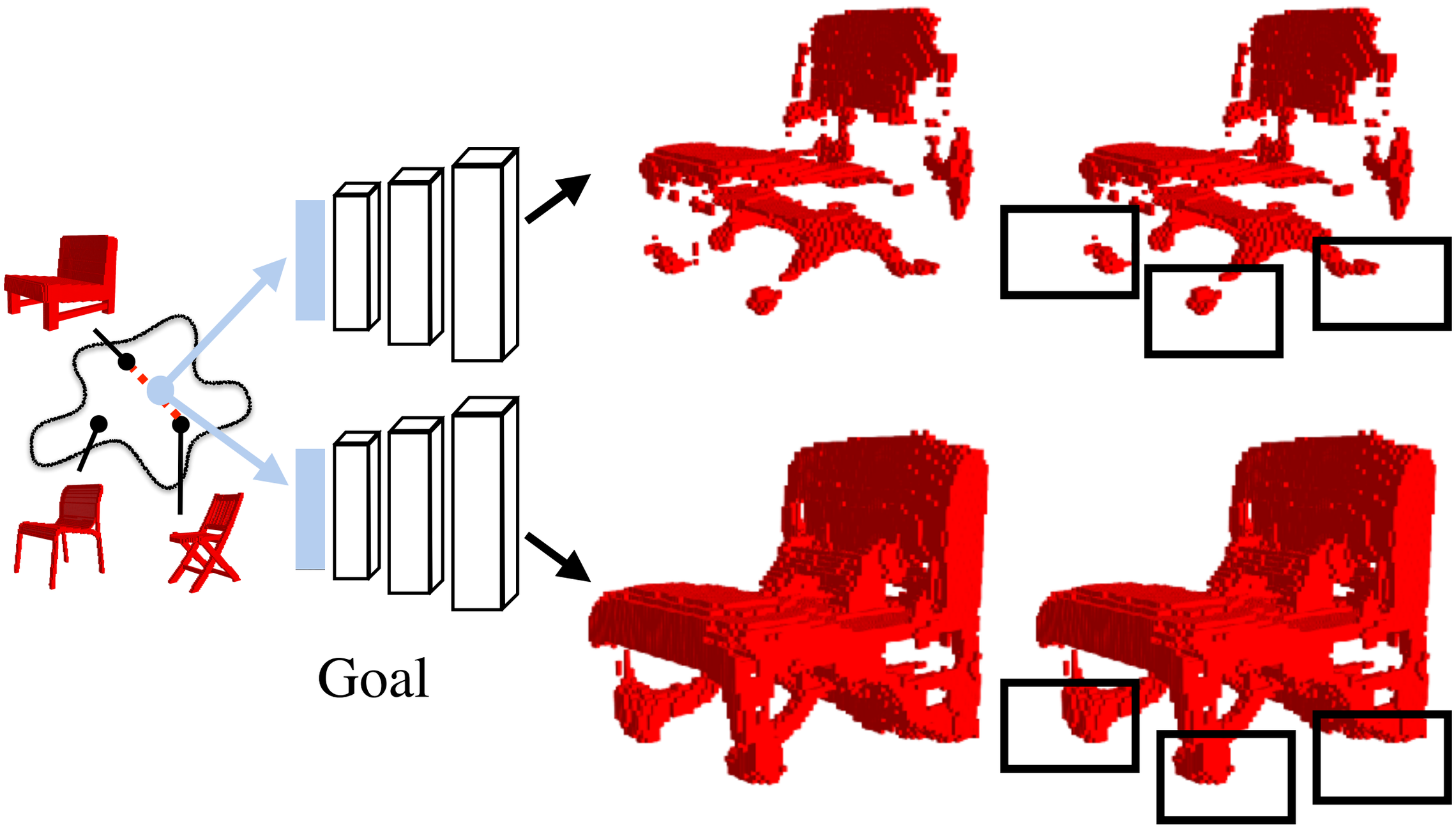
Structure-Aware Shape Synthesis

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

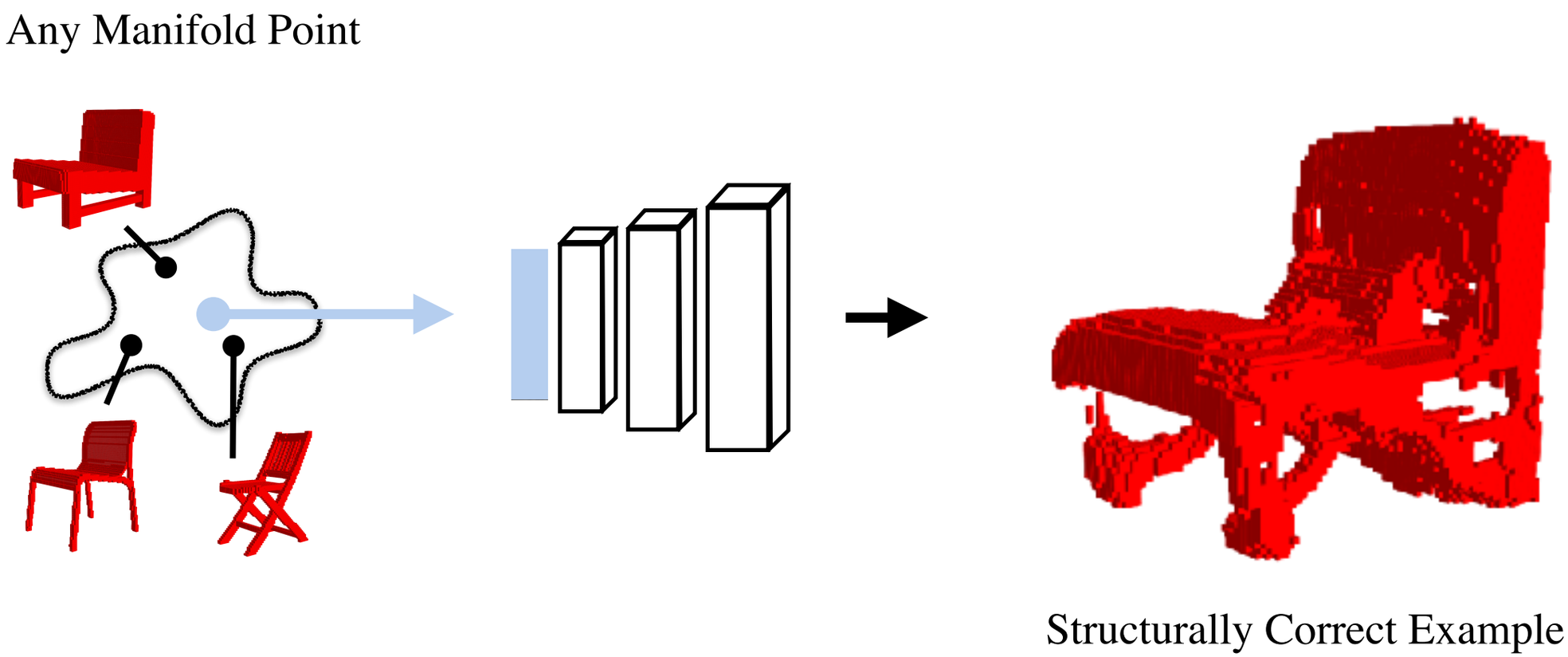
Challenge



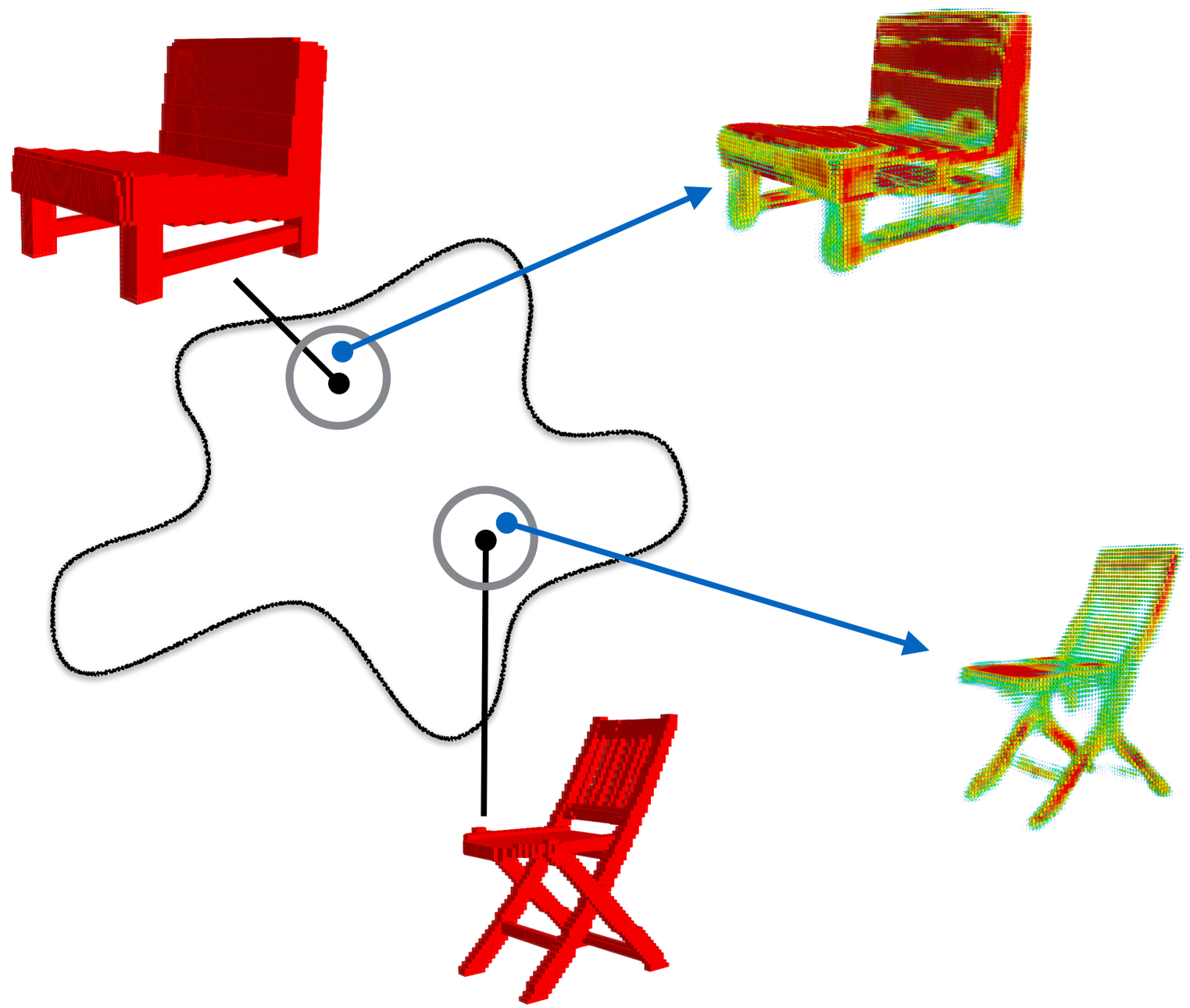
Structure-Aware Synthesis



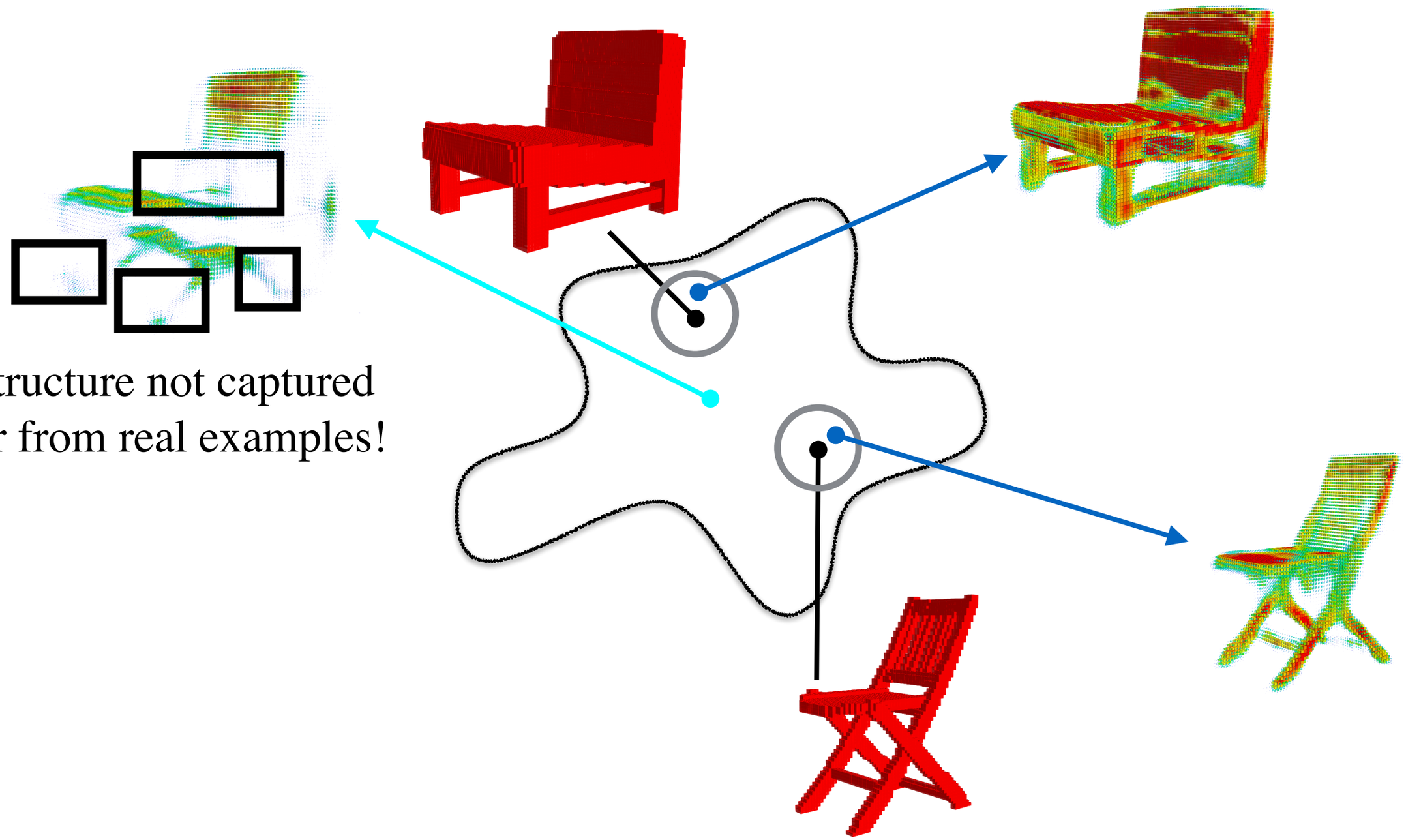
Goal



Manifold Learning

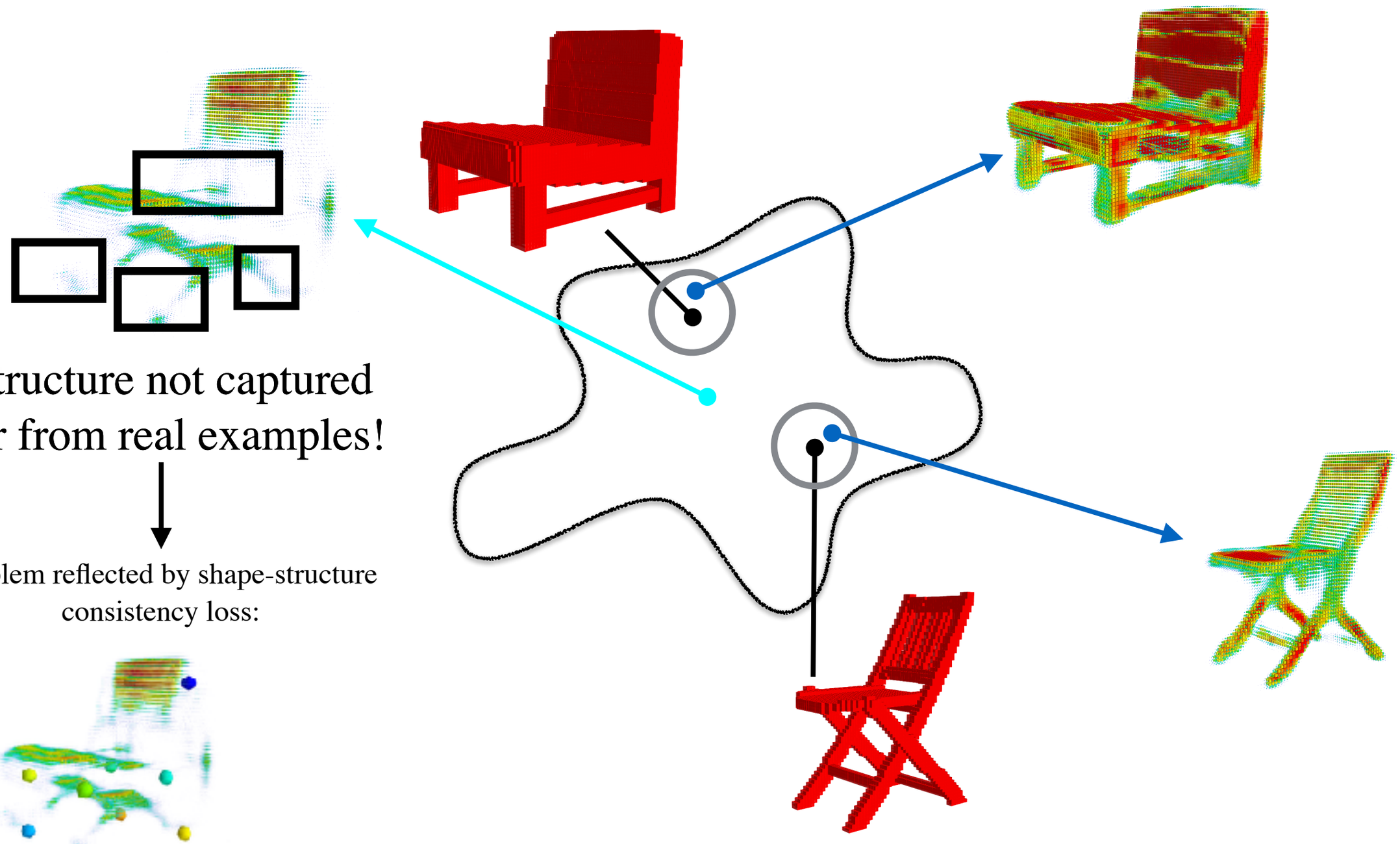


Manifold Learning



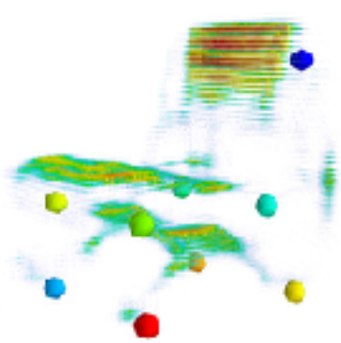
Structure not captured
far from real examples!

Manifold Learning



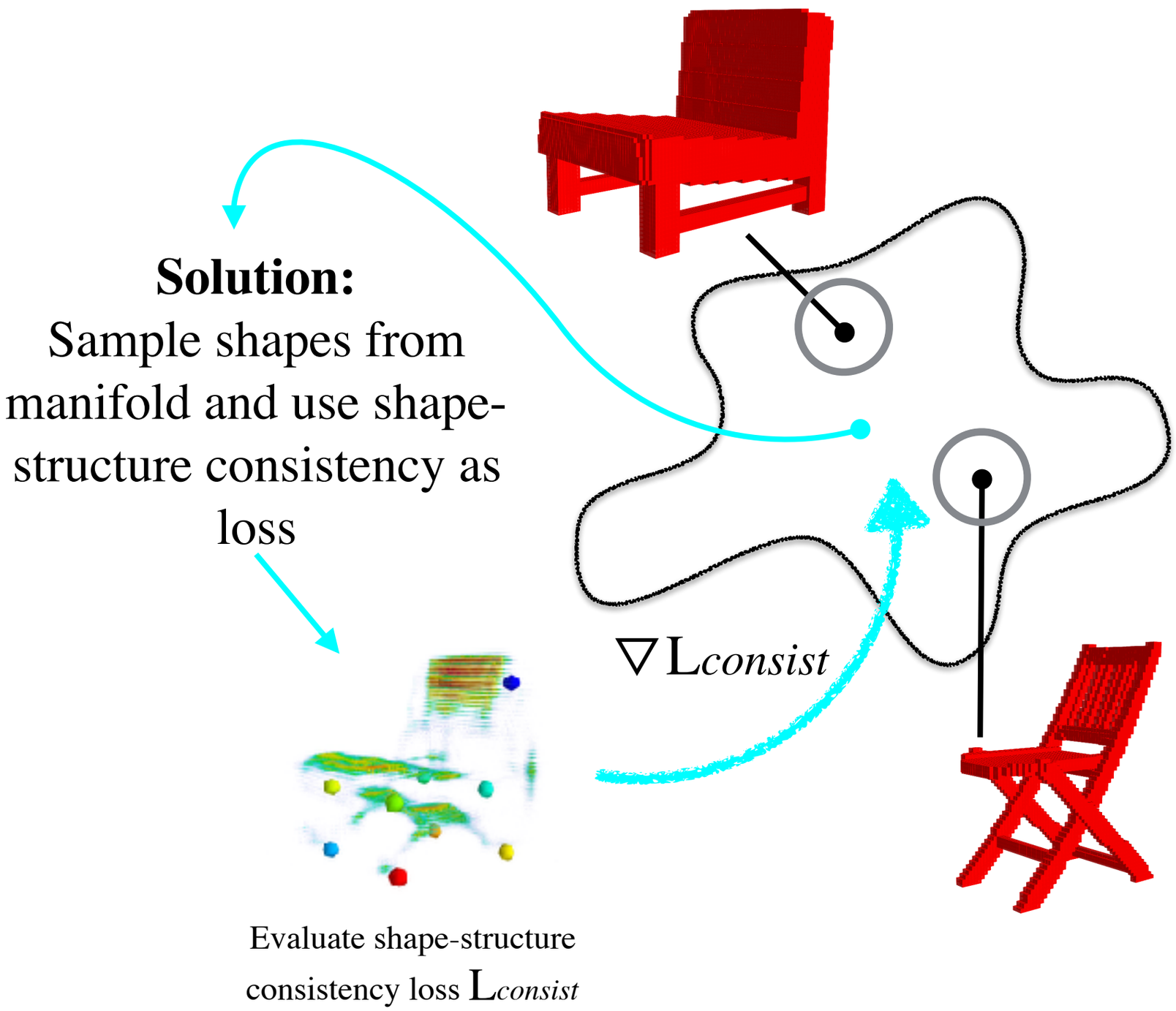
Structure not captured far from real examples!

Problem reflected by shape-structure consistency loss:

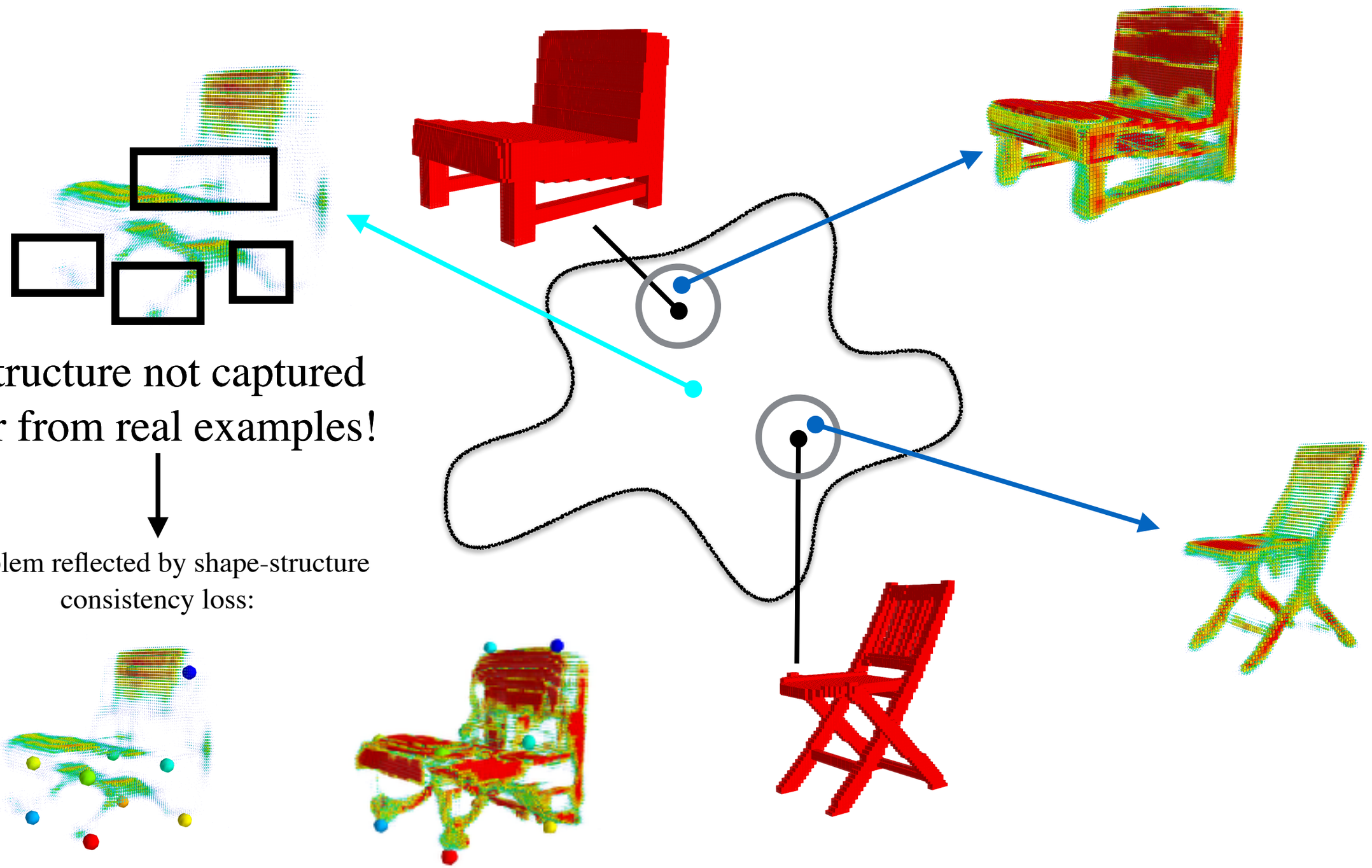


Shape Only

Manifold Learning

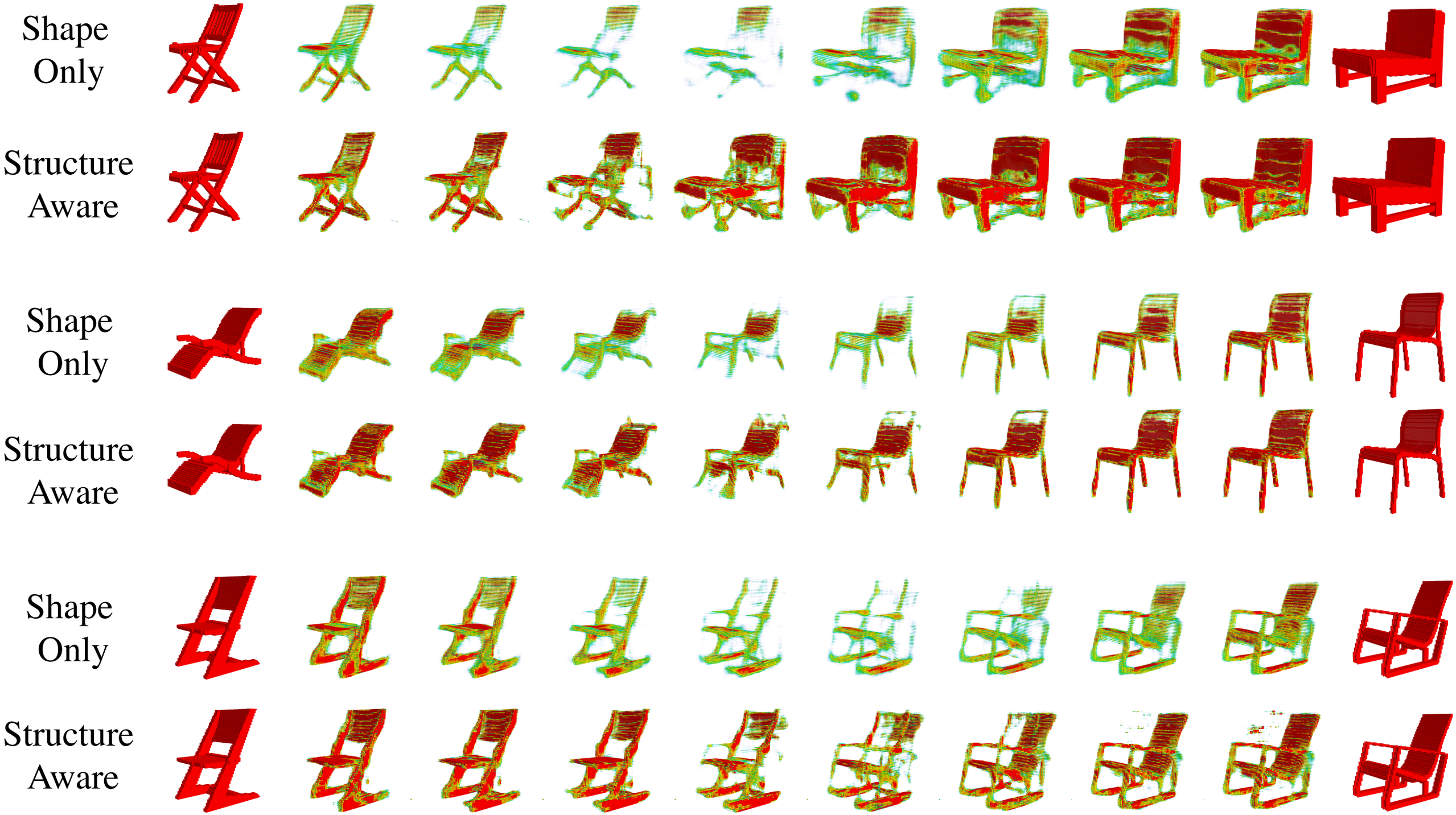


Manifold Learning

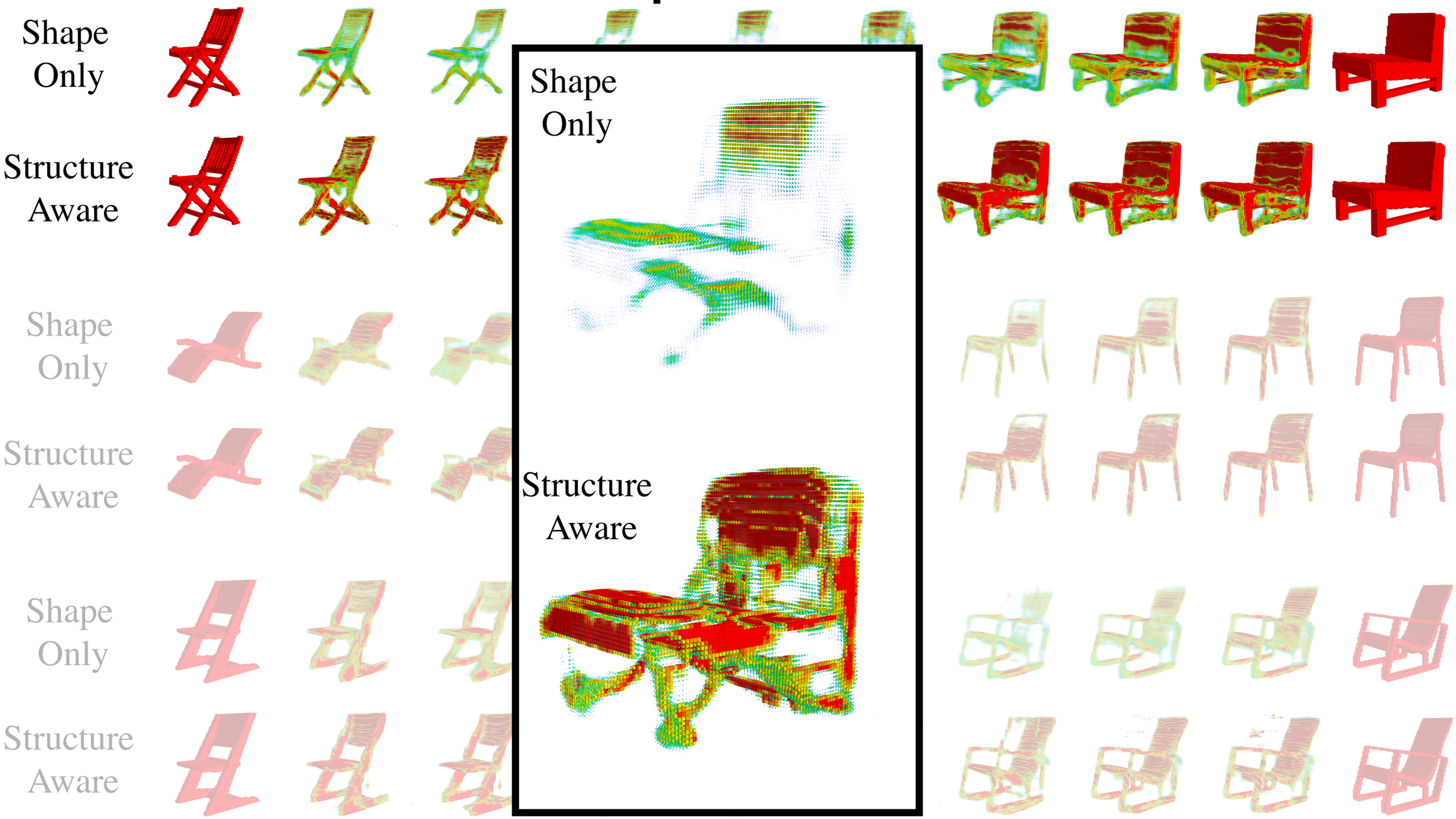


Interpolation

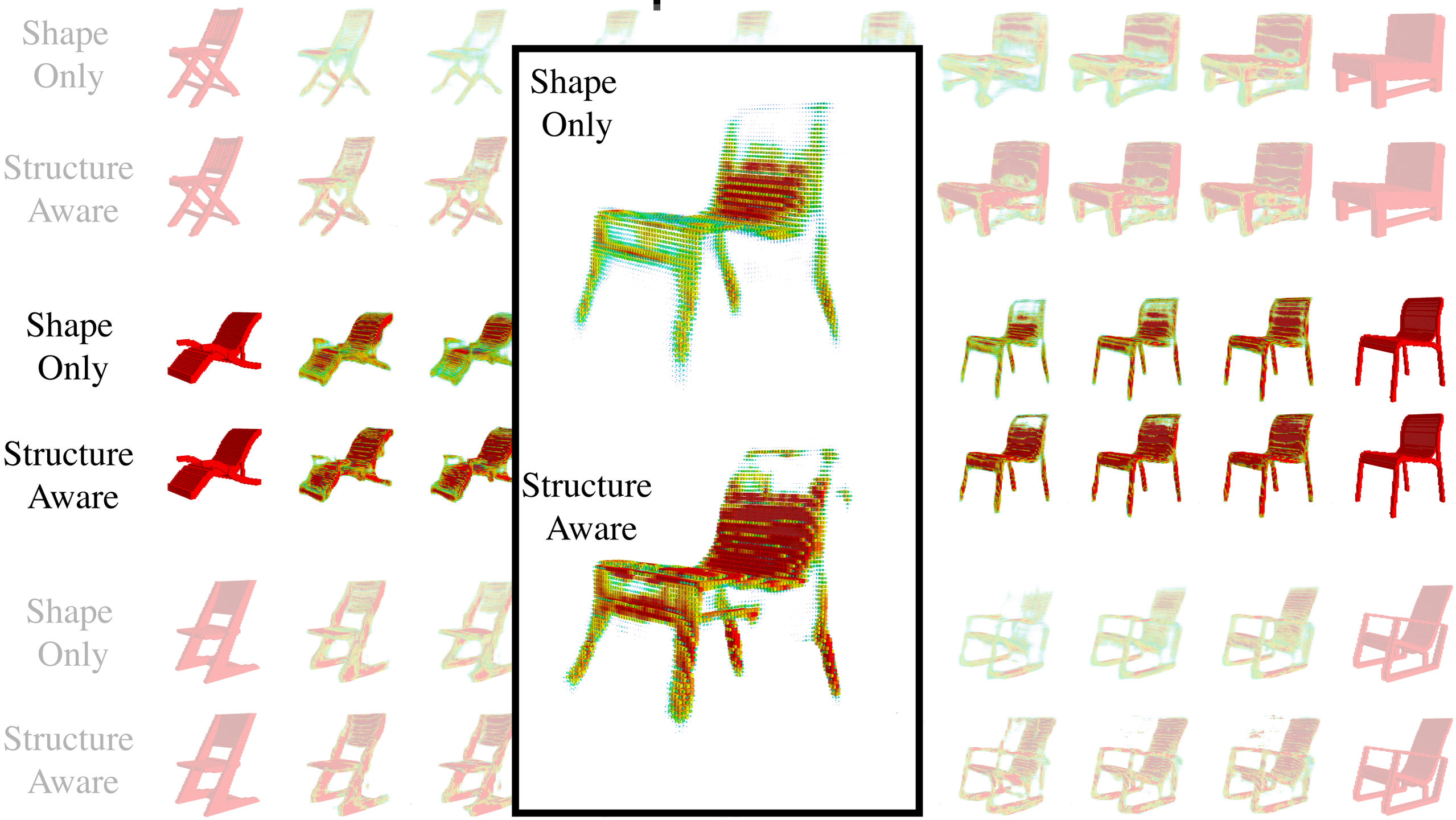
Interpolation



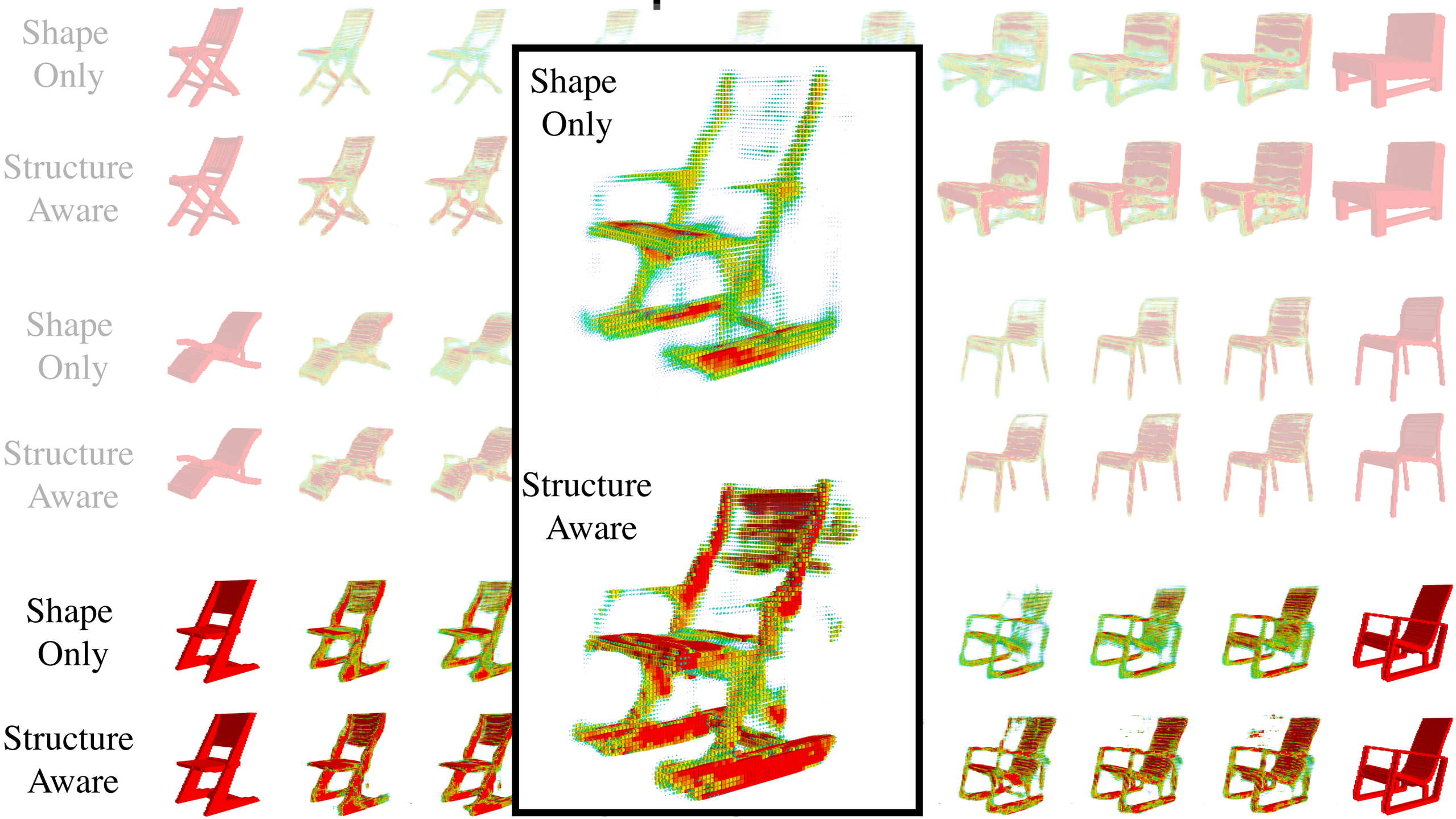
Interpolation



Interpolation

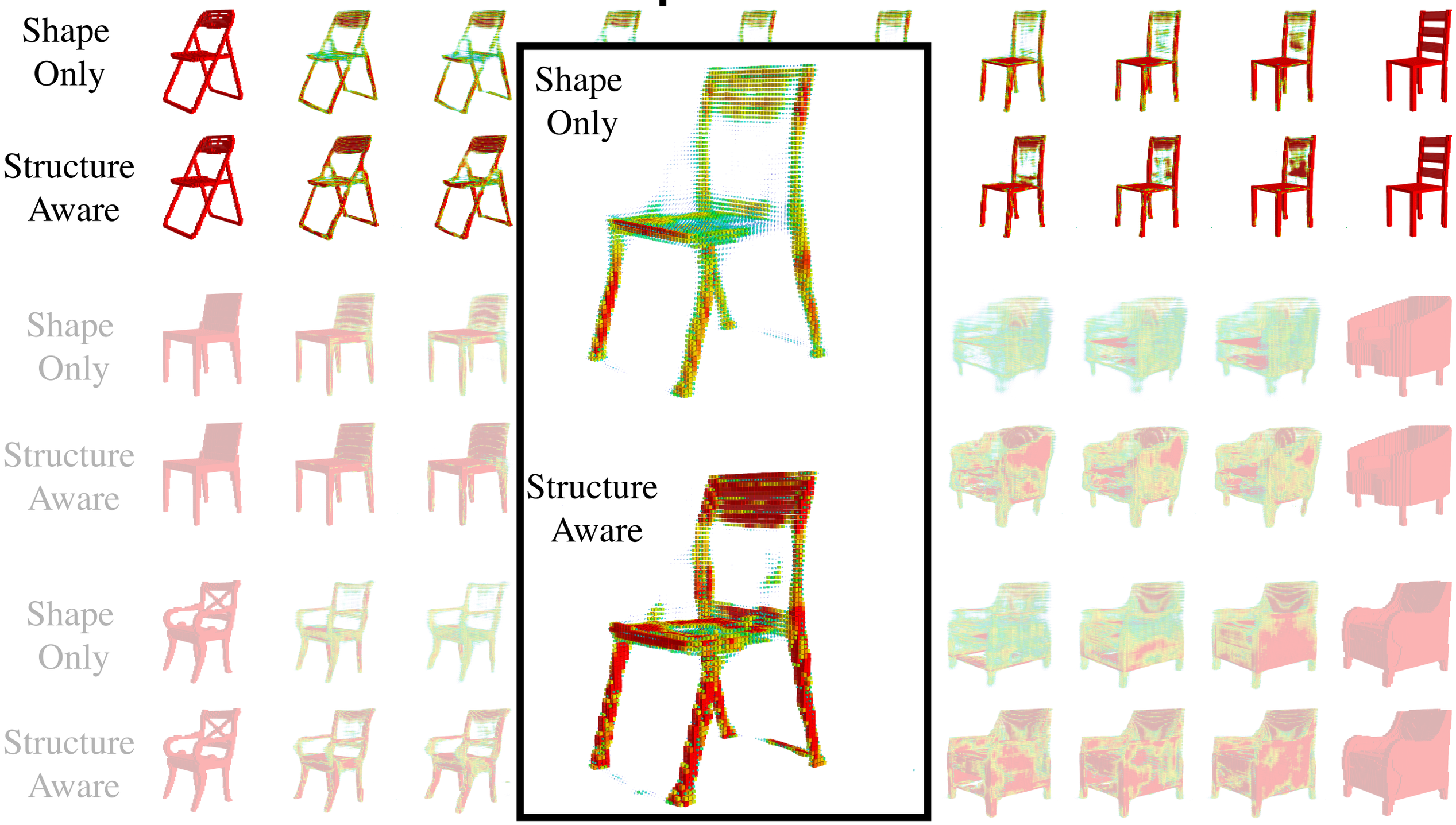


Interpolation

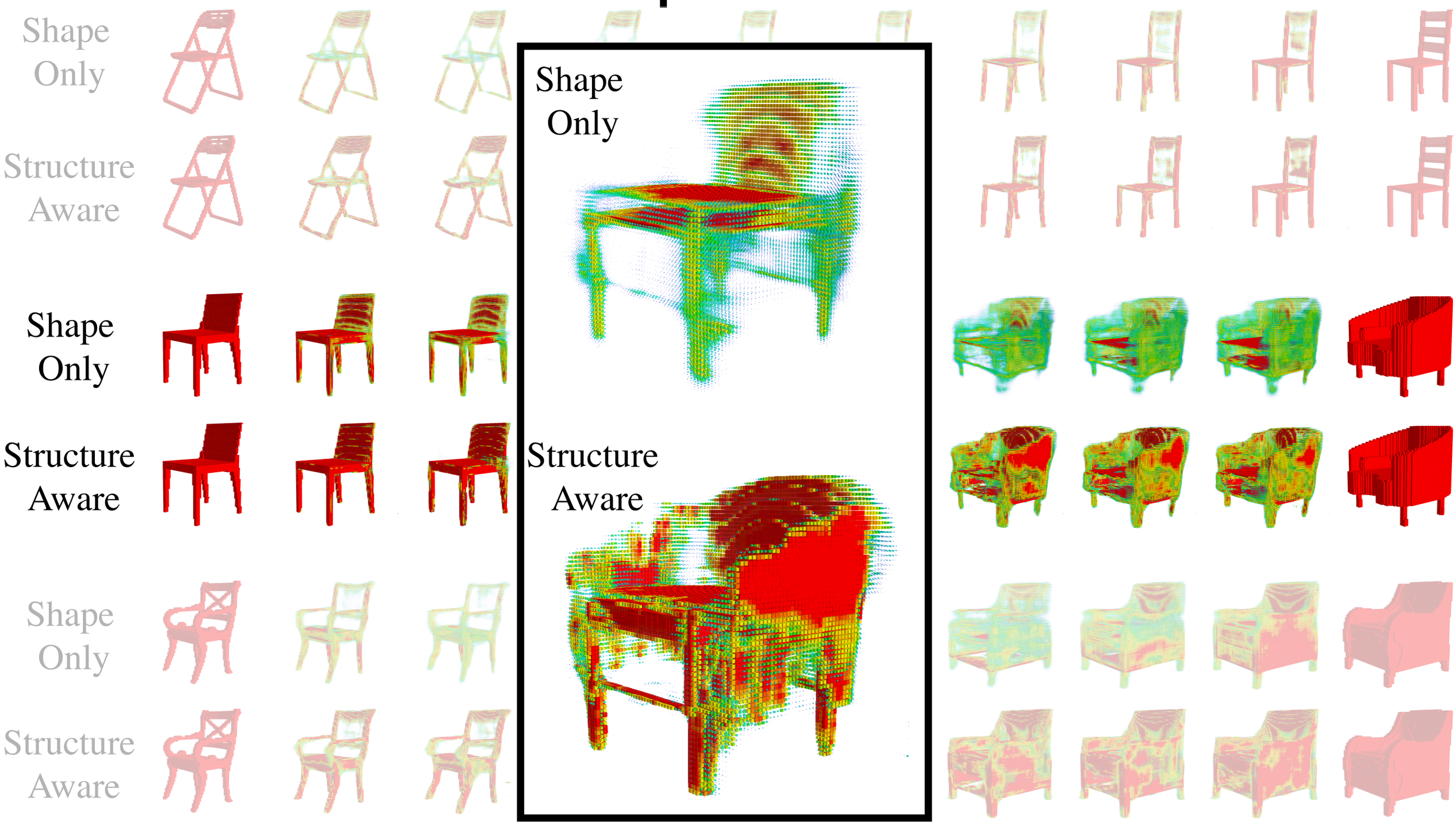


Interpolation

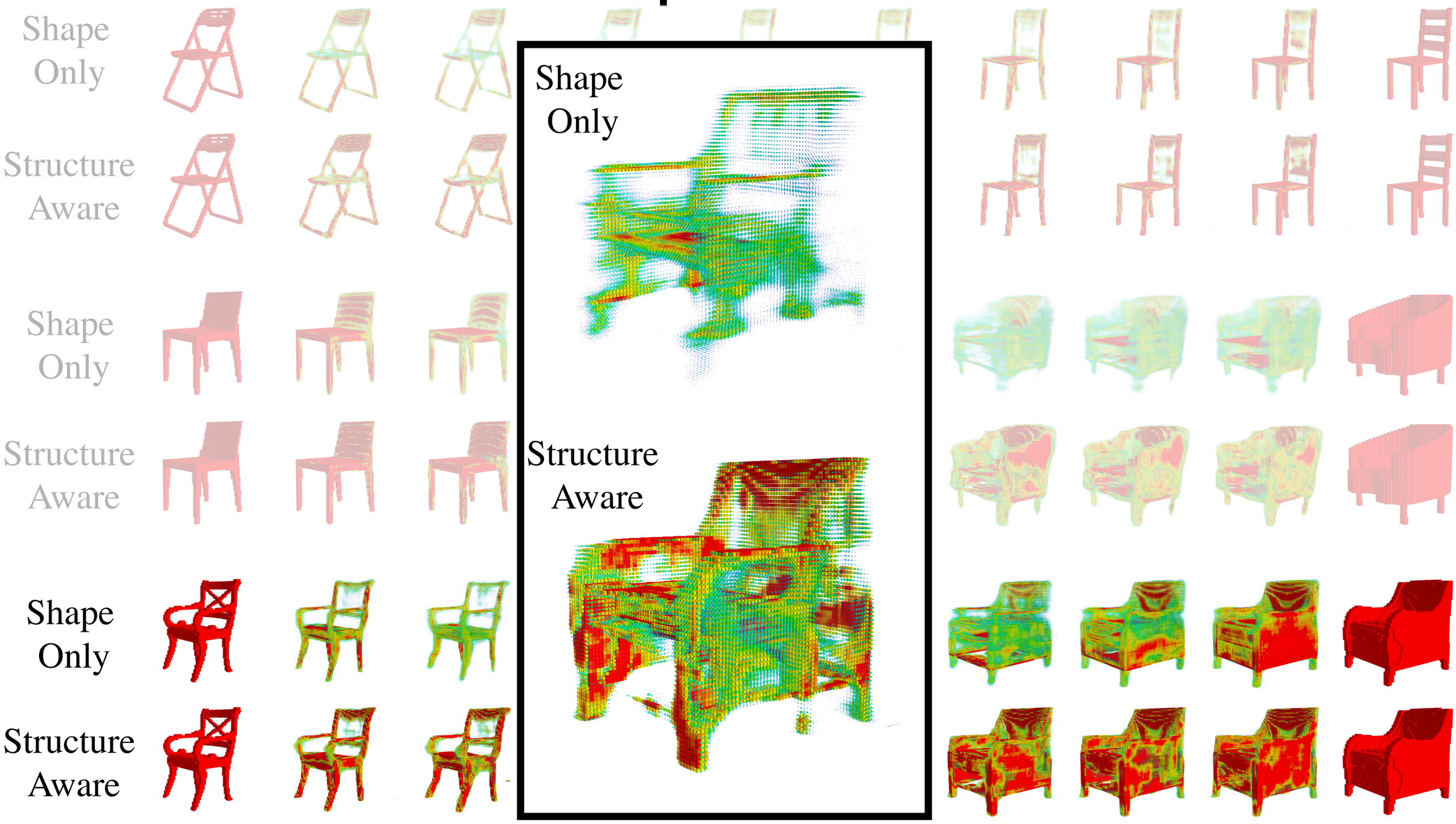
Interpolation



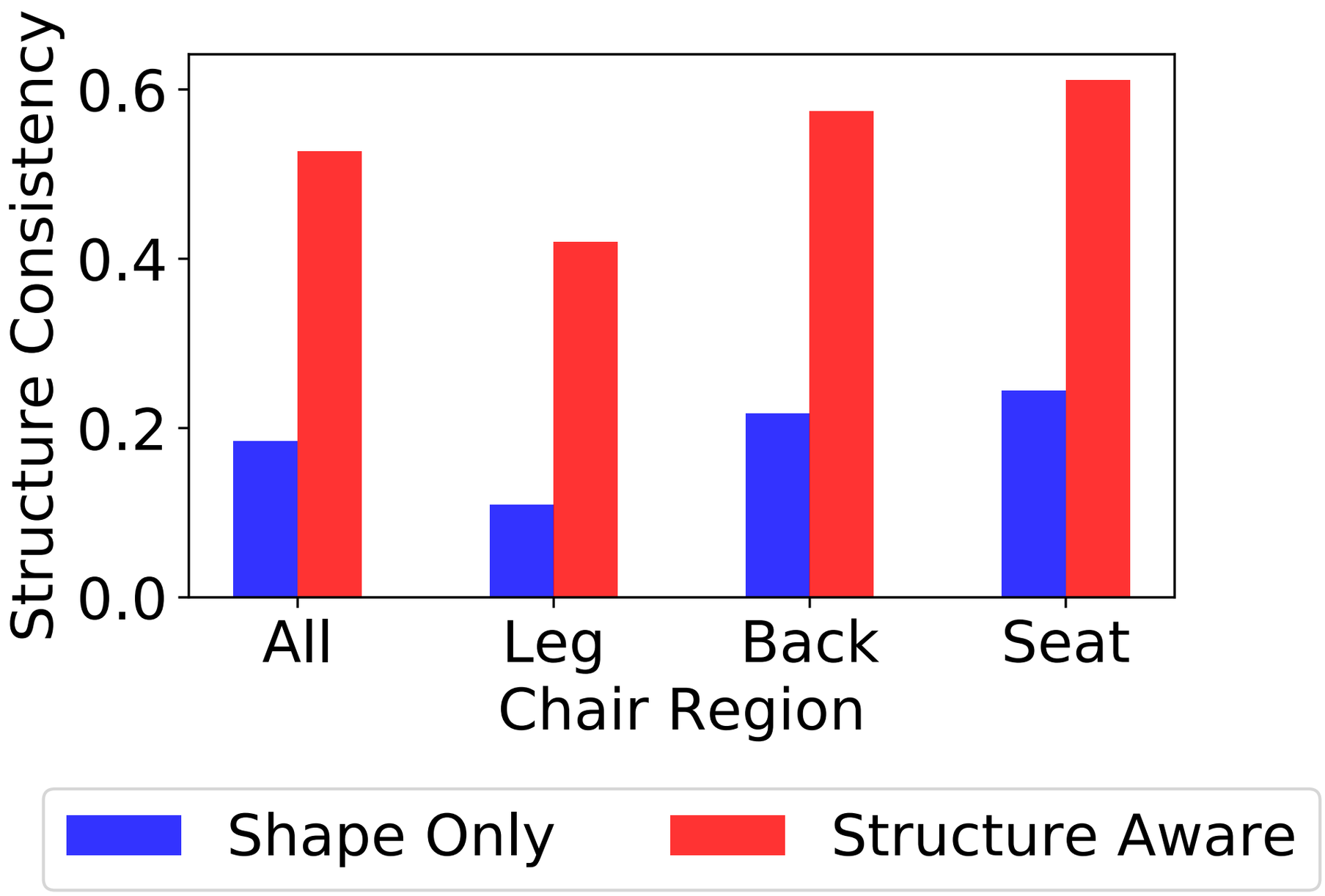
Interpolation



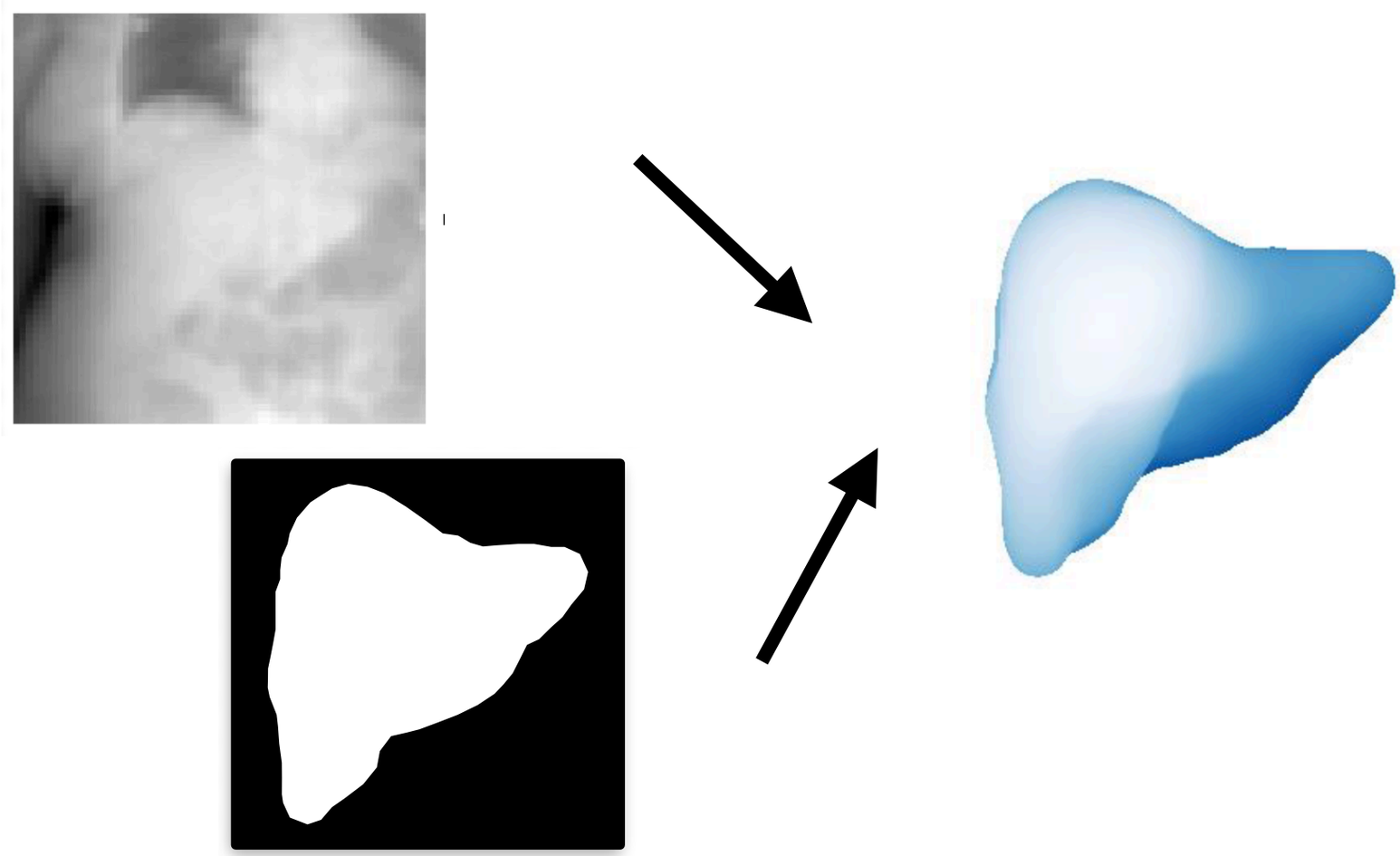
Interpolation



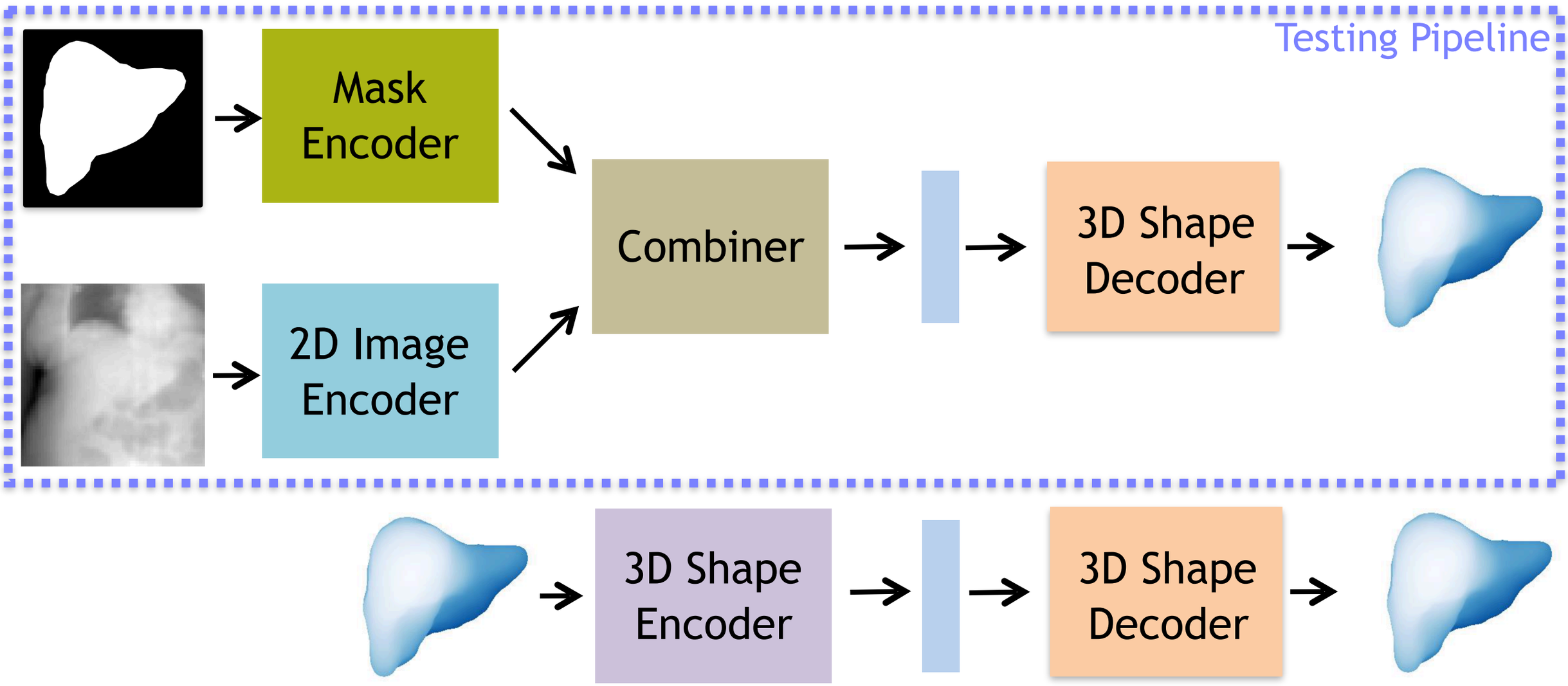
Landmark Consistency



Structure-Aware Liver Reconstruction



Structure-Aware Liver Reconstruction



Objective

We optimize the networks using a combination loss function L:

Kullback Leibler divergence

Encoder Output

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

Mask Loss

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

GT Mask Pred. Mask

BCE Loss

GT Shape Pred. Shape

BCE Loss

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

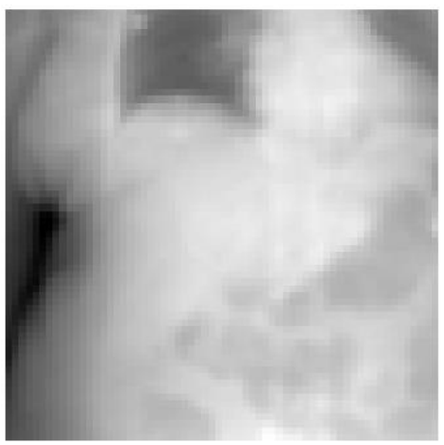
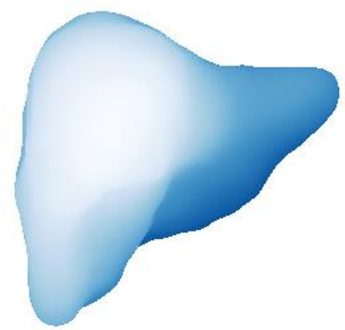
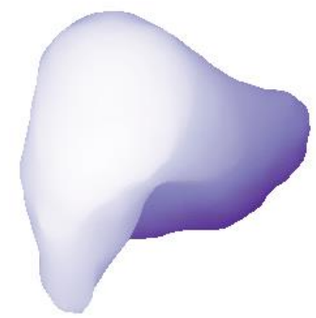
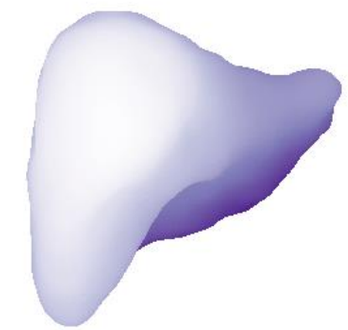
Reconstruction Loss

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

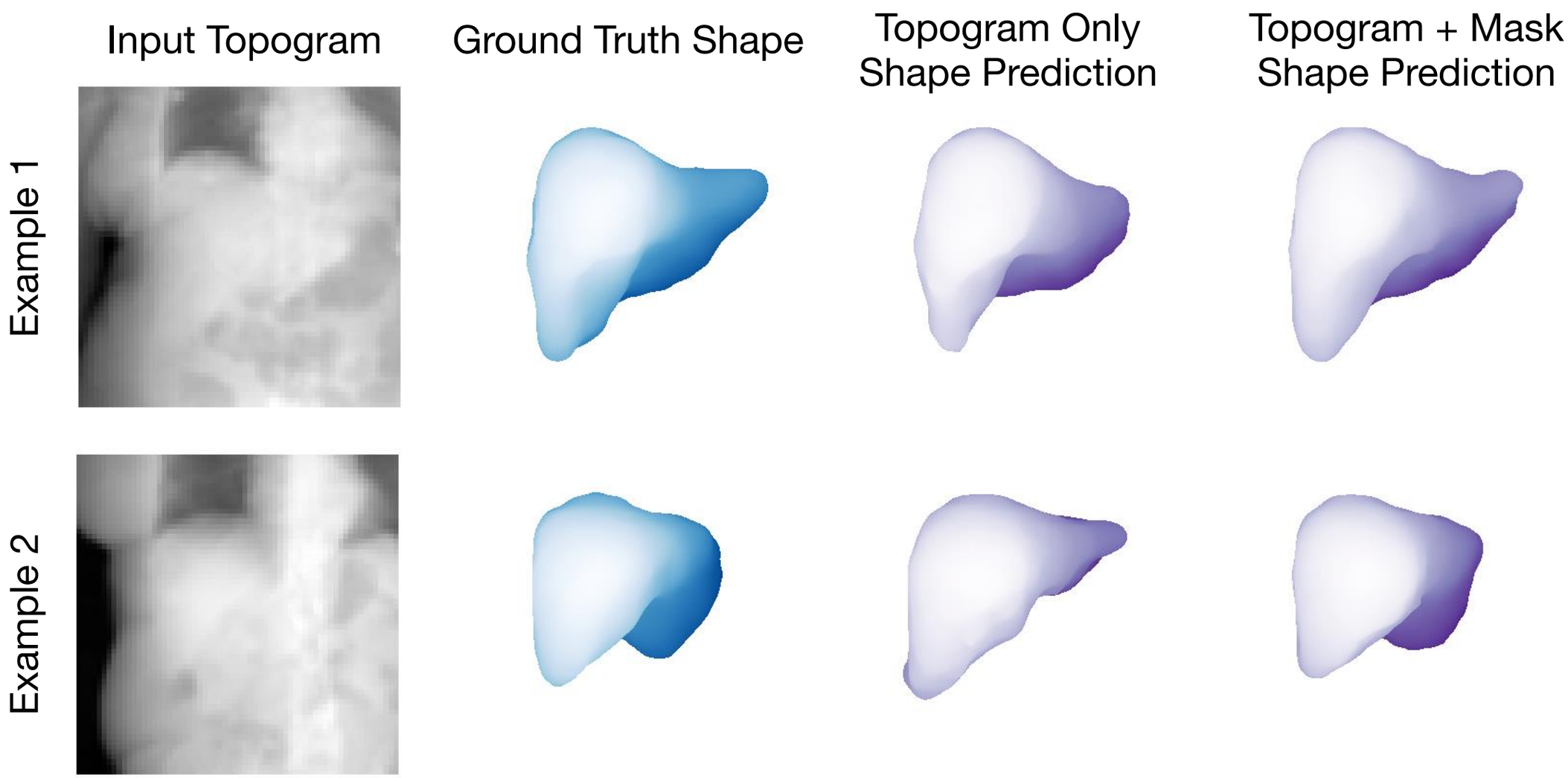
Results

	Input Topogram	Ground Truth Shape	Topogram Only Shape Prediction	Topogram + Mask Shape Prediction
Example 1				
Example 2				

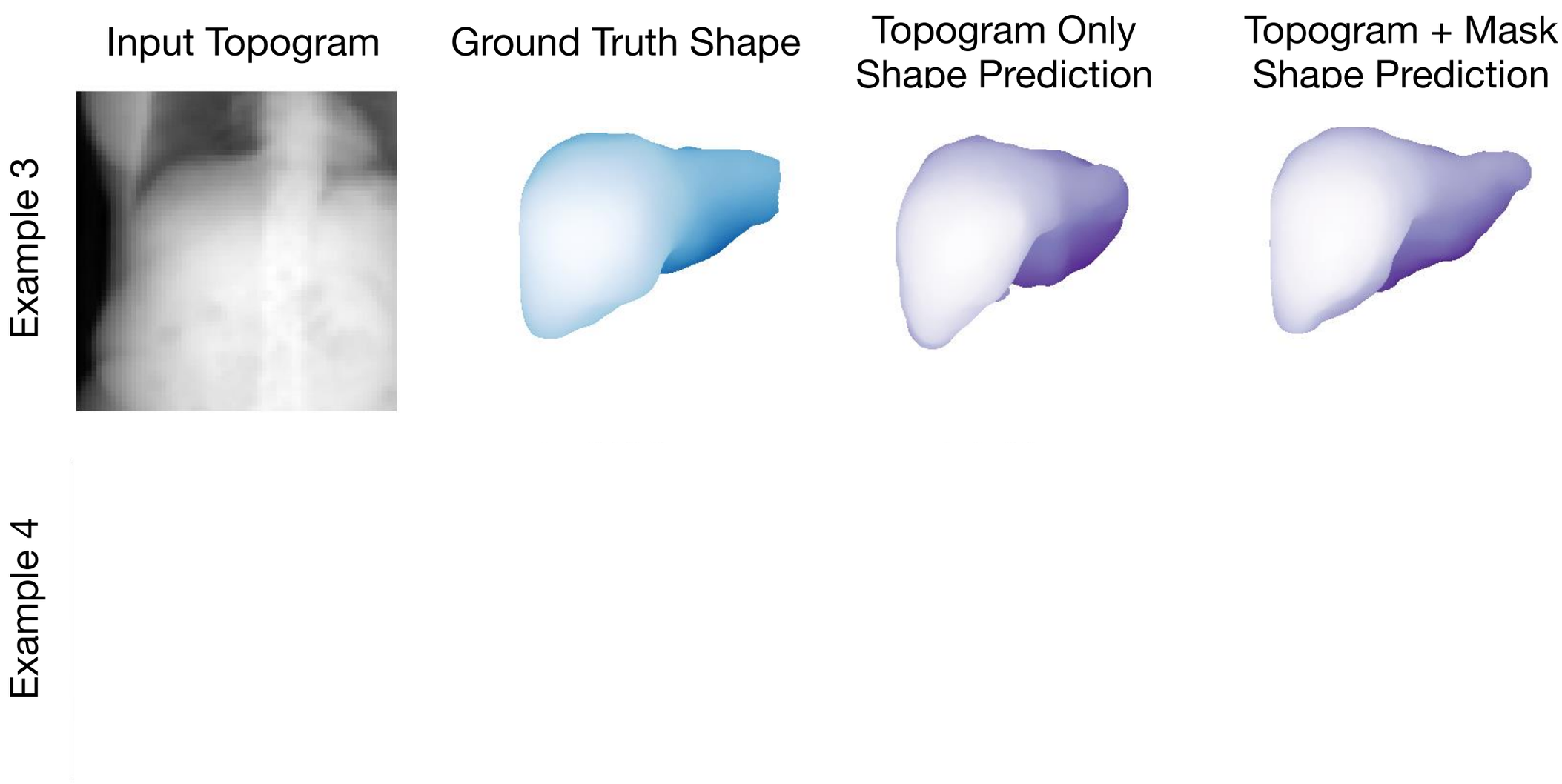
Results

	Input Topogram	Ground Truth Shape	Topogram Only Shape Prediction	Topogram + Mask Shape Prediction
Example 1				
Example 2				

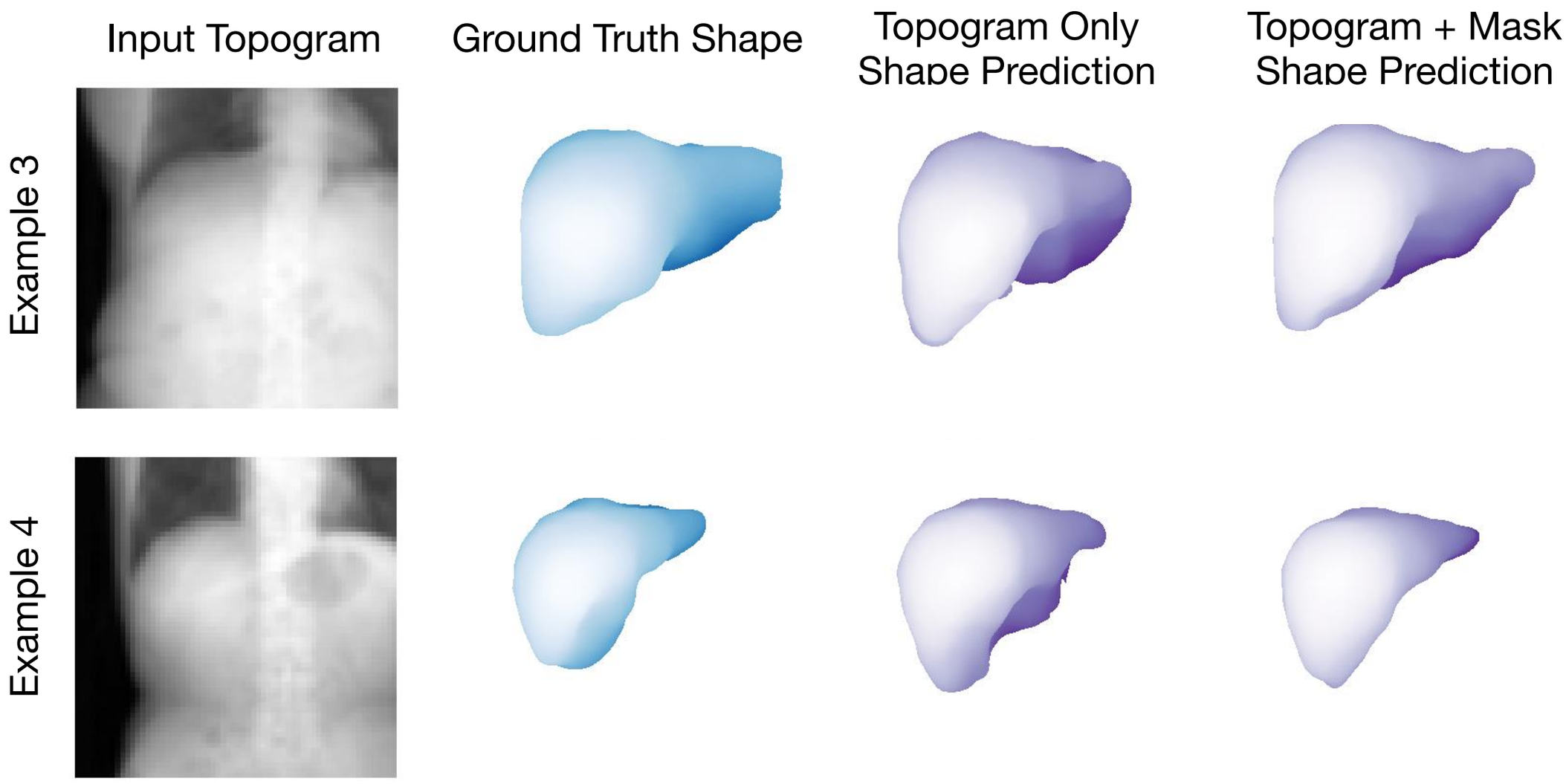
Results


Input Topogram
Ground Truth Shape
Topogram Only
Shape Prediction
Topogram + Mask
Shape Prediction
Example 1
Example 2

Results


Input Topogram
Ground Truth Shape
Topogram Only
Shape Prediction
Topogram + Mask
Shape Prediction
Example 3
Example 4

Results

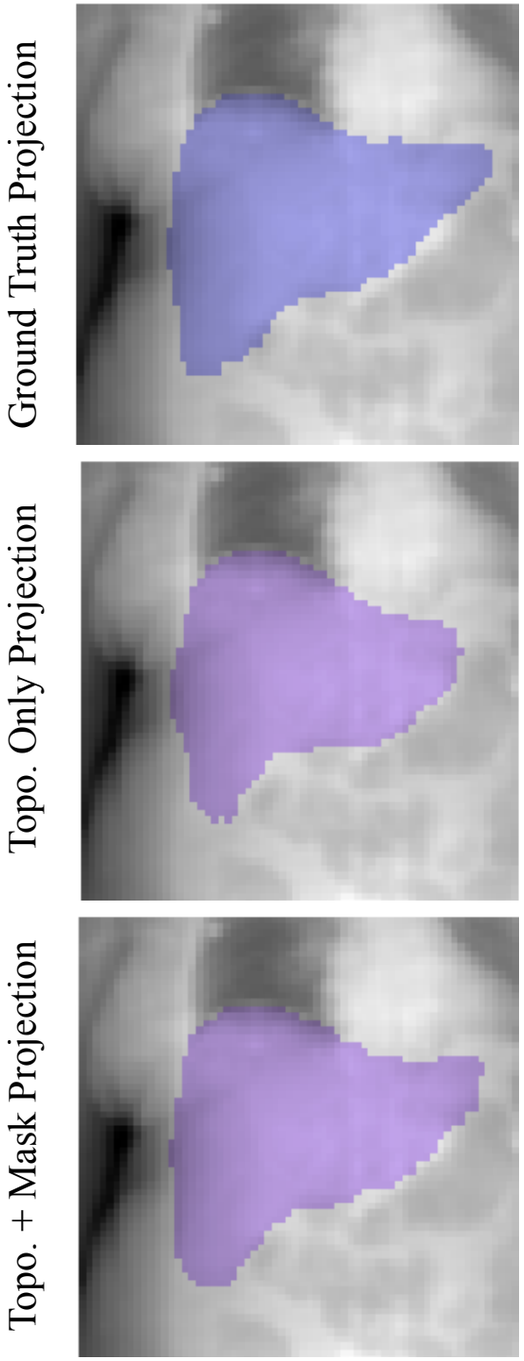

Input Topogram
Ground Truth Shape
Topogram Only
Shape Prediction
Topogram + Mask
Shape Prediction
Example 3
Example 4

Results

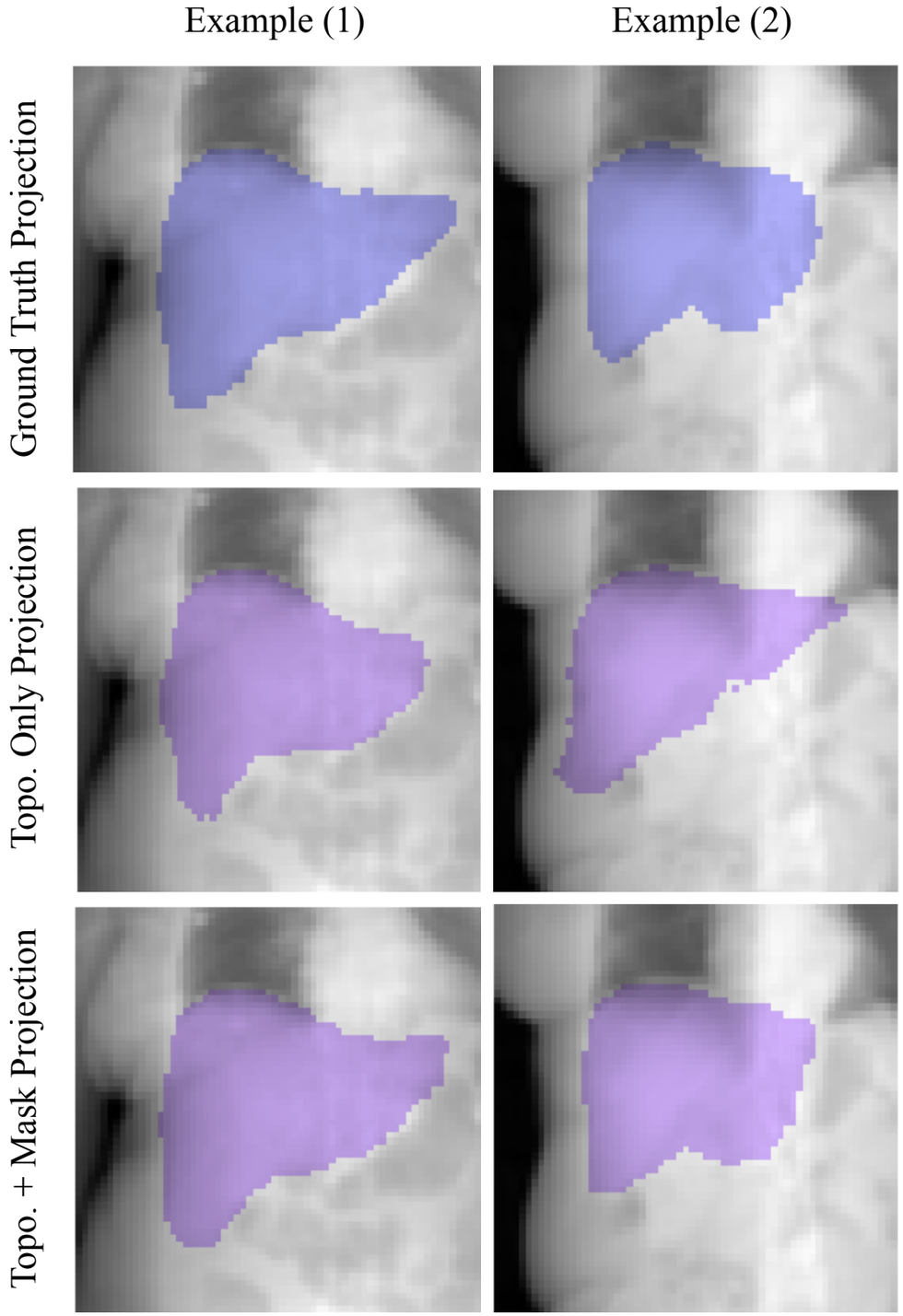
	Example (1)	Example (2)	Example (3)
Ground Truth Projection			
Topo. Only Projection			
Topo. + Mask Projection			

Results

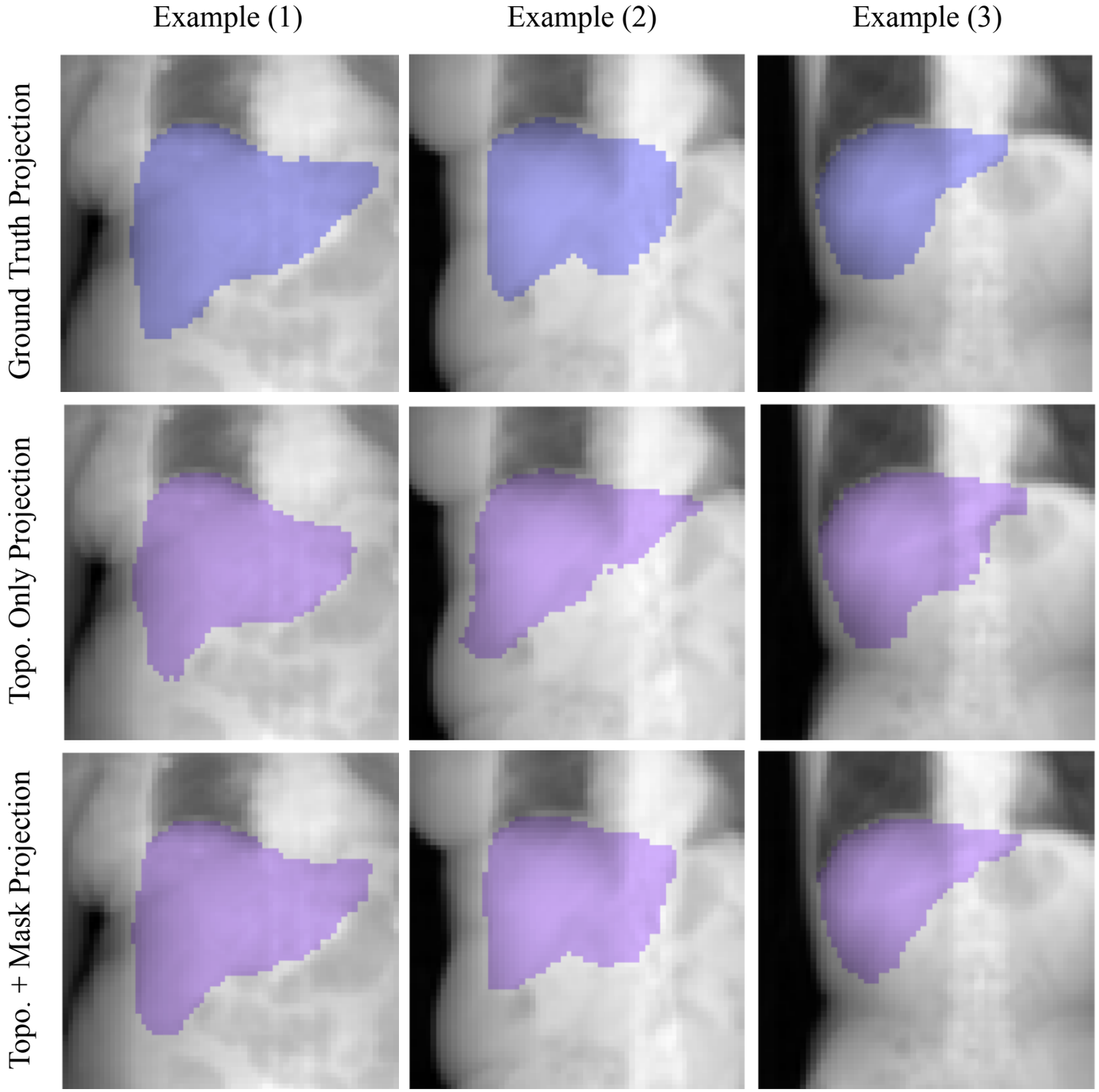
Example (1)



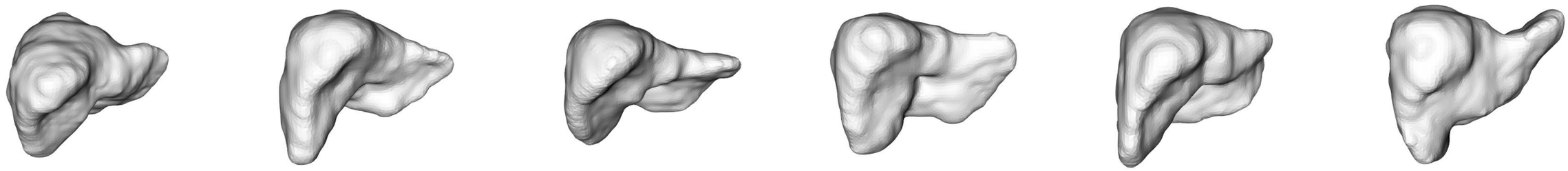
Results


Example (1)
Example (2)
Ground Truth Projection
Topo. Only Projection
Topo. + Mask Projection

Results


Example (1)
Example (2)
Example (3)
Ground Truth Projection
Topo. Only Projection
Topo. + Mask Projection

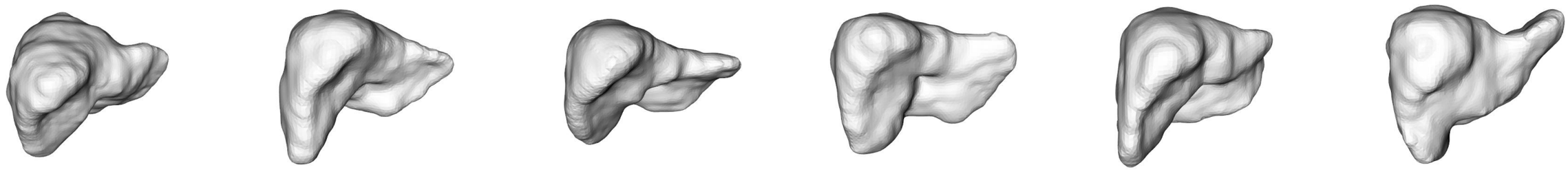
Volume Prediction



V_{gt} - ground truth volume V_{pred} - predicted volume

$$\mathrm{V}_f = \|V_{pred} - V_{gt}\| / V_{gt}$$

Volume Prediction



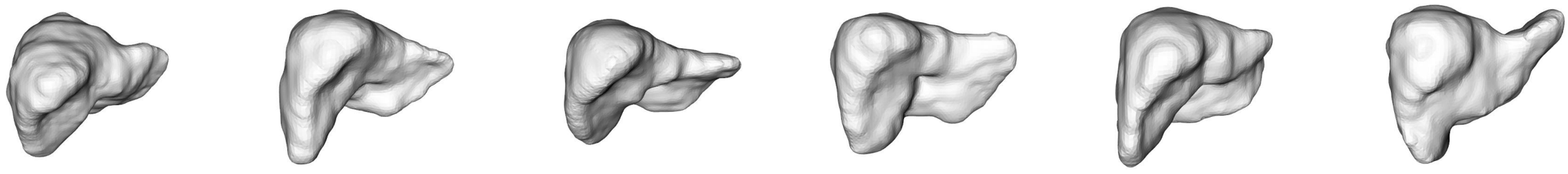
Metric	Topogram Only	Topogram + Mask
Volume Error (V_f)	0.10	**0.06**

Mean Volume Error evaluation and comparison.

V_{gt} - ground truth volume V_{pred} - predicted volume

$$\mathrm{V}_f = \|V_{pred} - V_{gt}\| / V_{gt}$$

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

$$\mathrm{V}_f = \|V_{pred} - V_{gt}\| / V_{gt}$$

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.

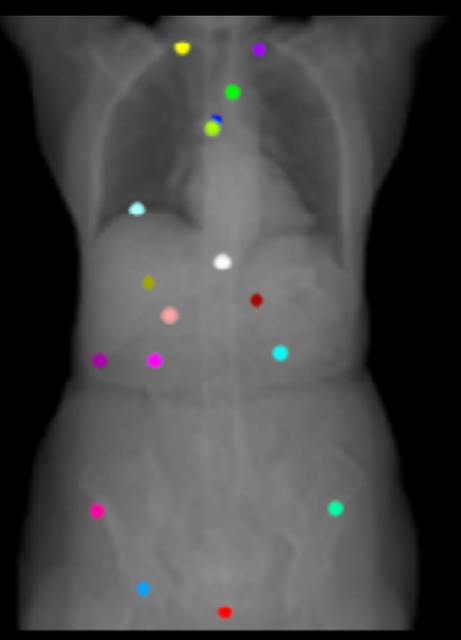
Interactive Techniques

B Teixeira, V. Singh, K. Ma, B. Tamersoy, 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

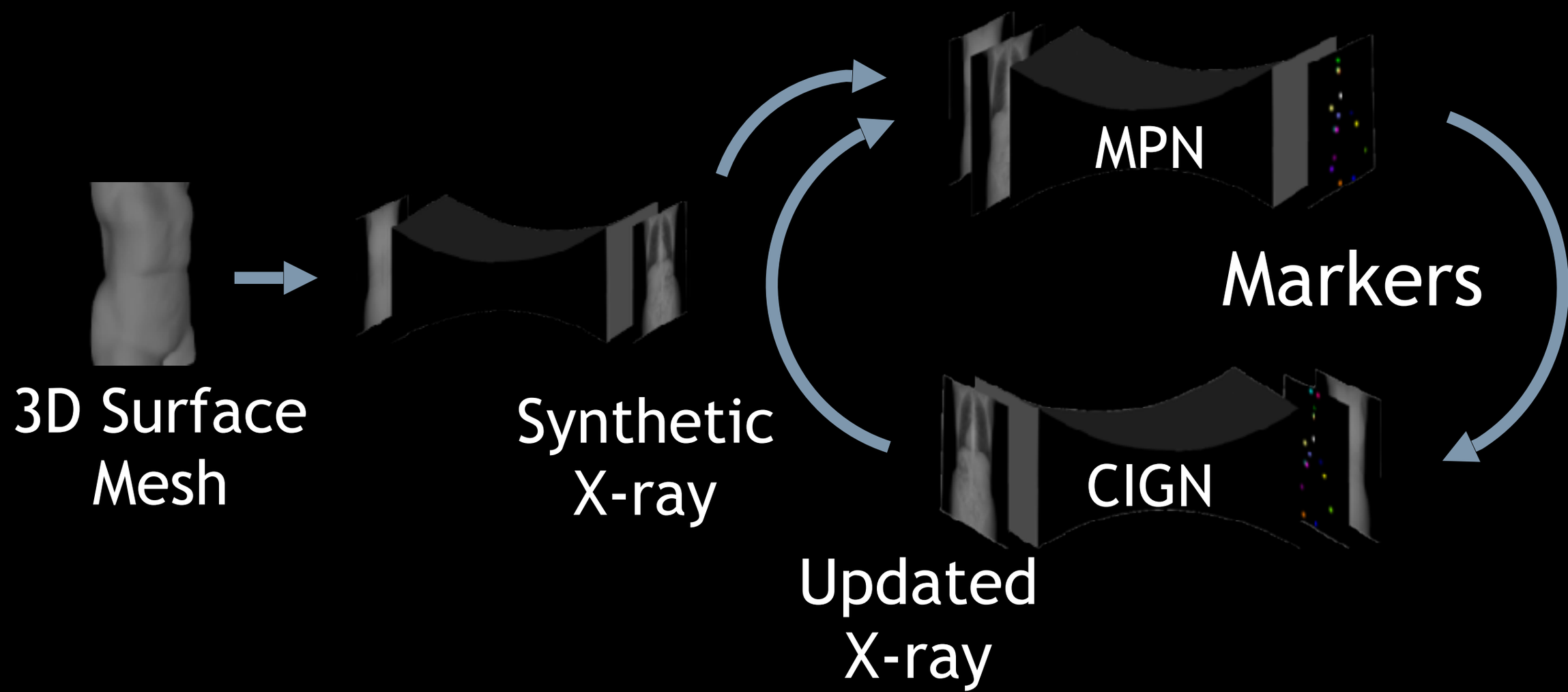


Markers

Real X-ray (For comparison)

[Slides by Brian Teixeira]

Approach Overview



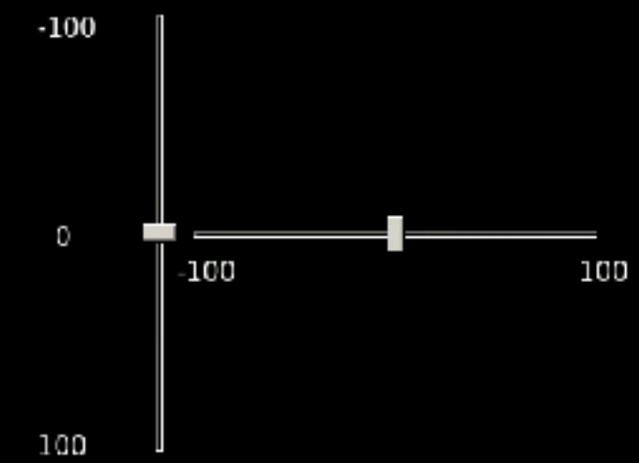
[Slides by Brian Teixeira]

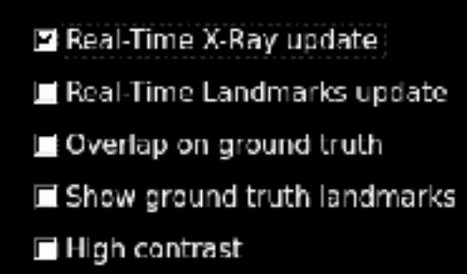
Markers as Parametrization for Synthetic X-ray

Surface Mesh

Synthetic X-ray

Marker Overlay





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

[Slides by Brian Teixeira]

Results on Testing Set

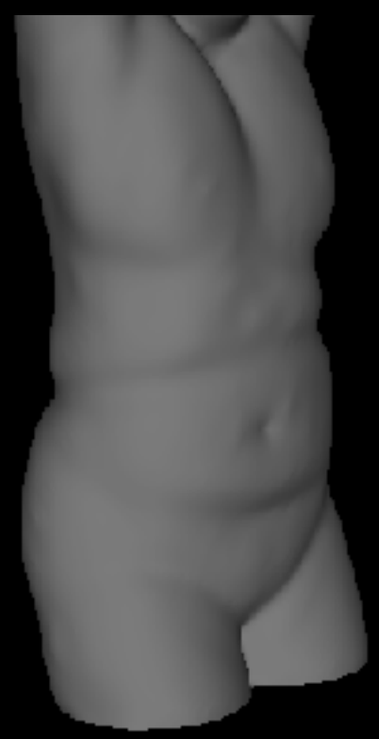
Synthetic X-rays

Ground Truth X-rays

[Slides by Brian Teixeira]

Synthetic X-ray to Detect Pathologies

Trauma Patient Data with no Left Lung



3D Surface Mesh

Real X-ray

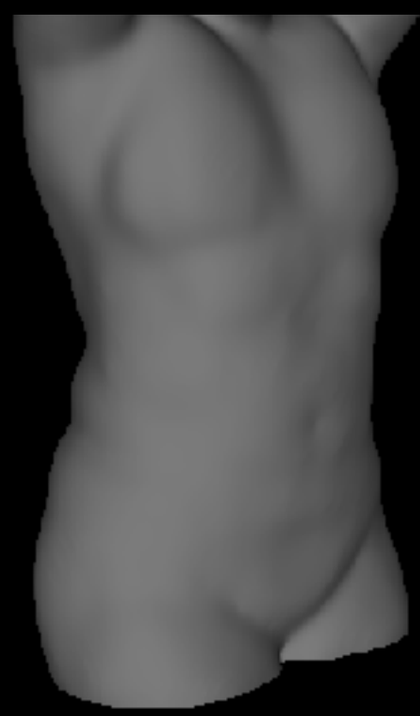
Synthetic X-ray

Difference Overlay

[Slides by Brian Teixeira]

Synthetic X-ray to Detect Pathologies

Patient with no visual salient pathologies



3D Surface Mesh

Real X-ray

Synthetic X-ray

Difference Overlay

No salient pathologies detected

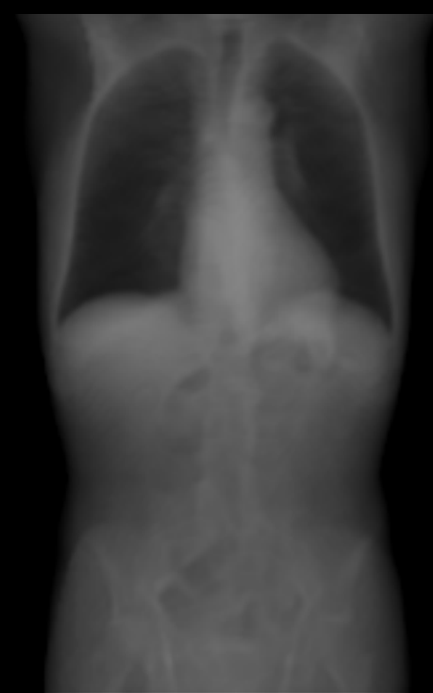
[Slides by Brian Teixeira]

Synthetic X-ray to Detect Implants

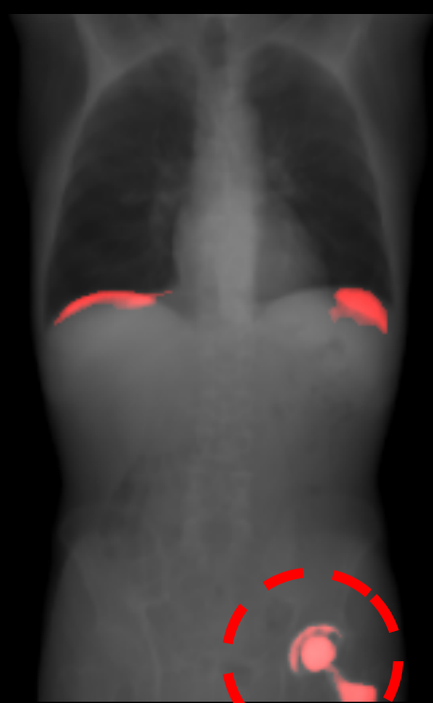
Patient with metallic implant in the left leg

3D Surface Mesh

Real X-ray



Synthetic X-ray



Difference Overlay

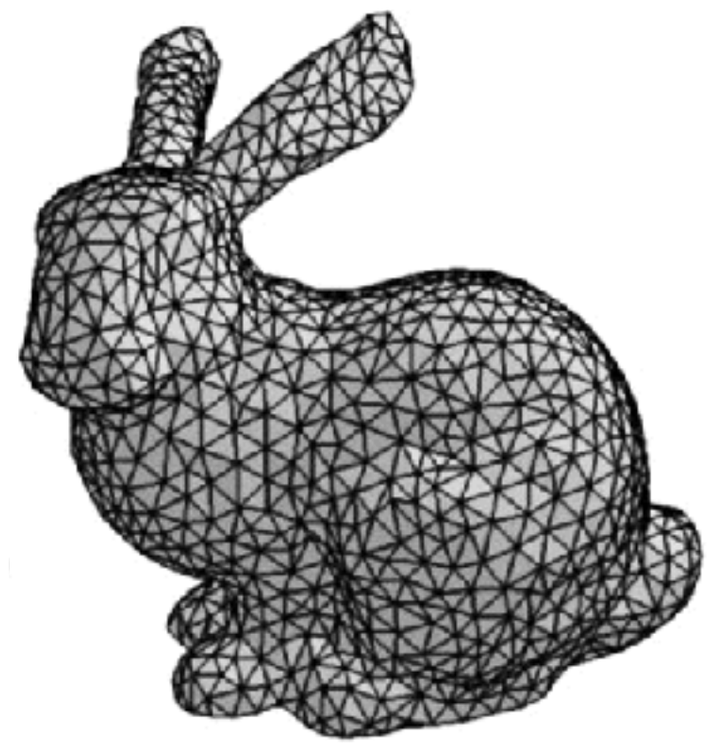
[Slides by Brian Teixeira]

Future Work

Other Organs

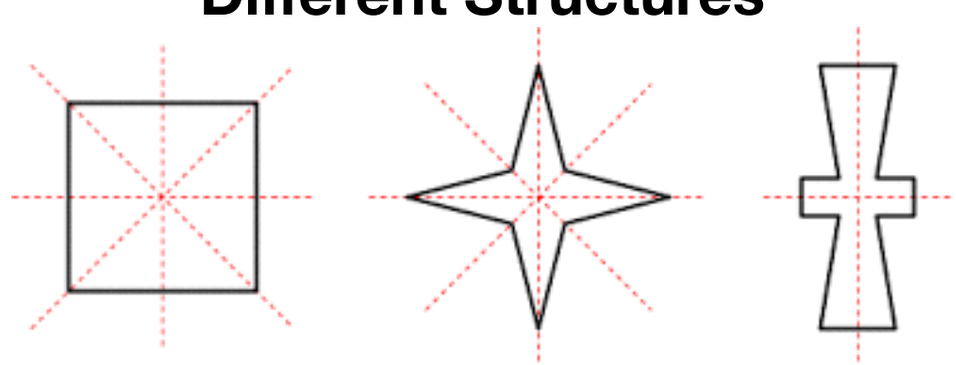
[www.123rf.com]

Different Shape Representations



[Predrag Novakovic]

Different Structures



[www.math.cmu.edu]

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Kai Ma


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Thank you!

Questions?