

3D Functionality Analysis for Shape Modeling via Partial Matching

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What is object functionality?



A functional chair



A broken chair

Can we model a shape and make sure it is functional?



Can we model a shape with more functions?

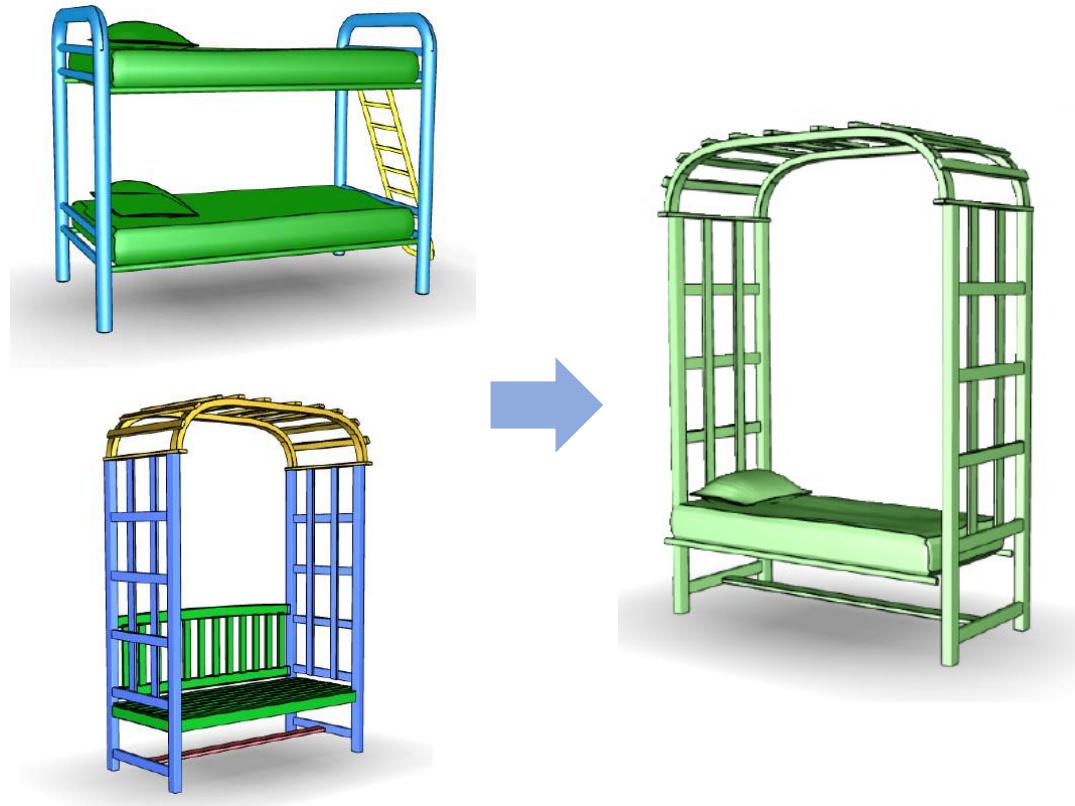


3D Functionality Analysis for Shape Modeling via Partial Matching

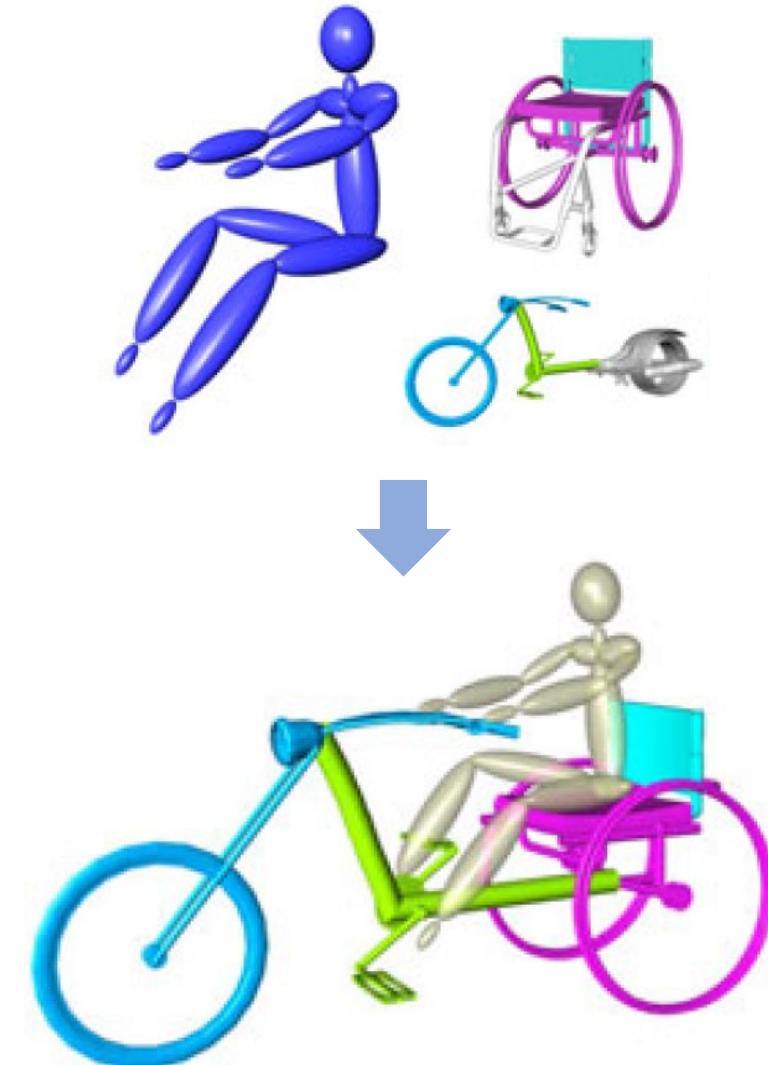
Problem Statement

- Functionality-aware modeling
- Cross-category shape hybridization
- 3D functionality analysis for hybrid shape evaluation

Related Work



[Zheng et al. 2013]



[Fu et al. 2017]

Our Contributions

- We propose a novel 3D functionality analysis method, based on functionality partial matching, for evaluating functionalities of hybrid shapes.
- We incorporate our functionality analysis into a shape evolution framework and present a functionality-aware modeling tool to evolve a set of 3D objects.
- The generated shapes show the potential for data augmentation that improves 3D shape segmentation with atypical inputs.

Our Method

Method Overview

Evolutionary shape modeling framework

- Part groups
- Evolutionary operations [Xu et al. 2012]

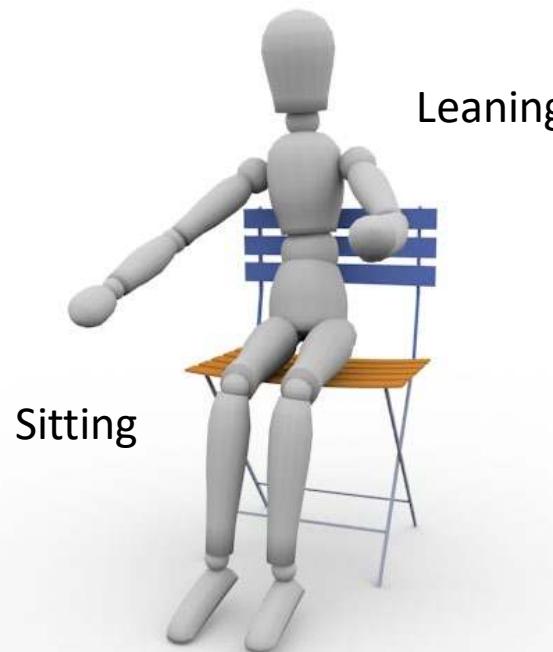
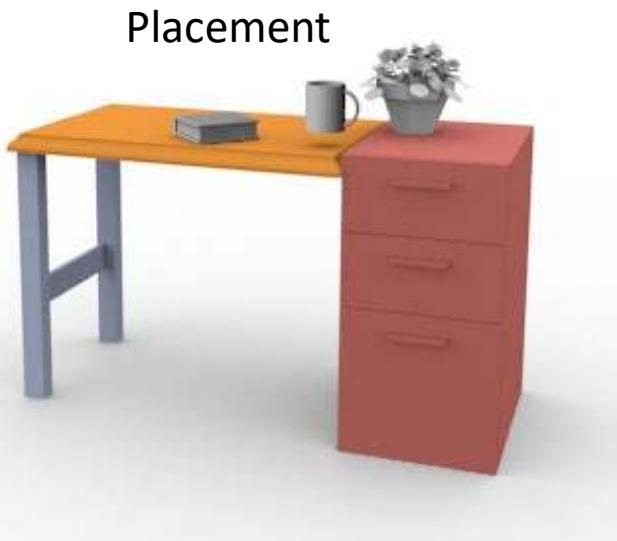
3D functionality analysis

- Category functionality model [Hu et al. 2016]
- Functionality partial matching

Input: Segmented Objects



Functional Part Labels



Part Groups

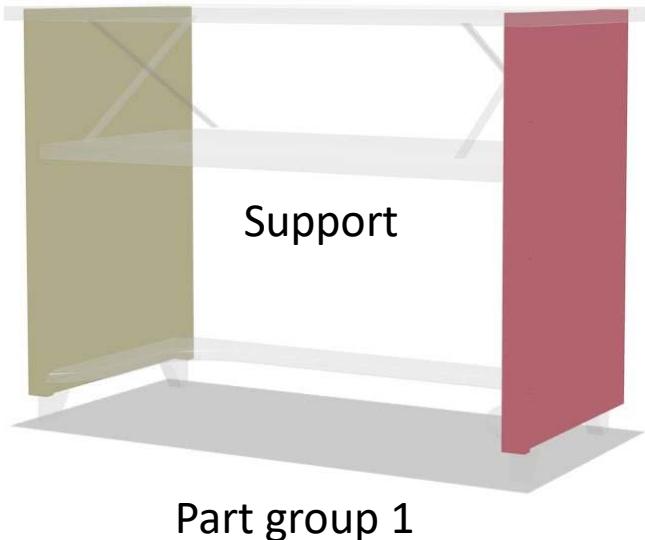


Part group 1

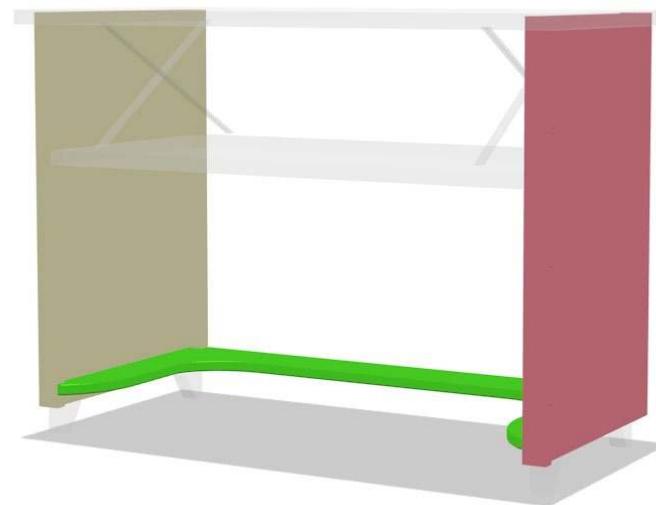
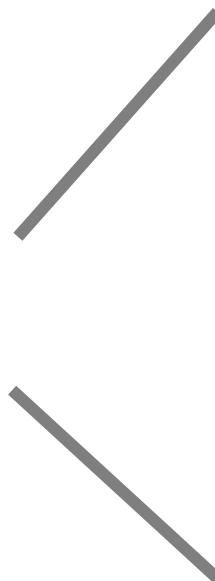
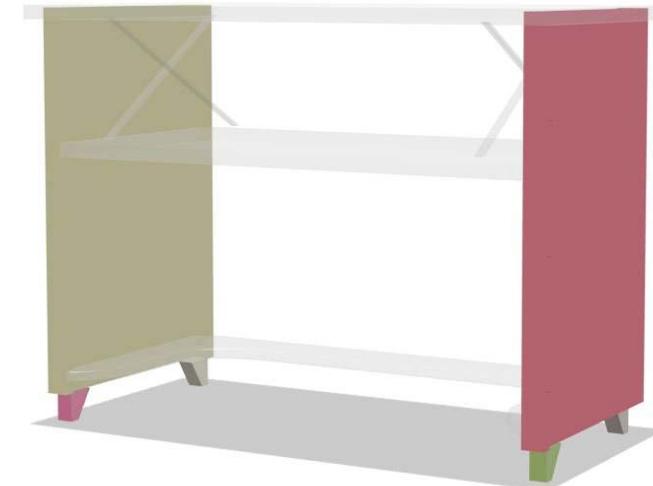


Part group 2

Part Groups



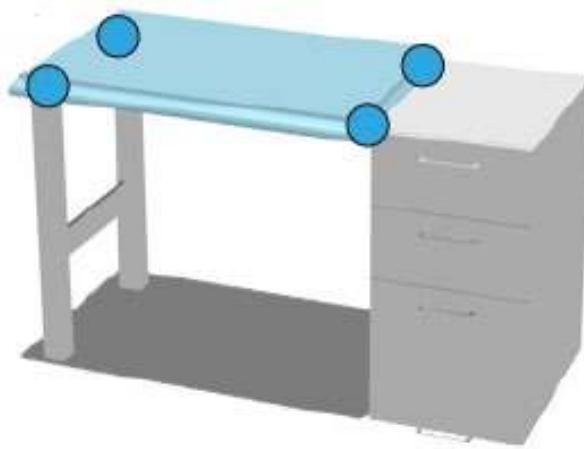
Part group 2



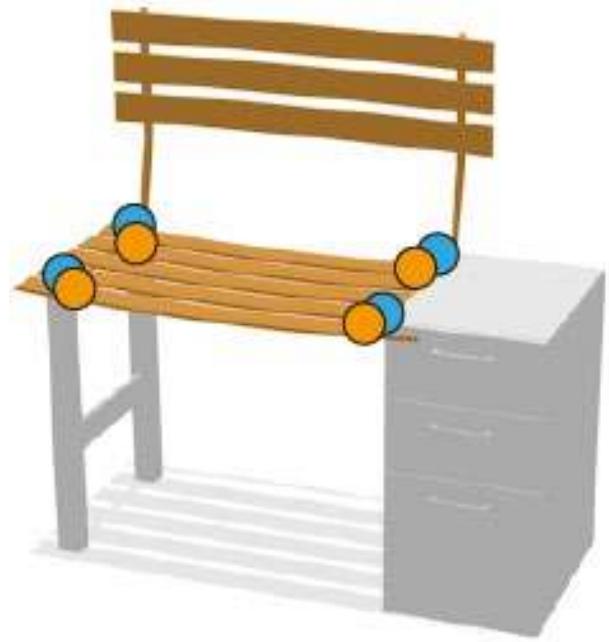
Part Group Exchange



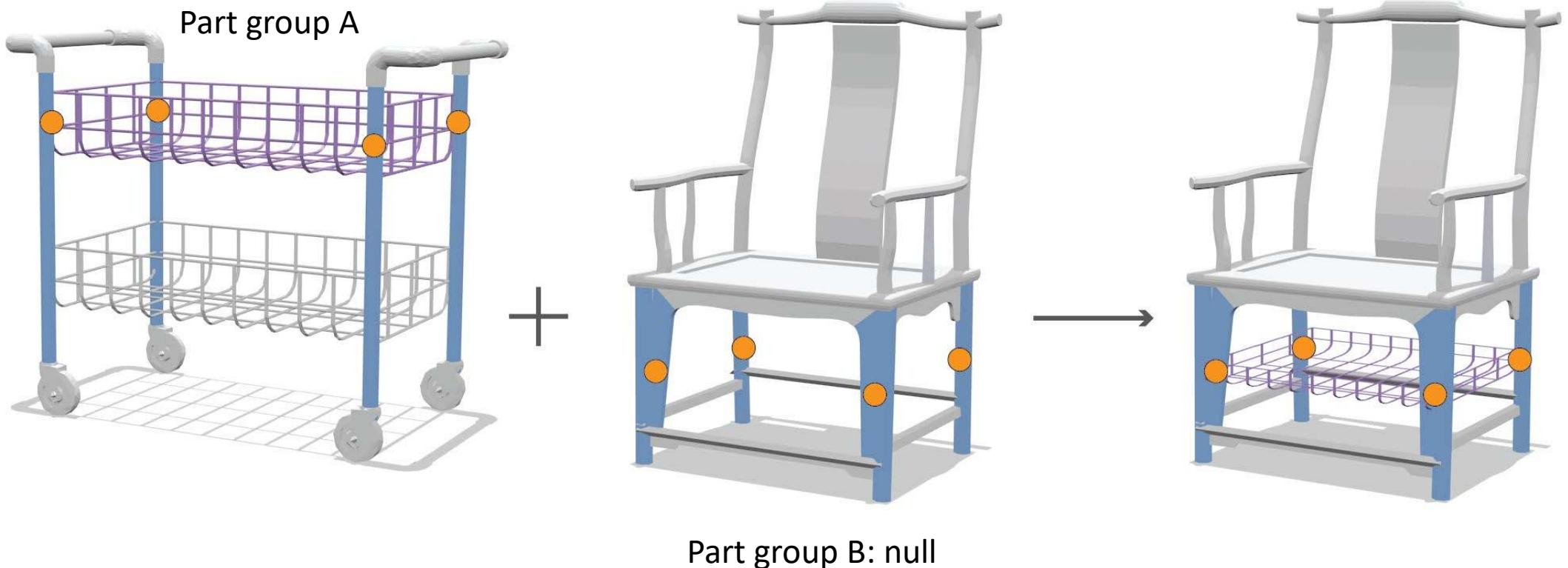
Part group A



Part group B



Part Group Insertion

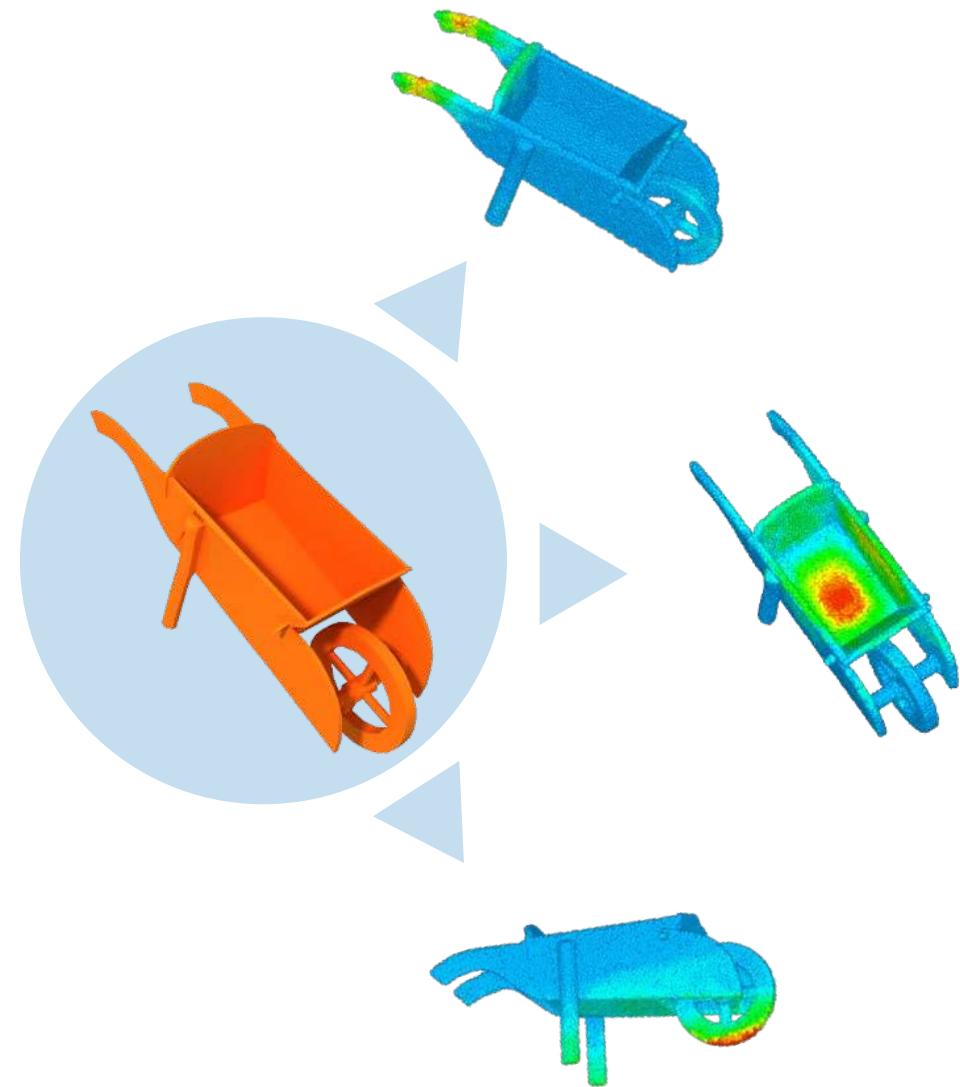
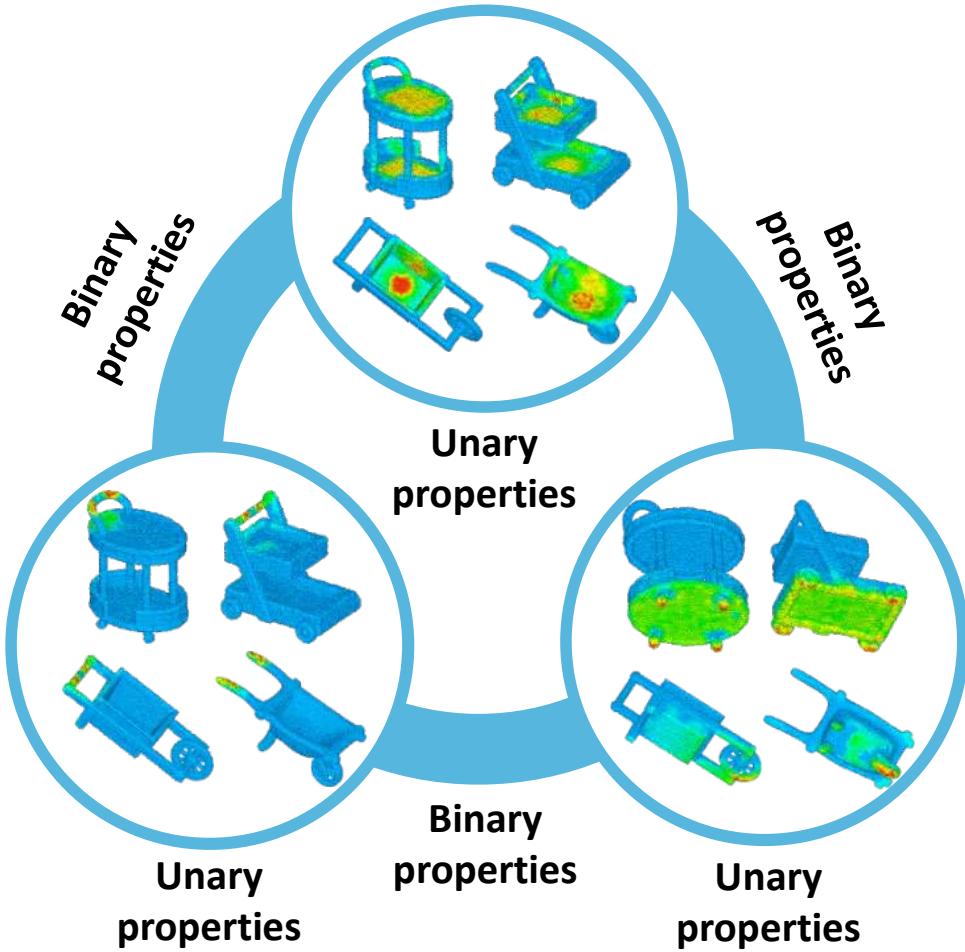


Functionality Analysis



Functionally plausible

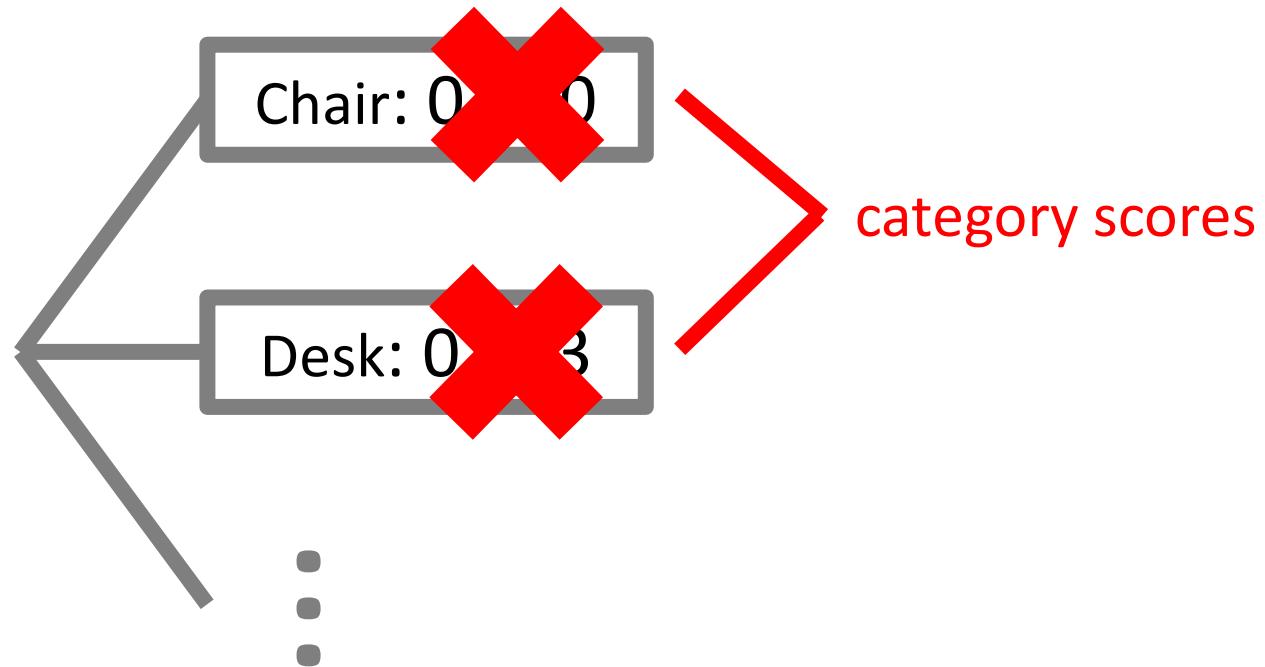
Category Functionality Model



Category Functionality Model



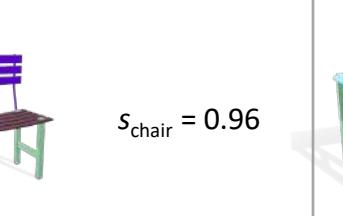
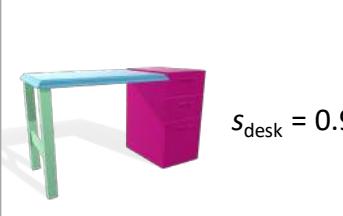
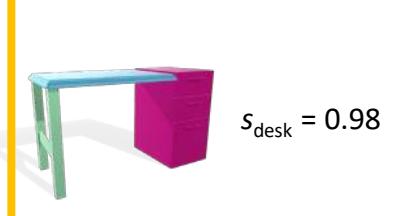
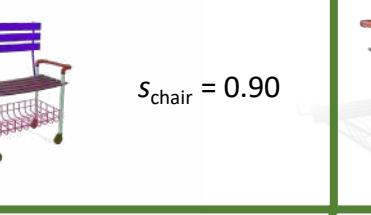
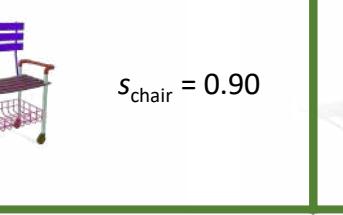
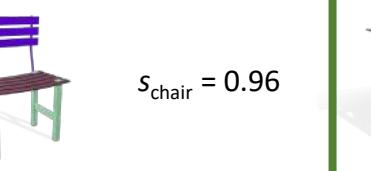
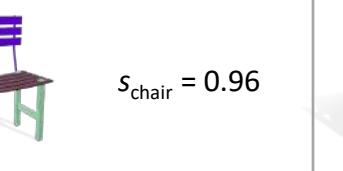
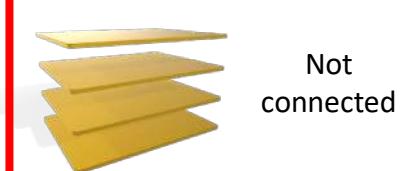
Hybrid shape



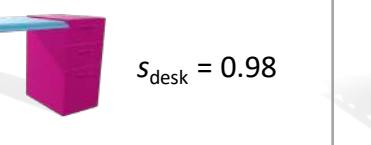
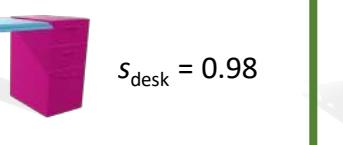
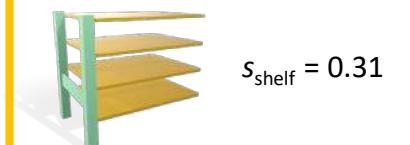
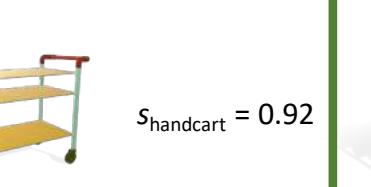
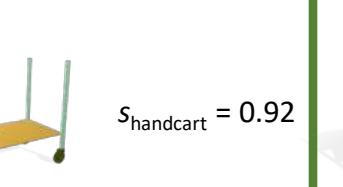
Category models [Hu et al. 2016]

Full matching	Partial matching (combinatorial search)			# of shapes		
	$s_{\text{chair}} = 0.44$ $s_{\text{desk}} = 0.00$		$s_{\text{chair}} = 0.96$		$s_{\text{desk}} = 0.98$	37 (911s)
	$s_{\text{chair}} = 0.90$ $s_{\text{handcart}} = 0.57$		$s_{\text{chair}} = 0.93$		$s_{\text{handcart}} = 0.98$	136 (4377s)
	$s_{\text{chair}} = 0.73$ $s_{\text{shelf}} = 0.69$		$s_{\text{chair}} = 0.96$		$s_{\text{shelf}} = 0.94$	150 (3830s)
	$s_{\text{desk}} = 0.63$ $s_{\text{shelf}} = 0.38$		$s_{\text{desk}} = 0.98$		$s_{\text{shelf}} = 0.96$	134 (3448s)
	$s_{\text{handcart}} = 0.68$ $s_{\text{shelf}} = 0.53$		$s_{\text{handcart}} = 0.96$		$s_{\text{shelf}} = 0.97$	376 (10809s)

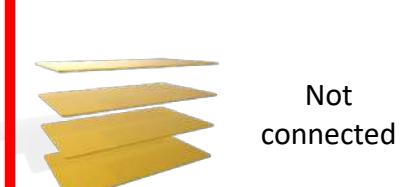
Reverse beam search (width = 2)

 $s_{\text{chair}} = 0.96$  $s_{\text{desk}} = 0.98$  $s_{\text{chair}} = 0.96$  $s_{\text{desk}} = 0.98$  $s_{\text{chair}} = 0.08$  $s_{\text{desk}} = 0.98$  $s_{\text{chair}} = 0.90$  $s_{\text{handcart}} = 0.98$  $s_{\text{chair}} = 0.90$  $s_{\text{handcart}} = 0.96$  $s_{\text{chair}} = 0.00$  $s_{\text{handcart}} = 0.86$  $s_{\text{chair}} = 0.96$  $s_{\text{shelf}} = 0.93$  $s_{\text{chair}} = 0.96$  $s_{\text{shelf}} = 0.94$  $s_{\text{chair}} = 0.96$ 

Not connected

 $s_{\text{desk}} = 0.98$  $s_{\text{shelf}} = 0.97$  $s_{\text{desk}} = 0.98$  $s_{\text{shelf}} = 0.96$  $s_{\text{desk}} = 0.98$  $s_{\text{shelf}} = 0.31$  $s_{\text{handcart}} = 0.92$  $s_{\text{shelf}} = 0.96$  $s_{\text{handcart}} = 0.92$  $s_{\text{shelf}} = 0.95$ 

Not connected



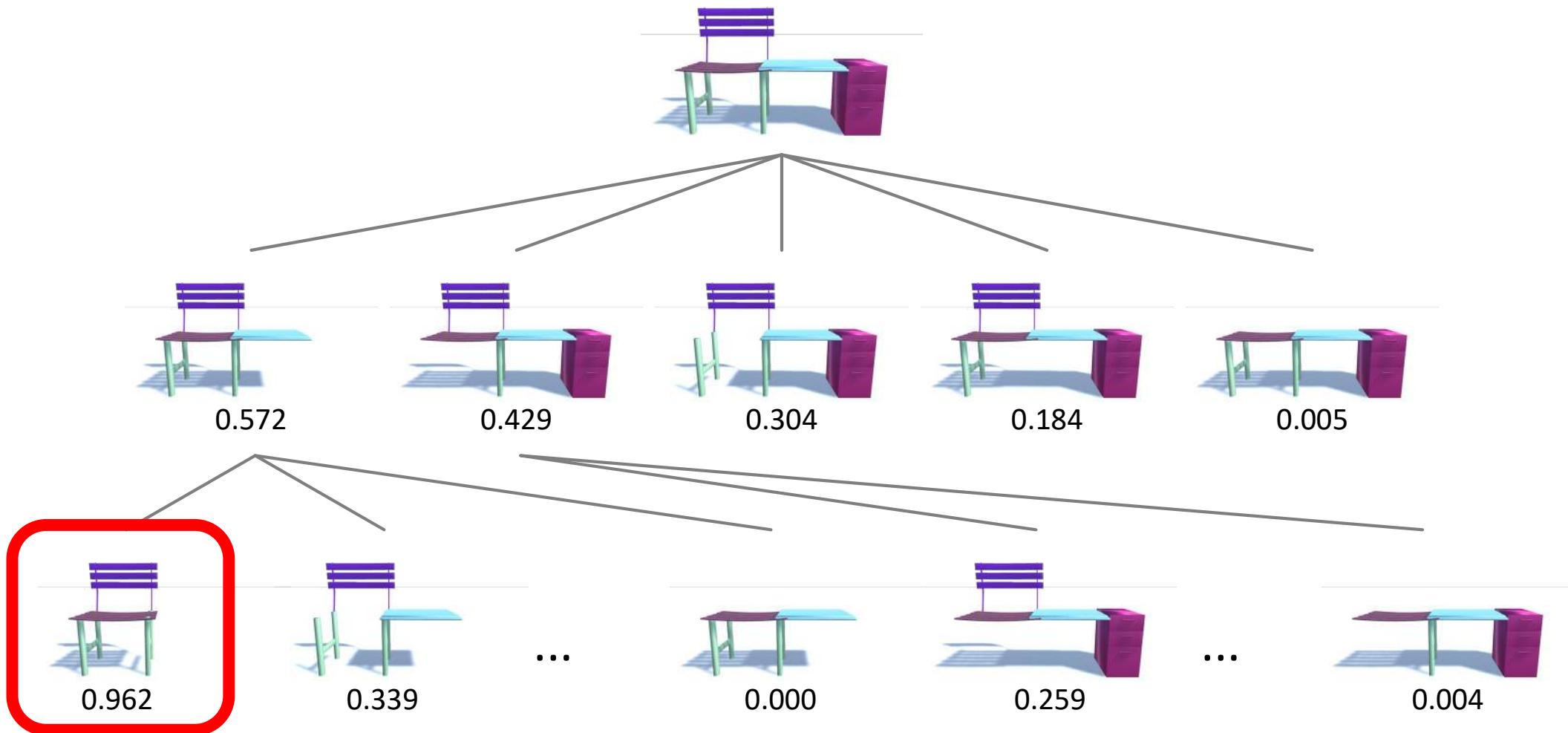
Not connected

of shapes: 20.6 (534s)

of shapes: 38.8 (1274s)

of shapes: 3 (58s)

Reverse Beam Search



Reverse Beam Search



Chair: 0.962



Desk: 0.988



Functional-plausibility score: 0.988

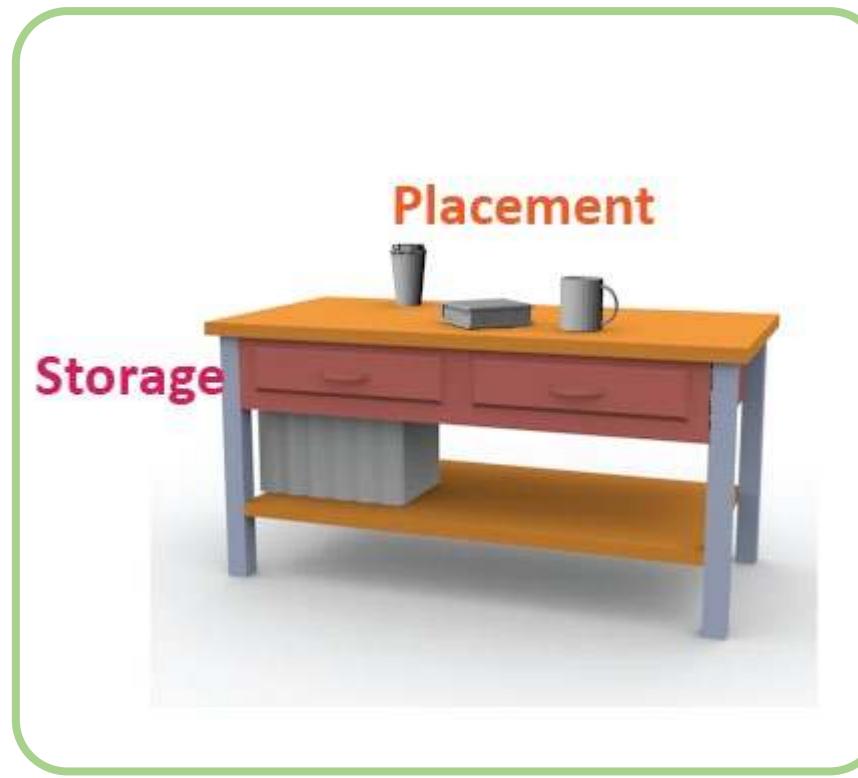
Results and Applications

Shape Modeling



User preferred shapes

Shape Modeling



Constrained Modeling



Initial population

Constrained Modeling



Placement, Storage

Constrained Modeling



Sitting, Leaning

Constrained Modeling



Grasping, Rolling

Unconstrained Modeling



Initial population

Unconstrained Modeling



Generation 1

Unconstrained Modeling



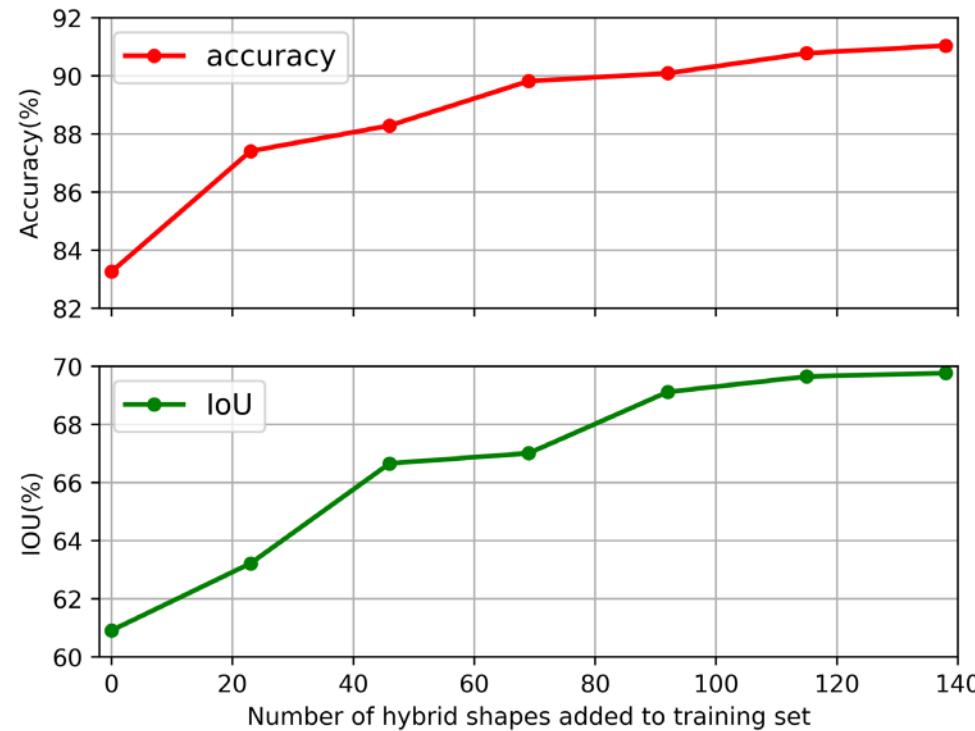
Generation 2

Unconstrained Modeling

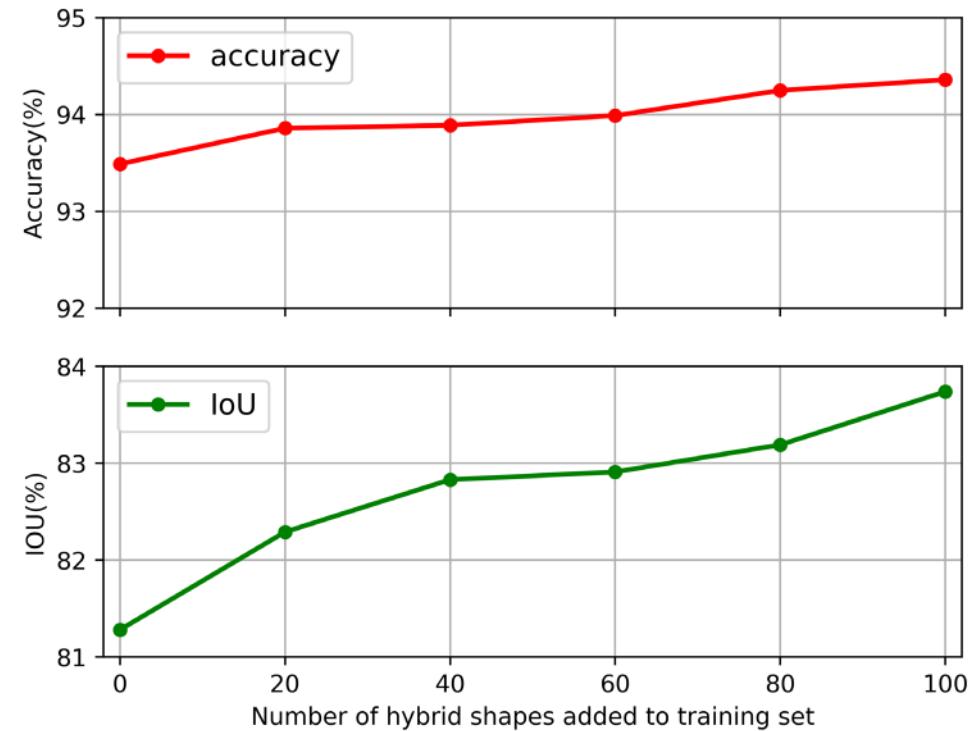


Generation 3

Data Augmentation for Partial Shape Segmentation



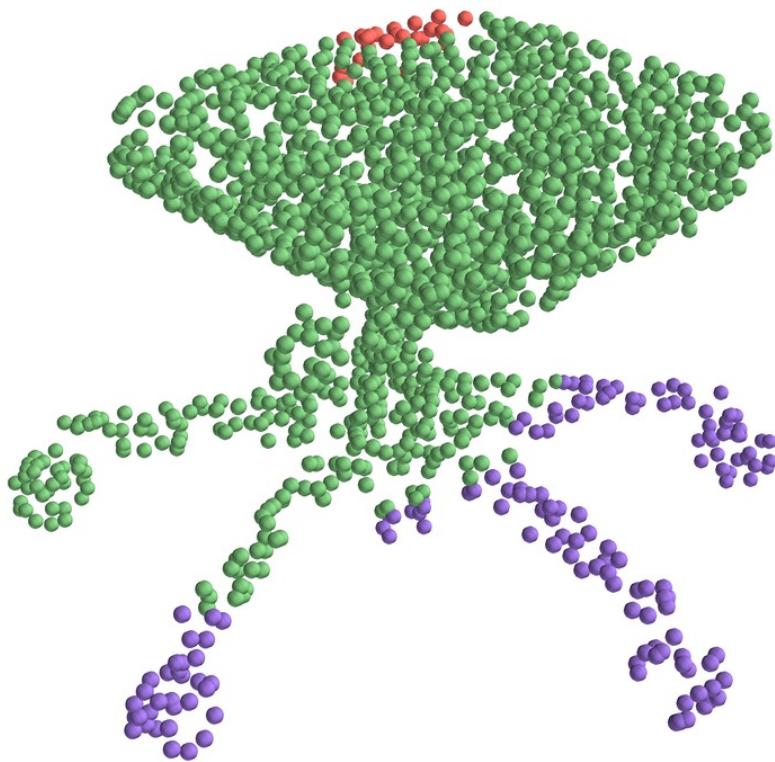
Chairs



Tables

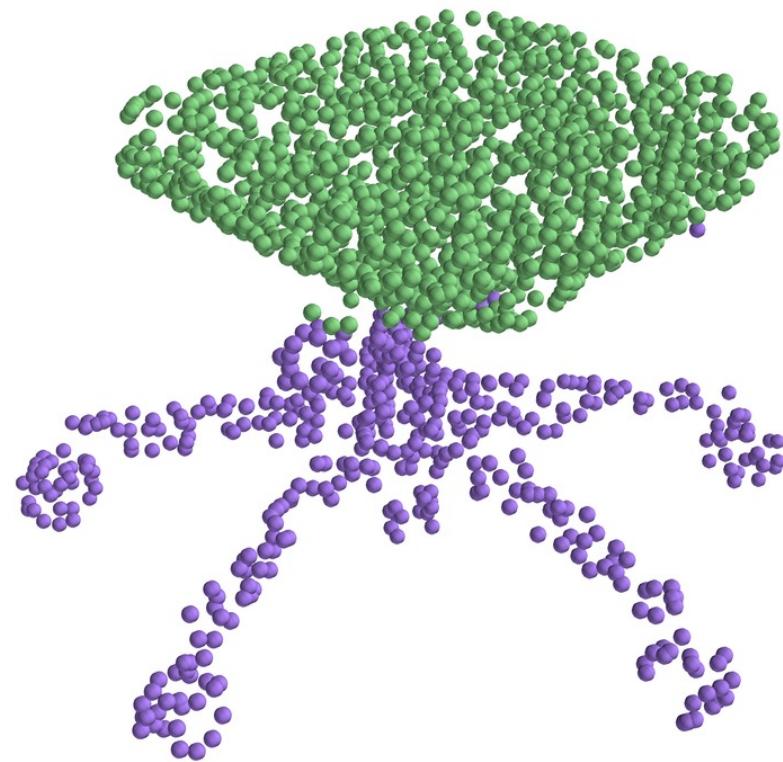
PointNet [Qi et al. 2017] shape segmentation

Data Augmentation



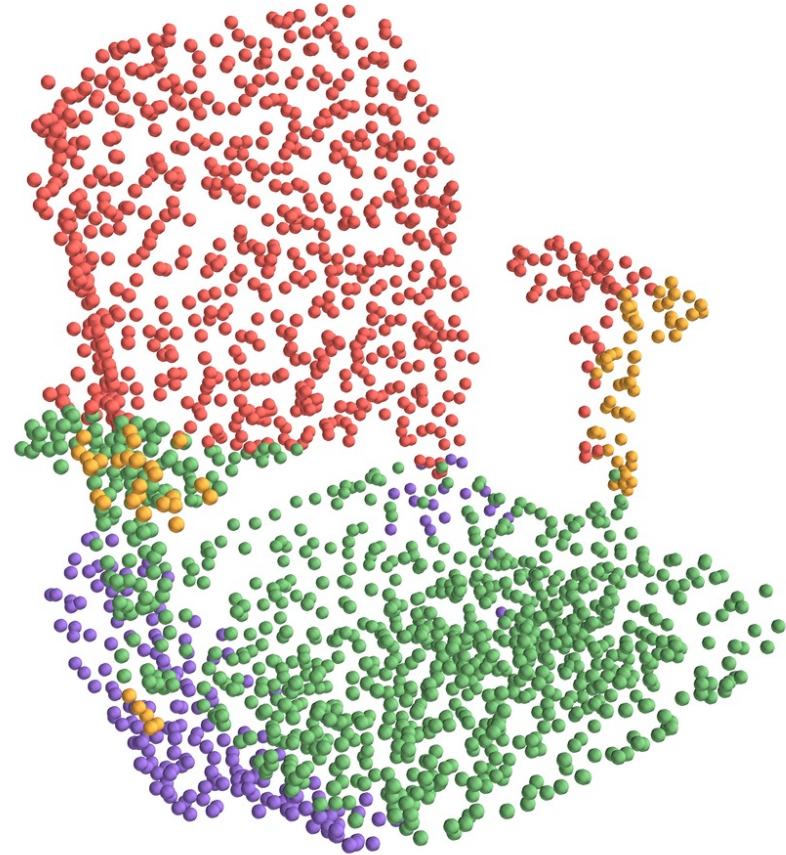
Initial segmentation

Data Augmentation



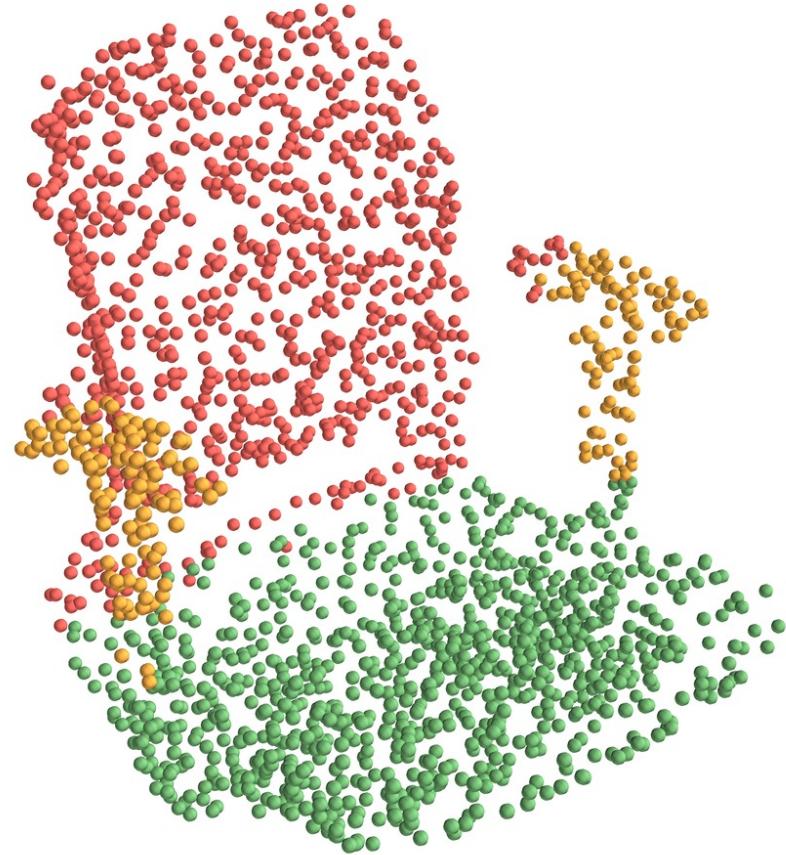
Segmentation with data augmentation

Data Augmentation



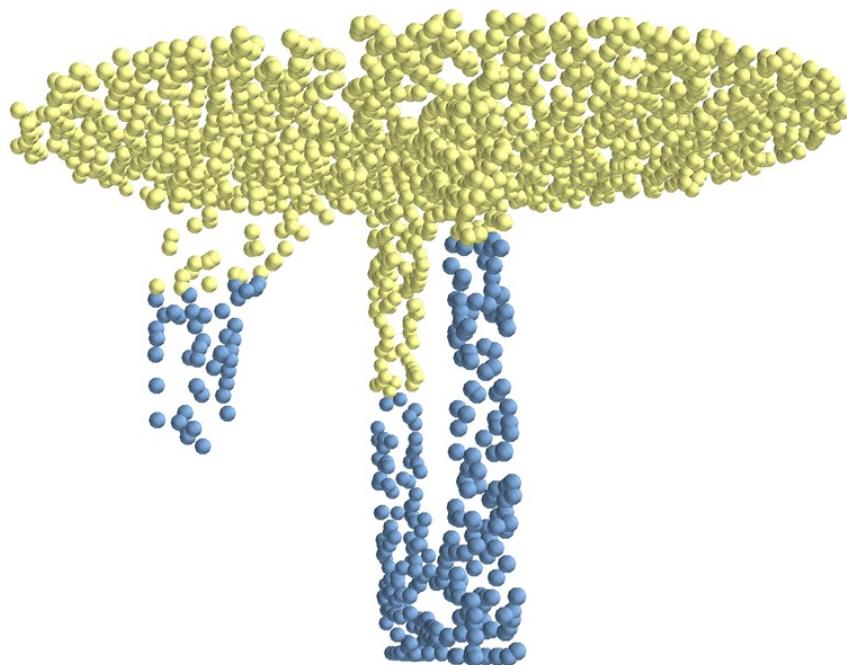
Initial Segmentation

Data Augmentation



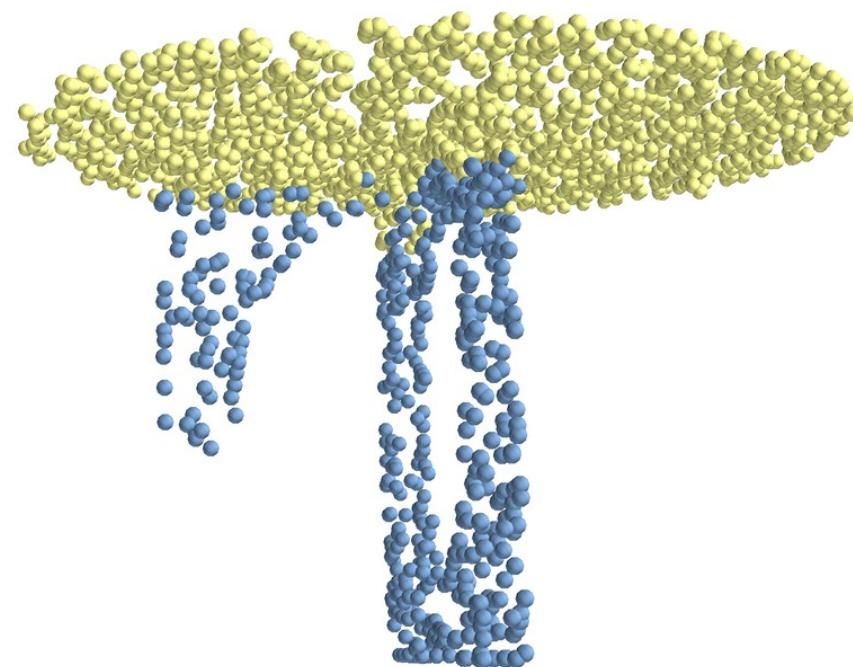
Segmentation with data augmentation

Data Augmentation



Initial Segmentation

Data Augmentation



Segmentation with data augmentation

Conclusion

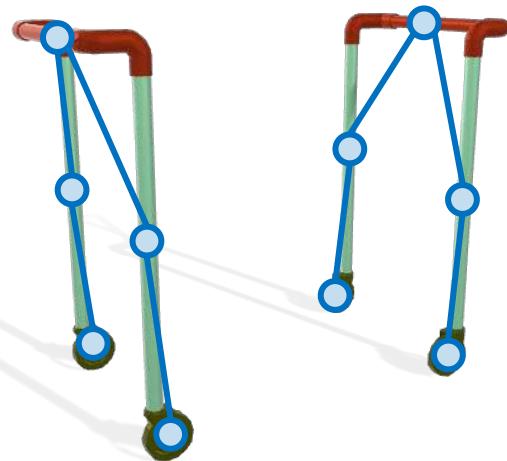
- With the help of functionality partial matching, we show that our evolutionary modeling tool can generate a large and diverse population of functionally plausible hybrid shapes.
- The generated shapes can be used to complement existing dataset for data augmentation.

References

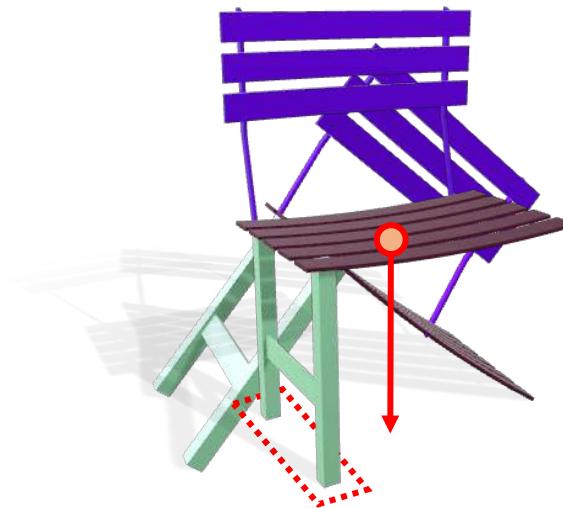
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- C. R. Qi, H. Su, K. Mo, and L. J. Guibas. 2017. PointNet: Deep learning on point sets for 3D classification and segmentation. In *Proc. IEEE Conf. on Computer Vision and Pattern Recognition*, 652–660.

Thank you!

Appendix: Shape Validity Check



Part-wise connectivity



Physical balance



Functional space