RASP: Revisiting 3D Anamorphic Art For Shadow-Guided Packing of Irregular Objects




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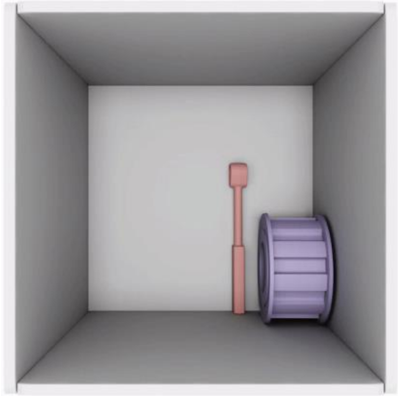
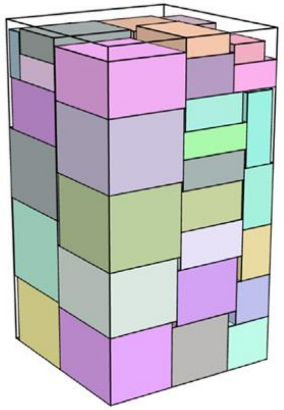
Background

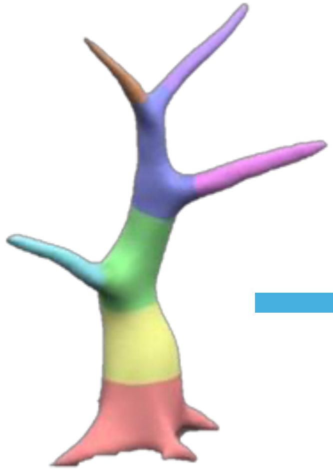
3D Packing Problems



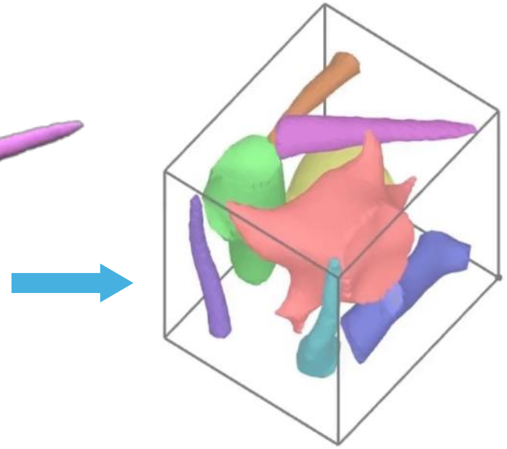
First person view of packing



A well packed container



A 3D Model

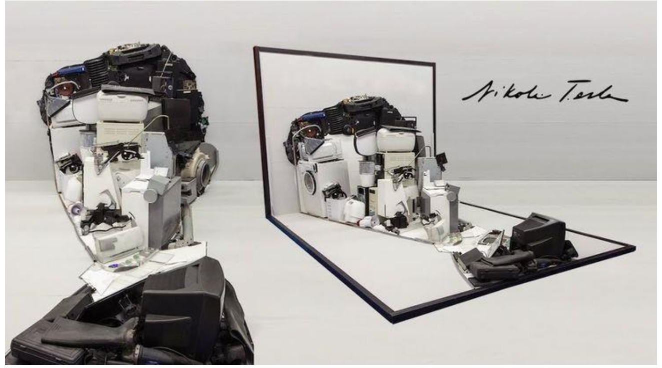


Packing the parts into a box

Shadow Art and 3D Anamorphic Art

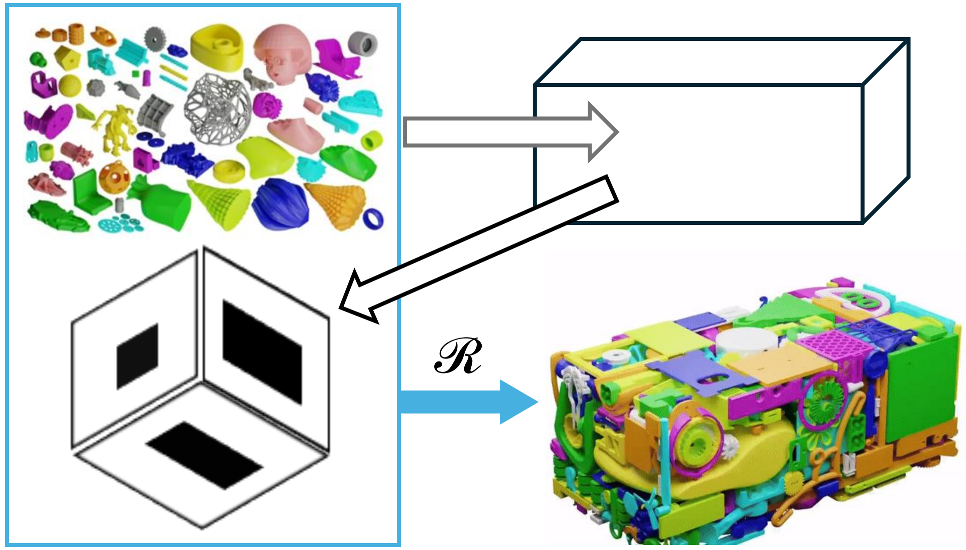
Sunset over Manhattan

Wild mood swings



Portrait of Nikola Testa using appliances

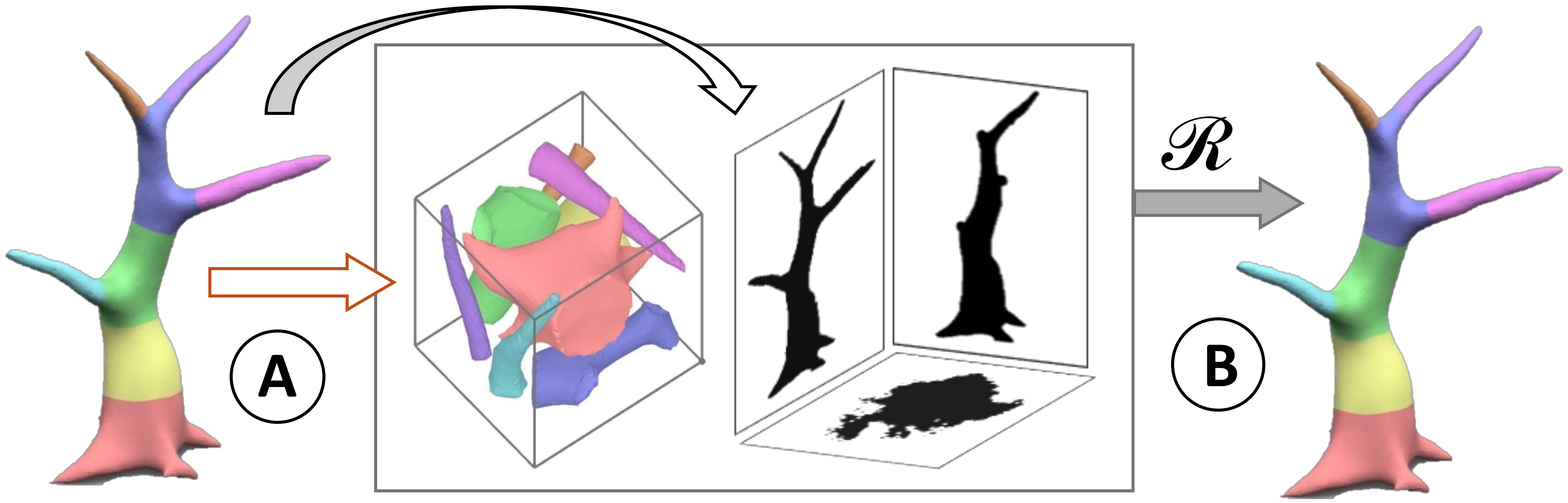
Shadow Guided 3D Packing



Dual Interpretation of the Problem

(A) 3D Packing Problem

(B) 3D Part Assembly



Existing Research

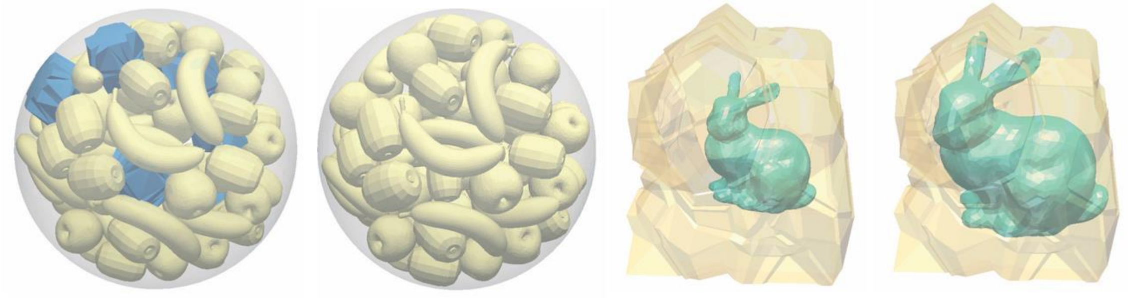
3D Packing Problem

- **Classical Algorithms**
  Ocloo et al. [2020], Paquay et al. [2016]
  Formulates as Mixed Integer Linear Programming.
  Receive an optimal solution but cannot address large object numbers.

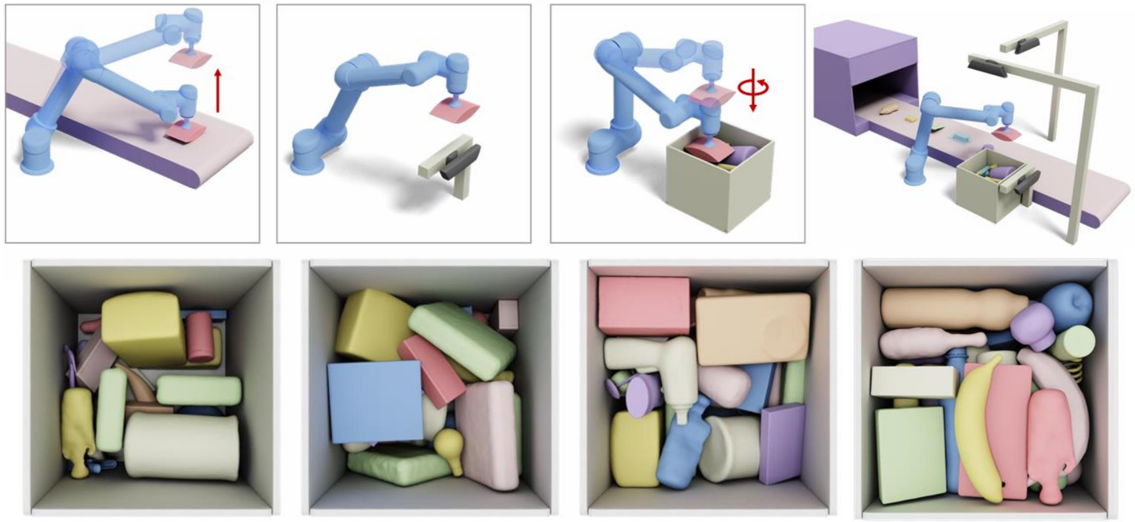
- **Heuristic Algorithms**
  Gürbüz et al. [2009] Largest Area First-Fit (LAFF).
  Toffolo et al. [2017] Two level stacks-based method.
  Shorter time but low-quality solutions.

- **Meta-Heuristic Algorithms**
  Xiang et al. [2018], Li et al. [2014]
  Genetic Algorithm and Greedy based solution.
  High-quality approximate solutions but search process is time-consuming.

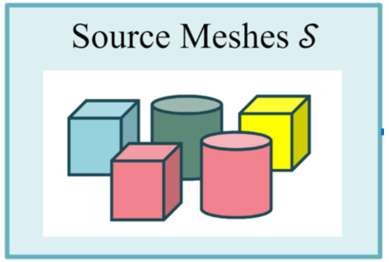
Packing Irregular Objects in 3d Space via Hybrid Optimization, Ma et al. [2018]



Learning Physically Realizable Skills for Online Packing of General 3d Shapes, Zhao et al. [2023]



Methodology

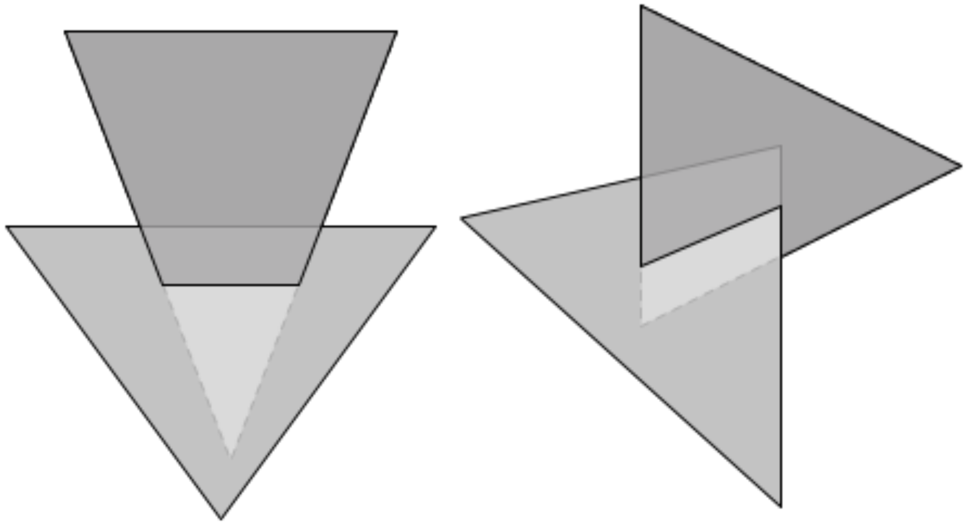


Methodology

Traditional Methods of Identifying Mesh Intersection in 3D

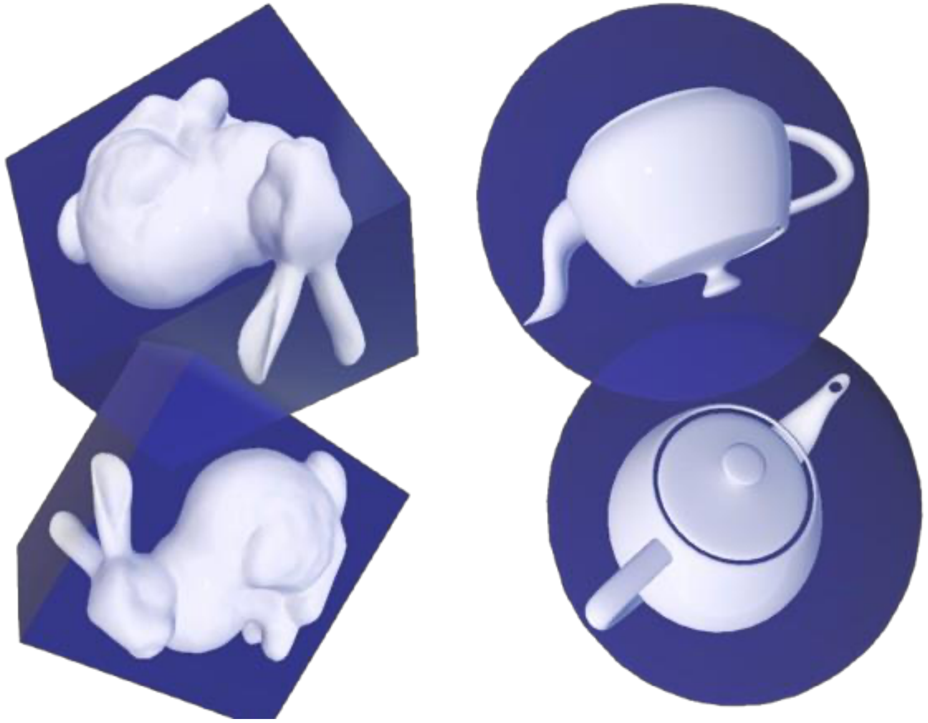
→ Triangular Face Based

Heavy in terms of compute.



→ Bounding Based

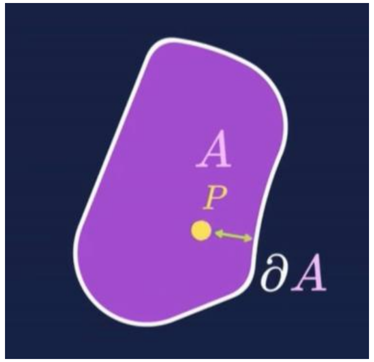
Prone to false positives.

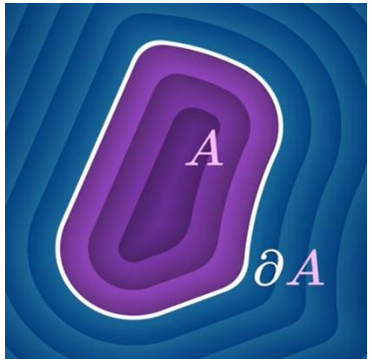


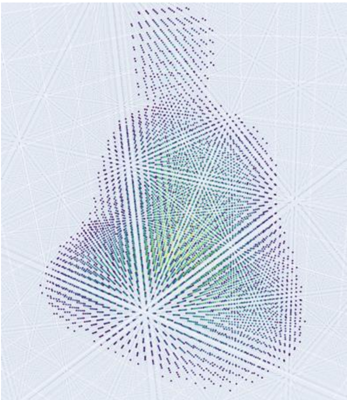
Methodology

Signed Distance Function for Finding Mesh Intersection

$$d_A(P) := \begin{cases} \text{dist}(P, \partial A), & P \text{ outside} \\ -\text{dist}(P, \partial A), & P \text{ inside} \end{cases}$$

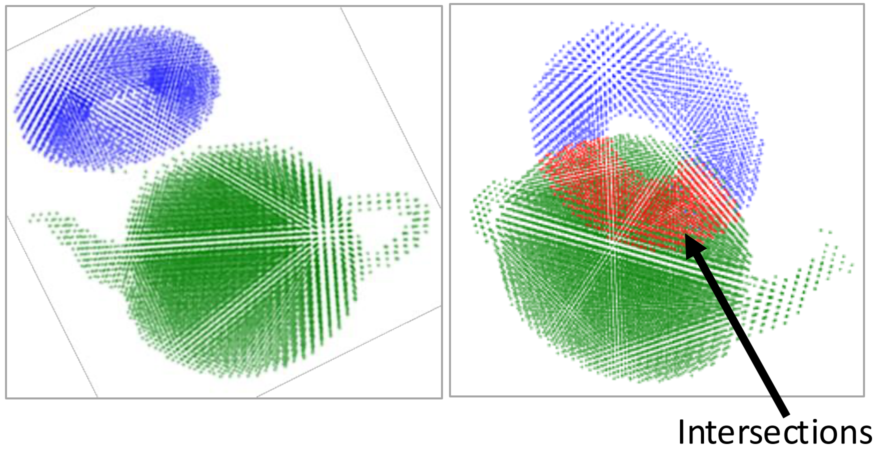






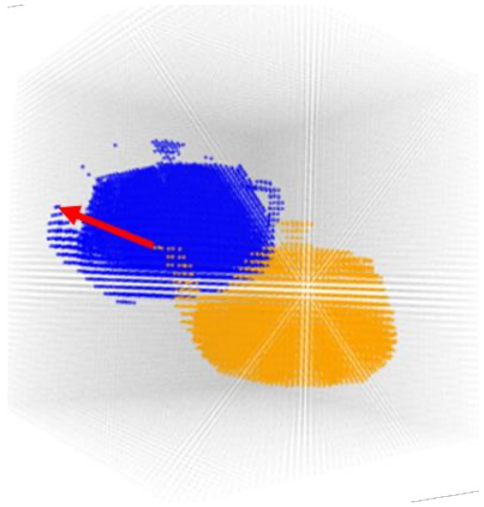
We precompute the SDF of each mesh at a fixed set of query points in the bounding volume $\mathcal{V}$

Finding the intersections is now simply counting the points for which the SDF values are less than zero with respect to more than one objects in $\mathcal{V}$



We do not need to compute the SDF(s) in every iteration.

We warp the previous SDF to the new SDF through a linear transformation of the learned rotation and translations.



Methodology

Silhouette Loss

$$\mathcal{L}_{sil} = \frac{1}{MNK}\sum_{k=1}^{K}\sum_{i=1}^{MN} ||I_k(i) - \widehat{I}_k(i)||_2^2$$

Intersection Loss

$$\mathcal{L}_{is} = \sum_{\mathbf{p}\in\mathcal{C}_p} D_{is}(\mathbf{p})$$

$$D_{is}(\mathbf{p}) = \sum_{\{\forall O_i | \widetilde{S}_{O_i}(\mathbf{p})<0\}} -\widetilde{S}_{O_i}(\mathbf{p})$$

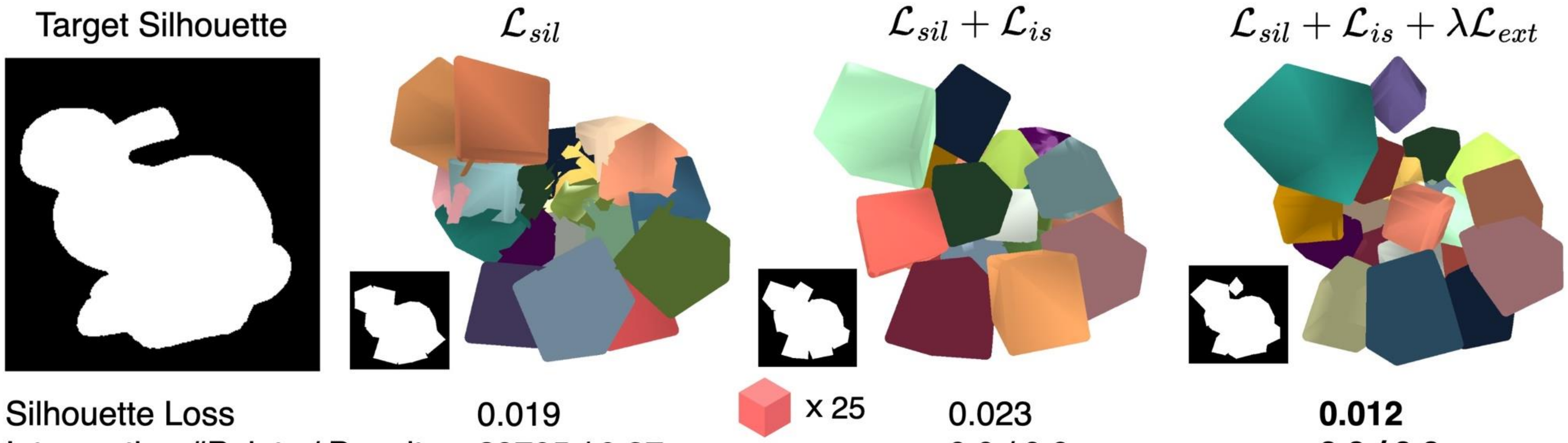
Container Extrusion Loss

$$\mathcal{L}_{ext} = \sum_{i=1}^{N}\sum_{\mathbf{v}\in V_i} \max(-\epsilon, S_{\mathcal{C}}(\mathbf{v}))$$

Total Loss

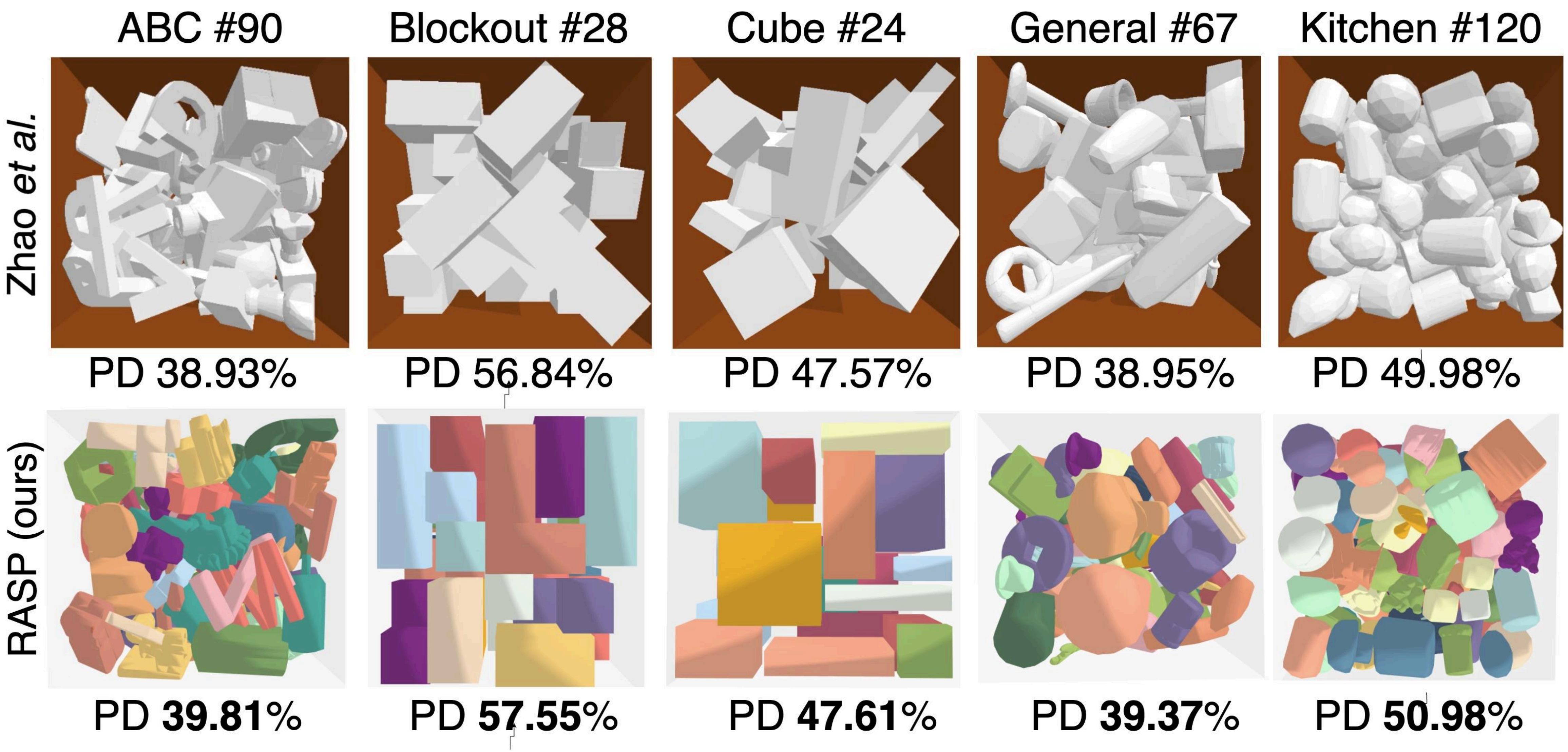
$$\mathcal{L}_{total} = \mathcal{L}_{sil} + \mathcal{L}_{is} + \lambda\mathcal{L}_{ext}$$

$$\lambda = 0.001$$



	$\mathcal{L}_{sil}$	$\mathcal{L}_{sil} + \mathcal{L}_{is}$	$\mathcal{L}_{sil} + \mathcal{L}_{is} + \lambda\mathcal{L}_{ext}$
Silhouette Loss	0.019	0.023	**0.012**
Intersection #Points / Density	29705 / 0.37	0.0 / 0.0	**0.0 / 0.0**

Packing Results on IR-BPP Dataset

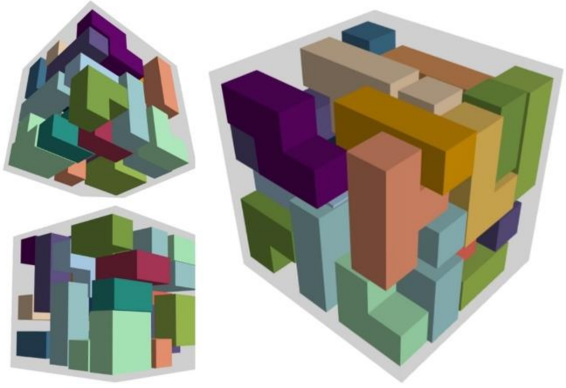


Packing Results

ABC

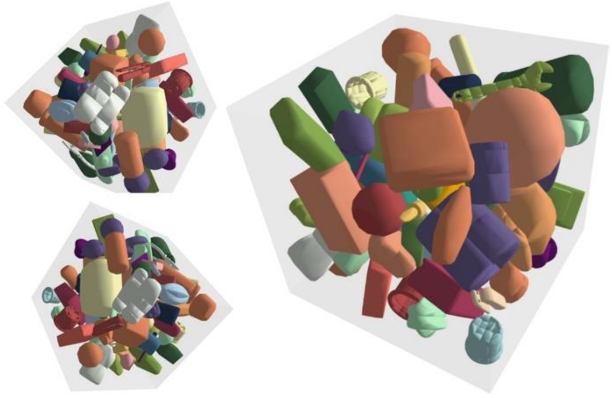
Number of Objects: **90**
Packing Density: **40%**

Block Out



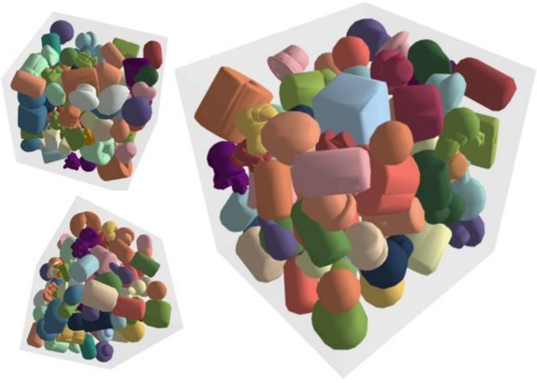
Number of Objects: **28**
Packing Density: **57%**

General

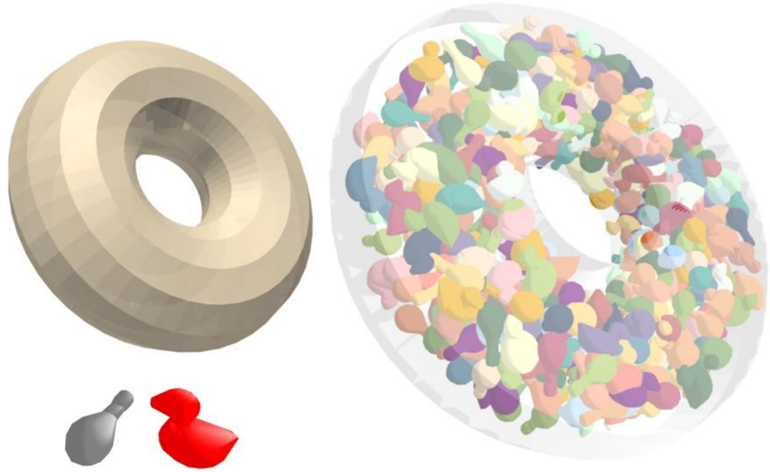


Number of Objects: **67**
Packing Density: **40%**

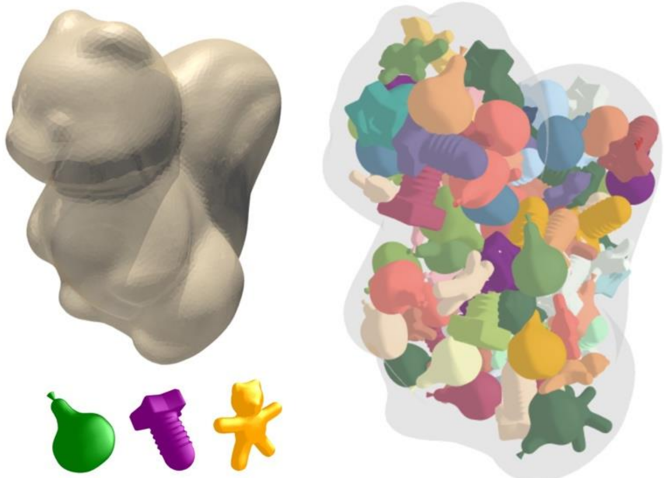
Kitchen



Number of Objects: **120**
Packing Density: **50%**

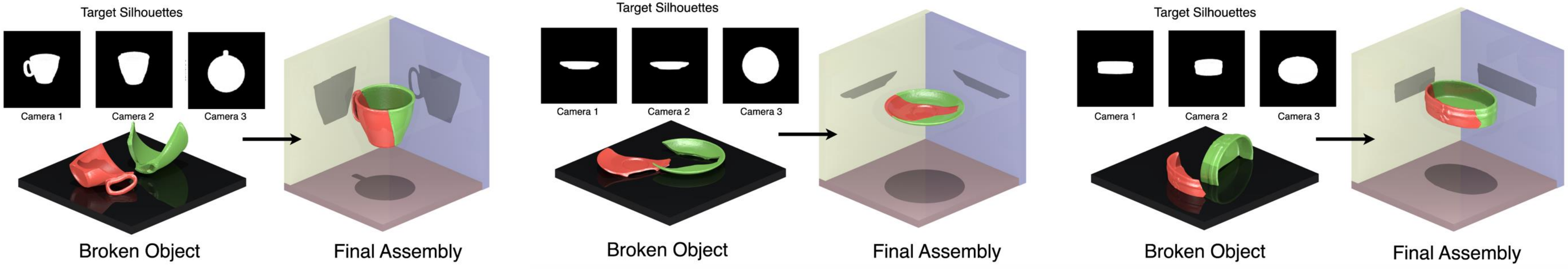


Number of Objects: **550** Packing Density: **58%**

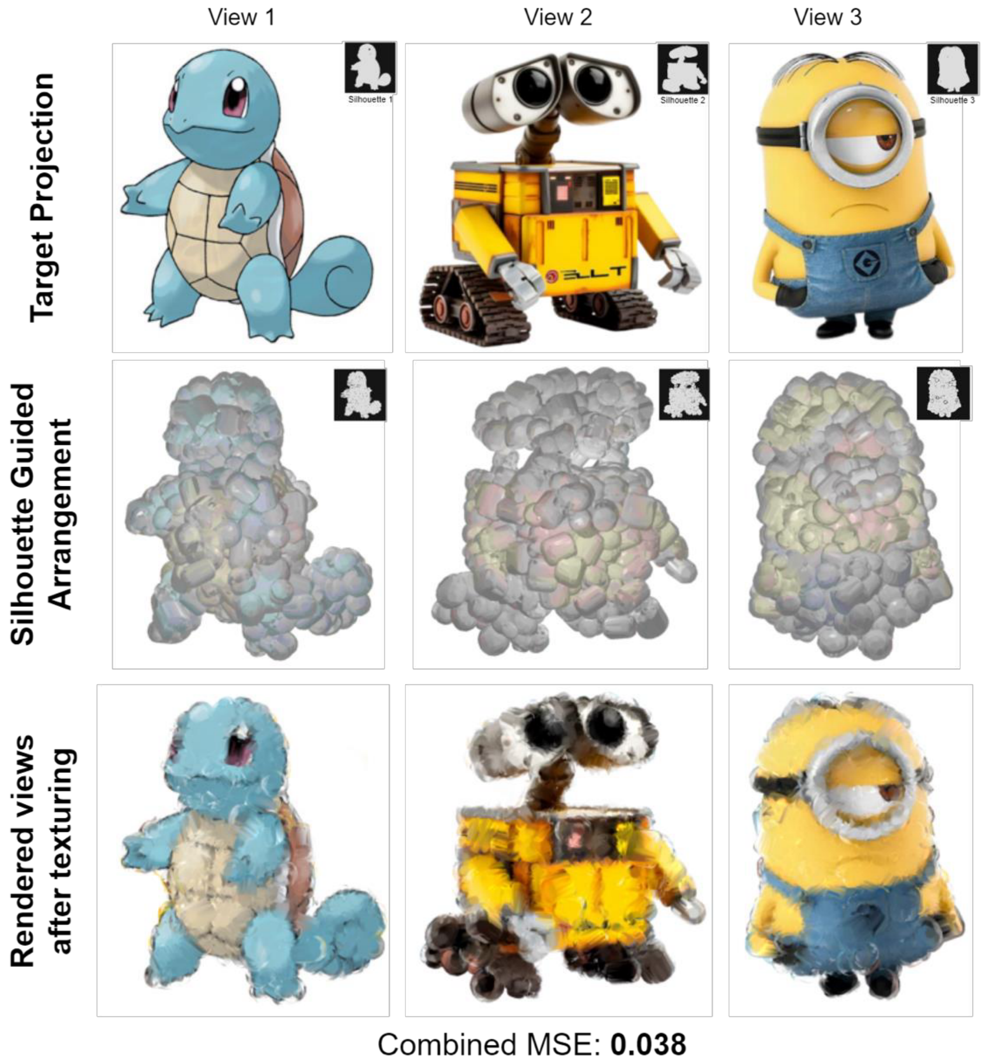


Number of Objects: **115** Packing Density: **34%**

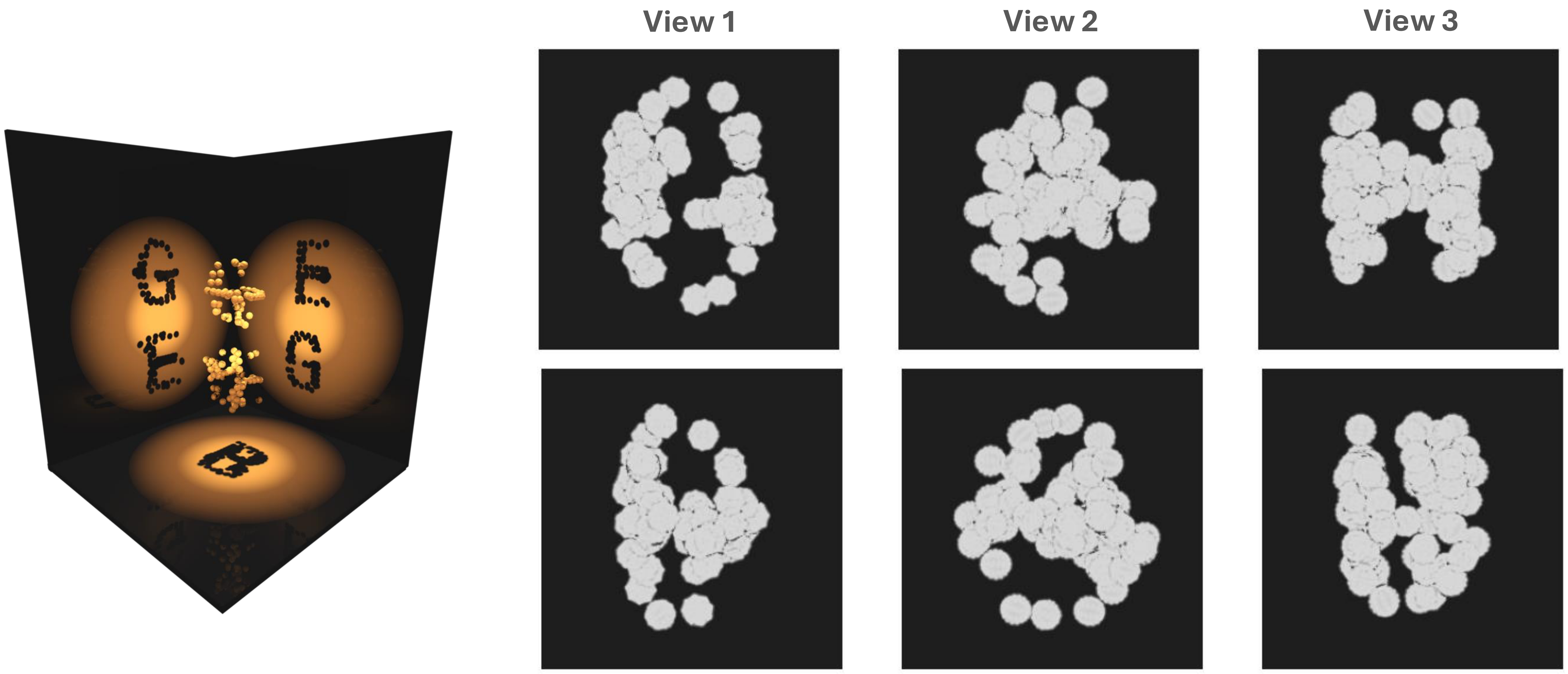
3D Part Assembly Results on the Fantastic Breaks Dataset



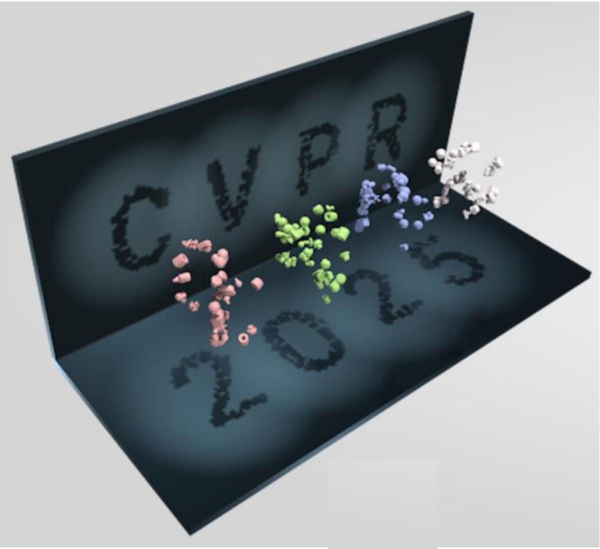
3D Anamorphic Art

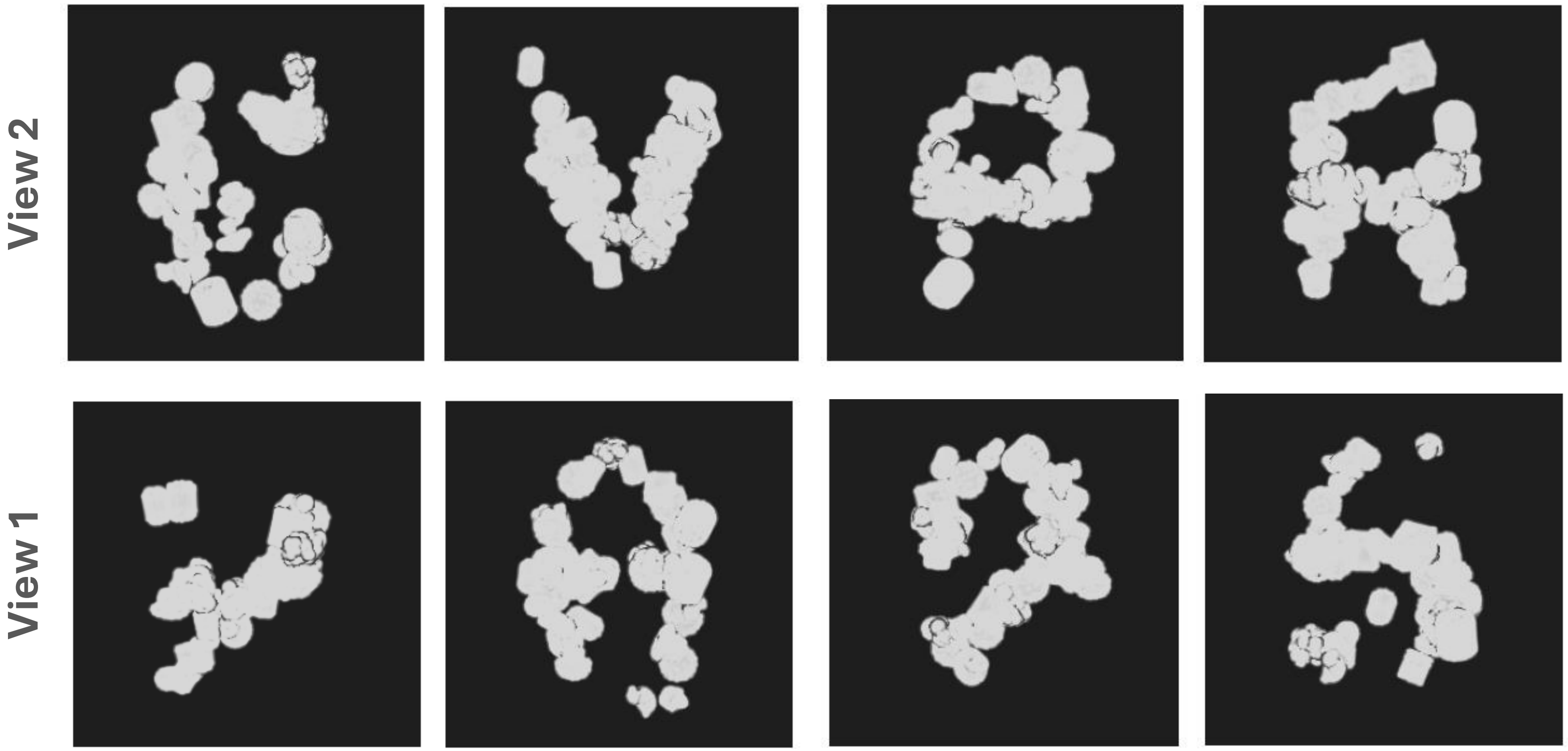


3D Anamorphic Art



3D Anamorphic Art





Contributions

We propose a differentiable rendering-based framework to tackle irregular object packing by drawing inspiration from 3D Anamorphic Art.

We present a novel SDF-based approach to manage inter-object intersections and object-container extrusions, enhanced by an image-based loss function.

We demonstrate that RASP can also be applied to part assembly without the need for explicit 3D ground truth supervision.

We illustrate compelling visual effects that cater to multi-view anamorphic art.

To the best of our knowledge, this is the first approach to address packing (and part assembly) using only shadows or projections, guided by the principles of differentiable rendering.

References

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