Structure-Aware Surface Reconstruction via Primitive Assembly

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Introcuction

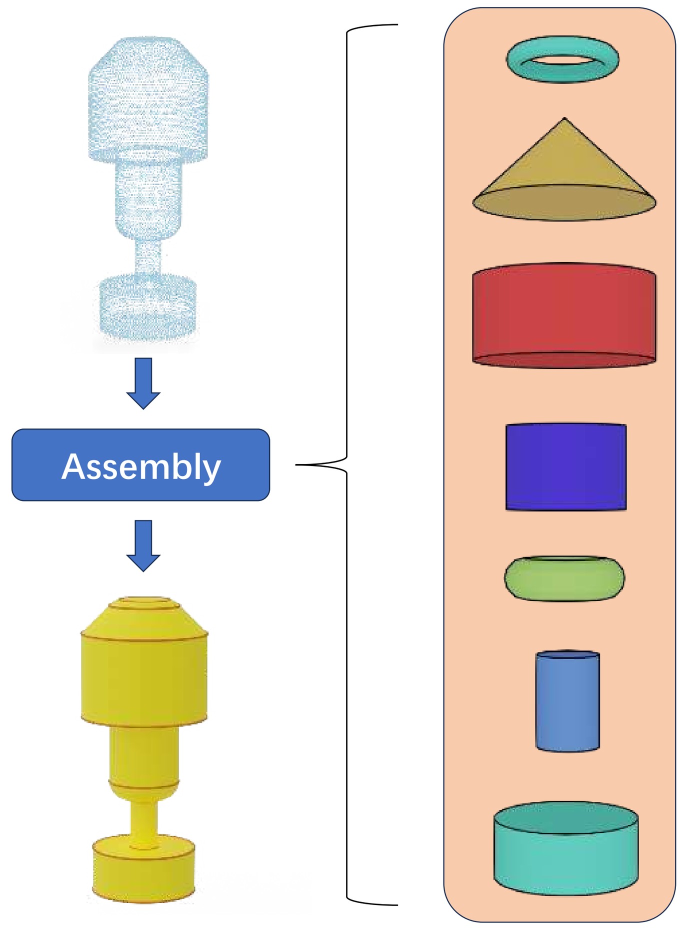

Fig.1 : Primitive assembly

- Fast, feature-preserving reconstruction is a highly coveted technique in geometric modeling. Implicit methods have difficulty preserving sharp features, while plane-based assembly methods can be time-consuming and less accurate when handling complex objects.
- We propose a novel and efficient method for reconstructing manifold surfaces from point clouds by assembling primitives.

Overview

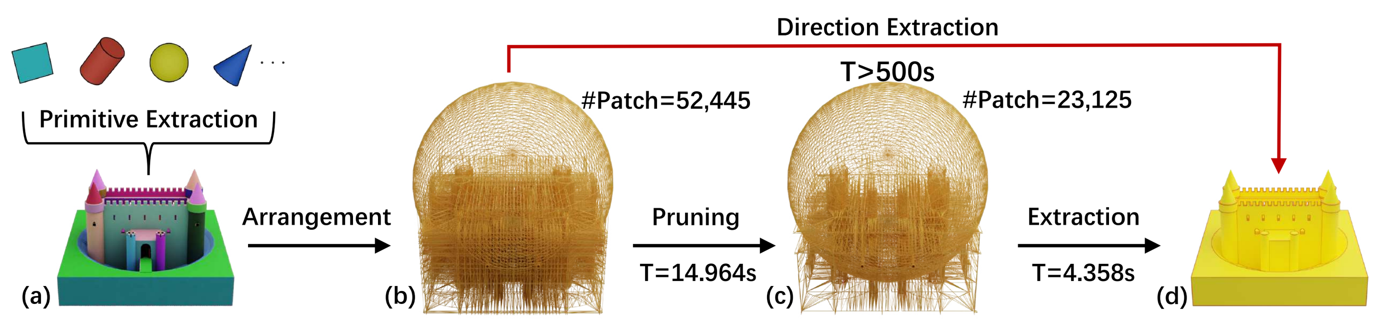

Fig.2 : Overview of the our method.

Fig.2 represents the main steps of our method :

- We first extract primitives from point cloud and use arrangement algorithm to generate candidate patches. (a)→(b)
- Then, we introduce an effective pruning mechanism to discard redundant patches and speed up surface extraction a lot. (b)→(c)
- The optimal patches are selected by binary linear programming and assembled as manifold and watertight surfaces. (c)→(d)

The **significant time gap** between the two routes (**black** and **red**) demonstrates the effectiveness of our pruning mechanism which is our core contribution.

Pruning

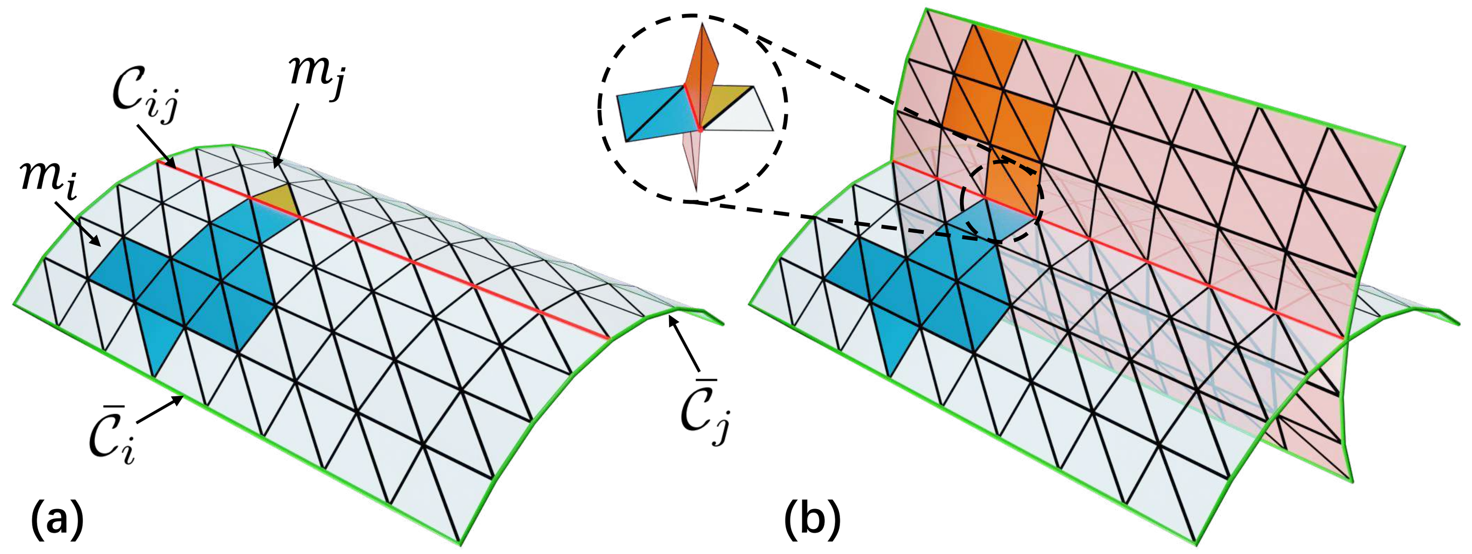

Fig.3 : Visual description of patch pruning.

The proposed pruning mechanism is composed of two steps, initialization and pruning, as presented subsequently.

- **Initialization :** We first select a set of representative triangle meshes (colored **blue**) with high point coverage.
- **Pruning :** Next, representative triangle meshes are propagated around. however, some triangles (colored **yellow**) will not be propagated since the block from propagated triangles (colored **orange**) from another primitive. All unpropagaed triangles will be discarded.

Surface Extraction

Patch-induced binary linear programming :

$$\min_{\mathcal{X}_{\tilde{\mathcal{M}}}} \quad \mathbf{U}(\mathcal{X}_{\tilde{\mathcal{M}}}) + \lambda \mathbf{B}(\mathcal{X}_{\tilde{\mathcal{M}}}),$$

$$s.t. \begin{cases} \sum\limits_{\tilde{m}_i \cap \tilde{m}_j \neq \emptyset, i \neq j} (x_{\tilde{m}_i} + x_{\tilde{m}_j}) = 0 \ or \ 2, \tilde{m}_i, \tilde{m}_j \in \tilde{\mathcal{M}} \\ x_{\tilde{m}_i} \in \{0,1\}, \quad i = 1,2,3\ldots|\tilde{\mathcal{M}}|. \end{cases}$$

Fidelity loss :

$$\mathbf{U}(\mathcal{X}_{\tilde{M}}) = \sum_{\tilde{m} \in \tilde{\mathcal{M}}} x_{\tilde{m}} \cdot \left(\frac{\mathcal{A}_{\tilde{m}} - \bar{\mathcal{A}}_{\tilde{m}}}{\mathcal{A}} - \frac{|\mathcal{P}_{\tilde{m}}|}{|\mathcal{P}|} \right)$$

Complexity loss :

$$\mathbf{B}(\mathcal{X}_{\tilde{\mathcal{M}}}) = \frac{1}{L} \sum_{i,j} |\mathcal{C}_{ij}| \cdot x_{\tilde{m}_i} \cdot x_{\tilde{m}_j}$$

Experiments & Application

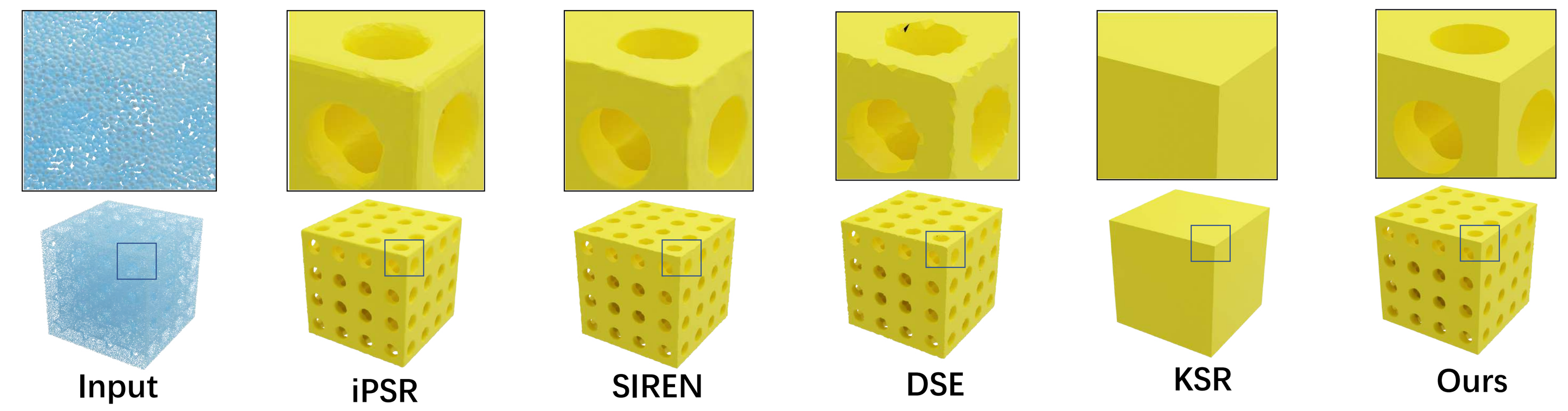

Fig.4 : Comparisons with state-of-the-art approaches.

Metrics	iPSR[20]	SIREN[45]	DSE[40]	KSR[3]	Ours	
					w	w/o
SMH (%)	4.23	41.79	3.15	169.44	2.45	2.45
Time (s)	201.589	1208.124	303.865	570.468	45.5	56.777

Tab.1 : Numerical comparison of Fig.4

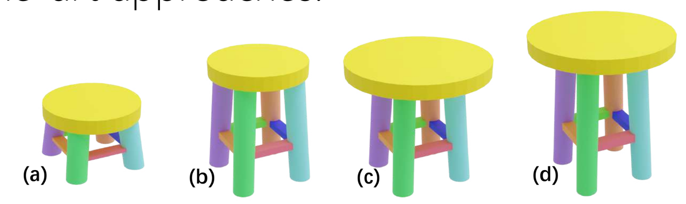

Fig.5 : Application to model editing

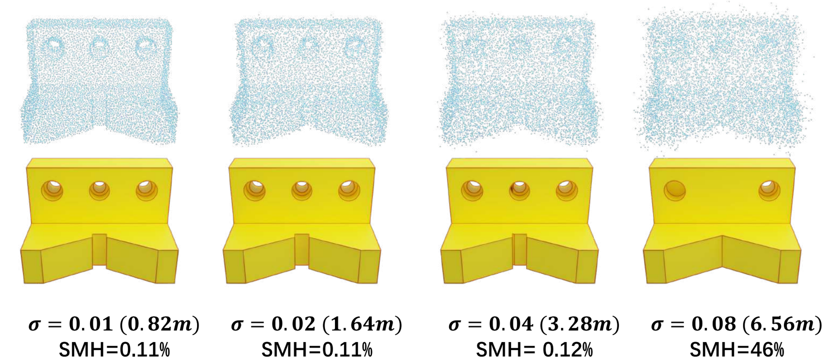

Fig.6 : Noise test

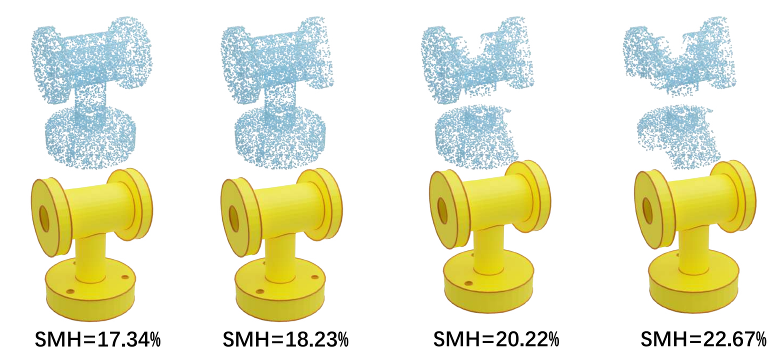

Fig.7 : Occlusion test

Methods / Metrics	iPSR[20]	SIREN[45]	DSE[40]	KSR[3]	ComplexGen[17]	CAPRI-Net[48]	Ours
SMH (%)	2.71	24.89	4.06	26.43	24.24	15.87	4.81
Time (s)	24.064	1565.217	32.800	4.208	553.089	183.844	3.728

Tab.2 : Numerical comparisons on the ABC300 dataset.

Conclusion & Contribution

To summarize, the main technical contributions include: :

- An efficient structure-aware reconstruction method that produces accurate surface models while preserving the underlying intrinsic primitive structures of the input point clouds.
- A patch pruning technique that avoids the time-consuming global collision detection and accelerates the surface extraction by a large margin.
- A patch-induced binary linear programming for assembling manifold and watertight surfaces from candidate active patches, which significantly reduces the search space and helps achieve efficient and accurate surface reconstruction.