Neural Feature Matching in Implicit 3D Representations

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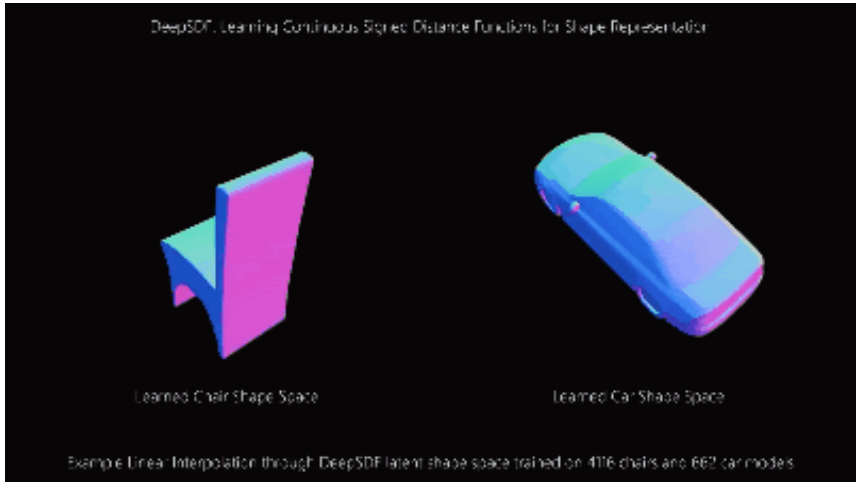


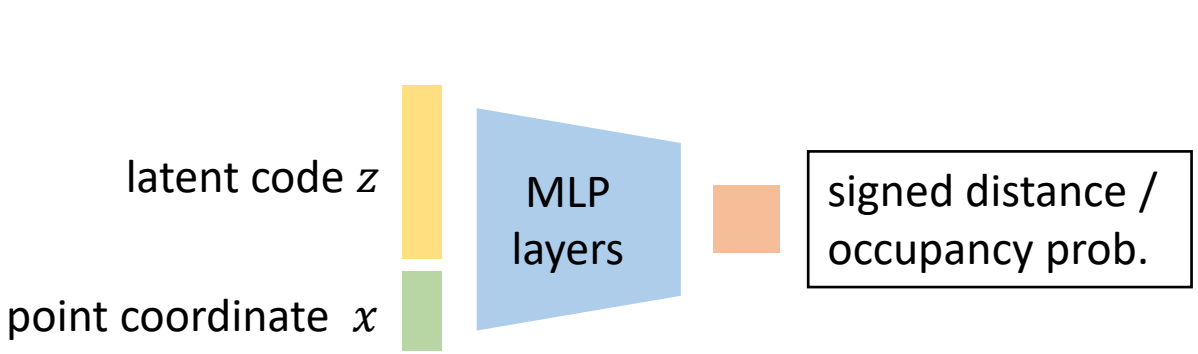
Motivation

Smooth interpolation in latent-coded implicit functions

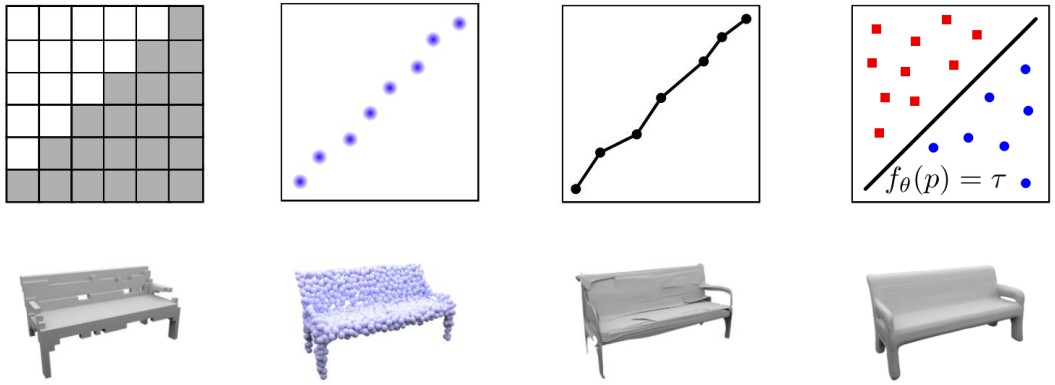
Park et al. DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation.

Neural implicit 3D representations

[Mescheder et al. CVPR'19]



latent-coded implicit function

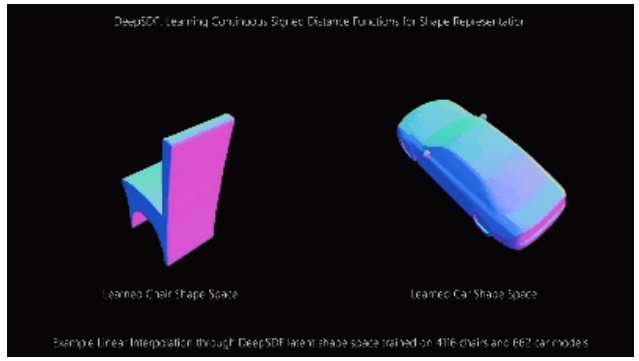


voxel | point cloud | mesh | implicit function

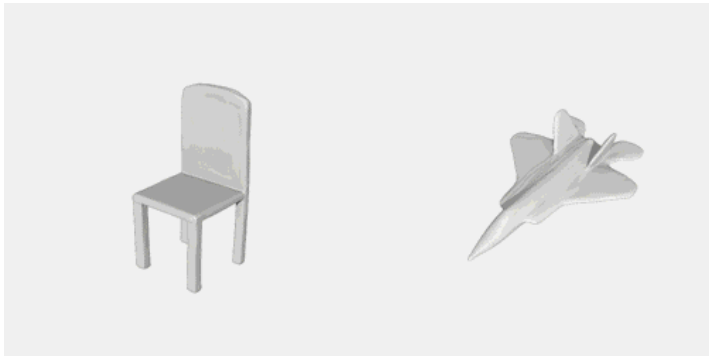
3D shapes as implicit field function $F(x; z)$

- continuous and resolution-free
- represent arbitrary topology

Smooth interpolation



[Park et al. CVPR'19]

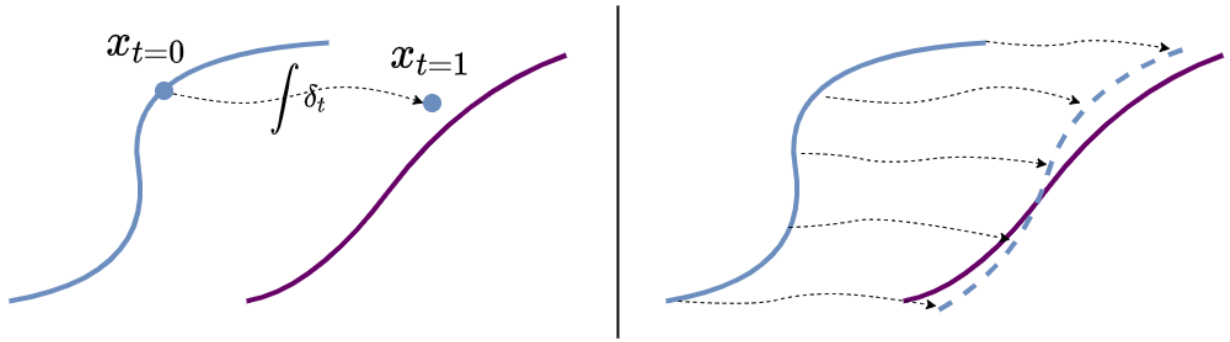


[Chen & Zhang, CVPR'19]

[Chen & Zhang, CVPR'19]

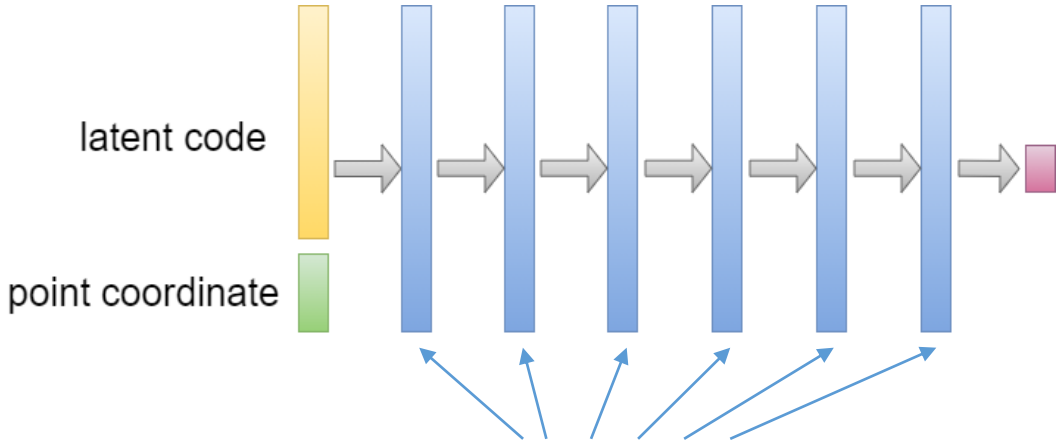
- Smooth and high-quality interpolated shapes
  - benefit from continuous input point coordinate
- In need of point-level interpretation (which point goes where)
  - understand the model
  - useful in computer-aided design, cross-shape texture mapping, etc.

Park et al. DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation
Chen & Zhang. Learning Implicit Fields for Generative Shape Modeling



Method

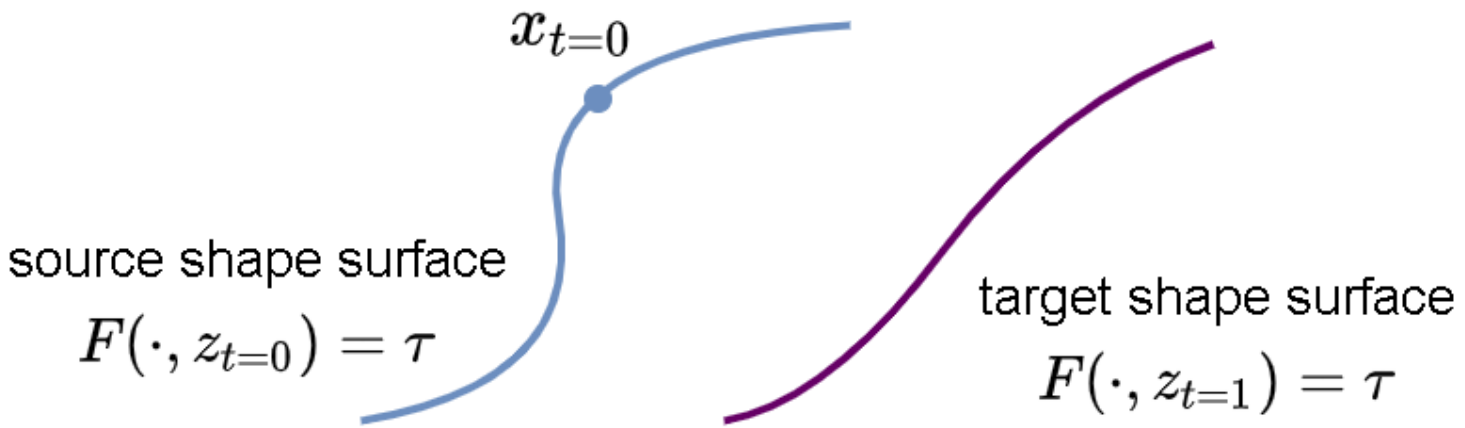
Tracking point interpolation path with matching feature similarity



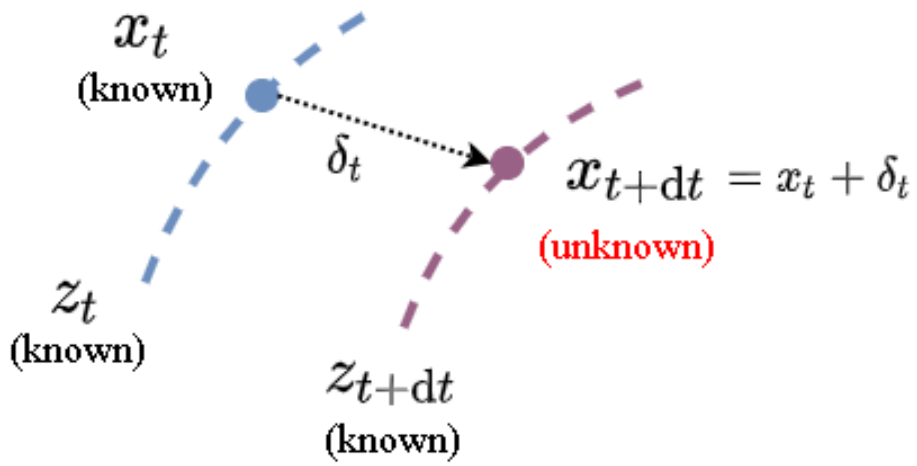
Chen & Zhang. IM-Net, CVPR'19

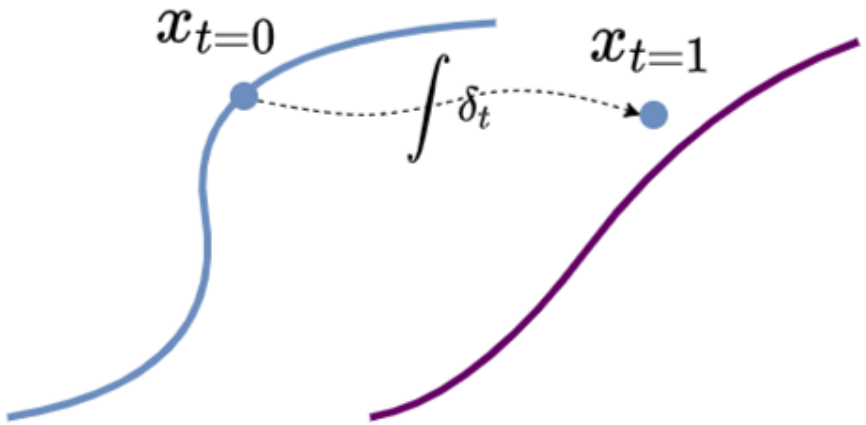
implicit features $\Phi(x; z)$

- Implicit network pretrained for shape autoencoding
- Implicit feature as point descriptor
- Matching points with feature similarity over interpolation



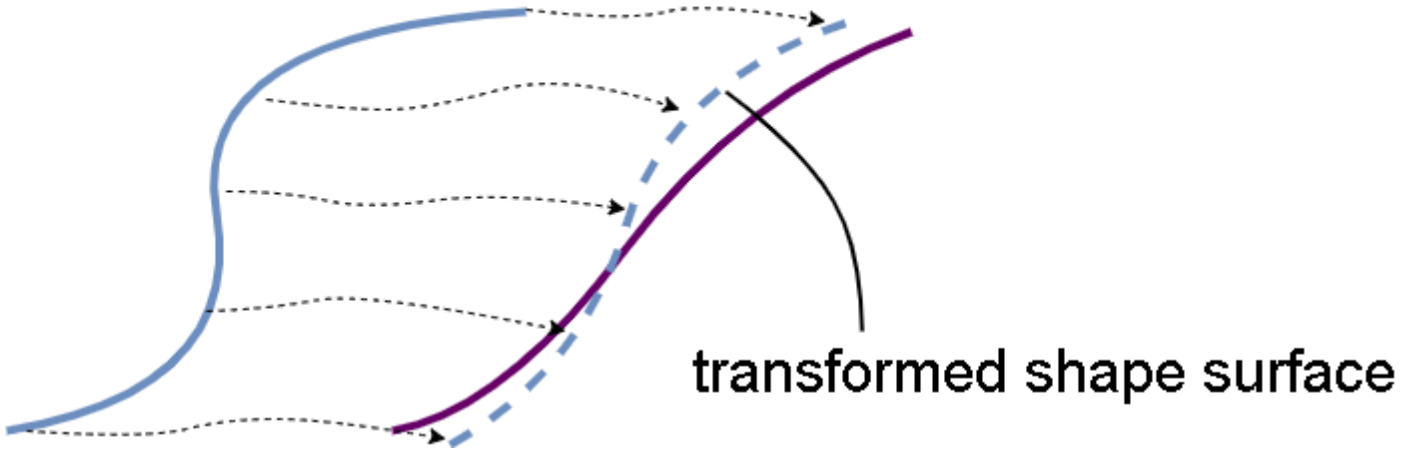
- Extract iso-surface from implicit field
- Initial x on source shape surface



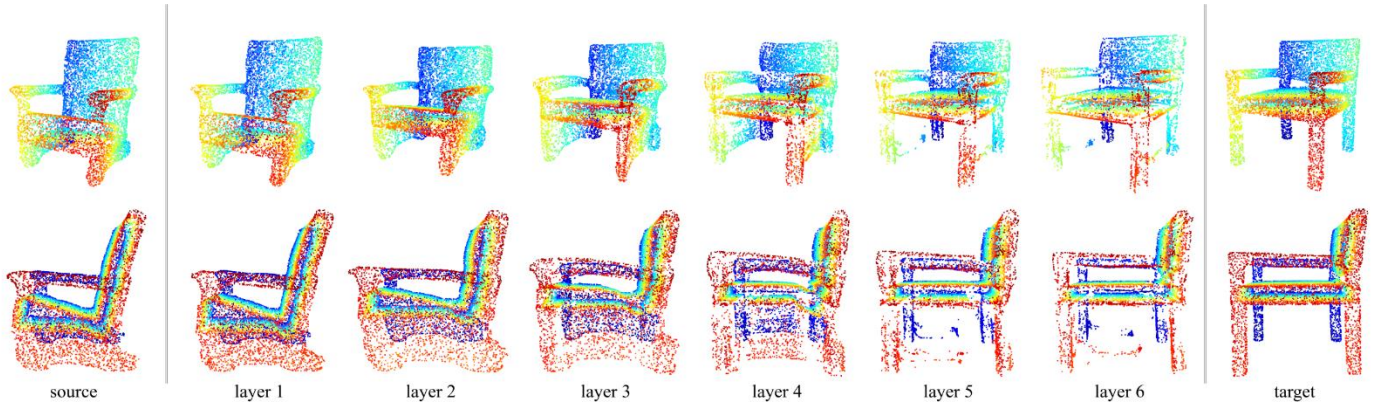


$$\delta_t = \underset{\delta_t}{\operatorname{argmin}} \|\Phi(x_t + \delta_t, z_{t+\mathrm{d}t}) - \Phi(x_t, z_t)\|$$

- Solve displacement δ_t in small timestep $\mathrm{d}t$ in interpolation
  - minimise feature difference from stepping z
  - Gauss-Newton update using Jacobian on coordinate $J = \nabla_x \Phi$
  - regularisation to prevent drift from noise
- Integrate displacements for point trajectory



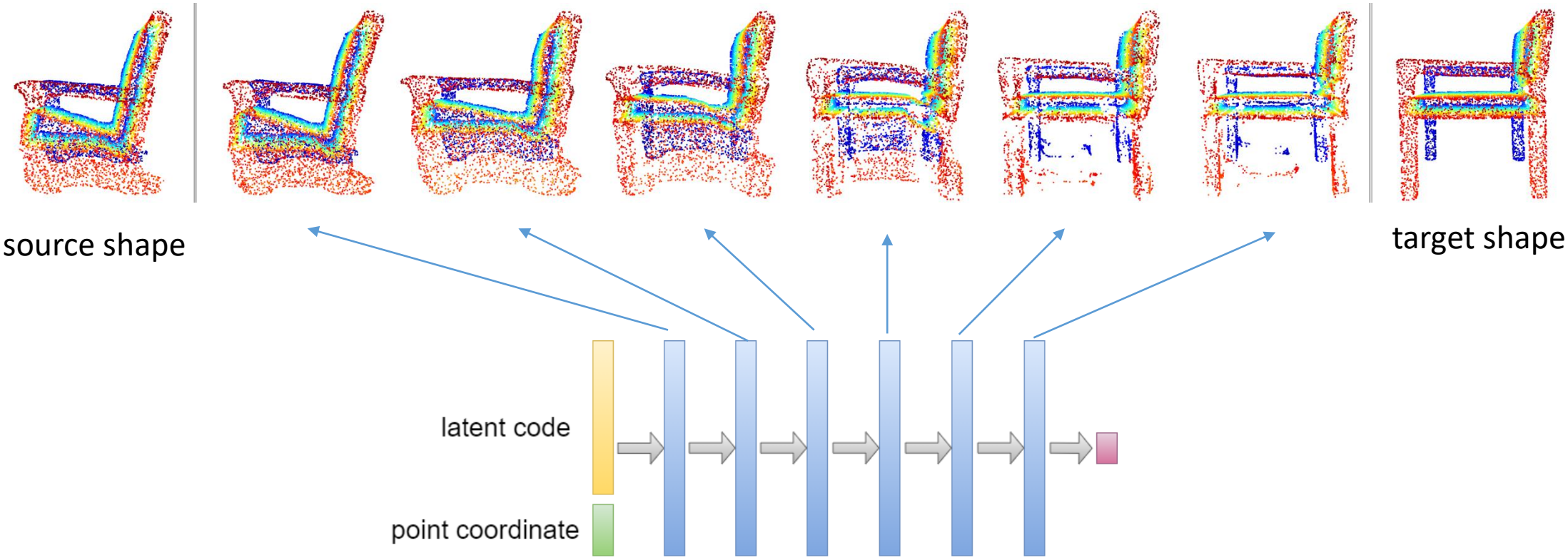
- Repeat for a set of sampled points for the transformed shape
  - not necessarily the exact target surface (but close)
  - helps to understand implicit features



Analysis

Hierarchical function in implicit function layers.

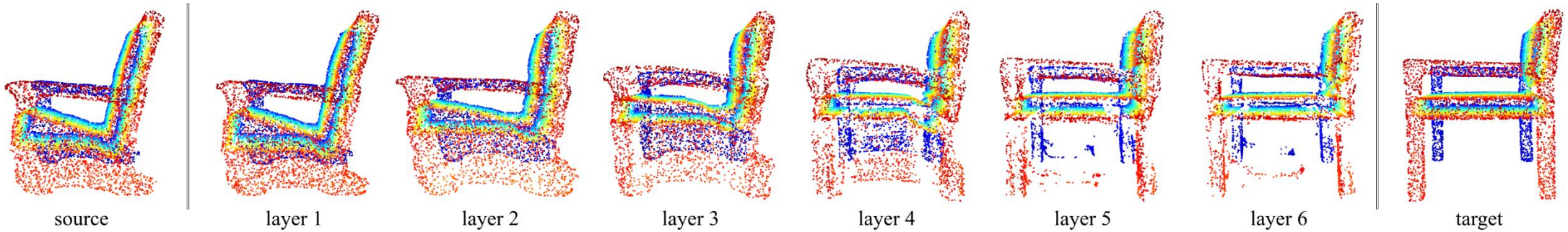
Hierarchy in layers

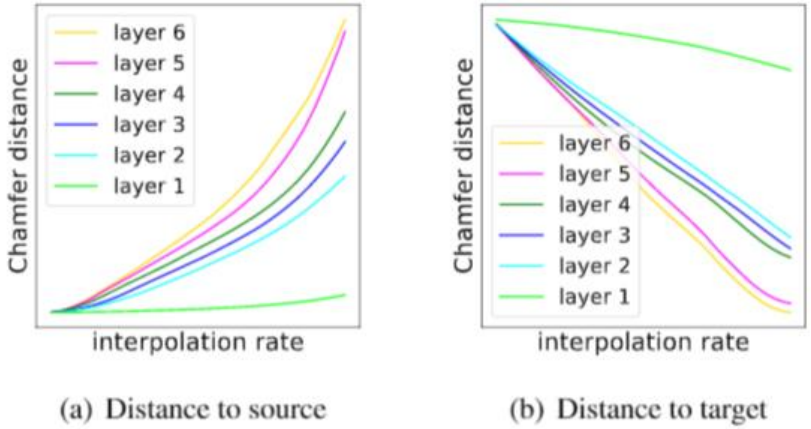


Resulting shapes from feature matching
using different layer features

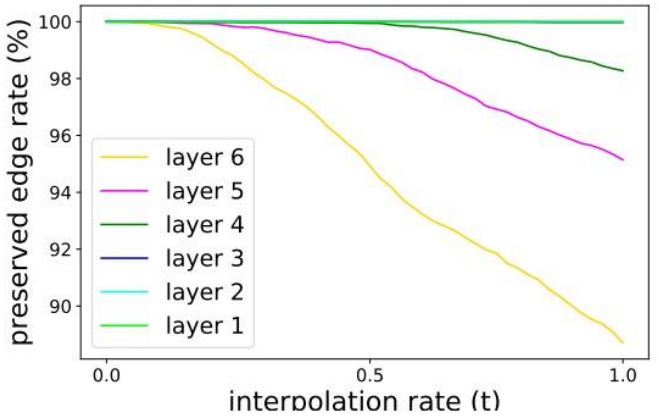
Hierarchy in layers

- Earlier layers encode coarse outline.
- Deeper layers encode finer details.



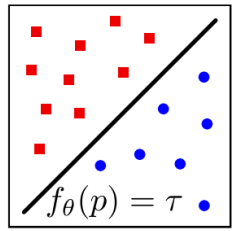


resulting shape closer to the target as layer goes deeper



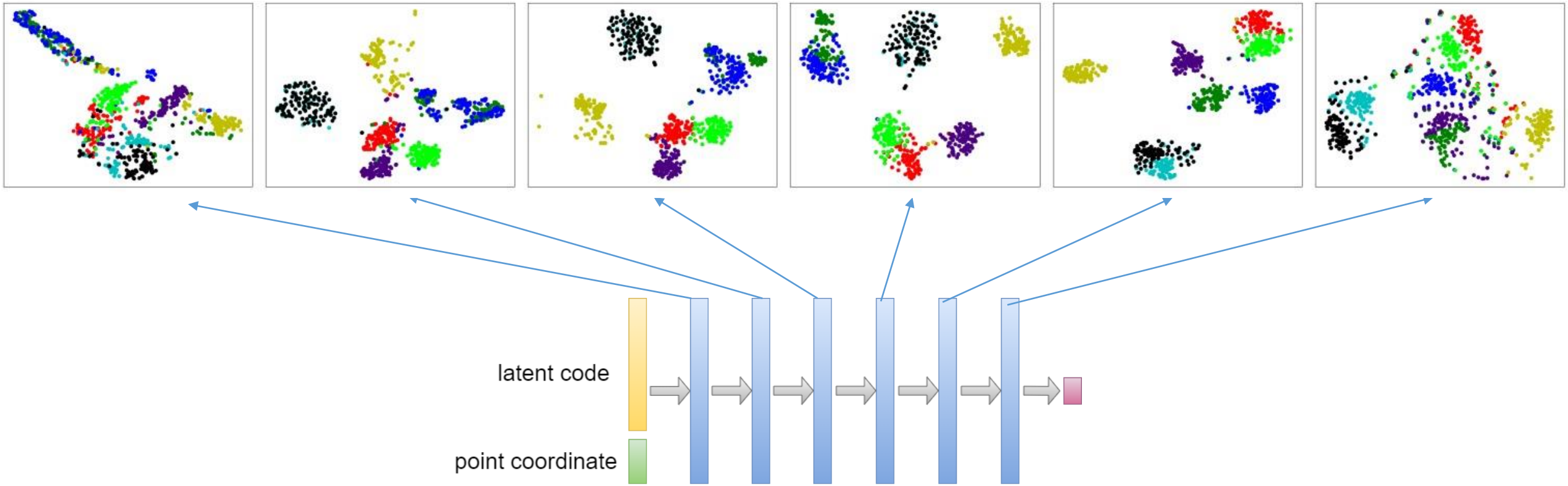
only the final layers change local details

Hierarchy in layers



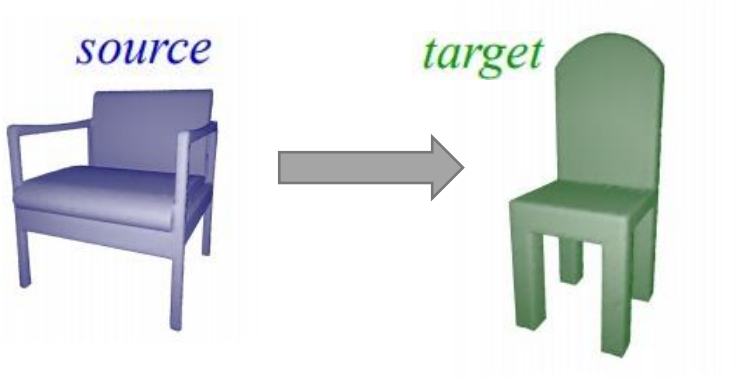
Mid-layers have distinct features.

- starting layers: more low-level geometry
- final layers: more local detail; to map all surface points to the same output τ.



Application: Mesh Deformation

in existence of inconsistency in topology or semantic parts



Application: Mesh Deformation

with inconsistency in topology/semantic parts

appearance fitting

Appearance fitting

- minimise Chamfer distance
- unnaturally distorted arms

feature matching (ours)

Feature matching

- minimise difference in generalisable implicit features
- arms at right place (without semantic part annotation)

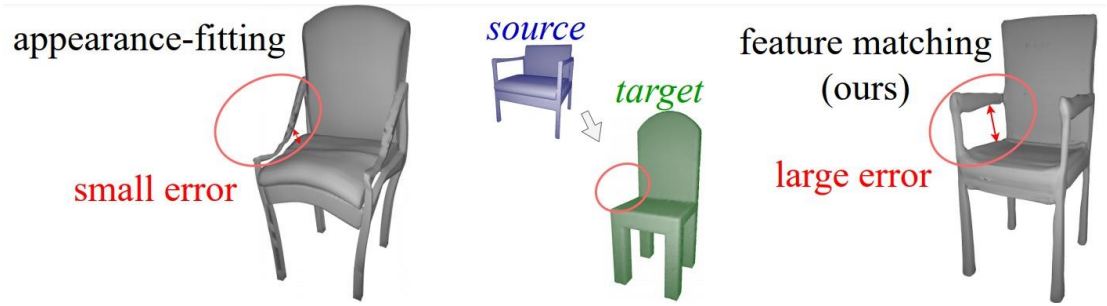
Quantitative Results

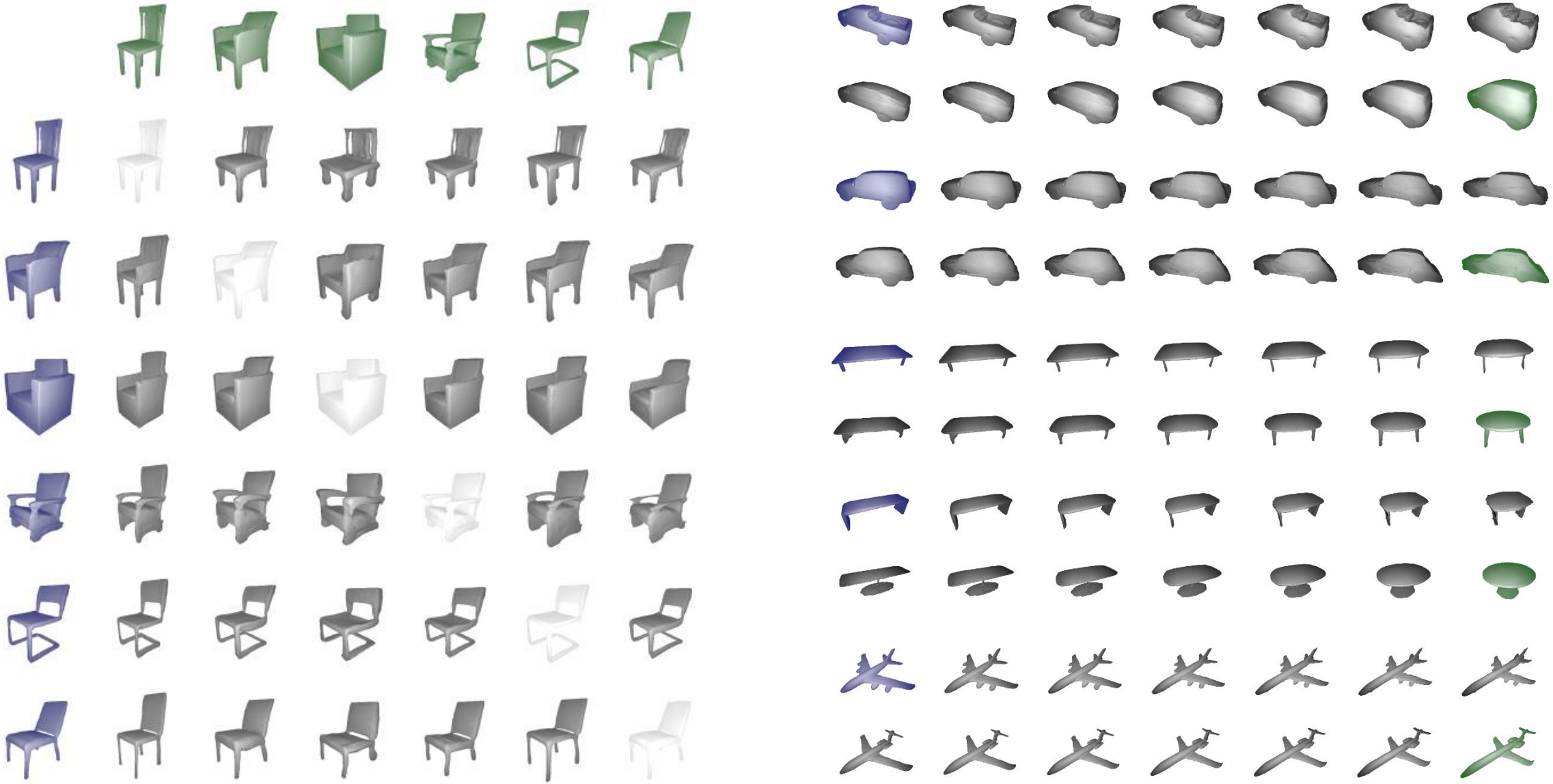
Table 1. Matching measures between the deformed shape and the target. CD($\times$0.001) / EMD($\times$0.01).

Shape category	chair		airplane		table	
Part-level evaluation	×	✓	×	✓	×	✓
ShapeFlow (Jiang et al., 2020a)	1.365 / **6.750**	4.285 / 5.794	**0.378 / 5.194**	5.551 / 5.229	- / -	- / -
MeshODE (Huang et al., 2020)	**1.187** / 7.281	4.148 / 5.315	- / -	- / -	**2.564 / 8.298**	14.859 / 7.578
NeuralCage (Yifan et al., 2020)	4.372 / 8.563	6.477 / 6.319	- / -	- / -	11.367 / 11.116	21.676 / 9.378
This paper	1.744 / 7.143	**3.772 / 3.256**	0.935 / 5.601	**5.458 / 4.193**	4.998 / 8.387	**14.748 / 4.174**

- Feature matching outperforms appearance-fitting in part-level measures

- Limitation of standard shape-level matching measures
  - biased towards appearance-fitting: unnatural distortion returns lower error
  - part-level measures introduced, better reflecting matching quality in such cases





Feature matching works well for shapes in a variety of styles and categories.

Conclusion

- Point trajectory with minimum feature difference in interpolation.

- Hierarchy in implicit layer features
  - earlier layers for coarser shape outlines;
  - later layers for finer shape details.

- Apply to mesh deformation
  - handles inconsistencies in topology and semantic parts.
  - no part annotation needed in training or inference