DUDF: Differentiable Unsigned Distance Fields with hyperbolic scaling

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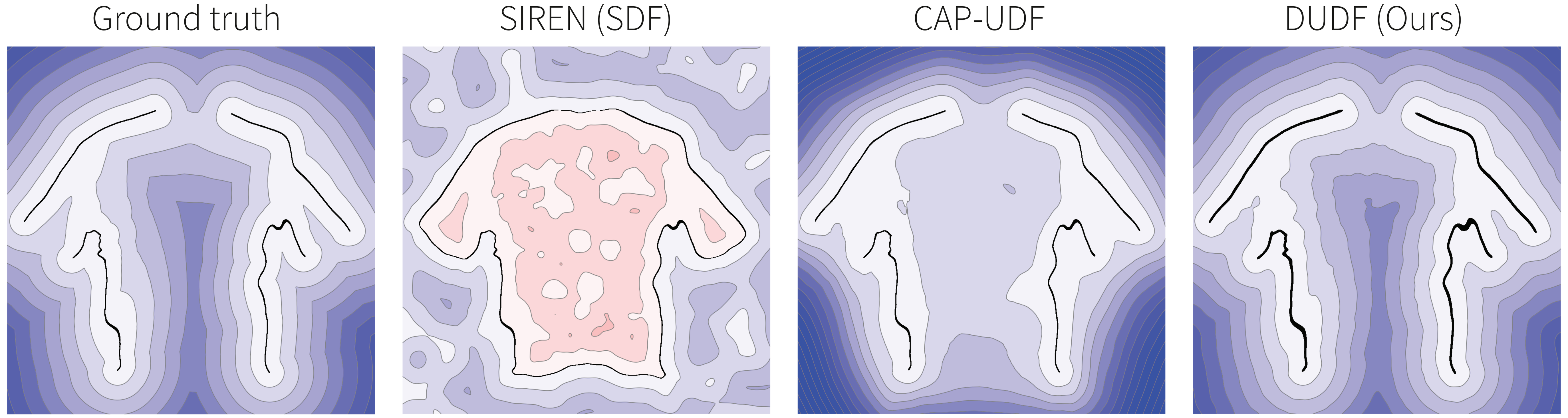
Motivation & Challenges

- Implicit Neural Representations (INRs) have achieved high-quality results for modeling **closed surfaces**.
- State-of-the-art methods for **open surfaces** often suffer from a lack of detail and frequent topological errors, such as incorrectly closing holes.

Proposed Method: We introduce a novel approach tailored for open surface implicit representation based on **differentiable neural networks** (SIREN) to achieve greater accuracy.

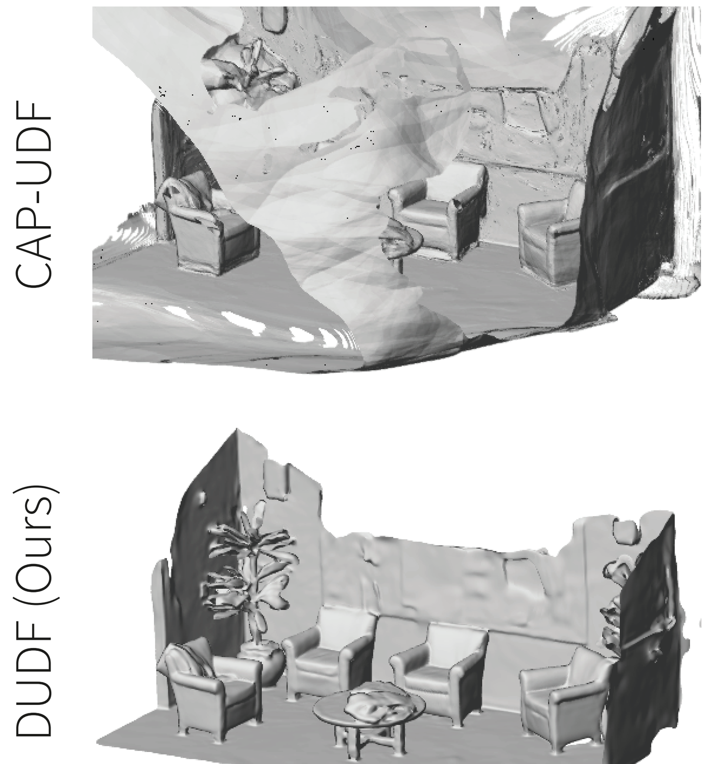
Results

- DUDF shows better performance than SOTA on both, open and closed surfaces.



Rendering

- Our representations precisely approximate the distance field, enhancing compatibility with **sphere tracing rendering** algorithms.
- DUDF's ability to compute the normal field enables the use of illumination techniques, which was not possible with earlier methods.



Method

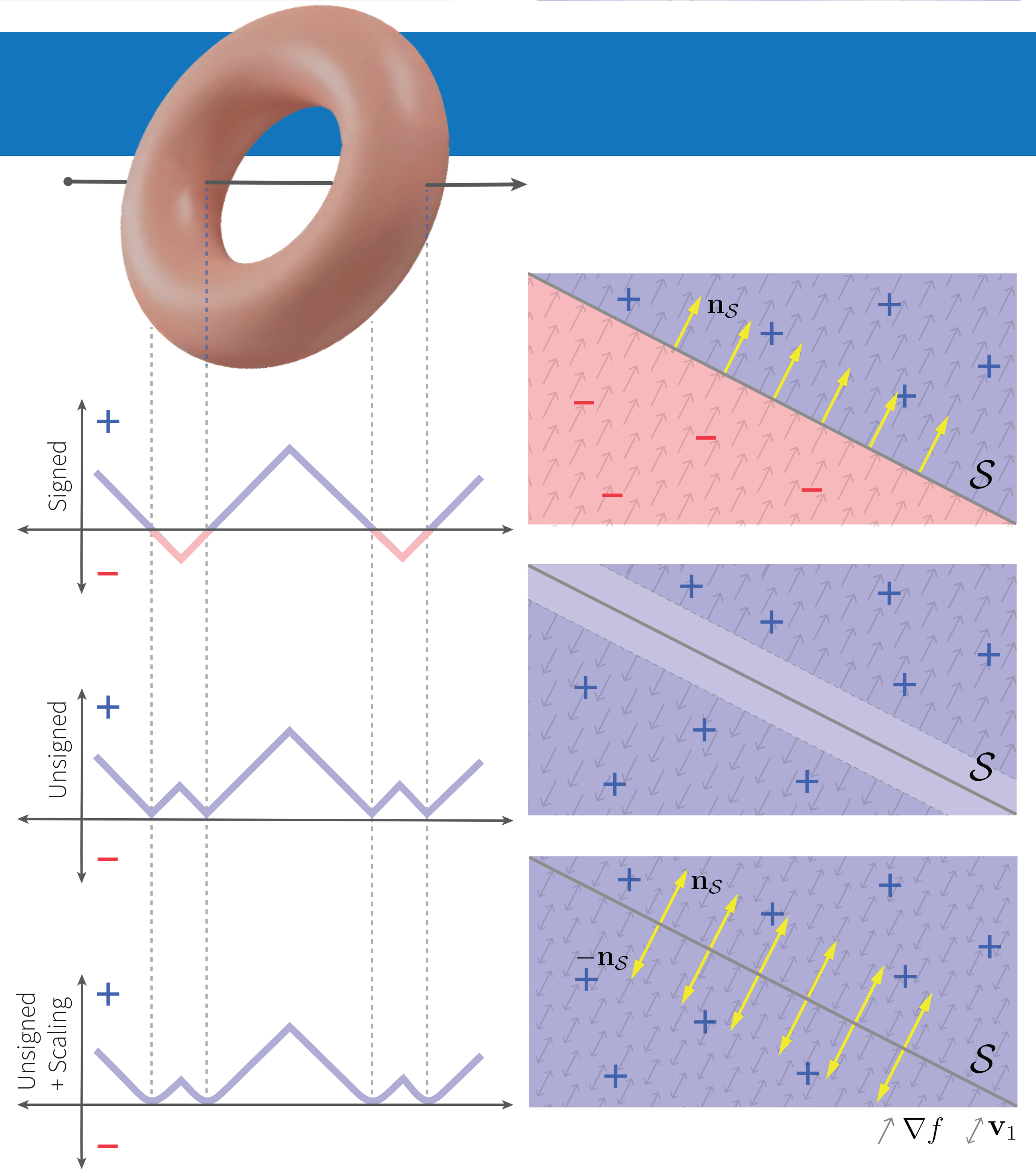
- Unsigned distance function $d_{\mathcal{S}}$ is not differentiable at the isosurface $\mathcal{S}$, hence it cannot be approximated with differentiable NNs.
- Instead, we approximate:

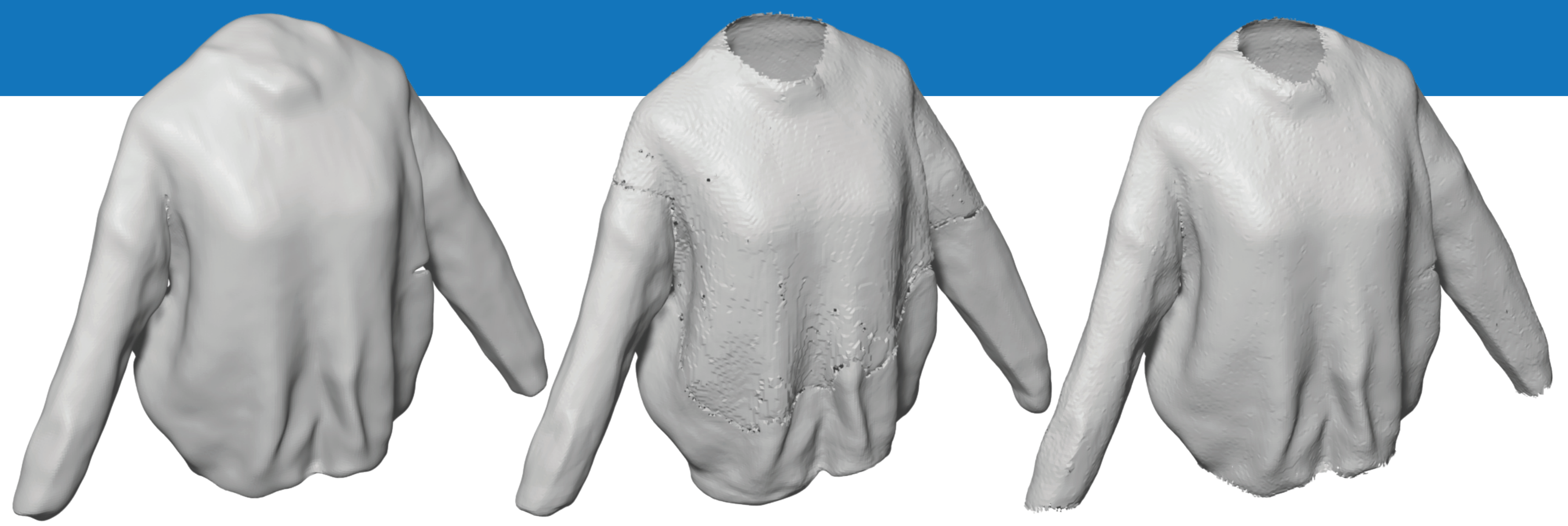
$$t_{\mathcal{S}}(\mathbf{x}) = d_{\mathcal{S}}(\mathbf{x}) \tanh(\alpha d_{\mathcal{S}}(\mathbf{x}))$$

which is solution of the **Eikonal** problem:

$$\begin{cases} \|\nabla f\| = \tanh(\alpha d_{\mathcal{S}}) + \alpha d_{\mathcal{S}}(1-\tanh^2(\alpha d_{\mathcal{S}})). \\ f|_{\mathcal{S}} = 0 \\ \nabla f|_{\mathcal{S}} = \mathbf{0} \\ \mathbf{v_1}(f|_{\mathcal{S}}) = \pm \mathbf{n}_{\mathcal{S}} \end{cases}$$

- We align the field's maximum principal curvature $\mathbf{v_1}$ with the surface normals $\mathbf{n}_{\mathcal{S}}$ for better reconstruction and computation of **topological properties** .





Conditioning

- We condition our differentiable neural networks to satisfy the Eikonal problem:

$$\mathcal{L} = \lambda_e \mathcal{L}_{\text{Eikonal}} + \lambda_d \mathcal{L}_{\text{Dirichlet}} + \lambda_n \mathcal{L}_{\text{Neumann}} + \lambda_g \mathcal{L}_{M\ \text{Curv}}$$

$$\mathcal{L}_{\text{Eikonal}} = \int_{\mathcal{C}} |\|\nabla f_\theta(\mathbf{x})\| - \phi(\mathbf{x})| d\mathbf{x} \qquad \mathcal{L}_{\text{Neumann}} = \int_{\mathcal{S}} \|\nabla f_\theta(\mathbf{x})\| d\mathbf{x}$$

$$\mathcal{L}_{\text{Dirichlet}} = \int_{\mathcal{S}} |f_\theta(\mathbf{x})| d\mathbf{x} \qquad \mathcal{L}_{MCurv} = \int_{\mathcal{S}} 1 - |\mathbf{v_1}(\mathbf{x}) \cdot \mathbf{n}_{\mathcal{S}}(\mathbf{x})| d\mathbf{x}$$

Curvatures

- From the computed normal field we can extract high order surface properties such as **mean and gaussian curvature** using automatic differentiation methods. Unaivalable with earlier methods.