Rethinking Directional Parameterization in Neural Implicit Surface Reconstruction

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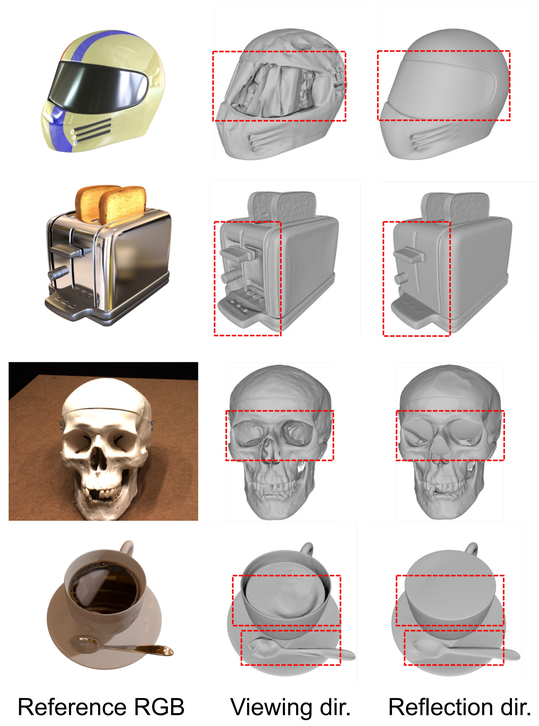
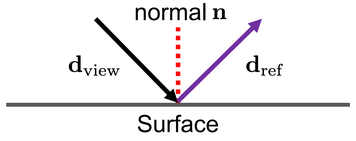
Motivation

Existing directional representations in neural implicit surface reconstruction methods will bias the reconstruction quality of different types of objects:

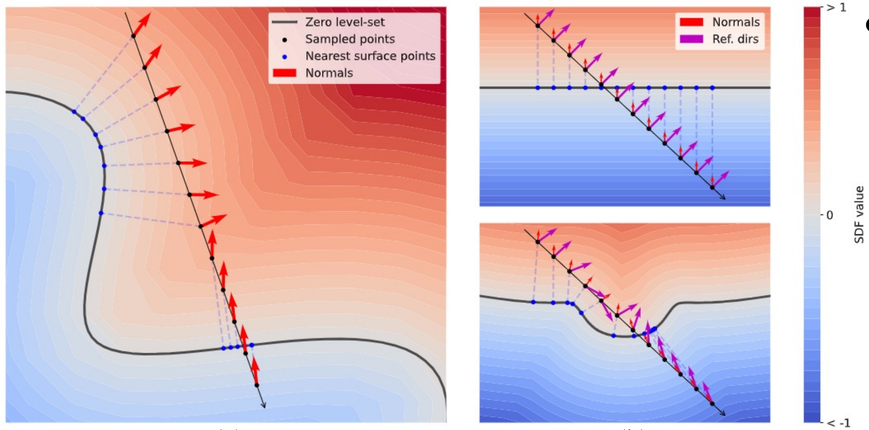


- Relationship between viewing direction and reflection direction:

$$\mathbf{d}_{\text{ref}} = 2(\mathbf{d}_{\text{view}} \cdot \mathbf{n})\mathbf{n} - \mathbf{d}_{\text{view}}$$



Analysis



Different from viewing direction, reflection direction 1) **depends on learnable geometry** (i.e., normals) and 2) **may vary significantly during the optimization**. These two factors lead to the following issues that exist during the optimization process:

(a) Wrongly associating the update of intersecting surface with unrelated surface.

(b) Introducing high-frequency variations to the input of the radiance network.

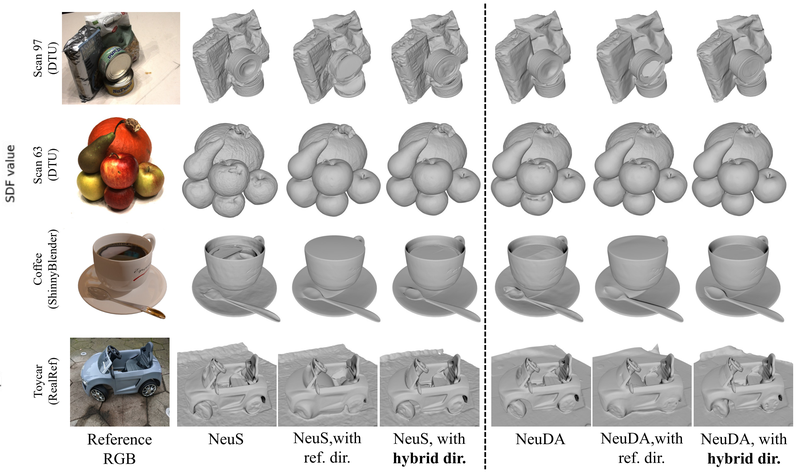
Our Solution

We notice that both issues are caused by using reflection direction at sampling points beyond a certain distance from the intersecting surface. Using viewing direction at these points can avoid these issues. Finally, we propose the **hybrid directional representation**:

$$\mathbf{d}_{\text{hyb}} = \text{normalize}(\alpha \cdot \mathbf{d}_{\text{ref}} + (1-\alpha) \cdot \mathbf{d}_{\text{view}})$$
$$\alpha = \exp(-\gamma \cdot \text{detach}(|f(\mathbf{x})|))$$

Experiments

- Qualitative results



- Quantitative results

Table 1: Results on DTU dataset

Methods	Scan of Diffuse Objects											Scan of Specular Objects					Total
	24	37	40	55	65	83	105	106	114	118	122	Avg.	63	69	97	110	Avg.	Avg.
NeuS [29]	0.83	0.98	0.56	**0.37**	**0.59**	**1.45**	0.78	0.52	0.36	**0.45**	**0.45**	**0.67**	1.13	**0.60**	0.95	1.43	1.03	0.77
NeuS, w/ reflection dir.	1.39	4.39	0.73	0.39	1.34	1.49	0.92	0.59	0.36	0.46	0.54	1.14	1.11	0.63	1.46	0.92	1.03	1.11
NeuS, w/ hybrid dir. (Ours)	**0.81**	**0.97**	**0.54**	0.38	0.61	1.47	**0.77**	**0.51**	**0.35**	**0.45**	0.47	**0.67**	**1.10**	**0.60**	**0.85**	**0.90**	**0.86**	**0.72**
NeuDA [2]	**0.51**	**0.76**	**0.39**	0.37	**0.56**	**1.37**	0.79	0.50	0.34	0.42	**0.46**	**0.59**	1.08	0.57	1.13	0.80	0.90	0.67
NeuDA, w/ reflection dir.	0.58	1.03	0.63	0.37	0.79	1.45	0.89	0.51	0.37	0.43	0.50	0.69	1.03	0.55	0.90	0.76	0.81	0.72
NeuDA, w/ hybrid dir. (Ours)	0.53	0.77	0.40	**0.36**	0.57	1.38	**0.76**	**0.47**	**0.33**	**0.41**	0.47	**0.59**	**1.02**	**0.54**	**0.76**	**0.75**	**0.77**	**0.63**

Table 2: Results on Shinny Blender dataset

Methods	helmet		toaster		coffee		car		Avg.	
	Acc. ↓	MAE ↓	Acc. ↓	MAE ↓	Acc. ↓	MAE ↓	Acc. ↓	MAE ↓	Acc. ↓	MAE ↓
NeuS [29]	4.88	3.20	3.31	2.85	1.97	1.06	0.86	0.95	2.76	2.02
NeuS, w/ reflection dir.	0.31	0.36	**0.39**	0.94	3.30	1.37	0.48	0.73	1.12	0.85
NeuS, w/ hybrid dir. (Ours)	**0.29**	**0.34**	0.45	**0.92**	**0.64**	**0.55**	**0.43**	**0.72**	**0.45**	**0.63**
NeuDA [2]	5.73	3.77	5.98	3.39	1.16	0.81	0.87	1.03	3.44	2.25
NeuDA, w/ reflection dir.	0.34	0.37	1.03	1.71	3.66	1.53	0.62	0.87	1.41	1.12
NeuDA, w/ hybrid dir. (Ours)	**0.32**	**0.36**	**0.95**	**1.54**	**0.55**	**0.57**	**0.60**	**0.84**	**0.61**	**0.83**