DANI-Net: Uncalibrated Photometric Stereo by **D**ifferentiable Shadow Handling, **A**nisotropic Reflectance Modeling, and **N**eural **I**nverse Rendering

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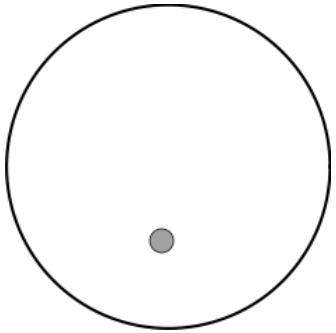
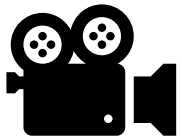
Overview



Directional Distant Light

Capturing

Observed Images



Orthographic Linear Camera

Observed Images

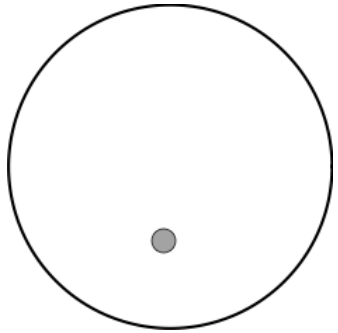
Neural Inverse Rendering

Surface Normal

Diffuse Reflectance

Specular Reflectance

Soft Shadow



Light Conditions

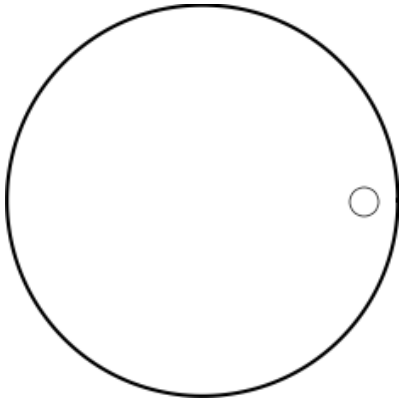
Overview

Relighting with realistic appearance given any light directions.

Relighting RGB

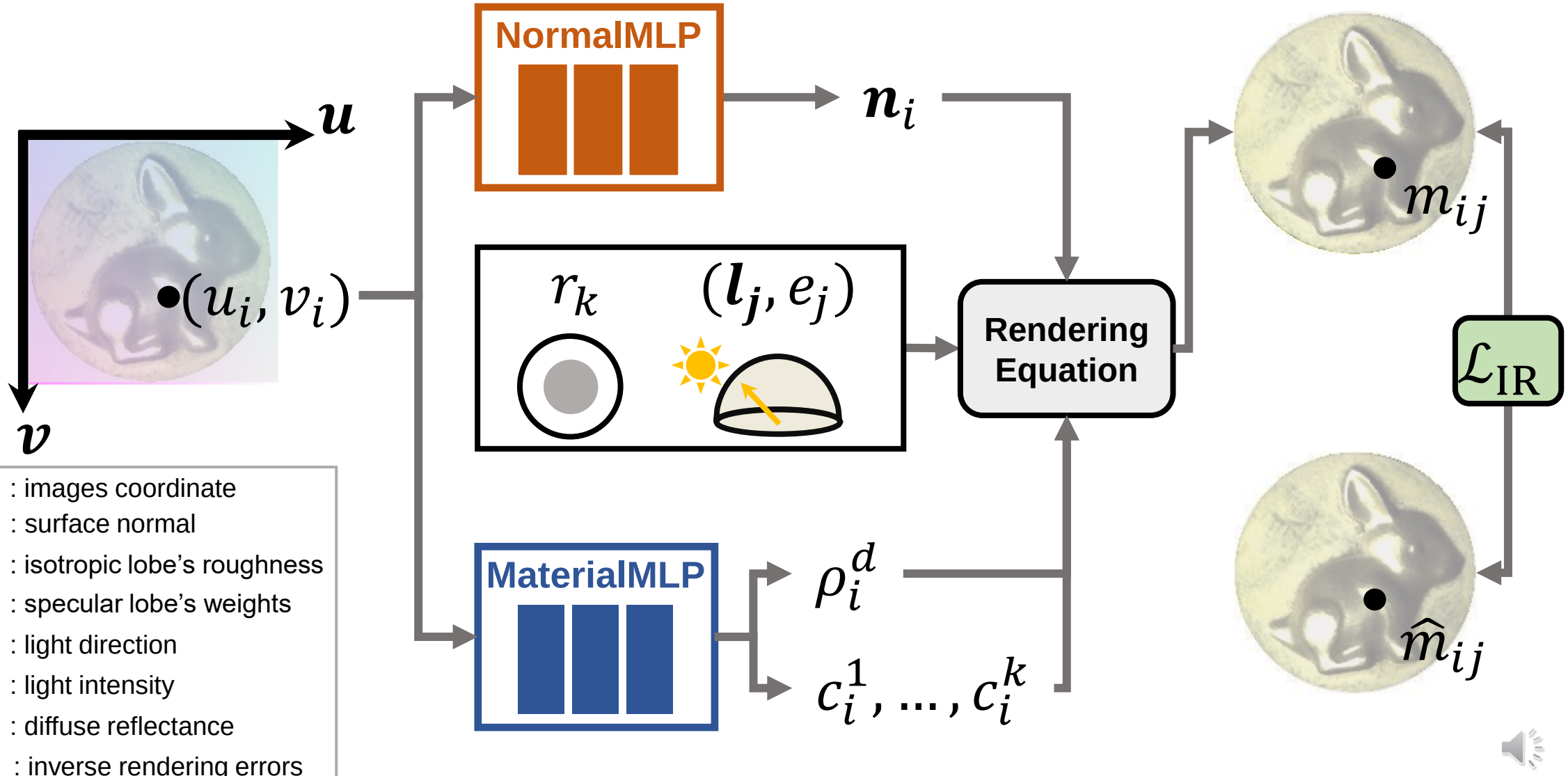
Soft Shadow

BRDF



Directional Light

Motivation

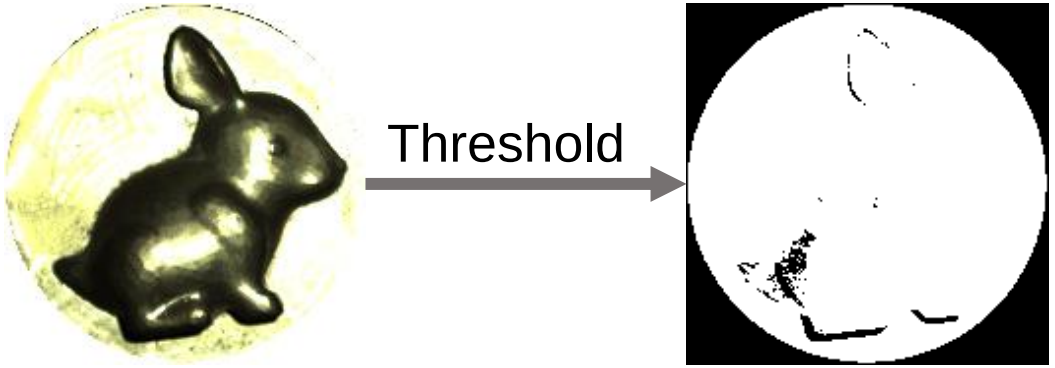


u, v	: images coordinate
$\boldsymbol{n}_{ij}$	: surface normal
r^k	: isotropic lobe's roughness
c_i^k	: specular lobe's weights
$\boldsymbol{l}_j$	: light direction
e_j	: light intensity
ρ_i^d	: diffuse reflectance
$\mathcal{L}_{\mathrm{IR}}$	: inverse rendering errors
m_{ij}	: rendered RGB
$\hat{m}_{ij}$	: observed RGB

[SCPS-NIR] Li et al. "Self-calibrating photometric stereo by neural inverse rendering". In Proc. European Conference on Computer Vision (ECCV), 2022.

Motivation

✗ Explicit Shadow Handling



Observed Images | **Pre-computed Shadow**

- Shadow maps are **noisy.**
- Shadow maps cannot be updated.
- Cues conveyed in the shadow are not exploited.

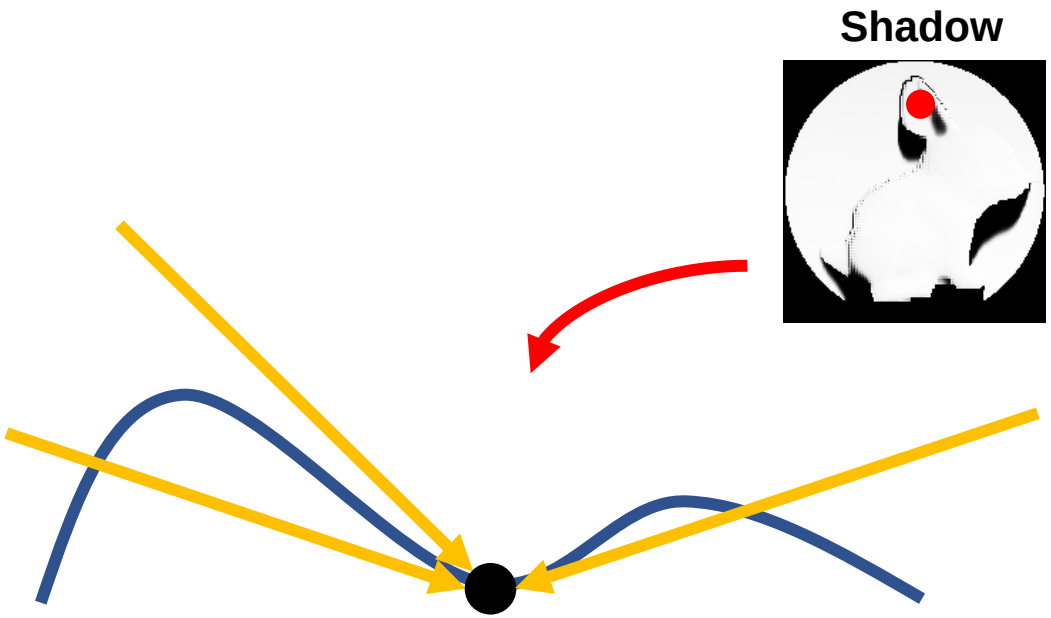
✗ Anisotropic Reflectance Modeling

Reference Image | **Relighting Image**

- The isotropic reflectance model cannot fit well on the **anisotropic** reflectance.

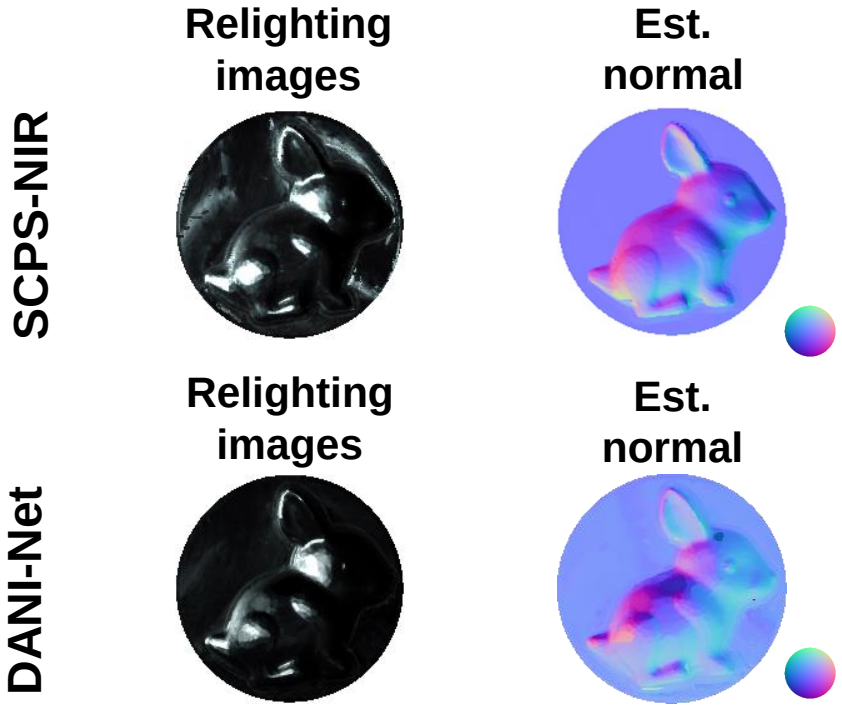
Motivation

Why shadow matters?



Shadow reveals **global shape-light** information (cues) that helps solve UPS.

Why reflectance matters?



Accurate reflectance model helps derive **accurate** surface normal.

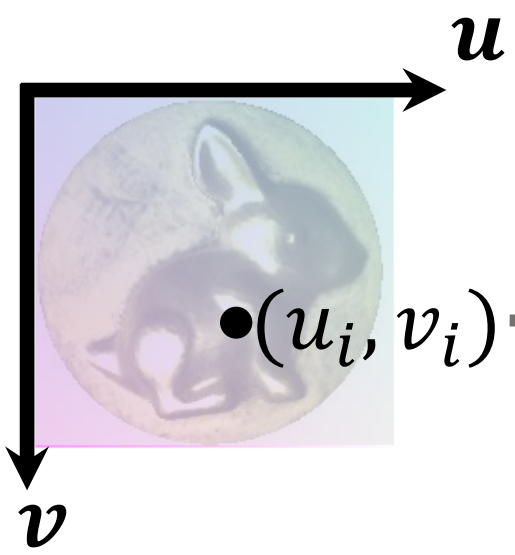
Method – Differentiable Shadow Handling

Goals

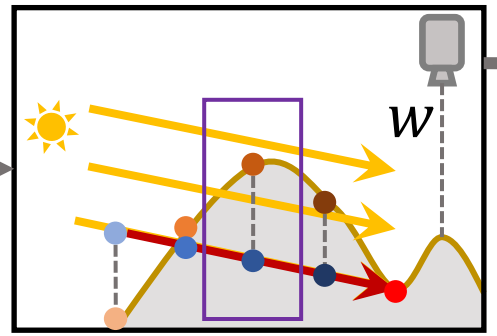
- ☑ Update the shadow map iteratively.
- ☑ Exploit shadow cues for shape-light optimization.

Challenges

- Shadow is calculated on depth map differentiably.
- The computational cost will increase.
- Depth to normal is necessary for inverse rendering.

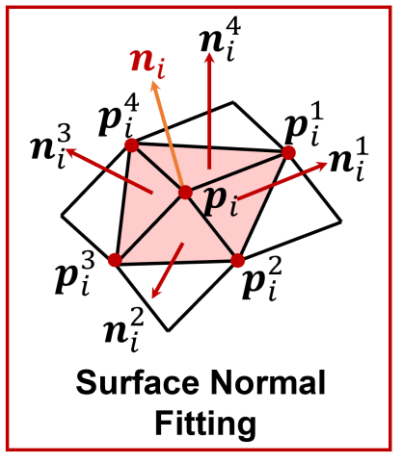


w_{ij}



$$min(w_{ij}^k - \hat{w}_{ij}^k)$$

$$\text{Sigmoid}(\alpha(\cdot) + \beta) \rightarrow s_{ij}$$



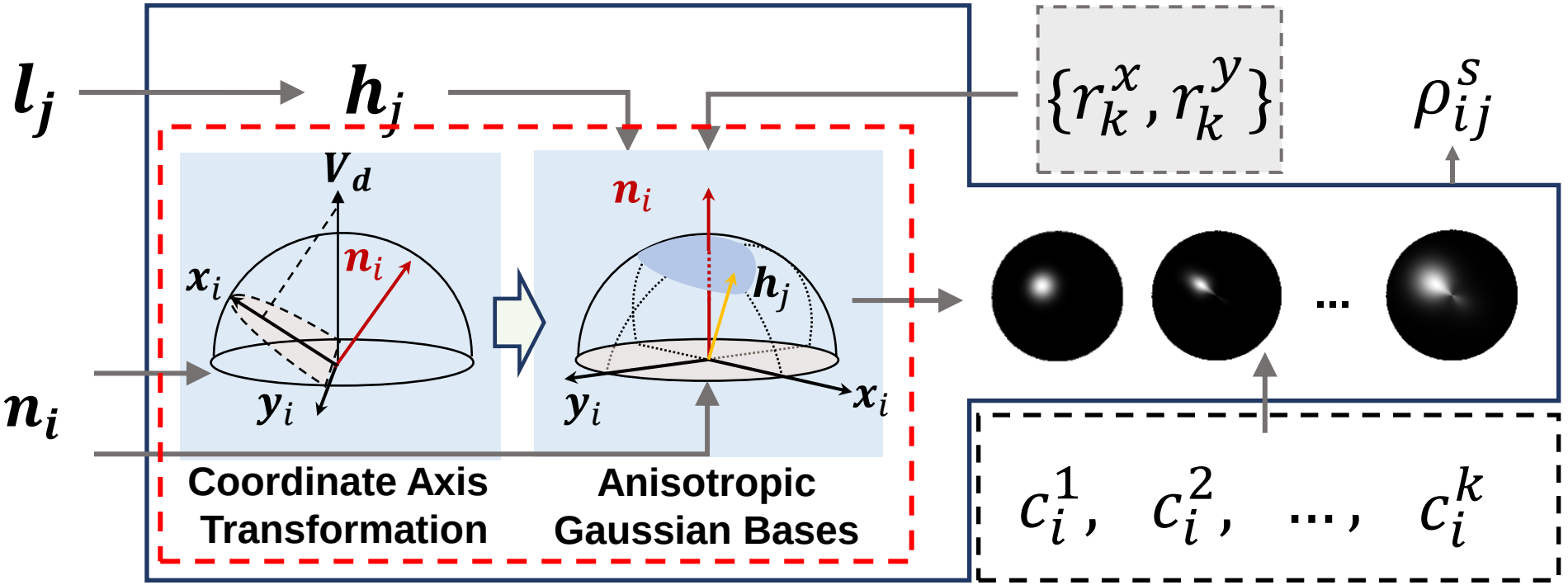
n_{ij}

- Edge preserving
- Efficient backpropagation

u, v	: images coordinate
w_i	: depth
l_j	: light direction
s_{ij}	: cast shadow
n_{ij}	: surface normal

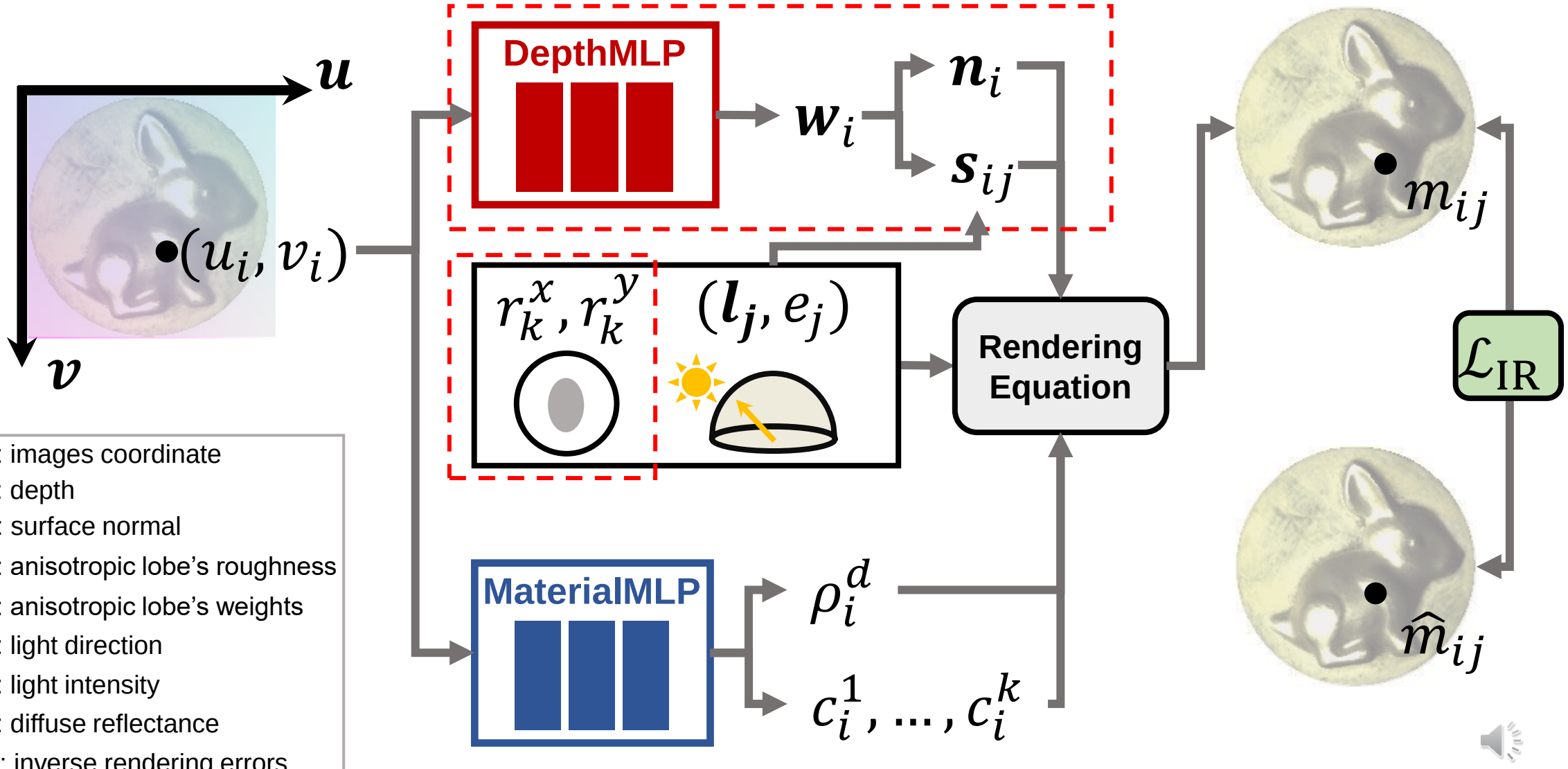
Bi-linear Grid Sampling

Method – Anisotropic Reflectance Modeling



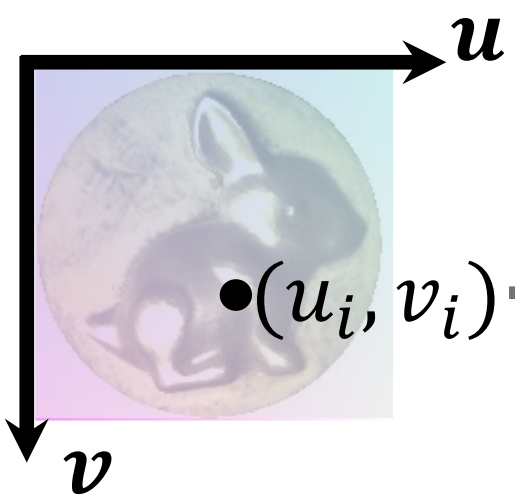
- n_j : surface normal
- l_j : light direction
- h_j : half-vector
- ρ_{ij}^s : anisotropic specular reflectance
- r_k^x, r_k^y: anisotropic lobe's roughness
- c^k : anisotropic bases weights

Method – Neural Inverse Rendering



u_i, v_i : images coordinate
w_i : depth
$\boldsymbol{n}_{ij}$: surface normal
r_k^x, r_k^y: anisotropic lobe's roughness
c_i^k : anisotropic lobe's weights
$\boldsymbol{l}_j$: light direction
e_j : light intensity
ρ_i^d : diffuse reflectance
$\mathcal{L}_{\mathrm{IR}}$: inverse rendering errors
m_{ij} : rendered RGB
$\hat{m}_{ij}$: observed RGB

Method – Optimizing DANI-Net



DepthMLP

w_i

n_i

s_{ij}

$\mathcal{L}_{\mathrm{Si}}$

r_k^x, r_k^y (l_j, e_j)

Rendering Equation

m_{ij}

$\mathcal{L}_{\mathrm{IR}}$

MaterialMLP

ρ_i^d

$c_i^1, \ldots, c_i^k$

$\hat{m}_{ij}$

u_i, v_i : images coordinate
w_i : depth
$\boldsymbol{n}_{ij}$: surface normal
r_k^x, r_k^y : anisotropic lobe's roughness
c_i^k : anisotropic lobe's weights
$\boldsymbol{l}_j$: light direction
e_j : light intensity
ρ_i^d : diffuse reflectance
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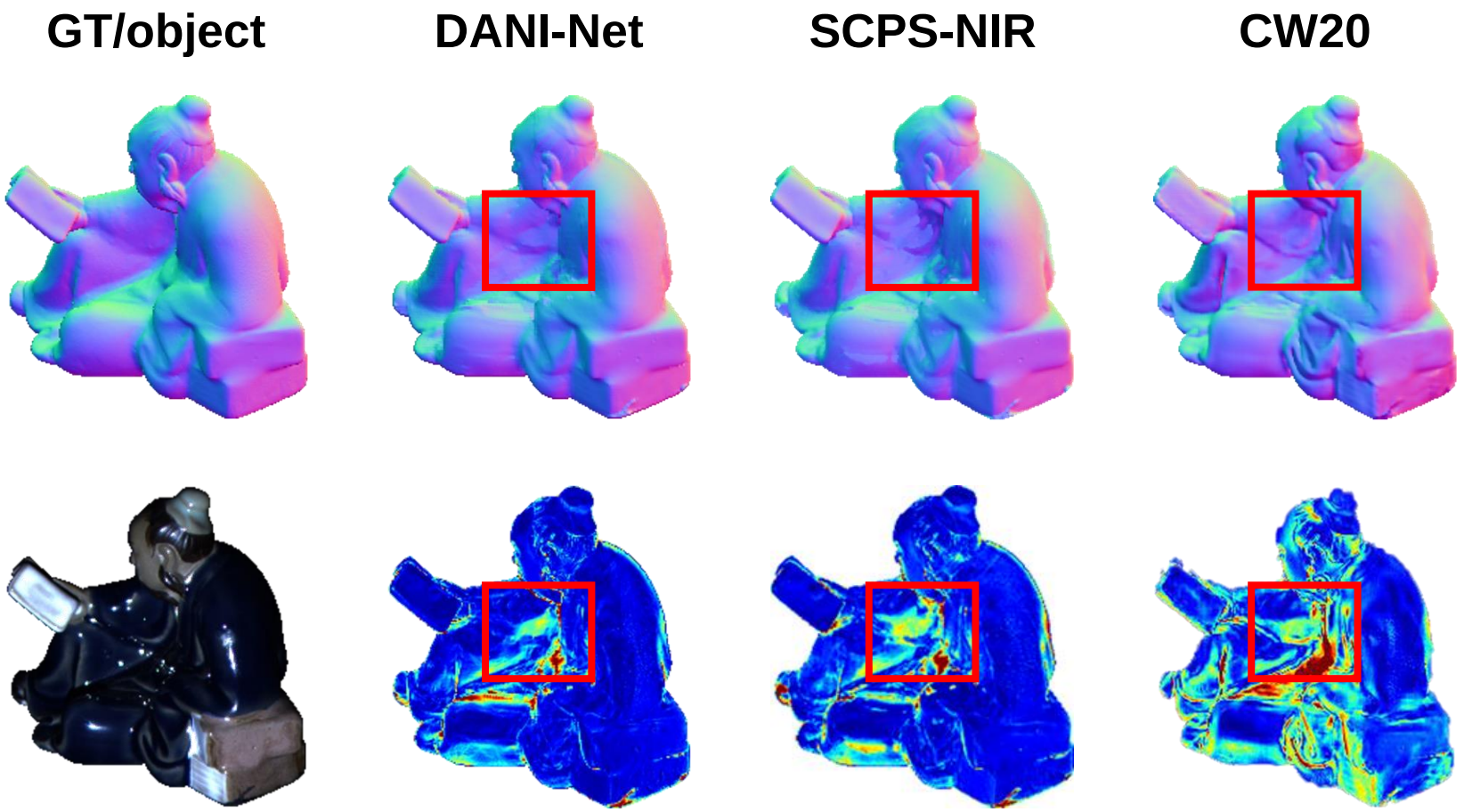
Total Variational Loss
Ep. 0 – 500 (n_i: Ep. 0 – 1500)

Silhouette Loss
Ep. 0 – 2000

L1 Loss
Ep. 0 – 2000

Results Comparison

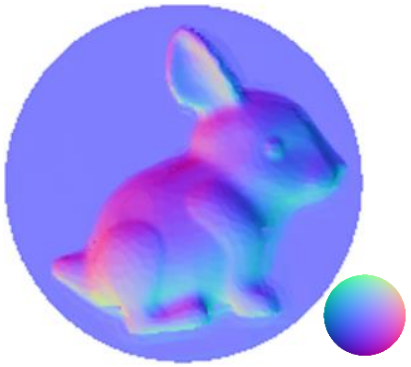


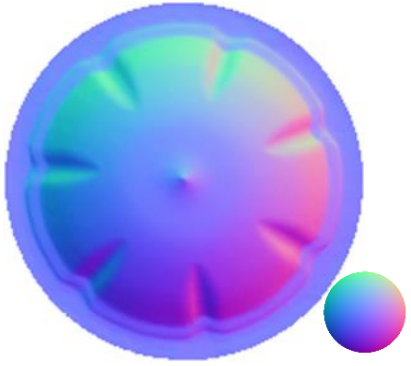
Results Comparison

Relighting Images

Est. normal

Est. shadow



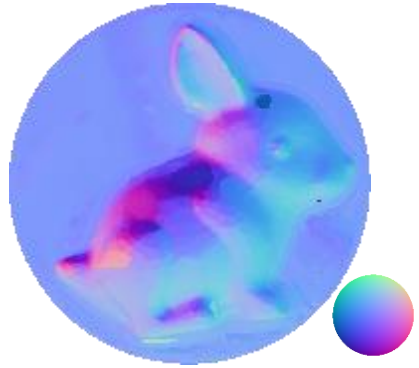


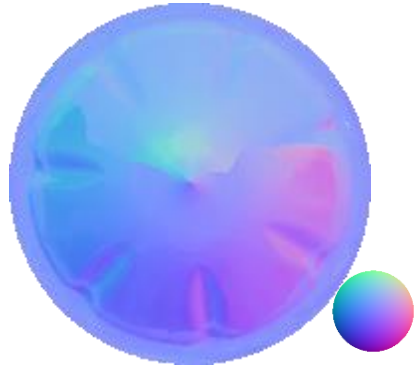
DANI-Net

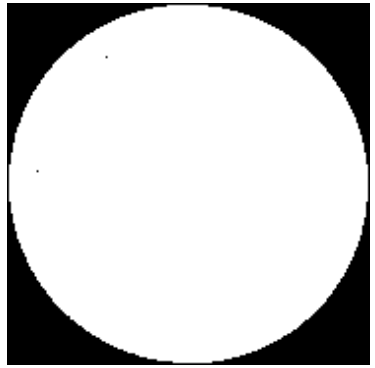
Relighting Images

Est. normal

Est. shadow

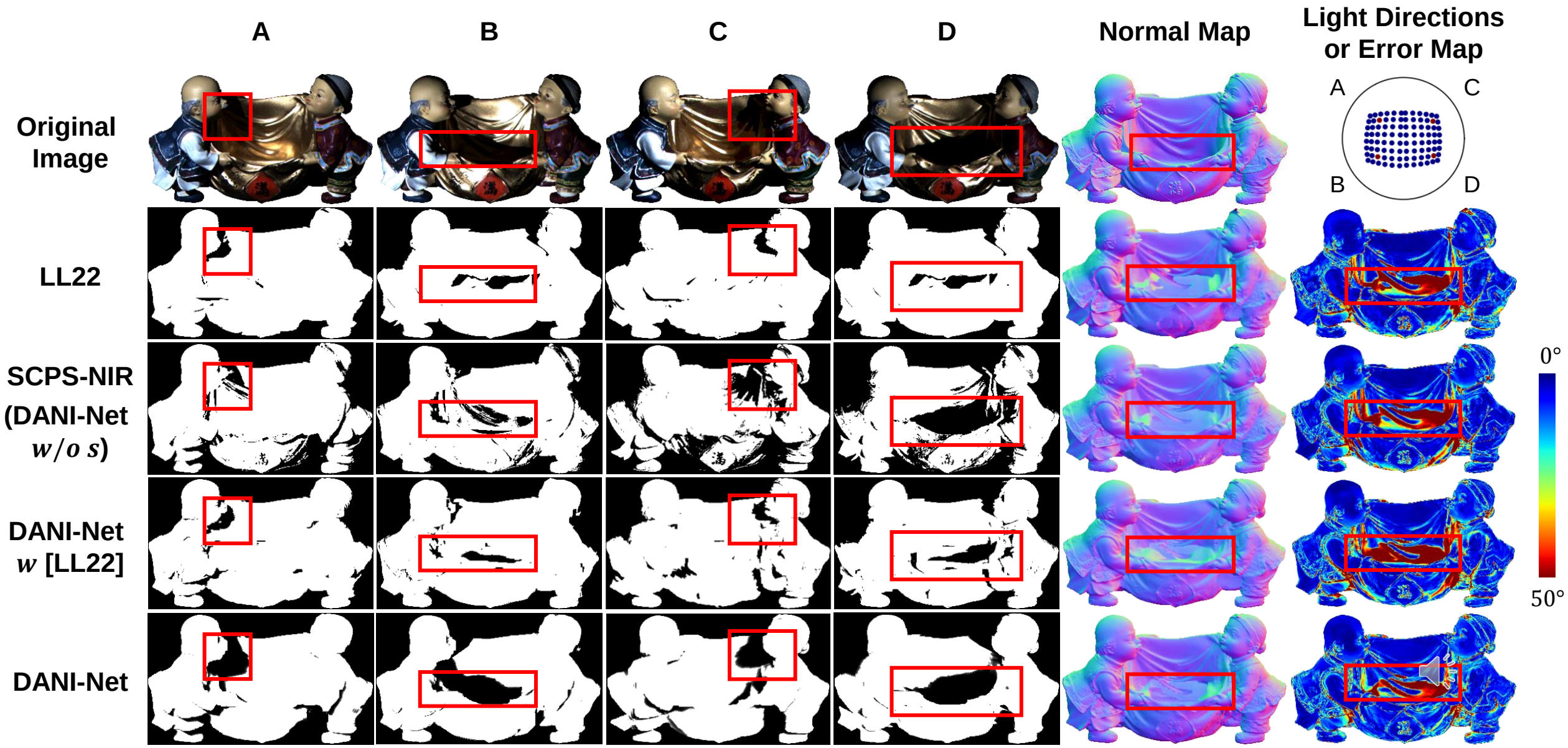






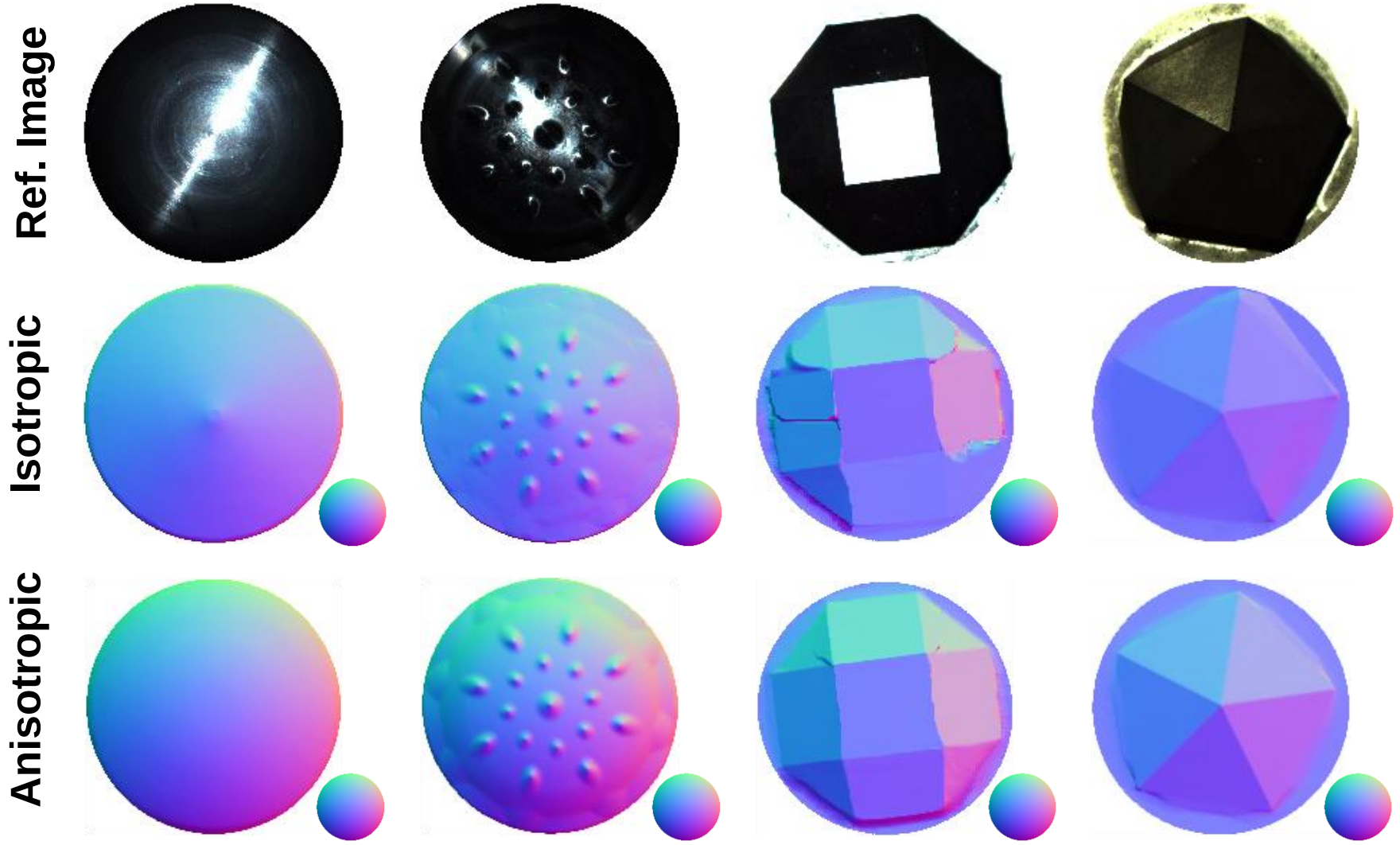
SCPS-NIR

Ablation Study on Shadow Map



[LL22] Junxuan Li and Hongdong Li. Neural reflectance for shape recovery with shadow handling. In Proc. Computer Vision and Pattern Recognition (CVPR), 2022.

Ablation Study on Anisotropic Reflectance Modeling



Conclusion

DANI-Net

Unsupervised Uncalibrated Photometric Stereo.

Differentiable Shadow Handling.

Anisotropic Reflectance Modeling.

Neural **I**nverse Rendering.

Realistic Rendering, Relighting.