北京航空航天大學 BEIHANG UNIVERSITY

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NeuFace: Realistic 3D Neural Face Rendering from Multi-view Images

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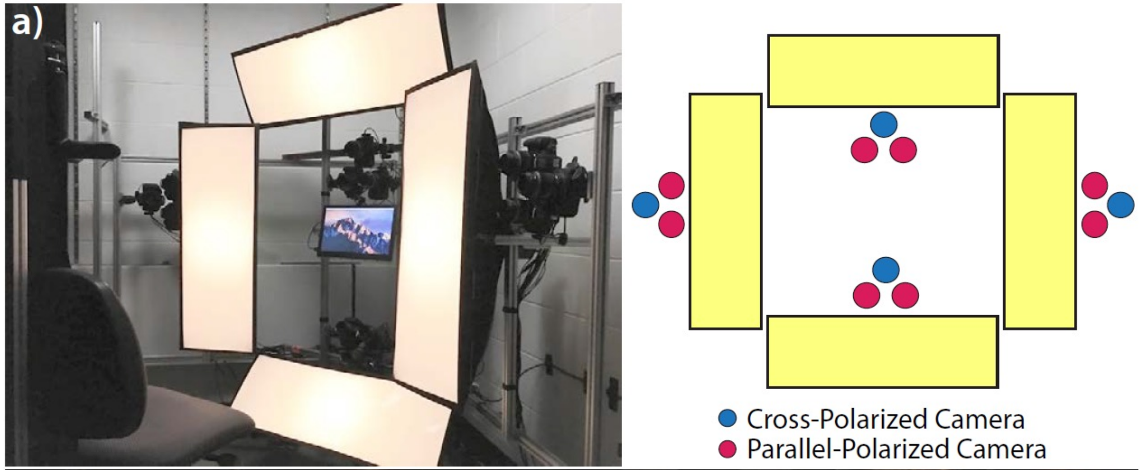
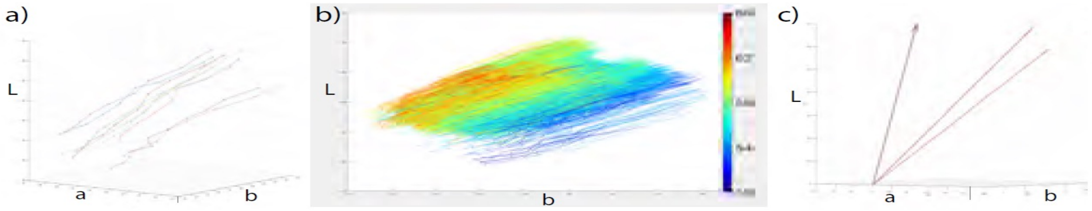
Rendered Geometry Diffuse Specular Relighting

Face Geometry & Appearance Capture

Active: OLAT/Multi-phased Light



Passive: Polarized Camera



Passive: Dynamic Blood Flow Input

NVIDIA. Realistic Digital Human Rendering with Omniverse RTX Renderer. SIGGRAPH 2021 Session.
Jérémy Riviere, et.al. Single-Shot High-Quality Facial Geometry and Skin Appearance Capture. TOG 2020.
Paulo Gotardo, et.al. Practical Dynamic Facial Appearance Modeling and Acquisition. TOG 2018.

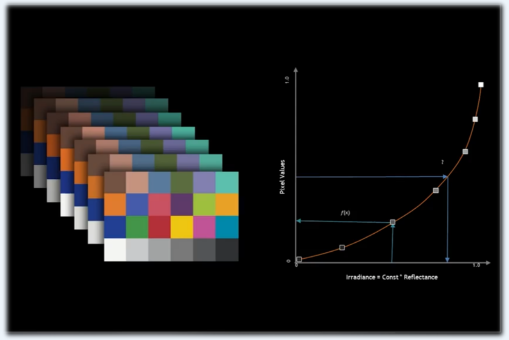
Face Geometry & Appearance Capture

DATA ACQUISITION

- ~8400 images with time-multiplexed, multi-phased polarized and constant illuminations
- ~180GB of data

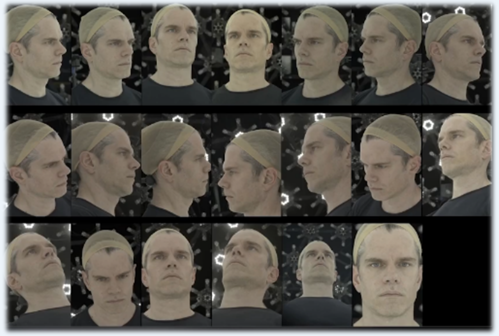
RADIOMETRIC CALIBRATION

- Recovering sensor response curve
- Calibrating color by capturing color chart with multiple illuminations



MULTI-VIEW RECONSTRUCTION

- Correspondence finding, depth fusion and surface reconstruction
- Mesh parameterization and texture projection



MATERIAL ESTIMATION

- Light estimation
- Decomposing reflectance by polarized images (or dynamic images)

➢ **An elaborately designed workflow:**

- Depending on the expertise of the engineers with significant manual efforts;
- The multi-step process inevitably brings diverse optimization goals.

NVIDIA. Realistic Digital Human Rendering with Omniverse RTX Renderer. SIGGRAPH 2021 Session.

Our Goal

- **Recovering facial geometry and appearance from multi-view images:**
  - Uncalibrated, unpolarized multi-view RGB images (~40)
  - Unknow illumination (but nearly white)
- **High-quality results with a simple and complete end-to-end workflow.**

Challenges

Complicated Material

- The multi-layered facial skin leads to complex view dependent and spatially-varying highlights.

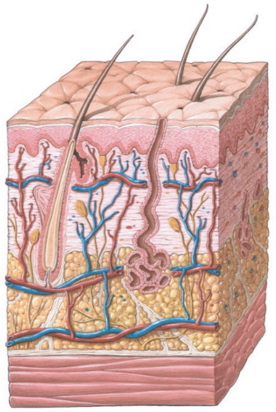
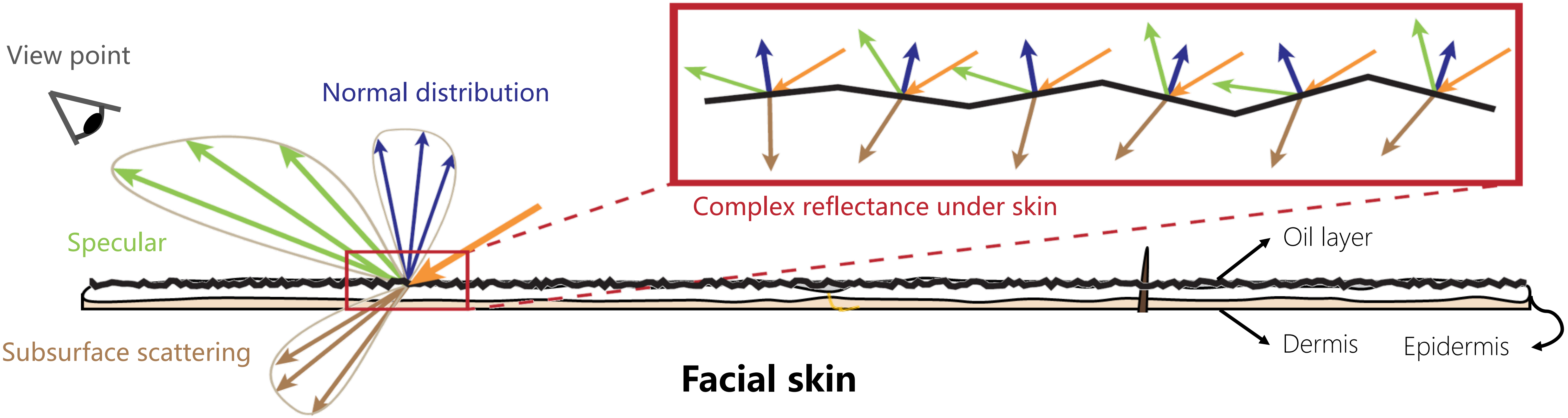


Image courtesy of A.D.A.M.



Challenges

Complicated Material

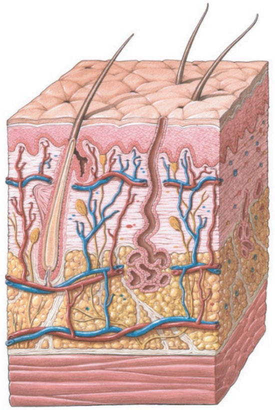
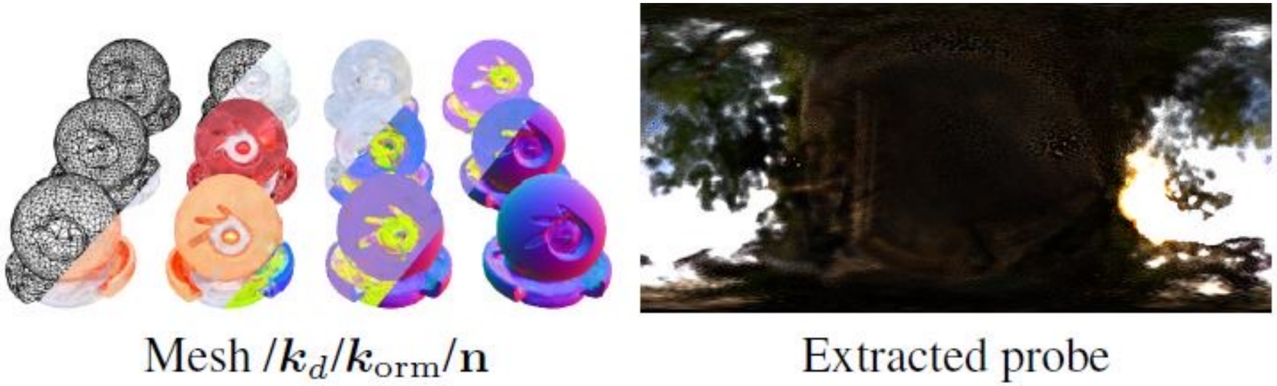


Image courtesy of A.D.A.M.

- The multi-layered facial skin leads to complex view dependent and spatially-varying highlights.
- The exploited physical priors are incapable of describing human face😔:
  - Physical priors: Phong[1], Torrance and Sparrow*, and Disney BRDF model[2]

[1]Ref-NeRF (CVPR 2022)



[2]DIFFREC (CVPR 2022)

Jacob Munkberg, et.al. Extracting triangular 3D models, materials, and lighting from images. CVPR 2022.
Dor Verbin, et.al. Ref-NeRF: Structured view-dependent appearance for neural radiance fields. CVPR 2022.

Challenges

Complicated Material

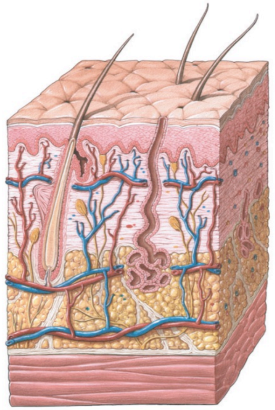
➢ The multi-layered facial skin leads to complex view dependent and spatially-varying highlights.

➢ The exploited physical priors are incapable of describing human face😔:

- Physical priors: Phong[1], Torrance and Sparrow*, and Disney BRDF model[2]

➢ Solving the rendering equation is computationally-expensive😔:

- Monte Carlo sampling is typically required.



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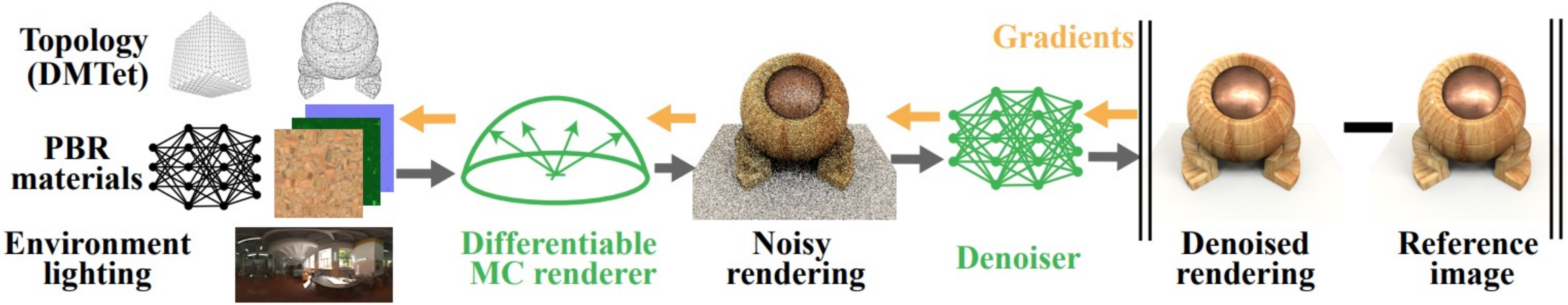
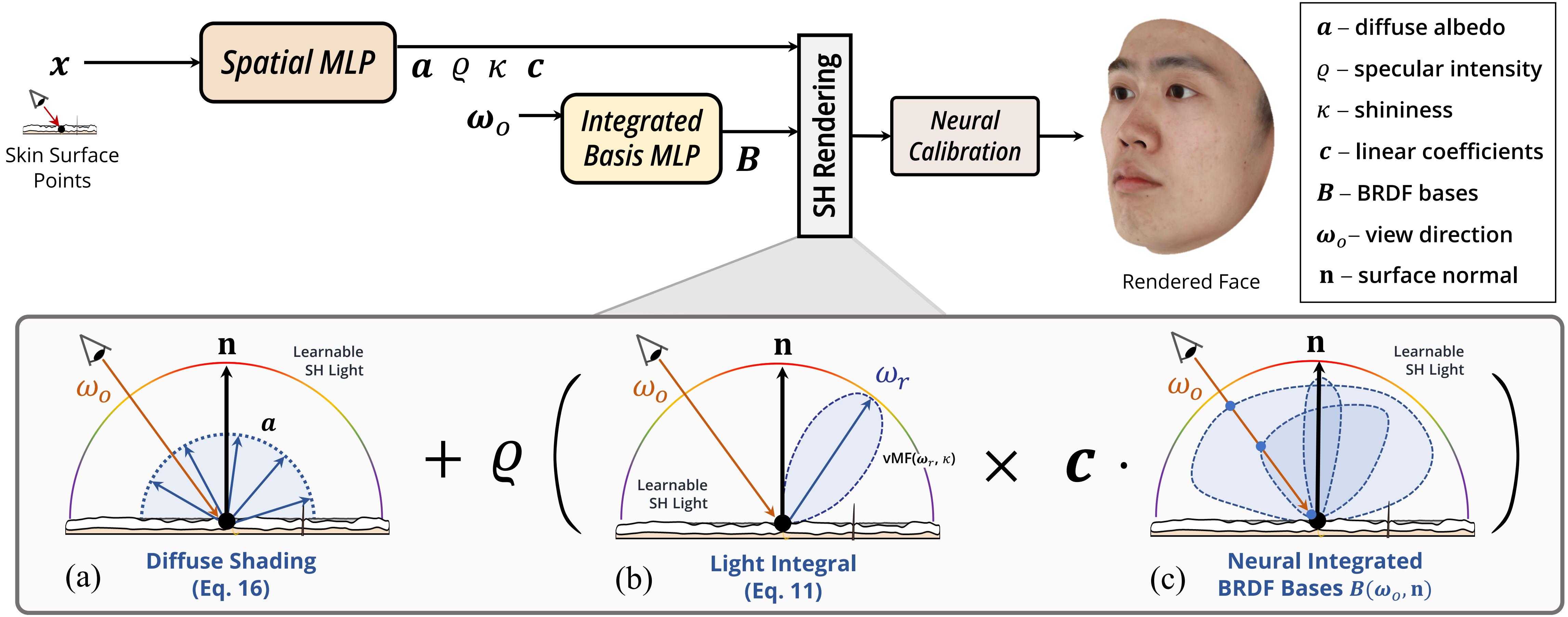


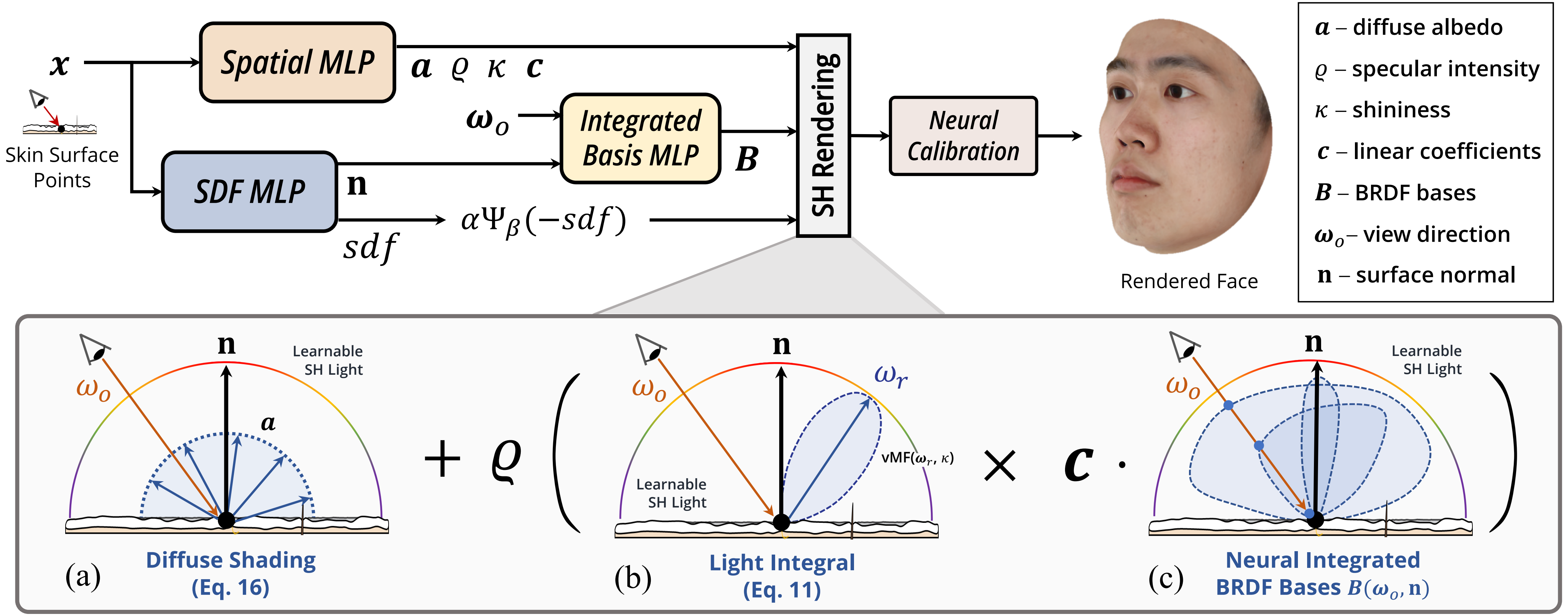
Jon Hasselgren, et. al. Shape, Light & Material Decomposition from Images using Monte Carlo Rendering and Denoising. NeurIPS 2022.

NeuFace Overview



$$L_o(x, \omega_o) = \int_\Omega f_\mathrm{d}(x, \omega_i, \omega_o) L_i(x, \omega_i)(\omega_i \cdot \mathbf{n}) \mathrm{d}\omega_i + \varrho \int_\Omega f_\mathrm{s}(x, \omega_i, \omega_o) L_i(x, \omega_i)(\omega_i \cdot \mathbf{n}) \mathrm{d}\omega_i$$

NeuFace Overview



$$L_o(x,\omega_o) = \frac{\alpha(x)}{\pi}\sum_{l=0}\sum_{m=-l}^{l} \Lambda_{lm} c_{lm} Y_{lm}(\mathbf{n}) + \varrho \cdot c(x) \cdot B(\omega_o, \mathrm{n}) \sum_{l=0}\sum_{m=-l}^{l} e^{-\frac{l(l+1)\rho}{2}} c_{lm}(x,\omega_o) Y_{lm}(\omega_r)$$

Method

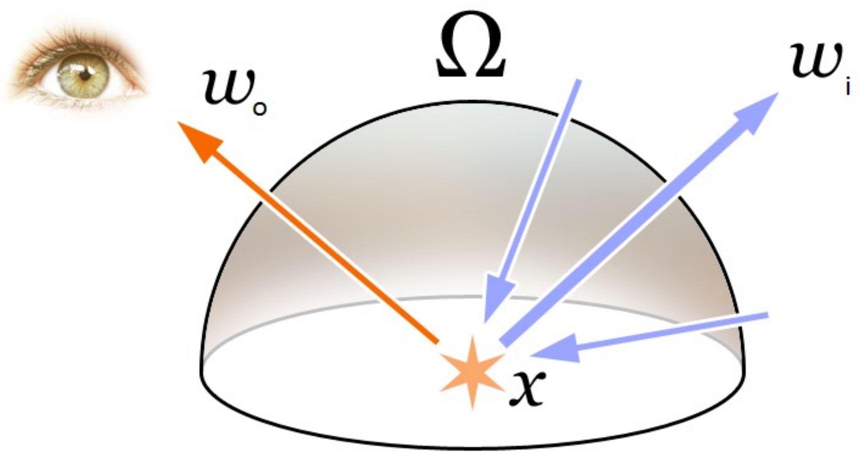
➢ **A novel physically-based neural rendering framework.**

Specular intensity ϱ

$$L_o(x,\omega_o) = \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i \cdot \mathbf{n})\mathrm{d}\omega_i + \varrho \int_\Omega f_\mathrm{s}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i \cdot \mathbf{n})\mathrm{d}\omega_i$$

Diffuse term L_d

Specular term L_s



Step 1. Split Integral

Specular intensity ϱ

$$L_o(x,\omega_o) = \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i + \varrho\int_\Omega f_\mathrm{s}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i$$

Diffuse term L_d

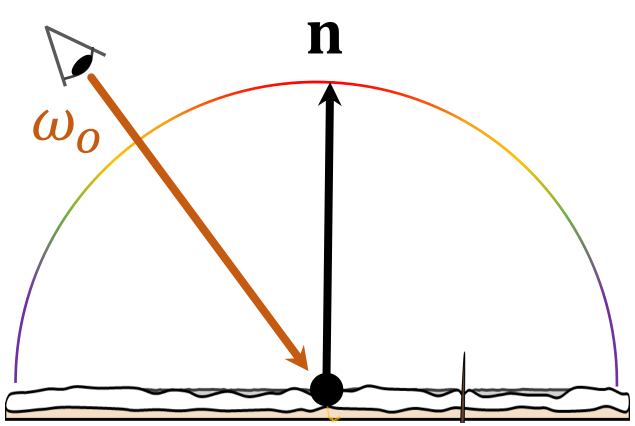
Specular term L_s

$$\int_\Omega f_s(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot \mathrm{n})d\omega_i$$

$$=\int_\Omega f_s(x,\omega_i,\omega_o)(\omega_i\cdot \mathrm{n})d\omega_i \int_\Omega D(h)L_i(x,\omega_i)d\omega_i$$

Material integral   Light integral

Split-sum approximation (from Unreal Engine)



Step 2. Material Integral

Specular intensity ϱ

$$L_o(x,\omega_o) = \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i + \varrho\int_\Omega f_\mathrm{s}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i$$

Diffuse term L_d

Specular term L_s

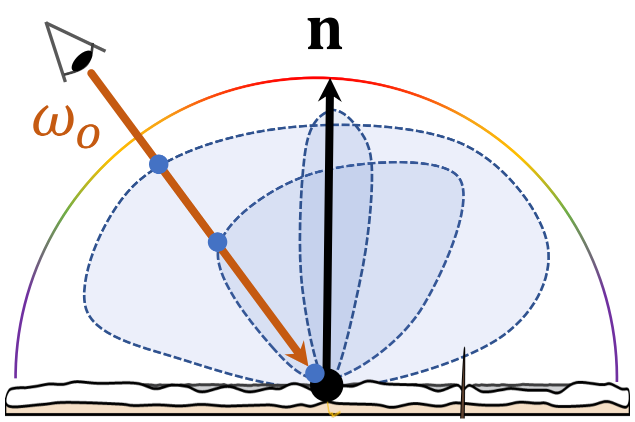
$$\int_\Omega f_s(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathrm{n})d\omega_i$$

$$=\int_\Omega f_s(x,\omega_i,\omega_o)(\omega_i\cdot\mathrm{n})d\omega_i\int_\Omega D(h)L_i(x,\omega_i)d\omega_i$$

Material integral Light integral

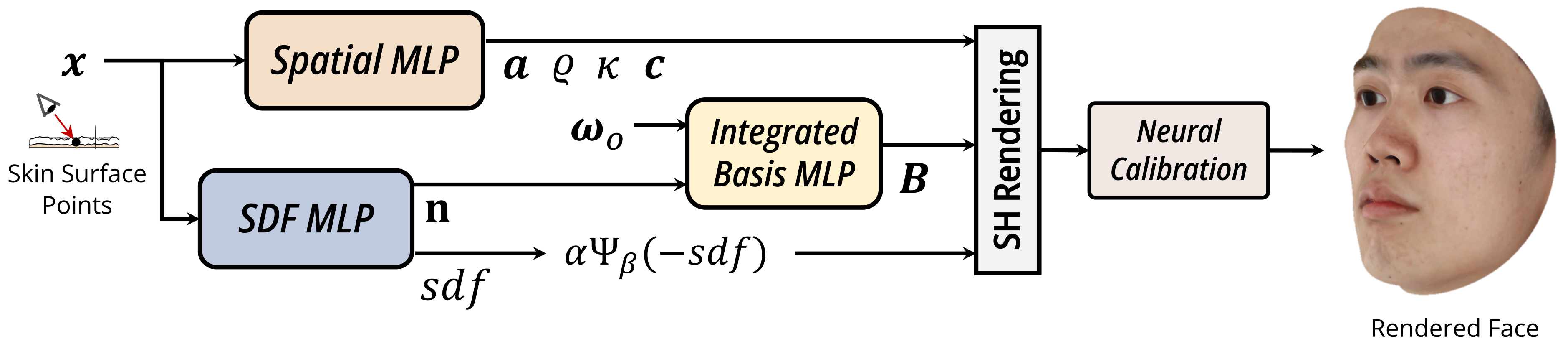
$$=\boldsymbol{c}(x)\cdot\boldsymbol{B}(\omega_i,\omega_o,\mathrm{n})\int_\Omega D(h)L_i(x,\omega_i)d\omega_i$$

A similar specular structure should be low-rank



Low-rank BRDF (rank 3)

Step 2. Material Integral



- $\boldsymbol{a}$ – diffuse albedo
- ϱ – specular intensity
- κ – shininess
- $\boldsymbol{c}$ – linear coefficients
- $\boldsymbol{B}$ – BRDF bases
- $\boldsymbol{\omega}_o$ – view direction
- $\mathbf{n}$ – surface normal

$$\int_\Omega f_s(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot \mathrm{n})d\omega_i$$

$$=\int_\Omega f_s(x,\omega_i,\omega_o)(\omega_i\cdot \mathrm{n})d\omega_i \int_\Omega D(h)L_i(x,\omega_i)d\omega_i$$

Material integral — Light integral

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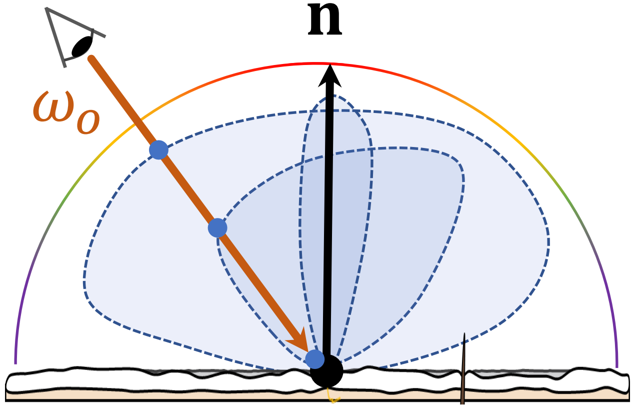

Low-rank BRDF (rank 3)

Step 3. Light Integral

Specular intensity ϱ

$$L_o(x,\omega_o) = \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i + \varrho\int_\Omega f_\mathrm{s}(x,\omega_i,\omega_o)L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i$$

Diffuse term L_d

Specular term L_s

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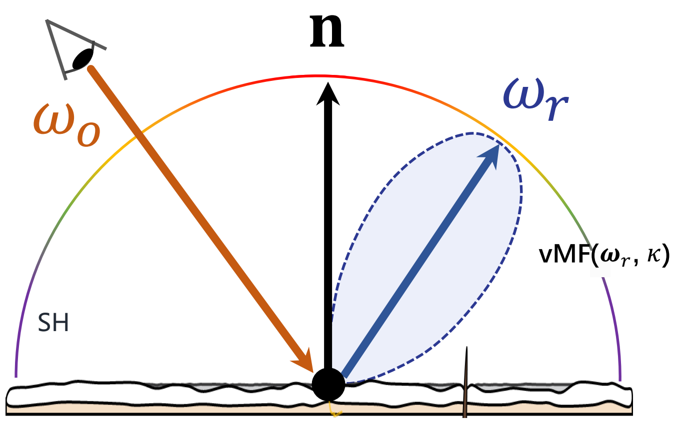
Material integral — Light integral

$$= \boldsymbol{c}(x)\cdot\boldsymbol{B}(\omega_i,\omega_o,\mathrm{n})\int_\Omega D(h)L_i(x,\omega_i)d\omega_i$$

$$= c(x)\cdot B(\omega_i,\omega_o,\mathrm{n})\sum_{l=0}^{l}\sum_{m=-l}^{l} e^{-\frac{l(l+1)\rho}{2}} c_{lm}(x,\omega_o)Y_{lm}(\omega_r)$$



Light Integral

Approximate the light term by properties of Spherical Harmonics

Step 4. Diffuse Modeling

Specular intensity ϱ

$$L_o(x,\omega_o) = \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i + \varrho\int_\Omega f_\mathrm{s}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i$$

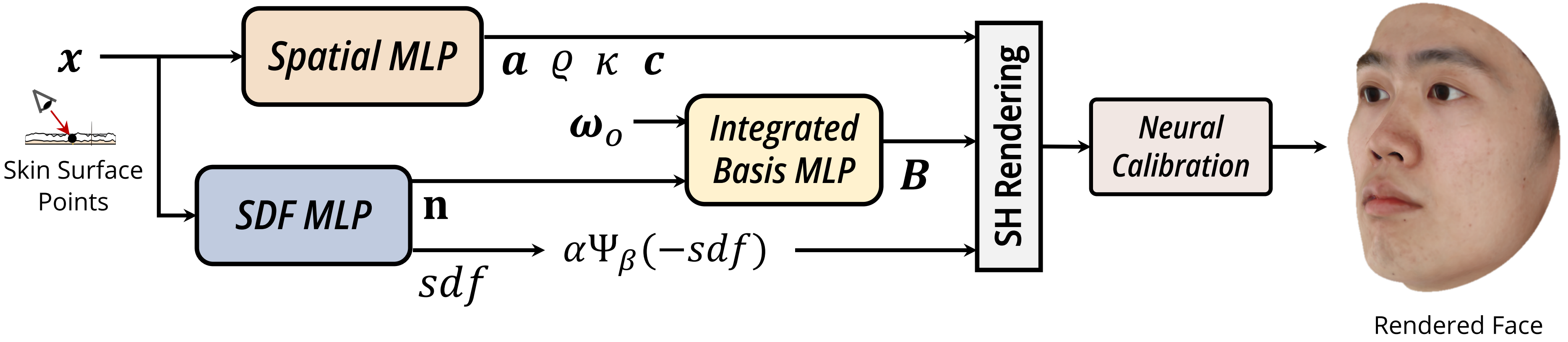
Diffuse term L_d — **Specular term L_s**

$$\begin{aligned}
L_\mathrm{d}(x,\omega_o) &= \int_\Omega f_\mathrm{d}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i \\
&= \frac{\alpha(x)}{\pi}\int_\Omega \sum_{l=0}\sum_{m=-l}^{l} c_{lm} Y_{lm}(\omega_i)\,(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i \\
&= \frac{\alpha(x)}{\pi}\sum_{l=0}\sum_{m=-l}^{l} c_{lm}\int_\Omega Y_{lm}(\omega_i)(\omega_i\cdot\mathbf{n})\mathrm{d}\omega_i \\
&= \frac{\alpha(x)}{\pi}\sum_{l=0}\sum_{m=-l}^{l} \Lambda_{lm} c_{lm} Y_{lm}(\mathbf{n})
\end{aligned}$$

$$\Lambda_{lm} = \begin{cases} \dfrac{2\pi}{3}, l = 1 \\ \dfrac{(-1)^{\frac{l}{2}+1}\pi}{2^{l-1}(l-1)(l+2)}\dbinom{l}{l/2}, l \text{ is even} \\ 0, l \text{ is odd} \end{cases}$$

Analytical solution of the diffuse term using the Funk-Hecke theorem

Step 4. Diffuse Modeling



- a – diffuse albedo
- ϱ – specular intensity
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$$L_{\mathrm{d}}(x,\omega_o) = \int_\Omega f_{\mathrm{d}}(x,\omega_i,\omega_o) L_i(x,\omega_i)(\omega_i \cdot \mathbf{n})\mathrm{d}\omega_i$$

$$= \frac{\alpha(x)}{\pi} \int_\Omega \sum_{l=0} \sum_{m=-l}^{l} c_{lm} Y_{lm}(\omega_i)\,(\omega_i \cdot \mathbf{n})\mathrm{d}\omega_i$$

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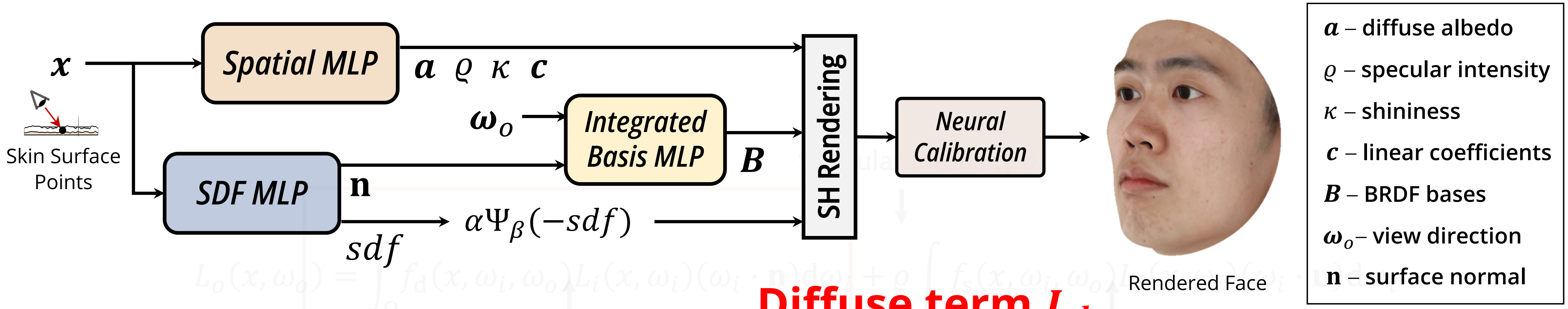

Diffuse term L_d

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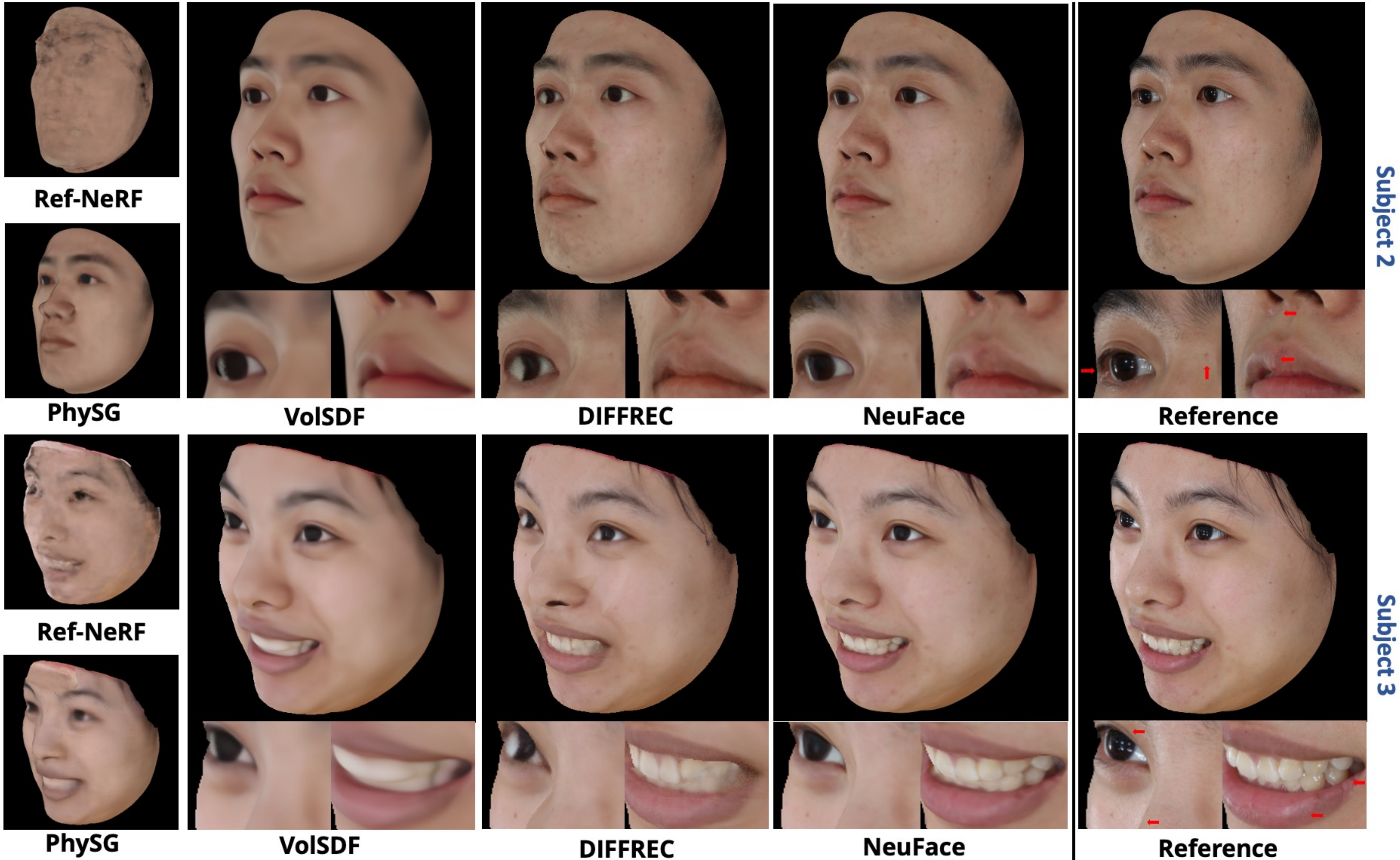
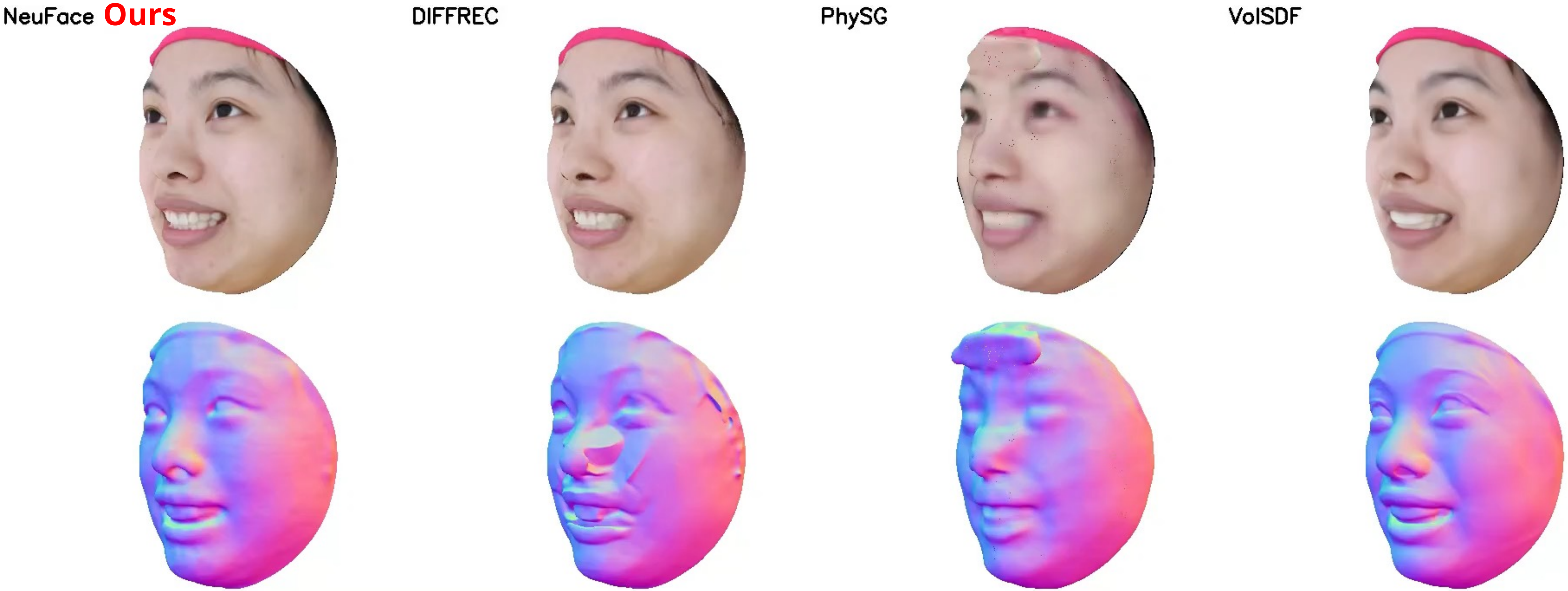
Specular term L_s

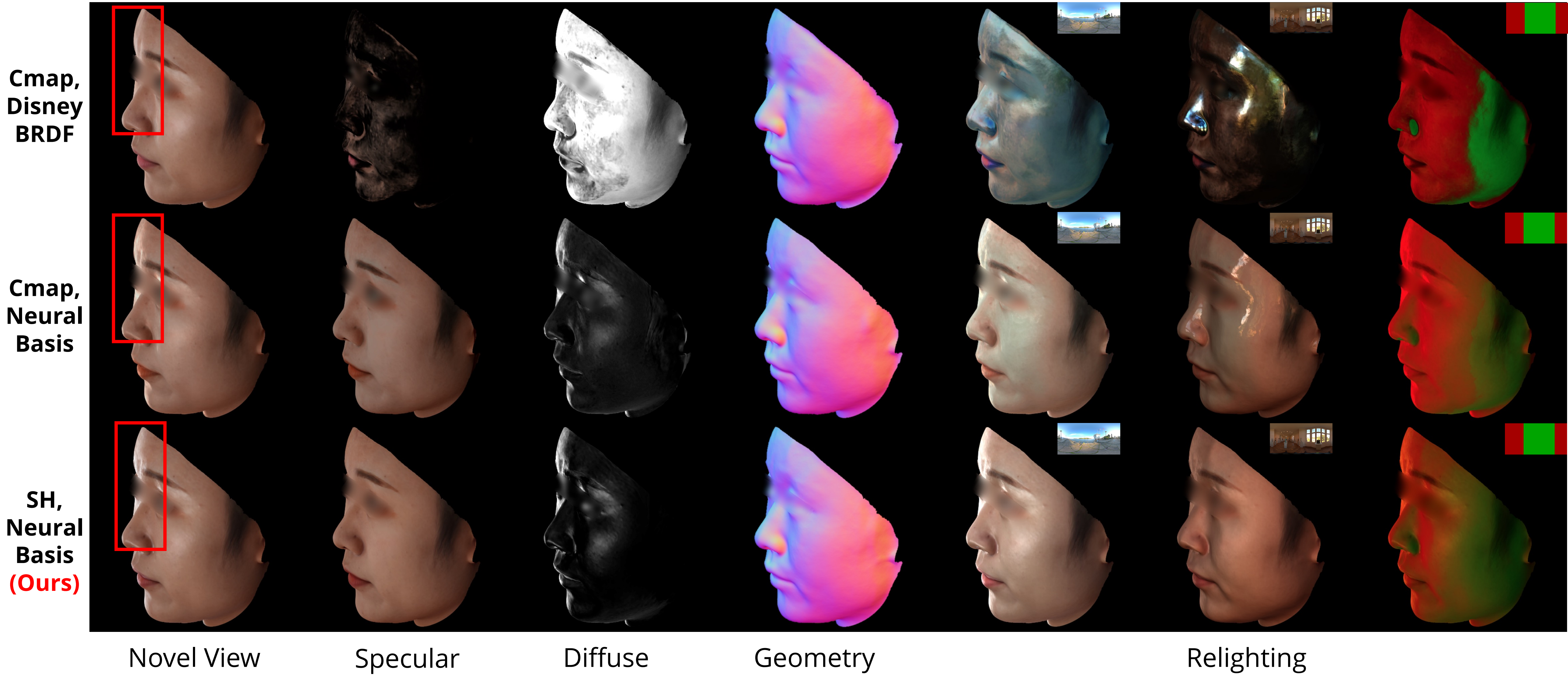
Comparison with Other Neural Rendering Methods



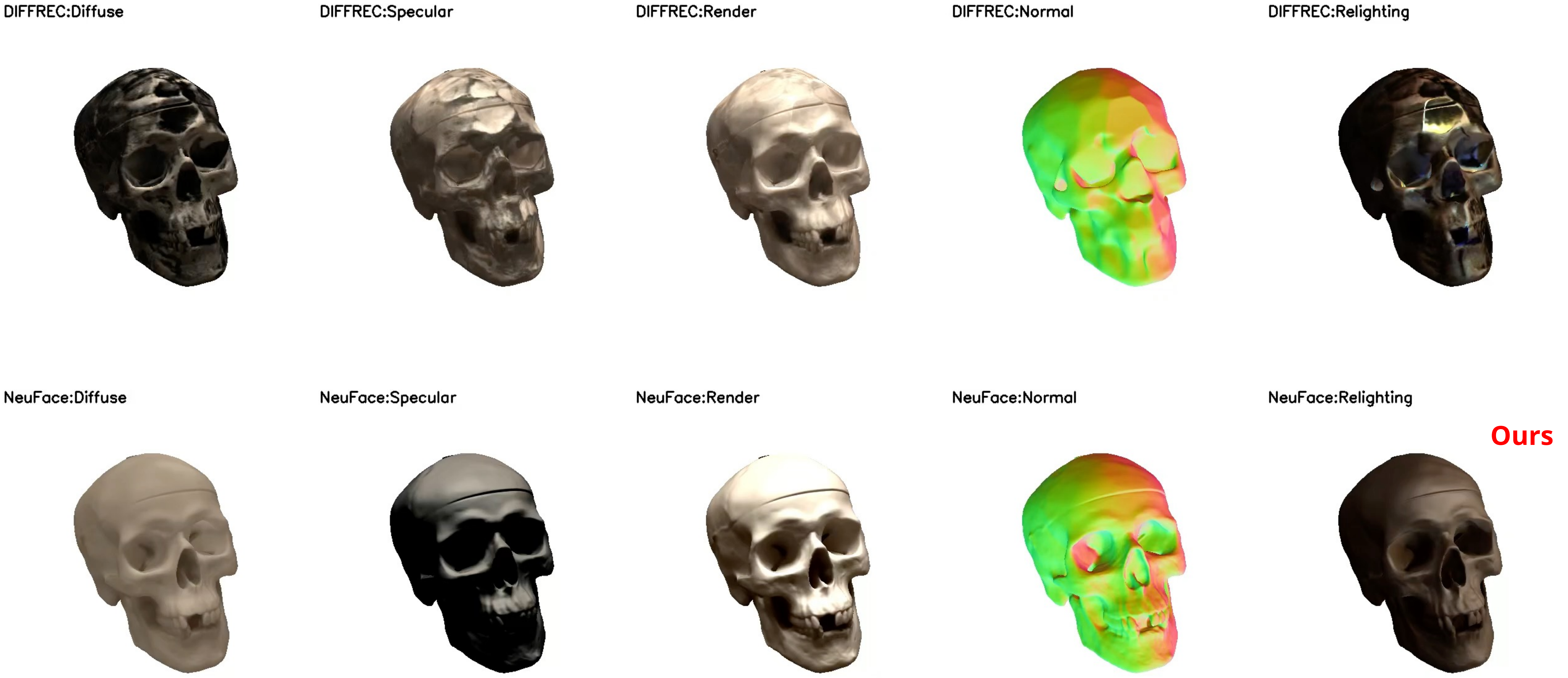
Comparison with Other Neural Rendering Methods



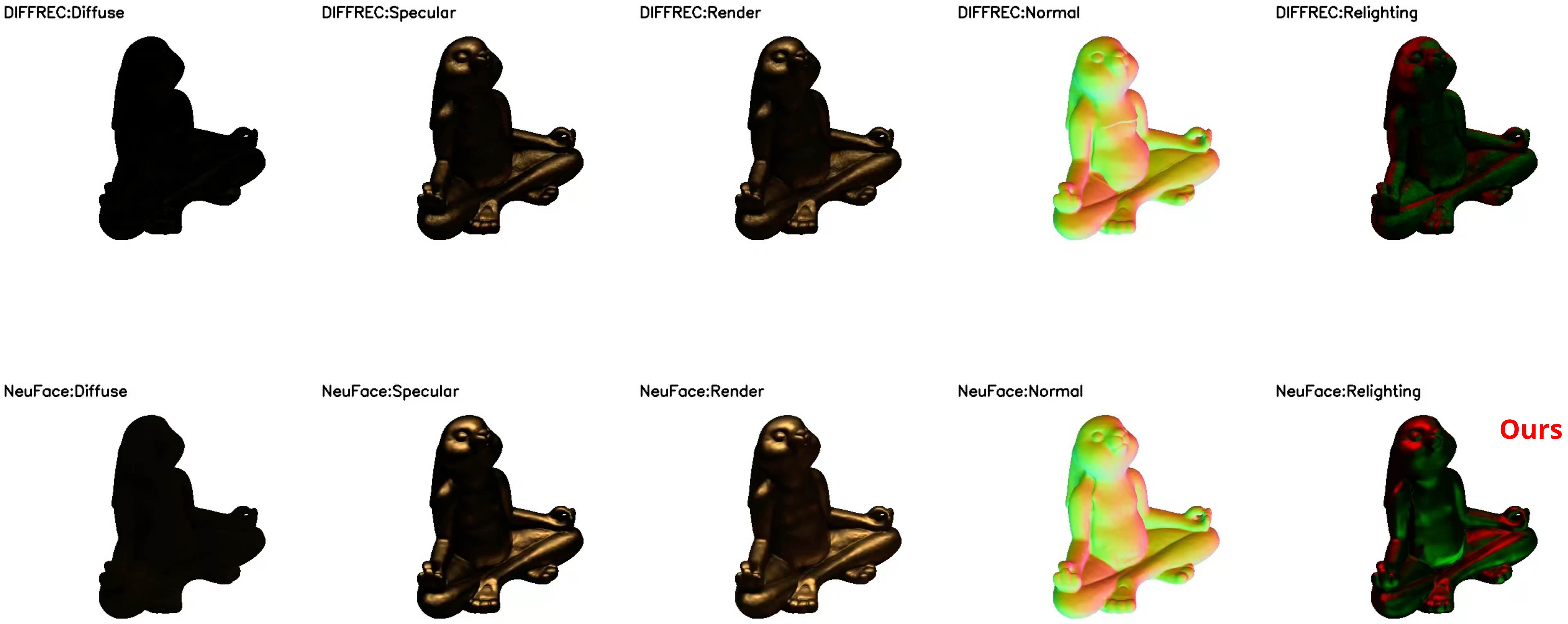
Ablation Study



Extension to Common Objects



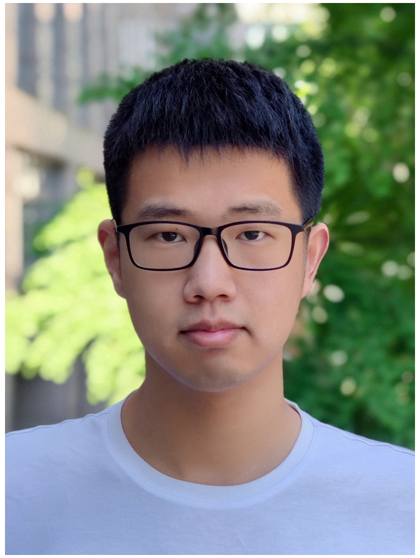
Extension to Common Objects



IRIP Laboratory
https://irip.buaa.edu.cn

Code and video are available at https://github.com/aejion/NeuFace.

Thank you !



Mingwu Zheng

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