Recovering Real-world Reflectance Properties and Shading from HDR Imagery

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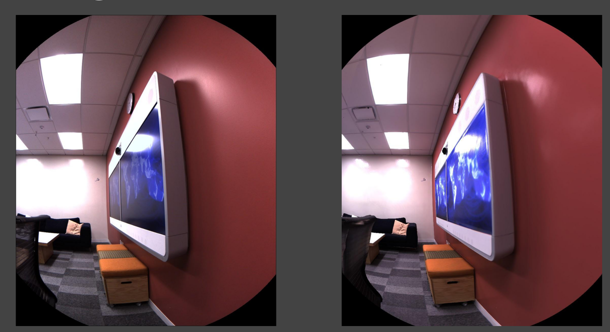
Introduction

- Estimate material parameters for each object in large scale scenes

➢ Enables faithful reconstructions
➢ Plausible scene relighting
➢ Visually accurate rendering of virtual objects



Camera Capture Proposed

Rendering Equation and BRDF Model

Rendering equation:

$$I(p) = L_o(x, \omega_o) = \int_{\mathcal{H}^2} f_r(x, \omega, \omega_o) L(x, \omega) \langle \omega, n \rangle \, \mathrm{d}\omega$$

Split BRDF into diffuse (albedo) and non-diffuse (specular appearance) part:

$$f_r(x, \omega, \omega_o) = f_\mathrm{d}(x) + f_\mathrm{nd}(x, \omega, \omega_o)$$

$$f_\mathrm{d}(x; \rho) = \rho(x) \quad \text{(Diffuse/Albedo)}$$

$$f_\mathrm{nd}(x, \omega, \omega_o; \varphi, \psi) = G(\varphi) D(\varphi) F(\psi) \quad \text{(Non-Diffuse)}$$

Plug into rendering equation:

$$L_o(x, \omega_o) = L_\mathrm{d}(x) + L_\mathrm{nd}(x, \omega_o)$$

$$L_\mathrm{d}(x) := \rho(x) \int_{\mathcal{H}^2} L(x, \omega) \langle \omega, n \rangle \, \mathrm{d}\omega$$

$$L_\mathrm{nd}(x, \omega_o) := \int_{\mathcal{H}^2} f_\mathrm{nd}(x, \omega, \omega_o; \varphi, \psi) L(x, \omega) \langle \omega, n \rangle \, \mathrm{d}\omega$$

Lit Diffuse HDR Texture

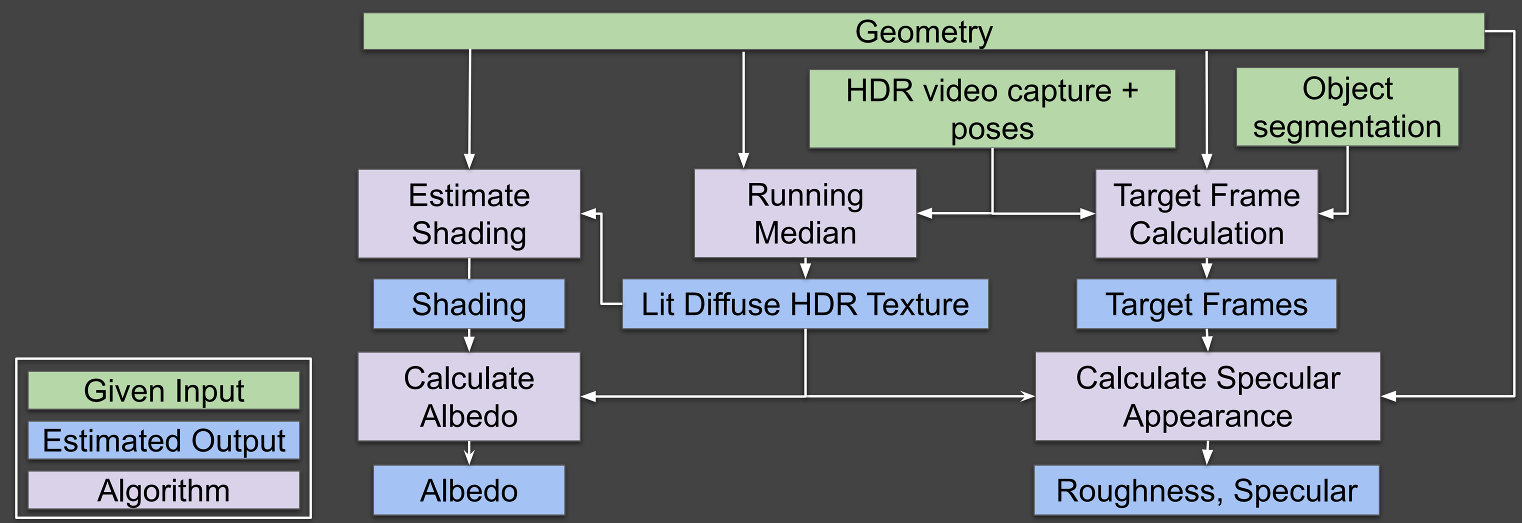
- Running mean on HDR 16-bit data has artifacts
- Use running median instead of mean
- Assume median texture equals diffuse radiance L_d

$\Longrightarrow$ Median texture = L_d = Lit diffuse HDR texture

Running Mean

Running Median

Algorithm



Albedo and Shading Estimation

- First estimate shading, then solve for albedo in closed form:

$$\overbrace{L_\mathrm{d}(x)}^{\text{Median Texture}} = \overbrace{S(x)}^{\text{Shading}} \cdot \overbrace{\rho(x)}^{\text{Albedo}} \Longrightarrow \rho(x) = \frac{L_\mathrm{d}(x)}{S(x)}$$

$$S(x) = \int_{\mathcal{H}^2} L(x, \omega) \langle \omega, n \rangle \, \mathrm{d}\omega \approx \sum_{i=1}^{N} L(x, \omega_i) \langle \omega_i, n \rangle$$

- Cast N rays $(x, \omega_i), i = 1, \dots, N$, at each point $x \in \mathbb{R}^3$ in direction $\omega_i \in \mathcal{H}^2$
- At each rays hitpoint $\tilde{x}_i \in \mathbb{R}^3$: $L(x, \omega_i) = L_\mathrm{d}(\tilde{x}_i)$

L_d Shading ($N = 100$) Shading ($N = 10000$)

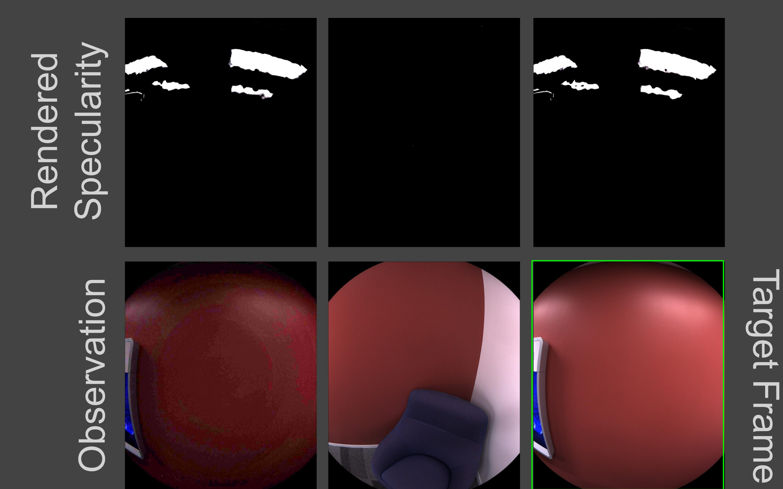
Target Frame Calculation

Use *only 1* target frame for each object:

- Less computational complexity
- Fast

Target frame should fulfill:

- $\mathcal{A}_1$: High chance of specular highlight caused by direct illumination
- $\mathcal{A}_2$: HDR capture consists of valid pixels, i.e. not over-/under-saturated



$\mathcal{A}_1$	✔	✘	✔
$\mathcal{A}_2$	✘	✔	✔

Specular Appearance Estimation

$$I^i(p) = I^i_\mathrm{d}(p) + I^i_\mathrm{nd}(p; \varphi^i, \psi^i)$$

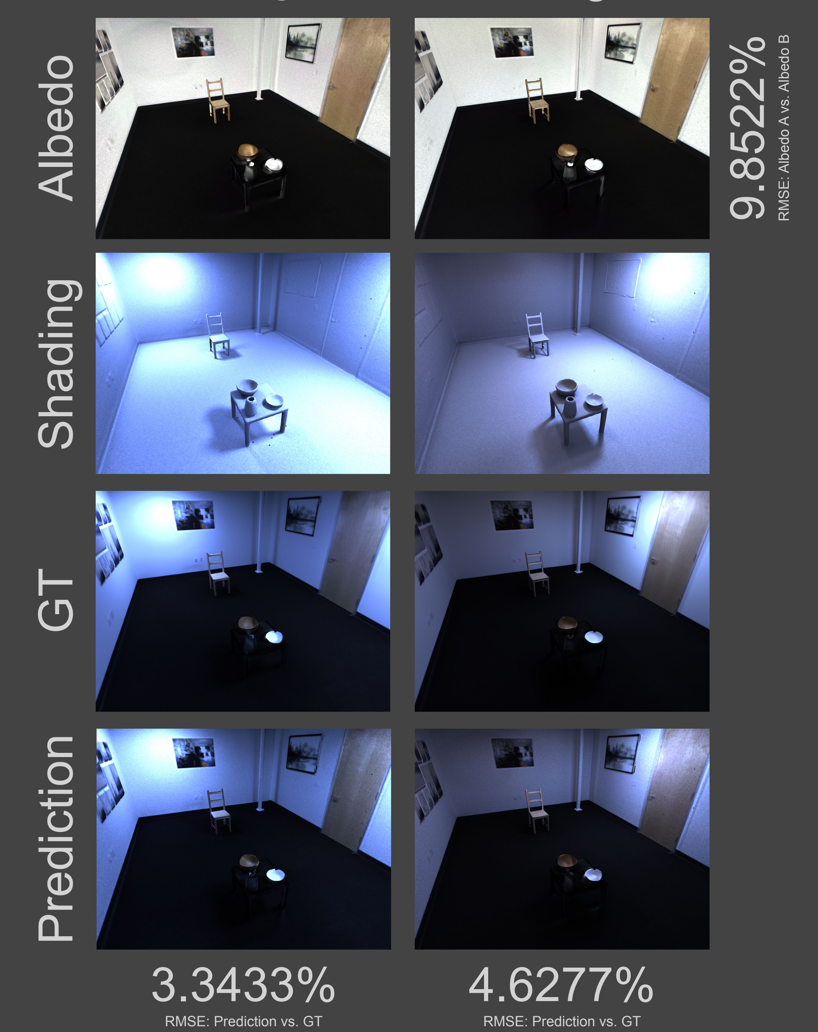
- $I^i(p)$: i-th objects target frame
- $I^i_\mathrm{d}(p)$: Diffuse part (rendered using L_d)
- $I^i_\mathrm{nd}(p; \varphi^i, \psi^i)$: Non-diffuse part

$$\min_{\varphi^i, \psi^i \in [0,1]} \sum_{p \in \Omega^i} \| I^i(p) - (I^i_\mathrm{d}(p) + I^i_\mathrm{nd}(p; \varphi^i, \psi^i)) \|^2, \quad \forall i$$

$\Longrightarrow$ Grid search in φ^i, with nested least squares optimization in ψ^i

Evaluation

Albedo/Shading



Specular Appearance

Relighting