

Appearance-from-Motion

Recovering Spatially Varying Surface Reflectance
under Unknown Lighting

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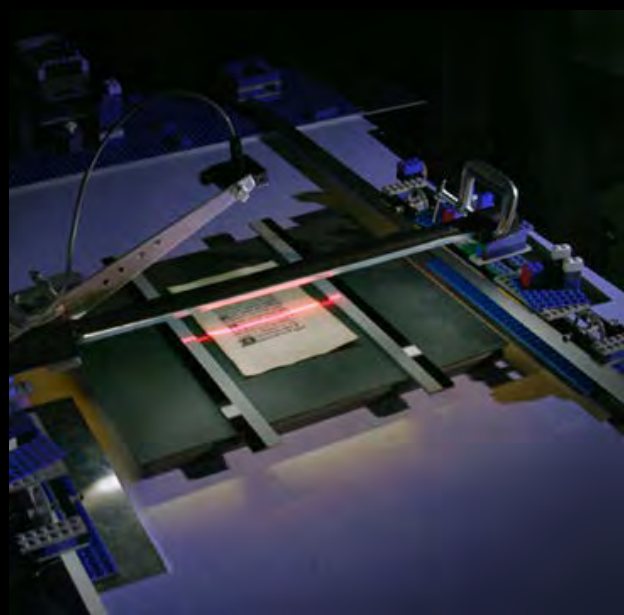
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Reflectance acquisition methods



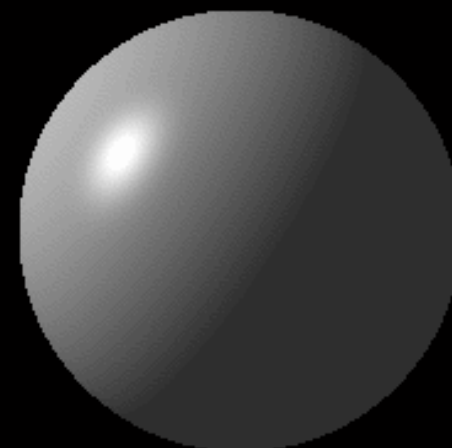
Controlled lighting

[Holroyd et al. 2010; Gardner et al. 2003; Tunwattanapong et al. 2013; Aittala et al. 2013]



Measure the lighting

[Hertzmann and Seitz 2003; Romeiro et al. 2008; Ren et al. 2011]



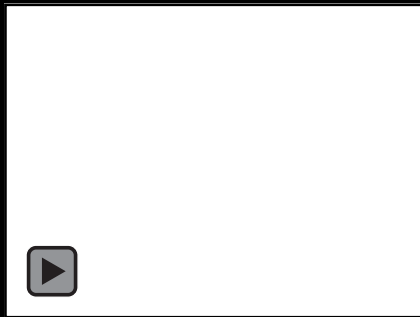
Homogeneous Simple reflectance model Unknown lighting

[Romeiro and Zickler 2010; Nishino et al. 2001; Haber et al. 2009]

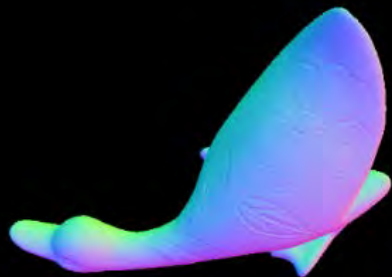
Appearance from motion

Input:

- Video of rotating object under **unknown** natural illumination
- Known geometry



Input video sequence



Known geometry



Output:

- Spatially varying surface reflectance



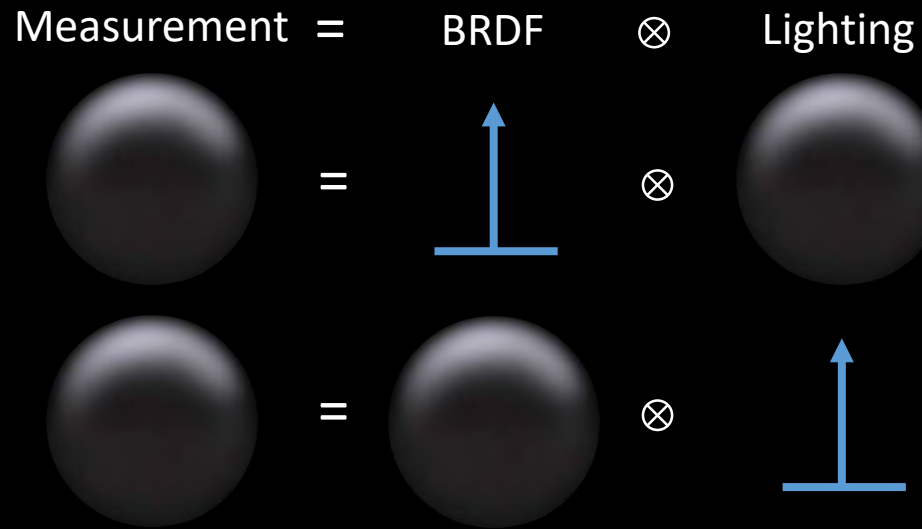
Recovered reflectance



Rendering result

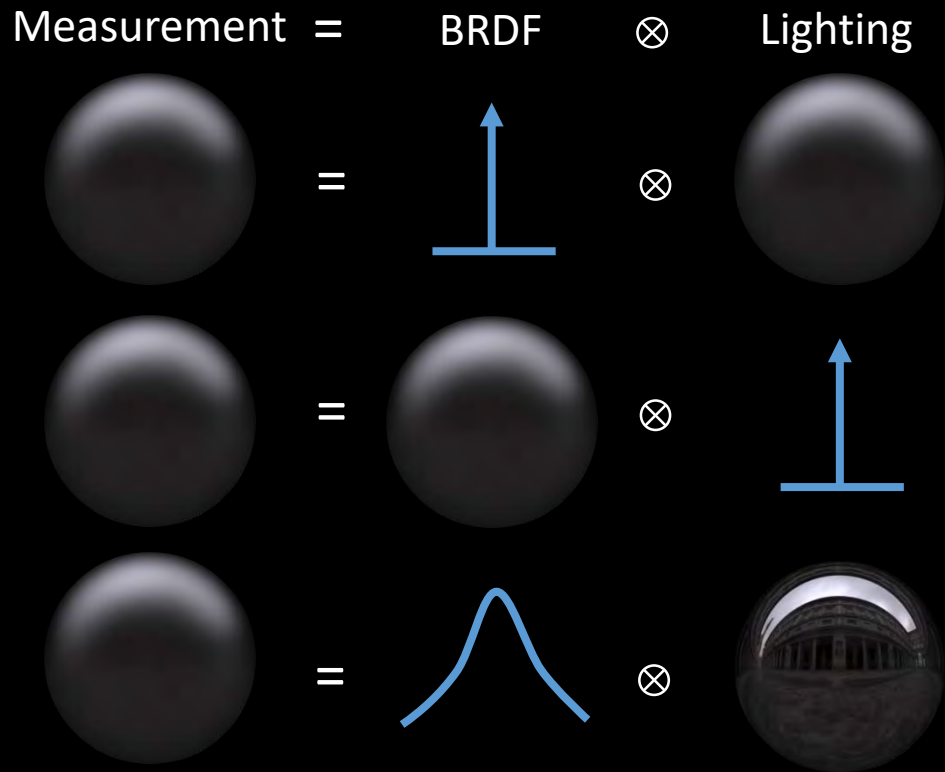
Key challenge

- Ambiguity between BRDF and lighting



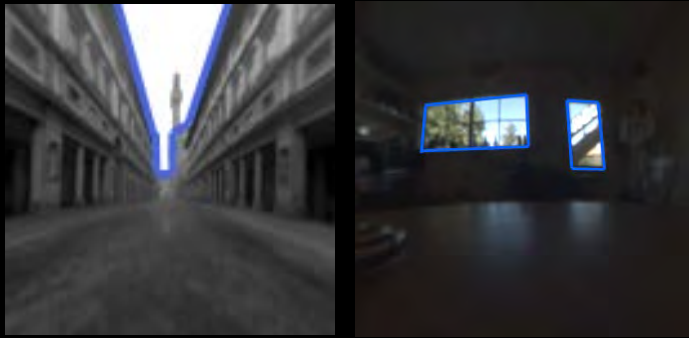
Key challenge

- Ambiguity between BRDF and lighting

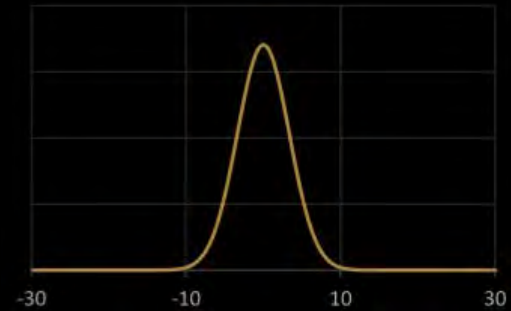


Key priors

- Priors for lighting and BRDFs
 - Sparse sharp edges in environmental lighting
 - Isotropic microfacet BRDF



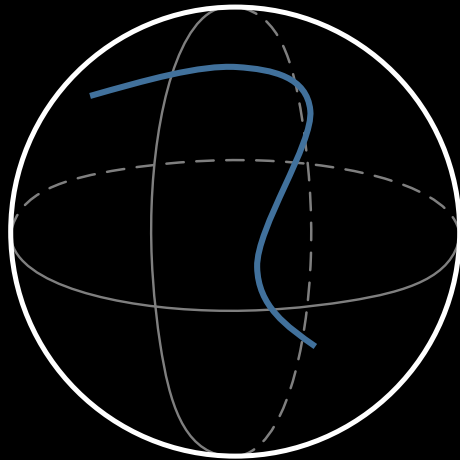
Sparse sharp edges in the environment lighting



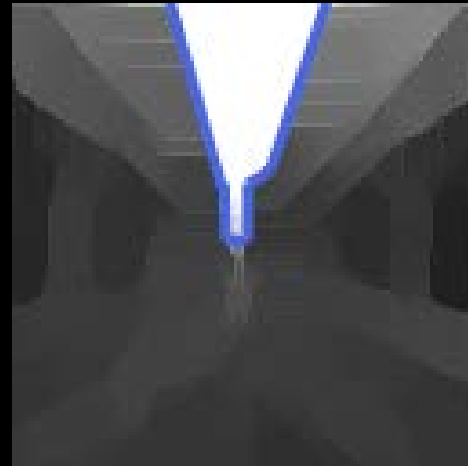
Isotropic monotonic reflectance

Our solution

- Estimate BRDF and lighting iteratively



Estimate BRDF

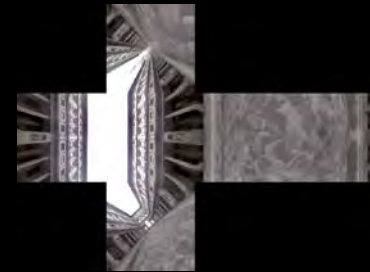


Estimate lighting

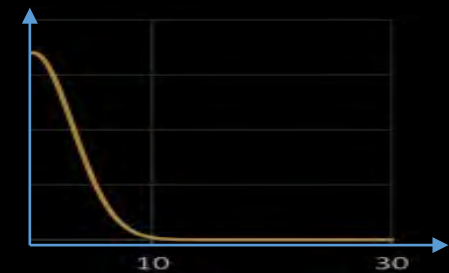
Technical details

Models and assumptions

- Geometry
 - Known geometry and registration to the frames
- Lighting
 - Environment lighting (distant)
 - Stored in “cross” parameterization
 - **Static environment**
- Surface reflectance
 - Isotropic microfacet BRDF
 - NDF is 1D tabulated function
 - Monotonically decreasing function
 - **Estimated for every surface pixel**

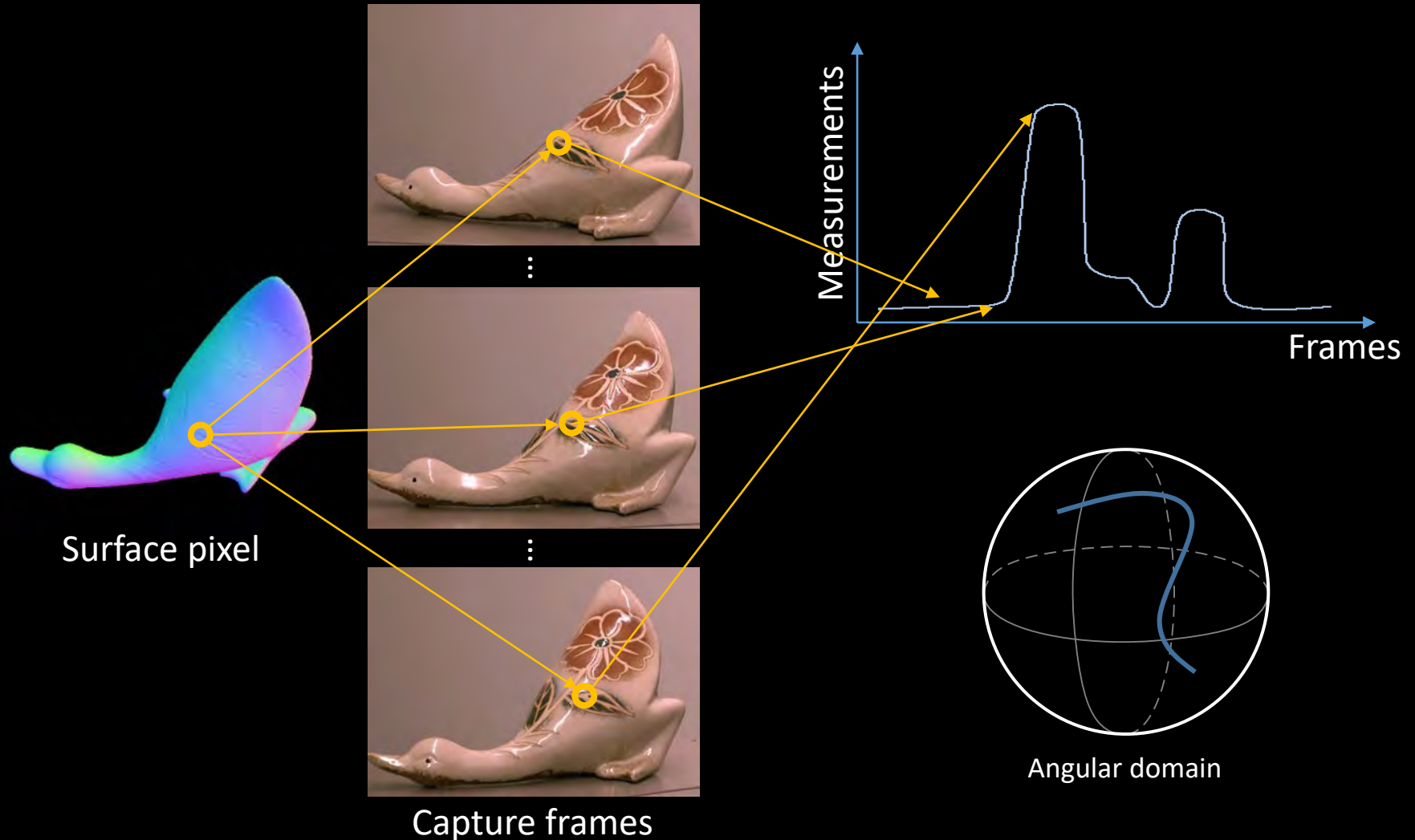


$$\rho(\omega_i, \omega_o) = \frac{\rho_d}{\pi} + \rho_s f_s(\omega_i, \omega_o)$$



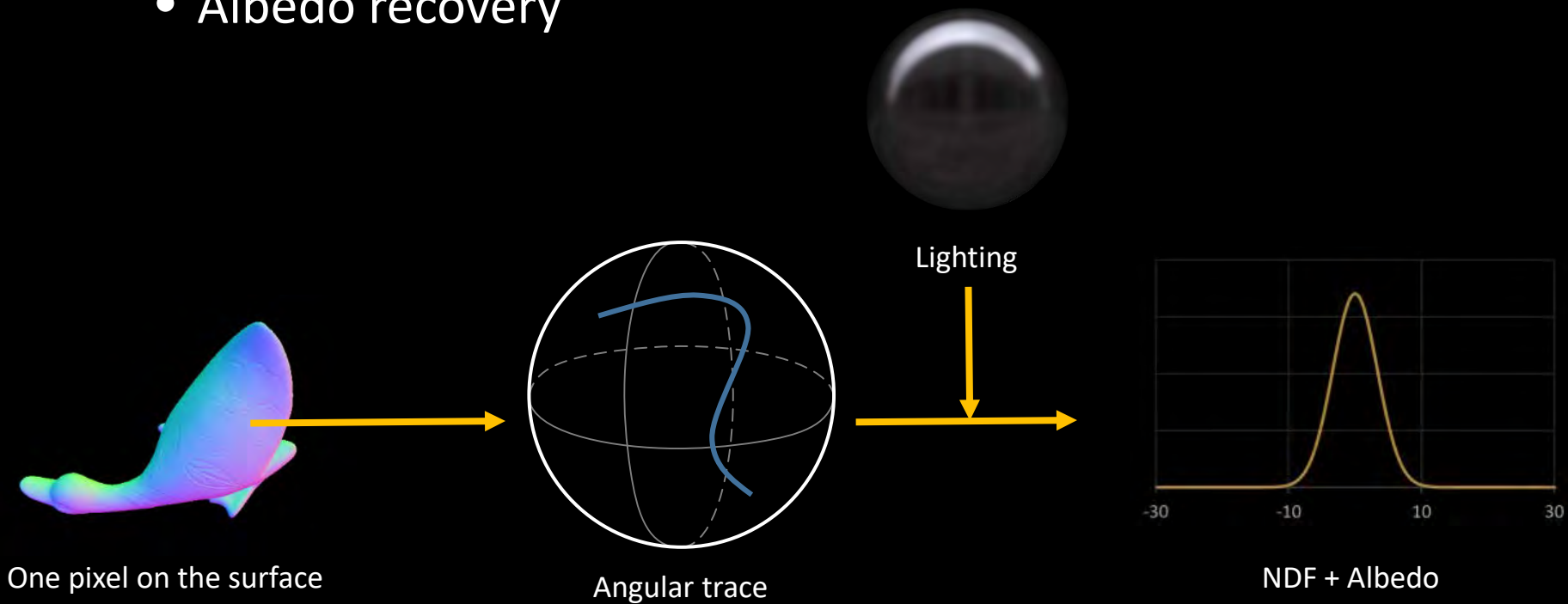
Measurement

- Temporal reflectance trace

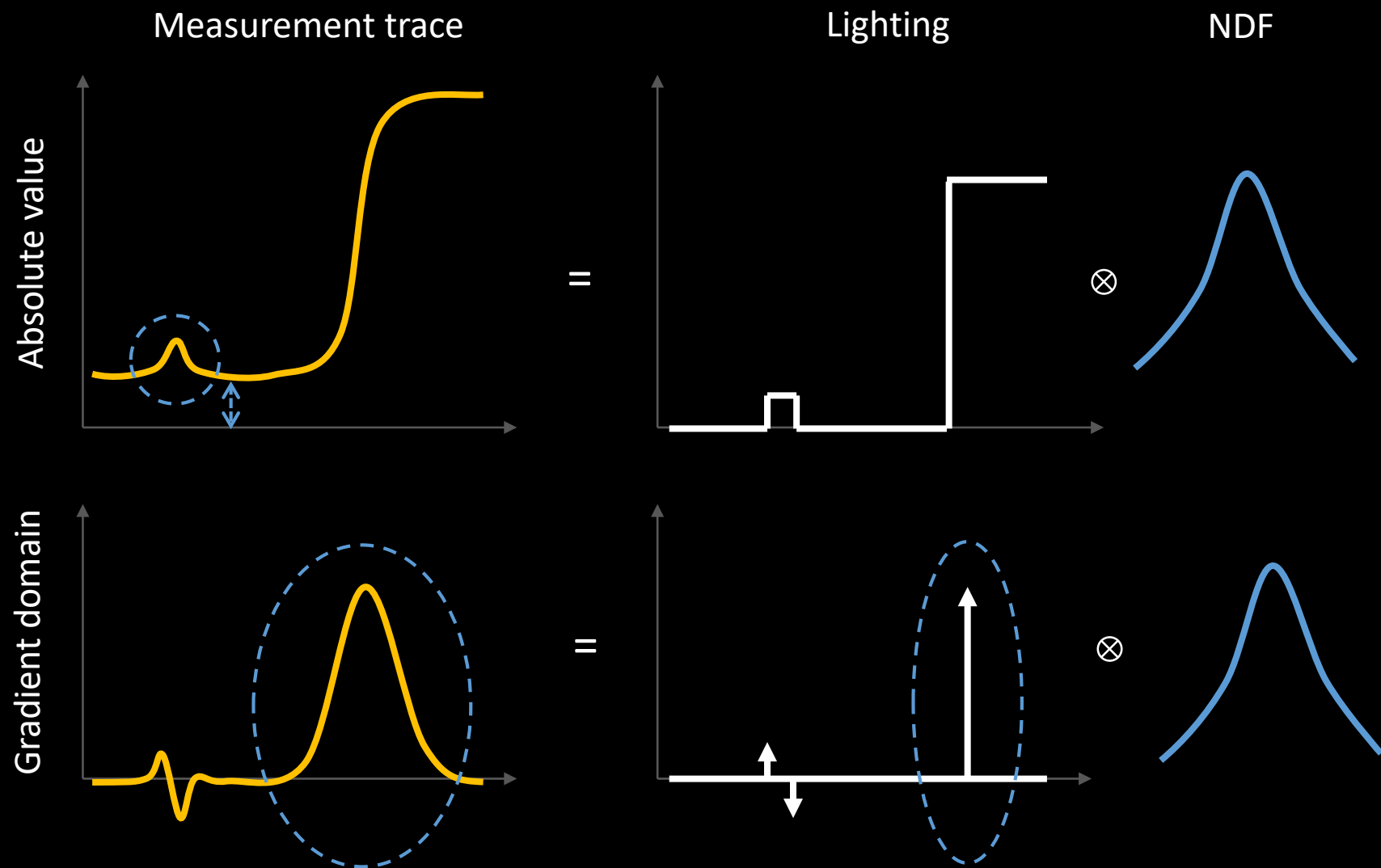


Estimate BRDF

- Estimate BRDF for each pixel independently
 - Fix lighting from previous iteration
 - NDF recovery
 - Albedo recovery

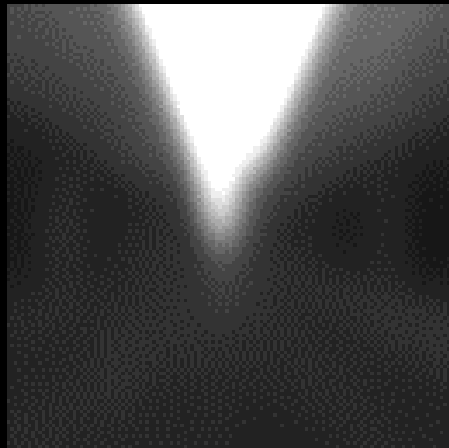


NDF recovery

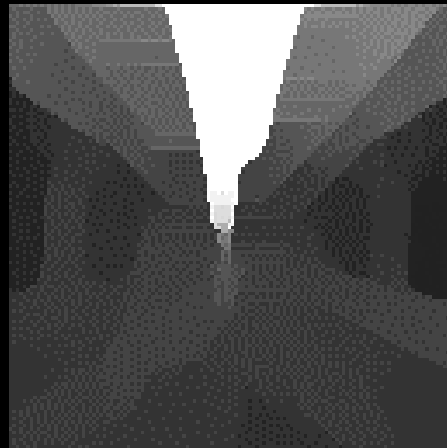


NDF recovery

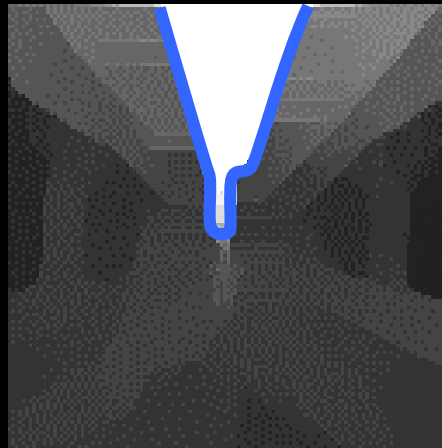
- Robust discontinuity detection [Xu and Jia 2010]
 - High contrast discontinuity
 - Compare to neighbors



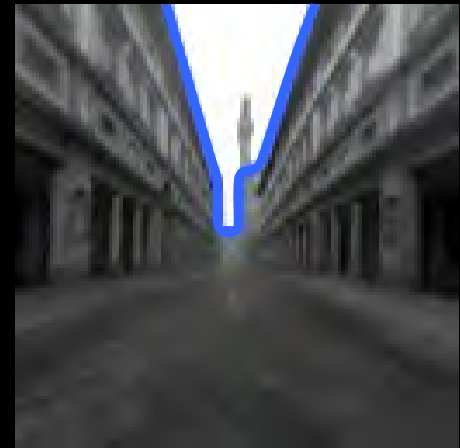
Lighting



Shock filter*
[Osher and Rudin 1990]

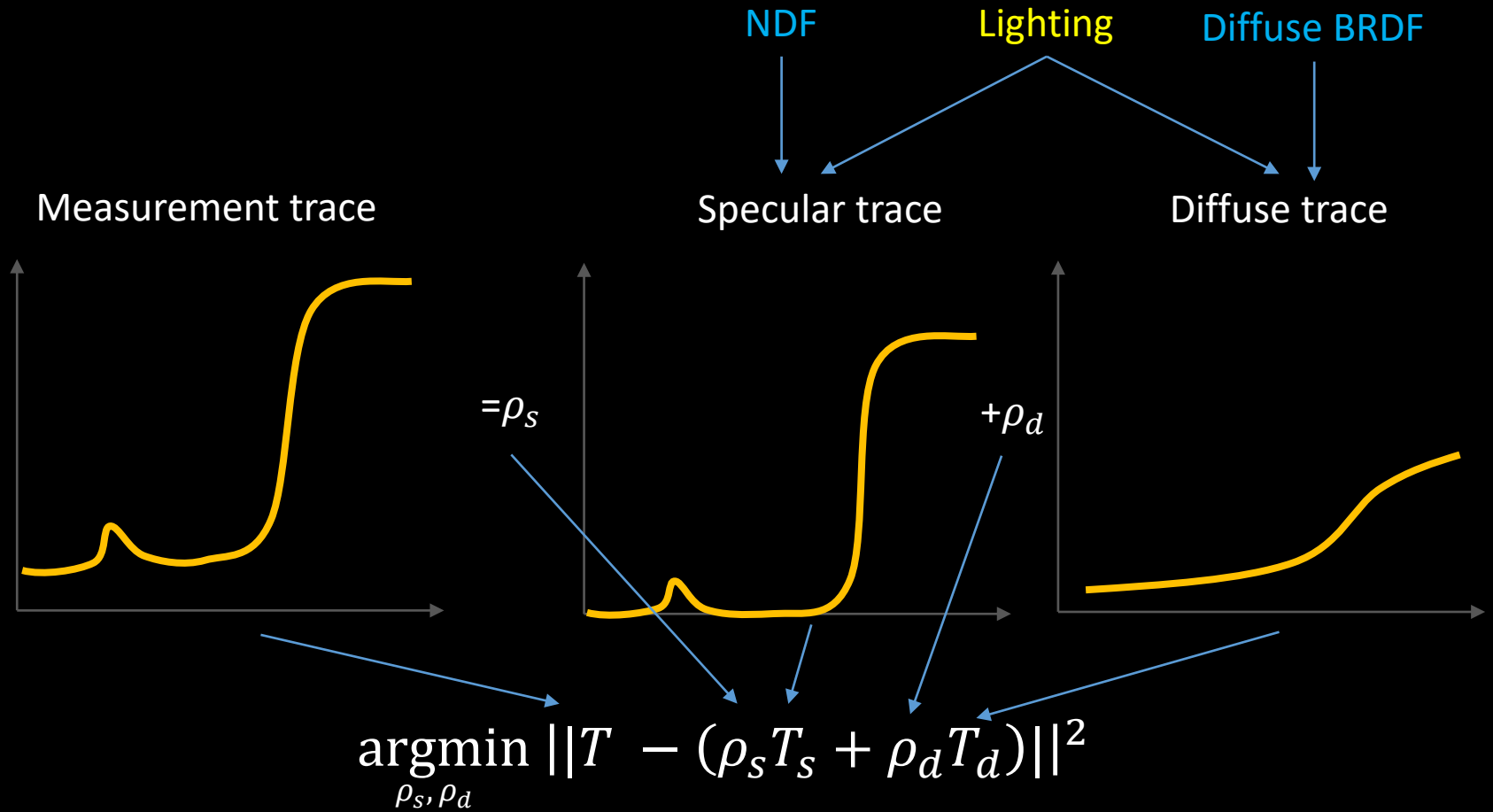


Selected edge



Reference

Albedo recovery



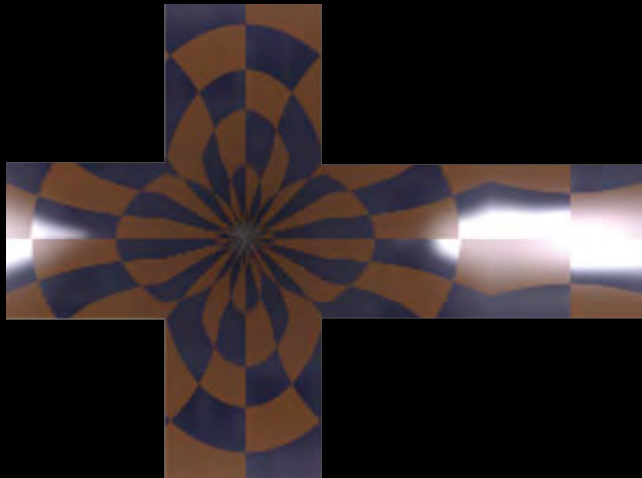
Lighting recovery

$$\operatorname{argmin}_L \sum_t \sum_x w_x ||I - \rho \otimes L||^2 + \lambda ||\nabla L||^{0.8}$$

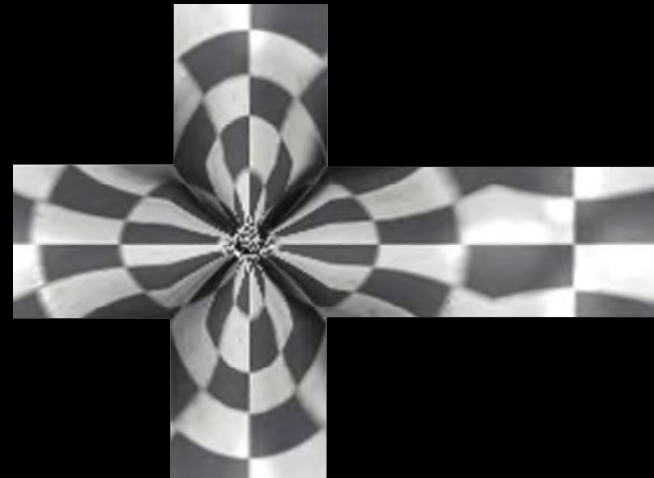
- Fixed BRDF
- Constraints
 - Consistent lighting for all the frames
 - Sparsely of the gradient
- Solver
 - Stochastic deconvolution [Gregson et. al. 2013]
- Robustness weighting

Estimate lighting

- Weight the measurement based on
 - Confident in recovered BRDF : prefer robust estimated BRDF
 - Bandpass behavior of the BRDF : prefer shinny BRDF
 - Specular signal-to-noise ratio : prefer stronger specular BRDF



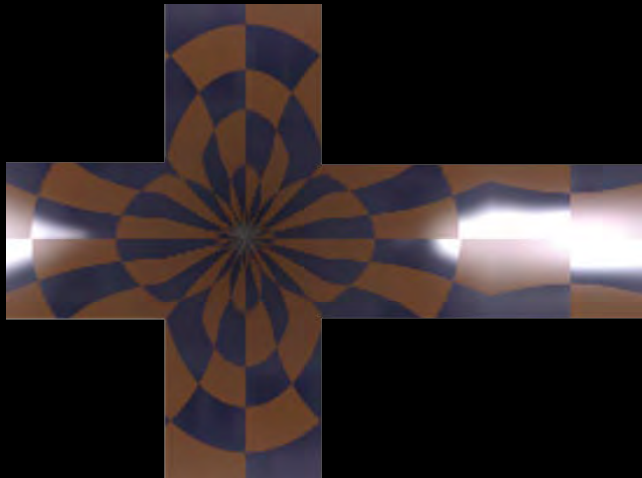
Measurement



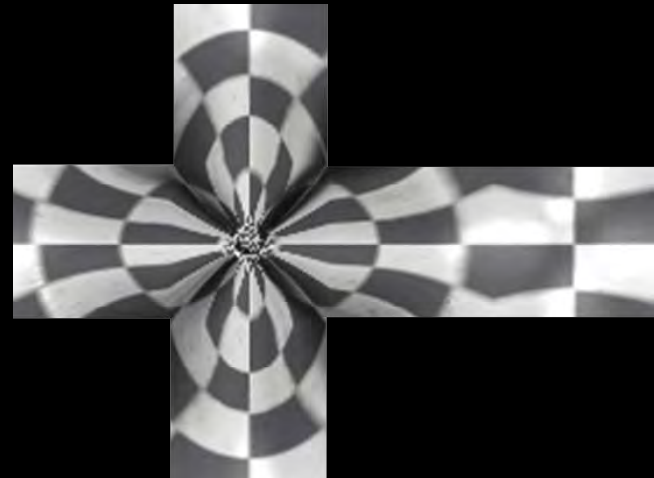
Weight map

Estimate lighting

- Weight the measurement based on
 - Confident in recovered BRDF : prefer robust estimated BRDF
 - Bandpass behavior of the BRDF : prefer shinny BRDF
 - Specular signal-to-noise ratio : prefer stronger specular BRDF



Measurement



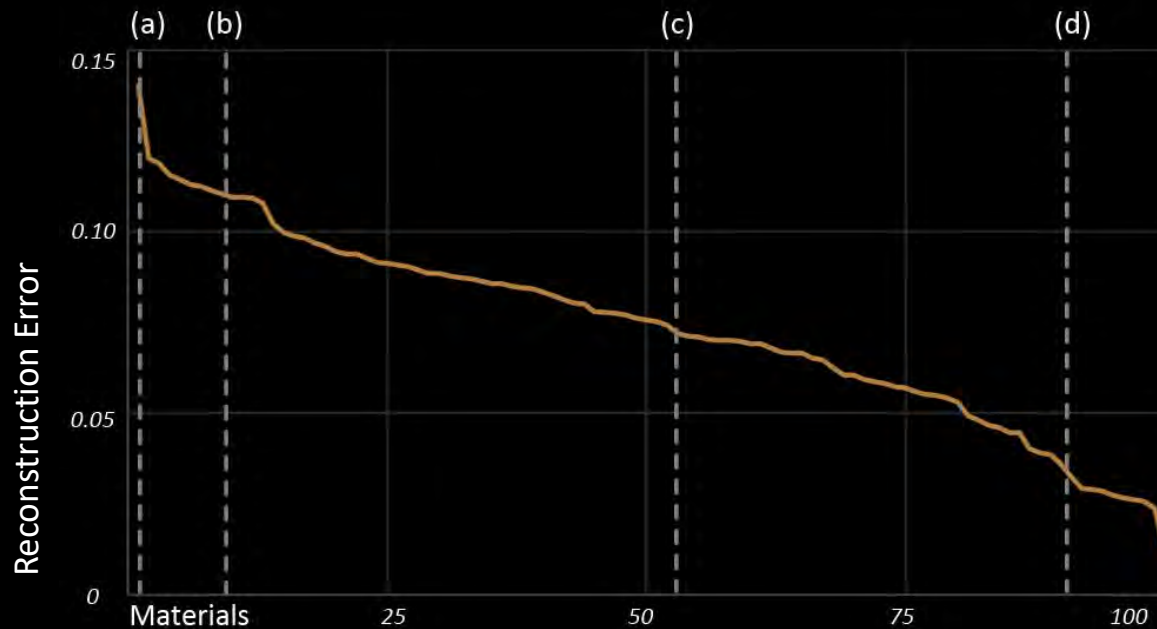
Weight map

Implementation

- Geometry
 - Scanned with Artec 3D scanner
 - Registration with ICP and optical flow
- Radiance
 - Canon EOS 5D Mark II, single exposure RAW
 - LDR video, assume gamma 2.2
- Performance
 - Capture image 300 – 1200 frames
 - 8 – 10 hours on Xeon E5-2690

Results

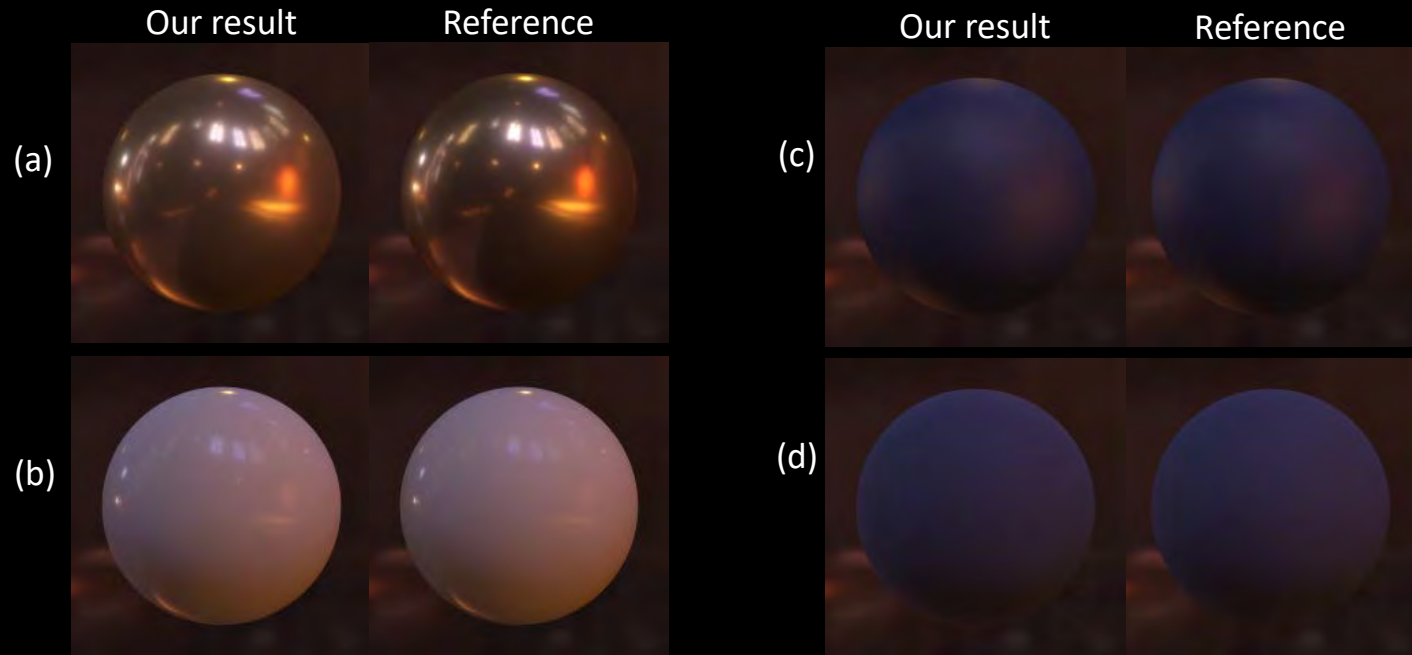
- Robust and good results for different kinds of real world materials
- Validation on MERL/MIT BRDF dataset



100 Physically Measured BRDF in MERL/MIT Dataset

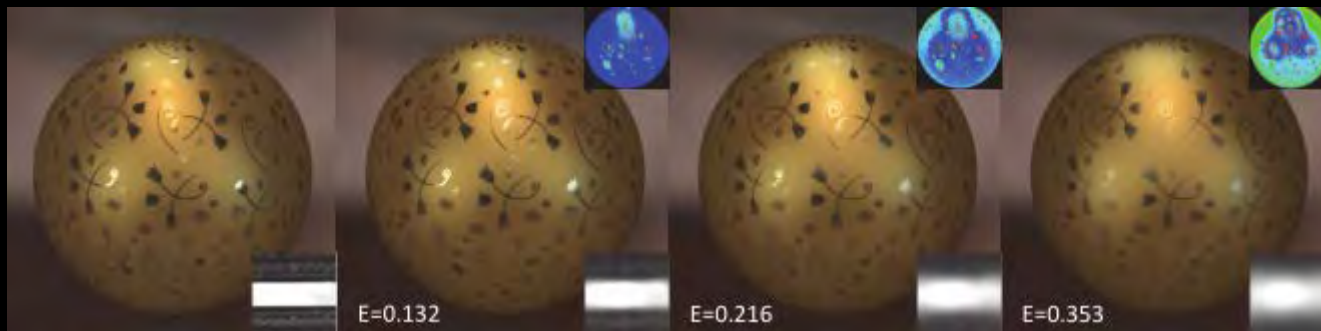
Results

- Robust and good results for different kinds of real world materials
- Validation on MERL/MIT BRDF dataset



Robustness - lighting

- Blurred light



(a) Reference

(b) $\sigma=0.04$

(c) $\sigma=0.08$

(d) $\sigma=0.12$

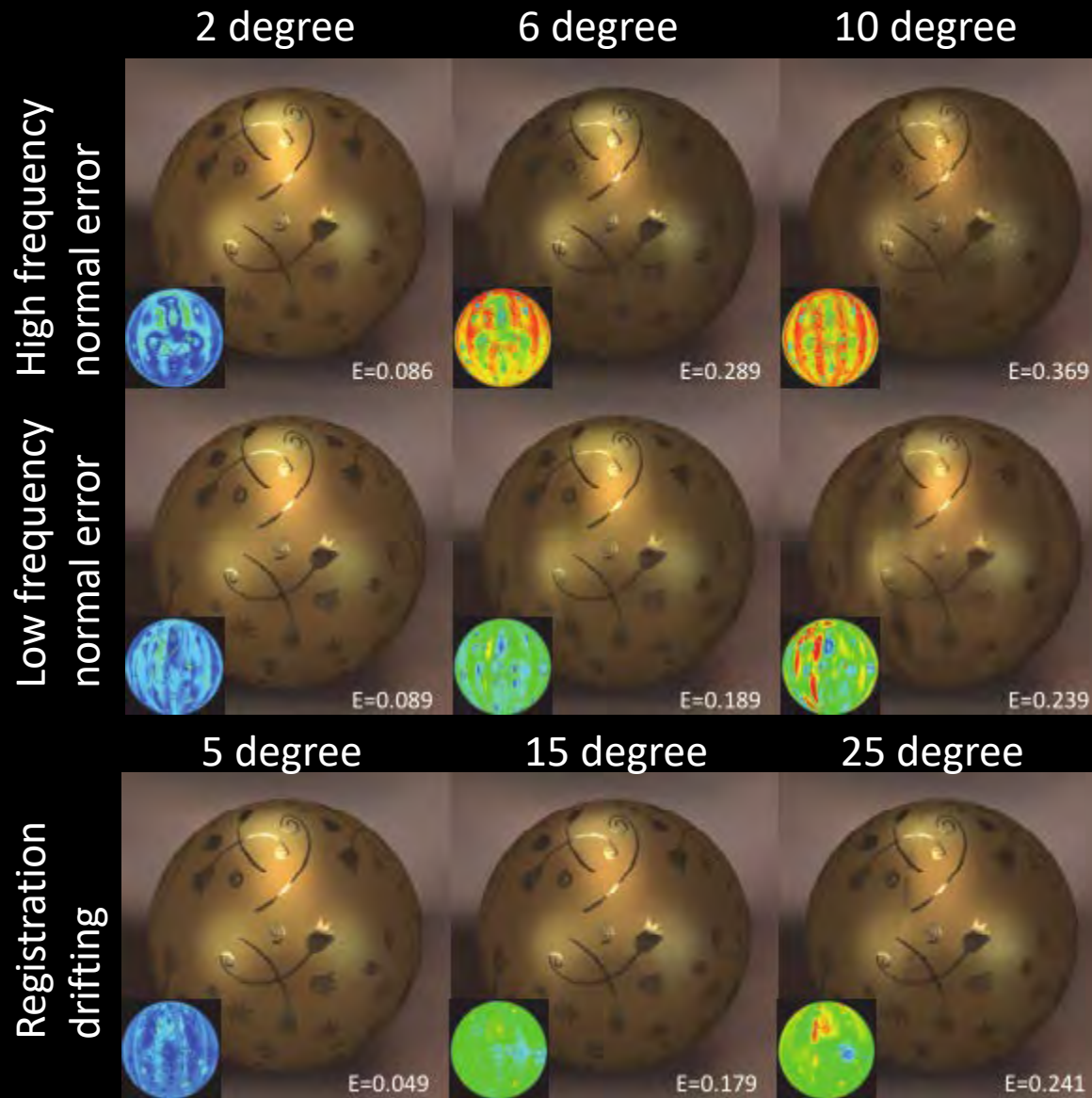
- Consistency with different lighting



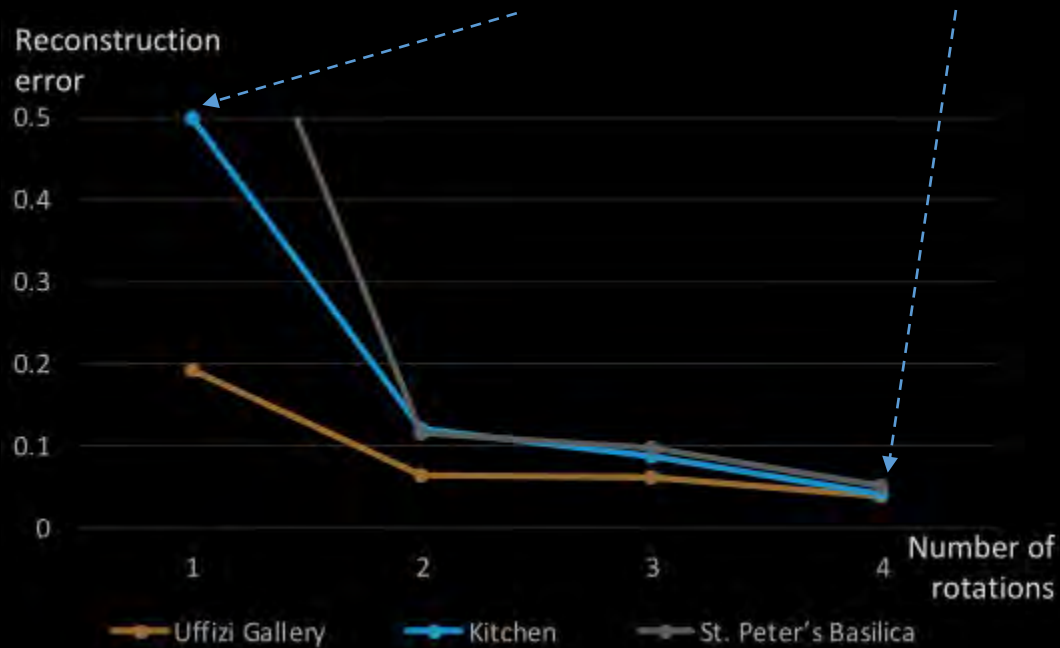
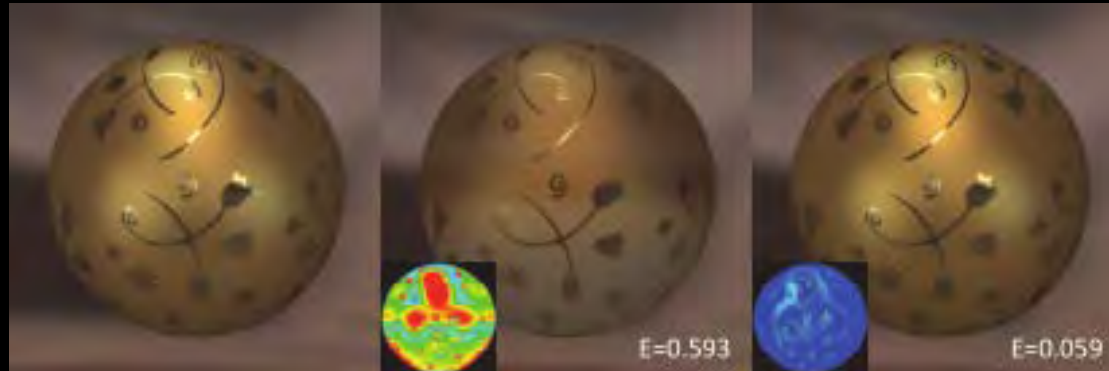
$E=0.021$

$E=0.040$

Robustness - geometry



Robustness - motion



Conclusion

- Appearance from Motion
 - Recovering spatially varying isotropic surface reflectance
 - Unknown natural illumination
 - Supports a wide variety of materials
 - Simplify the appearance acquisition process
- Future works
 - Self-occlusions and inter-reflections
 - Joint recovery shape and appearance

Acknowledgements

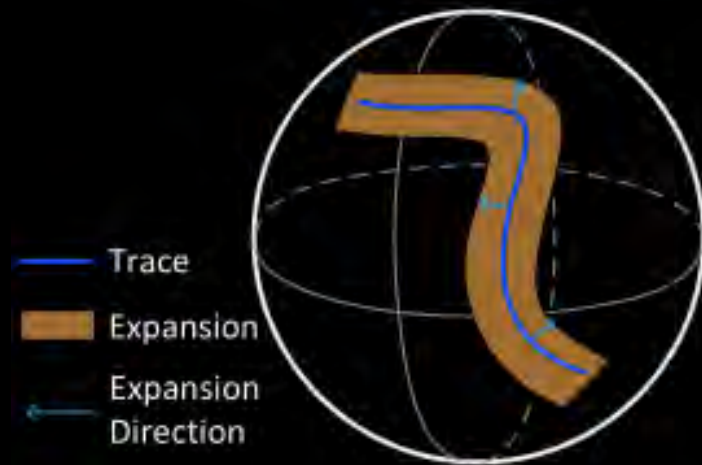
- Reviewers for constructive feedback
- Funding agency
 - Pieter Peers was partially funded by NSF grants IIS-1217765, IIS-1350323, and a gift from Google
- Dataset
 - HDR probe by P. Debevec
 - MERL/MIT dataset by W. Matusik et. al.
 - Mitsuba renderer

Robustness

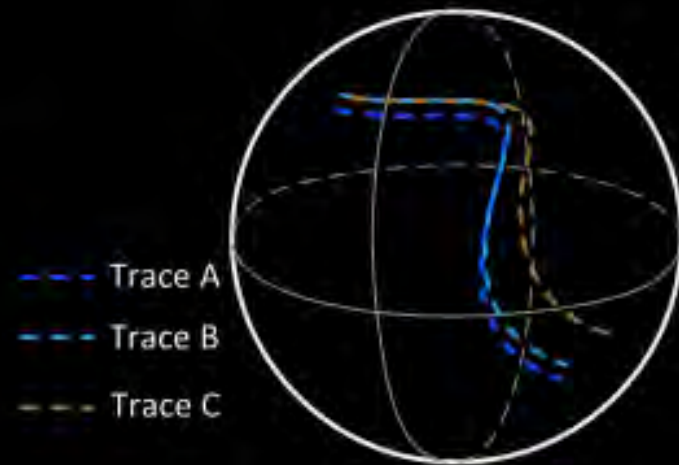
- Lighting
 - Contrast of the discontinuity
 - Smoothed light source
- Rotation
 - Every pixel cross discontinuity 2-4 rotation
- Geometry
 - Normal error < 2 degree
 - Registration error < 15 degree

Initialization

- NDF : trace expansion
- Specular coefficient : trace intersection
- Diffuse albedo compensation : clamping the lighting



Trace expansion



Trace intersection

Key challenge

- Ambiguity between lighting / BRDF

