Appearance-from-Motion

Recovering Spatially Varying Surface Reflectance under Unknown Lighting

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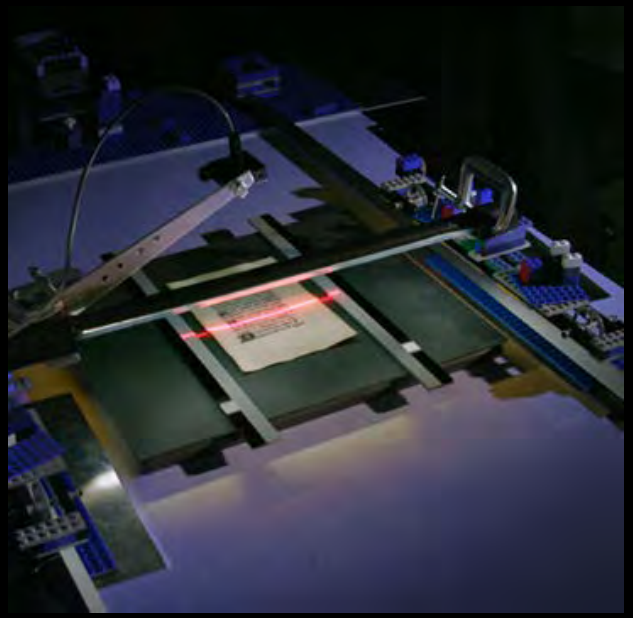
Reflectance acquisition methods

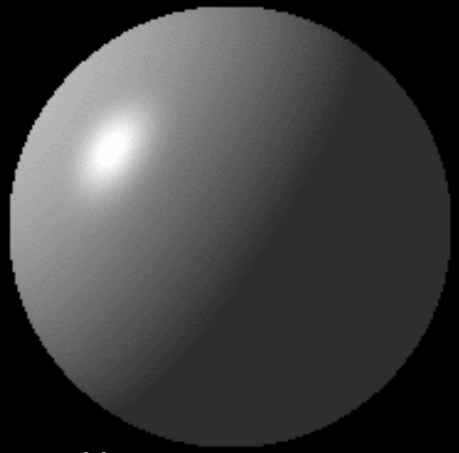


Controlled lighting

[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

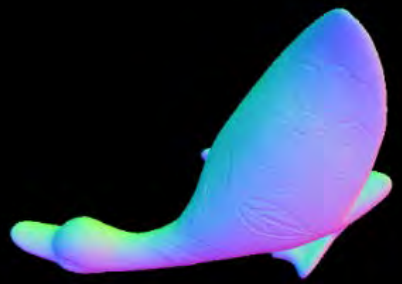
[Romeiro and Zickler 2010; Nishino et al. 2001; Haber et al. 2009]

Appearance from motion

Input:

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

Input video sequence



Known geometry

Output:

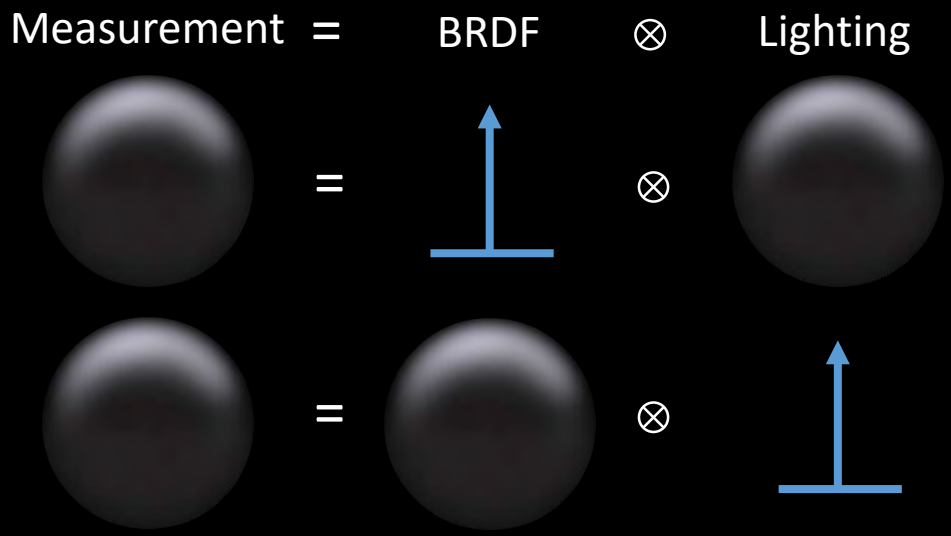
- Spatially varying surface reflectance

Recovered reflectance

Rendering result

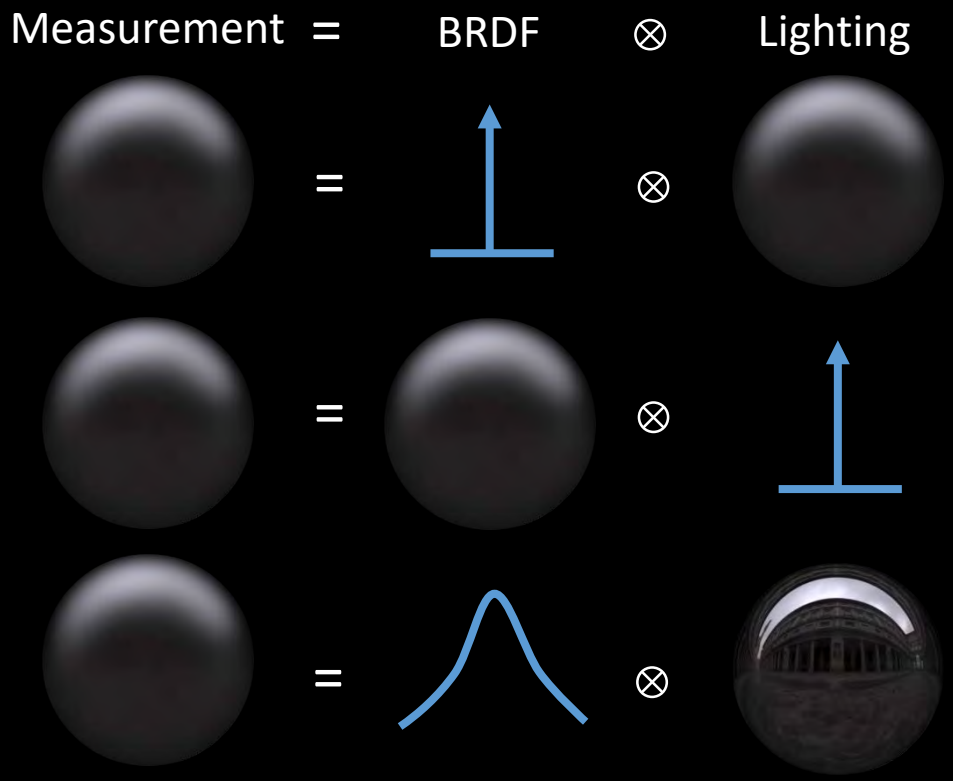
Key challenge

- Ambiguity between BRDF and lighting



Key challenge

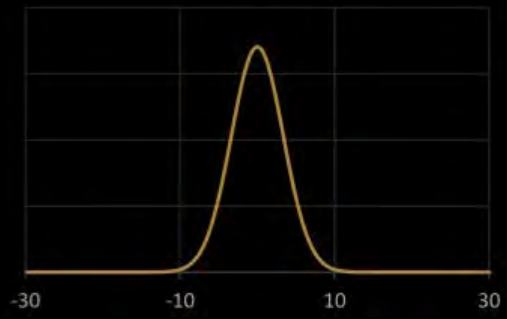
- Ambiguity between BRDF and lighting



Key priors

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

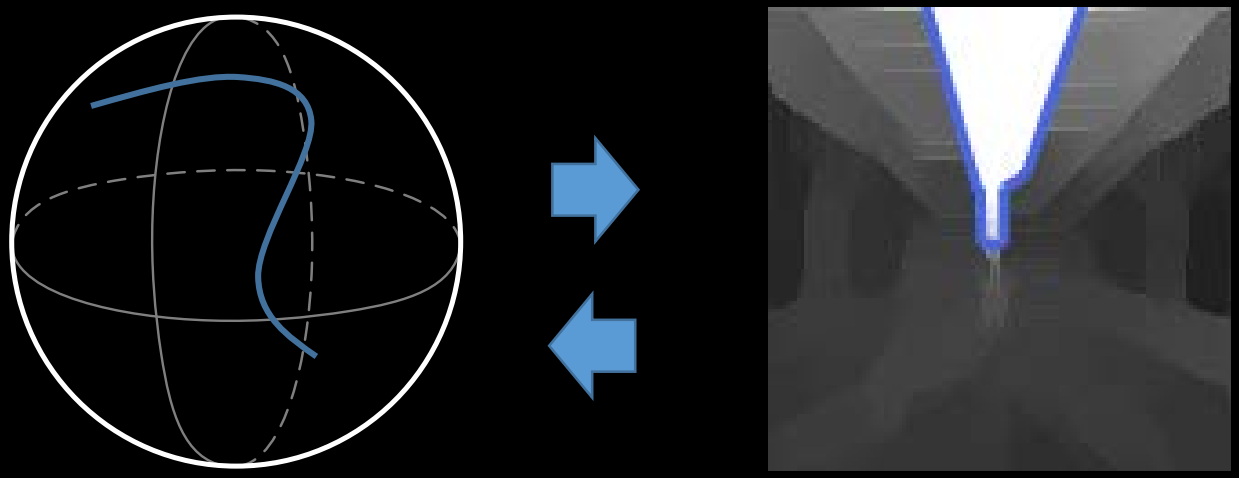
Sparse sharp edges in the environment lighting



Isotropic monotonic reflectance

Our solution

- Estimate BRDF and lighting iteratively



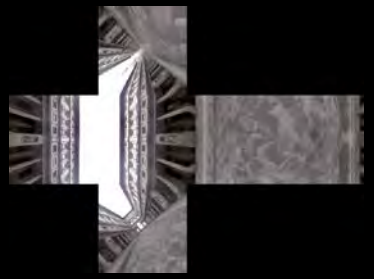
Estimate BRDF

Estimate lighting

Technical details

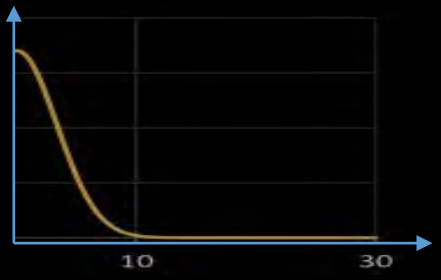
Models and assumptions

- Geometry
  - Known geometry and registration to the frames
- Lighting
  - Environment lighting (distant)
  - Stored in “cross” parameterization
  - Static environment



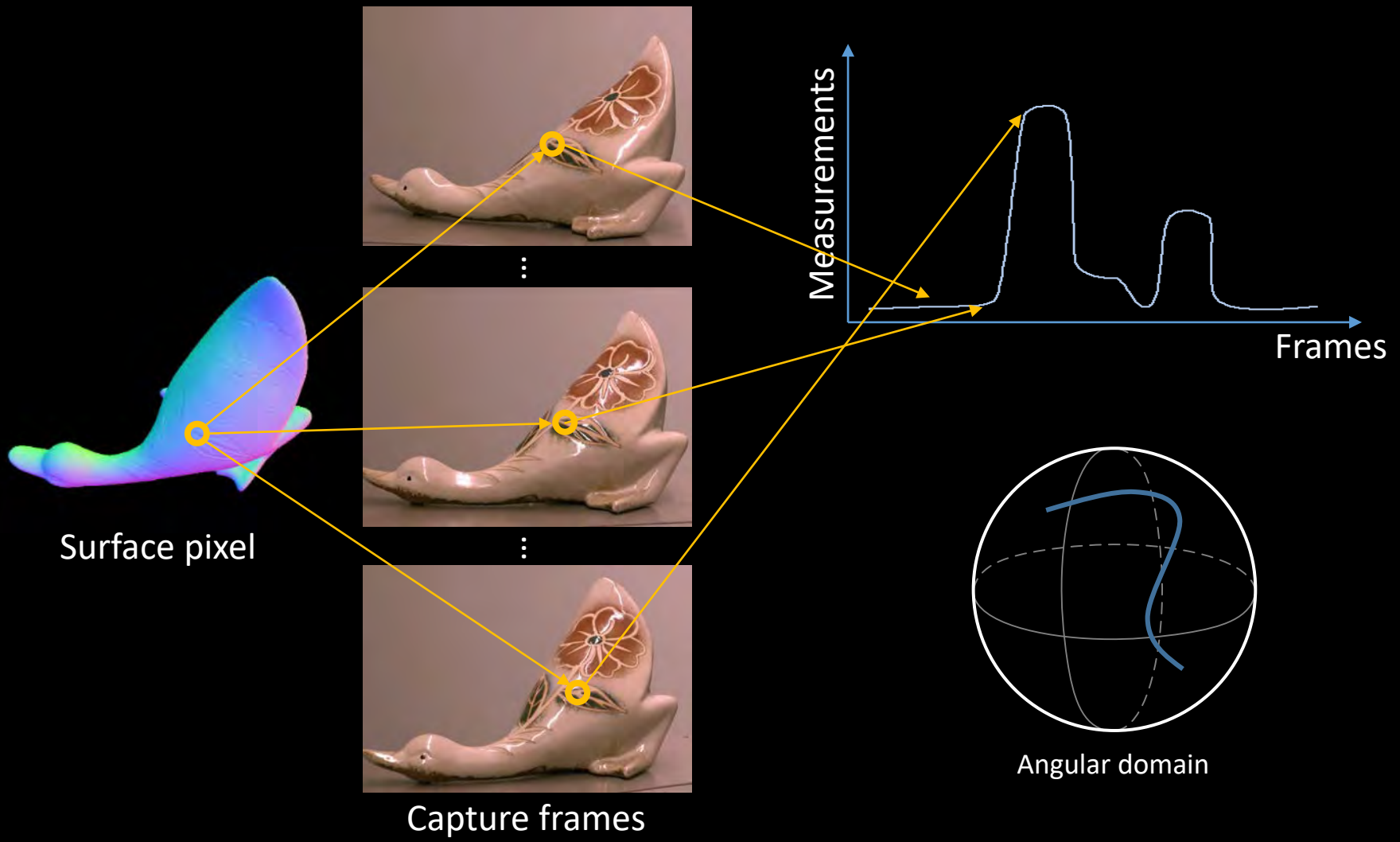
- Surface reflectance
  - Isotropic microfacet BRDF
  - NDF is 1D tabulated function
  - Monotonically decreasing function
  - Estimated for every surface pixel

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



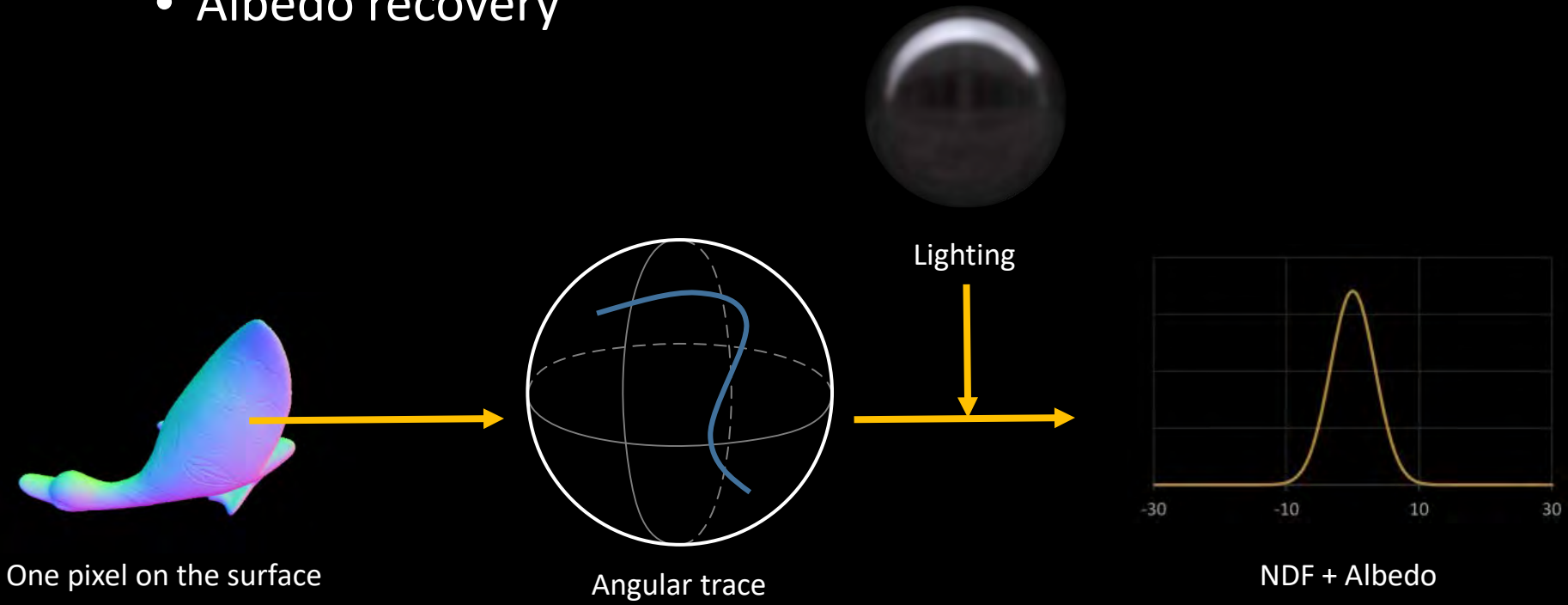
Measurement

- Temporal reflectance trace

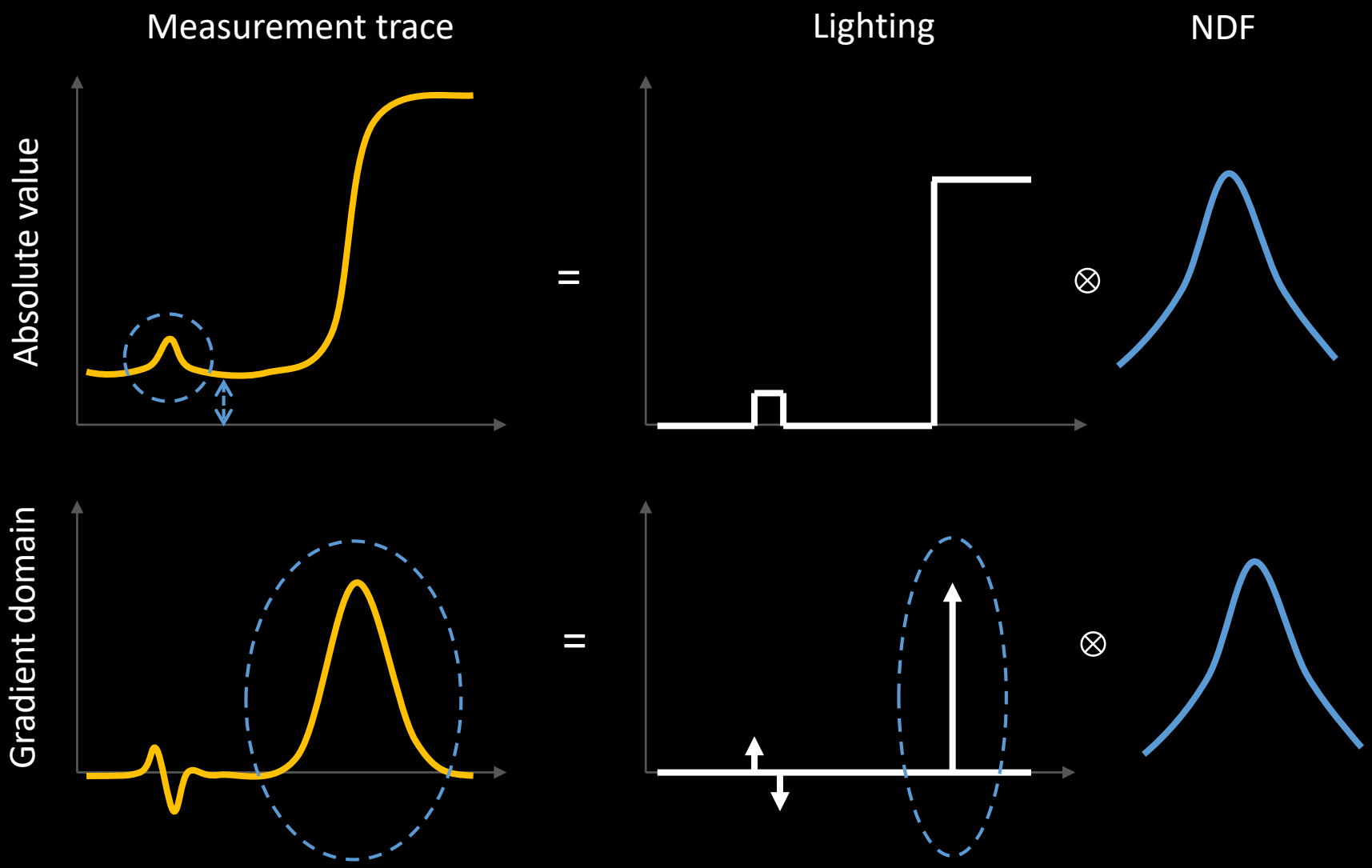


Estimate BRDF

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

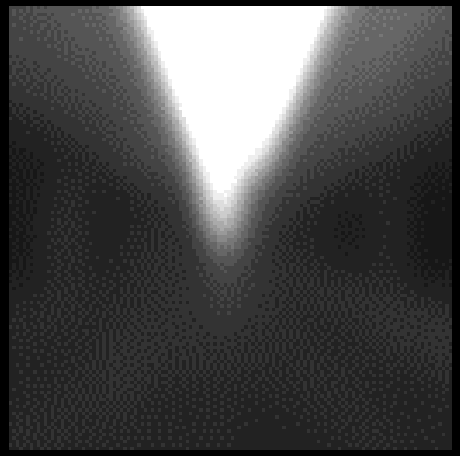


NDF recovery

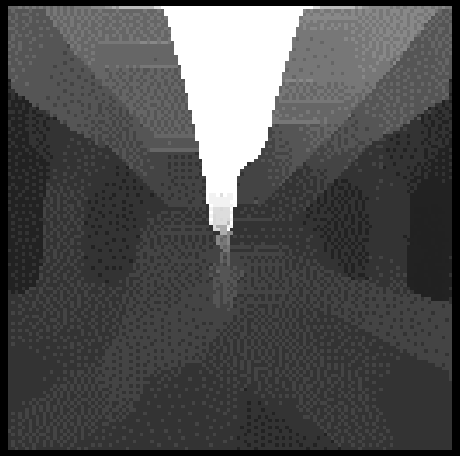


NDF recovery

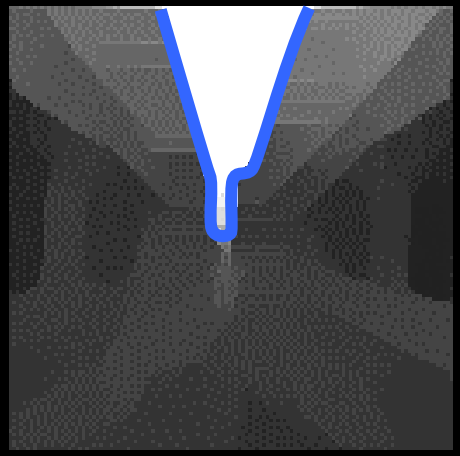
- Robust discontinuity detection **[Xu and Jia 2010]**
  - High contrast discontinuity
  - Compare to neighbors



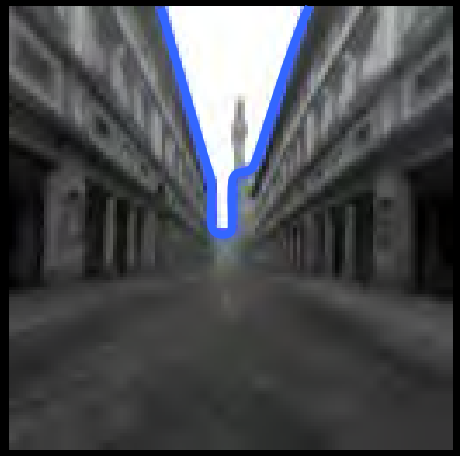
Lighting



Shock filter*
[Osher and Rudin 1990]

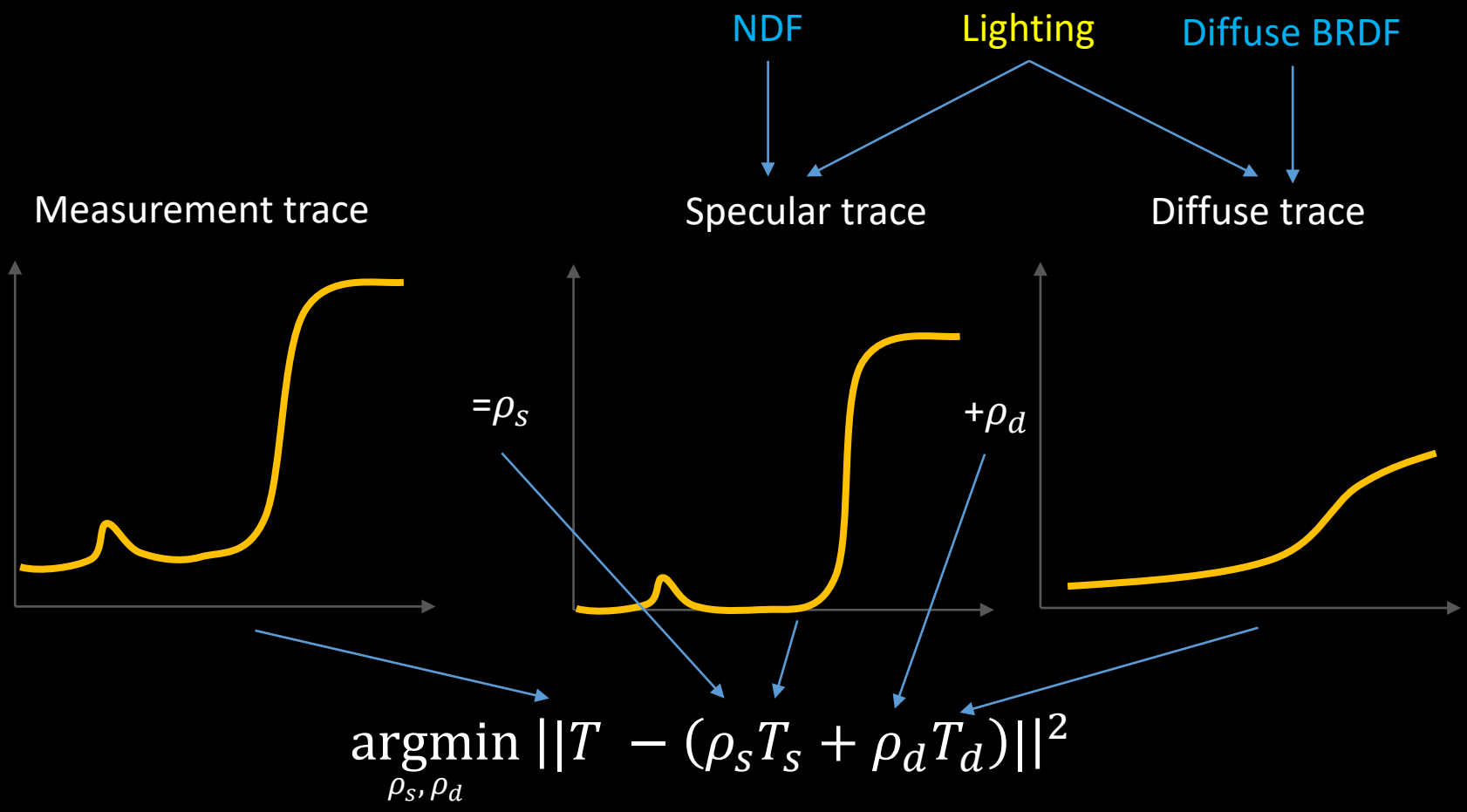


Selected edge



Reference

Albedo recovery



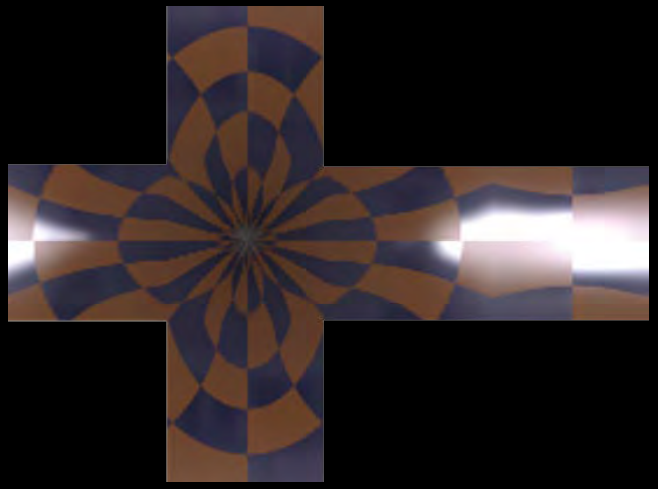
Lighting recovery

$$\underset{L}{\operatorname{argmin}} \sum_{t} \sum_{x} w_x ||I - \rho \otimes L||^2 + \lambda || \nabla L||^{0.8}$$

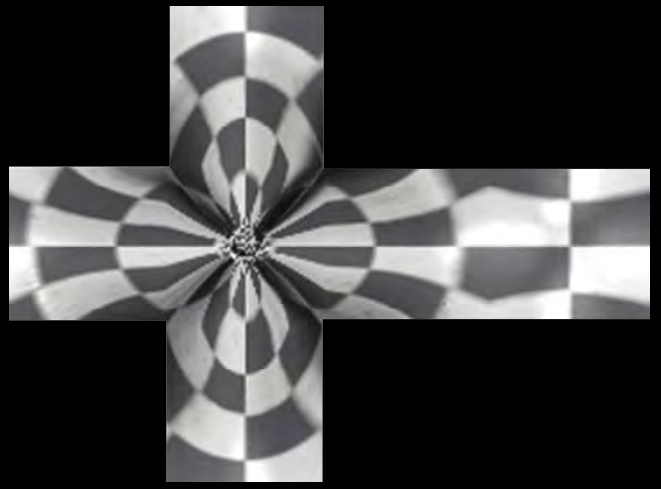
- Fixed BRDF
- Constraints
  - Consistent lighting for all the frames
  - Sparsely of the gradient
- Solver
  - Stochastic deconvolution **[Gregson et. al. 2013]**
- Robustness weighting

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
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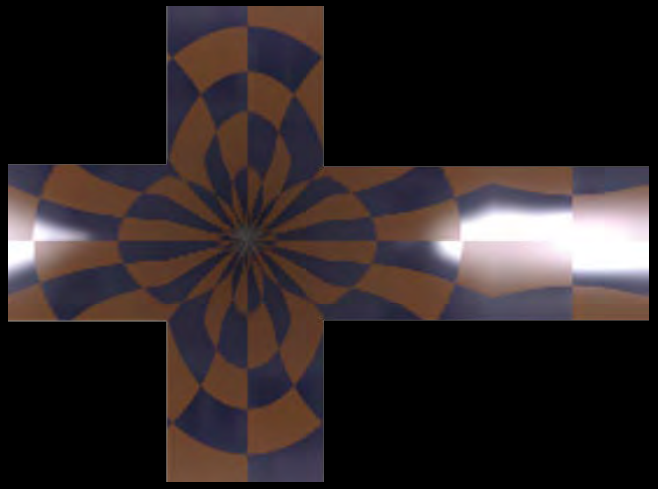
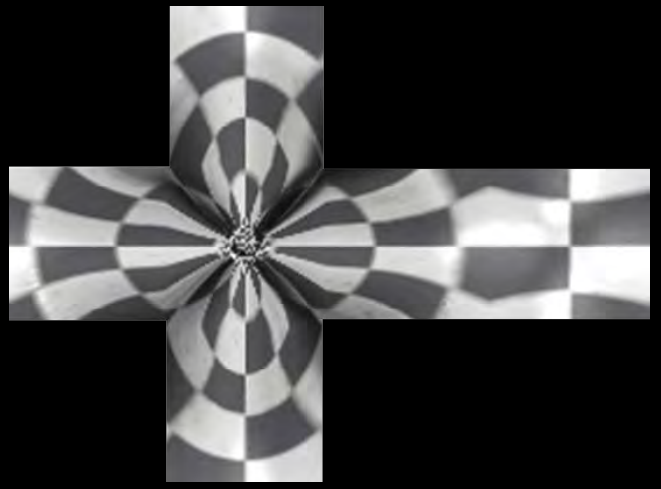
  - Specular signal-to-noise ratio : prefer stronger specular BRDF



Measurement



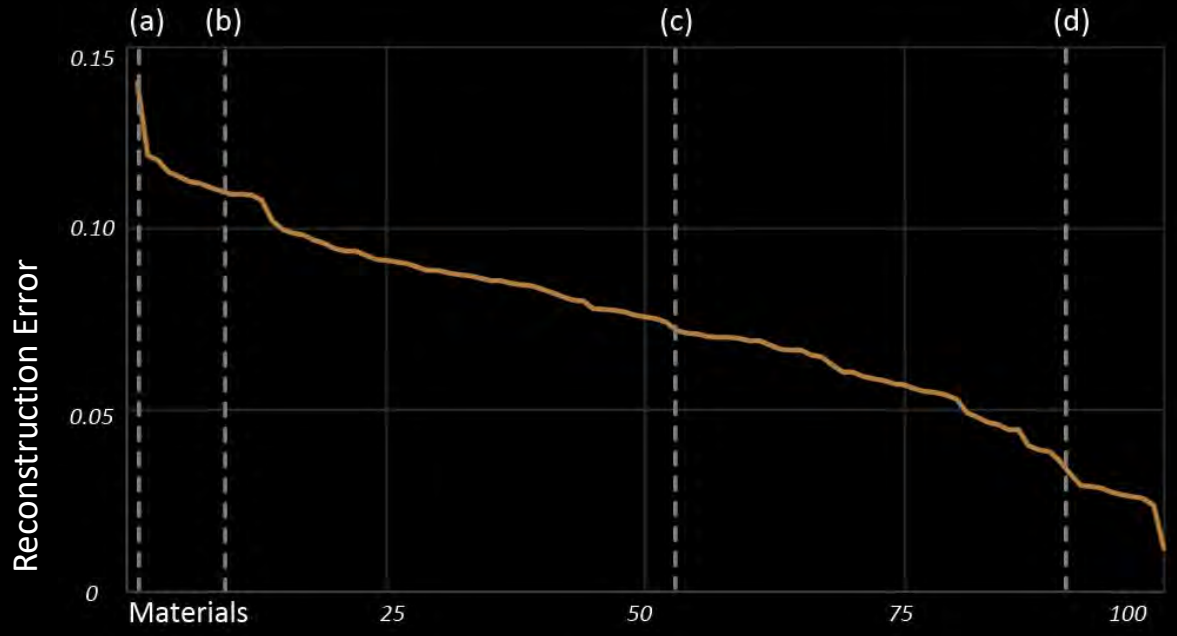
Weight map

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

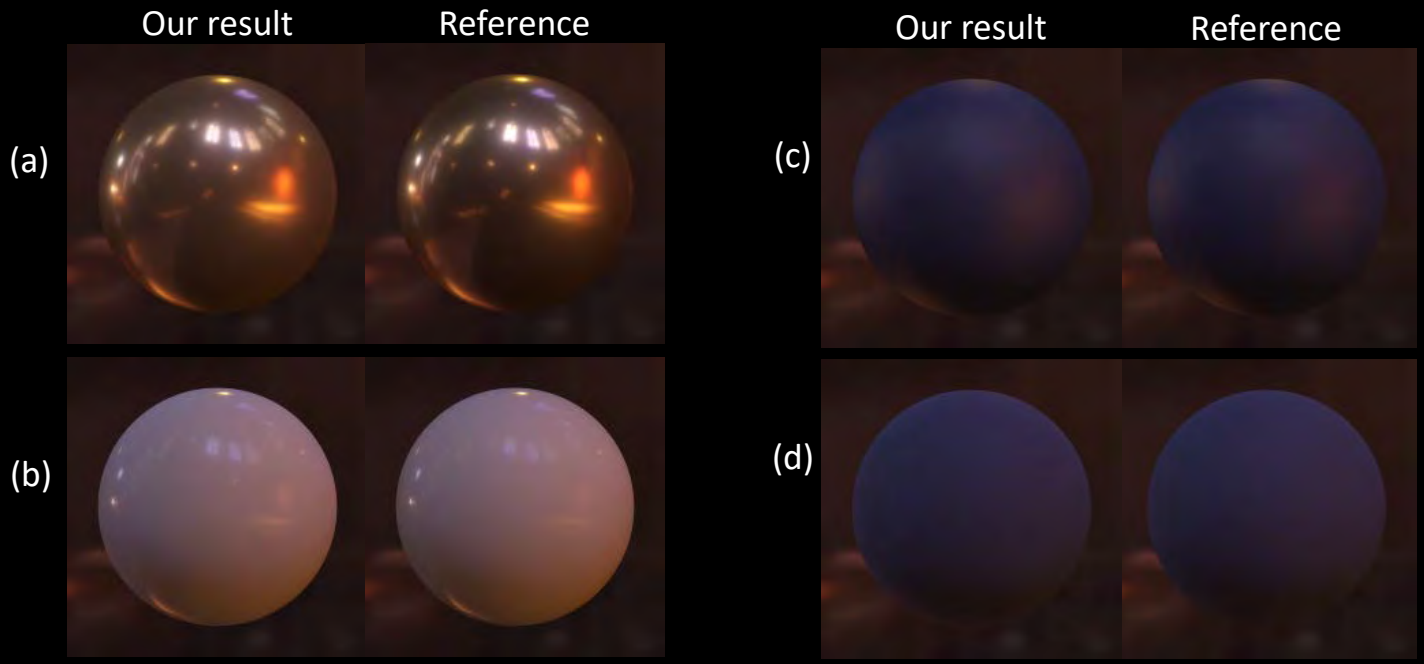
- Robust and good results for different kinds of real world materials
- Validation on MERL/MIT BRDF dataset



100 Physically Measured BRDF in MERL/MIT Dataset

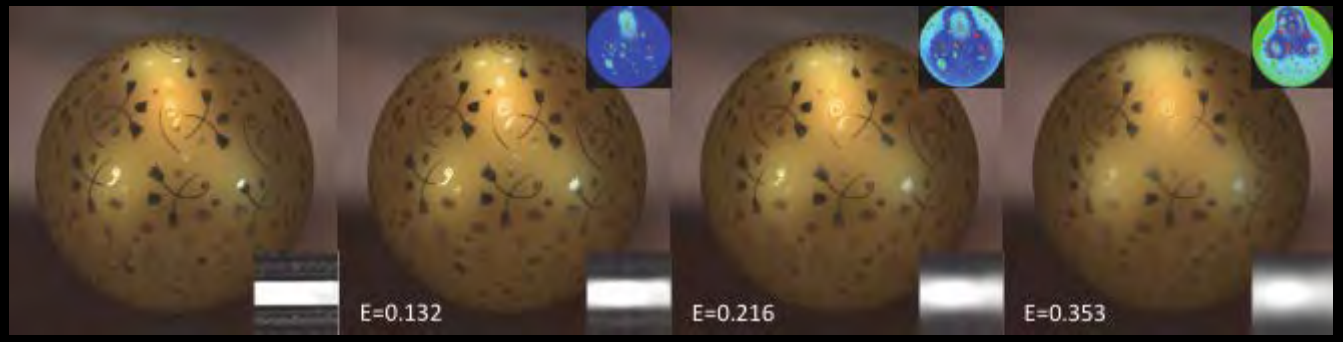
Results

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



Robustness - lighting

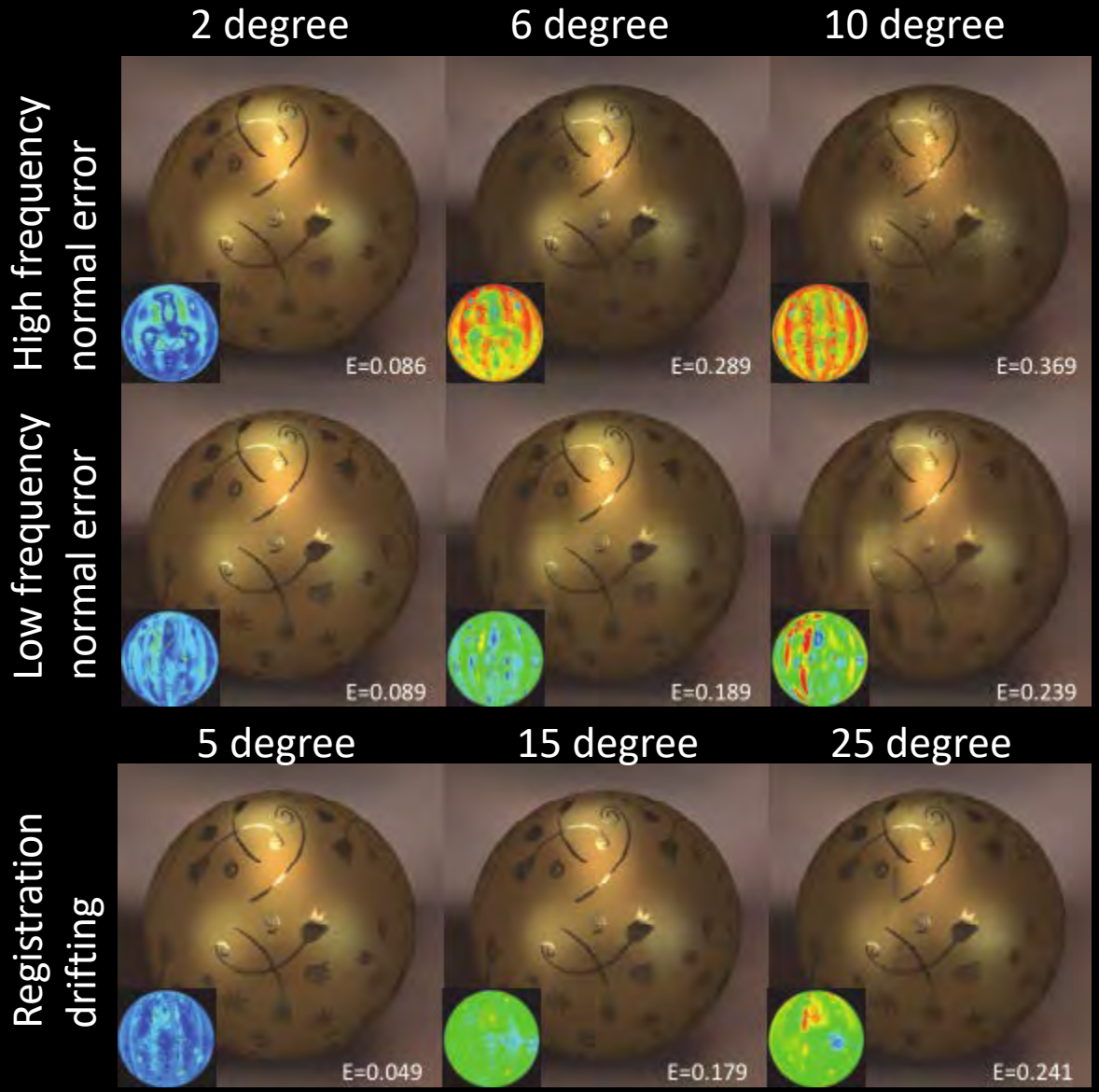
- Blurred light



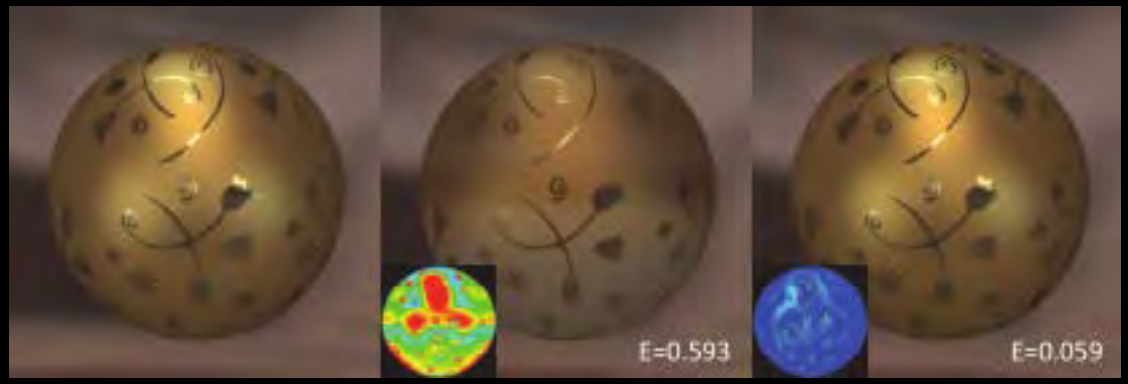
(a) Reference (b) σ=0.04 (c) σ=0.08 (d) σ=0.12

- Consistency with different lighting

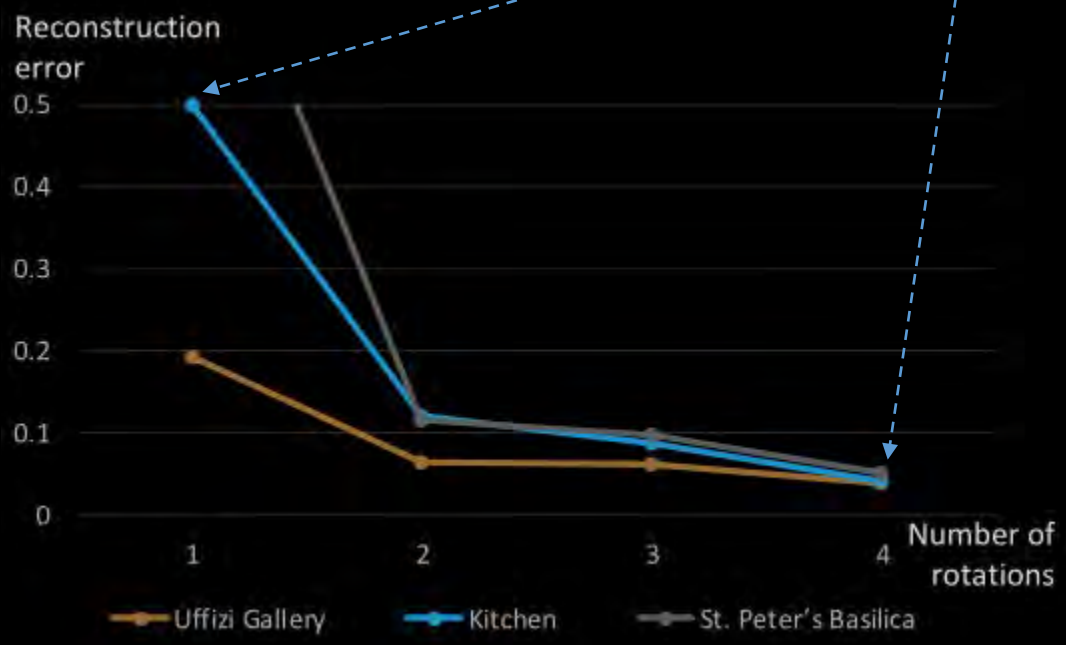
Robustness - geometry



Robustness - motion



Reference 1 rotation 4 rotations



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

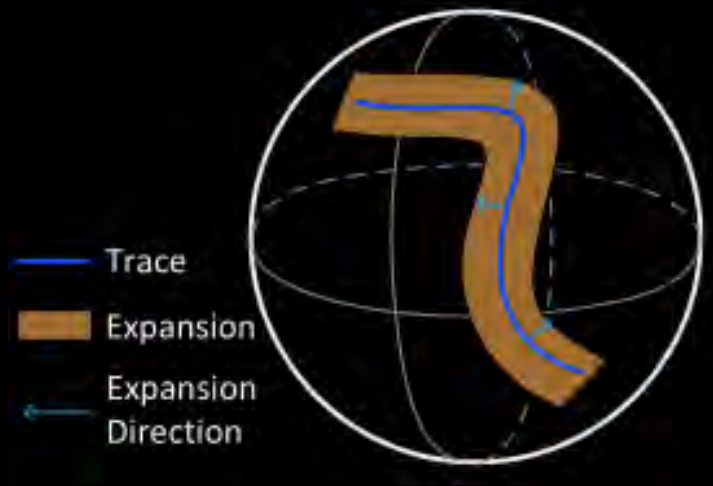
- Reviewers for constructive feedback
- Funding agency
  - Pieter Peers was partially funded by NSF grants IIS-1217765, IIS-1350323, and a gift from Google
- Dataset
  - HDR probe by P. Debevec
  - MERL/MIT dataset by W. Matusik et. al.
  - Mitsuba renderer

Robustness

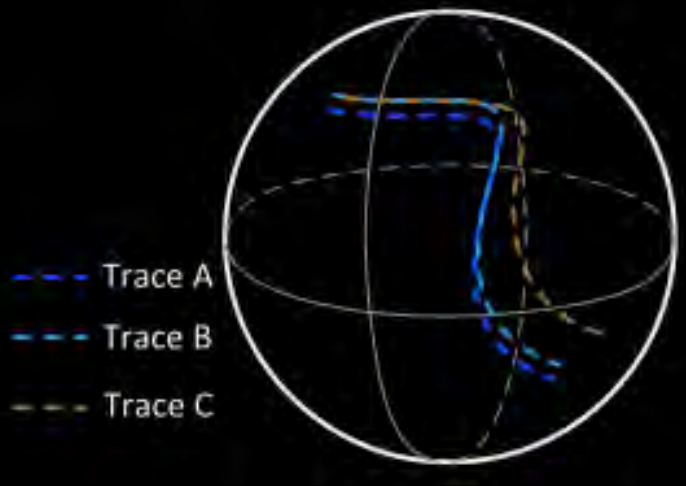
- Lighting
  - Contrast of the discontinuity
  - Smoothed light source
- Rotation
  - Every pixel cross discontinuity 2-4 rotation
- Geometry
  - Normal error < 2 degree
  - Registration error < 15 degree

Initialization

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



Trace expansion



Trace intersection

Key challenge

- Ambiguity between lighting / BRDF