The 5th Eurographics Workshop on Material Appearance Modeling: Issues and Acquisition

Experimental Analysis of BSDF Models

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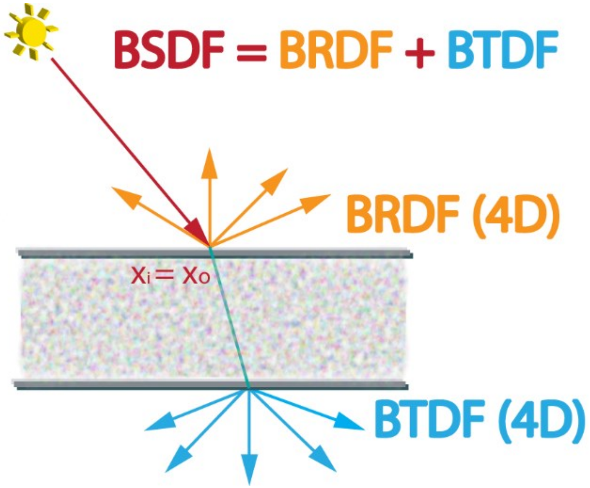
Introduction

- *Optically thin, translucent materials, such as papers, glasses and daylight redirecting films, are represented by Bidirectional Scattering Distribution Functions (BSDFs) [NRH*77].*

- *The BSDF is a sum of Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Transmittance Distribution Function (BTDF) [NRH*77], therefore it represents both light reflection and light transmission of translucent materials.*



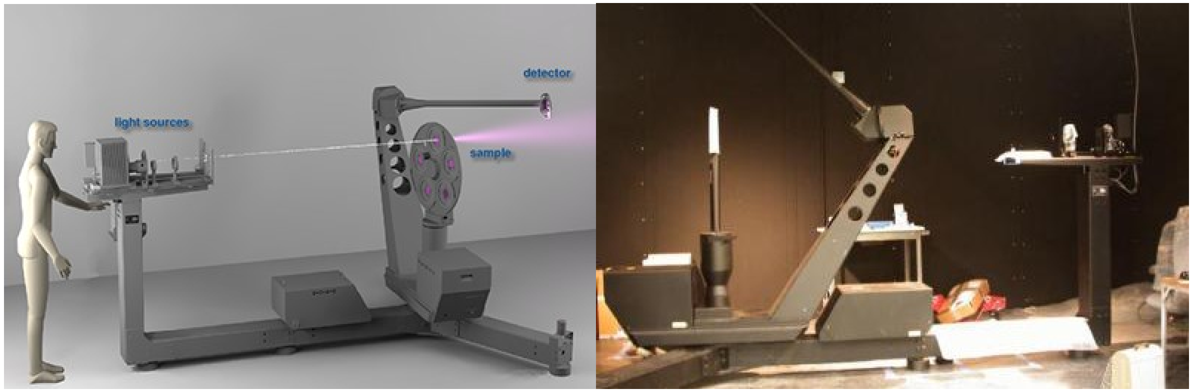
Introduction

Walter et al. [WMLT07]
A Microfacet-Based BSDF Model

Ward et al. [WKB12]
A Data-Driven BSDF Representation

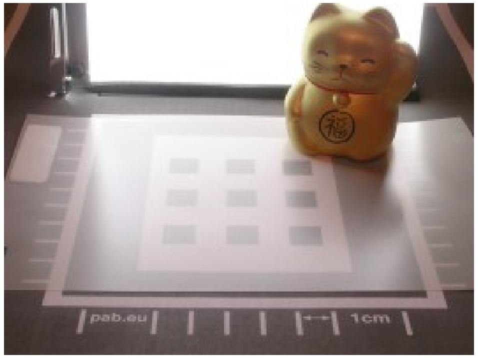
Problem: Finding Anisotropic BSDF Measurements

Introduction



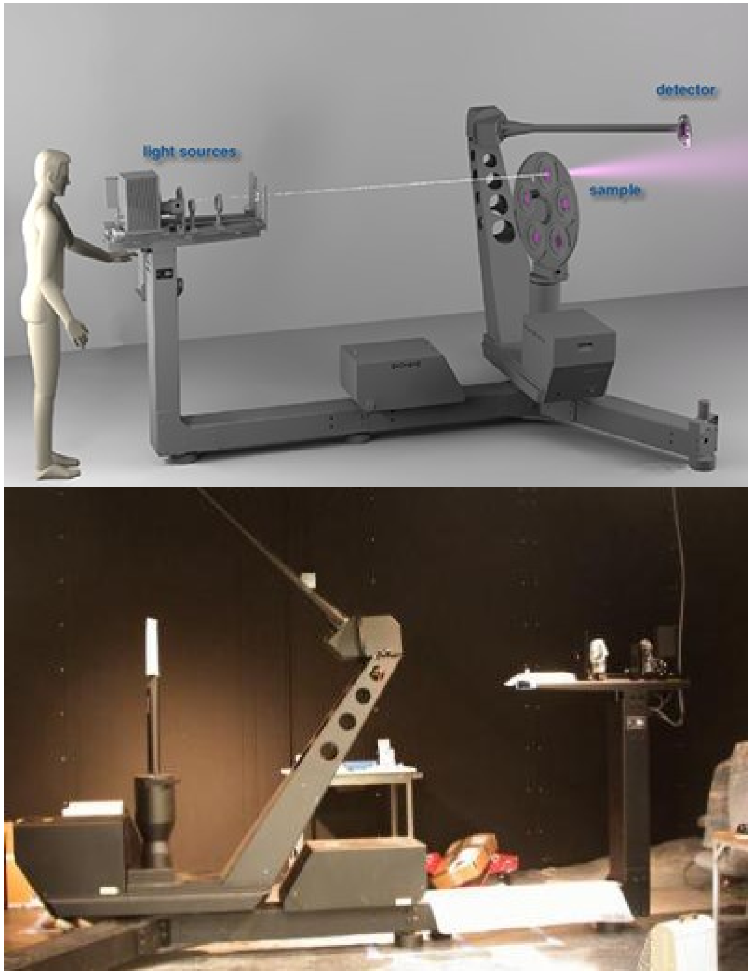
Apian-Bennewitz [AB14]

pgII gonio-photometer

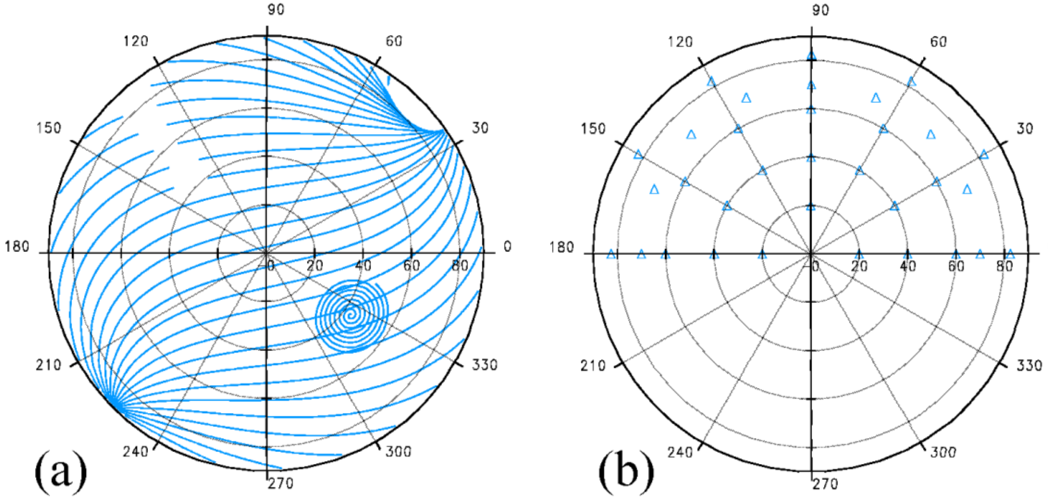


Problem: Finding A Large BSDF Database

BSDF Data Set and Acquisition



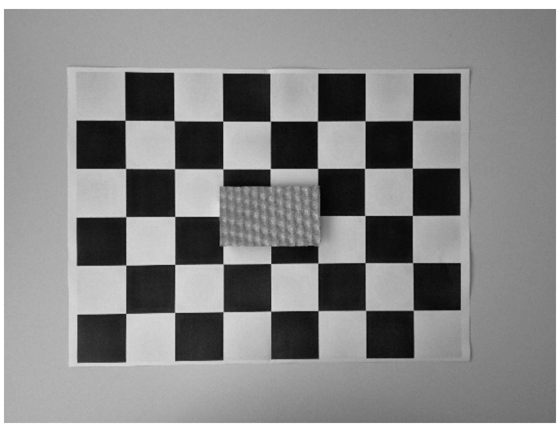
Apian-Bennewitz [AB14]
pgII gonio-photometer



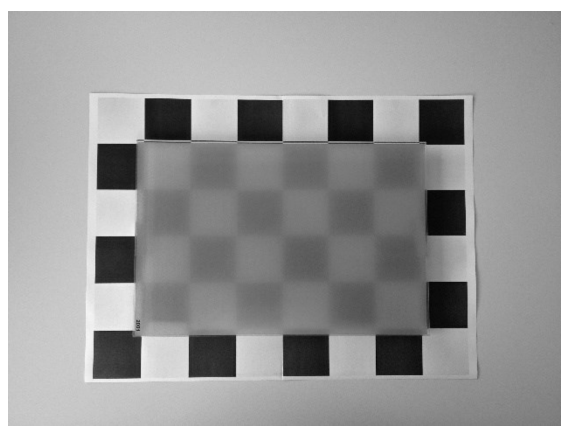
(a) Outgoing directions, (b) Incoming directions
pgII gonio-photometer

BSDF Data Set and Acquisition

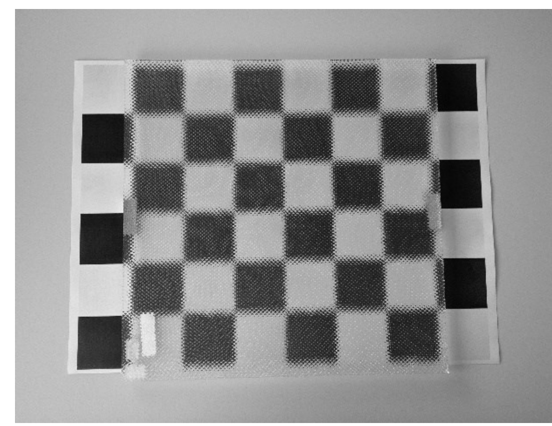
Real photographs from our ***pgII gonio-photometer*** setup



Hunter douglas material

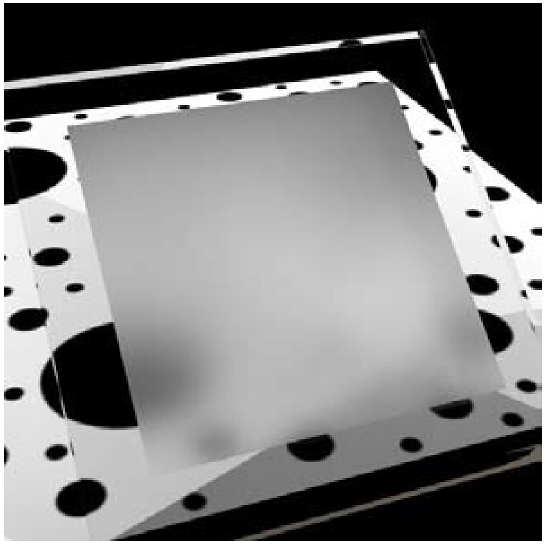


Orange glass material



Structured glass material

BSDF Models



Walter et al. [WMLT07]
A Microfacet-Based BSDF Model

Ward et al. [WKB12]
A Data-Driven BSDF Representation

- *These BSDF models differ in their degrees of freedom and goals, and we focus on the numerical ability to fit our measured BSDF data, computation times and storage needs.*

Walter et al. BSDF Model

- *Walter et al.'s [WMLT07] BSDF model can be formalized as:*

$$f(\omega_i, \omega_o) = \frac{k_d}{\pi} + k_{sr} \frac{F(\omega_i, \omega_{hr}, f_{0r}) G(\omega_i, \omega_o, \omega_{hr}, \alpha_r) D(\omega_{hr}, \alpha_r)}{4|\omega_i \cdot \omega_n||\omega_o \cdot \omega_n|}$$

$$+ k_{st} \frac{|\omega_i \cdot \omega_{ht}||\omega_o \cdot \omega_{ht}|}{|\omega_i \cdot \omega_n||\omega_o \cdot \omega_n|} \times \frac{\eta_o^2 (1 - F(\omega_i, \omega_{ht}, f_{0t})) G(\omega_i, \omega_o, \omega_{ht}, \alpha_t) D(\omega_{ht}, \alpha_t)}{(\eta_i (\omega_i \cdot \omega_{ht}) + \eta_o (\omega_o \cdot \omega_{ht}))^2}$$

ω_i: *incoming light vector*

ω_o: *outgoing view vector*

$$\omega_{hr} = \frac{(\omega_i + \omega_o)}{\|\omega_i + \omega_o\|} : \textit{halfway reflection vector}$$

$$\omega_{ht} = \frac{-(\eta_i \omega_i + \eta_o \omega_o)}{\|\eta_i \omega_i + \eta_o \omega_o\|} : \textit{halfway transmission vector}$$

k_d, k_{sr}, k_{st}: *diffuse, specular reflection and specular transmission coefficients*

η_i, η_o: *index of refraction for the incident and the transmitted side of the surface*

α_r, α_t: *width parameter for the incident and the transmitted side of the sur*

f_{0r}, f_{0t}: *Fresnel coefficient for the incident and the transmitted side of the ce*

Walter et al. BSDF Model

- *To compute Fresnel term, we use Schlick approximation [Sch94] as:*

$$F(\omega_i, \omega_h, f_0) = f_0 + (1 - f_0)(1 - (\omega_i \cdot \omega_h))^5$$

- *To compute $G(\cdot)$ term, we use Smith approximation as:*

$$G(\omega_i, \omega_o, \omega_h, \alpha) \approx G_1(\omega_i, \omega_h, \alpha) G_1(\omega_o, \omega_h, \alpha)$$

- *To compute $G_1(\cdot)$ and $D(\cdot)$ term, we use the following GGX distribution:*

$$D(\omega_h, \alpha) = \frac{\alpha^2 \chi^+(\omega_h \cdot \omega_n)}{\pi cos^4\theta_h (\alpha^2 + tan^2\theta_h)^2}$$

$$G_1(\omega, \omega_h, \alpha) = \chi^+\left(\frac{\omega \cdot \omega_h}{\omega \cdot \omega_n}\right) \frac{2}{1 + \sqrt{1 + \alpha^2 tan^2\theta}}$$

$\chi^+(a)$: *the positive function*

Walter et al. BSDF Model

- *We extend Ngan et al.'s [NDM05] fitting procedure to represent measured BSDFs by Walter et al.'s analytical BSDF model.*

- *We apply a constrained nonlinear optimization technique. We estimate:*

$\alpha_r, \alpha_t, \eta_o, \eta_i, f_{0r}, f_{0t}$: *nonlinearly by using a constrained minimization algorithm*

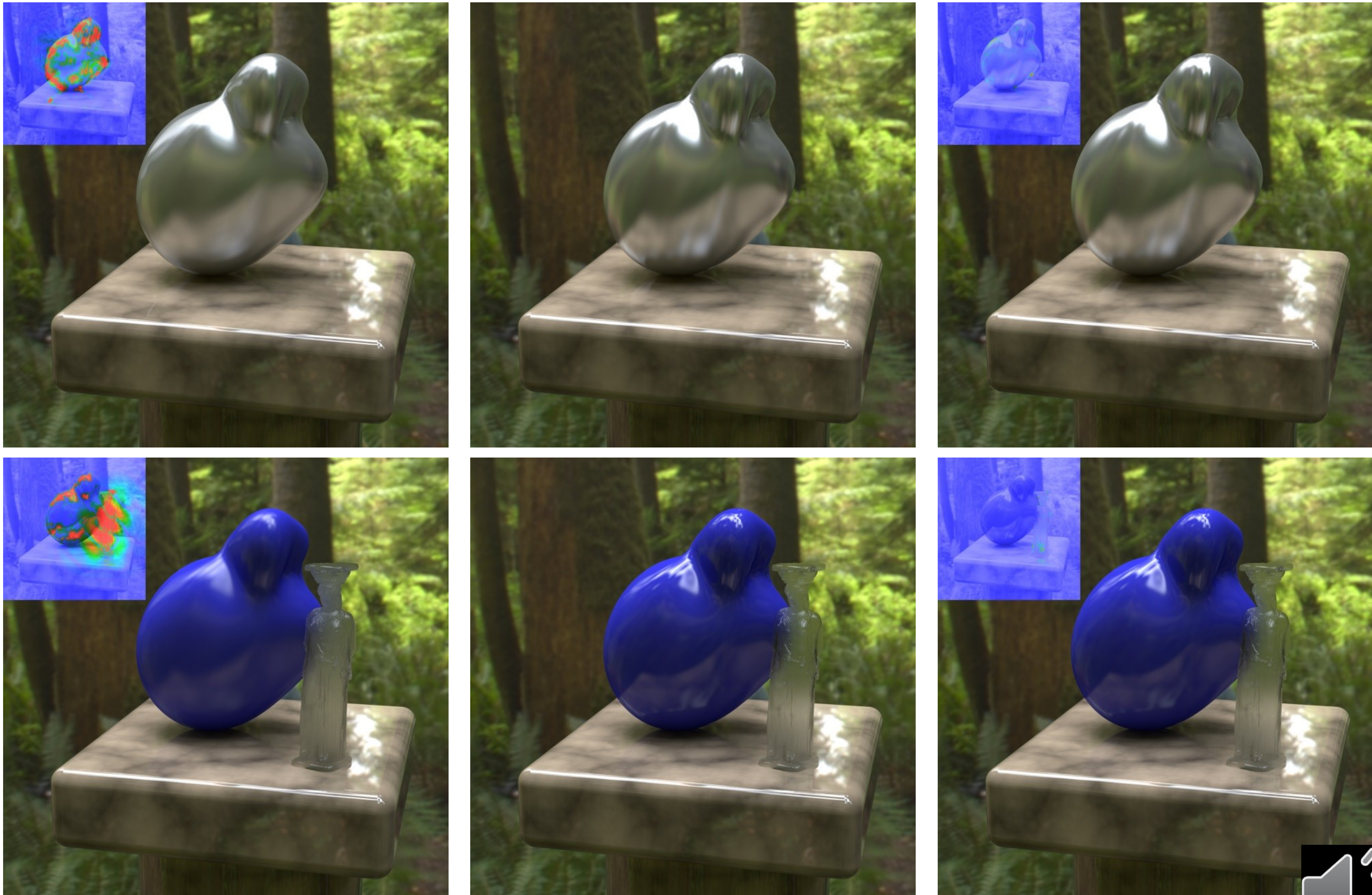
k_d, k_{sr}, k_{st}: *computed analytically as a subprocedure based on a linear least square optimization*

- *To optimize fitting results for finding a global minimum, we restart the optimization with a different set of initial guesses and we take a set of parameters which leads the minimum L^2 error.*

Ward et al. BSDF Representation

- *Ward et al. [WKB12] proposed an XML representation and an Open Source C library to support BSDFs in rendering applications.*
  - *It allows for the efficient representation, query and Monte Carlo sampling of real-world BSDFs in a model-free framework.*
  - *It includes two data-driven BSDF representation.*
    - *Matrix-based BSDF representation.*
    - *Tensor tree BSDF representation.*
  - *It helps to handle advanced schemes such as Complex Fenestration Systems (CFSs).*
  - *Isotropic BSDF data is represented in* $(\theta_i, \theta_o, \phi_{diff} = \phi_o - \phi_i)$ *parameters, anisotropic BSDF data is represented* $(\theta_i, \phi_i, \theta_o, \phi_o)$ *parameters.*

Ward et al. BSDF Representation



Matrix-based BSDF representation

Reference image

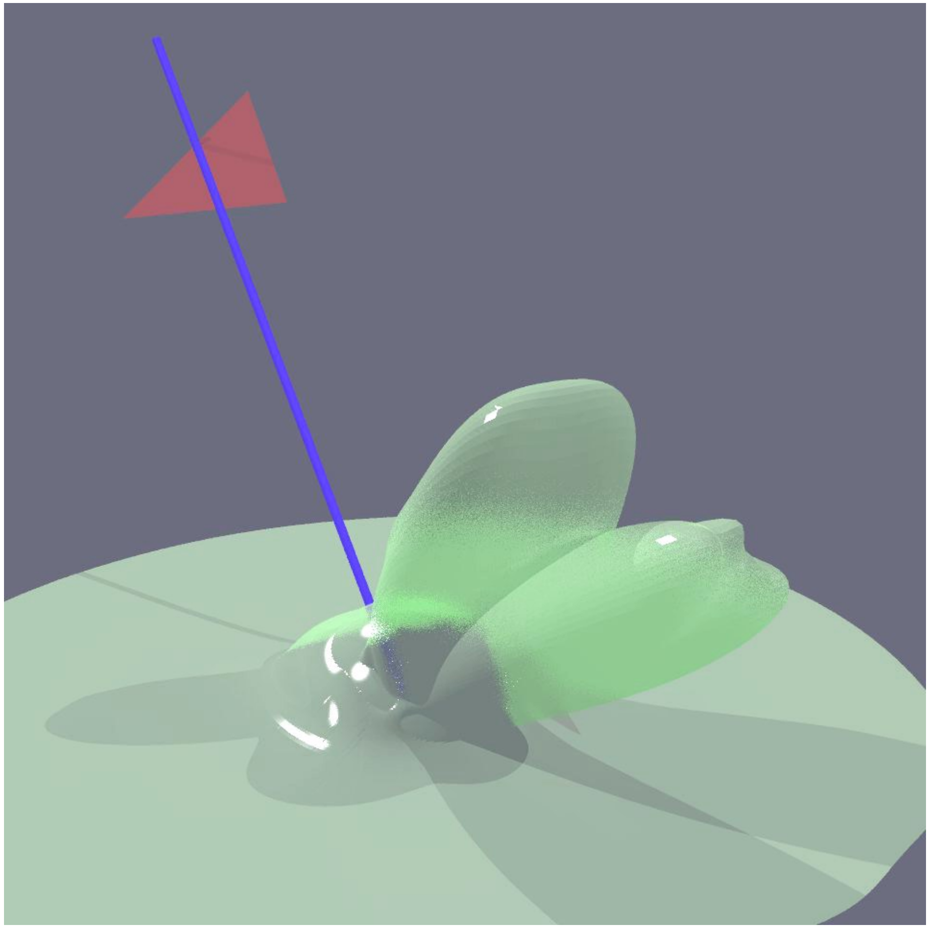
Tensor tree BSDF representation

Ward et al. BSDF Representation

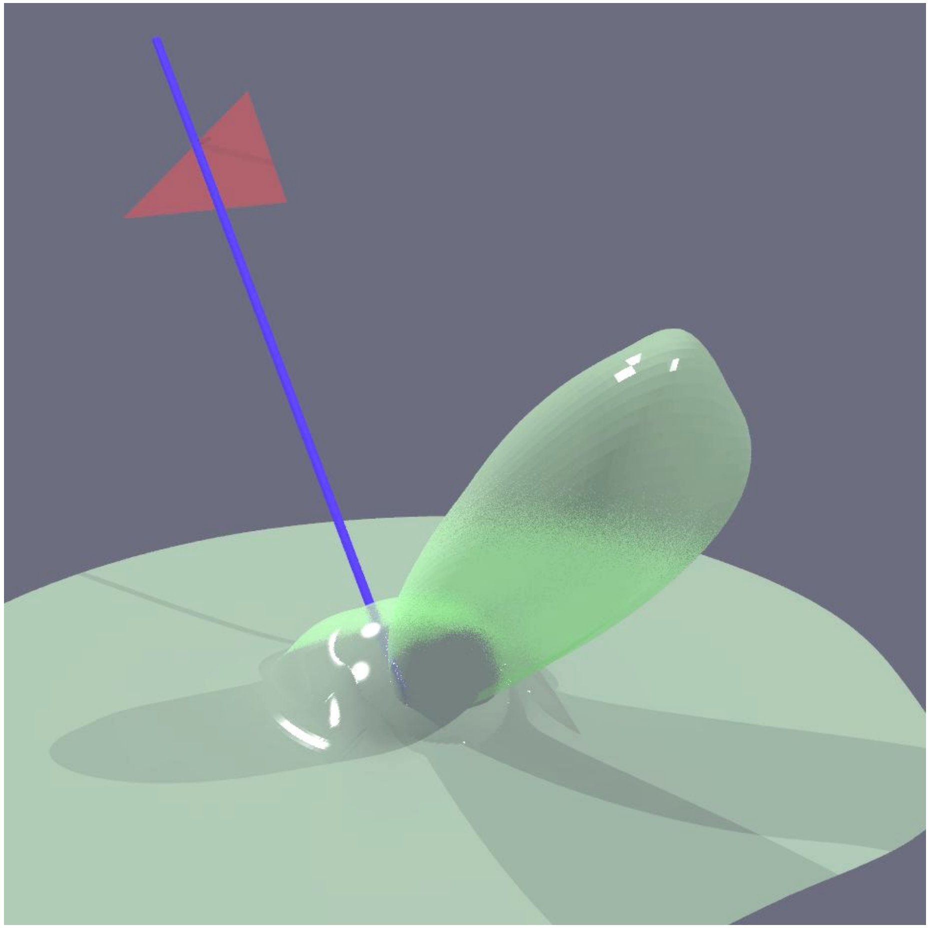
- *Since our BSDF measurements are sparse and irregular, we need to fill these BSDF measurements accurately to be able to represent them with Tensor tree BSDF representation.*

- *In this work, we use Ward et al.'s [WKB14] Lagrangian based interpolation technique for filling our sparse set of incident angle measurements. It includes three steps:*
  - *For each incident direction, measured BSDF values are fitted by a sum of Gaussian lobes.*
  - *A spherical Delaunay triangulation of the incident directions are constructed.*
  - *For each edge of the triangulation, a transport plan is computed for shifting Gaussian lobes in the first vertex to Gaussian lobes in the second vertex.*

Ward et al. BSDF Representation



Linear interpolation



Ward et al.'s [WKB14] Lagrangian mass transport based interpolation

Experimental Results

- *To investigate abilities of BSDF models, we used our BSDF measurements and BSDF measurements from BME database [AB14].*

- *The nonlinear parameters of Walter et al. [WMLT07] BSDF model is estimated by using* `fmincon` *[WMNO11] function in MATLAB library.*

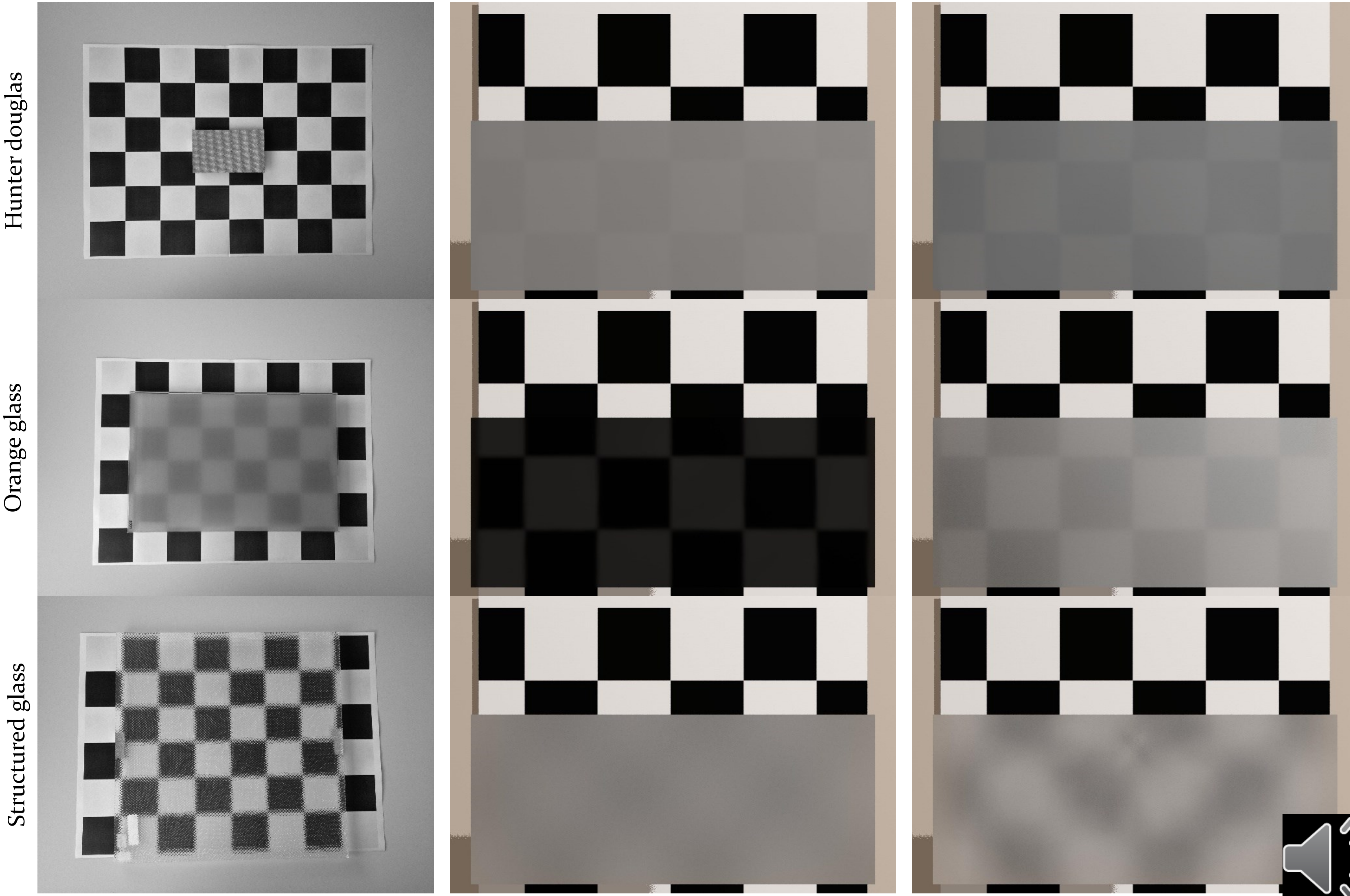
- *We optimize L^2 errors [NDM05] in this fitting procedure, and linear parameters are estimated as a subprocedure based on a linear least square optimization.*

Experimental Results

- *To represent BSDF measurements with Ward et al. [WKB12] Tensor tree BSDF representation, we first interpolated it by Ward et al. [WKB14] interpolation technique.*

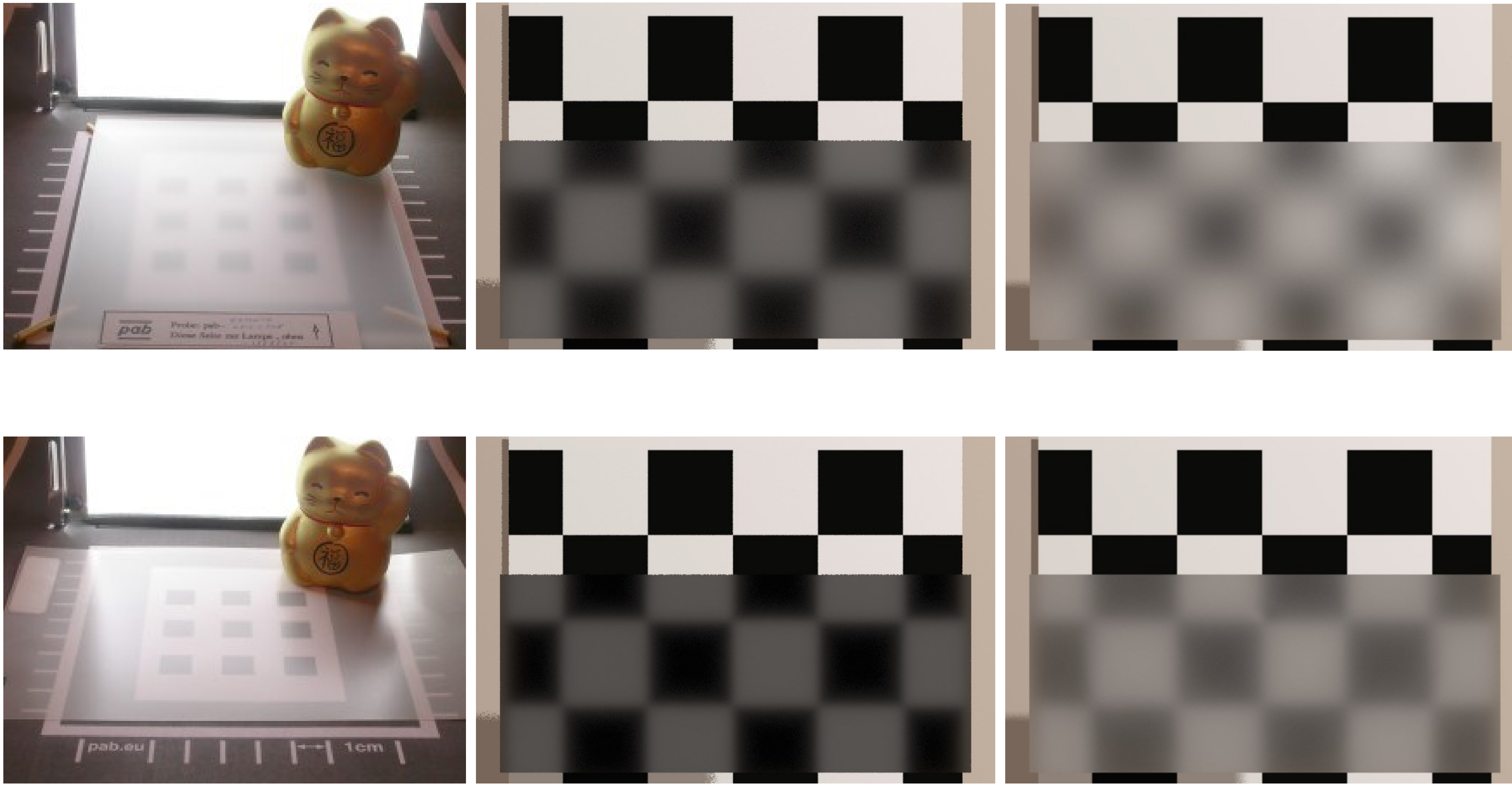
- *To simulate both Walter et al.'s BSDF model and Ward et al.'s interpolation technique in RADIANCE [LS98], tensor tree BSDF representations are constructed by using* `bsdf2ttree` *function in RADIANCE.*

Experimental Results



(a) Photograph (b) Walter et al. [WMLT07] (c) Ward et al. [WKB12]

Experimental Results



(a) Photograph (b) Walter et al. [WMLT07] (c) Ward et al. [WKB12]

Experimental Results

Material Name	Measured	Walter et al. [WMLT07]	Ward et al. [WKB12]
Hunter douglas	257MB	0.25MB	23.7MB
Orange glass	158MB	0.28MB	18.6MB
Structured glass	195.8MB	0.76MB	20.6MB

Table 1: Required storage spaces of BSDF measurements and BSDF representations for various materials.

- *On a 4-core laptop, average computation times of Walter et al.'s BSDF model and Ward et al.'s BSDF interpolation technique are 12 minutes, and 46 minutes, respectively.*

Conclusions

- *We measured BSDF data from 3 different optically thin, translucent materials, and made experimental analysis on these BSDF measurements and BSDF measurements from BME database by representing them with various BSDF models.*

- *We have shown that compared to Walter et al.'s BSDF model, Ward et al.'s data-driven BSDF representation provides more accurate representations, while it requires ~60× storage needs and ~4× computation times.*

- *We're planning to make publicly available our BSDF measurements and fitting results for giving a start to construct a huge BSDF database.*

Thank You...

Thank You