Toward Efficient Capture of Spatially Varying Material Properties

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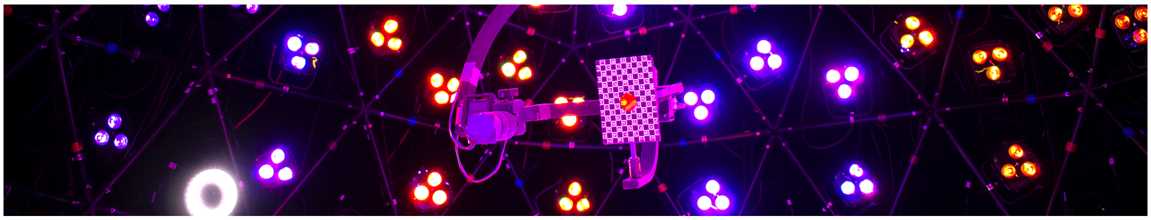

Figure 1: Part of our physical system of highly controllable lights, cameras, and sample orientation.

ABSTRACT

Improvements in the science and art of computer-graphics rendering, particularly with a shift in recent decades toward more physically driven models in both real-time and offline rendering, have motivated improvements in material models. However, real-world materials are often still significantly more complex in their observable light scattering than current shading models used to represent them in renderers. In order to represent these complexities at higher visible fidelity, improved methods for material acquisition and representation are desired, and one important area of continued study is capture and representation of properties of spatially varying physical materials. We present developing efforts toward acquiring and representing those spatially varying properties that build on recent work concerning parameterization techniques to improve the efficiency of material acquisition.

CCS CONCEPTS

• **Computing methodologies → Reflectance modeling**.

KEYWORDS

Appearance Modeling, Reflectance & Shading Models

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1 INTRODUCTION

Material acquisition (or capture) refers to using measurements of light scattering upon interaction with a surface that can inform mathematical or data-driven shader models and estimate a Bidirectional Scattering Distribution Function (BSDF), or in the case of opaque materials, a simpler reflectance model (BRDF) [Guarnera and Guarnera 2018]. Motivated by improvements in importance sampling for path-tracing, Dupuy and Jakob presented an efficient and adaptive data-driven method that estimates the Visible Normal Distribution Function (VNDF) [Heitz and d'Eon 2014] with a backscattering capture pass and uses that to better parameterize material acquisition sampling and storage [Dupuy and Jakob 2018]. It is however limited to non-spatially varying materials.

Here we present work in progress towards efficient capture and representation of spatially varying material scattering. Questions we are investigating and discuss here include: (1) How feasible is it to do VNDF estimation on multiple, related materials on a surface (such as differing patches on a butterfly wing – see Figure 2) captured simultaneously? (2) What adjustments to the backscattering technique would aid in this? (3) What are methods for efficient sampling after VNDF estimation? and (4) What are methods for efficient representation of possibly related materials?

2 BACKGROUND AND RELATED WORK

A variety of methods of modeling appearance have been proposed and have grown in complexity both to leverage more capable rendering hardware and to adopt techniques from the maturing field of computer graphics. Surveys by [Weyrich et al. 2008] and [Guarnera and Guarnera 2018] comprehensively cover material-model parameterizations and appearance-capture systems. Models include isotropic and anisotropic BRDFs, transmission and therefore scattering (BSDFs), spatially varying versions (SVBSDFs), and wavelength-dependent functions. Predominant recent efforts for estimating SVBRDFs have focused on convenient, simplified approaches using single-shot, mobile-device photography and deep-learning algorithms to infer material properties [Deschaintre et al. 2019] rather than accurate, detailed capture of scattering values across a surface.

[Dupuy and Jakob 2018] proposed a new parameterization paired with a goniophotometer-based system for capturing and representing BRDFs of non-spatially varying materials. A key component of this method is utilizing a smaller capture of retroreflective (where light and viewing directions are the same) response of a material

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sample in order to estimate the VNDF of a microfacet BRDF model. The VNDF is then used for generating a series of directions for gathering a meaningful set of reflectance data without the need for more dense angular sampling in areas of low information.

Figure 2: A spatially varying sample, a *Battus philenor* butterfly wing, at various lighting and viewing directions.

At some scale nearly all materials could be better represented by SVBRDFs, and even at current practical scales of rendering, many materials necessitate such a representation (hence the use of multiple layers of a variety of "texture" maps to control properties over a surface in current computer-graphics production workflow). We build on the methods presented in [Dupuy and Jakob 2018] with the goal of capturing spatially varying properties and eventually transmission as well; these in turn can facilitate studying scattering from complex phenomena such as feathers [Baron et al. 2022].

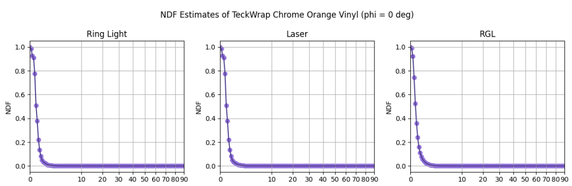

Figure 3: NDF estimation from backscattering measurements.

3 APPROACH AND DISCUSSION

A large, custom Variable Illumination Sphere (VarIS) with hundreds of RGBW lights is used for generating incident light directions with one or more camera sensors for view sampling. An actively controlled, rotating stage enables dense angular sampling. High-resolution, no-optical-low-pass-filter (OLPF) camera sensors and spatial registration enable capture of a spatially varying material sample. This is currently RGB-based, but we are investigating mechanisms to augment the system for capturing more spectral bins. VarIS can potentially leverage optimizations such as parallel, multi-viewpoint capture. A 532nm green laser similar to that in [Dupuy and Jakob 2018] is employed to replicate the backscattering procedure for estimation of the material's Normal Distribution Function (NDF), using a similar set of 128 angular samples around the surface normal. We are also testing a lens-based ring light, which in early work compares well with the laser-based procedure, but can be used to illuminate a larger surface sample where properties may spatially vary versus an assumed single-response point of a material. Figure 3 shows NDF estimations for "chrome orange" from practical retroreflection captures using the ring light and laser as well as data from the original RGL dataset [Dupuy and Jakob 2018].

NDF estimation is followed by VNDF "sampling" for determining a configuration of pairs of incident and viewing directions for a full material capture. We are also comparing a similar procedure but fitting parameters of the widespread GGX NDF model based on the estimated NDF data and using those parameters for sampling the GGX VNDF according to [Heitz 2018]. The resulting directional pairs are mapped to stage axis rotations and indices of the RGBW light devices in our physical system VarIS.

Figure 4 shows a test of our first theoretical (ahead of practical) implementation via a synthetic appearance-capture environment using renders of original material data from [Dupuy and Jakob 2018] with PBRT v4 [Pharr et al. 2023]. The figure compares sampling the adaptive VNDF data in our implementation, sampling the GGX VNDF using NDF-fitted parameters, and the original RGL approach. We are working to improve our interpolation methods, investigate other possible discrepancies, test our practical implementation fully, and compare the adaptive-VNDF and GGX-VNDF sampling methods over a variety of real-world materials.

Figure 4: Simulated renders of "cc_ibiza_sunset" material while rebuilding techniques (model by Yasutoshi Mori).

Ultimately the system will support full scattering (BSDF) capture. Our physical system easily permits gathering transmission data, but additional theory around a transmission NDF term will need to be developed. We will also fully utilize the photograph-based system and perform statistical analysis throughout the adaptive pipeline to find regions of interest and clusters that represent spatially varying features for material capture and sampling.

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