A six-flux transfer approach for efficient layered materials rendering

Joël Randrianandrasana
University of Reims
Champagne-Ardenne
United Visual Researchers

Patrick Callet
MINES ParisTech

Laurent Lucas
University of Reims
Champagne-Ardenne

Figure 1: The model of Belcour [Belcour 2018] suffers from severe energy losses with scattering volumes due to its single-scattering approximation and its lack of support for back-scattering. Our transfer matrix approach overcomes these issues and provides results close to the ground-truth computed with Guo's stochastic approach [Guo et al. 2018]. In these examples, a unit depth non-absorbing medium with scattering coefficient σ_s = 0.755 and varying Henyey-Greenstein (HG) g parameters lies on top of a smooth gold substrate. HG g asymmetry parameter is respectively set to 0.9 and to 0 in the left and right inset.

CCS CONCEPTS

• **Computing methodologies → Reflectance modeling**.

KEYWORDS

BRDF, Layered materials, Transfer matrix

ACM Reference Format:
Joël Randrianandrasana, Patrick Callet, and Laurent Lucas. 2020. A six-flux transfer approach for efficient layered materials rendering. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Posters (SIGGRAPH '20 Posters), August 17, 2020*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3388770.3407453

1 INTRODUCTION

A multi-lobe approach was recently proposed to efficiently handle layered materials rendering [Belcour 2018] as an alternative to state-of-the-art accurate yet expensive approaches [Guo et al. 2018; Jakob et al. 2014]. To this end, the author introduces a low-order statistical representation for light-matter interactions and derives new *adding equations* for the framework. However, scattering volumes are poorly supported as the method does not account for back-scattering and resorts to single scattering approximations to avoid expensive *doubling* operations. In practice, this incurs severe energy losses yielding inconsistent dark appearances with increasing volume scattering (Fig. 1). Unfortunately, the adding equations introduced by the author can not be easily extended to handle both forward and backward propagating flux.

SIGGRAPH '20 Posters, August 17, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7973-1/20/08.
https://doi.org/10.1145/3388770.3407453

We overcome these limitations with an efficient solution based on the *transfer matrix*. Under this formalism, each scattering component of the stack (scattering volume and interface) is described through a lightweight matrix, layering operations reduce to simple matrix products, and total flux accounting for multiple scattering are obtained thanks to matrix operators.

2 OUR APPROACH

To achieve high fidelity appearances, we propose to isolate light having undergone one or more scattering events in a medium (secondary flux) from light not scattered by any medium of the structure (primary flux). Moreover, a significant amount of light might be scattered back with highly scattering media. Thus, we propose to split the secondary flux into forward and backward contributions. Accounting for the vertical directions of propagations in the structure, we thus describe the light distribution at any depth of the structure as a six-flux vector. The net balance relating the total flux sitting on each side of any component of the structure (or any combination of them) takes a general order-six matrix form for which generic multiple scattering operators are easily derived. We obtain the closed-form transfer matrix of a homogeneous participating medium by approximating the transport occurring in an infinitesimally thin slab and derive the matrix for any arbitrary depth with the exponential matrix method. In the case of an interface, the general transfer matrix further simplifies as no interaction happens between primary and secondary flux.

To compute the shapes of the outgoing lobes with the transfer matrix formalism, we further approximate each light-matter interaction in the structure as Henyey-Greenstein (HG) phase functions convolution as it reduces to simple asymmetry parameters product. In practice, this translates the (energy, mean, variance) statistical representation of the previous work [Belcour 2018] to a (energy, mean, asymmetry) representation. Participating media are easily handled as they are usually described with this function. In the case of interface components, we provide a simple analytical fit for GGX-based rough interfaces. Based on this representation, we compute the shapes of the outgoing primary and secondary flux due to a layer of the stack as weighted sums of HG lobes. Thanks to HG convolution properties, the asymmetry of the resulting lobes can be computed with the same transfer matrix formalism and multiple scattering matrix operators.

Starting from the incident medium, we approximate the BRDF of the stack as a mixture of forward and backward GGX lobes sharing the same mean directions following the same iterative approach than previous work [Belcour 2018].

3 RESULTS AND FUTURE WORK

Our approach handles stacks of rough interfaces with visual results comparable to state-of-the-art efficient methods [Belcour 2018]. While the latter suffers from drastic energy losses, our approach provides results close to the ground truth, even with strongly backscattering media (Fig. 1). As a downside, our approach incurs additional computational costs mainly due to the order-six matrix products and additional lobes calculus. While stochastic approaches [Guo et al. 2018] introduce significant variance and computation cost with increasing volume scattering, the six-flux approach provides high fidelity results with a low sample budget. As the main limitation, only isotropic interfaces are currently supported due to the underlying HG representation. Future work will investigate if the approach is suitable for interactive rendering on the GPU.

REFERENCES

Laurent Belcour. 2018. Efficient rendering of layered materials using an atomic decomposition with statistical operators. *ACM Transactions on Graphics (ToG)* 37, 4 (2018), 73.

Yu Guo, Miloš Hašan, and Shuang Zhao. 2018. Position-free Monte Carlo simulation for arbitrary layered BSDFs. *ACM Transactions on Graphics (ToG)* 37, 6 (2018), 1–14.

Wenzel Jakob, Eugene d'Eon, Otto Jakob, and Steve Marschner. 2014. A comprehensive framework for rendering layered materials. *ACM Transactions on Graphics (ToG)* 33, 4 (2014), 118.