A six-flux transfer approach for efficient layered materials rendering

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A SIX-FLUX TRANSFER APPROACH FOR EFFICIENT LAYERED MATERIALS RENDERING

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PROBLEM

Many objects of our everyday life include scattering volume layers (dust deposition, weathering, pigments, ...). While layered materials composed of rough interfaces are well handled by state-of-the-art efficient rendering approaches, participating media layers remain poorly supported. In practice, this incurs severe energy losses yielding inconsistent dark appearances with increasing volume scattering.

RELATED WORK

Accurate solutions: Highly accurate methods have been proposed in recent years. However, these approaches reveal impractical for low-time budget rendering due to expensive per-material precomputations [1] or because of additional variance due to their stochastic nature [2].

Efficient methods: Belcour [3] recently introduced a low computation cost multi-lobe approach. 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. Unfortunately, the framework introduced by the author can not be easily extended to handle both forward and backward propagating flux and scattering volumes of arbitrary depths.

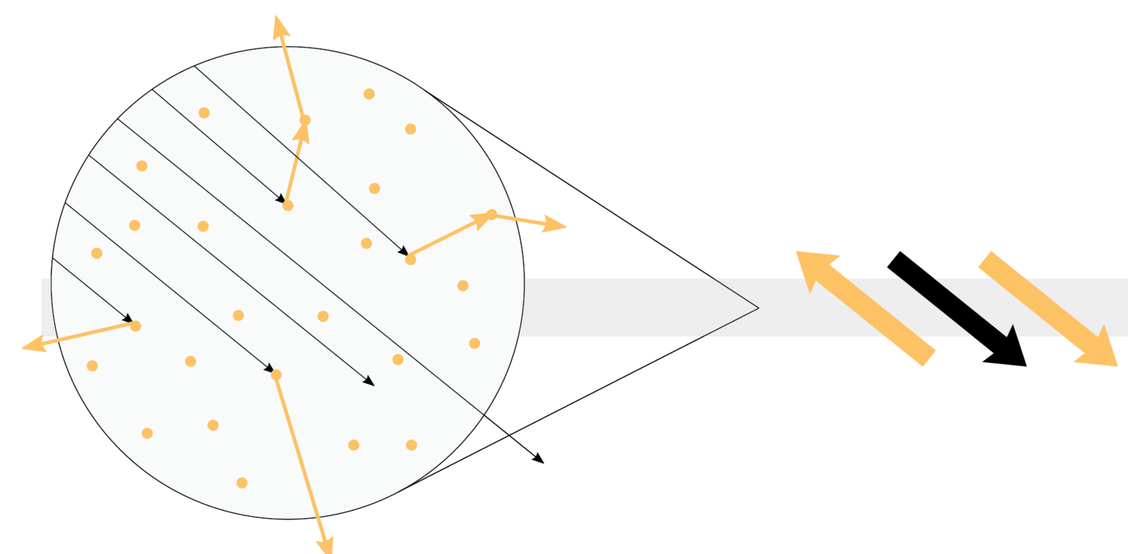
OVERVIEW

We overcome these limitations with an efficient solution based upon a transfer matrix modeling. Under this formalism, each 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.

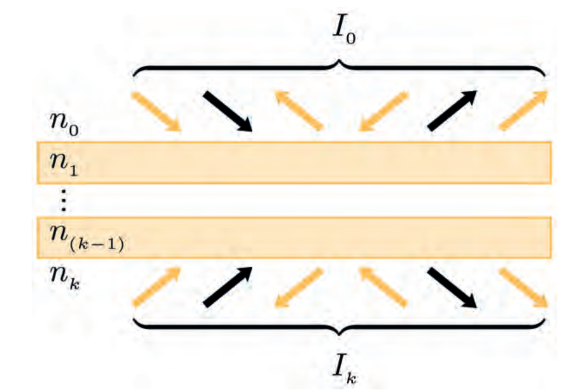
To be fully compliant with the matrix formalism, we propose to approximate light-matter interactions within the structure with Henyey-Greenstein (HG) phase function convolution products as they reduce to simple asymmetry parameters multiplications.

THE SIX-FLUX 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 in the structure (primary flux). Moreover, as a significant amount of light might be scattered back with scattering media, we propose to split the secondary flux into forward and backward contributions.



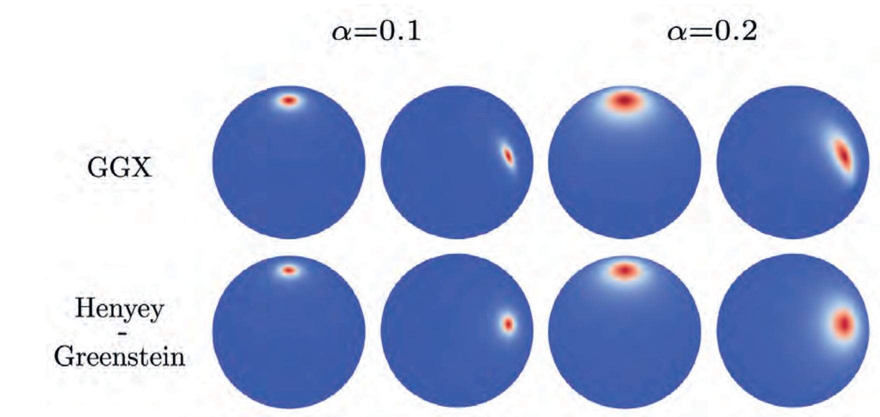
Accounting for the upward and downward directions of propagations in the structure, we thus describe the light distribution at any depth of the structure as a six-flux vector. The net balance relating the total flux sitting on each side of any stack component of the structure (interface, volume layer, or any combination of them) takes a general order-six matrix form.



$$I_o = \overbrace{M_{01} \dots M_{(k-1)k}}^{M_{0k}} \; I_k$$

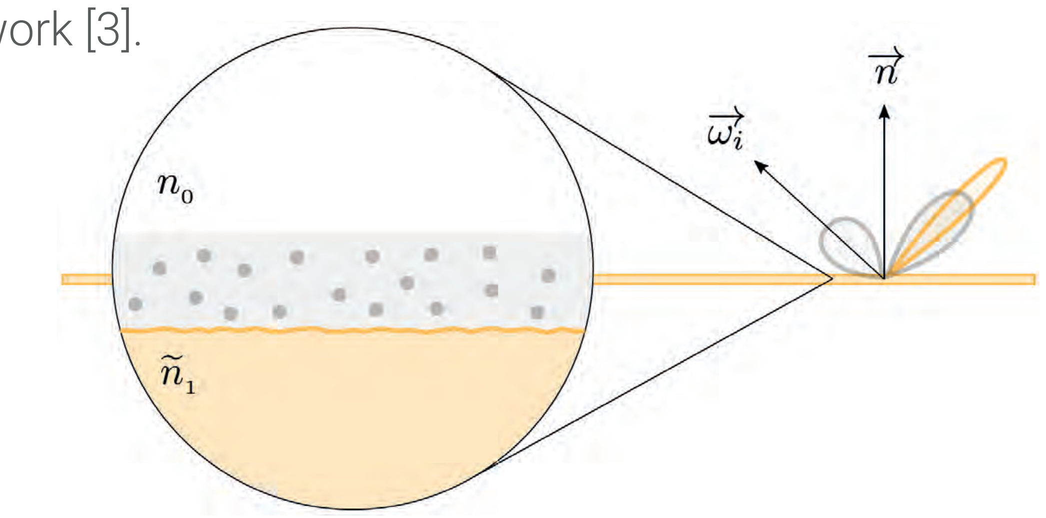
In this form, generic matrix operators for primary and secondary reflectances accounting for internal multiple scattering are easily derived based on the BRDF boundary conditions. We obtain the transfer matrix of a homogeneous participating medium by approximating the transport occurring in an infinitesimally thin slab and derive the matrix for any arbitrary depth with the exponential matrix method. In the case of an interface, the 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 HG phase functions convolution as they simply express as asymmetry parameters products. Thus, we describe each lobe through an (energy, mean, asymmetry) statistical representation. Participating media are naturally handled as they are usually described with this phase function. In the case of interface components, we provide a simple analytical fit for GGX-based rough interfaces.



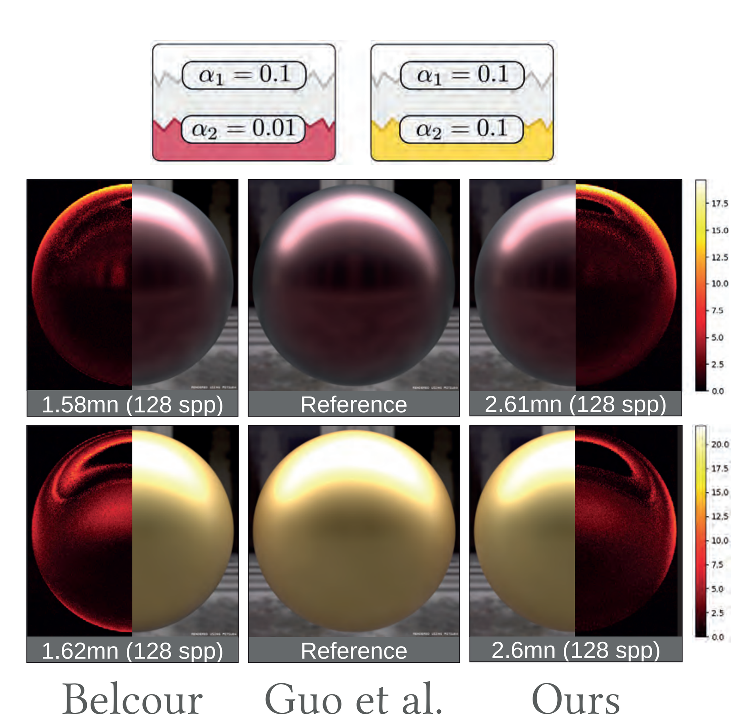
Based on this representation, we compute the shapes of the outgoing primary and secondary flux due to a layer of the stack as weighted sums of HG lobes. Thanks to HG convolution properties, the asymmetry parameters of the resulting lobes can be computed with the same transfer matrix formalism and multiple scattering matrix operators.

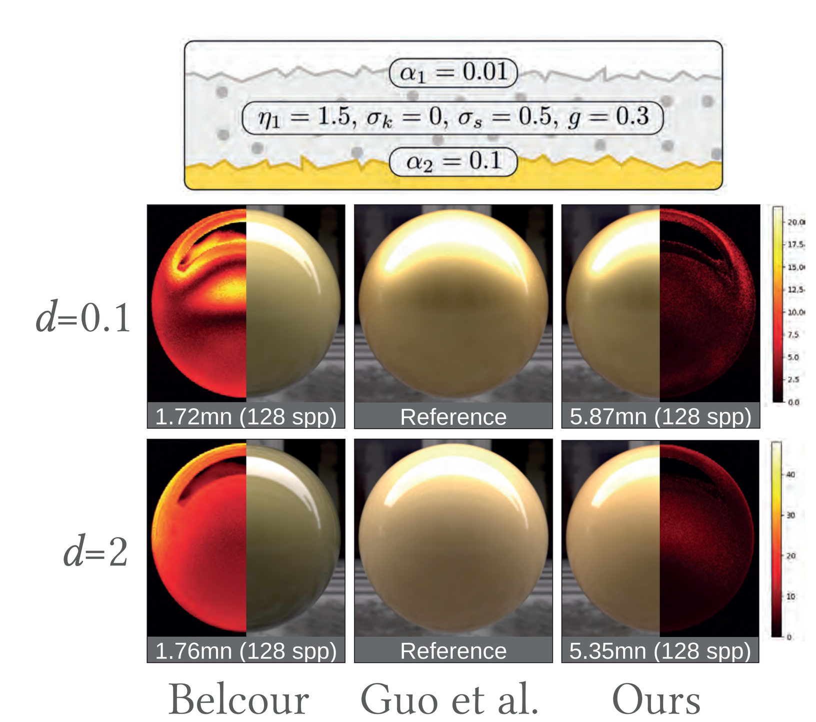
Starting from the incident medium, we approximate the BRDF of the stack as a mixture of forward and backward GGX lobes sharing the same mean directions following the same iterative approach than previous work [3].

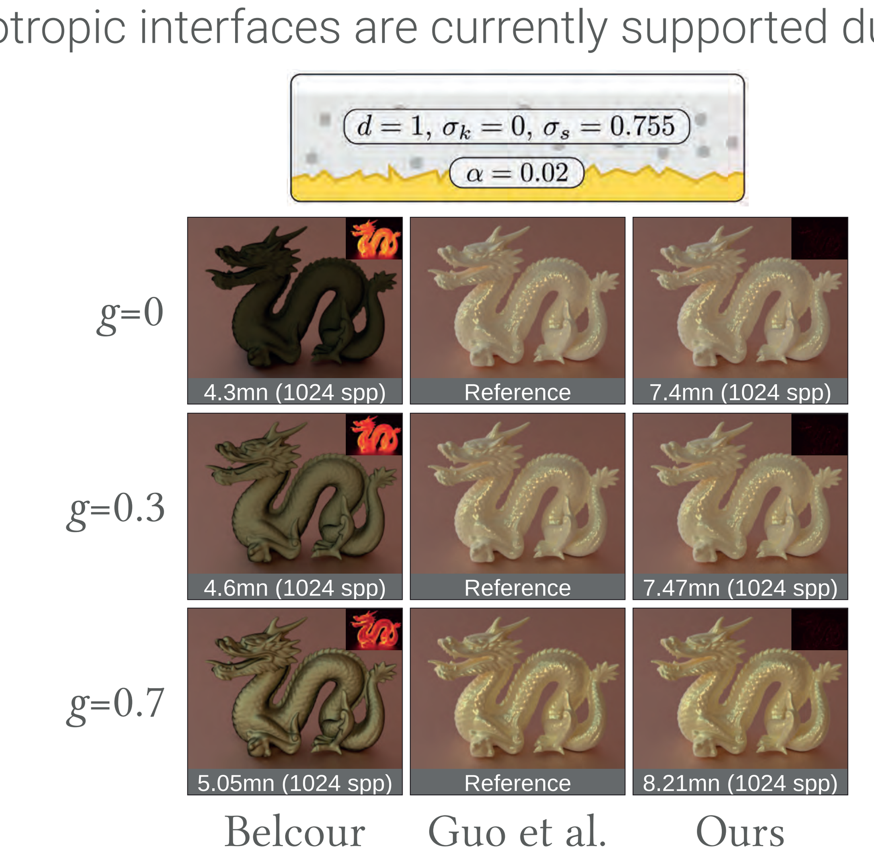


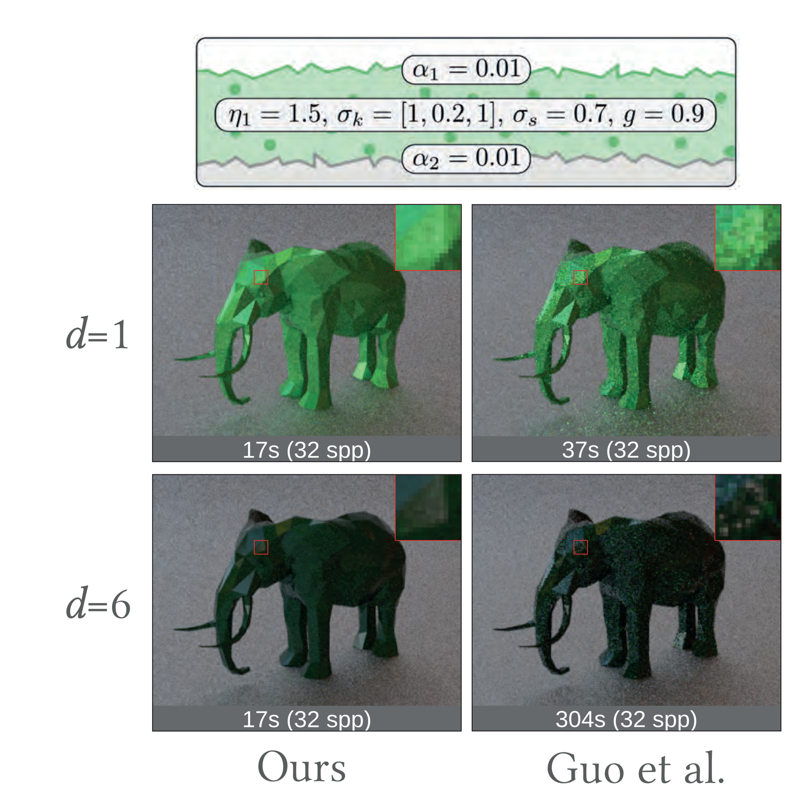
RESULTS

We implemented our approach in the Mitsuba renderer. All the results shown in this section use the path integrator. Our approach handles stacks of rough interfaces with visual results comparable to state-of-the-art efficient methods [3]. While the latter suffers from drastic energy losses, our approach provides results close to the ground truth, even with strongly backscattering media. Additional computational costs are mainly due to the order-six matrix products and additional lobes calculus. While stochastic approaches [2] 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.









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