Workshop on Material Appearance Modeling (2014)
H. Rushmeier and R. Klein (Editors)

Linear Transport Theory and Applications to Rendering

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Abstract

In this talk, I will give an overview of one-dimensional Linear Transport Theory, which concerns itself with the study of random scattering and absorption processes and the inference of large-scale behavior from simple local scattering models. Research over the last 75 years has led to a rich toolbox of solution techniques for these types of problems, including Monte Carlo, Diffusion Theory, H-functions, Discrete Ordinates, and the Adding-Doubling method. I will give an intuitive overview of each of these techniques and discuss advantages and disadvantages. Following this, I will discuss how this problem is relevant to rendering, where it leads to a flexible and efficient method for rendering general layered materials.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture

1. Outline

Light transport simulations in computer graphics are typically conducted in the framework of linear transport theory [Cha60]. Given a local description of the relevant scattering laws, the objective is to solve for the equilibrium distribution of light. In this talk, I will focus on 1-dimensional transport theory developed to simulate light transport in the ocean or planetary atmospheres where the positional dependence of the problem can be reduced to the depth coordinate. This is a long-studied problem in statistical physics, where a rich toolbox of specialized numerical solution techniques has been developed over the last 75 years.

In the context of rendering, the main application of this theory is the derivation of BSDF models for layered materials. Many such models have been proposed for layered or coated structures of one kind or another [HK93, Sta01, EKM01, Pre02, WW07] but all are limited to particular special cases or lacking in terms of accuracy. There is a surprising lack of accurate computational models for scattering from any systems more complex than a single layer or a single interface. Even the simplest nontrivial system, of a single scattering medium bounded by a smooth interface, is only roughly approximated by standard BRDF models. A recent research effort [JDJM14] investigated a general system for computing arbitrary layered BSDFs with internal scattering. This talk is a high-level survey of tools from transport theory that can be used to construct such a system.

I will begin with a review of the 1D radiative transfer equation and Monte Carlo and diffusion-based solution approaches. Next, I will discuss the principle of invariance [Amb43] and radiative transfer solutions in terms of H-functions [Cha60]. To motivate the following techniques, I will present Stokes' classical analysis of a stack of glass plates [Sto60] and segue into the discrete space theory of radiative transfer [GH69]. This leads to the Discrete Ordinates [Cha60] and Adding-Doubling [vdH80] methods. Finally, I will mention some of the sparsity properties of the underlying matrices, and how they can be used to build a system that remains practical over a large range of model parameters.

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DOI: 10.2312/mam.20141295

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