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WBSDF for Simulating Wave Effects of Light and Audio

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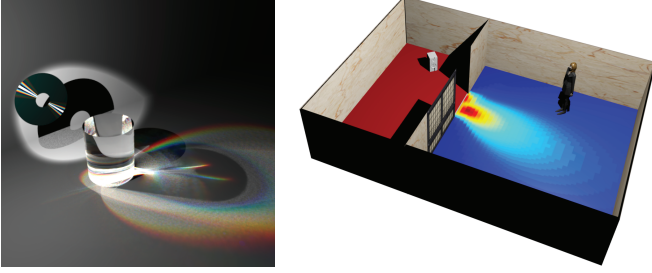


Figure 1: We propose the Wave BSDF (WBSDF) for rendering wave phenomena in light and audio. The WBSDF behaves as a local scattering function, while simulating interference globally, and allows for easy integration into traditional ray-based methods.

1 Introduction

Diffraction is a common phenomenon in nature when dealing with small scale occluders. It can be observed on biological surfaces, such as feathers and butterfly wings, and man-made objects like rainbow holograms. In acoustics, the effect of diffraction is even more significant due to the much longer wavelength of sound waves. In order to simulate effects such as interference and diffraction within a ray-based framework, the phase of light or sound waves needs to be integrated.

We introduce a novel method for creating Bidirectional Scattering Distribution Functions (BSDFs) that efficiently simulate diffraction and interference in light and sound in ray-based frameworks. The reflected or scattered radiance of a ray indirectly and independently encodes the mutual phase information among the rays, conveniently allowing for interference after multiple bounces. Previous work has described how to add local diffraction and interference effects to the Bidirectional Reflection Distribution Function (BRDF) [Stam 1999]. However, a traveling ray does not carry phase information and therefore is unable to interfere in a later stage. Our BSDFs, derived from the Wigner Distribution Function (WDF) in wave optics, abstract away the complexity of phase calculations. Traditional ray-based renderers, without modifications, can directly use these WBSDFs.

2 Wave Based BSDF

In optics, parallel waves are often described as a function of spatial frequency u and position x . Any wavefront can be subdivided in a series of parallel waves, each with its own spatial frequency. In the paraxial zone, where the observation is near the optical axis, this spatial frequency is related to the wavelength and the direction of rays, which is normal to the wavefront, as $u = (\sin \theta)/\lambda$. When a wave is transmitted or reflected it is transformed due to its microstructure.

As pointed out in previous research [Zhang and Levoy 2009; Oh et al. 2010], the light field L in position-angle space exhibits similar properties as the Wigner Distribution Function (WDF) representation R in spatial-frequency space: $L(x, \theta) \sim R(x, (\sin \theta)/\lambda)$.

This transformation function for incoming and outgoing wavefronts in this space is 4D under the assumption of a thin element, which is calculated using the well-studied WDF:

$$W_t(x, u) = \int t\left(x + \frac{x'}{2}\right) t^*\left(x - \frac{x'}{2}\right) e^{-i2\pi x' u} dx', \quad (1)$$

where $t(x)$ is a complex function describing amplitude and phase variation of the wave due to the surface structure and $*$ denotes complex conjugate. Note that $W_t(x, u)$ may contain positive as well as negative real-valued coefficients. However, after integration of all incoming rays, for example in a camera aperture, its value – intensity – always becomes non-negative.

We can therefore write the light and audio transport for wave rendering for thin microstructures as:

$$R_o(x, u_o) = R_e(x, u_o) + \int W_t(x, -u_o - u_i) R_i(x, u_i) du_i. \quad (2)$$

Where R_o and R_i are the incoming and outgoing light or sound and the BRDF is calculated using the WDF. R_e is the light or sound emitted by the object. This simple method precomputes the BSDF for the entire microstructure, which can be used independently for each patch. Hence, the WBSDF allows us to use traditional ray-based rendering pipelines to synthesize wave effects of light and sound.

We can derive the light or audio transport for coherent as well as incoherent sources. Together with optimizations, such as importance sampling and lookup tables, we can efficiently simulate wave phenomena in the near and far field.

3 Results

We implemented this as a new material plugin for PBRT to generate diffractive materials. In order to make the renderer work with this new material, we only disable the security check for non-negative radiance. No further changes were made to the framework. Using photon mapping as a global illumination technique, the rendering took 1700s to render on a 3GHz Core. Additionally, we used a ray tracer for audio rendering without phase tracking. We simulated an interesting effect where a closing sliding door can increase the audio intensity. These results are shown in figure 1.

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