Birefringence-Based Real-Time Rendering of Translucent Material

Qun Gao and Shuangjiu Xiao

***Abstract*—In this paper, a new rendering method is proposed for translucent material in which birefringence is considered. We introduce birefringence (double refraction) to calculation scattering for translucent material rendering. A ray goes into two rays when it passes through a birefringence material. These shaded points are contributed by two refractive rays and these samples are selected in two refractive rays. We implement the method in translucent material rendering and good results are achieved.**

***Index Terms*—BSSRDF, birefringence, scattering, translucent.**

I. Introduction

Scattering is an important optical phenomenon considered in illumination models in computer graphics. It has much effect in sub-surface and translucent materials. When the light goes through a translucent material, it will be multiple scattering and absorbed in the material. There are several techniques for rendering translucent media. Some media have a feature, birefringence. There are not many researches on birefringence-based rendering of translucent media.

In this paper, a new technique for translucent media rendering based on birefringence is presented. This method is integrating birefringence and scattering.

The related work is in section 2 and birefringence is also in section 2. Section 3 presents the main algorithm of our method. The implement and results are in section 4. Finally in section 5, conclusions are drawn and future researches are discussed.

The major contributions of the proposed approach include:

- The feature of birefringence: there is rarely research on birefringence. We propose a new method on it and good results are achieved.
- The cost time: After we add the birefringence feature, the cost time are almost the same as the cost time before.

II. Related Work

A. Scattering

Nicodemus [1] proposed BSSRDF (Bidirectional Surface Scattering Distribution Function).

BRDF (Bidirectional Reflection Distribution Function) is a method that light entering a material leaves the material at the same position.

Reference [2] proposed a complete BSSRDF. This method divided into single scattering and multiple scattering for simulating translucent material. BSSRDF can describe light transport between any two rays that hit a surface.

In [3], they introduce a simple method which can be implemented in a simple ray-tracer, and with the use of some trickery, in a Z-buffer render.

The [4] present a novel approach for real-time rendering of translucent surfaces and the computation of subsurface scattering is performed by first converting over the 3D model surface into an integration over a 2D texture space.

The model in [5] accounts for both subsurface and surface scattering, and uses only four parameters to simulate the interaction of light with human skin

The [6] introduces an efficient two-pass rendering method for translucent material. This paper decouples the computation of irradiance at the surface from the evaluation of scattering inside the material.

There is a new method in [7] which based on volumetric photon mapping for multiple scattering. The method can be simulated much more efficiently by using a two-pass particle tracing and density estimation approach.

There is a new approach for tracing non-constant, refractive media base on the ray equations of gradient-index optics in [8]. Approximation in [9] have the airlight integral from scattering media whose density is modeled as a sum of Gaussians.

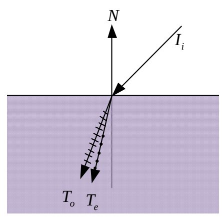

Fig. 1. Displacement of unpolarized light through a birefringent material

B. Birefringence

Birefringence is the optical property of a material. The material is anisotropic. With the decomposition of a ray of light into two rays when it passes through this material, birefringence is as a synonym for double refraction. As in Fig. 1, there are two refractive rays.

In a uniaxial material, rays with polarization are called the extraordinary ray and ordinary ray (T_e and T_o in Fig. 1). The two rays travel in different paths.

$$\Delta n = n_e - n_o \tag{1}$$

This material has more than one refractive index. The index of ordinary ray is n_o and the index of extraordinary ray is n_e. The Birefringence is the margin between n_o and n_e, as

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in (1).

C. BSSRDF

The BSSRDF in [2] consists of two terms, a single scattering term and a multiple scattering term. The first term through path tracing achieve an approximate simulation for the cases that light scatter once inside material. And the incoming and outgoing rays intersect. The second term achieves an approximation for diffusion through a dipole point source[6]. The light enters and leaves at different points.

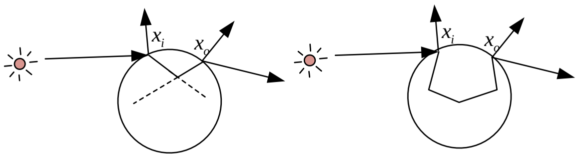


Fig. 2. Displacement of a single scattering and a multiple scattering

S relates the outgoing radiance, $L_o(x_o,\vec{\omega}_o)$ at the point x_o in direction $\vec{\omega}_o$, to the incident flux, $\Phi_i(x_i,\vec{\omega}_i)$ at the point x_i from direction $\vec{\omega}_i$:

$$dL_o(x_o,\vec{\omega}_o) = S(x_i,\vec{\omega}_i;x_o,\vec{\omega}_o)\,d\Phi_i(x_i,\vec{\omega}_i) \qquad (2)$$

III. Main Algorithm

Light scattering in refractive media is an important optical phenomenon. We introduce birefringence (double refraction) to single scattering for material which has this feature. In the single scattering, there is one light scatter inside material.

A. Single Scattering

As in Fig. 3, camera viewpoint is I. The P is the shaded surface point. Samples P_{sample} are selected along outgoing ray T_o. The equation (3) describe for Fig. 3.

$$L_o^{(1)}(x_o,\overrightarrow{\omega_o}) = \frac{\sigma_s(x_o)Fp(\overrightarrow{\omega_i}\cdot\overrightarrow{\omega_o})}{\sigma_{tc}} e^{-s_i'\sigma_t(x_i)} e^{-s_o'\sigma_t(x_o)} L_i(x_i,\vec{\omega}_i) \qquad (3)$$

Without birefringence, samples P_{sample} are selected along outgoing ray T_o. And using Snell's law, S_i' is derived from S_i. Then the single term is calculated [3].

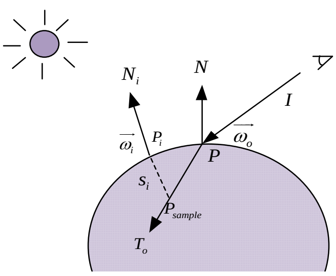


Fig. 3. Displacement of single scattering along the refracted outgoing ray T_o.

B. Single Scattering with Birefringence

From Fig. 4, T_o is the ordinary ray and T_e is the extraordinary ray.

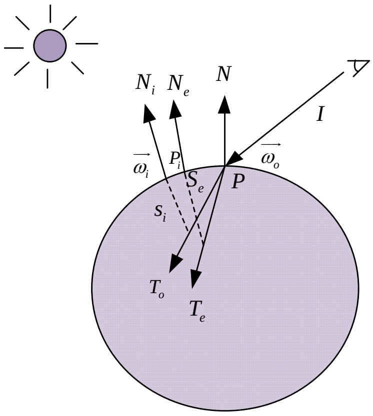


Fig. 4. Displacement of single scattering with birefringence.

The (3) should change to (4) with birefringence feature. It has two parts, the effect of ordinary ray and extraordinary ray.

$$L_o^{(1)\prime}(x_o,\overrightarrow{\omega_o}) = L_o^{(1)}(x_o,\overrightarrow{\omega_o}) + L_e^{(1)}(x_o,\overrightarrow{\omega_o}) \qquad (4)$$

The part $L_e^{(1)}$ in (4) is contributed by the extraordinary ray. From the physical phenomenon and the simulations before, we can introduce (5).

$$L_e^{(1)}(x_o,\overrightarrow{\omega_o}) = \frac{\sigma_s(x_o)Fp(\overrightarrow{\omega_{i-e}}\cdot\overrightarrow{\omega_o})}{\sigma_{tc}} e^{-s_i'\sigma_t(x_i)} e^{-s_o'\sigma_t(x_o)} L_i(x_i,\vec{\omega}_{i-e}) \qquad (5)$$

TABLE I: The Equation of Single Scattering

$\sigma_t = \sigma_a + \sigma_s$	Extinction Coefficient
σ_a	Absorption Coefficient
σ_s	Scattering Coefficient
$\sigma_{tc} = \sigma_t(x_o) + G\sigma_t(x_i)$	Combined Extinction Coefficient

After using (4), there is another outgoing ray T_e. We select some samples along T_o and T_e. When got the color and intensity over surface from all of the samples, we should average the value. The number of samples is N. The pseudo code is shown below:

- $scattering = 0$
- For each $P_{o-sample}$ in T_o
- $p_{o-sample} \rightarrow S_i$
- $S_i \rightarrow (\overrightarrow{\omega_i}, N_i)$
- $scattering += value(\overrightarrow{\omega_i}, N_i)$
- For each $P_{e-sample}$ in T_e

- $p_{e-sample} \to S_e$
- $S_e \to (\overrightarrow{\omega_e}, N_e)$
- $scattering += value(\overrightarrow{\omega_e}, N_e)$
- $scattering /= 2 * N$

These equations describe some coefficients for the calculation [4] (see Table I). Those coefficients are different for many kinds of material.

IV. Implement and Results

For single scattering, it through path tracing achieves an approximate simulation for the cases that light scatter once inside material. The single term depends on the scattering coefficients and the phase function between the refracted directions.

We have implemented the birefringence-based Real-Time rendering. In this paper, we render a cup with birefringence in several methods. All simulations have been done on a 2.8GHz Intel core i5-2300 CPU and NVIDIA GeForce GTX570 GPU.

TABLE II: The Coefficients and Indexes

n_e	n_t	Δn	$\sigma_s\,[mm^{-1}]$	$\sigma_t\,[mm^{-1}]$
1.64	1.61	0.03	0.7	0.714

There are relative parameters for a certain kind of translucent material (see Table II). These data are used in the simulations for 3D cup.

(a) Single scattering with double refraction

(b) Single scattering without double refraction

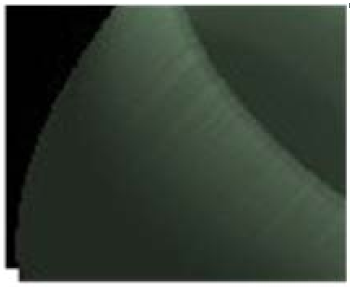
Fig. 5. Displacement of single scattering with and without birefringence.

Fig. 5 is the contrast between single scattering with double refraction and single scattering without double refraction.

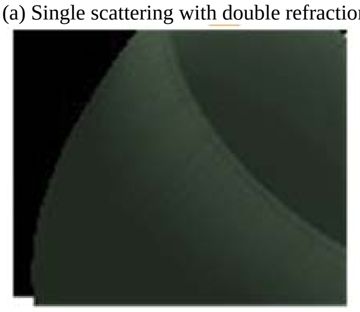
Fig. 6 is the contrast in detail between single scattering with double refraction and single scattering without double refraction. We can know that the former is better for translucent.

There are multiple scattering in Fig. 7. Those pictures of multiple scattering have the feature of translucent.

From the six pictures, we can see the feature of translucent, like jade.



(a) Single scattering with double refraction



(b) Single scattering without double refraction

Fig. 6. Detail of single scattering with and without birefringence.

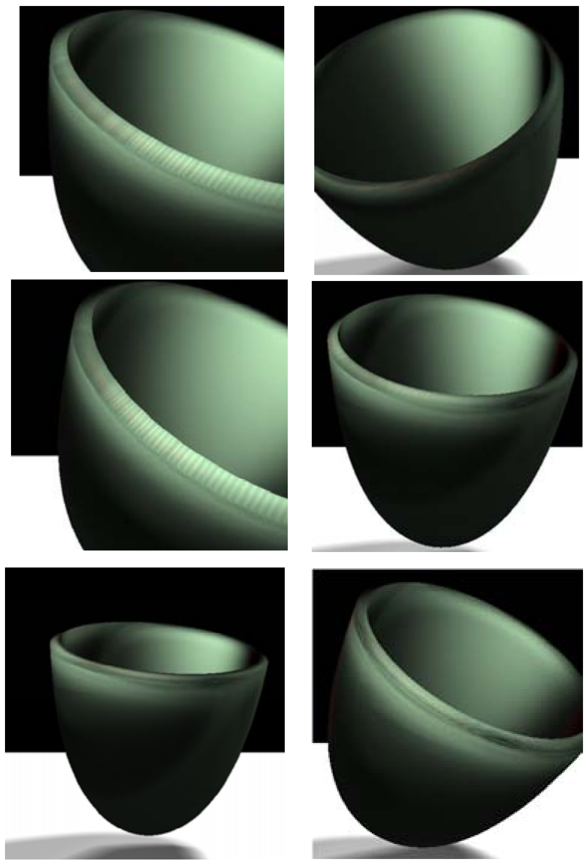


Fig. 7. Multiple scattering with double refraction.

V. Conclusions

In this paper, we propose a new rendering method for real-time rendering of translucent material. For simulating single scattering, we introduce double refraction.

The double refraction, birefringence, has two refractive rays. A ray goes into two rays when it passes through a birefringent material. In our method, these shaded points are contributed by two refractive rays and these samples are selected in two refractive rays. The cost time is almost the same as before.

In future work, we are interested in how to apply the birefringence to multiple scattering and it is also a key point in our study.

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