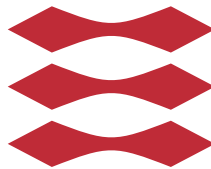


Real-Time Rendering of Translucent Materials with Directional Subsurface Scattering

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Introduction (draft)

Subsurface scattering (SS) is a physical phenomenon that naturally occurs in a wide range of natural materials. Some of the materials that exhibit a strong SS effect in everyday life are milk, human skin and marble. Subsurface scattering is that phenomenon that occurs when light is partially absorbed by an object, bounces inside ("scatters") and finally exits the surface on another point of the material (see Figure 1.1). The phenomenon that results is generally known as *translucency*. We can see some examples of translucency in Figure 1.2

Since the beginning of computer graphics, various attempts have been performed in order to physically model subsurface scattering. Some of these models involve Monte Carlo simulations of the light entering the medium [Pharr and Hanrahan, 2000], other focus on approximating the diffusion of light within the material using an analytical approach [Jensen et al., 2001].

The first model that proposed an analytical approach was the one by Jensen et al. [2001], as an approximation of the radiative transfer equation. This approximation has then been exploited by different authors, in order to account for multi-layered materials [Donner and Jensen, 2005], heterogeneous materials [Wang et al., 2010] and thin surfaces [Wang et al., 2010]. A recent analytical approximation, proposed by Frisvad et al. [2013], extends the approximation in order to account for the directionality of the incoming light.

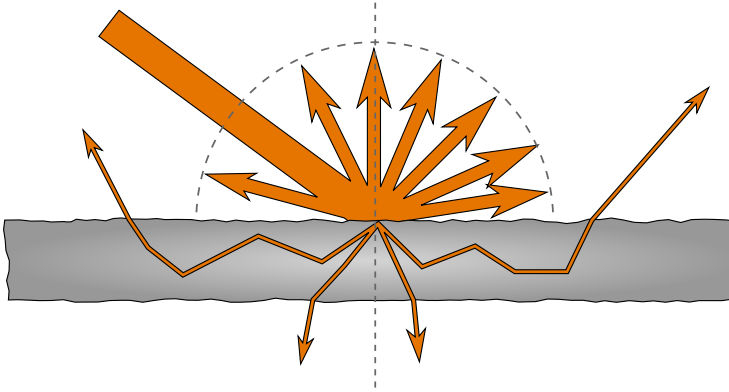


Figure 1.1: Diagram of subsurface scattering. Most of the incoming light gets reflected, but some of it enters the material and leaves it at a different point.

In recent years, with the advent of programmable graphics cards (GPU), it has become possible to exploit these algorithms and bring them to interactive frame rates, and in some cases even to real time rendering. Jensen and Buhler [2002] were the first to propose an efficient implementation (though not real time and on CPU) for rendering subsurface scattering using an octree. More recently, several methods have been proposed, including image-based splats, sum-of-Gaussians filtering, and grid-propagation based methods.

In this thesis we want to employ some cutting edge GPU techniques, with the aid of the programmable pipeline, to implement Frisvad et al. directional model in a real-time fashion. This method should achieve real time results (i.e. in the range of 30 to 60 frames per second) for a wide range of natural materials.

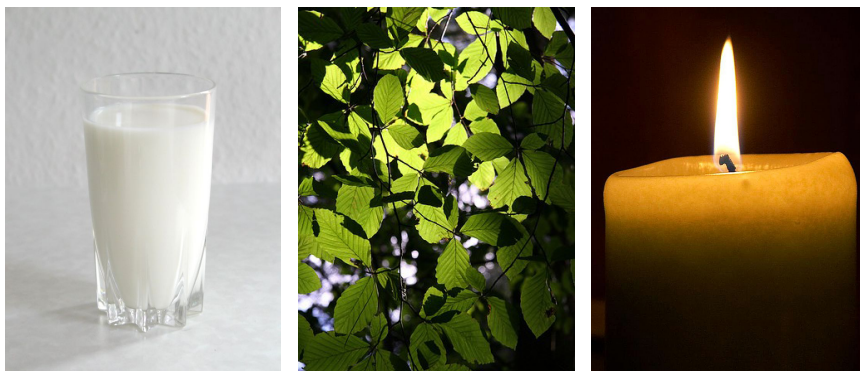


Figure 1.2: Some examples of translucent materials: milk, leaves and a candle. Images courtesy of Wikimedia Commons.

CHAPTER 2

Related Work

When it comes down to approaching rendering of subsurface scattering, all approaches rely on approximating correctly the radiative transport equation (RTE). There are many ways to effectively approach the problem:

Analytical One class of solutions consists of approximating the RTE via an analytical model. These model can have different level of complexity and computation times, and are adaptable to a wide range of materials. However, often they rely on assumptions on the scattering parameters that limit their applicability.

Numerical In this other class of solutions, a numerical solution for the RTE is actually computed. While providing an exact solution, the computation times are longer, or the methods rely on heavy pre-computation in order to achieve interactivity.

2.1 Analytical techniques

When it comes to analytical techniques, two different areas must be distinguished. The first area is the research on the actual models, while the second is

research on how the actual models can be implemented efficiently. Each model is usually represented by a specific function called BSSRDF (Bidirectional Sub-surface Scattering Reflectance Distribution Function), that describes how light propagates between two points on the surface, given the direction of the incoming light and the position of the viewer.

2.1.1 Models

Regarding the models, the first and most important is the dipole developed by Jensen et al. [2001]. The model relies on an approximation of the RTE, called the diffusion approximation, that relies on the assumption on highly scattering materials. In this case, a BSSRDF for a planar surface in a semi-infinite medium can be obtained. The BSSRDF needs only the distance between two points to be calculated, and with some precautions can be also extended to arbitrary geometry. This model does not include any single scattering term, that needs to be evaluated separately. The model was then further extended in order to account for multi-layered materials [Donner and Jensen, 2005].

A significant improvement on the model was later given by D'Eon [2012], that improved the model to better fit path traced simulations without any extra computation cost. A more advanced model based on quantization was proposed by D'Eon and Irving [2011], that introduced a new physical foundation in order to improve the accuracy of the original diffusion approximation. Finally, some higher order approximation exist [Frisvad et al., 2013], in order to account for the directionality of the incoming light and single scattering. This allows a more faithful representation of the model at the price of extended computation times.

Finally, for real-time critical applications (such as games), translucency is often estimated as a function of the thickness of the material, that is added to a lambertian term [Tomaszewska and Stefanowski, 2012]. While not physically accurate, this technique allows to have a fast translucency effect that can be easily added to existing deferred pipelines.

2.1.2 Implementations

Most research on efficient implementations of a subsurface scattering analytical model has been made on the original model by Jensen et al. [2001]. The first efficient implementation was proposed by Jensen and Buhler [2002], based on a two-pass hierarchical integration approach. Samples on the model are organized in an octree data structure, that then is used to render the object. In the

first step, the radiance from the light is stored in the points. In the second pass, using the octree, the contribution from neighboring points is computed, clustering far points in order to speedup calculations. In the original paper, the single scattering term is approximated with as a BRDF approximation.

Lensch et al. [2002] approached the problem by subdividing the subsurface scattering contribution into two: a direct illumination part and a global illumination part (i.e. the light shining through the object). The global illumination part is pre-computed as vertex-to-vertex throughput and then summed to the direct illumination term in real-time. Translucent shadow maps [Dachsbacher and Stamminger, 2003] use an approach similar to standard shadow maps: they render the scene from the light point of view, and then calculate the dipole contribution in one point only from a selected set of points, according to a specified sampling pattern. As in Lensch et al. [2002], the contribution is split into global and local to permit faster computations. Mertens et al. [2003b] propose a fast technique based on radiosity hierarchical integration techniques, that unlike the previous implementation can handle deformable geometry.

Another important category of methods is screen space methods. Mertens et al. [2003a] propose an image space GPU technique that pre-computes a set of sample points for the area integration and then performs the integral over multiple GPU passes. d'Eon et al. [2007] proposes a method in image-space, interpreting subsurface scattering as a sum of images to which a gaussian filter has been applied. The gaussians are then summed with weights that make them fit the diffusion approximation. Jimenez et al. [2009] improves further the technique, giving more precise results in case of skin. Shah et al. [2009] present a fast technique that render the object as a series of splats, using GPU blending to sum over the various contributions.

Regarding more advanced models, the better and the quantized dipole can be applied to any of the previous implementations, since they do not require additional information that the standard dipole. On the other hand, the directional dipole requires the direction of the incoming light as part of its calculations, so it is generally not applicable to the mentioned implementations.

2.2 Numerical techniques

Numerical techniques for subsurface scattering are often not specific, but come for free or as an extension of a global illumination numerical approximation, since the governing equations are essentially the same. Given their generality, they are usually slower than their analytical counterpart, and often rely on heavy

pre-computation steps in order to achieve interactive frame rates. Jensen’s Photon Mapping[Jensen and Christensen, 1998] was originally developed to render anisotropic subsurface scattering. Classical approaches as a full Monte-Carlo simulation implementation of the light-material interaction[Dorsey et al., 1999], and finite-difference methods exist in literature[Stam, 1995].

Precomputed radiance transfer methods is another class of general global illumination methods, that generally pre-compute part of the lighting and store it in tables[Donner et al., 2009], allowing to retrieve it efficiently with an additional memory cost.

Some methods have been introduced in order to devise more efficient approximations when it comes to the specific problem of subsurface scattering. Stam [1995] uses the diffusion approximation with the finite difference method on the object discretized on a 3D grid. Fattal [2009] uses as well a 3D grid, that is swept with a structure called light propagation map, that stores the intermediate results until the simulation is complete.

Wang et al. [2010], instead of performing the simulation on a discretized 3D grid, makes the propagation directly in the mesh, converting it into a grid of tetrahedrons called the QuadGraph. This grid can be optimized to be GPU cache friendly, and provide a real-time rendering of deformable heterogeneous objects. The problem in this method is that the Quadgraph is slow to compute and has heavy memory requirements for the GPU.

A recent method called SSLPV - Subsurface Scattering Light Propagation Volumes [Børllum et al., 2011] extends a technique originally developed by Kaplanyan and Dachsbacher [2010] to propagate light efficiently in a scene using a set of discretized directions on a 3D grid. The method allows real-time execution times and deformable meshes with no added pre-computation step.

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