Radiance Caching for Fast Global Illumination with Arbitrary BRDFs

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Global illumination is a physically accurate calculation of lighting in an environment. This simulation involves estimating light intensity at any visible point of the environment. The complexity of the task lies in the fact that light can reach the visible points not only directly from a light source but it can also undergo many reflective/refractive events on its way from the source. The properties of light reflection on a surface are fully described by a BRDF – bi-directional reflective distribution function – that describes how much light coming from certain direction is scattered to a different direction. BRDF corresponds to a 'look' of the surface. For the purpose of lighting simulation, we distinguish three types of BRDFs: *diffuse*, reflecting light to all directions equally regardless of the direction from which it comes; *specular*, acting as a perfect mirror and *glossy*, which is basically anything between diffuse and specular. Glossy BRDFs are the most hard to simulate since there is no special property that can be exploited to ease the task of lighting simulation.

In our contribution we propose a method to make Monte Carlo lighting simulation in presence of glossy materials feasible even when we take into account multiple light scattering events. The method exploits the fact that there is a strong coherence in indirect light field reaching a point in the scene. By indirect light field we mean all light reaching certain point that has been reflected at least once on its way from light source. Indeed, the expected change of this light field with change of position is very low and this fact can be exploited to speed up the computation by *interpolating the indirect light field* from a number of high quality samples. The basic idea of the algorithm is based on Ward's irradiance caching [1]. The algorithm is and extension of ray tracing and proceeds as follows: rays are cast into scene from camera, for every ray/surface intersection direct lighting and perfectly specular term are computed as in standard ray tracing and then comes the caching: Are there any samples representing indirect incoming light near this point? If yes, use these samples to interpolate the indirect lighting, otherwise compute a new indirect light sample, use it as indirect light for this point and moreover store it into the cache. In this way the cache is filled in a view dependent manner and as it gets filled, the indirect light can by estimated by a mere interpolation for more and more points. In Ward's work this scheme was used only for diffuse BRDFs and the physical quantity stored in the cache was the *irradiance* – a cosine weighted integral of all light arriving at a point from any direction. For a diffuse surface the reflected light in any direction is a mere product of surface reflectivity and irradiance. This makes irradiance caching a very effective and efficient algorithm. Glossy BRDFs are, however, in Ward's framework simulated by a direct application of Monte Carlo sampling that is very slow.

Our work extends the notion of caching of incoming light from caching irradiance to caching the full incoming radiance field at a point. Doing this allows us to interpolate on non-diffuse surfaces saving a lot of computation time. Even if we work with very different quantities, the basic structure of the caching algorithm remains the same as in the original paper.

Radiance at a point is a function defined on hemisphere. We represent it by *hemispherical harmonics* (HSH), a technique we developed for the purpose of representing arbitrary function on hemisphere. With HSH a function is exactly represented by an infinite sum of products of coefficients and hemispherical basis functions and can be approximated by truncating this sum to a finite number of non-zero coefficients. Therefore the radiance samples in the cache consist of a vector of HSH coefficients. To interpolate between samples, we interpolate the coefficients, which is a valid approach since the HSH is a linear orthogonal basis.

Computation of outgoing light at a point is a hemispherical integral of incoming radiance field multiplied by the BRDF. In our system we represent BRDFs by a HSH expansions which simplifies the hemispherical integral to computing a dot product of BRDF and incoming radiance coefficients: an operation which is many times faster than Monte Carlo estimation of the integral.

Interpolation of radiance samples may lead to visible artifact that can be alleviated by using a higher order interpolation scheme. To this end Ward [2] proposes to compute irradiance gradients and use them as additional information for interpolation. We extend this approach by computing gradient for every coefficient of our HSH radiance representation, which in effect implies a very high order interpolation scheme that yields additional precision of the interpolation. We also propose a novel technique for computing the translational gradient which not only is better theoretically justified but also provides more accurate results.

We propose an adaptive representation of BRDFs. Each BRDF is represented by only as many coefficients as needed to obtain a user-specified accuracy. The radiance field at any point is represented by the same number of coefficients as is needed for the BRDF of the surface the point lies on (since more coefficients would be cut off anyway by BRDF low-pass filtering). This yields an elegant solution to the problem of choosing the number of coefficients for radiance representation. It is also important that we do not require any knowledge from the user to successfully use the algorithm: he or she provides only the desired accuracy.

Another problem that arises in a practical implementation of the caching is the HSH rotation. Every radiance sample is represented in its local coordinate frame determined by surface normal and tangent. The coordinate frames have to be aligned before the coefficients can be interpolated which leads to a HSH rotation. A general HSH rotation is a very costly operation and it is not affordable to perform it every time we interpolate. We solved this problem by decomposing the rotation into the ZYZ Euler angles (every rotation can be decomposed into three elementary rotation around Z, Y, Z axes) and approximating the Y rotation by its first order Taylor expansion. The rotation matrix for this approximation is tridiagonal and it is therefore very efficient to use it for rotation.

In conclusion we have proposed a complete solution for radiance interpolation that allows an efficient global illumination in scenes with general BRDFs. The techniques we have developed to this end are general and can be used for different purposes.

References:

[1] WARD, G. – RUBINSTEIN, F. - CLEAR, R.: *A Ray Tracing Solution for Diffuse Interreflection.* Computer Graphics, Vol. 22, No. 4 1988.

[2] WARD, G. – HECKBERT, P.: *Irradiance Gradients.* Proceedings of 2nd Eurographics Workshop on Rendering, 1992.

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