Non-Linear Kernel-Based Precomputed Light Transport

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Introduction

We propose a real-time method for rendering static objects with complex materials under distant all-frequency lighting. Existing precomputed light transport approaches [Sloan et al. 2002; Ng et al. 2003] can render objects with complex material properties (e.g., anisotropy, translucency) and complex global illumination effects (e.g., inter-reflections, soft shadows, subsurface scattering). However, they are either restricted to low-frequency illumination or they assume a fixed viewer.

In this sketch we propose a solution that allows both. Our method is based on two components: (1) a compact non-linear representation for precomputed light transport that can be integrated rapidly with the distant all-frequency illumination, and (2) a new interpolation scheme that enables rendering of an arbitrary viewpoint from only a sparse set of precomputed views. Figure 1 shows an object rendered using our method.

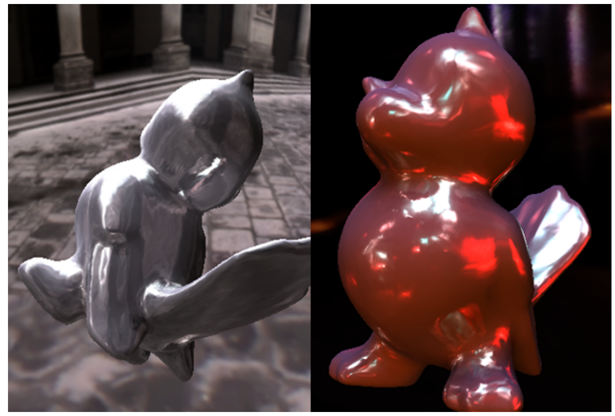

Figure 1: A highly glossy object illuminated under two different environments. Notice the inter-reflections of the tail on the head (left image) and foot (right image). Models rendered at 3.7 fps on a 3 Ghz PC with an NVIDIA FX 3000 graphics card.

Algorithm

Consider a static object with possibly complex material properties and complex light interactions between its elements. We consider images of this object under all possible distant illuminations . We can view the scene as "a black box" linear system that transforms the input radiance into the output radiance. This linear system can be written as:

$$L_o(\mathbf{x},\omega_o) = \sum_{\omega_i} T(\mathbf{x},\omega_o,\omega_i) L_i(\omega_i) = \mathbf{T}(\mathbf{x},\omega_o)\cdot\mathbf{L}_i, \qquad (1)$$

where $\mathbf{x}$ is a point on the surface, ω_o is the outgoing direction, ω_i is the incoming direction, $\mathbf{L}_i$ is the vector of (distant) incident radiance, $\mathbf{T}()$ is the light transport kernel (represented as a vector, with a coordinate for each direction ω_i), and L_o is the exitant radiance [Ng et al. 2003]. Both incident radiance $\mathbf{L}_i$ and the transport kernel $\mathbf{T}()$ are sampled over the sphere of incoming directions. $\mathbf{T}()$ captures the complex transport effects occurring in the scene.

Precomputation. For a fixed $\mathbf{x}$ and ω_o, we obtain the transport vector $\mathbf{T}(\mathbf{x},\omega_o)$ using backward photon tracing. We trace N photons, starting along direction $-\omega_o$ onto point $\mathbf{x}$, through the scene until they intersect a surrounding *receiver sphere* of "infinite" radius (corresponding to the distant environment map) and record the power and direction of each photon at the point of intersection. Using density estimation on this path traced data we can calculate $\mathbf{T}()$ for all incoming directions. We precompute $\mathbf{T}(\mathbf{x},\omega_o)$ at each $\mathbf{x}$ (using a texture atlas) and for 92 fixed view directions uniformly distributed over the sphere.

Representation. In contrast to previous work on precomputed light transport [Sloan et al. 2002] that represents the transport vector using a linear basis approximation (e.g. Spherical Harmonics), we represent the transport vector with a non-linear approximation. $\mathbf{T}()$ is represented as a sum of constant-valued box functions (1 inside the box and 0 outside the box) of arbitrary size and position:

$$\mathbf{T} = \sum_j w_j K_j, \qquad (2)$$

where K_j defines the size and position of box j and w_j is a scalar weight of the box. This representation has two advantages: an efficient integration algorithm and a simple interpolation technique that allows us to approximate $\mathbf{T}(\mathbf{x},\omega_o')$ for an arbitrary (i.e. not precomputed) direction ω_o'.

Fast Integration. Using this representation, we can approximate Equation 1 efficiently:

$$\begin{aligned} L_o(\mathbf{x},\omega_o) &= \Big(\sum_j w_j(\mathbf{x},\omega_o) K_j(\mathbf{x},\omega_o)\Big)\cdot\mathbf{L}_i \\ &= \sum_j w_j(\mathbf{x},\omega_o)\big(K_j(\mathbf{x},\omega_o)\cdot\mathbf{L}_i\big) \qquad (3)\end{aligned}$$

Using a summed area table representation for $\mathbf{L}_i$, we can compute $K_j\cdot\mathbf{L}_i$ quickly.

Arbitrary Views. For an arbitrary outgoing direction, ω_o', it is not sufficient to interpolate the resulting L_o from the nearest precomputed view directions because of possible high-frequency view-dependent components (e.g., specular reflections). Instead, we synthesize a new light transport vector $\mathbf{T}(\mathbf{x},\omega_o')$ by interpolating the box parameters (K_j and w_j) from the three nearest precomputed directions. The synthesized transport vector is a barycentric combination of the three nearest transport vectors. $\mathbf{T}(\mathbf{x},\omega_o')$ is then integrated with the incident lighting (Equation 3) to produce the exitant radiance $L_o(\mathbf{x},\omega_o')$ at position $\mathbf{x}$ along direction ω_o'.

References

NG, R., RAMAMOORTHI, R., AND HANRAHAN, P. 2003. All-frequency shadows using non-linear wavelet lighting approximation. *ACM Transactions on Graphics 22*, 3 (July), 376–381.

SLOAN, P., KAUTZ, J., AND SNYDER, J. 2002. Precomputed radiance transfer for real-time rendering in dynamic, low-frequency lighting environments. *ACM Transaction on Graphics 21*, 3 (July), 527–536.