Importance Sampling for Video Environment Maps

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Overview

Realism in image synthesis increases significantly when real-world lighting captured into environment maps (EM) is used to illuminate rendered scenes. Tremendous progress in the development and accessibility of high dynamic range (HDR) video cameras enable direct capturing of HDR video environment maps (VEM). In this work we present an interactive system for fully dynamic lighting of a scene using captured HDR VEM. The key component of our system is an algorithm for efficient decomposition of HDR VEM into a set of representative directional light sources, which can be used for the direct lighting computation with shadows on graphics hardware. The resulting lights have favorable properties in terms of flickering reduction and their number can be adaptively changed to keep a constant framerate while good spatial distribution (stratification) properties are maintained. We can handle a large number of light sources with shadows using novel techniques, which reduce the cost of BRDF-based shading and visibility computations.

VEM Decomposition into Directional Light Sources

For the HDR VEM acquisition we use a photometrically calibrated HDRC VGAx (IMS CHIPS) camera with a fish-eye lens. We decompose each captured EM into a set of directional light sources, which are well suited for the shadow computation and shading using graphics hardware. In our decomposition approach we treat the pixel luminance values in the EM as a discrete 2D probability density function (PDF) and we draw samples (light source directions) from this distribution following procedures established in the Monte Carlo literature. For this purpose we select our inverse transform method [HDS03], which exhibits unique continuity and uniformity properties that are desirable in our application. The method guarantees the bicontinuity property for any non-negative PDF, which means that a small change in the input sample position over the unit square is always transformed into a small change in the resulting position of light source over the EM hemisphere. The uniformity property is important to achieve a good stratification of the resulting light source directions.

Lighting: Progressive Refinement and Temporal Coherence

To temporal flickering in the resulting frames we choose the same set of initial samples over the unit square for each VEM frame, which are then processed using our inverse transform method. Since our emphasis is on interactive applications, we use a progressive sequence of samples in which adding new samples does not affect the position of samples already used for shading computations, while good sample stratification properties are always preserved. We achieve the progressiveness of sampling sequence using quasi-Monte Carlo sequences such as the 2D Halton sequence. We perform Lloyd's relaxation over the initial sample positions in the unit square in a preprocessing step. This allows us to achieve a blue noise sample pattern on the hemisphere.

Since even local changes in the EM lead to global changes of the PDF, the direction of virtually all light sources may change from frame to frame, which causes unpleasant flickering in the rendered images. We apply a perception-inspired, low-pass FIR filtering to the trajectory of each light motion over the hemisphere and also to the power of the light sources.

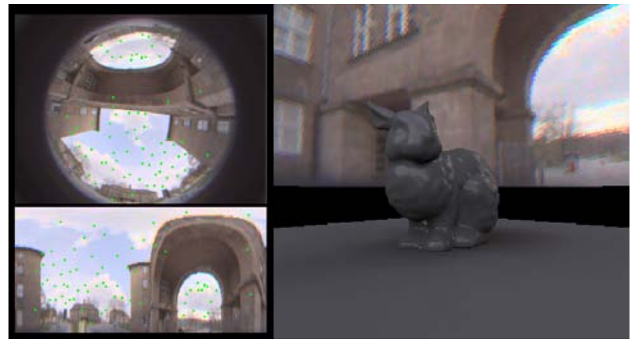

Figure 1: A snapshot of our system. Left: distribution of directional lights (marked as the green dots) over a VEM frame as captured using the fish-eye lens (top) and shown in the polar projection (bottom). Right: BUNNY illuminated by the 72 directional lights, rendered with shadows maps at 7 FPS and the image resolution 320×240 pixels.

Rendering: Improving Shadow Computation Performance

The light sources after temporal filtering are used in the pixel shader of a GPU. The main computational bottleneck is the shadow map computation for hundreds of light sources. We propose an algorithm that for a given extent of the normal vector directions of a shaded pixel efficiently eliminates most of the invisible light sources. Furthermore, for glossy surfaces we consider more precise shading computation for lighting coming around the reflected ray direction in respect to the observer position, while we reduce the number of light sources for the remaining directions. The stratification and progressiveness properties enable simple adding more lights for selected angular regions without affecting the directions of already distributed lights. Optionally, we cluster lights with similar directions corresponding to the regions of concentrated energy in the EM e.g., around the sun position, to reduce the shadow computation cost even further.

Results & Conclusions

Our system runs on a PC with a 3 GHz Pentium4 processor and NVidia GeForce 6800GT graphics card. We achieve the performance of 22 FPS for the VEM capturing and directional light generation with filtering and 7 fps for asynchronous rendering with 72 light sources and shadows at the image resolution 320×240 pixels.

Our system lifts common limitations of existing rendering techniques, which cannot handle at interactive speeds HDR image-based lighting captured in dynamic real world conditions along with complex shadows, fully dynamic geometry, and arbitrary reflectance models evaluated on a GPU. Our approach does not require any costly preprocessing and has modest memory requirements to achieve those goals. The main use of the proposed system can be envisioned in mixed reality applications in which real and synthetic objects are illuminated by consistent lighting at interactive framerates (refer to the accompanying video).

References

HAVRAN V., DMITRIEV K., SEIDEL H.-P.: Goniometric diagram mapping for hemisphere. Short Presentations (Eurographics 2003), 2003.