Radially-Symmetric Reflection Maps

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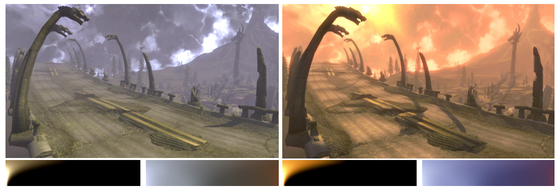

Figure 1: A scene in Brütal Legend at two different times of day, with the blended reflection maps for sun and sky lights.

1 Introduction

When designing lighting for outdoor scenes, area lights can represent distant sources such as the sun and sky with greater shading fidelity than is possible with simple directional or hemispherical lights, but the combination of dynamic area light sources and complex BRDFs is challenging to render efficiently in real-time. Prefiltered reflection maps are a popular solution to this problem, but for applications which need a wide variety of light sources and materials, the texture data requirements of cubic reflection maps can be prohibitive in terms of memory overhead and render efficiency. In addition, traditional environment map representations are difficult for artists to directly paint and refine for use in scene lighting.

In this paper we propose a new representation for distant, radially-symmetric area light sources, one which requires far less texture memory, is more efficient to render, and which is more intuitive for artists to work with than cubic reflection maps. In *Brütal Legend*, the game for which this technique was developed, radially-symmetric reflection maps are the core element of our outdoor lighting model, providing a solution for distant area lights that meets both the artistic and engineering needs of a large, open-world game.

2 Radially-Symmetric Reflection Maps

A *radially-symmetric reflection map* is a variant of a reflection map [Miller and Hoffman 1984] which is specialized to describe a distant radially-symmetric light source such as the sun or sky. The source environment map is a 1-dimensional texture with each texel representing the incoming radiance over a zone of the unit sphere, and the filtered reflection map is a 2-dimensional texture with each column corresponding to a spherical zone and each row corresponding to a BRDF lobe. The source environment map can be directly painted by an artist, who can view the 1-dimensional drawing as a gradient describing the color of incoming light from the north to south poles. Each texel of the source map covers a spherical zone of uniform height and solid angle, so all texels contribute equally to the radiant intensity of the light source.

Once the source image has been painted, it is convolved with each BRDF kernel that is required by the run-time. In this paper, we consider only materials which are a linear combination of Lambert diffuse and Phong specular lobes, but as with standard reflection maps, RSRM can be extended to other combinations of radially-symmetric lobes [Kautz and McCool 2000]. Since the Lambert diffuse lobe has the same shape as the normalized Phong specular lobe of exponent 1, we will focus on the specular convolution, which is computed with the following summation:

$$L_o(\theta_o) = \frac{k_s \omega_l}{2\pi} \sum_{\theta_i=0}^{\pi} L_i(\theta_i) \sum_{\phi_i=0}^{\pi} (\boldsymbol{r}(\theta_o, 0) \cdot \boldsymbol{l}(\theta_i, \phi_i))^s \qquad (1)$$

In Equation 1, the outgoing radiance of the spherical zone about zenith angle θ_o is computed by summing the weighted contributions from each zone of incoming light. The contribution from each zone θ_i is equal to its incoming radiance L_i times its total BRDF weight, which is estimated by summing the exponentiated cosine weight $(\boldsymbol{r} \cdot \boldsymbol{l})^s$ for a series of azimuths ϕ_i across the spherical zone. The radial symmetry of the incoming and outgoing light allows us to use a fixed azimuth for $\boldsymbol{r}$ and to sample $\boldsymbol{l}$ over only half the zone. The constant k_s is the BRDF normalization factor for Phong exponent s, and ω_l is the uniform solid angle of spherical patches of incoming light.

3 Real-Time Rendering

Once the convolutions have been generated for a light source, they are combined as the rows of a 2-dimensional reflection map for use in rendering. For specular light contributions, the reflection map is accessed with the $(\boldsymbol{r} \cdot \boldsymbol{l})$ dot product, where $\boldsymbol{l}$ is the light's axis of symmetry, and a row index for the specular exponent of the material. For diffuse lighting, the reflection map is accessed with the $(\boldsymbol{n} \cdot \boldsymbol{l})$ dot product and a constant row index for exponent 1, returning values equivalent to a diffuse irradiance environment map. Surfaces with spatially-varying BRDFs can be supported by allowing the specular row index to vary per-pixel. Because of the compact size of an RSRM, these texture fetches are very lightweight, and the shader math is comparable to that for a simple directional light. Time of day transitions can also be accomplished by blending between RSRM textures on the GPU.

The dimensions of RSRMs will depend on the needs of the application, but in *Brütal Legend* the filtered reflection maps are stored at 256x8 resolution with 8 bits per color component. These LDR values are modulated by the full HDR color of the light in a pixel shader. With each RSRM representing a separate light source, we have found this to provide enough texture detail to avoid banding artifacts, while maintaining fast texture fetches.

References

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