Lighting Technology of *The Last of Us Part II*

Hawar Doghramachi
Naughty Dog, LLC

ABSTRACT

Since the majority of the world of *The Last of Us Part II* has overcast lighting conditions, ambient lighting was a crucial component of our rendering system. Developing a game that is mainly ambient lit is already a challenge on its own, but we also had to deal with limited amount of processing power and memory on our target platform, *Playstation 4*. In this abstract we will mainly focus on improvements of our baked ambient lighting system that enabled us to produce convincing and consistent lighting results while maintaining our target of 30 fps and remaining within our limited memory budget.

CCS CONCEPTS

• **Computing methodologies** → Rendering.

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KEYWORDS

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1 INTRODUCTION

The baked ambient lighting system of *The Last of Us Part II* supported light-mapping, vertex lighting and third order spherical harmonics-based probe lighting. While dynamic foreground environment was limited to probe lighting, static background environment could choose between any of these options. One of our main goals was to improve probe lighting, so that probe lit objects integrated well into their surrounding environment.

2 DOMINANT LIGHTING

In previous *Naughty Dog* games we were already extracting dominant lighting from our spherical harmonics-based ambient probes to improve directionality of lighting. However, since this was done only once for the entire object, probe lit objects had still a flat look and didn't integrate well into their environment. To improve on this, we perform dominant light extraction per pixel and mask out the SH probe environment on the hemisphere, that is facing away from the lit surface normal with the help of a SH triple product tensor [Sloan 2008].

Previously we mainly relied on Ambient Capsules/ Volumes [Iwanicki 2013] to provide shadowing for extracted dominant light, which works well between objects, but is not viable for self-shadowing due to the coarse approximation nature of this approach. Thus only non-directional SSAO was used for self-shadowing purposes. To be able to provide more accurate self-shadowing for the directional light component, we are now tracing in screen-space a visibility cone against the depth buffer that is treated as a height field, thus producing soft shadowing results, which is crucial for ambient lighting. We also repurpose this technique for direct sun and local light shadows by using a narrower search cone angle.

3 VOLUMETRIC PROBE LIGHTING

In the past probe lit objects interpolated once, usually in the center of the object, the 10 closest ambient light probes to calculate ambient lighting; unfortunately this approach had not enough spatial frequency to accurately capture the surrounding lighting environment. We now perform this interpolation for each of the 8 corners of the object-oriented bounding box of each object and store the results as 2x2x2 texel blocks in a 3D texture atlas. To avoid for small objects that the same probes are interpolated for each of the 8 corners, the contribution of each probe is weighted according to its orientation towards the sample location. Later in the lighting stage, we interpolate per-pixel between these texels via a trilinear hardware texture lookup. Since probe lit objects have in general moderate extents, this approach significantly improved spatial frequency while being still cheap enough for our performance budget. To further reduce runtime costs, we cache the 3D texture atlas entries and only update them when the corresponding object has moved or changed extents.

4 PROBE DERINGING

Third order spherical harmonics-based ambient probe lighting is prone to ringing artifacts when the captured lighting environment is strongly directional. To remove SH ringing, we perform at bake time an adaptive windowing approach [Sloan 2017]. However, due to aforementioned runtime extraction of dominant lighting with SH masking, ringing is often reintroduced into the SH lighting environment. Since ringing primarily happens on surface areas that are facing away from the dominant light, at runtime we remove ringing by first determining the dominant light direction from the SH environment prior masking and then lowering the extraction amount as the surface normal deviates from this direction.

5 PROBE OCCLUSION

A major problem with traditional probe lighting is light leaking due to missing occlusion. To solve this problem, ambient light probes store additional occlusion information. At bake time we cast several hundred rays from each light probe to the surrounding environment and project the closest hit distances via a Non Negative Least Square Solver onto the 6 faces of a virtual cube. To increase accuracy, we orient the cube in a way that it aligns with the 2 directions of most occlusion. By using compression techniques like e.g. Spherical Fibonacci Mapping [Keinert et al. 2015], we managed to store the occlusion information in just 8 bytes per probe and remain within our limited memory budget. At runtime we calculate for each sampled SH probe an occlusion depth by doing a weighted sum of the 6 virtual cube faces according to the sample direction. The occluder depth is compared to the distance of the probe sample location to the light probe to determine if a probe is occluded. We replace the binary comparison result by a smooth Hermite interpolation to avoid hard transitions.

6 HYBRID PROBE LIGHTING

Due to high memory requirements of vertex lighting and resolution issues of light-mapping, artists started to increasingly use probe lighting even for static background objects. However, since probe lit background objects can have large extents, the spatial frequency of our volumetric probe lighting system was in these cases not high enough to produce convincing results.

We observed that in our mainly overcast lighting environments, the change in chrominance of lighting was significantly lower than the change in luminance. Exploiting this observation, we introduced a hybrid lighting technique, where we only store the luminance of the lighting environment per vertex, and combine it with the chrominance from the volumetric probe lighting system. This significantly improved lighting quality, while reducing the memory footprint per vertex from 16 to 4 bytes (we store HDR data for base and directional lighting components).

REFERENCES

Michał Iwanicki. 2013. Lighting Technology of The Last of Us. In *ACM SIGGRAPH 2013 Talks*.

Benjamin Keinert, Matthias Innman, Michael Sänger, and Marc Stamminger. 2015. Spherical Fibonacci Mapping. *TOG* 34, 6 (2015).

Peter-Pike Sloan. 2008. Stupid Spherical Harmonics (SH) Tricks. In *GDC 2008*.

Peter-Pike Sloan. 2017. Deringing Spherical Harmonics. In *SIGGRAPH Asia 2017 Technical Briefs*.