Importance Sampling of Many Lights with Adaptive Tree Splitting

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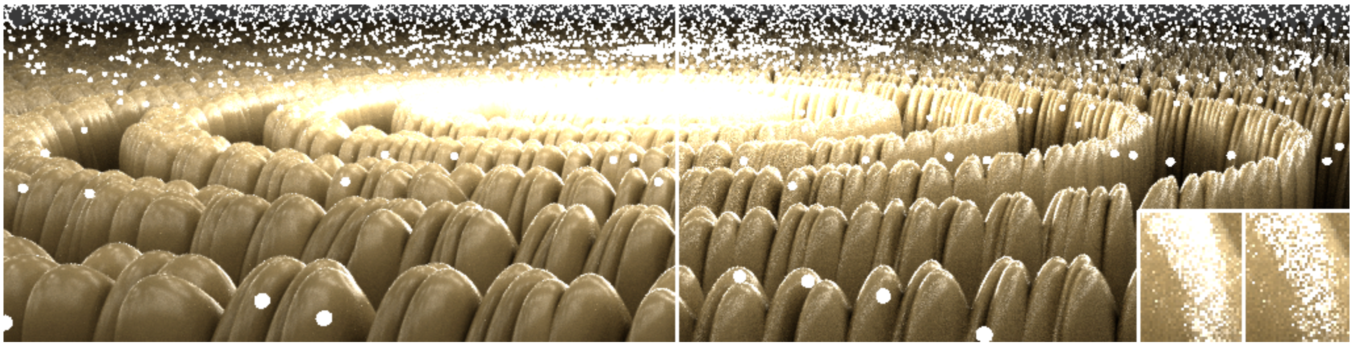

Figure 1: Scene with 10,000 lights rendered in 5 minutes. On the left with adaptive splitting and the right without, equal time comparison. The magnified detail shows the benefit of taking into account the BSDF in the splitting heuristic.

ABSTRACT

We present a technique to importance sample large collections of lights. A bounding volume hierarchy over all lights is traversed at each shading point using a single random number in a way that importance samples their predicted contribution. We further improve the performance of the algorithm by forcing splitting until the importance of a cluster is sufficiently representative of its contents.

CCS CONCEPTS

• **Computing methodologies → Ray tracing**;

KEYWORDS

illumination, ray tracing, many lights

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1 MOTIVATION AND PREVIOUS WORK

Direct lighting calculations are a critical part of modern path tracing renderers with next event estimation. While sampling from simple light shapes [Shirley et al. 1996] is well understood, relatively little attention has been devoted to the problem of efficiently sampling from large collections of such shapes. Above a few dozen lights the mere act of looping over the lights becomes quite costly, even more so if shadow rays are cast.

Very early work on this problem [Shirley et al. 1996] recognized that while a uniform or energy based PDF over the lights can produce reasonable results when all lights have similar influence over the image, this quickly breaks down in scenes where the light sources have more localized influence. Building a probability density function (PDF) per point is impractical as it would require the loop over all lights we are trying to avoid. Recent concurrent work [Vévoda and Křivánek 2016] amortizes the creation of localized PDFs within cells of a uniform grid, but does not give specific guidance on how to set the optimal cell size.

We draw inspiration from work like Lightcuts [Walter et al. 2005] which builds a hierarchy over the lights and reduces computation by how it decides to traverse this tree. However, we do not discretize area lights into points, nor do we attempt to include any virtual point lights to represent global illumination. Our hierarchy is solely focused on accelerating direct lighting while remaining unbiased.

Our goal is to find a hierarchical organization of the lights that allows a unique PDF to be adapted to every shading point on the fly. The two key elements of our approach are therefore the tree construction and traversal mechanism.

2 TREE CONSTRUCTION

We organize lights into a binary tree very similar to the BVH usually used for ray intersection. Our construction algorithm is nearly identical as it partitions lights along spatial dimensions only. The difference is that we replace the number of primitives in the surface area heuristic (SAH) by a measure of the total light power. We keep track of the orientation cone of normals of each cluster so that the splitting heuristic can reflect that it is preferable to keep lights with similar orientations together by favoring splits that also divide the orientation bounds. This small change to the SAH lets us better

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equalize the overall contribution of each cluster to the scene and keep lights with similar orientations in different branches of the tree.

After construction, each cluster stores spatial bounds, a cone of surface normals as well as the energy total for all lights contained by the cluster. These quantities are used by the traversal algorithm described below.

3 IMPORTANCE SAMPLED TREE TRAVERSAL

Our binary tree can be traversed stochastically to randomly choose a single light. At every branch in the tree we compute an importance term I that approximates the potential contribution of lights within the cluster. We choose between the left or right subtrees by assigning the probability $P_L = I_L/(I_L + I_R)$ to the left child and similarly P_R for the right. A single random number ξ that we rescale after each decision guides the traversal until we reach a leaf.

The better I approximates the actual contribution of lights in the cluster, the more variance reduction we can expect. We approximate the geometric term of the lighting equation as the BRDF is already mostly accounted for by MIS and *splitting* in the next section. The inverse squared distance to the cluster is approximated by the distance to the bounds center. This works well if the cluster is far away from the shading point. When the cluster is close or when the bounds contain the shading point, this is less effective. The splitting heuristic described in the following section can mitigate this weakness.

The importance I also includes a cosine term that represents the largest possible cosine between the light normals and the direction towards the shading point. We can compute this efficiently from the bounding cone of normals stored in each cluster. Finally the total energy of lights within the cluster is included to give higher weight to brighter lights.

On its own, this stochastic traversal already allows unbiased rendering of scenes with many lights. It works particularly well for collections of emitting triangle lights (mesh lights) as seen in Figure 2. For participating media we use the same algorithm but substitute the closest point along the ray to each cluster to evaluate the importance formula.

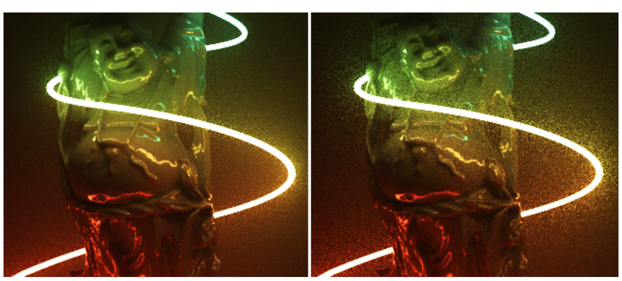

Figure 2: A mesh light and participating media using our method (left) and with uniform energy-based sampling (right). Both images rendered in 2 minutes.

4 ADAPTIVE SPLITTING HEURISTIC

A weakness of our importance sampled tree traversal is that the predicted importance I is sometimes inaccurate, particularly near the root of the tree where the bounds are large. We mitigate this weakness of our algorithm by forcing *splitting* during traversal until we gain confidence over the quality of our importance criteria I. This process resembles the *cut* selection from the Lightcuts algorithm. At each light cluster, we first compute a score for the current node to know if we should continue traversal into both children or let the importance sampled traversal algorithm take over. We drive this scoring process by both the bounding box of the cluster (clusters that contain the shading point are always split) but also by an approximation of the BRDF's cone of influence to give higher weight to distant clusters that are likely to fall within the specular highlight.

The effects of this adaptive heuristic can be seen in Figure 1 where the specular highlights in particular can be undersampled when relying on stochastic traversal alone. We emphasize that multiple importance sampling is used in both images. The undersampling occurs because the choice of I cannot recognize that lights within the specular direction should have higher weight. This effect is most pronounced at medium roughness when neither the BRDF nor the importance I are a good proxy for the final contribution. While we experimented with ways to include the effect of the BRDF into I directly, the low quality of estimates at higher levels of the tree made our adaptive splitting heuristic much more successful.

5 RESULTS

We highlight another seemingly simple example in Figure 3 where a million lights are added to the ceiling of a Cornell Box. We have omitted many implementation details for lack of space. Indeed the actual details of tree construction heuristics, importance heuristic and splitting heuristic all have a measurable impact on the success of our method. We refer the reader to the supplemental material for additional examples of the effects of these heuristics on the actual frames.

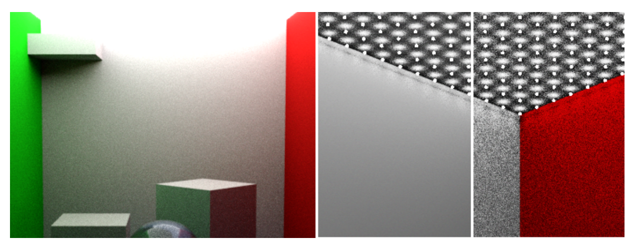

Figure 3: A cornell box lit by a million lights on the ceiling. This is a case where lights are non-local. The under-exposed detail on the right half shows the layout and compares to uniform sampling (far right)

REFERENCES

Peter Shirley, Changyaw Wang, and Kurt Zimmerman. 1996. Monte Carlo Techniques for Direct Lighting Calculations. *ACM Trans. Graph.* 15, 1 (Jan. 1996), 1–36. DOI: http://dx.doi.org/10.1145/226150.226151

Petr Vévoda and Jaroslav Křivánek. 2016. Adaptive Direct Illumination Sampling. In *SIGGRAPH ASIA 2016 Posters (SA '16)*. ACM, New York, NY, USA, Article 43, 2 pages. DOI: http://dx.doi.org/10.1145/3005274.3005283

Bruce Walter, Sebastian Fernandez, Adam Arbree, Kavita Bala, Michael Donikian, and Donald P. Greenberg. 2005. Lightcuts: A Scalable Approach to Illumination. *ACM Trans. Graph.* 24, 3 (July 2005), 1098–1107. DOI: http://dx.doi.org/10.1145/1073204.1073318