A Resampled Tree for Many Lights Rendering

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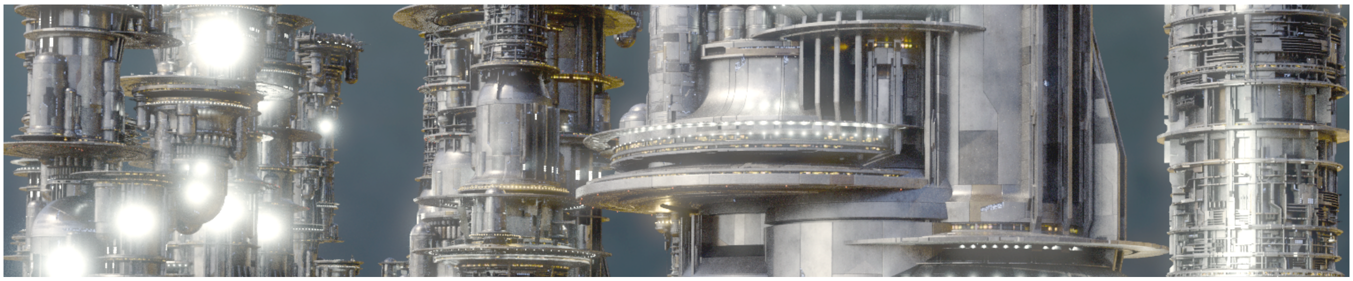

Figure 1: A 100k lights scene from Ant-Man and the Wasp: Quantumania © Marvel Studios. Our new system is able to render specular highlights better than a pure tree-based approach thanks to resampling.

ABSTRACT

We propose a new hybrid method for efficiently sampling many lights on a scene that combines a simplified spatial tree with a resampling stage. Building on previous methods that work with a split or cut of the light tree, we introduce the idea of probabilistic splitting to eliminate noise boundaries. This yields a subset of lights that is then reduced to a smaller and bounded set for full light/BSDF evaluation and resampling. Our main contribution is the stochastic splitting formulation combined with a reservoir set technique which limits samples to an arbitrary number to avoid variable size collections.

KEYWORDS

: illumination, ray tracing, many lights

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1 INTRODUCTION

Rendering with many lights is a challenging problem. Efficiently choosing the relevant emitters to a shading point involves finding a balance between performance and variance. We seek to render with as few shadow rays per pixel as possible. It is therefore key to design a good importance sampling technique. We propose a new resampling tree technique that leverages our previous Adaptive Tree Splitting (ATS) [Conty Estevez and Kulla 2018] with a reservoir resampling approach inspired by [Bitterli et al. 2020]. Our solution is GPU-friendly, not limited to primary bounces, and naturally supports the rendering of participating media with many-lights.

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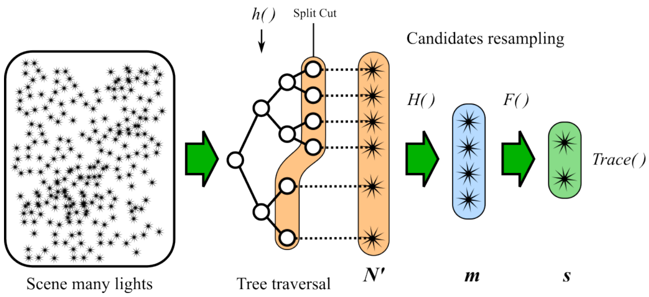
2 OVERVIEW OF OUR SAMPLING

In our previous research [Conty Estevez and Kulla 2018], we employed a complex sampling tree that integrated both spatial and emitter orientation partitioning. This design enabled us to establish an importance measure that considered the orientation of the light and its impact on the shading point. Although beneficial, this approach incurs a high traversal cost. However, this cost was justified as the traversal process was solely accountable for generating the final samples. In our current approach, we have opted to streamline this traversal process for enhanced speed. Instead of relying entirely on the traversal for sample quality, we now defer the refinement of the samples to a subsequent resampling stage.

Table 1: Semantics of the numbers used for our tree sampling

Symbol	Meaning	Example
γ	Splitting rate	1
N	total lights in the scene	many
$N' \leq N$	candidates from the split tree traversal	$1-60$
$m \leq N'$	reduced candidates by resampling with H	16
$s \leq m$	reduced shadow rays by resampling with F	$1-4$

The tree's structure consists of clusters of emitters at internal nodes and individual single emitters at leaf nodes. We employ a tree importance heuristic, H, to guide the traversal. This heuristic is exclusively spatial when evaluating clusters, and we will refer to this relaxed version as $h()$. When assessing individual emitters, H incorporates directionality as well. This aspect of the heuristic proves particularly effective and precise for flat and spot light emitters. Consequently, the sampling pipeline can be summarized as follows:



(1) Traverse the tree only with a spatial heuristic $h()$.
(2) Stochastically split big clusters (expand both subbranches) resulting on multiple N' lighting candidates.
(3) Resample the N' candidates using a more expensive heuristic $H()$ to narrow down the list to a bounded set.
(4) Further resample the m elements bounded set with full light/BSDF evaluation $F()$ to select s shadow rays.

We expose a splitting rate $[0, \infty)$ parameter γ to control the probability of splitting a cluster. Notably, heuristics tend to be less effective for larger clusters near the top of the tree, resulting in a mixture of both suitable and unsuitable candidates. The effectiveness of these candidates is more accurately assessed using $H()$ at the tree's leaves (the actual emitters). This assessment forms the basis of our initial resampling process.

By combining one light traversal and two resampling stages we go from many N lights in the scene to N' unbounded candidate lights, then narrow down to m user controlled candidates and finally s shadow rays. This satisfies our constraint that $s \leq m \leq N' \leq N$.

At the final resampling stage, we conduct a comprehensive evaluation of the Bidirectional Scattering Distribution Function (BSDF) and the irradiance E of a random light sample S_i from light L_i. Subsequently, the final reservoir resampling is a form of product sampling the full light and BSDF evaluation $F()$.

Stochastic Splitting and Reservoir Set. Splitting means both branches of a node are traversed instead or only one randomly. We define a splitting probability for every node that is strictly decreasing as the tree grows deeper and the clusters get smaller. By using the same random number for the whole traversal, every shading point sees a different random cut of the tree. This effectively hides noise discontinuities without a significant variance increase. The details about the resulting PDFs are provided in the supplemental material. All the visited lights from this traversal go into the next resampling stages based on our Reservoir Set.

For this idea to work we needed to extend the concept of reservoir sampler [CHAO 1982] to produce more than just one result from the inputs. That is, from an unlimited input set, select a random subset of n distinct samples chosen according to the same importance measure. Hence, similar to [Talbot 2005] we create n independent weighted reservoir samplers, each containing a single item, but we distribute the input candidates among them randomly. The result is that every reservoir in the set sees a random sub-sequence of the input stream. This randomization strategy effectively eliminates any bias in the order of the input candidates and avoids duplicates.

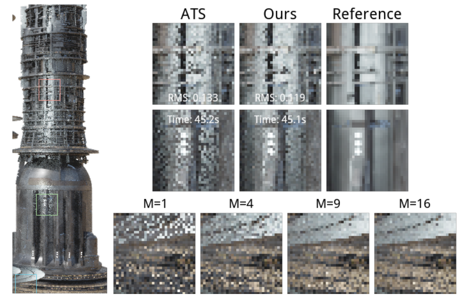


Figure 2: Scene featuring over 80,000 lights. The first two insets show an improvement in variance of our method against Adaptive Tree Splitting. Third inset shows how varying reservoir count M improves variance. Image © Marvel Studios.

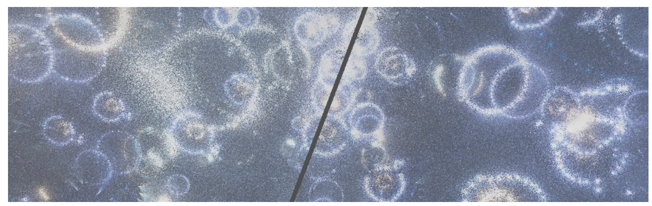


Figure 3: Approximately equal time comparison of two splitting heuristics where the one on the right extends further away and therefore splits more aggressively.

3 PARAMETERIZATION AND RESULTS

We deployed this algorithm to production last year, and have observed decreases in noise and render times. We also implemented it on GPU, where we benefit from our s parameter's effect of tracing the same number of shadow rays for each sample to reduce divergence. We evaluated our method on three test scenes, comparing against our previous implementation and analyzing optimal parameters. We observe the benefit of increasing reservoir size m on the Chronopolis environment, gaining significant improvements in variance in glossy metallic areas.

Participating Media. We have observed in scenes with participating media that our new technique is significantly more efficient than our previous method. We use a production environment to experiment with two measures of split probability functions. Fig 3 compares the two heuristics where the more aggressive one improves results. See the supplemental document for details and convergence plots.

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