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Paper Review

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In this document, I will review the paper: Differentiable Monte Carlo Ray Tracing through Edge Sampling, published in ACM Transactions on Graphics, December 2018.

Paper Review

Introduction

There is a rise of algorithms which requires differentiation of a optimization function with the input parameters, eg. Back-propagation. There is the need for a rendering algorithm which can be differentiated with respect to arbitrary input parameters, such as camera location direction, scene geometry, lights, material appearance and texture etc. The rendering integral is not differentiable at object boundaries. It is a step function whose diff is a Dirac delta function. Current deep learning models make a layer between the.... This algorithms is integrated with PyTorch for usability.

Detailed Summary

This paper has introduced a novel 'edge' sampling method. Pixel color is formalized as an integration over all light paths that pass through the pixel filter. Used MC sampling to estimate the integral and it's gradient. Integral is discontinuous due to edges of geometry and occlusion. Grad of discontinuous integrand is Dirac delta function, therefore traditional sampling has zero probability of capturing δ function.

- Method : Split it into smooth and discontinuous regions, for smooth - traditional area sampling with automatic differentiation. For discontinuous part, use novel edge sampling method.
- Edge sampling method: Define different function spaces and count the contribution of specific kinds of edges, then uniformly sample on the silhouette edges. Secondary illumination and occlusion can be handled naturally. The mathematics behind is proved and we obtain derivative of the scene with respect to screen space gradients, then with respect to ϕ, the camera parameters by chain rule.
- The user can compute a scalar loss on output image and obtain gradient by back-propagating to the scene parameters. The method was verified and tested for several synthetic scenes covering a variety of effects including occlusion, various materials, global illumination etc. Bottleneck for high resolution images is the edge sampling method. Use the hierarchical sampling method.

Nutshell: A differentiable MC ray-tracing algorithm that is capable of generating correct and unbiased gradients with respect to arbitrary input scene parameters. For this, we have introduced a novel edge sampling algorithm to take the geometric discontinuities into consideration, and derived the appropriate measure conversion. For increased efficiency, we use a new discrete hierarchical sampling method to focus on relevant edges as well as continuous edge importance sampling.

Strength and Mechanisms

- Rigorous Proof of mathematical correctness of gradient is given.
- The paper's code is efficient (using C++) and open source (on Github).
- It is integrated with PyTorch API, which facilitates easier manipulation of tensors, deep learning models etc.
- Better than the previous OpenDR and Neural 3D Mesh renderer as they give incorrect derivatives in some cases.

Weaknesses

- Not generalized for inter-penetrative geometries, Shader discontinuities, that is the scope of future work.
- Performance limited on CPU. Not implemented on GPU where larger deep learning architectures are trained.

Ideas for improvement & Future Work

Future work is to develop better sampling algorithms (eg. incorporate bidirectional path tracing. Better compiler techniques to optimize automatic differentiation code and supporting GPU backends. Other light transport phenomena, eg. differentiating motion blur requires sampling on 4D edges with extra time dimension. Interpenetrating geometries, shader discontinuities are some of the future works.

References

- Differentiable Monte Carlo Ray Tracing through Edge Sampling.
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