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Unifying Points, Beams, and Paths in Volumetric Light Transport Simulation

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Figure 1: *We present a new rendering algorithm, unified points, beams, and paths (UPBP), for light transport simulation in participating media. UPBP combines a number of volumetric estimators based on points and beams with Monte Carlo path sampling techniques, all of which have complementary strengths and weaknesses. The bottom row shows the contributions of the various volumetric transport techniques to the final image at the top.*

Light scattering in participating media is responsible for many important visual phenomena. However, simulation of these effects can incur a large computational cost as variations in media density (e.g., haze vs. skin), scattering albedo (wine vs. milk), and scattering anisotropy result in significantly different light interaction behaviors. As such, designing a single light transport simulation algorithm that is robust to these variations is an important research direction.

Two classes of light transport simulation approaches widely adopted in image synthesis excel at rendering complex volumetric shading effects: those based on Monte Carlo integration [1] and those based on "photon" density estimation [2]. Several different volumetric density estimators specialize in handling complex effects such as indirect caustics, where bidirectional Monte Carlo path-tracing (BPT) performs poorly. While previous work has empirically demonstrated the power of the density estimation techniques, no well-founded analysis of their relative performance has existed.

We perform a canonical variance analysis of the various volumetric radiance estimators categorized by Jarosz et al. [2] in order to quantify the behavior of their relative performance under different configurations. We show that while beam-based estimators are beneficial for relatively sparse media, dense media are still often better handled by point-based density estimators.

Based on
our findings, we seek to combine the strengths of all potential volumetric estimators with the versatility of bidirectional path tracing in a principled way. To that end, we develop an extension of multiple importance sampling [4] that accommodates the combination of these fundamentally different approaches into a single rendering algorithm (see Fig. 1). The algorithm, which we call *unified points, beams, and paths (UPBP)*, excels at rendering scenes with different kinds of media, where previous specialized techniques each fail in complementary ways (see Fig. 2). In summary, our work makes the following major contributions:

- We present a variance analysis showing the complementary merits of point- and beam-based volumetric estimators.
- We extend multiple importance sampling to enable the combination of point-based, beam-based, and Monte Carlo volumetric estimators.
- We implement a practical combined algorithm for robust light transport simulation in scenes with different media.

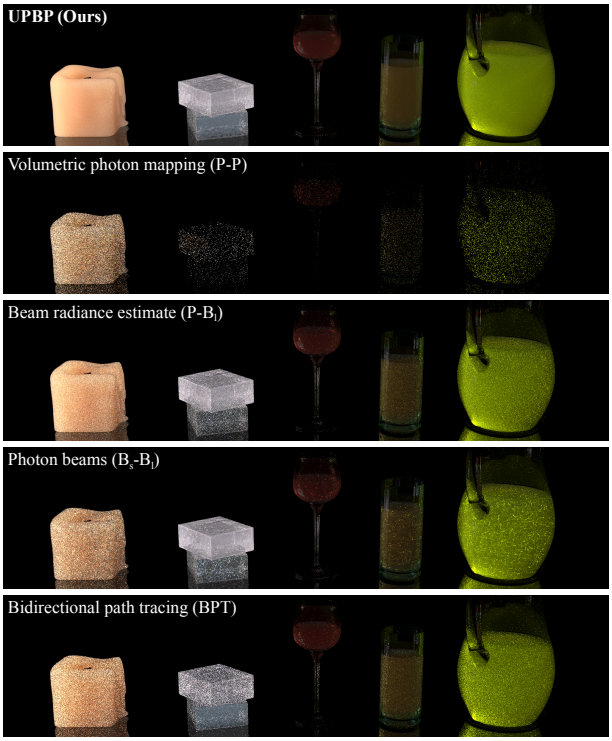

Figure 2: *Equal-time comparison of our UPBP algorithm against previous work on the Still Life scene from Fig. 1. Only volumetric transport is shown.*

For further details and results, please refer to [3] or the paper web site at http://cgg.mff.cuni.cz/˜jaroslav/papers/2014-upbp/.

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