Photon surfaces for robust, unbiased volumetric density estimation

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Introduction

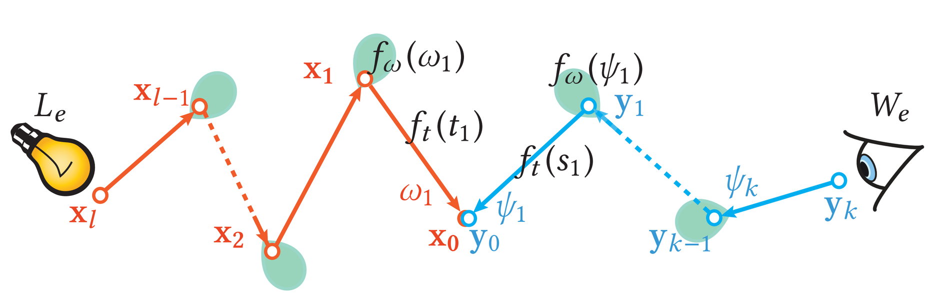
Previous work [Bitterli and Jarosz '17] made **unbiased** volumetric density estimation possible, but in practice, bias needs to be introduced to remove singularities.

We show how to stay **unbiased** while removing singularities.

Our approach includes two parts:

- A **framework** for deriving "photon surface" estimators.
- A way to **remove singularities** from the resulting estimators by **combining** them using *multiple importance sampling* (MIS) [Veach and Guibas '95].

Photon surfaces

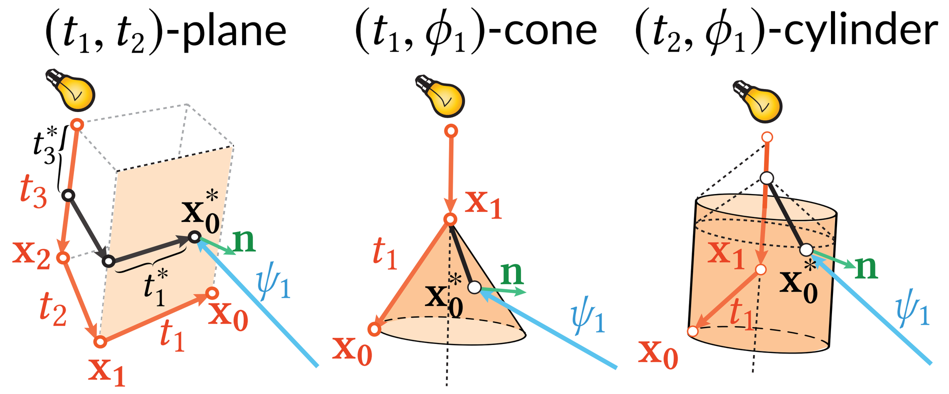


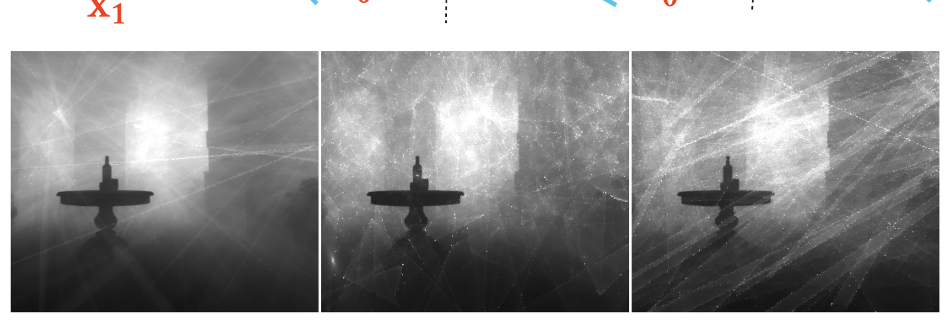
Traditional photon mapping [Jensen and Christensen '98; Jarosz et al. '08, '11] gathers the path contribution inside a **finite-sized kernel** $K(g)$, where g is the vector between the end points of the camera and light subpaths.

The finite kernel allows paths to contribute even if the subpath endpoints don't coincide, but this also introduces bias. Theoretically, an infinitesimal **Dirac delta kernel** would remove bias, but would be impossible to sample with Monte Carlo. We use a 3D **Dirac delta kernel** to eliminate bias, but then *analytically* **pre-integrate** 3 sampled dimensions: the distance along the camera ray, and 2 arbitrary sampling dimensions along the photon subpath.

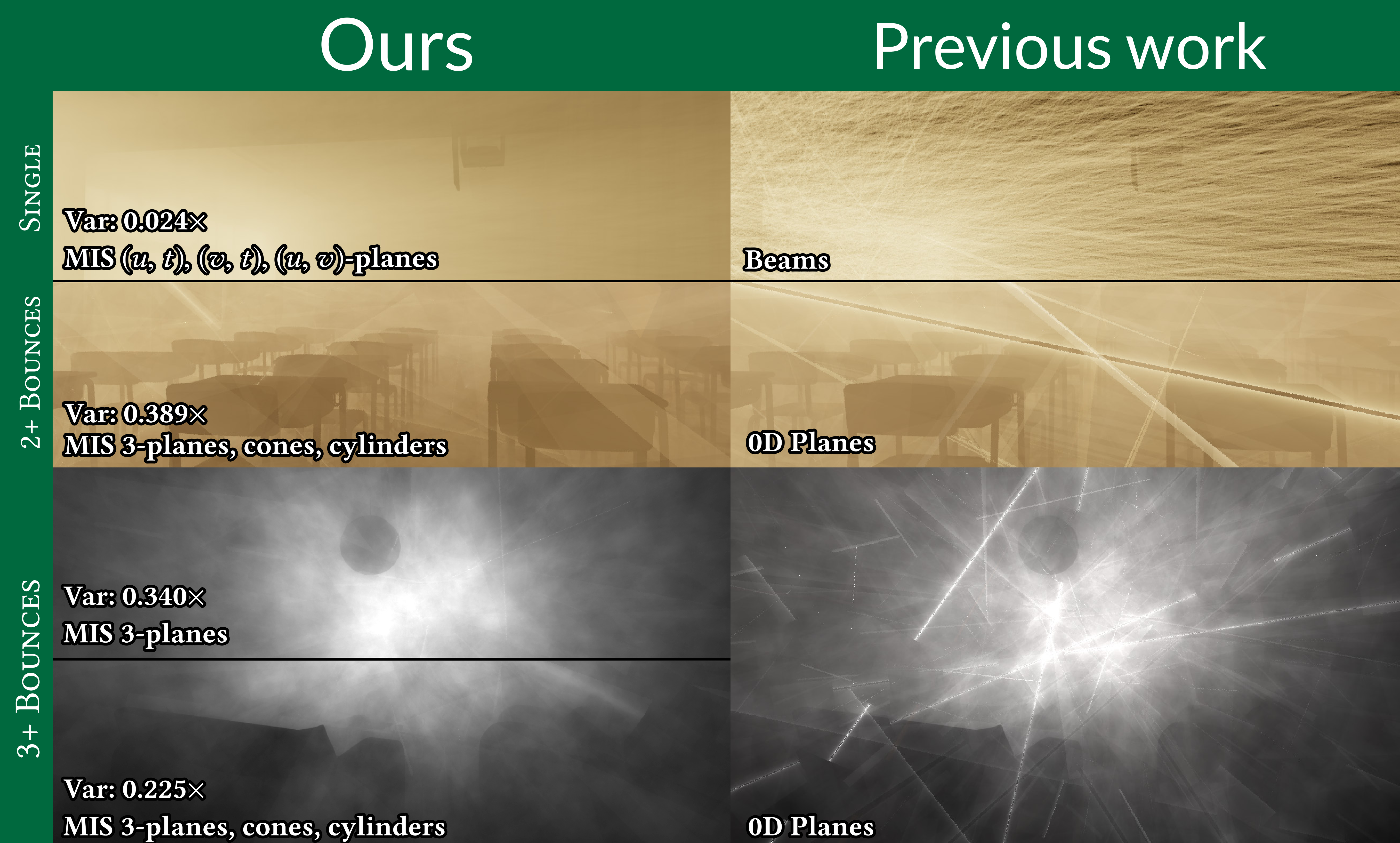
Intuitively, pre-integration along the photon subpath produces "photon surfaces" sweeping the position of the photon for all possible values of the 2 analytically integrated dimensions. Each choice of these 2 dimensions produces a different unbiased photon surface. We can choose any **directional** dimensions $\cos\theta, \phi$; **distance** dimension t; or dimensions u, v on the **light source**, e.g.:

(t_1, t_2)-plane (t_1, ϕ_1)-cone (t_2, ϕ_1)-cylinder





We created a new class of ***unbiased photon density estimators*** and combined them using ***multiple importance sampling***.



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Removing singularities

Each individual photon surface estimator suffers from **singularities**—e.g. at grazing angles or at the apex of a photon cone—which we would like to remove.

Path sampling PDFs: Since each camera ray–photon surface intersection corresponds to one **light path**, we can interpret each estimator as a **path sampling strategy** with a corresponding **PDF**. Singularities on a photon surface correspond to paths that are vanishingly unlikely to be sampled (extremely low PDF).

Being able to evaluate a path PDF for each estimator enables combining several different photon surface estimators using multiple importance sampling. As long as a singular path in one estimator has a non-zero PDF with another estimator, the singular estimator will be down-weighted, eliminating the singularity.

Here's an example of combining 2 different estimators:

MISing a continuum of strategies: The various choices of 2 analytic dimensions create a large, but *countable* number of photon surface strategies that we can combine using MIS to mitigate singularities. Additionally, there are *infinitely* many possible u, v parametrizations for the light source (e.g., all possible u, v rotations on a planar light), each resulting in photon surfaces with different PDFs and singularities. We extend traditional MIS—which can combine a discrete number of strategies—to combine such a *continuum* of strategies.

References

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