Path Sampling and Reusing in Light Transport Simulation
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Abstract
Robust light transport simulation is a challenging problem in photorealistic rendering. Existing Monte Carlo methods rely on path sampling. However, path sampling process is expensive and algorithm convergence requires a large number of path samples. We introduce a new type of intermediate sub-path to connect light sub-paths and camera sub-paths by vertex merging. An intermediate sub-path can be reused in multiple full paths so that our algorithm makes use of more path samples. By building a path graph, path samples are reused and constructed more efficiently. We adopt our algorithm to path integral framework with multiple importance sampling. Experimental results of our algorithm show consistency and improvement over other previous methods.

Problem
Given a 3D scene, generate realistic images by light transport algorithms, which simulate the emission and scattering of light in the environment.

Related Work
- Bidirectional path tracing (BPT) [Veach and Guibas, 1994]
  - Trace light sub-paths and camera sub-paths, then connect them.
- Photon Mapping (PM) [Jensen, 1996]
  - Reuse light photons via density estimation.
- Multiple Importance Sampling (MIS) [Veach and Guibas, 1995]
  - Combine different algorithms. BPT + PM = VCM [Georgiev et al., 2012]

Motivation
- Reuse more sub-paths, since more path samples result in faster convergence rate.
- Capture paths that are difficult to find by previous algorithms.

Our Approach
- Pipeline
  This illustration shows the work flow of our algorithm. Light sub-paths, intermediate sub-paths and camera sub-paths are traced from light sources, diffuse surfaces and camera, respectively. The remaining scattering process is the same for all types of sub-paths.

- Path Reusing via Path Graph
  Information of sub-paths, including path vertex position, measurement contribution function, probability density function, weighting function, etc., are stored in a k-d tree. If the start position of a sub-path is close to a vertex of another sub-path, these two sub-paths can be concatenated by vertex merging (VM). The range search lookup is efficient in a k-d tree. If the start position of a sub-path is close to a vertex of another sub-path, these two sub-paths can be concatenated by vertex merging (VM). The range search lookup is efficient in a k-d tree. Consider sub-paths as nodes and the relations of path concatenation as edges, we can construct a directed graph called path graph.

Results
The test scene is extended from classical Cornell Box. The light source is surrounded by a box. This result shows intermediate sub-paths are effective in concatenating light and camera sub-paths, since it is hard to directly connect light and camera sub-paths due to the occlusion. By constructing more path samples, our algorithm achieves faster error convergence rate. We compared our algorithm with previous light transport works.

Future Work
- Our algorithm can be extended to scenes with participating media and volumetric materials. Since the spatial distribution of sub-paths are much denser in participating media than on surfaces, we expect a better performance of our path reusing algorithm.
- Our algorithm will be more robust if we relax some constraints, e.g., the length of camera sub-path can be arbitrary long, and camera sub-paths are allowed to directly connect with light and intermediate sub-paths. This requires several modifications of our MIS framework.