COMBINING VOLUMETRIC ESTIMATORS

Jaroslav Křivánek
Charles University – Render Legion | Chaos Group
UNIFYING POINTS, BEAMS, AND PATHS IN VOLUMETRIC LIGHT TRANSPORT SIMULATION

Jaroslav Křivánek
Charles University in Prague

Iliyan Georgiev
Light Transportation Ltd.

Toshiya Hachisuka
Aarhus University

Petr Vévoda
Charles University in Prague

Martin Šík
Charles University in Prague

Derek Nowrouzezahrai
University of Montreal

Wojciech Jarosz
Disney Research Zurich
Goal: Robust rendering of media

- Robust to: media properties, lighting

- high scattering
  - dense
  - diffuse lighting

- rare

- low scattering
  - focused lighting
  - low scattering
Existing volumetric rendering algorithms

- **MC path integration**
  - Path tracing [Kajiya ‘86, Rushmeier and Torrance ‘88]
  - Bidirectional path tracing [Laforetune and Willems ‘96]

- **Photon density estimation**
  - Volumetric photon mapping [Jensen and Christensen ‘98]
  - Beam radiance estimate [Jarosz et al. ‘08]
  - Photon beams [Jarosz et al. ‘11]

- No existing algorithm can handle all cases
Bidirectional path tracing
1 hour
Volumetric photon mapping
1 hour
Beam radiance estimate
1 hour
Photon beams
1 hour
UPBP algorithm
1 hour
Approach: Combine estimators

- **Multiple Importance Sampling** [Veach and Guibas ‘95]

- **Previous work**
  - Bidirectional path tracing (**BPT**) [Veach and Guibas ‘95]
  - Vertex connection and merging (**VCM**) [Georgiev et al. ‘12]
  - Unified path sampling (**UPS**) [Hachisuka et al. ‘12]

- **Our algorithm**
  - “Unified points beams and paths” (**UPBP**)
Contributions

■ “Does it make sense to combine the estimators?”
  □ Variance analysis of estimators

■ “How can we combine the estimators?”
  □ Extended multiple importance sampling

■ “How do we make the method practical?”
  □ A combined volume rendering algorithm
VOLUMETRIC PHOTON DENSITY ESTIMATORS
RADIANCE REP.: photon **points**

**QUERY**

- **Point - Point**
- **Beam - Point**

- **Point - Beam**
- **Beam - Point**

[Jarosz et al. ’11a]

- **Photon beams**
  - “Short” beams
  - “Long” beams

- **Query beams**
  - The same story
Bottom line: Many estimators

Points

“Short” Beams

“Long” Beams

×

Points

“Short” Beams

“Long” Beams
Why combine points and beams?

- Won’t photon beams always outperform photon points?

100k photon points  

reference  

5k photon beams  

from [Jarosz et al. ’11a]
VARIANCE ANALYSIS
Variance analysis – Canonical setup
Variance analysis – Expected value

MC methods for volumetric light transport – Combining estimators
Variance analysis – Estimators

MC methods for volumetric light transport – Combining estimators

"Long" beam

"Short" beam

Point

transmittance
Variance analysis results

- Variance analysis results for different kernel widths in rare and dense media.
- Normalized std. dev. (NSD) plotted against kernel width (mean free path).
- Short beam and Point estimators compared at different kernel widths.

MC methods for volumetric light transport – Combining estimators
## Variance analysis results

<table>
<thead>
<tr>
<th></th>
<th>rare media</th>
<th>dense media</th>
</tr>
</thead>
<tbody>
<tr>
<td>beams:</td>
<td>🟢</td>
<td>🟥</td>
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<tr>
<td>points:</td>
<td>🟥</td>
<td>🟢</td>
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“HOW TO COMBINE?”

EXTENDED MIS
Our MIS extension

- Extended MIS – accommodate all the different estimators
- Compatible with RR interpretation of density estimation kernels (like VCM [Georgiev et al. ‘12])
- Alternative view: extended path space [Hachisuka et al. ’12, Hachisuka et al. ’17]
“HOW TO IMPLEMENT IT?”

THE COMBINED ALGORITHM
Estimator choice

- Point-Point
- Beam-Point
- Point-Beam
- Beam-Beam
“Long” vs. “short” beams

- “Short” photon beams
- “Long” query beams
Family of estimators

- Bidirectional path tracing
Light tracing
UPBP – Algorithm overview

MC methods for volumetric light transport – Combining estimators
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MC methods for volumetric light transport – Combining estimators
RESULTS
Full transport

rare, fwd-scattering fog

back-scattering
high albedo

back-scattering
Medium transport only
Previous work comparison, 1 hr

Point-Point 3D ($\approx$vol. ph. map.)

Point-Beam 2D (=BRE)

Beam-Beam 1D (=photon beams)

Bidirectional PT
Previous work comparison, 1 hr

- **Point-Point 3D**
- **Point-Beam 2D**
- **Beam-Beam 1D**
- **Bidirectional PT**
Point-Point 3D
Point-Beam 2D
Beam-Beam 1D
Bidirectional PT

Weighted contributions
UPBP, 1 hr
MC methods for volumetric light transport – Combining estimators
MC methods for volumetric light transport

**Beam-Point 2D (BRE)**

**UPBP**

**Beam-Beam 1D (photon beams)**
Limitations & future work

- **Efficiency-based combination**

- **Overhead**
  - Number of samples from different estimators
**Take-home message**

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<th>Dense Media</th>
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<tbody>
<tr>
<td><strong>Beams:</strong></td>
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<td>👎</td>
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<td><strong>Points:</strong></td>
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</table>
Source code

SmallUPBP
A (not too) small physically based volumetric renderer

http://www.smallupbp.com/
Acknowledgment

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