Monte Carlo Methods for Volumetric Light Transport Simulation
Advanced methods

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DARTMOUTH VISUAL COMPUTING LAB
Advanced methods

Photon tracing/mapping
Many-light methods
Combining techniques
Radiance caching
Advanced methods

Photon tracing/mapping
Many-light methods
Combining techniques
Radiance caching
More from Johannes…
Photon Tracing in Participating Media
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Radiance estimation

[Jensen & Christensen 98]
Radiance estimation

[Jensen & Christensen 98]
Radiance estimation

Density/radiance estimation on surface

[Jensen & Christensen 98]
Radiance estimation

Density estimation as you ray march

[Jensen & Christensen 98]
Radiance estimation

Density estimation as you ray march

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[Jensen & Christensen 98]
Radiance estimation

Density estimation as you ray march

[Jensen & Christensen 98]
A Volume Caustic

500,000 photons. 1 minute

Henrik Wann Jensen
Subsurface Scattering

Henrik Wann Jensen
Radiance estimation

[Jensen & Christensen 98]
Radiance estimation

[Jensen & Christensen 98]
Drawbacks

Large Step-size

[Jensen & Christensen 98]
Drawbacks

Large Step-size

[Jensen & Christensen 98]
Drawbacks

Large Step-size

Very Small Step-size

[Jensen & Christensen 98]
Radiance estimation

[Jarosz et al. 08]
Radiance estimation

How to find the photons?

[Jarosz et al. 08]
Beam Radiance Estimate

[Jarosz et al. 08]
Beam Radiance Estimate

[Jarosz et al. 08]
Beam Radiance Estimate

[Jarosz et al. 08]
Beam Radiance Estimate

Monte Carlo Methods for Volumetric Light Transport Simulation

[Jarosz et al. 08]
Cars on Foggy Street

Beam Estimate

Traditional Estimate
So Far...

Volumetric Photon Mapping (VPM)  
[Jensen & Christensen 98]
So Far...

Volumetric Photon Mapping (VPM)  
[Jensen & Christensen 98]
So Far...

Volumetric Photon Mapping (VPM) [Jensen & Christensen 98]

Query
Point
So Far...

Volumetric Photon Mapping (VPM) [Jensen & Christensen 98]

<table>
<thead>
<tr>
<th>Query x Data</th>
</tr>
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<tbody>
<tr>
<td>Point x Point</td>
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So Far...

Volumetric Photon Mapping (VPM)  
[Jensen & Christensen 98]

<table>
<thead>
<tr>
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<tr>
<td>Point</td>
<td>x Point</td>
<td>(3D)</td>
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So Far...

Volumetric Photon Mapping (VPM)
[Jensen & Christensen 98]

The Beam Radiance Estimate (BRE)
[Jarosz et al. 08]
So Far...

**Volumetric Photon Mapping (VPM)**
[Jensen & Christensen 98]

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**The Beam Radiance Estimate (BRE)**
[Jarosz et al. 08]

<table>
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[Jensen & Christensen 98]

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The Beam Radiance Estimate (BRE)  
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Volumetric Photon Mapping (**VPM**)  
[Jensen & Christensen 98]

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The Beam Radiance Estimate (**BRE**)  
[Jarosz et al. 08]

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<td>Beam x Point (2D)</td>
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Other possibilities

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<td></td>
</tr>
<tr>
<td>Beam</td>
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[Jarosz et al. 11]
Volumetric photon mapping

Photon Points

[Jarosz et al. 11]
Volumetric photon mapping

Photon Points

[Jarosz et al. 11]
Volumetric photon mapping

[Jarosz et al. 11]
Volumetric photon mapping

Photon Beams $\times$ Point Query

[Jarosz et al. 11]
Volumetric photon mapping

Photon Beams x Beam Query

[Jarosz et al. 11]
Underwater Sun Beams

Photon Points

100K Photon Points
~ 204 seconds/frame

Photon Beams

25K Photon Beams
~ 200 seconds/frame

Roughly Equal Time
Underwater Sun Beams

Photon Points

100K Photon Points
~ 204 seconds/frame

Photon Beams

25K Photon Beams
~ 200 seconds/frame

Roughly Equal Time
Photon Points
Photon Points

[Photon Points
[Jensen & Christensen 98]
Photon Points

[Photon Points, Esp. 3D Blur]

[Collision estimator]

[Jensen & Christensen 98]

[collision estimator]

[Spanier & Gelbard 69]
Photon Beams

[Jarosz et al. 11]
Photon Beams

[Jarosz et al. 11]
(Long) Photon Beams

1D Blur

“Long” Beams
[Jarosz et al. 11]
(expected value est.)
[Spanier & Gelbard 69]
(Short) Photon Beams

1D Blur

“Short” Beams
[Jarosz et al. 11]
(Short) Photon Beams

1D Blur

“Short” Beams
[Jarosz et al. 11]
(track-length value est.)
[Spanier & Gelbard 69]
Beyond Photon Beams?
Beyond Photon Beams?

We can keep going to higher dimensional “photons”!
Photon Planes

0D Blur
Unbiased

[Bitterli & Jarosz 17]
Photon Volumes

0D Blur
Unbiased
[Bitterli & Jarosz 17]
Photon Beams

[Bitterli & Jarosz 17]
Photon Beams

[Bitterli & Jarosz 17]
Photon Beams

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[Bitterli & Jarosz 17]
Photon Beams

Track-length or Expected Value estimator

[Bitterli & Jarosz 17]
Photon Beams

Collision estimator

Track-length or Expected Value estimator

[Bitterli & Jarosz 17]
Beam Marching

[Bitterli & Jarosz 17]
Beam Marching

[Bitterli & Jarosz 17]
Photon Plane

[Bitterli & Jarosz 17]
Plane Marching

[Bitterli & Jarosz 17]
Plane Marching

[Bitterli & Jarosz 17]
Photon Volume

[Reference: Bitterli & Jarosz 17]
Photon Planes (unbiased)
3.77× Speedup
Photon Planes (1D blur)
14.14× Speedup
Photon Beams (1D blur)
Volumetric Photon Mapping

[Jensen and Christensen 1998]
[Jarosz et al. 2008]

requires a lot of photons
Volumetric Photon Mapping requires a lot of photons.

Photon Beams have great caustics and multi-scattering is slow.

(Jensen and Christensen 1998) [Jarosz et al. 2008] [Jarosz et al. 2011a] [Jarosz et al. 2011b]
Volumetric Photon Mapping

[Jensen and Christensen 1998]
[Jarosz et al. 2008]

requires a lot of photons

Photon Beams

[Jarosz et al. 2011a]
[Jarosz et al. 2011b]

great caustics, multi-scattering slow

Virtual Point Lights

[Keller 1997]
[Walter et al. 2005]
[Raab et al. 2008]
Singularities or Energy Loss

Engelhardt et al. 2010

VPLs - no clamping
Singularities or Energy Loss

VPLs - no clamping

VPLs - clamping

Engelhardt et al. 2010
Singularities or Energy Loss

VPLs - no clamping

VPLs - clamping

Reference

Engelhardt et al. 2010
Volumetric Photon Mapping

- Requires a lot of photons

Virtual Point Lights

- Suffers from singularities, flickering

Photon Beams

- Great caustics, multi-scattering slow
Volumetric Photon Mapping

- [Jensen and Christensen 1998]
- [Jarosz et al. 2008]

requires a lot of photons

Virtual Point Lights

- [Keller 1997]
- [Walter et al. 2005]
- [Raab et al. 2008]

suffers from singularities, flickering

Photon Beams

- [Jarosz et al. 2011a]
- [Jarosz et al. 2011b]

great caustics, multi-scattering slow

Virtual Ray Lights

- [Novak et al. 2012]
Comparison

Fruit Juice

- homogeneous
- anisotropic (HG g = 0.55)

512x512
Surface illumination (Photon Mapping)

Single scattering (Photon Beams)

Multiple scattering
Comparison

Multiple scattering
Multiple Scattering Only

Virtual Ray Lights
Progressive Photon Beams
Virtual Point Lights
Multiple Scattering Only

Virtual Ray Lights  Progressive Photon Beams  Virtual Point Lights
Temporal Stability

Virtual Ray Lights

Virtual Point Lights

1 minute/frame

1 minute/frame
Temporal Stability

Virtual Ray Lights

Virtual Point Lights

1 minute/frame

1 minute/frame
Combining techniques

UPBP (Unified Points, Beams, and Paths)
[Křivánek et al. 14]
A simple, yet difficult scene
Bidirectional Path Tracing
Bidirectional Photon Mapping
Bidirectional Photon Beams
Bidirectional Beam Radiance Estimate
Automatic combination

UPBP (Unified Points, Beams, and Paths)

[Křivánek et al. 14]
Radiance caching

Illumination changes slowly

- Compute lighting and cache for reuse by nearby rays

[Jarosz et al. 2008a]
Radiance caching

Illumination changes slowly
- Compute lighting and cache for reuse by nearby rays

[Jarosz et al. 2008a]
Radiance caching

Illumination changes slowly
- Compute lighting and cache for reuse by nearby rays

Extension of (ir)radiance caching
- [Ward 88, Ward & Heckbert 92]
- [Křivánek 05a, b]
- [Jarosz et al. 12, Schwarzhaupt et al. 12]
Radiance caching

Illumination changes slowly
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Extension of (ir)radiance caching
- [Ward 88, Ward & Heckbert 92]
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[Jarosz et al. 08a, b]
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- [Křivánek 05a, b]
- [Jarosz et al. 12, Schwarzhaupt et al. 12]
- [Jarosz et al. 08a, b]
- [Marco et al. 18]

Monte Carlo Methods for Volumetric Light Transport Simulation
No gradients

[Jarosz et al. 2008a]
With gradients

[Jarosz et al. 2008a]
[Jarosz et al. 2008a]
Path tracing
1st order radiance caching [Jarosz et al. 2008a]
1st order radiance caching

(occlusion-unaware gradient)

[Jarosz et al. 2008a]
(occlusion-aware gradient + hessian)

2nd order radiance caching

[Marco et al. 2018]
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