Path Integral Methods for Light Transport Simulation: Theory & Practice

EUROGRAPHICS 2014 Tutorial

Tutorial materials are available from
http://cgg.mff.cuni.cz/~jaroslav/papers/2014-ltstutorial/index.htm

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Synopsis. The tutorial presents a survey of the recent advances in robust light transport simulation methods. Based on a clear exposition of the path integral framework we discuss a wide range of algorithms, and discuss issues that arise when applying these advanced methods in practice.

Keywords. Global illumination, Light transport simuilation, Monte Carlo methods, Path integral.

Abstract

We are witnessing a renewed research interest in robust and efficient light transport simulation based on statistical methods. This research effort is propelled by the desire to accurately render general environments with complex materials and light sources, which is often difficult with the currently employed solutions. In addition, it has been recognized that advanced methods, which are able to render many effects in one pass without excessive tweaking, increase artists' productivity and allow them to focus on their creative work. For this reason, the movie industry is shifting away from approximate rendering solutions toward physically-based rendering methods, which poses new challenges in terms of strict requirements on image quality and algorithm robustness.

Many of the recent advances in light transport simulation, such as the robust combination of bidirectional path tracing with photon mapping (Vertex Connection and Merging / Unified Path Space), or the new Markov chain Monte Carlo methods are made possible by interpreting light transport as an integral in the space of light paths. However, there is a great deal of confusion among practitioners and researchers alike regarding these path space methods.

The goal of this tutorial is twofold. First, we present a coherent review of the path integral formulation of light transport and its applications, including the most recent ones. We show that rendering algorithms that may seem complex at first sight, are in fact naturally derived from this general framework. A significant part of the tutorial is devoted to the application of Markov chain Monte Carlo methods for light transport simulation, such as Metropolis Light Transport and its variants. We include an extensive empirical comparison of these MCMC methods. The second part of the tutorial discusses practical aspects of applying advanced light transport simulation methods in practical architectural visualization and VFX tasks.

Intended audience

Industry professionals and researchers interested in recent advances in robust light transport simulation for realistic rendering with global illumination.

Prerequisites

Familiarity with rendering and with concepts of global illumination computation is expected.

Level of difficulty

Intermediate

Tutorial length

Half-day (2×90 minutes)

Syllabus

1. Introduction & Welcome (*Křivánek*)
   (10 min)

2. Path Integral Formulation of Light Transport (*Křivánek*)
   (25 min)
   - Light transport as an integral over light paths
   - Monte Carlo integration primer
   - Path sampling methods and path probability density
   - Unidirectional path sampling: Path tracing, Light tracing, imitations

3. Bidirectional Path Sampling Techniques (*Křivánek*)
   (25 min)
   - Virtual point light rendering as a path sampling technique, limitations
   - Combining different path sampling techniques
   - Bidirectional path tracing
   - Limitations of local path sampling, SDS paths

4. Combining Photon Mapping and Bidirectional Path Tracing (*Georgiev*)
   (30 min)
   - (Progressive) photon mapping
   - Combining photon mapping with bidirectional path tracing
   - Consistency and convergence rate
   - Discussion: advantages & limitations

   Break

5. Markov Chain and Sequential Monte Carlo Methods (*Kaplanyan*)
   (25 min)
   - Markov chains
   - Metropolis-Hastings algorithm
   - Metropolis light transport
   - Normalization, start-up bias and stratification
   - Different mutation strategies and their properties
   - Light transport with sequential Monte Carlo

6. Comparison of Advanced Light Transport Methods (*Kaplanyan*)
   (30 min)
   - Ordinary Monte Carlo methods
   - Metropolis light transport with different mutation strategies
   - Energy redistribution path tracing
   - Markov chain progressive photon mapping
   - Population Monte Carlo light transport

7. Advanced Light Transport in the VFX/Archiviz industry (*Cañada*)
   (30 min)

- Stage of the Industry - the reasons for accurate light transport in practice.
- Current problems, solutions, and workarounds.
- What's next?

8. Conclusion (*all*)

Tutorial presenter information

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Jaroslav is an associate professor at Charles University in Prague. Jaroslav received his Ph.D. from IRISA/INRIA Rennes and the Czech Technical University (joint degree) in 2005. In 2003-2004 he was a research associate at the University of Central Florida. In 2008-2010 he was a Marie Curie research fellow at the Cornell University. His primary research interest is realistic rendering and light transport simulation.

Iliyan Georgiev *Saarland University*
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Iliyan is a graphics researcher at Saarland University, Germany, pursuing a Ph.D. degree. He received a B.Sc. degree in computer science from Sofia University, Bulgaria, and a M.Sc. degree in computer science from Saarland University. His primary research topics are high performance ray tracing and Monte Carlo methods for physically-based light transport simulation. His aspiration for practical rendering solutions has given him the opportunity to work with leading companies like Chaos Group (V-Ray), Disney, and Weta Digital.

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Anton S. Kaplanyan is a graphics researcher at Karlsruhe Institute of Technology (KIT), Germany. Additionally he is pursuing his Ph.D. His primary research and recent publications are about advanced light transport methods in global illumination. Prior to joining academia Anton had been working for Crytek at various positions from senior R&D graphics engineer to lead researcher. He received his M.Sc. in Applied Mathematics at National Research University of Electronic Technology, Moscow in 2007.

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Juan joined Next Limit in 2001 to work in the Realflow development team and later he moved to the newborn Maxwell research team. Since then Juan held several positions in the team, leading it since 2007. He holds a bachelor's degree in Mechanical Engineering and a degree in Environmental Sciences.

Previous appearance of the presented material

This tutorial is derived from the SIGGRAPH 2013 course “Recent Advances in Light Transport Simulation: Theory & Practice”. Based on the positive feedback we have received on the course we have been invited to bring the material to the EUROGRAPHICS 2014 audience.

Presentation materials and tutorial notes

Up-to-date materials are available form http://cgg.mff.cuni.cz/~jaroslav/papers/2014-ltstutorial/index.htm.