A Framework for Transient Rendering

Adrian Jarabo¹
Raul Buisan¹
Universidad de Zaragoza

Julio Marco¹
Wojciech Jarosz²

Adolfo Muñoz¹
Diego Gutierrez¹

¹Universidad de Zaragoza
²Disney Research Zürich
Steady-State Light Transport

Infinite Speed of Light
Steady-State Light Transport
Steady-State Light Transport

Infinite Speed of Light
Transient Light Transport

Finite Speed of Light

299,792,458 $[m/s]$
Transient Light Transport
Transient Light Transport

So if we see at picosecond resolution...
Transient Light Transport
Transient Light Transport

But, is breaking this assumption really useful?
Femto-Photography [Velten2013]
• Visible geometry  [Wu2014, OToole2014...]
• Transparent Objects  [Kadambi2013]
• Hidden geometry  [Velten2012...]
• Reflectance  [Naik2011...]
• GI Components Separation  [Wu2014...]
• ...
Simulation helps:

• Forward-model for inverse problems
• Can test new systems before building them
• Freedom to tweak the physics
The Problem

\[ L(x) \]

\[ x \]
The Problem

\[ L(x) \]

\[ \frac{dL(x)}{dt} = \int_{T}^{t} L_t(tx, t) dt \]
The Problem

\[ L(x) \]

\[ L_t(x, t) \]

[Picoseconds]
The Problem
The Problem

Camera

Light

Participating Media

Camera

Dragon
The Problem
The Problem
The Problem

\[ t_s = (d_1 + d_2 + d_3) \frac{\eta}{c} + \Delta t_1 + \Delta t_2 \]
The Problem
The Problem
The Problem
The Problem
The Problem

![Diagram showing the problem with time (T) and length (L) axes, with regions marked as Bad and OK, indicating fluctuations in performance over time. The diagram suggests periods of success (OK) and failure (Bad).]
The Problem

1. How to reconstruct time-resolved light?

2. How to distribute samples along time?
Our Contribution

1. How to reconstruct time-resolved light?

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Our Contribution

1. How to reconstruct time-resolved light?

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Histogram Density Estimation

[Jarabo2012, OToole2014, Ament2014]

Reconstructed Signal

\[ O(N^{-\frac{1}{3}}) \]

Reconstructed Signal

\[ t \text{ [picoseconds]} \]
Kernel-Based Density Estimation

Reconstructed Signal
Progressive
Kernel-Based Density Estimation
Progressive
Kernel-Based Density Estimation
Binning $O\left(N^{-\frac{1}{3}}\right)$ $\gg$ Kernel-Based $O\left(N^{-\frac{4}{5}}\right)$
Our Contribution

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Our Contribution

1. How to reconstruct time-resolved light?

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Time-Based Sampling
Time-Based Sampling
Time-Based Sampling

\[ L \]

t [picoseconds]
Time-Sampling

Set of techniques for time-based sampling in participating media

1. Next Segment Distance
2. Shadow Connection
3. Angular Sampling
$\sigma_s = 0.9$

$\sigma_a = 0.1$
Kernel-Based Density Estimation
+
Time Sampling
Our Contribution

1. How to reconstruct time-resolved light

2. How to distribute samples along time
Additional Results
More Results in the Supplementary Video

Including:

1. Birefringency
2. Chromatic dispersion *in time*
3. Comparison with captured data
Discussion & Future Work

• Error introduced by Kernel DE
  Signal-aware Kernel Bandwidth [Kaplanyan2013]
  Error Metric [Hachisuka2010]

• Sampling Surface Light Transport
  Caustic \textit{in time} $\rightarrow$ Manifold Exploration [Jakob2012]
Discussion & Future Work

• Help developing new techniques using transient light propagation
• Educational tool
• Useful for other fields?
  – Astrophysics, Neutron Transport, Sound Rendering....
Conclusions

1. Formalized Transient Rendering
2. Kernel-Based Reconstruction for Transient LT
3. Sampling Techniques along Time
4. Non-trivial effects of Transient LT

Code, Videos and Data at:

http://giga.cps.unizar.es/~ajarabo/pubs/transientSIGA14
Time-Sampling

Set of techniques for time-based sampling in participating media

1. Next Segment Distance
2. Shadow Connection
3. Angular Sampling
1. Next subpath Segment Distance
2. Shadow Connection

\[ t_1 + t_2 \in [t_a, t_b] \]
3. Angular Sampling