Spectral and Decomposition Tracking for Rendering Heterogeneous Volumes

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Adjoint-Driven Russian Roulette and Splitting in Light Transport Simulation

• “We must make more path that contributes more.”
• Before rendering, estimate radiances at points
• While rendering, multiply particle weight and estimated radiance => RR/splitting factor
• Do splitting if higher than 1
• Do Russian roulette if lower than 1
• Use passthrough weight window to further lower variance
Spectral and Decomposition Tracking for Rendering Heterogeneous Volumes
Motivation
Paths in Participating Media

- Participating media is filled with particles
Paths in Participating Media

- Particles scatter & absorb rays
Paths in Participating Media

• Especially when the media is not homogenous
Backgrounds
Paths in Participating Media

- When does a single scattering (or absorption) occur?
  - Free path = a path segment between collision
Closed-Form Tracking

- When does a single scattering (or absorption) occur?

- We can (randomly) sample scattering location right away, from simple exponential distribution
  - Simple!
Sampling In Graph

- Distance-Extinction Coefficient graph
Sampling In Graph

• Distance-Extinction Coefficient graph

• We sample distance, check if scattering occurs.
  • In homogenous media, it always scatters, as we sampled with prior knowledge to probability density
Through Heterogenous Media
Through Heterogenous Media

• No simple closed-form solution
Through Heterogenous Media

- Regular tracking, ray marching [Perlin and Hoffert 1989], **delta tracking** [Raab et al. 2008], residual ratio tracking [Novák 2014] ...
Delta Tracking
Delta Tracking (Woodcock Tracking)

- [von Neumann 1951] proposed sampling method with arbitrary sampling distribution
- [Raab et al. 2008] brought it to rendering with participating media
- Fill in space with *fictitious* particles, uniformly
- Hitting real particle, ray scatters
- Hitting fictitious particle, ray continues moving
Delta Tracking

• What does filling space with fictitious particle means?
Delta Tracking

• What does filling space with fictitious particle means?

• How is this different from ray marching?
Delta Tracking

- Ray marching has constant step size
- Delta tracking (randomly) samples step size
- Step size is sampled \textit{as if} the media is uniform
  - Uniform with majorant (highest) extinction coefficient
- In other words, fictitious particles are obstructing rays, like real particles
- However they \textbf{do not collide}, they only affect step size
  - This (not a) collision is called null collision
- \textbf{Unbiased!}
Delta Tracking Algorithm

• While true,
  • Sample distance
  • Move and sample collision rate
  • Continue if null collision / Break if real collision

```c
float sampleDistance(Point x0, Direction ω)
{
    //sample with the maximum extinction σ_t
    float t = -log(rand()) / σ_t;

    while (σ_t(x₀ + tω) < rand())
        t -= log(rand()) / σ_t;

    return t;
}
```

**Algorithm 1:** Unbiased distance sampling for arbitrary media.

From [Raab et al. 2008]
Delta Tracking

- Null collision
- Real collision
- Sampled step (using exponential distribution)
Decomposition Tracking
Decompositing Media Particles

- Decompose media into two parts
  - Control: Homogenous (uniform with lowest density)
  - Residual: Heterogenous
Decompositing Media Particles

- Find free path separately
Decompositing Media Particles

- Find free path separately

- And use smaller one
Decomposition Tracking In Graph

- Standard delta tracking considers whole extinction coefficient at each point
Decomposition Tracking In Graph

- Decomposition tracking decomposes extinction coefficient into two part
  - Control and Residual
Decomposition Tracking In Graph

- Distance sampling in control part is closed-form
  - Simple exponential distribution
Decomposition Tracking In Graph

- For residual part, do delta tracking
  - Sample distance, move, check collision
  - Should lookup extinction coefficient at each point
Decomposition Tracking In Graph

• Use smaller distance comparing two result
Decomposition Tracking In Graph

- Why do we do both when we only need minimum?
- Do control part first, residual part later
Decomposition Tracking In Graph

- It saves many lookups!
Result of Decomposition Tracking

- Less lookups

Spectral and Decomposition Tracking for Rendering Heterogeneous Volumes

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[contains audio]
Result of Decomposition Tracking

- Less lookups, higher performance
Result of Decomposition Tracking

- Less lookups, higher performance

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Spectral Tracking
Weighted Delta Tracking

• From Galtier et al. [2013]
• Small tweak to delta tracking to allow non-bounding extinction coefficient

[Image from the paper: Standard Delta Tracking vs. Weighted Delta Tracking]
Weighted Delta Tracking

• To compensate, calculate & multiply weight at each point
  • Thus *weighted*

• Pros
  • We can use not-exact, non-bounding extinction coefficient

• Cons
  • Weight may diverge
  • Variance can increase
Spectral Tracking

- Exploit those weight schemes for spectral, wavelength dependent effects

Repeat:
Step forward using fpsc.
If scat using scat prob:
  Apply \((weight_1, weight_2, weight_3)\).
  Change direction.
Else if fict using fict prob:
  Apply \((weight_1, weight_2, weight_3)\).
Delta Tracking: Spectral Effect

- Standard delta tracking does separate delta tracking for each wavelength
Delta Tracking: Spectral Effect

• Standard delta tracking does separate delta tracking for each wavelength
Delta Tracking: Spectral Effect

- Standard delta tracking does separate delta tracking for each wavelength

- Results in colored noises
Spectral Tracking

- Same path for wavelengths, only weights differs
Spectral Tracking

• Same path for wavelengths, only weights differs

Repeat:
Step forward using fpsc.
If scat using scat prob:
   Apply \((weight_1, weight_2, weight_3)\).
Change direction.
Else if fict using fict prob:
   Apply \((weight_1, weight_2, weight_3)\).

• 3-vector for RGB case
Spectral Tracking

- Same path for wavelengths, only weights differs

- Same path means no more colored noises!
Figure 1. A cloudscape rendered with a combination of our spectral and decomposition tracking techniques, which gracefully handle chromatic media and reduce collision coefficient evaluations. The insets on the right were computed in equal time, with our method yielding $3.5 \times$ lower MSE than delta tracking.
Spectral + Decomposition Tracking

Summary

• Decomposition tracking
  • Decompose media into control and residual part
  • Less lookups, more performance

• Spectral tracking
  • Exploit weights term for spectral effect
  • No colored noises, less variance
Decomposition Tracking: Strengths & Weaknesses

**Strengths**

- Less lookups
- High performance

**Weaknesses**

- Finding homogenous coefficient can be difficult
- Not very efficient when memory lookup is cheap
- Not compatible with PDF dependent methods
## Spectral Tracking: Strengths & Weaknesses

### Strengths
- No colored noises
- Less variance

### Weaknesses
- Weights can diverge; needs extra tuning
Quiz

• Please pick right words.

• Q1. Decomposition tracking samples distance value from (homogenous / heterogenous) part first.

• Q2. Spectral tracking needs (three different / one single) path for RGB rendering.