Spectral and Decomposition Tracking for Rendering Heterogeneous Volumes

Authors: Peter Kutz, Ralf Habel, Yining Karl Li, and Jan Novák. 2017
Presenter: Seo Hansol

Images are from the authors' slide otherwise notated

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

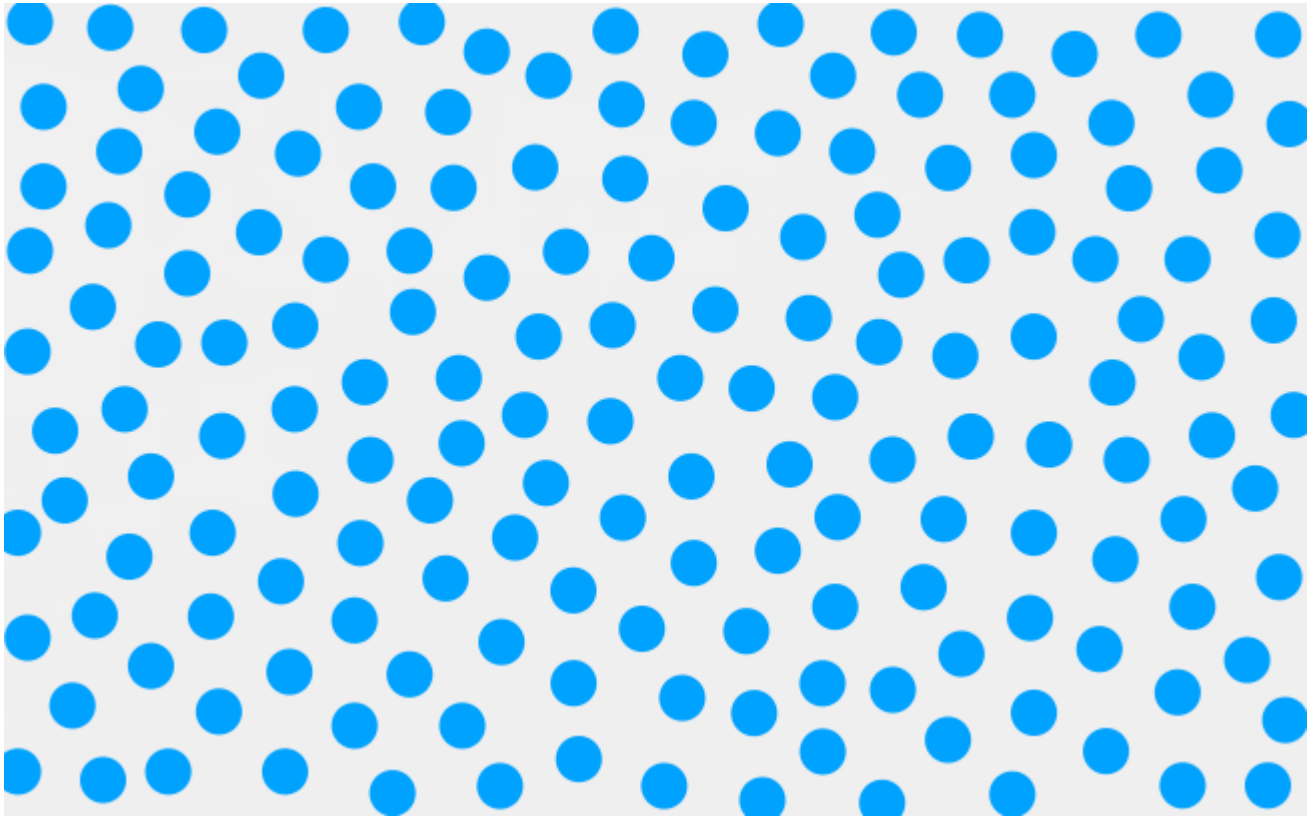
Spectral and Decomposition Tracking for Rendering Heterogeneous Volumes

Image from the paper

Motivation

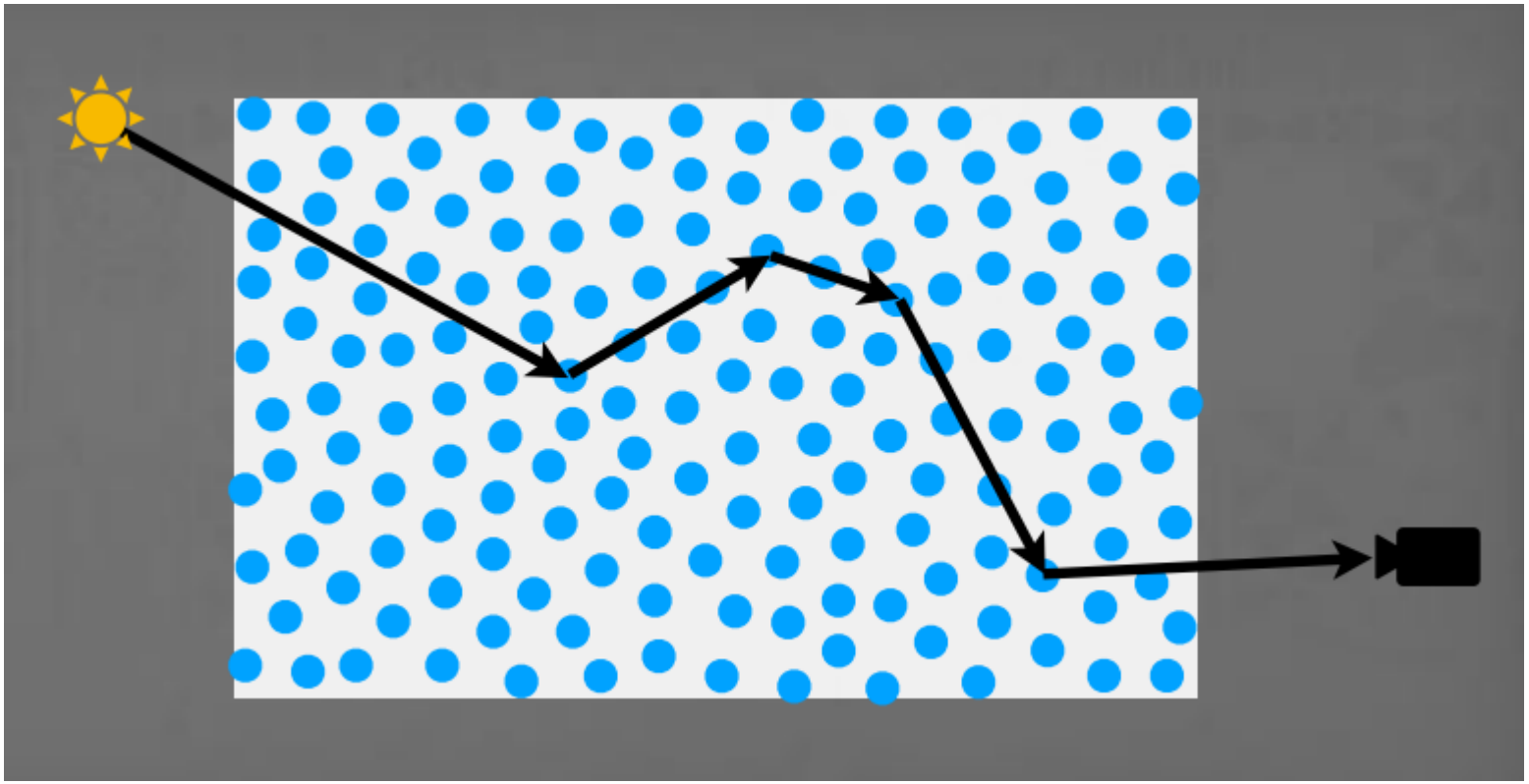
Paths in Participating Media

- Participating media is filled with particles



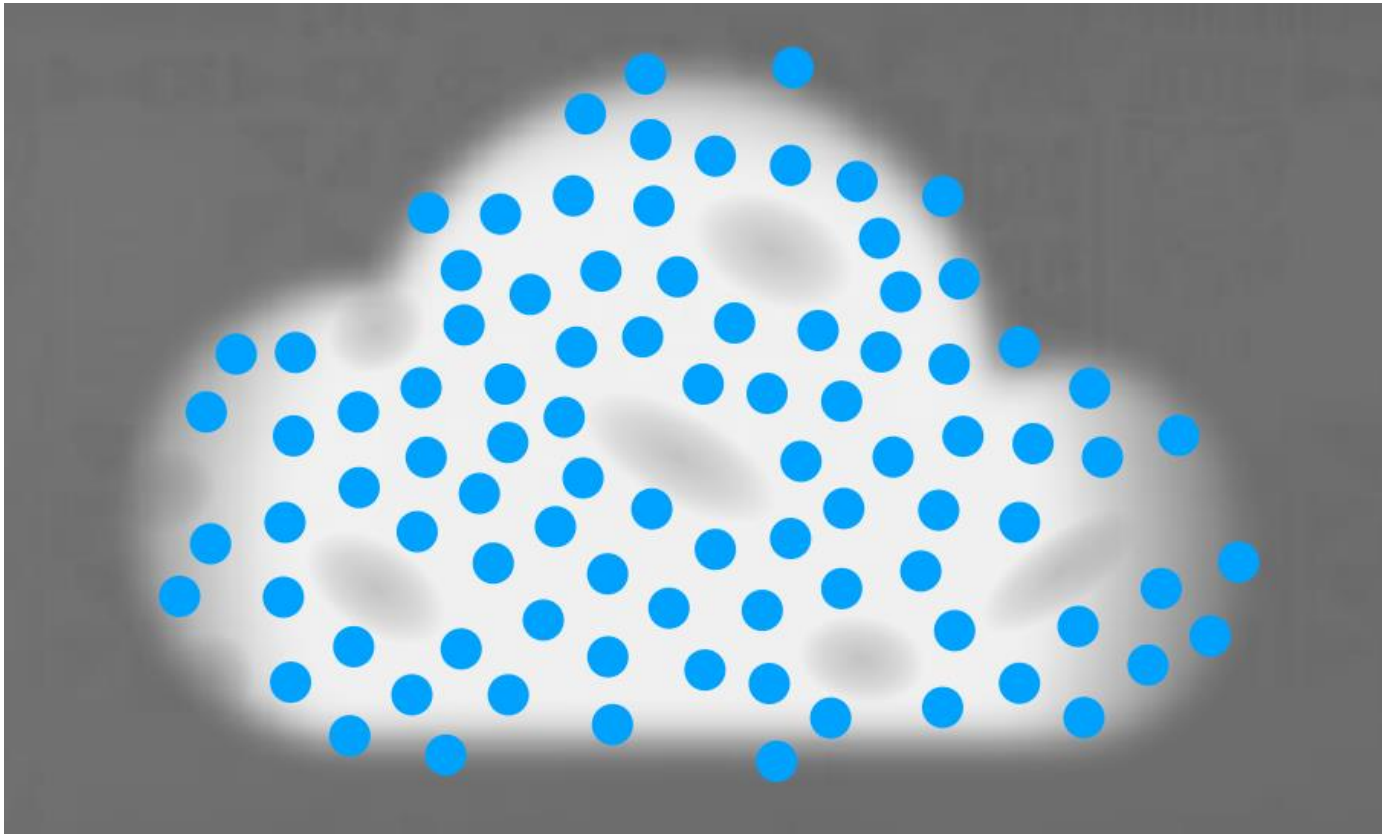
Paths in Participating Media

- Particles scatter & absorb rays



Paths in Participating Media

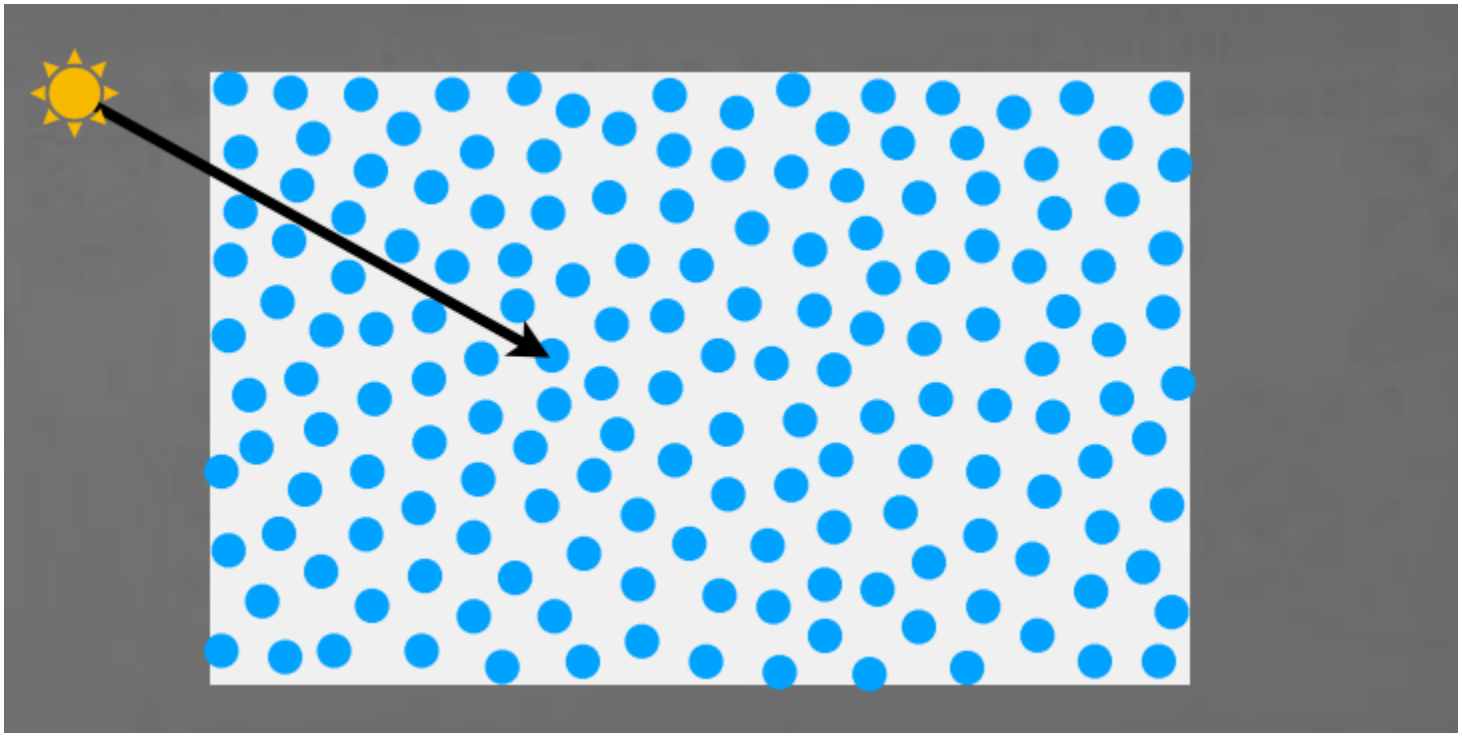
- Especially when the media is not homogenous



Backgrounds

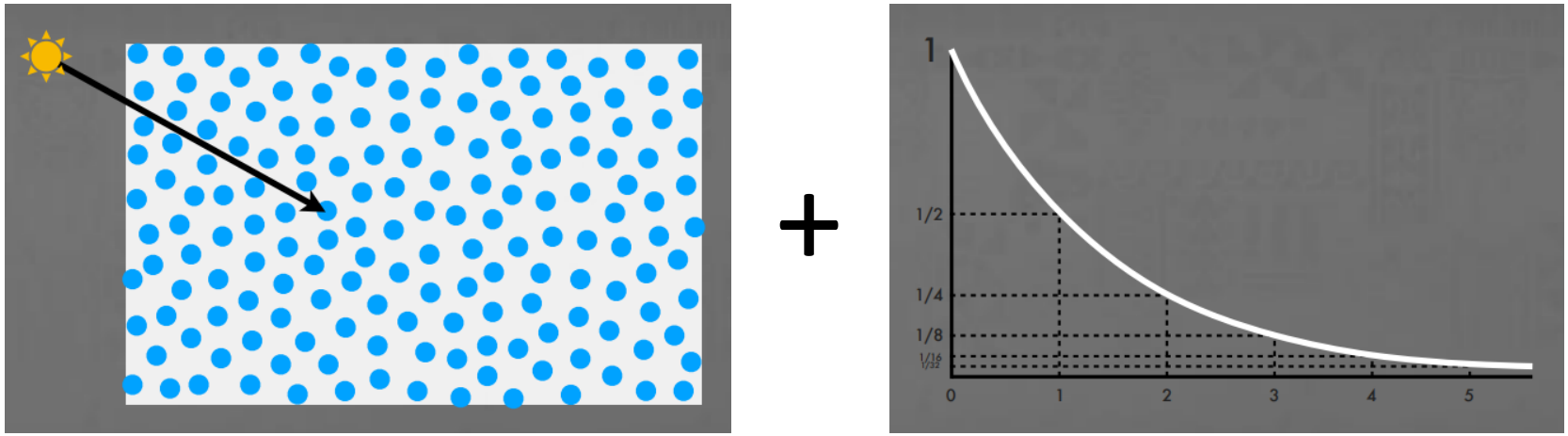
Paths in Participating Media

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



Closed-Form Tracking

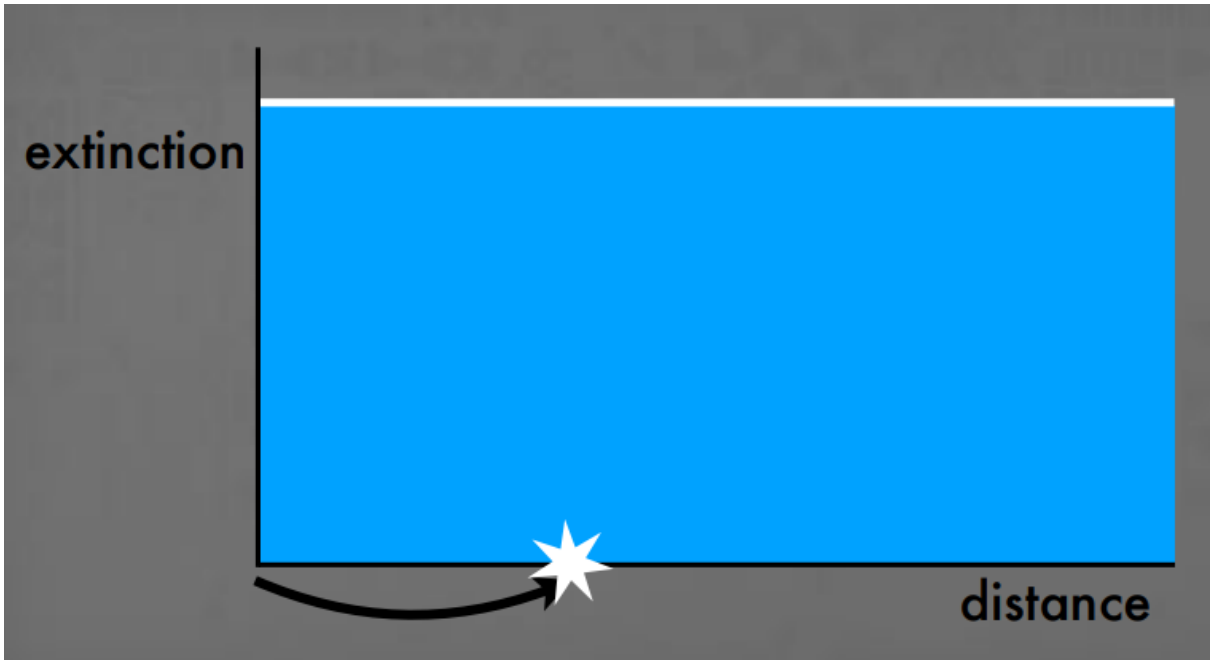
- When does a single scattering (or absorption) occur?



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

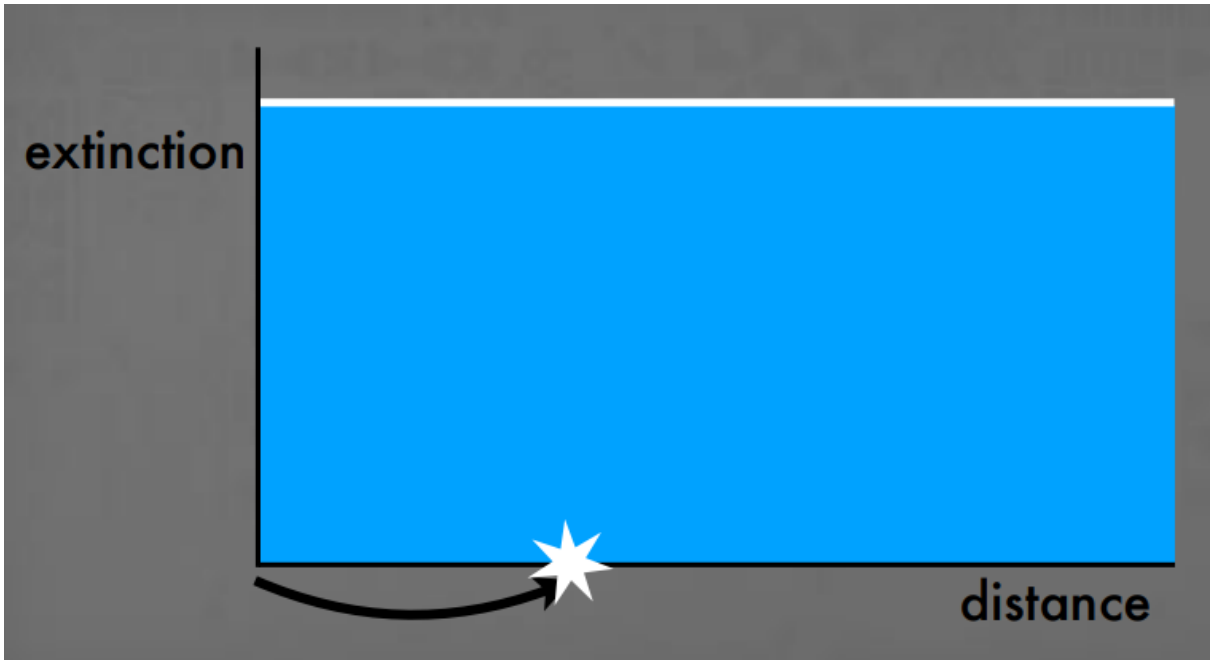
Sampling In Graph

- Distance-Extinction Coefficient graph



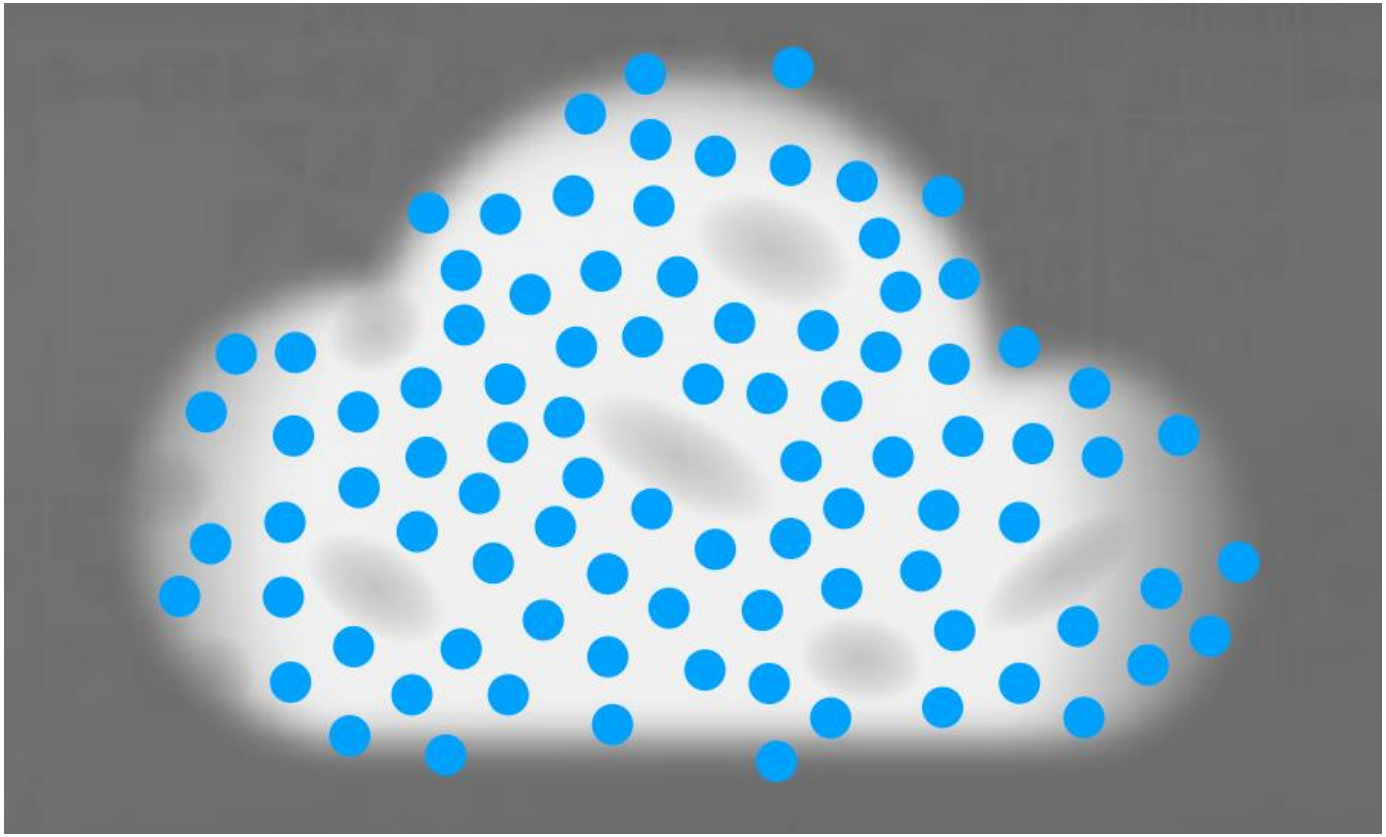
Sampling In Graph

- Distance-Extinction Coefficient graph



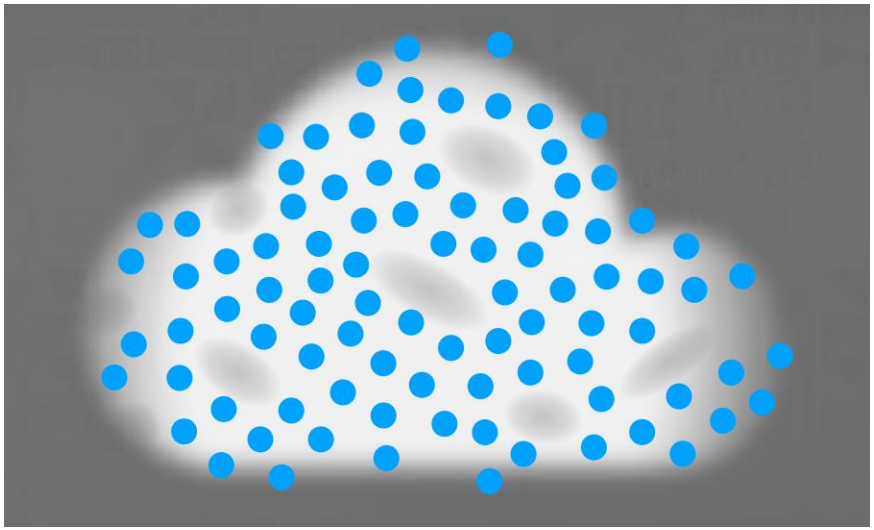
- We sample distance, check if scattering occurs.
  - In homogenous media, it always scatters, as we sampled with prior knowledge to probability density

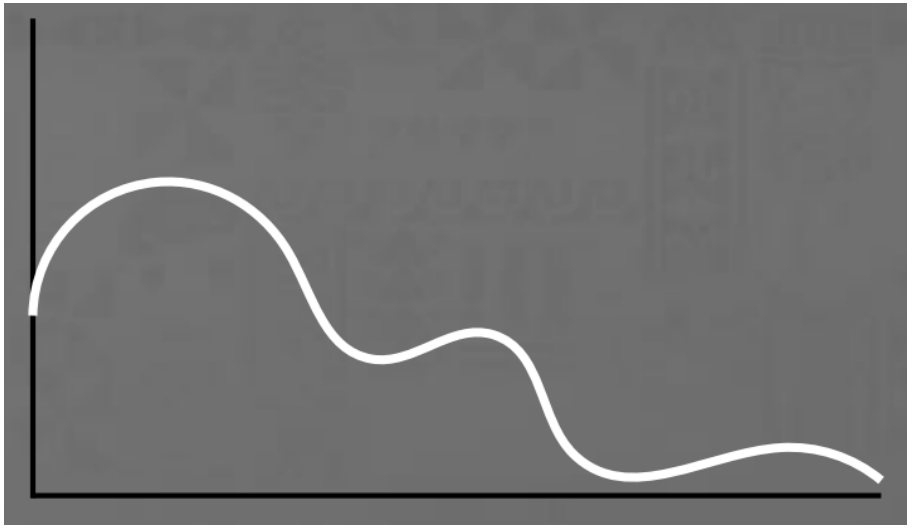
Through Heterogenous Media



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] ...

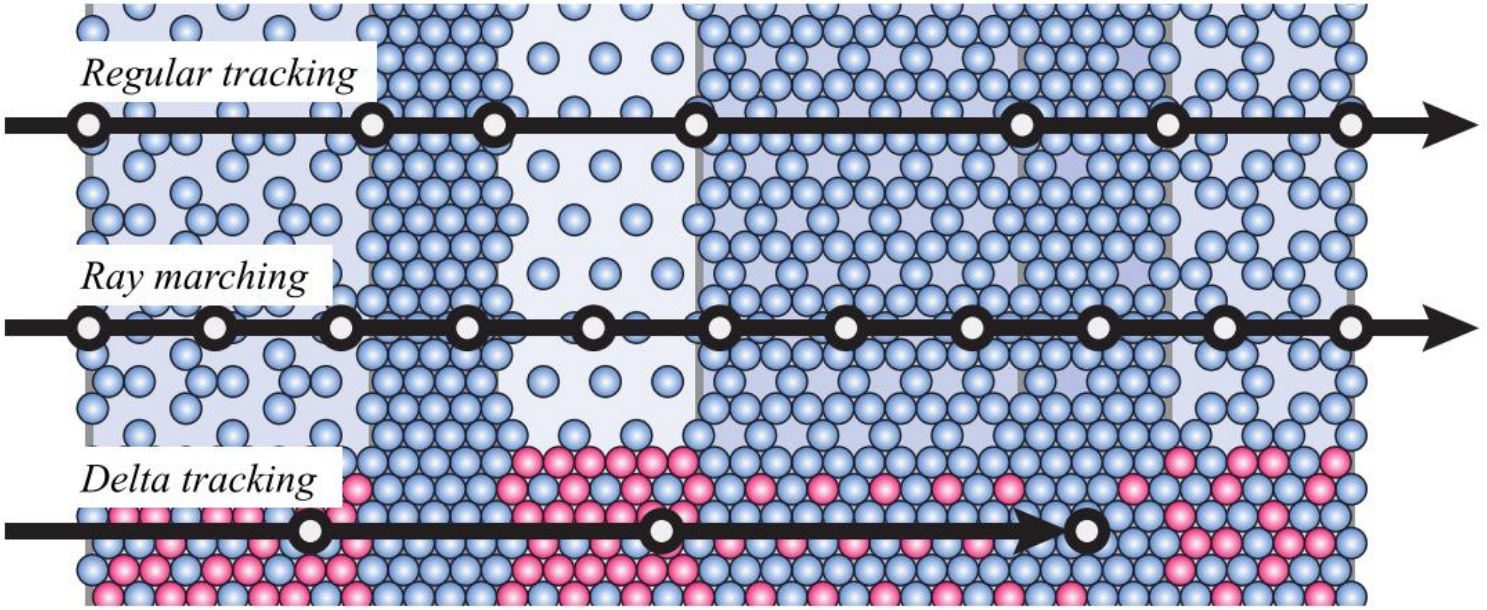


Image from [Novák 2014]

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

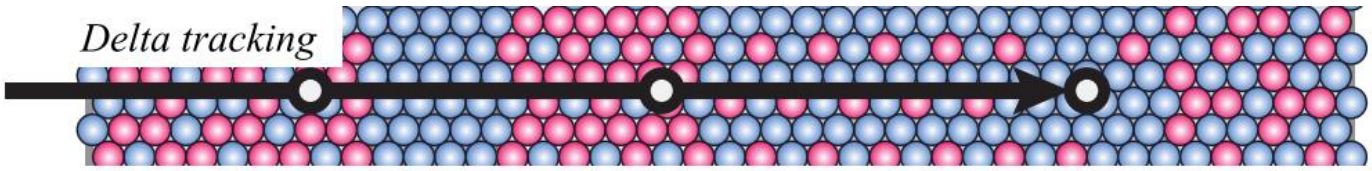
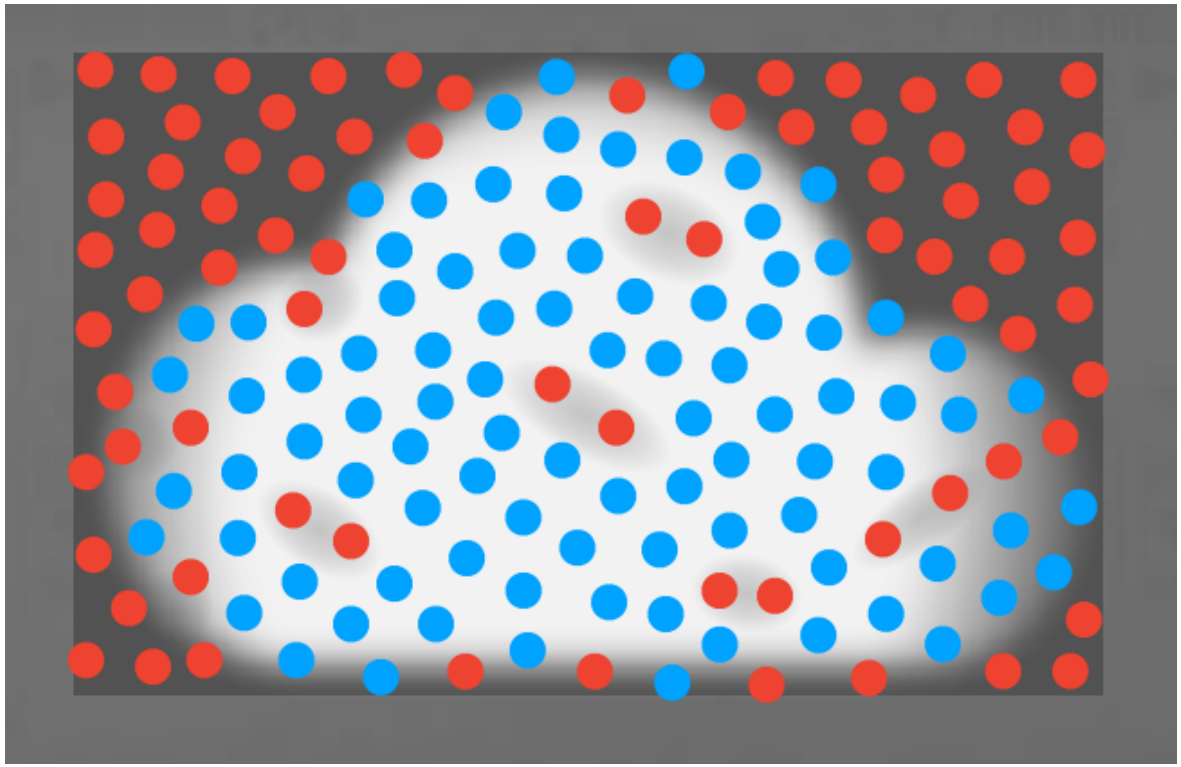


Image from [Novák 2014]

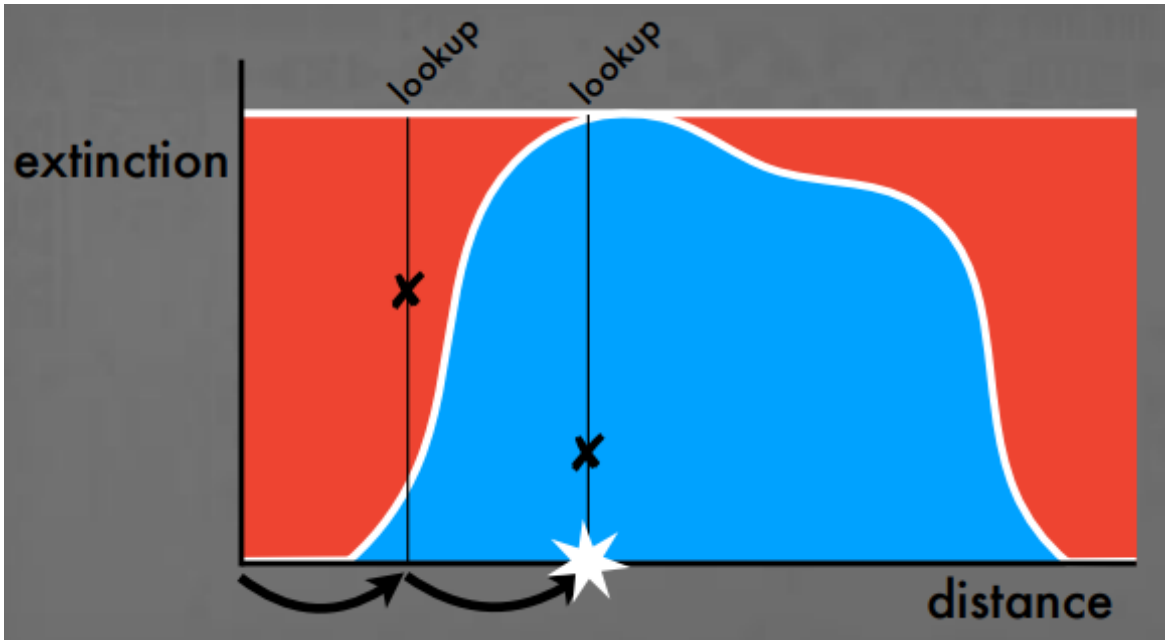
Delta Tracking

- 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 *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 do not collide, they only affect step size
  - This (not a) collision is called null collision
- **Unbiased!**

Delta Tracking Algorithm

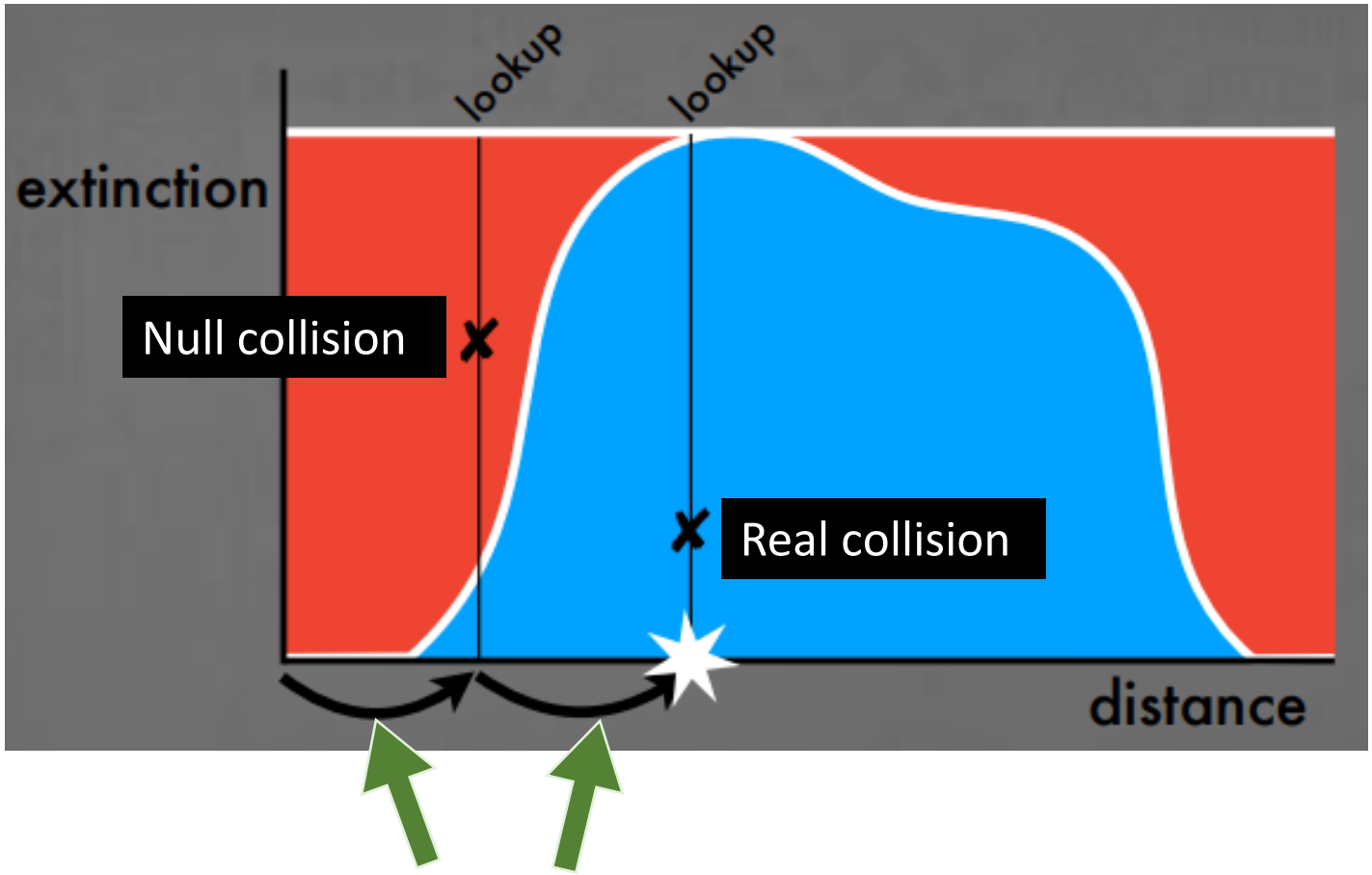
- While true,
  - Sample distance
  - Move and sample collision rate
  - Continue if null collision / Break if real collision

```
float sampleDistance(Point x_0, Direction ω)
{
    //sample with the maximum extinction σ_t
    float t = -log(rand()) / σ_t;

    while (σ_t(x_0+tω) / σ_t < rand())
        t -= log(rand()) / σ_t;

    return t;
}
```

Algorithm 1: Unbiased distance sampling for arbitrary media.

From [Raab et al. 2008]

Delta Tracking

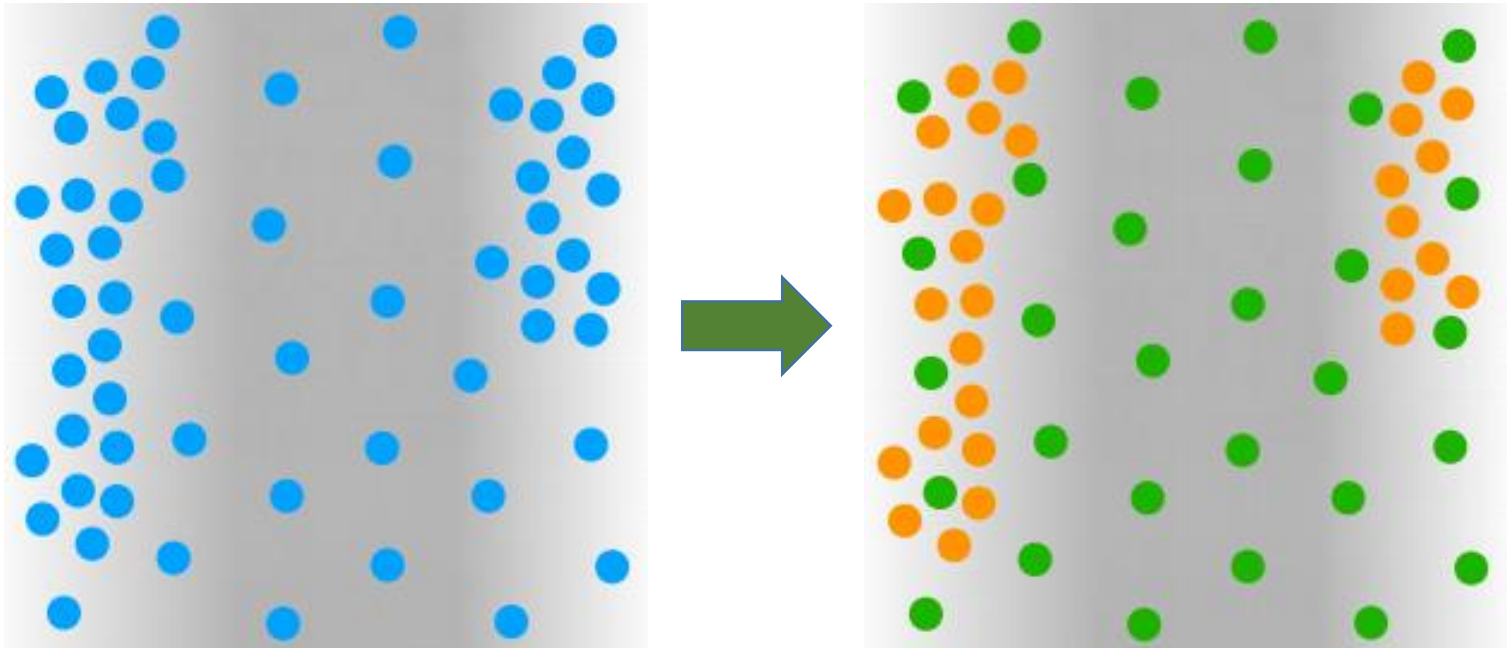


Sampled step
(using exponential distribution)

Decomposition Tracking

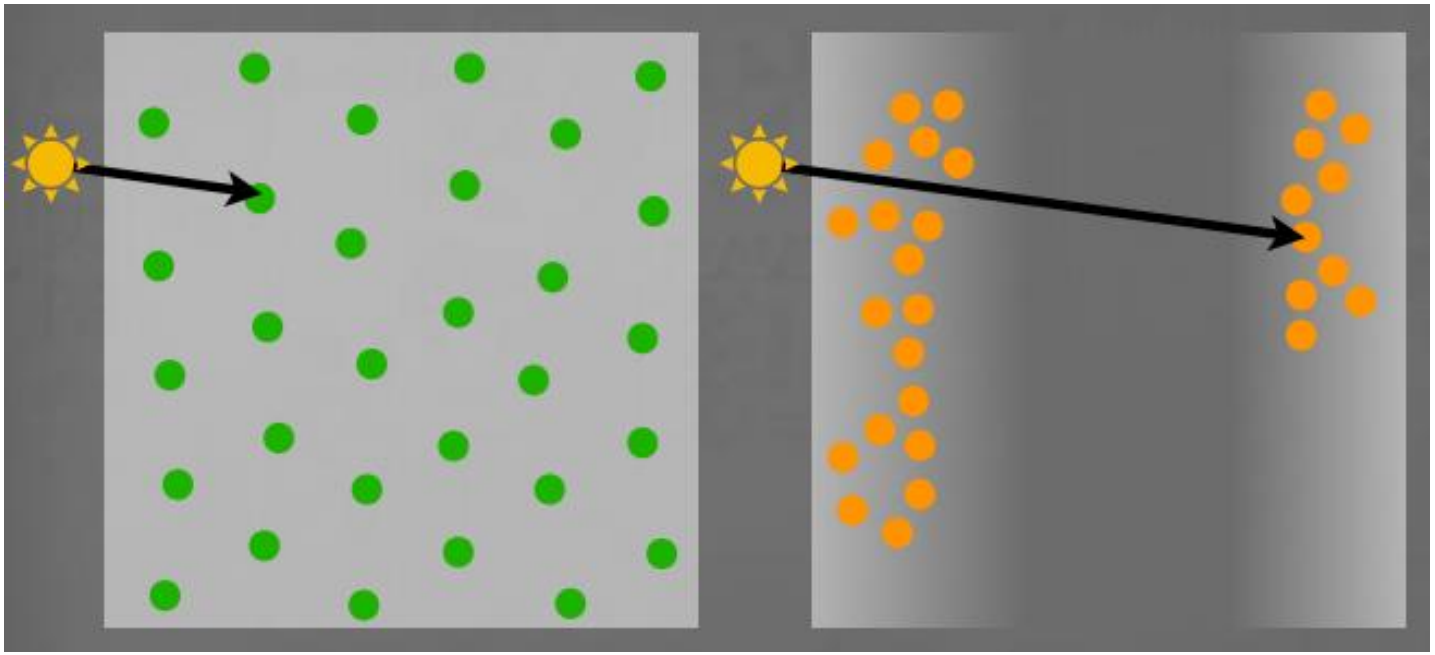
Decompositing Media Particles

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



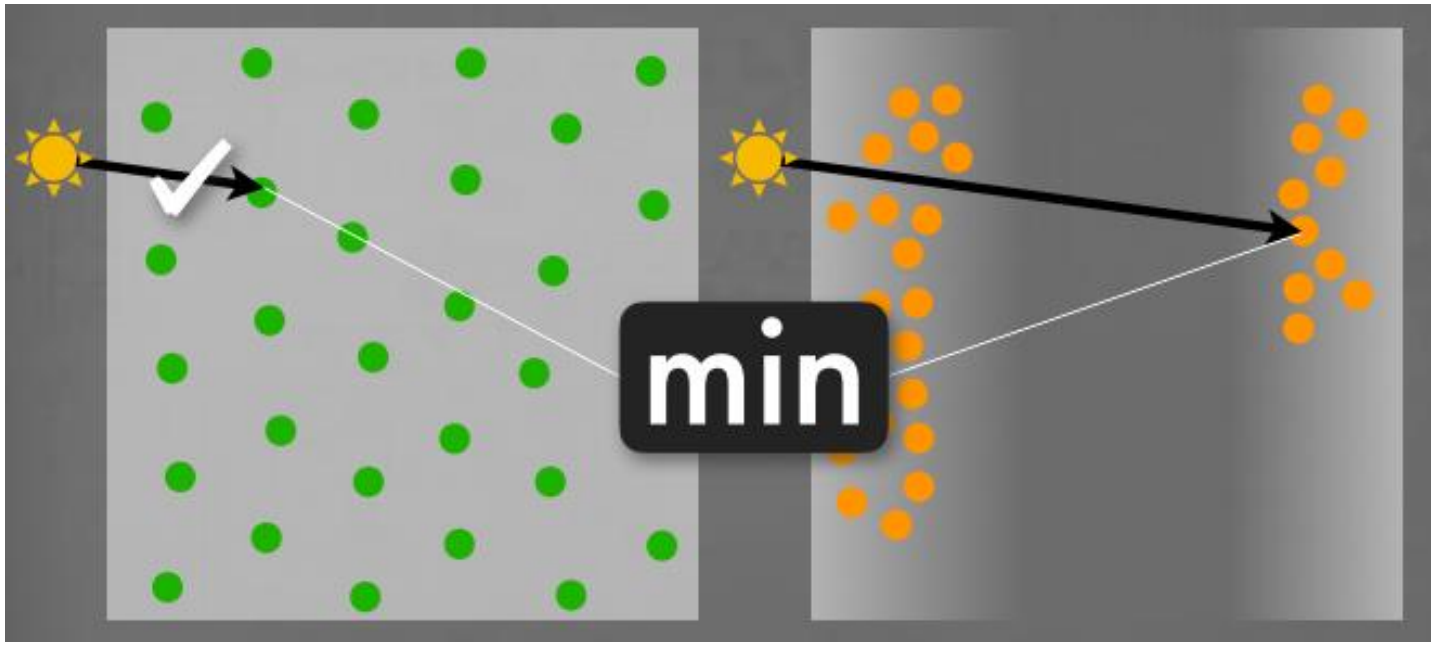
Decompositing Media Particles

- Find free path separately



Decompositing Media Particles

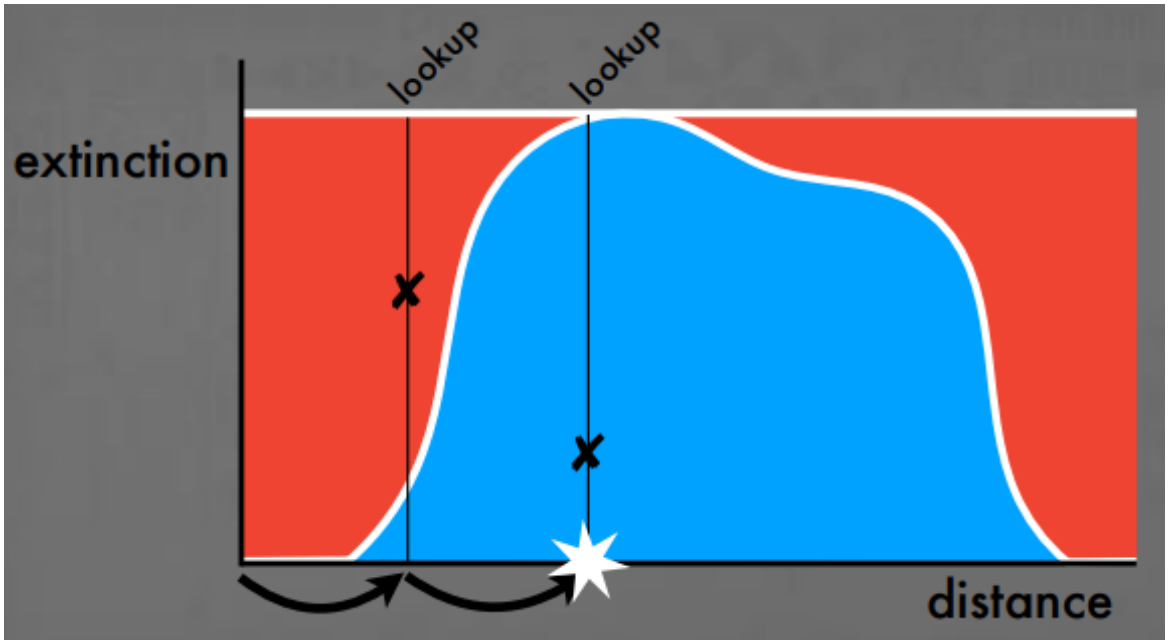
- Find free path separately



- And use smaller one

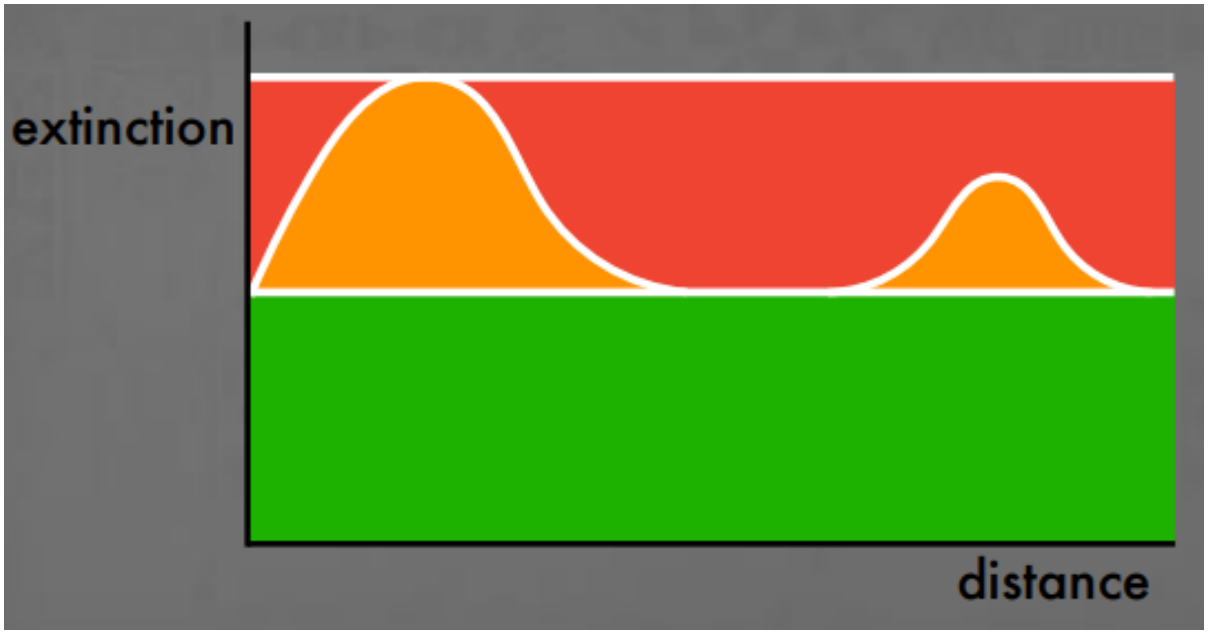
Decomposition Tracking In Graph

- Standard delta tracking considers whole extinction coefficient at each point



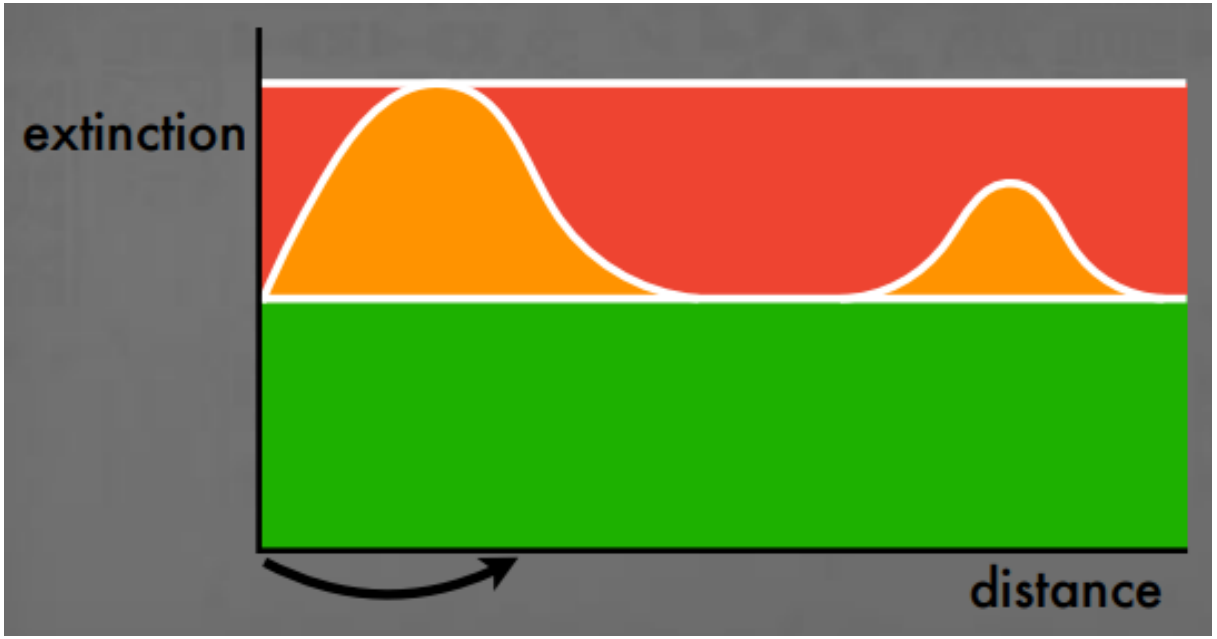
Decomposition Tracking In Graph

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



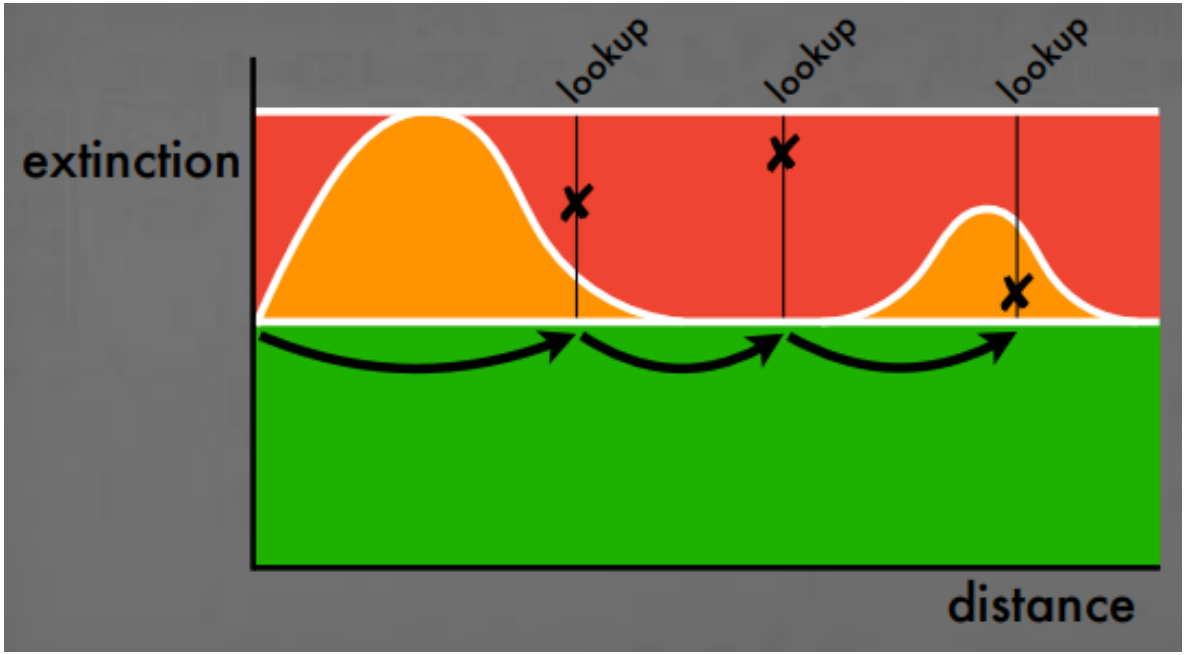
Decomposition Tracking In Graph

- Distance sampling in control part is closed-form
  - Simple exponential distribution



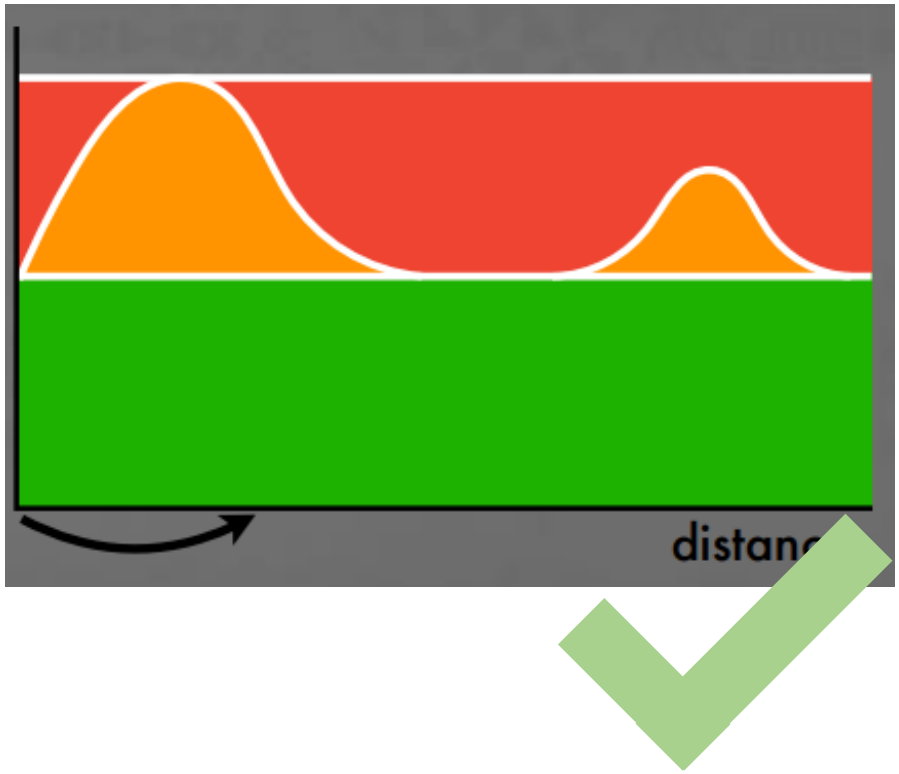
Decomposition Tracking In Graph

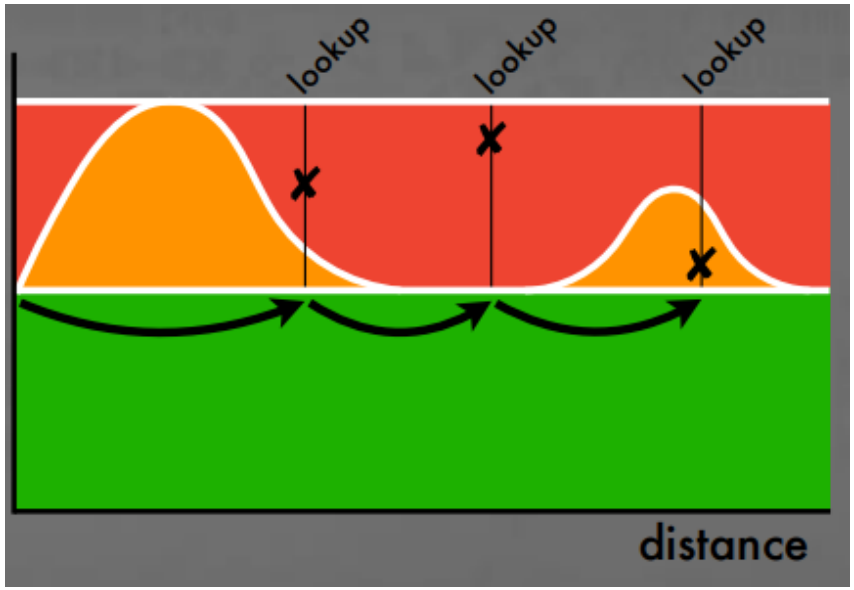
- For residual part, do delta tracking
  - Sample distance, move, check collision
  - Should lookup extinction coefficient at each point



Decomposition Tracking In Graph

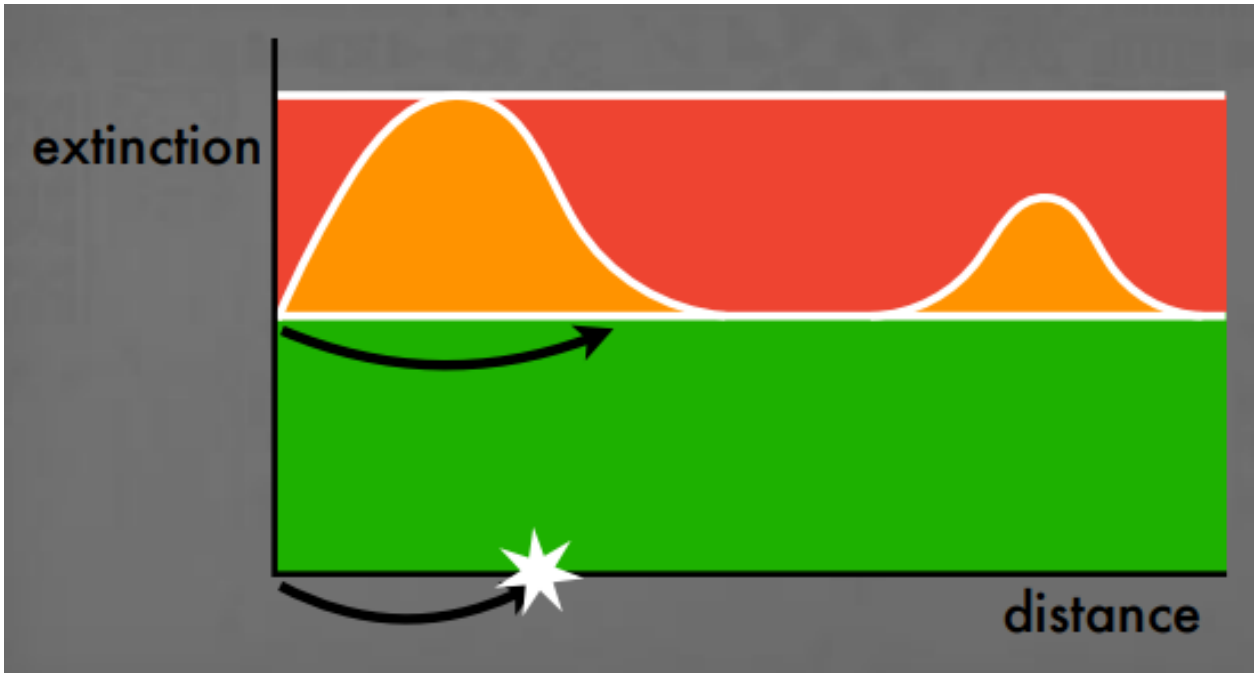
- Use smaller distance comparing two result





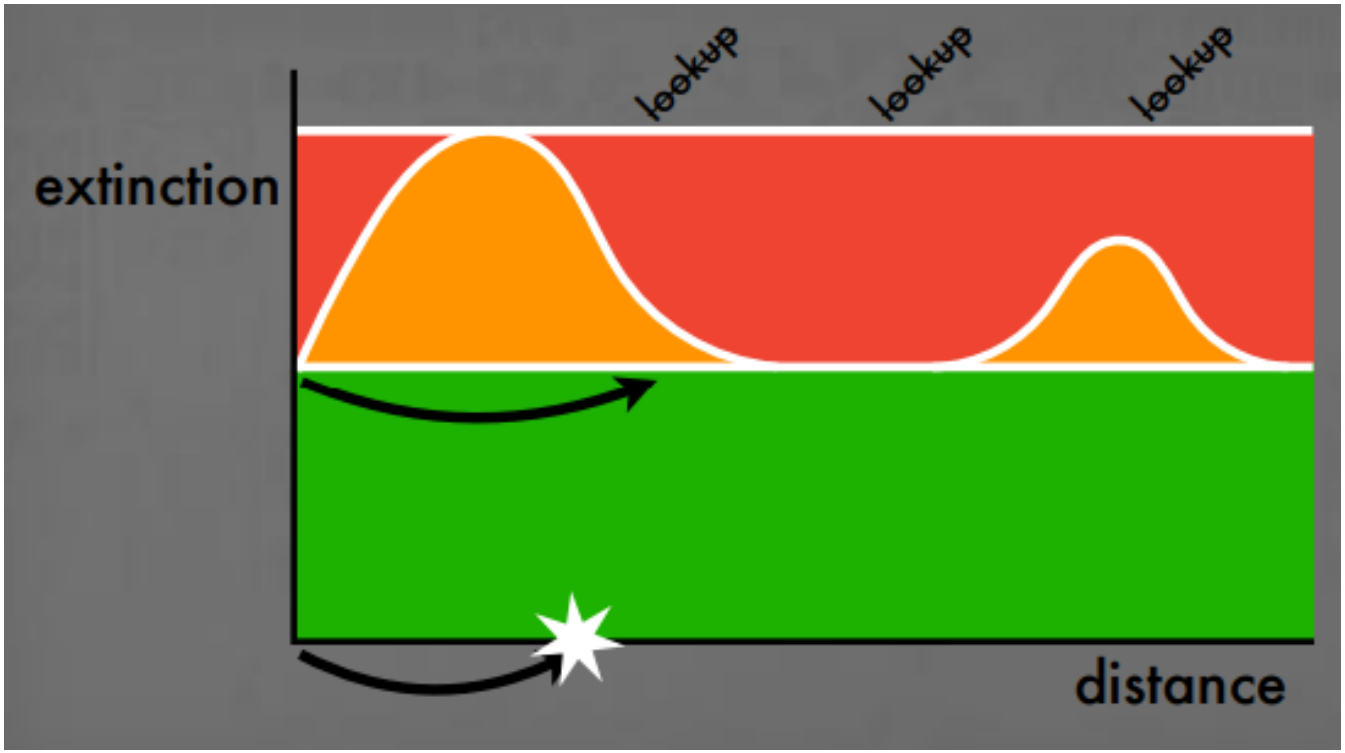
Decomposition Tracking In Graph

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



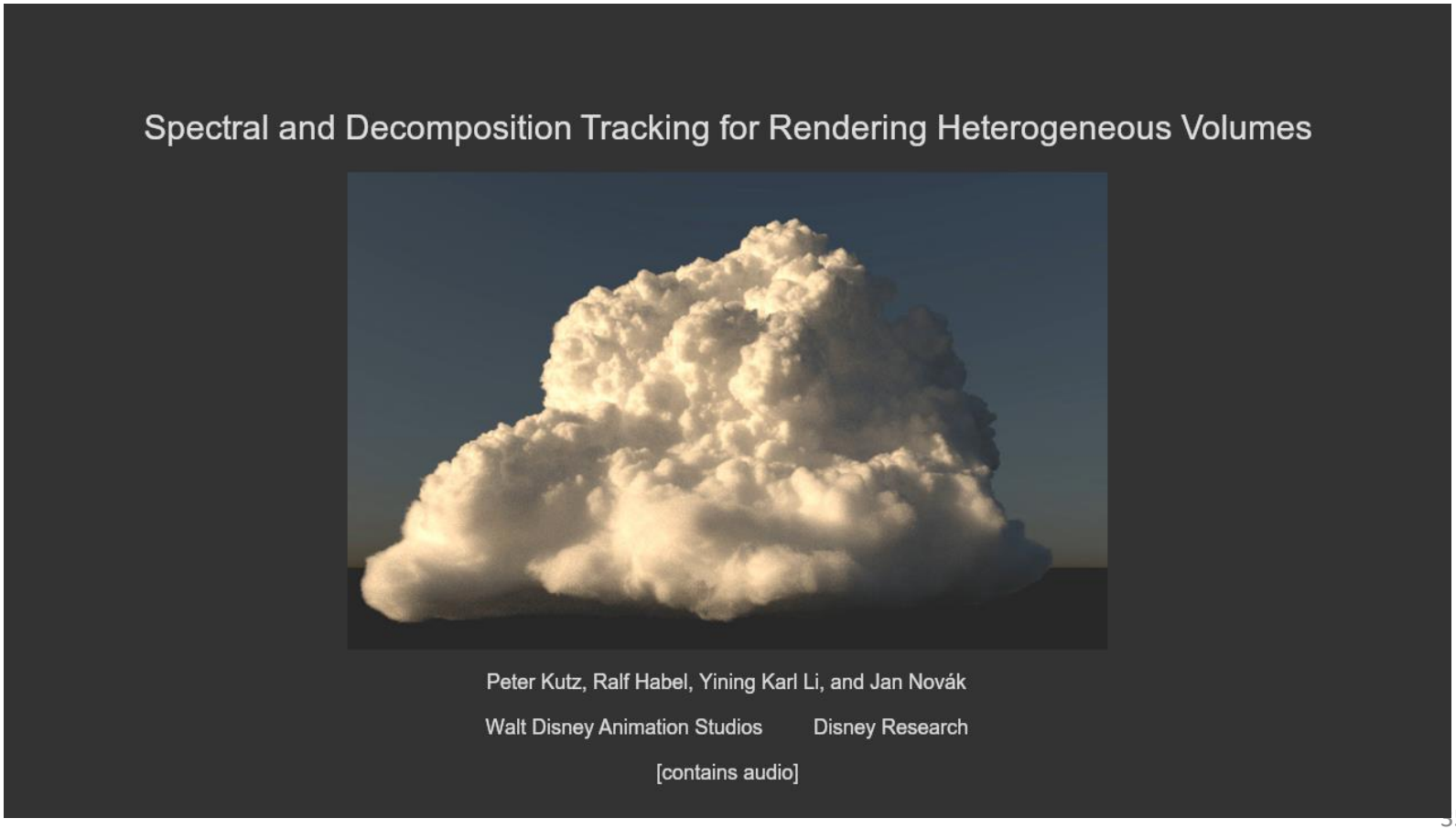
Decomposition Tracking In Graph

- It saves many lookups!



Result of Decomposition Tracking

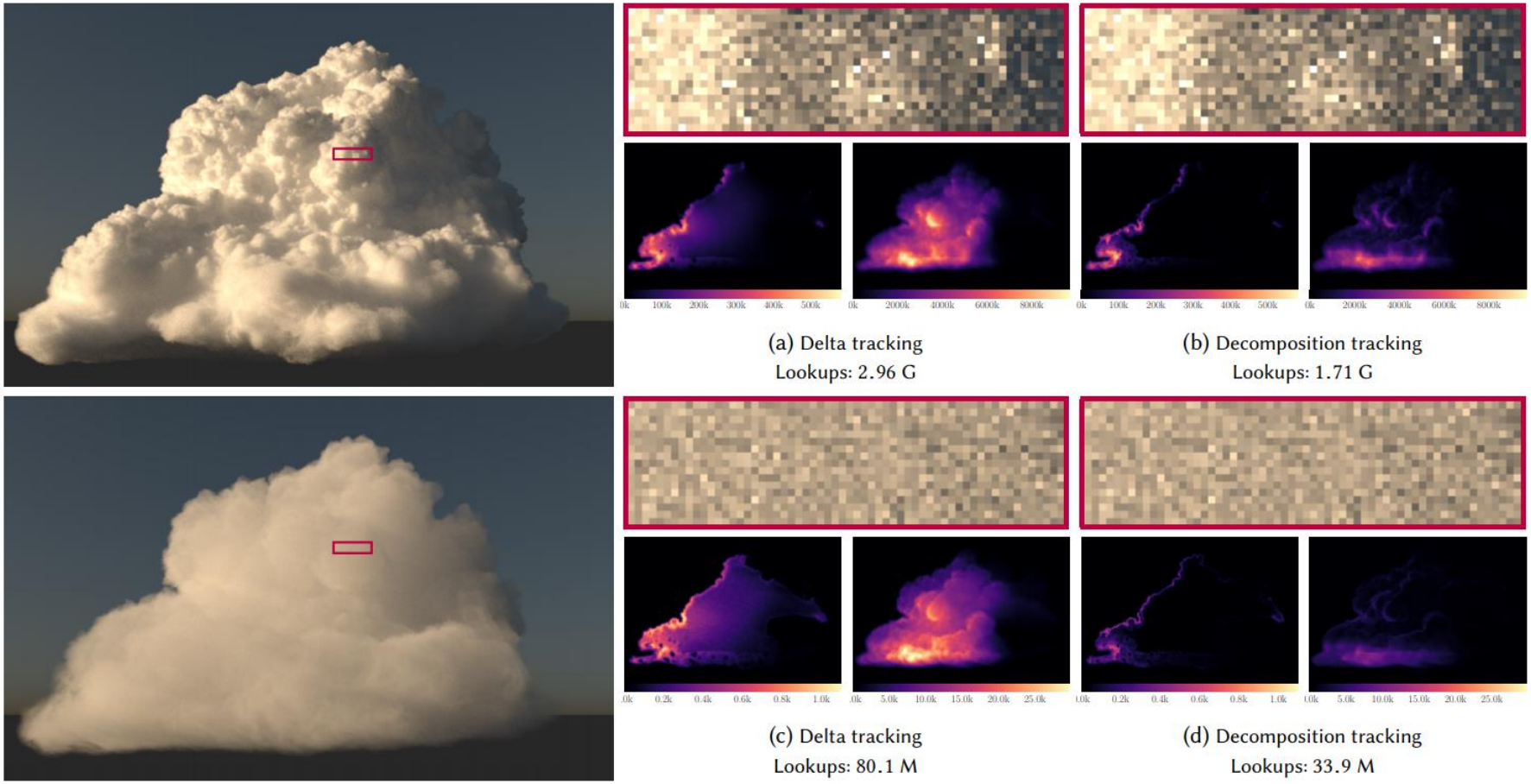
- Less lookups



Video of the authors

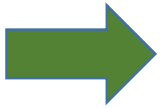
Result of Decomposition Tracking

- Less lookups, higher performance



Result of Decomposition Tracking

- Less lookups, higher performance



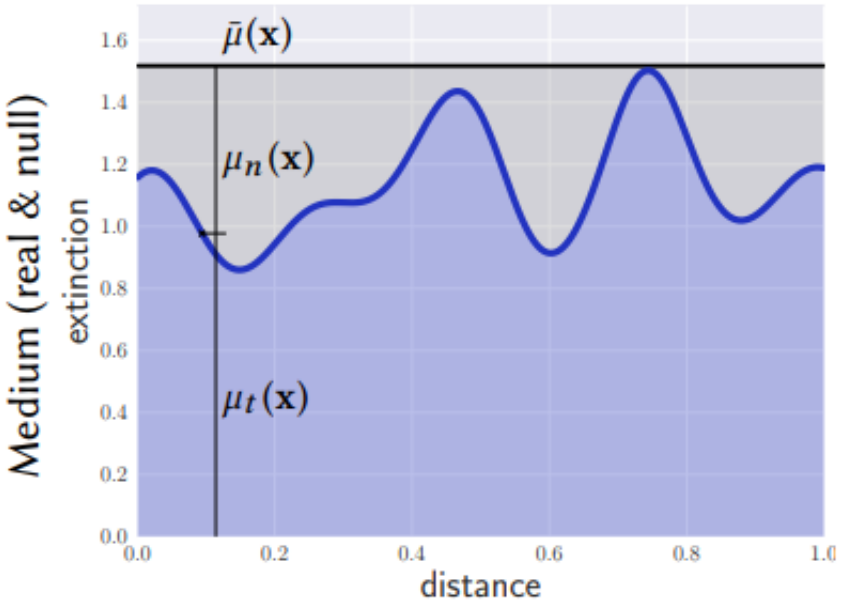
Octree depth	1	4	8	16
Octree leaves visited	1.86 G	2.06 G	3.11 G	4.05 G
Lookup num. (Delta)	106 G	22.8 G	2.96 G	2.49 G
Lookup num. (Decomp)	106 G	22.6 G	1.71 G	1.03 G
Lookup time (Delta)	20065 s	5785 s	1030 s	876 s
Lookup time (Decomp)	20065 s	5472 s	536 s	336 s
Octree time (Delta)	64 s	315 s	734 s	916 s
Octree time (Decomp)	64 s	319 s	714 s	918 s
Tracker time (Delta)	6108 s	1389 s	299 s	321 s
Tracker time (Decomp)	6108 s	1379 s	280 s	300 s

Image from the paper

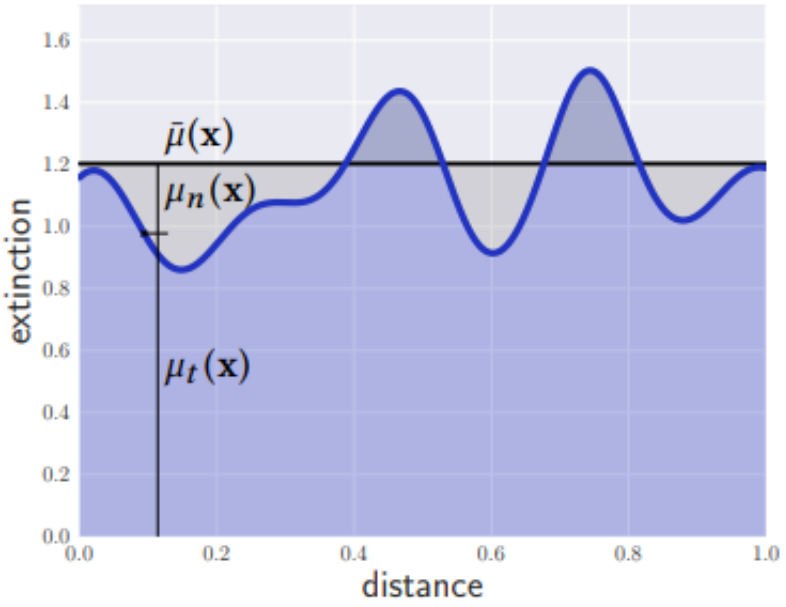
Spectral Tracking

Weighted Delta Tracking

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



Standard Delta Tracking



Weighted Delta Tracking

Image from the paper

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

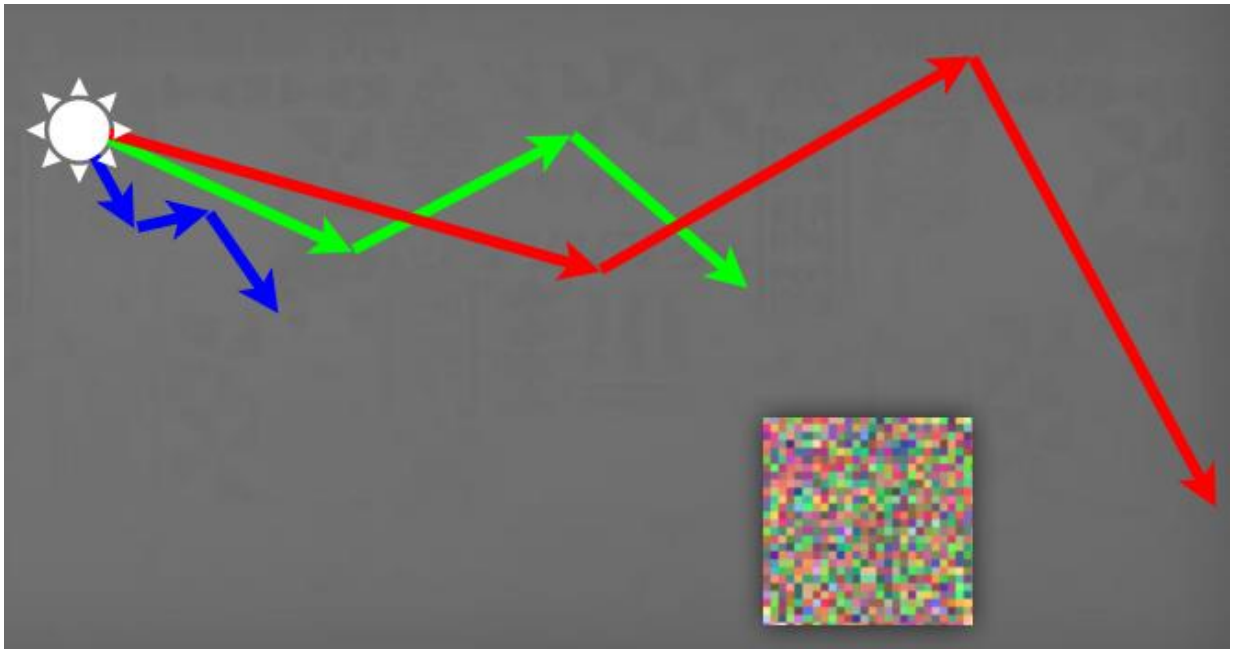
Spectral Tracking

- Exploit those weight schemes for spectral, wavelength dependent effects

```
Repeat:
   Step forward using fpsc.
   If scat using scat prob:
      Apply (weight1, weight2, weight3).
      Change direction.
   Else if fict using fict prob:
      Apply (weight1, weight2, weight3).
```

Delta Tracking: Spectral Effect

- Standard delta tracking does separate delta tracking for each wavelength



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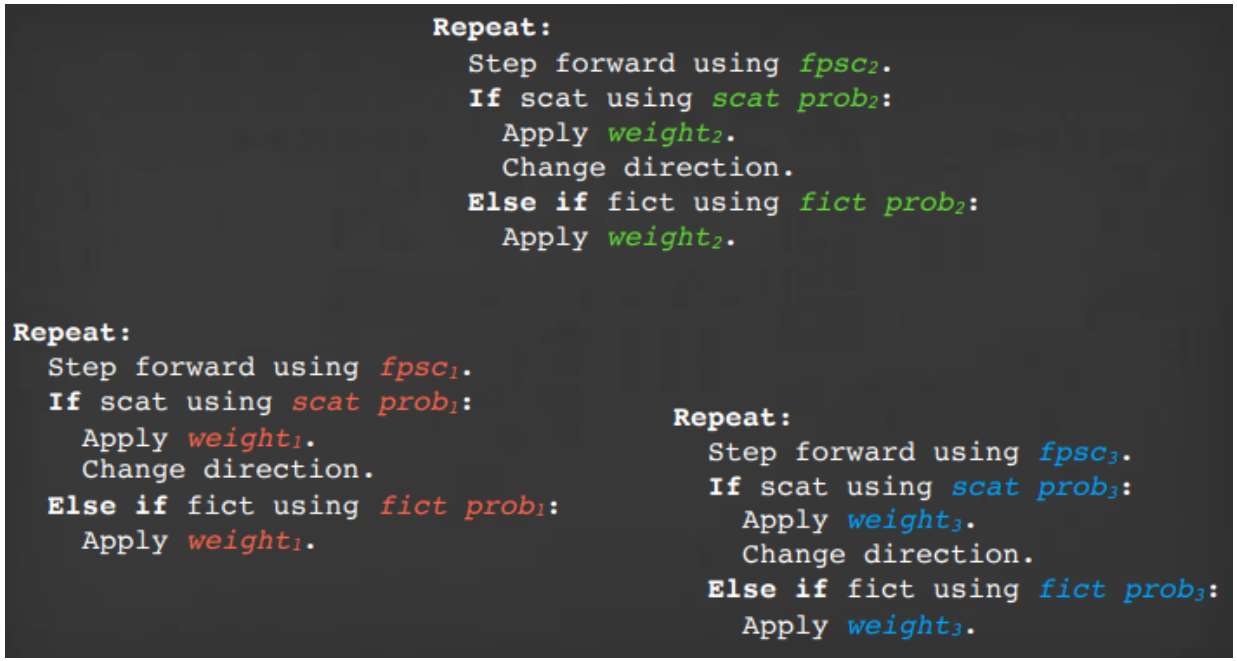

Delta Tracking: Spectral Effect

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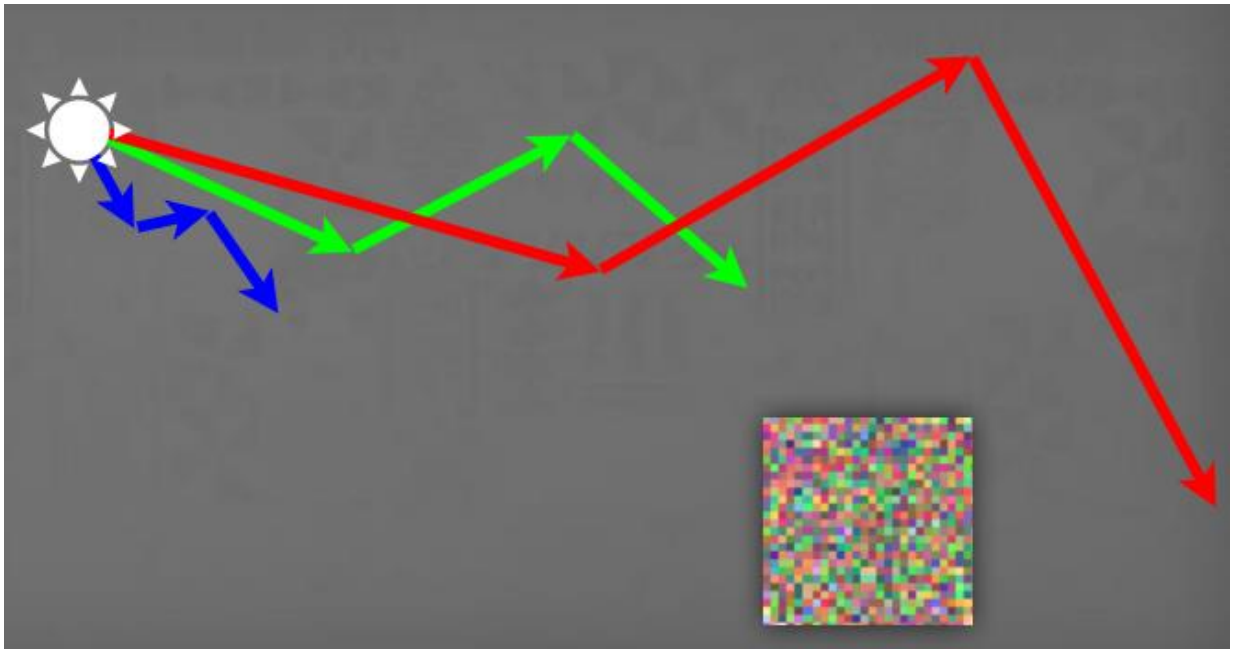


- Results in colored noises

Spectral Tracking

- Same path for wavelengths, only weights differs

```
Repeat:
  Step forward using fpsc.
  If scat using scat prob:
    Apply weight₂.
    Change direction.
  Else if fict using fict prob:
    Apply weight₂.
```

```
Repeat:
  Step forward using fpsc.
  If scat using scat prob:
    Apply weight₁.
    Change direction.
  Else if fict using fict prob:
    Apply weight₁.
```

```
Repeat:
  Step forward using fpsc.
  If scat using scat prob:
    Apply weight₃.
    Change direction.
  Else if fict using fict prob:
    Apply weight₃.
```

Spectral Tracking

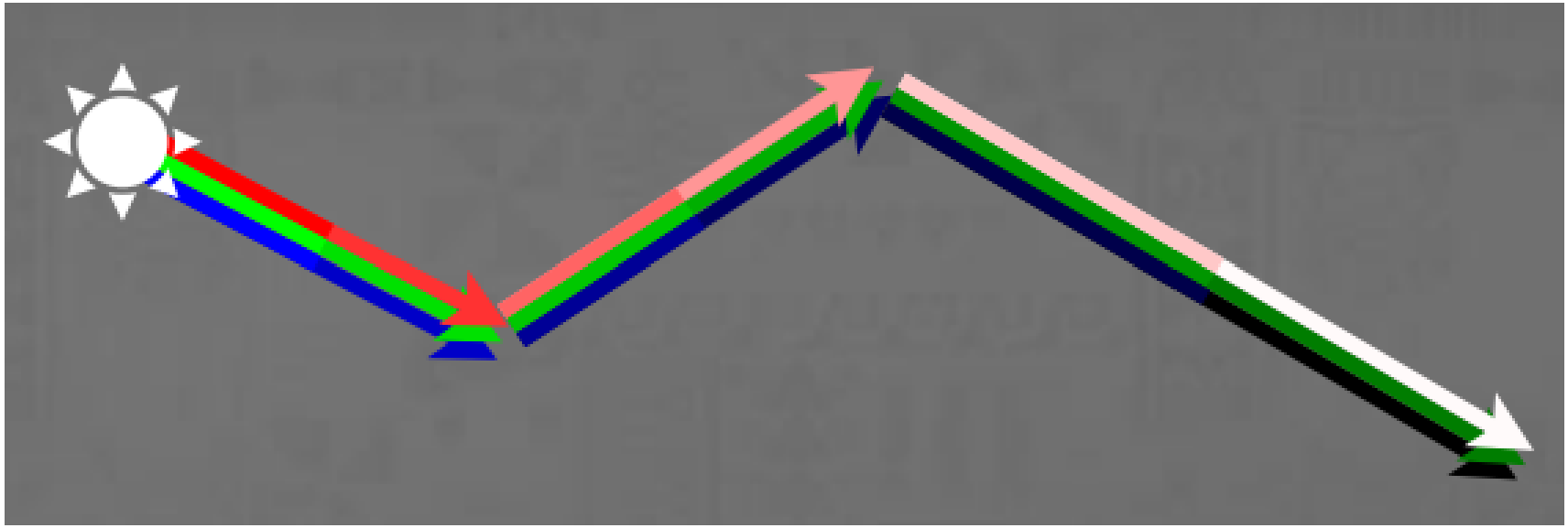
- Same path for wavelengths, only weights differs

```
Repeat:
   Step forward using fpsc.
   If scat using scat prob:
      Apply (weight1, weight2, weight3).
      Change direction.
   Else if fict using fict prob:
      Apply (weight1, weight2, weight3).
```

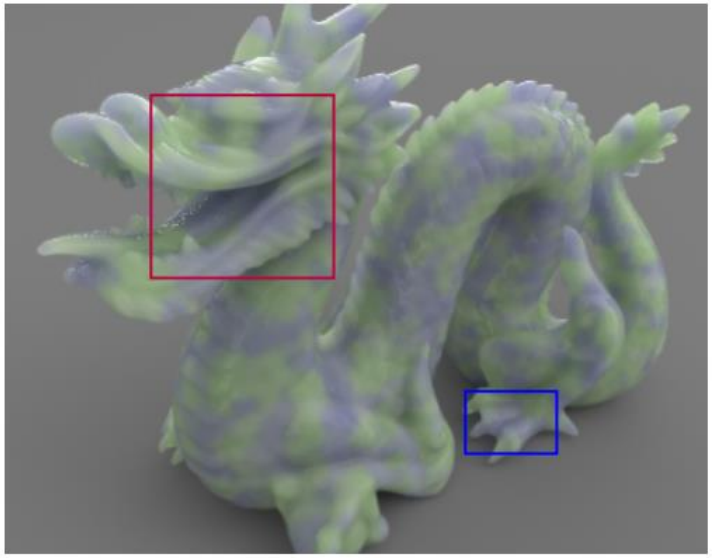
- 3-vector for RGB case

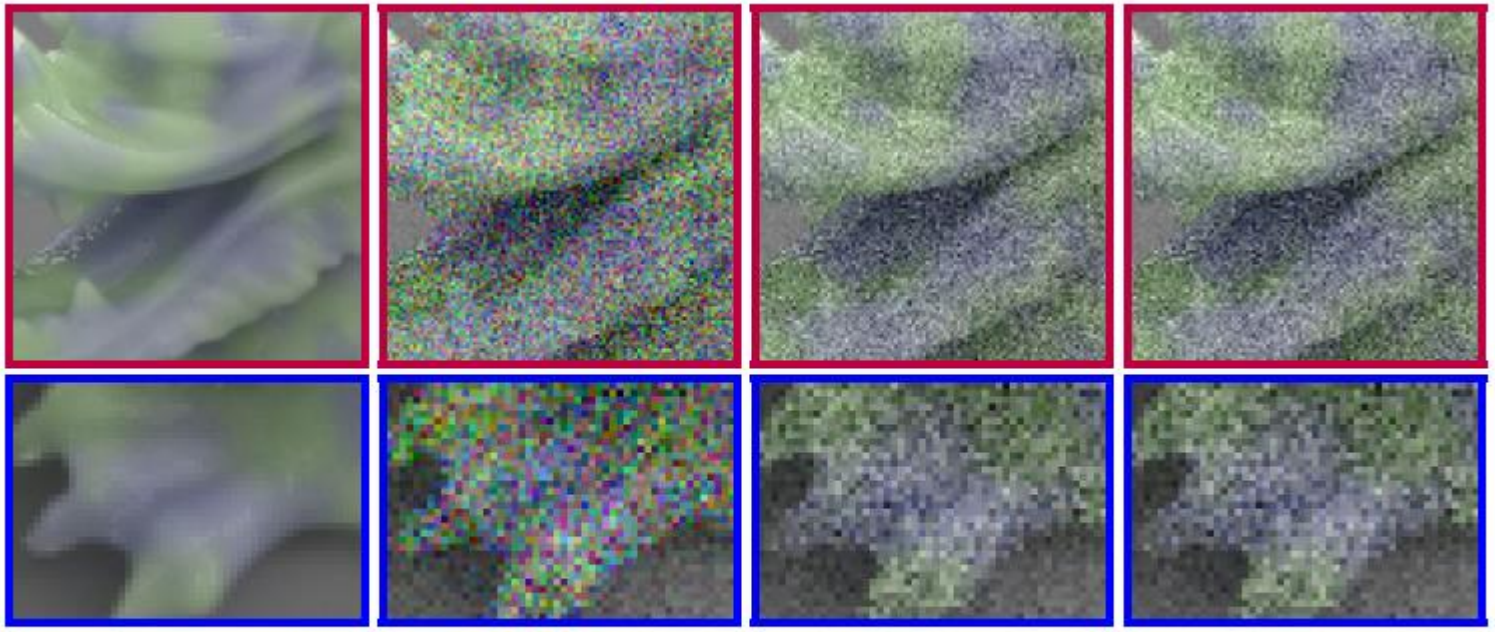
Spectral Tracking

- Same path for wavelengths, only weights differs



- Same path means no more colored noises!





(a) Ground truth

(b) Delta tracking
RMSE: 0.0939
LTUV: 296.2K
133s

(c) Spectral tracking
RMSE: 0.0559
LTUV: 109.8K
112s

(d) Spec. & dec. tracking
RMSE: 0.0569
LTUV: 53.5K
88s!

Image from the paper

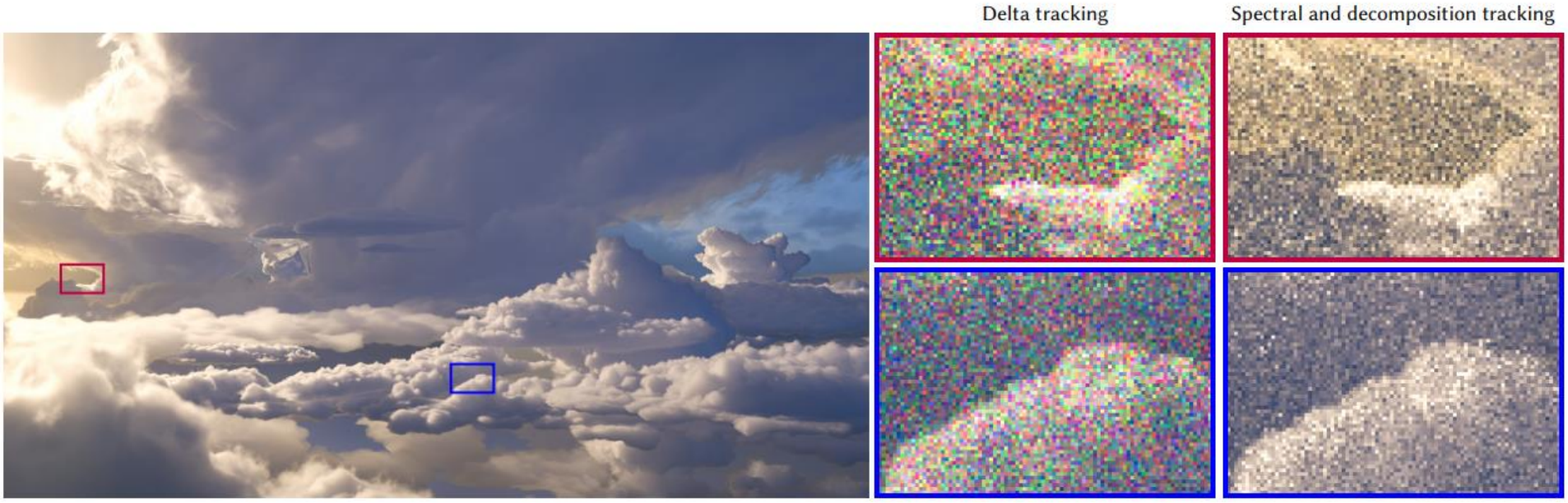


Figure 1. A cloudscape rendered with a combination of our spectral and decomposition tracking techniques, which gracefully handle chromatic media and reduce collision coefficient evaluations. The insets on the right were computed in equal time, with our method yielding 3.5× lower MSE than delta tracking.

Image from the paper

Spectral + Decomposition Tracking

- http://drz.disneyresearch.com/~jnovak/publications/SDTracking/supplementary/cloudscape/index.html

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.