

SIGGRAPH 2015

Xroads of Discovery





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The 42nd International Conference and Exhibition
on Computer Graphics and Interactive Techniques



Multi-Scale Modeling and Rendering of Granular Materials

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Carsten Dachsbacher² Steve Marschner⁴ Markus Gross^{1,3} Wojciech Jarosz^{1,5}

¹Disney Research Zürich ²Karlsruhe Institute of Technology ³ETH Zürich ⁴Cornell University ⁵Dartmouth College



Cornell University



Dartmouth

Motivation



Motivation



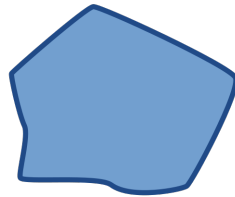
Motivation



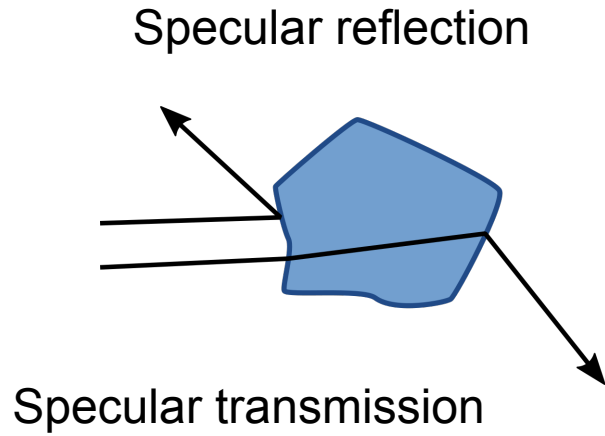
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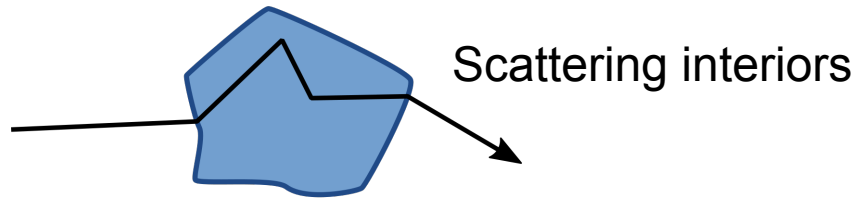
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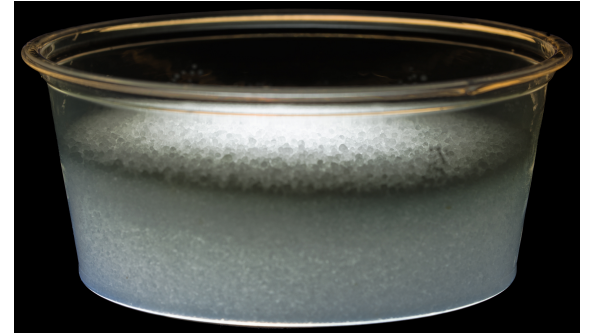
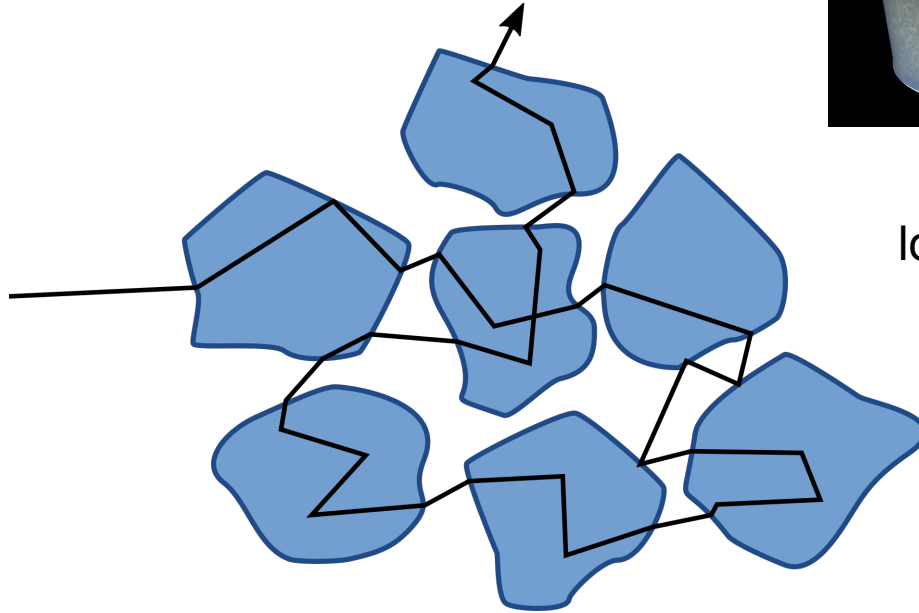
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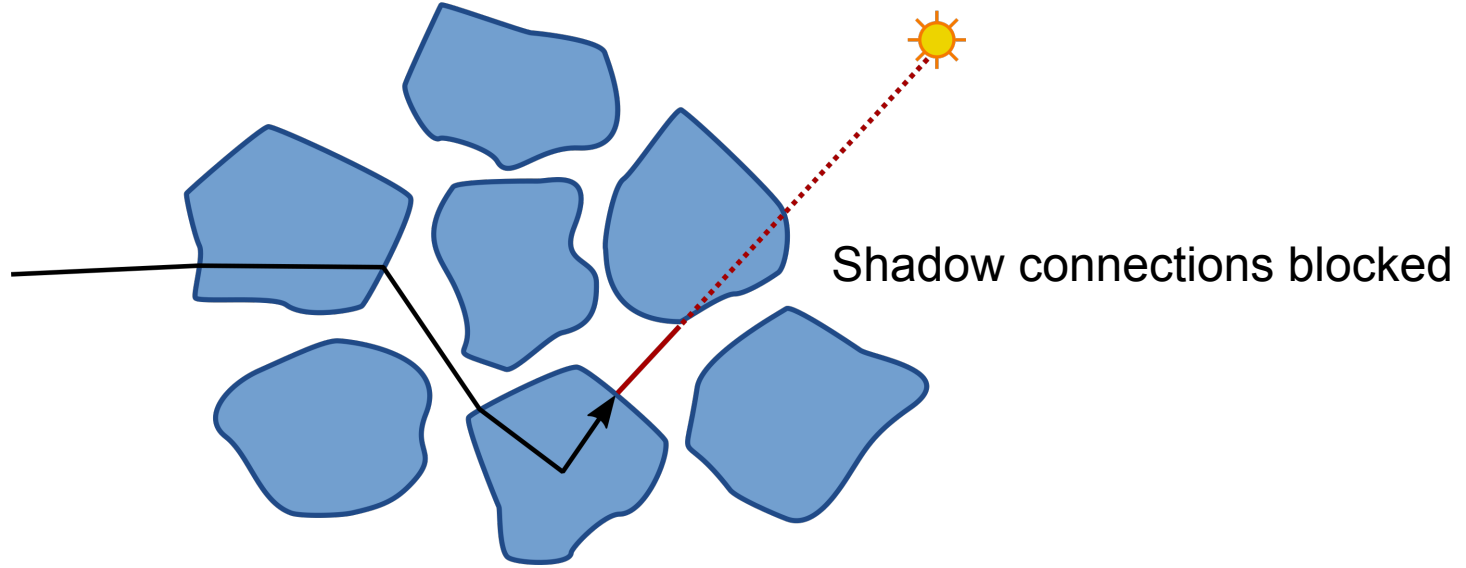


Motivation

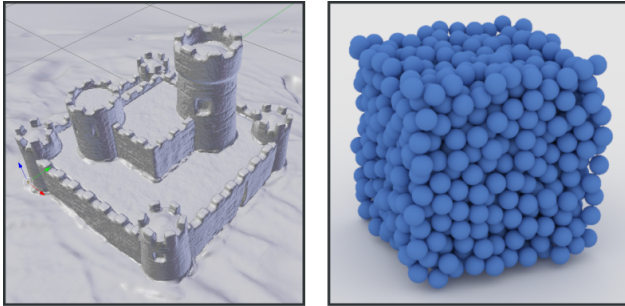


High grain albedo:
long paths contribute

Motivation

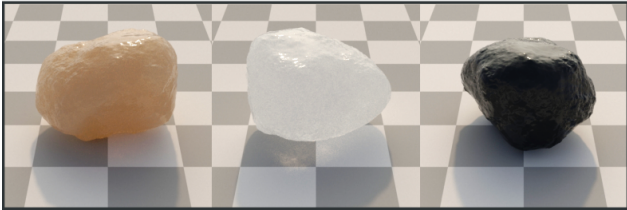
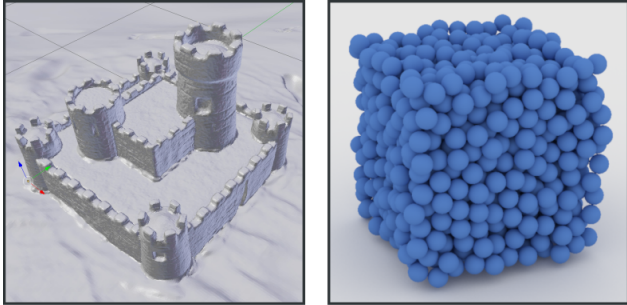


Modeling Granular Materials



Macro mesh / Grain bounding spheres.

Modeling Granular Materials



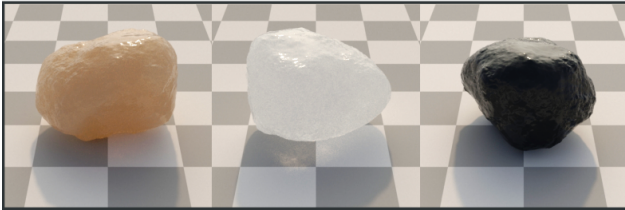
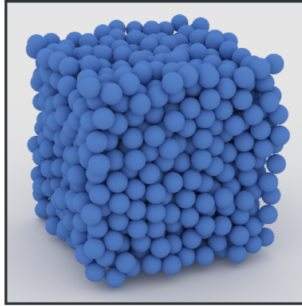
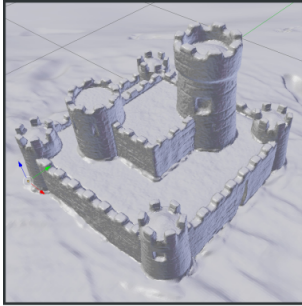
85%

10%

5%

A few grains for instancing.

Modeling Granular Materials



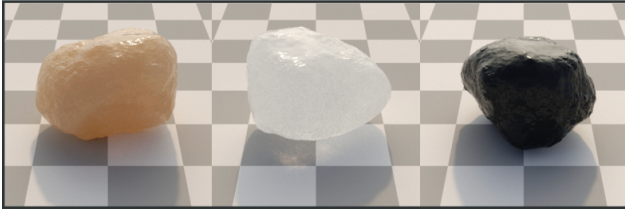
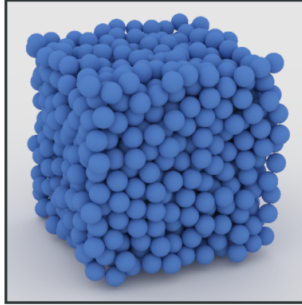
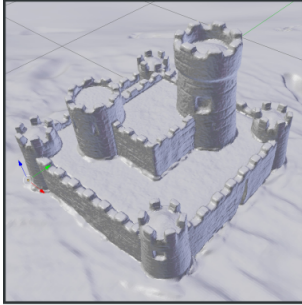
85%

10%

5%

Grains can be randomly mixed and oriented.

Modeling Granular Materials



85%

10%

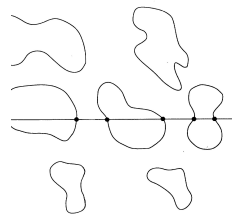
5%

Related Work



Li et al. 2005

A hybrid Monte Carlo method for accurate and efficient subsurface scattering.



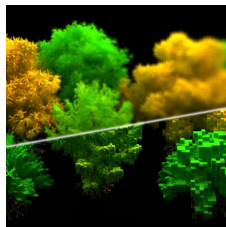
Torquato and Lu 1993

Chord-length distribution function for two-phase random media.



Zinke and Weber 2007

Light scattering from filaments.

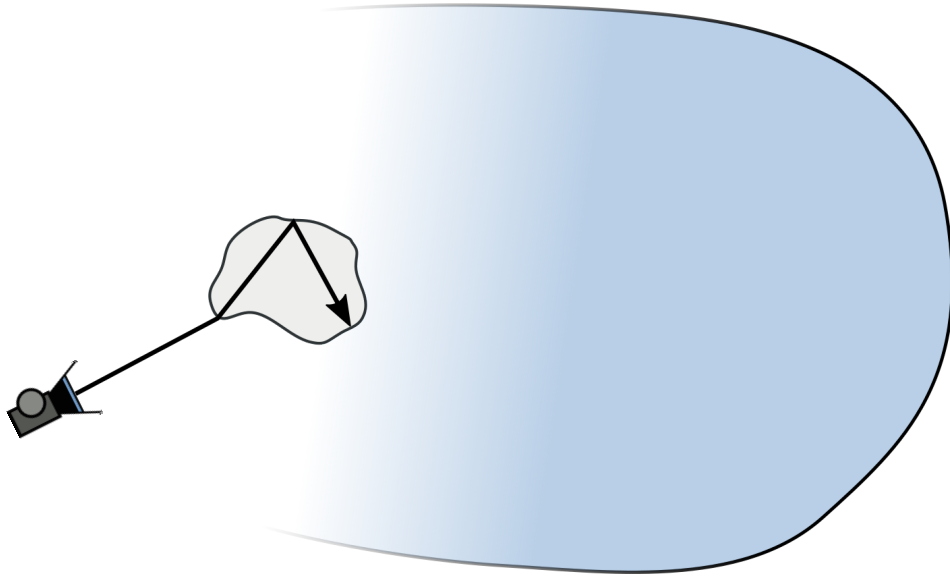


Heitz et al. 2015

The SGGX Microflake Distribution.

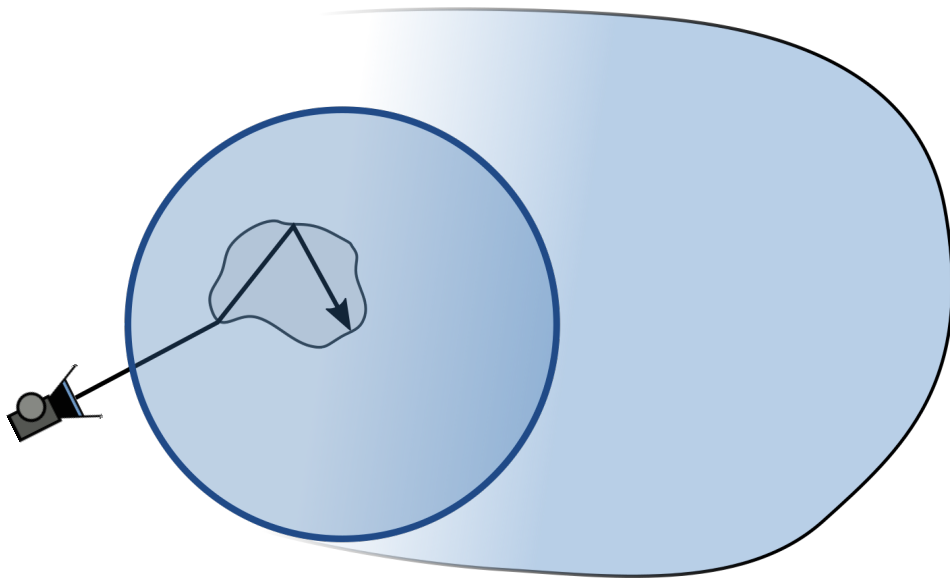
... and many more.

Shell Transfer Functions



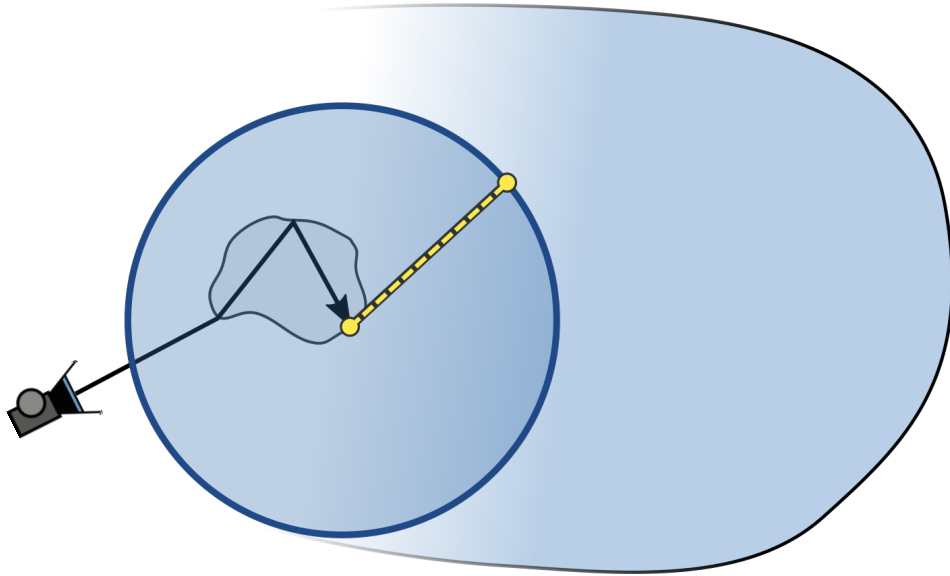
[Moon et al. 2007: Rendering Discrete Random Media Using Precomputed Scattering Solutions.]

Shell Transfer Functions



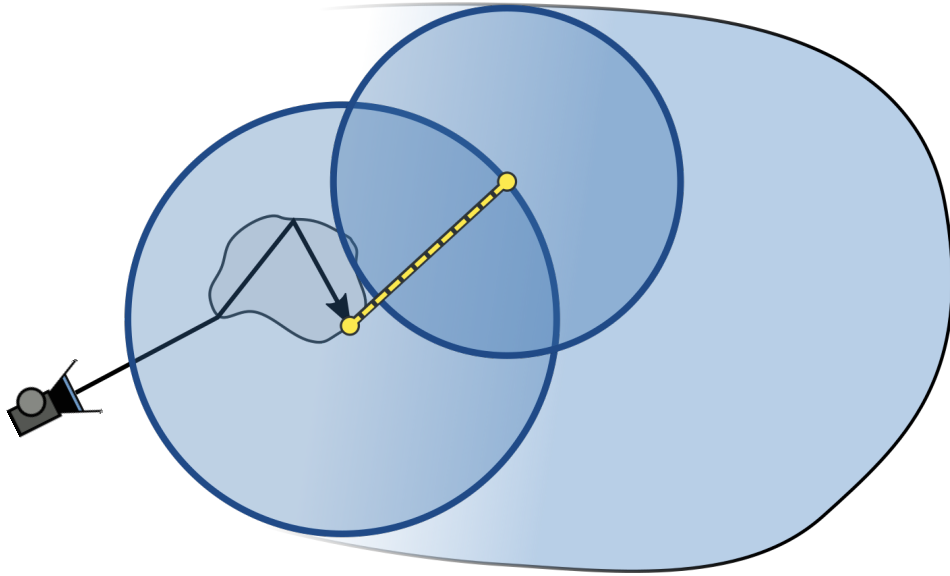
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Shell Transfer Functions



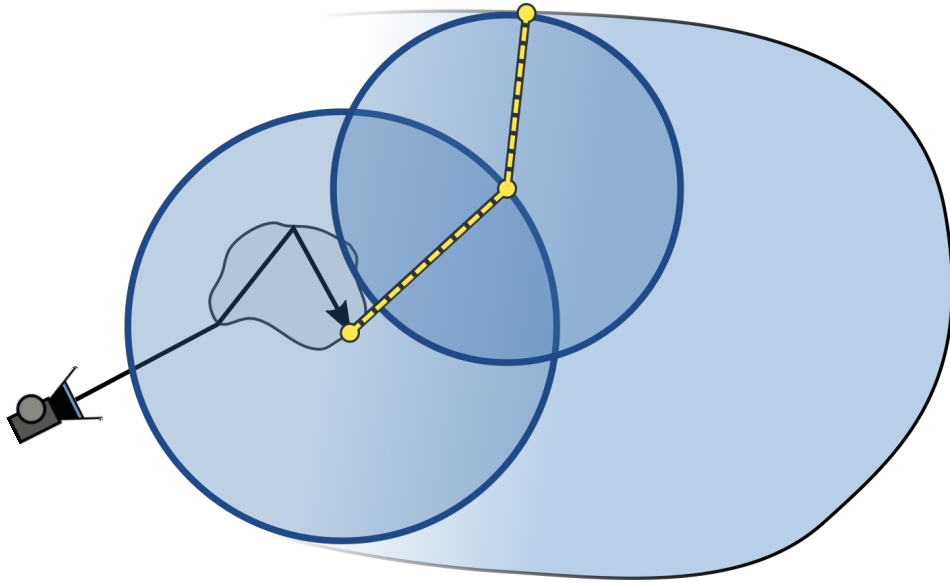
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Shell Transfer Functions



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Shell Transfer Functions



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What do we want?

Like Moon et al.,

- Avoid tracing grain geometry when possible
- Exit the medium quickly

However,

- Avoid global precomputation
- Multi-scale: Switch as early as possible.

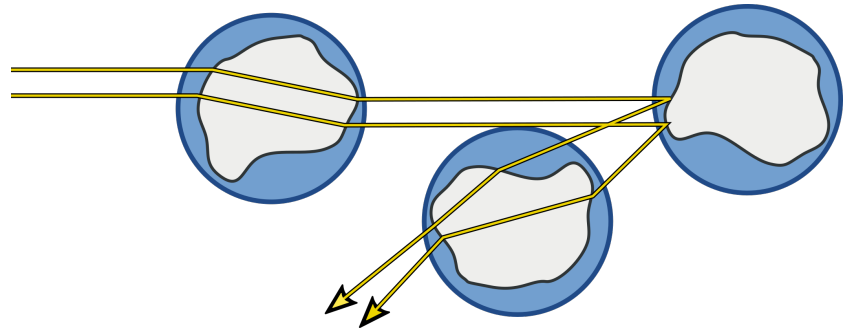
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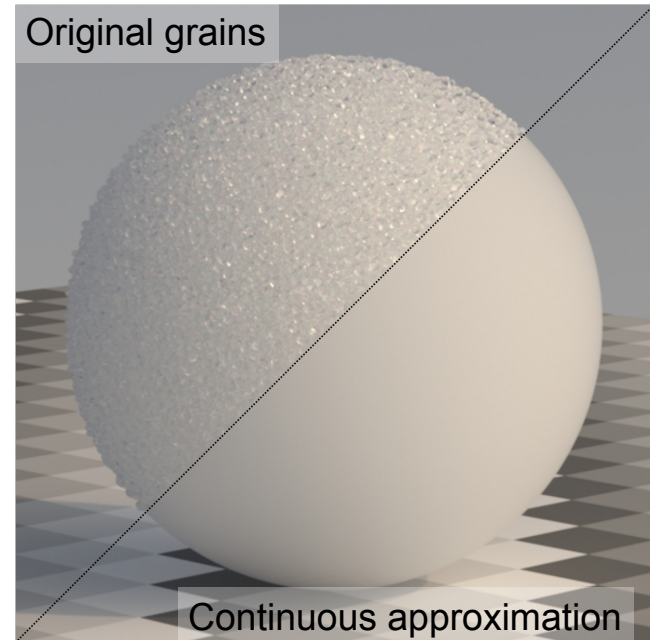
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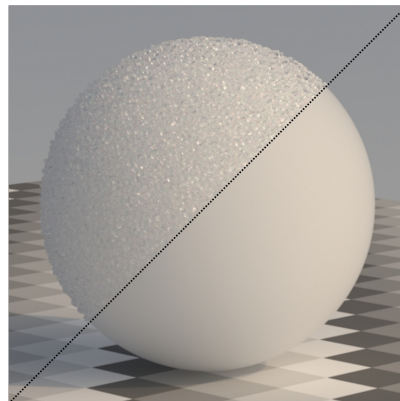
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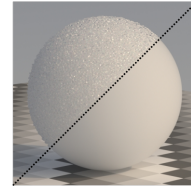
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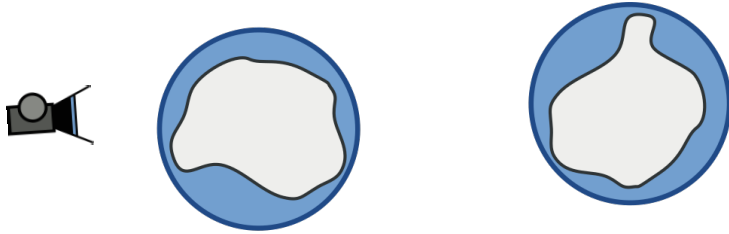
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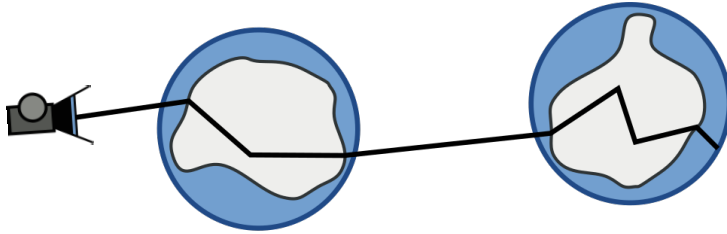
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Our Technique

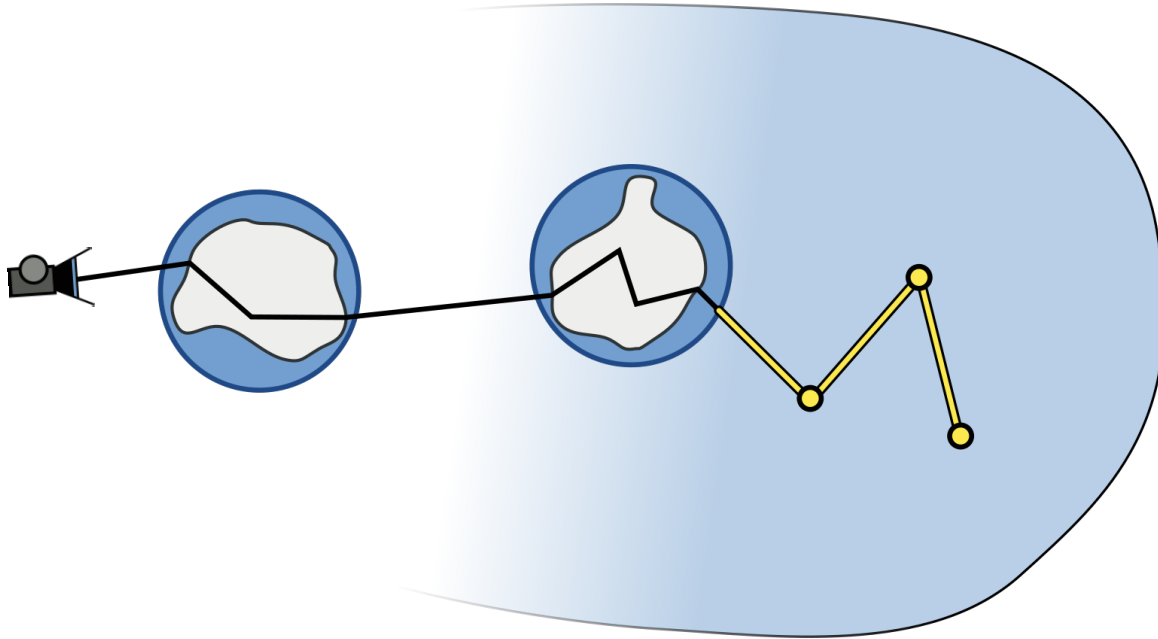


Our Technique



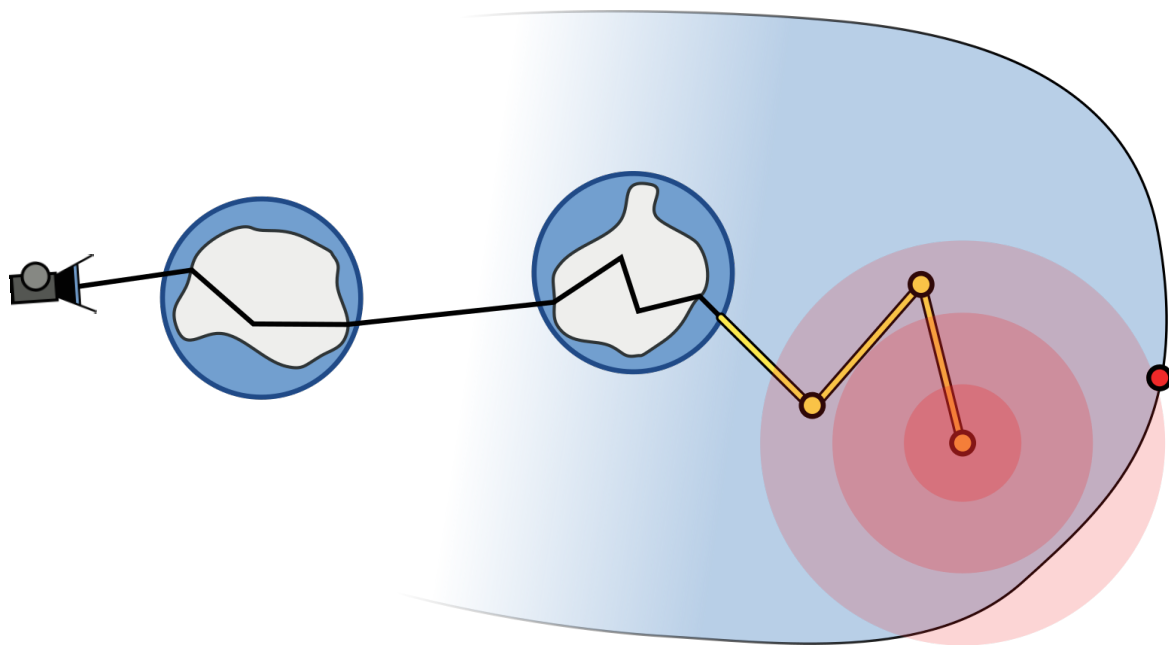
Explicit Path Tracing (EPT)

Our Technique



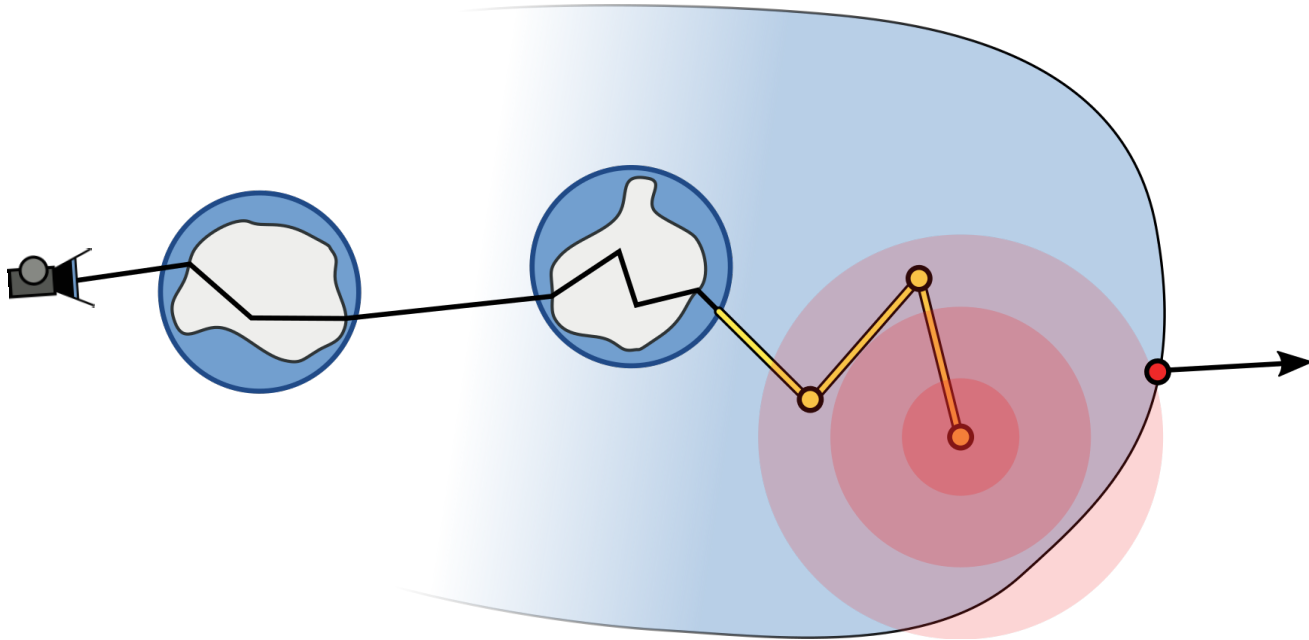
Volumetric Path Tracing (VPT)

Our Technique



Diffusion Approximation (DA)

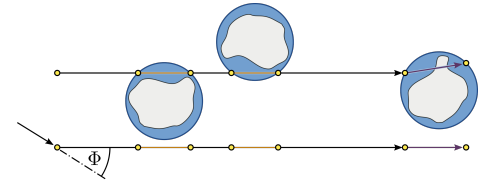
Our Technique



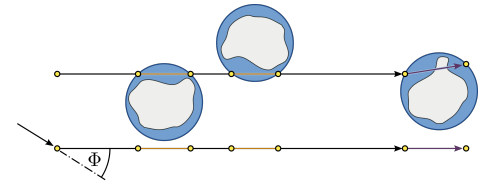
EPT + VPT + DA

Overview

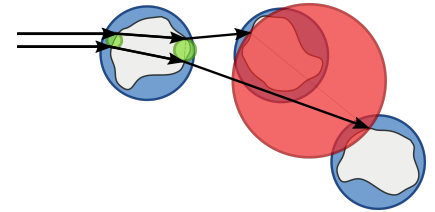
Overview



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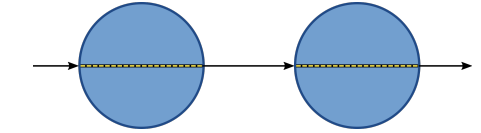


2. Automatic switching

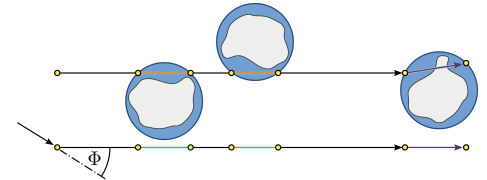


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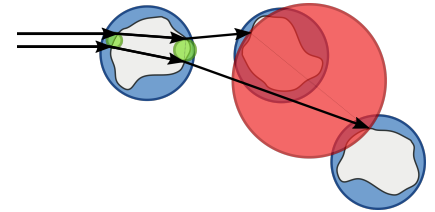
0. Conceptual model for light transport in grains



1. Deriving parameters for VPT / DA



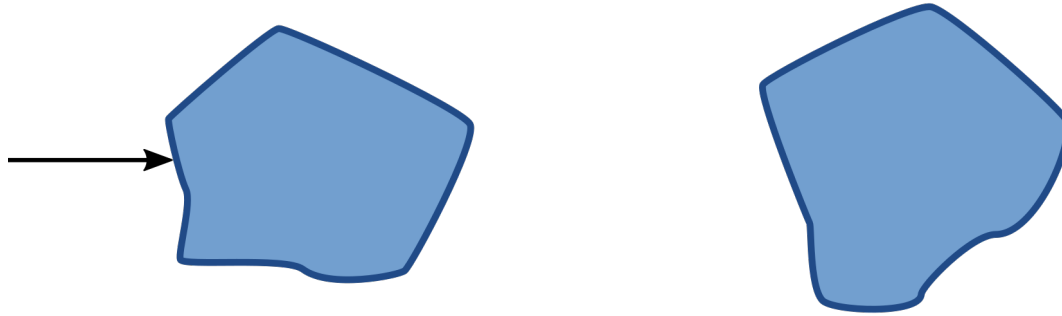
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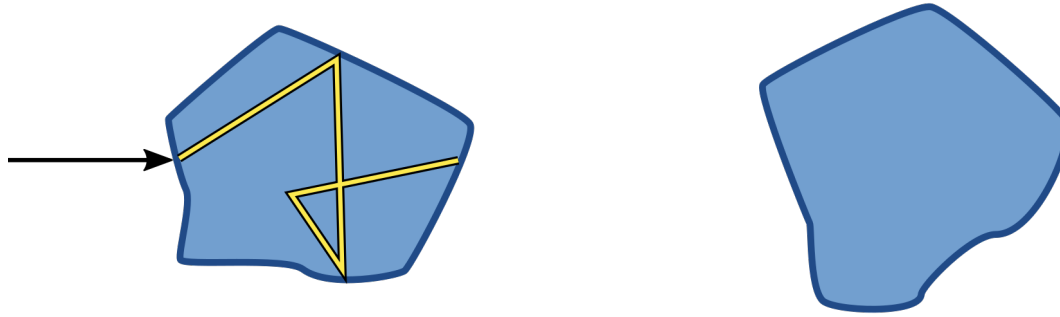
Conceptual Model: Light Transport in Grains



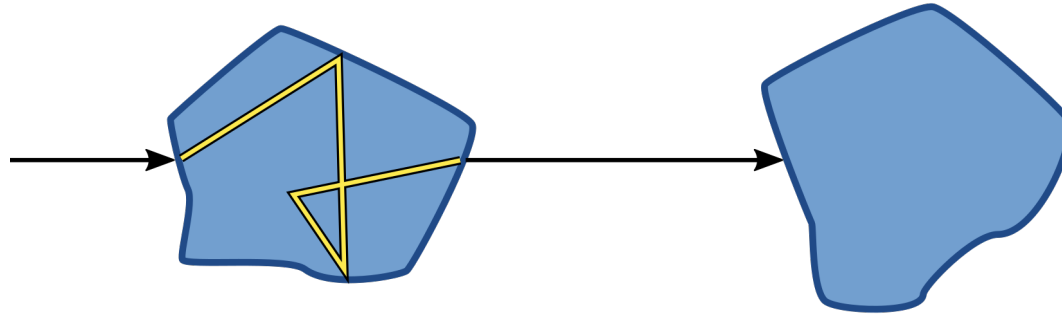
Conceptual Model: Light Transport in Grains



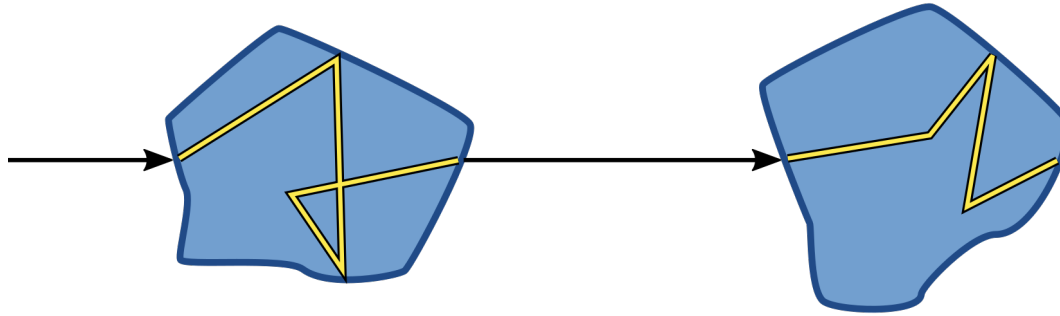
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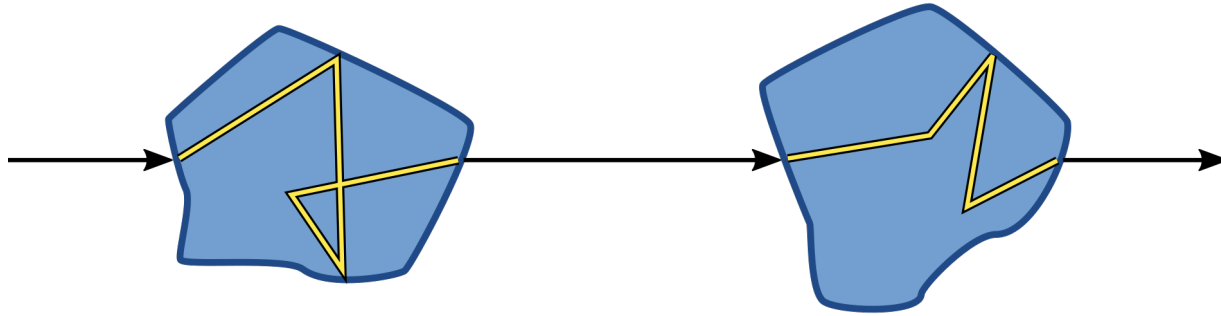
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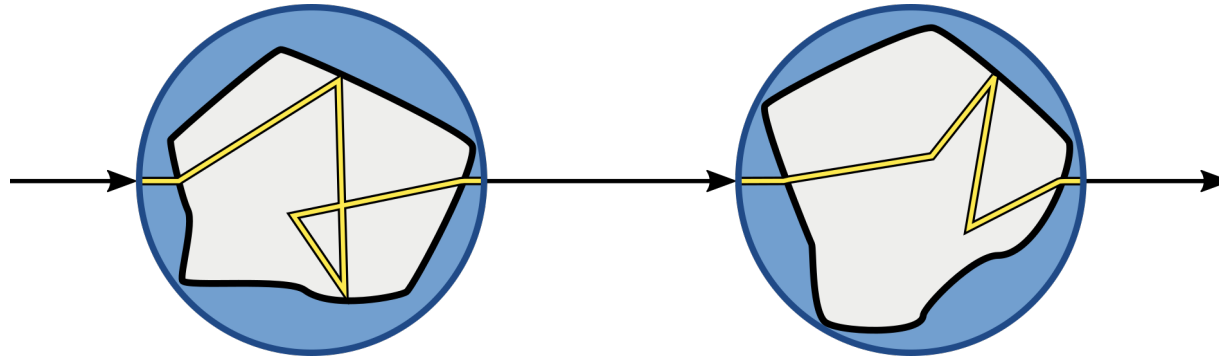
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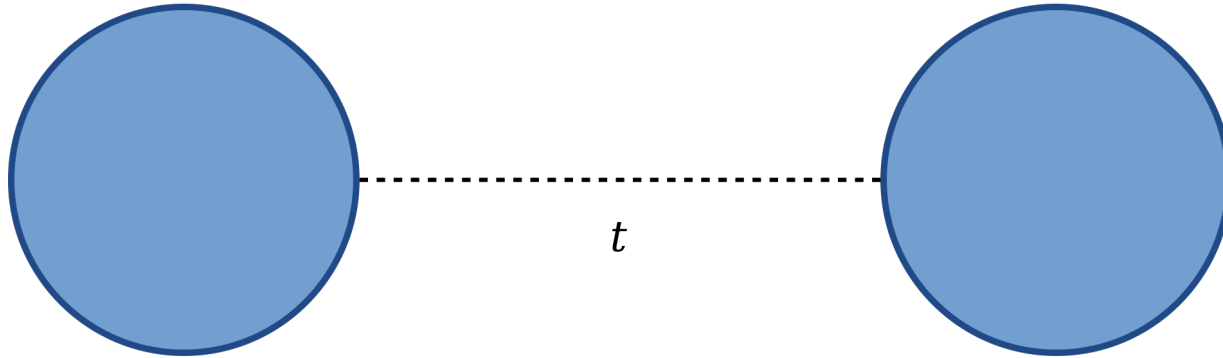
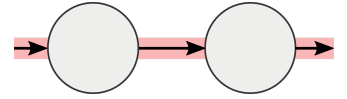


Conceptual Model: Light Transport in Grains

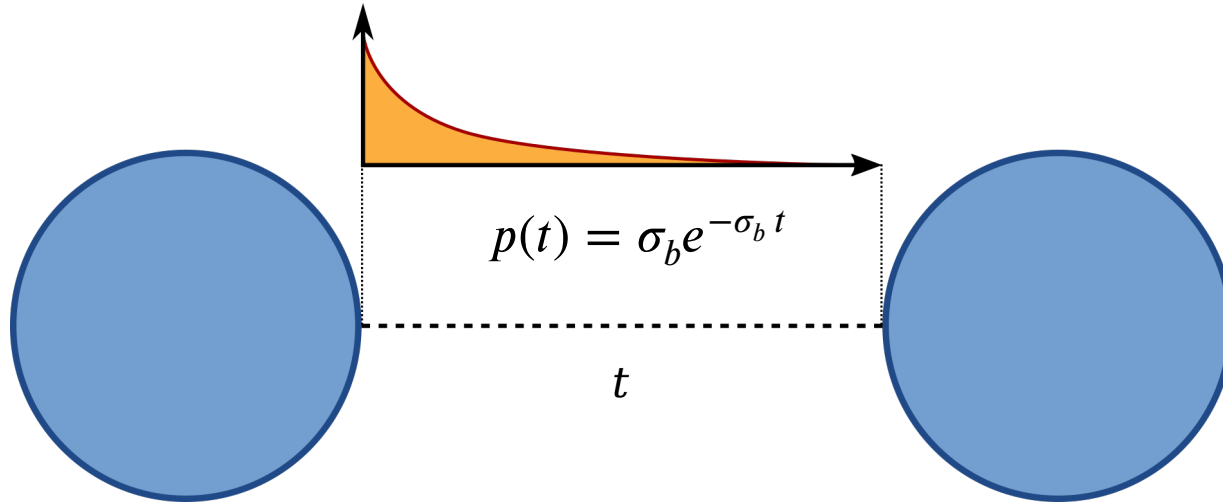
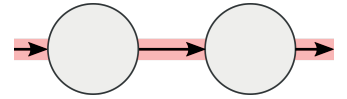


Non-intersecting bounding spheres!

Free Paths in Sphere Packings

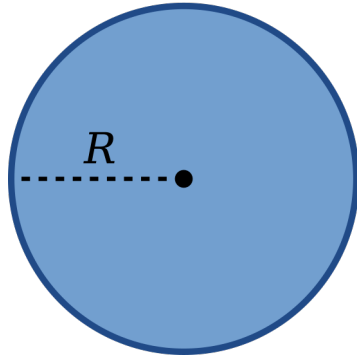
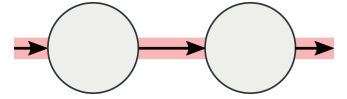


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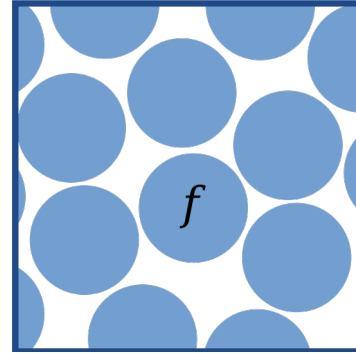


[Dixmier 1978: Une nouvelle description des empilements aléatoires et des fluides denses.]

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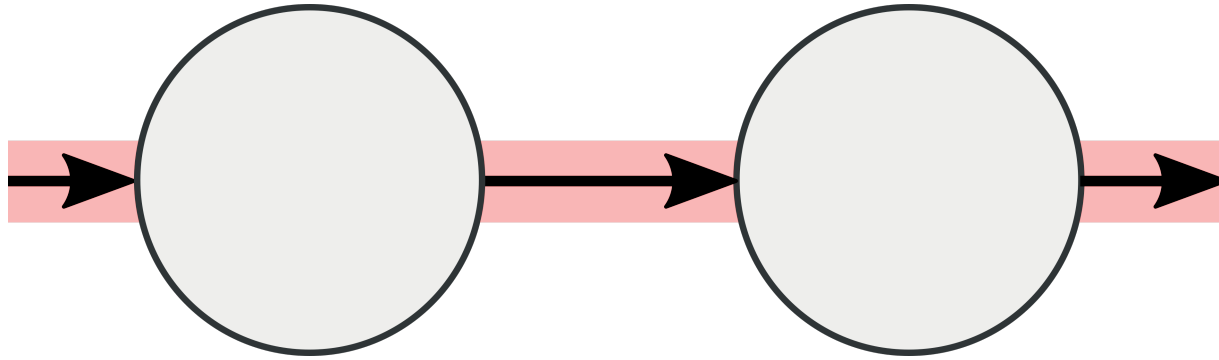


$$p(t) = \sigma_b e^{-\sigma_b t}$$
$$\sigma_b = \frac{3}{4R} \frac{f}{1-f}$$

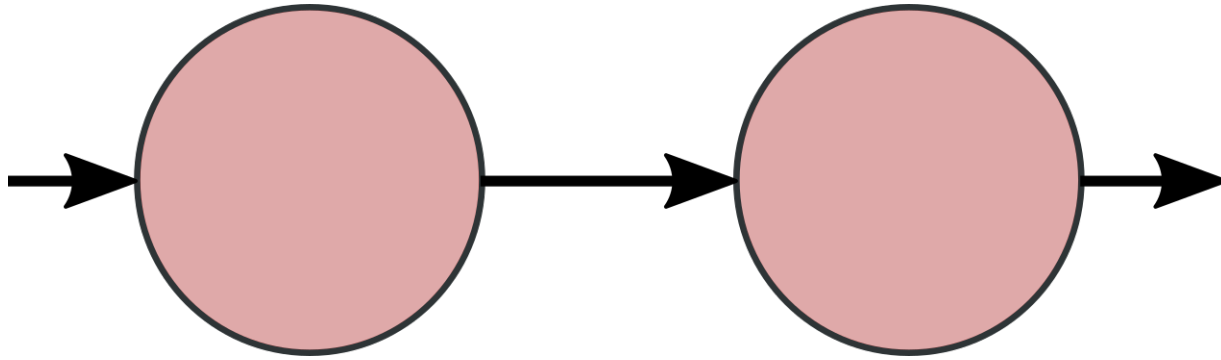


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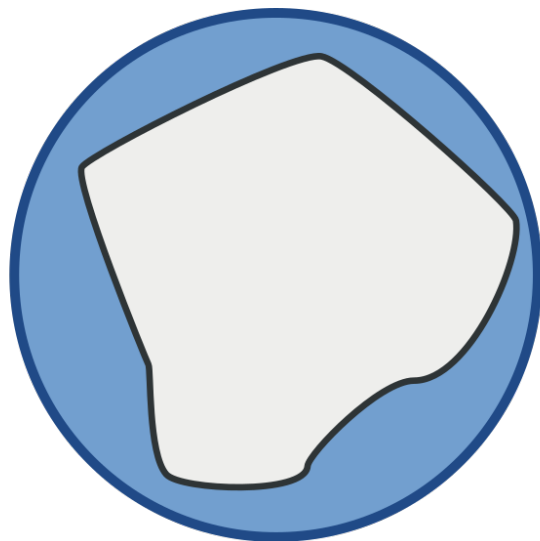
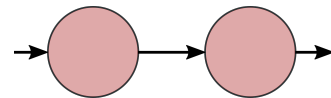


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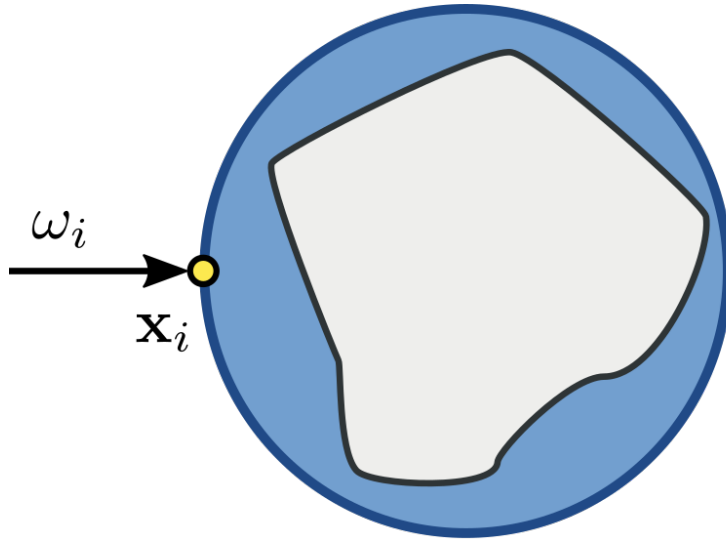
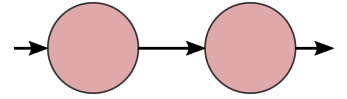


Non-point scattering: Teleportation Scattering Distribution Function (TSDF)

TSDF: Teleportation Scattering Distribution Function

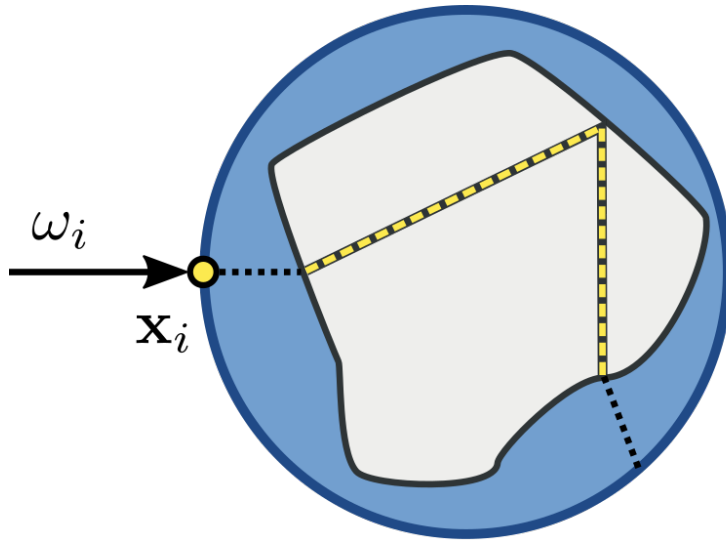
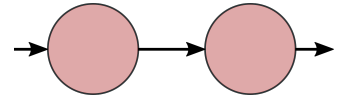


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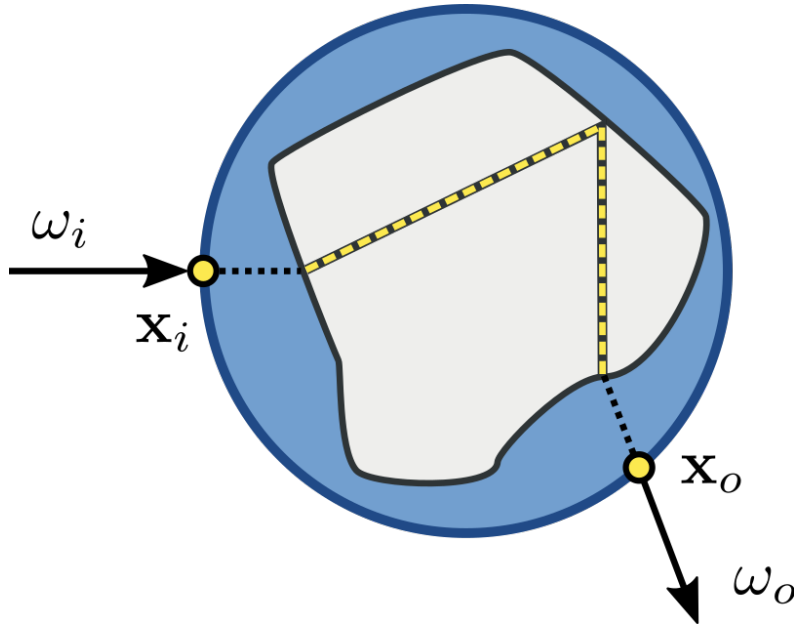
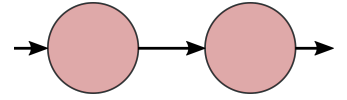
- Monte Carlo-simulation of photons scattering on a single grain

TSDF: Teleportation Scattering Distribution Function



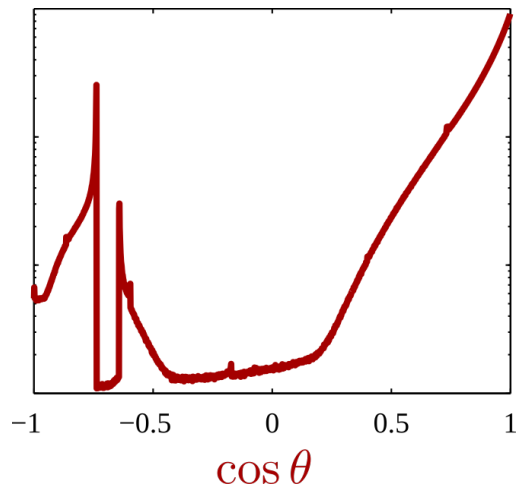
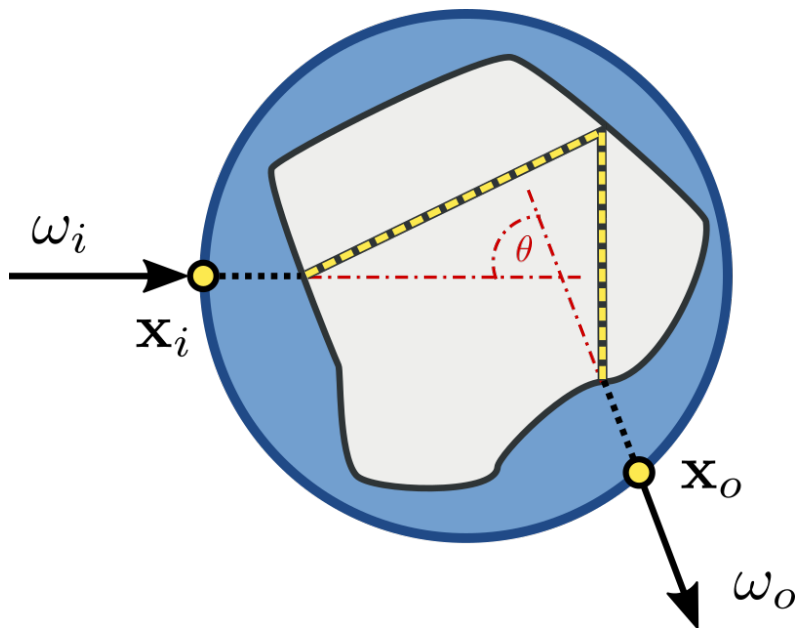
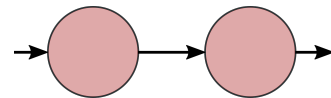
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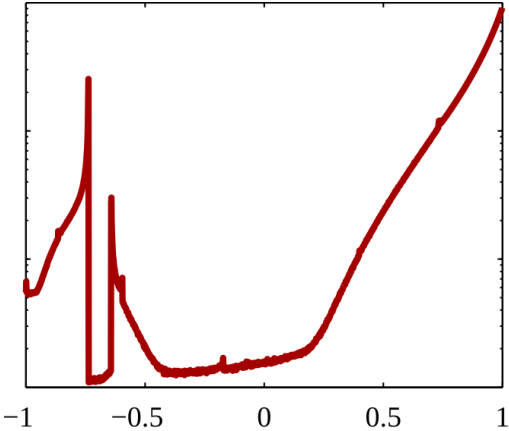
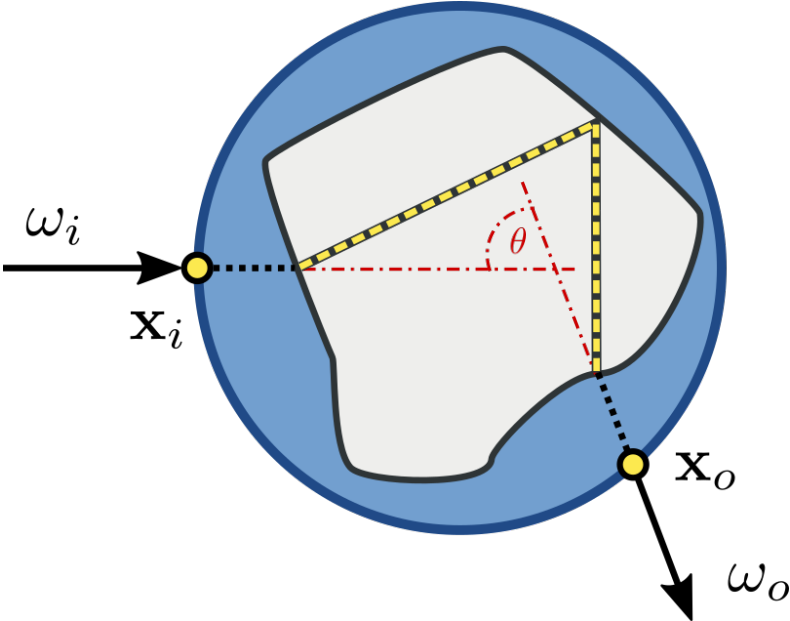
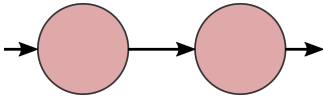


- Monte Carlo-simulation of photons scattering on a single grain
- Tabulate deflection angle and conditional teleportation vector

TSDF: Teleportation Scattering Distribution Function



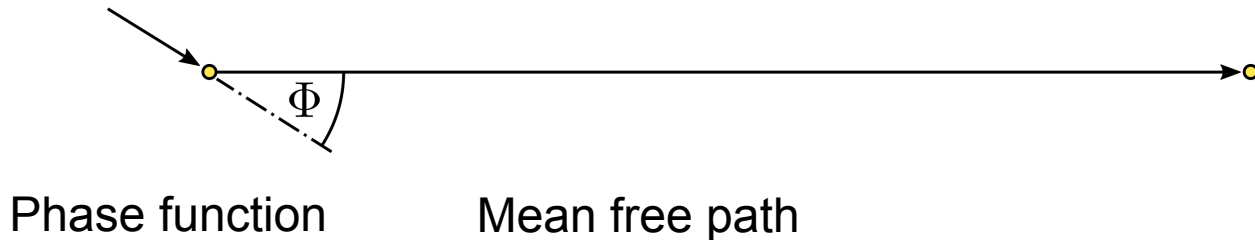
TSDF: Teleportation Scattering Distribution Function



$$\{\alpha, \lambda_s, \beta, \lambda_\delta\}$$

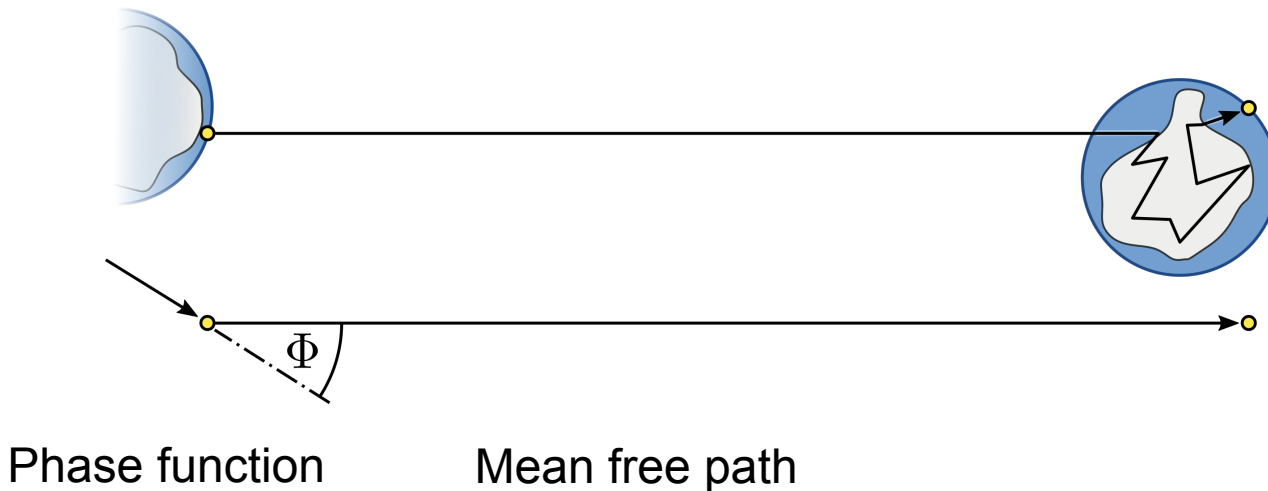
Volumetric Path Tracing (VPT)

Deriving Parameters from Teleportation Path Tracing



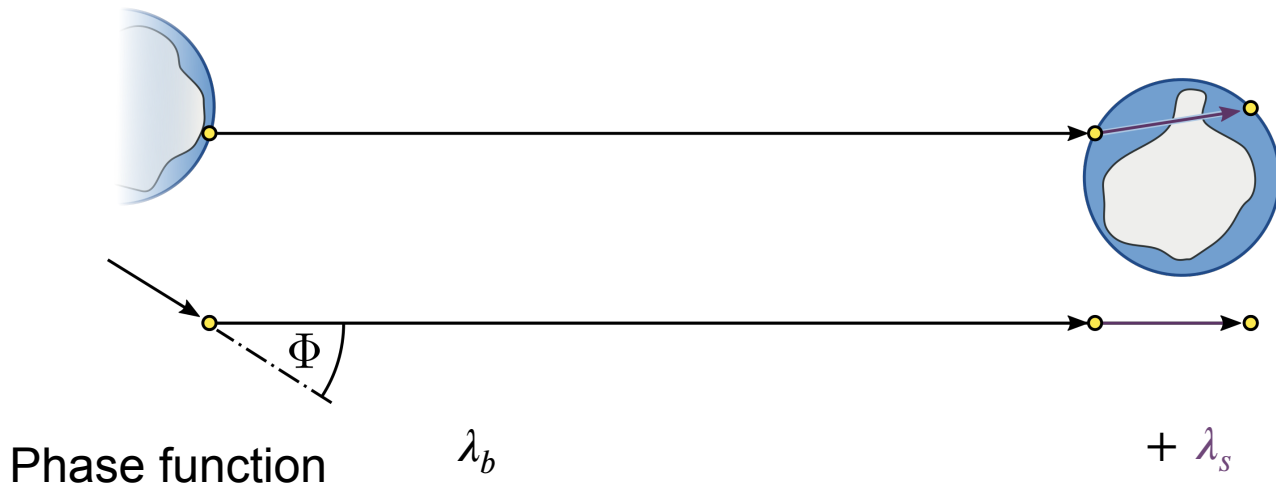
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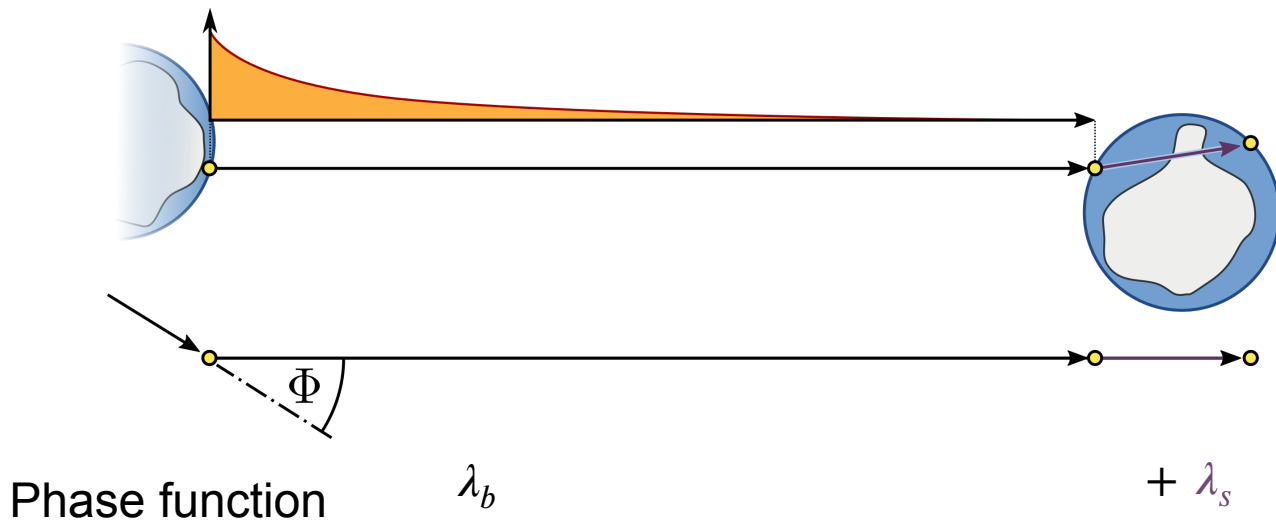
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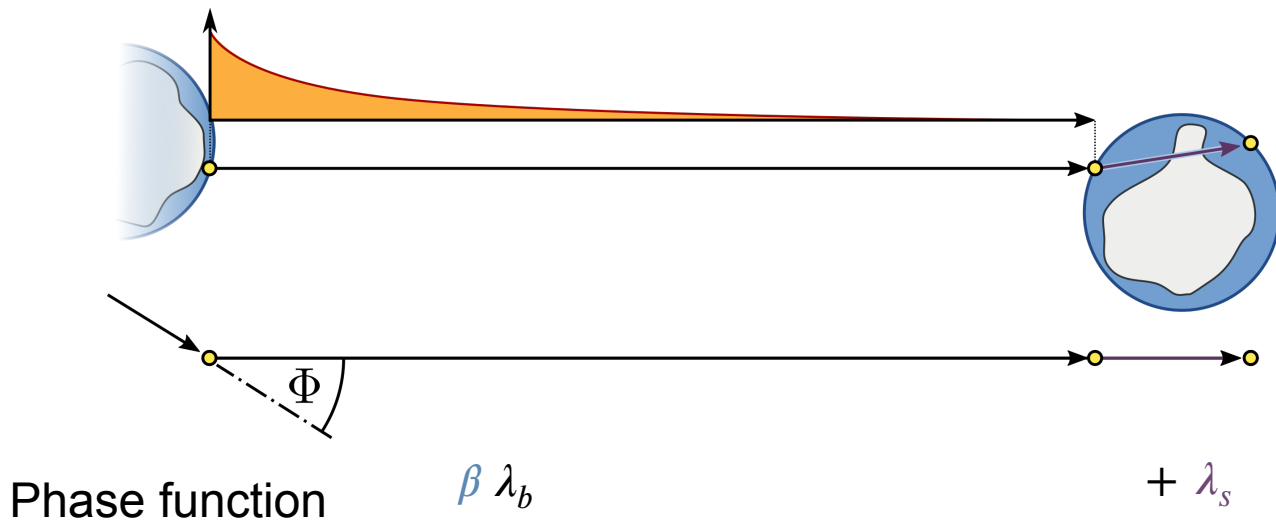
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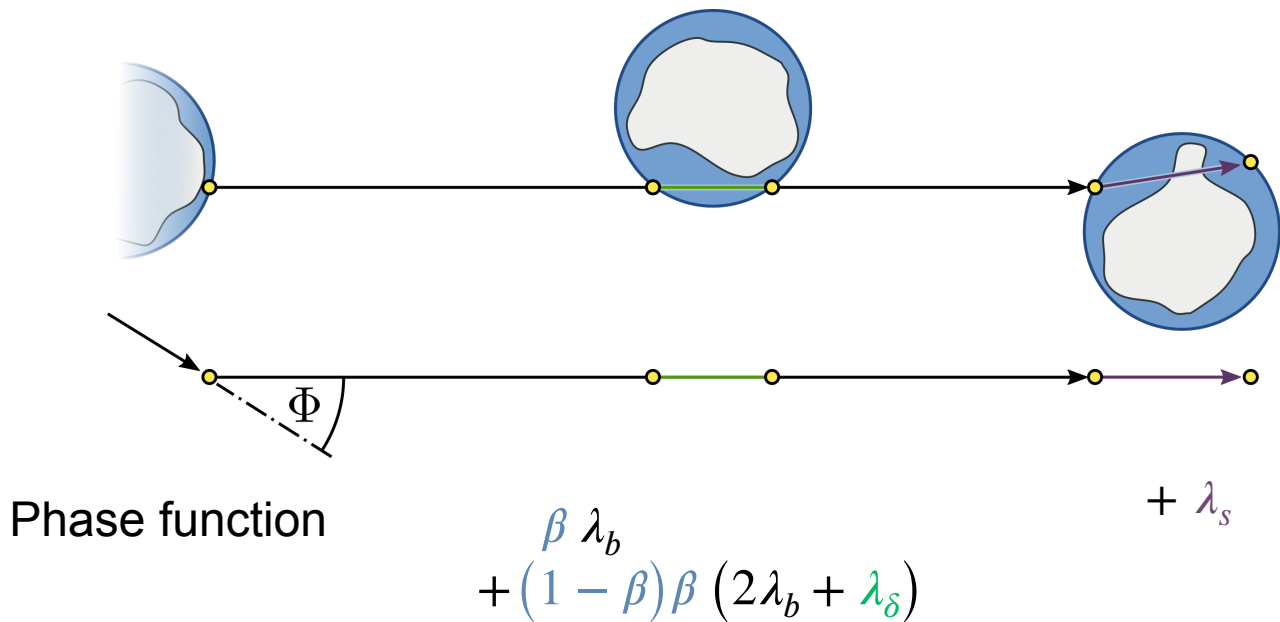
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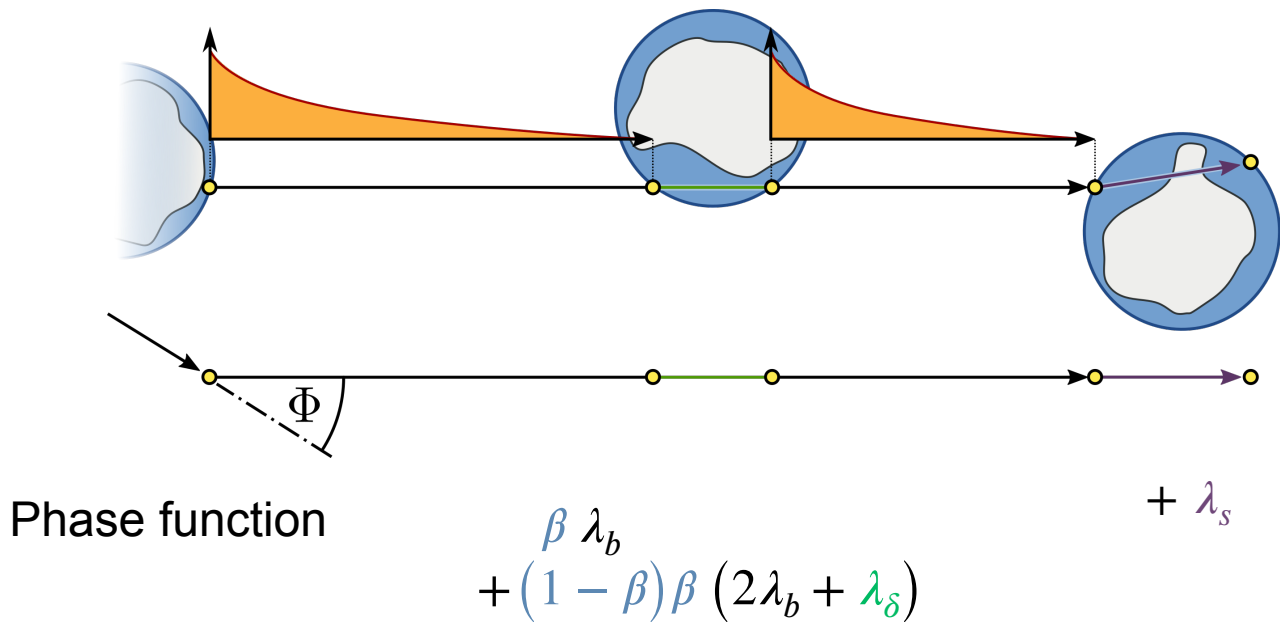
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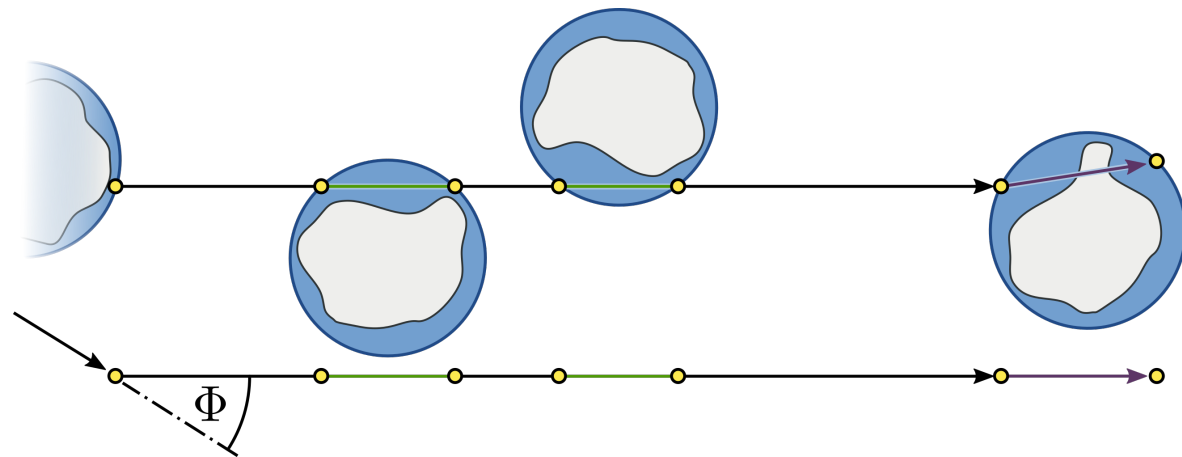
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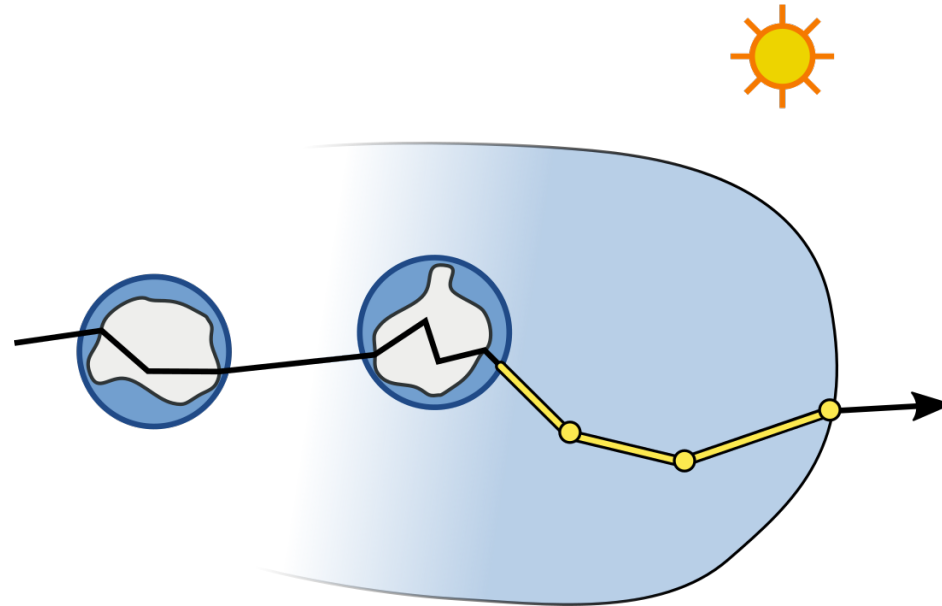
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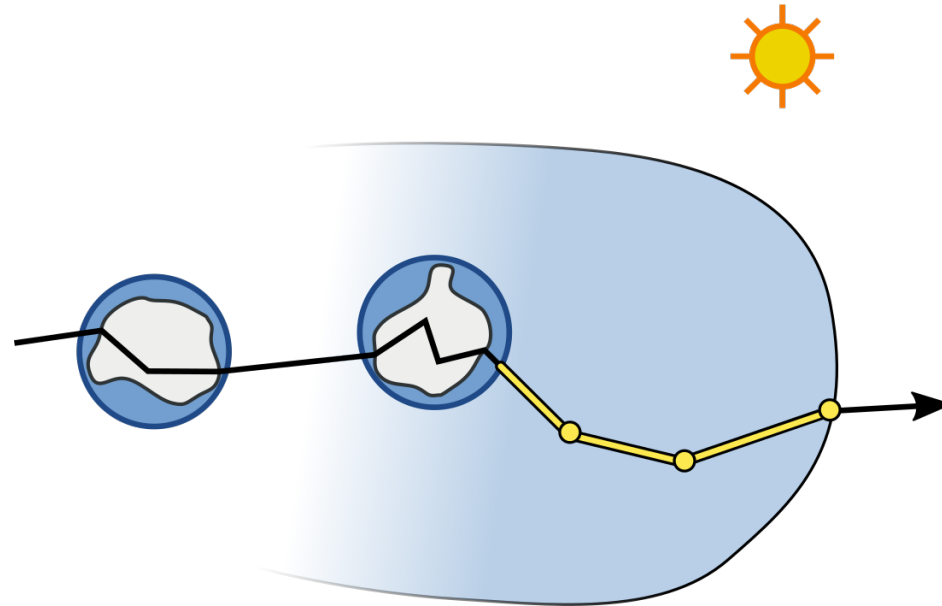
Phase function

$$\begin{aligned} & \beta \lambda_b \\ & + (1 - \beta) \beta (2\lambda_b + \lambda_s) \\ & + (1 - \beta)^2 \beta (3\lambda_b + 2\lambda_s) \dots \end{aligned} \quad + \lambda_s$$

Volumetric Path Tracing (VPT)

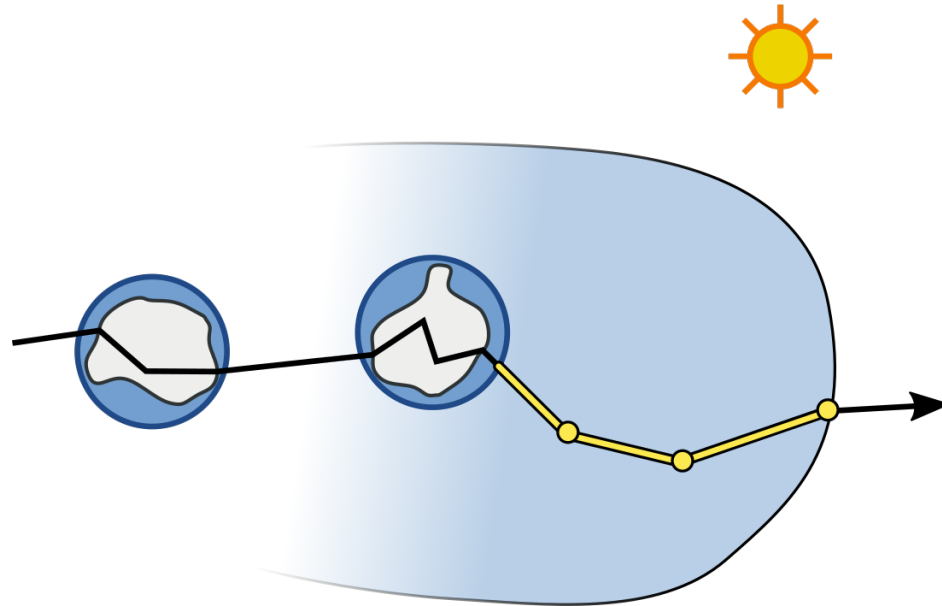


Volumetric Path Tracing (VPT)



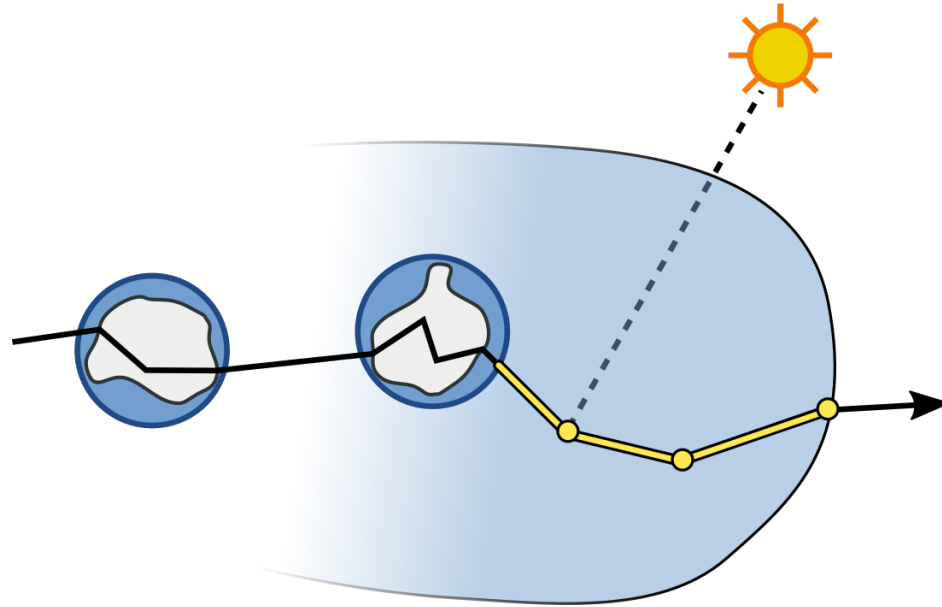
Low order: Explicit Path Tracing

Volumetric Path Tracing (VPT)

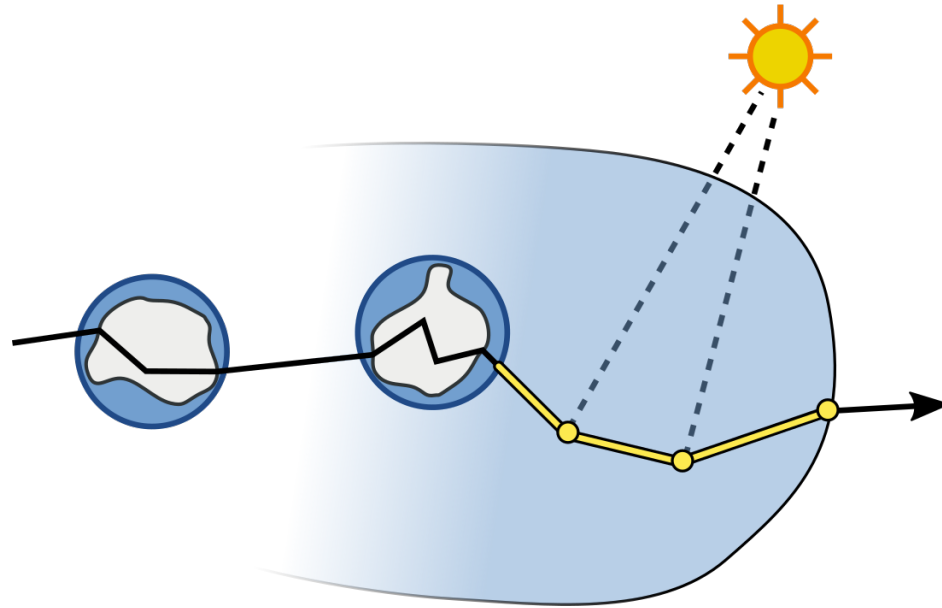


High order: Volumetric Path Tracing

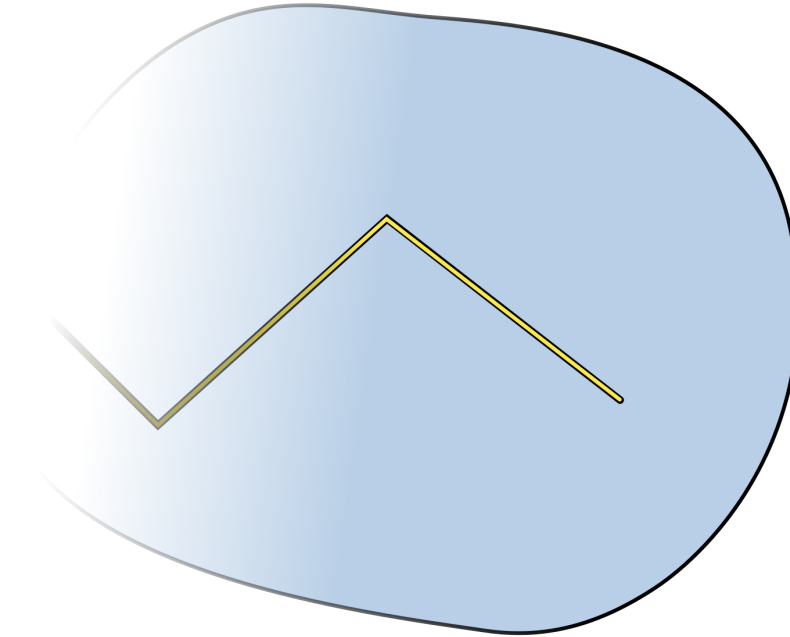
Volumetric Path Tracing (VPT)



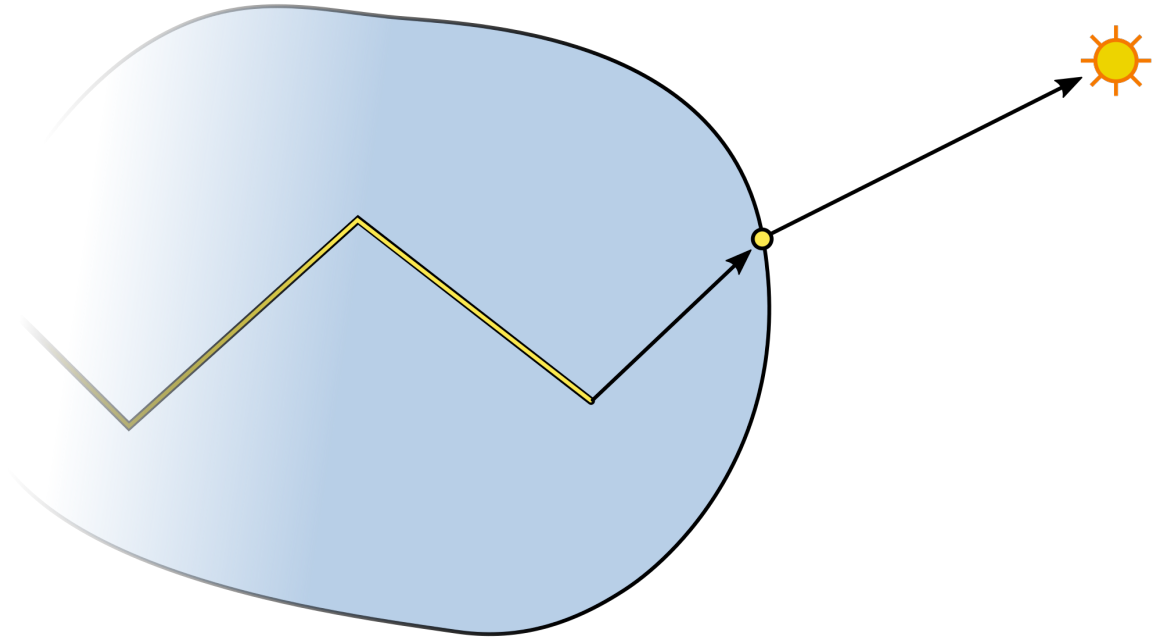
Volumetric Path Tracing (VPT)



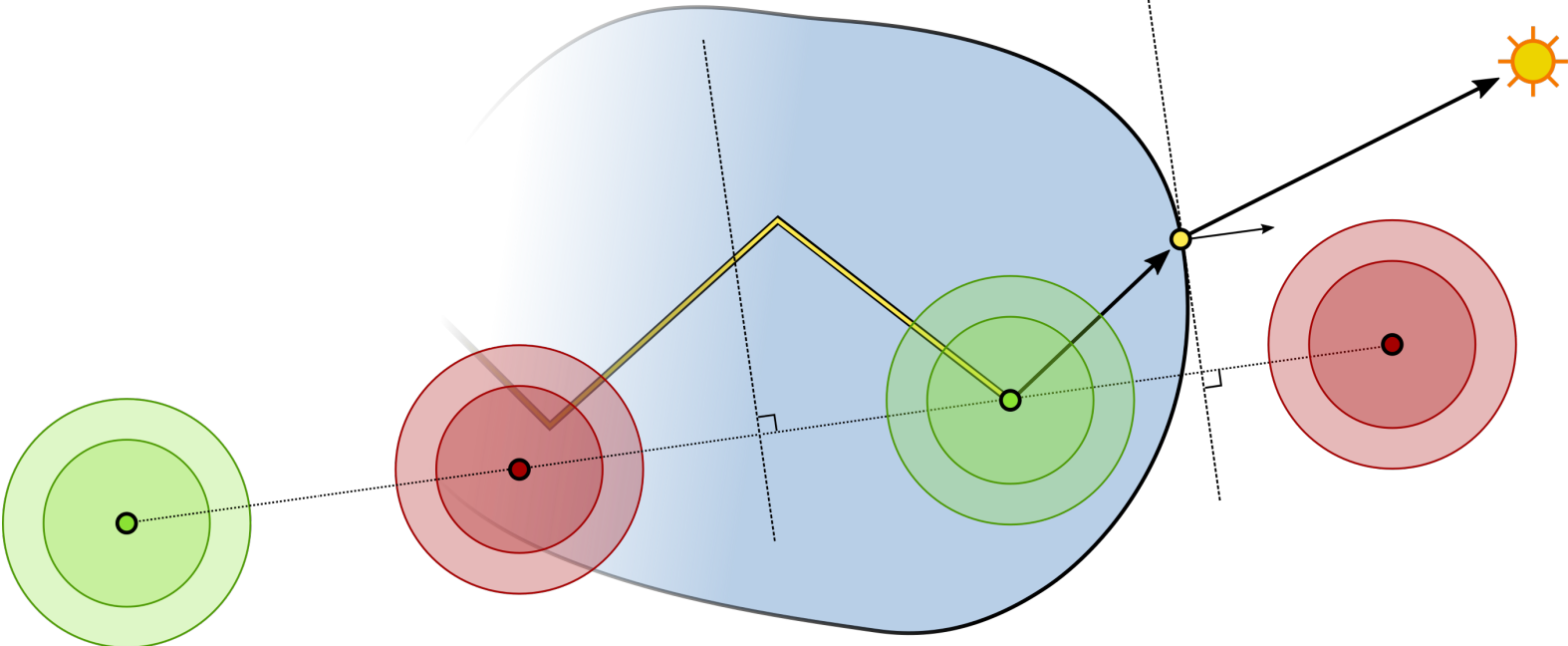
Diffusion Approximation (DA)



Diffusion Approximation (DA)



Diffusion Approximation (DA)



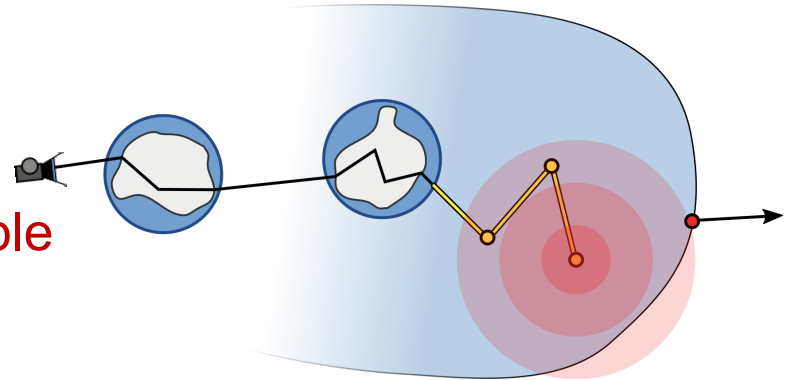
What do we want?

Like Moon et al.,

- Avoid tracing grain geometry when possible
- Exit the medium quickly

However,

- Avoid global precomputation
- Multi-scale: Switch as early as possible



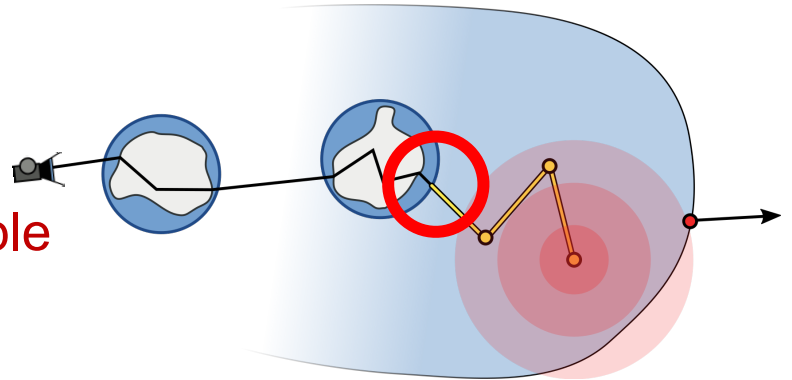
What do we want?

Like Moon et al.,

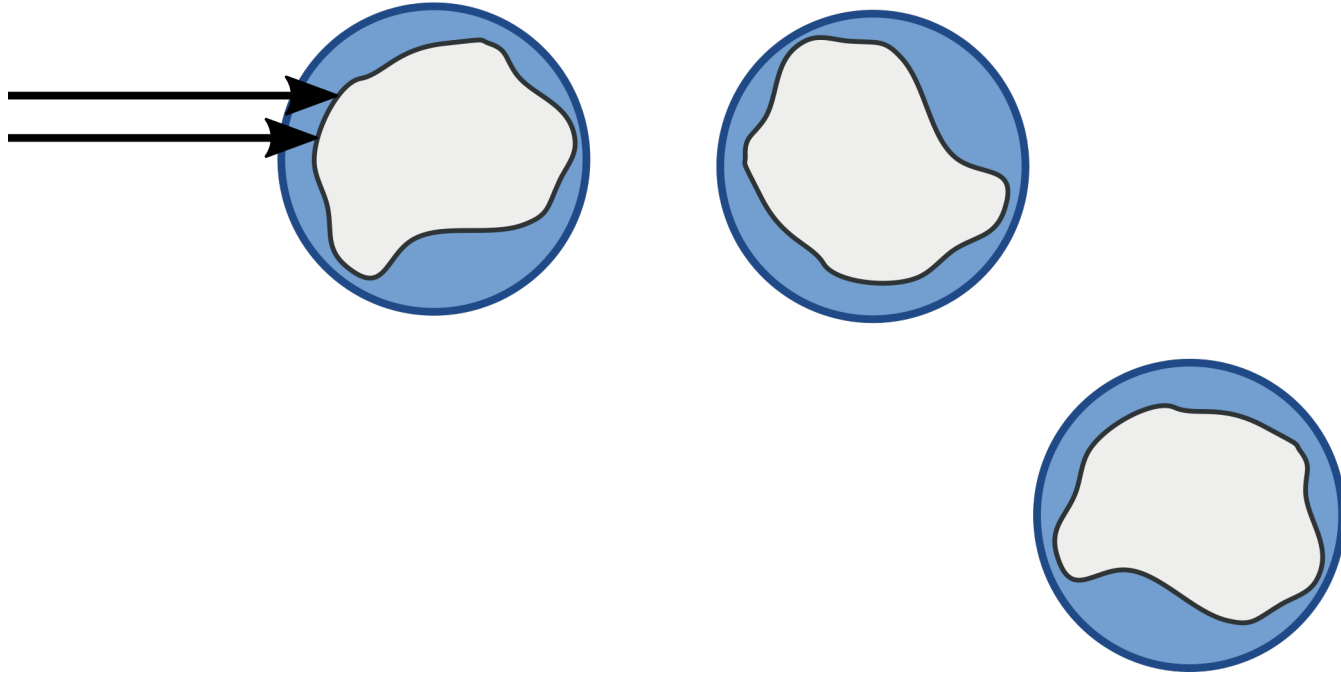
- Avoid tracing grain geometry when possible
- Exit the medium quickly

However,

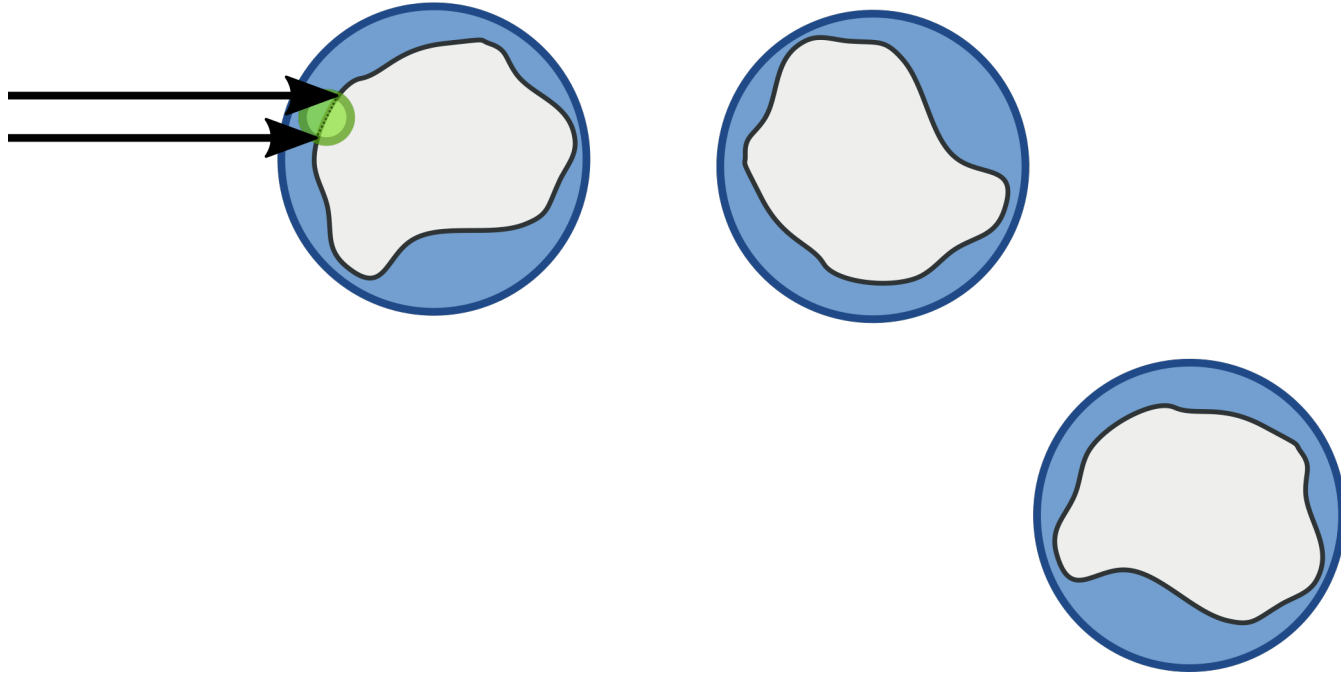
- Avoid global precomputation
- Multi-scale: Switch as early as possible



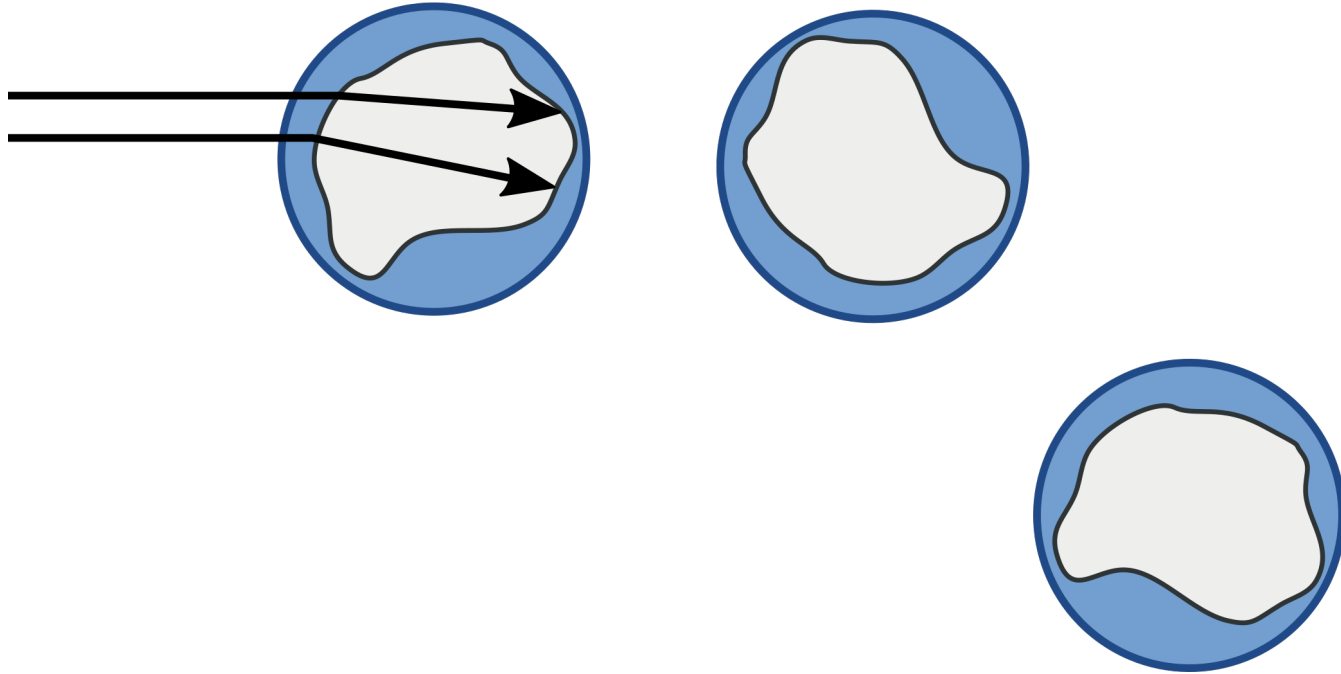
Switching to VPT



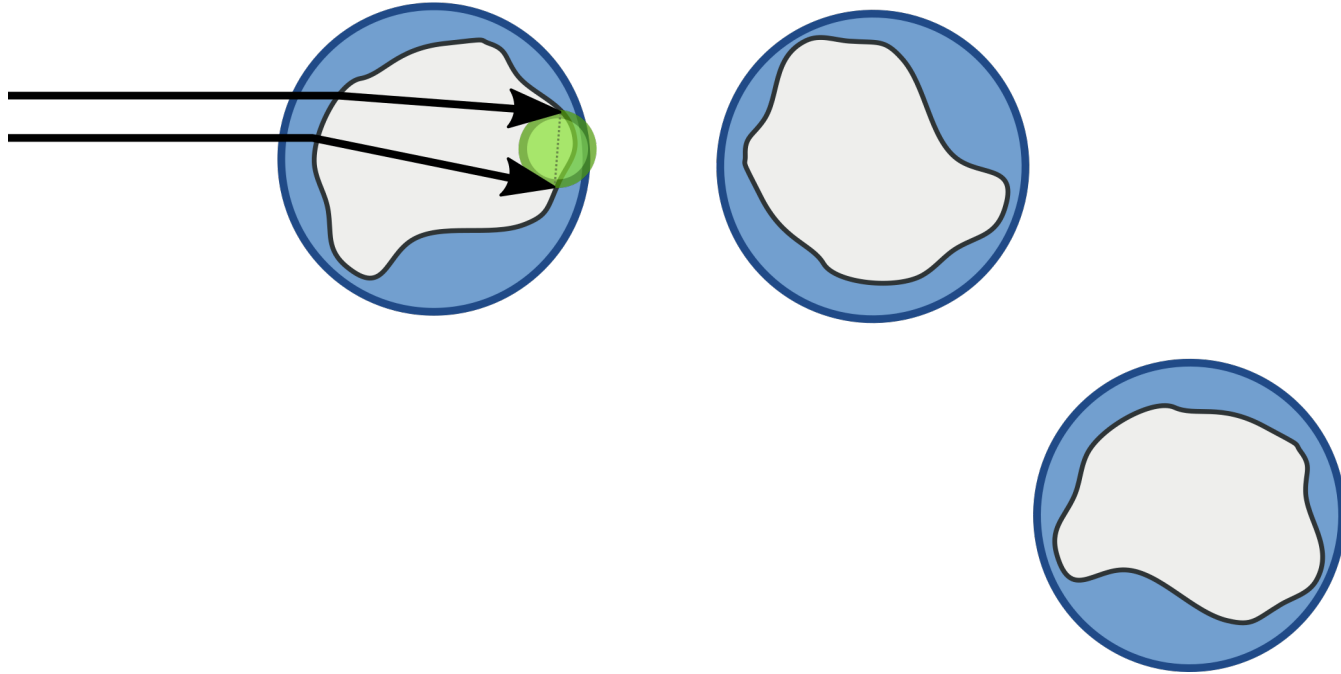
Switching to VPT



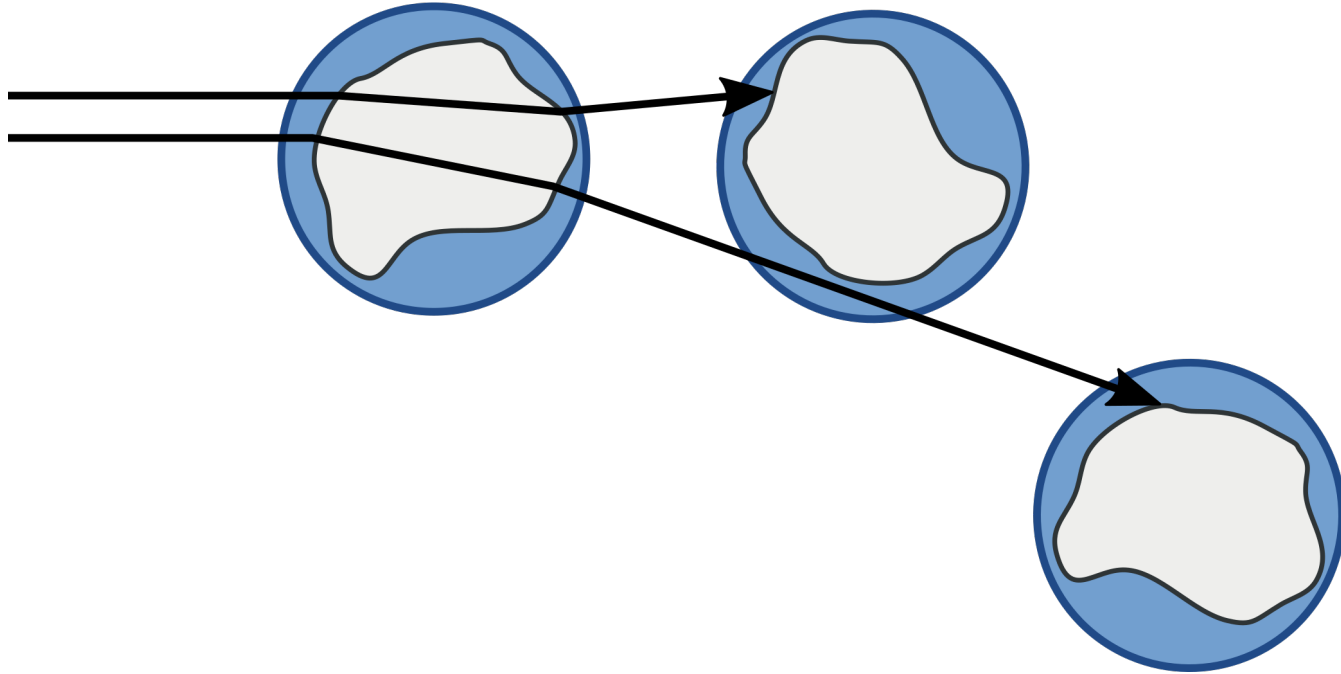
Switching to VPT



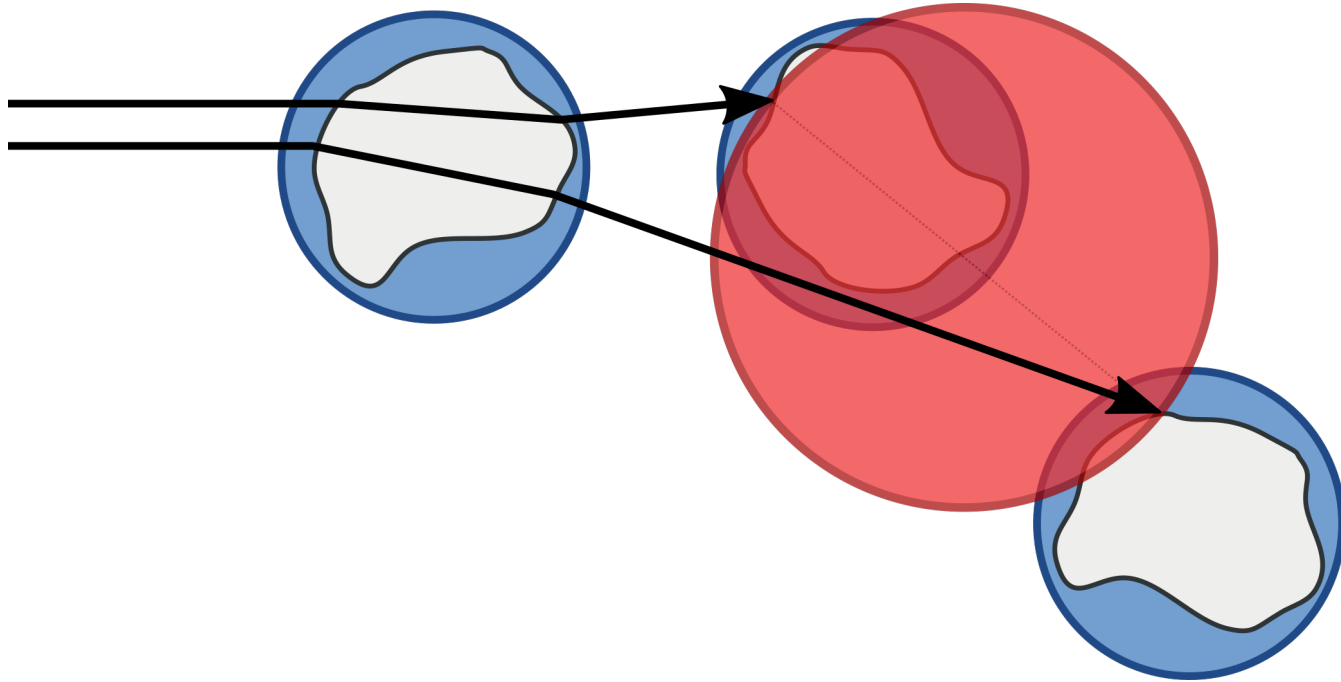
Switching to VPT



Switching to VPT

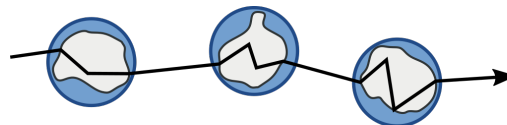


Switching to VPT

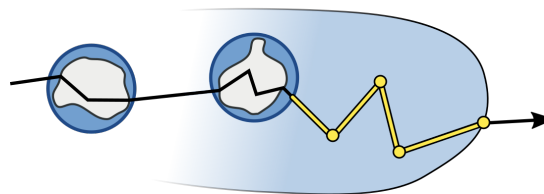


Techniques

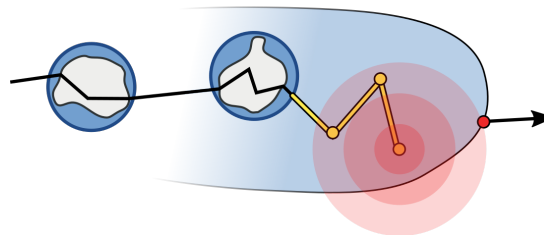
Explicit Path Tracing (EPT)



+ Volumetric Path Tracing (+VPT)

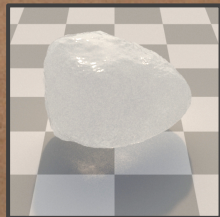
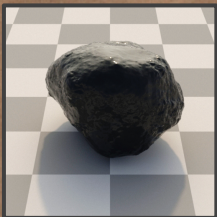
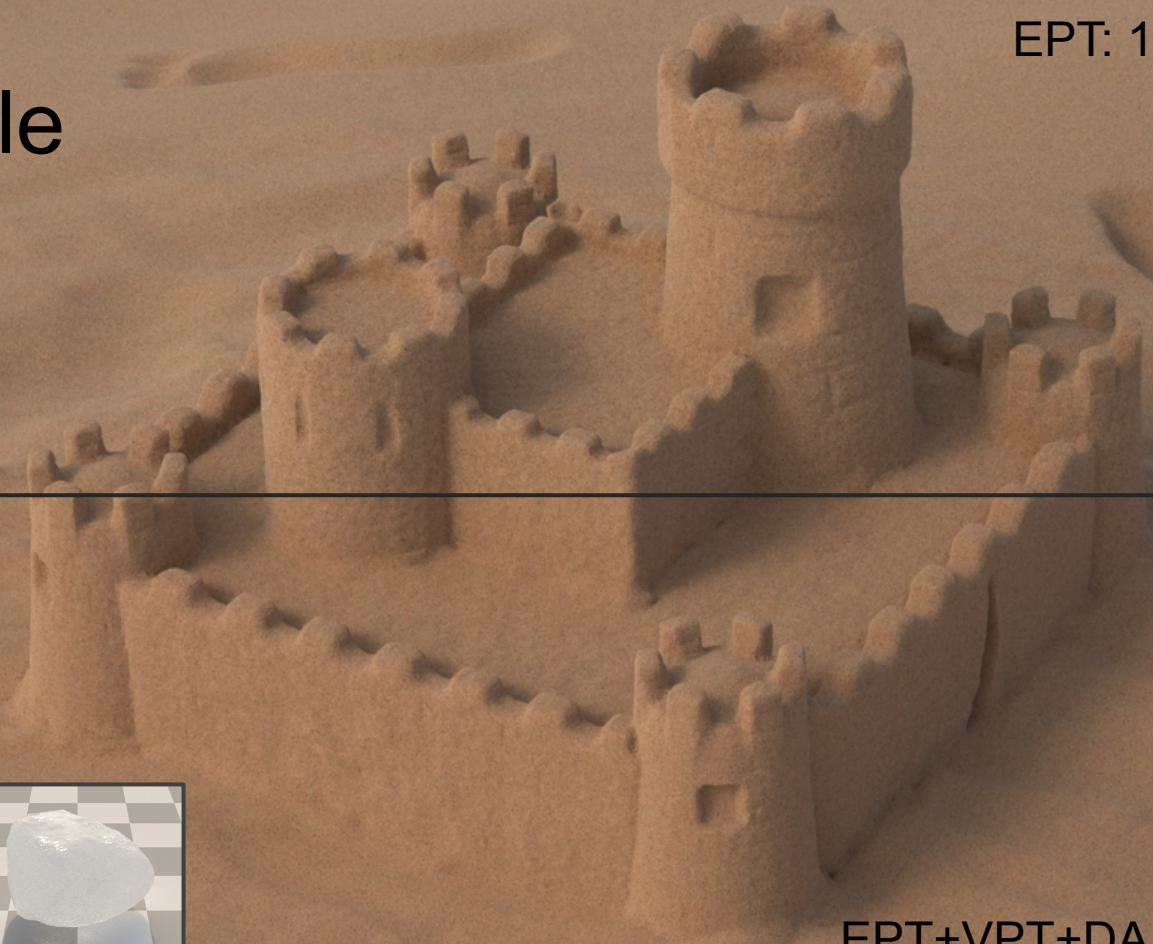


+ Diffusion Approximation (+DA)



EPT: 1736 hrs

Sand Castle

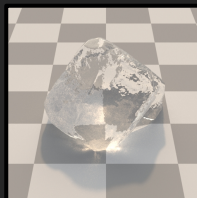
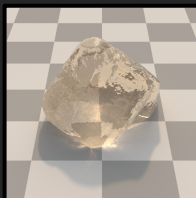
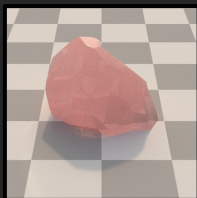
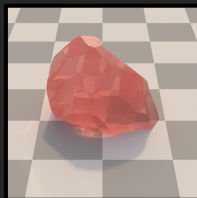
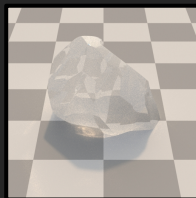
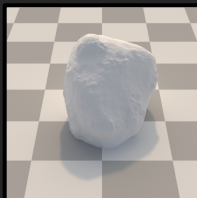
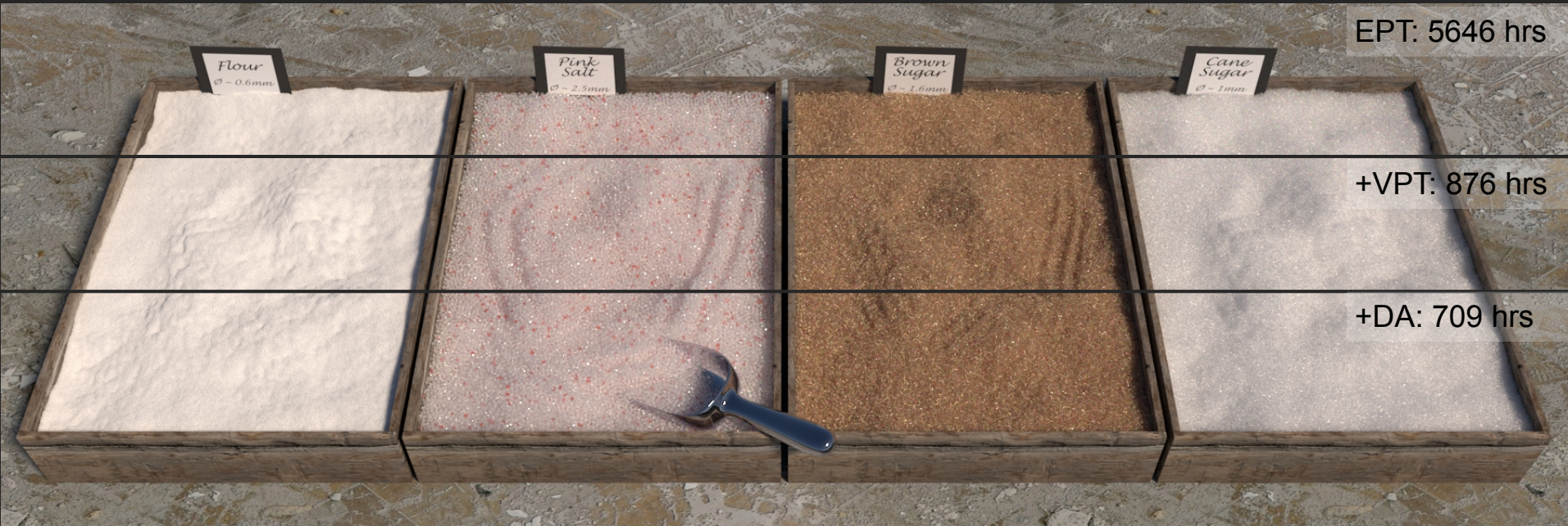


EPT+VPT+DA: 789 hrs

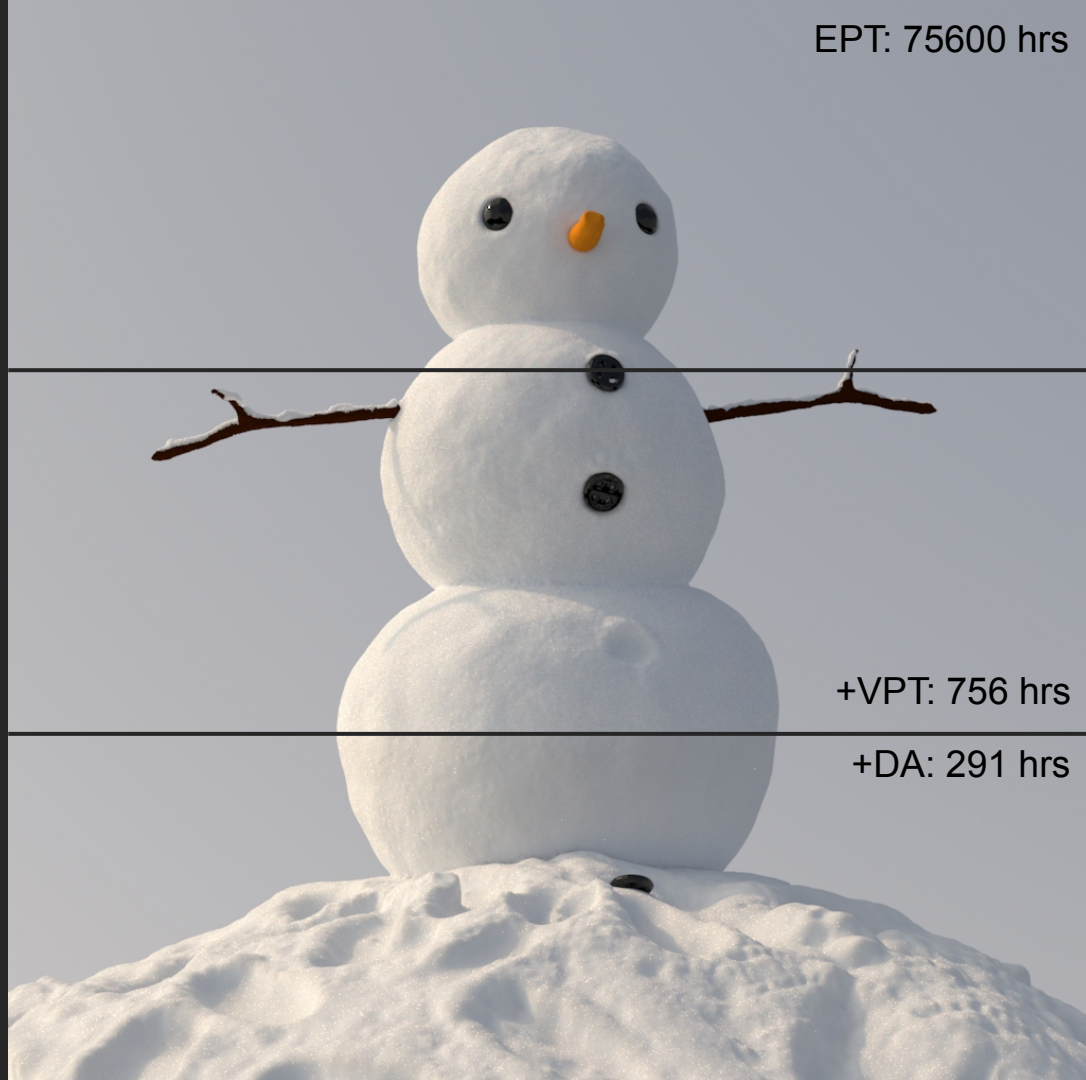
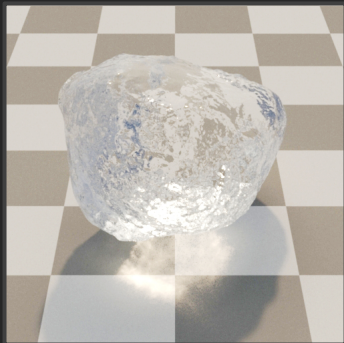




Spices



Snowman



EPT: 75600 hrs

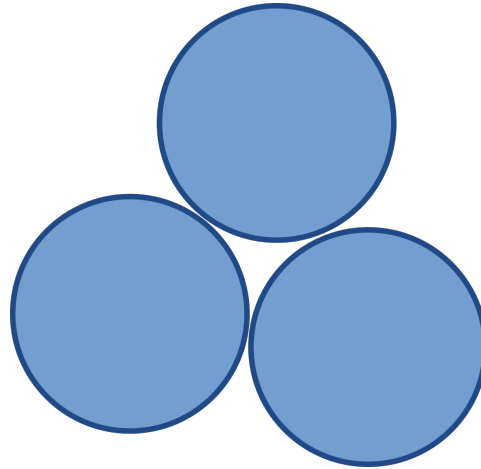
+VPT: 756 hrs

+DA: 291 hrs

Granular materials are
impractical to render

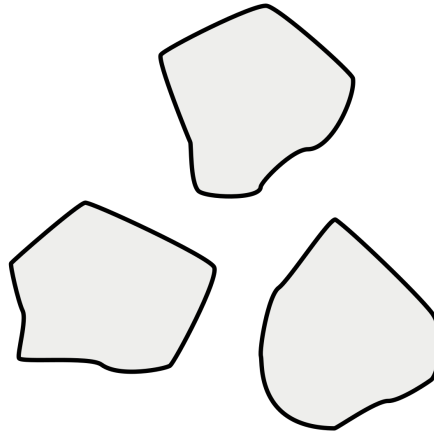
Granular materials are
practical to render

Future Work



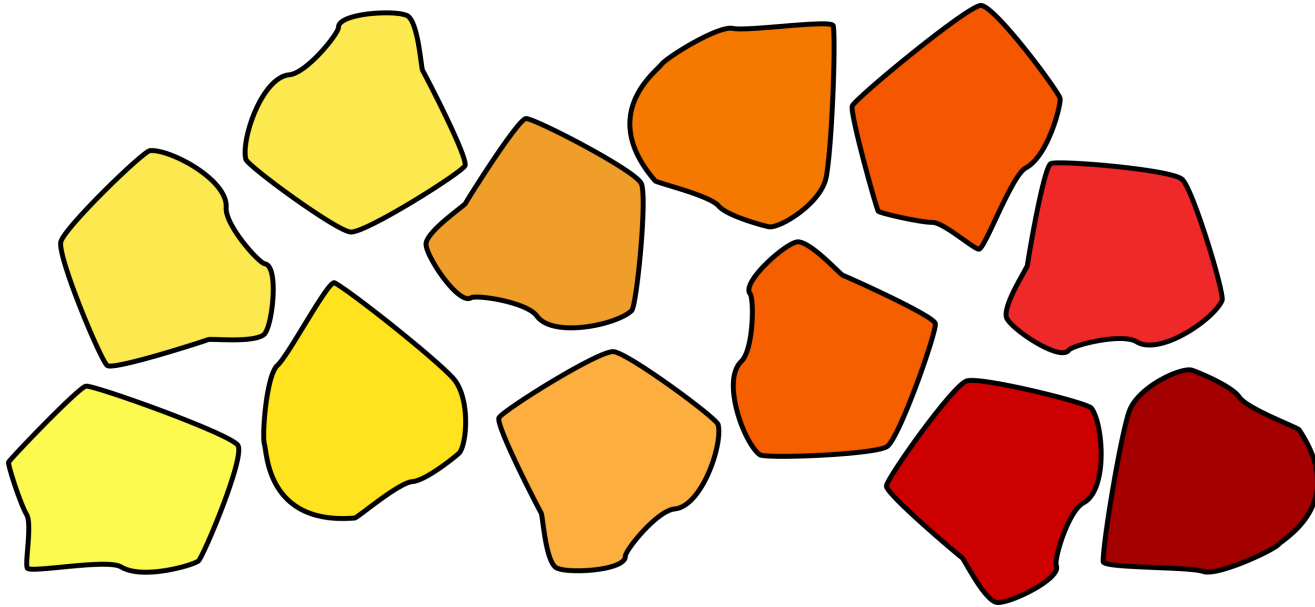
Packing densities $> 64\%$
(Anisotropic grains, e.g. rice!)

Future Work



Packing densities $> 64\%$
(Anisotropic grains, e.g. rice!)

Future Work

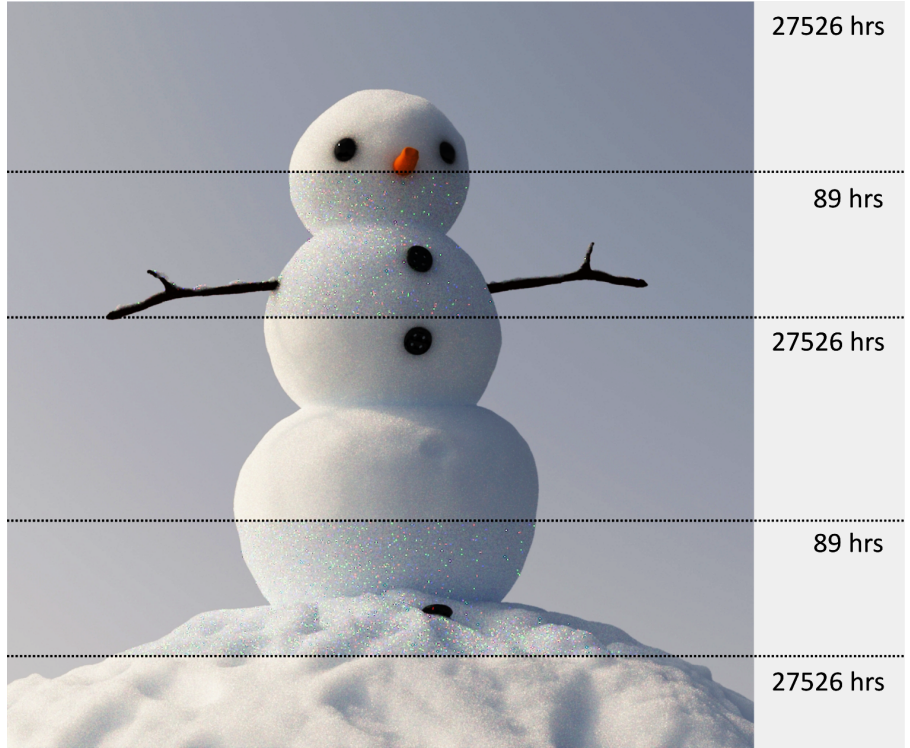


Spatially varying medium properties.

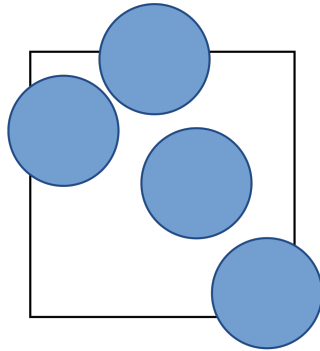


Thank You!

Backup

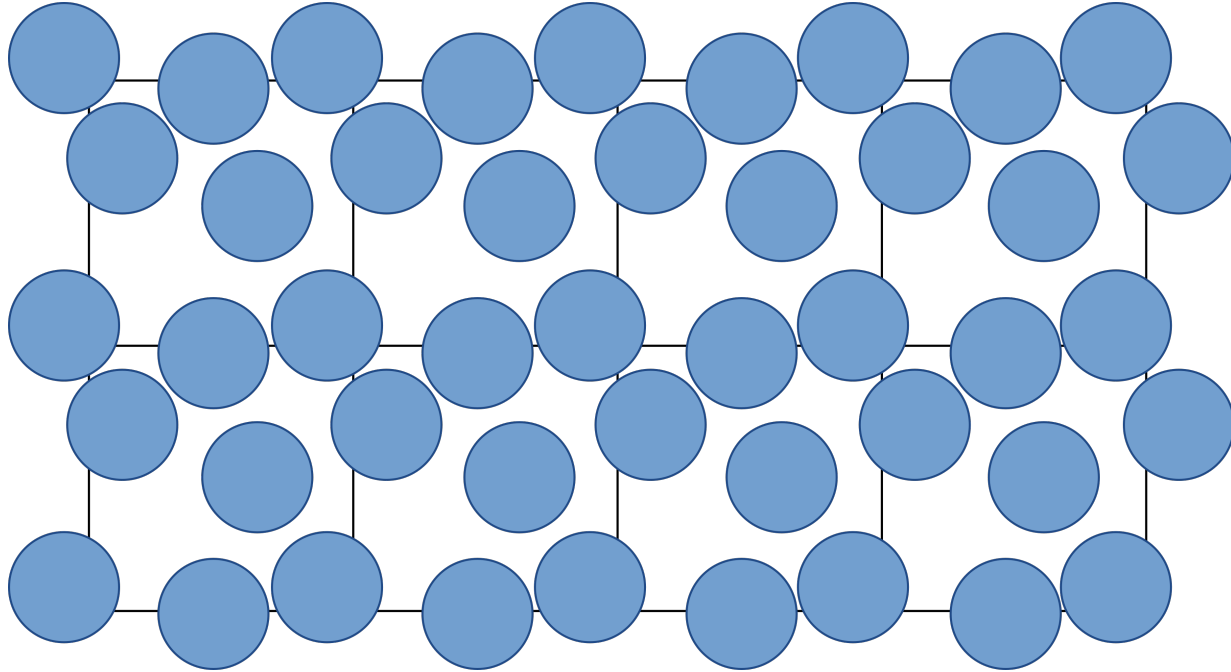


Modeling Granular Media Procedurally



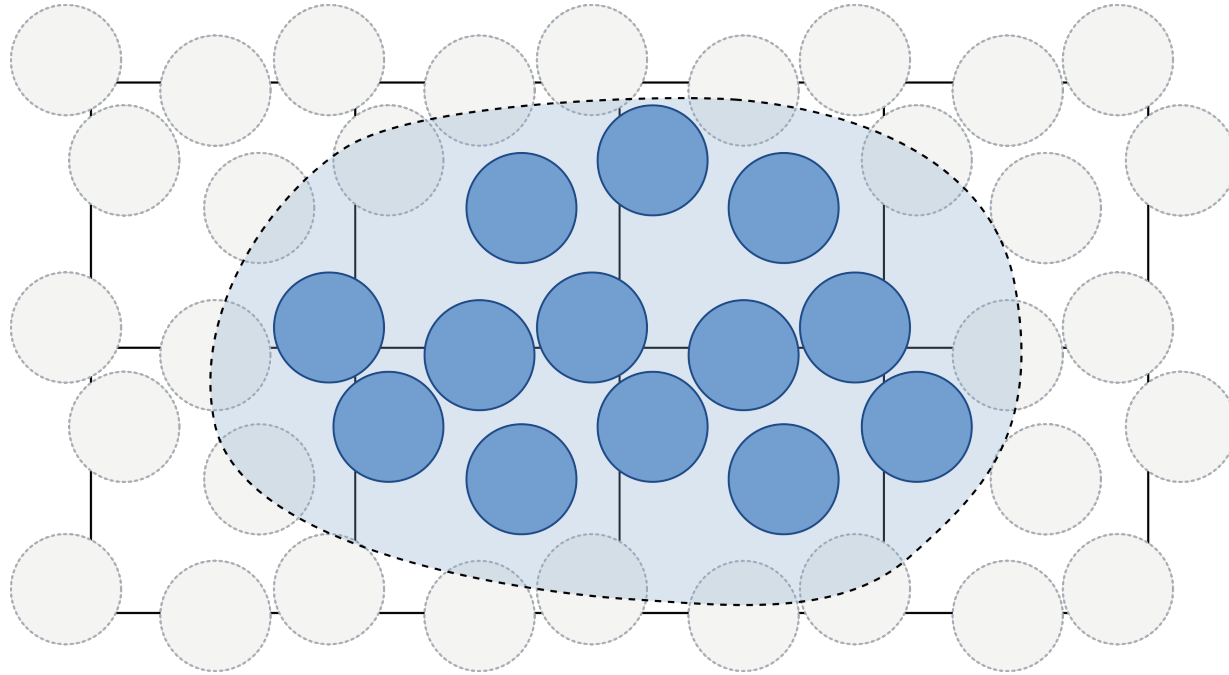
Box packed with spheres

Modeling Granular Media Procedurally



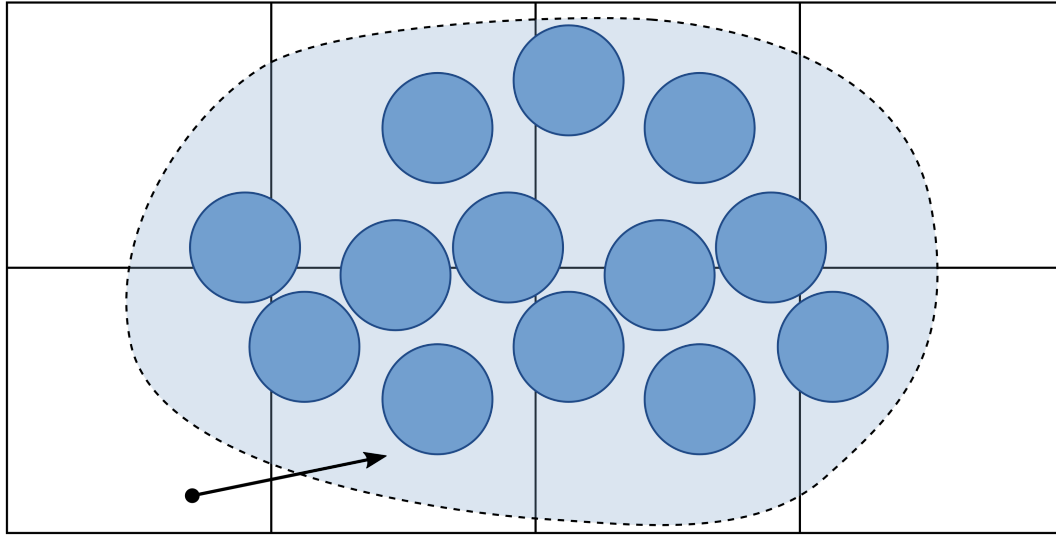
Infinite space of spheres.

Modeling Granular Media Procedurally



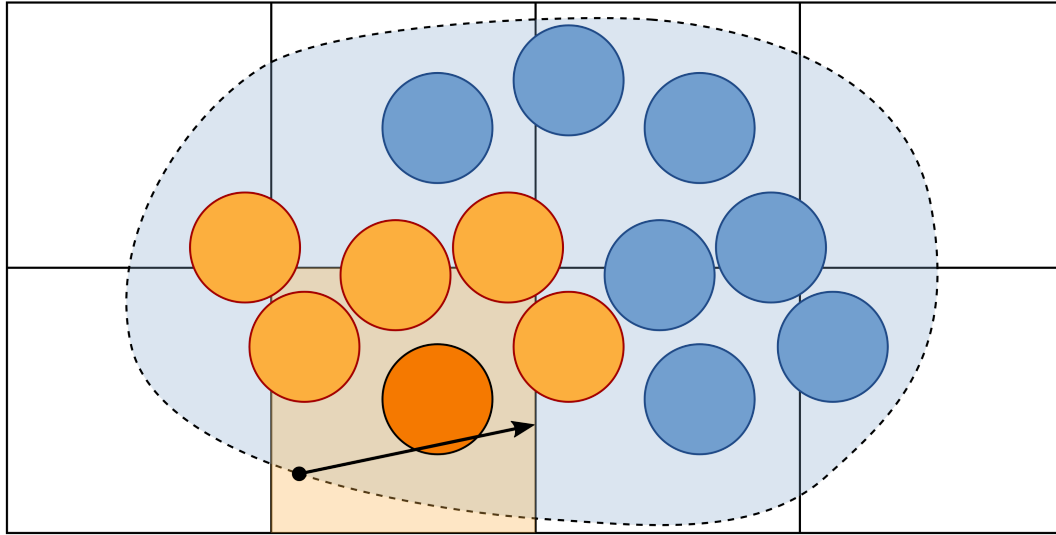
Cut out macro shape.

Modeling Granular Media Procedurally



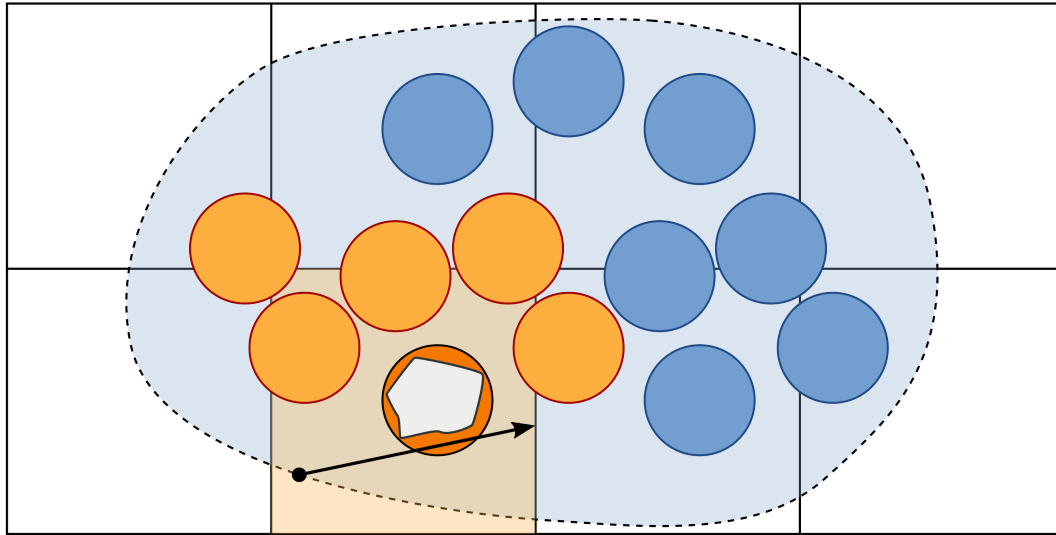
Raytracing: find entry point.

Modeling Granular Media Procedurally



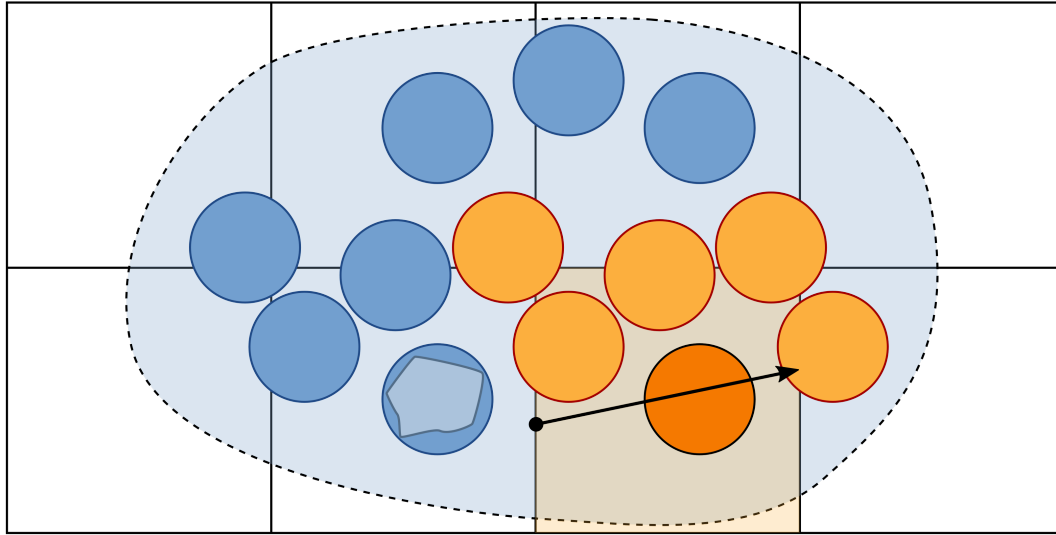
Find intersection with sphere in current cell.

Modeling Granular Media Procedurally



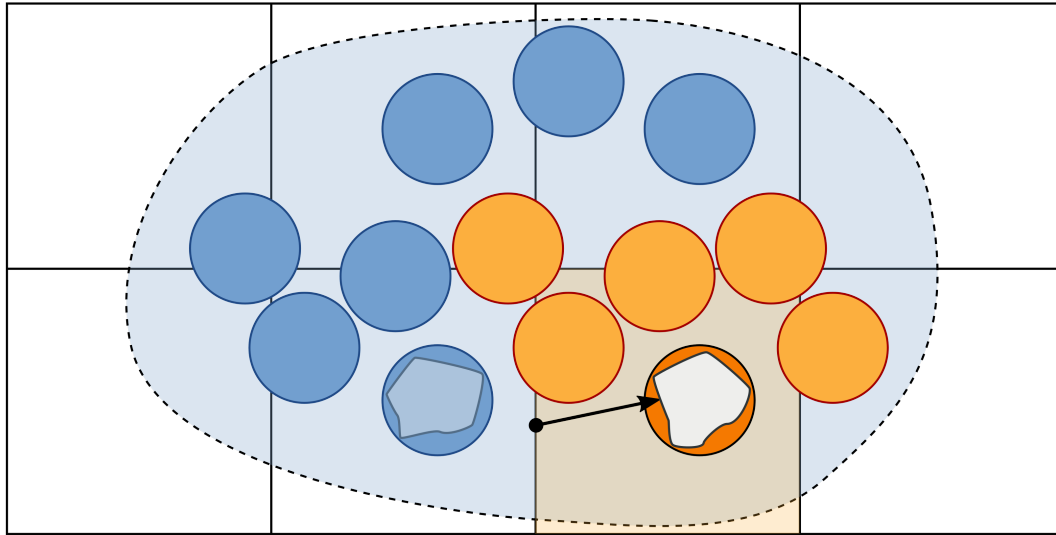
Randomized instantiation. Intersect grain mesh.

Modeling Granular Media Procedurally

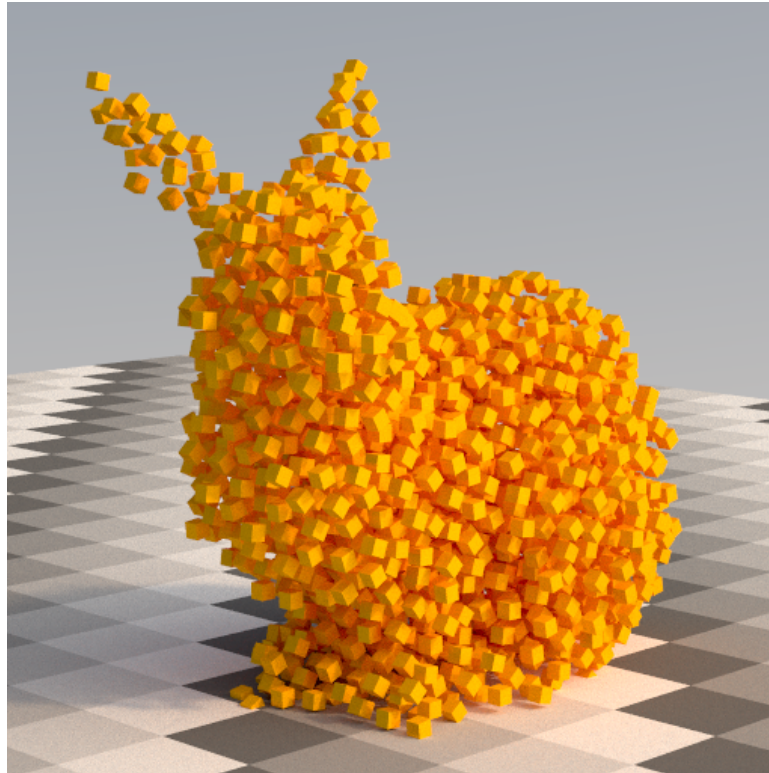


Find next grid cell and repeat.

Modeling Granular Media Procedurally



Modeling Granular Media Procedurally



Diffusion Approximation – Corner Bias



Path Tracing



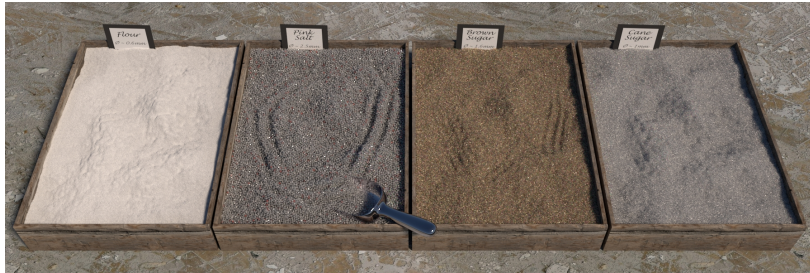
+ VPT



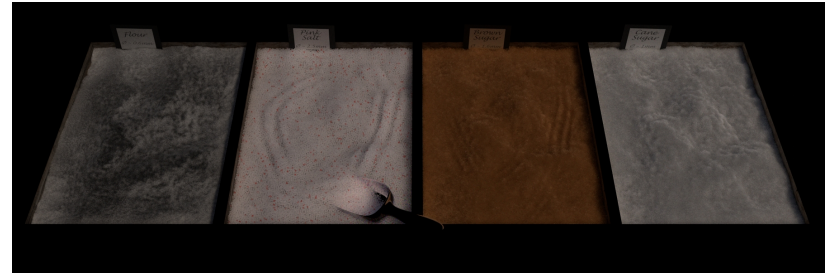
+ DA

Switching - Spices

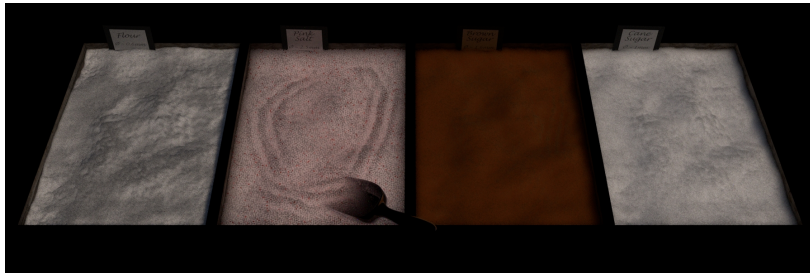
EPT



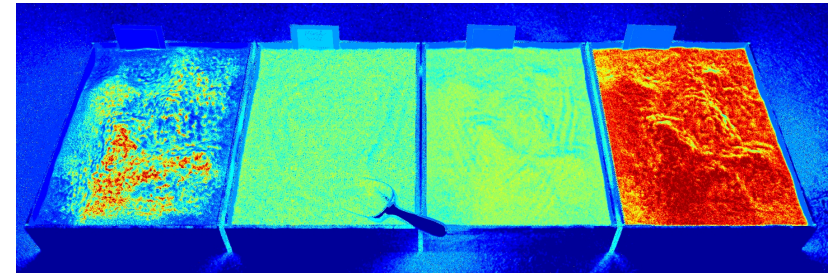
VPT



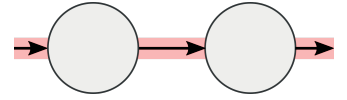
DA



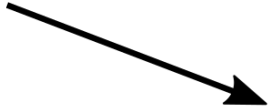
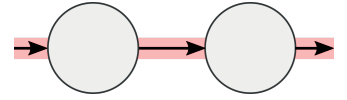
Switch Depth



Teleportation Path Tracing

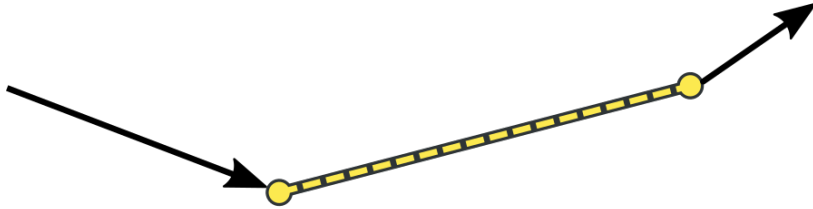
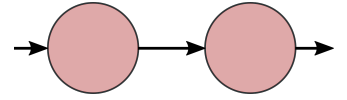


Teleportation Path Tracing



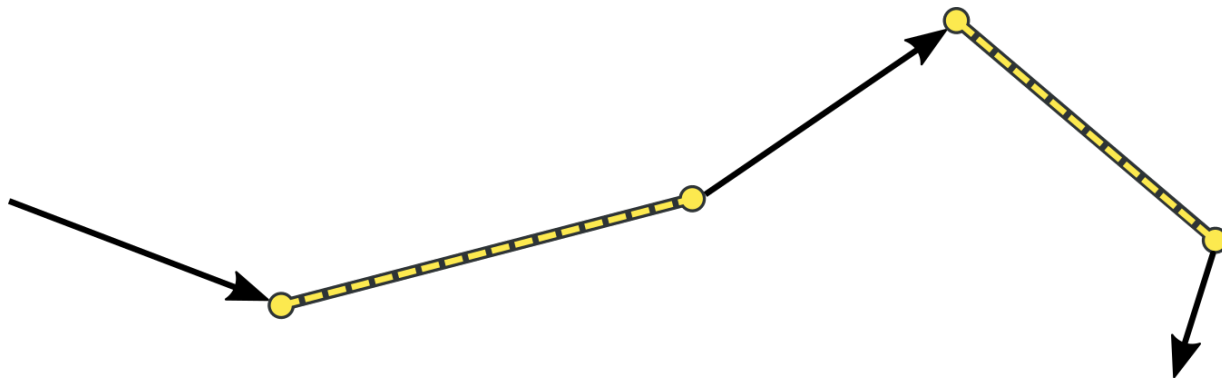
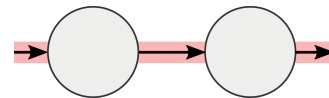
Sample free path

Teleportation Path Tracing



Sample TSDF

Teleportation Path Tracing



Sample TSDF