

Multiple-Scattering Microfacet BSDFs with the Smith Model

Eric Heitz

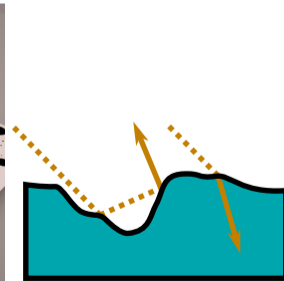
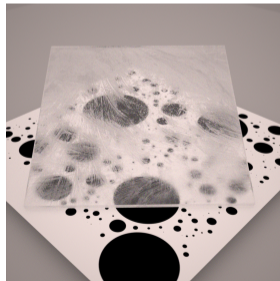
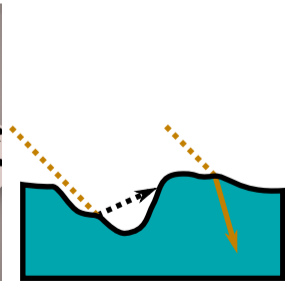
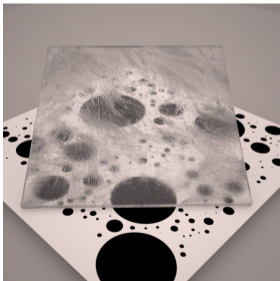
Johannes Hanika

Eugene d'Eon

Carsten Dachsbacher

Karlsruhe Institute of Technology

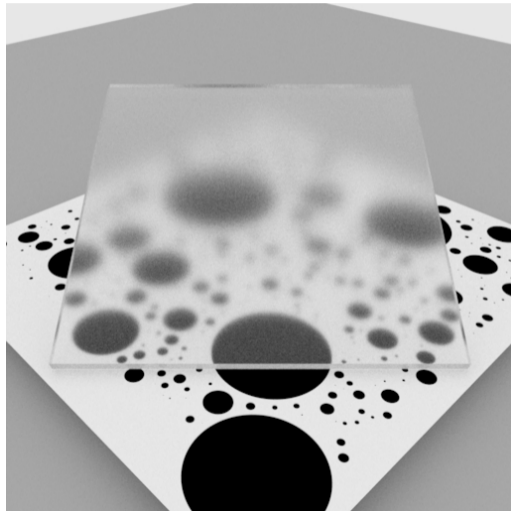
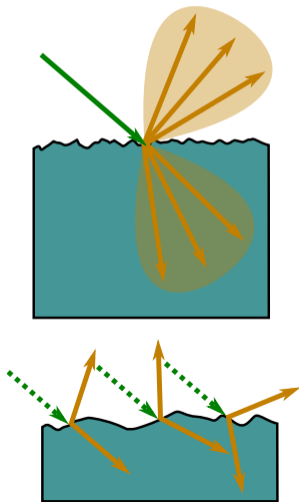
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Introduction

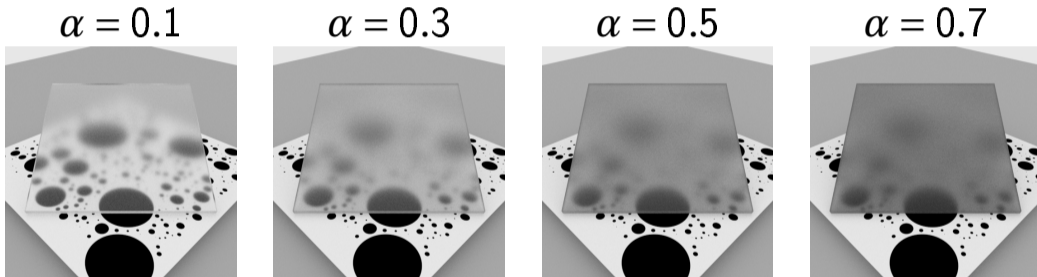
Introduction

Current Microfacet BSDFs



Introduction

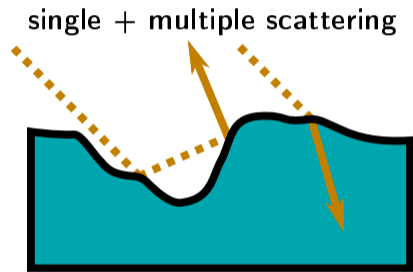
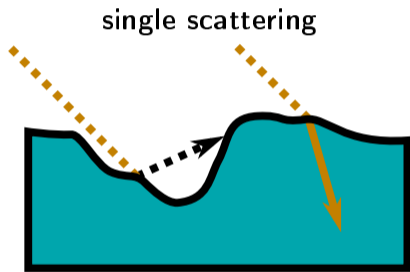
Current Microfacet BSDFs



There is an energy conservation issue with high roughness values.

Introduction

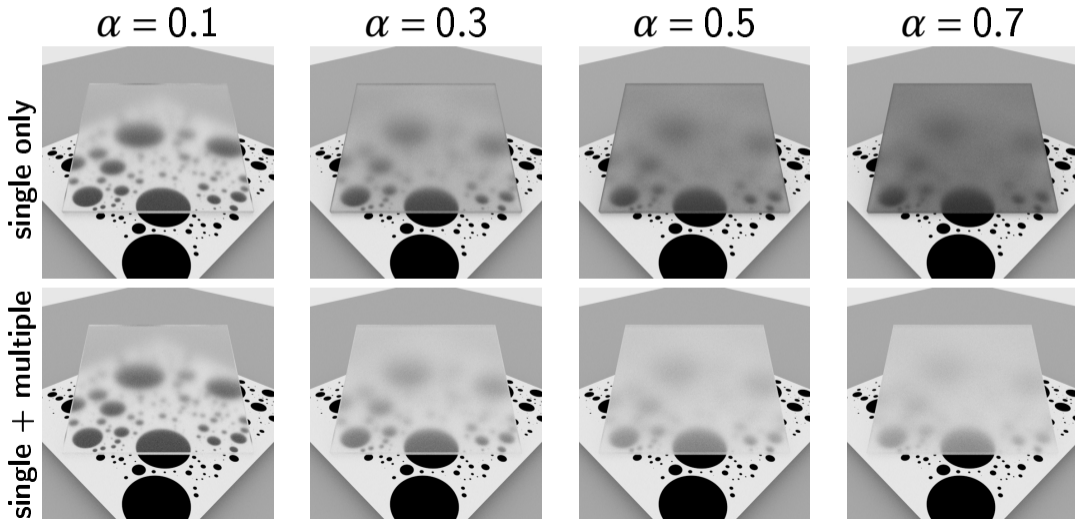
Current Microfacet BSDFs



This is because microfacet theory does not incorporate multiple scattering, i.e. rays bouncing multiple times are discarded, hence the visible energy loss

Introduction

Motivation for Multiple-Scattering BSDFs in Rendering



Introduction

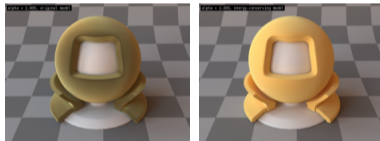
Previous Work on “Multiple-Scattering BSDFs” in Rendering

- *A Microfacet Based Coupled Specular-Matte BRDF Model with Importance Sampling*

Kelemen et al. 2001

- *A Comprehensive Framework for Rendering Layered Materials*

Jakob et al. 2014

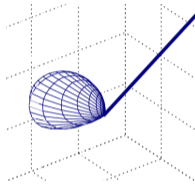
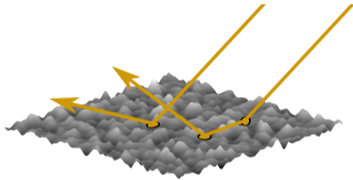


- ▶ Energy conservation enforced with arbitrary diffuse-like terms
- ▶ Independent of the microsurface model
- ▶ Does not predict multiple scattering for a given microsurface model

Introduction

Position of our Work

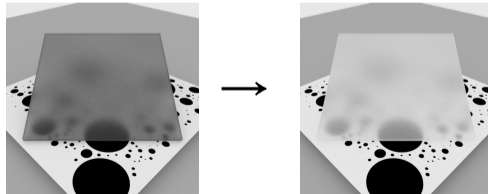
- ▶ We investigate multiple scattering emerging from a given microsurface model.



How does light scatter multiple times on this microsurface?

Use the model to make predictions and compare!

- ▶ With a meaningful model, energy conservation comes as a side effect.



Talk Outline

Why investigate multiple scattering with the Smith 1967 microsurface model?

Why now (2015)?

What are the main ideas of our multiple-scattering model?

How do we model the microsurface?

How do we validate our model?

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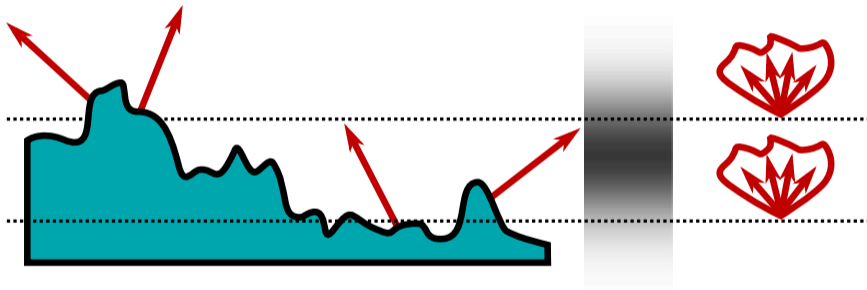
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Motivation for the Smith Microsurface Model

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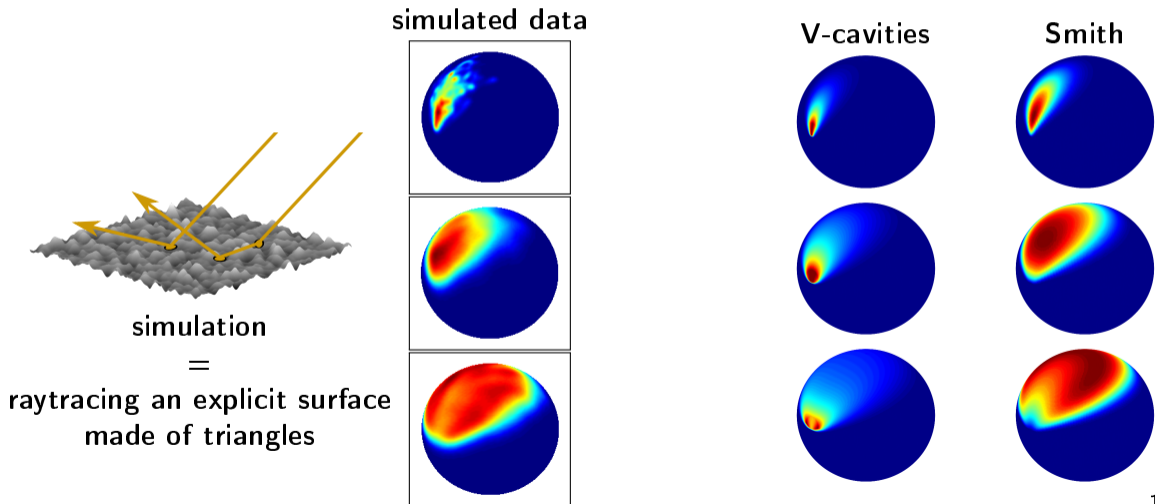
Simplicity



Main assumption: the microsurface has independent heights and slopes.

Motivation for the Smith Microsurface Model

Good Agreement with Simulated Data (Single Scattering)



Motivation for the Smith Microsurface Model

State of the Art in Computer Graphics

e.g.



Talk Outline

Why investigate multiple scattering with the Smith 1967 microsurface model?

- Simple assumptions, good predictions, computer graphics state of the art

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Motivation for the Smith Microsurface Model

Previous Work in Physics (see Christophe Bourlier's website)

- ▶ Simulations with explicit surfaces (triangles) instead of microfacet models, e.g.
The polarized emissivity of a wind-roughened sea surface: A Monte Carlo model
Henderson et al. 2003
- ▶ Models for the microsurface albedo/reflectivity, limited to 2 bounces, e.g.
Multiple scattering in the high-frequency limit with second-order shadowing function from 2D anisotropic rough dielectric surfaces: I. Theoretical study
Bourlier et al. 2004
Polarized infrared reflectivity of 2D sea surfaces with two surface reflections
Li et al. 2014
- ▶ No multiple-scattering BSDFs with the Smith microsurface model!

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Why investigate multiple scattering with the Smith 1967 microsurface model?

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- Smith multiple-scattering BSDFs not available yet, even in physics

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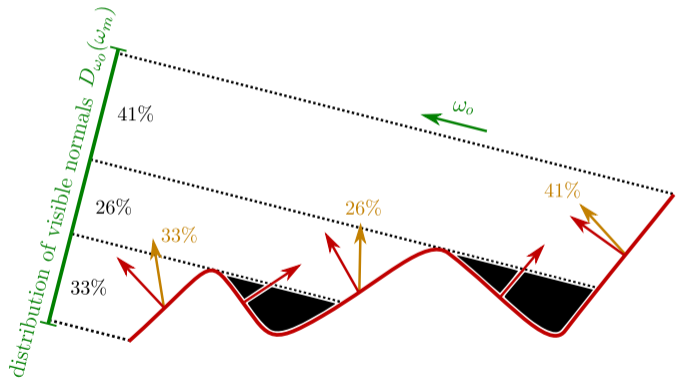
How do we model the microsurface?

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Recent Advances with the Smith Model

Recent Advances with the Smith Model

New Insights into Smith Masking-Shadowing (2014)



masking function

=

conservation of
the projected area

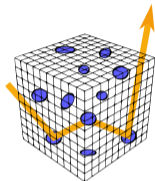
- *Understanding the Masking-Shadowing Function in Microfacet-Based BRDFs*

Heitz 2014

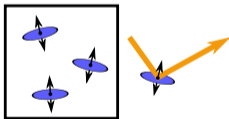
Recent Advances with the Smith Model

Microflake Theory (2010, 2015)

voxel grid



microflake
distributions



- *A radiative transfer framework for rendering materials with anisotropic structure*

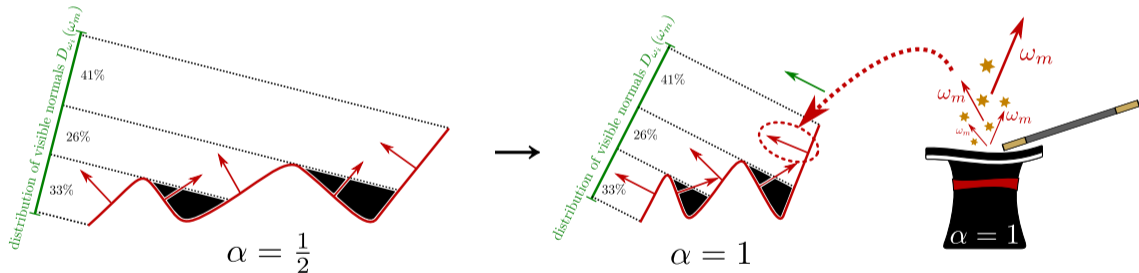
Jakob et al. 2010

- *The SGGX Microflake Distribution*

Heitz et al. 2015

Recent Advances with the Smith Model

New Importance Sampling Technique for Smith BSDFs (2014)



- Importance Sampling Microfacet-Based BSDFs using the Distribution of Visible Normals

Heitz and d'Eon 2014

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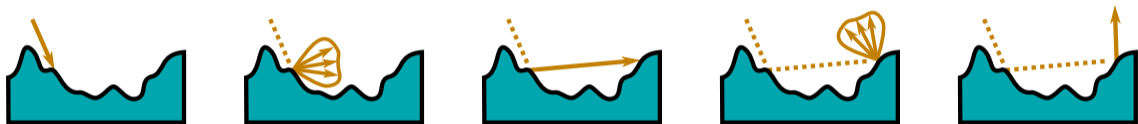
How do we model the microsurface?

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Insights

Insights

Multiple Scattering on the Microsurface

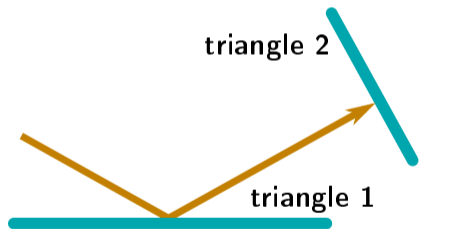


Defining and computing multiple scattering on microsurfaces is difficult.

Insights

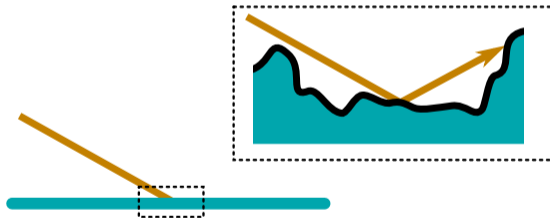
What is the Problem?

intersection outside the microsurface



computed by the path tracer ✓

intersection inside the microsurface

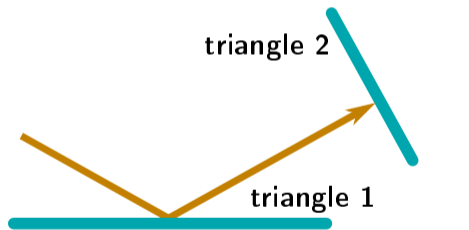


we don't know how to compute ✗

Insights

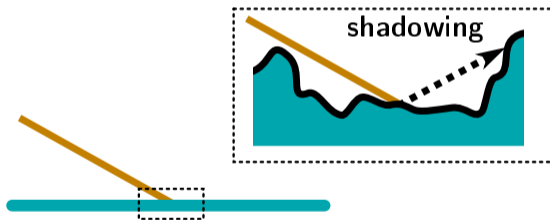
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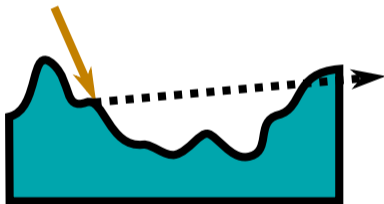


shadowing function = set to 0

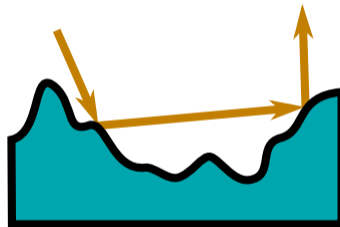
Insights

What is the Problem?

shadowing



multiple scattering

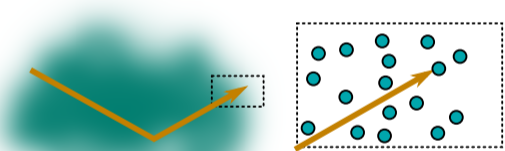


shadowing function = set multiple scattering to 0

Insights

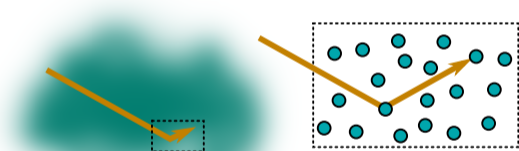
What about Microflake Volumes?

long intersections inside the volume



path tracer ✓

short intersections inside the volume



path tracer ✓

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- **Insight: multiple scattering in microflake volumes is computed by the path tracer**

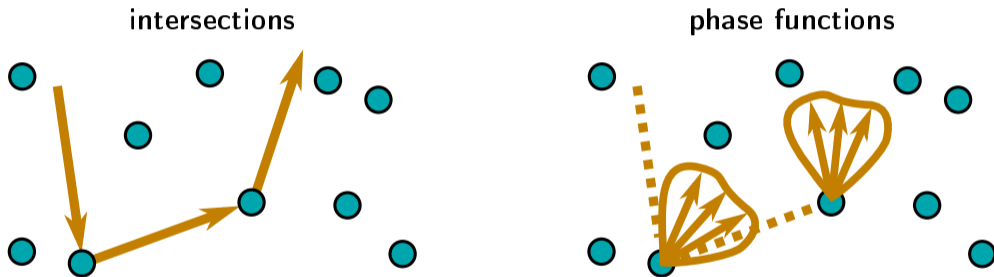
How do we model the microsurface?

How do we validate our model?

Overview of our Model

Overview of our Model

How do Microflake Volumes Work?

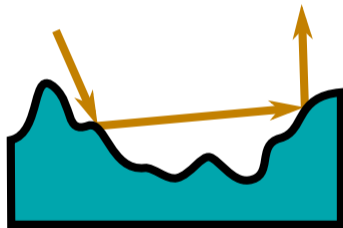


The path tracer is fed inside microflake volumes with intersections and phase functions.

Overview of our Model

Extension to Microsurfaces

intersections



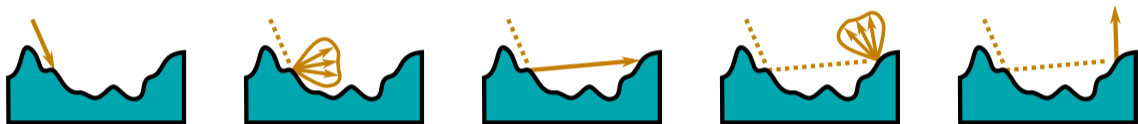
phase functions



We derive a microsurface scattering model with intersections and phase functions.

Overview of our Model

Definition of the Multiple-Scattering BSDF

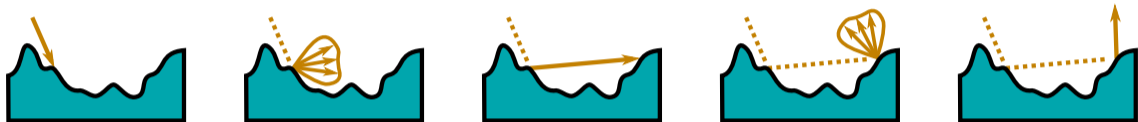


1 path

$$\text{multiple-scattering BSDF} = \mathbb{E}[\text{paths}]$$

Overview of our Model

BSDF Importance Sampling



generate a path and return when it leaves the microsurface

BSDF Unbiased Stochastic Evaluation



generate a path with next event estimation at each intersection

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- Insight: multiple scattering in microflake volumes is computed by the path tracer
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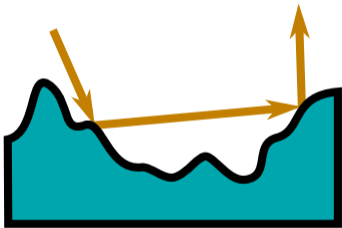
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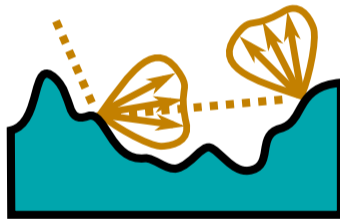
How do we validate our model?

Our Smith Microsurface Model

intersections

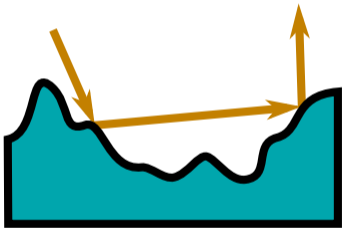


phase functions



Microsurface Intersections with the Smith Model

intersections

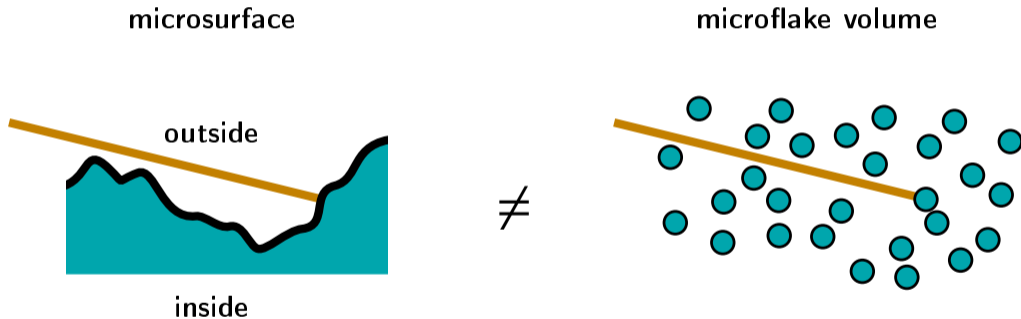


phase functions



Microsurface Intersections with the Smith Model

Differences Between Microsurfaces and Microflake Volumes

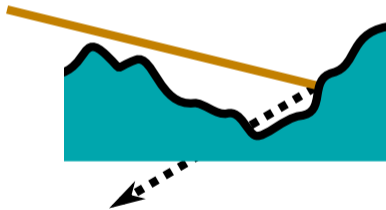


A microsurface is a sharp interface between “outside” and “inside”.

Microsurface Intersections with the Smith Model

Differences Between Microsurfaces and Microflake Volumes

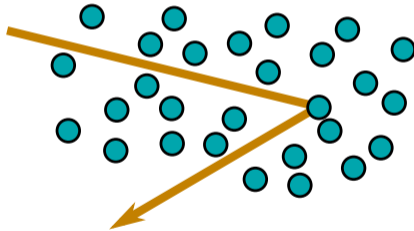
microsurface



cannot go through

\neq

microflake volume



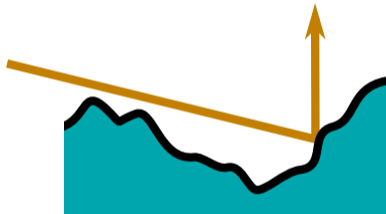
can go through

Rays going downwards have to intersect the microsurface.

Microsurface Intersections with the Smith Model

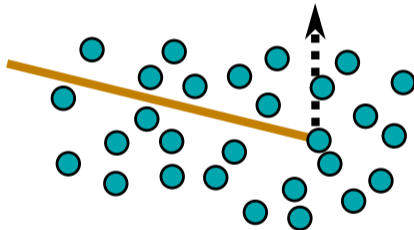
Differences Between Microsurfaces and Microflake Volumes

microsurface



no upper intersections

microflake volume



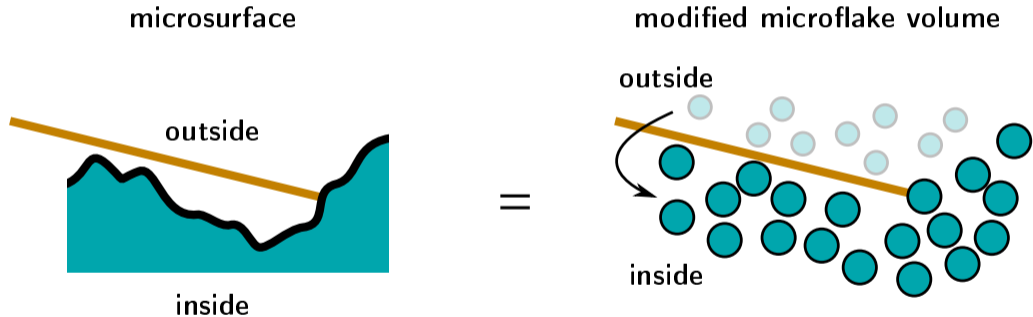
upper intersections possible

≠

Rays going upwards cannot intersect the microsurface.

Microsurface Intersections with the Smith Model

Turning a Microflake Volume into a Microsurface

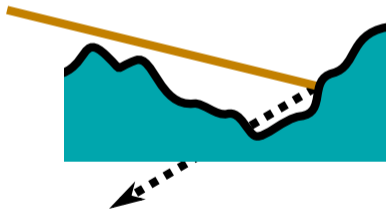


In the Smith model, the knowledge introduced by the ray creates the sharp interface.

Microsurface Intersections with the Smith Model

Turning a Microflake Volume into a Microsurface

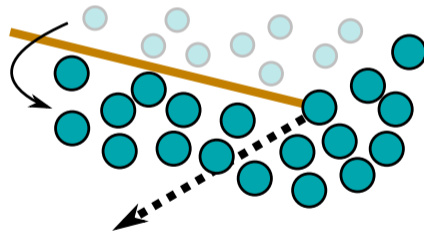
microsurface



cannot go through

=

modified microflake volume

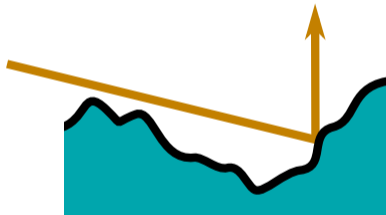


cannot go through

Microsurface Intersections with the Smith Model

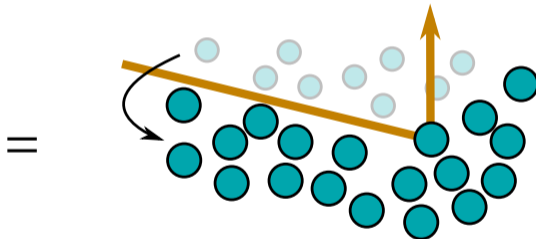
Turning a Microflake Volume into a Microsurface

microsurface



no upper intersections

modified microflake volume



no upper intersections

Microsurface Intersections with the Smith Model

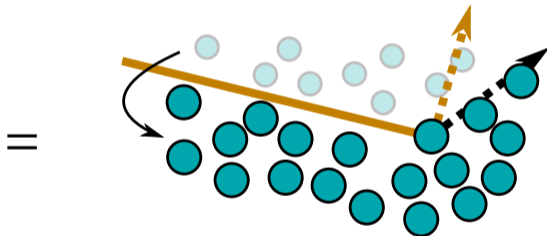
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microsurface



probability of next intersection =
Smith shadowing probability

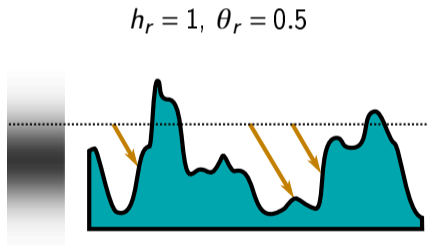
modified microflake volume



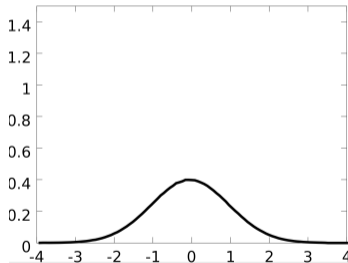
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Microsurface Intersections with the Smith Model

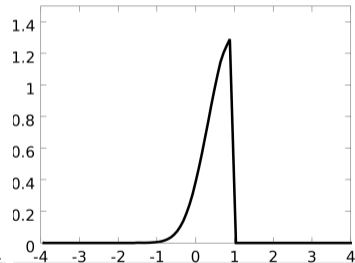
Sampling Intersections on the Microsurface



distribution
of heights



distribution
of visible heights



tracing rays on the microsurface = sampling the distribution of visible heights

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- Multiple-scattering BSDF = expectation of paths traced on the microsurface

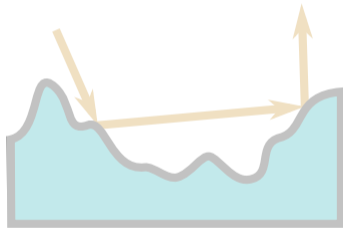
How do we model the microsurface?

- Intersection model = modified microflake volume

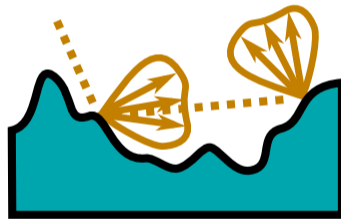
How do we validate our model?

Microsurface Phase Functions with the Smith Model

intersections



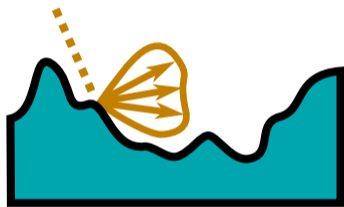
phase functions



Microsurface Phase Functions with the Smith Model

Application to Microsurfaces

phase function

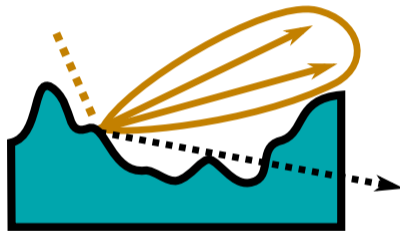


before leaving the microsurface

local scattering

masking only

single-scattering BSDF



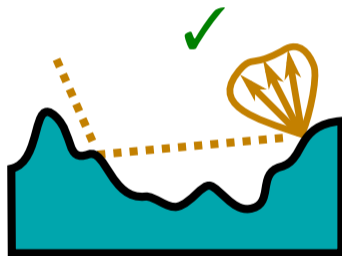
after leaving the microsurface

global scattering

masking and shadowing

Microsurface Phase Functions with the Smith Model

The Phase Function



Now we can define the phase function for any incident direction.

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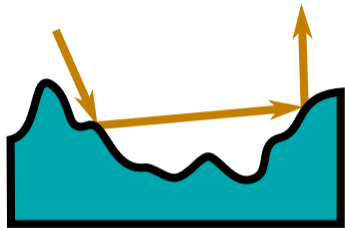
How do we model the microsurface?

- Intersection model = modified microflake volume
- Phase function = BSDF without shadowing extended to $[0, \pi)$

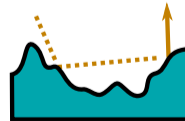
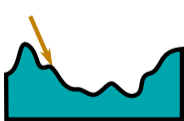
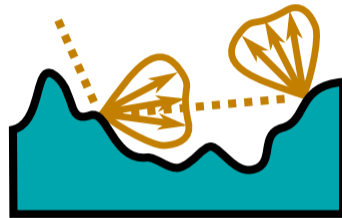
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Our Smith Microsurface Model

intersections



phase function



$$\text{multiple-scattering BSDF} = \mathbb{E}[\text{paths}]$$

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- Smith multiple-scattering BSDFs not available yet, even in physics

Why now (2015)?

- New insights(2014), microflake theory(2010,2015), new importance sampling(2014)

What are the main ideas of our multiple-scattering model?

- Insight: multiple scattering in microflake volumes is computed by the path tracer
- Multiple-scattering BSDF = expectation of paths traced on the microsurface

How do we model the microsurface?

- Intersection model = modified microflake volume
- Phase function = BSDF without shadowing extended to $[0, \pi)$

How do we validate our model?

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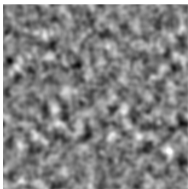
How do we validate our model?

- **We verified all the mathematical properties of the model**

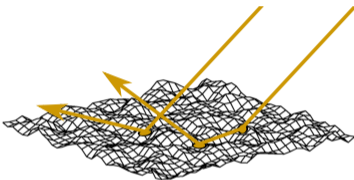
Validation: Comparison against Simulated Data

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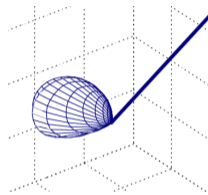
Beckmann surface
instance



raytracing



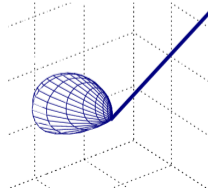
simulated data



$$\text{BSDF} = \mathbb{E}[\text{paths}]$$

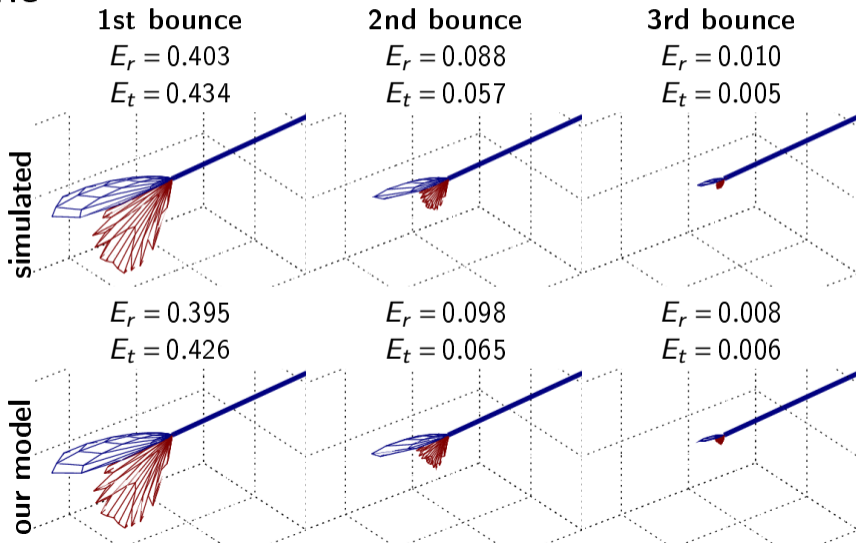


model's prediction



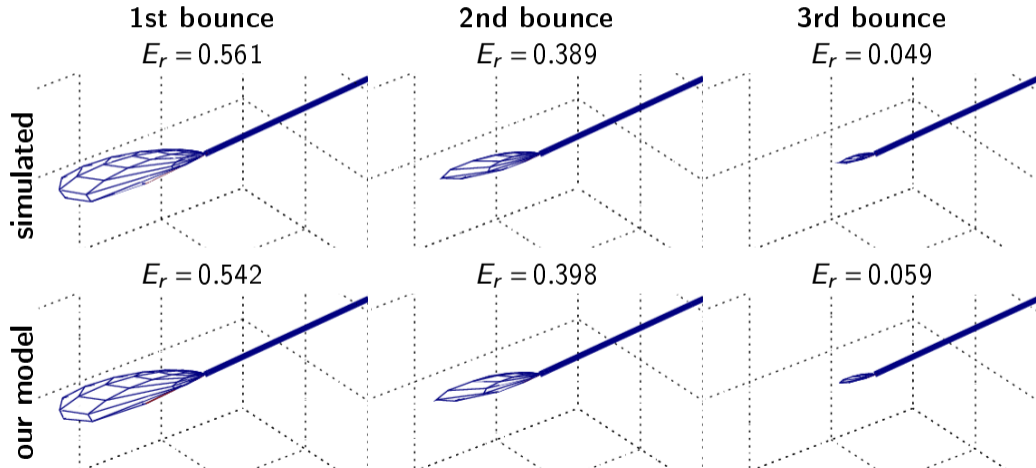
Validation: Comparison against Simulated Data

Dielectric



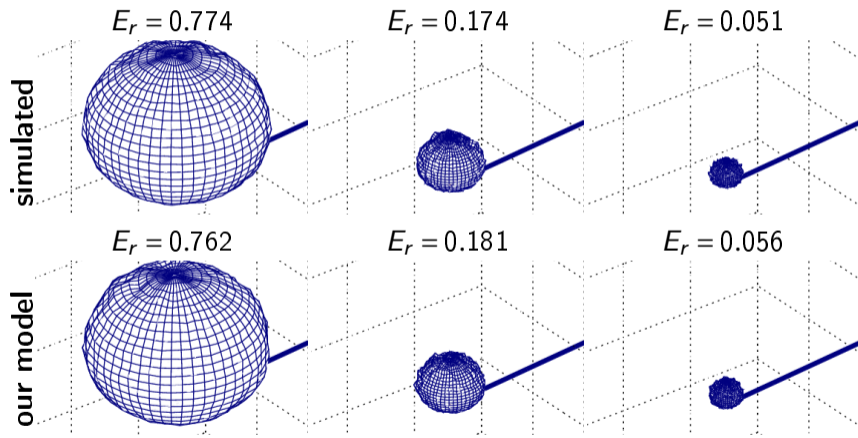
Validation: Comparison against Simulated Data

Conductor



Validation: Comparison against Simulated Data

Diffuse



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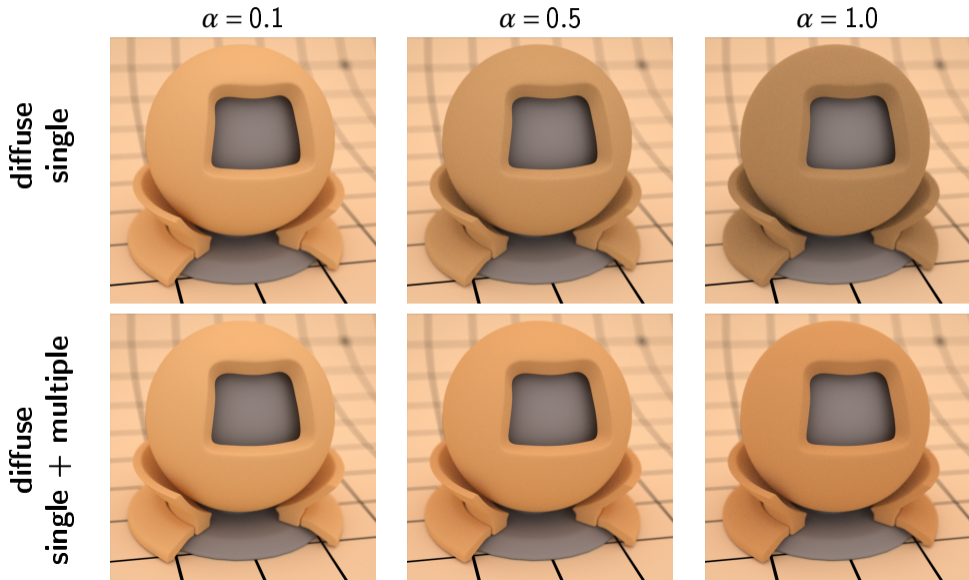
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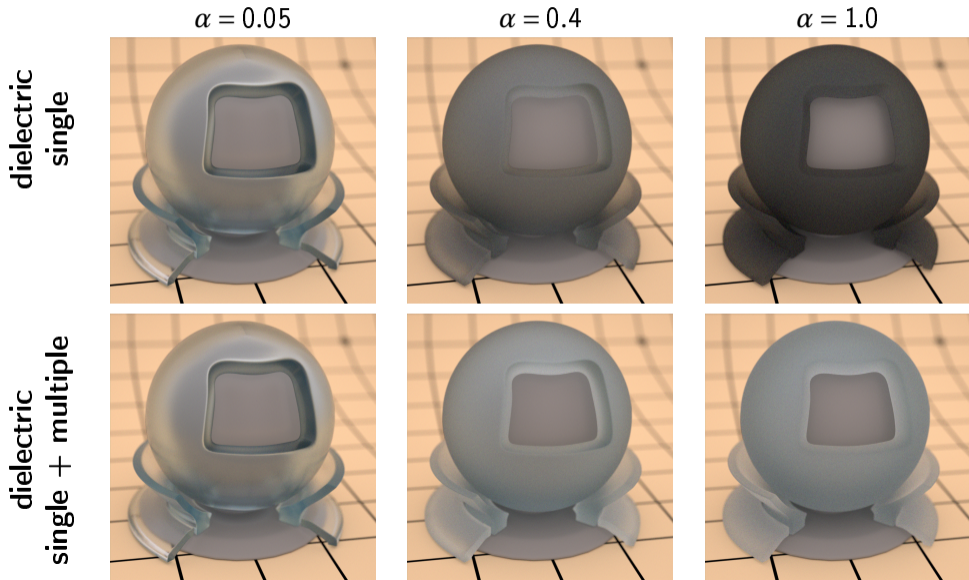
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Results

Results



Results



Results

single scattering



single + multiple scattering



87% overhead

Thank you for your attention :-)