Lecture 15:

Advanced Topics on Appearance Modeling

Computer Graphics and Imaging
UC Berkeley CS184/284A

Overview

Advanced Appearance Modeling

- UC Berkeley work
  - Detailed / glinty material (non-statistical BRDF)
  - Hair / fur (BCSDF)
- Others
  - Participating media
  - Translucent material (BSSRDF)
  - Cloth
  - Granular material
  - Procedural appearance

Detailed / Glinty Material

Motivation

- Not looking realistic, why?

[Car rendered in NVIDIA Iray]

[Mouse rendered in Autodesk 3DS Max]

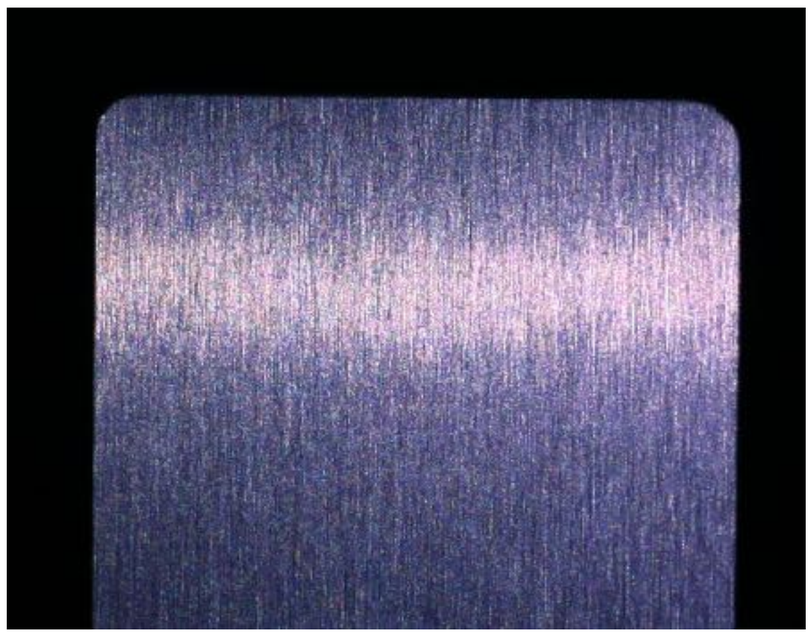
Real world is more complicated

[Real photograph of a car]

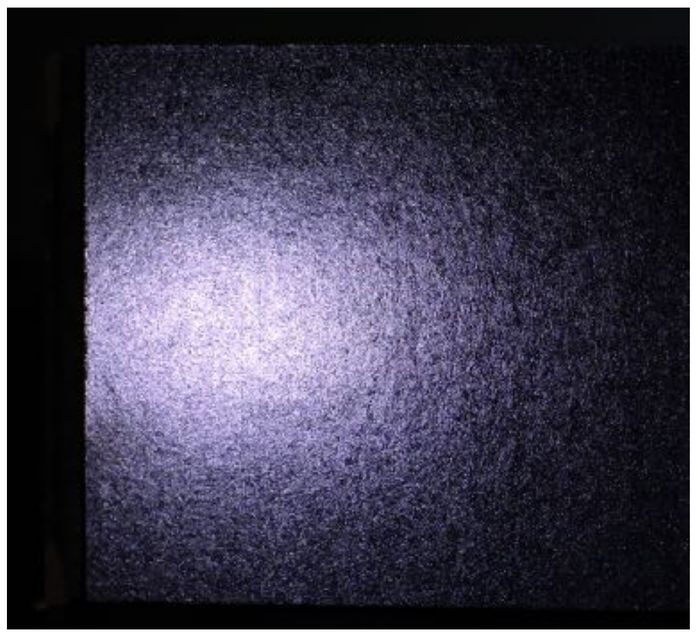
[Real video of a mouse]

More real world photos

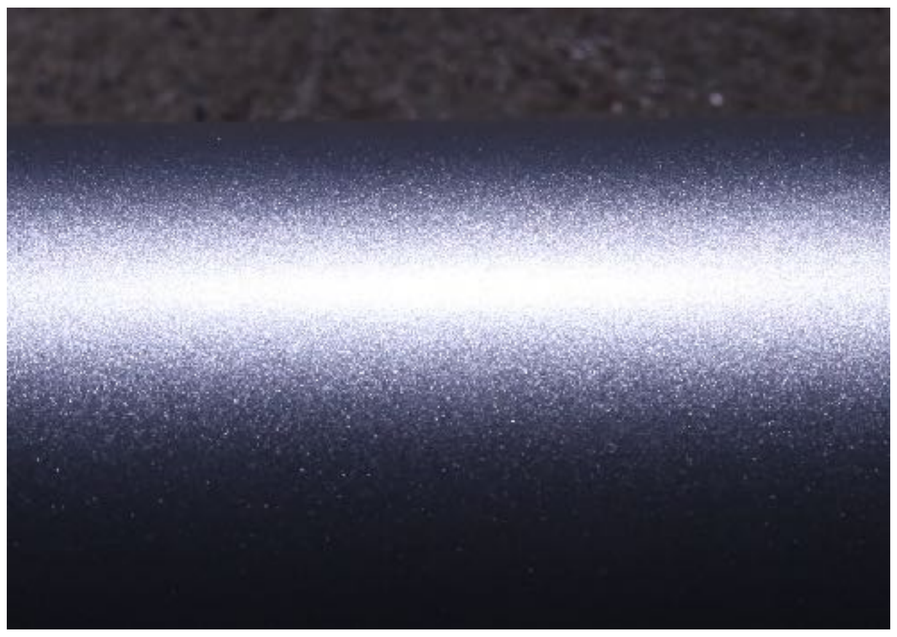
- No smooth appearance!



brushed metal



laminate



powder coating

Why details?

Microfacet model

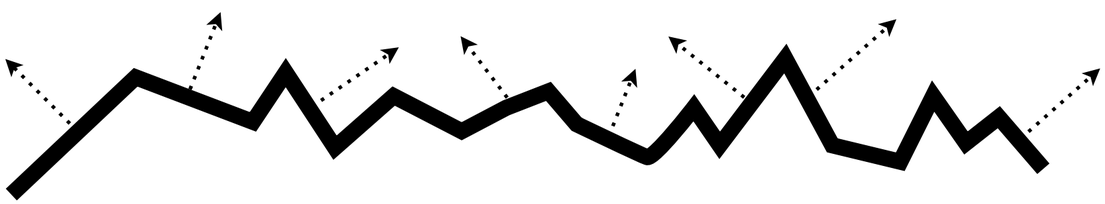
Why details?

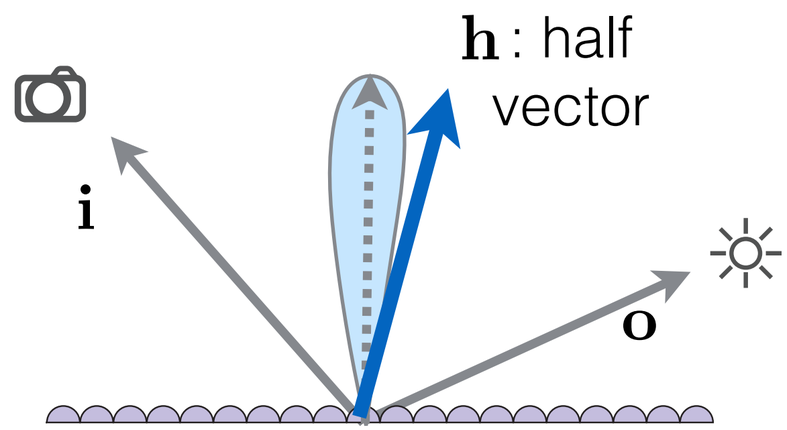
[Yan et al. 2014, 2016]

Why details?

[Yan et al. 2014, 2016]

Recap: Microfacet BRDF



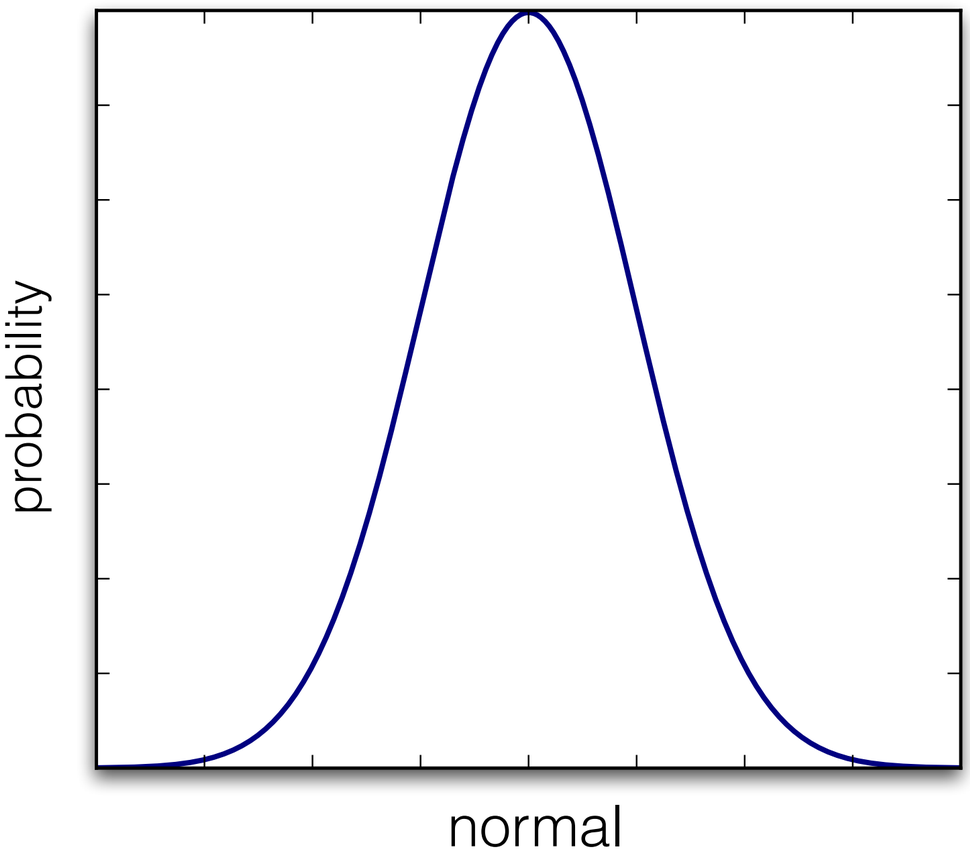


Surface = Specular microfacets + statistical normals

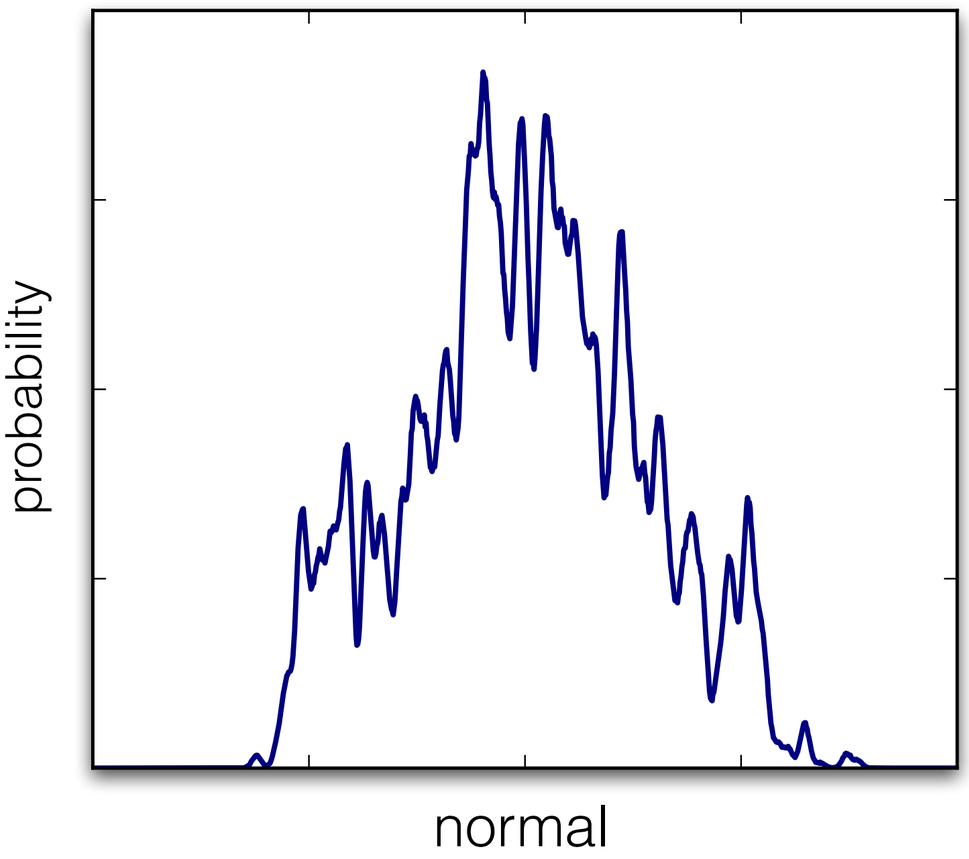
$$f(\mathbf{i},\mathbf{o}) = \frac{\mathbf{F}(\mathbf{i},\mathbf{h})\mathbf{G}(\mathbf{i},\mathbf{o},\mathbf{h})\mathbf{D}(\mathbf{h})}{4(\mathbf{n},\mathbf{i})(\mathbf{n},\mathbf{o})}$$

NDF: Normal Distribution Function

Statistical NDF vs. Actual NDF

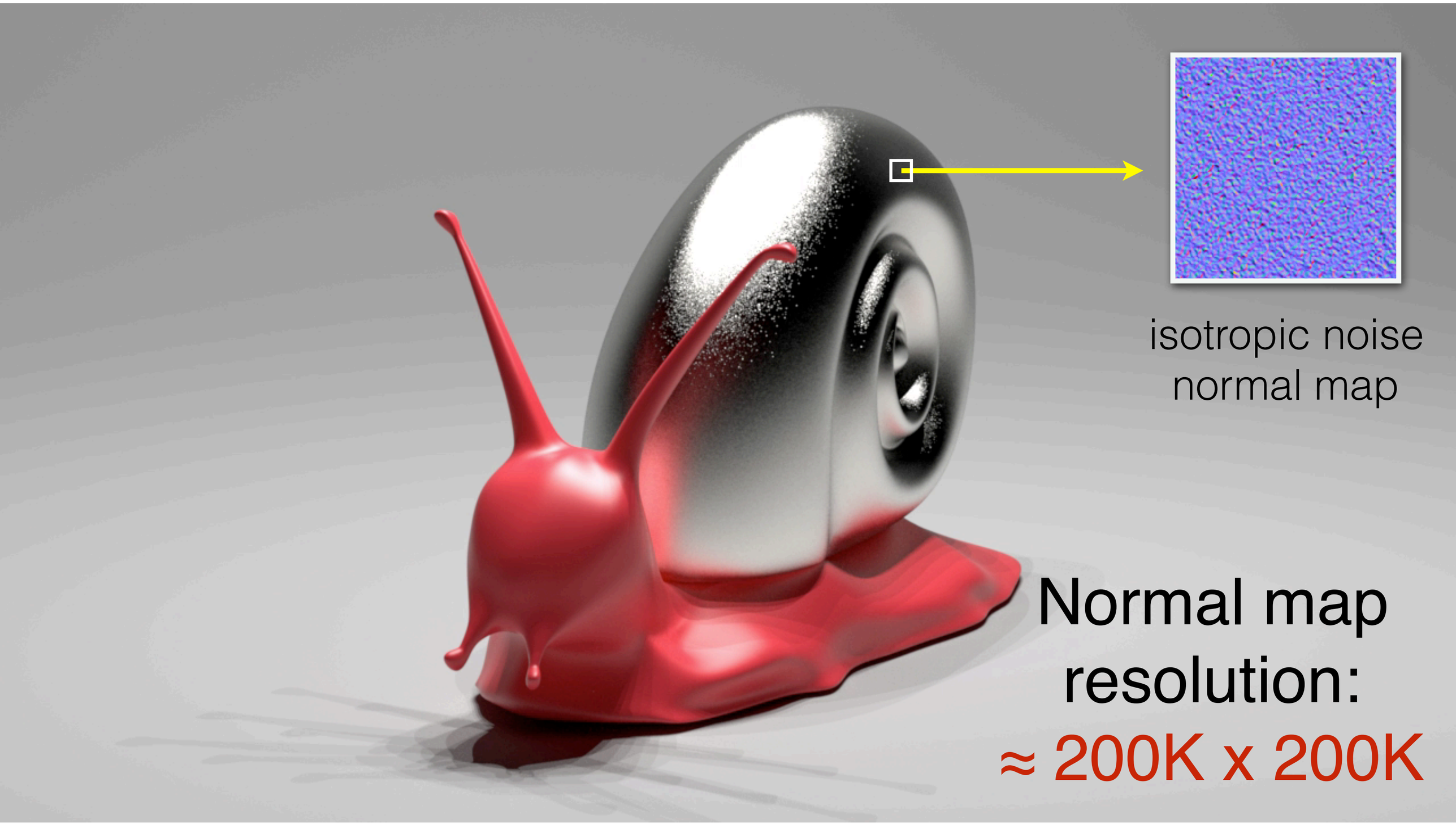


What we have
(microfacet — statistical)

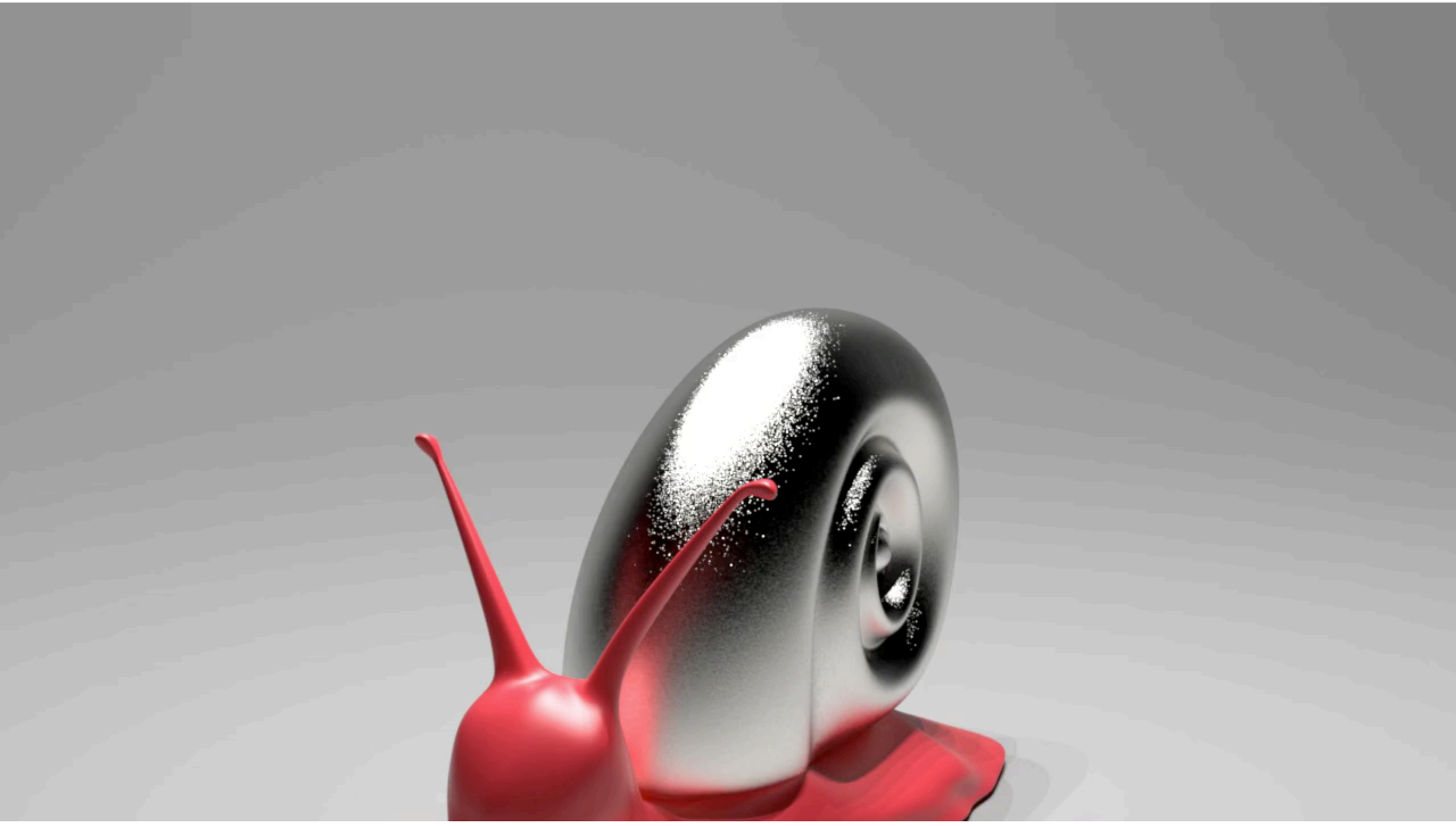


What we want

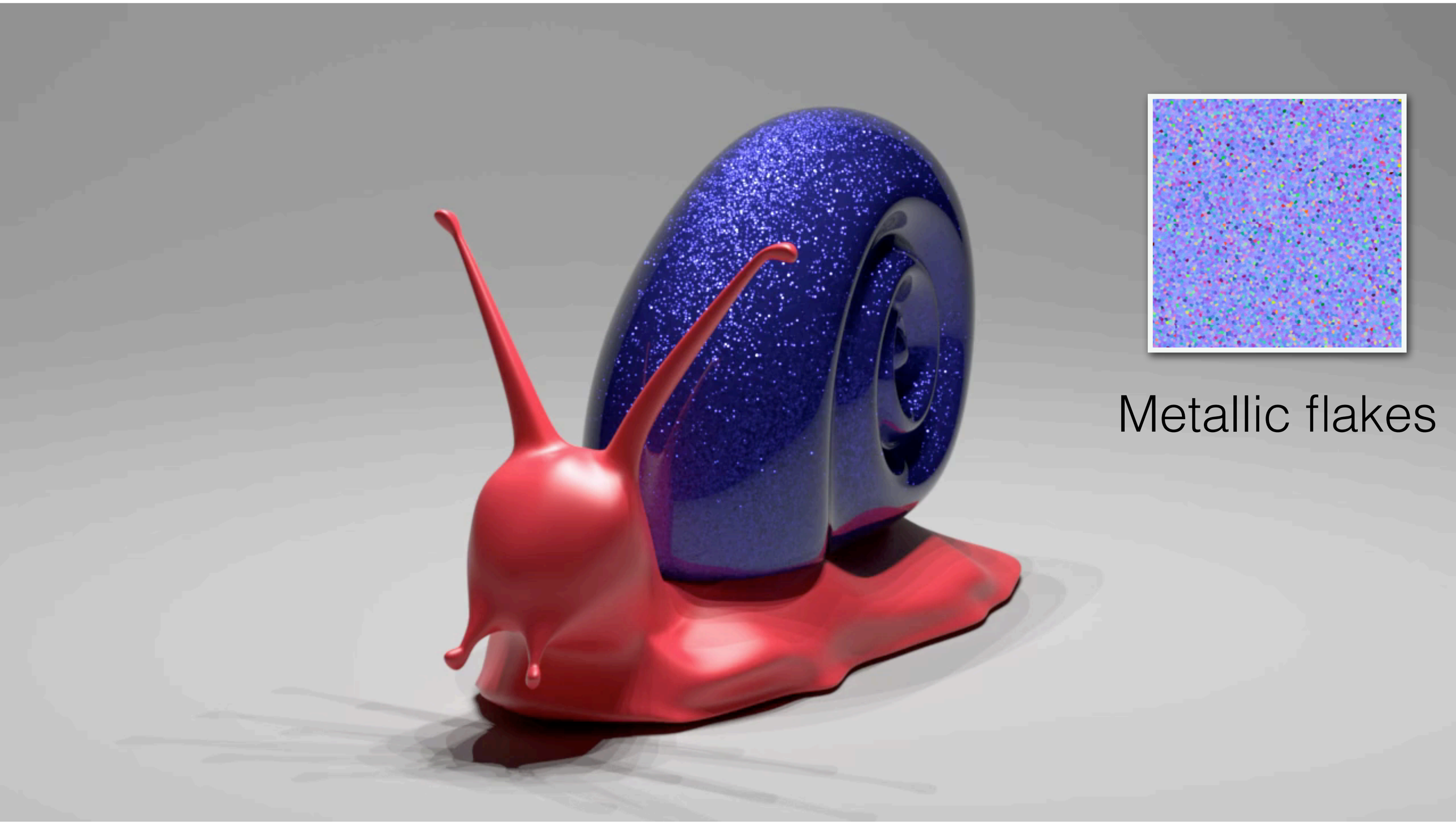
Define details



Define details

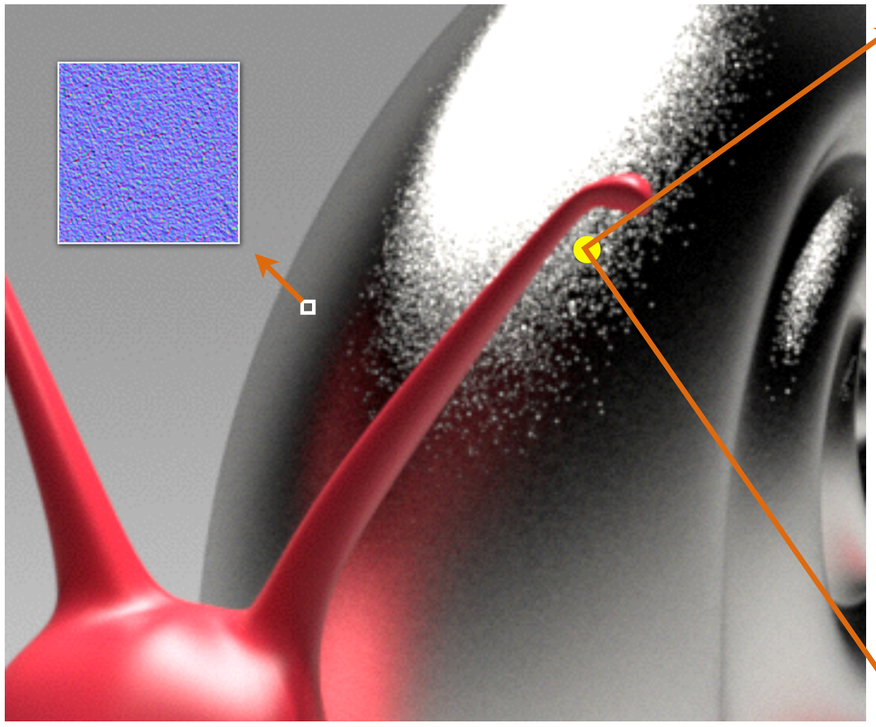


Different details



Metallic flakes

Rendering? Too difficult!

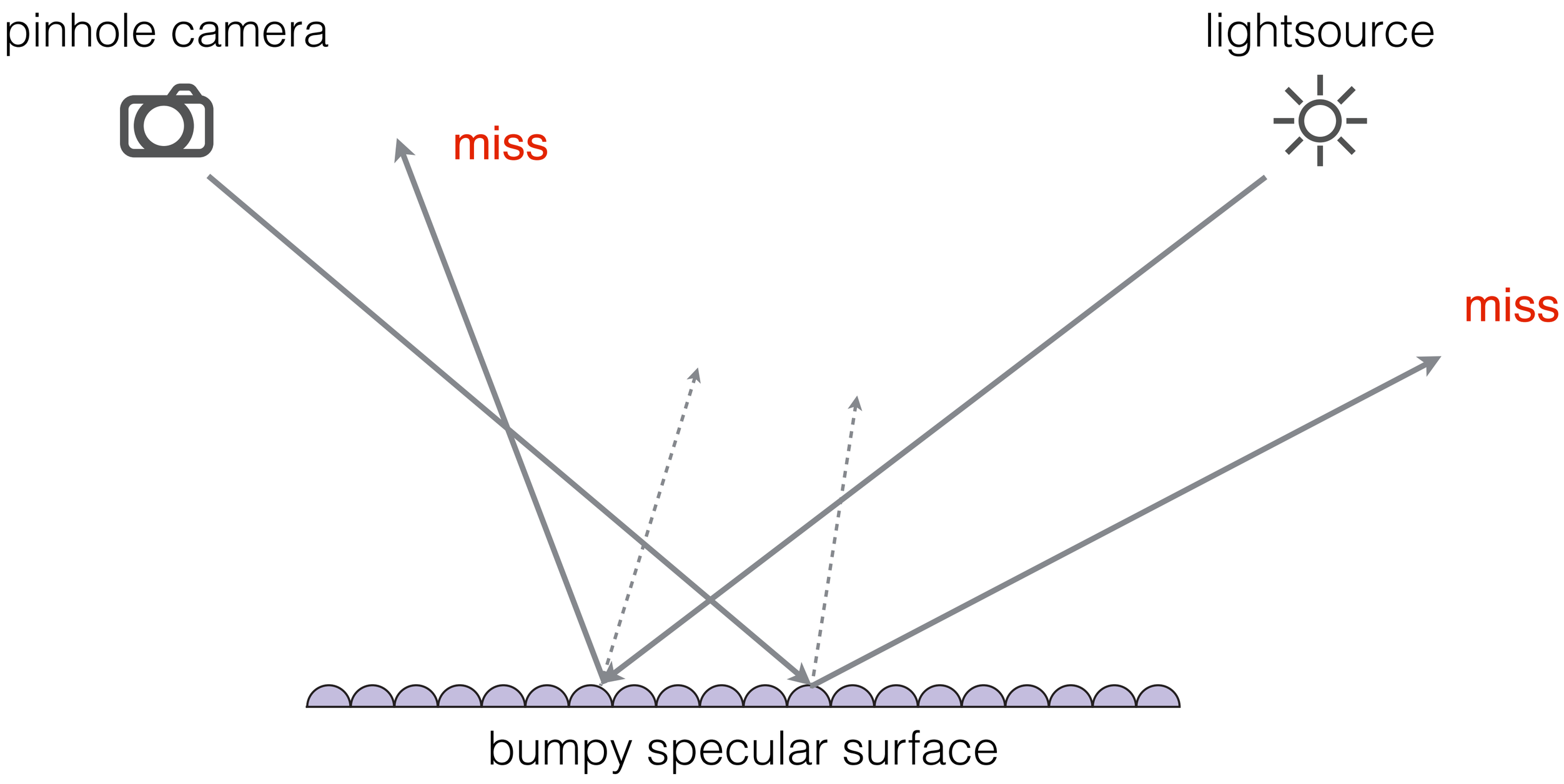


our result

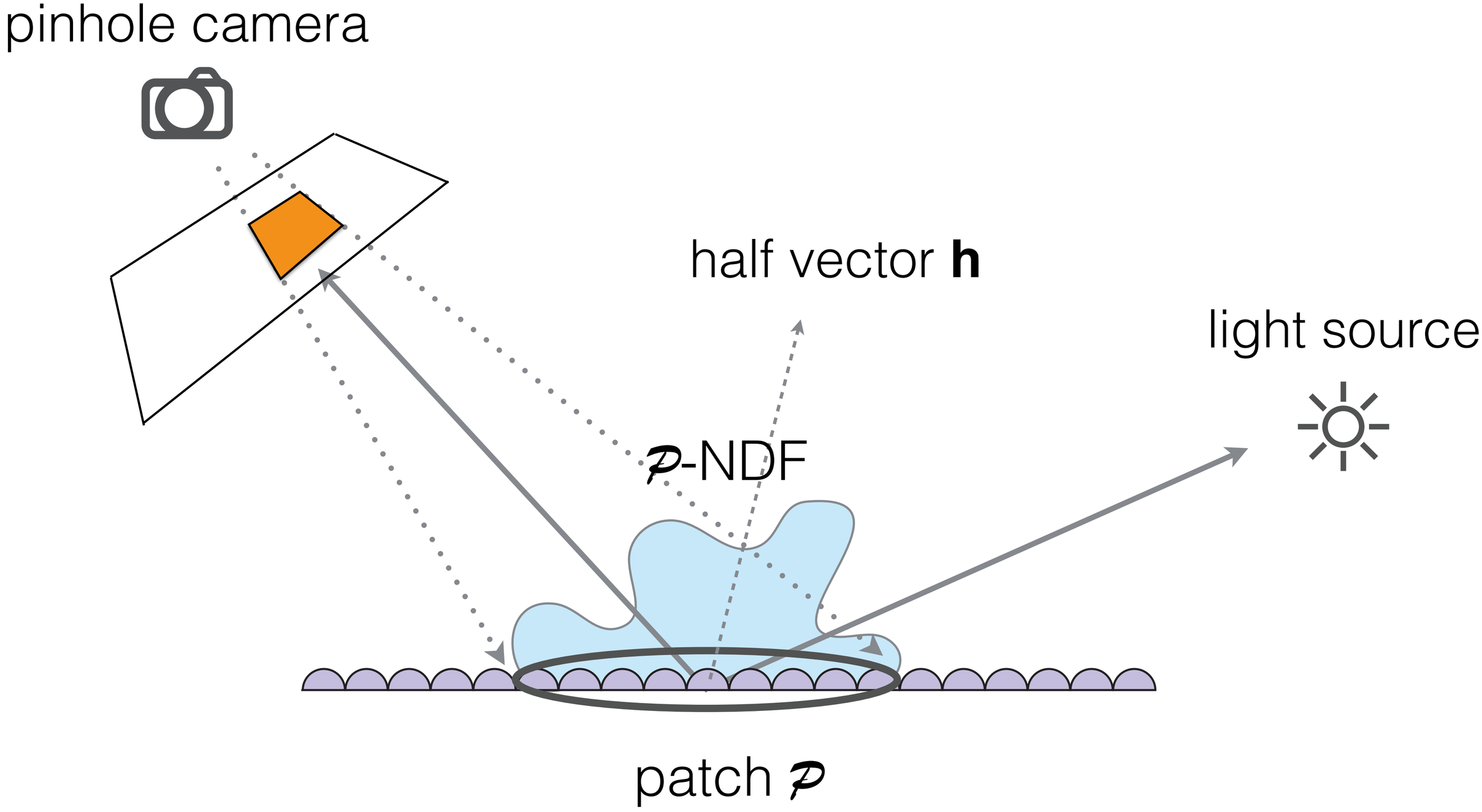
zoom of
a single pixel

naive sampling (2h)
(» 21.3 days to converge)

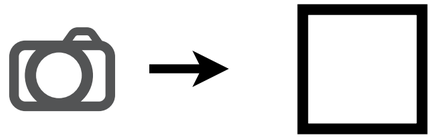
Difficult path sampling problem



Solution: BRDF over a pixel

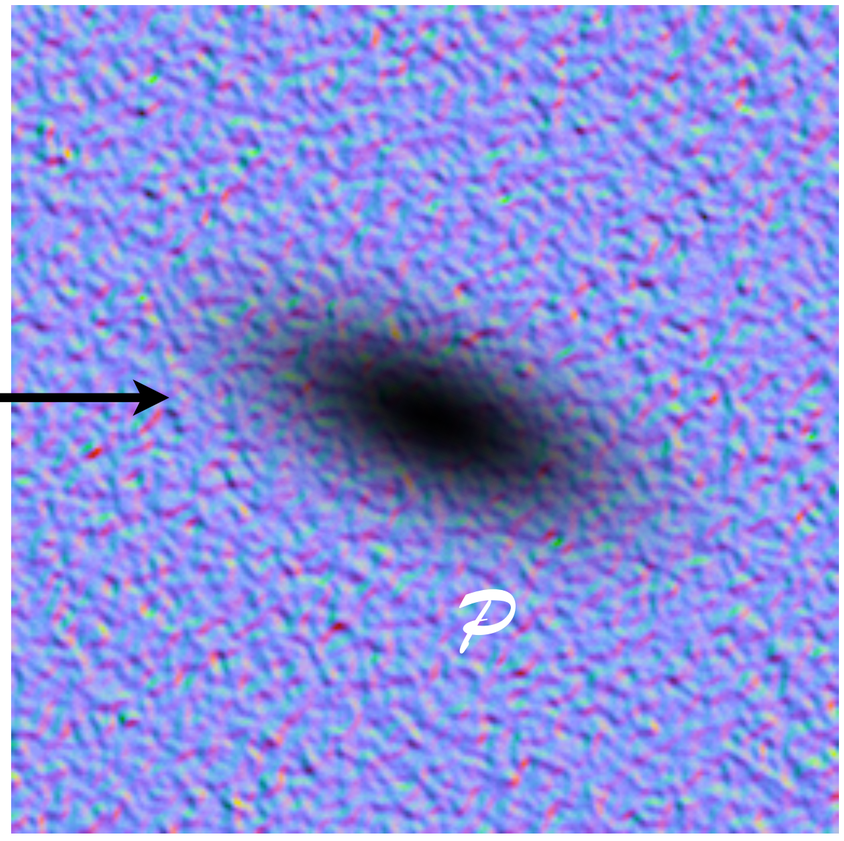


p-NDF over a pixel



camer

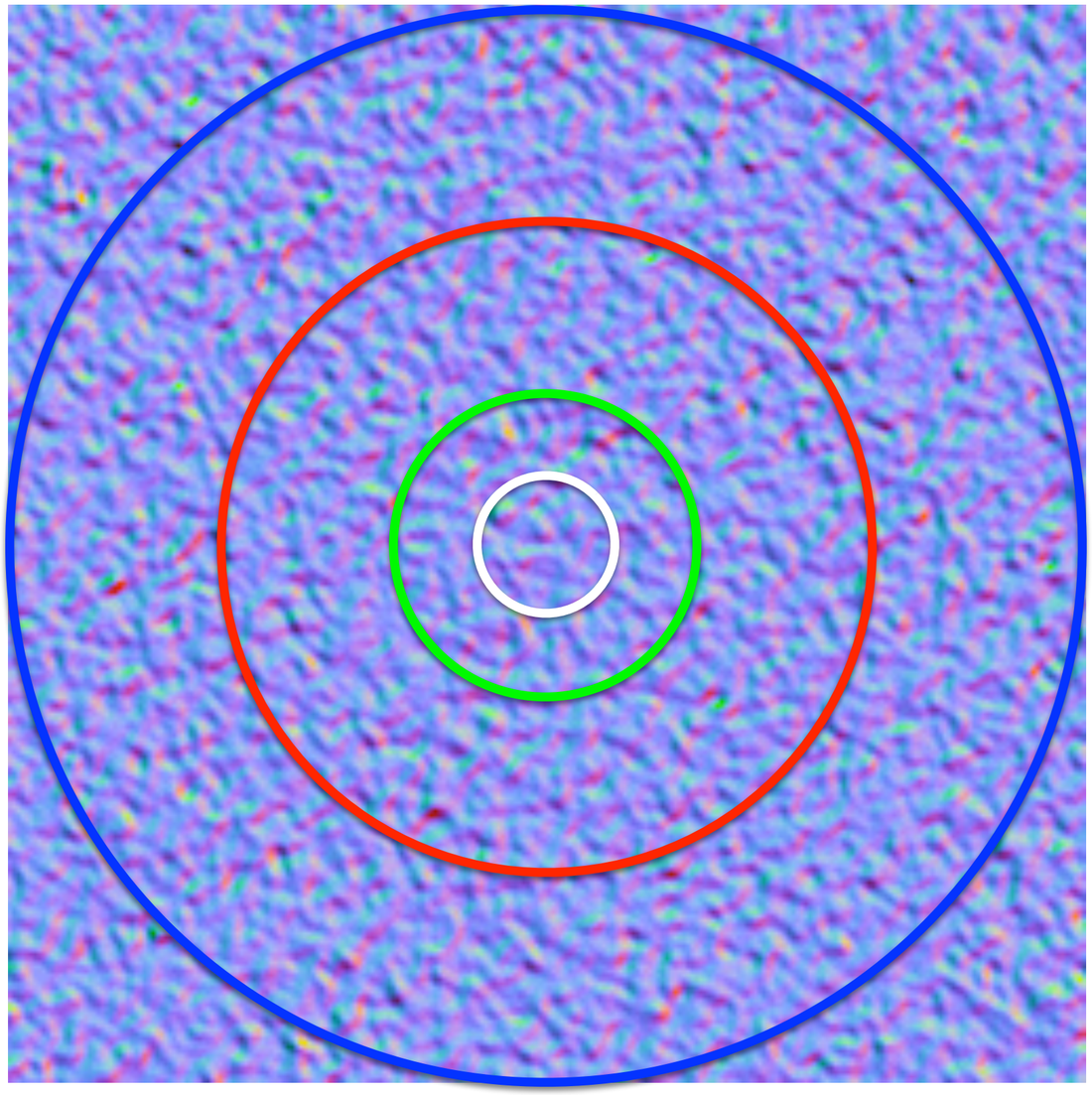
pixel



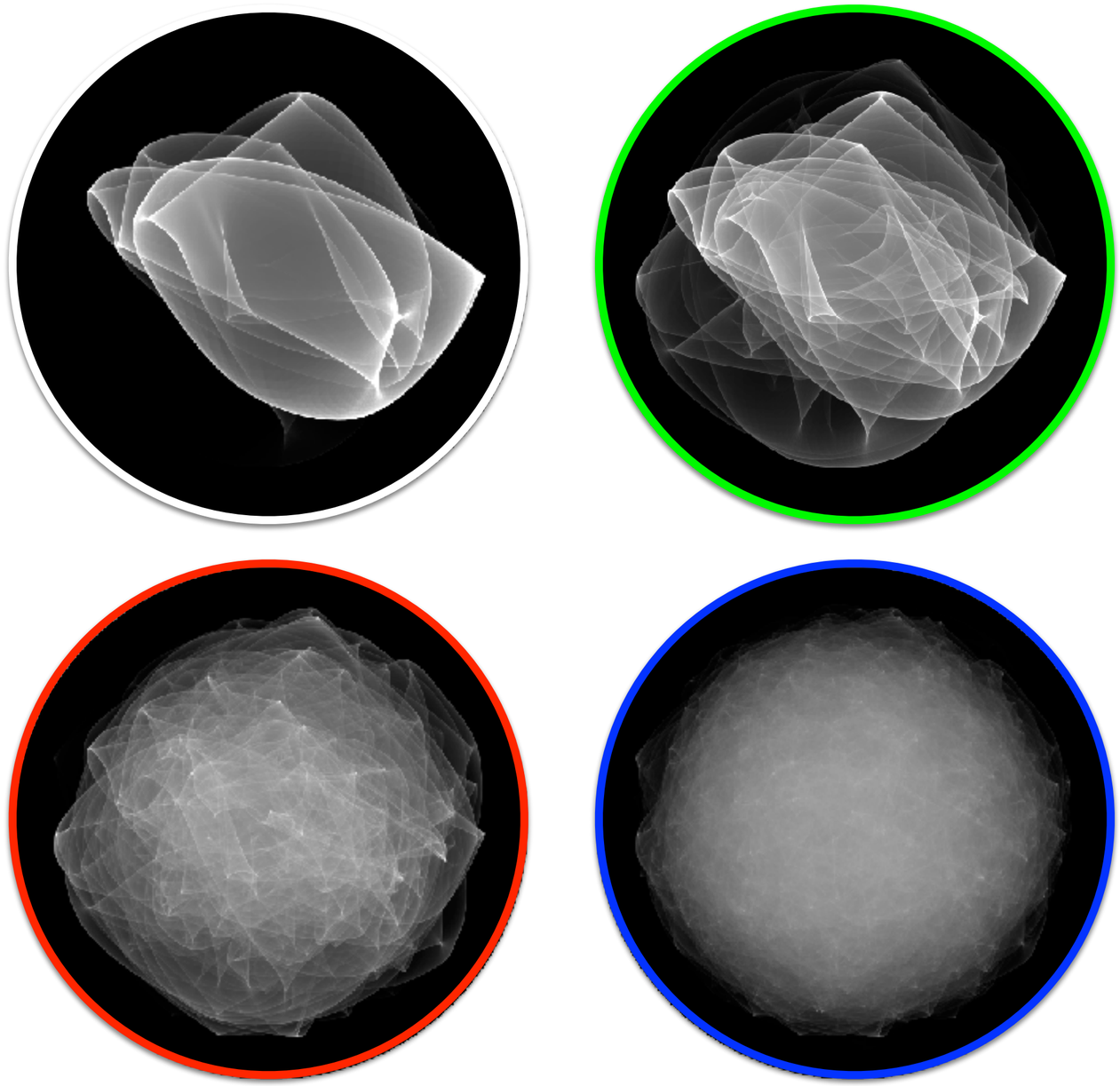
normal-

$\mathcal{P}$-NDF:
distribution of normals

p-NDFs have sharp features

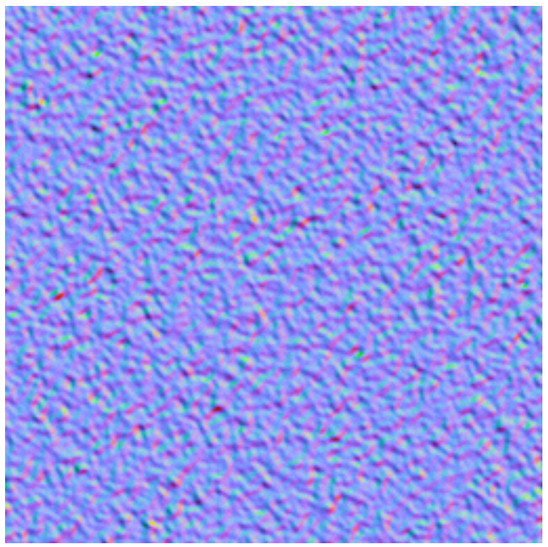
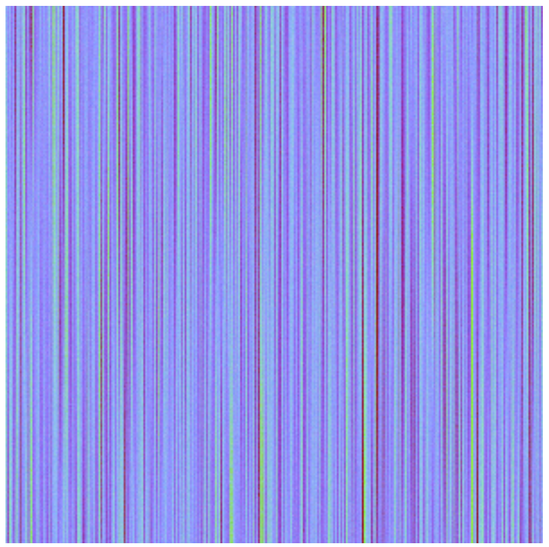
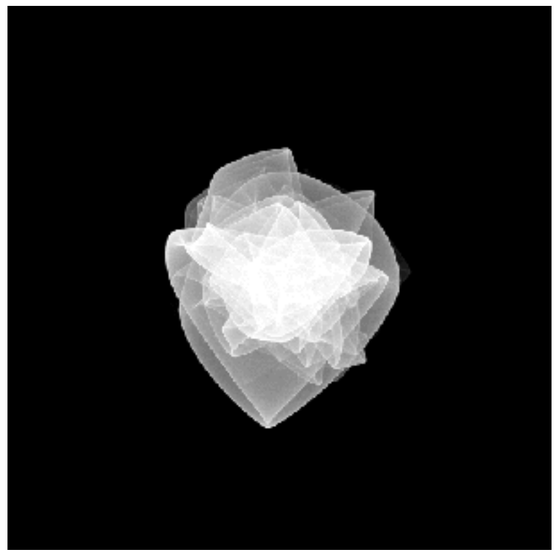
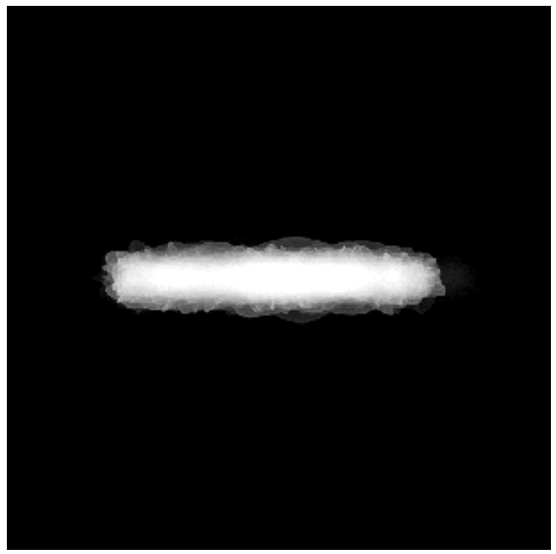
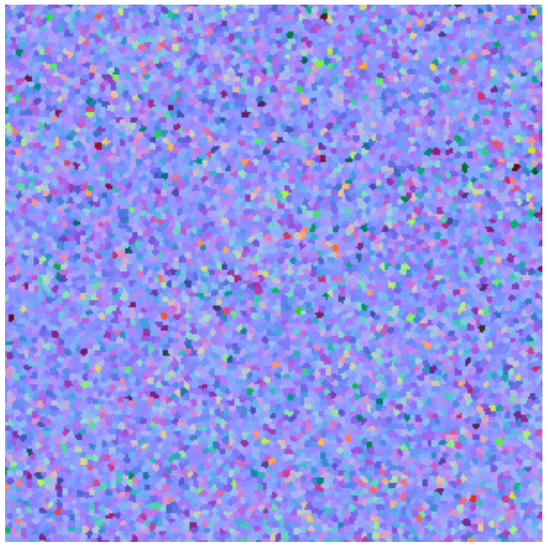
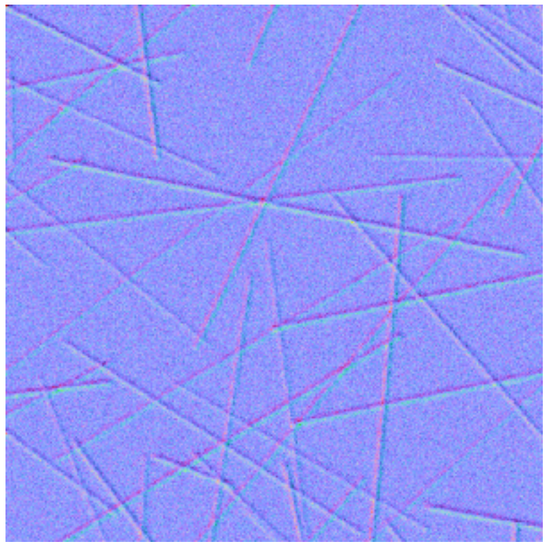
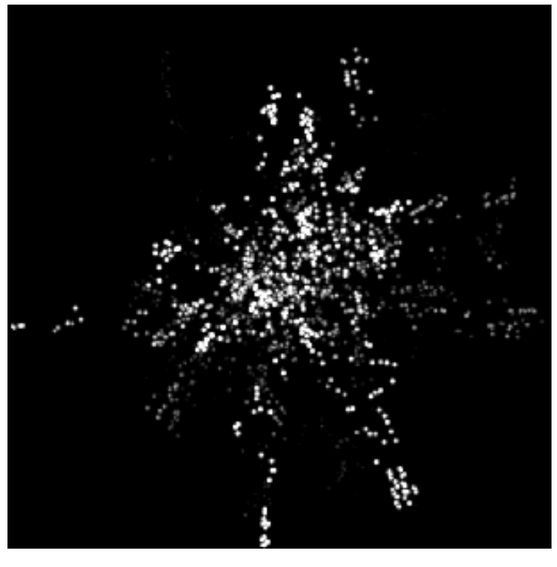
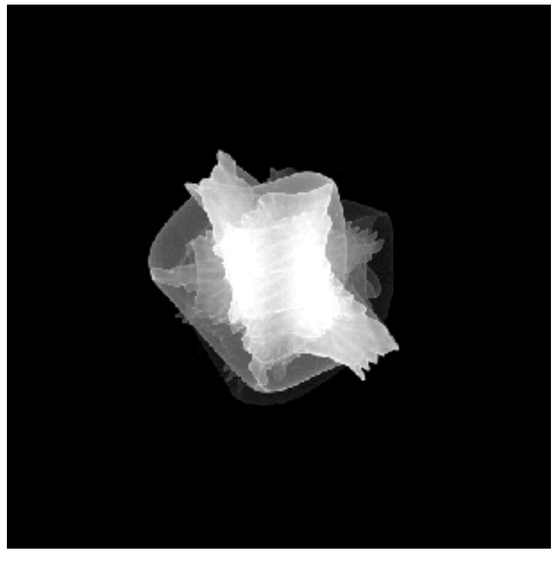


normal map



$\mathcal{P}$-NDFs

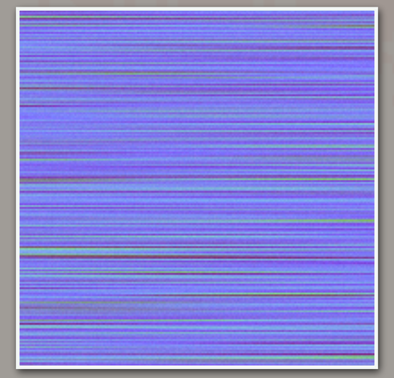
p-NDF shapes

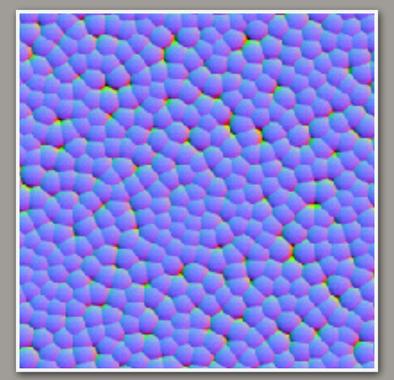
normal maps

$\mathcal{P}$-NDFs

Blender

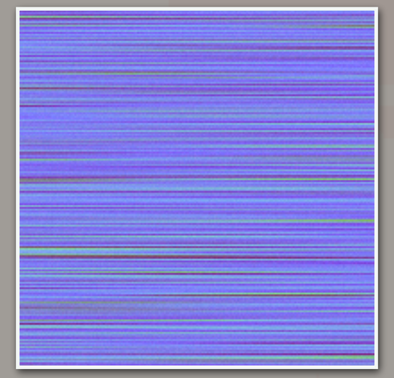


brushed metal

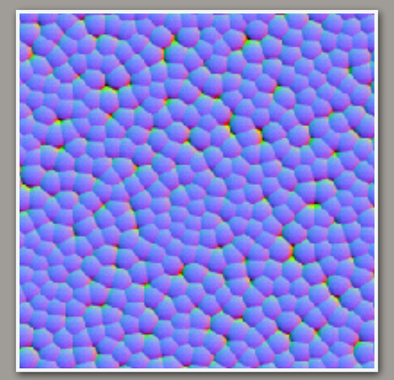


ellipsoid bumps

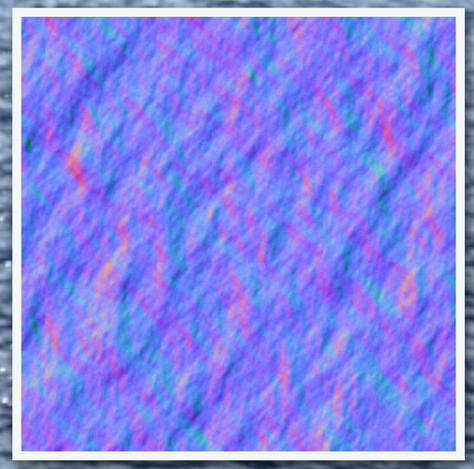
Blender: Zoom

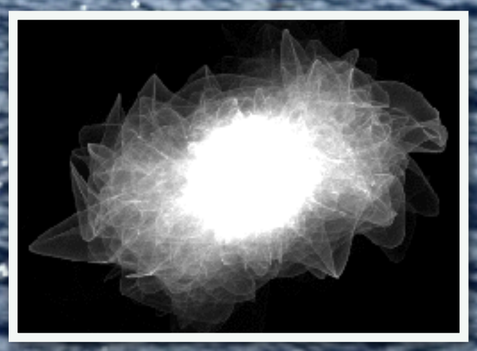


brushed metal



ellipsoid bumps



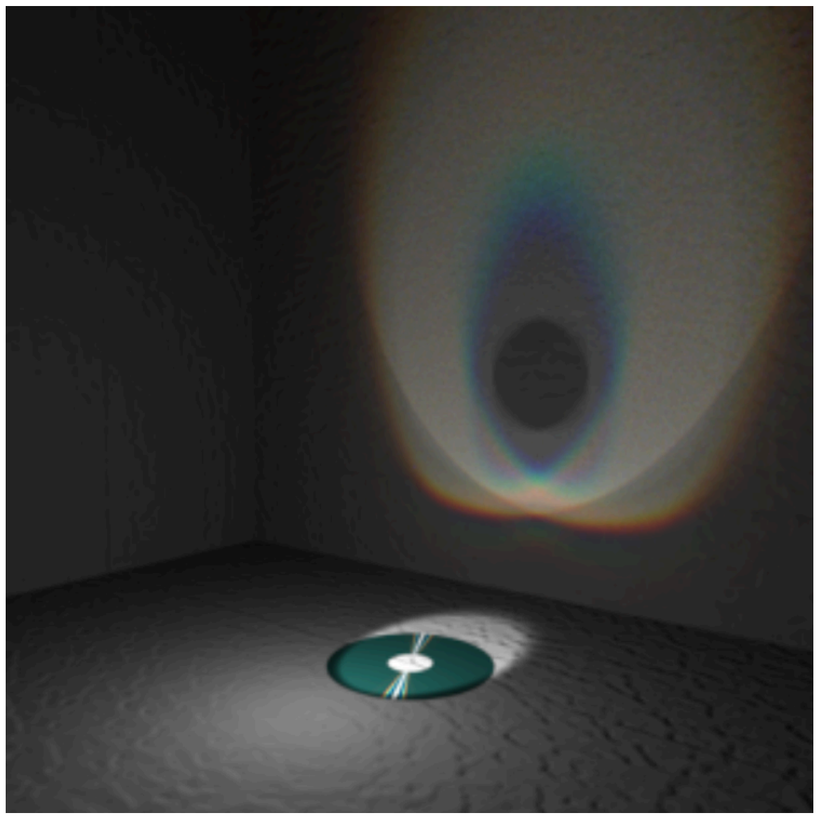


Ocean waves

Detailed / Glinty Material: Application

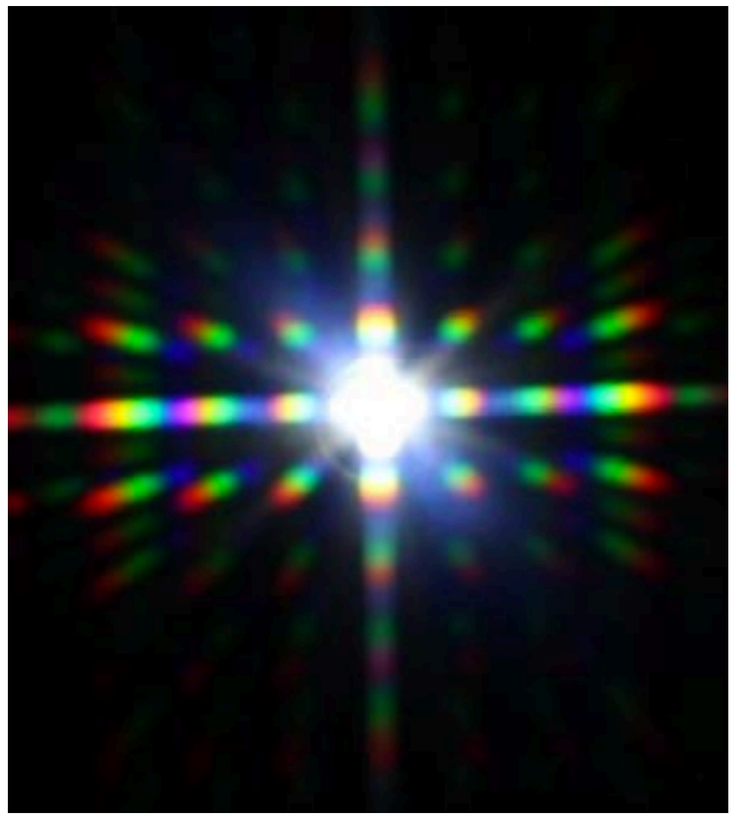
[Rise of the Tomb Raider. 2016 Square Enix]

Recent Trend: Wave Optics



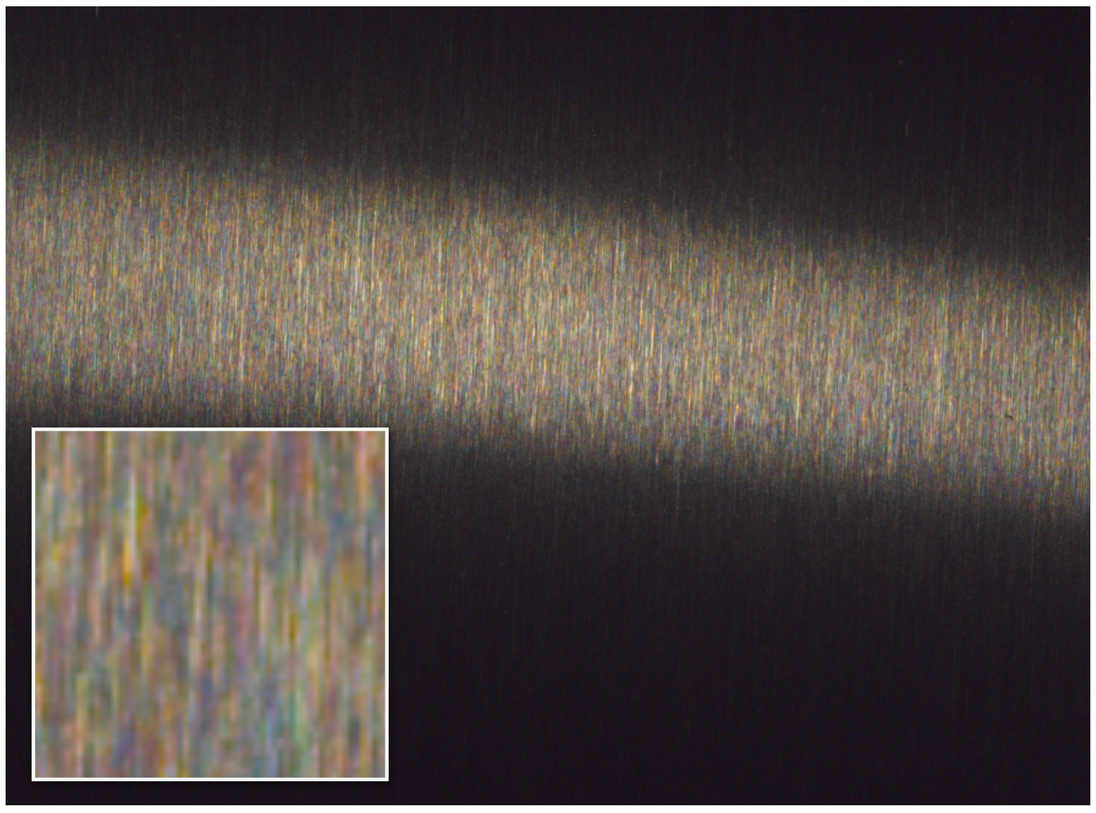
compact disk (CD)
[Cuypers 11]

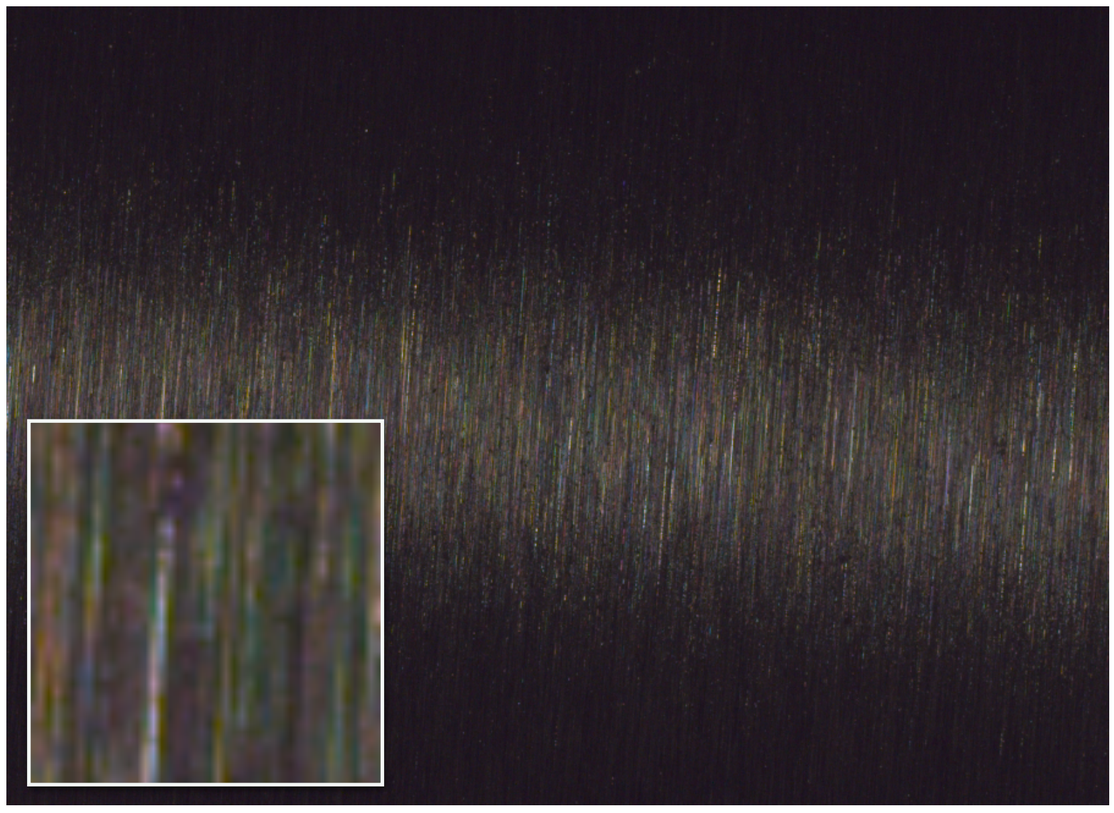
metallic film
[Laurent 17]



phone screen
[Toisoul 17]

Observations





photos of scratched metal

Observations

photo of a Macbook

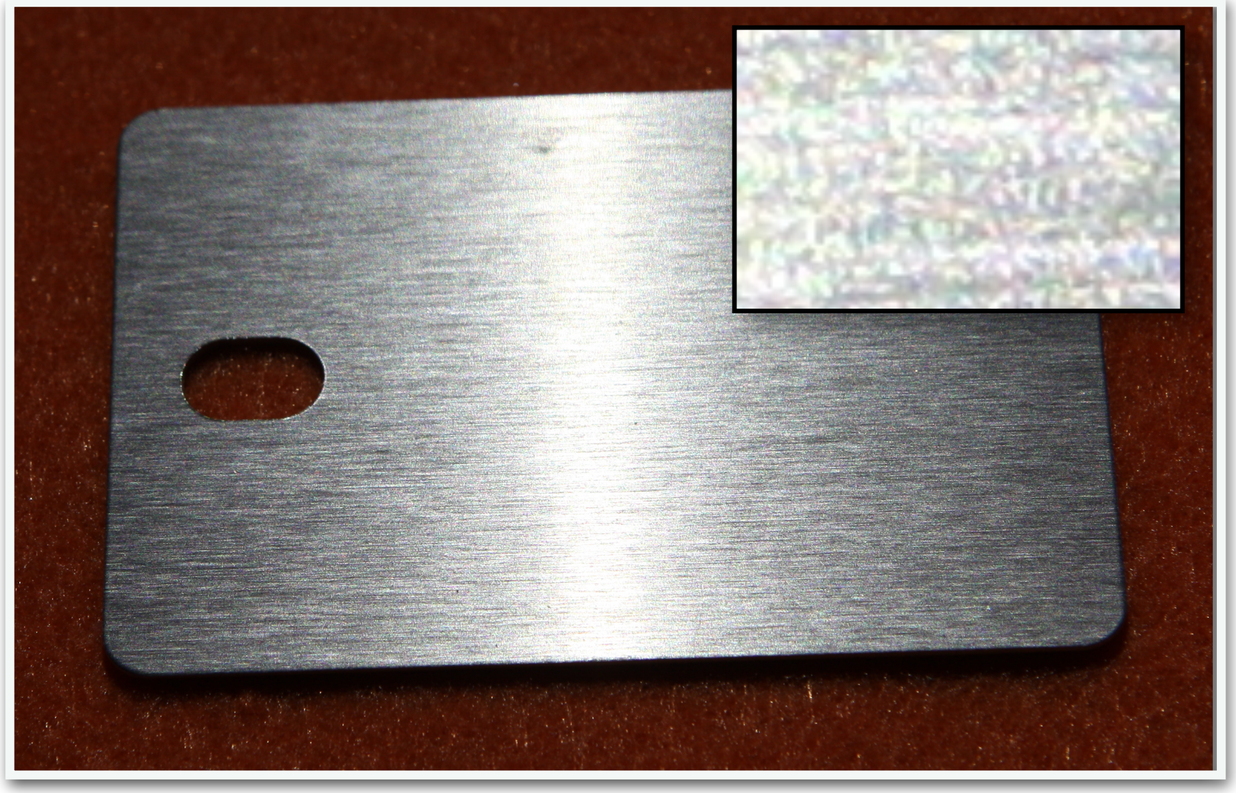
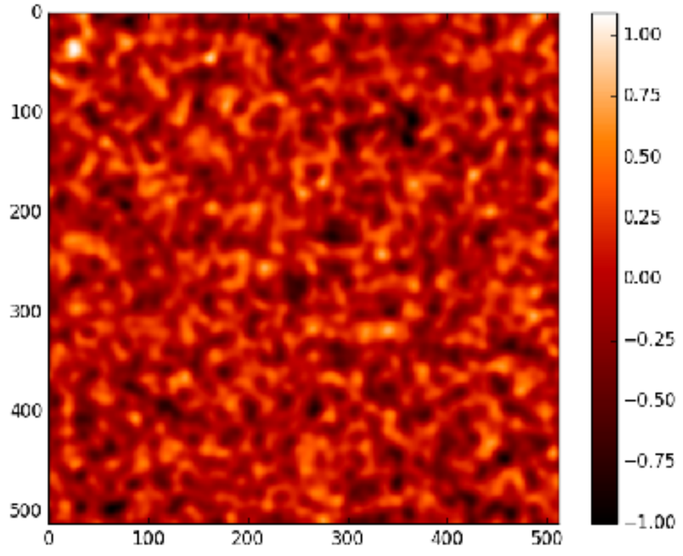
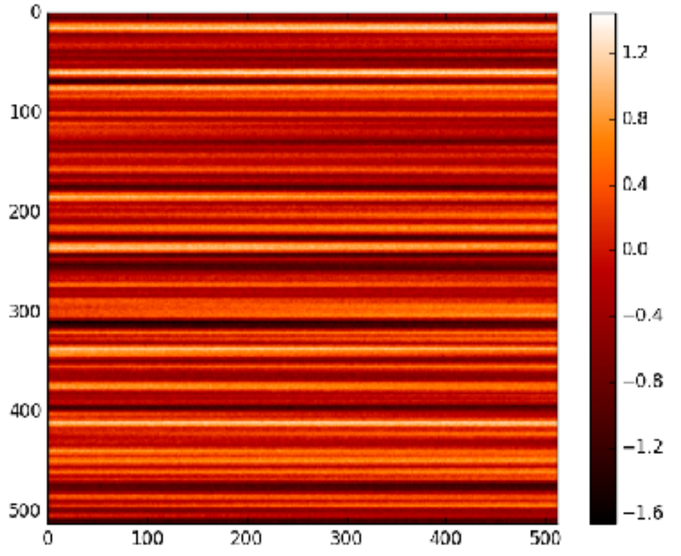


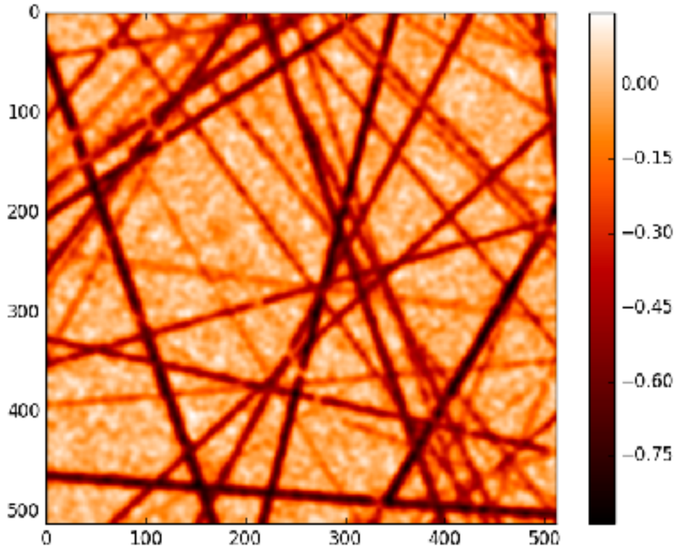
photo of an aluminum patch

Detailed Material under Wave Optics

Heightfields

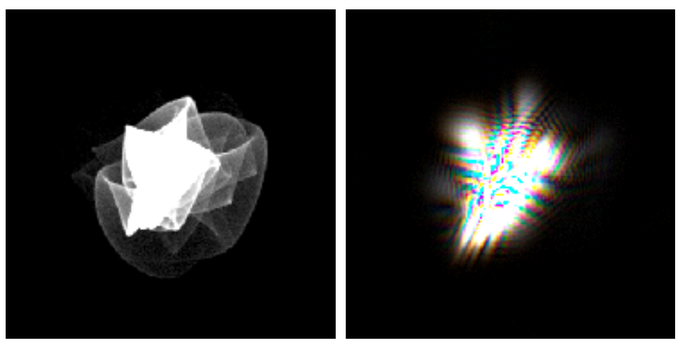




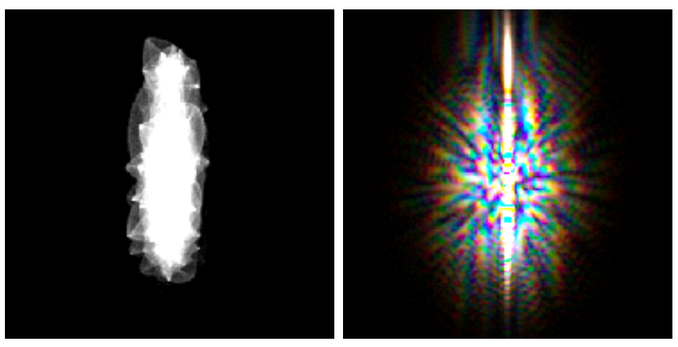


isotropic **brushed** **scratched**

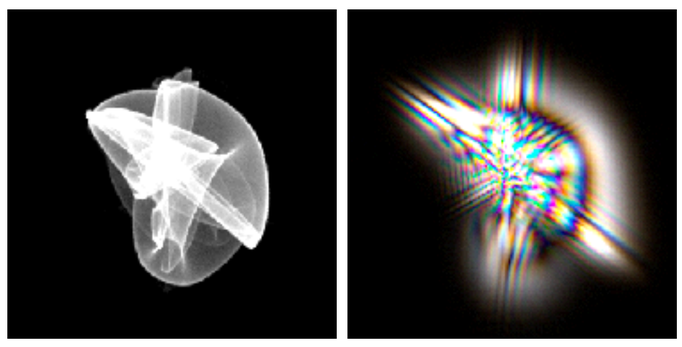
BRDFs



geometric **wave**

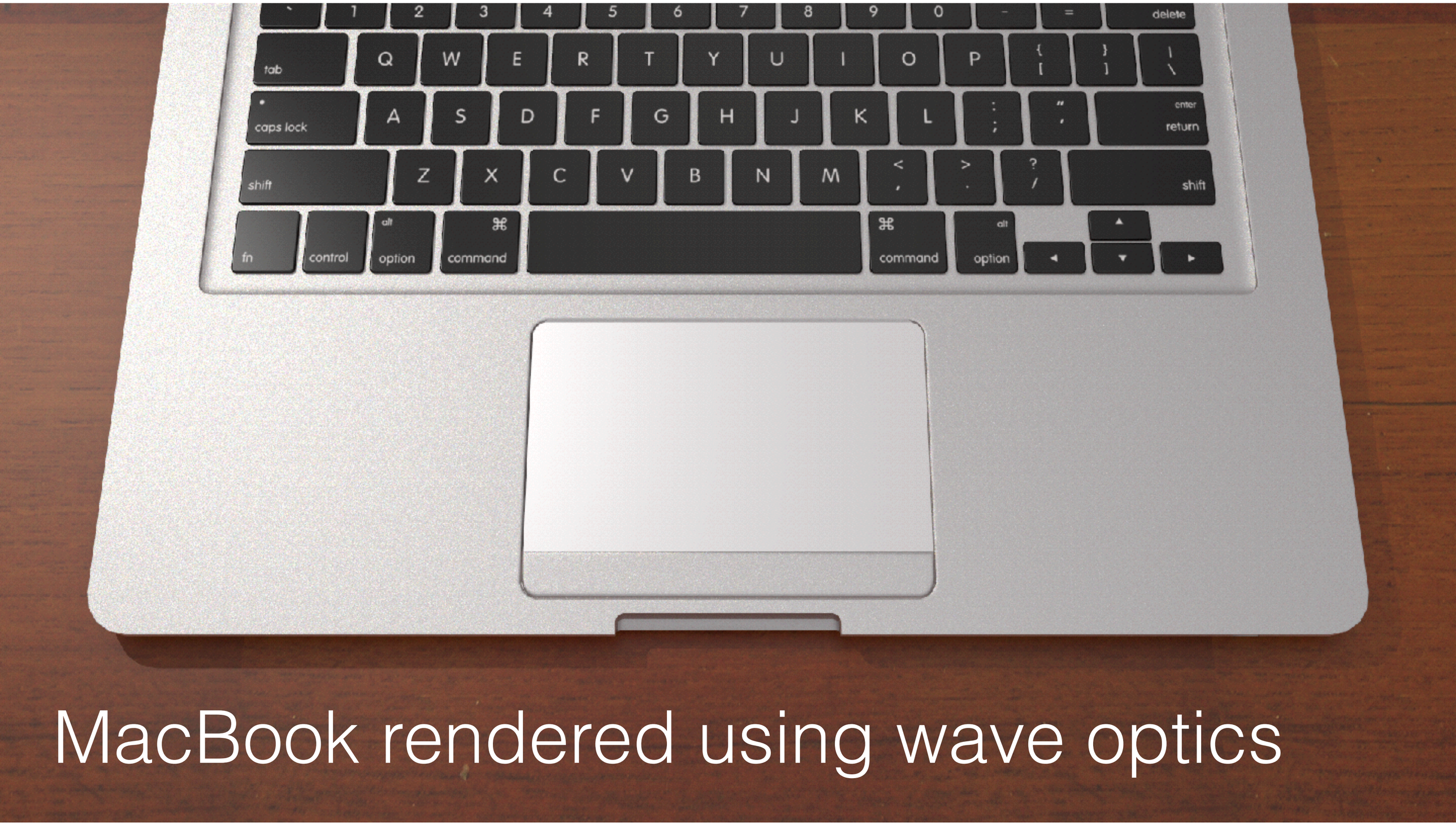


geometric **wave**



geometric **wave**

Detailed Material under Wave Optics



CS184/284A **[Yan et al. 2018]** **Ren Ng**


alt
fn
control
option
command

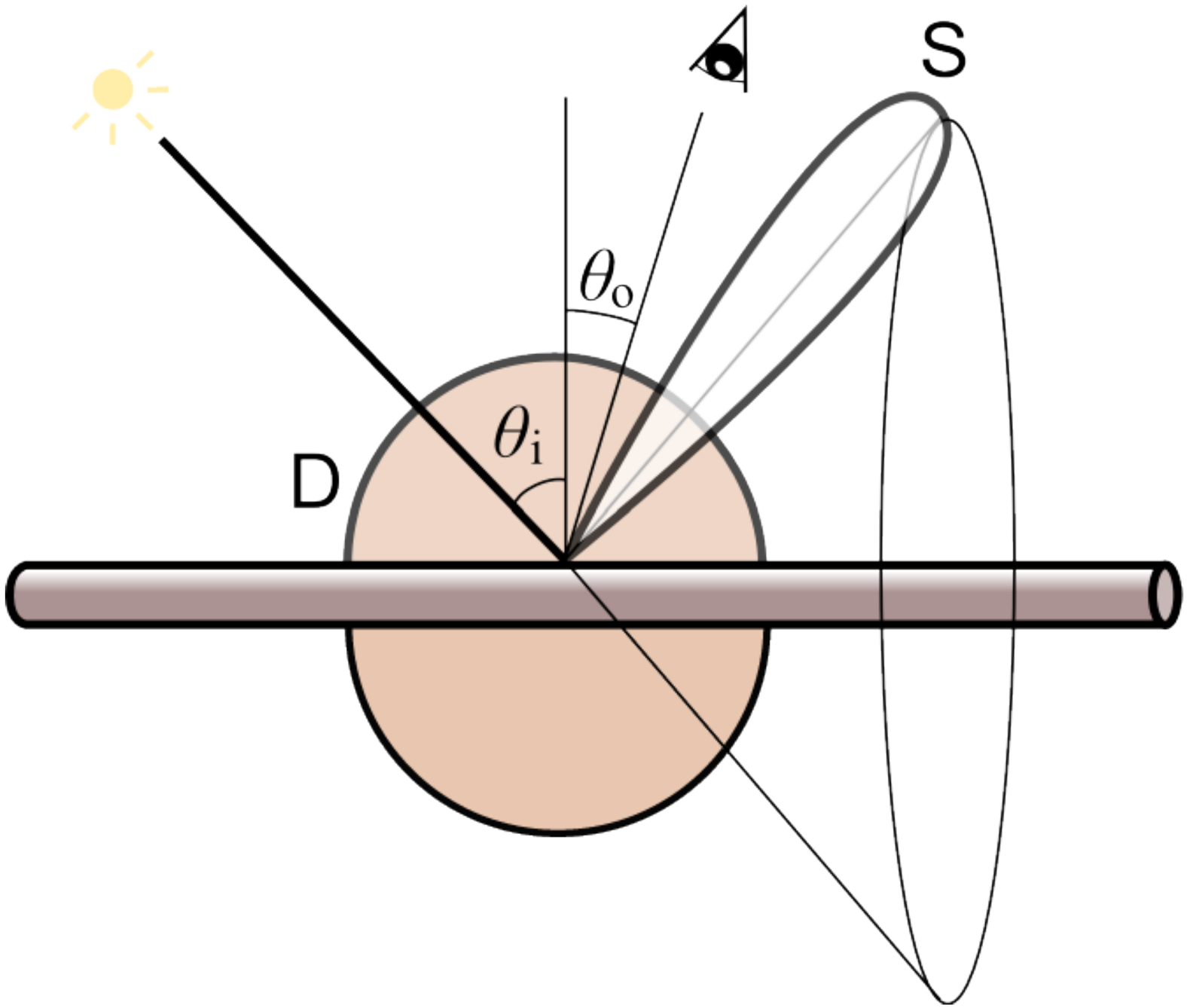
fn control alt option ⌘ command

Wave optics

Hair / Fur Appearance Models

Hair Appearance

Kajiya-Kay Model

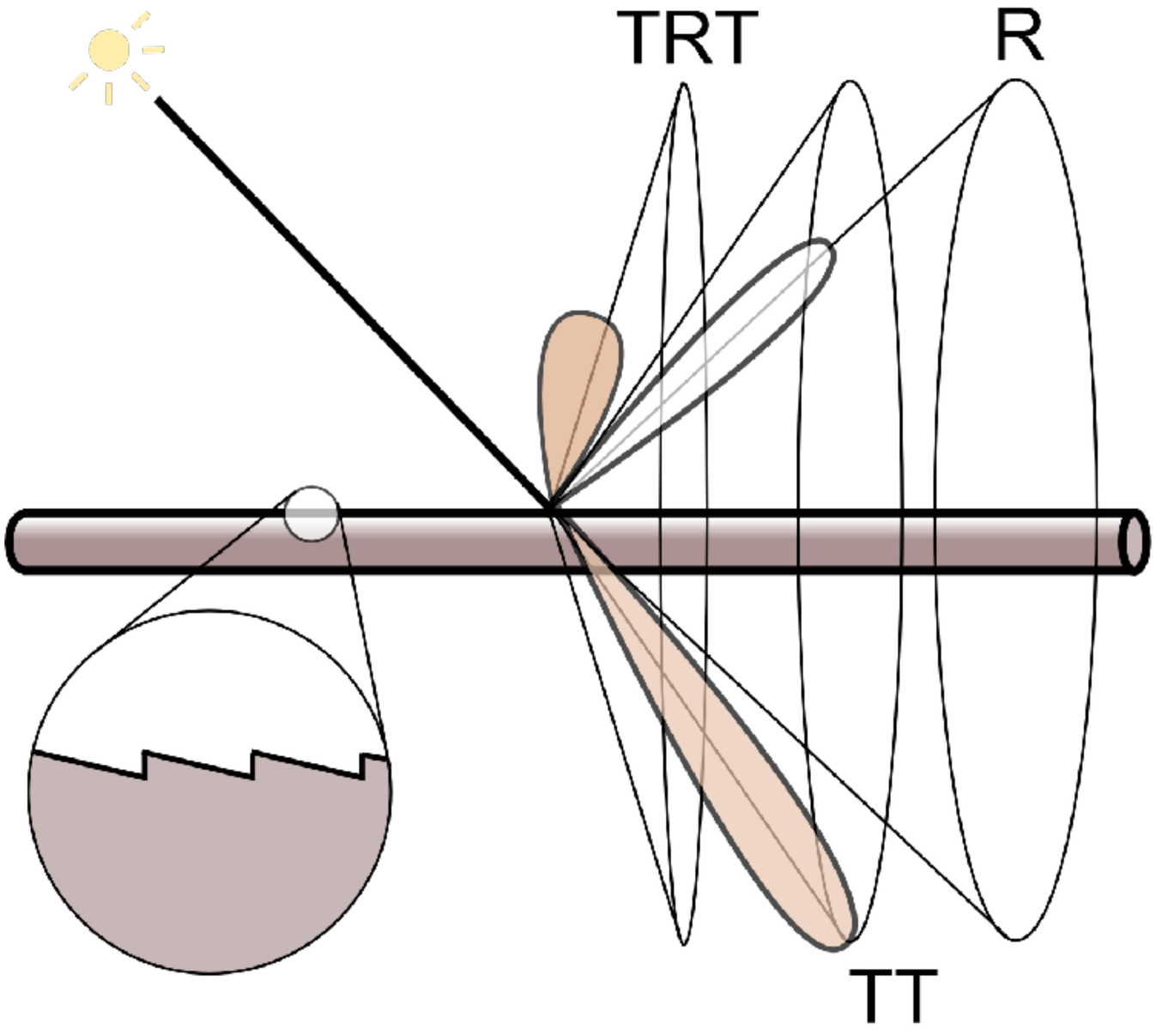


[Image courtesy of Chiwei Tseng]

Kajiya-Kay Model

[Yuksel et al. 2008]

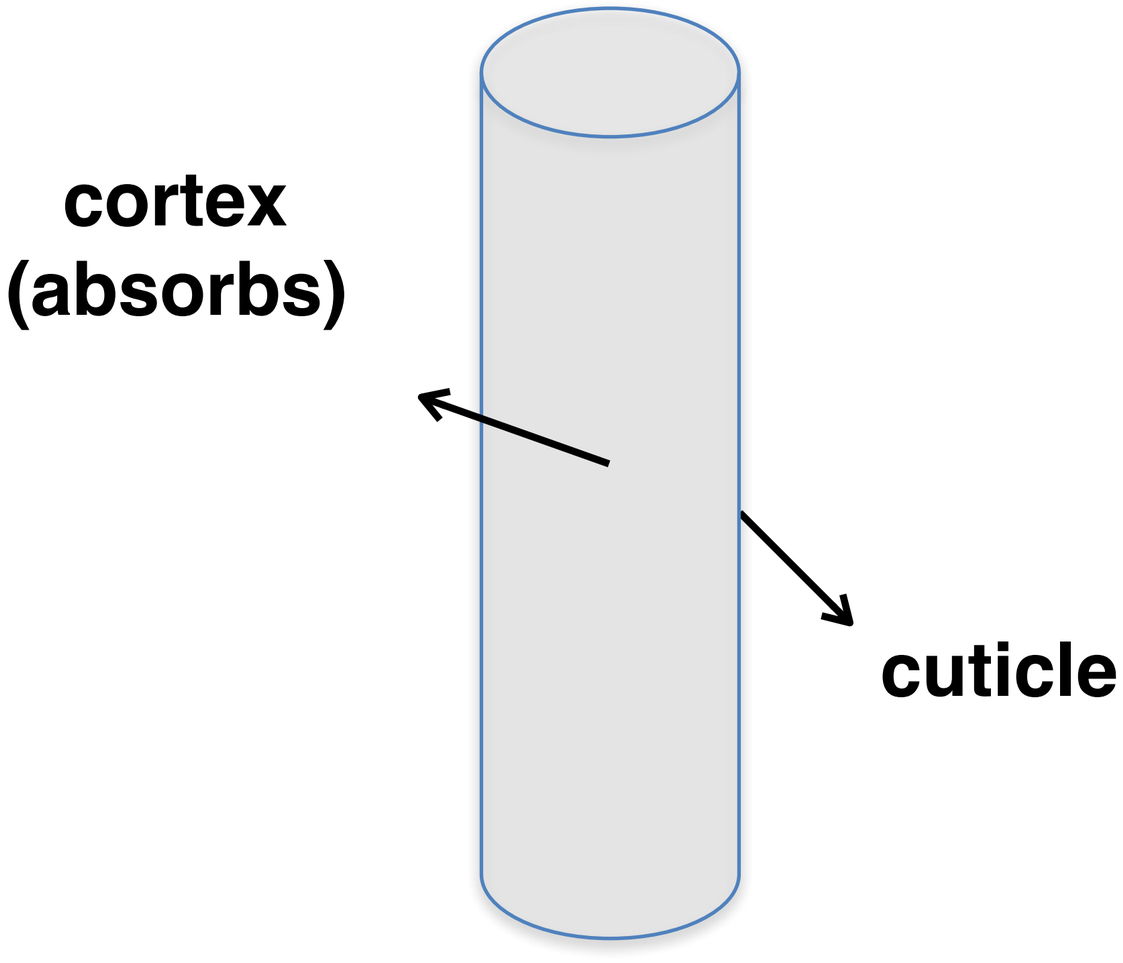
Marschner Model



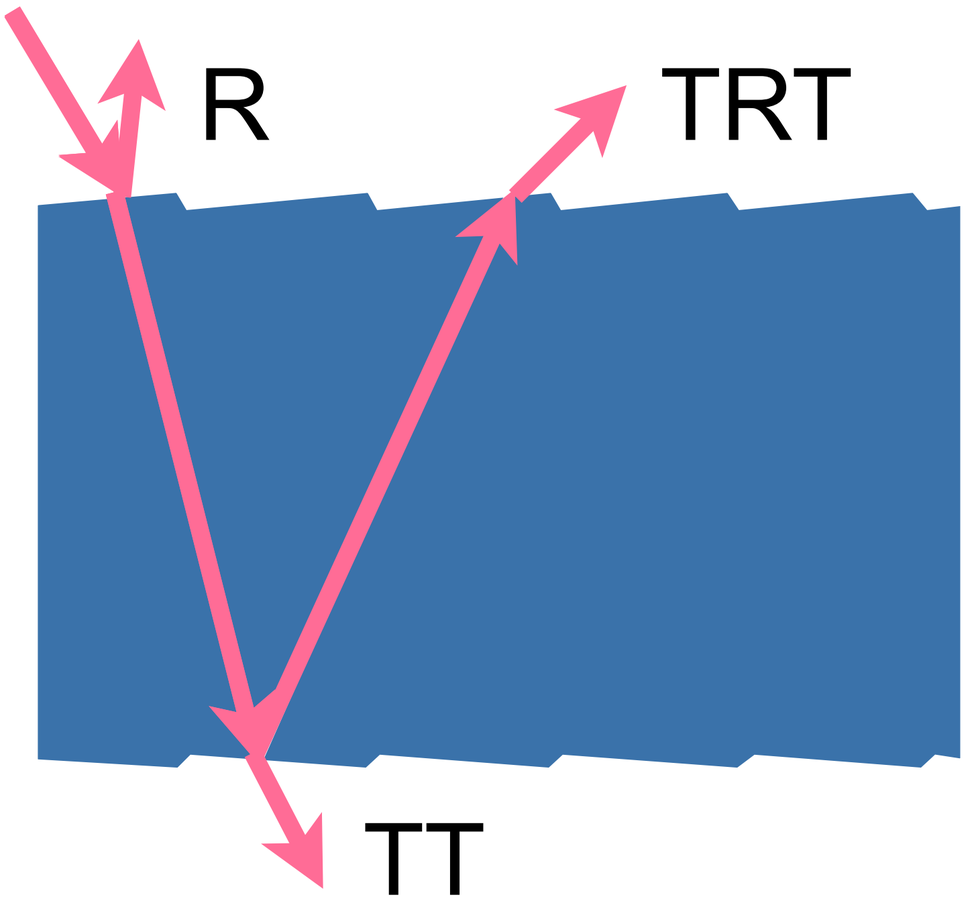
[Image courtesy of Chiwei Tseng]

Marschner Model

- Glass-like cylinder



- 3 types of light interactions:
  R, TT, TRT
  (R: reflection, T: transmission)



Marschner model

[Marschner et al. 2003]

[d'Eon et al. 2011]

Hair Appearance Model: Application

[Final Fantasy XV. 2016 Square Enix]

Hair Appearance Model: Application

[Zootopia. 2016 Disney]

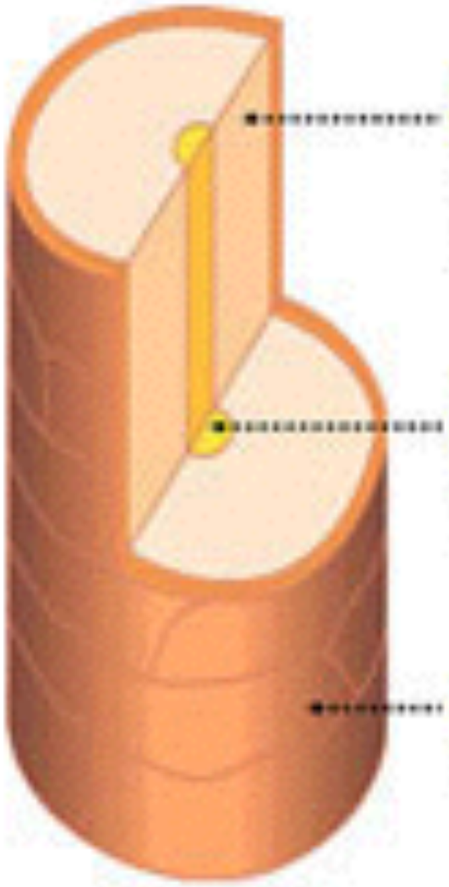
Fur Appearance — As Human Hair

- Cannot represent diffusive and saturated appearance

Rendered as human hair [Marschner et al. 2003]

Rendered as animal fur [Yan et al. 2015]

Human Hair vs Animal Fur



Cortex

- Contains pigments
- Absorbs light

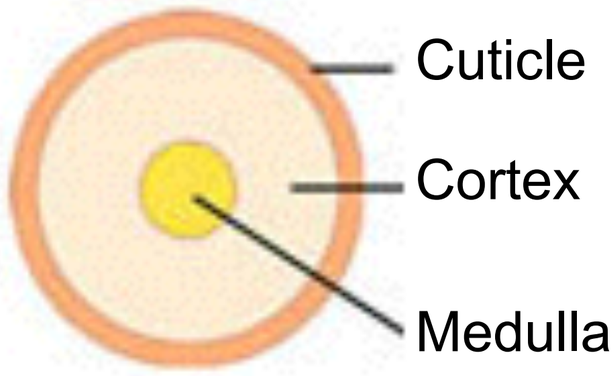
Medulla

- Complex structure
- Scatters light

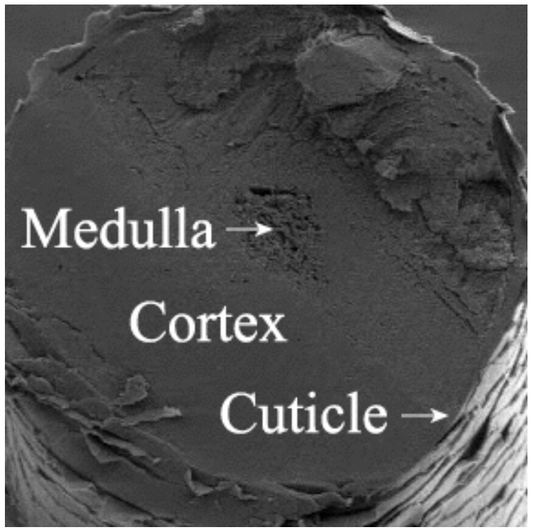
Cuticle

- Covered with scales

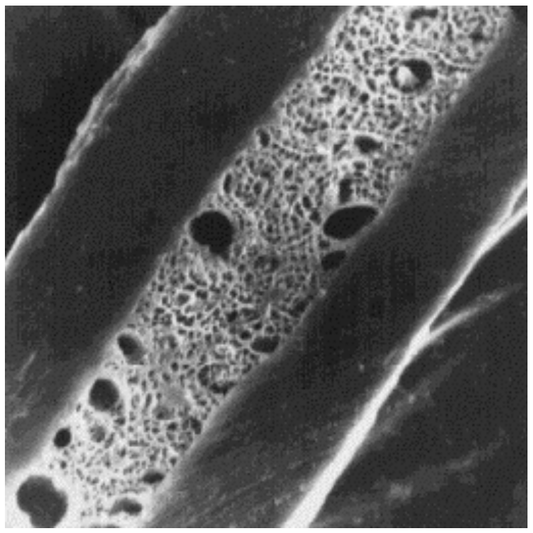
Common for hair/fur fibers



Human



Cougar



Difference between hair/fur fibers

Importance of Medulla

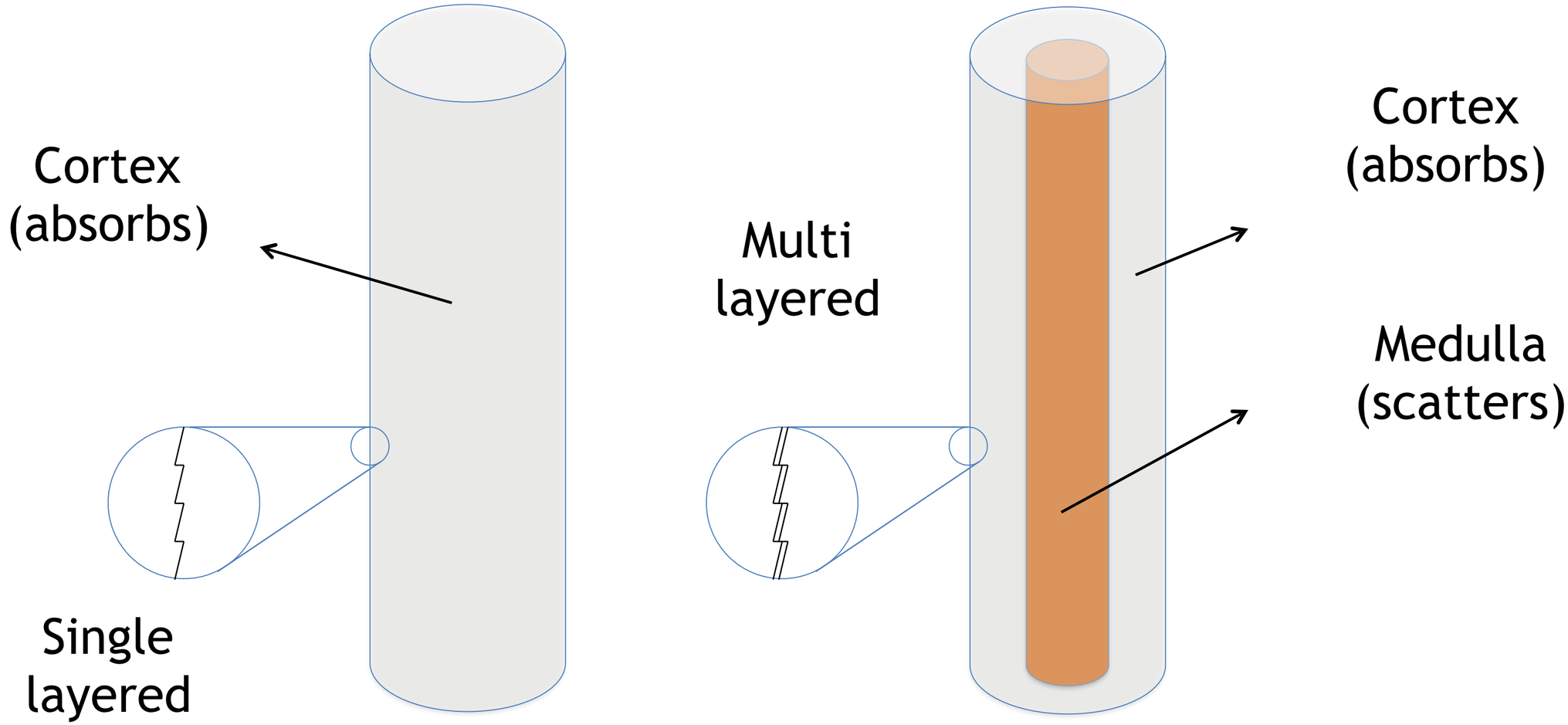
Increasing medulla size

Importance of Medulla

Without medulla

With medulla (**15%**)

Double Cylinder Model

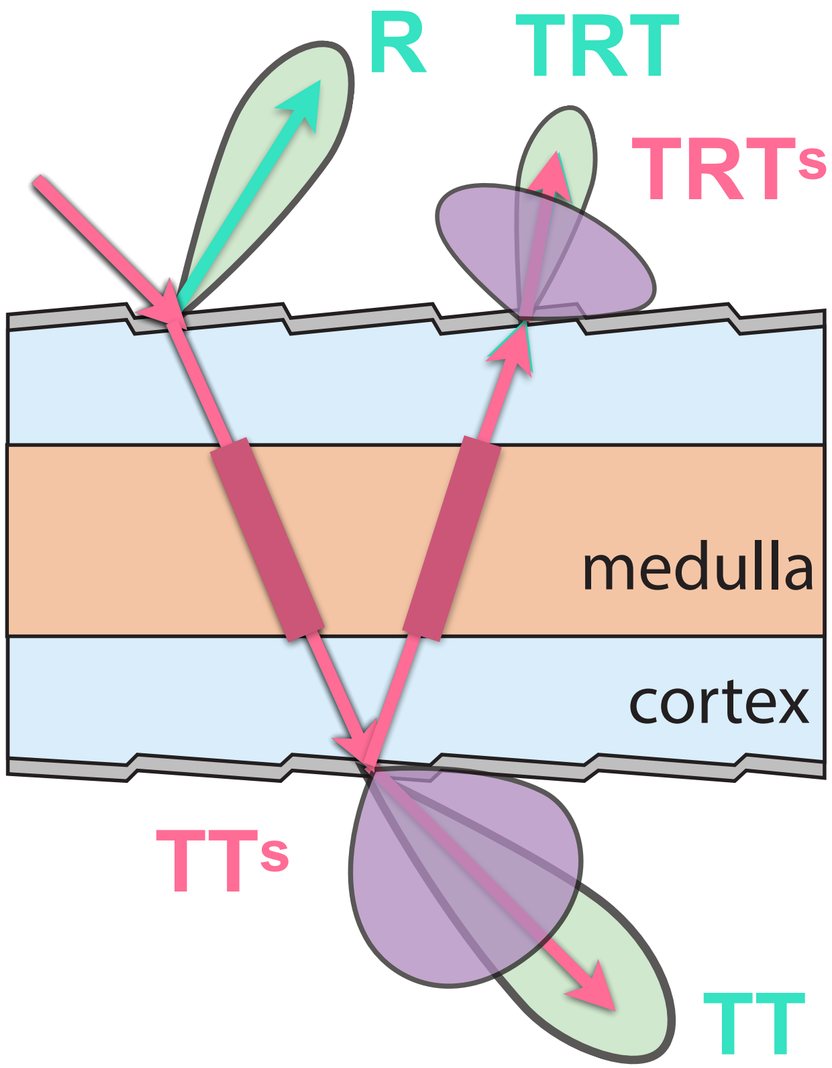


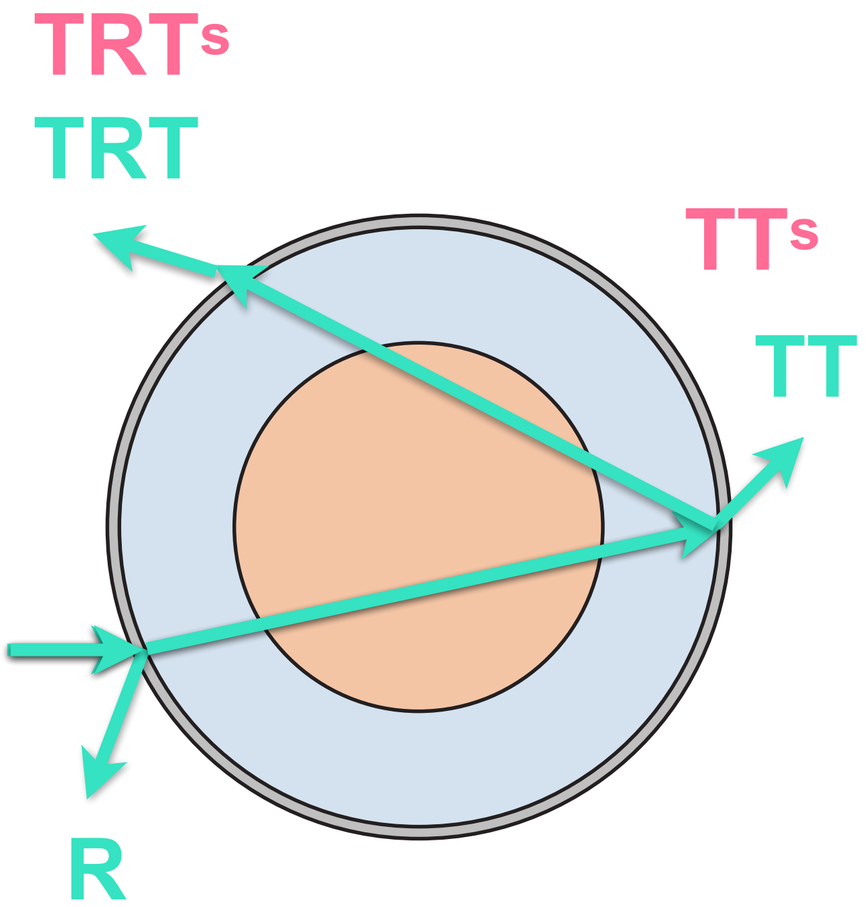
Marschner Model

Double Cylinder Model

[Yan et al. 2015, 2017]

Double Cylinder Model — Lobes





Double Cylinder Model — Lobes

All = R TT TRT TT^s TRT^s

Double Cylinder Model: Rendering

600,000 fur fibers

1024 samples / pixel

36.9 min / frame

Hamster

Double Cylinder Model: Application

CS184/284A

[War for the Planet of the Apes. 2017 movie]
(2018 Oscar Nominee for Best Visual Effects)

Ren Ng

Hair / Fur Rendering is Slow

Render using ray tracing

- Simulating light bouncing multiple times

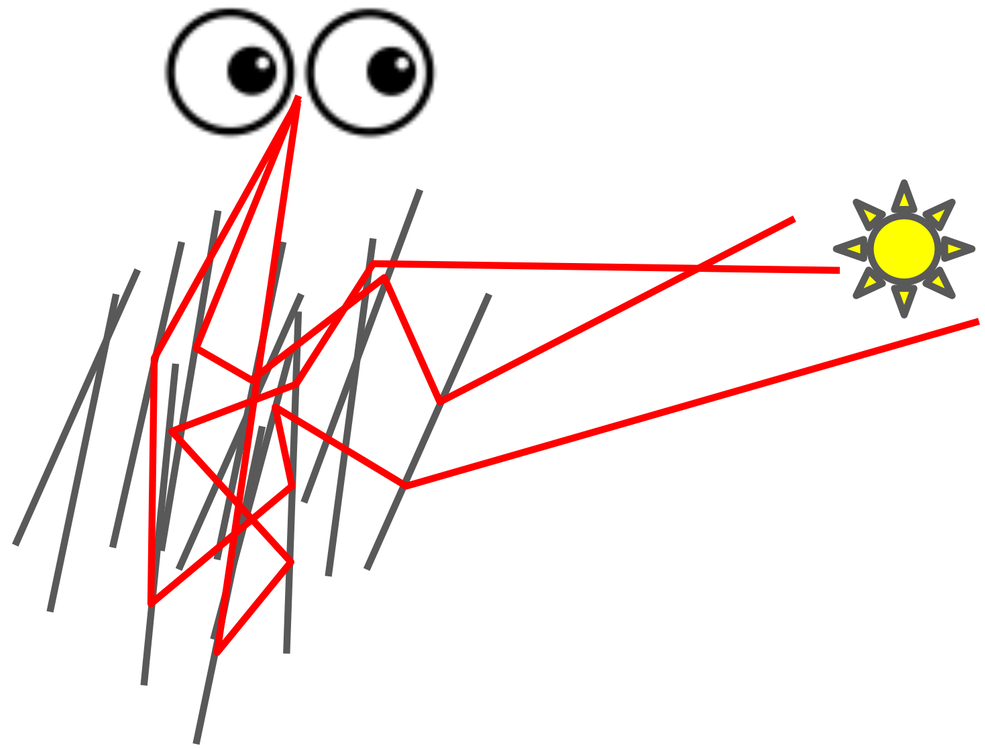
  light -> fur fiber #1

  -> fur fiber #2

  -> ...

  -> fur fiber #100

  -> ... -> eye



- Slow

Can we avoid tracing multiple bounces?

Observation

world’s fuzziest bunny

Very similar!

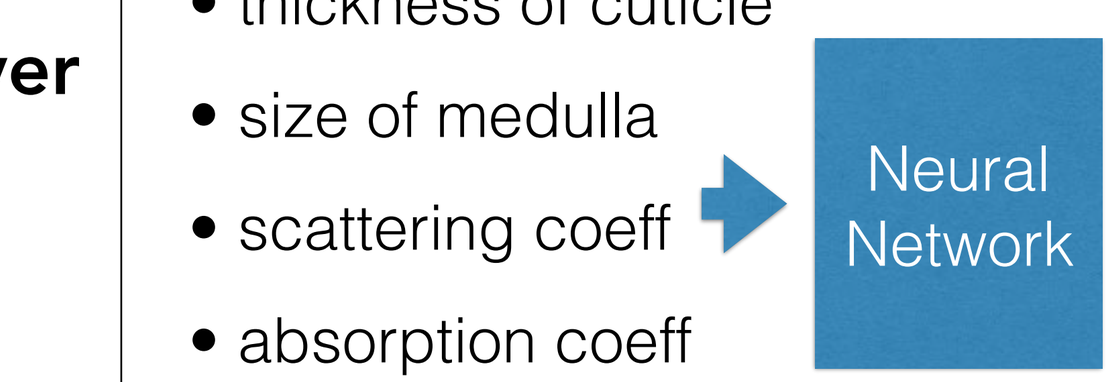
Between Physical Systems

Use a Neural Network

- 2 hidden layers
- 10 nodes per layer
- fully connected
- tanh activation

fur fibers' properties

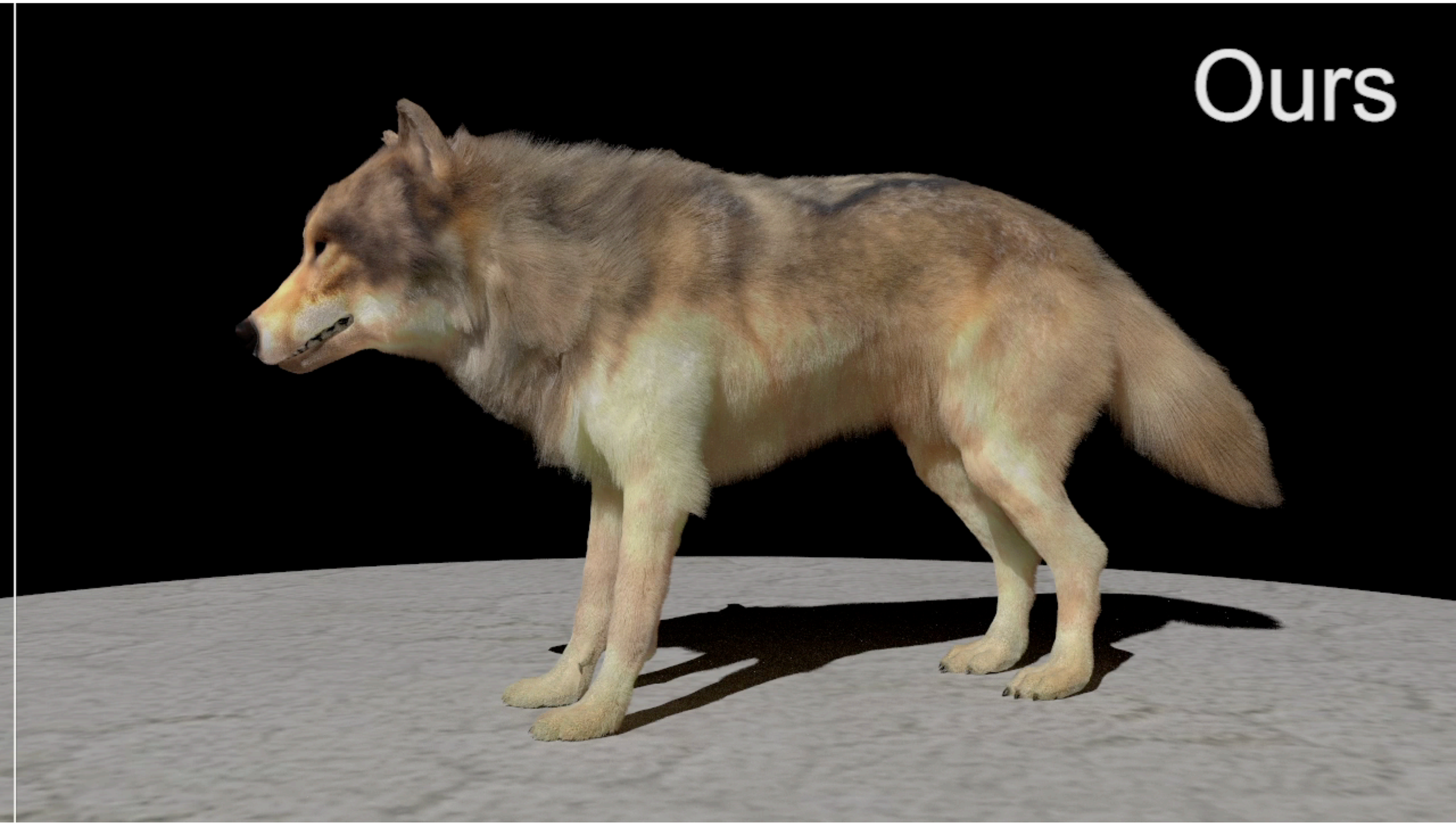
- thickness of cuticle
- size of medulla
- scattering coeff
- absorption coeff
- …
-



clouds' properties

- density
- scattering coeff
- absorption coeff

Render fur as cloud (how?)



Participating Media

Participating Media: Fog

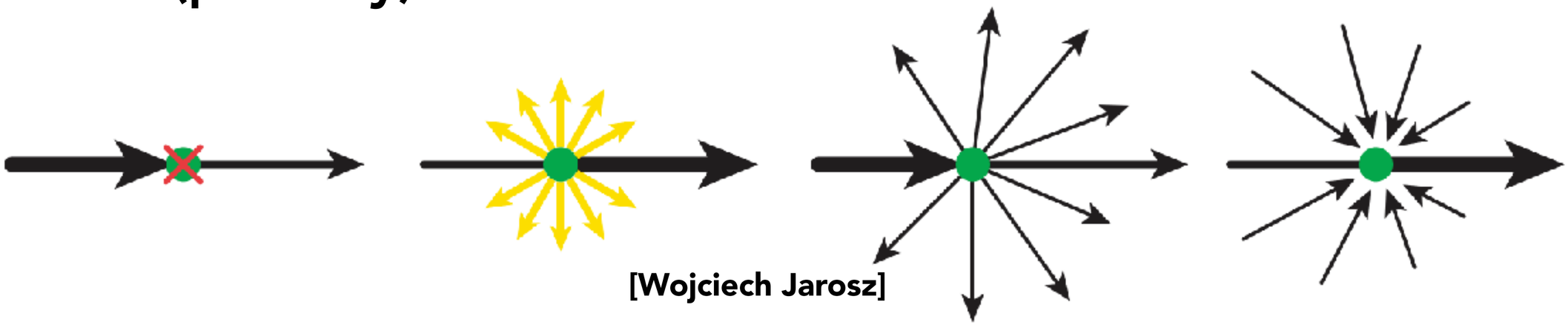
[Novák et al. 2012]

Participating Media: Cloud

[by thephotographer0]

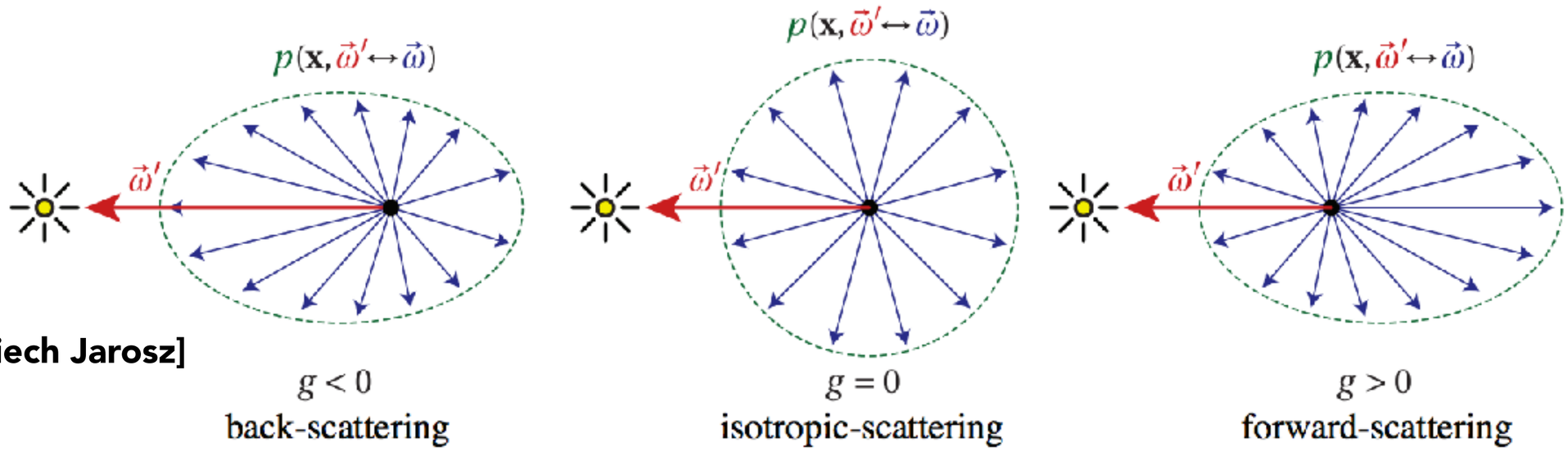
Participating Media

- At any point as light travels through a participating medium, it can be (partially) absorbed and scattered.



[Wojciech Jarosz]

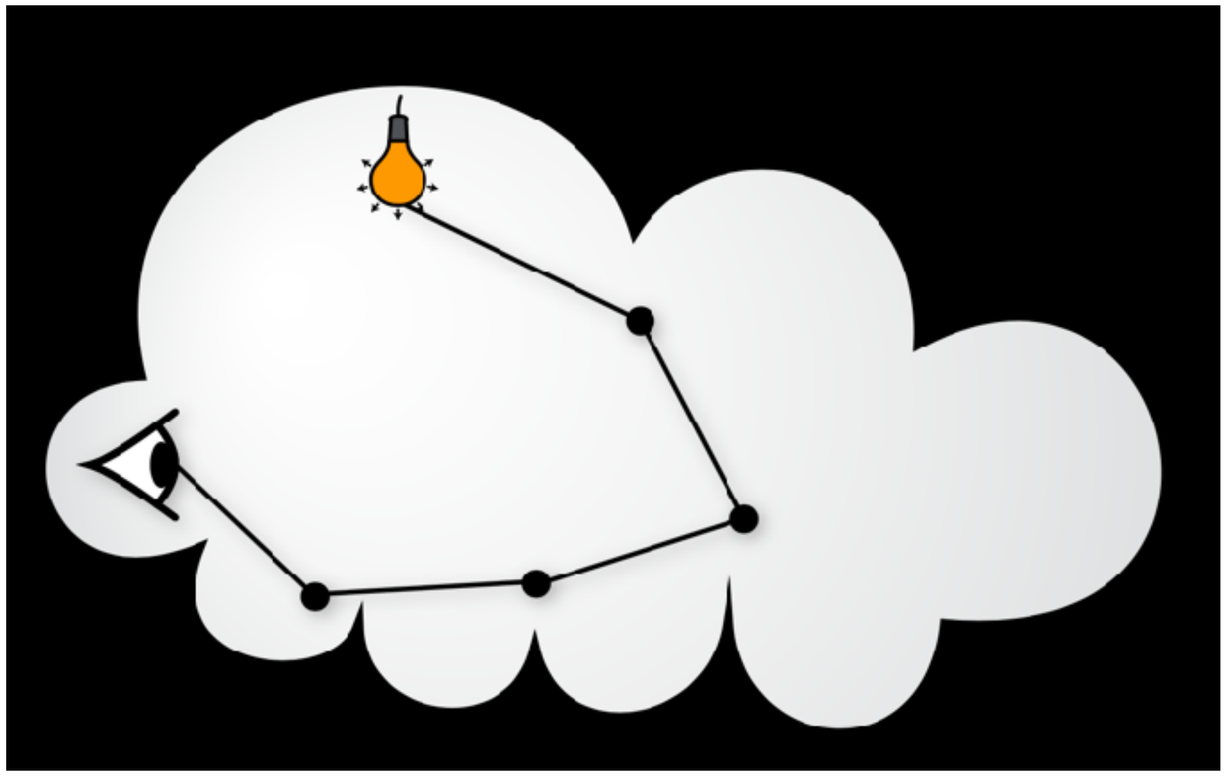
- Use Phase Function to describe the angular distribution of light scattering at any point x within participating media.

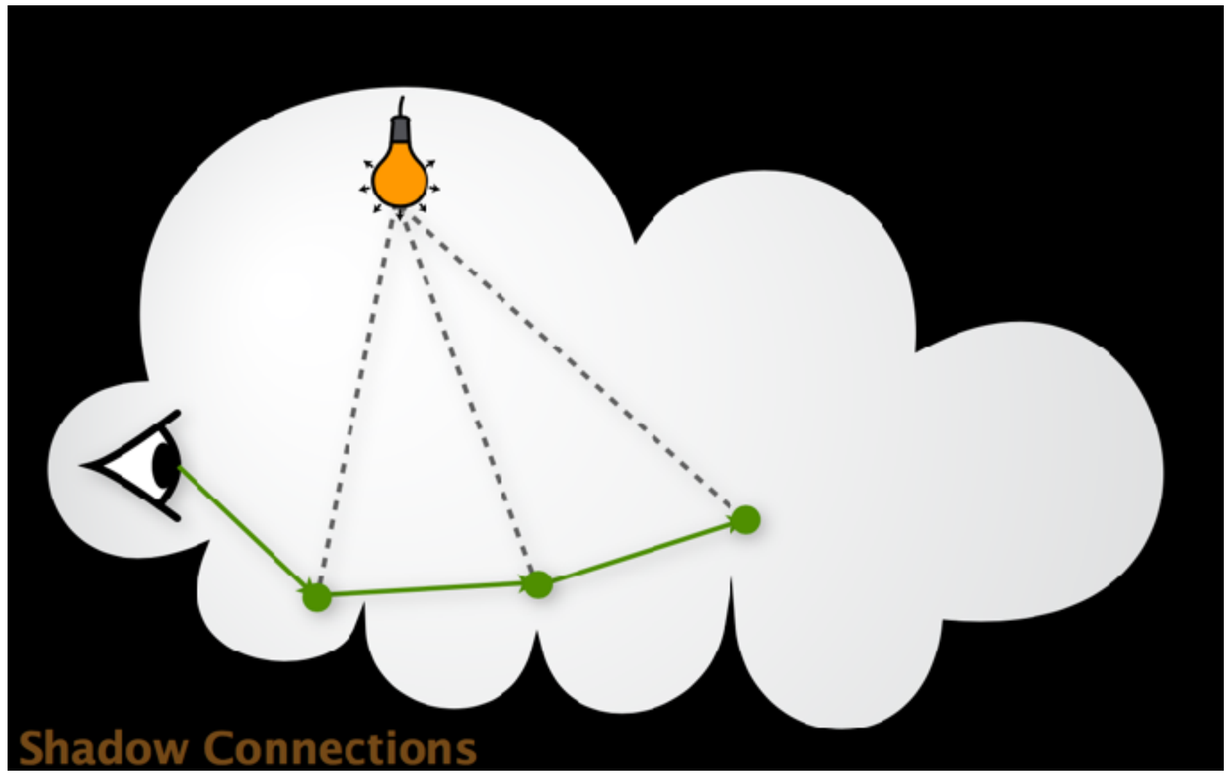


[Wojciech Jarosz]

Participating Media: Rendering

- Randomly choose a direction to bounce
- Randomly choose a distance to go straight
- At each ‘shading point’, connect to the light





[Derek Nowrouzezahrai]

Participating Media: Application

[Big Hero 6, 2014 Disney]

Participating Media: Application

[Assassin's Creed Syndicate. 2015 Ubisoft]

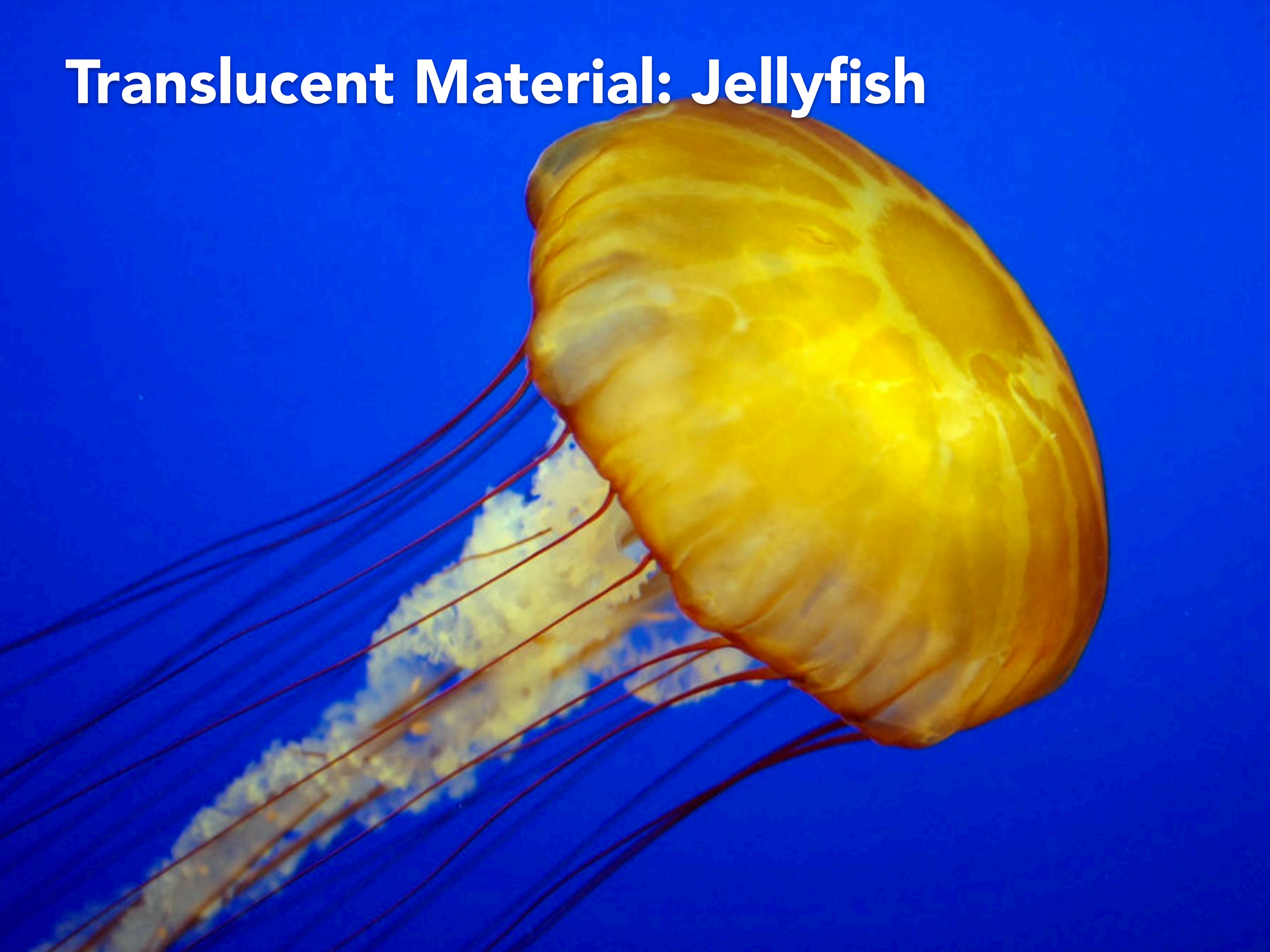
Participating Media: Demo

[Stomakhin et al. 2014]

Translucent Material (specific participating media)

Translucent Material: Jade

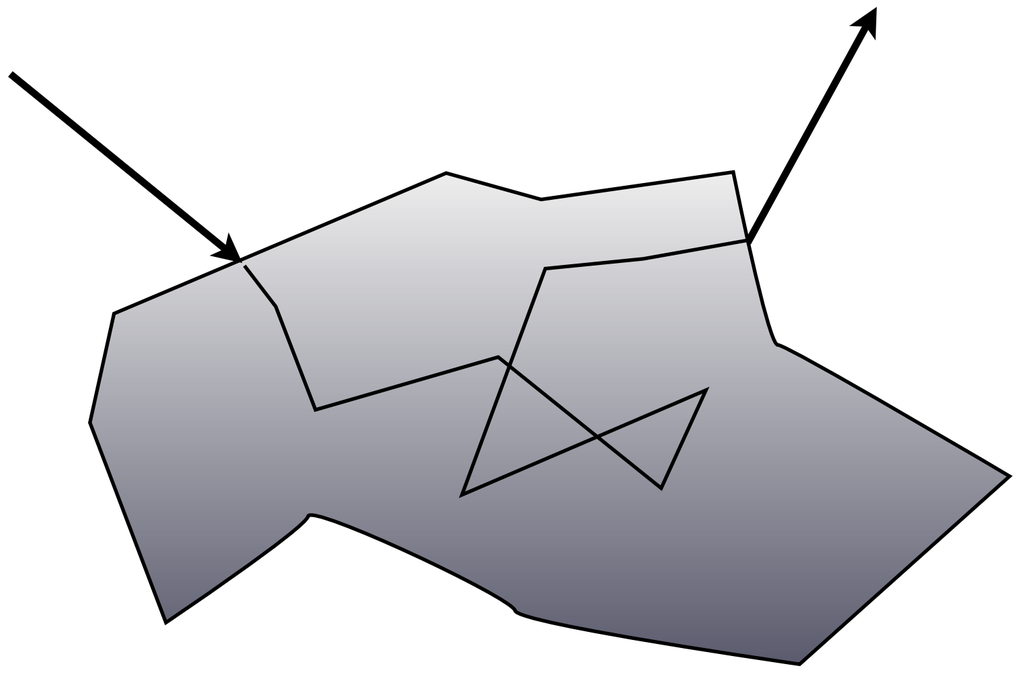
Translucent Material: Jellyfish



Subsurface Scattering

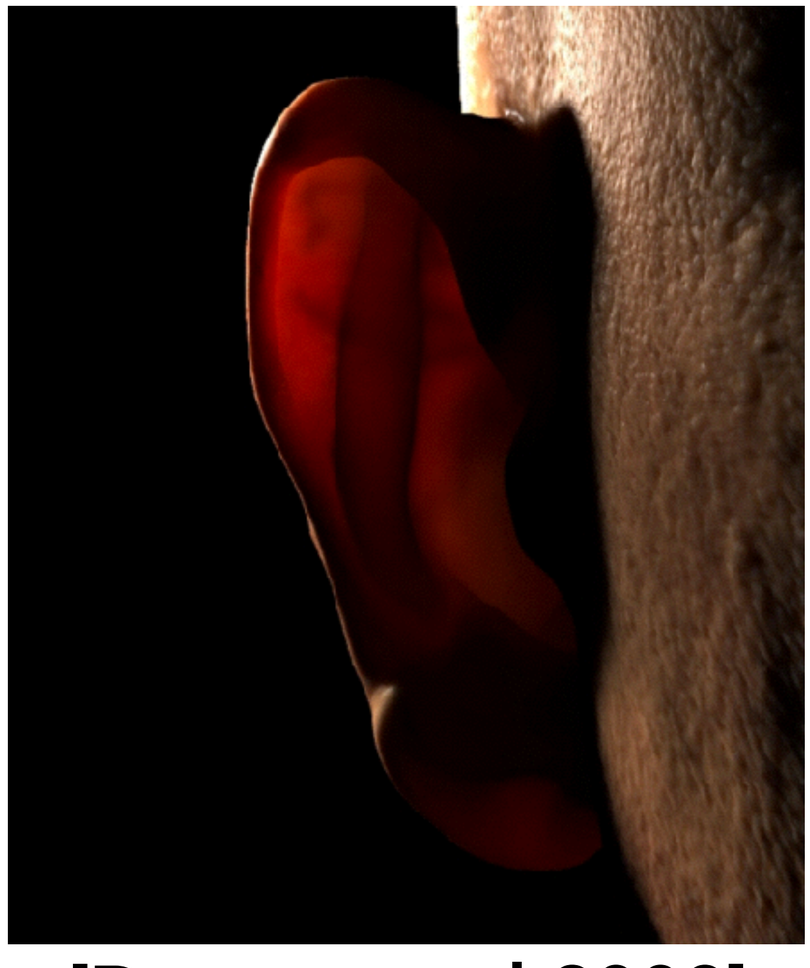
Visual characteristics of many surfaces caused by light exiting at different points than it enters

- Violates a fundamental assumption of the BRDF



- Different from transparent

[Jensen et al 2001]



[Donner et al 2008]

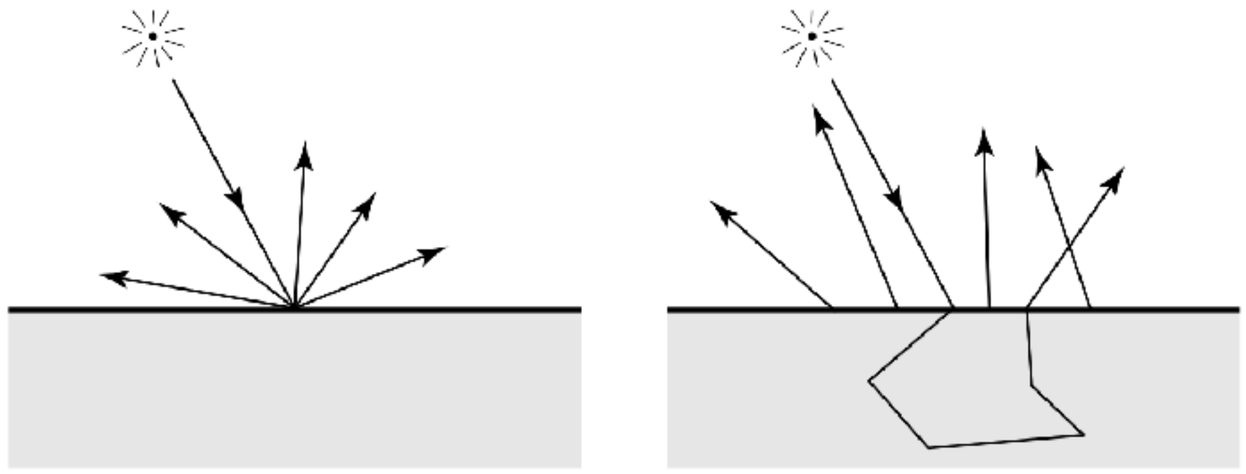
Scattering Functions

- BSSRDF: generalization of BRDF; exitant radiance at one point due to incident differential irradiance at another point:

$$S(x_i, \omega_i, x_o, \omega_o)$$

- Generalization of rendering equation: integrating over all points on the surface and all directions (!)

$$L(x_o, \omega_o) = \int_A \int_{H^2} S(x_i, \omega_i, x_o, \omega_o)\, L_i(x_i, \omega_i) \cos\theta_i \, \mathrm{d}\omega_i \, \mathrm{d}A$$

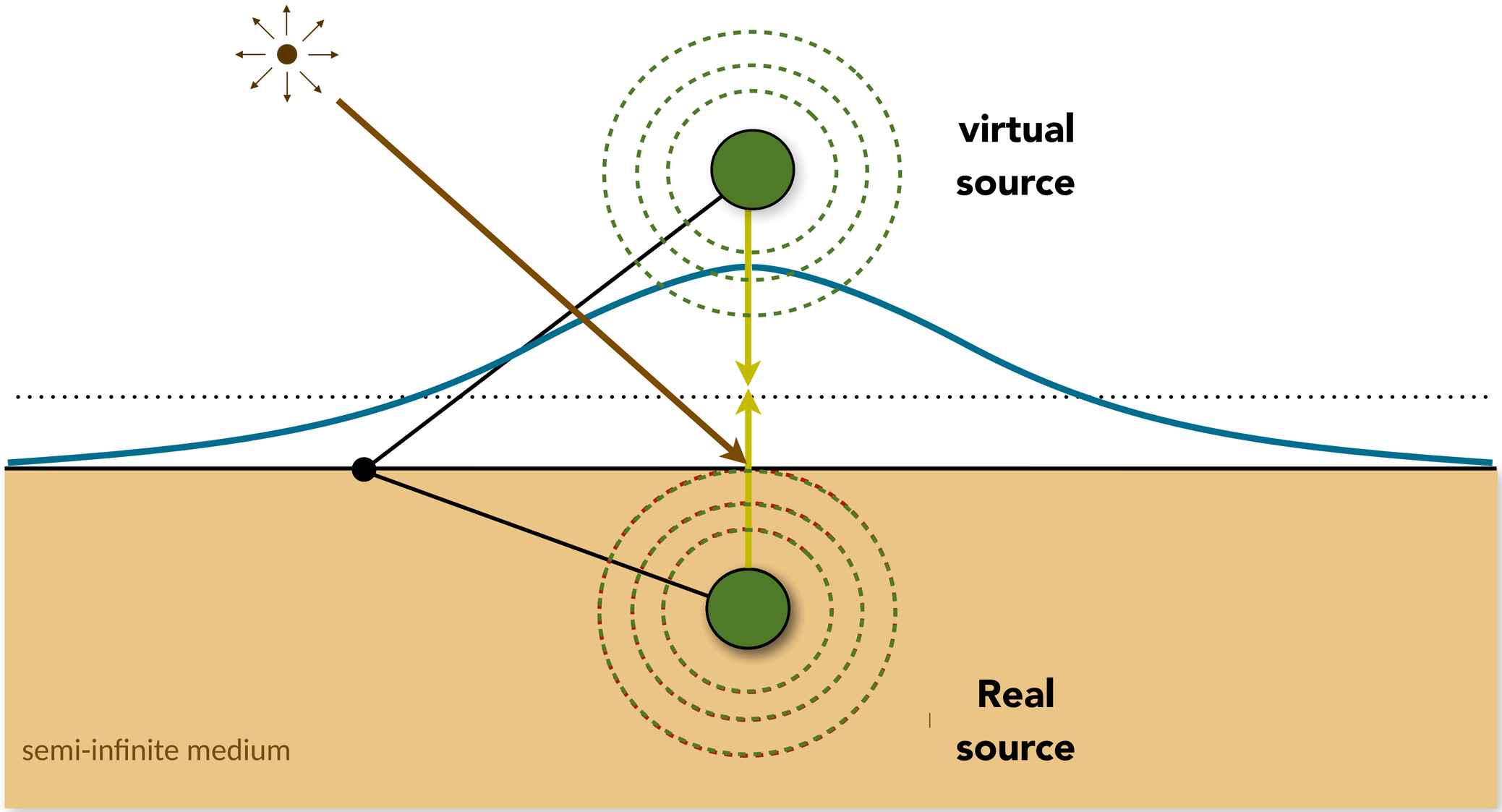


BRDF BSSRDF

[Jensen et al. 2001]

Dipole Approximation [Jensen et al. 2001]

- Approximate light diffusion by introducing two point sources.



[image from Habel et al. 2013]

BRDF

[Jensen et al. 2001]

BSSRDF

[Jensen et al. 2001]

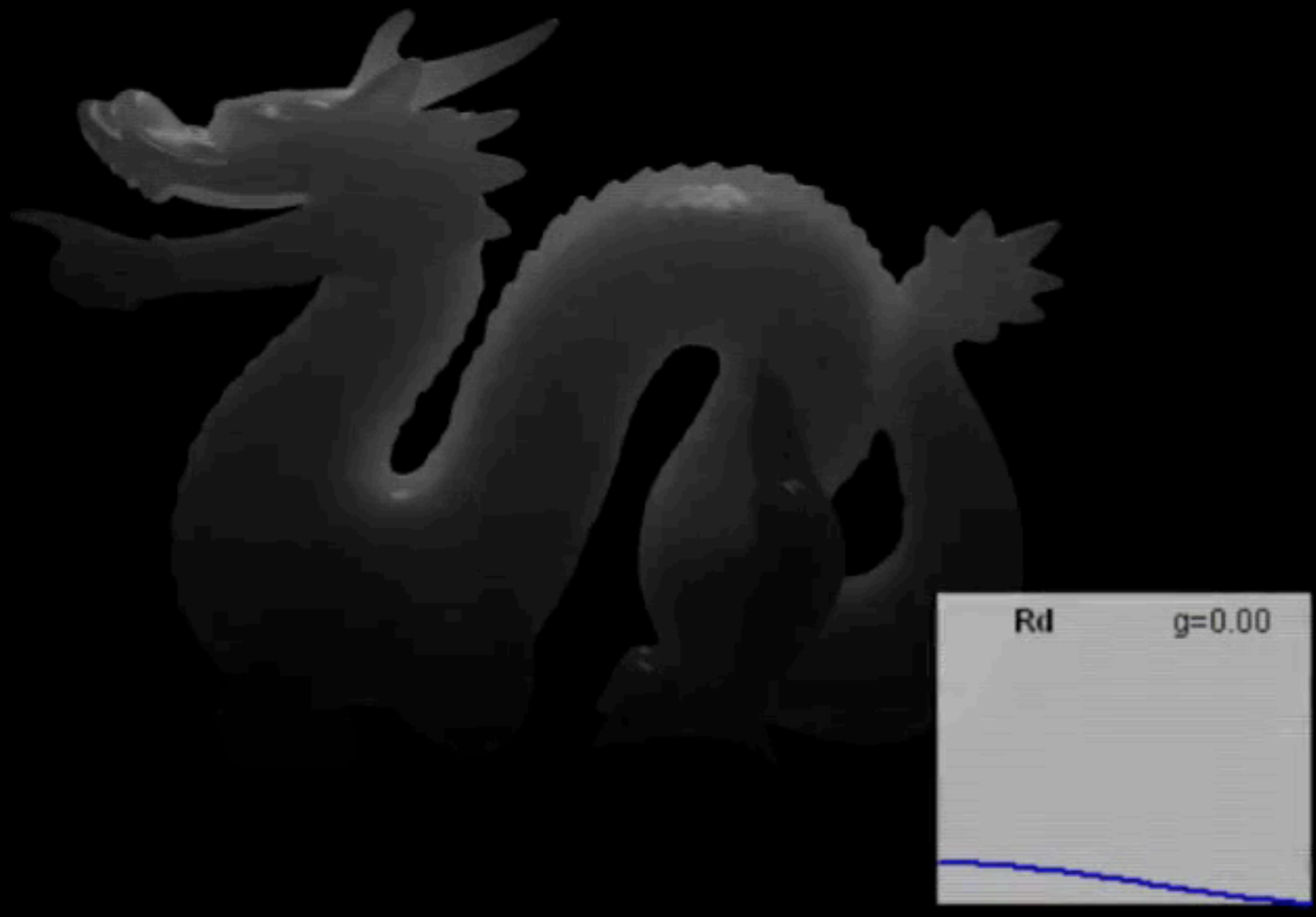
BRDF vs BSSRDF

BRDF

BSSRDF

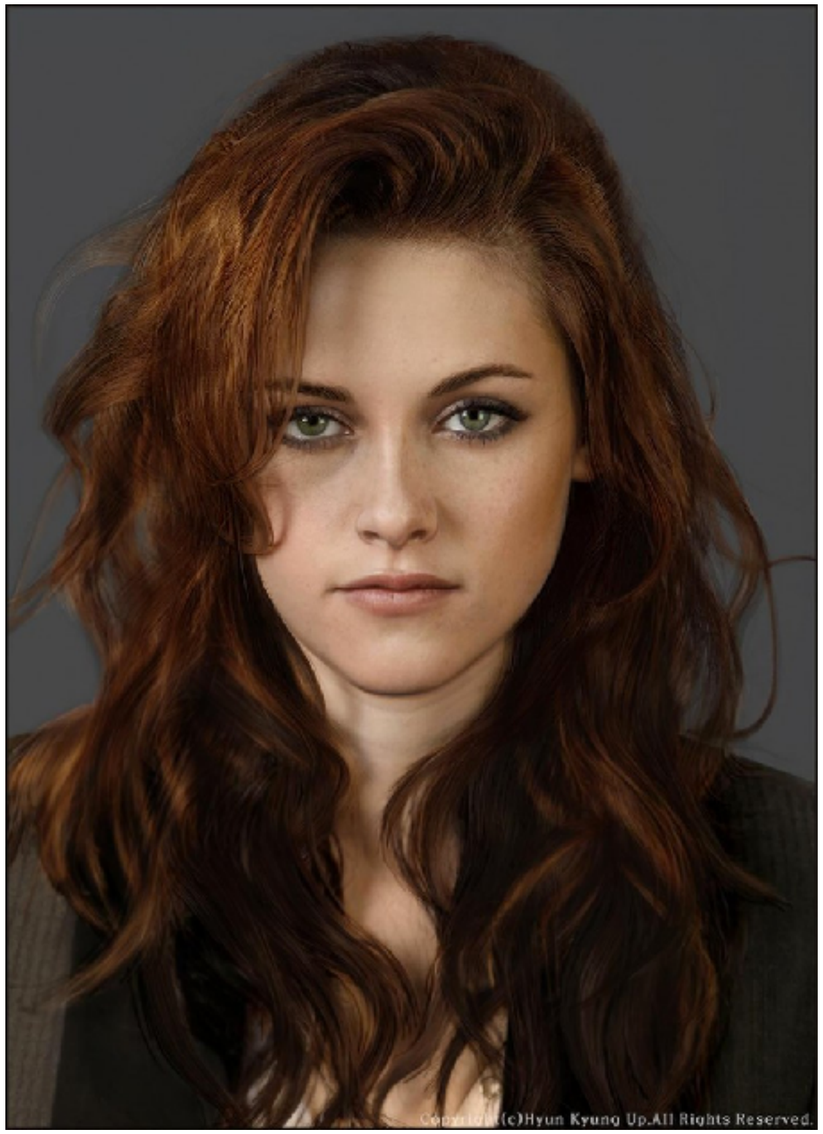
[Jensen et al. 2001]

BSSRDF: Demo



BSSRDF: Application

[Artist: Teruyuki and Yuka]



[Artist: Hyun Kyung]

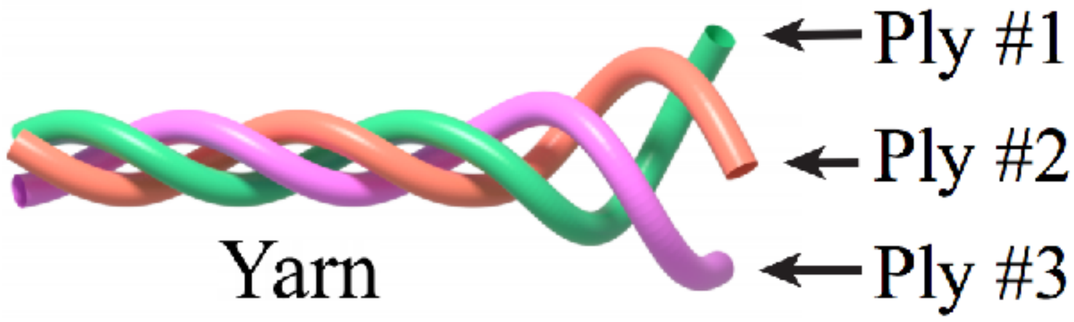
[Artist: Dan Roarty]

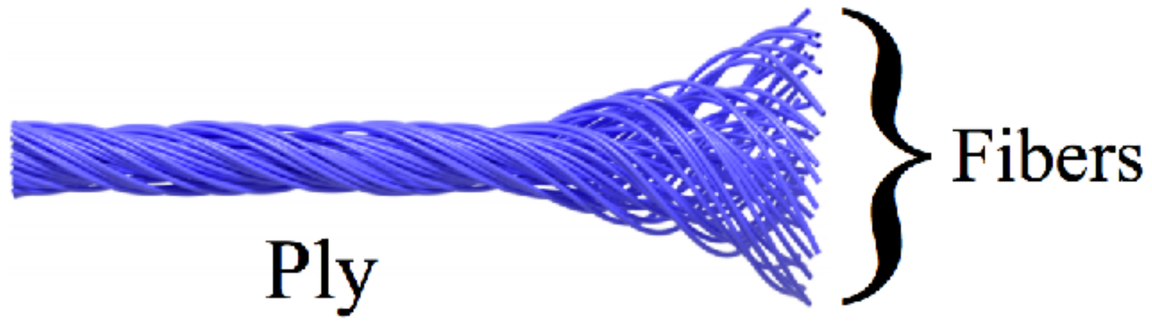
https://cgelves.com/10-most-realistic-human-3d-models-that-will-wow-you/

Cloth Models

Cloth

- A collection of twisted fibers!
- Two levels of twist

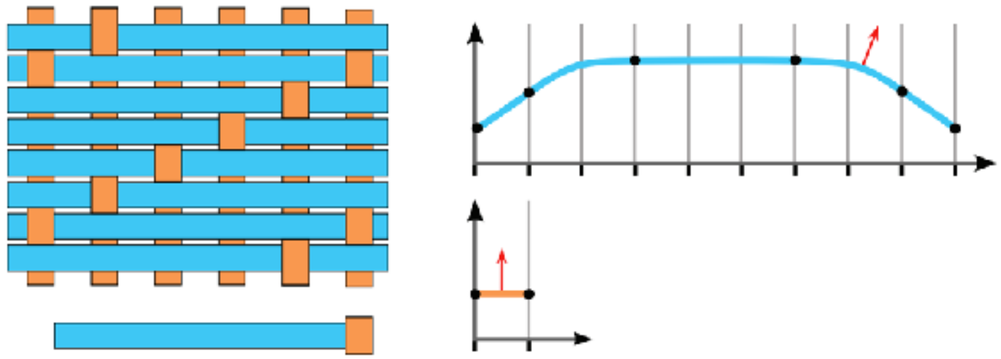


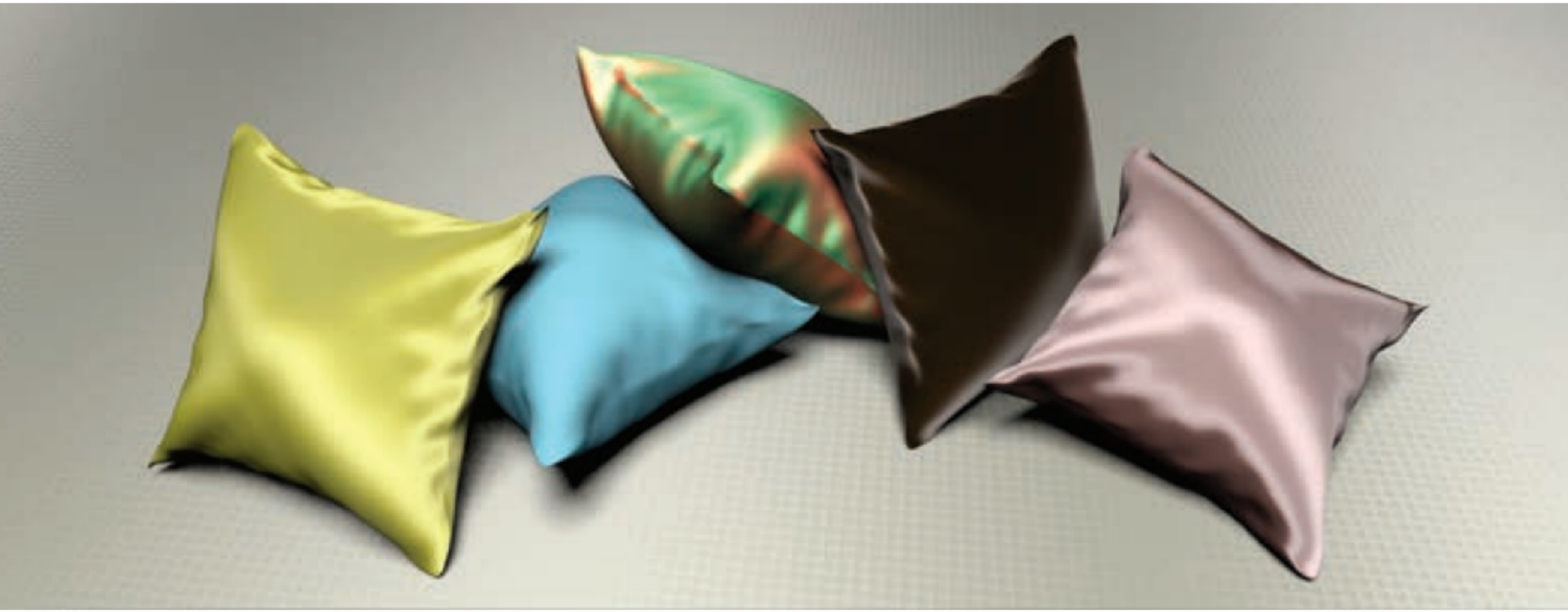


- Woven or knitted

Cloth: Render as Surface

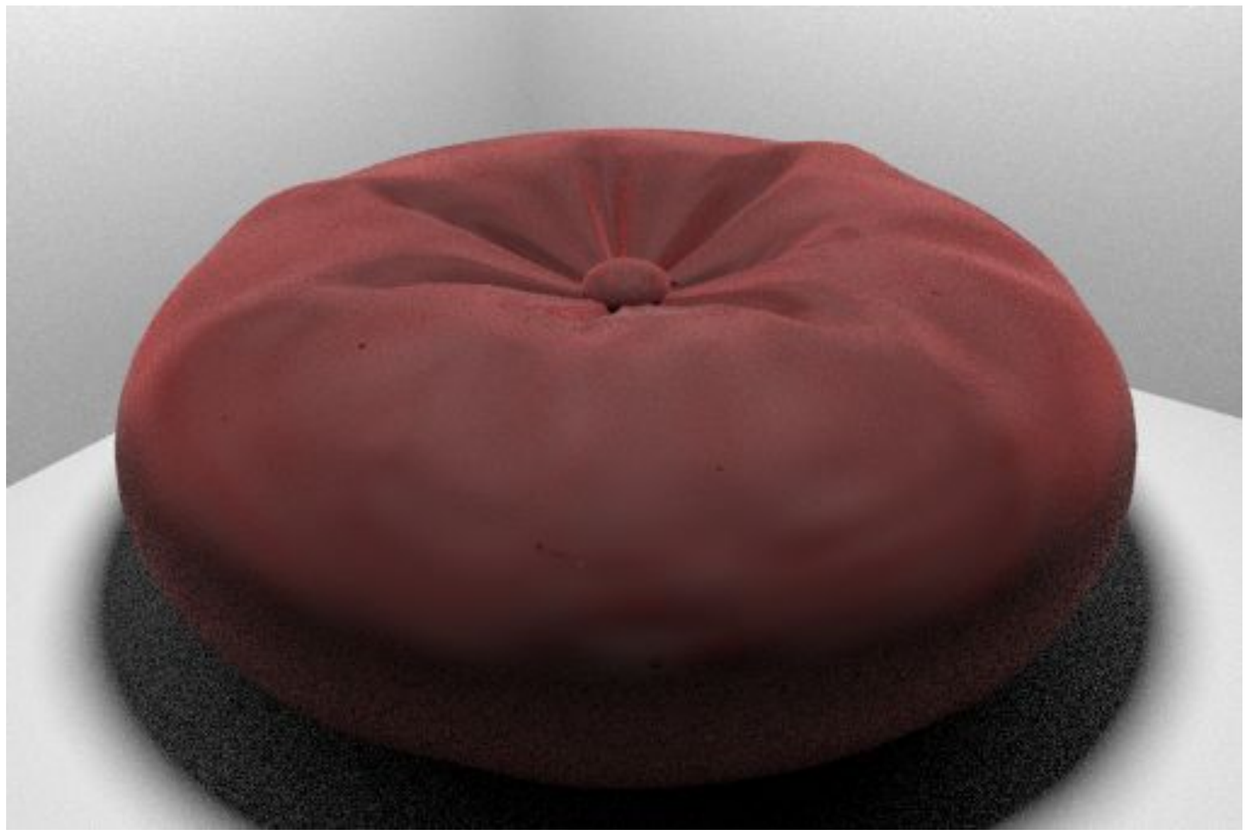
- Given the weaving pattern, calculate the overall behavior
- Render using a BRDF

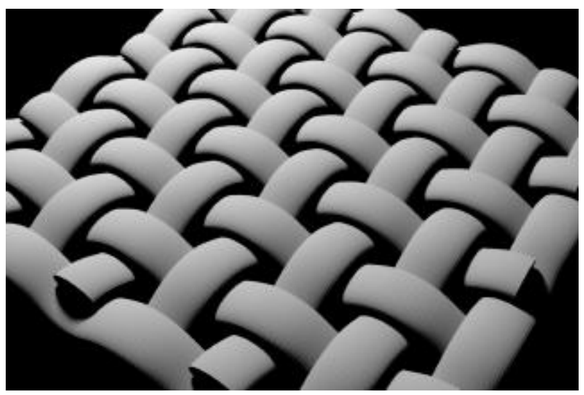




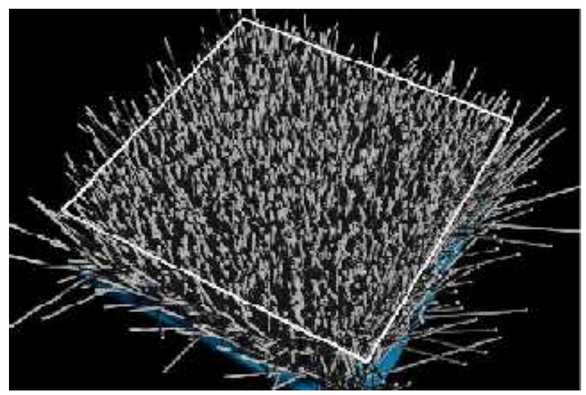
[Sadeghi et al. 2013]

Render as Surface — Limitation





[Westin et al. 1992]



Cloth: Render as Participating Media

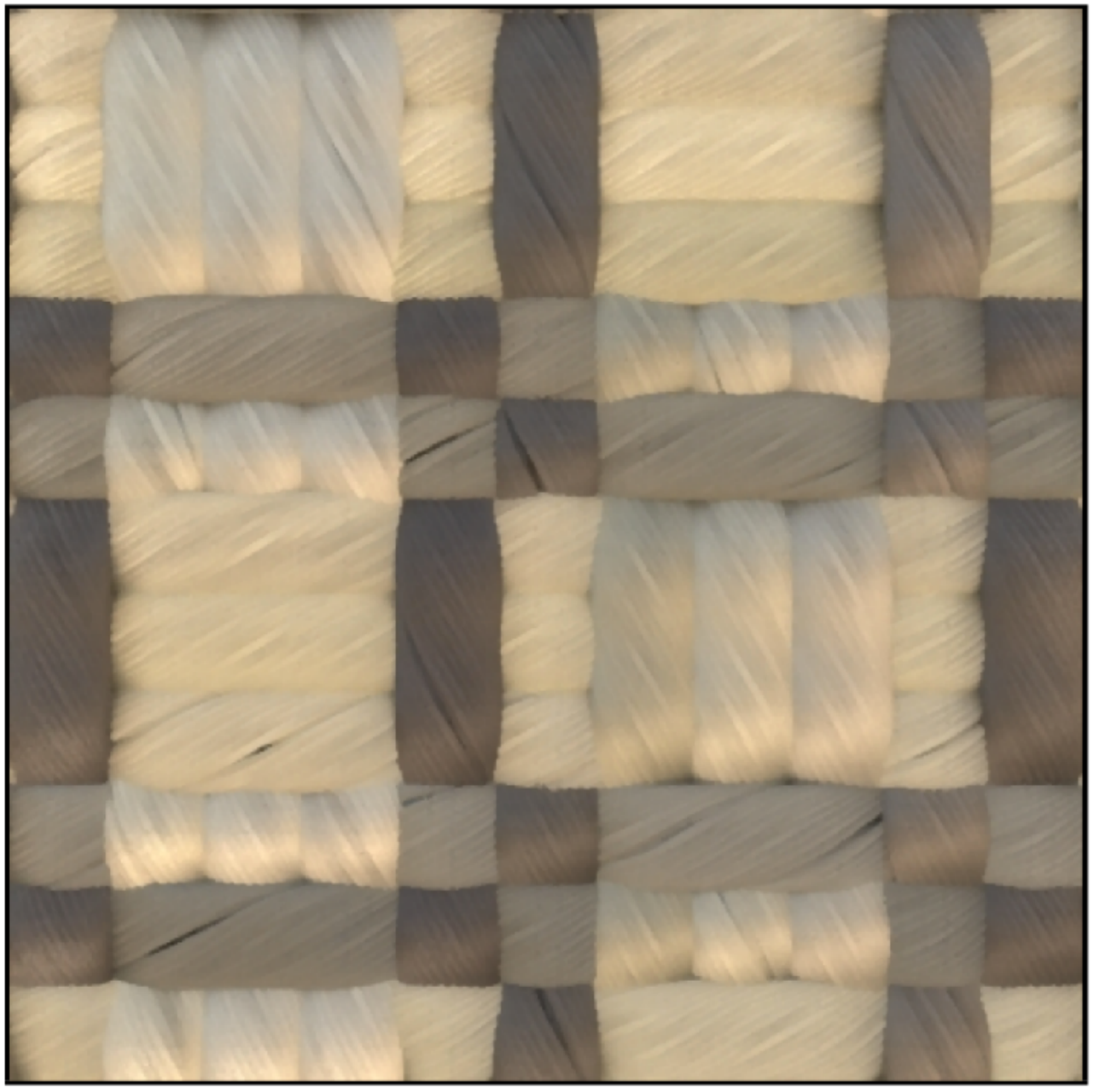
- Properties of individual fibers & their distribution -> scattering parameters
- Render as a participating medium

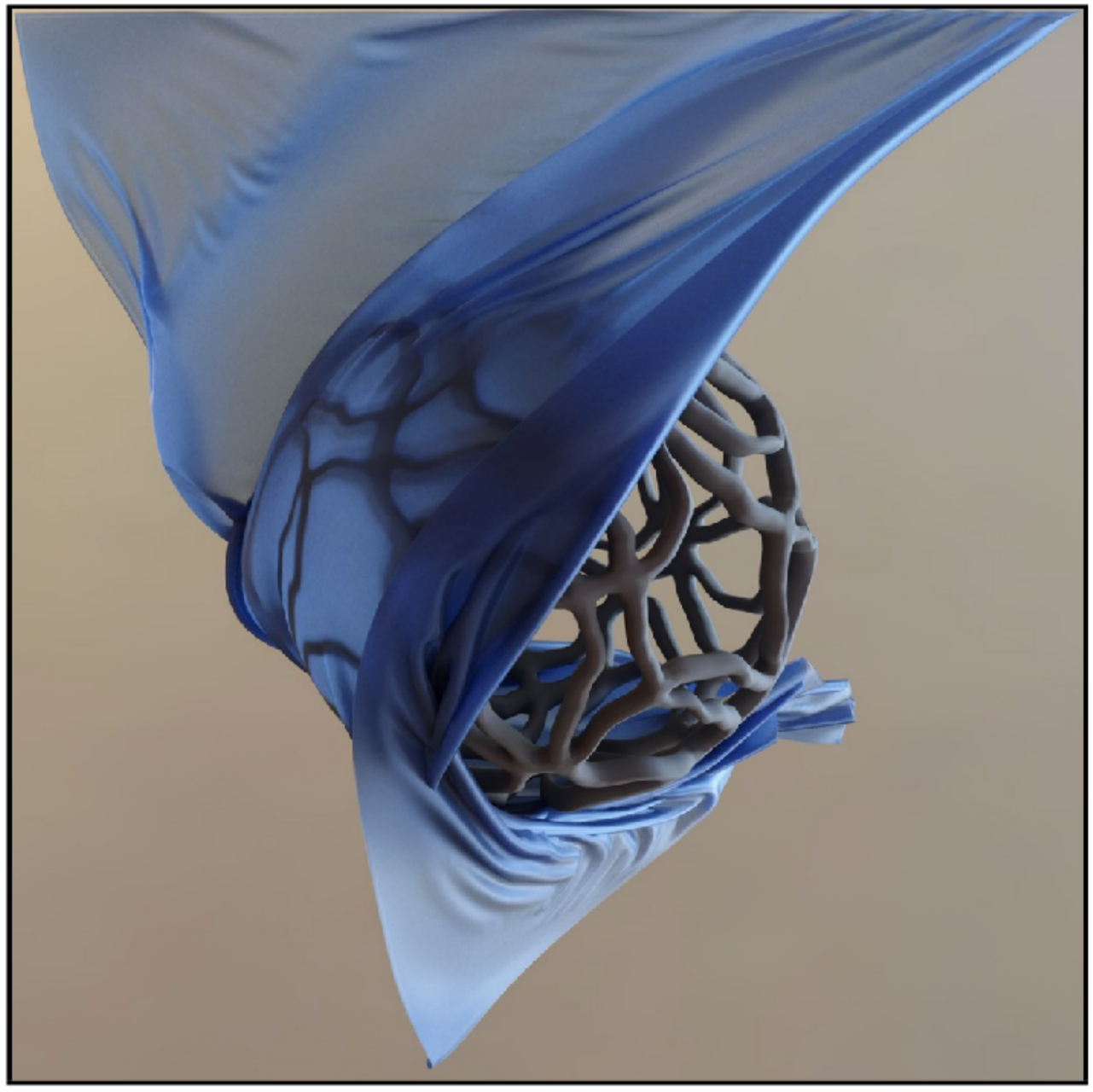
[Jakob et al. 2010]

[Schroder et al. 2011]

Cloth: Render as Actual Fibers

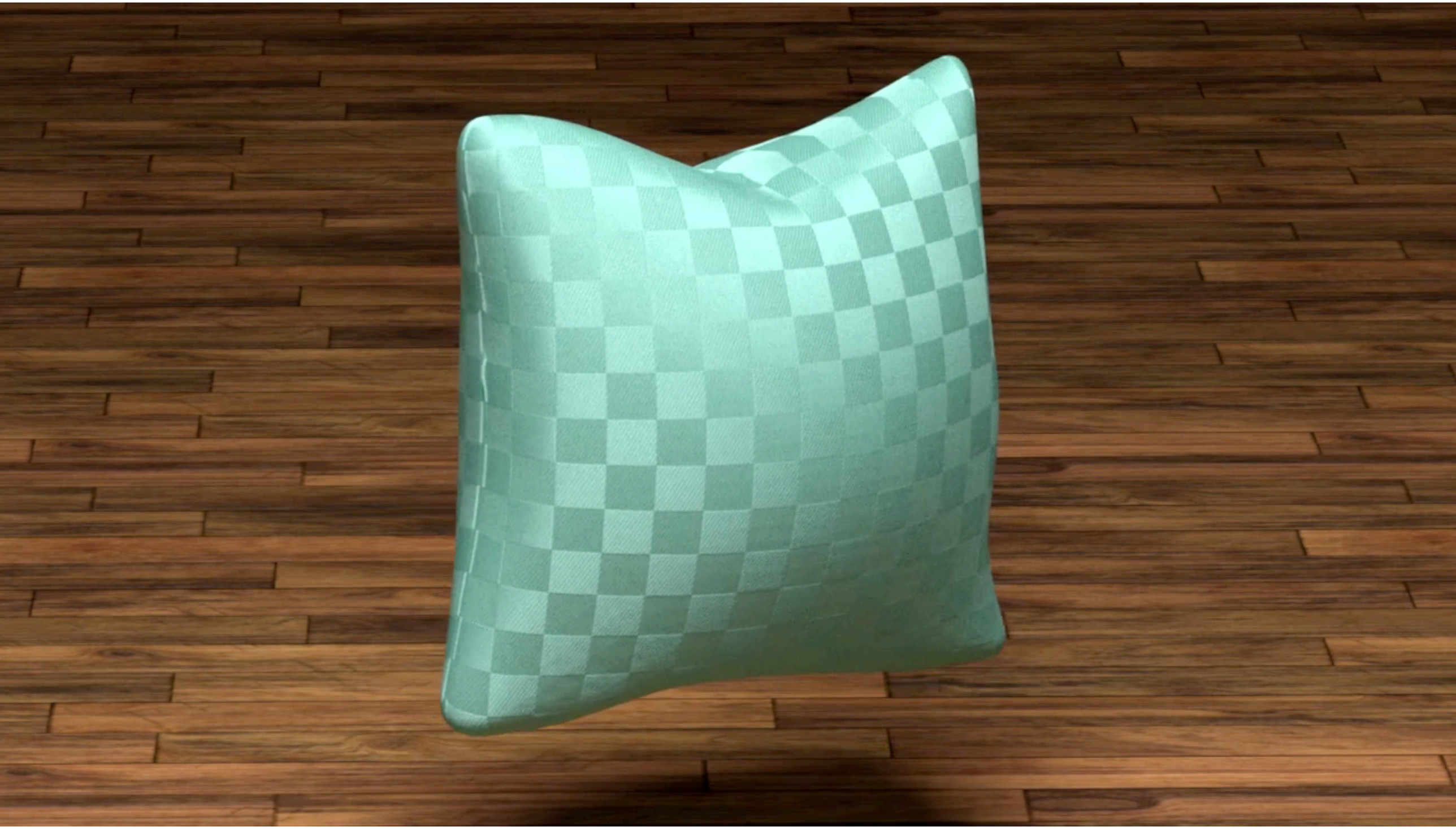
- Render every fiber explicitly!





[Kai Schroder]

Cloth: Demo



[Shuang et al. 2012]

Cloth: Application

[The BFG. 2016 Disney]

Cloth: Application

[Avametric, by Prof. James F. O'Brien]

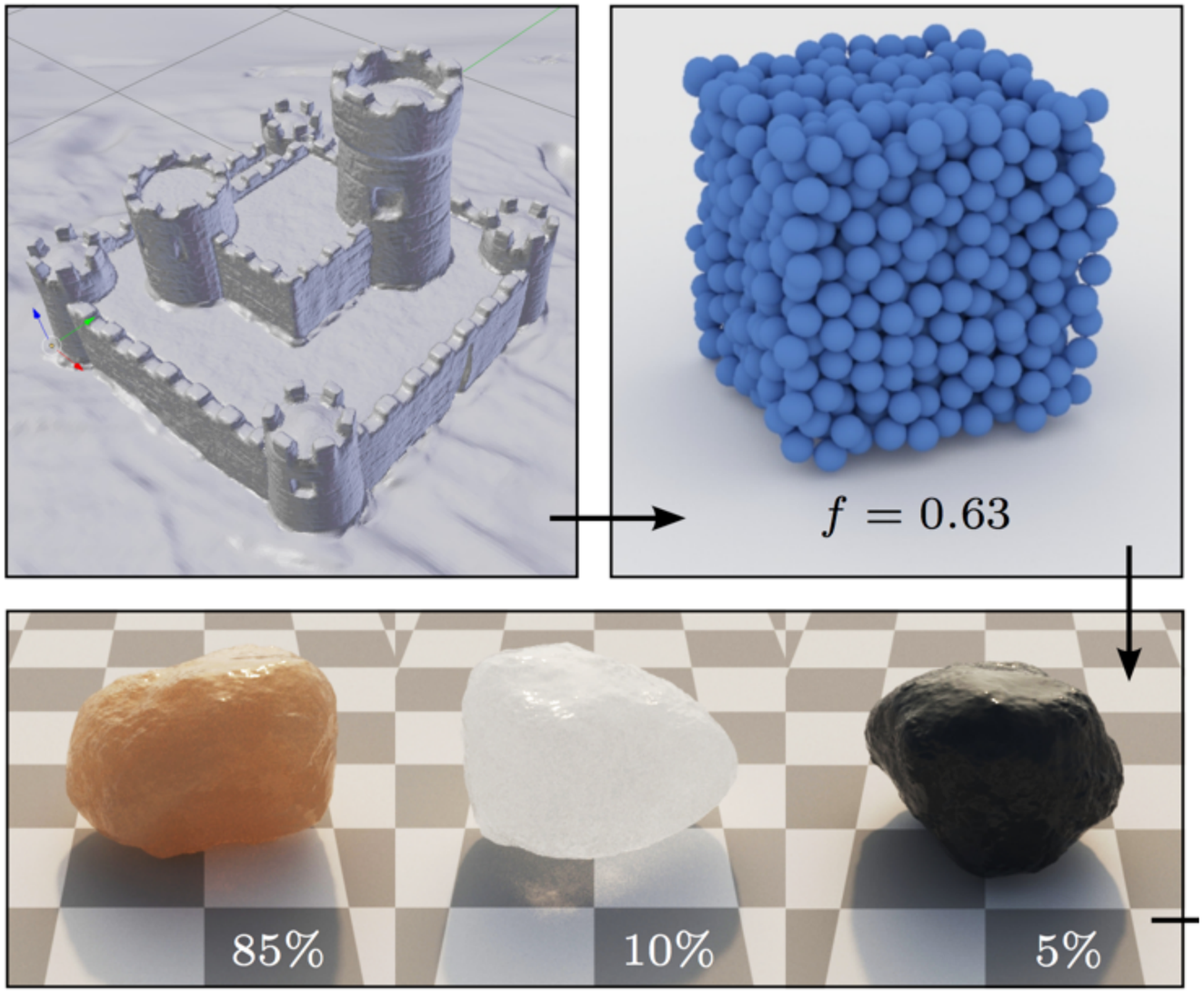
Granular Material

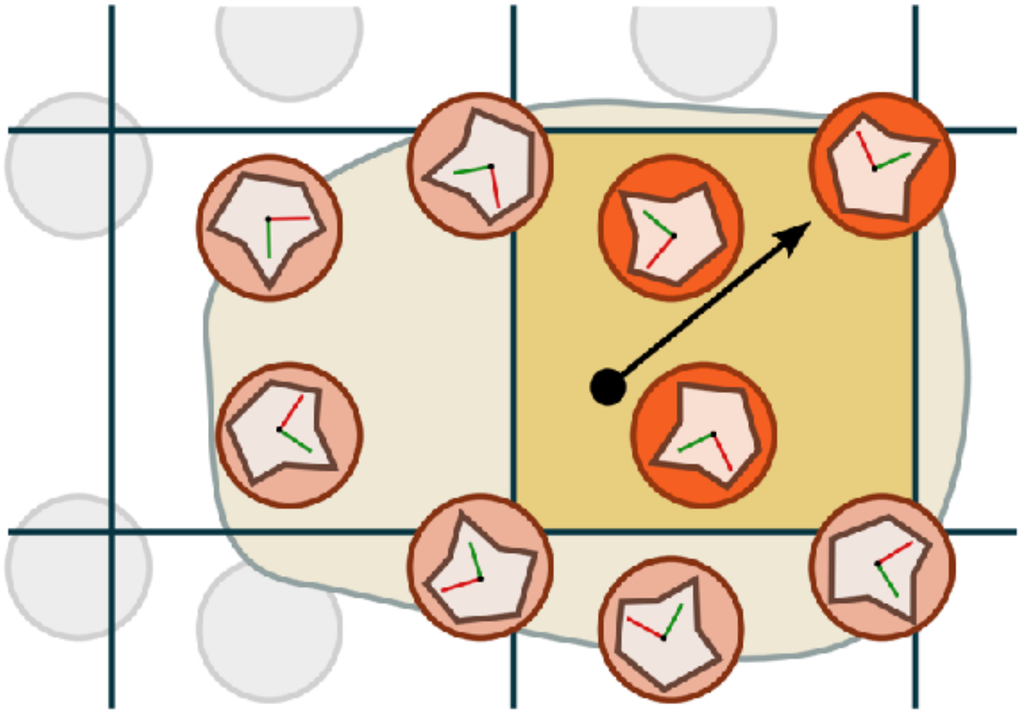
Granular Material

- What is granular material?

Granular Material

- Can we avoid explicit modeling of all granules?
  - Yes with procedural definition.





Granular Material

Granular Material: Application

[Piper. 2016 Pixar]

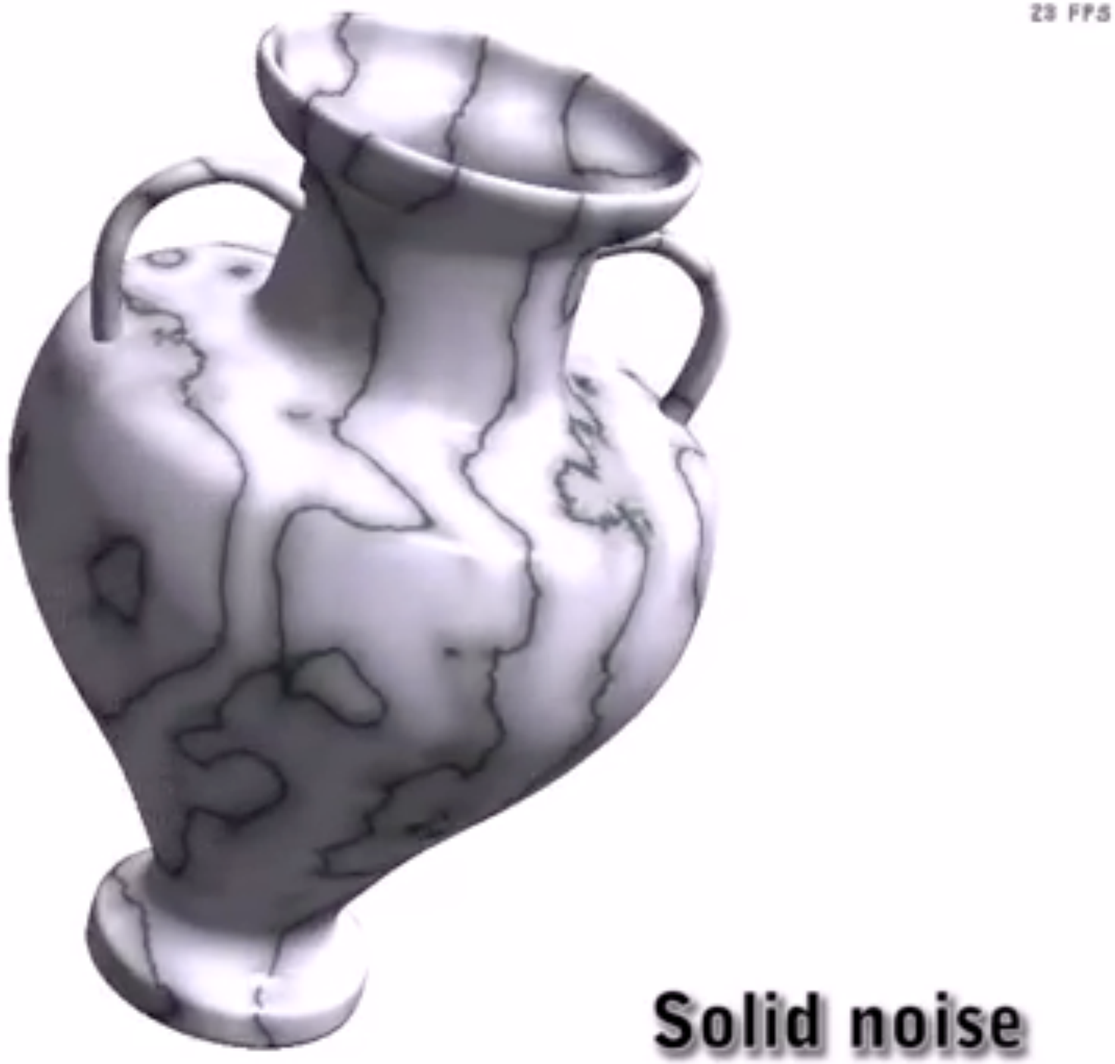
Procedural Appearance

Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.

Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.
  - 3D noise ->
    internal structure
    if cut or broken



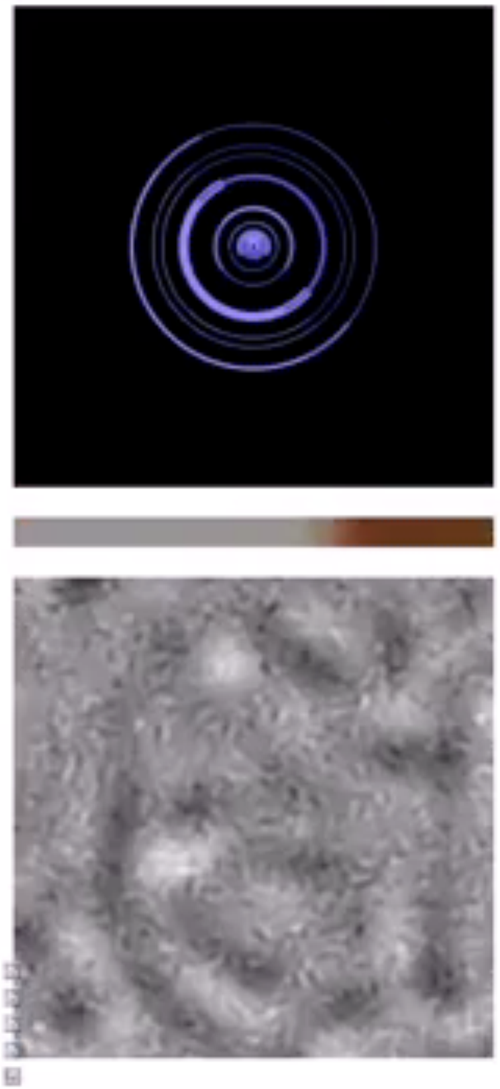
[Lagae et al. 2009]

Procedural Appearance

- Can we define details without textures?
  - Yes! Compute a noise function on the fly.
  - Thresholding
    (noise -> binary noise)

Example:

```
if noise(x, y, z) > threshold:
    reflectance = 1
else:
    reflectance = 0
```



[Lagae et al. 2009]

Procedural Appearance

- Complex noise functions can be very powerful.

Procedural Appearance

- Complex noise functions can be very powerful.

[Steve Worley]

Procedural Appearance

- Complex noise functions can be very powerful.

[Liu et al. 2016]

Procedural Appearance

- Complex noise functions can be very powerful.

[Liu et al. 2016]

Acknowledgments

Thanks to LingQi Yan for these slides.