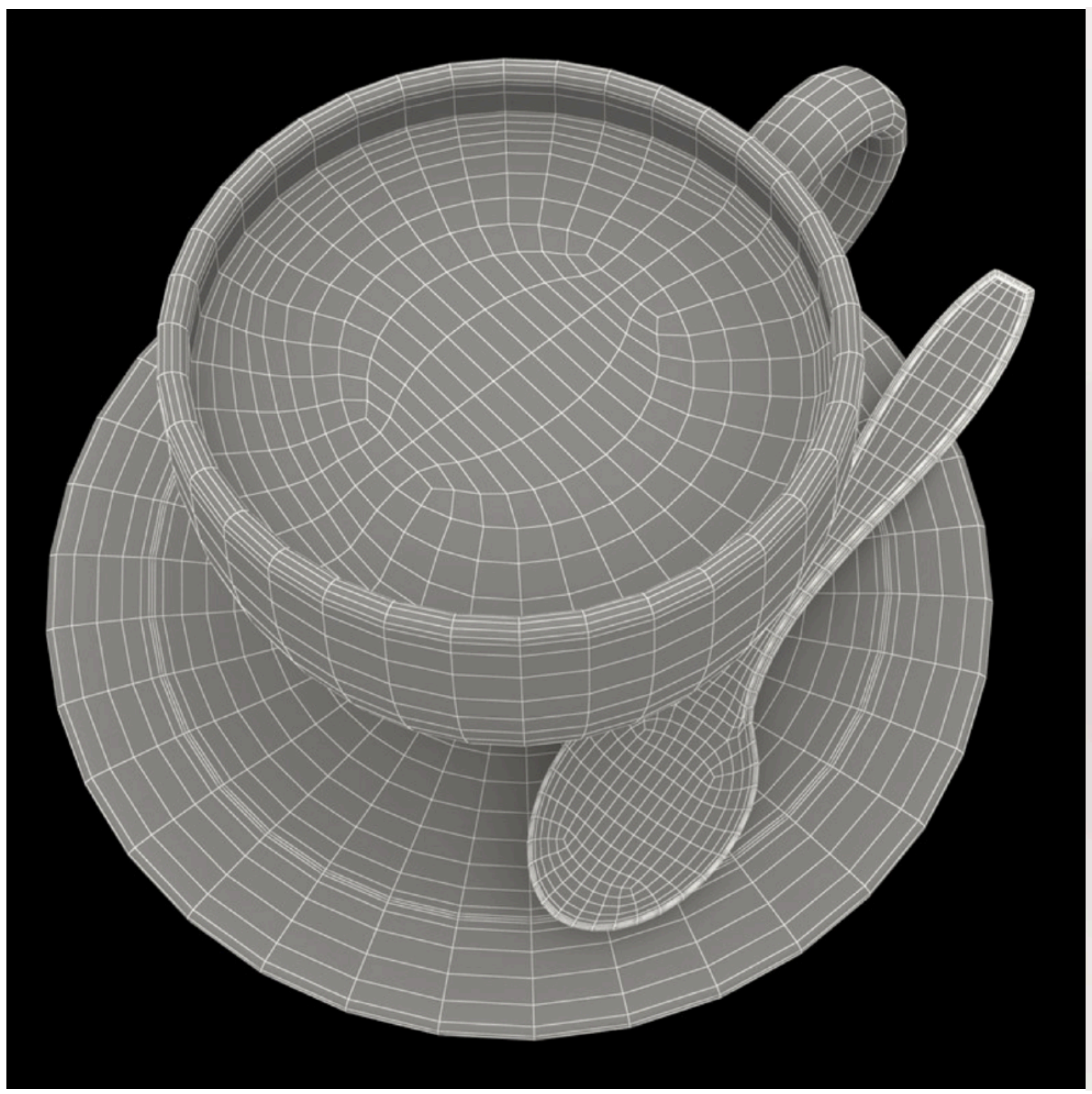
Lecture 14:

Introduction to Material Modeling

Computer Graphics and Imaging
UC Berkeley CS184/284A

What is Material in Computer Graphics?



3D coffee mug model

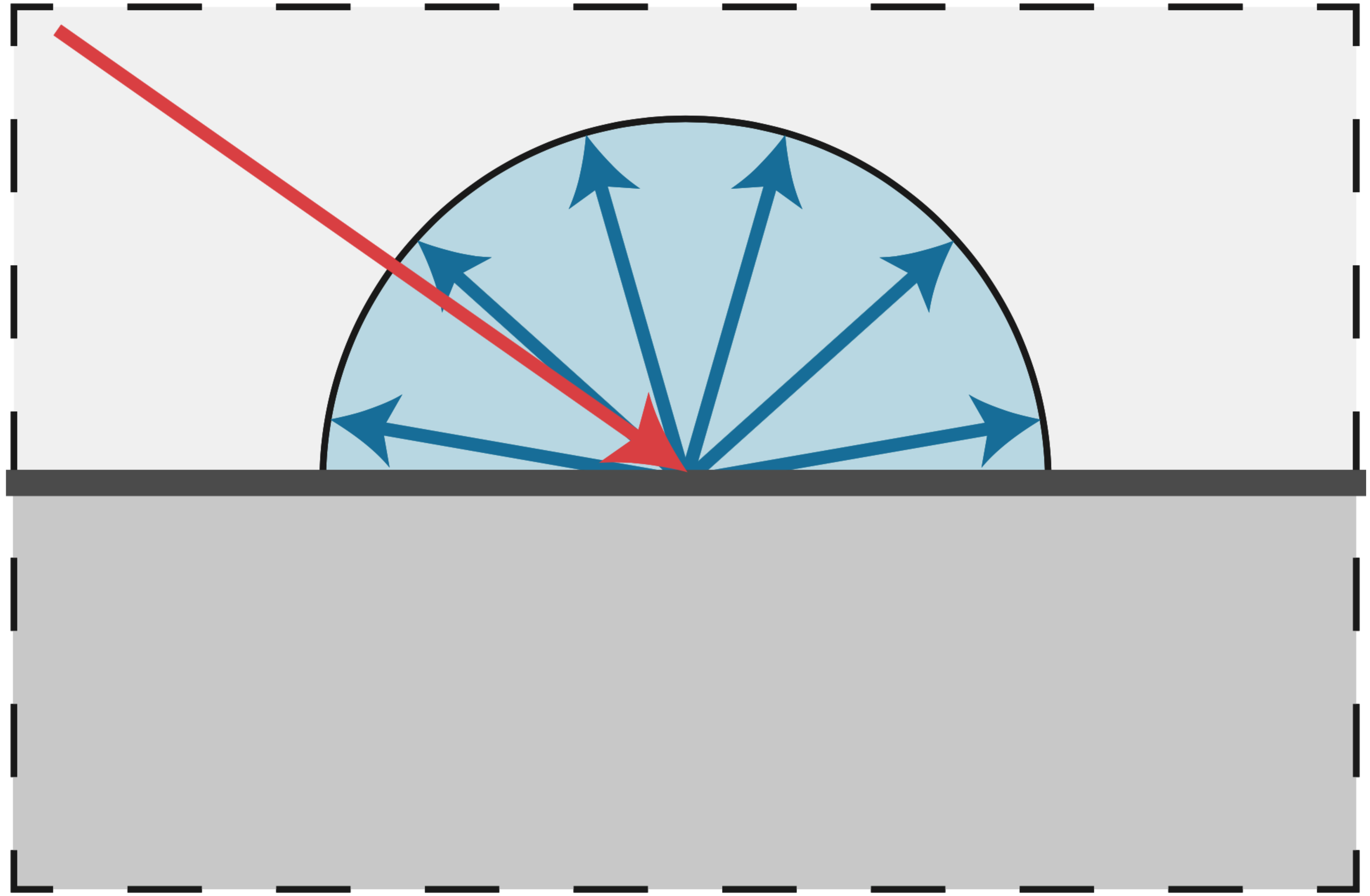
Rendered

Rendered

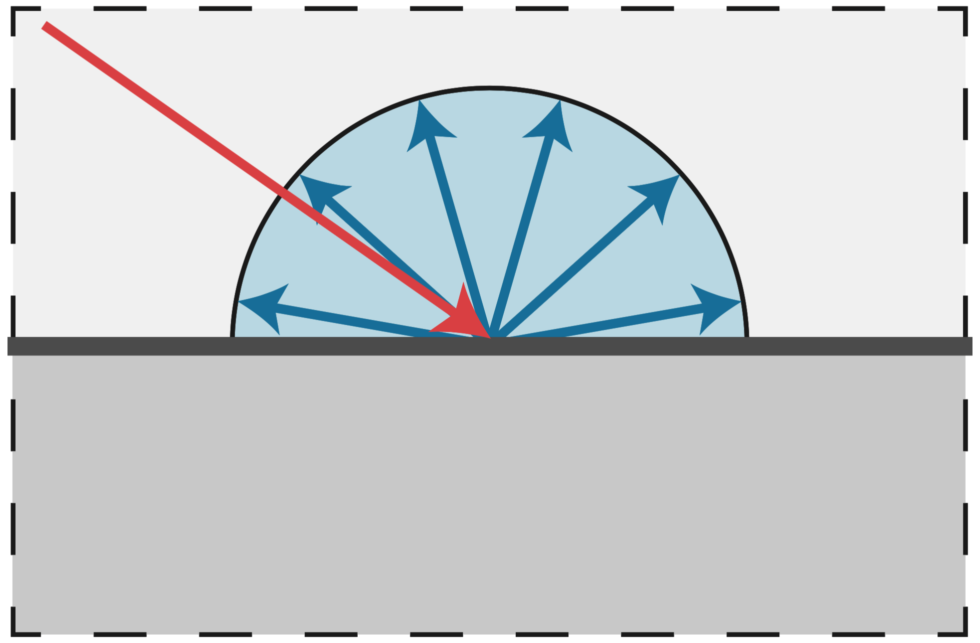
[From TurboSquid, created by artist 3dror]

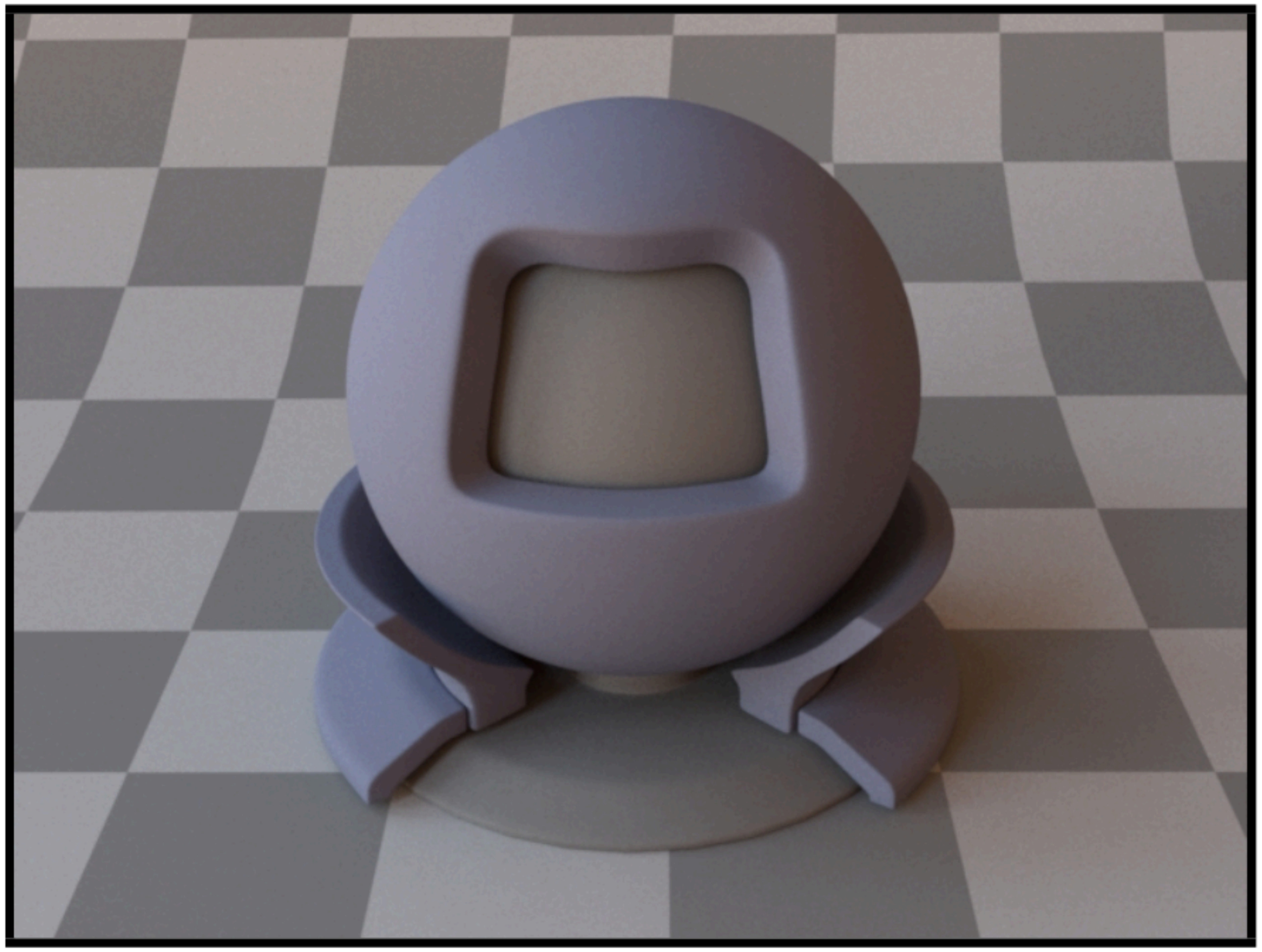
Material == BRDF

What is this material?

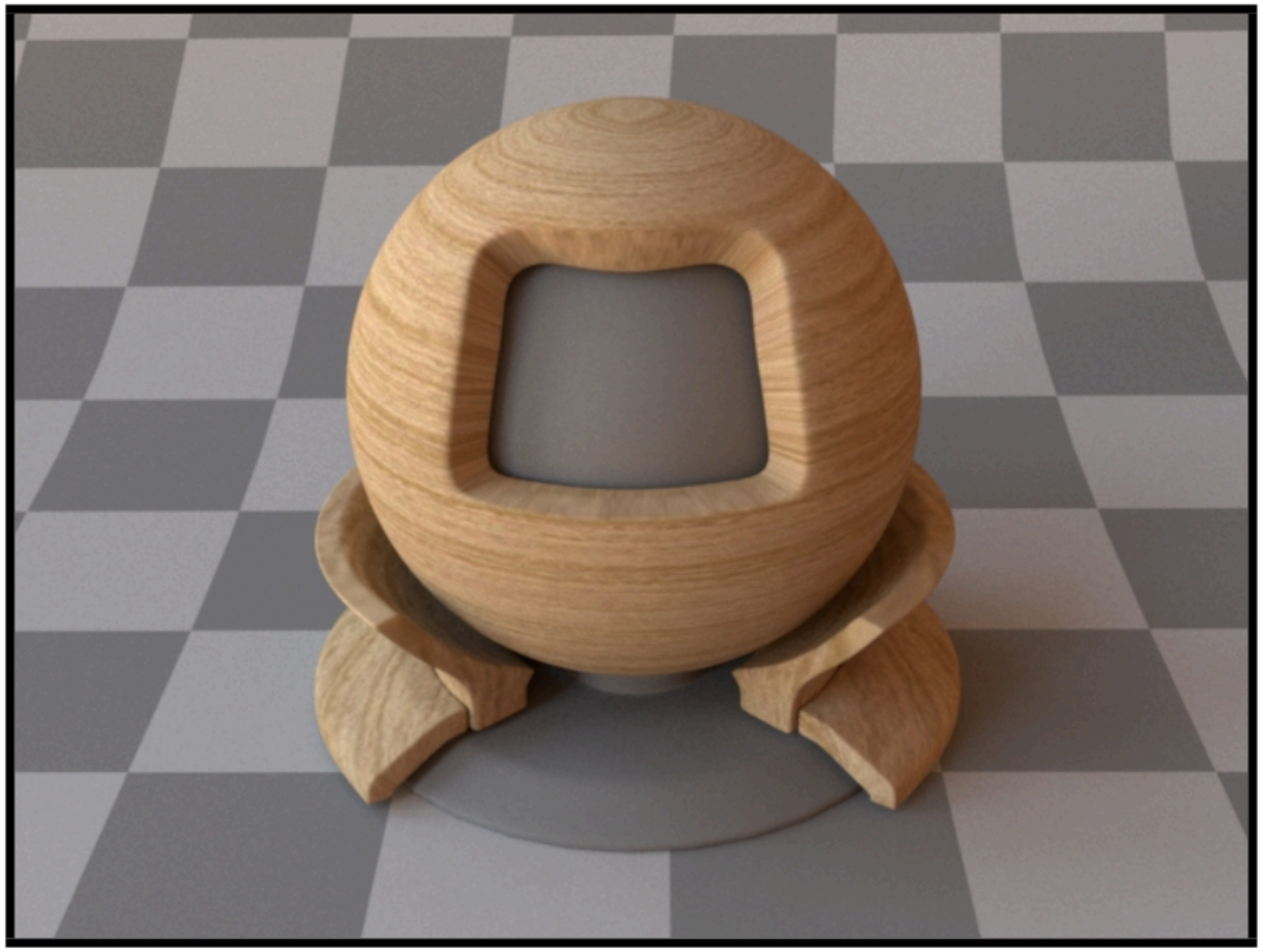


Diffuse / Lambertian Material (BRDF)



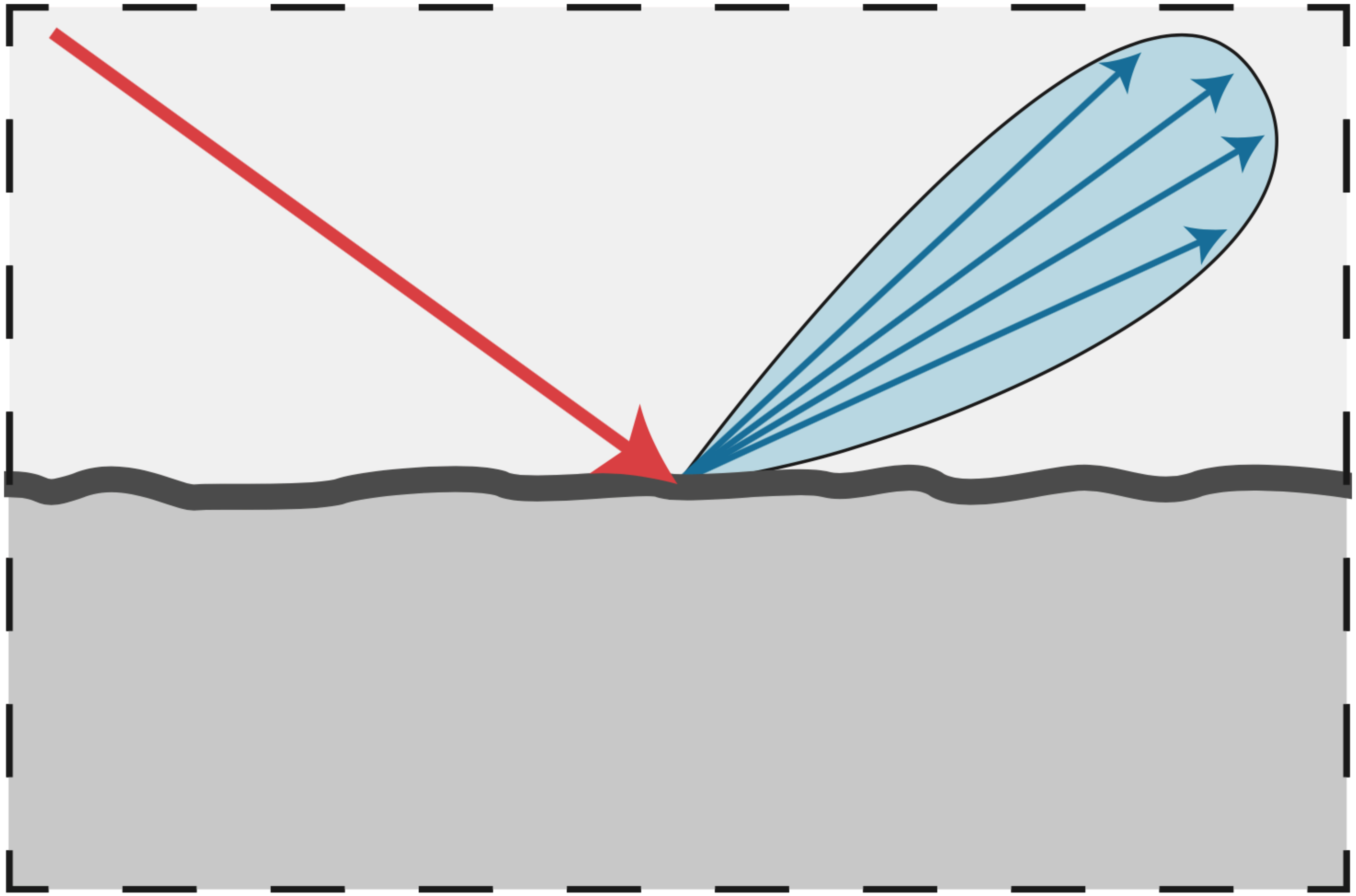


Uniform colored diffuse BRDF

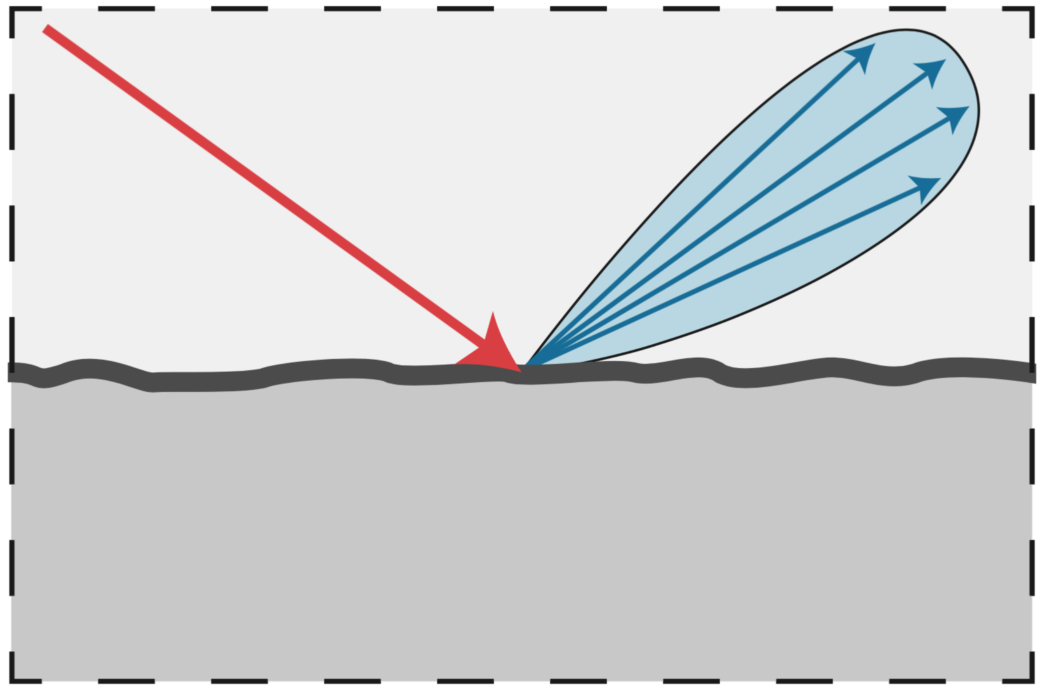


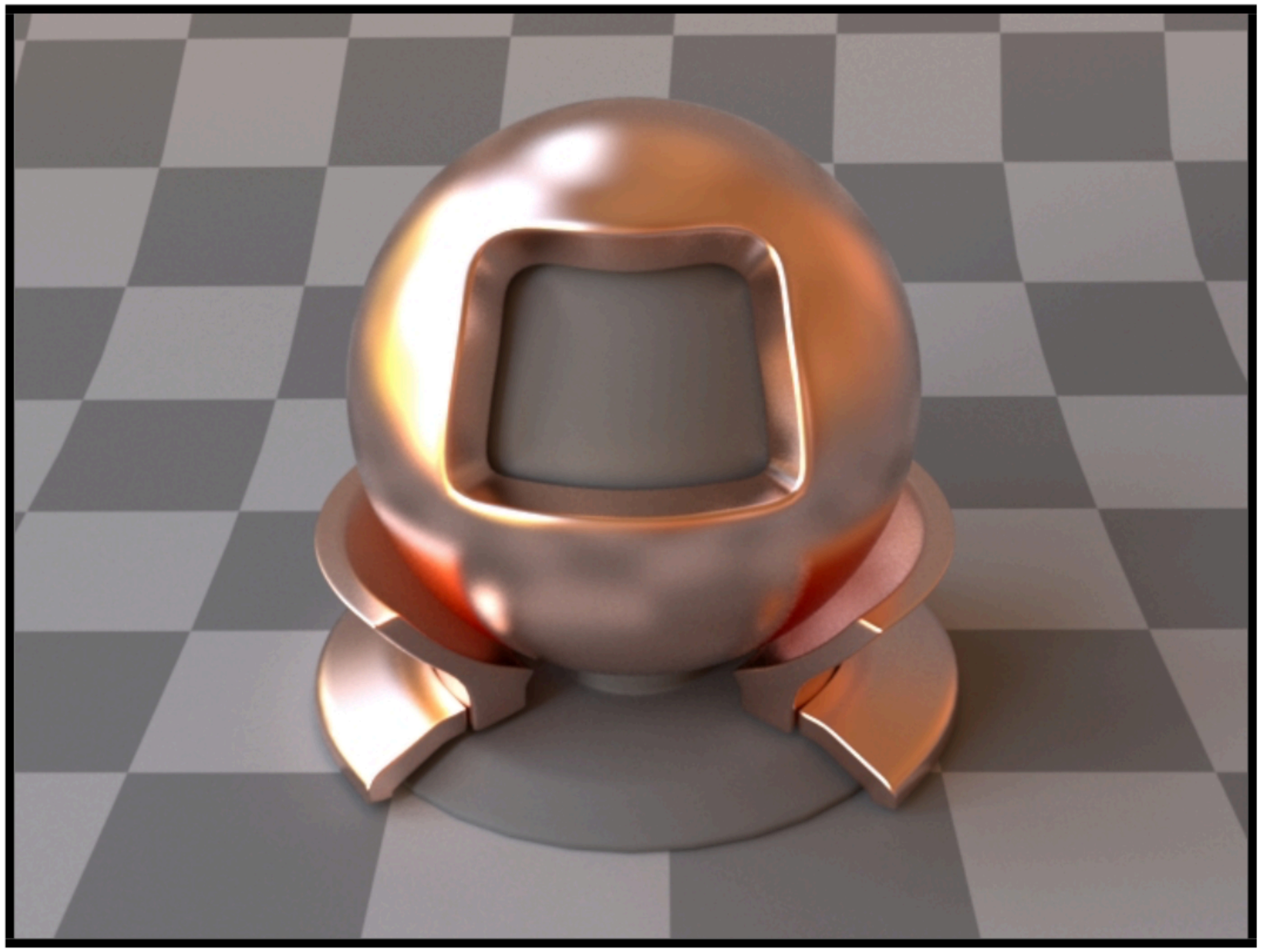
Textured diffuse BRDF

What is this material?

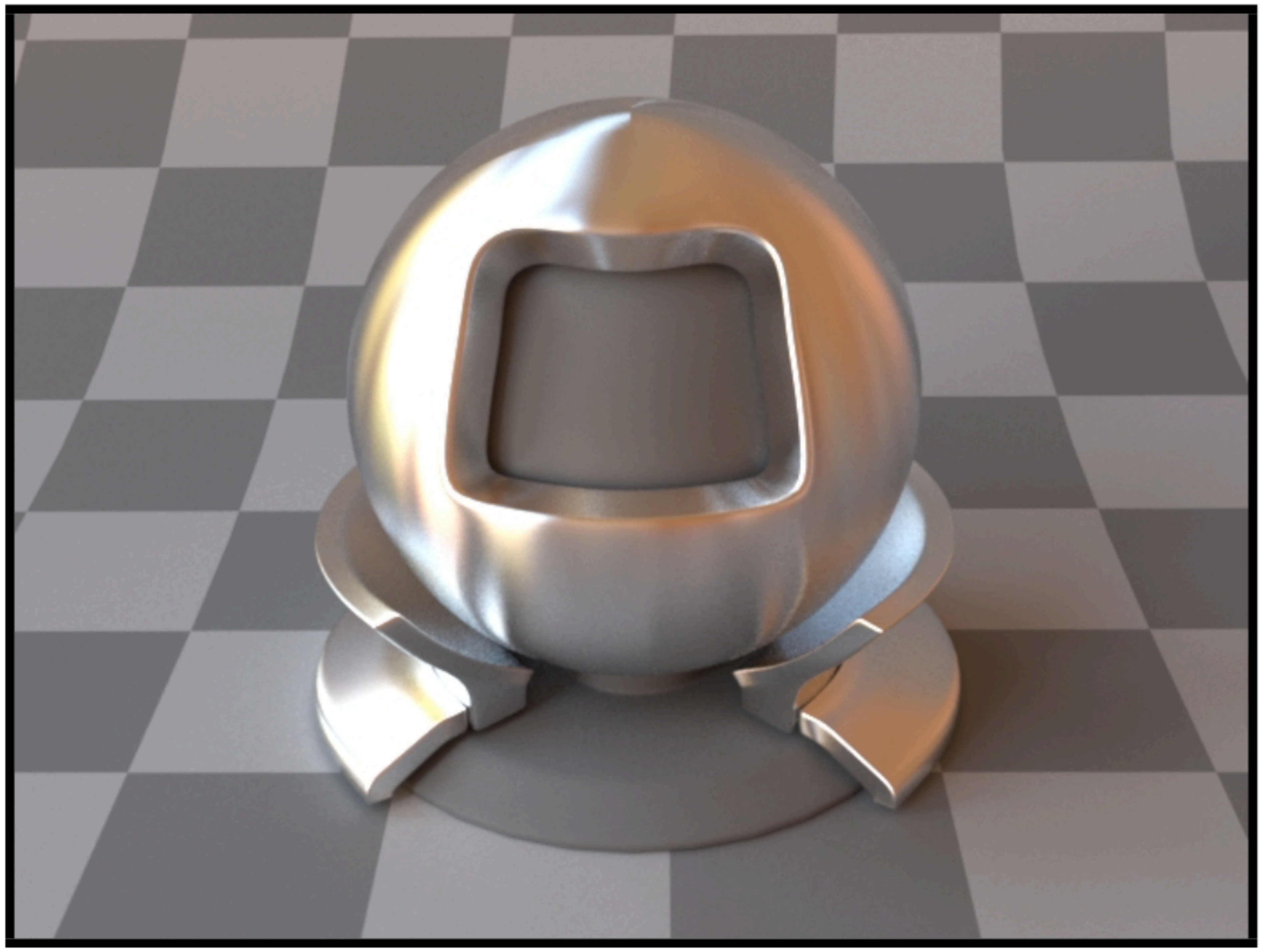


Glossy material (BRDF)





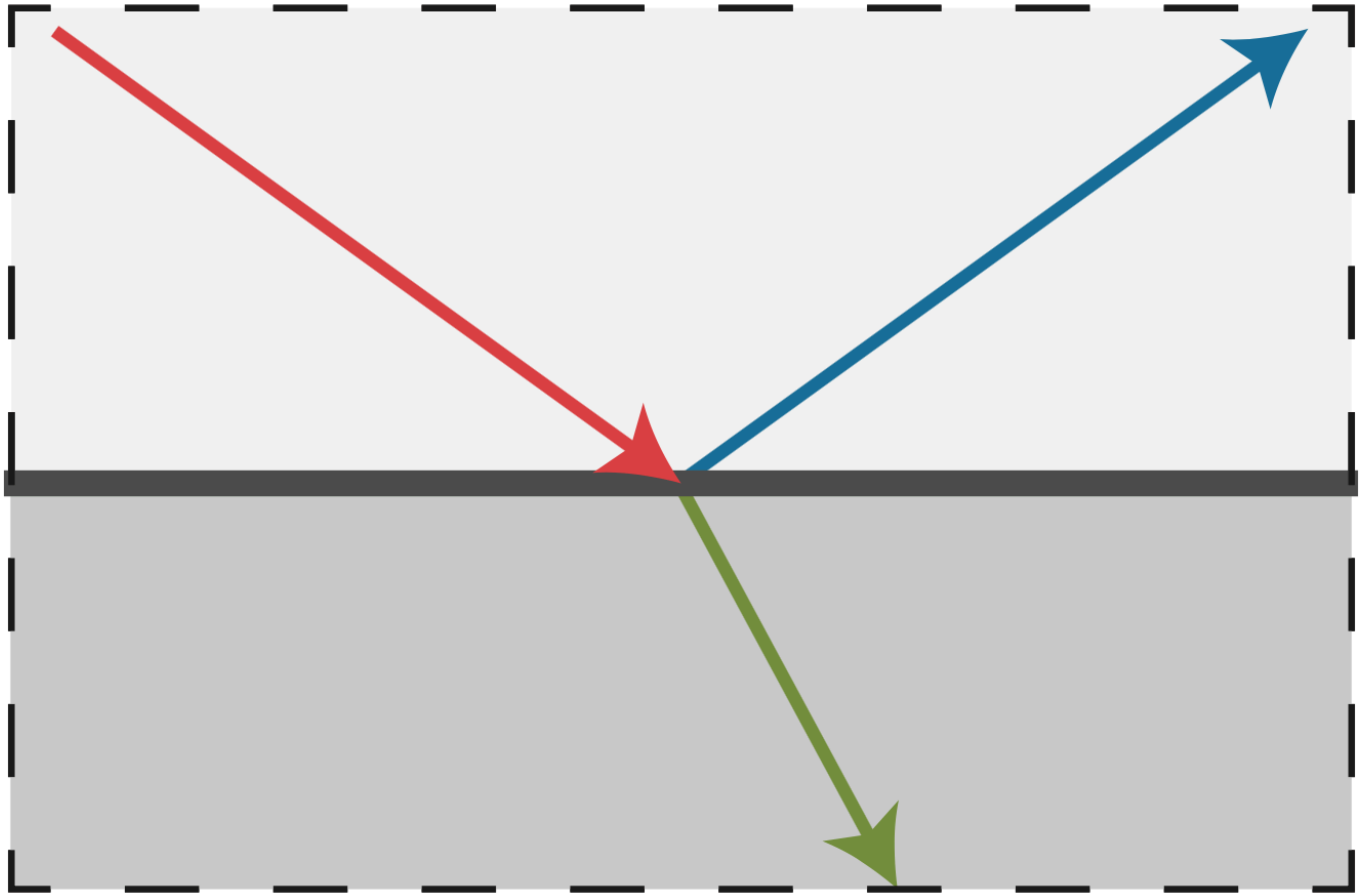
Copper



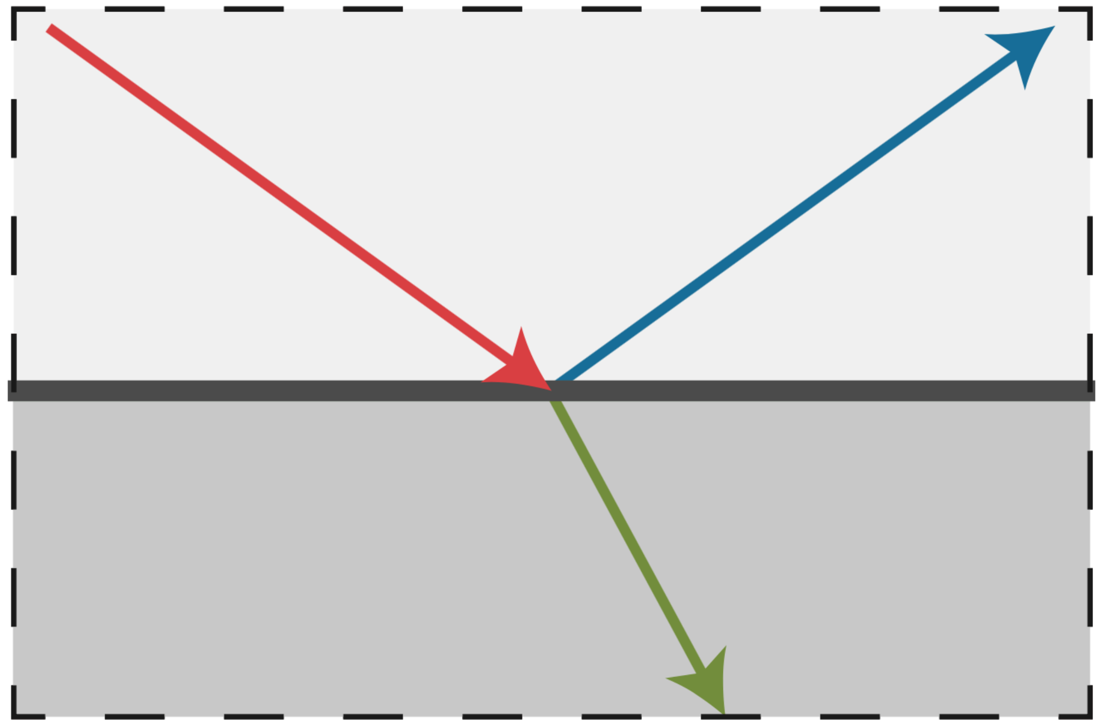
Aluminum

[Mitsuba renderer, Wenzel Jakob, 2010]

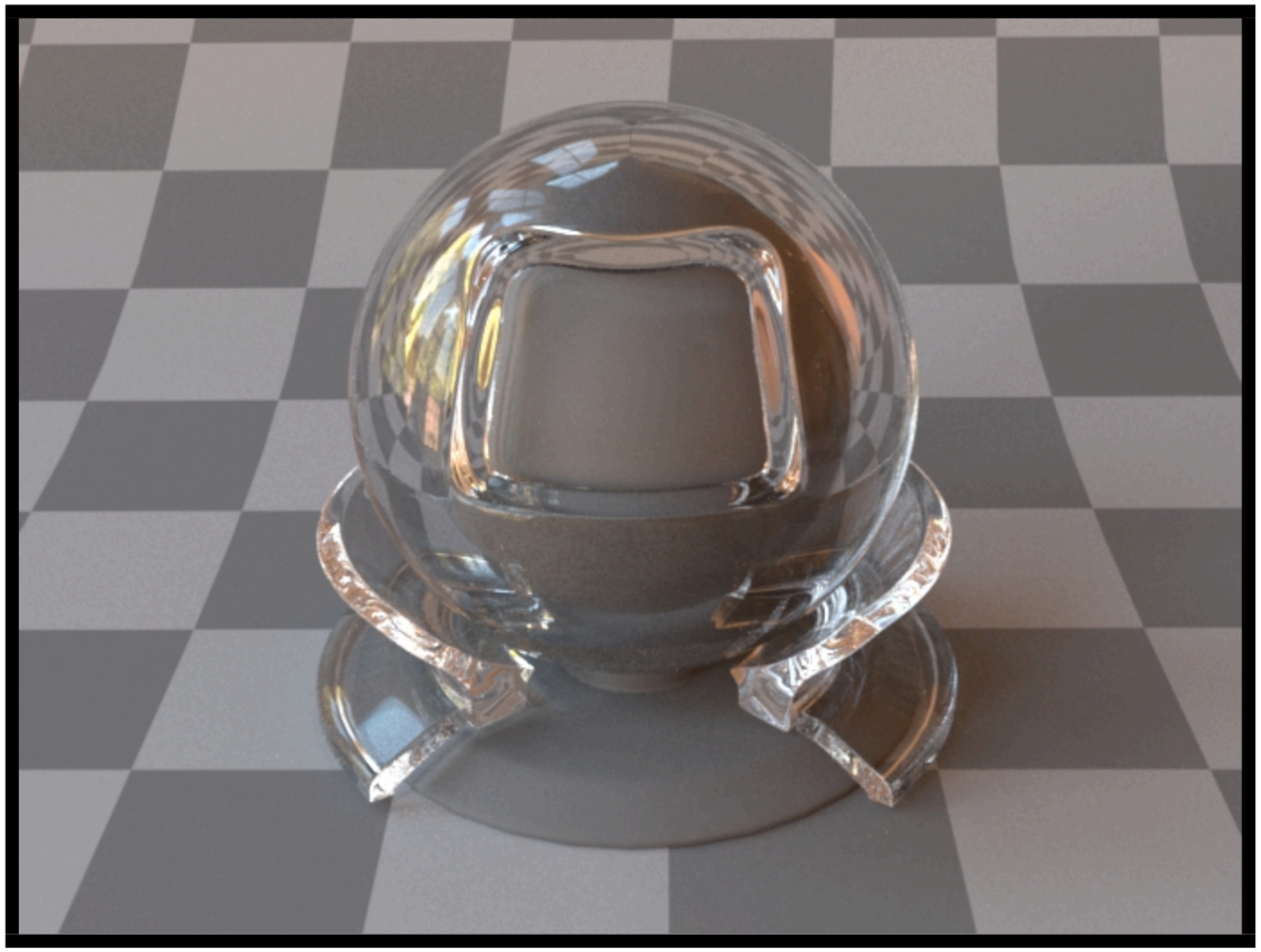
What is this material?



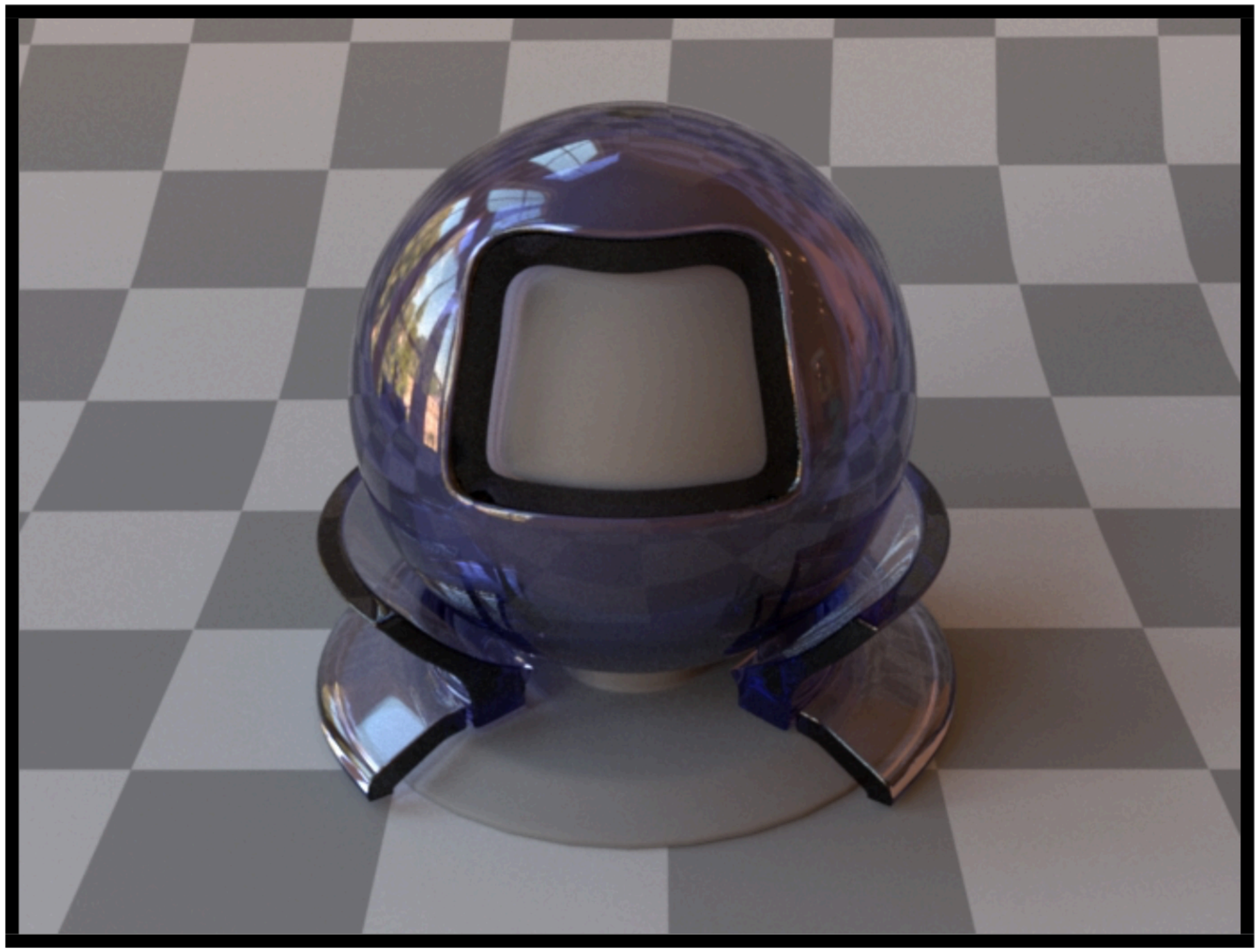
Ideal reflective / refractive material (BSDF*)



[Mitsuba renderer, Wenzel Jakob, 2010]



Air <-> plastic interface



Air <-> glass interface
(with absorption)

Microfacet Material Model

Microfacet Reflection

https://twitter.com/Cmdr_Hadfield/status/318986491063828480/photo/1

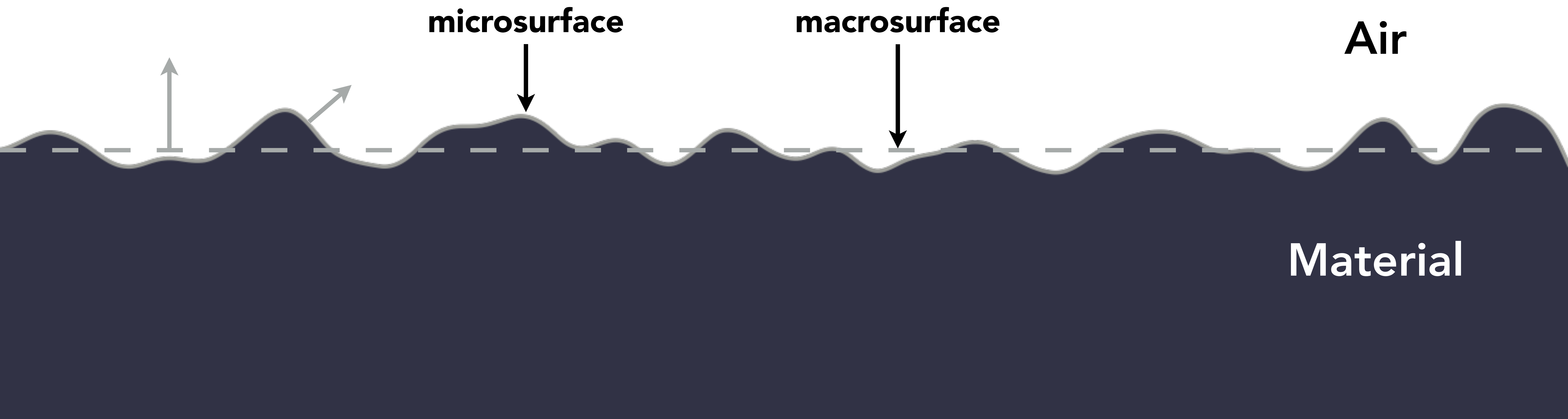
Microfacet Theory

Rough surface

- Macroscale: flat & rough
- Microscale: bumpy & specular

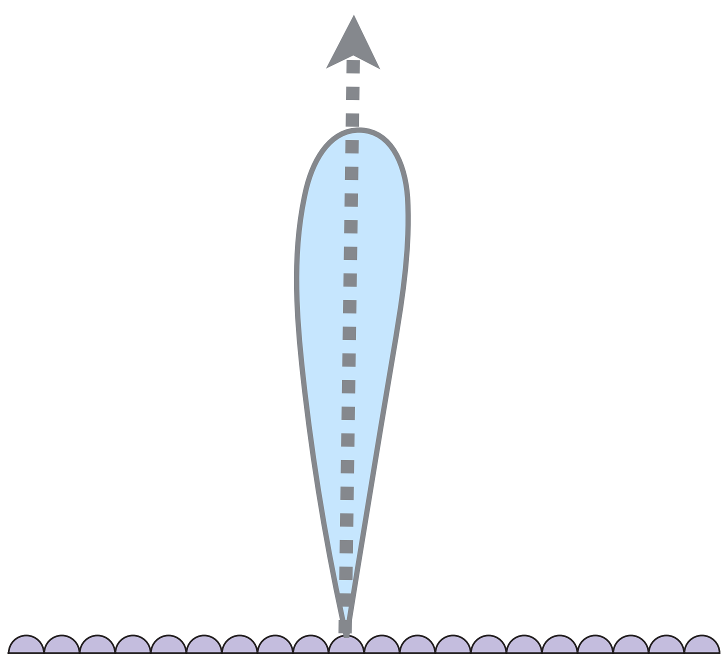
Individual elements of surface act like mirrors

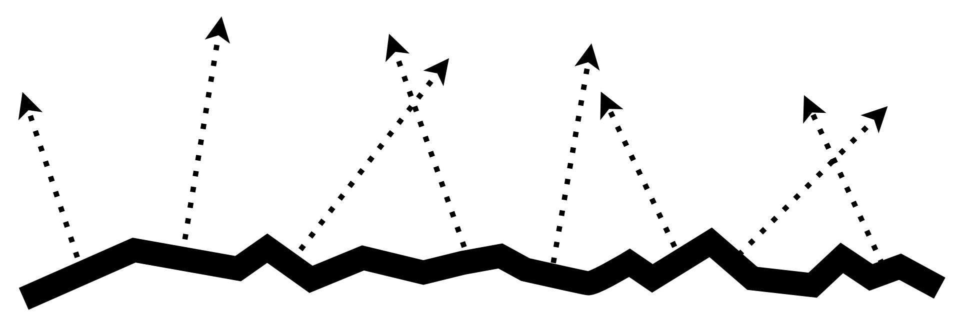
- Known as "microfacets"
- Each microfacet has its own normal vector

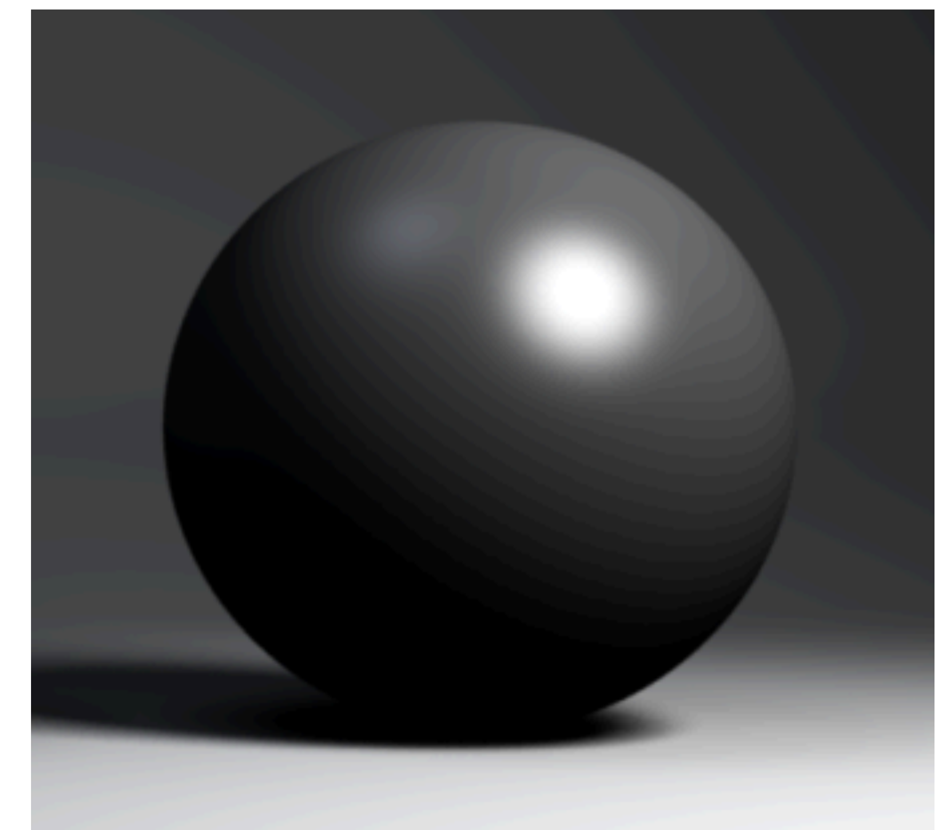


Microfacet BRDF

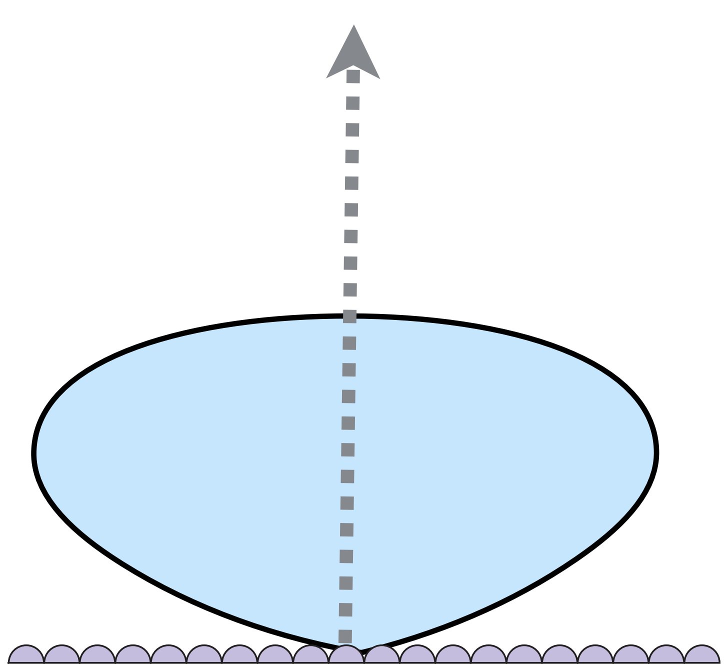
- Key: the distribution of microfacets’ normals
  - Concentrated <==> glossy

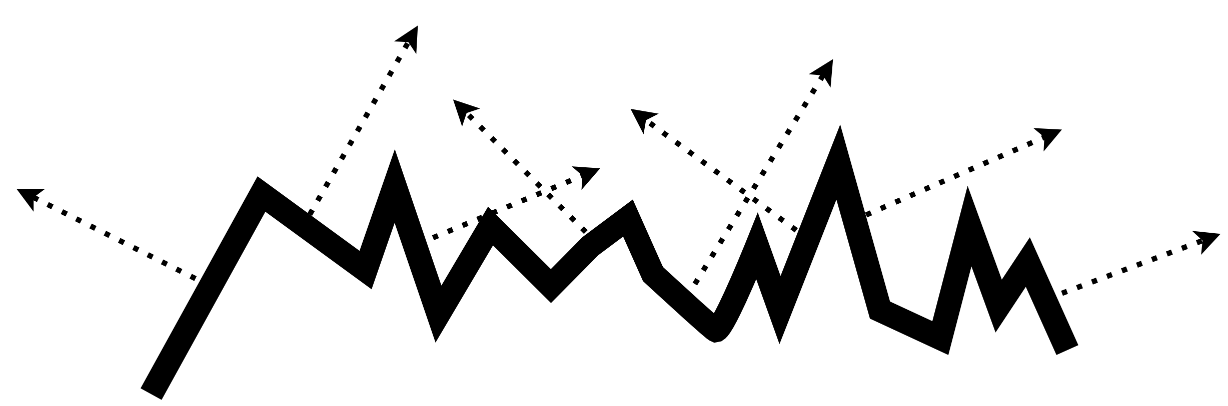


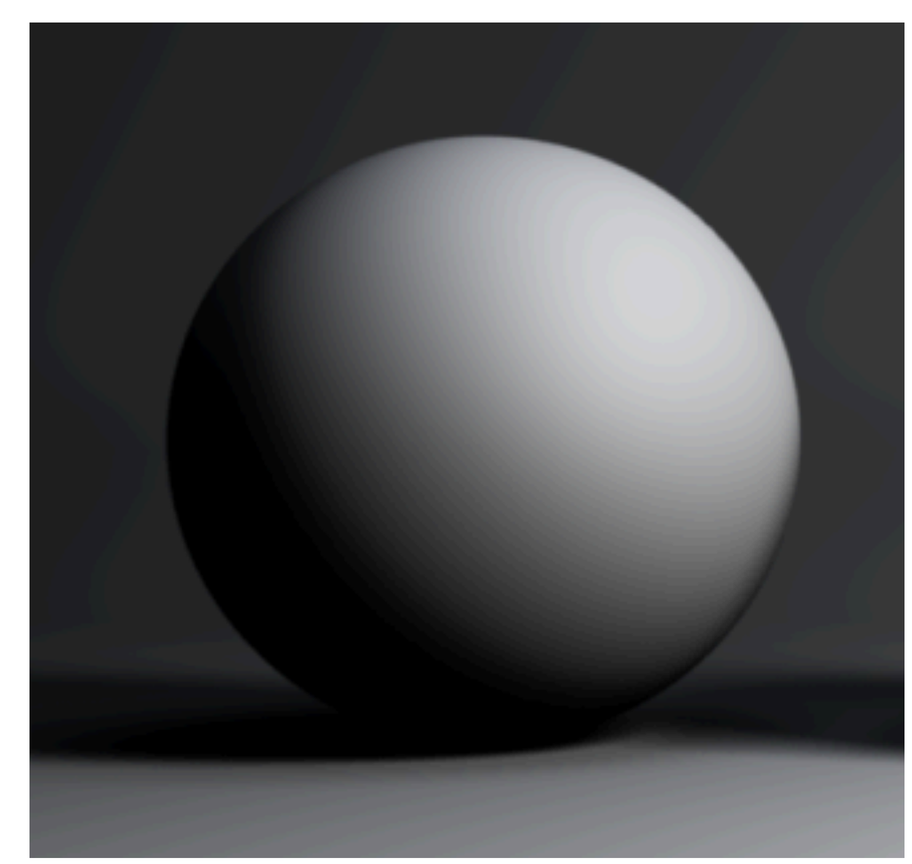




  - Spread out <==> diffuse

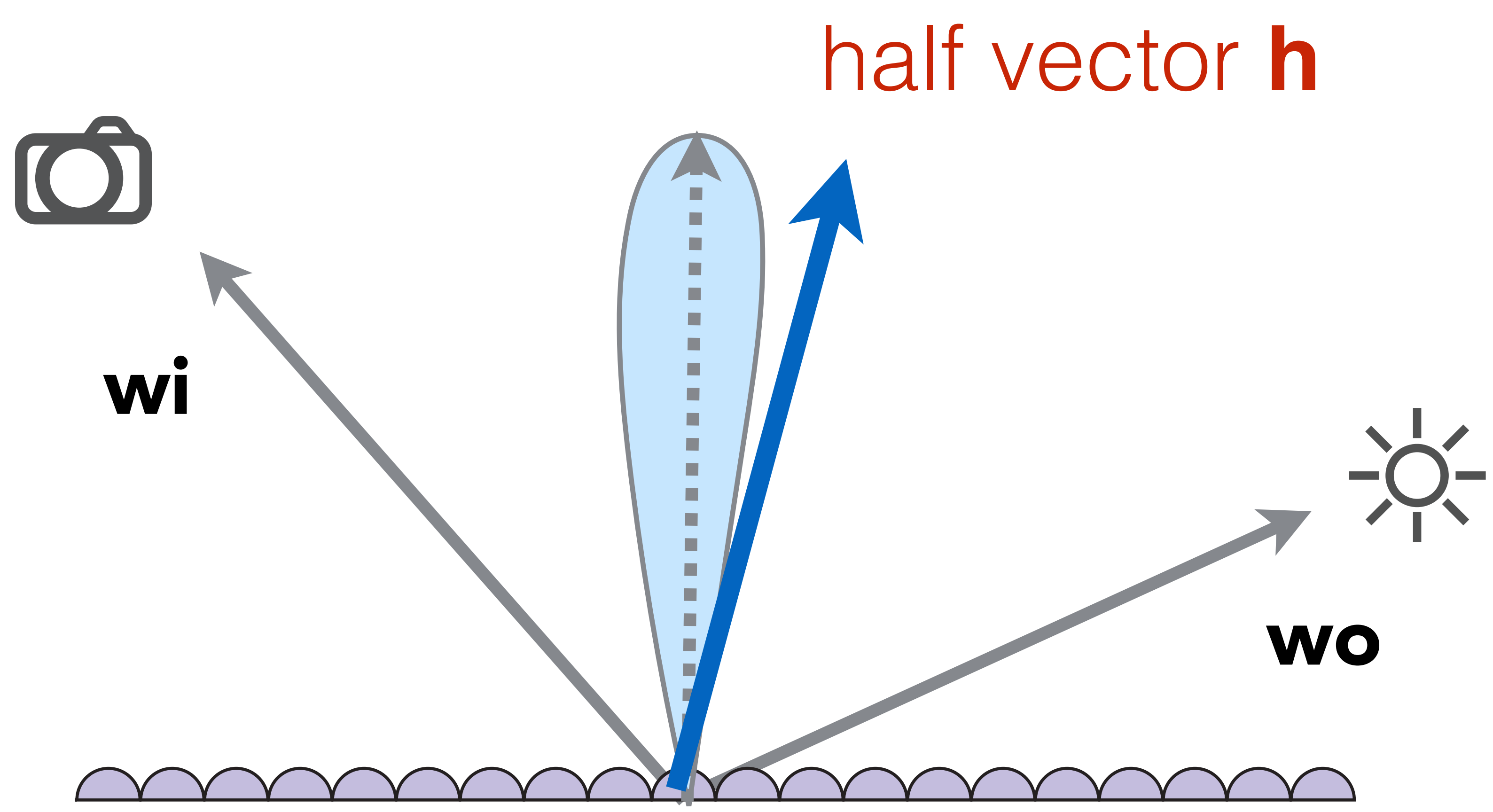


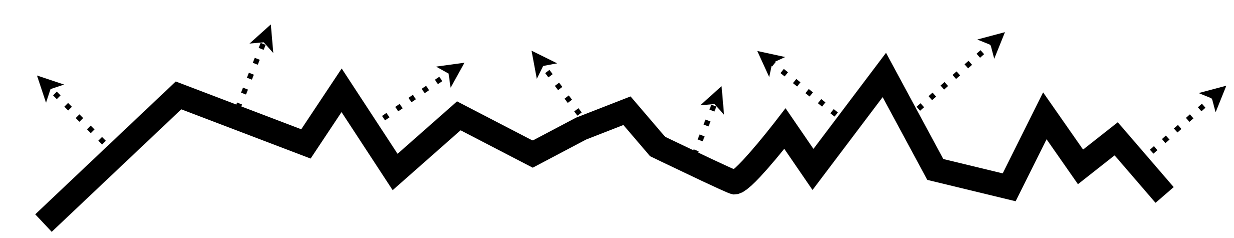




Microfacet BRDF

- **What kind of microfacets reflect wi to wo? (hint: microfacets are mirrors)**





Fresnel term | shadowing-masking term | **distribution of normals**

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

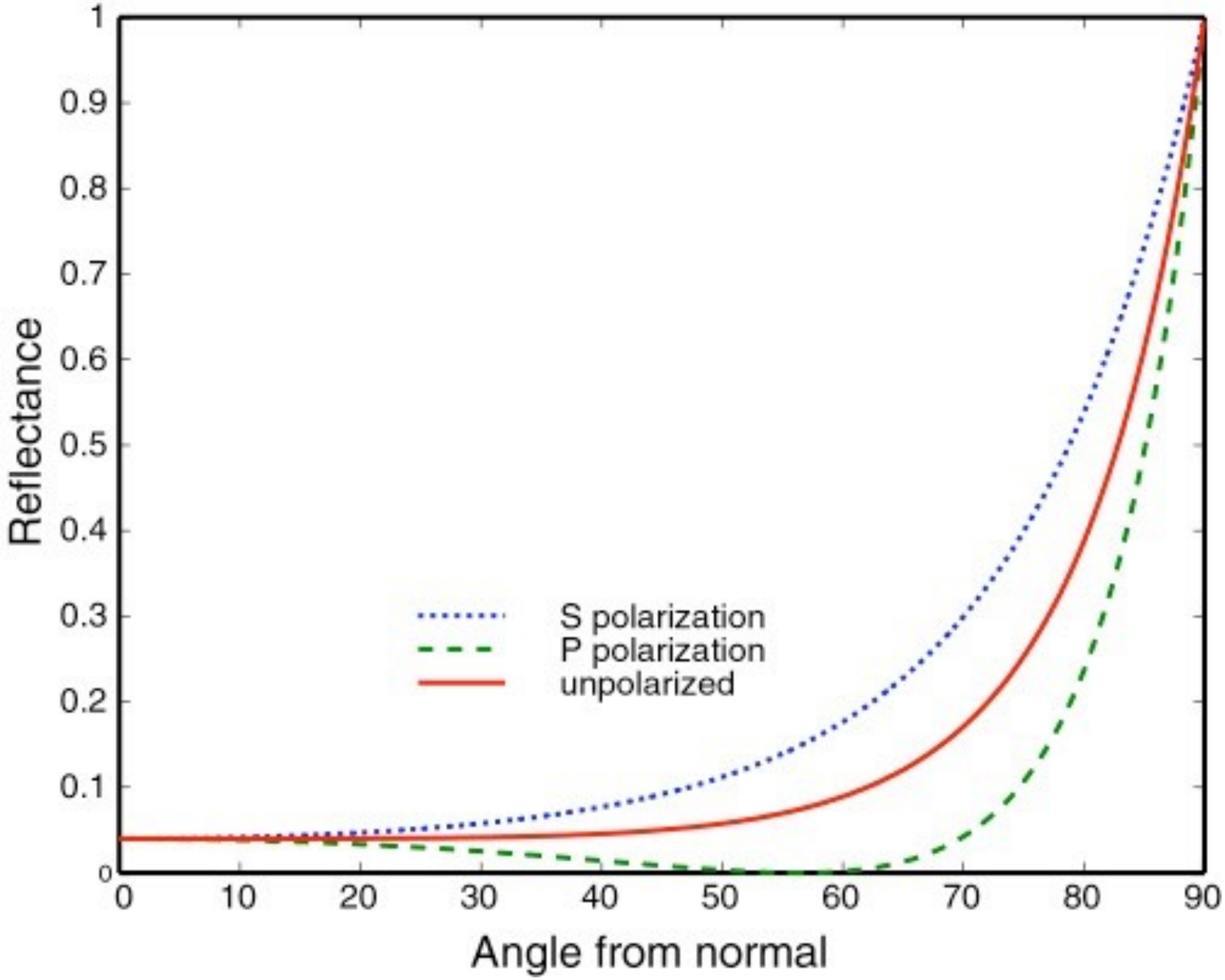
Fresnel Reflection Term

Reflectance depends on incident angle (and polarization of light)

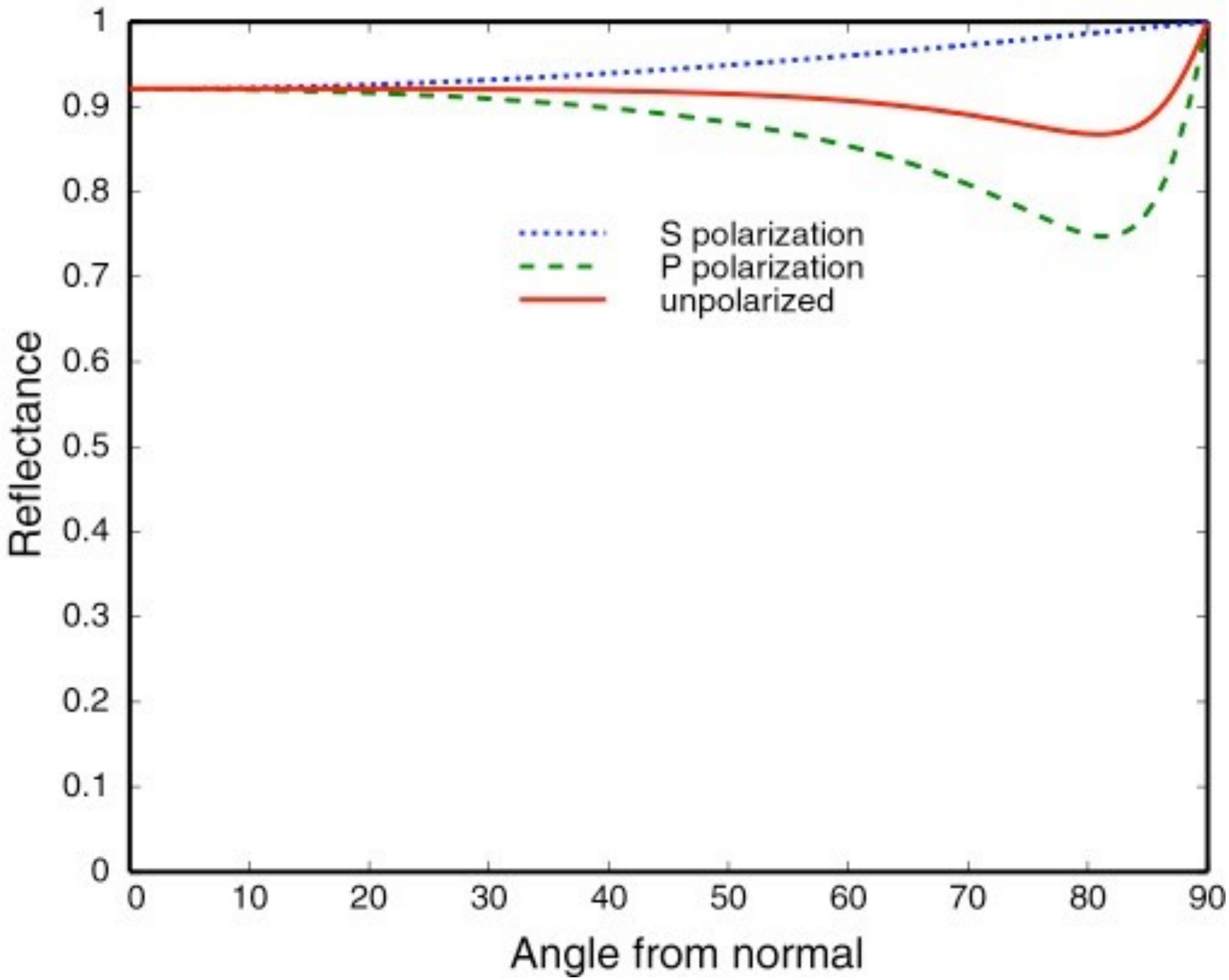
This example: reflectance increases with grazing angle

[Lafortune et al. 1997]

Fresnel Term (Dielectric, η =1.5)



Fresnel Term (Conductor)



Microfacet BRDF: Examples

[Autodesk Fusion 360]

Anisotropic BRDFs

Isotropic vs Anisotropic Reflection

- So far, Point light + Metal = Round / Elliptical highlight
- But some reflection highlights look very different

Inside an elevator

Isotropic vs Anisotropic Reflection

Isotropic

Anisotropic

Anisotropic BRDF: Brushed Metal

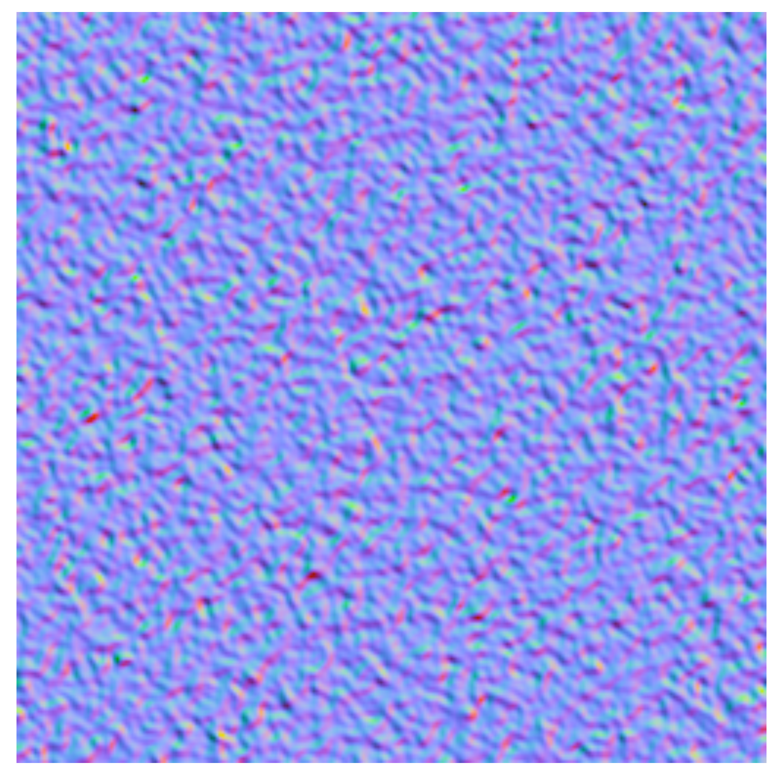
- How is the pan brushed?

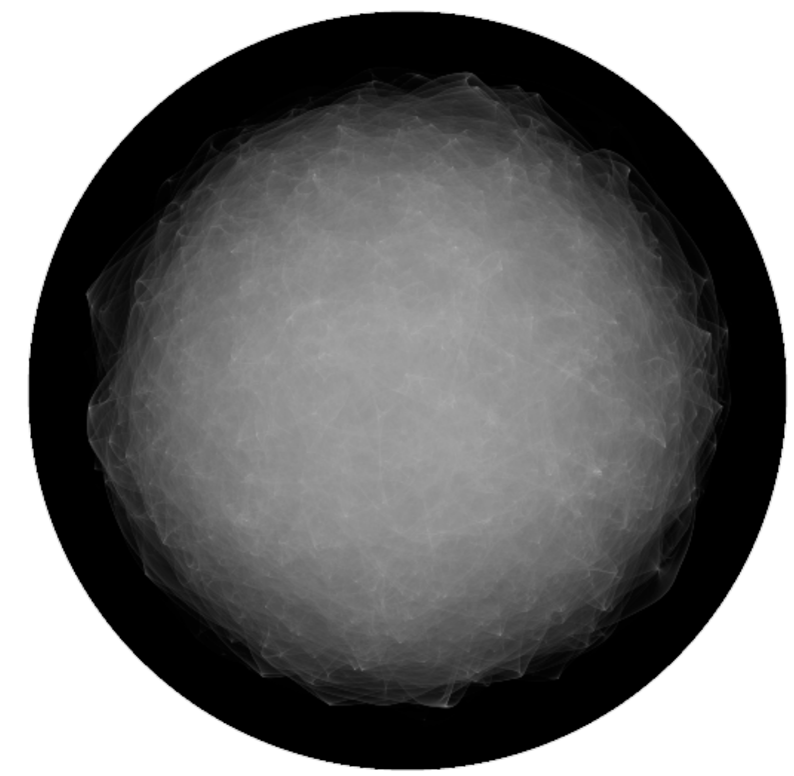
 [VRay renderer]

Isotropic / Anisotropic Materials (BRDFs)

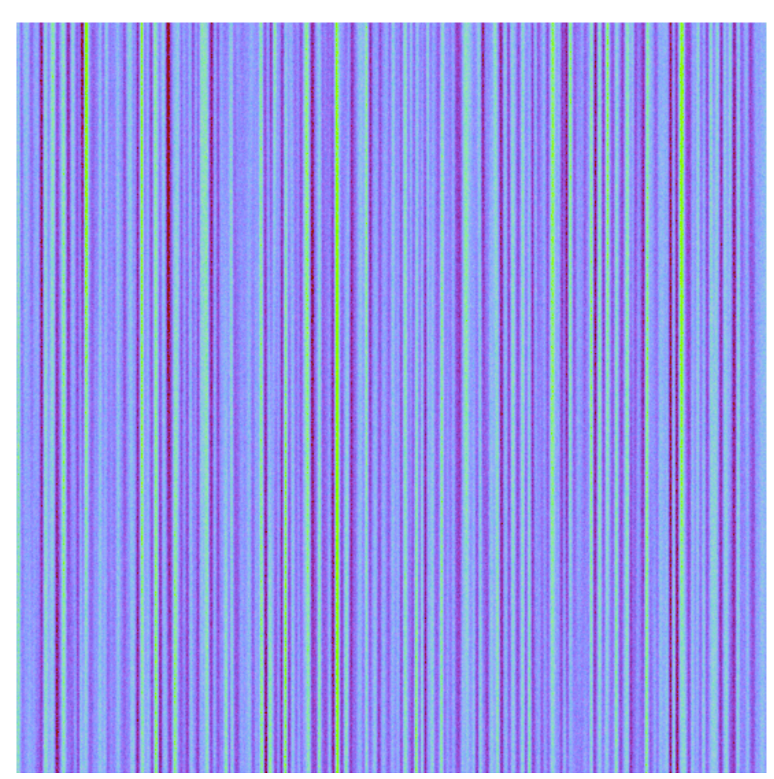
- Key: directionality of underlying surface

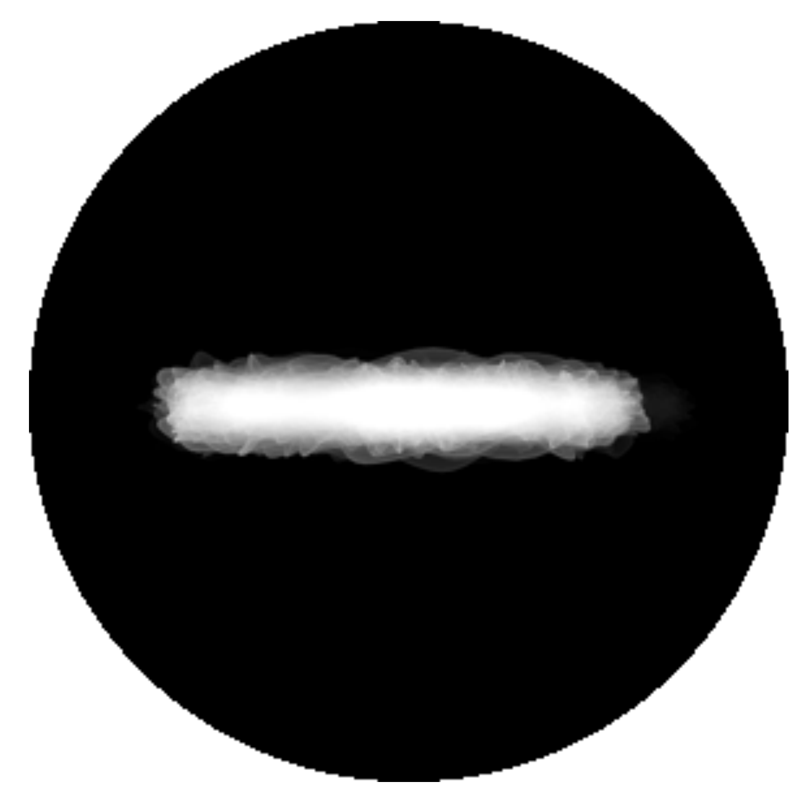
Isotropic





Anisotropic



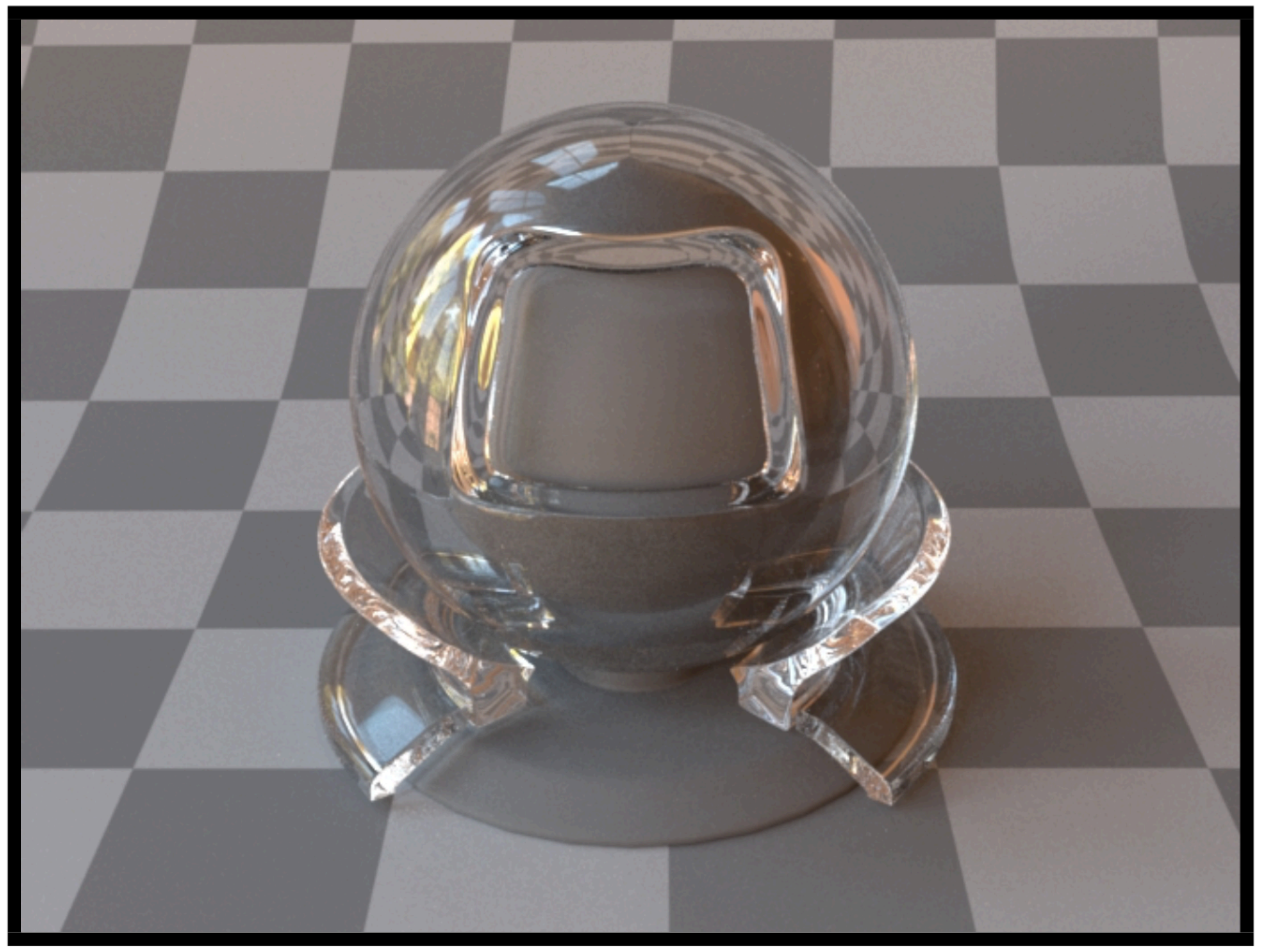


Surface (normals) BRDF (fix wi, vary wo)

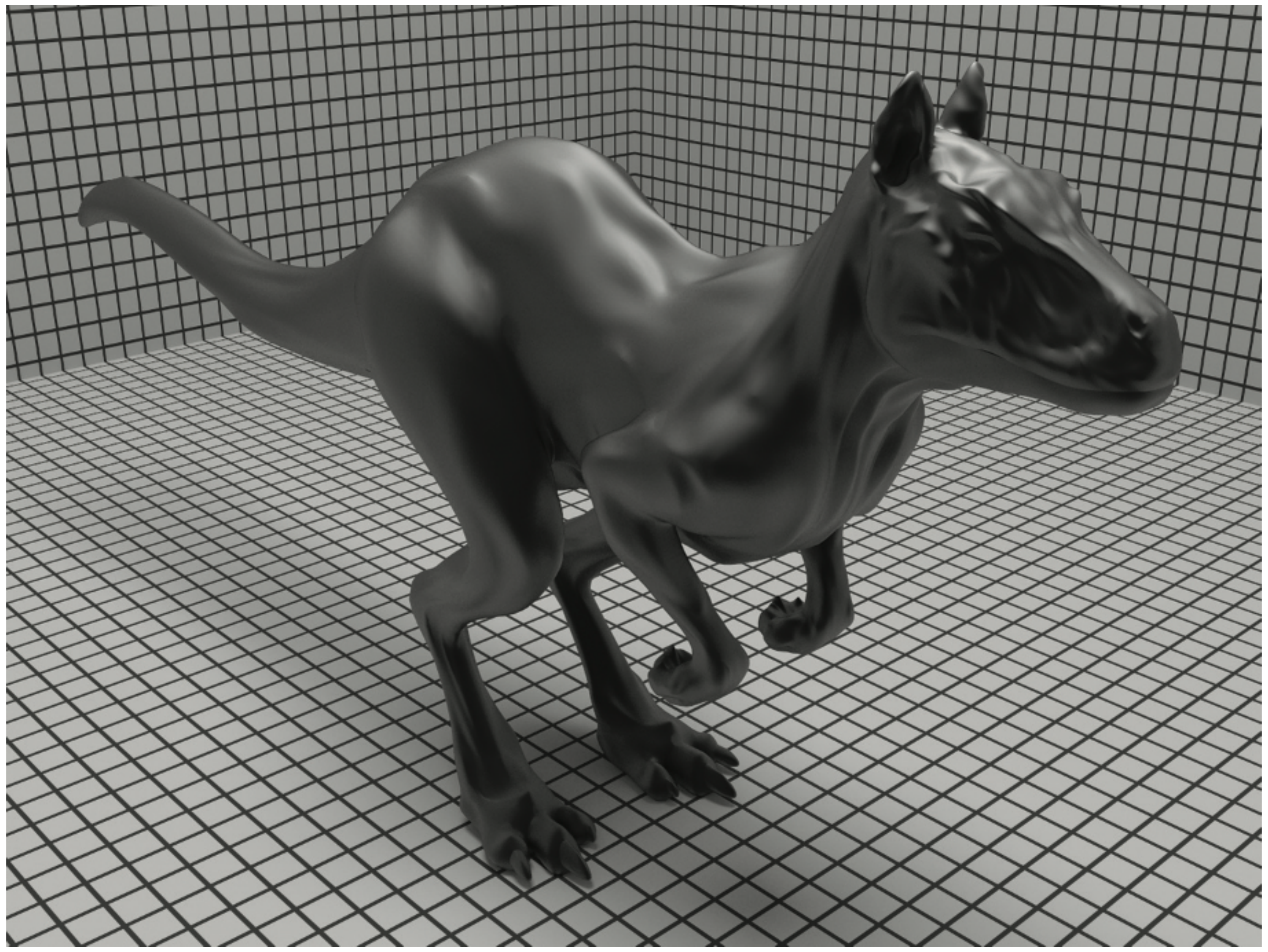
Isotropic BRDFs

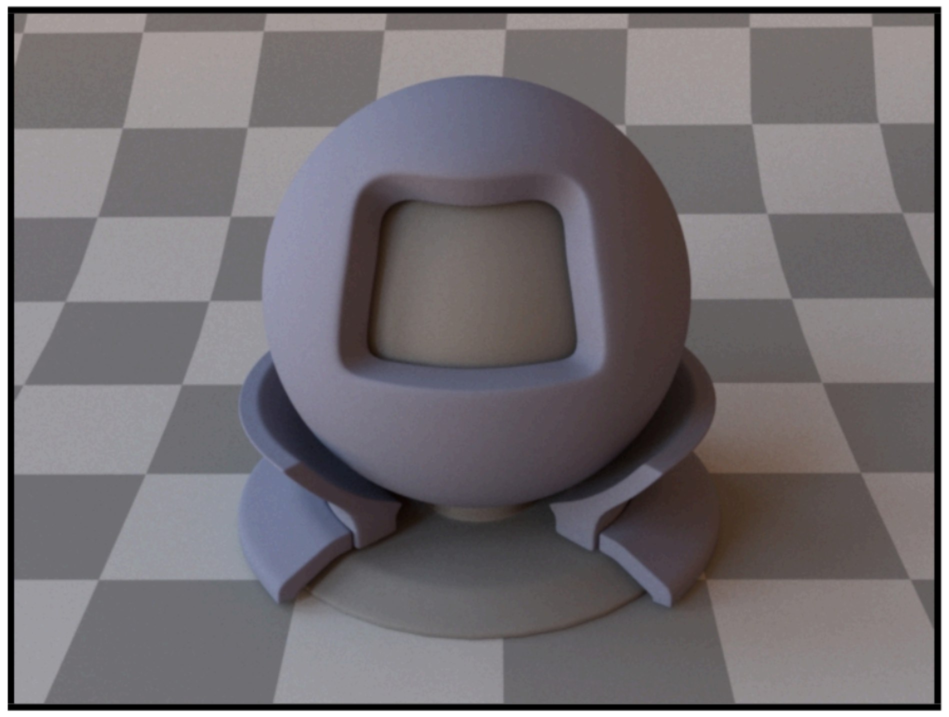
Reflection independent of azimuthal angle ϕ

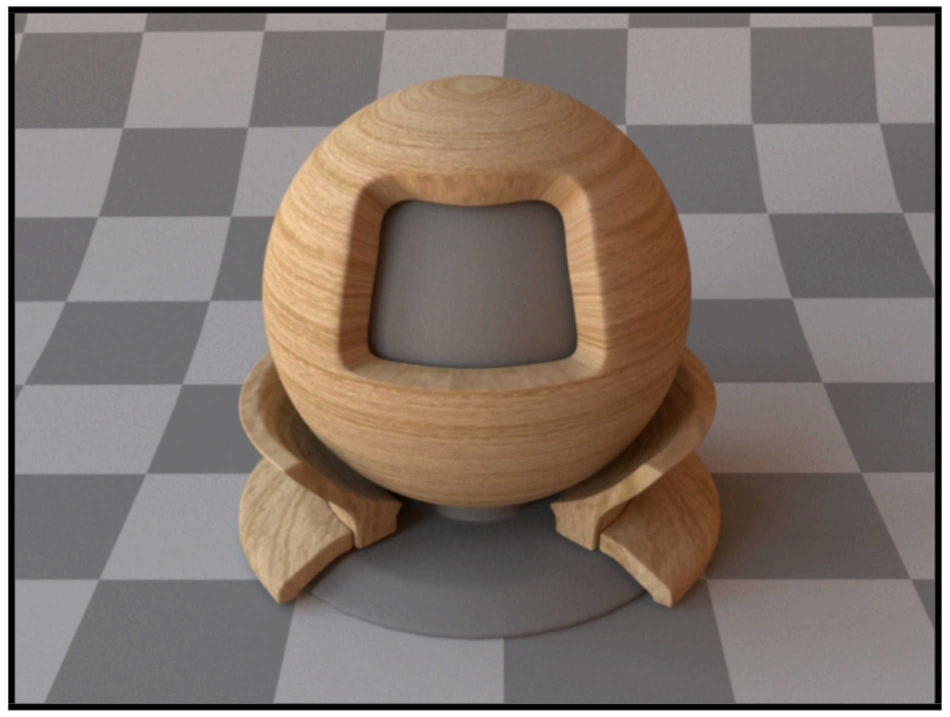
$$f_r(\theta_i, \phi_i; \theta_r, \phi_r) = f_r(\theta_i, \theta_r, \phi_r - \phi_i)$$



Results from surface microstructure that lacks directional structure





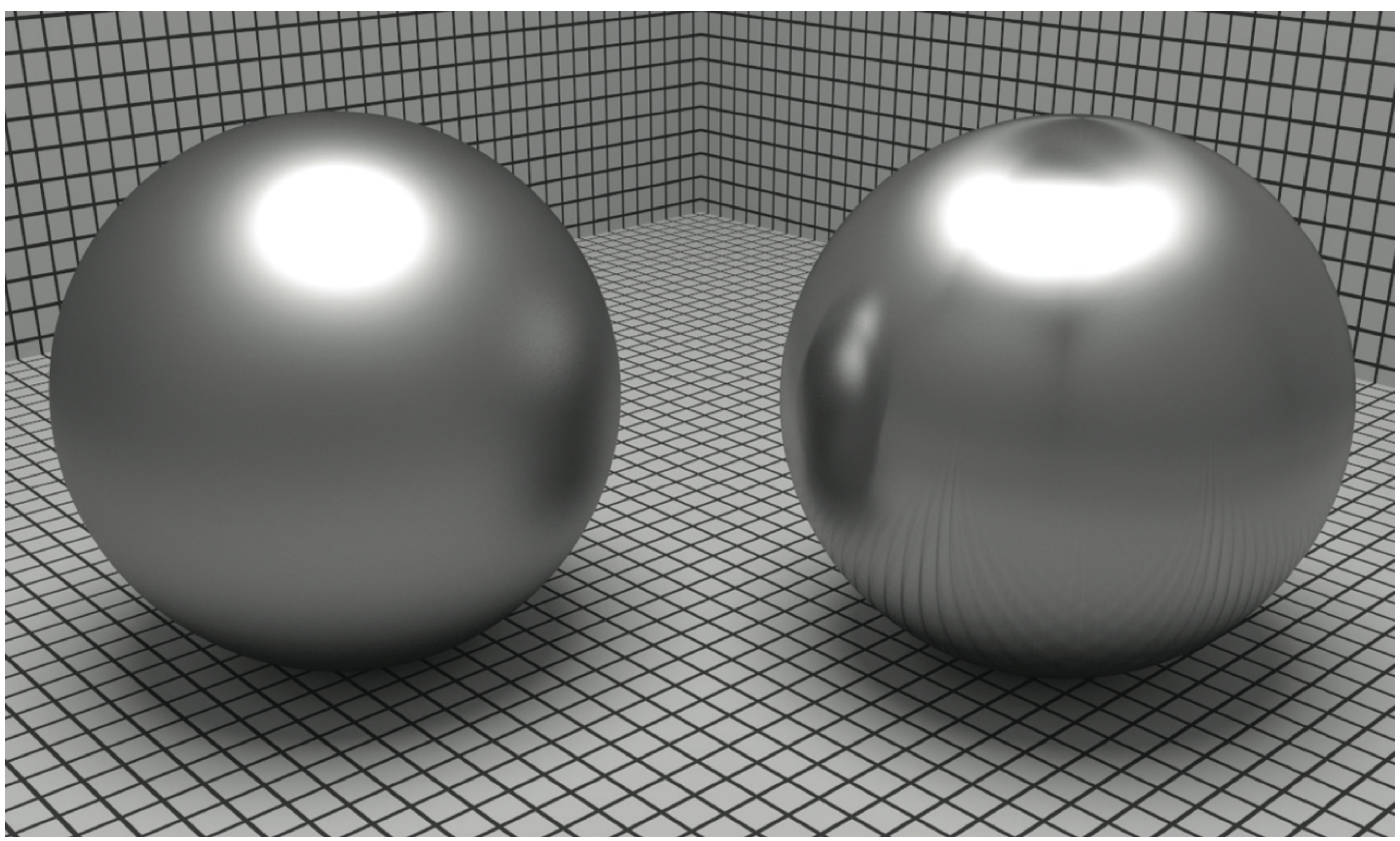


Anisotropic BRDFs

Reflection depends on azimuthal angle ϕ

$$f_r(\theta_i, \phi_i; \theta_r, \phi_r) \neq f_r(\theta_i, \theta_r, \phi_r - \phi_i)$$

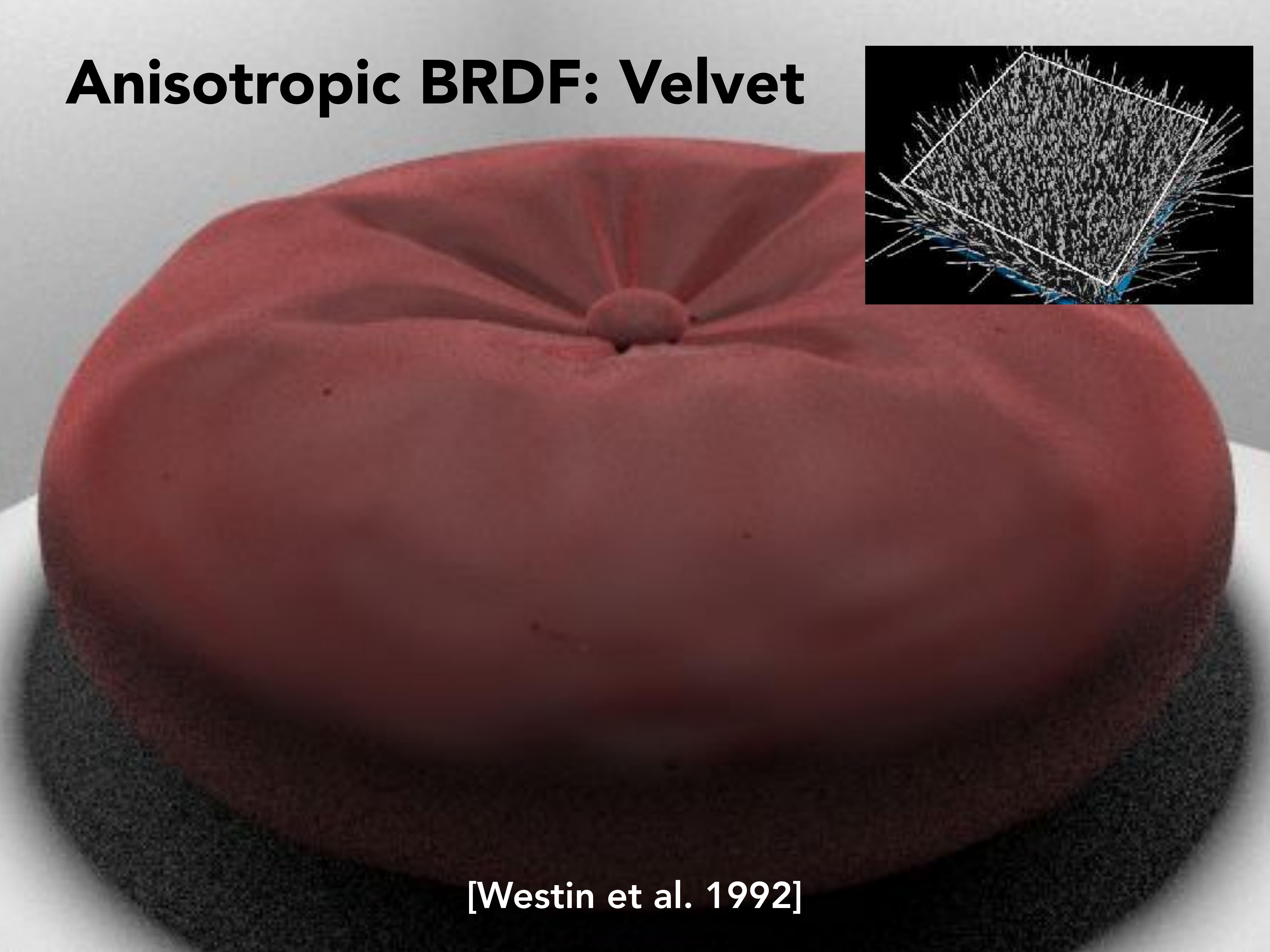
Results from oriented microstructure of surface, e.g., brushed metal



Anisotropic BRDF: Nylon

[Westin et al. 1992]

Anisotropic BRDF: Velvet



[Westin et al. 1992]

Anisotropic BRDF: Velvet

[https://www.youtube.com/watch?v=2hjoW8TYTd4]

Sampling of Advanced Material Modeling Topics (Slides courtesy Prof Lingqi Yan)

Detailed / Glinty Material

Why details?

Microfacet model

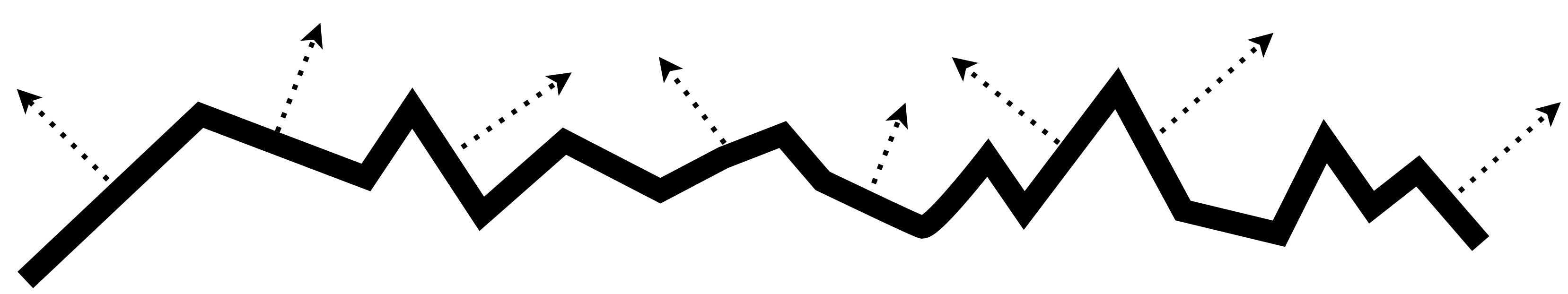
Why details?

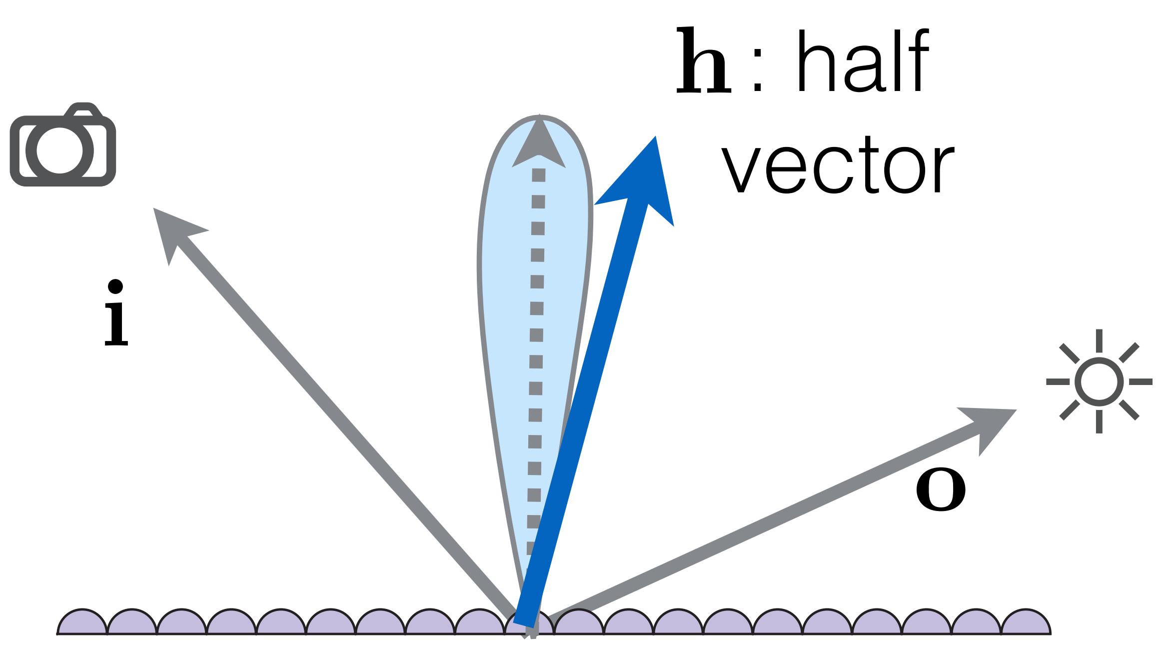
[Yan et al. 2014, 2016]

Why details?

[Yan et al. 2014, 2016]

Recap: Microfacet BRDF





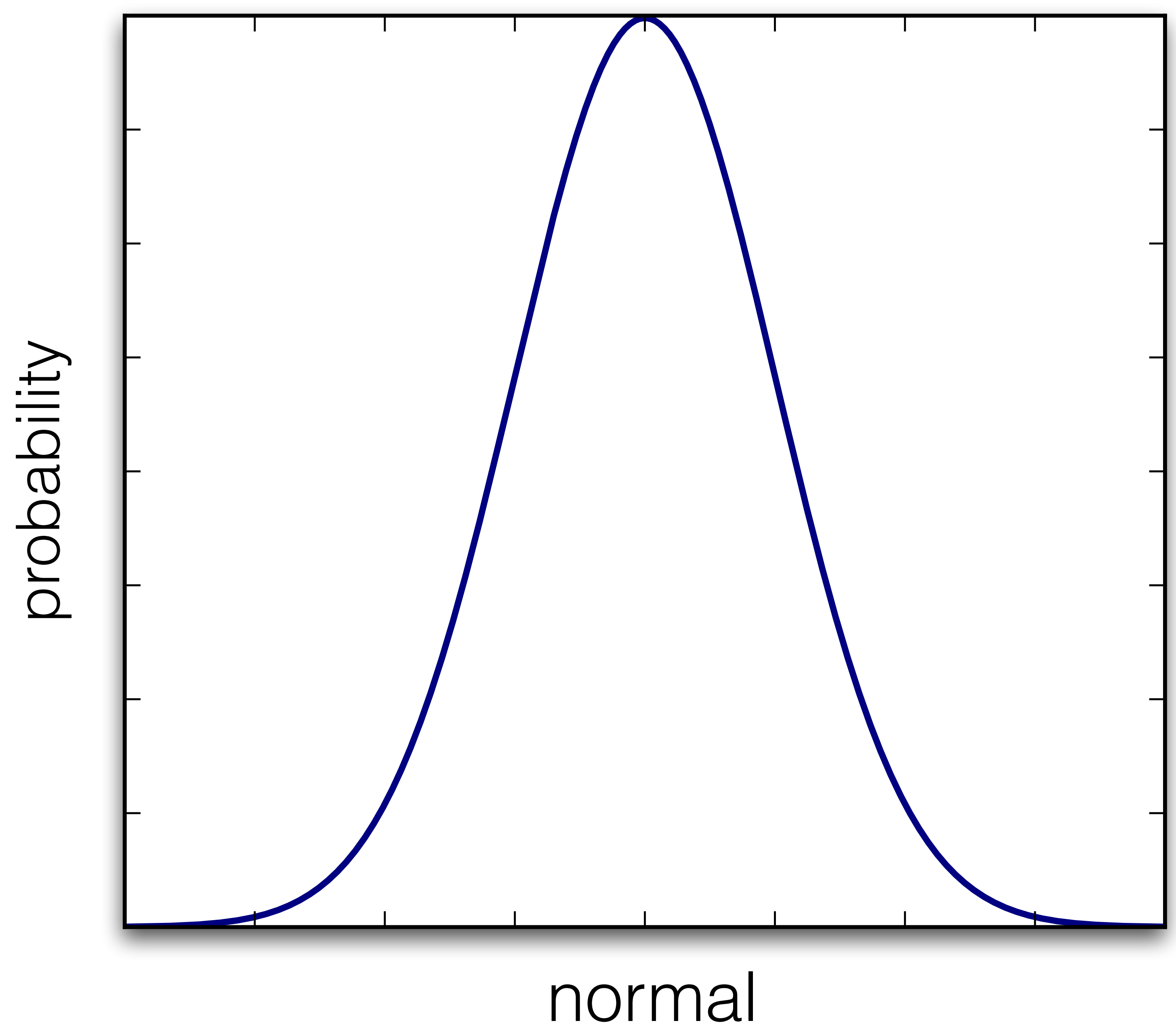
Surface = Specular microfacets + statistical normals

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

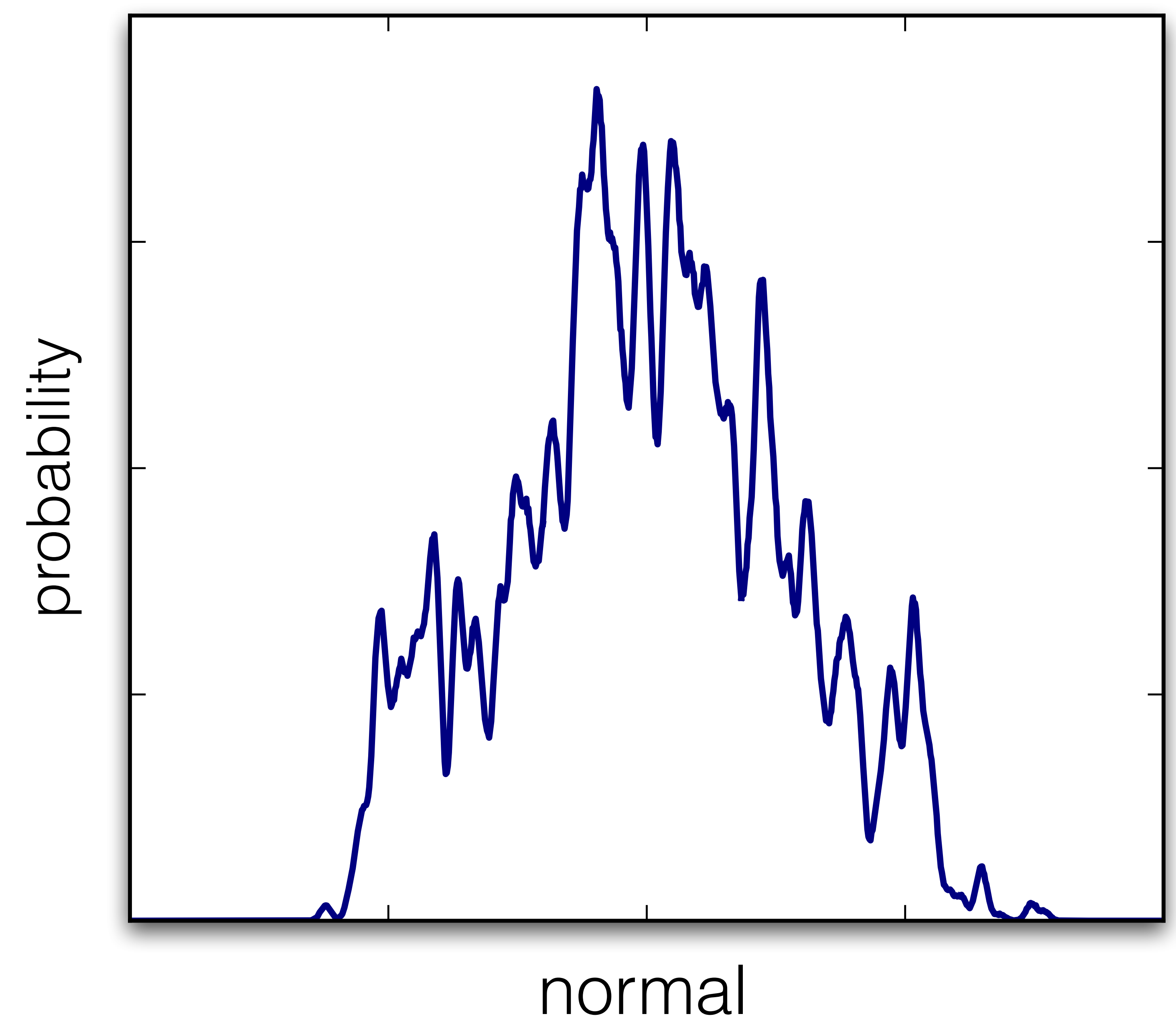
NDF: Normal Distribution Function

Statistical NDF vs. Actual NDF

Distribution of Normals (NDF)

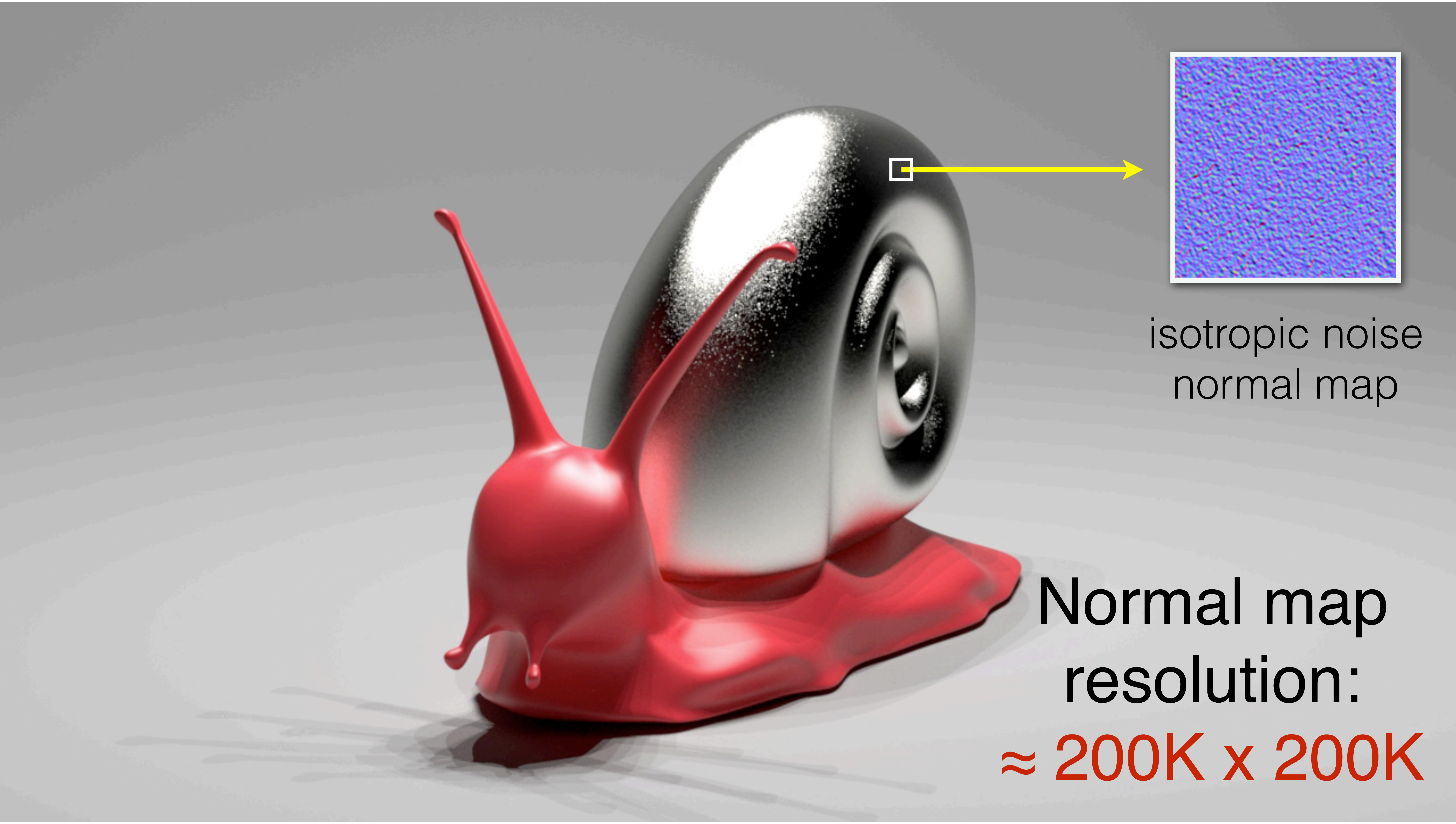


What we have
(microfacet — statistical)

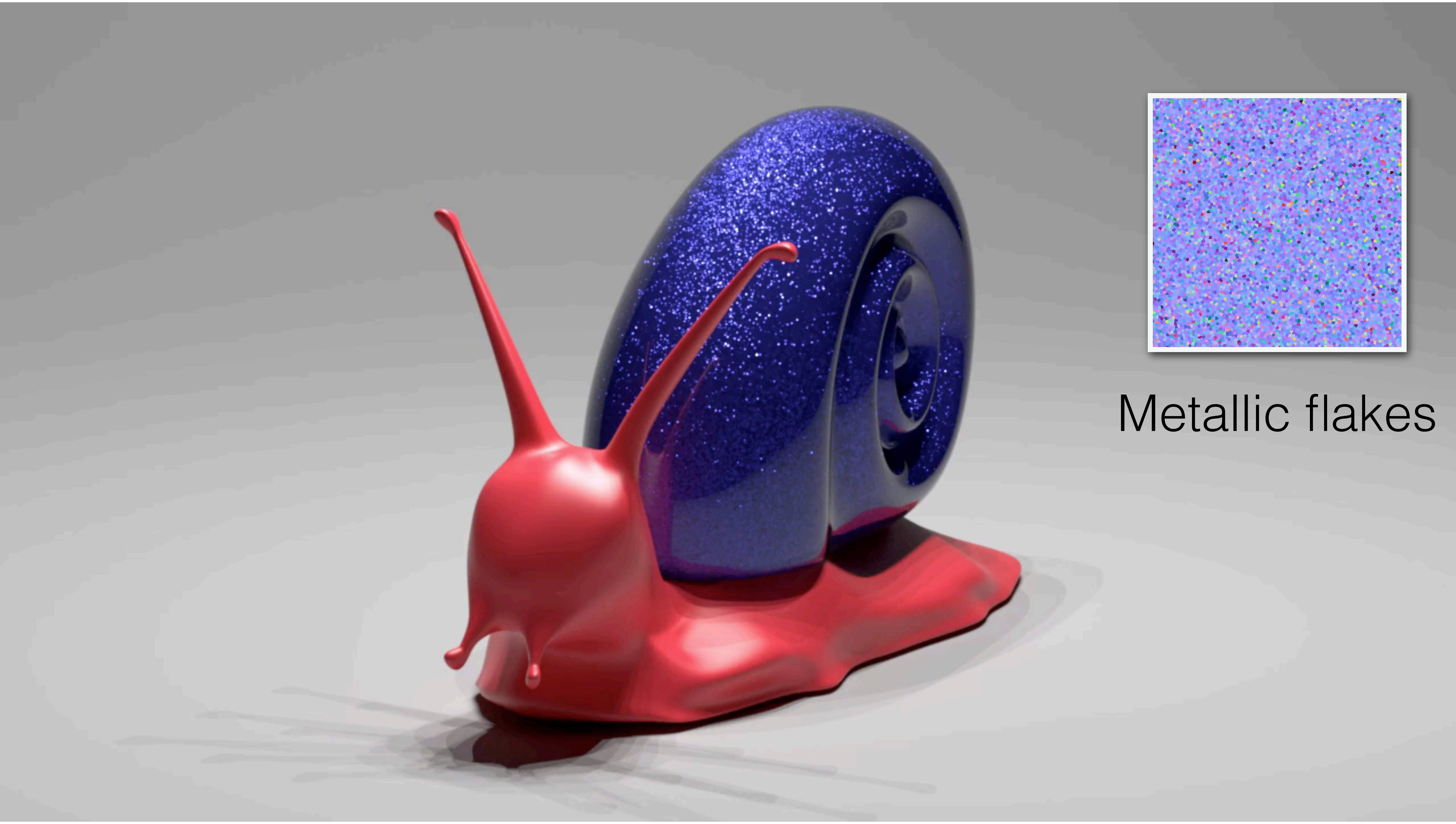


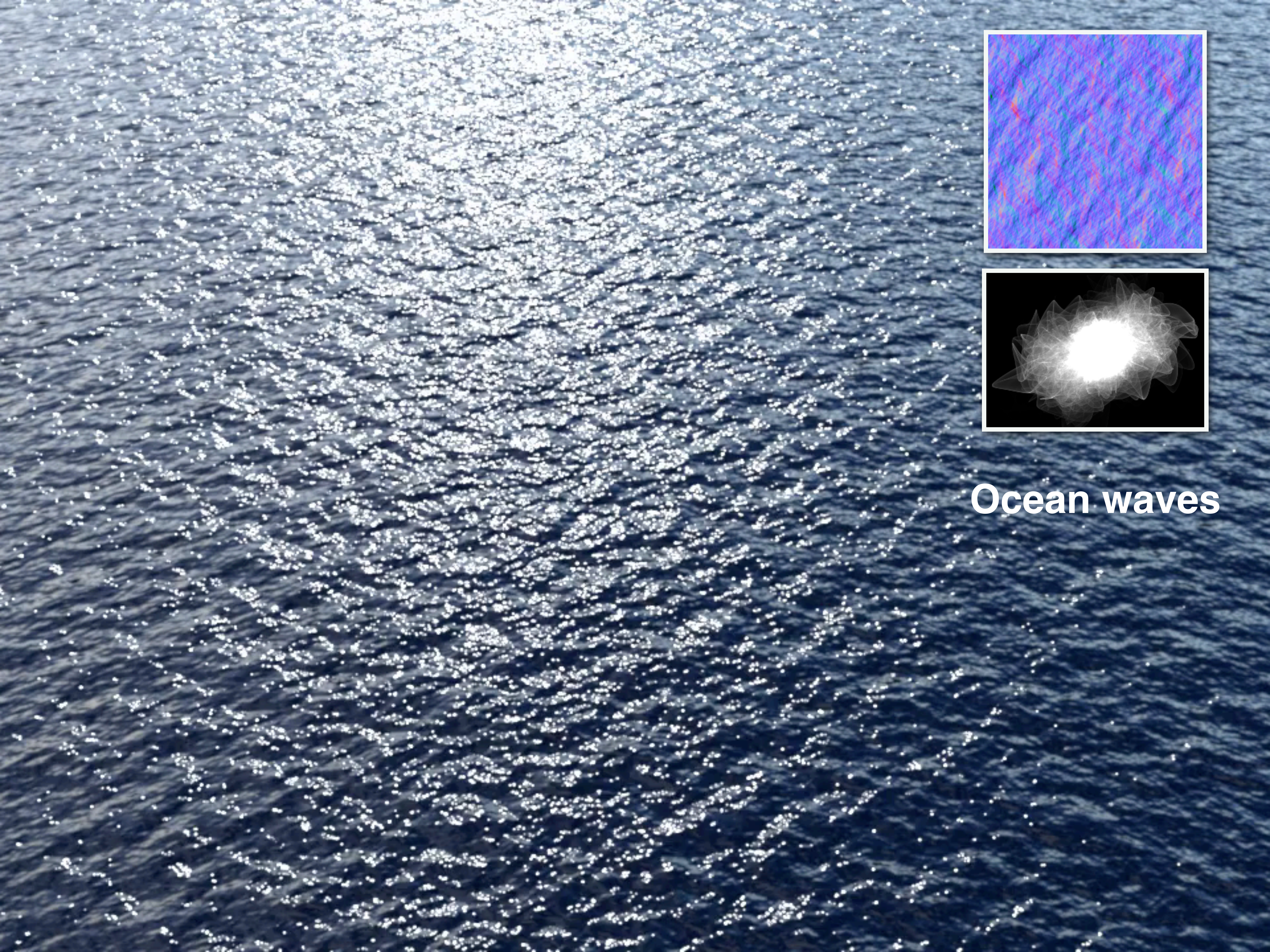
What we want

Define Details



Different Details

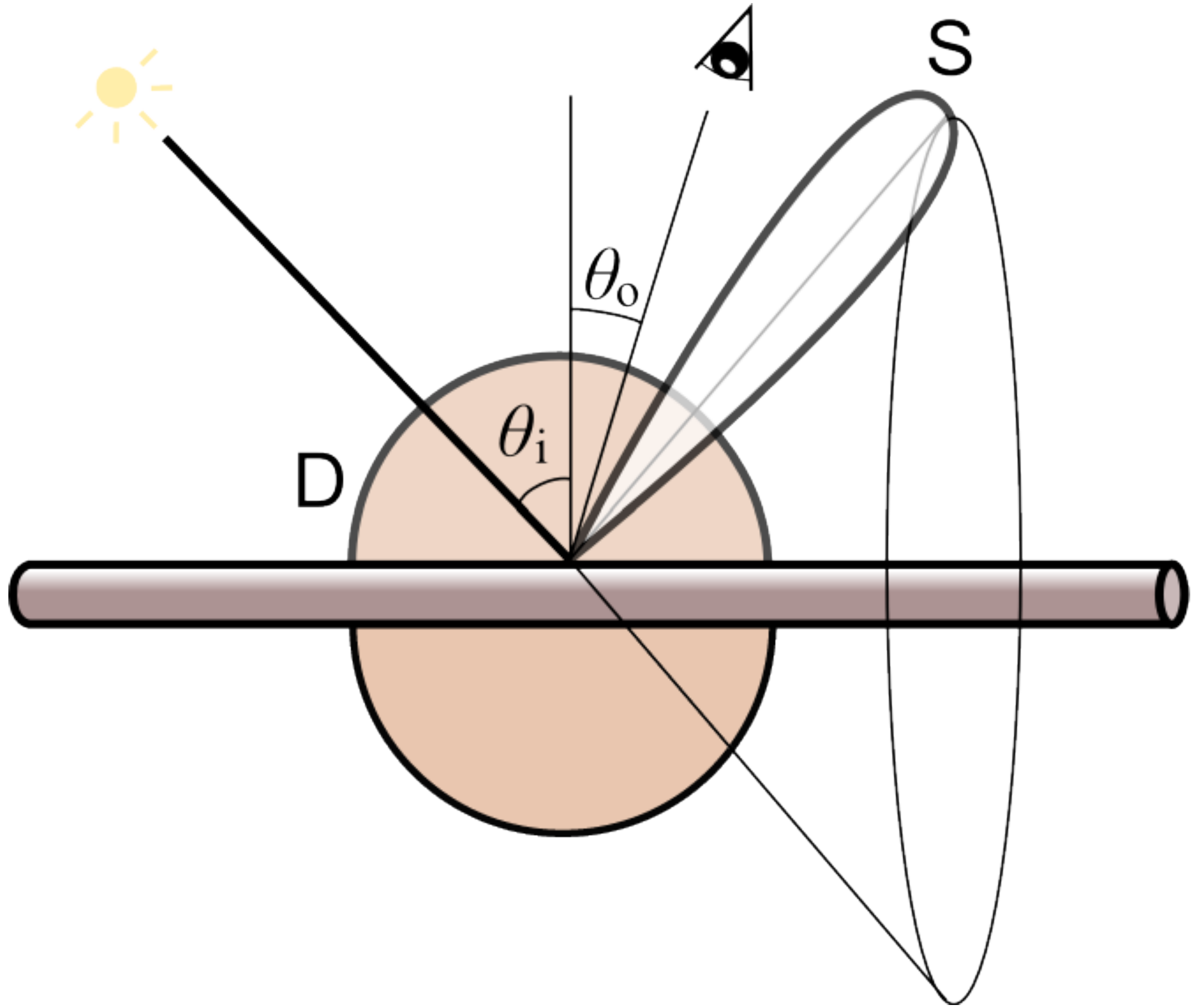



Ocean waves

Hair / Fur Appearance Models

Hair Appearance

Kajiya-Kay Model

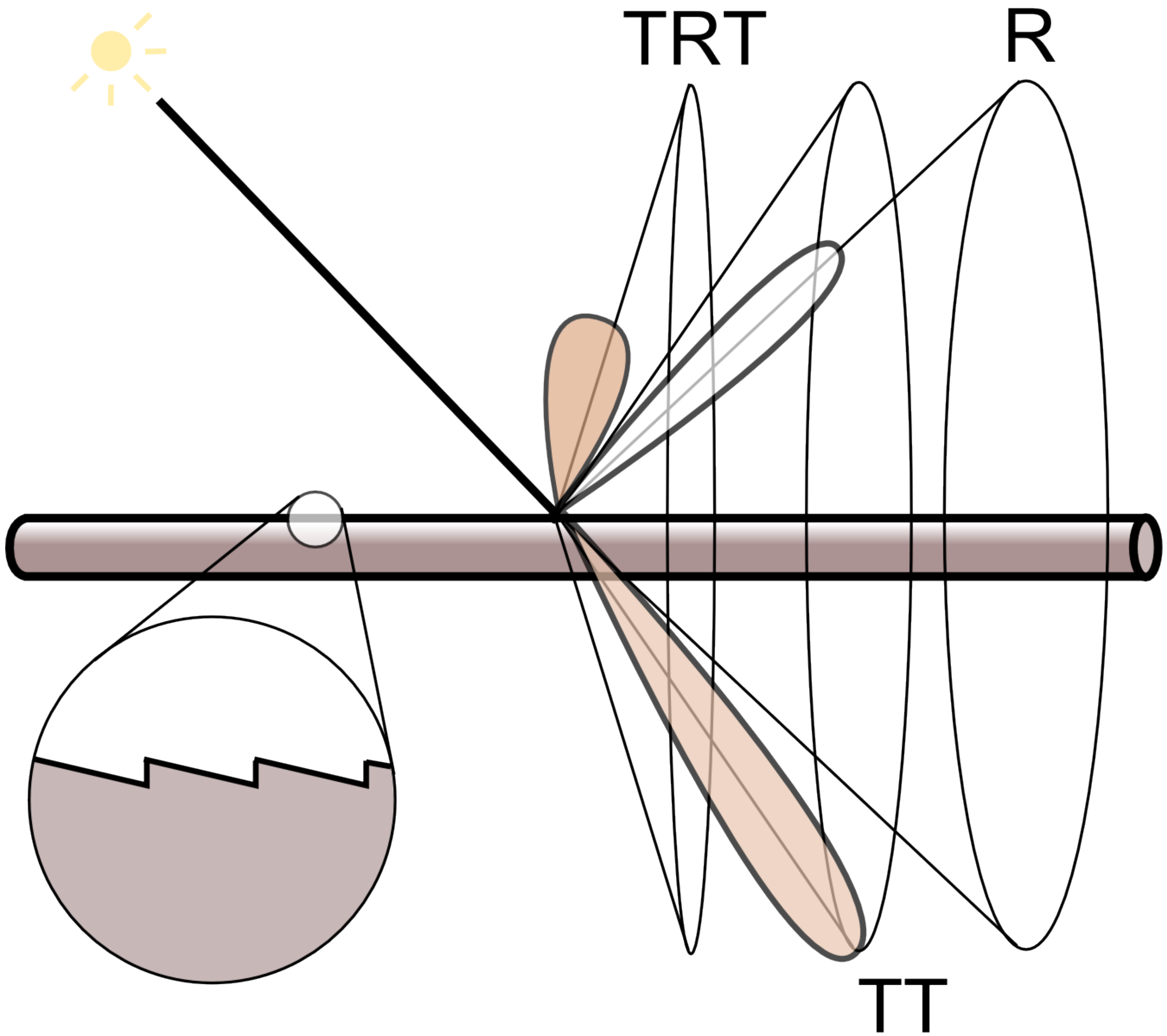


[Image courtesy of Chiwei Tseng]

Kajiya-Kay Model

[Yuksel et al. 2008]

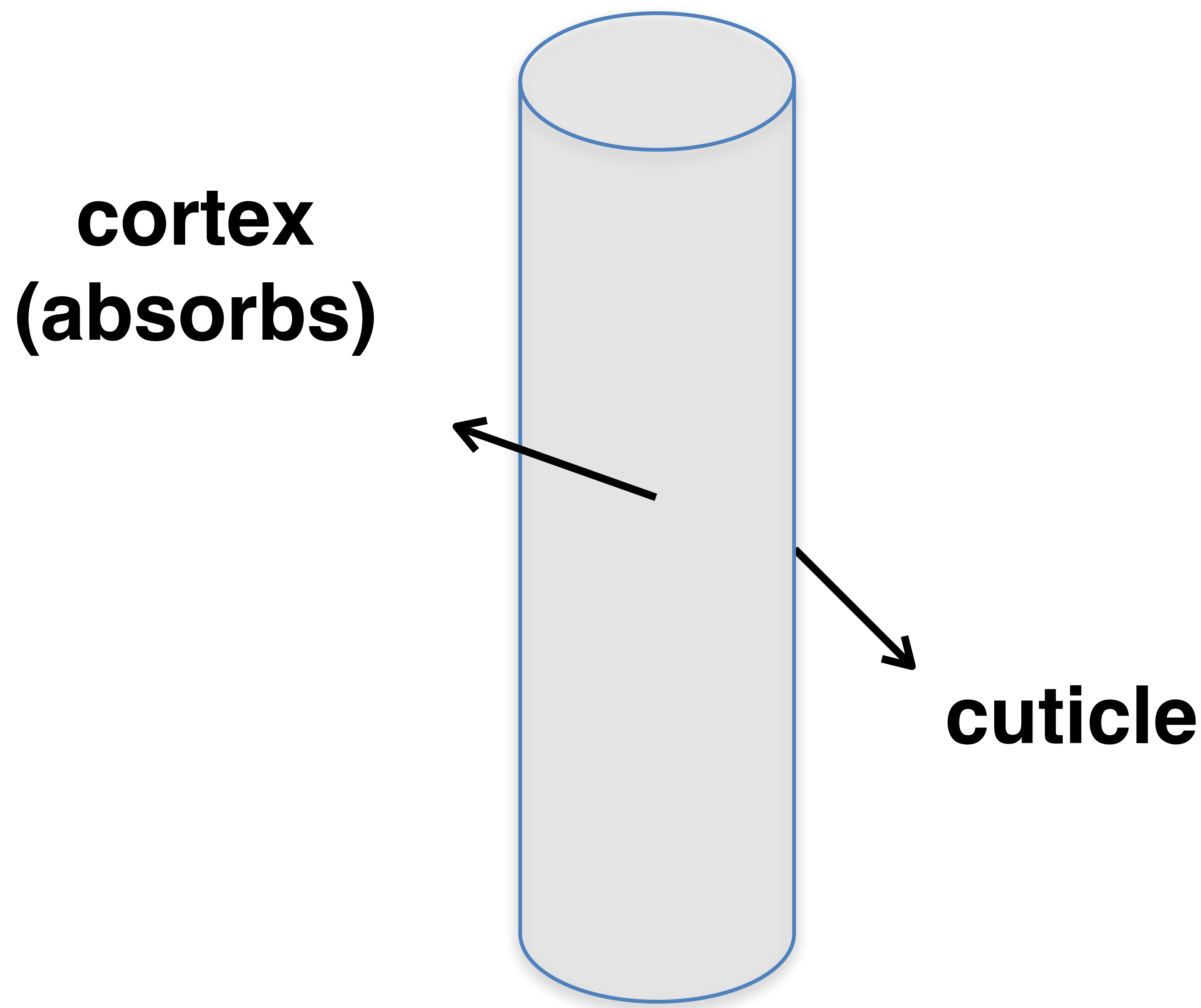
Marschner Model



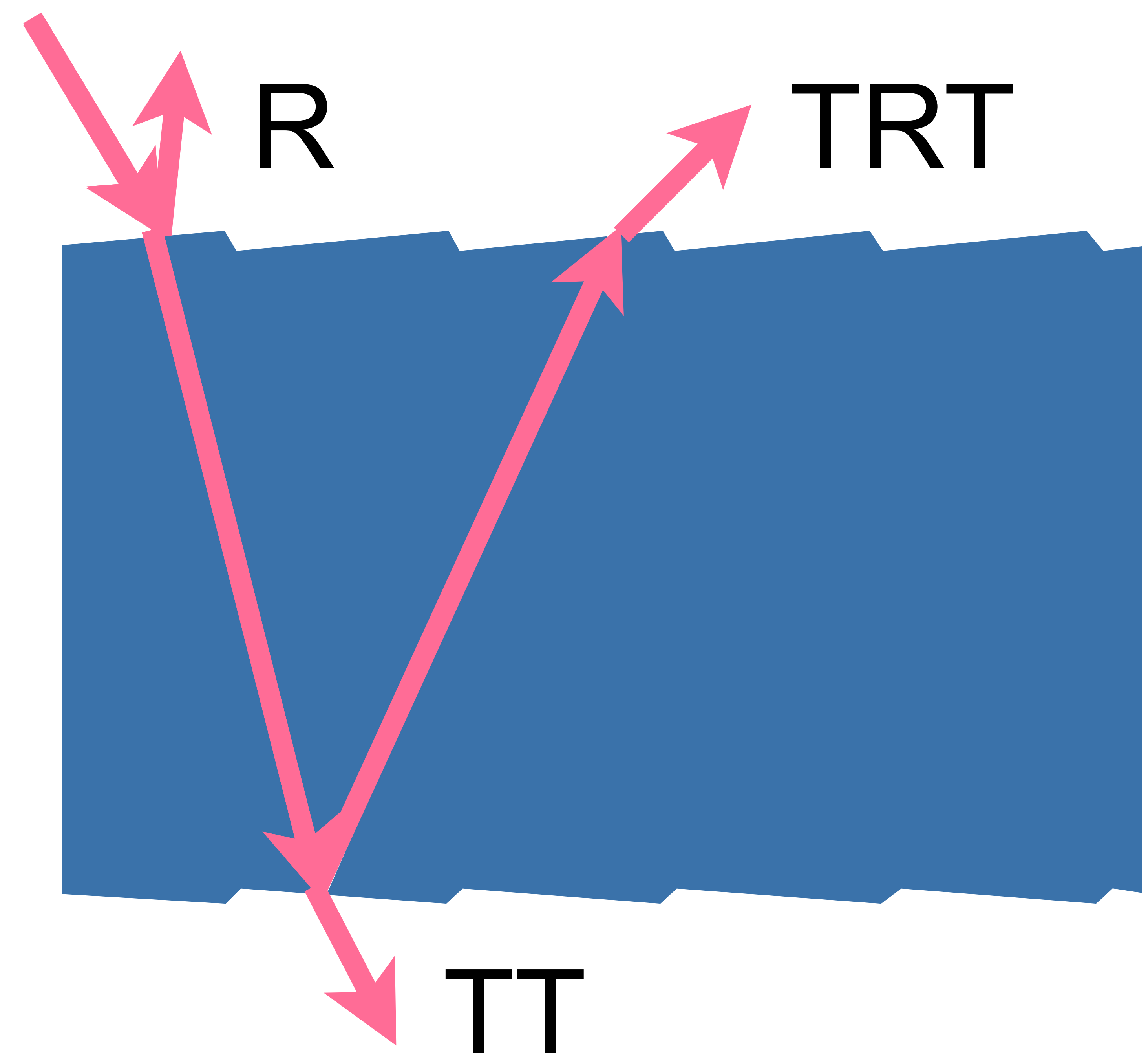
[Image courtesy of Chiwei Tseng]

Marschner Model

- Glass-like cylinder

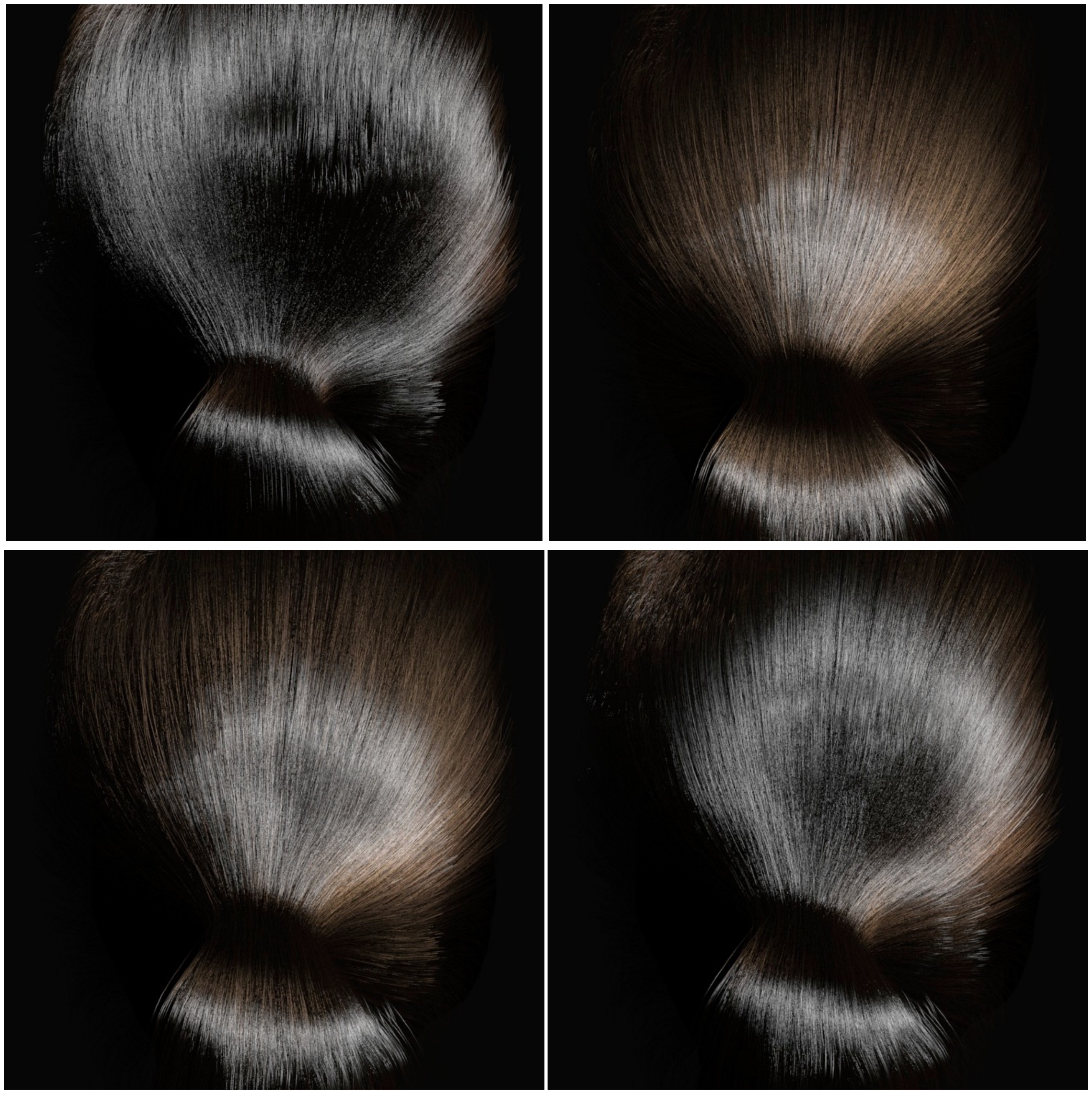


- 3 types of light interactions:
  R, TT, TRT
  (R: reflection, T: transmission)



[Marschner et al. 2003]

Marschner model



[Marschner et al. 2003]

[d'Eon et al. 2011]

Participating Media

Participating Media: Fog

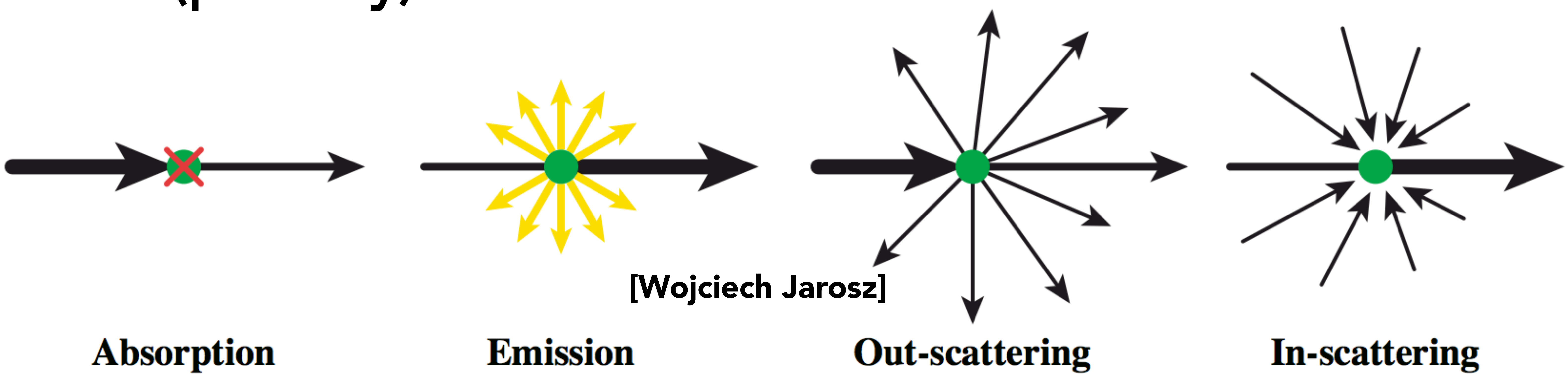
[Novák et al. 2012]

Participating Media: Cloud

[by thephotographer0]

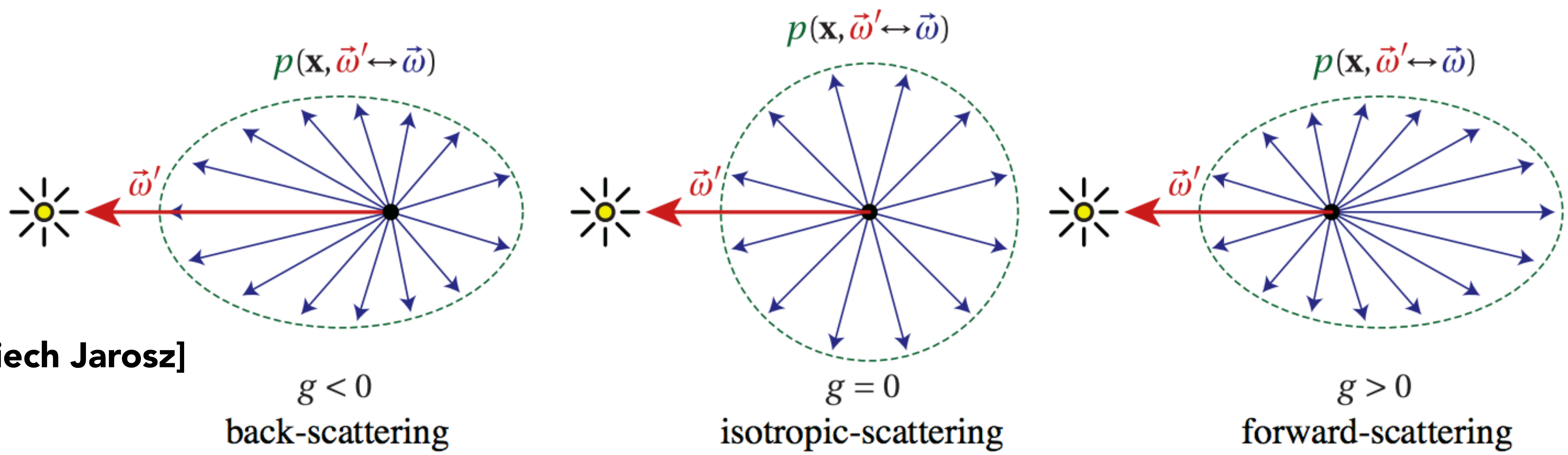
Participating Media

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



[Wojciech Jarosz]

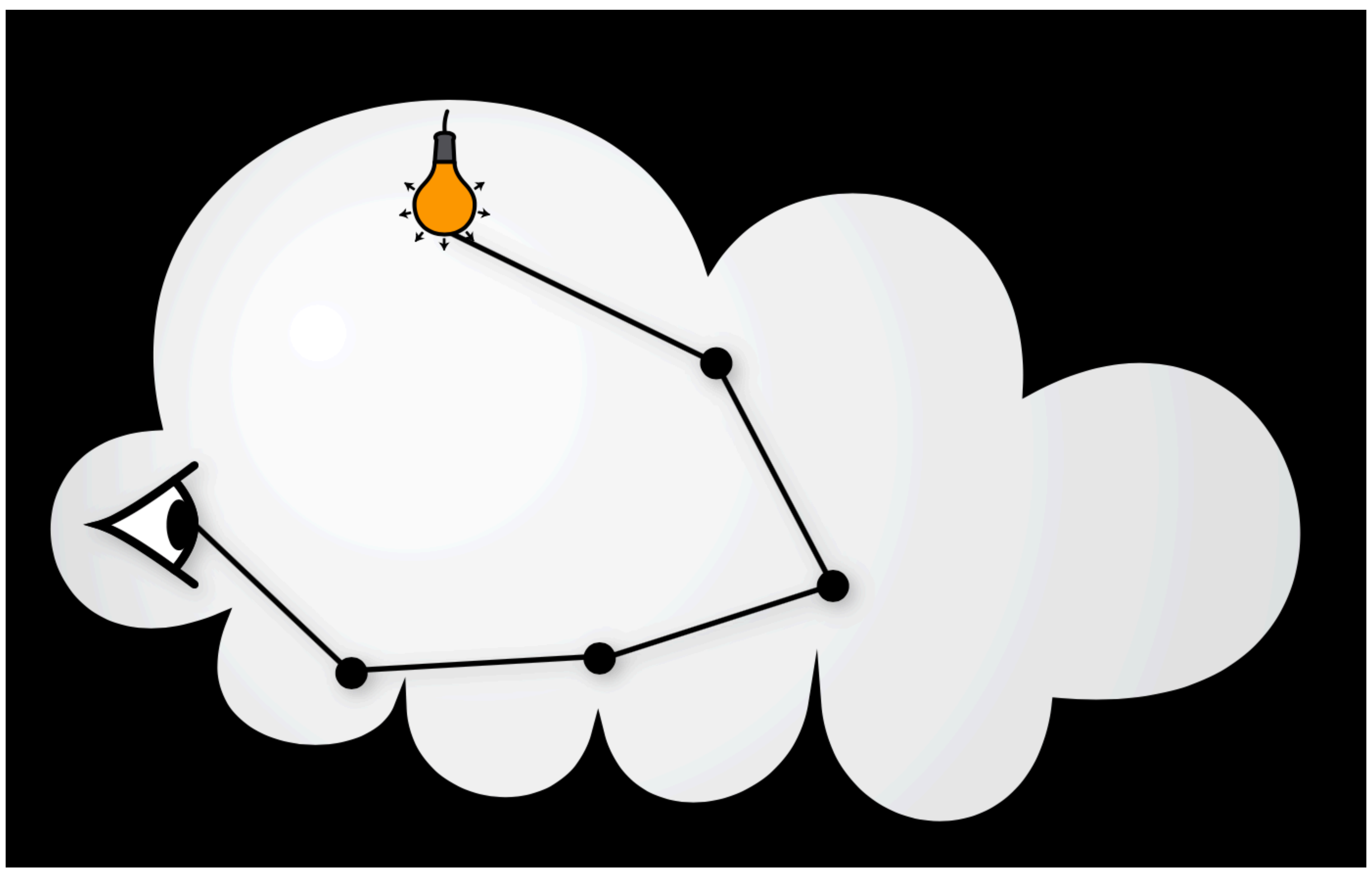
- Use Phase Function to describe the angular distribution of light scattering at any point x within participating media.

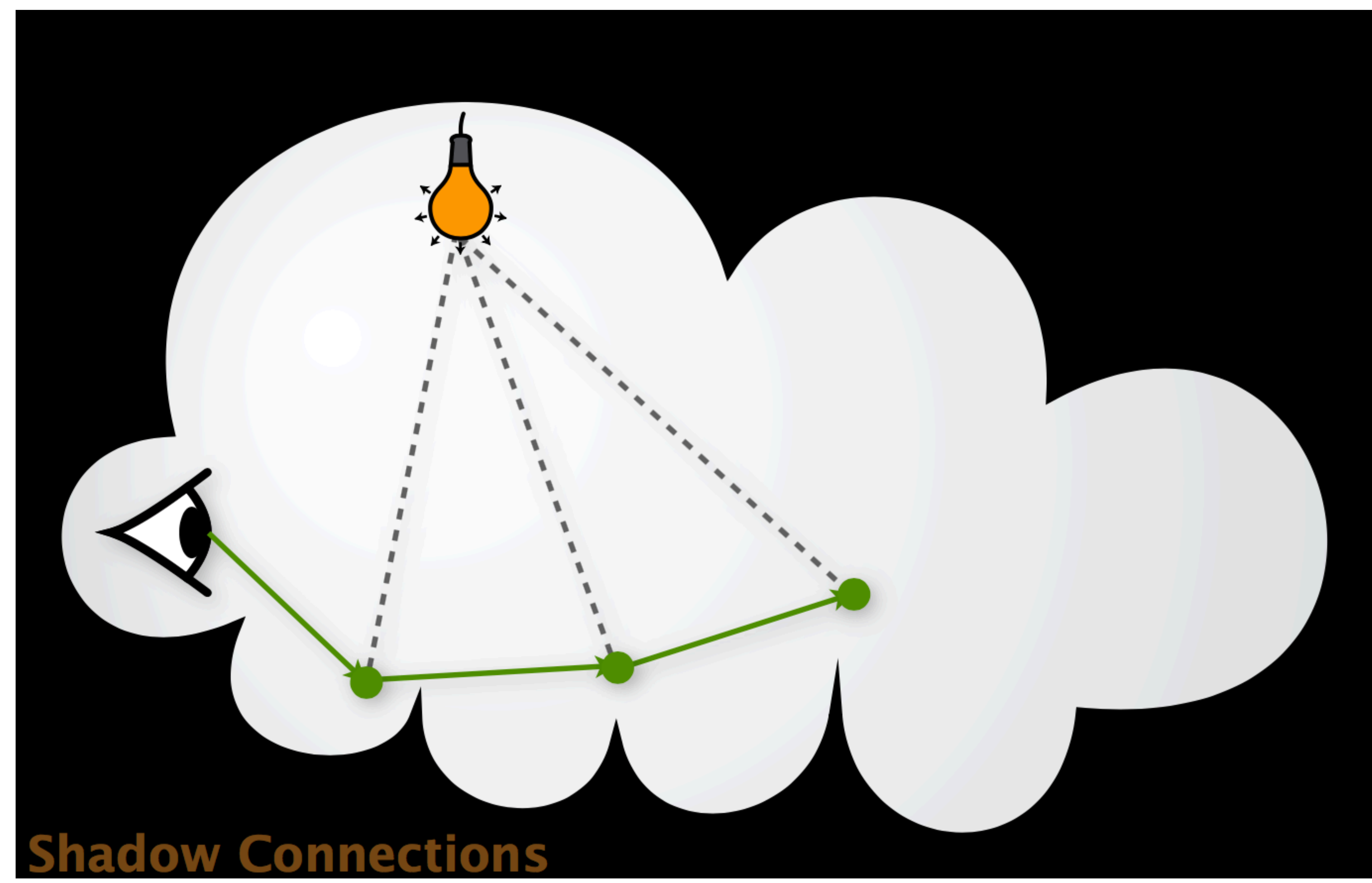


[Wojciech Jarosz]

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]

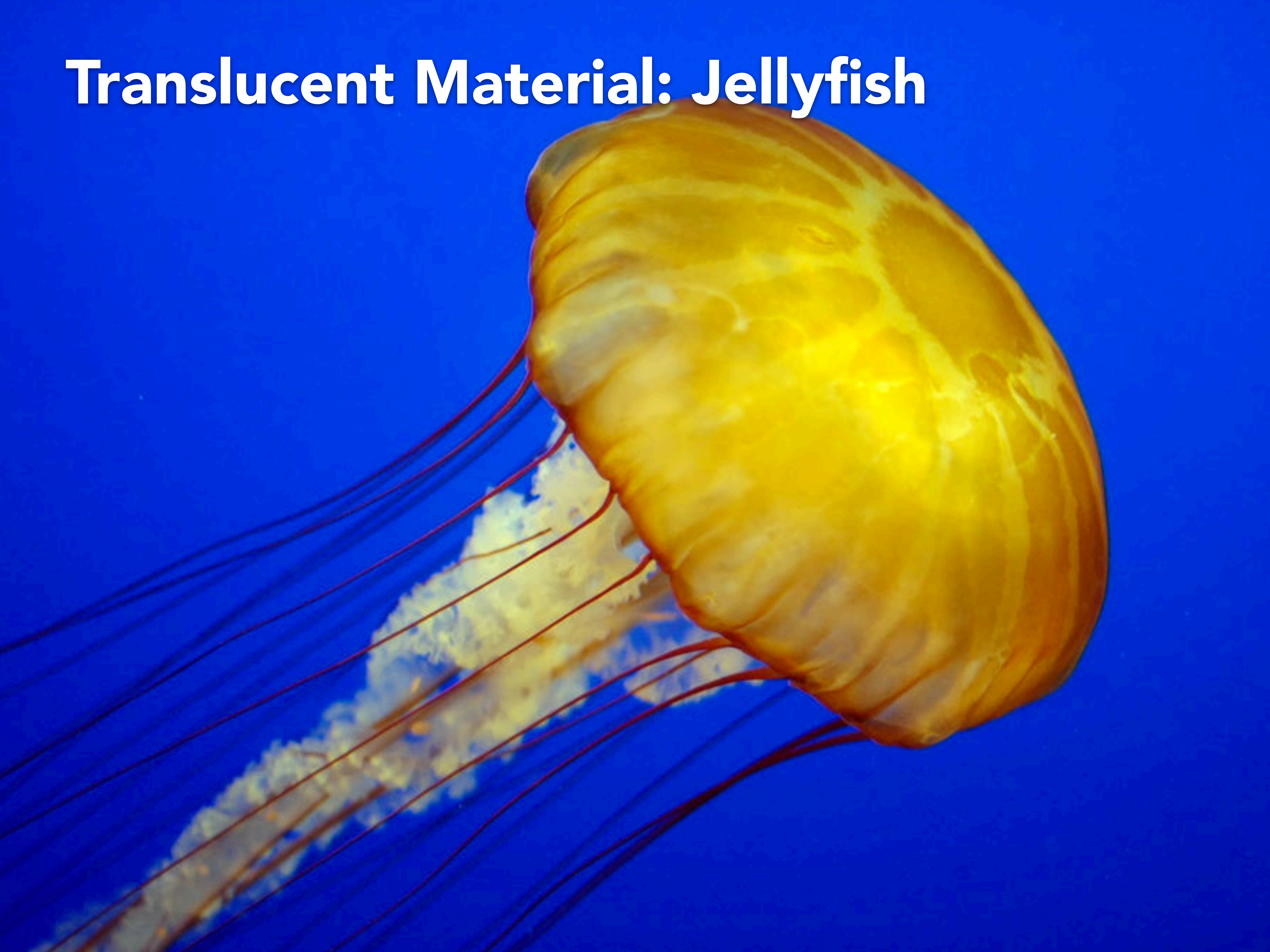
Participating Media: Application

[Assassin's Creed Syndicate. 2015 Ubisoft]

Translucent Material
(specific participating media)

Translucent Material: Jade

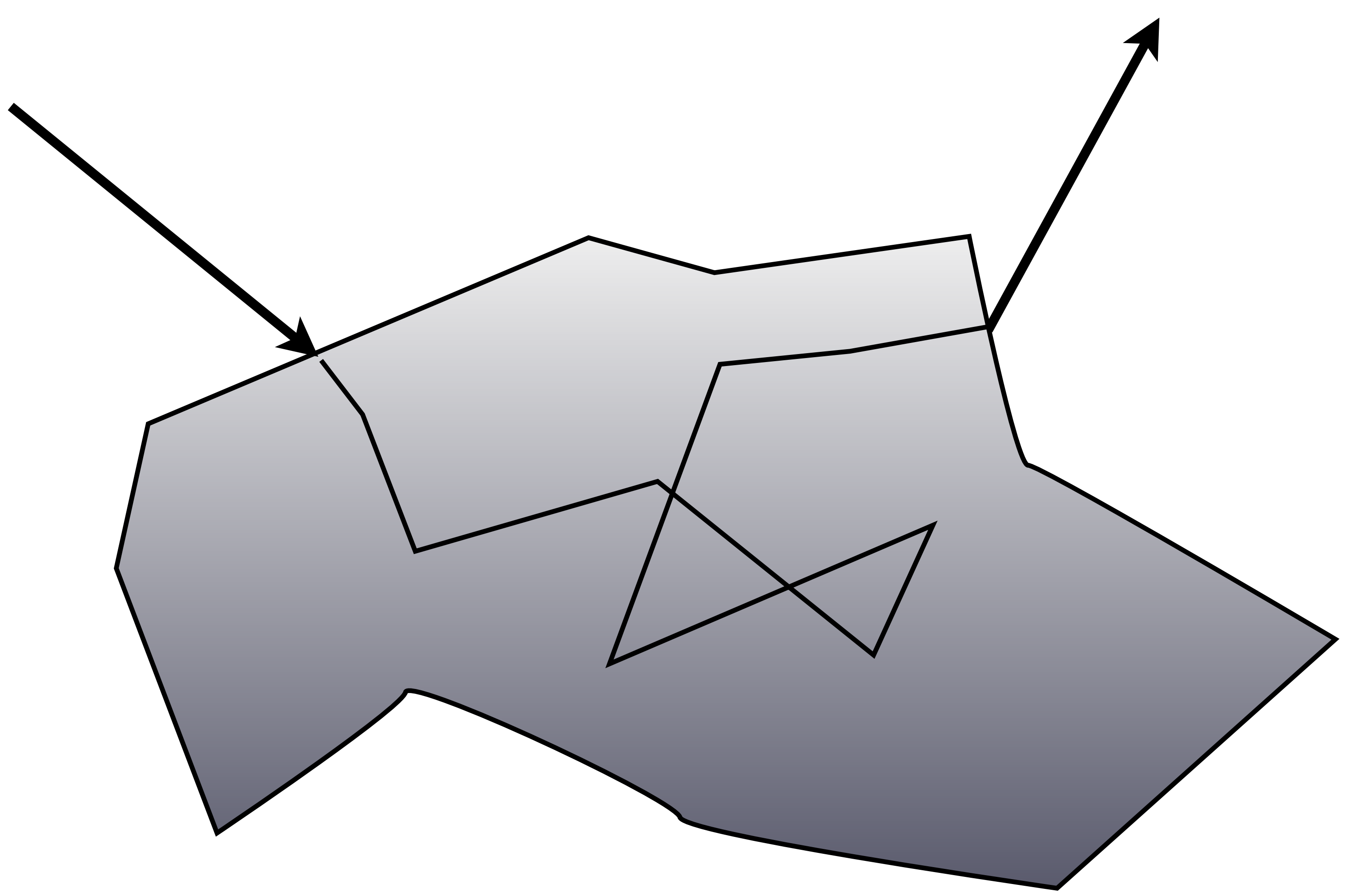
Translucent Material: Jellyfish



Subsurface Scattering

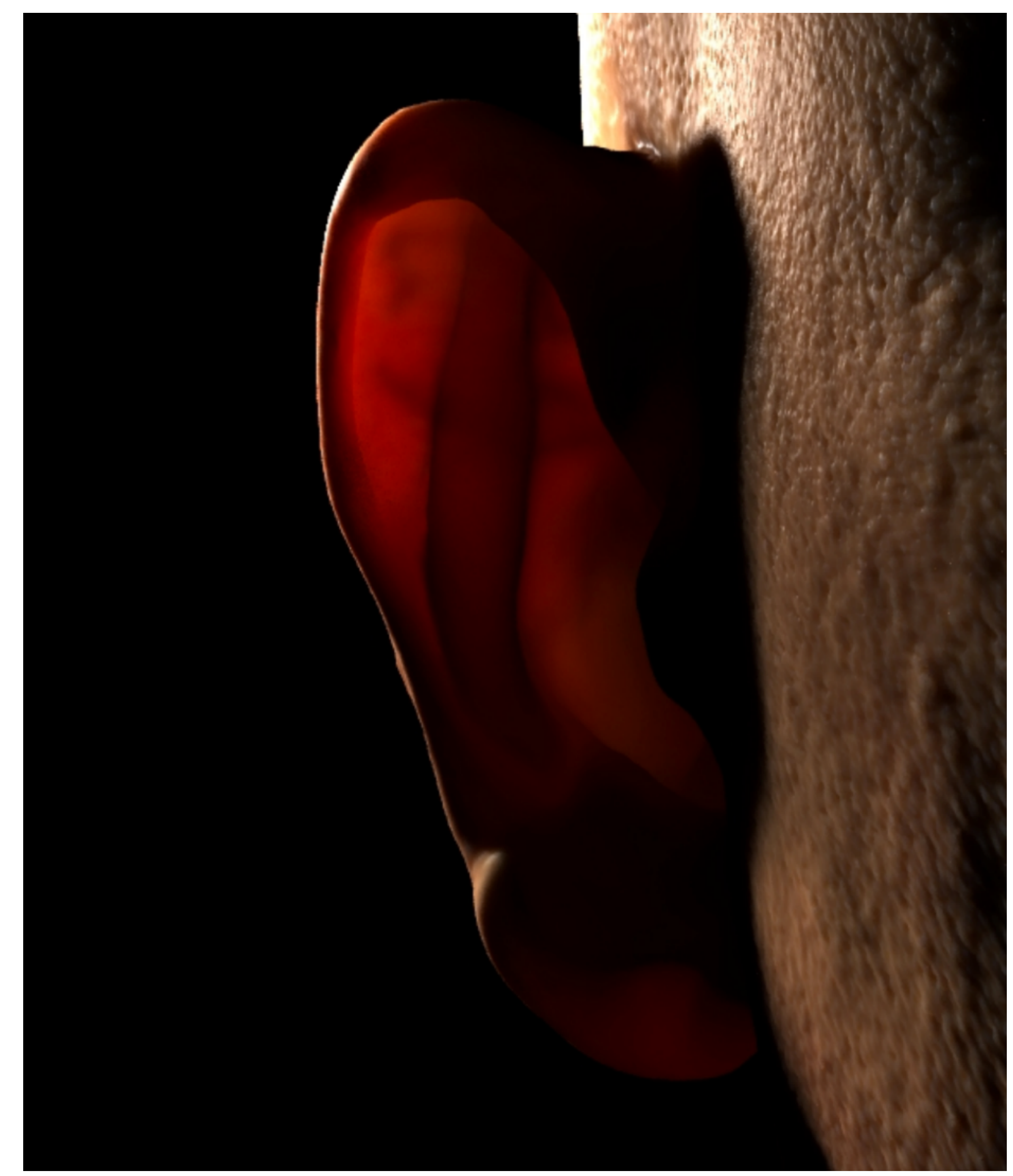
Visual characteristics of many surfaces caused by light exiting at different points than it enters

- Violates a fundamental assumption of the BRDF



- Different from transparent

[Jensen et al 2001]



[Donner et al 2008]

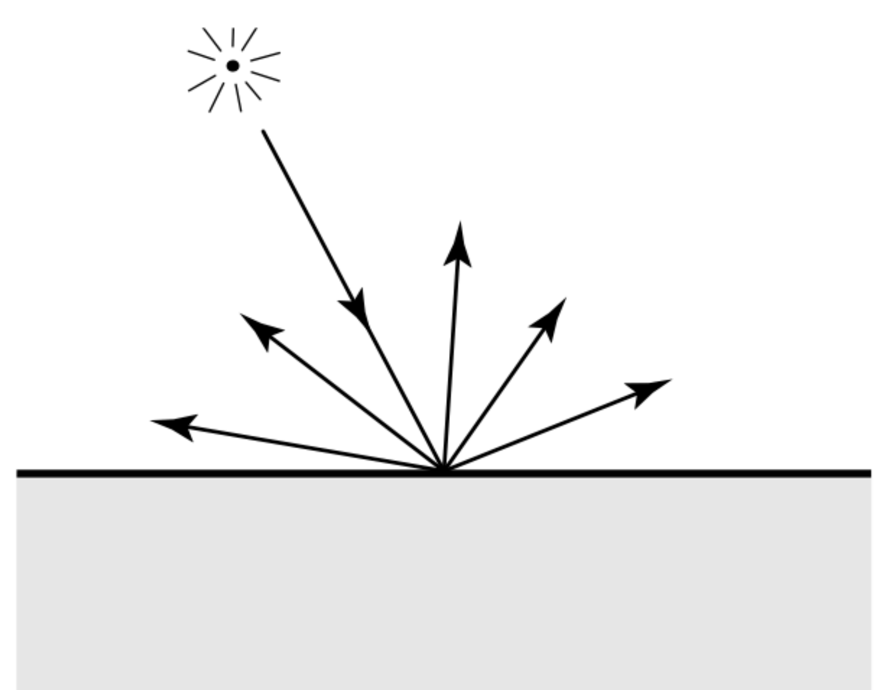
Scattering Functions

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

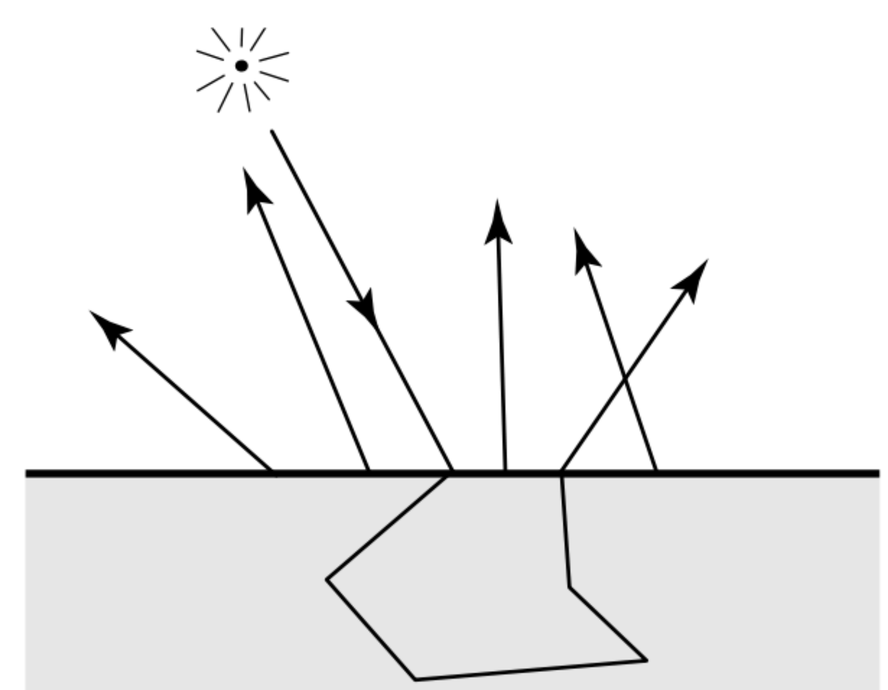
$$S(x_i, \omega_i, x_o, \omega_o)$$

- 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]

BRDF

[Jensen et al. 2001]

BSSRDF

[Jensen et al. 2001]

BRDF vs BSSRDF

BRDF BSSRDF

[Jensen et al. 2001]

Acknowledgments

Thanks to Lingqi Yan, Matt Pharr, Pat Hanrahan and Kayvon Fatahalian for slide resources.

Extra

Procedural Appearance

Procedural Appearance

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

[Lagae et al. 2009]

Procedural Appearance

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

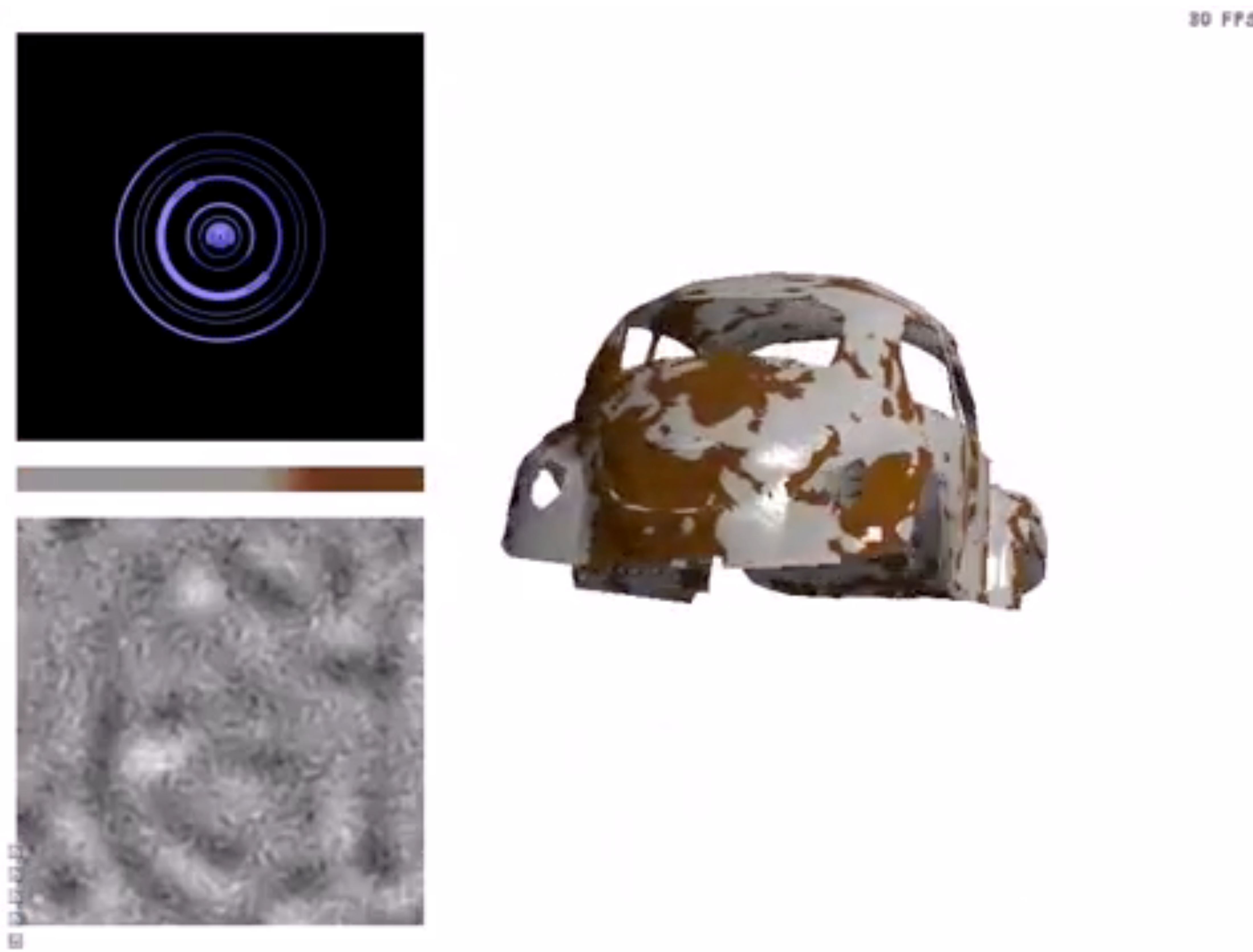
[Lagae et al. 2009]

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]