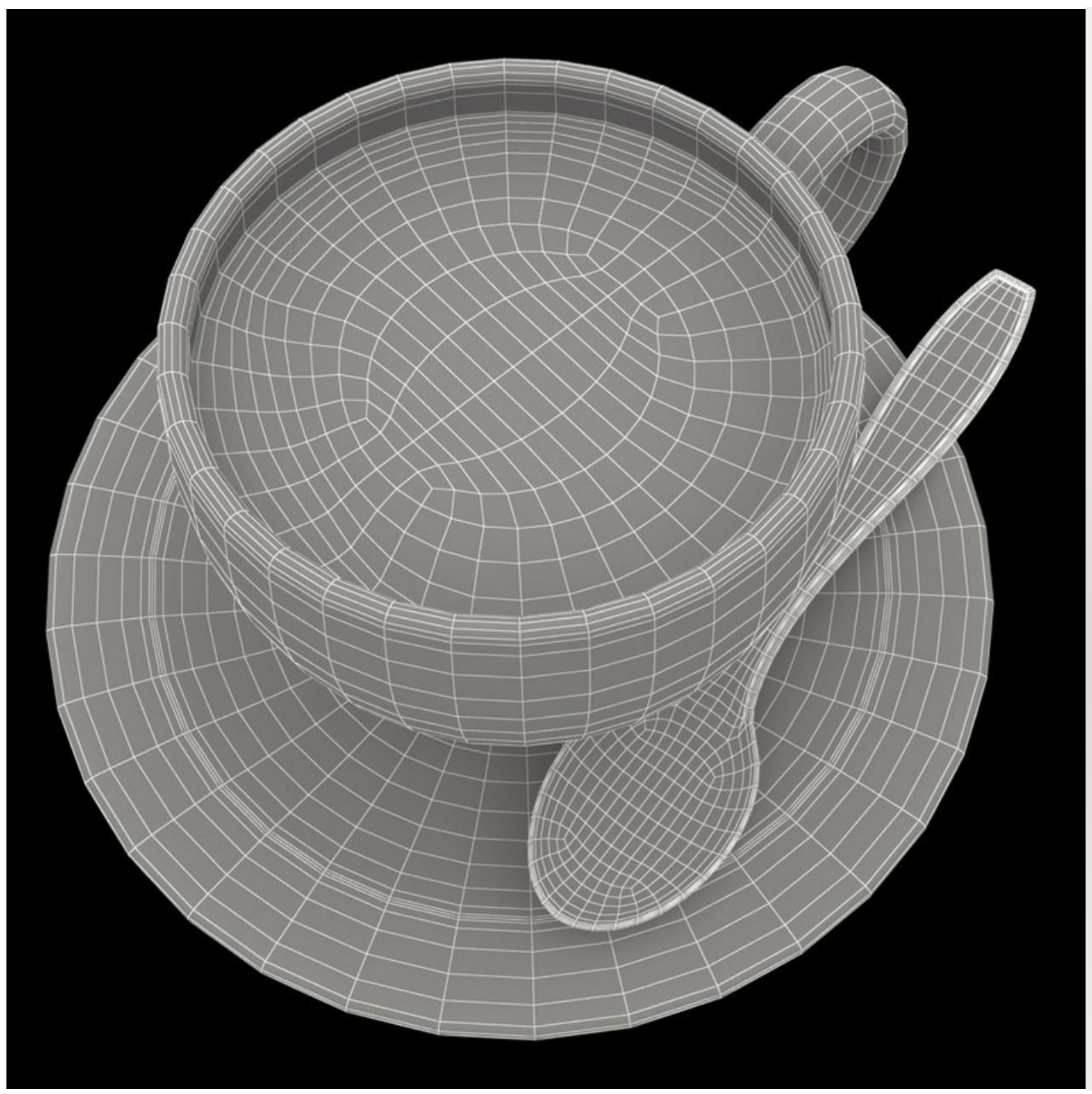
Lecture 16:

Introduction to Material Modeling

Computer Graphics and Imaging

UC Berkeley CS184

What is Material in Computer Graphics?



3D coffee mug model

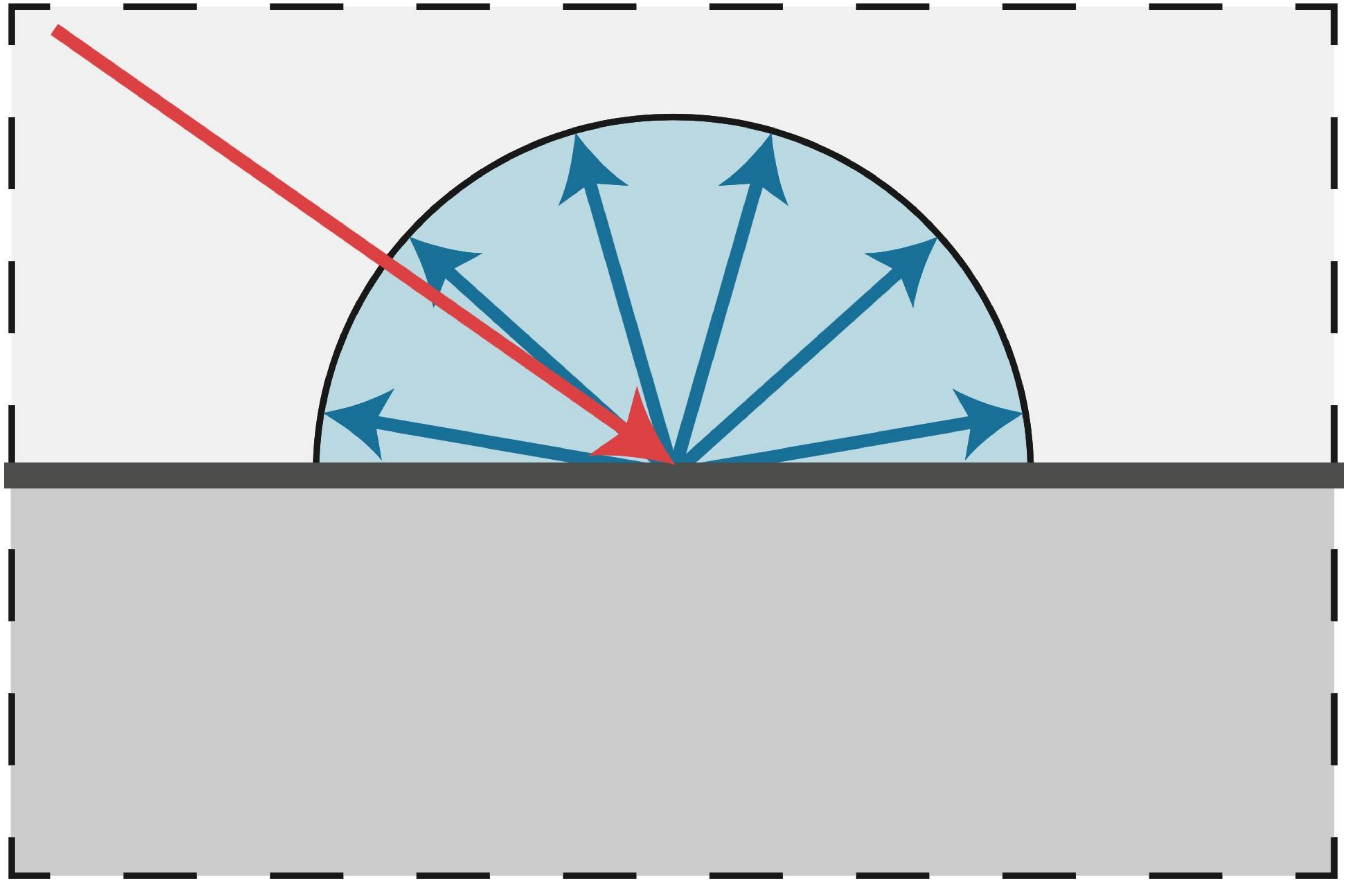
Rendered

Rendered

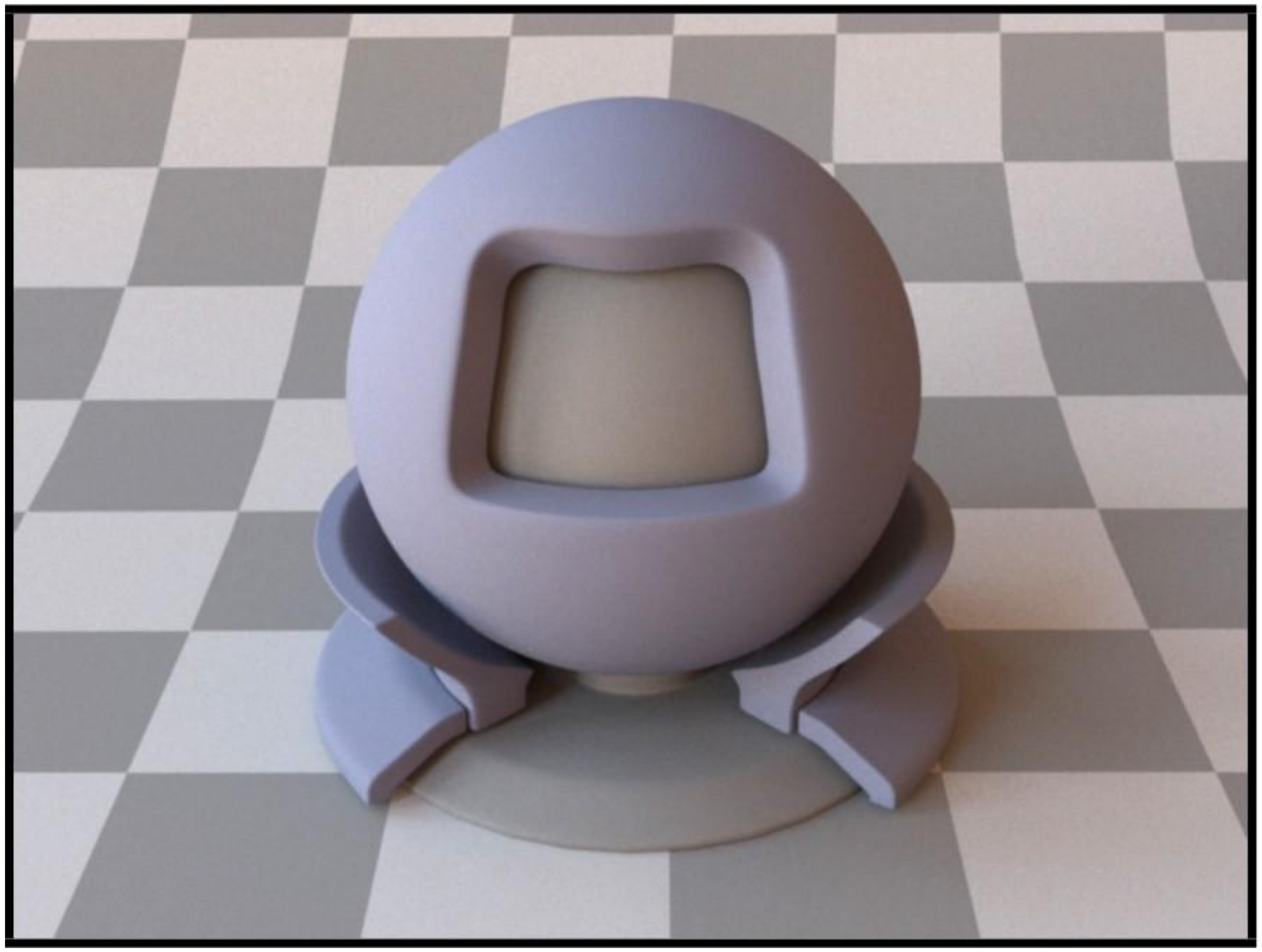
[From TurboSquid, created by artist 3dror]

Material ⇔ BRDF

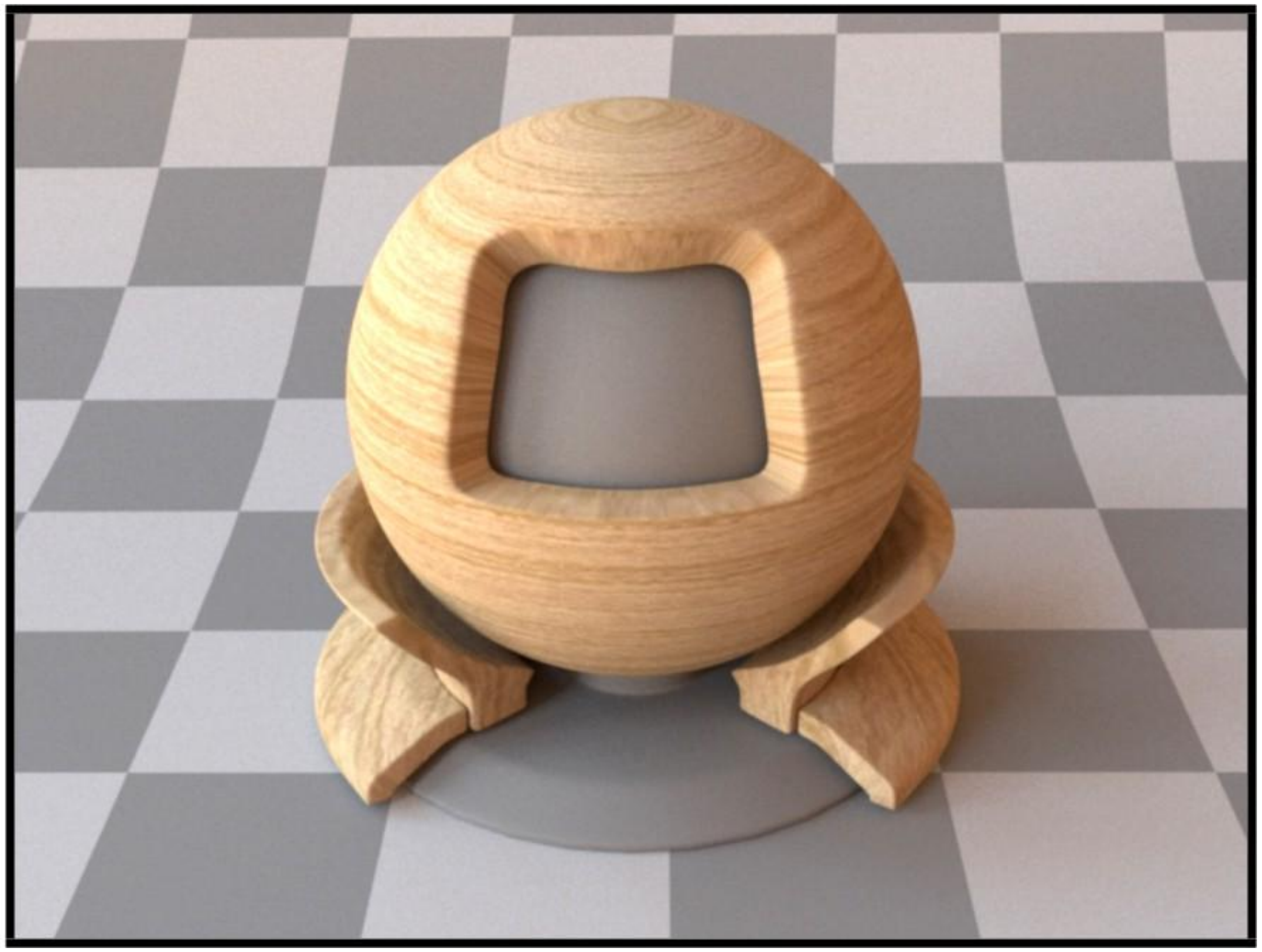
What is this material?



Diffuse / Lambertian Material (BRDF)



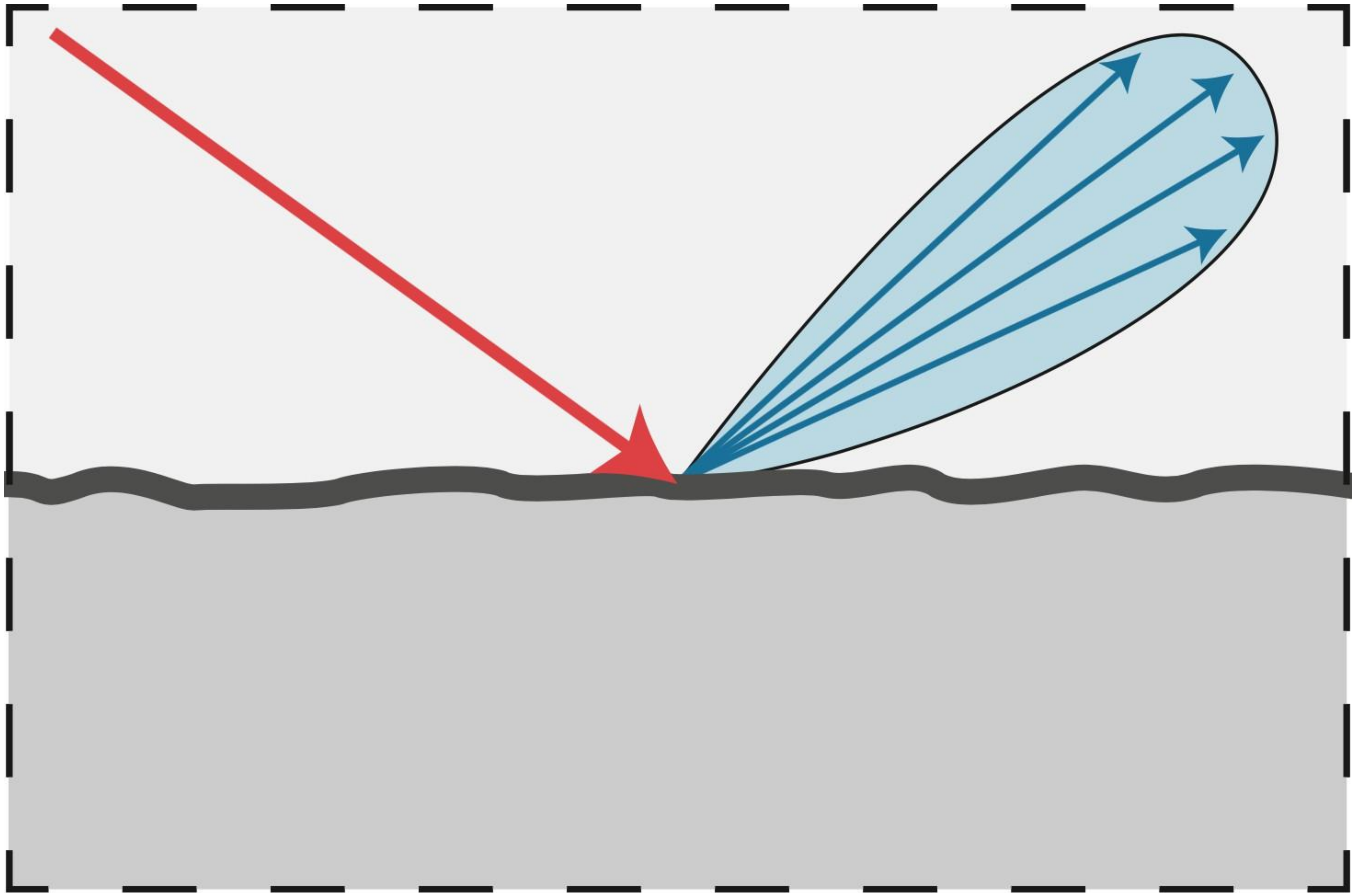
Uniform colored diffuse BRDF



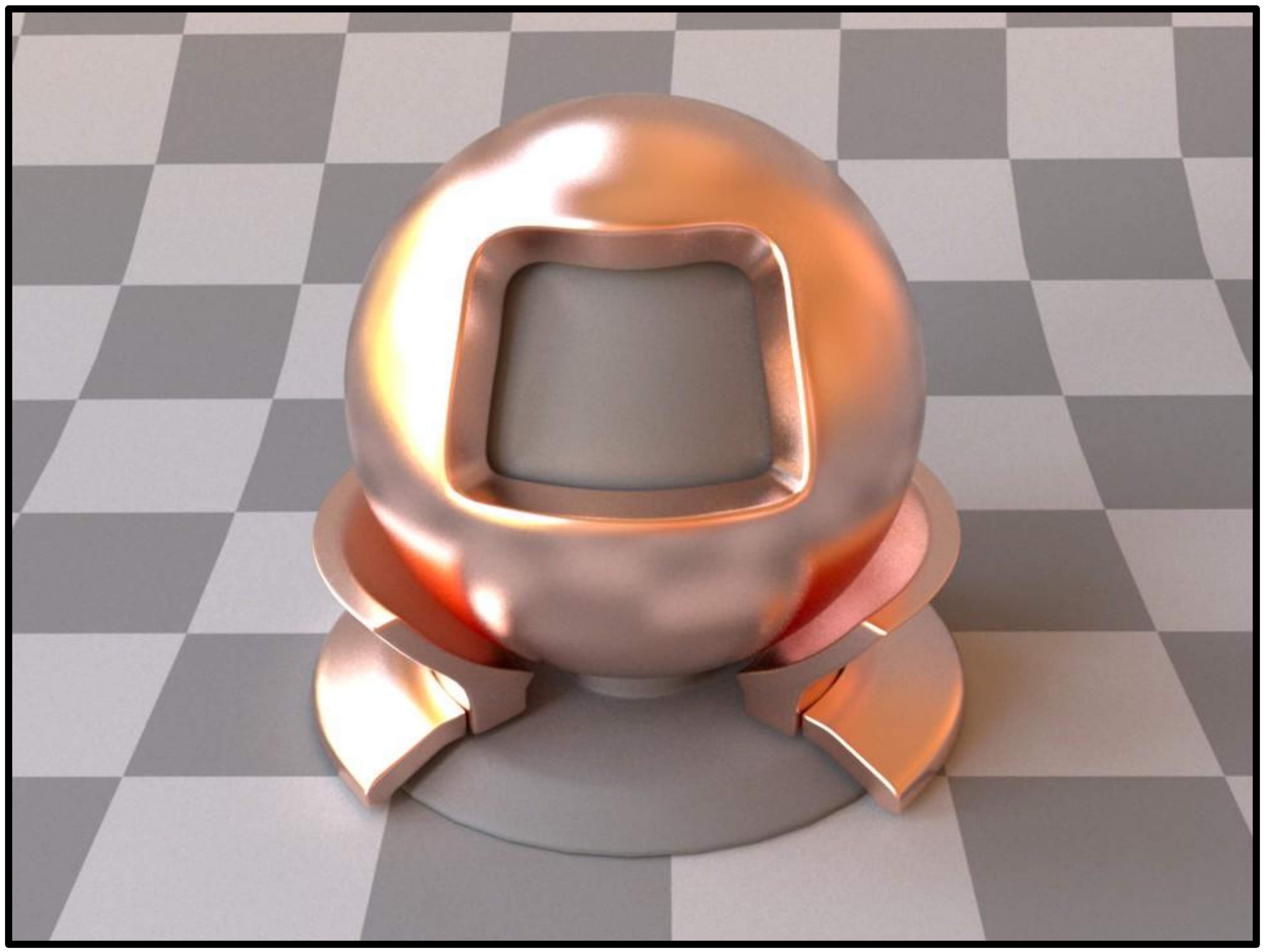
Textured diffuse BRDF

[Mitsuba renderer, Wenzel Jakob, 2010]

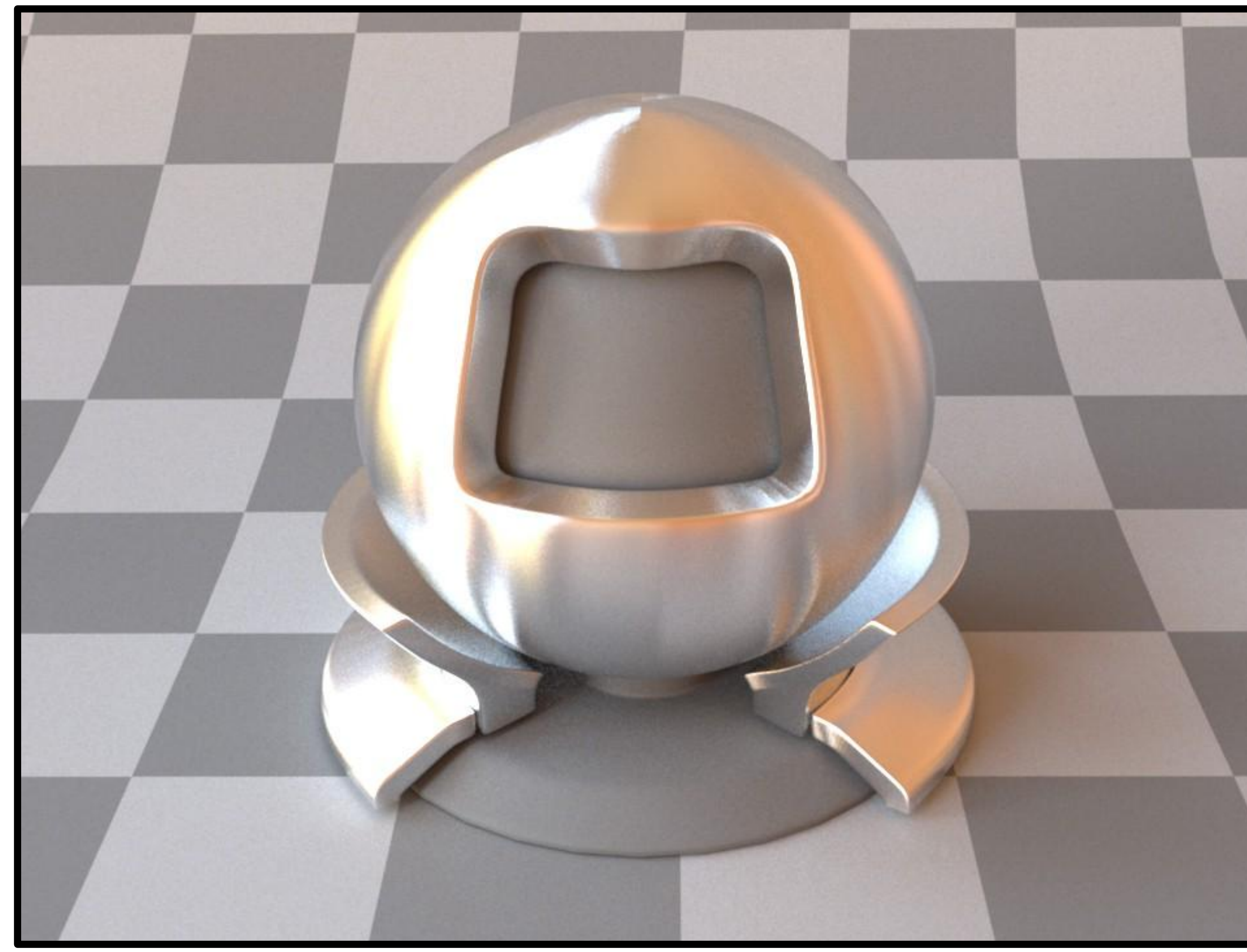
What is this material?



Glossy material (BRDF)



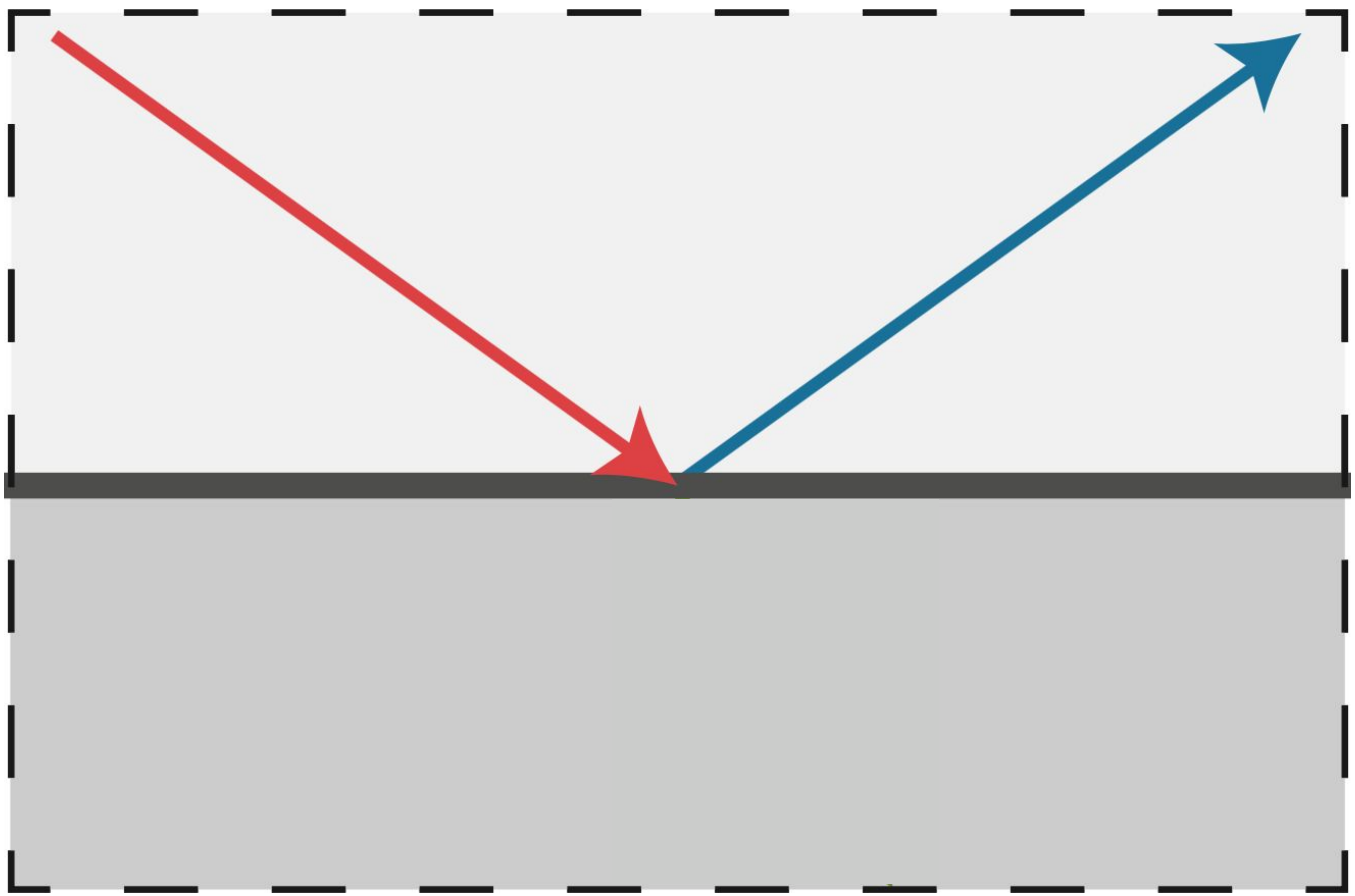
Rough Copper



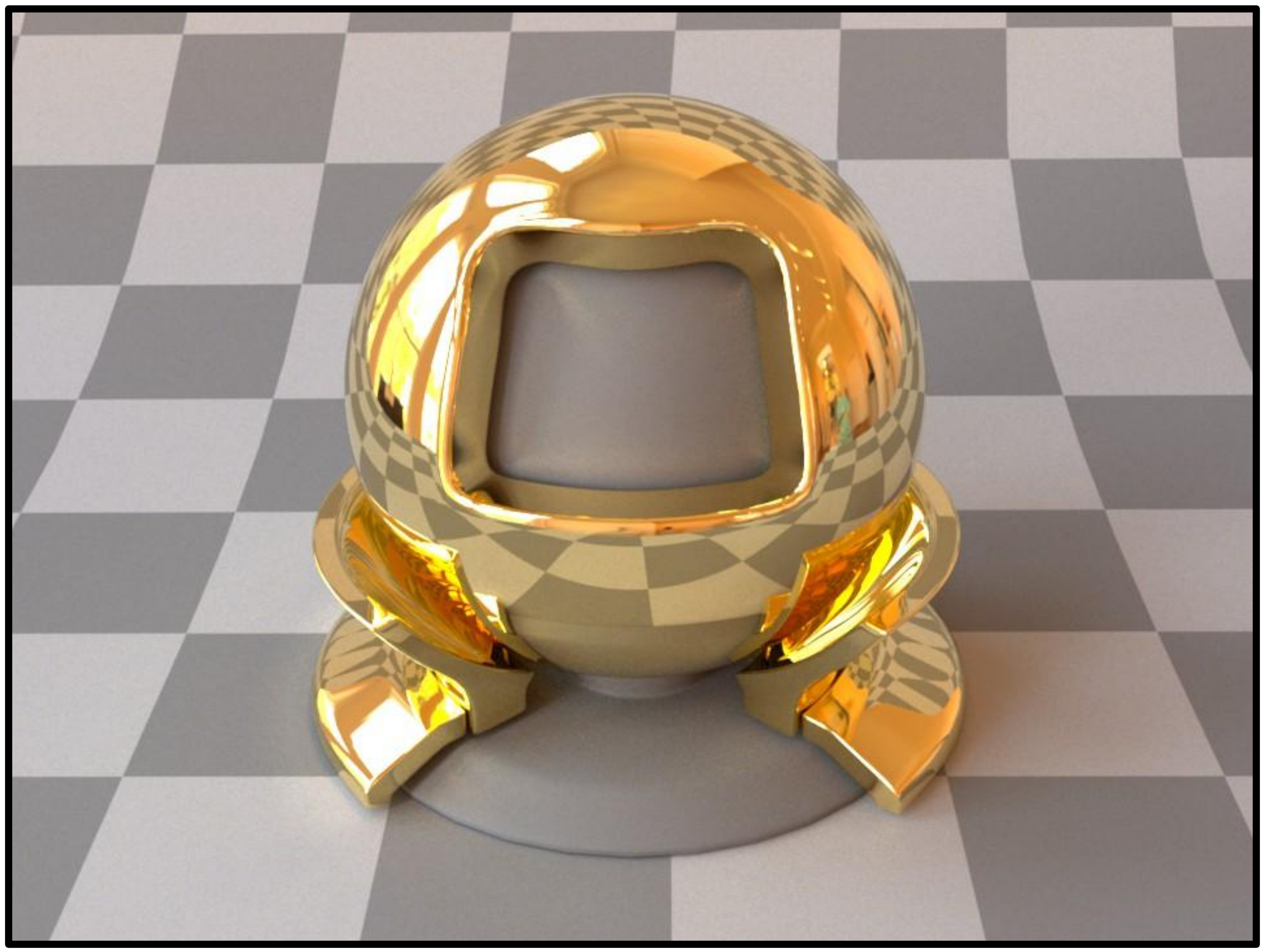
Brushed Aluminum

[Mitsuba renderer, Wenzel Jakob, 2010]

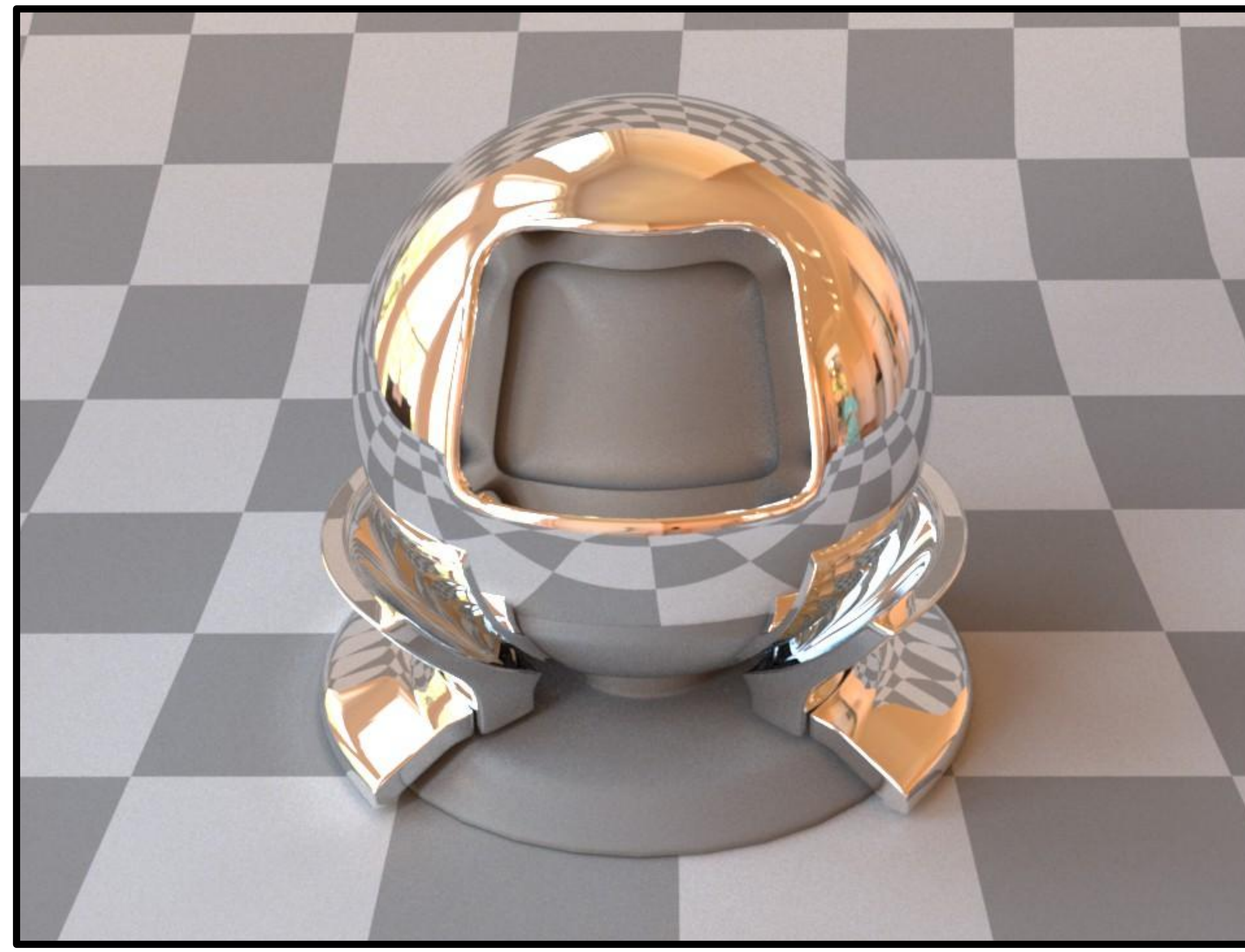
What is this material?



Ideal reflective material (BRDF)



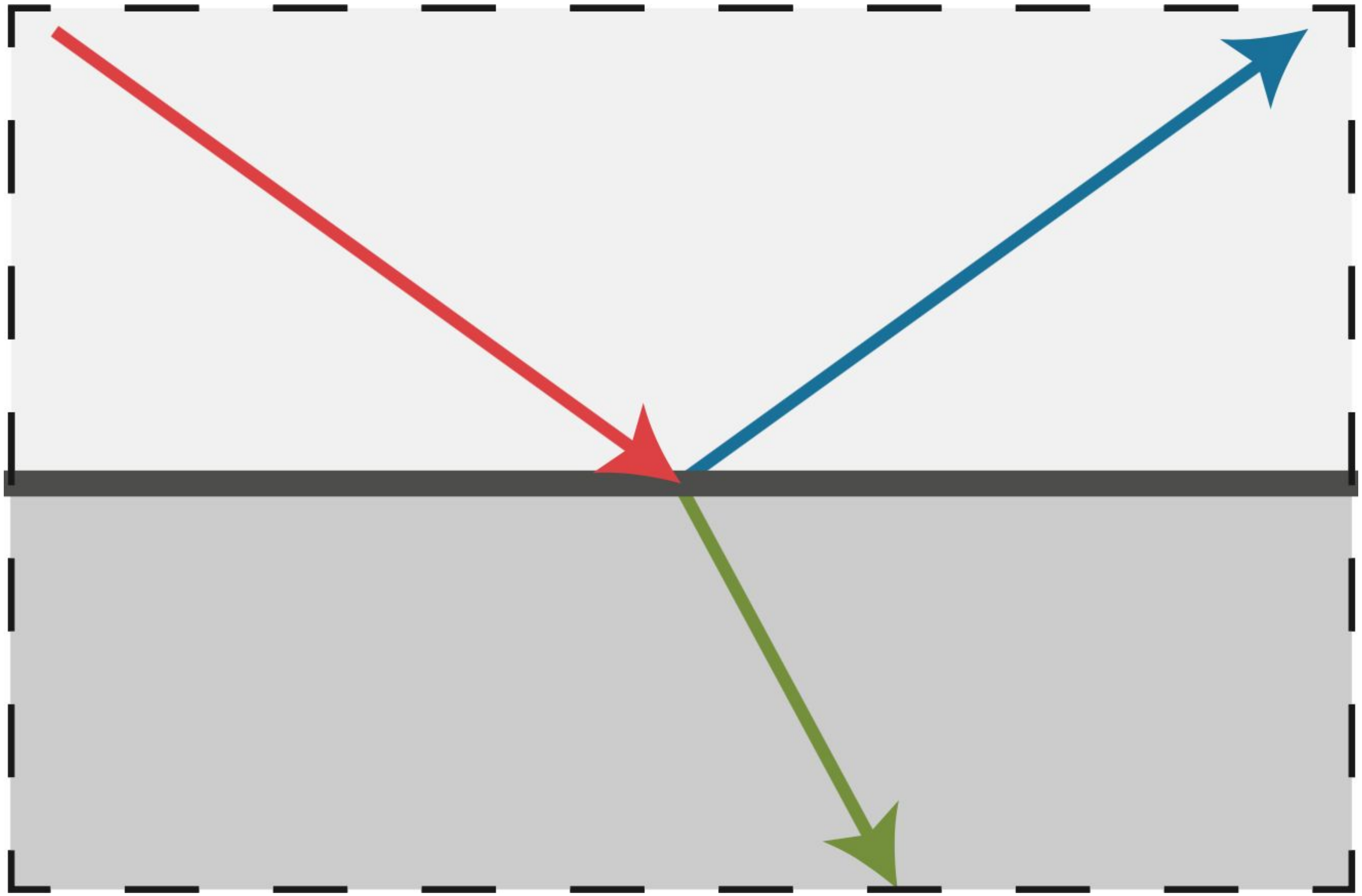
Gold



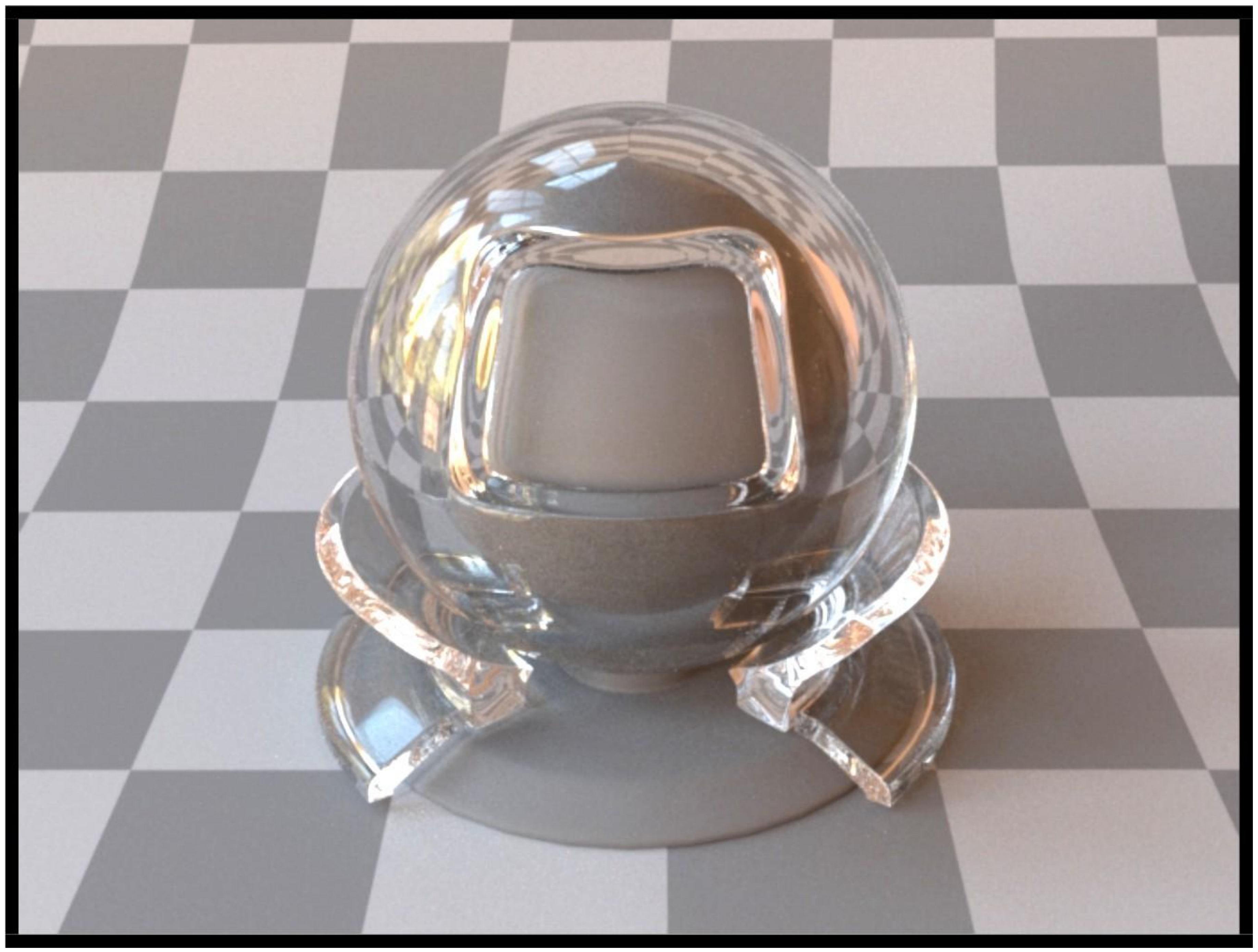
Aluminum

[Mitsuba renderer, Wenzel Jakob, 2010]

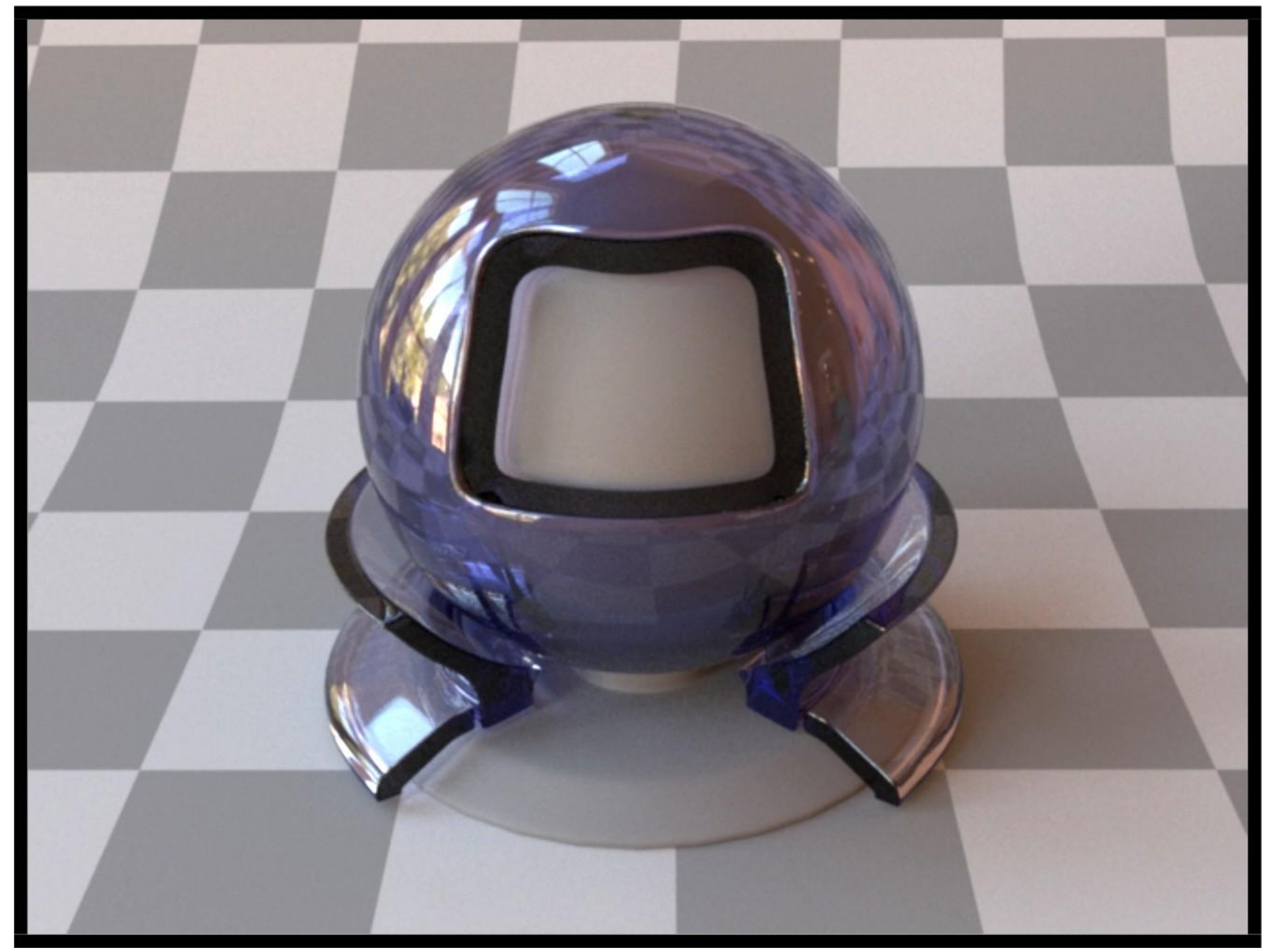
What is this material?



Ideal reflective / refractive material (BSDF*)



Air ←→ plastic interface

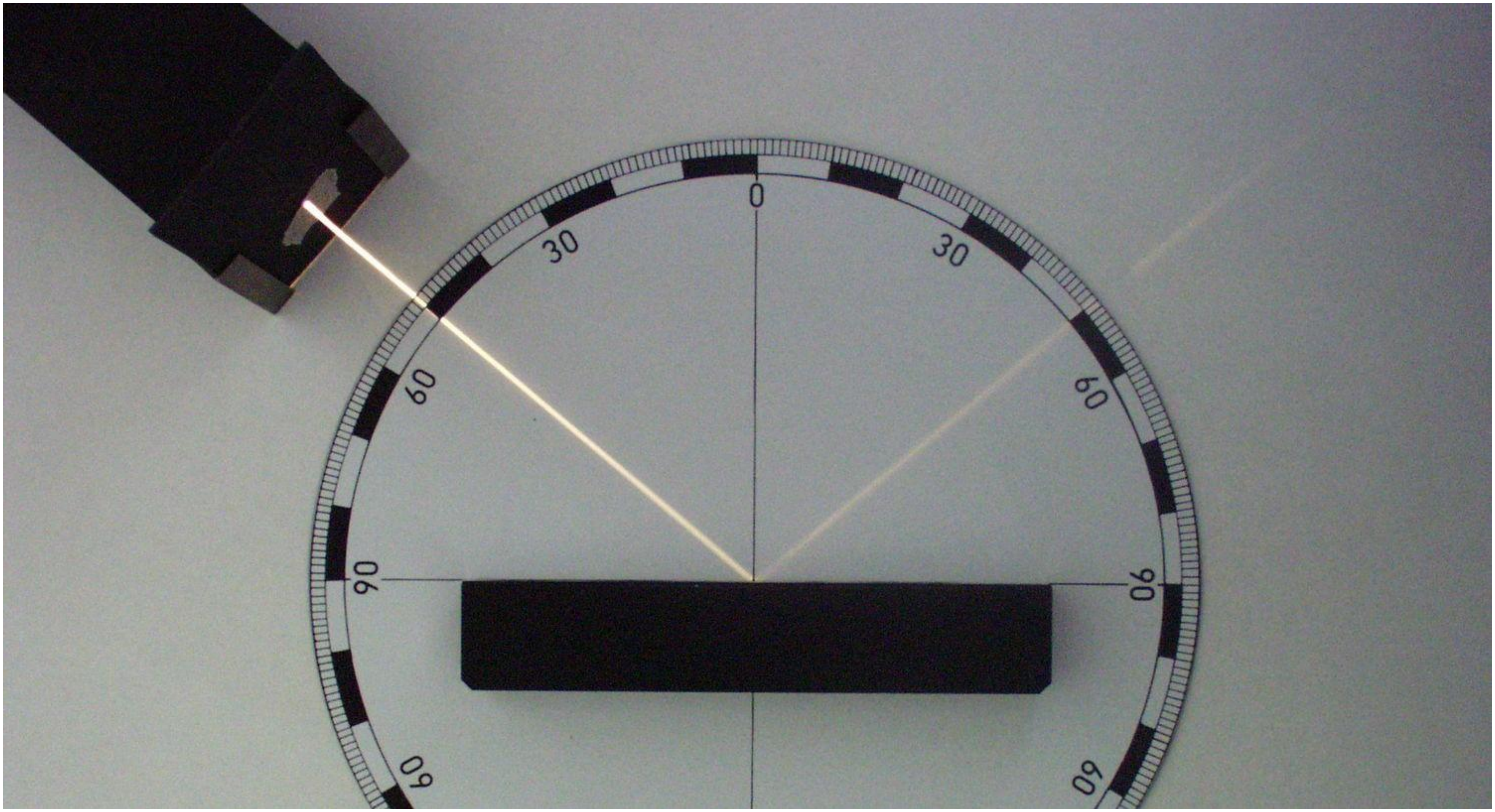


Air ←→ glass interface (with absorption)

[Mitsuba renderer, Wenzel Jakob, 2010]

Ideal Reflection and Refraction

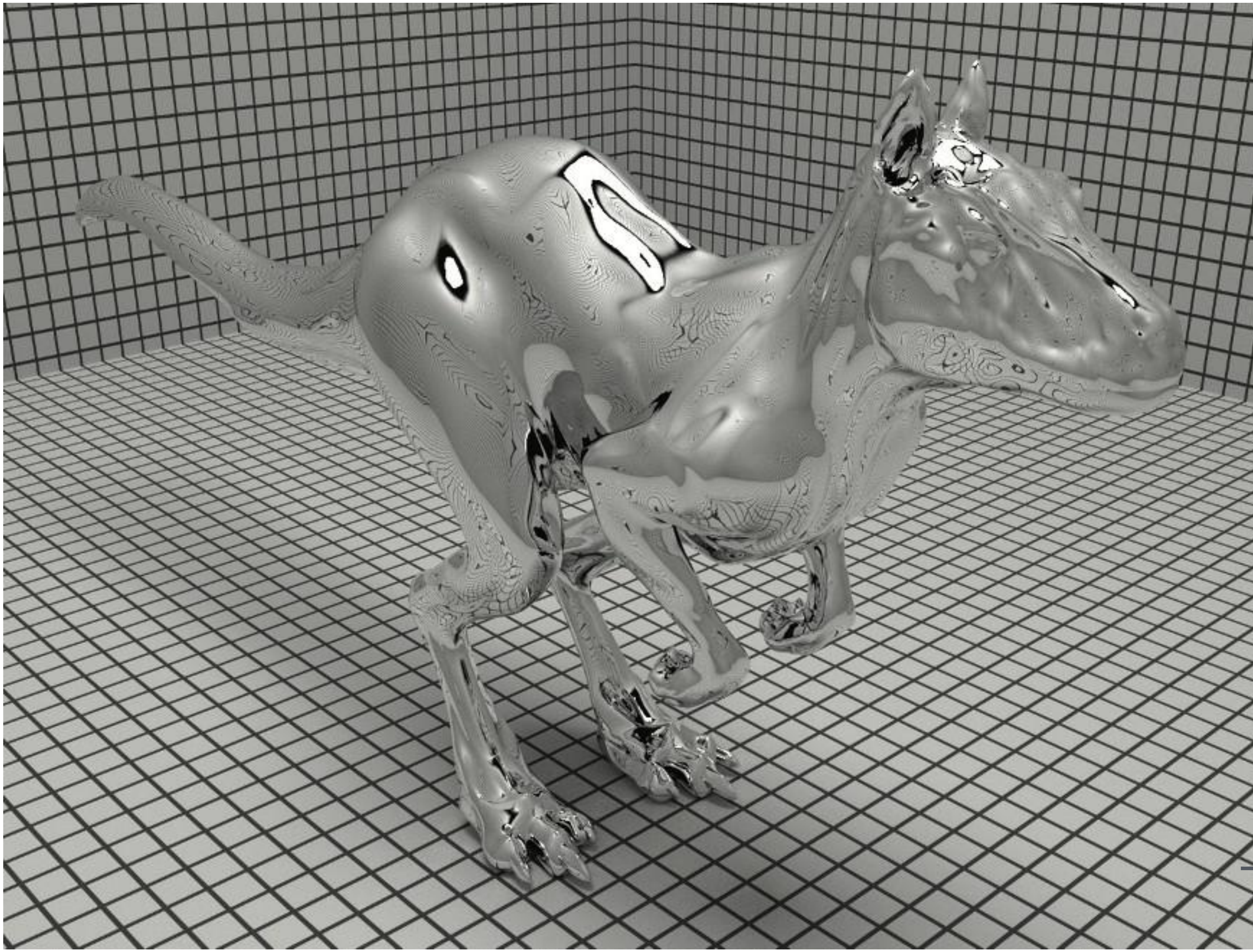
Perfect Specular Reflection



[Zátonyi Sándor]

Perfect Specular Reflection

Perfect Specular Reflection BRDF



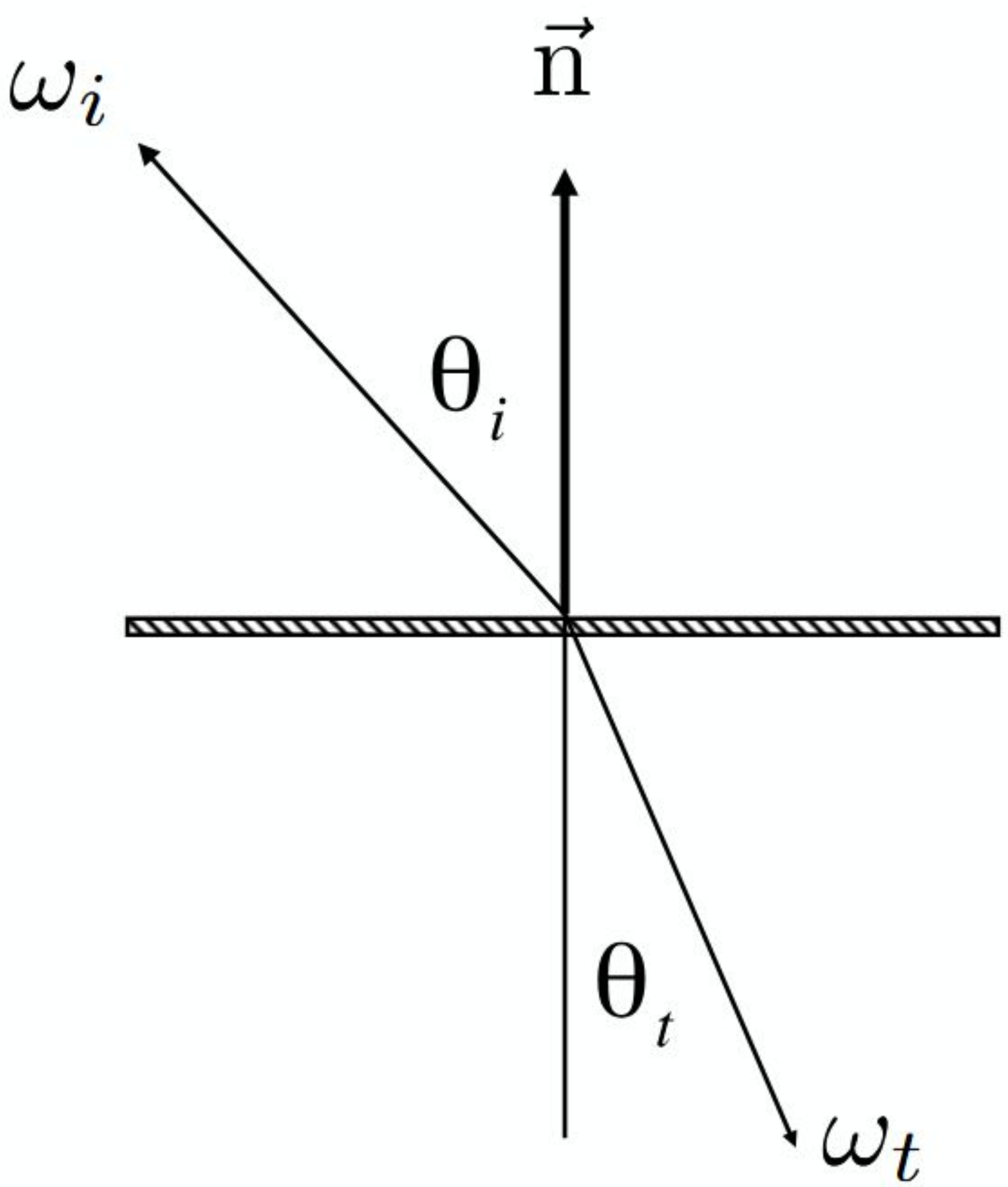
PBRT

Specular Refraction

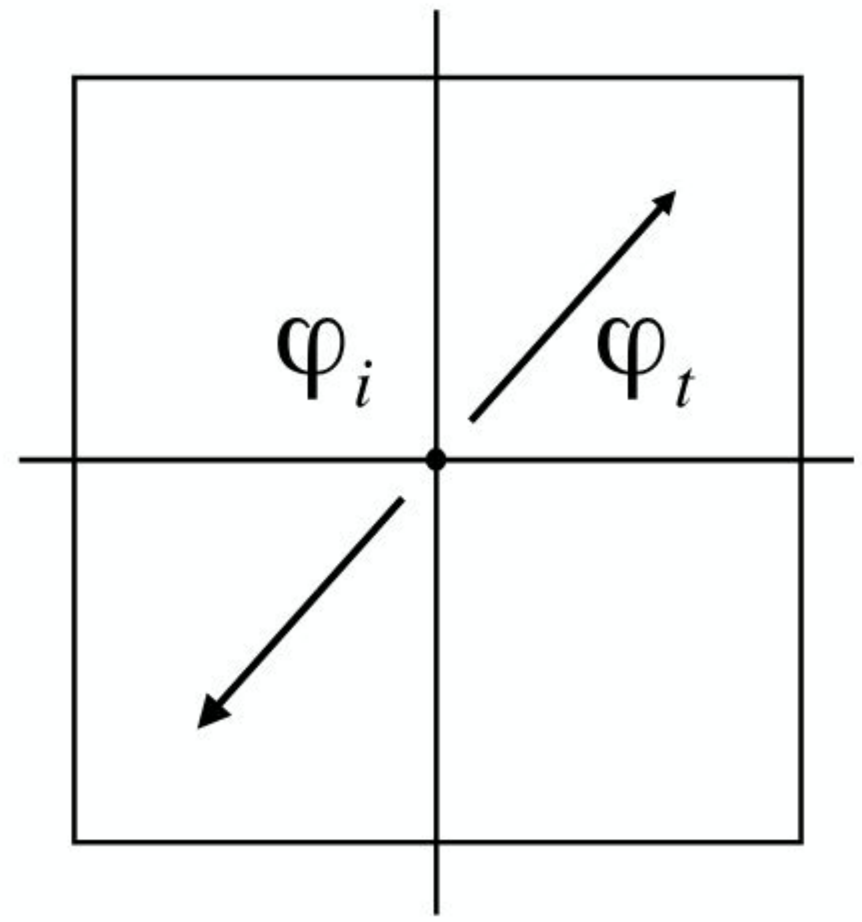
In addition to reflecting off surface, light may be transmitted through surface.

Light refracts when it enters a new medium.

Snell's Law



$$\eta_i \sin\theta_i = \eta_t \sin\theta_t$$



$$\varphi_t = \varphi_i \pm \pi$$

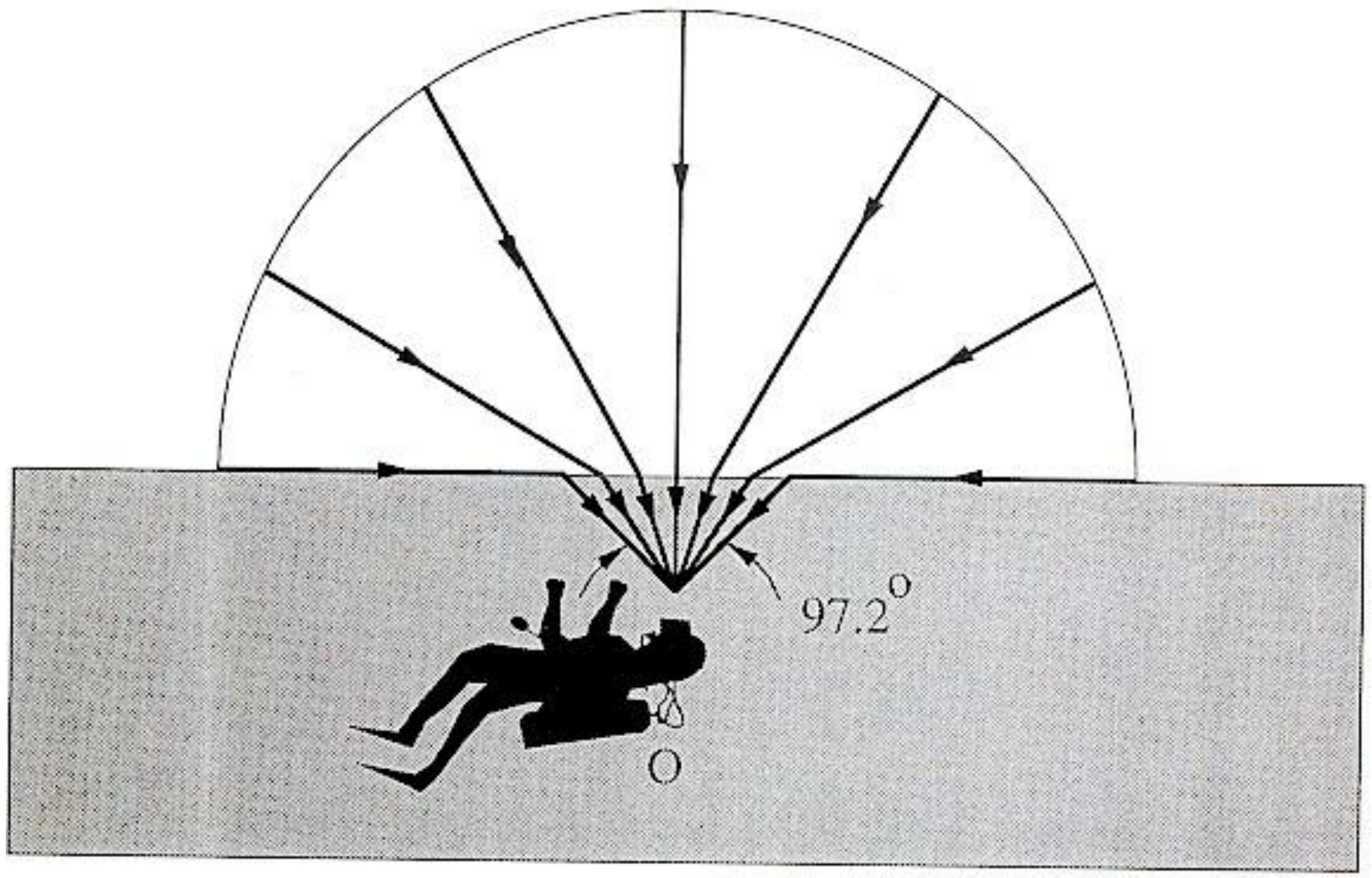
Medium	η*
Vacuum	1.0
Air (sea level)	1.00029
Water (20°C)	1.333
Glass	1.5-1.6
Diamond	2.42

* index of refraction is wavelength dependent (these are averages)

Law of Refraction

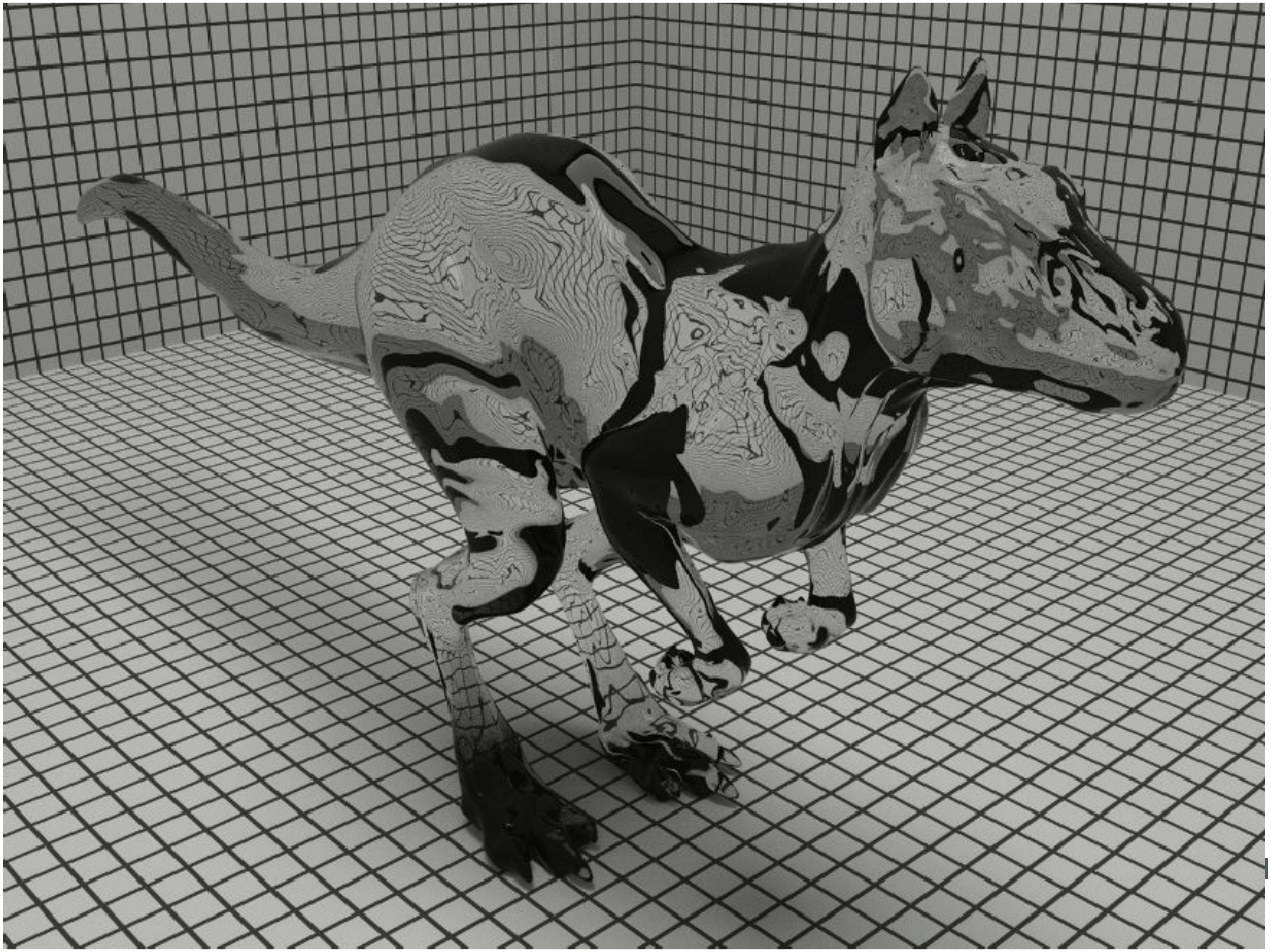
Snell's Window/Circle

Total internal reflection



[Livingston and Lynch]

Fresnel Reflection & Transmission



Microfacet Material Model

Microfacet Reflection

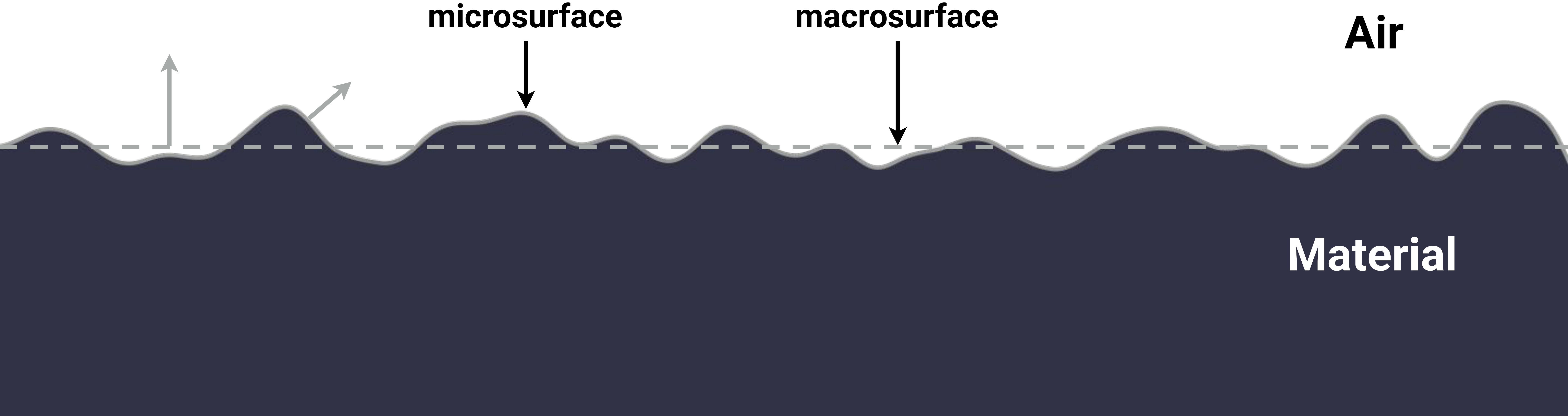
Microfacet Theory

Rough surface

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

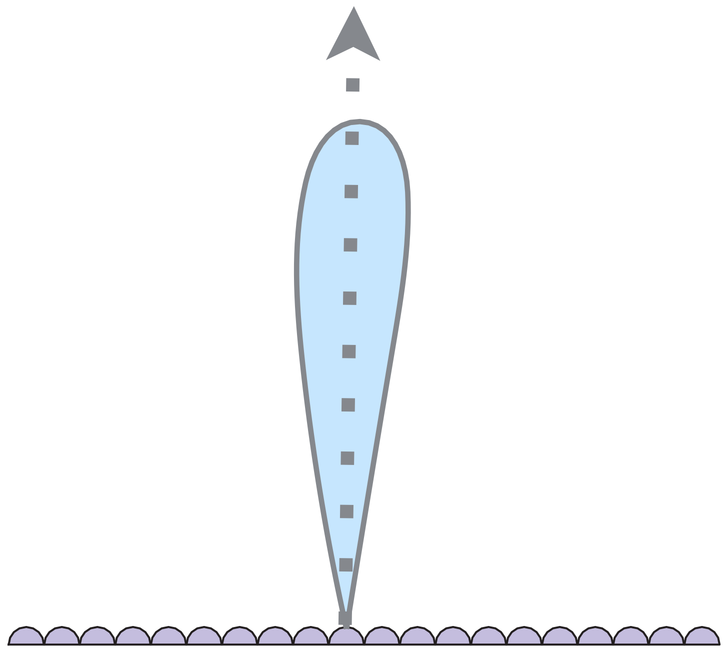
Individual elements of surface act like mirrors

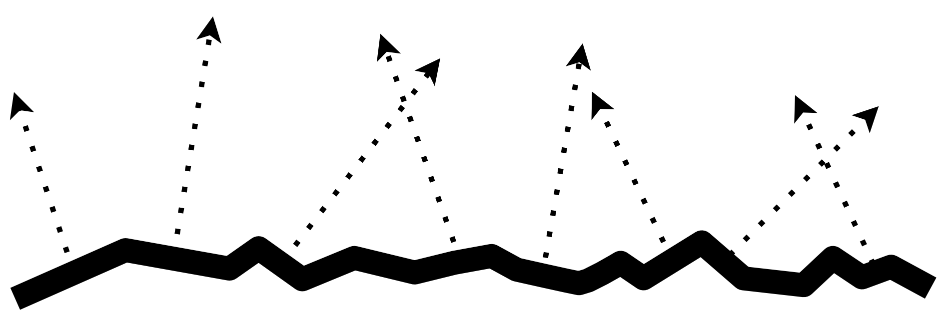
- Known as “microfacets”
- Each microfacet has its own normal vector

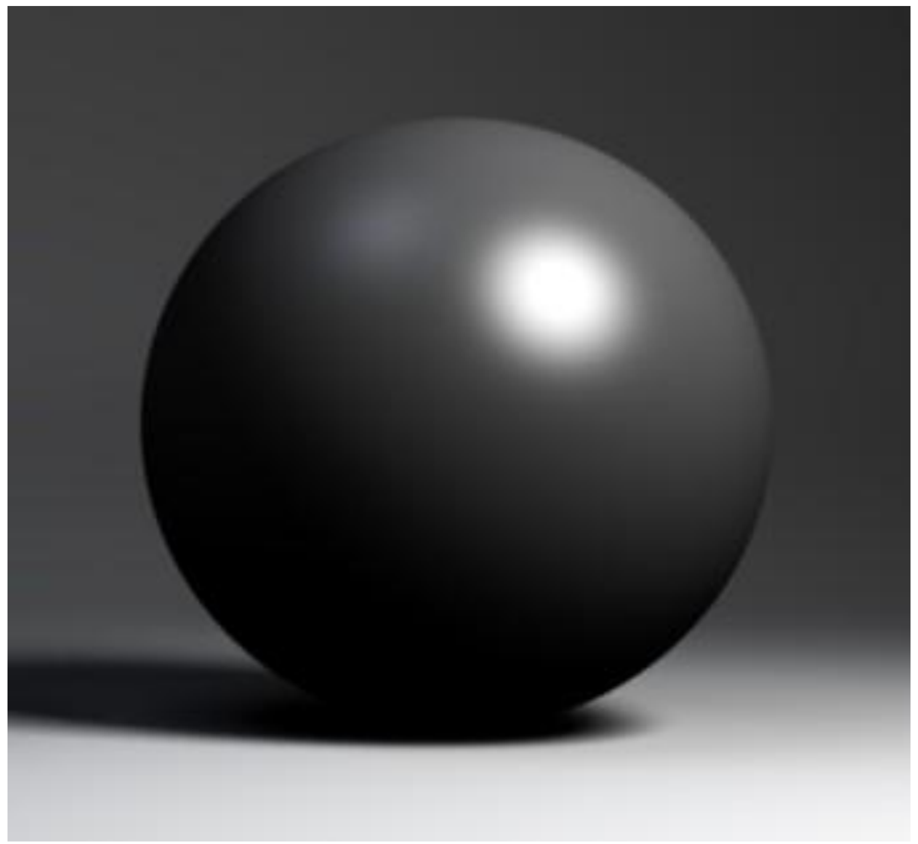


Microfacet BRDF

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

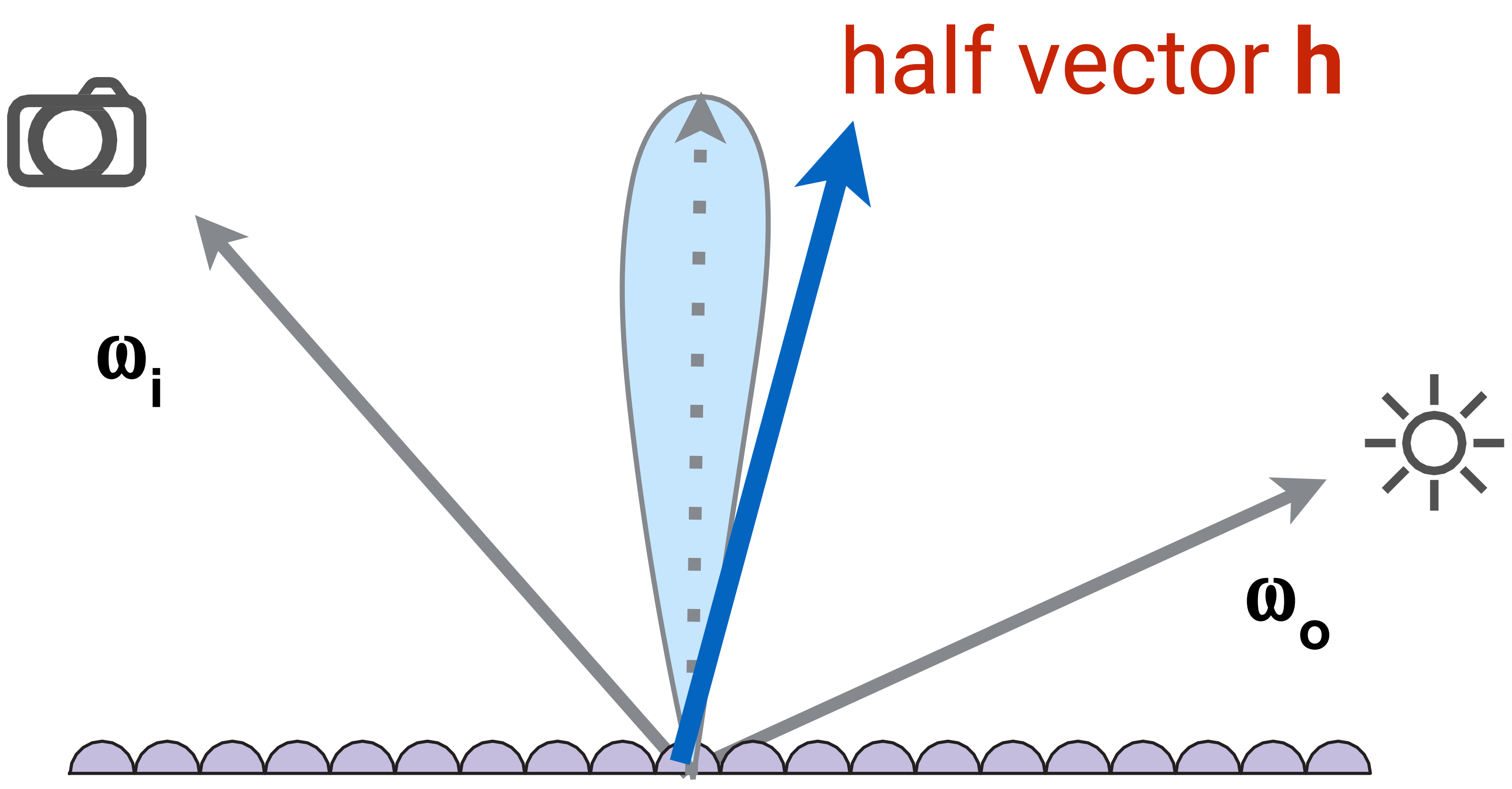


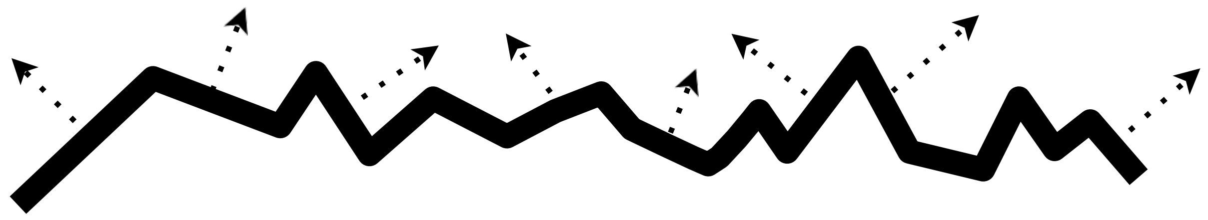




Microfacet BRDF

- **What kind of microfacets reflect ω_i to ω_o? (hint: microfacets are mirrors)**





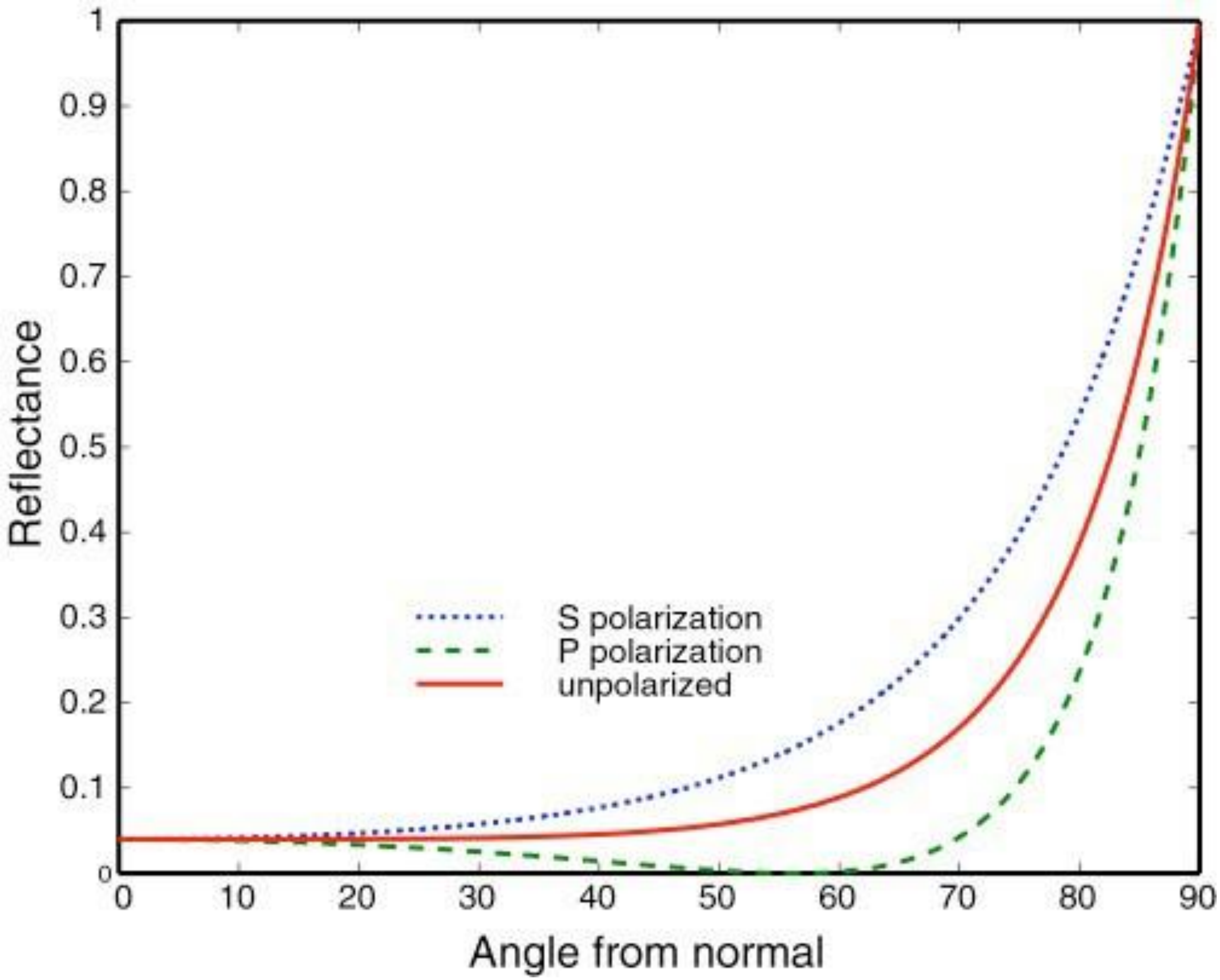
Fresnel Reflection Term

Reflectance depends on incident angle (and polarization of light)

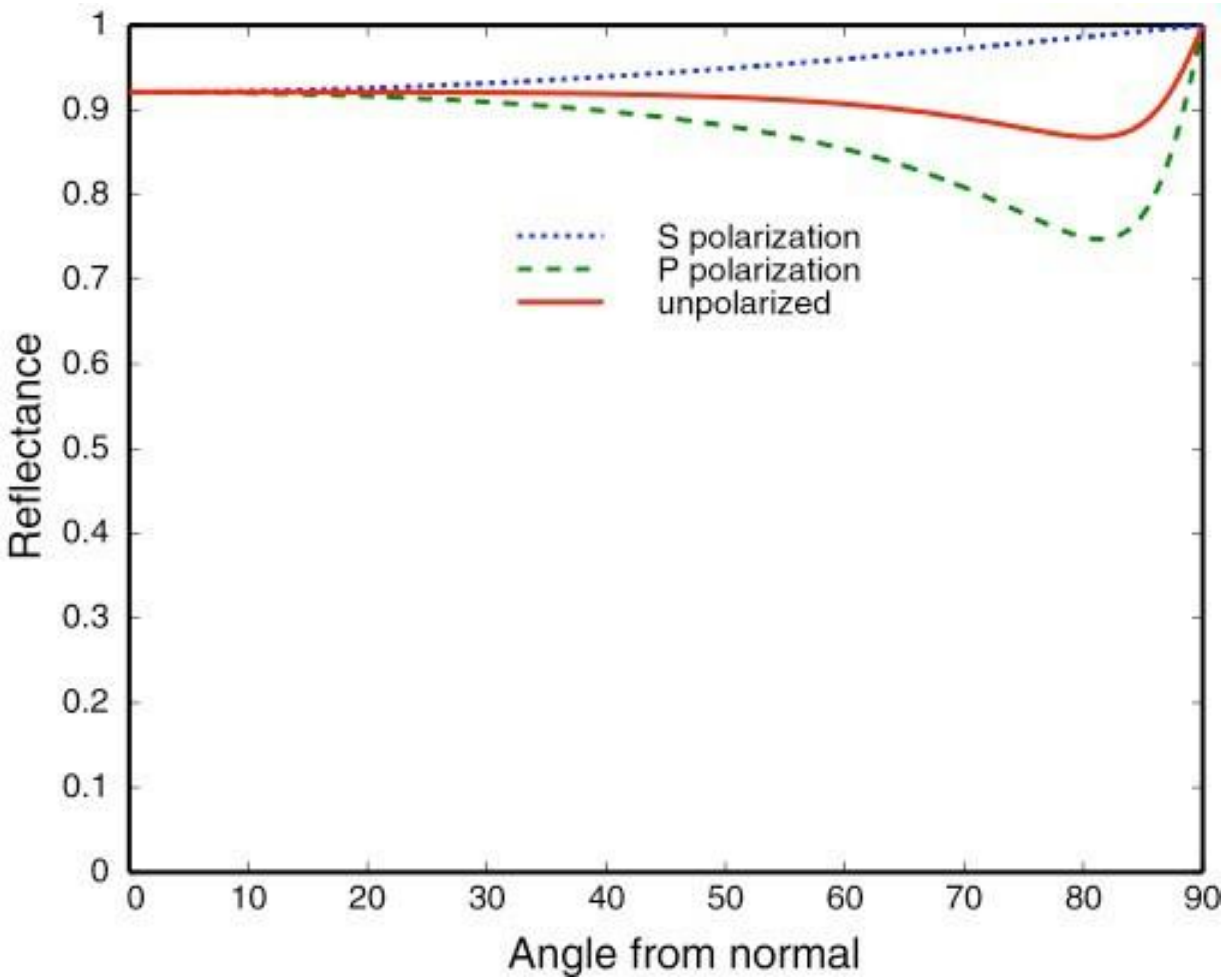
This example: reflectance increases with grazing angle

[Lafortune et al. 1997]

Fresnel Term (Dielectric, ⌘ =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?**

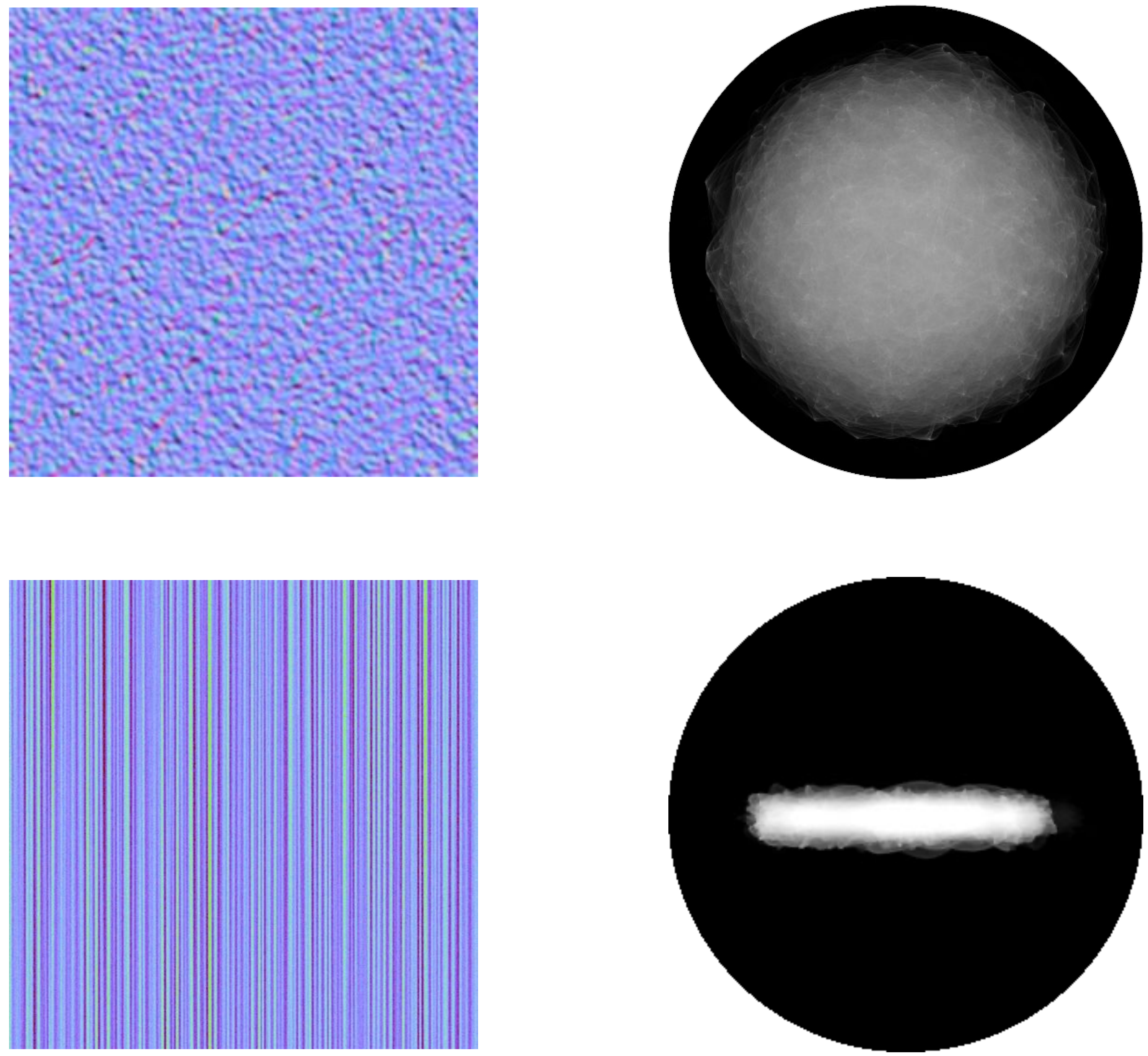
[VRay renderer]

Isotropic / Anisotropic Materials (BRDFs)

- **Key: directionality of underlying surface**

Isotropic

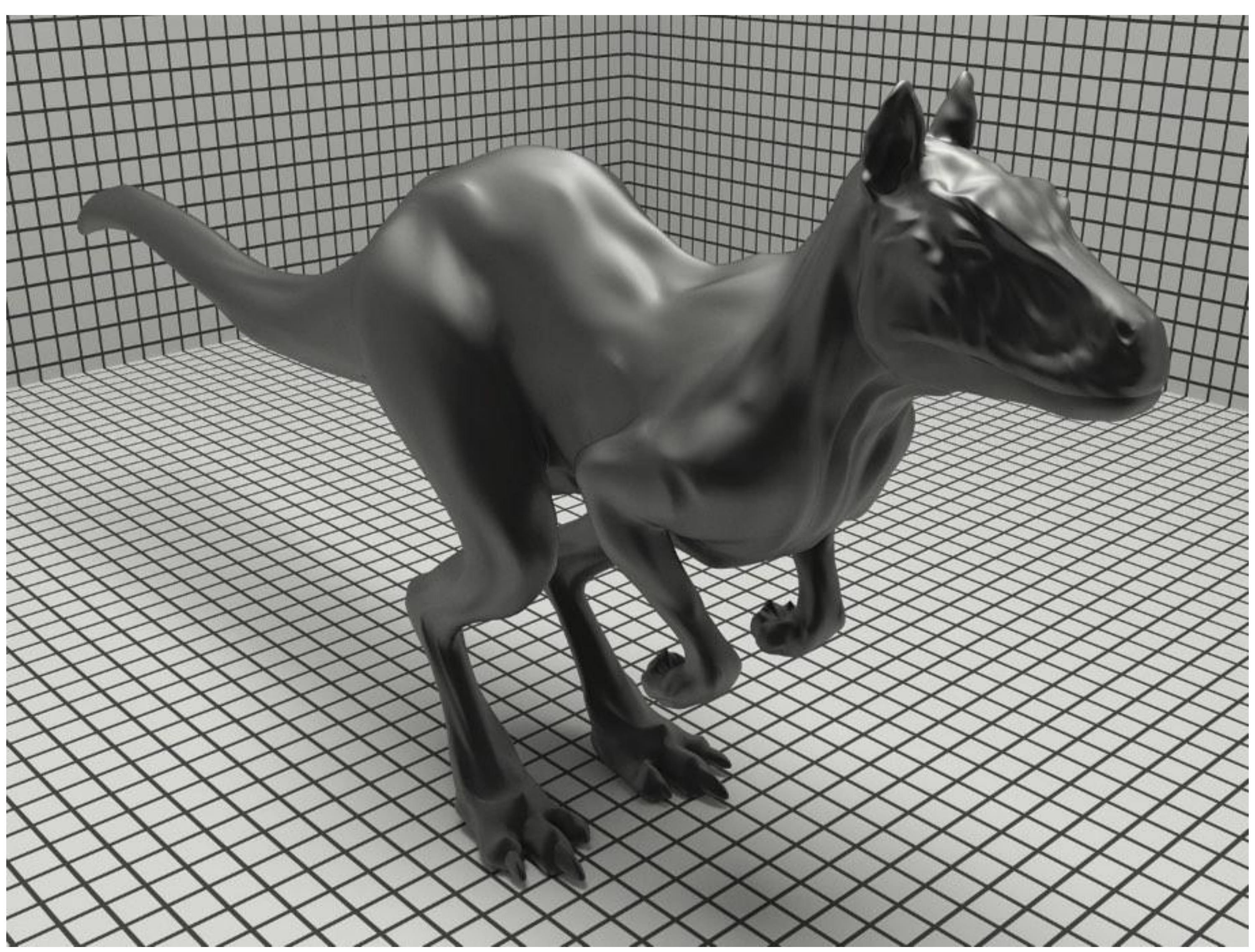
Anisotropic

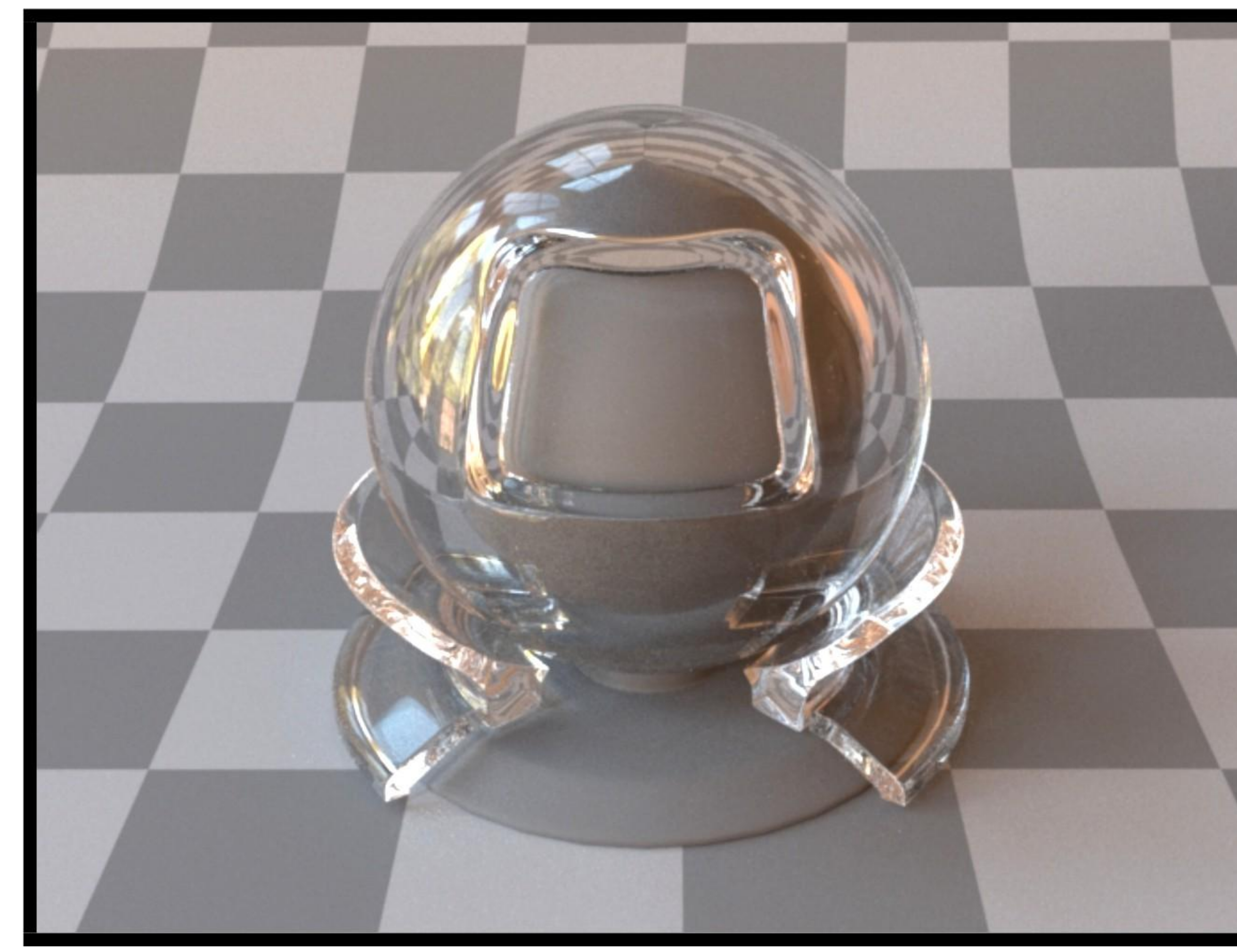


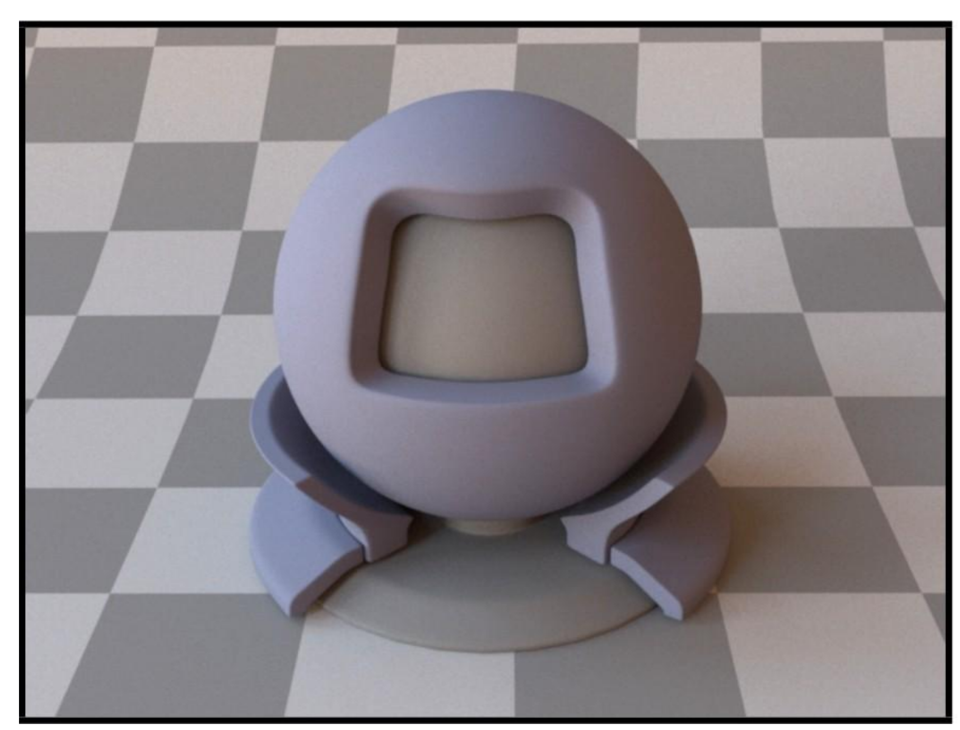
Surface (normals)

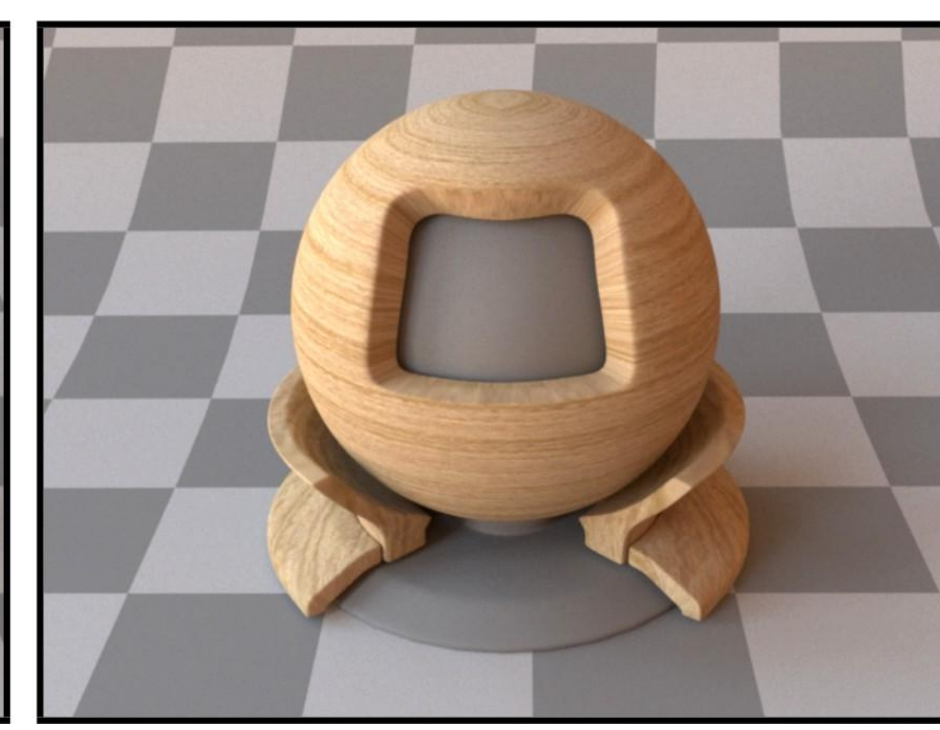
BRDF (fixed ω_i varying ω_o)

Isotropic BRDFs

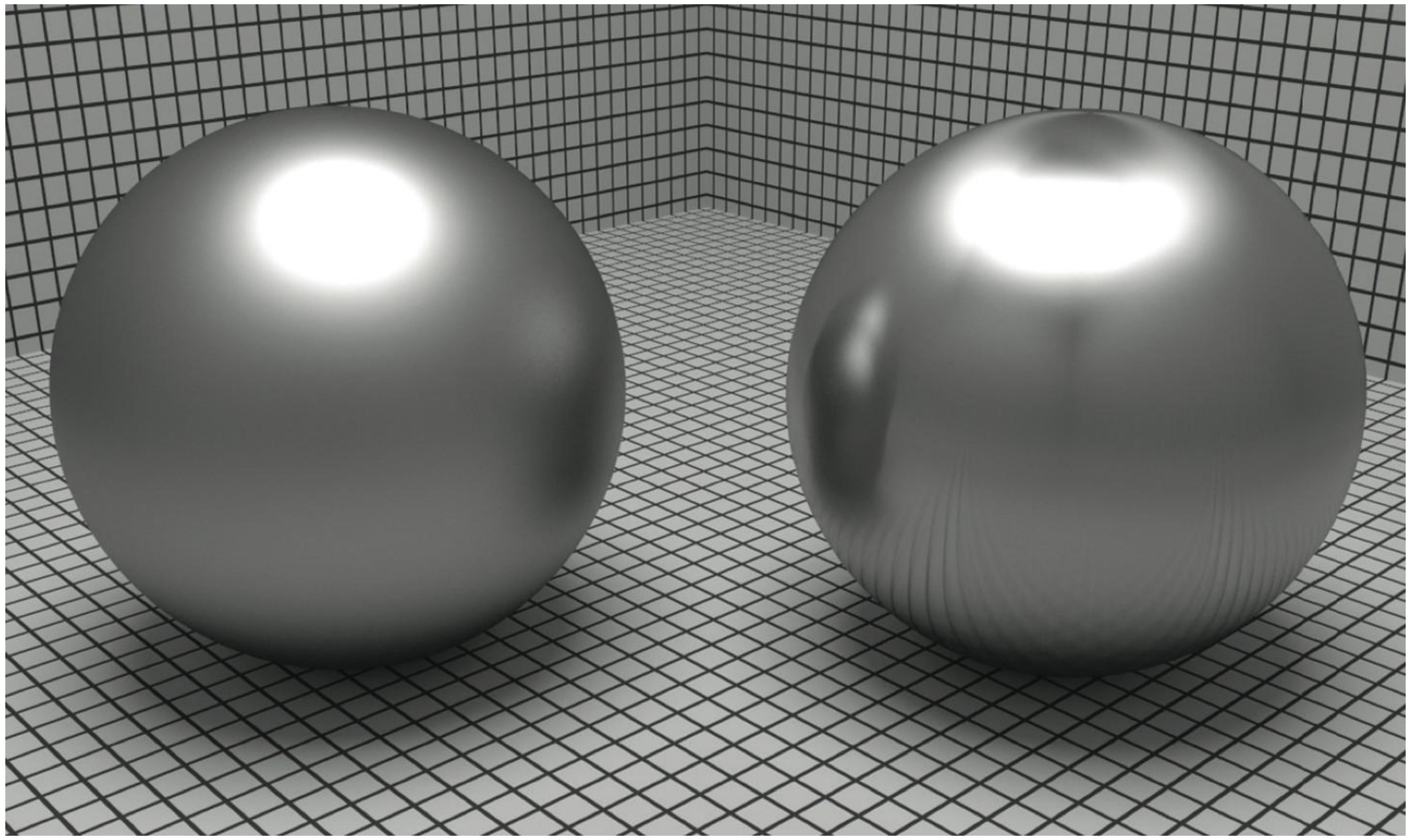








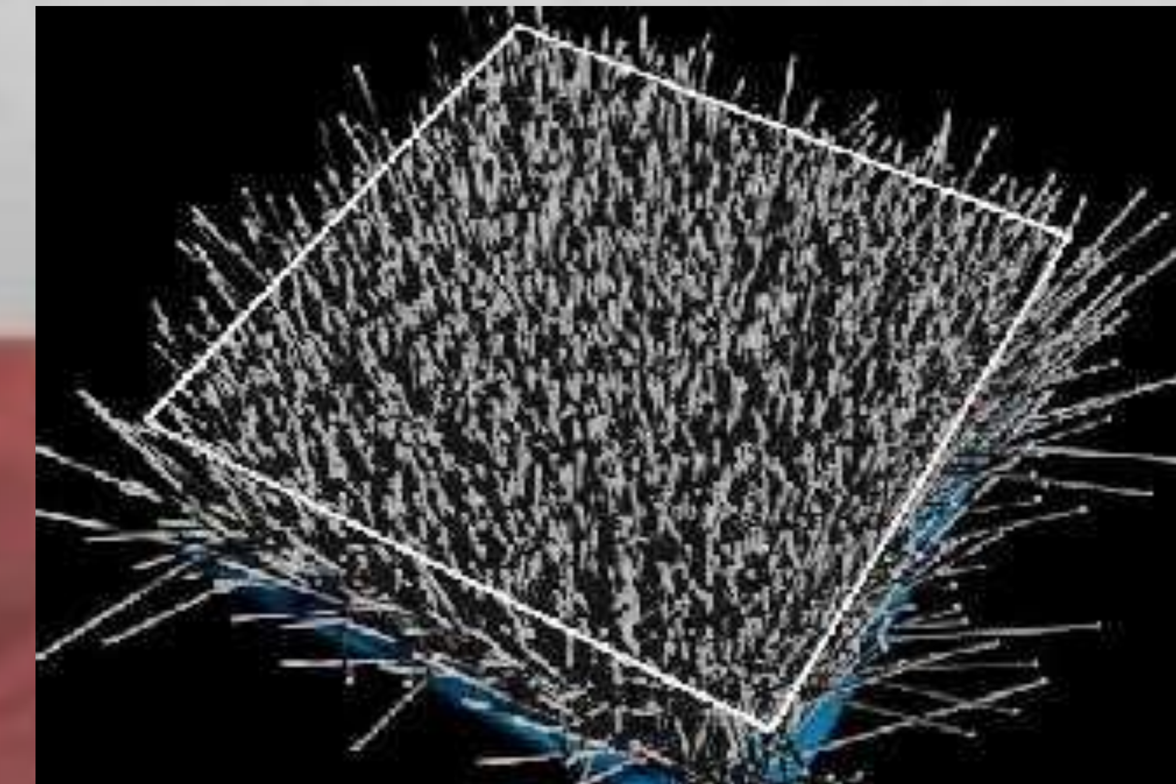
Anisotropic BRDFs



Anisotropic BRDF: Nylon

[Westin et al. 1992]

Anisotropic BRDF: Velvet



[Westin et al. 1992]

Sampling of Advanced Material Modeling Topics

(Slides courtesy Prof Lingqi Yan)

Detailed + Shiny Material

Why details?

Microfacet model

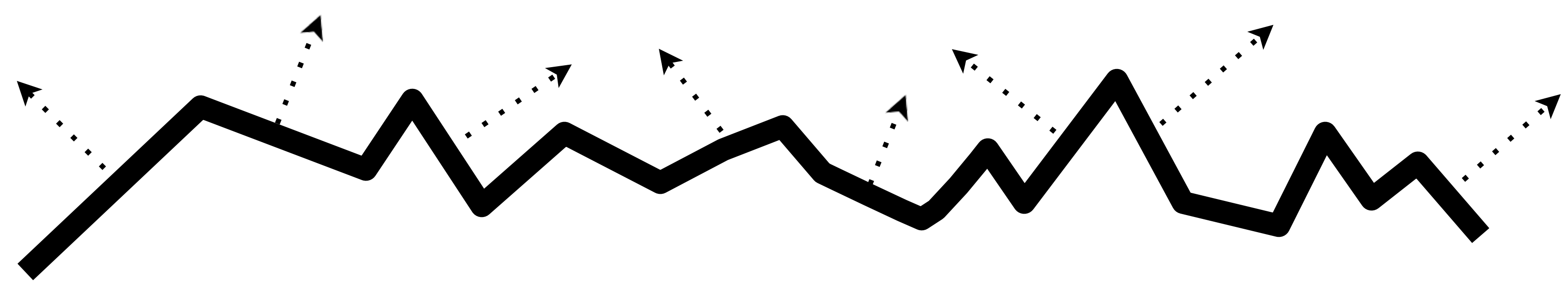
Why details?

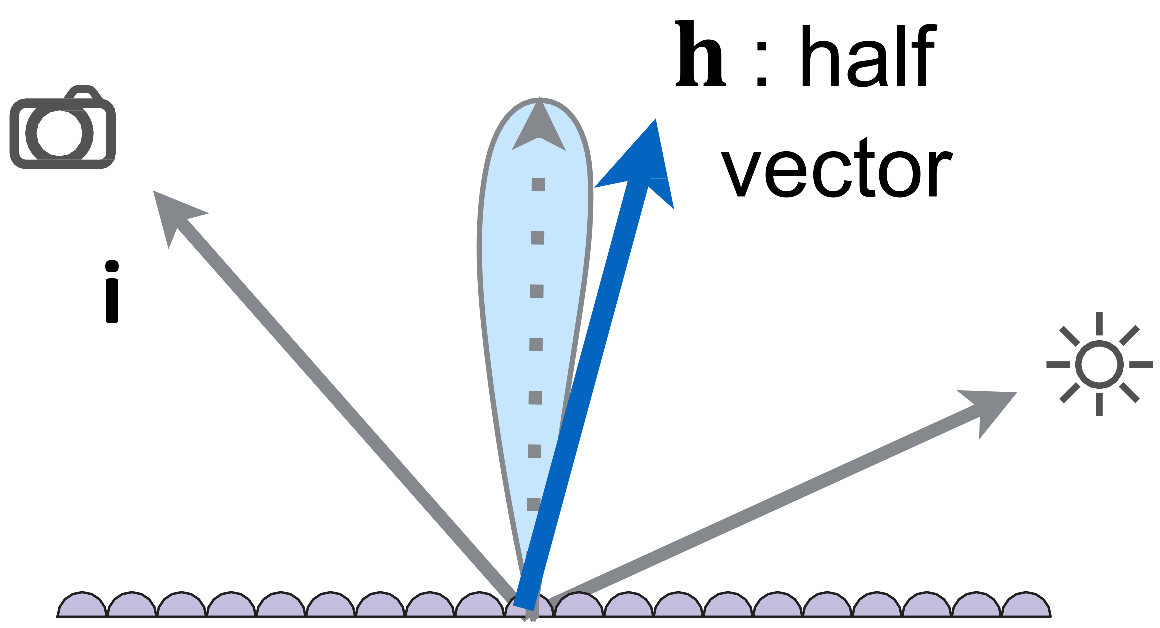
Microfacet model

Why details?

Microfacet model

Recap: Microfacet BRDF

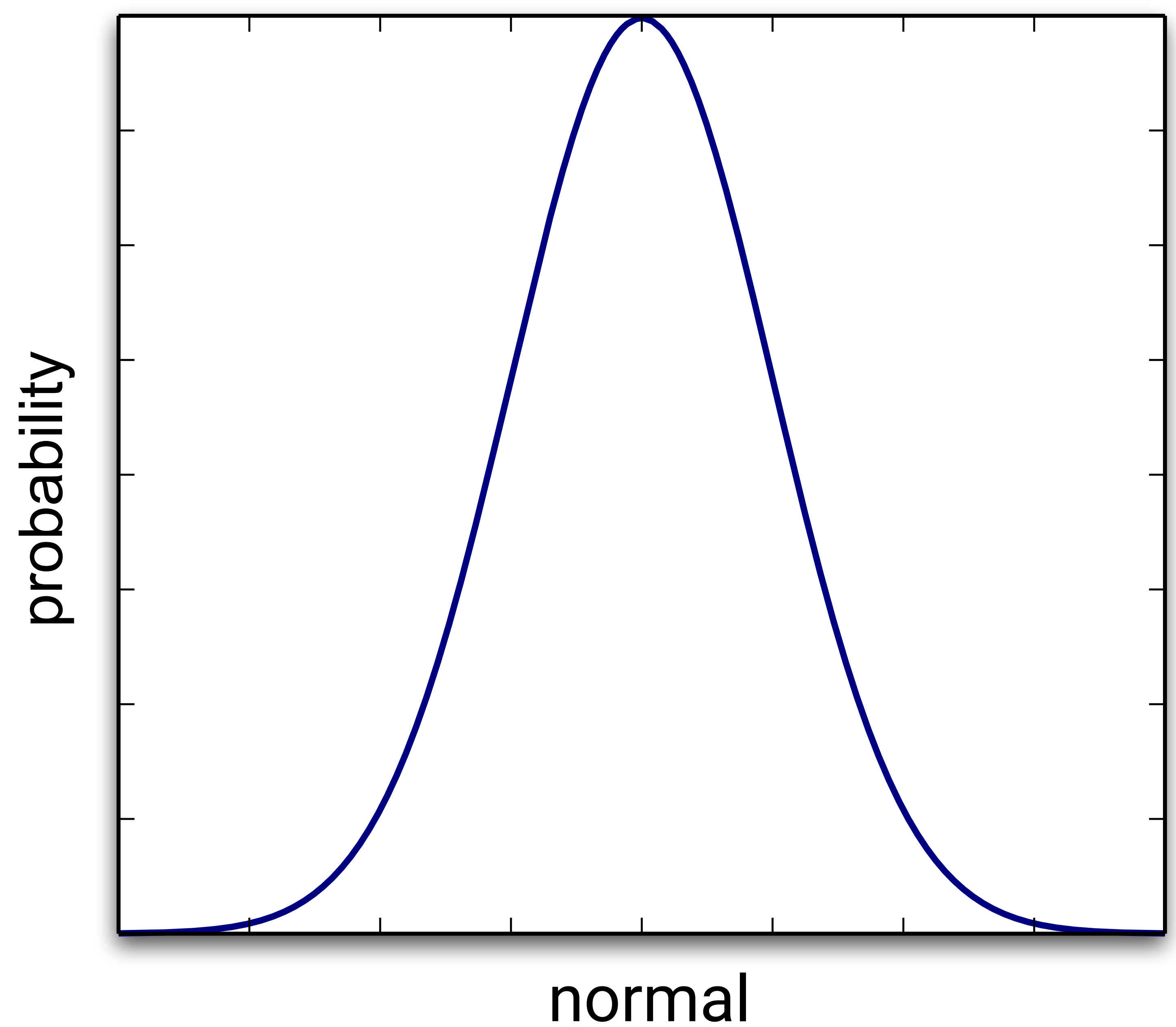




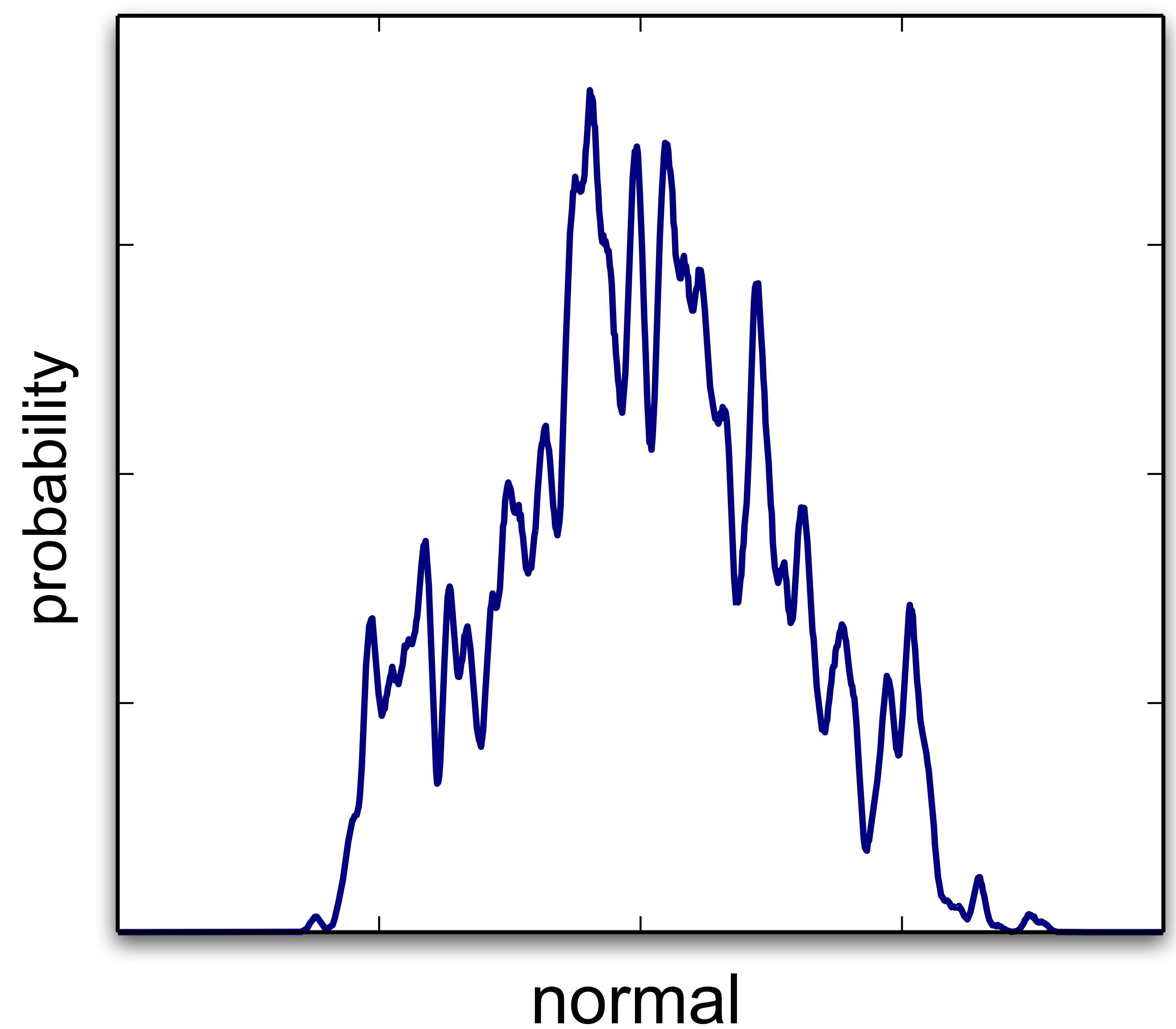
Surface = Specular microfacets + statistical normals

Statistical NDF vs. Actual NDF

Distribution of Normals (NDF)

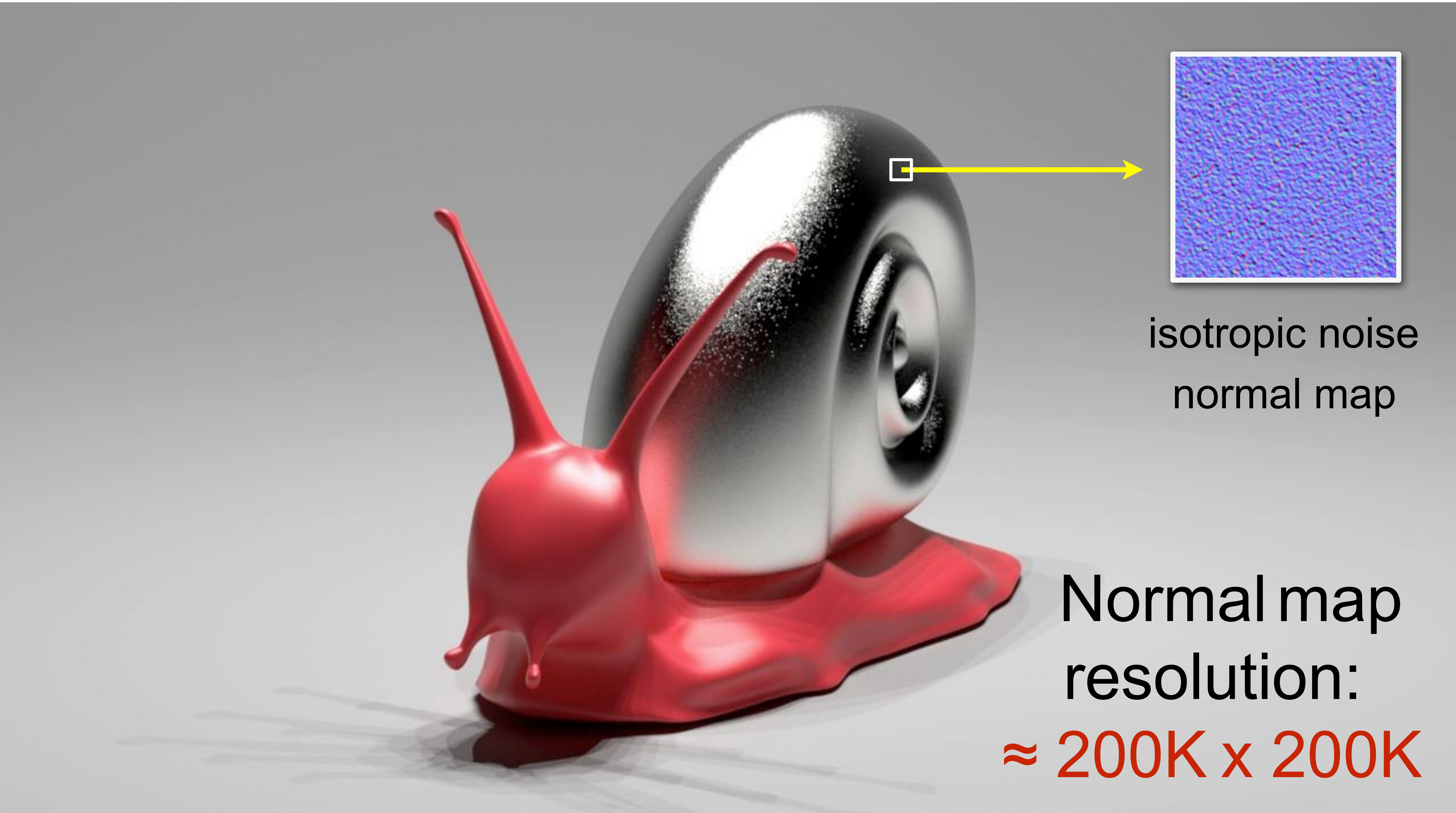


What we have
(microfacet — statistical)



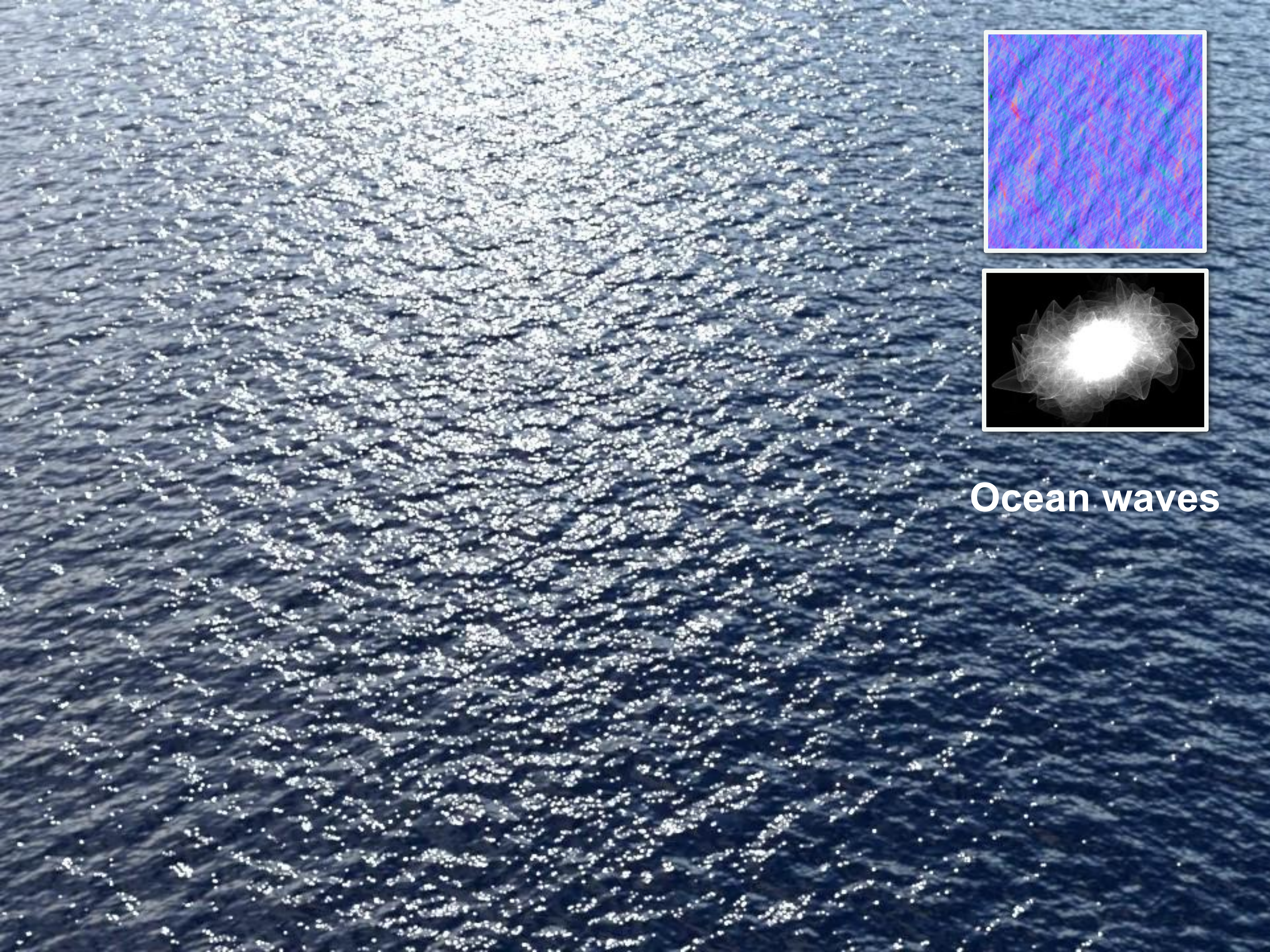
What we want

Define Details



Different Details

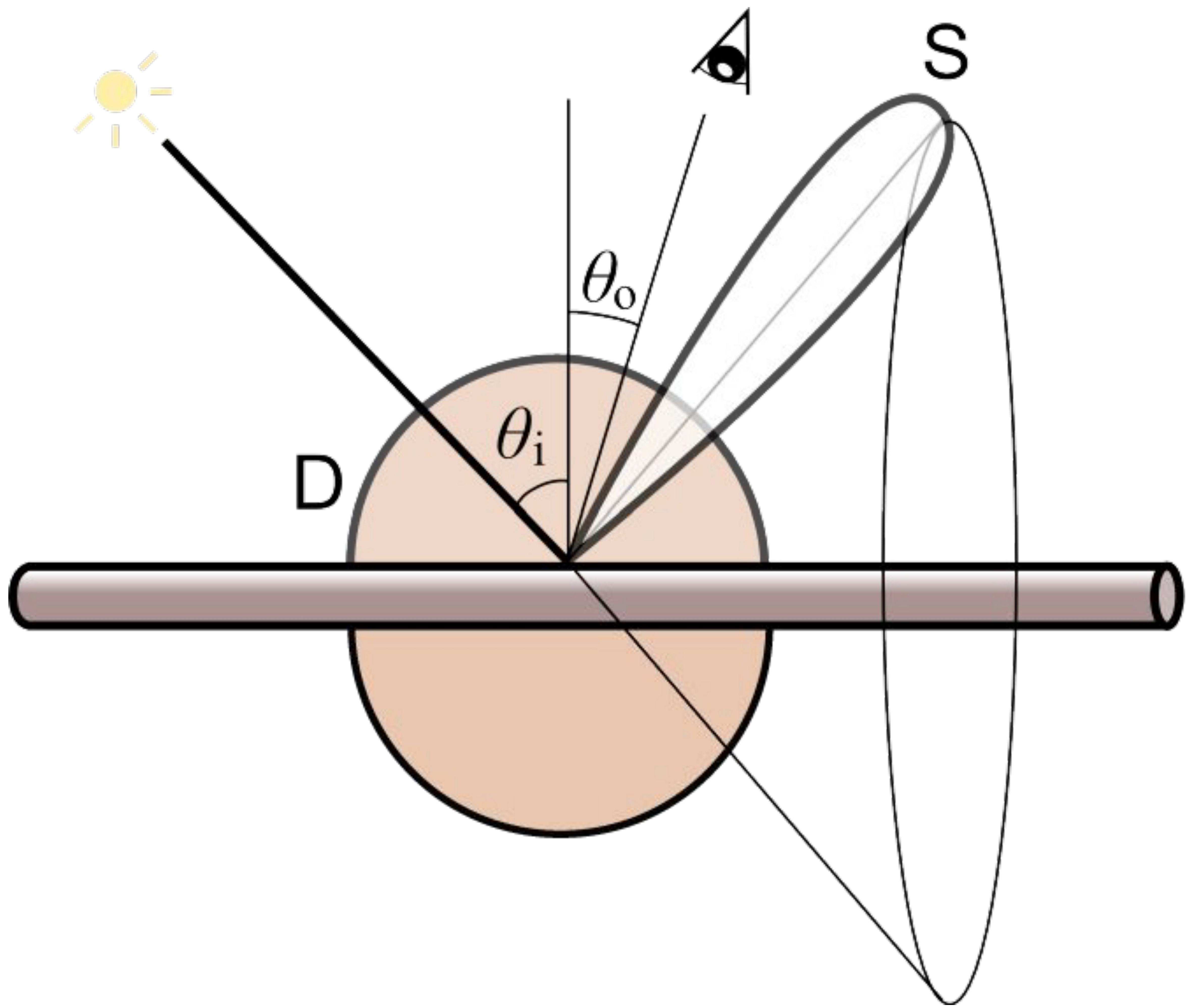
Ocean waves



Hair / Fur Appearance Models

Hair Appearance

Kajiya-Kay Model

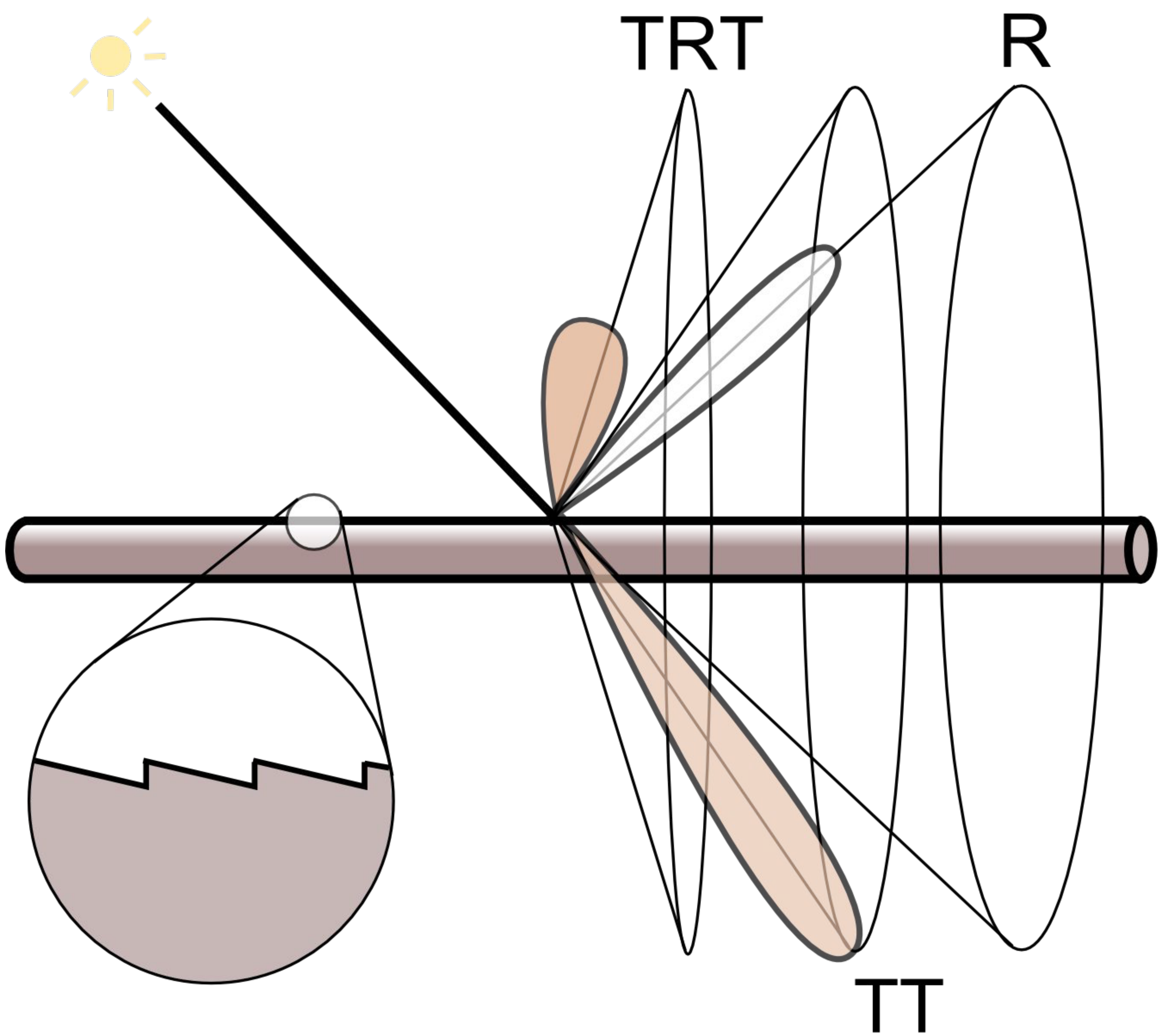


[Image courtesy of Chiwei Tseng]

Kajiya-Kay Model

[Yuksel et al. 2008]

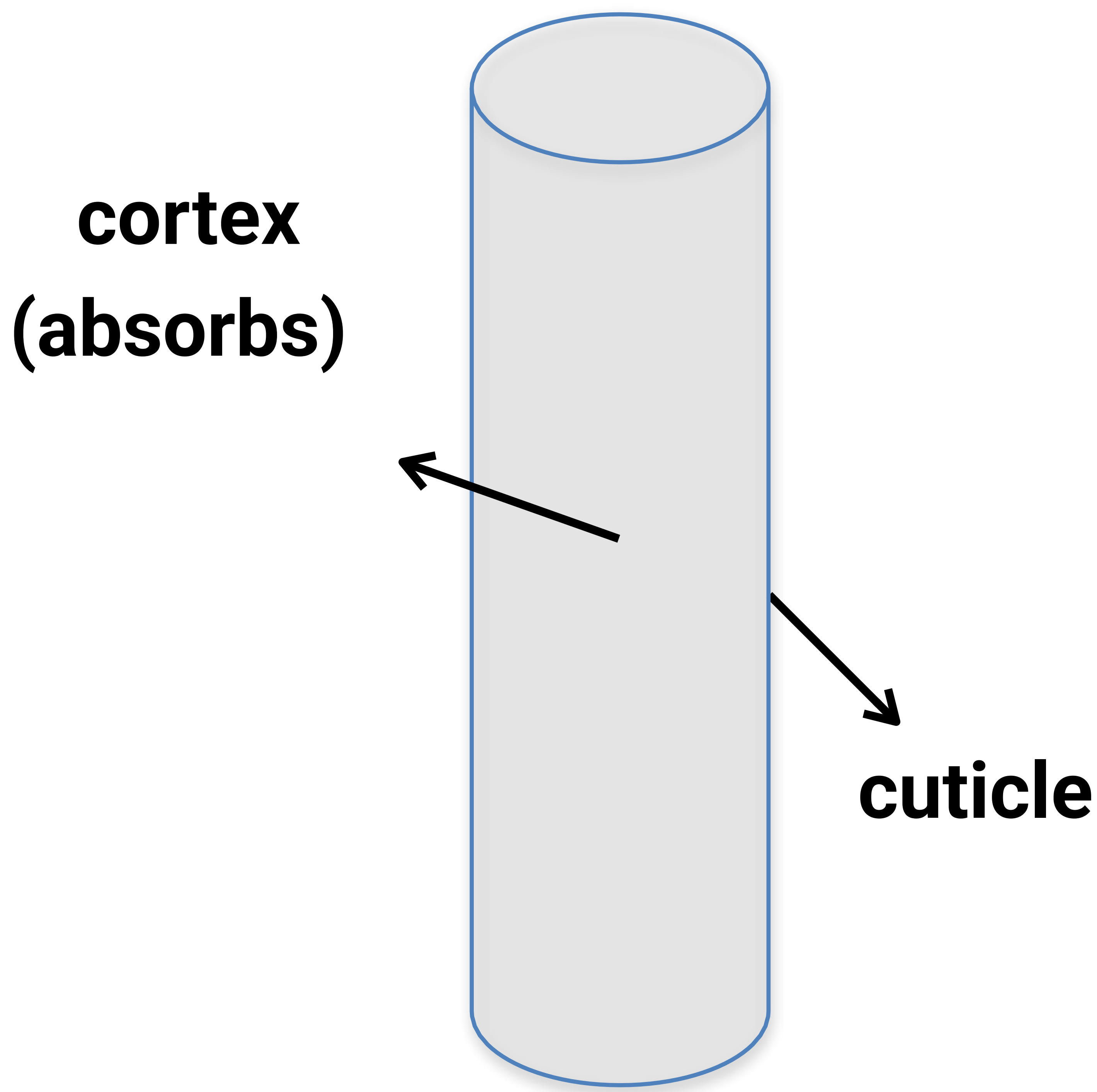
Marschner Model



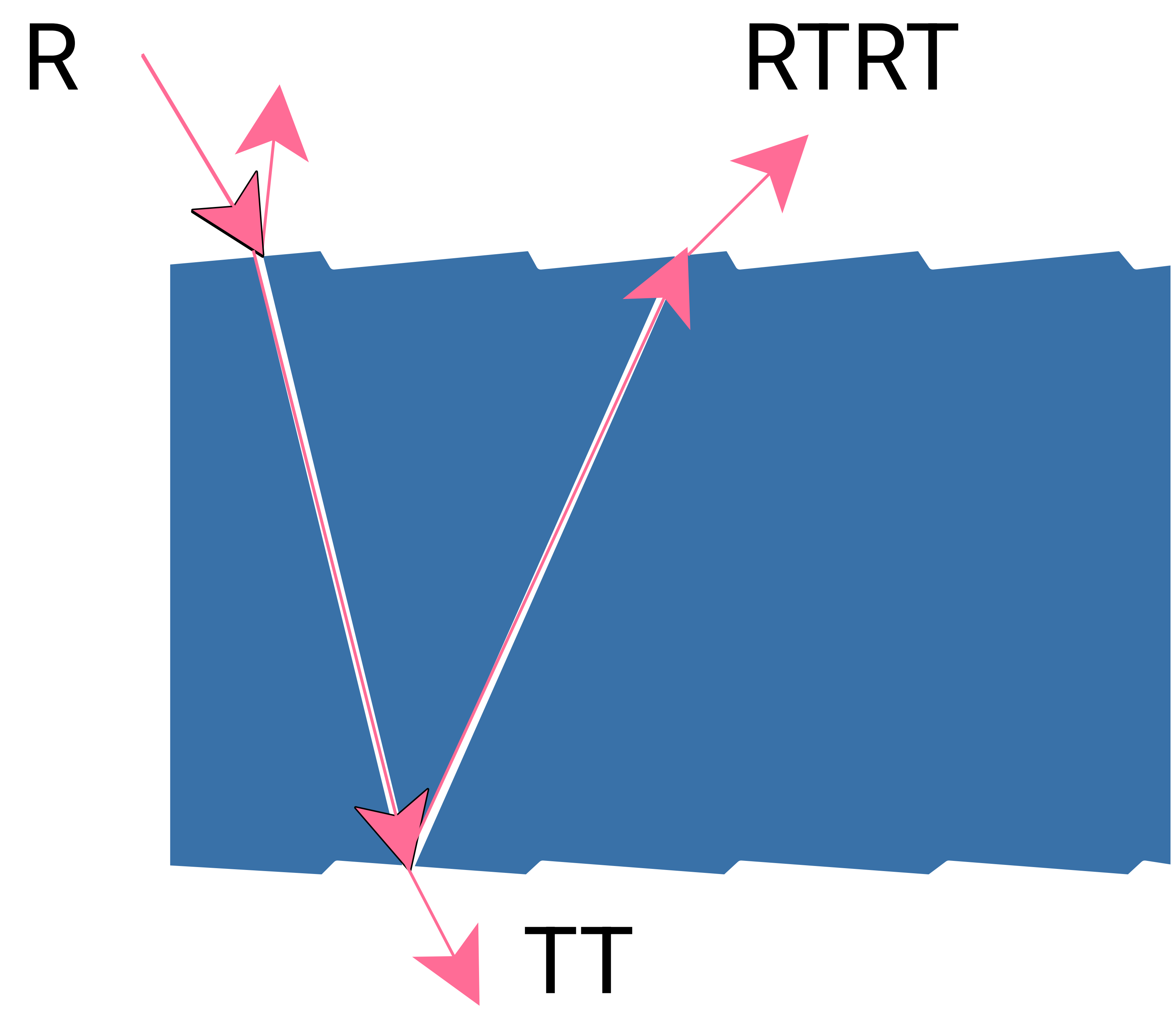
[Image courtesy of Chiwei Tseng]

Marschner Model

Model a 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

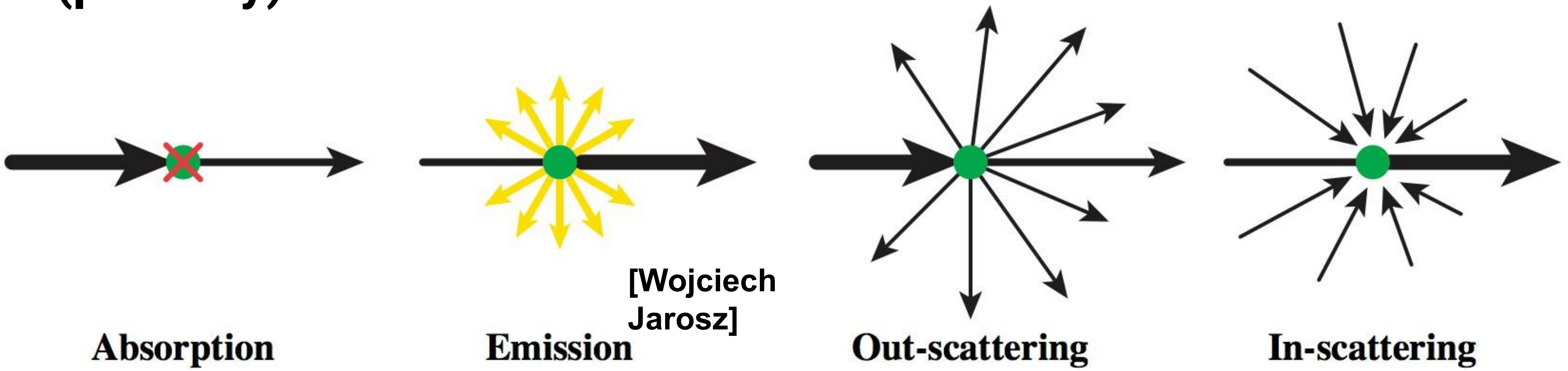
[Novák et al. 2012]

Participating Media: Cloud

[by thephotographer0]

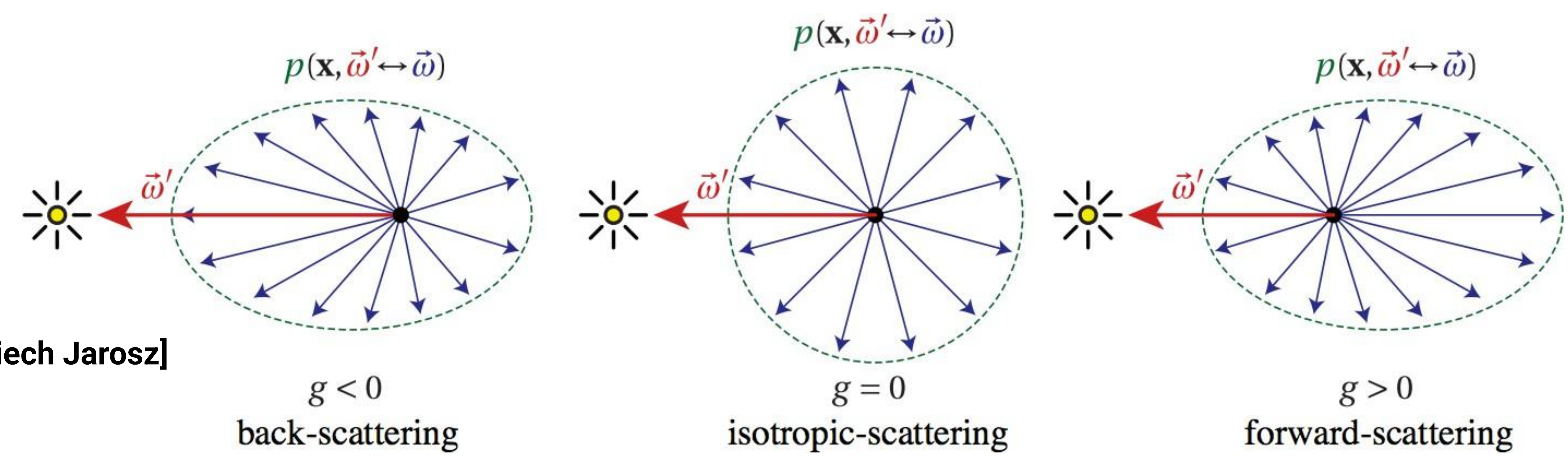
Participating Media

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



[Wojciech Jarosz]

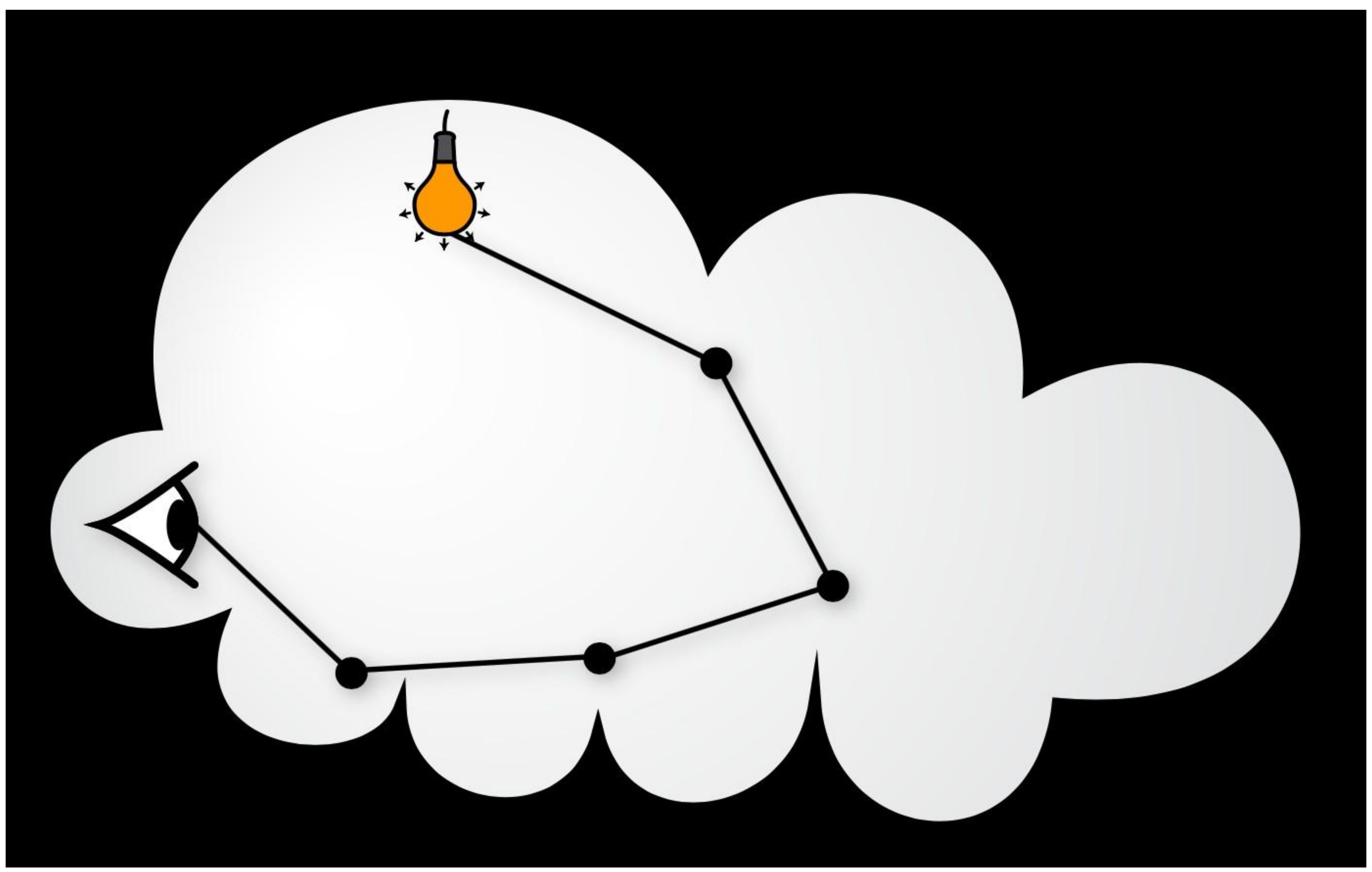
- **Use Phase Function to describe the angular distribution of light scattering at any point x within participating media.**

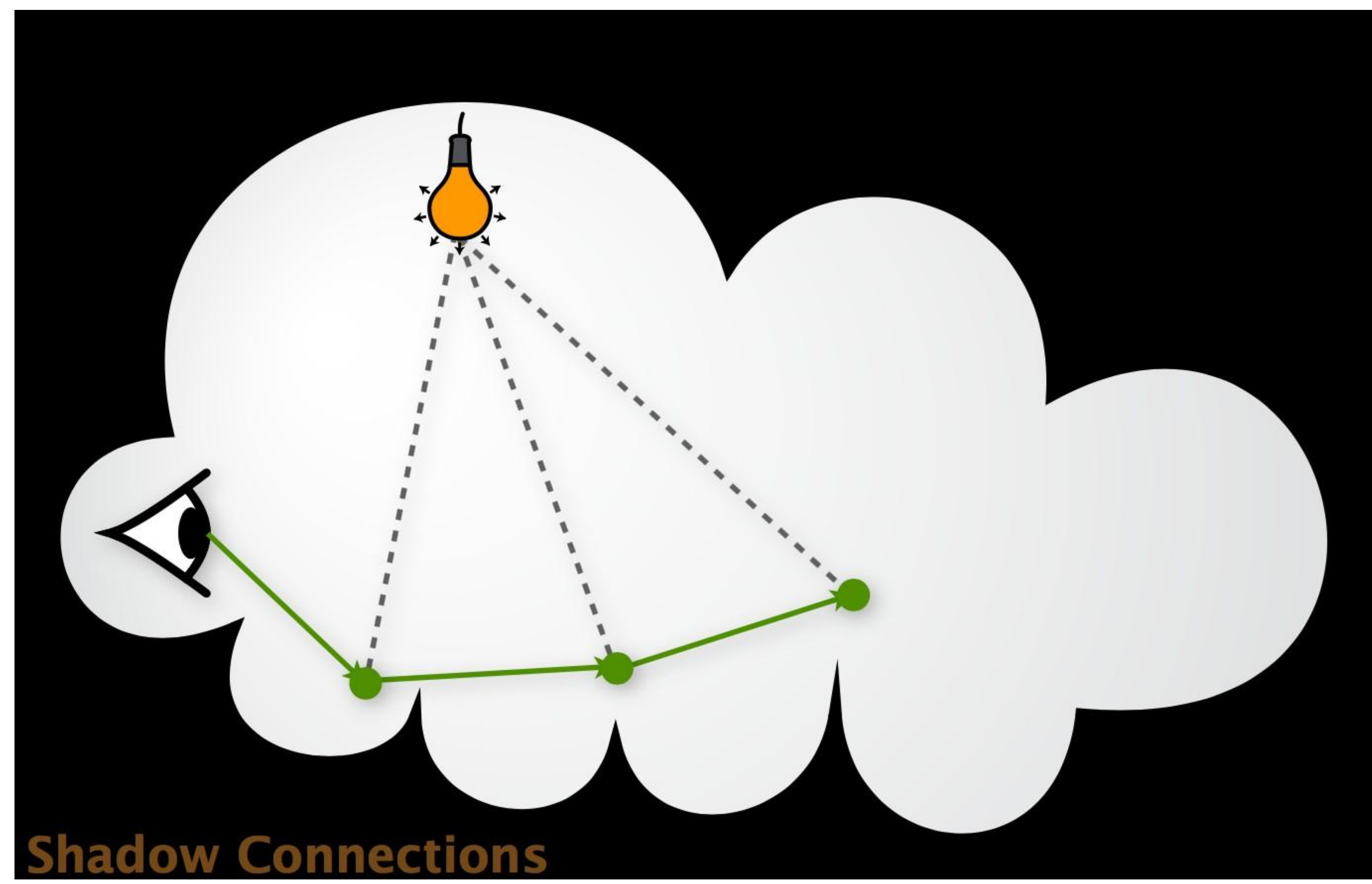


[Wojciech Jarosz]

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]

Translucent Material

(specified participating media)

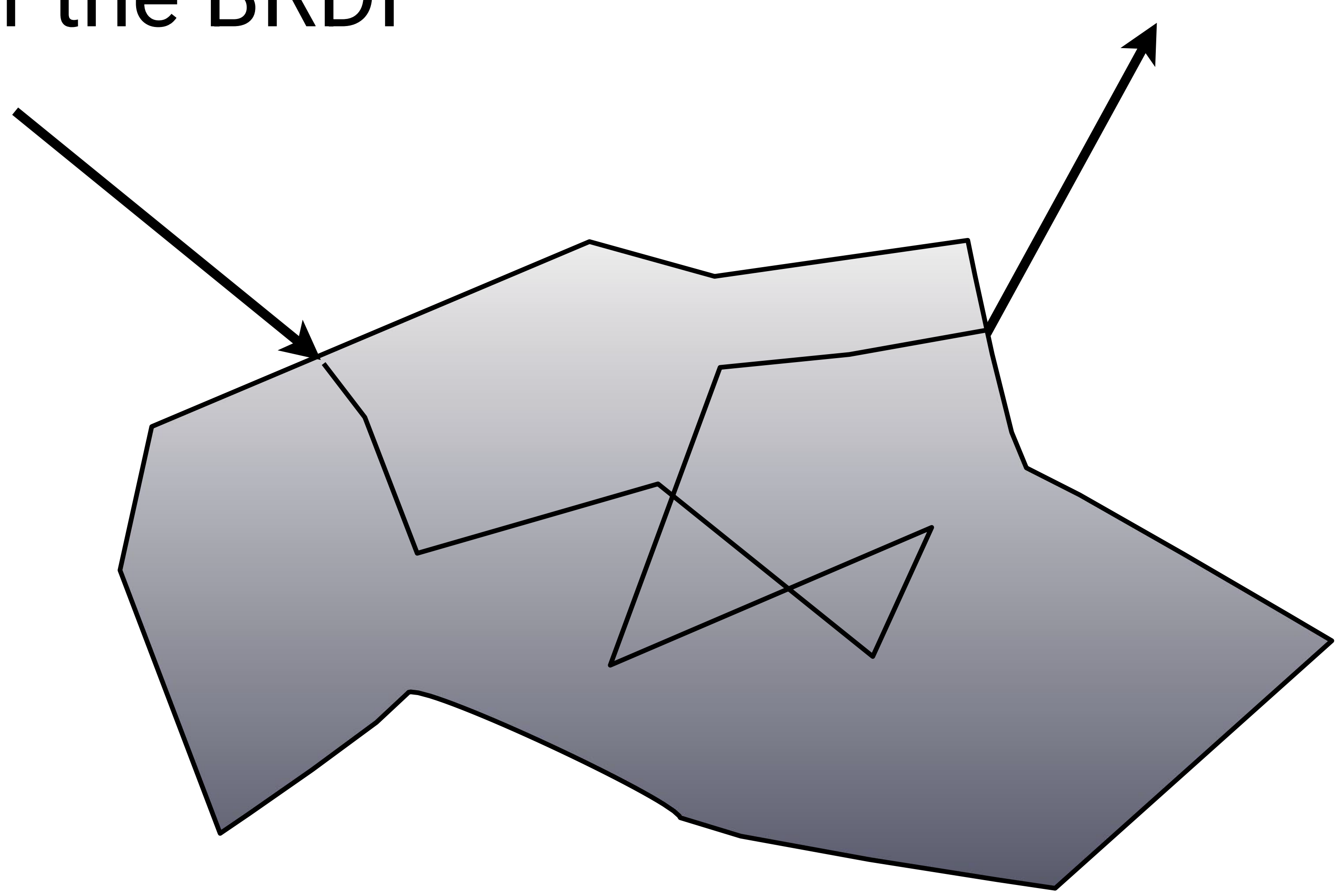
Translucent Material: Jade

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

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: Inverse Rendering

Recovering ***geometry****,* ***materials****,* ***lighting****,* ***and cameras*** *from images*

What is inverse rendering?

Forward rendering (this class)

Geometry
Materials
Lighting
Cameras

→ Rendered images

Use physically accurate models to render pretty images!

Inverse rendering

Captures images →

Geometry
Materials
Lighting
Cameras

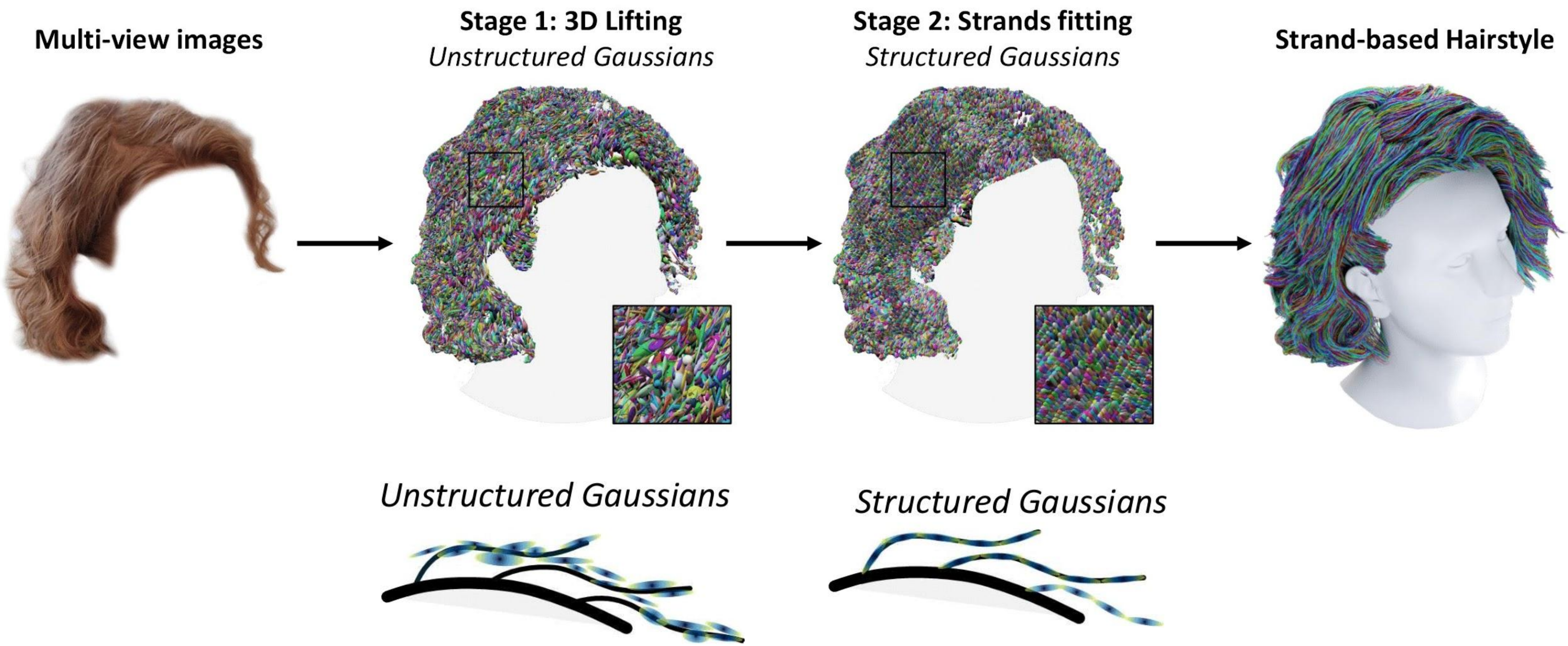
Recover the underlying properties from multiple observed images!

NeRFs and Gaussian Splatting are common techniques!

Inverse Rendering for Hair

Input video | Reconstruction | Rendering

Inverse Rendering for Hair



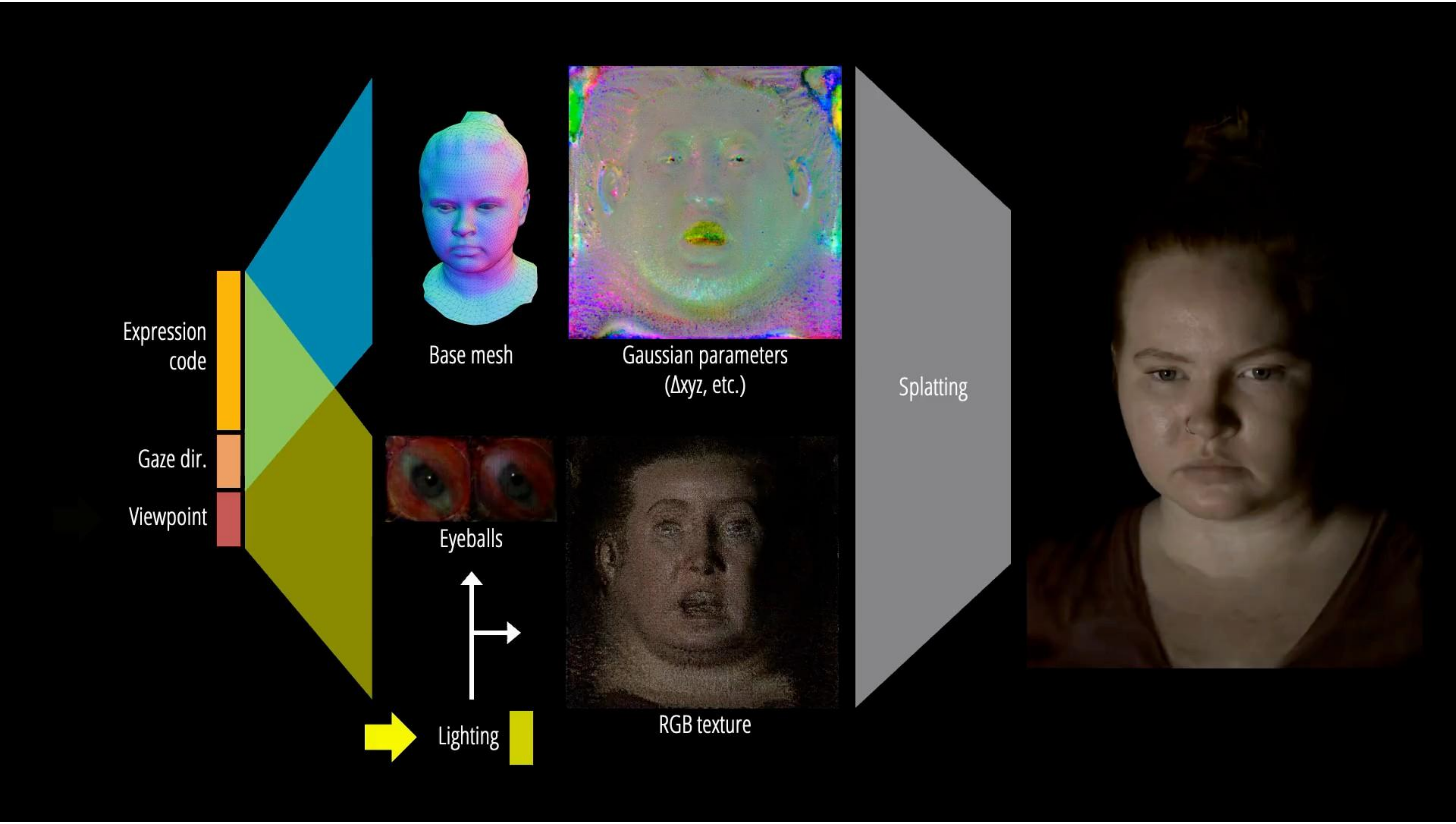
“Gaussian Haircut ✂️”, ECCV 2024

Inverse Rendering for Humans

“Relightable Gaussian Codec Avatars”, CVPR 2024

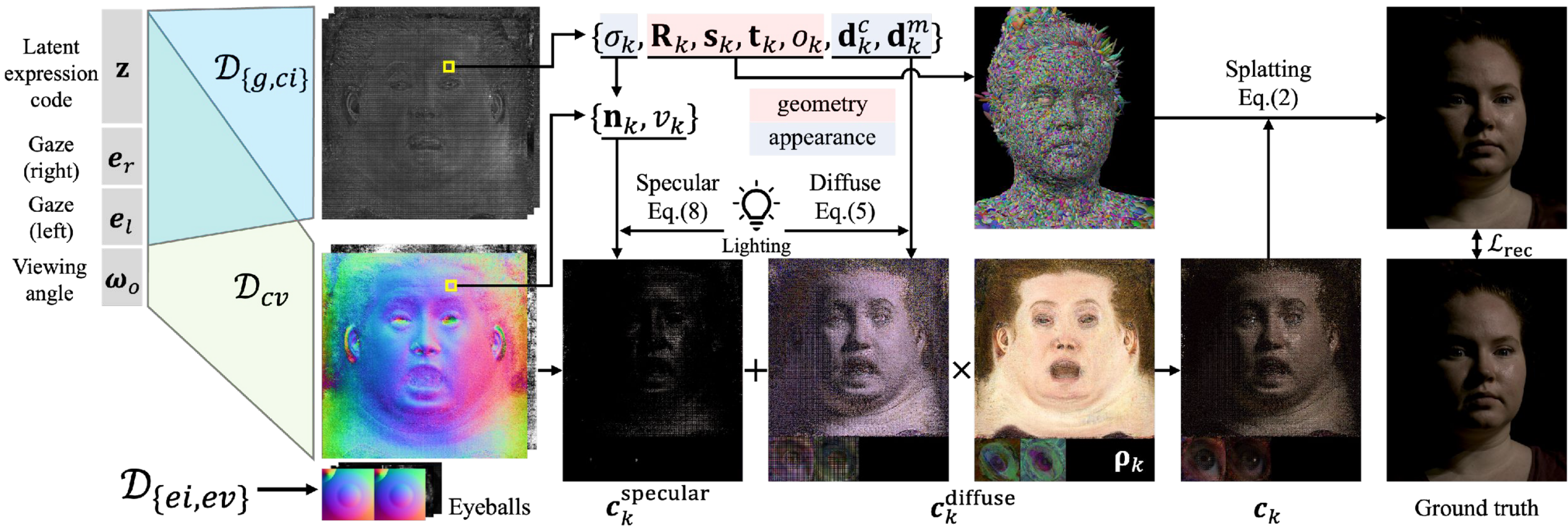
Meta

Inverse Rendering for Humans



“Relightable Gaussian Codec Avatars”, CVPR 2024

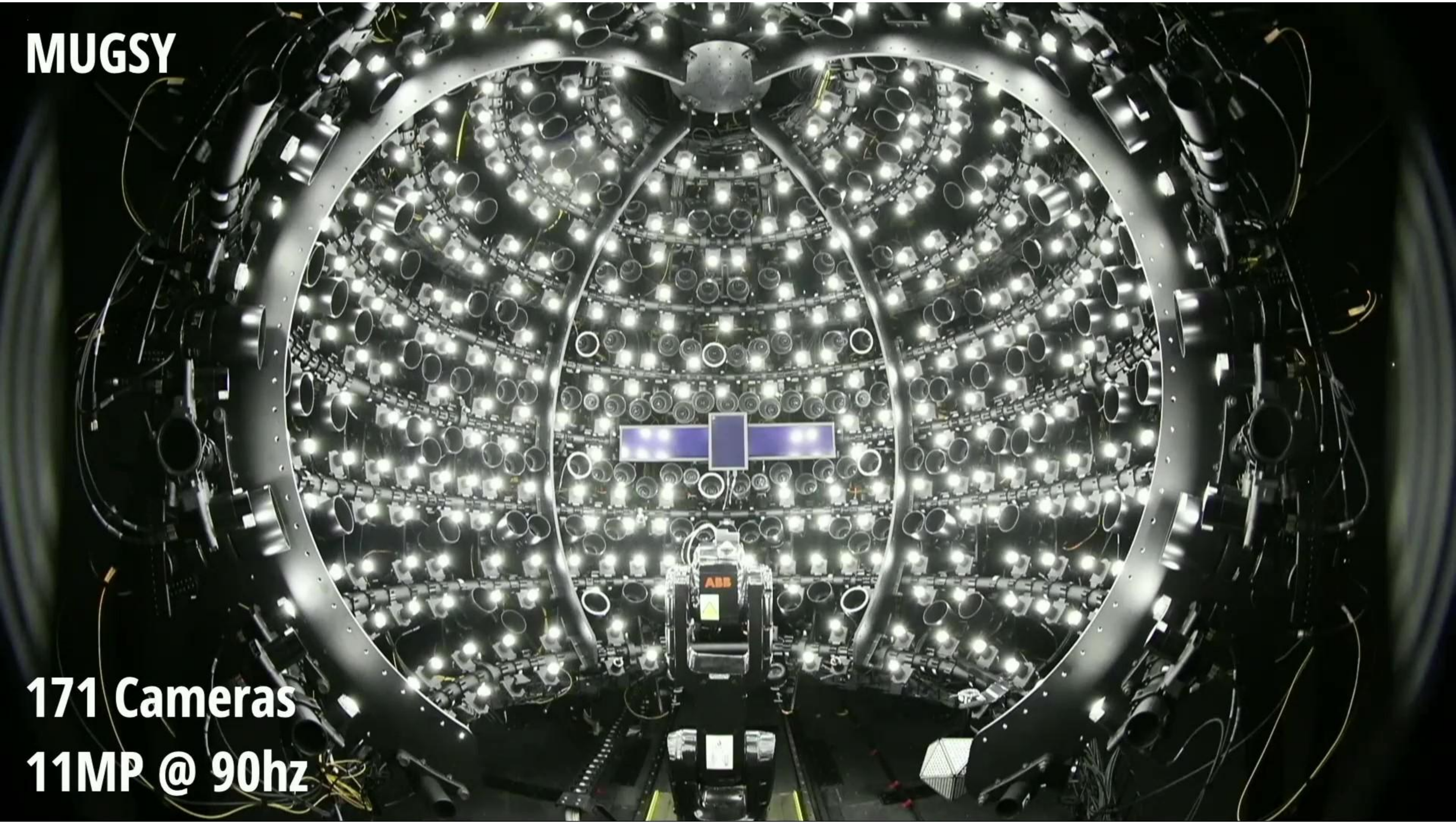
Inverse Rendering for Humans



"Relightable Gaussian Codec Avatars", CVPR 2024

Meta

Inverse Rendering for Humans



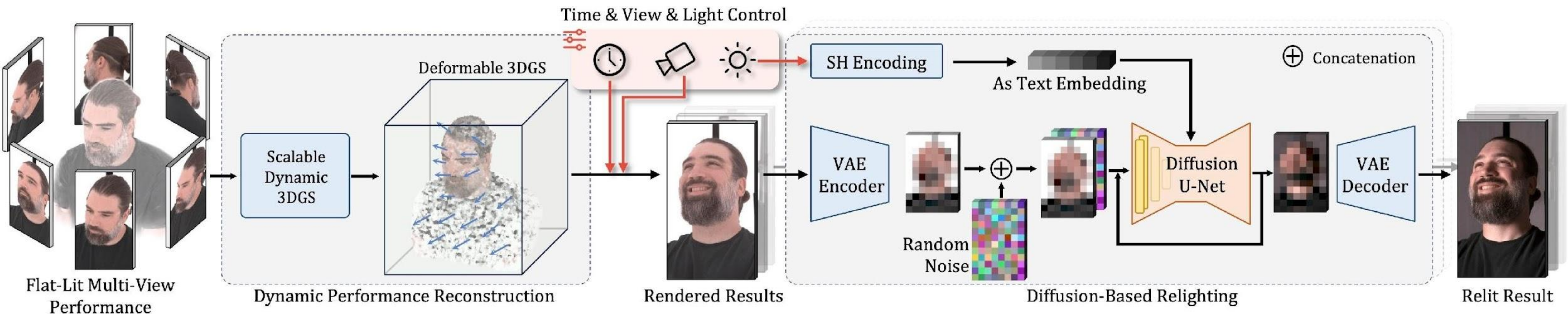
https://www.uploadvr.com/meta-codec-avatars-iphone-scan/ Meta

Inverse Rendering for Humans

"DifFRelight", SIGGRAPH Asia 2024

EYELINE STUDIOS™ POWERED BY NETFLIX

Inverse Rendering for Humans



“DifFRelight”, SIGGRAPH Asia 2024

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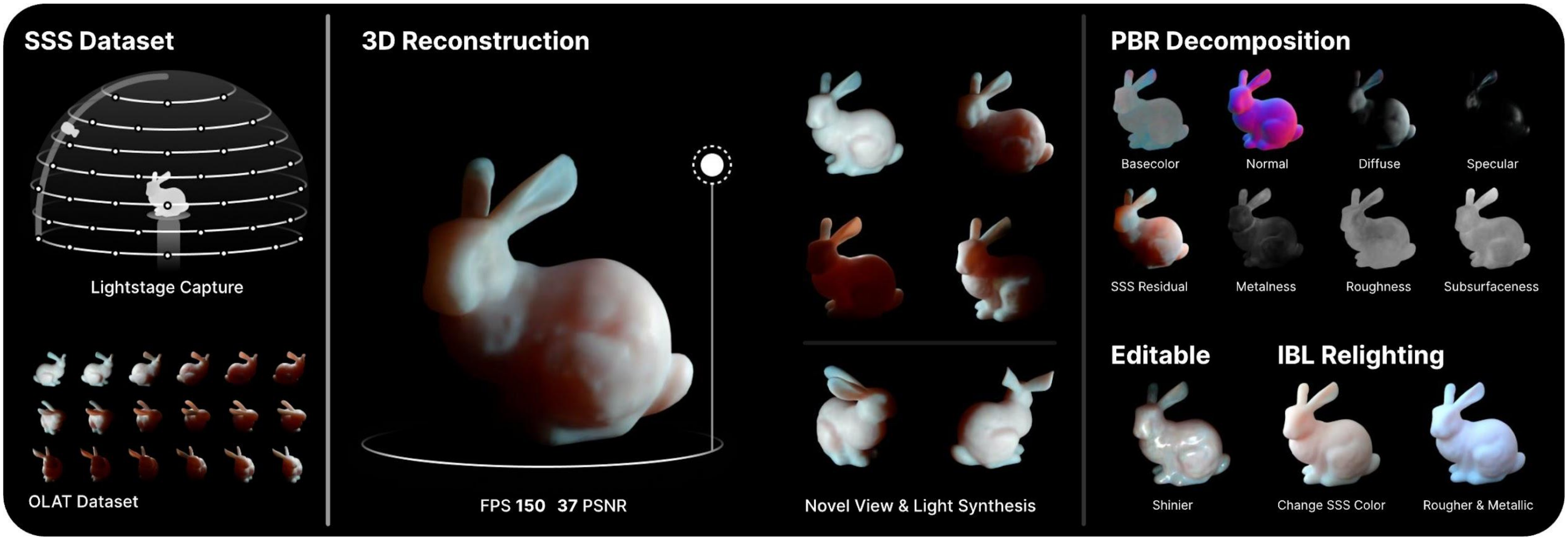
Inverse Rendering for Objects

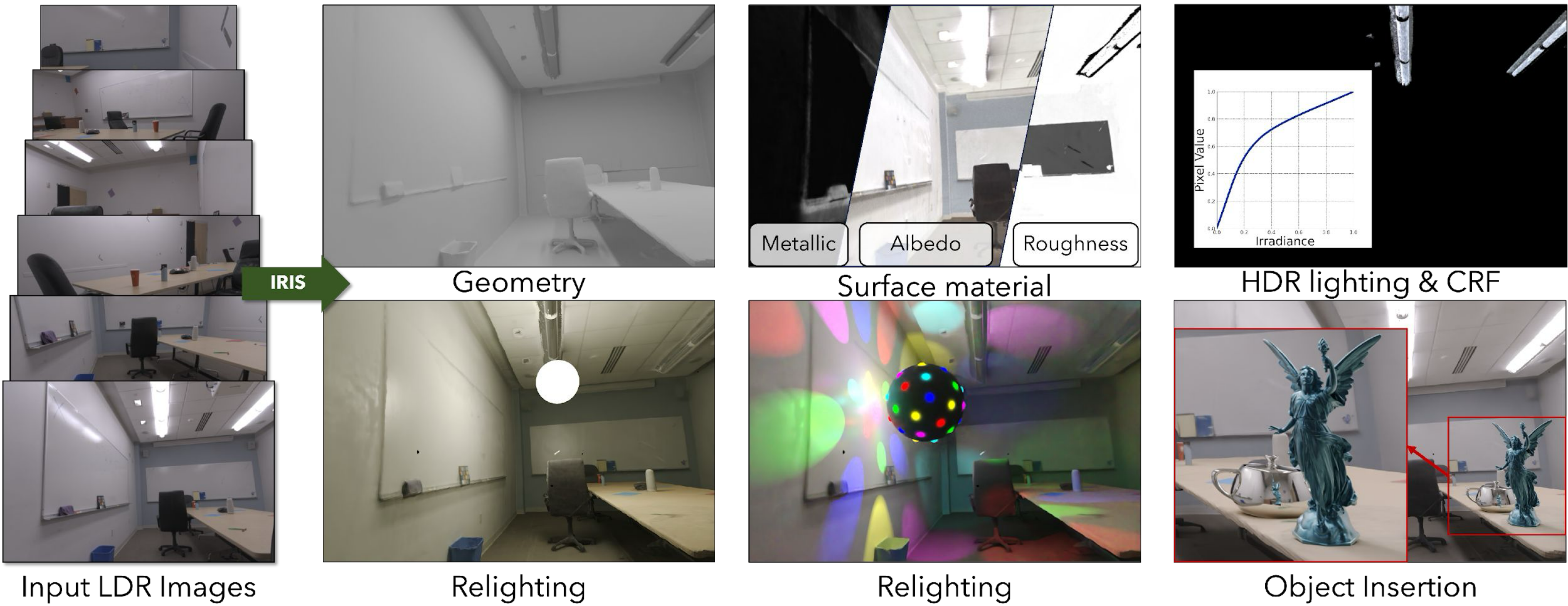


"Subsurface Scattering for Gaussian Splatting"

Inverse Rendering for Objects

"Subsurface Scattering for Gaussian Splatting"

Inverse Rendering for Scenes



CS184/284A

“IRIS: Inverse Rendering of Indoor Scenes”

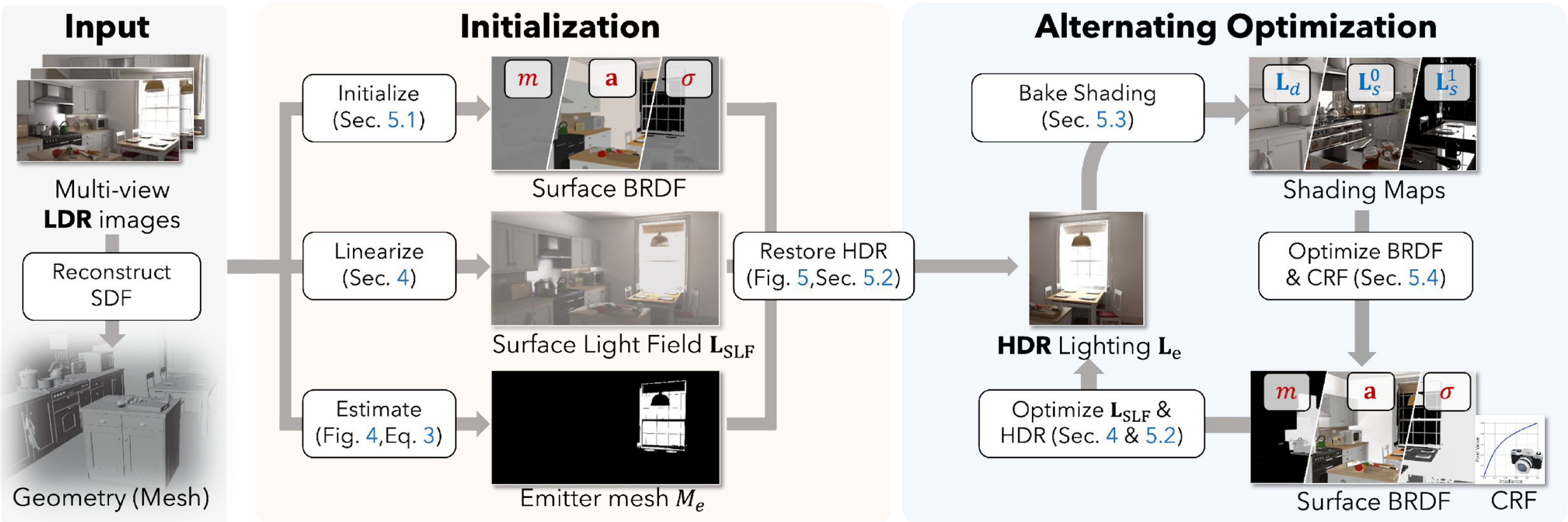
Inverse Rendering for Scenes

“IRIS: Inverse Rendering of Indoor Scenes”

Inverse Rendering for Scenes

"IRIS: Inverse Rendering of Indoor Scenes"

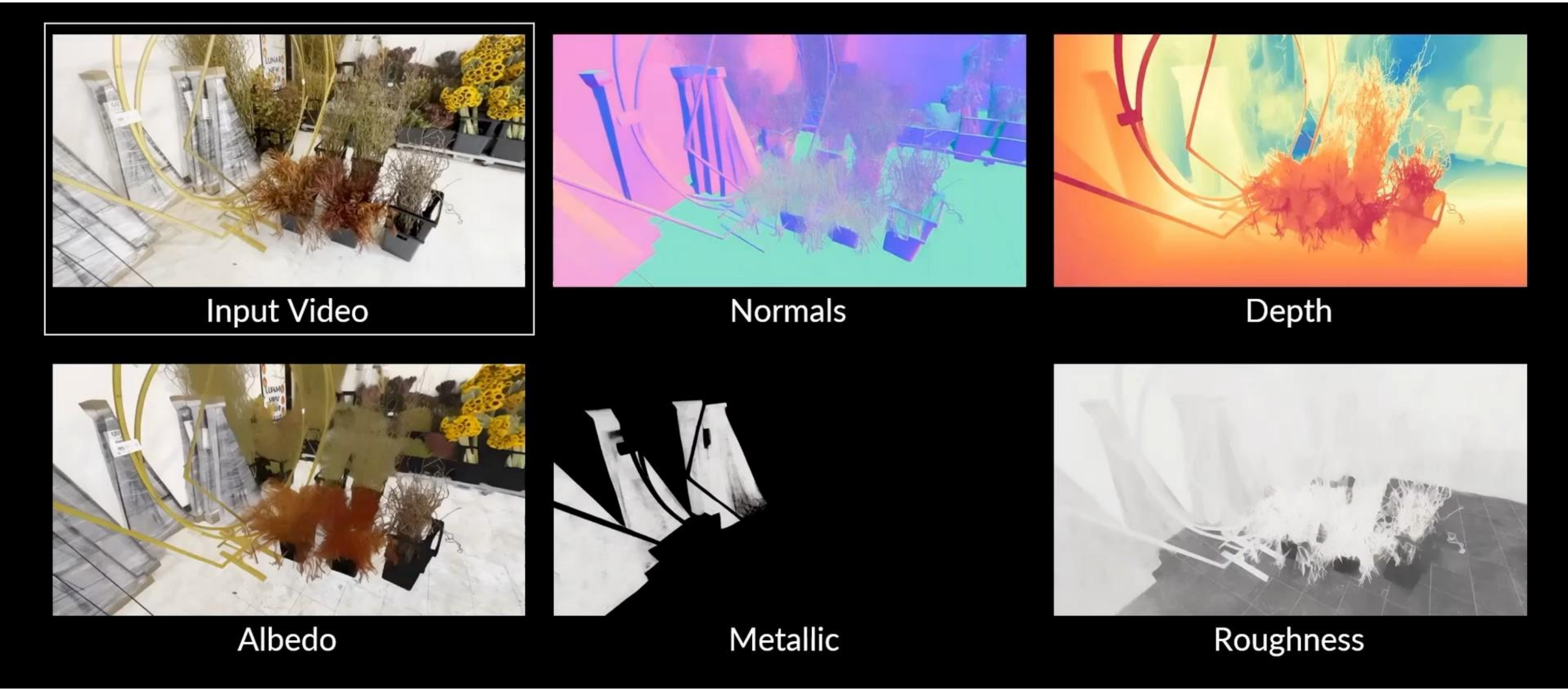
Inverse Rendering for Scenes



CS184/284A

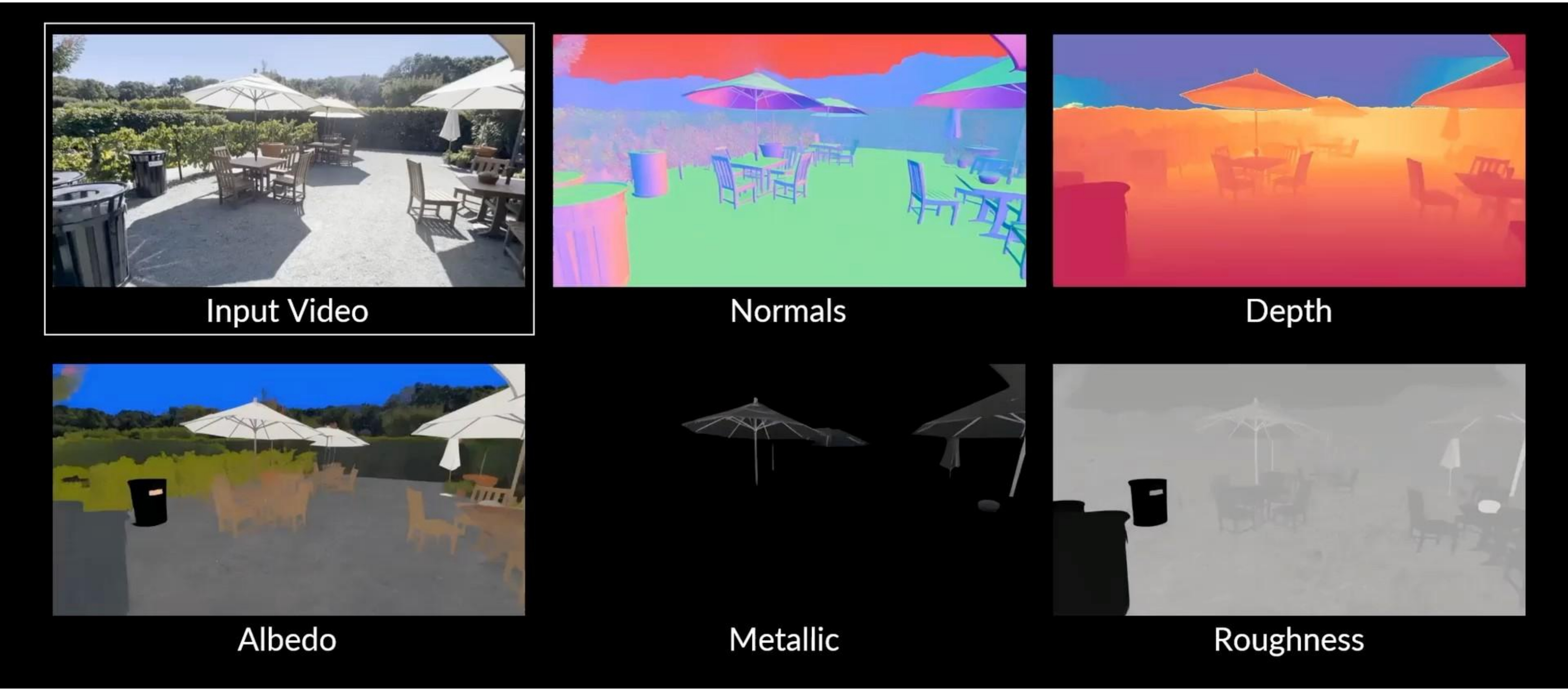
"IRIS: Inverse Rendering of Indoor Scenes"

Inverse Rendering for Scenes



“DiffusionRenderer”, CVPR 2025

Inverse Rendering for Scenes



CS184/284A

"DiffusionRenderer", CVPR 2025

Inverse Rendering for Scenes

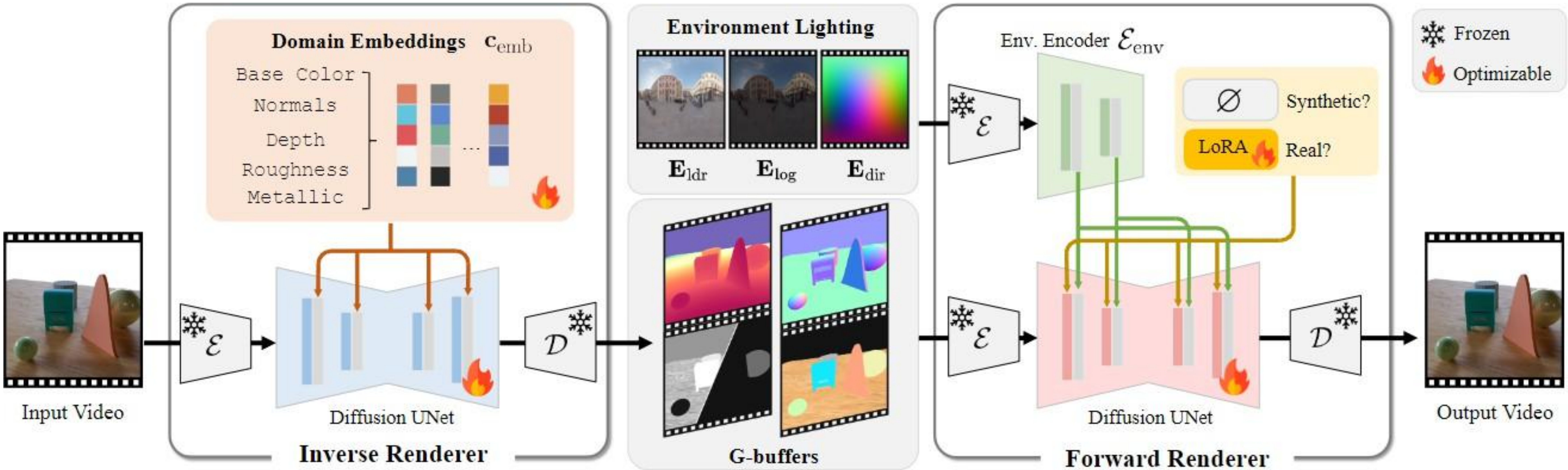
Object Insertion

Hover over each image to see the background without the virtual object.

CS184/284A

"DiffusionRenderer", CVPR 2025

Inverse Rendering for Scenes



“DiffusionRenderer”, CVPR 2025