



Micrograin BSDF Model for the Rendering of Porous Layers

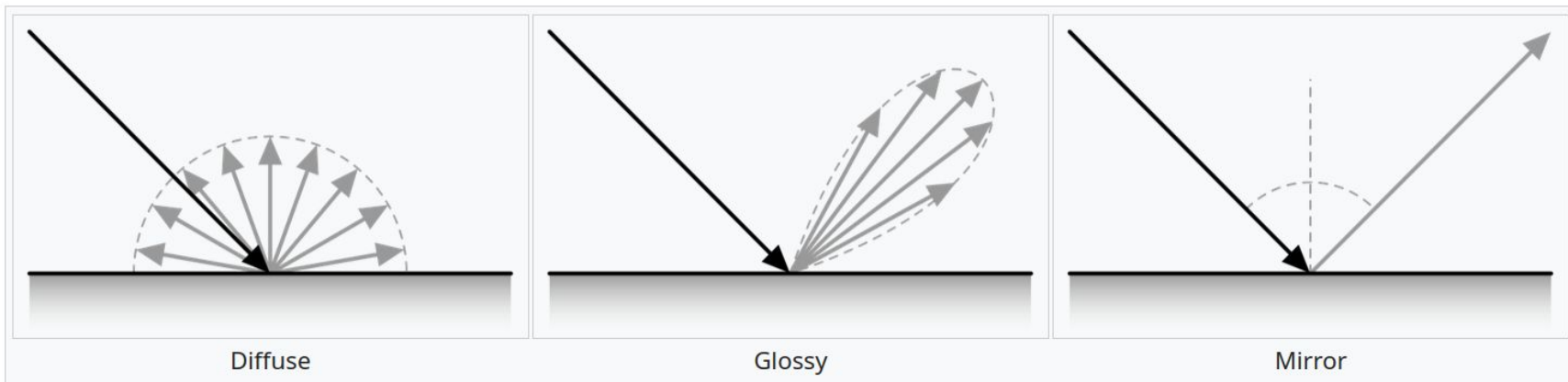
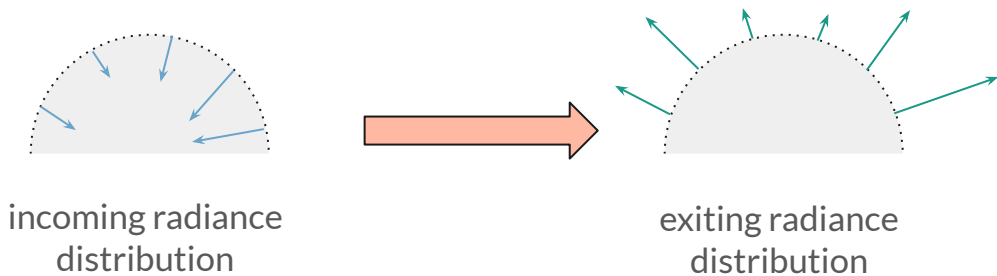
Simon Lucas, Mickaël Ribardière, Romain Pacanowski, Pascal Barla

GDL Gaspard Thévenon, 2025

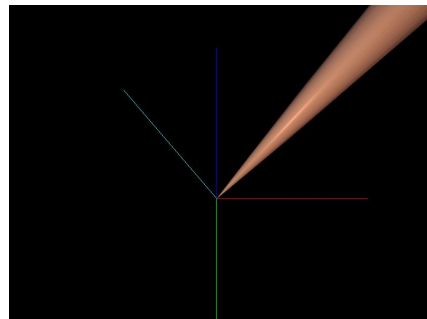
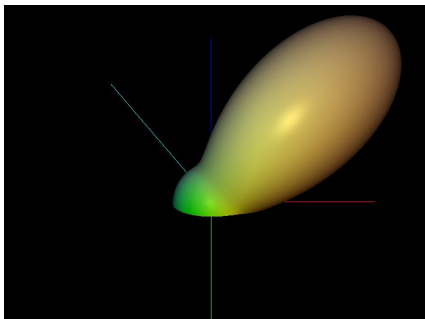
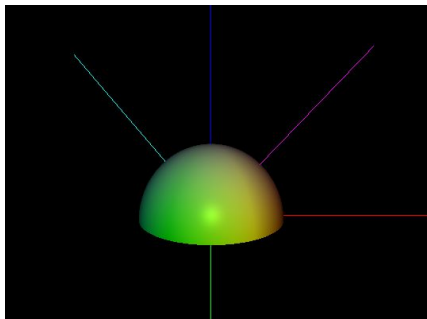
BRDF and Shading

$$f : \Omega^2 \rightarrow \mathbb{R}$$

Bidirectional Reflectance
Distribution Function:



BRDF and Shading



BRDF and Shading

Usual decomposition of reflected light:

$$f_r = k_d f_{\text{lambert}} + k_s f_{\text{cook-torrance}}$$

diffuse component

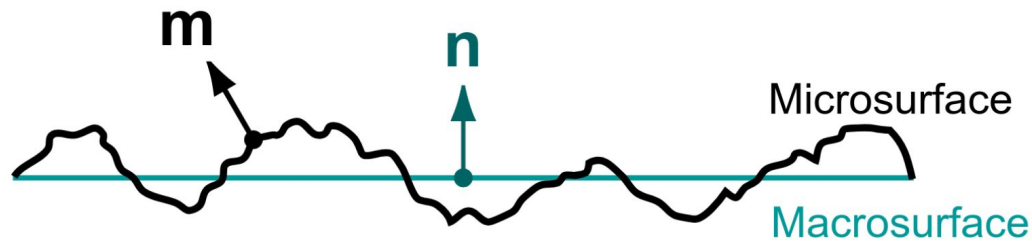
$$f_{\text{lambert}} = \frac{c}{\pi}$$

albedo: "base" color/texture of the material

glossy/specular component

Lots of models !

Microfacet BSDF theory



Now, there are two surfaces:

- The macrosurface, corresponding to the surface before, and which we want to render. It has a normal n
- The microsurface, composed of “microfacets”. It is perfectly specular, invisible to the eye. We don’t want to actually modelize this surface during rendering, but it statistically determines the macroscopic behavior of the surface. It has a theoretical normal m .

Microfacet BSDF theory

For example, if we take a light coming from one direction:



ROUGH SURFACE

More “chaotic”, so the distribution of the light reflection direction will be more uniform on the hemisphere.

> Corresponds to a *rough* behavior.

SMOOTH SURFACE

More deterministic, the distribution of the light reflection direction will tend towards a dirac.

> Corresponds to a *specular* behavior.

Cook-Torrance BSDF Model

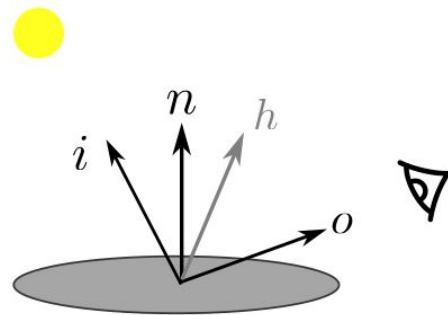
$$f_{\text{cook-torrance}} = \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

Normal Distribution Function

Geometry Function

Fresnel term

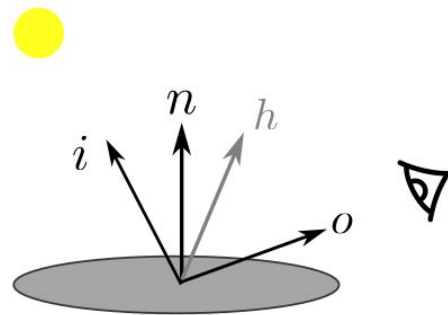
normalization



Cook-Torrance BSDF Model

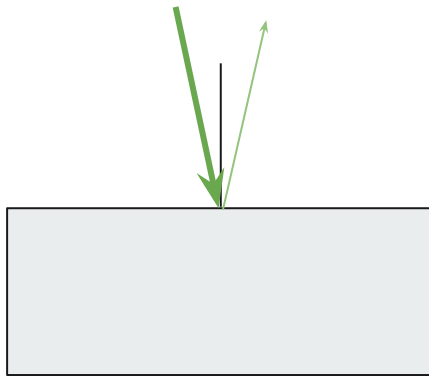
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Fresnel term

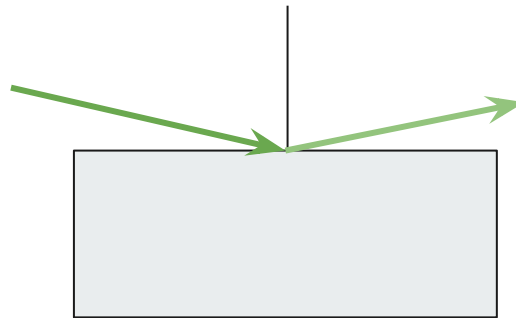


Cook-Torrance BSDF Model - Fresnel Term

Describes the proportion of incident light that is **reflected** (and not absorbed/transmitted).
This quantity depends on the light/viewing angles. Only wavelength-dependent term.



Normal incidence: maximum transmittance



Grazing angles: maximum reflection

Fresnel-Schlick approximation:
$$F(\mathbf{h} \cdot \mathbf{i}) = F_0 + (1 - F_0)(1 - (\mathbf{h} \cdot \mathbf{i}))^5$$

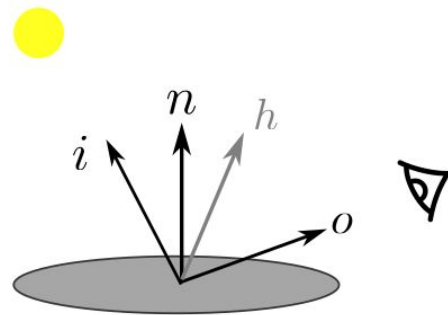
Cook-Torrance BSDF Model

Normal Distribution Function

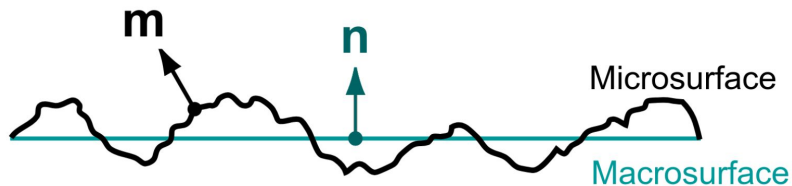
Proportion of microfacets which have the orientation h , in order to reflect light from i to o

(generally, only one bounce is considered)

$$f_{\text{cook-torrance}} = \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

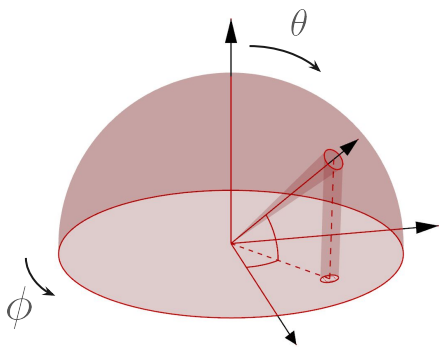


Cook-Torrance BSDF Model - Normal Distribution Function



$D(h)$ is the probability for a random surface point to have a microfacet normal h . Equivalently, it is the proportion of microfacets with normals h .

The NDF D is a distribution on directions, on the hemisphere. Usually defined using solid angles.

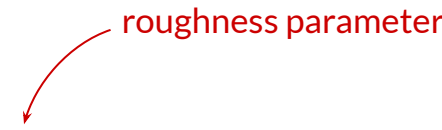


Cook-Torrance BSDF Model - Normal Distribution Function

But when there is usually no azimuthal dependence, so D becomes a 1D function:

$$D(\mathbf{h}_\theta) \in \mathbf{R}^+$$

Namely, the widely used Trowbridge-Reitz (GGX) NDF:

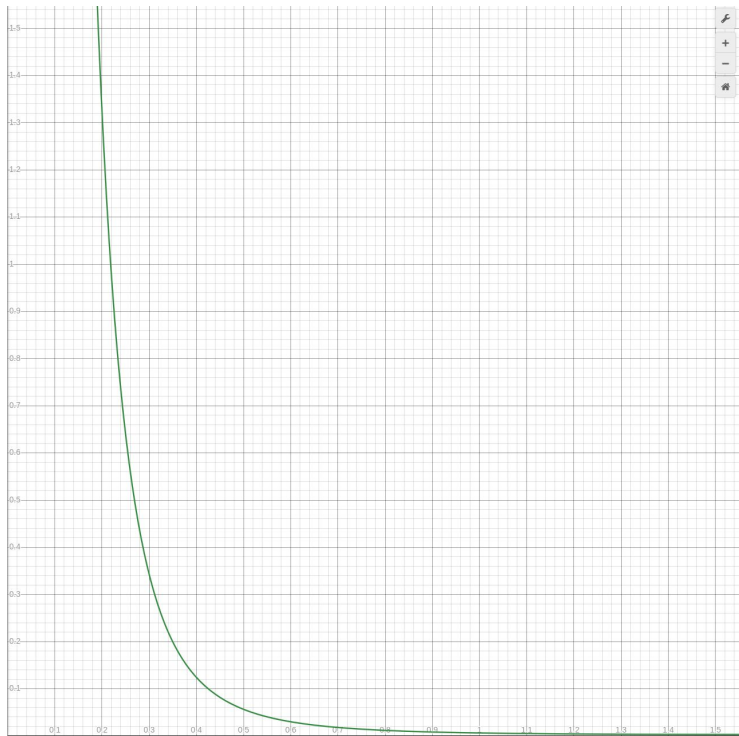
$$D(\mathbf{h}_\theta) = \frac{a^2}{\pi(\cos^2(\mathbf{h}_\theta)(a^2 - 1) + 1)^2}$$


roughness parameter

Cook-Torrance BSDF Model - Normal Distribution Function

Influence of this *roughness* parameter on the distribution:

Low roughness:

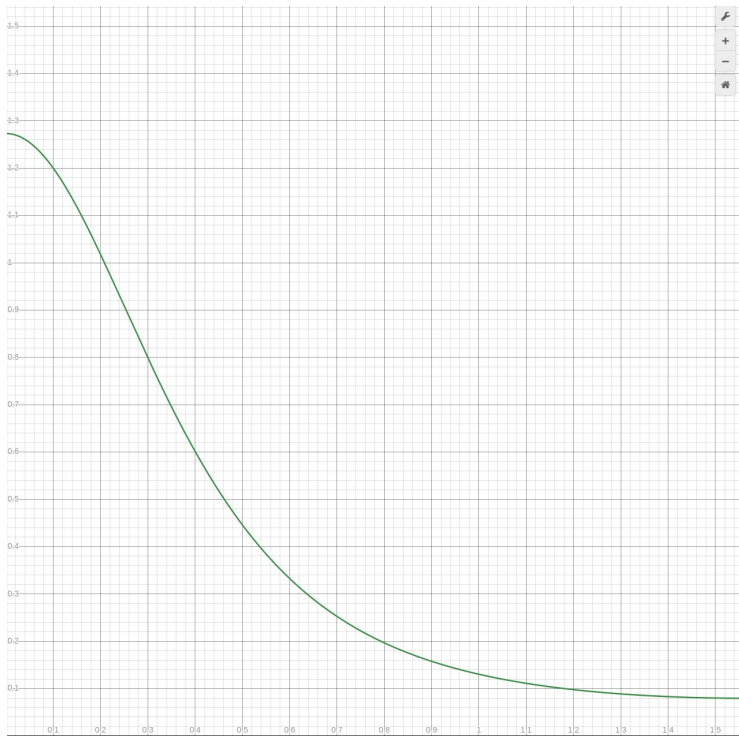


SMOOTH SURFACE

Cook-Torrance BSDF Model - Normal Distribution Function

Influence of this *roughness* parameter on the distribution:

High roughness:

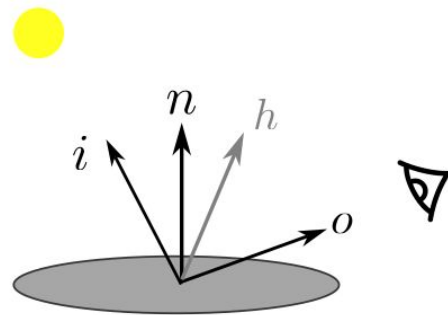


ROUGH SURFACE

Cook-Torrance BSDF Model

$$f_{\text{cook-torrance}} = \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

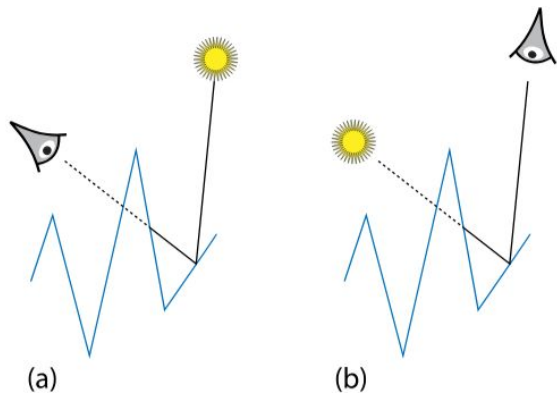
Geometry Function



Cook-Torrance BSDF Model - Geometry Function

Models the fraction of light that is reflected from i to o , without **self-obstruction**.

Usually computed using another function, Smith's *masking-shadowing* function $G_1(\omega, \omega_h)$:



meh

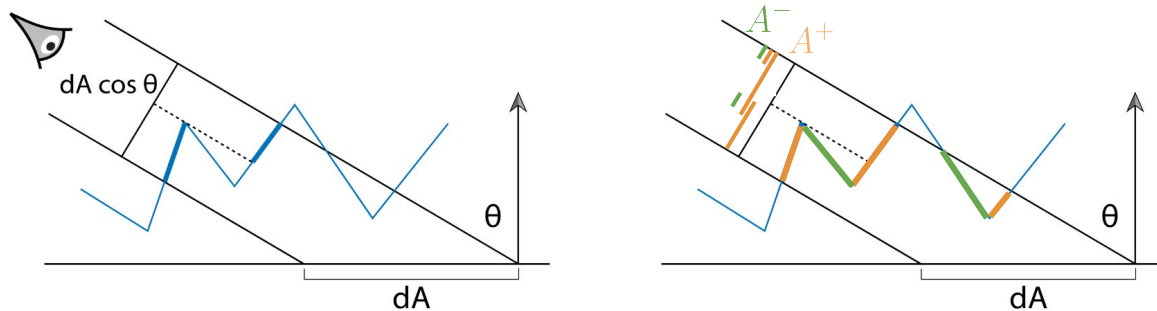
If we assume that visibilities from both directions are independent:

$$G(\omega_o, \omega_i) = G_1(\omega_o) G_1(\omega_i)$$

Cook-Torrance BSDF Model - Geometry Function

Models the fraction of light that is reflected from i to o, without **self-obstruction**.

Usually computed using another function, Smith's *masking-shadowing* function $G_1(\omega, \omega_h)$



$$G_1(\omega) = \frac{A^+(\omega) - A^-(\omega)}{A^+(\omega)} = \cos \theta$$



Micrograin BSDF Model for the Rendering of Porous Layers

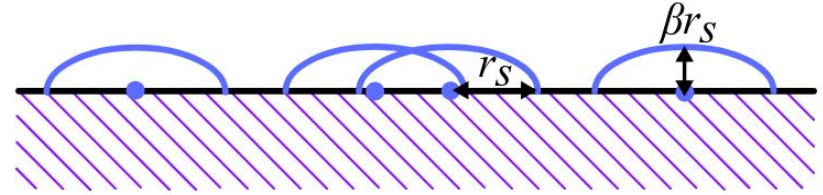
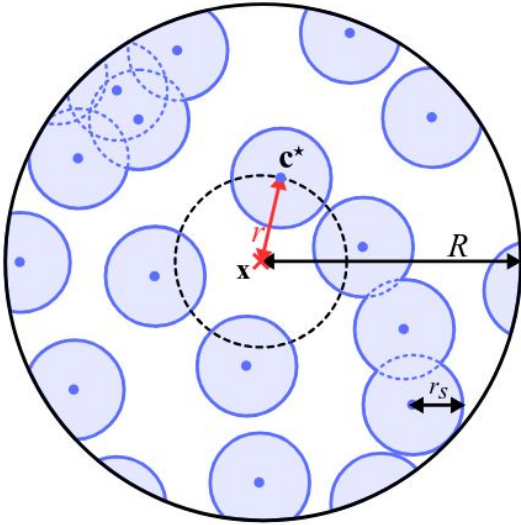
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Surface model

Bulk surface, with micrograins at the surface. They are “flattened” spheres with a given heights and circle sections radius.

They can intersect, and are uniformly distributed on the surface.

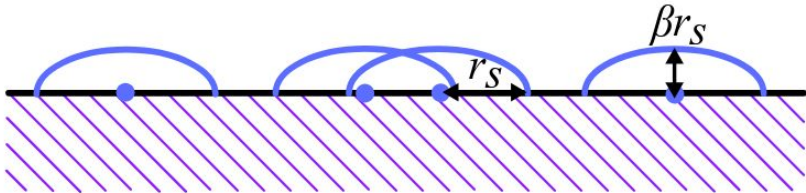
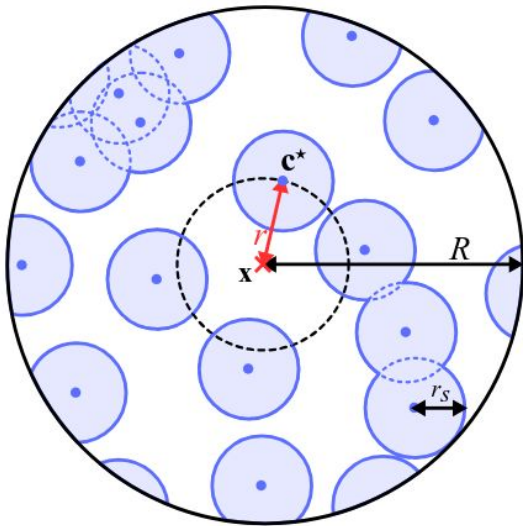


We also suppose given the micrograins density ρ (the number of micrograins per unit area)

$$f_r(\mathbf{i}, \mathbf{o}) = w^+(\mathbf{i}, \mathbf{o}) f_r^S(\mathbf{i}, \mathbf{o}) + (1 - w^+(\mathbf{i}, \mathbf{o})) f_r^B(\mathbf{i}, \mathbf{o})$$

proba that a light ray only interacts with micrograins

Surface model



$$f_r^S(\mathbf{i}, \mathbf{o}) = \frac{K_d}{\pi} \bar{T}(\mathbf{i}, \mathbf{o}) + \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

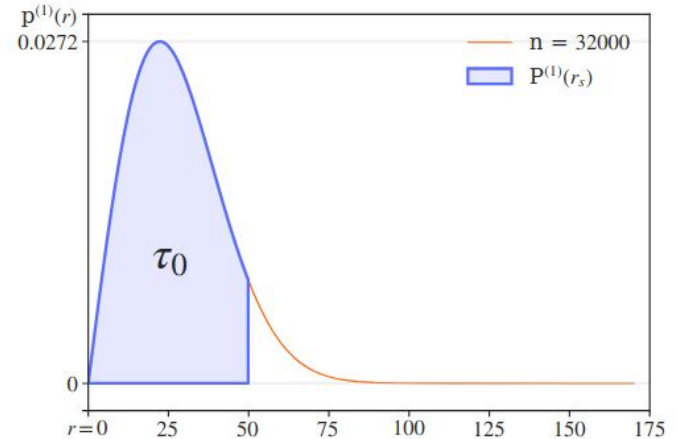
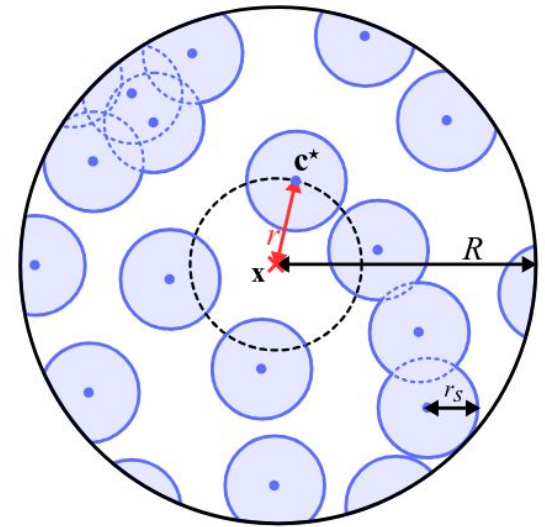
Filling factor

$$p(r) := \mathbf{P}(d^*(x) = r) = 2\pi\rho r e^{-\pi\rho r^2}$$

$$P(r') = p(r < r') = 1 - e^{-\pi\rho r'^2}$$

Special value of the CDF: $p(r < r_s) = \tau_0$

It corresponds to the fraction of area (seen from above) filled by micrograins



Cook-Torrance BSDF Model

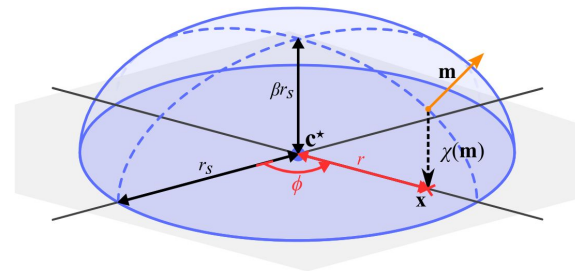
Normal Distribution Function

Geometry Function

Fresnel term

$$f_{\text{cook-torrance}} = \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

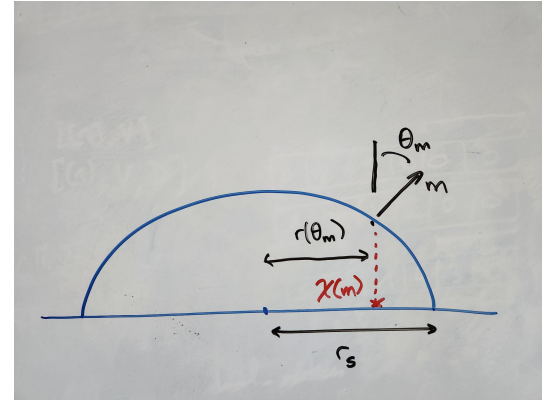
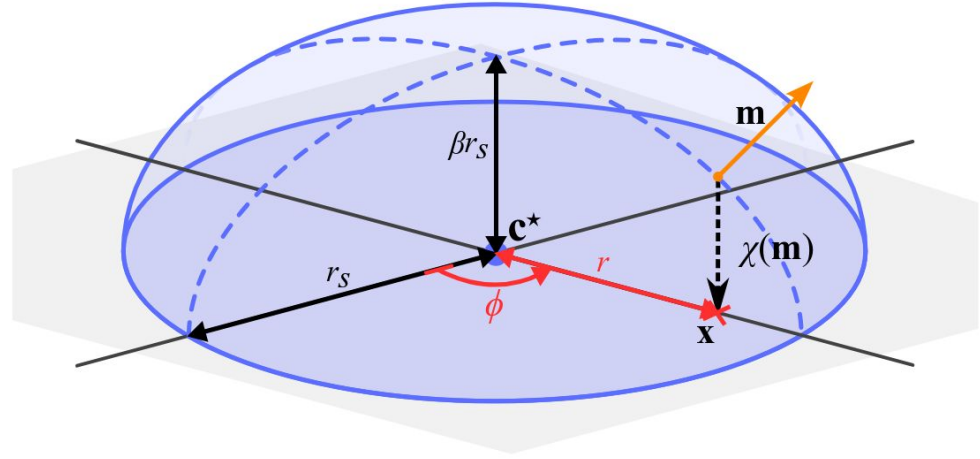
$w^+(\mathbf{i}, \mathbf{o})$ proba that light only interacts with micrograins



Normal distribution function

Proba that a point on a micrograin has normal $\mathbf{m}$:

$$p(\mathbf{m}) = \frac{p(\chi(\mathbf{m}))}{p(r < r_s)} = \frac{p(\chi(\mathbf{m}))}{\tau_0}$$



Normal distribution function

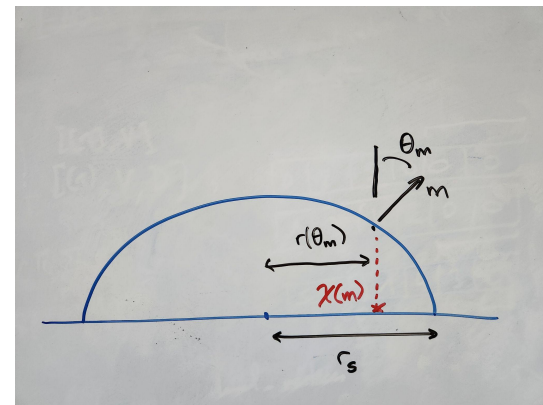
Normalization:

$$1 = \frac{1}{p(r < r_s)} \int_0^{r_s} p(r) dr = \dots = \int_{\omega_m \in \Omega} p(\mathbf{m}) r(\theta_m) \frac{J_r(\theta_m)}{\sin(\theta_m)} d\omega_m$$

change of variable

$$1 = \int_{\omega_m \in \Omega} D(\mathbf{m}) \cos(\theta_m) d\omega_m$$

what we want

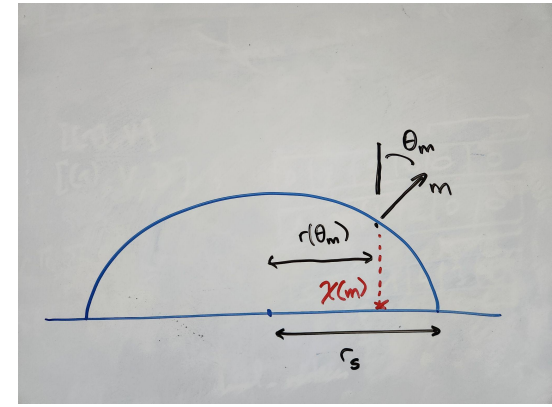


Normal distribution function

$$D(\mathbf{m}) = \frac{p(\mathbf{m})r(\theta_m)J_r(\theta_m)}{\sin \theta_m \cos \theta_m}$$

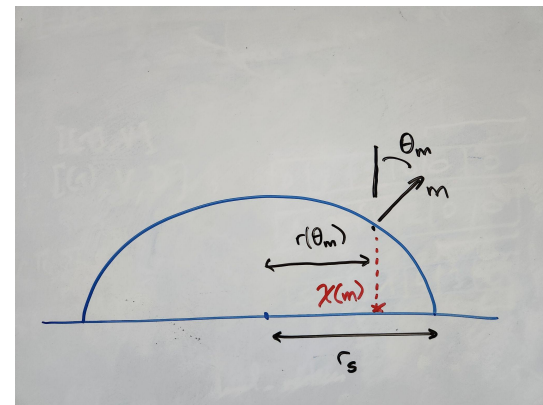


$$D(\mathbf{m}) = \frac{\beta^2 \rho r_s^2 e^{-\pi \rho r_s^2 \frac{\tan^2 \theta_m}{\beta^2 + \tan^2 \theta_m}}}{(1 - e^{-\pi \rho r_s^2})(\beta^2 + \tan^2 \theta_m)^2 \cos^4 \theta_m}$$



Normal distribution function

$$D(\mathbf{m}) = \frac{p(\mathbf{m})r(\theta_m)J_r(\theta_m)}{\sin \theta_m \cos \theta_m}$$



$$D(\mathbf{m}) = -\frac{\ln(1 - \tau_0)(1 - \tau_0)^{\frac{\tan^2 \theta_m}{\beta^2 + \tan^2 \theta_m}}}{\tau_0} D^{\text{GGX}}(\mathbf{m})$$

Normal distribution function - Parameters

purely specular

low roughness

high roughness

β

micrograins height

$\beta=0$

small β

big β

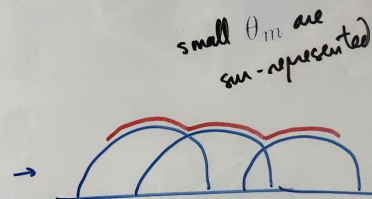
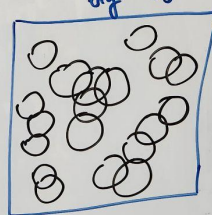
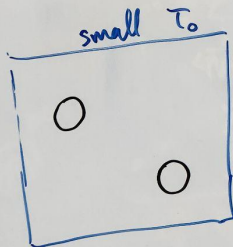


T_0

micrograins density

small T_0

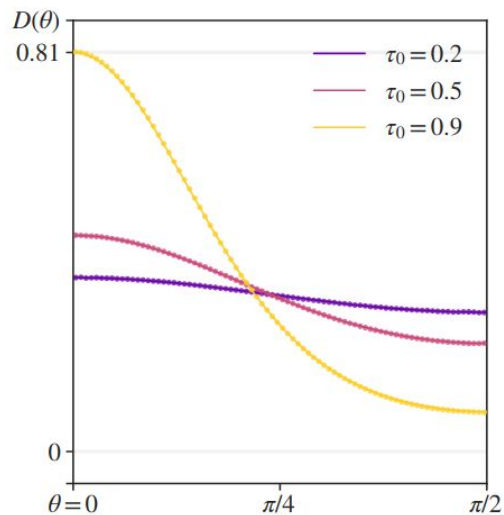
big T_0



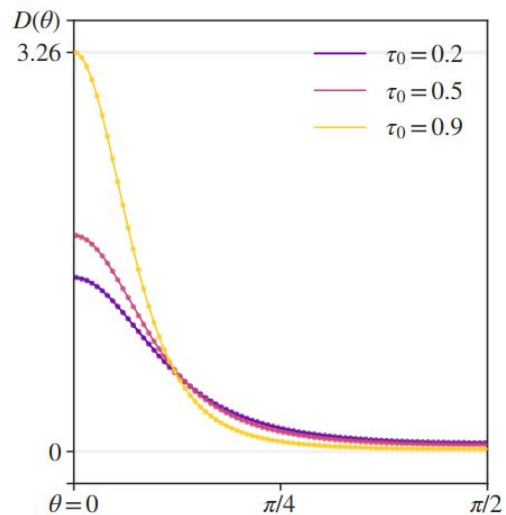
almost no intersection, micrograins
are isolated -> GGX model

a lot of intersections

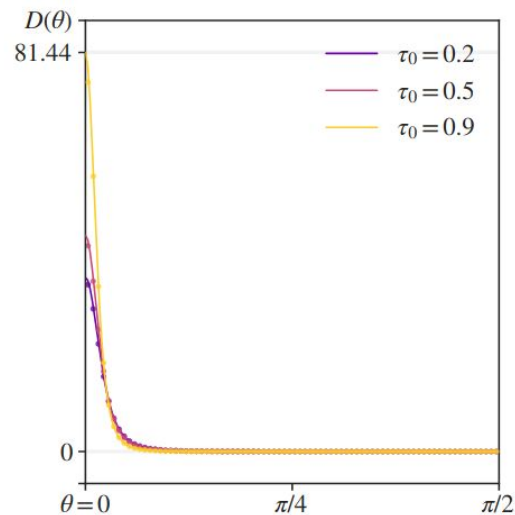
Normal distribution function - Parameters



(a) $\beta = 1$



(b) $\beta = 0.5$



(c) $\beta = 0.1$

Cook-Torrance BSDF Model

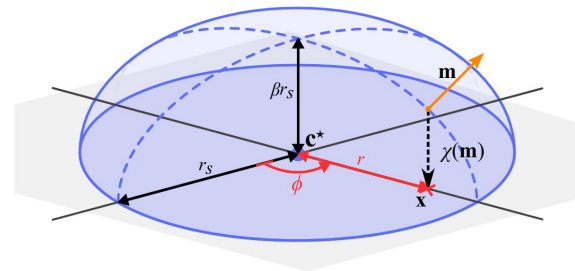
Normal Distribution Function

Geometry Function

Fresnel term

$$f_{\text{cook-torrance}} = \frac{D(\mathbf{h})G(\mathbf{i}, \mathbf{o})F(\mathbf{i} \cdot \mathbf{h})}{4|\mathbf{i} \cdot \mathbf{n}| |\mathbf{o} \cdot \mathbf{n}|}$$

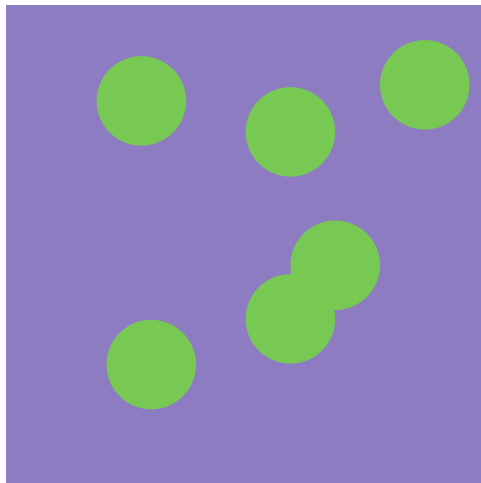
$w^+(\mathbf{i}, \mathbf{o})$ proba that light only interacts with micrograins



Visibility term

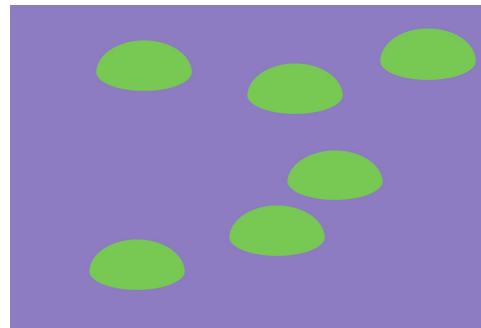
view angle:

$$\theta = 0$$



$$\tau_0 = \frac{\text{green square}}{\text{purple square} + \text{green square}}$$

$$\theta > 0$$

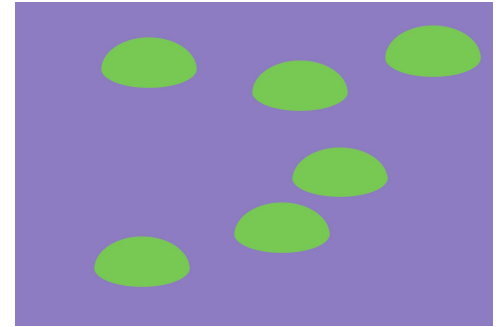


$$\tau_{\beta}(\theta) = \frac{\text{green square}}{\text{purple square} + \text{green square}}$$

Visibility term

Probability that light coming from direction $\mathbf{i}$ and reflected to direction $\mathbf{o}$ only interacts with micrograins:

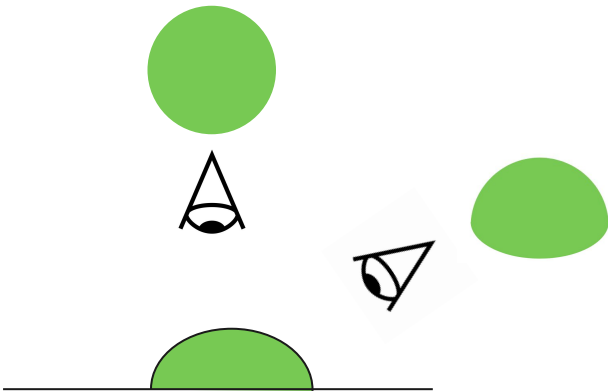
$$w^+(\mathbf{i}, \mathbf{o}) = 1 - \frac{(1 - \tau_\beta(\theta_i))(1 - \tau_\beta(\theta_o))}{1 - \tau_0}$$



$$\tau_\beta(\theta) = 1 - e^{-\pi r_s^2 \frac{\rho \gamma_\beta(\theta)}{\cos \theta}}$$

$$\tau_\beta(\theta) = \frac{\text{green square}}{\text{purple square} + \text{green square}}$$

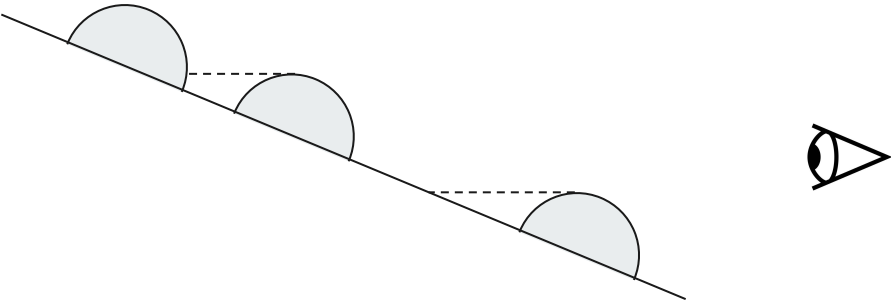
Visibility term



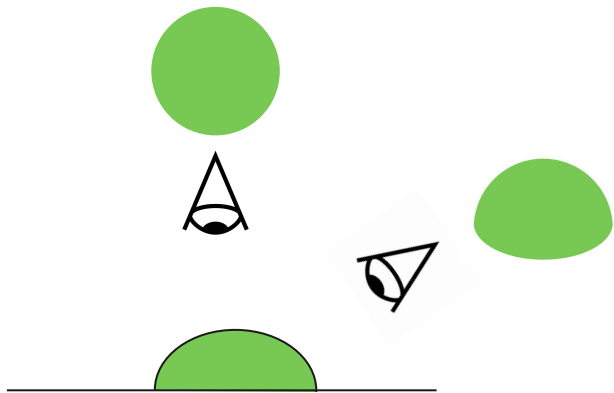
micrograins area compression factor

$$\tau_{\beta}(\theta) = 1 - e^{-\pi r_s^2 \frac{\rho \gamma_{\beta}(\theta)}{\cos \theta}}$$

micrograins self-occlusion



Visibility term



$$\gamma_{\beta}(\theta) = \text{Diagram of a sphere with a horizontal line through its center} = \frac{1}{2}(\underbrace{\tilde{\gamma}_{\beta}(\theta)}_{\sqrt{\cos^2 \theta + \beta^2 \sin^2 \theta}} + \cos \theta)$$

Thank you !

Questions ?