CS5630: Physically Based Realistic Rendering

Mariia Soroka

07: Light Reflection

Recap: Radiometric Units

Radiant Flux

$\Phi(W)$

Irradiance/
Radiant exitance

$\mathbf{E}\left(\frac{W}{m^2}\right) / \mathbf{M}\left(\frac{W}{m^2}\right)$

Intensity

$\mathbf{I}\left(\frac{W}{sr}\right)$

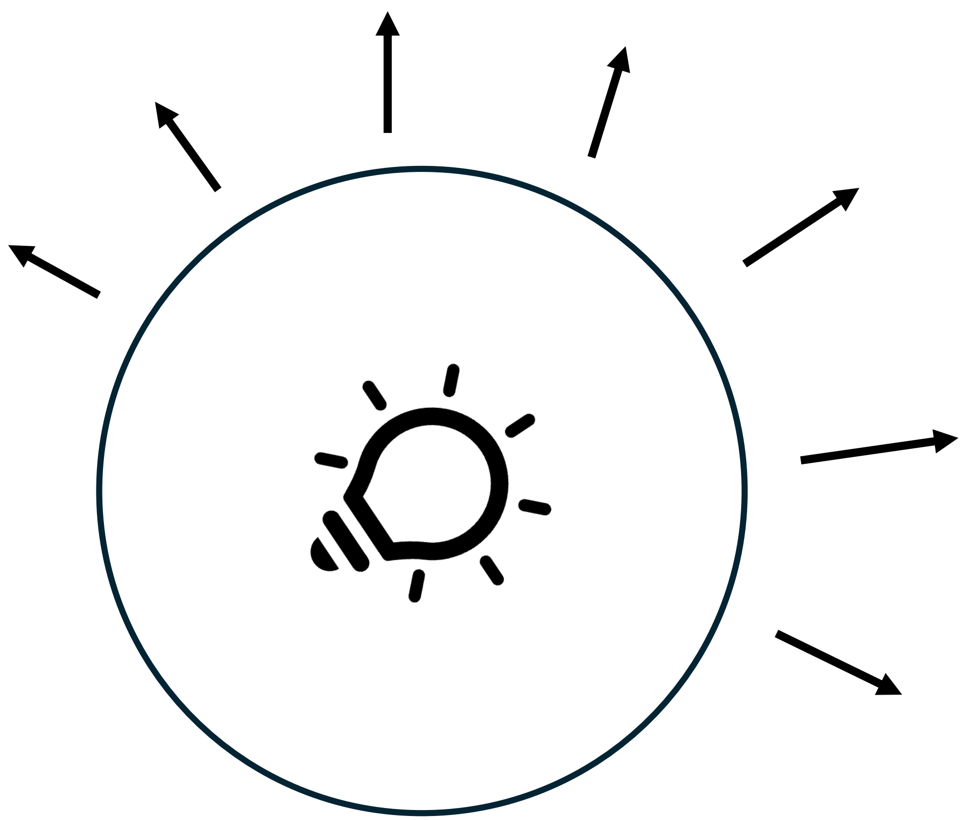
Radiance

$\mathbf{L}\left(\frac{W}{m^2\ sr}\right)$

Recap: Radiometric Units

Radiant Flux
$\Phi(W)$

-- How much energy a finite area emits or receives from all possible directions.



Light bulb brightness is stated in lumens – photometric counterpart of radiant flux

Recap: Radiometric Units

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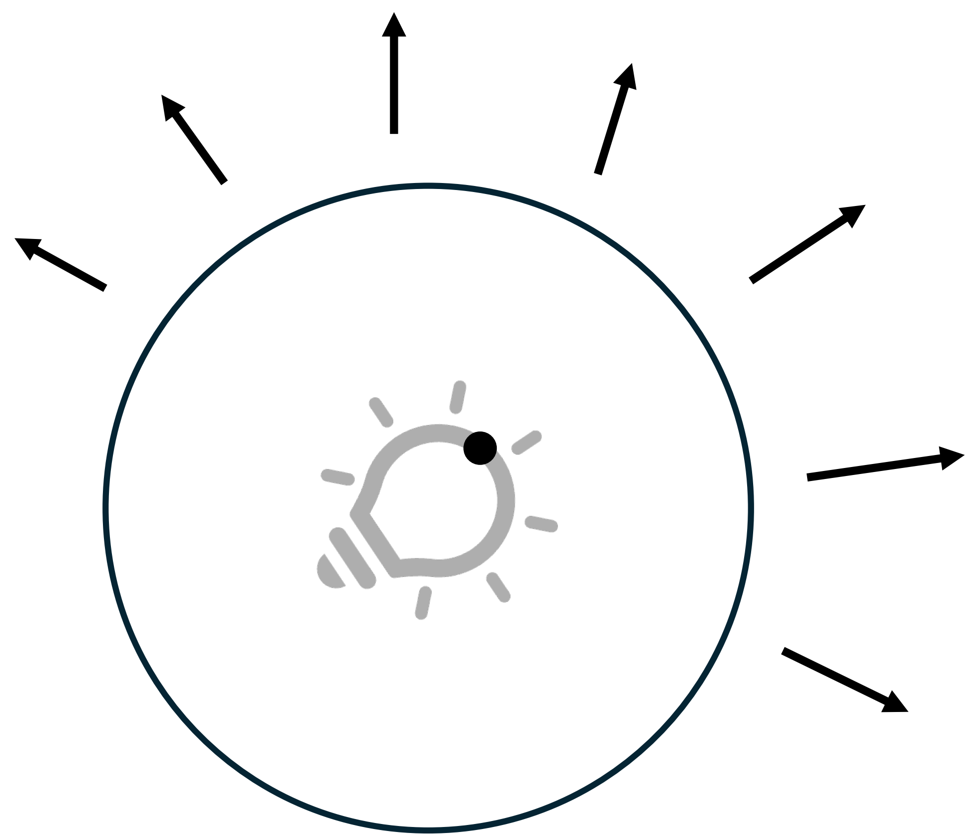
Recap: Radiometric Units

Irradiance/
Radiant exitance -- Area density of radiant flux

$E\left(\frac{W}{m^2}\right)$ / $M\left(\frac{W}{m^2}\right)$



Recap: Radiometric Units

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E$\left(\frac{W}{m^2}\right)$ **/ M**$\left(\frac{W}{m^2}\right)$

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I$\left(\frac{W}{sr}\right)$

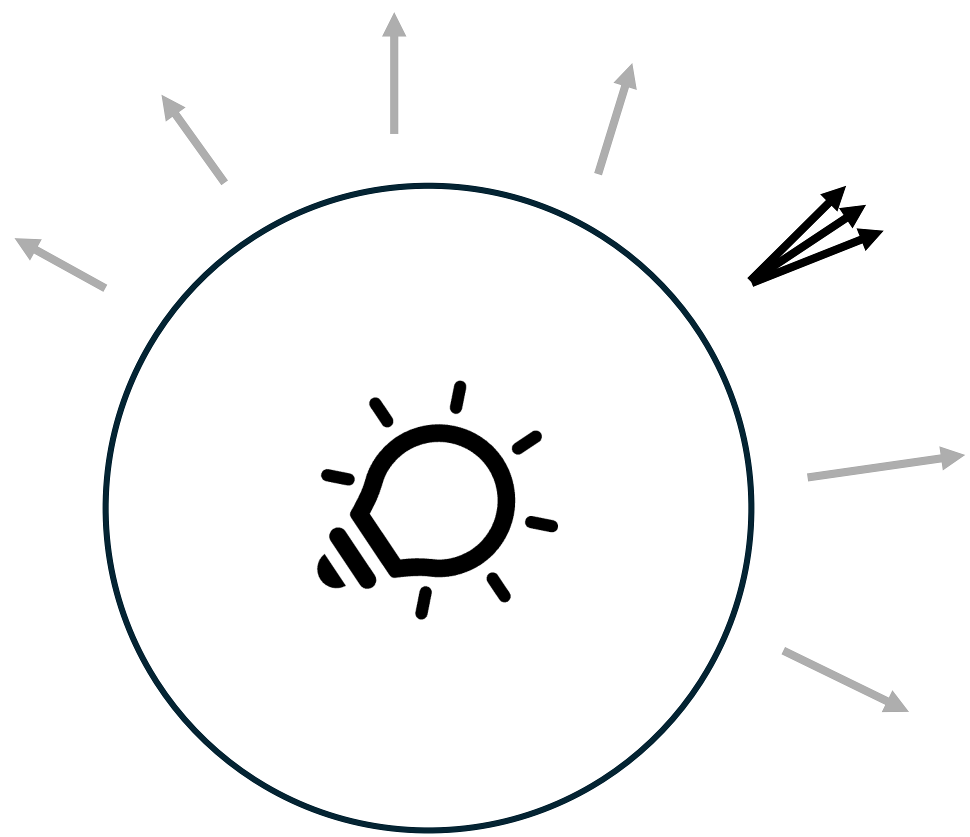
Radiance

L$\left(\frac{W}{m^2\ sr}\right)$

Recap: Radiometric Units

Intensity

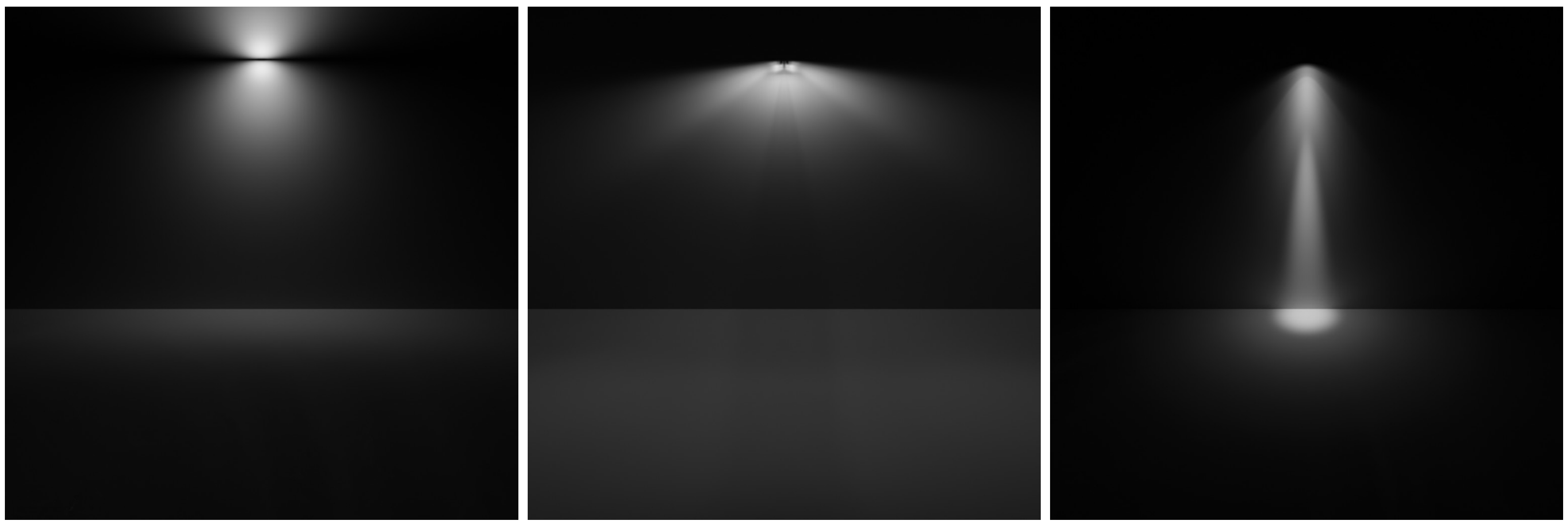
$I\left(\frac{W}{sr}\right)$ -- Solid angle density of radiant flux



Recap: Radiometric Units

Intensity

$I\left(\frac{W}{sr}\right)$ -- Solid angle density of radiant flux



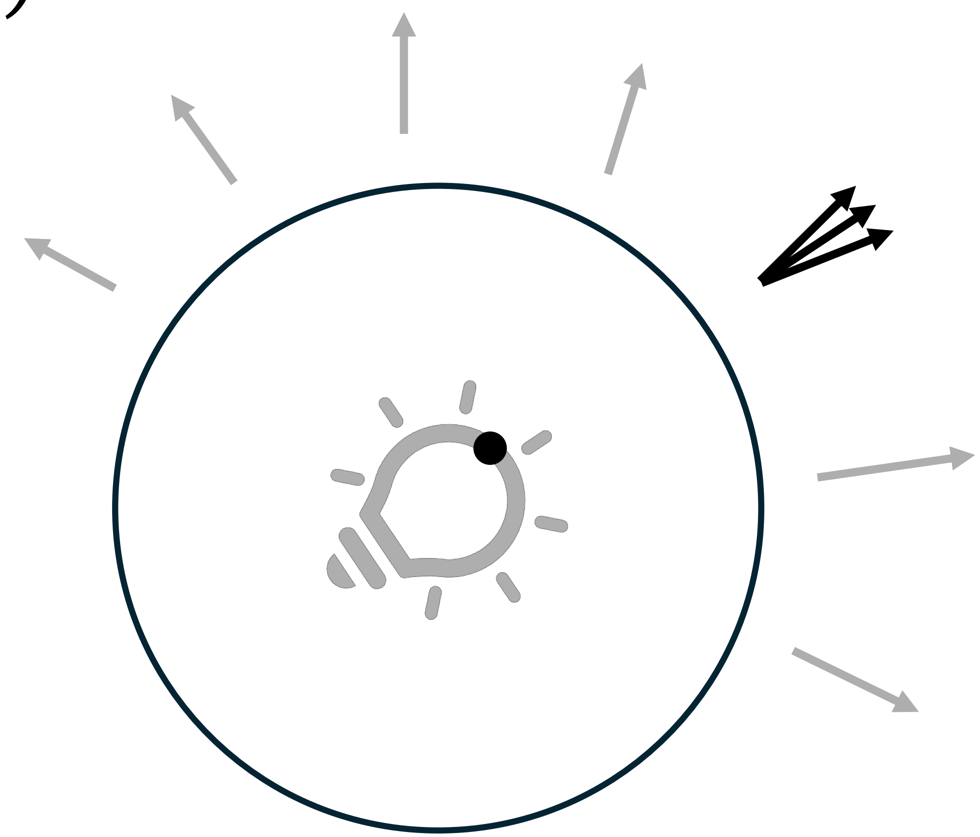
https://ieslibrary.com

Useful to describe light sources and light fixtures for interior design.

Recap: Radiometric Units

Radiance

$L\left(\frac{W}{m^2\ sr}\right)$ -- Solid angle density of irradiance



Recap: Radiometric Units

Radiance

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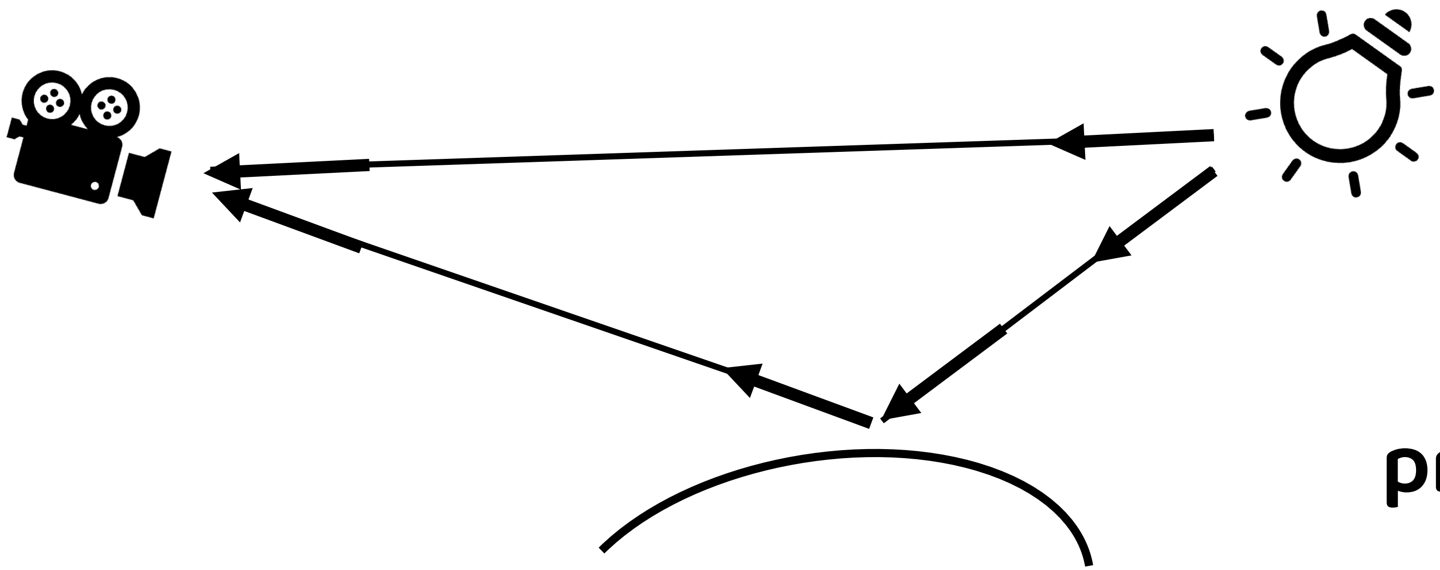
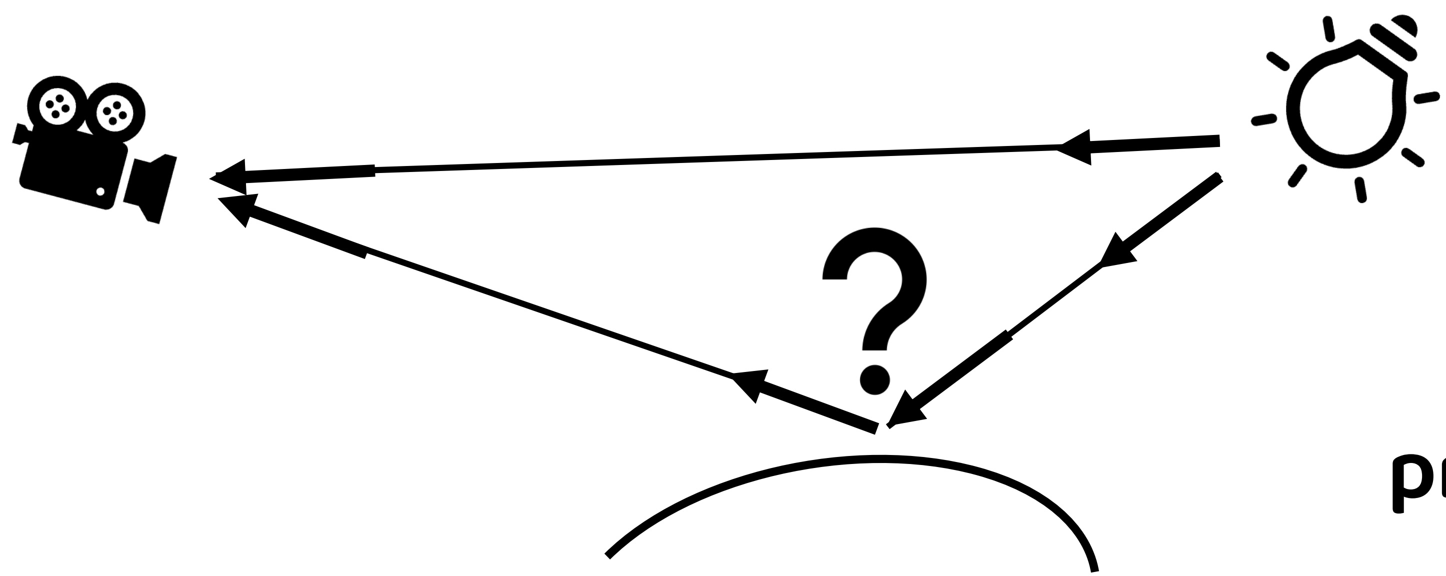


Radiance is preserved along rays

Recap: Radiometric Units

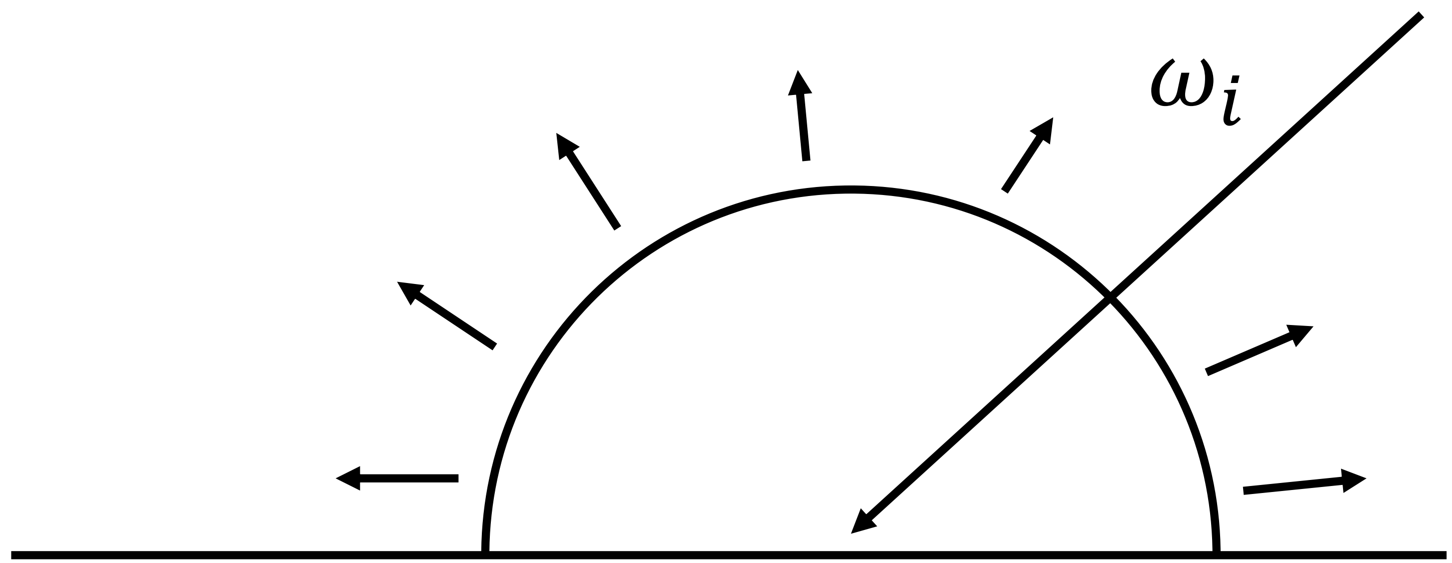
Radiance

$L\left(\frac{W}{m^2\,sr}\right)$ -- Solid angle density of irradiance



Radiance is preserved along rays

Lambertian Diffuse Reflectance



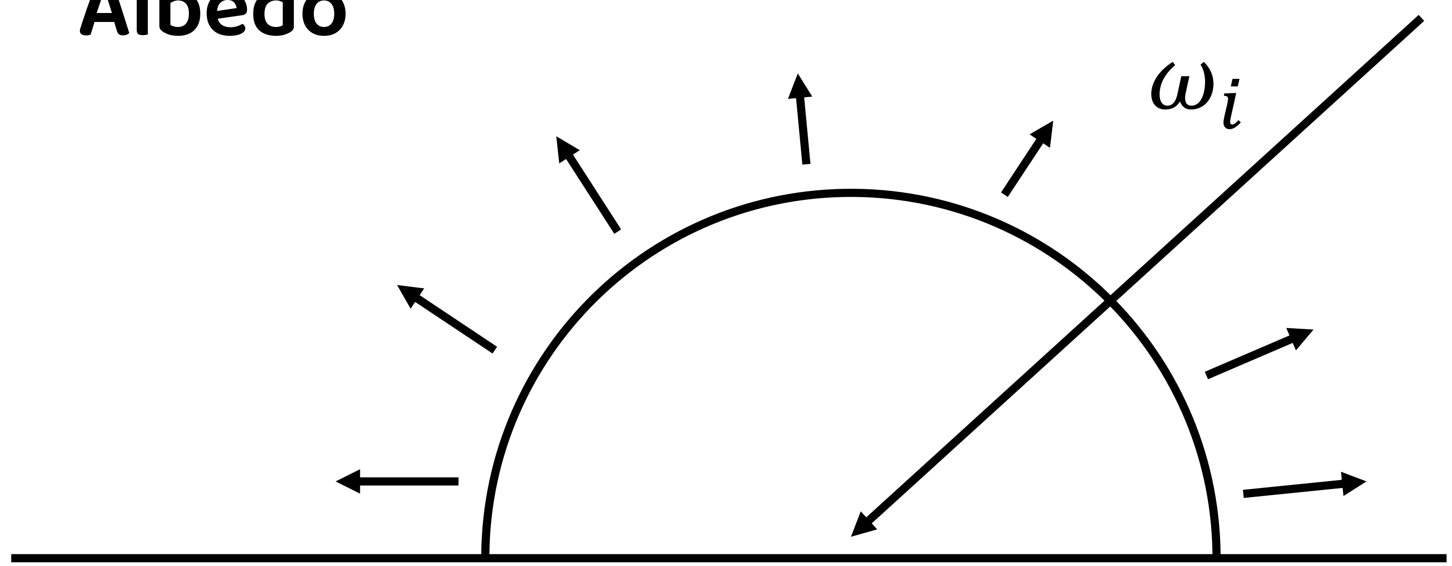
Lambertian Diffuse Reflectance

Irradiance

$$M = a\,E$$

Radiant Exitance

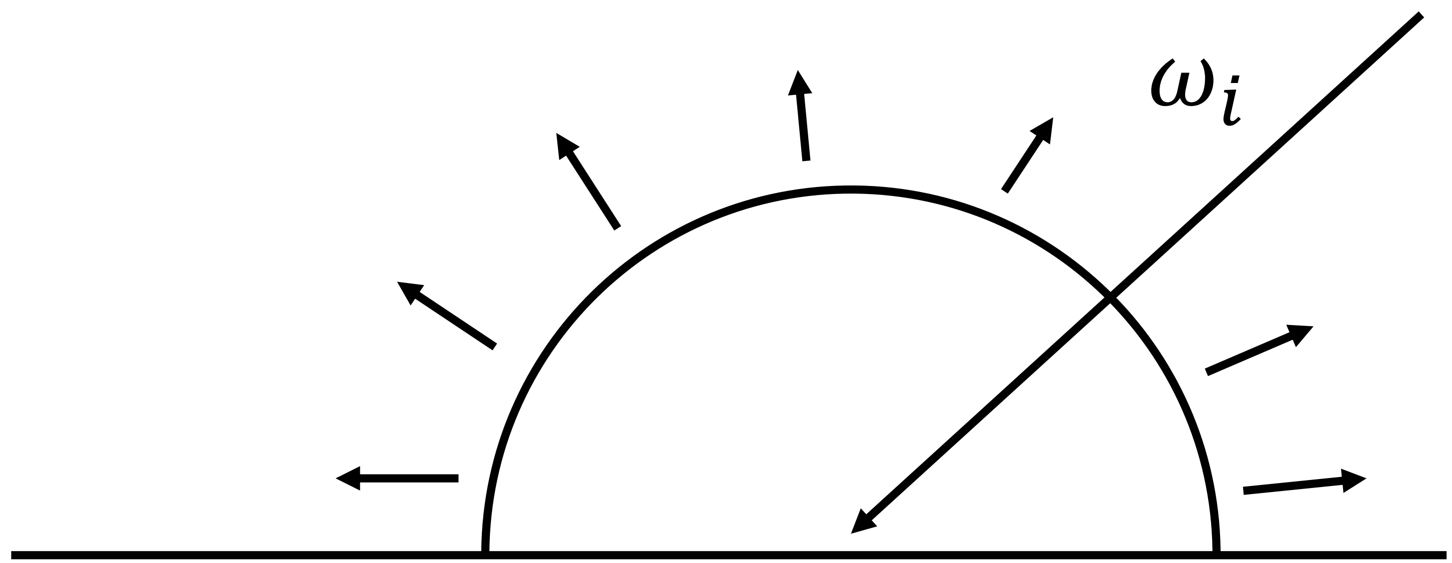
Albedo



Lambertian Diffuse Reflectance

$$M = a\,E$$

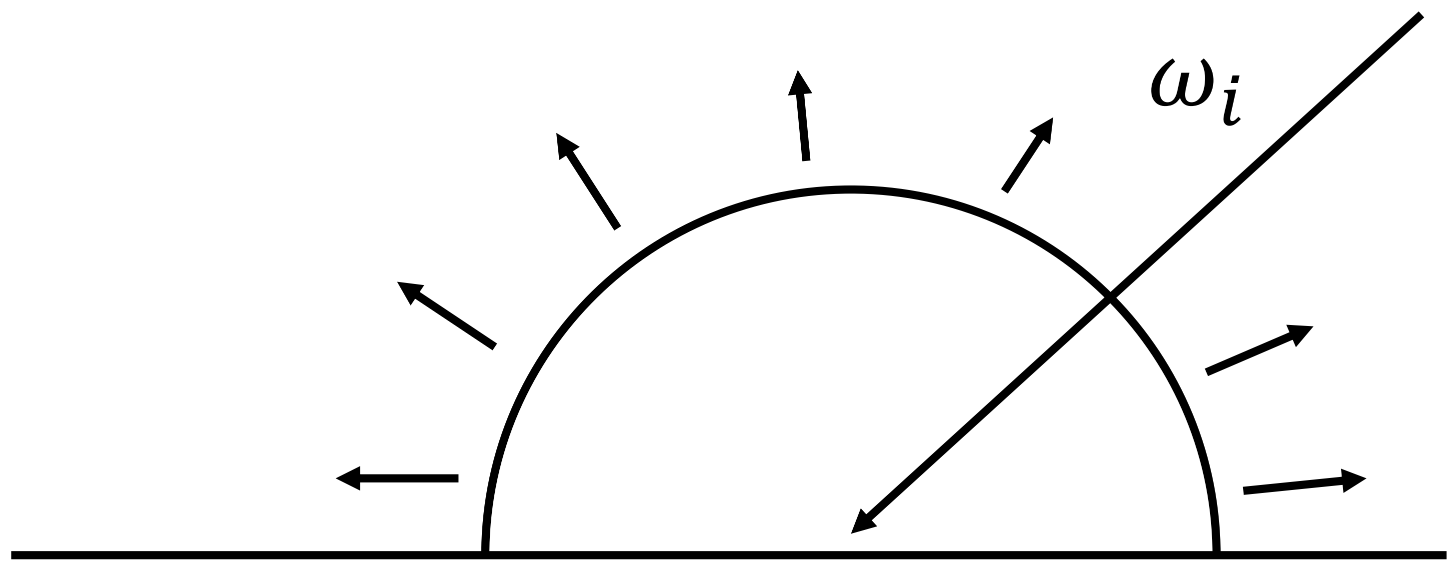
$$M = \int_{H^2} L_o(\omega)\,(\omega \cdot n)d\omega = \pi L_o = a\,E$$



Lambertian Diffuse Reflectance

$$M = a\,E$$

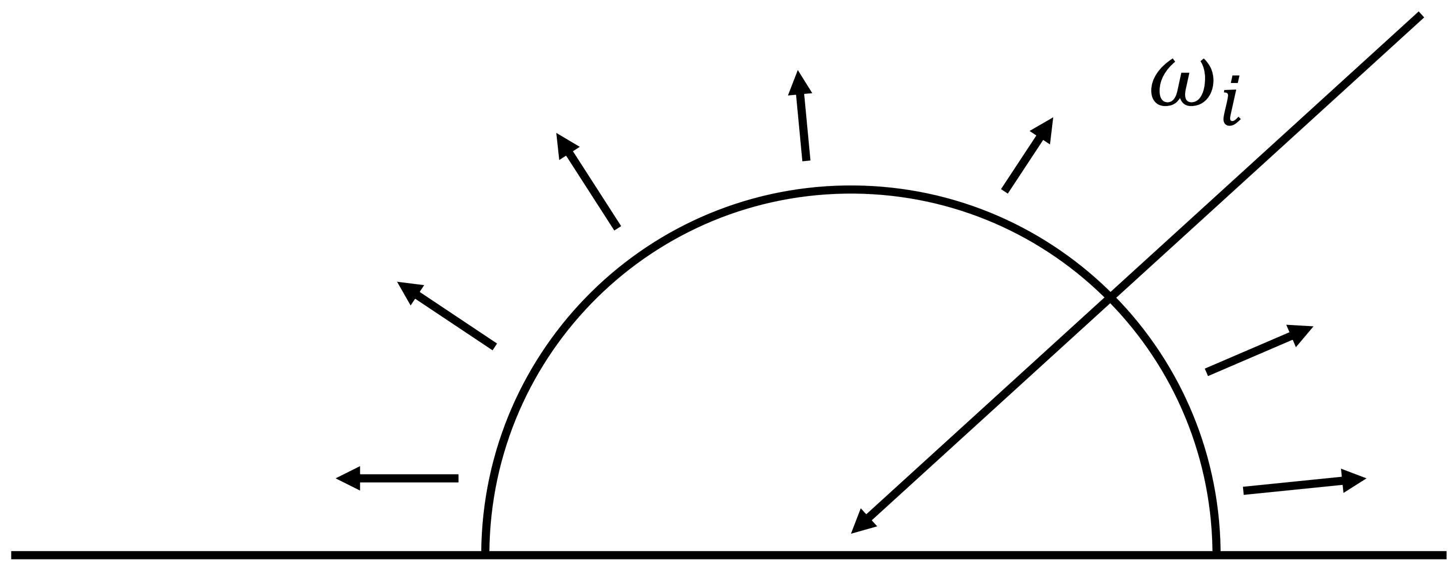
$$M = \int_{H^2} L_o(\omega)\,(\omega \cdot n)d\omega = \pi L_o = a\,E \implies L_o = \frac{a}{\pi}E$$



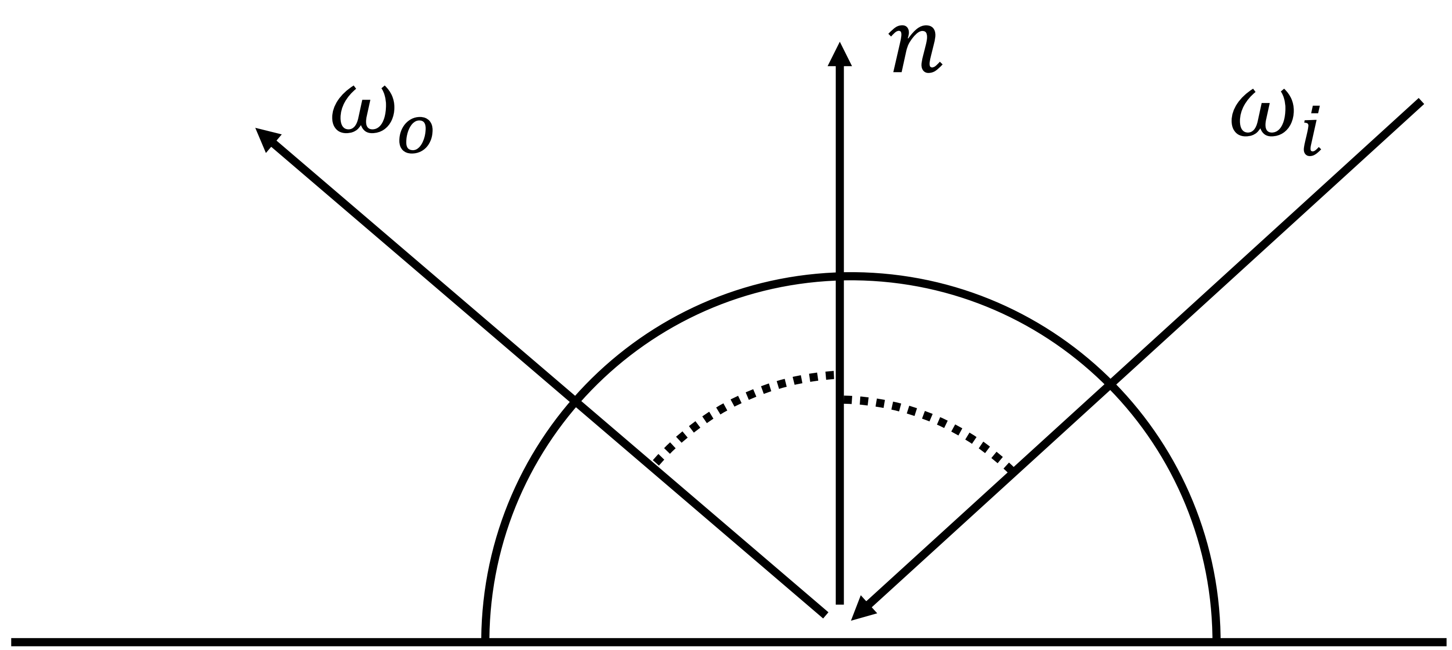
Lambertian Diffuse Reflectance

$$M = a\,E$$

$$L_o = \frac{a}{\pi}E = \frac{a}{\pi}\int_{H^2} L_i(\omega)\,(\omega \cdot n)d\omega$$

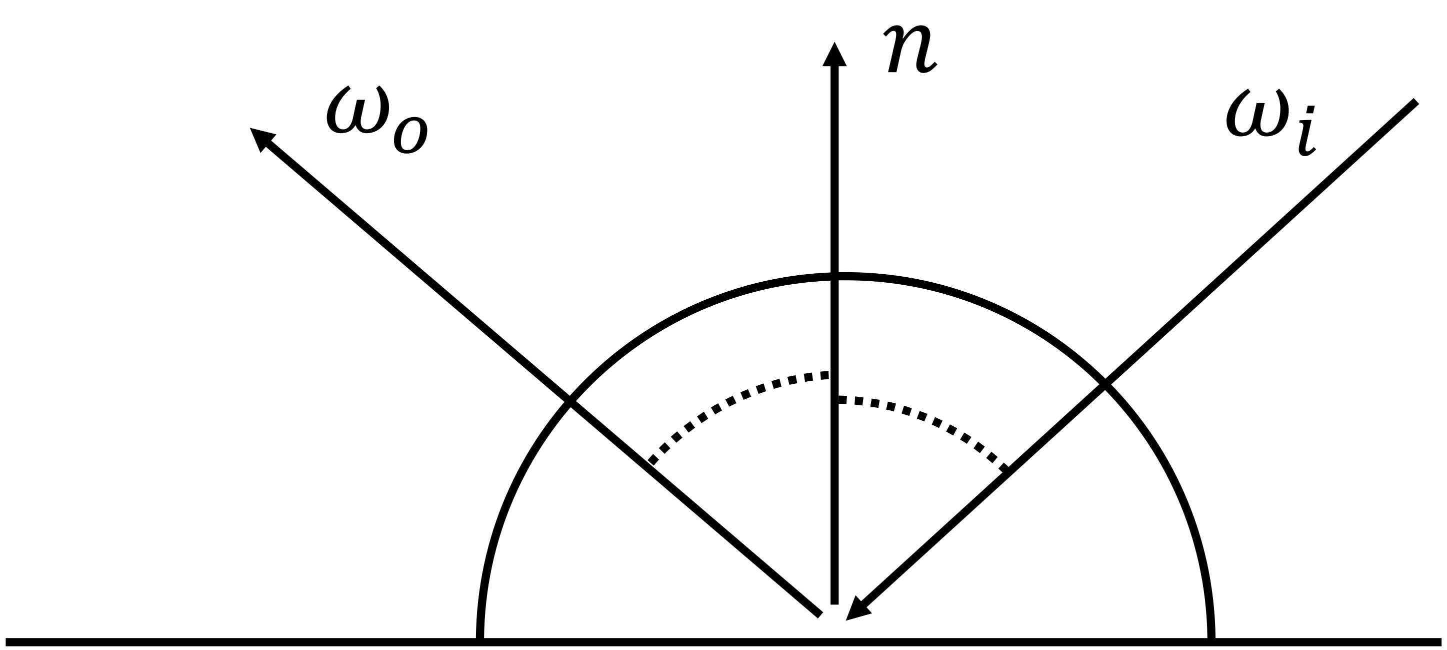


Specular Reflection



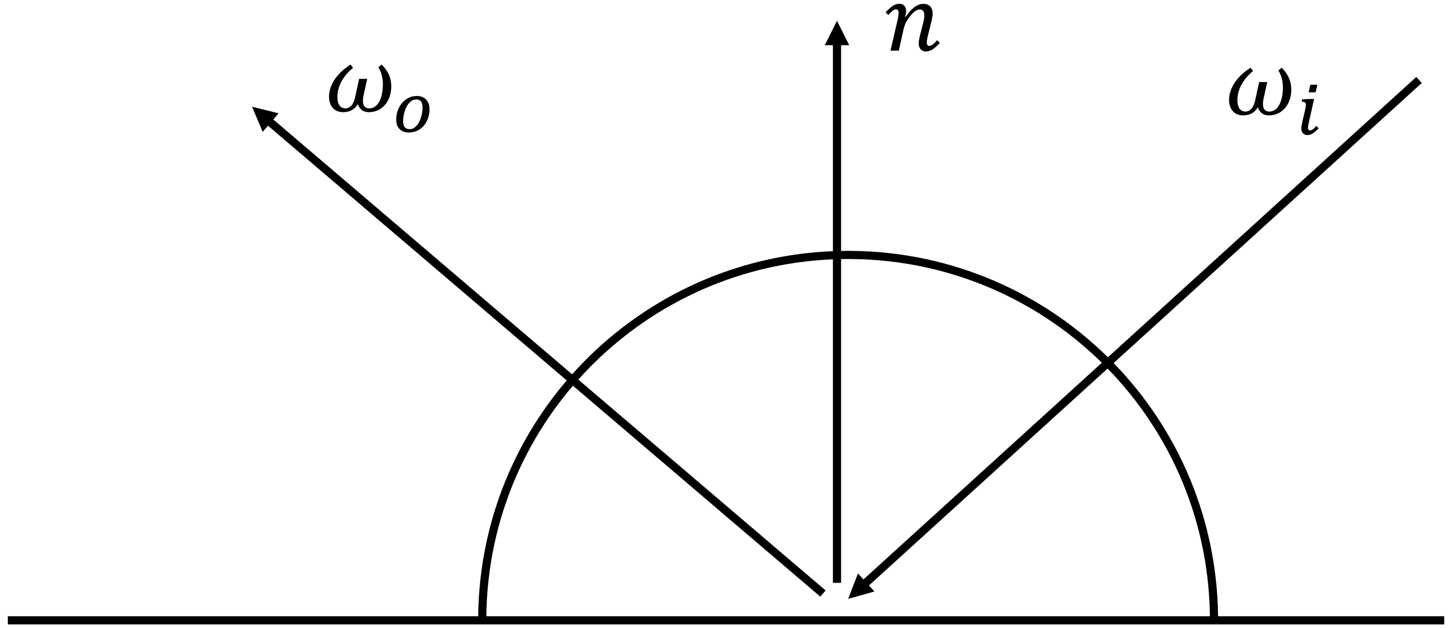
Specular Reflection

$$\omega_o = 2\mathrm{n}\,(\mathrm{n}, \omega_i) - \omega_i$$



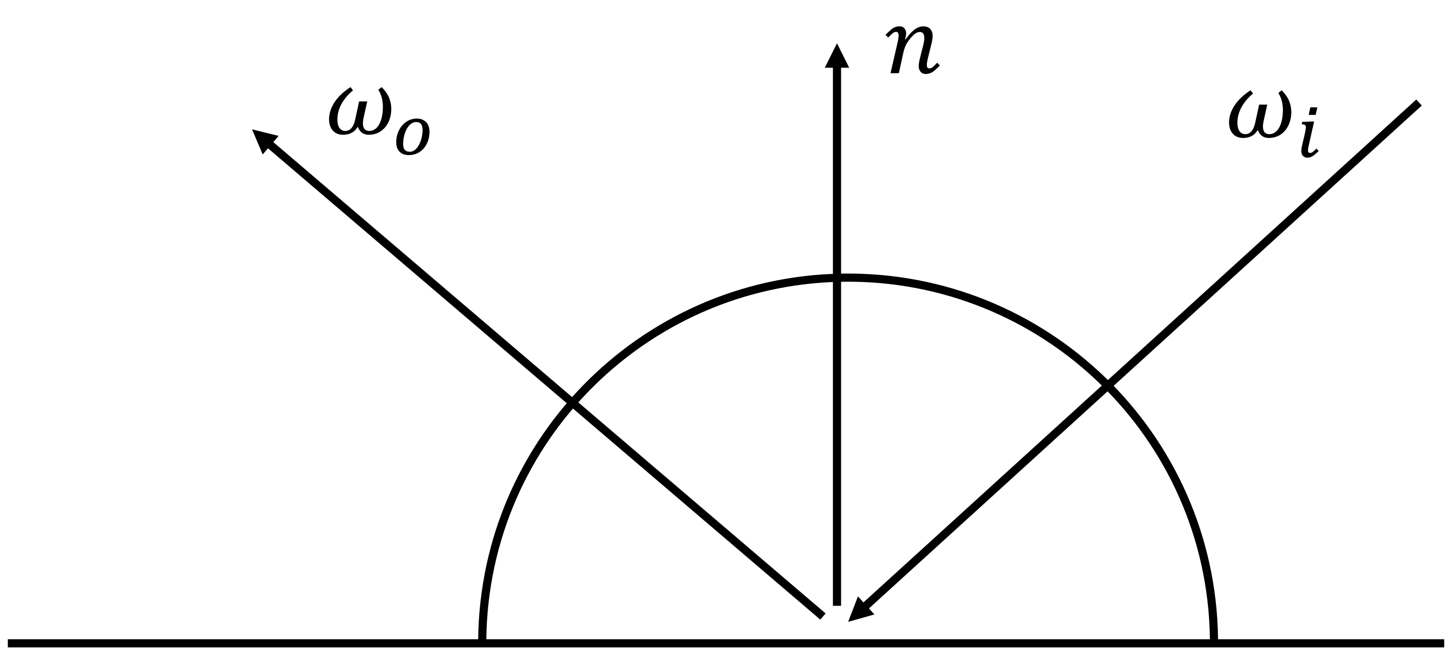
Generic Material

$$L_o = \frac{a}{\pi} E = \frac{a}{\pi} \int_{H^2} L_i(\omega)\,(\omega \cdot n) d\omega$$



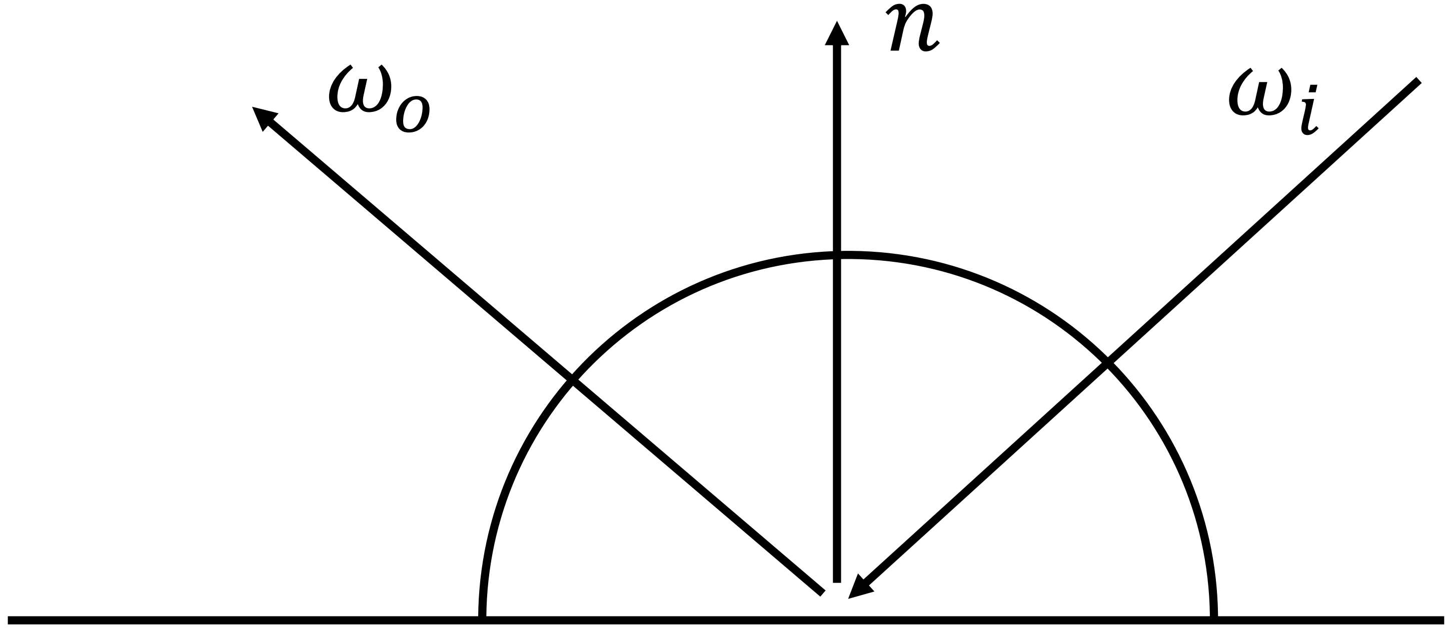
Generic Material

$$L_o(\omega_o) = \frac{a}{\pi}\int_{H^2} L_i(\omega)\,(\omega \cdot n)d\omega$$



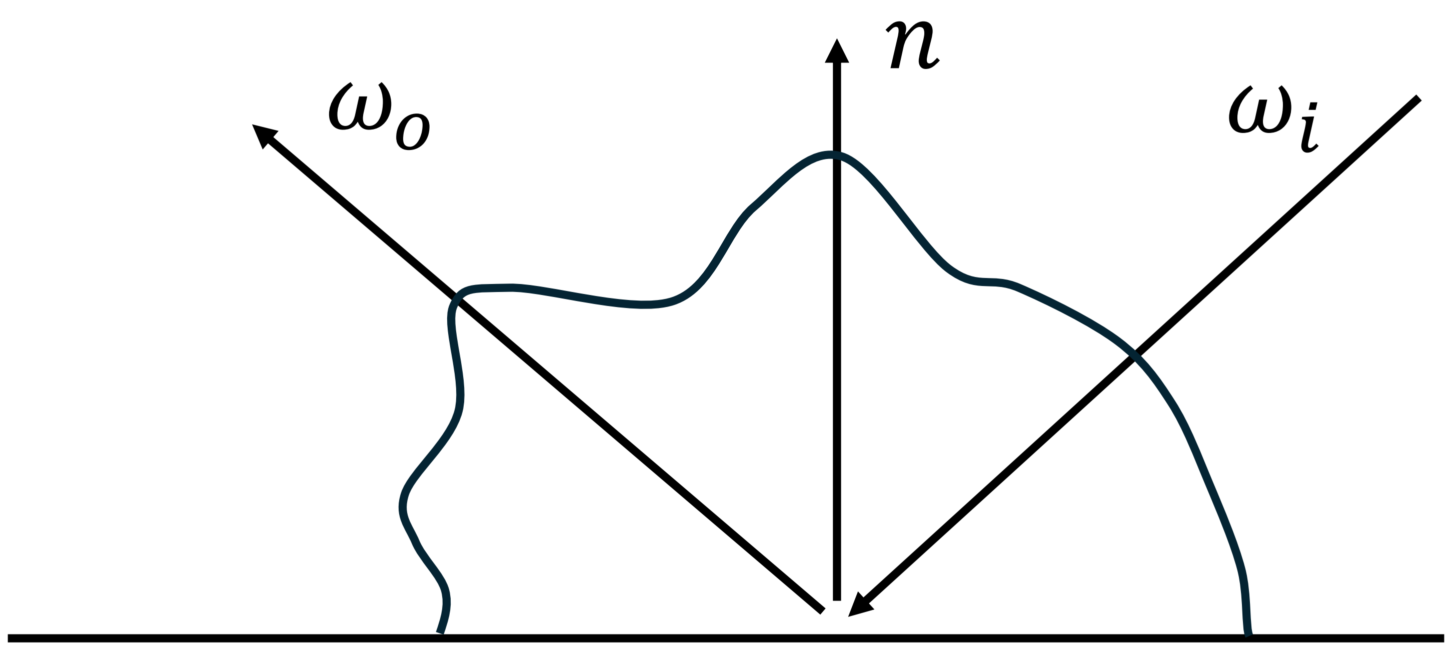
Generic Material

$$L_o(\omega_o) = \int_{H^2} \frac{a}{\pi} L_i(\omega)\,(\omega \cdot n) d\omega$$



Generic Material

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

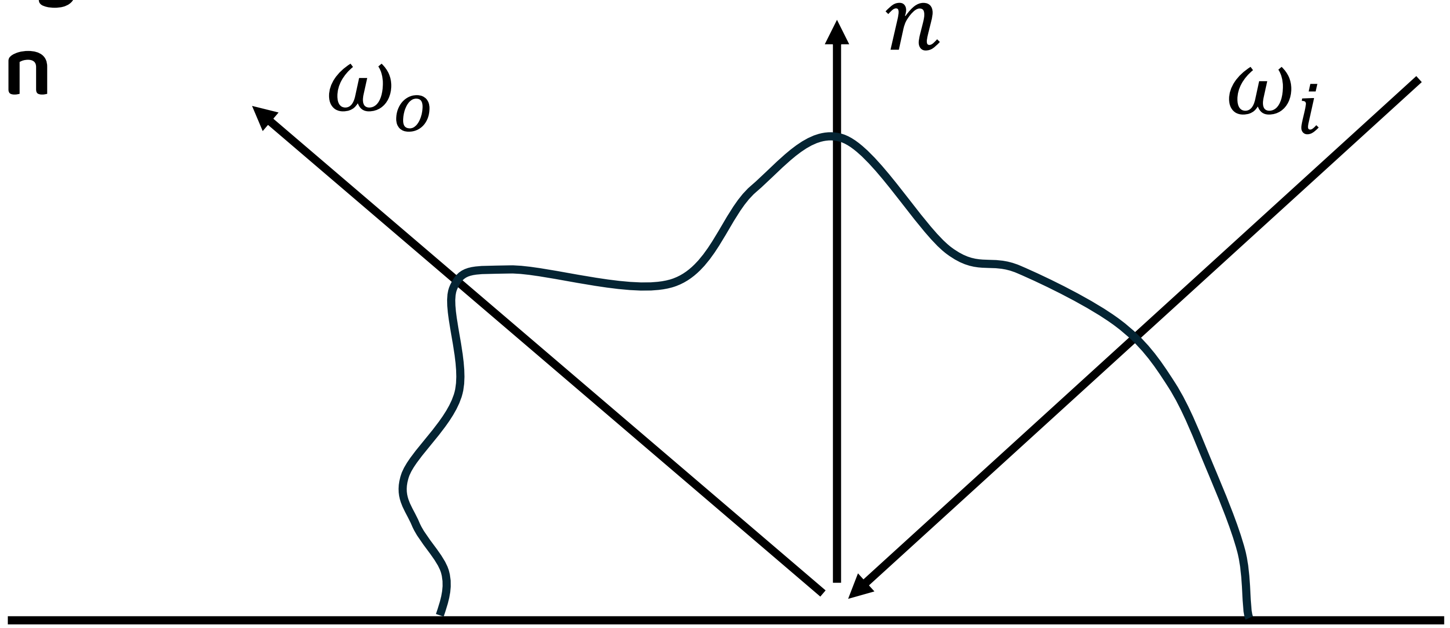


BRDF

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

Scattering equation

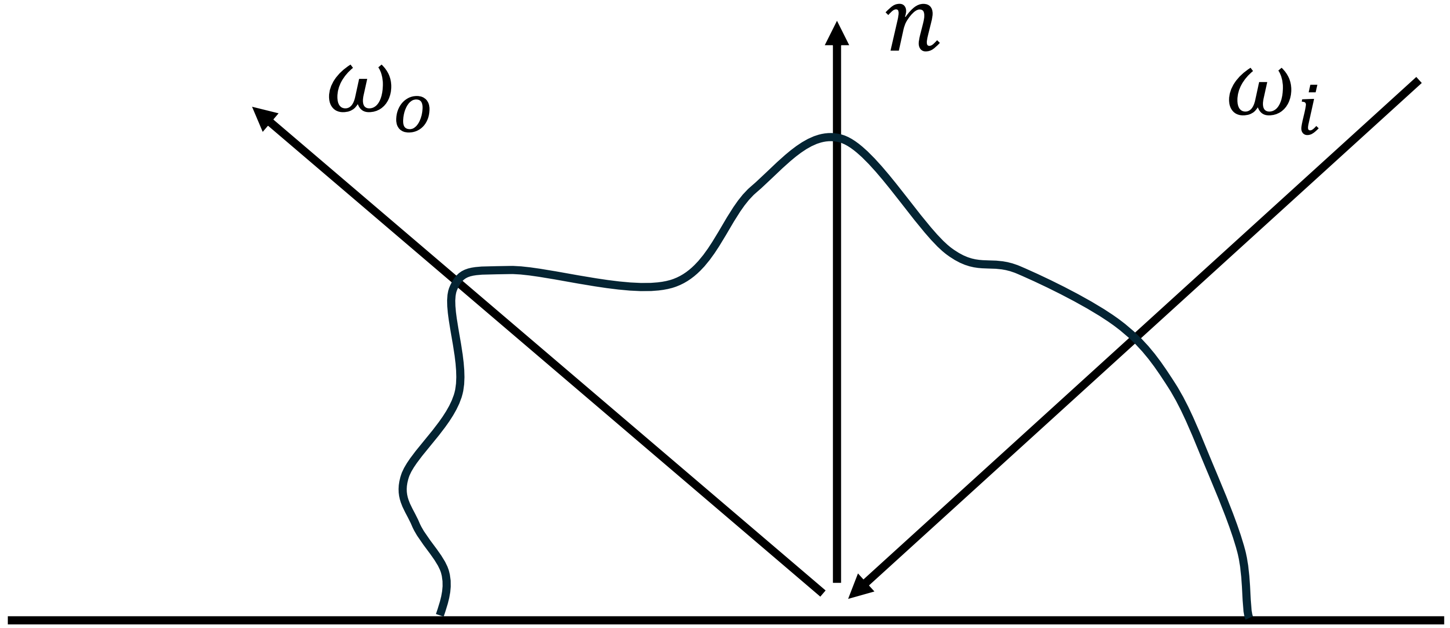
BRDF – bidirectional reflectance distribution function



BRDF

$$f_r(\omega,\omega_o) = \frac{dL_o(\omega_o)}{L_i(\omega)(\omega\cdot n)d\omega} = \frac{dL_o(\omega_o)}{dE(\omega)}$$

BRDF – bidirectional reflectance distribution function



BRDF

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

Properties?

BRDF

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

1. **Non-negative**
2. **Satisfies energy conservation i.e.** $\int_{H^2} f_r(\omega, \omega_o)(\omega \cdot n) d\omega < 1$
3. **Reciprocal** $f_r(\omega, \omega_o) = f_r(\omega_o, \omega)$

BRDF

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

What is BRDF of a Lambertian diffuse surface?

BRDF

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\,(\omega \cdot n)\,d\omega$$

BRDF – bidirectional reflectance distribution function

$$f_r^{Lamb}(\omega, \omega_o) = \frac{a}{\pi}$$

BRDF: perfectly specular surface

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

What is BRDF of a perfectly specular surface?

BRDF: perfectly specular surface

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

$$L_o(\omega_o) = \begin{cases} 0, & \omega_o \neq 2\mathrm{n}\ (\mathrm{n}, \omega_i) - \omega_i \\ R L_i(\omega_i), & \omega_o = 2\mathrm{n}\ (\mathrm{n}, \omega_i) - \omega_i \end{cases}$$

Specular reflectance

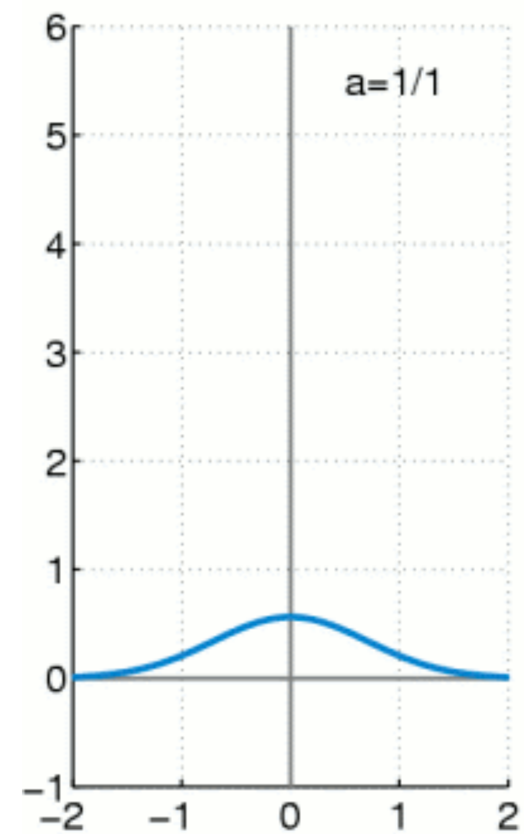
BRDF: perfectly specular surface

$$L_o(\omega_o) = \int_{H^2} f_r(\omega, \omega_o) L_i(\omega)\ (\omega \cdot n) d\omega$$

BRDF – bidirectional reflectance distribution function

$$L_o(\omega_o) = \begin{cases} 0, & \omega_o \neq 2\mathrm{n}\ (\mathrm{n}, \omega_i) - \omega_i \\ R L_i(\omega_i), & \omega_o = 2\mathrm{n}\ (\mathrm{n}, \omega_i) - \omega_i \end{cases}$$

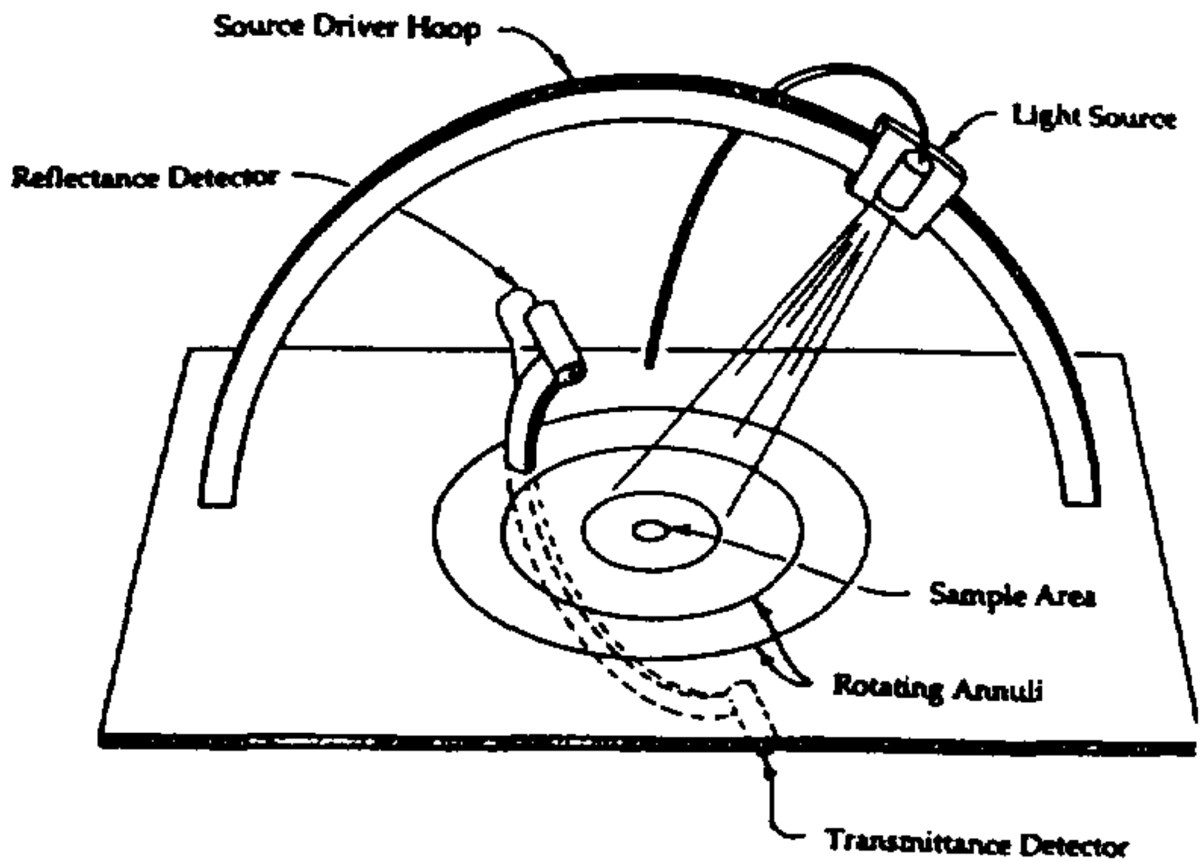
$$f_r^{Spec}(\omega_i, \omega_o) = \delta(2\mathrm{n}\ (\mathrm{n}, \omega_i) - \omega_i)$$



https://en.wikipedia.org/wiki/Dirac_delta_function

BRDFs: Where do they come from?

They can be measured!



Source: Gregory Ward

BRDFs: Where do they come from?

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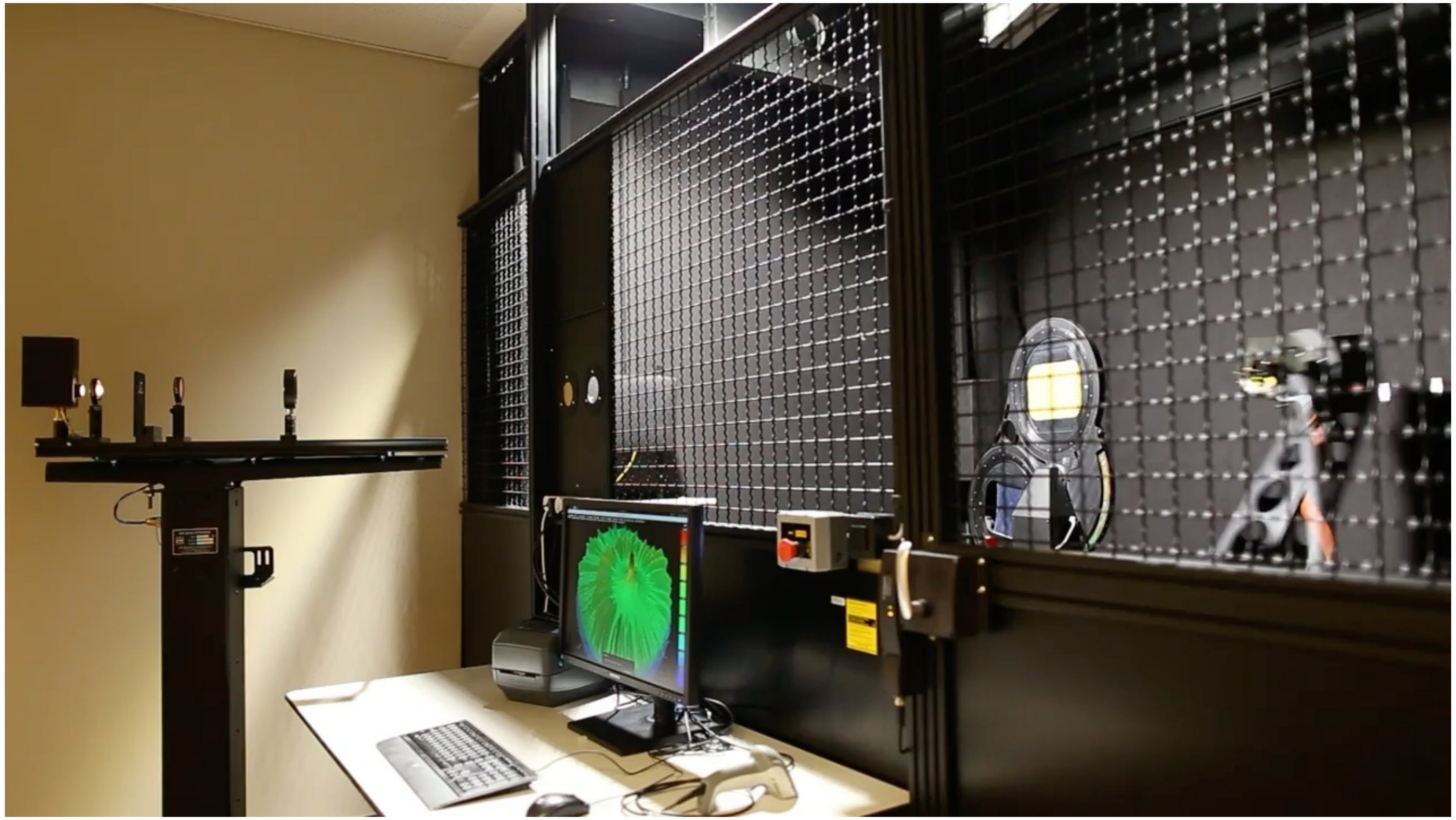

https://rgl.epfl.ch/pages/lab/pgII

BRDFs: Where do they come from?

… or one could simulate all micro interactions

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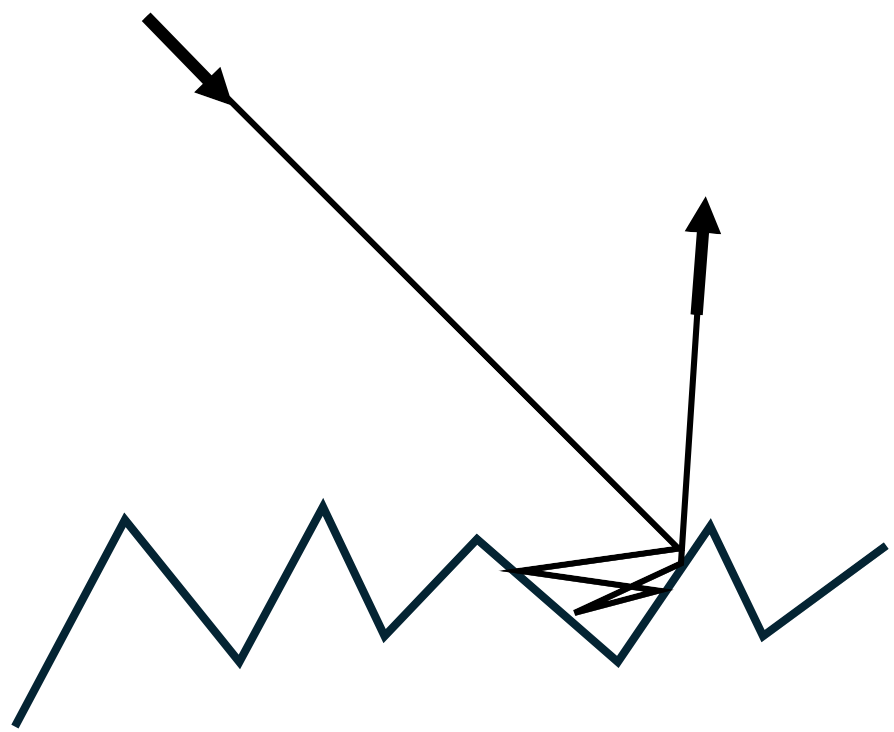
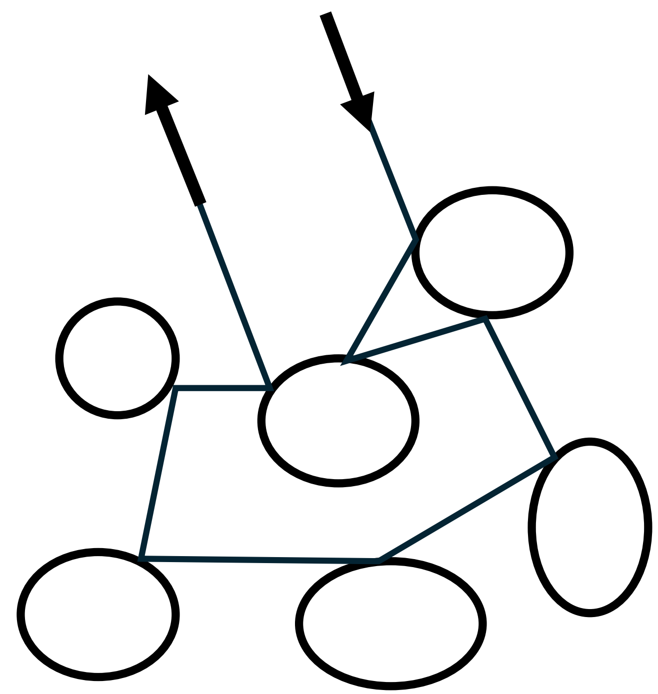




BRDFs: Where do they come from?

… or we could use an analytical function

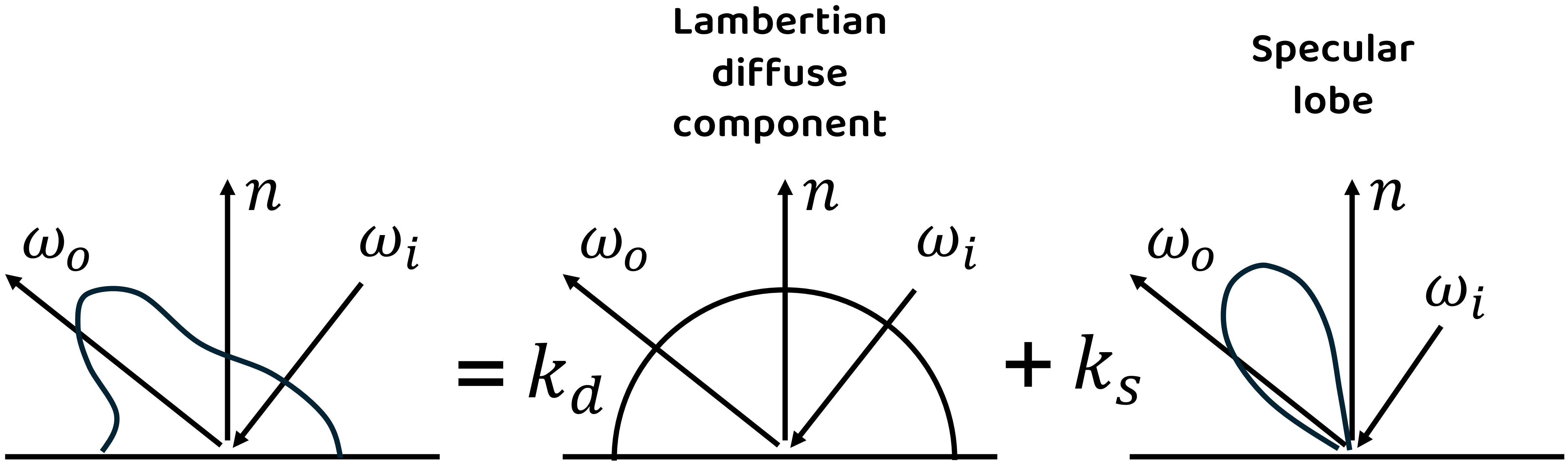
BRDFs: Where do they come from?

... or we could use an analytical function:

- physically based
- non-physically based

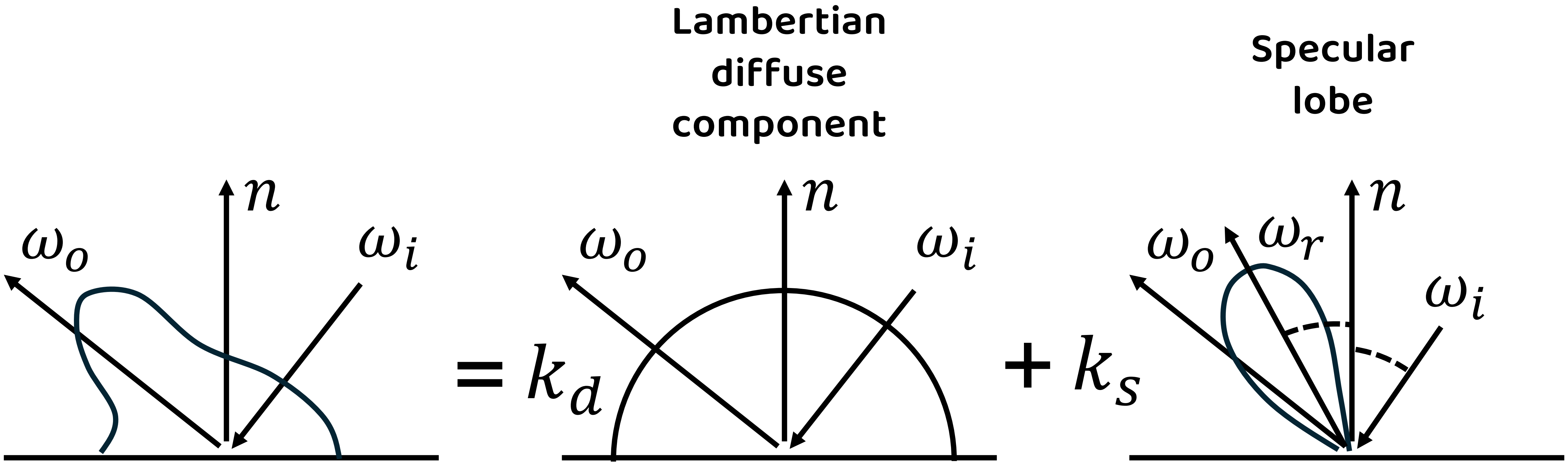
Modified Phong BRDF

… or we could use an analytical function



Modified Phong BRDF

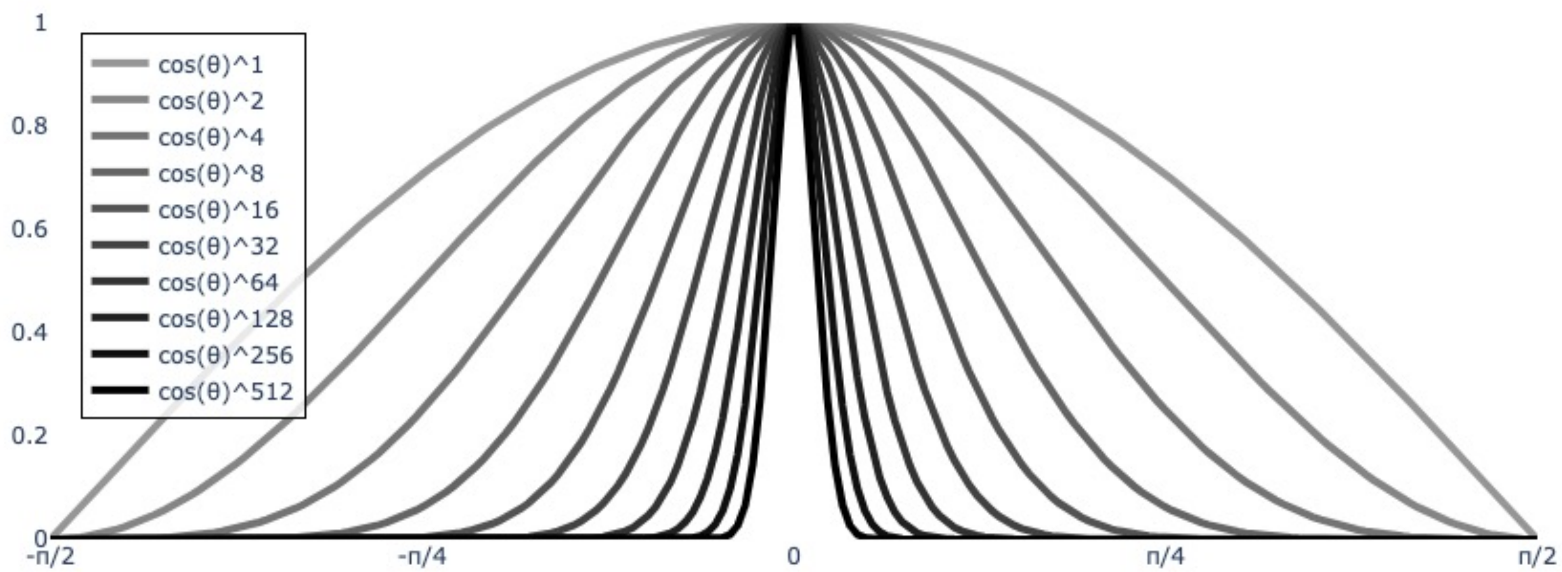
... or we could use an analytical function



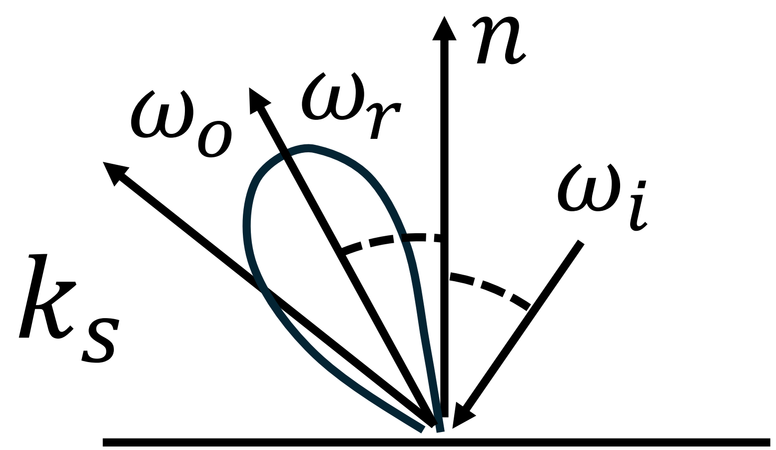
$$f_r^{Phong}(\omega_i, \omega_o) = \frac{k_d}{\pi} + k_s \frac{(\alpha + 1)(\omega_o, \omega_r)^{\alpha}}{2\pi}$$

Modified Phong BRDF

… or we could use an analytical function



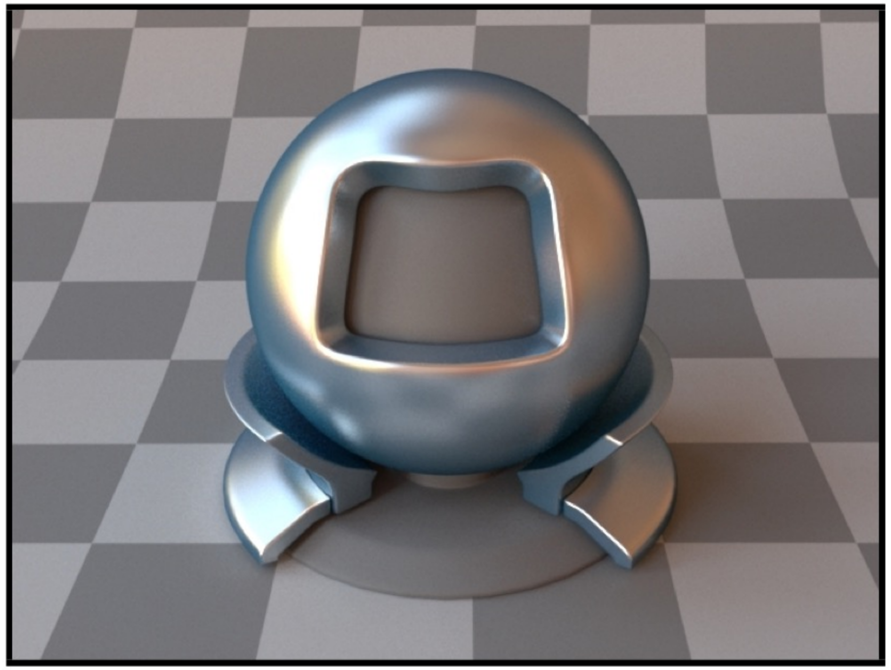
Specular lobe



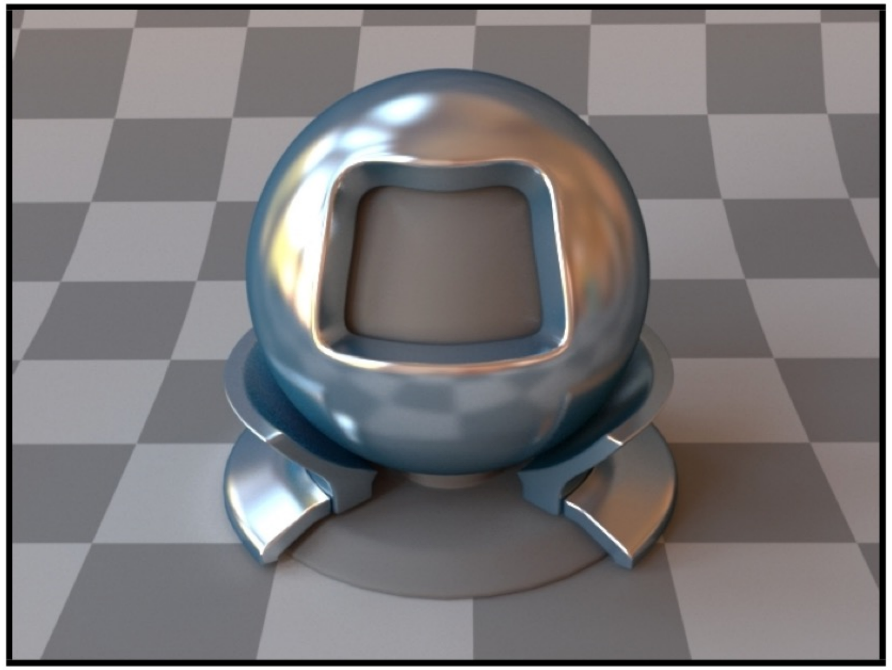
$$k_s \frac{(\alpha + 1)(\omega_o, \omega_r)^{\alpha}}{2\,\pi}$$

Modified Phong BRDF

... or we could use an analytical function



(a) Exponent = 60

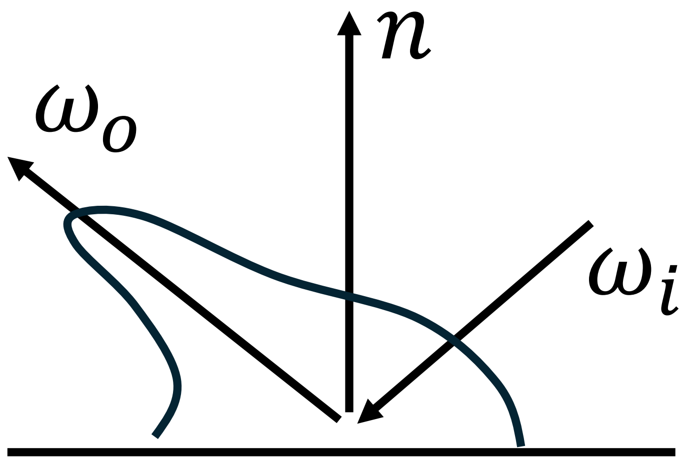


(b) Exponent = 300

Source: Mitsuba 0.6

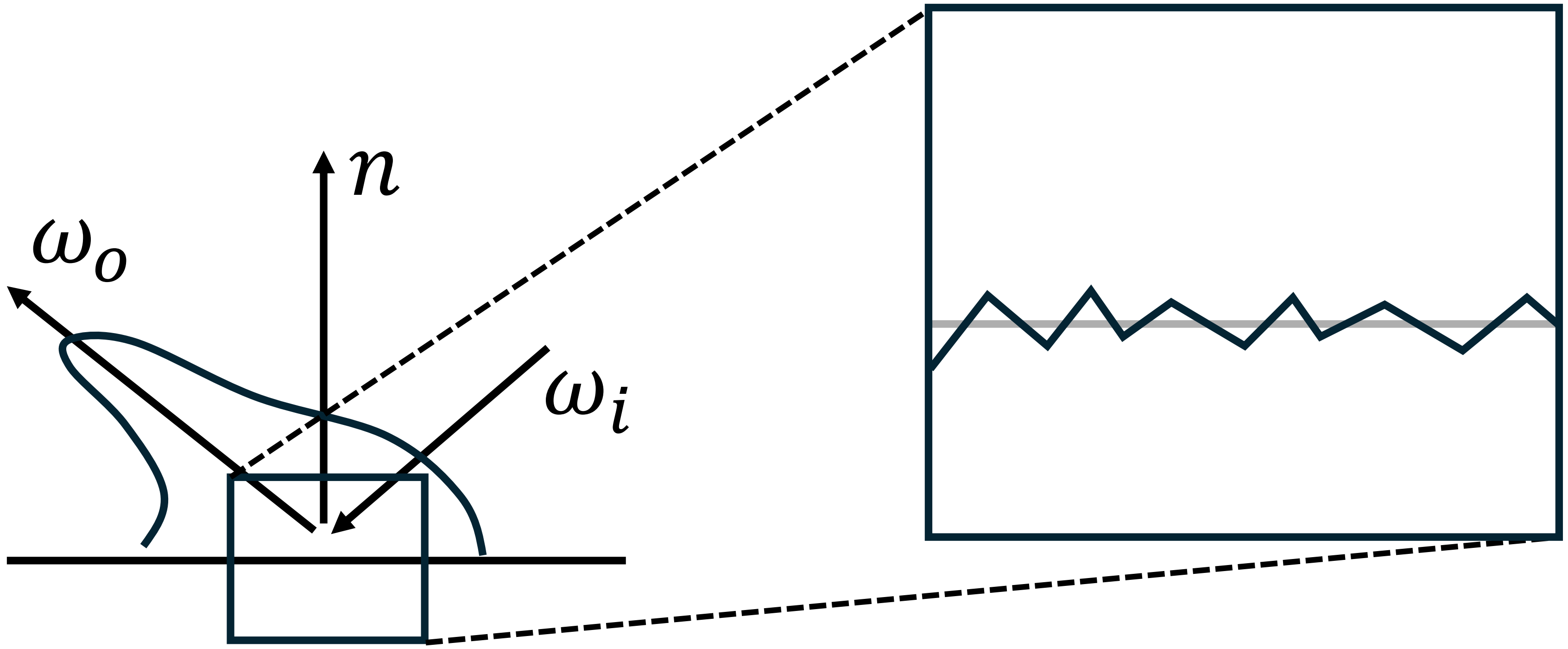
Microfacet BRDF

Parametrized by α_u, α_v -- roughness parameters

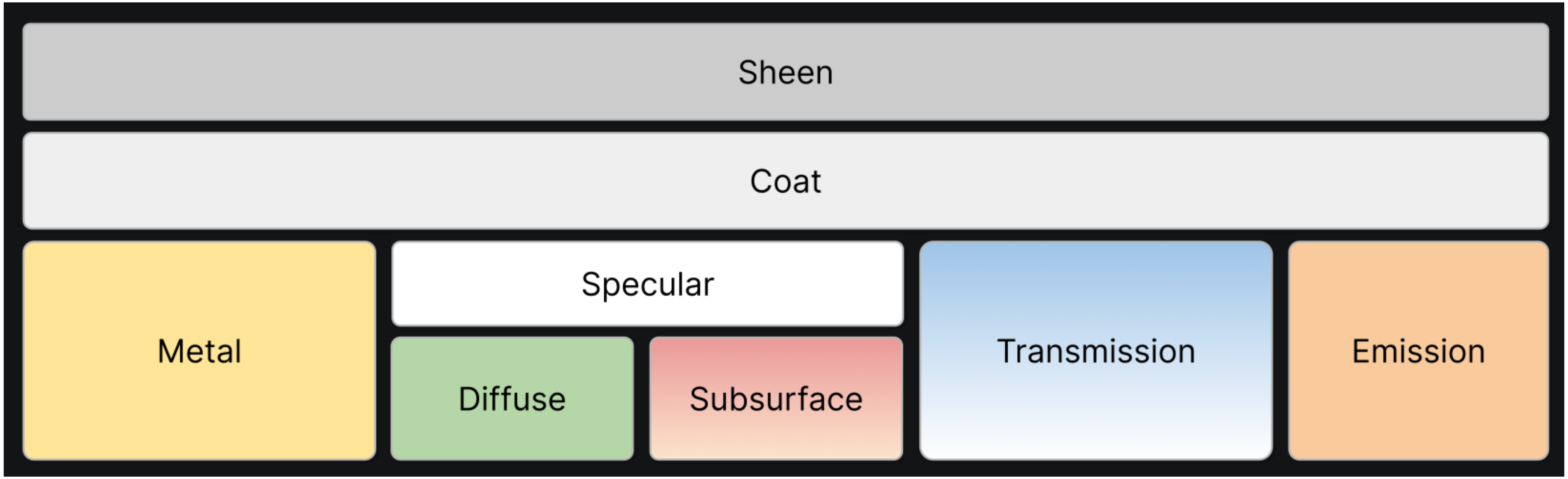


Microfacet BRDF

Parametrized by α_u, α_v -- roughness parameters

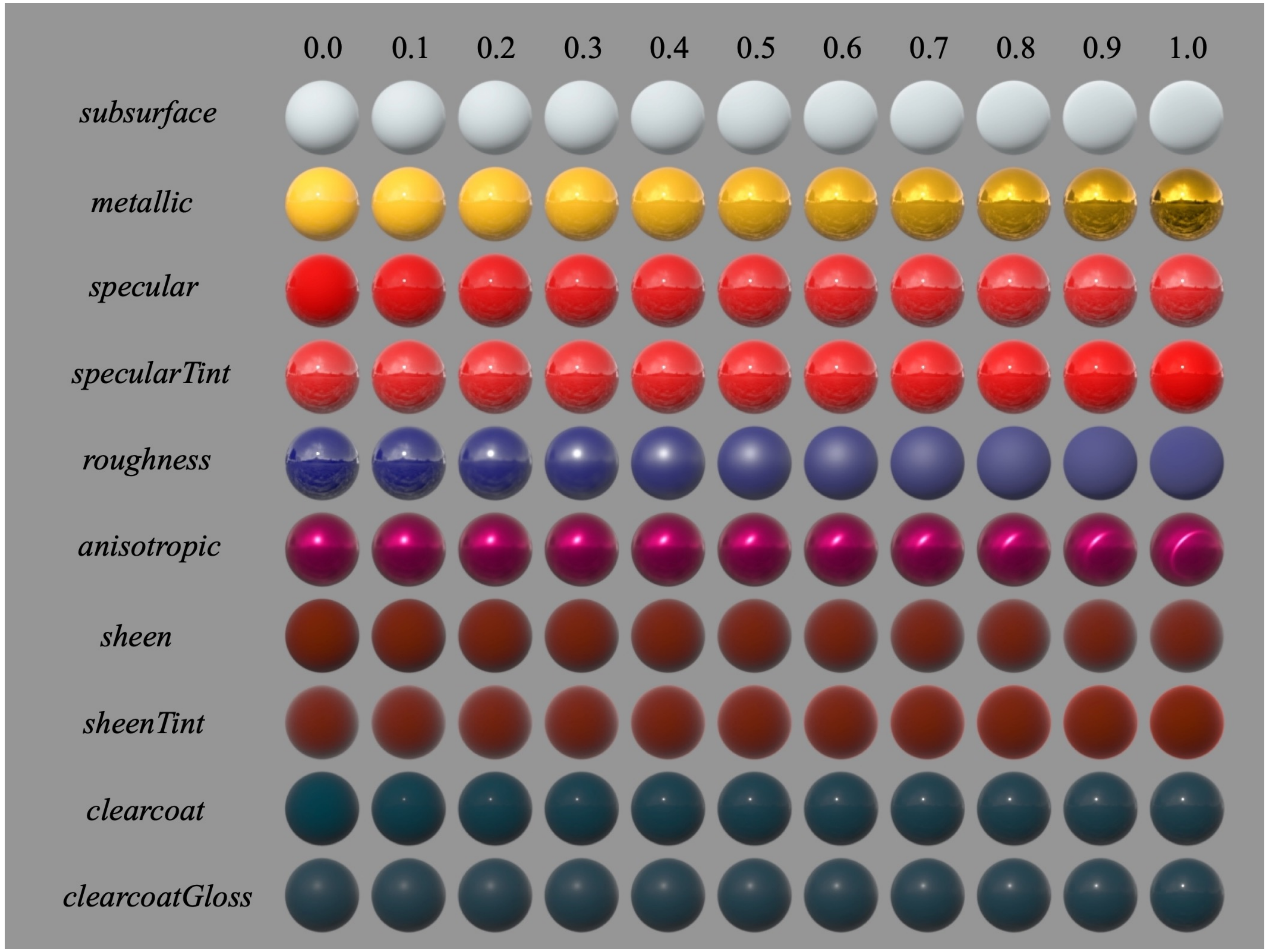


Disney BRDF



Source:Blender

Disney BRDF



Source: Brent Burley

BRDFs: Where do they come from?

… or one could fit an analytical function to measured data

… or one could use NNs to compress the measured data

BRDFs: Technical detail

We define BRDFs in the canonical coordinate system, i.e., $\boldsymbol{n} = (0,0,1)^T$, $\boldsymbol{s} = (1,0,0)^T$ and t= $(0,1,0)^T$, but in a renderer, we encounter surfaces with different orientations. It is important to convert all ray directions to the canonical frame before querying the BRDF value. Incorrect coordinate frames are the cause of many bugs.