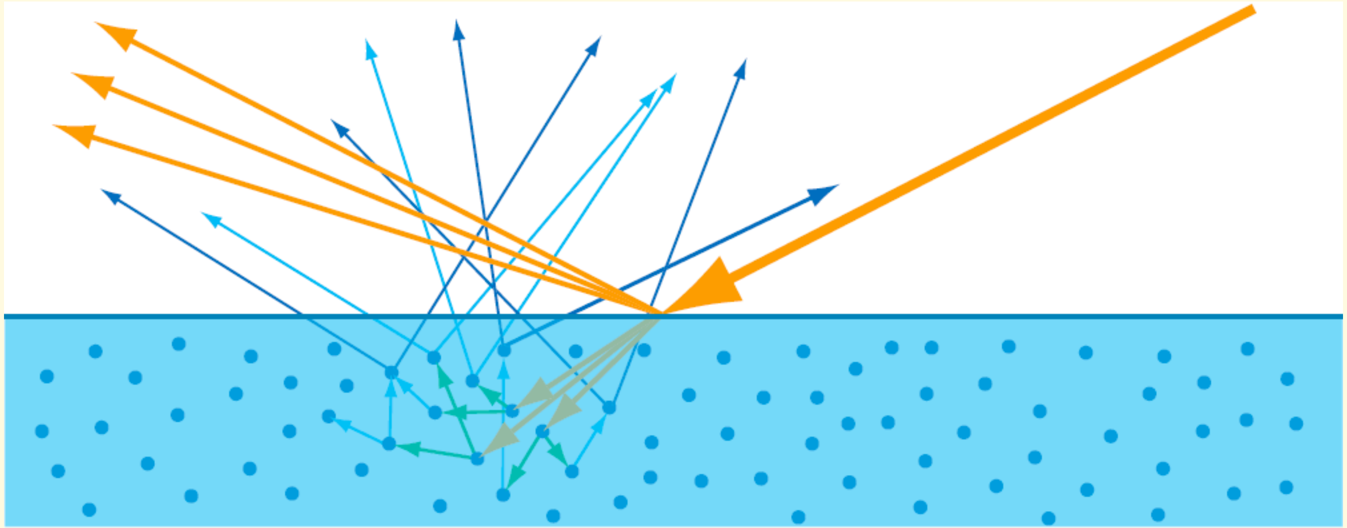
Game Engines

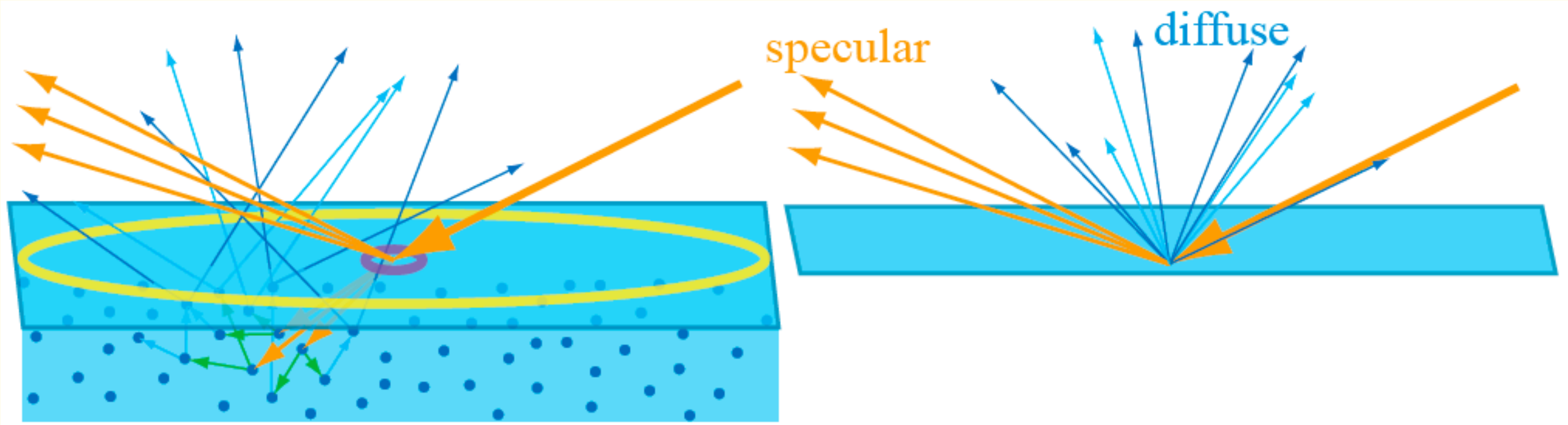
CMPM 164, F2019

Prof. Angus Forbes (instructor)
angus@ucsc.edu

Montana Fowler (TA)
mocfowle@ucsc.edu

Website: creativecoding.soe.ucsc.edu/courses/cmpm164
Slack: https://ucsccmpm164.slack.com

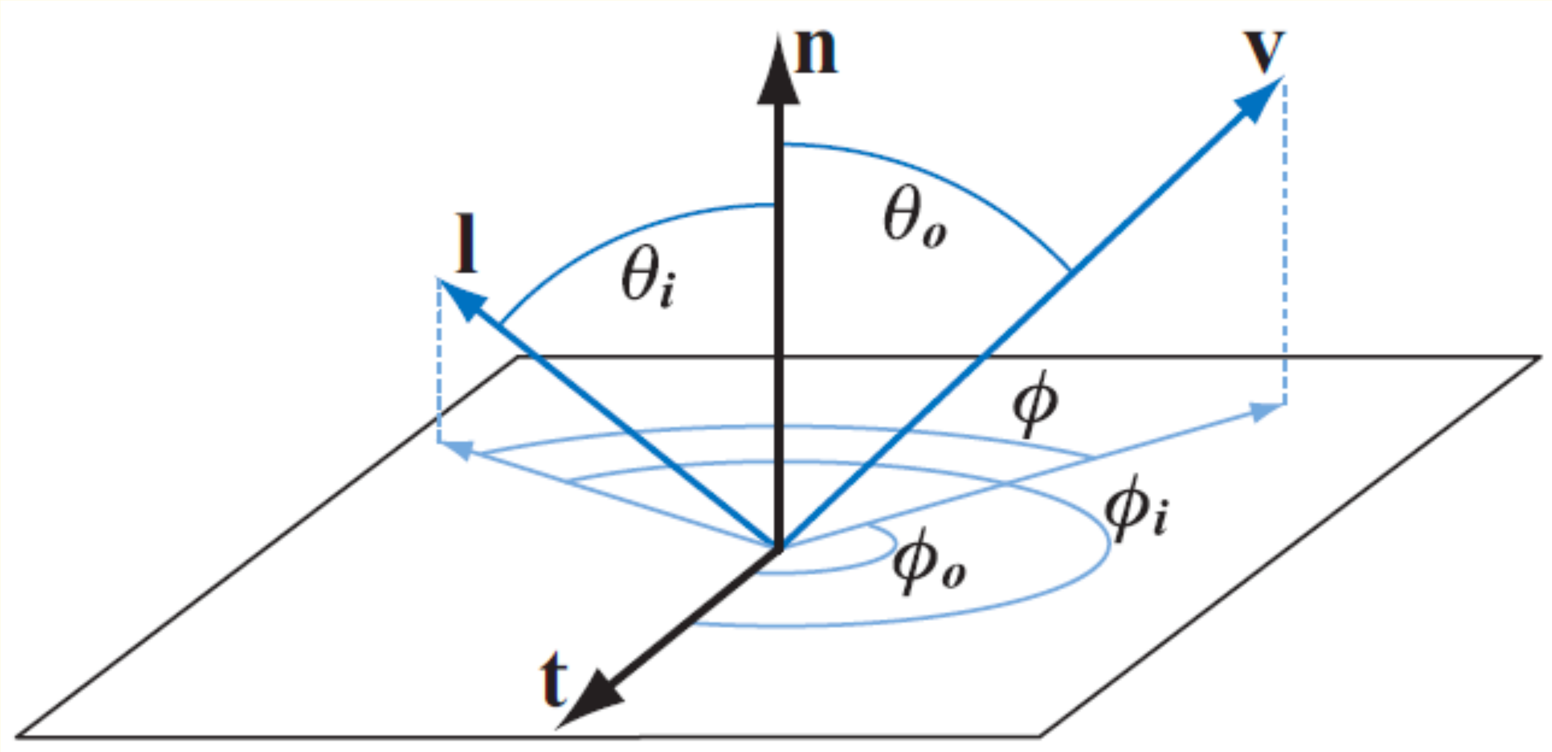



specular
diffuse

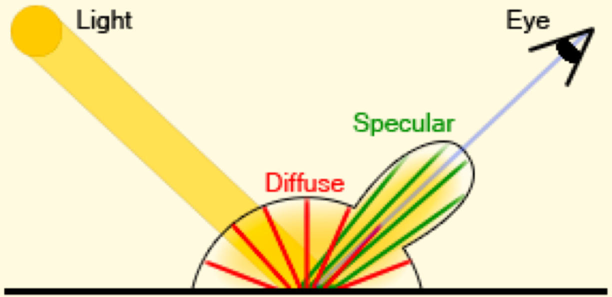
Bidirectional Reflectance Distribution Function (BRDF)

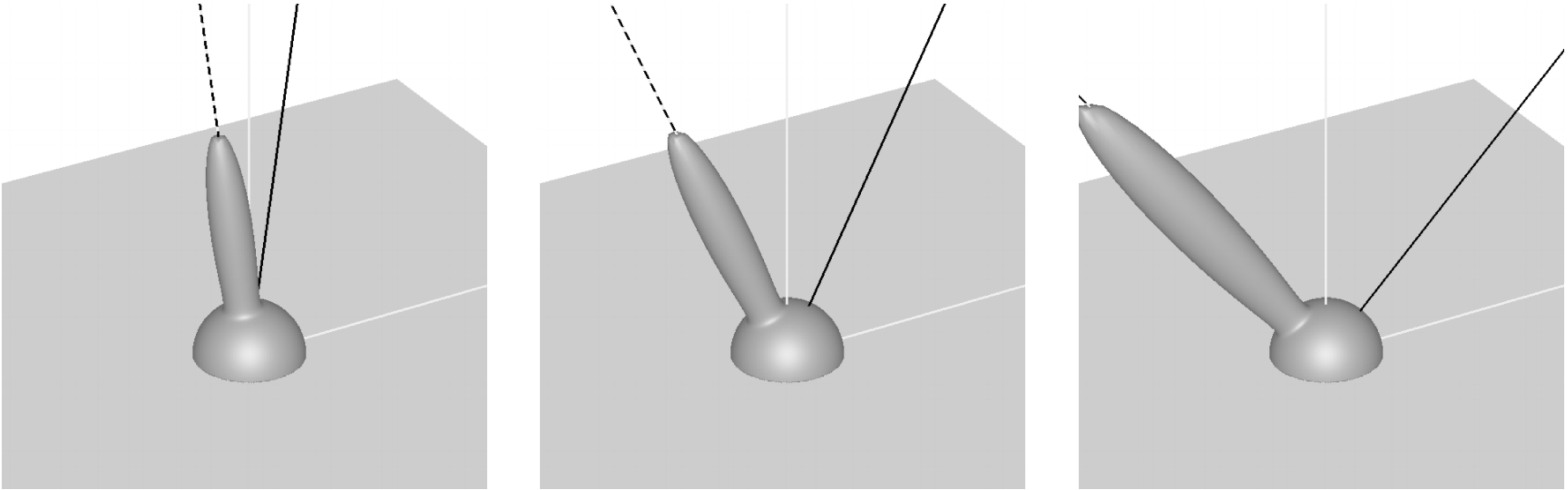
$L_{out}(v) = f(l,v) * L_{in}(l) * (n \cdot l)$

The outgoing radiance (L_{out}) is the sum of the incoming radiance (L_{in}) from each light visible to the point on the surface, multiplied by the "directness" of the light (calculated by the dot product between the light ray and the surface normal, as in Phong shading), multiplied by the output of a **BRDF** that models the *material* of the surface.

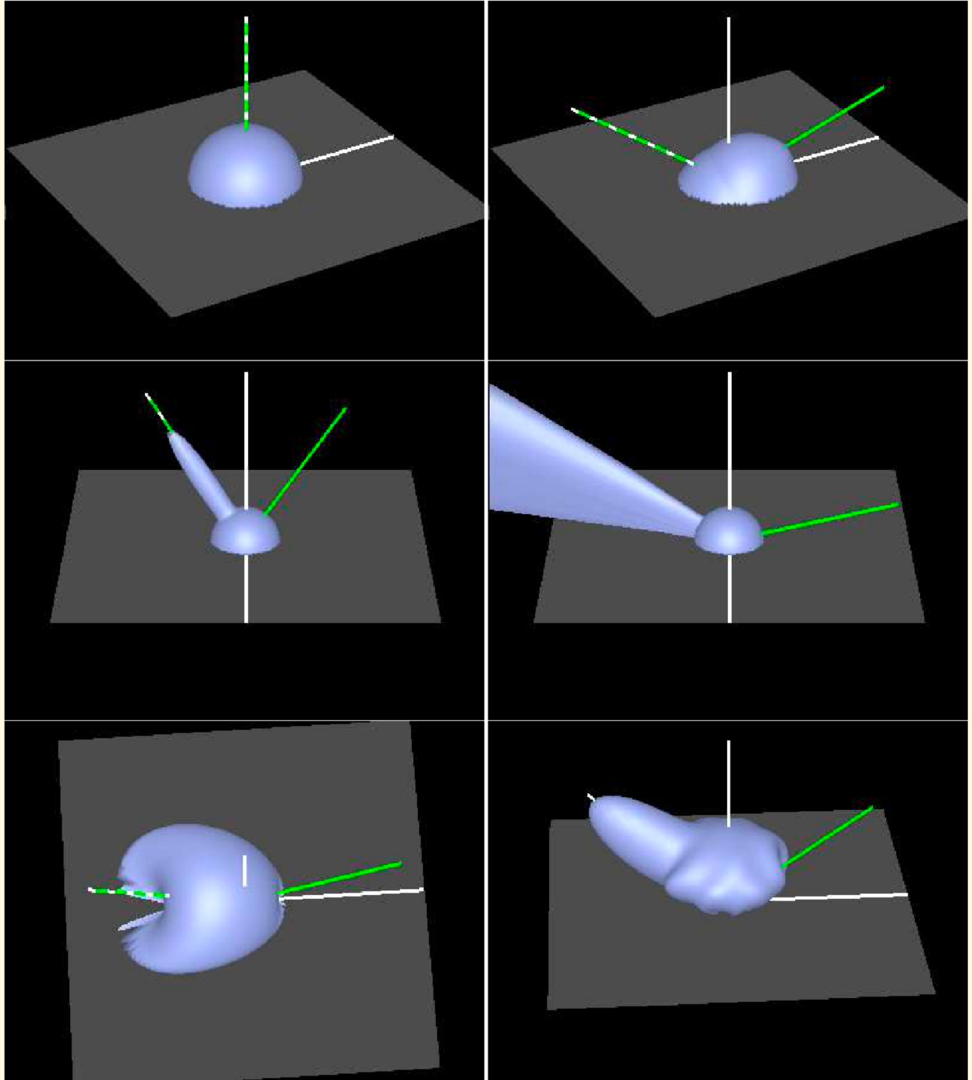


n
v
l
θ_i
θ_o
ϕ
ϕ_i
ϕ_o
t

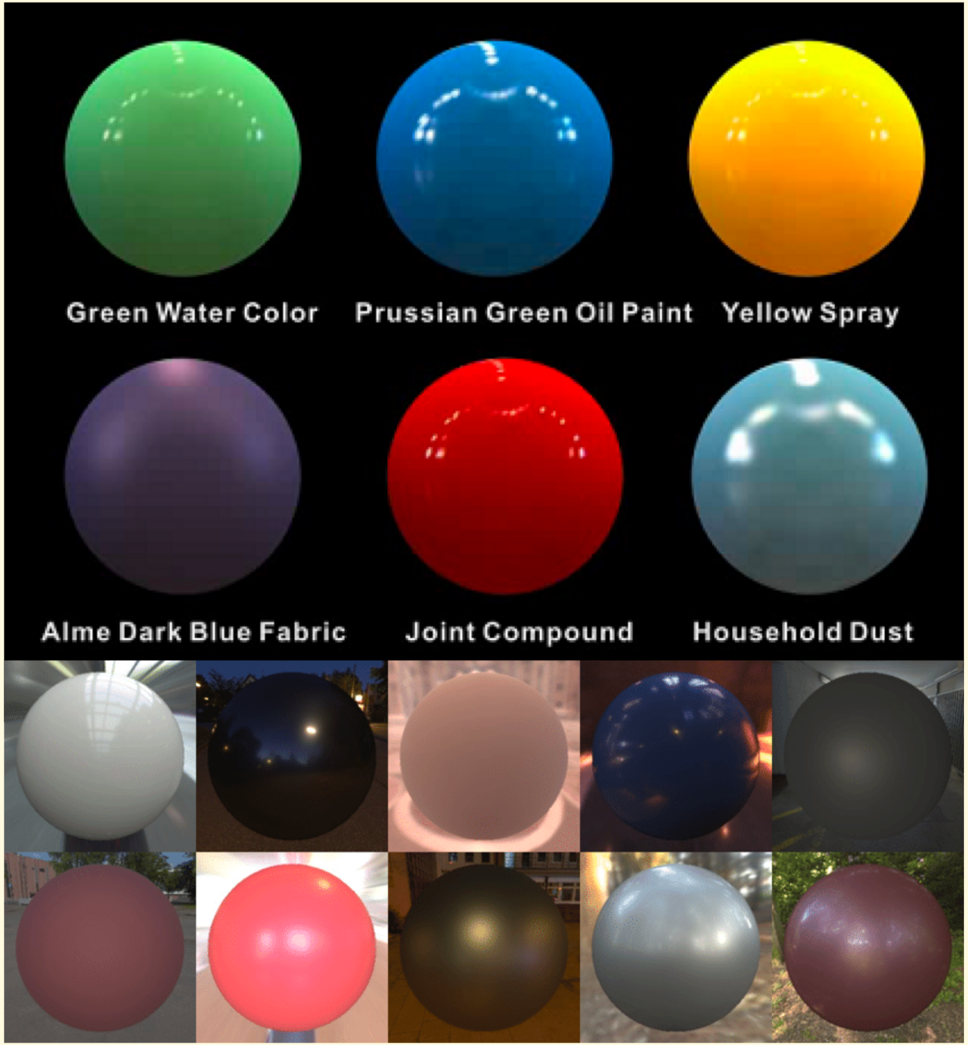


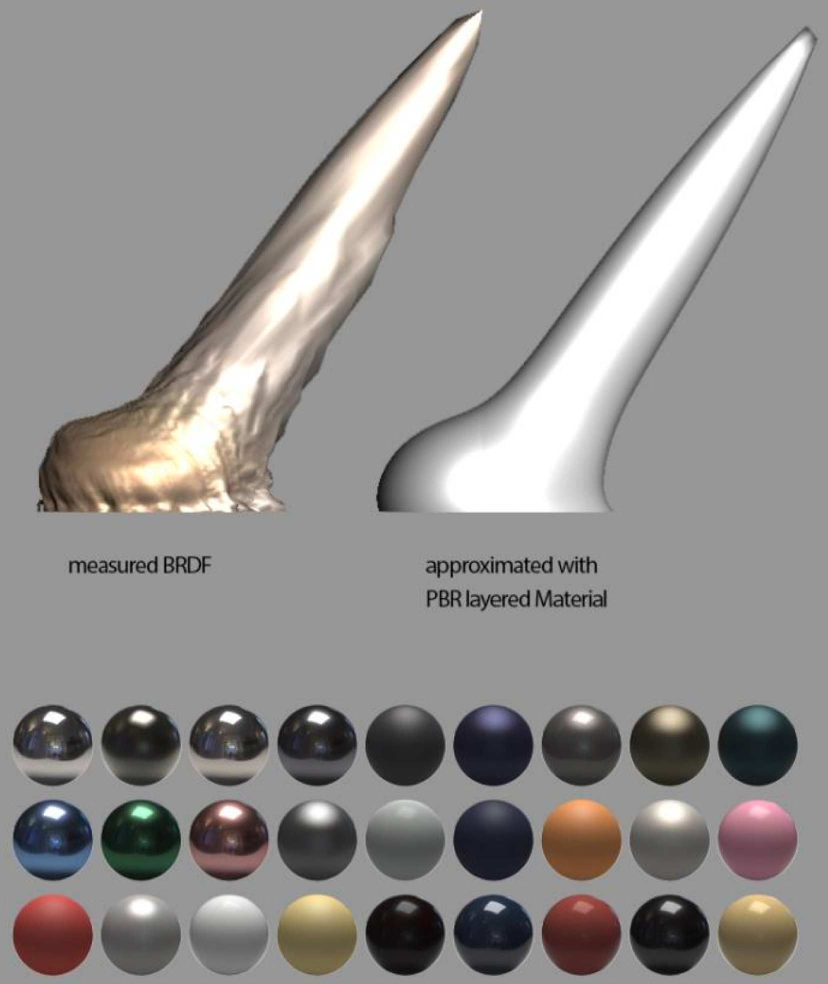


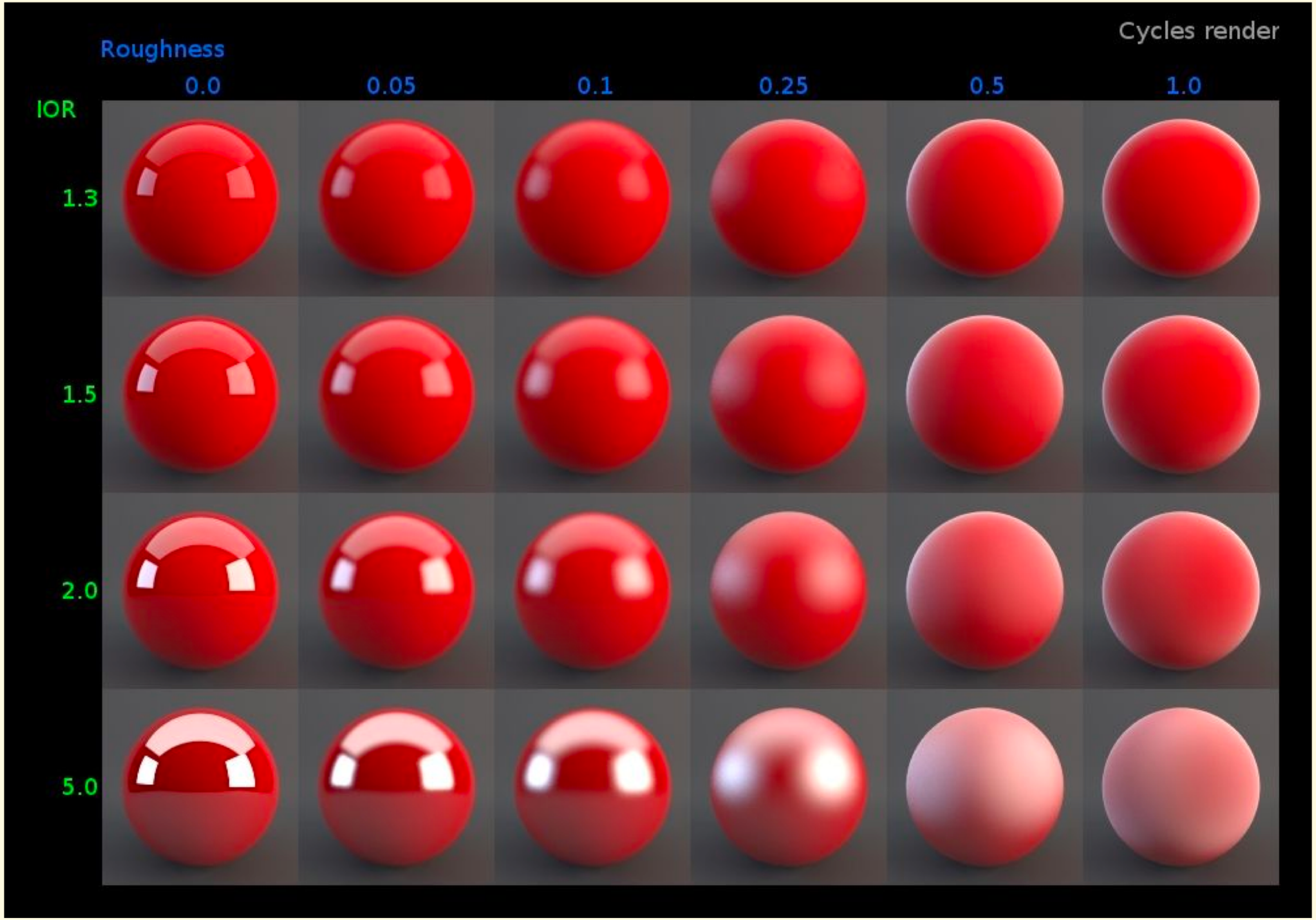
$\theta_i = 10^\circ$ $\theta_i = 20^\circ$ $\theta_i = 40^\circ$




SOC-210BDR
POWER DISTRIBUTION



Green Water Color
Prussian Green Oil Paint
Yellow Spray
Alme Dark Blue Fabric
Joint Compound
Household Dust


measured BRDF
approximated with
PBR layered Material


Cycles render
Roughness
0.0
0.05
0.1
0.25
0.5
1.0
IOR
1.3
1.5
2.0
5.0

GOLD

MATERIAL STUDY: STUDIO

	GOLD	GOLD PAINT	GOLD PAINT CRACKED	GOLD ROUGH	GOLD FOIL ROUGH
DIFFUSE COLOR:	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0	0 / 0 / 0
DIFFUSE AMOUNT:	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
SPEC COLOR:	255 / 213 / 128	226 / 193 / 112	165 / 165 / 165	146 / 124 / 72	255 / 213 / 128
SPEC AMOUNT:	100% (1.0)	100% (1.0)	100% (1.0)	100% (1.0)	100% (1.0)
ROUGHNESS:	35 / 35 / 35	57 / 57 / 57	70 / 70 / 70	100 / 100 / 100	65 / 65 / 65
FRESNEL:	Yes	Yes	Yes	Yes	Yes
IOR:	0.47	0.47	0.47	0.47	0.47

BRDF

The BRDF models “local reflectance” around a particular point on a surface, dependent only on the incoming light direction (L) and the view direction (L).

The BRDF approximates how much each individual light ray L contributes to the final reflected light of an opaque surface given its material properties.

“Bidirectional” because of the equivalence between l and v. if you swapped the rays, the local reflectance would be the same. For a BRDF to be physically plausible it has to respect the law of energy conservation i.e. the sum of reflected light should never exceed the amount of incoming light.

BRDF

For a BRDF to be physically plausible it has to respect the law of energy conservation i.e. the sum of reflected light should never exceed the amount of incoming light.

Phong is sometimes considered a BRDF (and takes the same L and V as inputs). However, Blinn-Phong is not considered *physically based* because it doesn't adhere to the energy conservation principle.

Game engines most often use the Cook-Torrance BRDF (1982), which models "mircofacets" in the material.

Cook-Torrance BRDF

"The model accounts for the relative brightness of different materials and light sources in the same scene. It describes the directional distribution of the reflected light and a color shift that occurs as the reflectance changes with incidence angle. A method for obtaining the spectral energy distribution of the light reflected from an object made of a specific real material is presented, and a procedure for accurately reproducing the color associated with the spectral energy distribution is discussed."

Cook-Torrance BRDF

"This paper presents a reflectance model for rough surfaces that is more general than previous models. It is based on geometrical optics and is applicable to a broad range of materials, surface conditions, and lighting situations."

Fig. 7. A variety of vases.

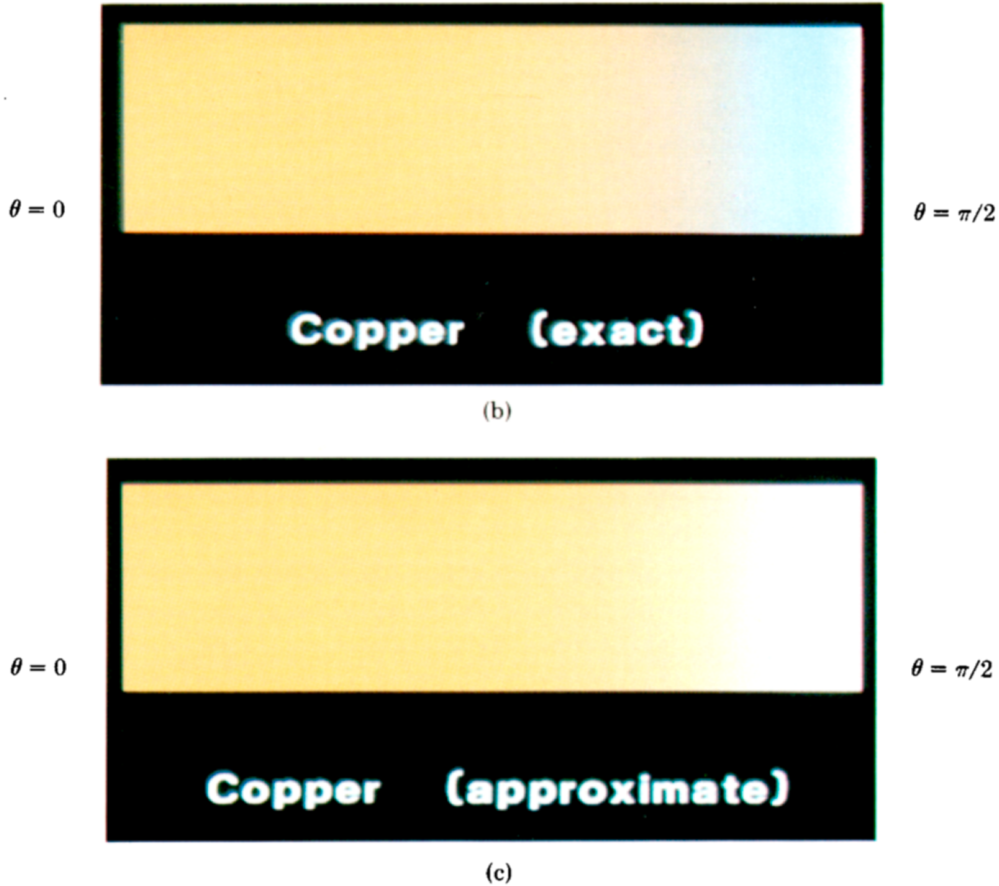


Fig. 5. (a) Reflectance of a copper mirror as a function of wavelength and incidence angle. (b) The color of copper as a function of incidence angle. (c) The color of copper as approximated by the method discussed in this paper.

BRDF

$$k_{\text{spec}} = \frac{DFG}{4(V \cdot N)(N \cdot L)}$$

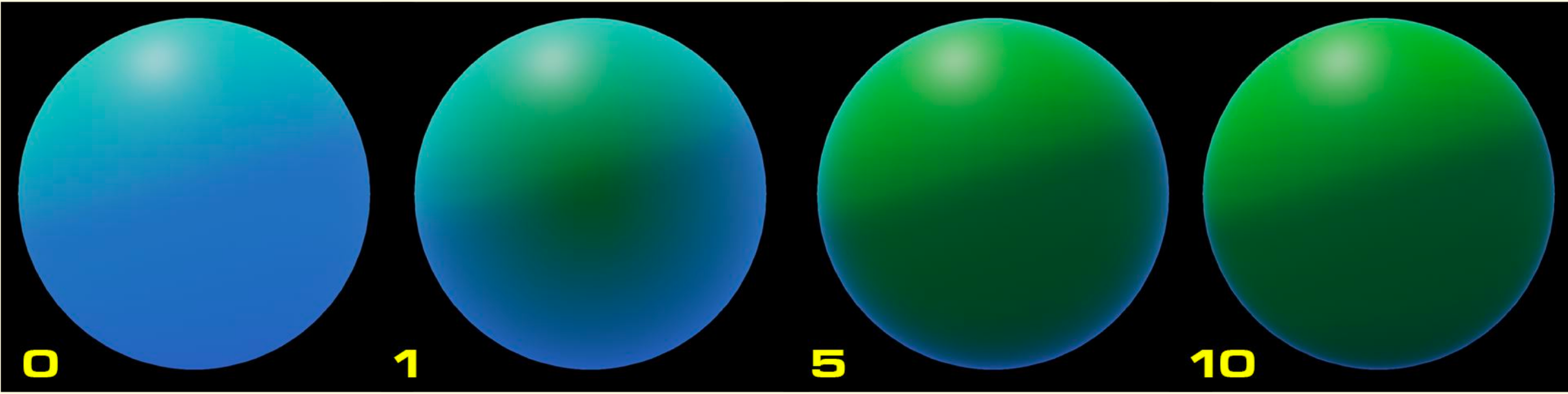
Fresnel equation (F): The Fresnel equation describes the ratio of surface reflection at different surface angles.

Normal distribution function (D): approximates the amount the surface's microfacets are aligned to the halfway vector influenced by the roughness of the surface; this is the primary function approximating the microfacets.

Geometry function (G): describes the self-shadowing property of the microfacets. When a surface is relatively rough the surface's microfacets can overshadow other microfacets thereby reducing the light the surface reflects.

BRDF

Fresnel effect = The increase in reflectance at glancing angles.

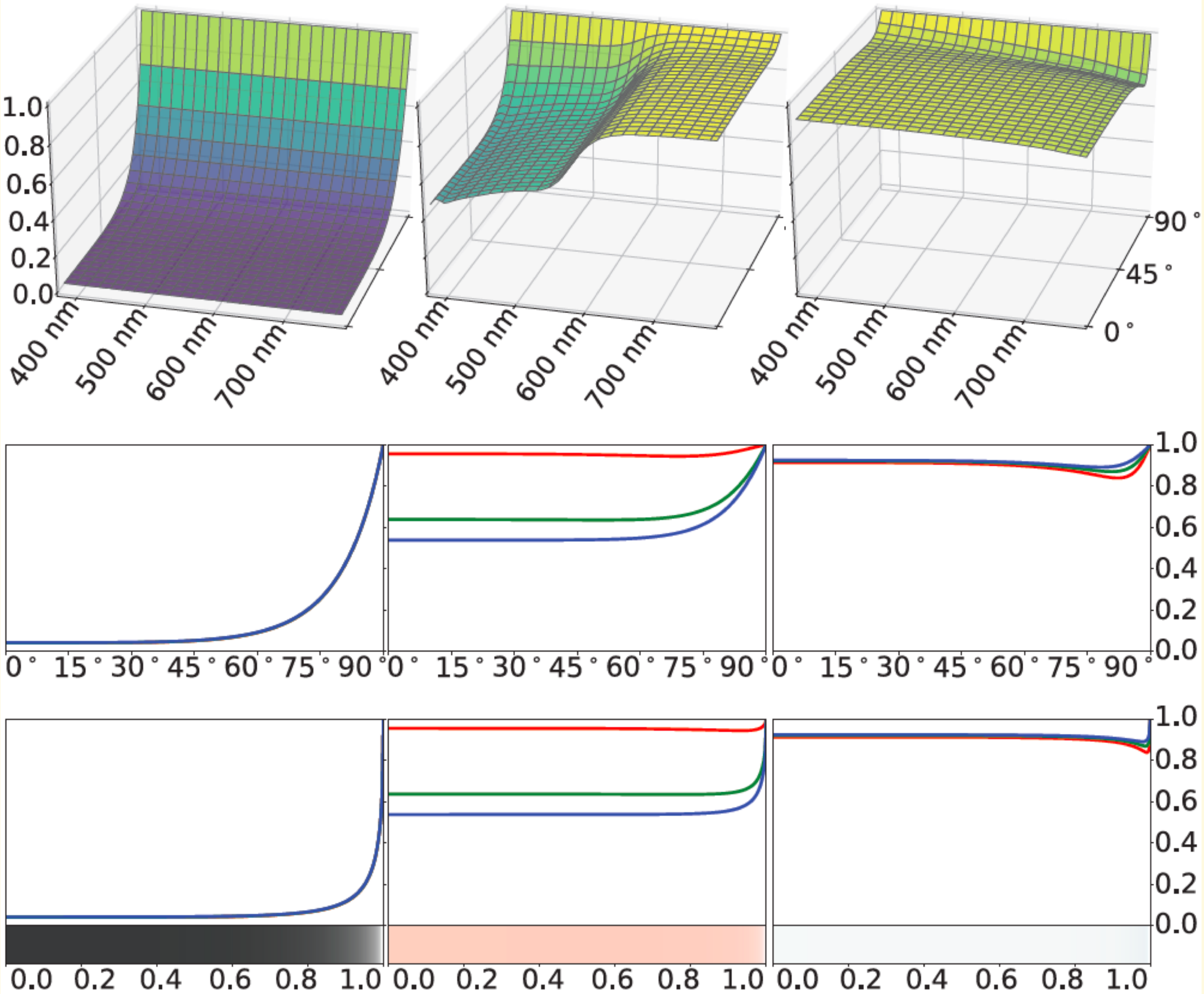


Top row:
Wavelength to incidence angle

Middle row:
Incidence angle to RGB

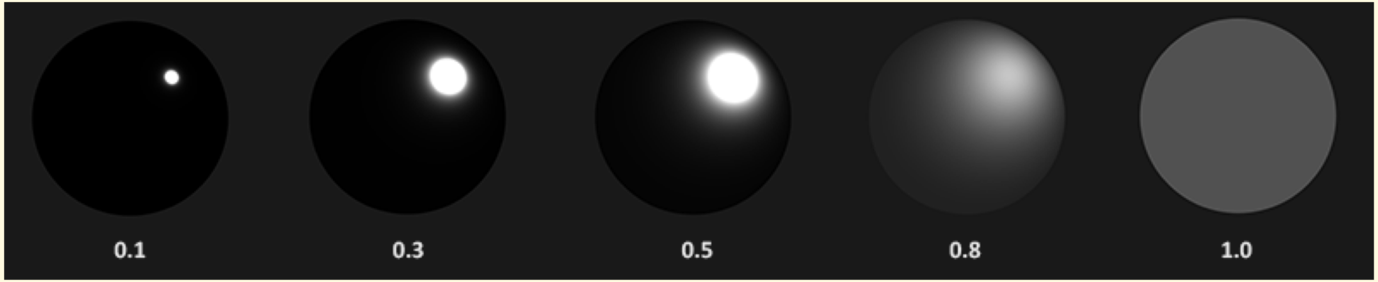
Bottom row: sine of Incidence angle to RGB

Left = glass
Middle = copper
Right = aluminum

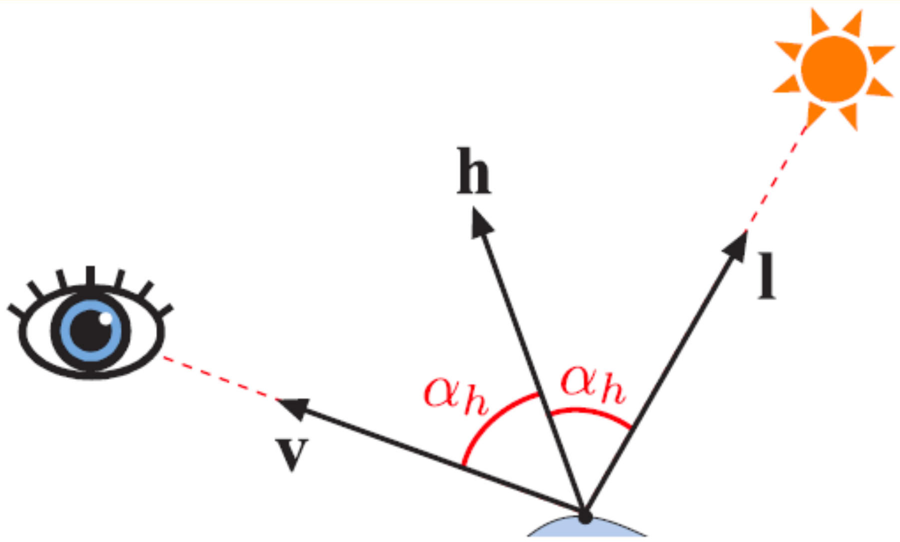


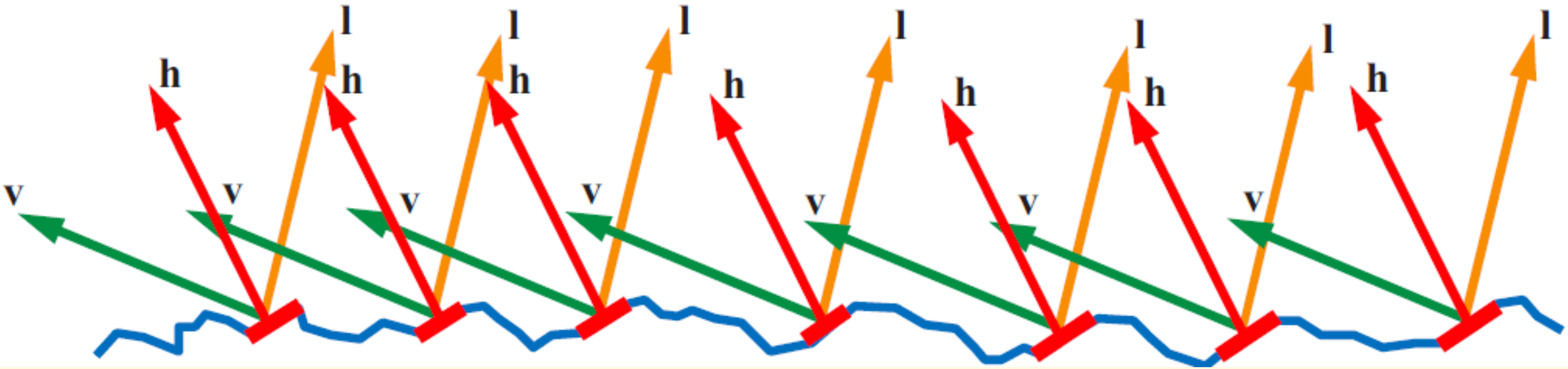
BRDF

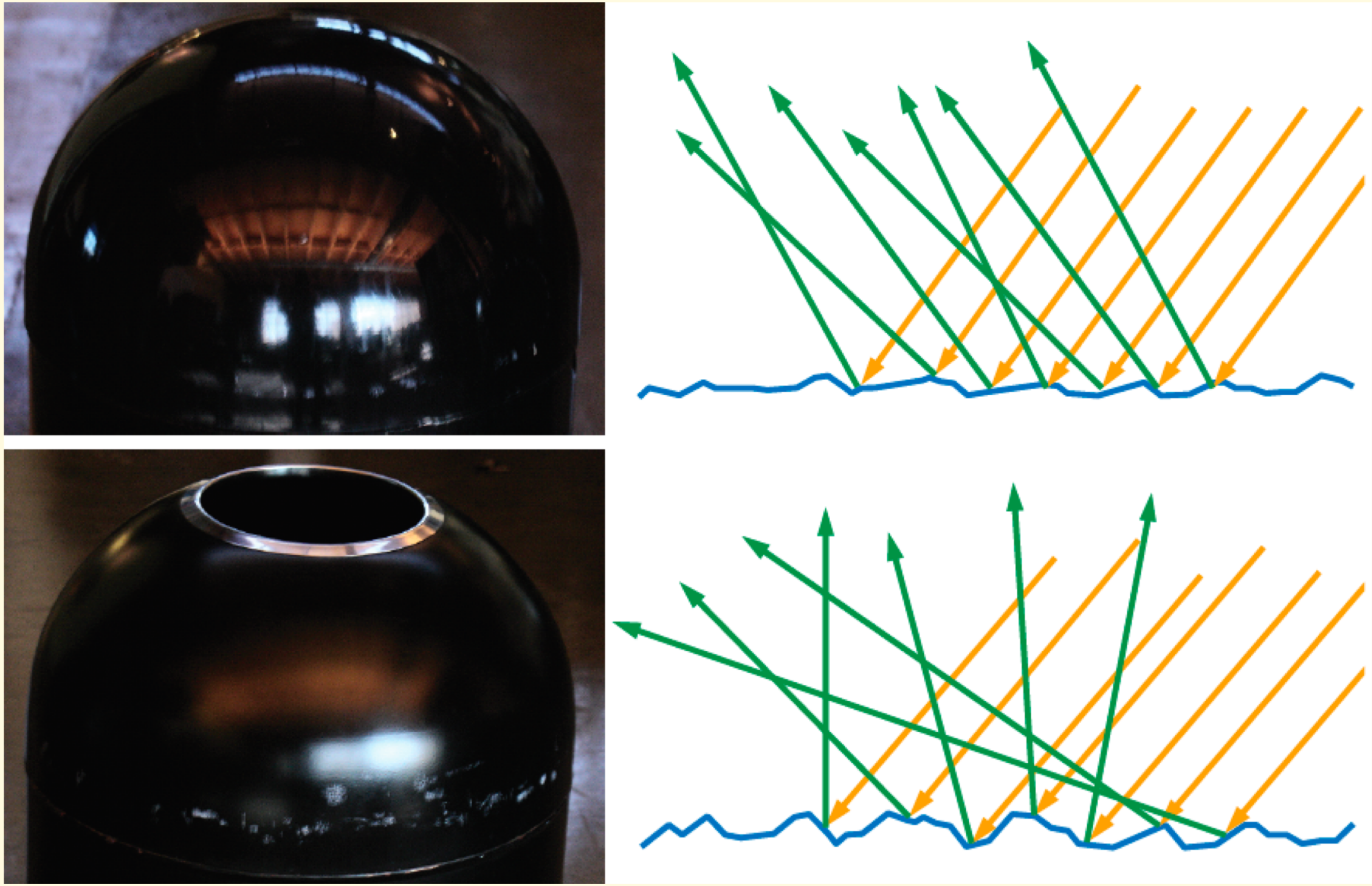
The normal distribution function approximates the amount the surface's microfacets are aligned to the halfway vector influenced by the roughness of the surface.

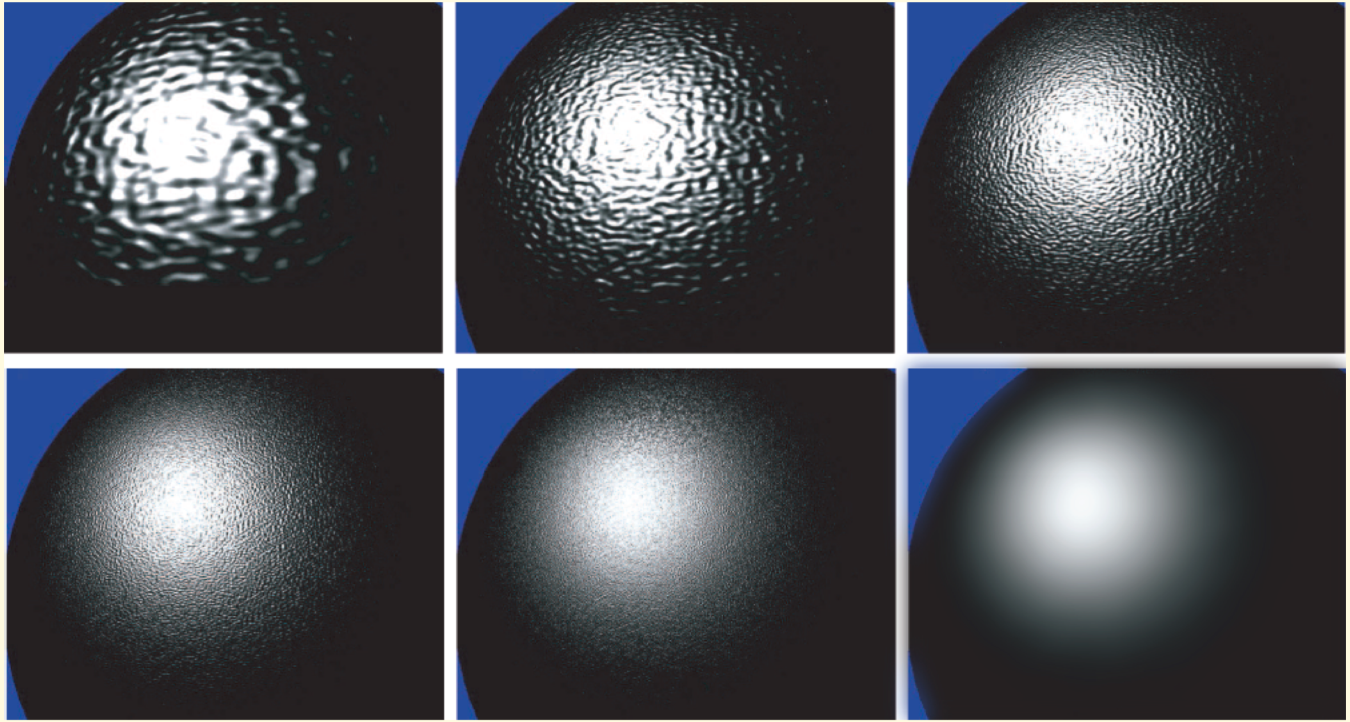


“The microfacet approximation employs a form of energy conservation: outgoing light energy should never exceed the incoming light energy.”


h
l
v
α_h
α_h

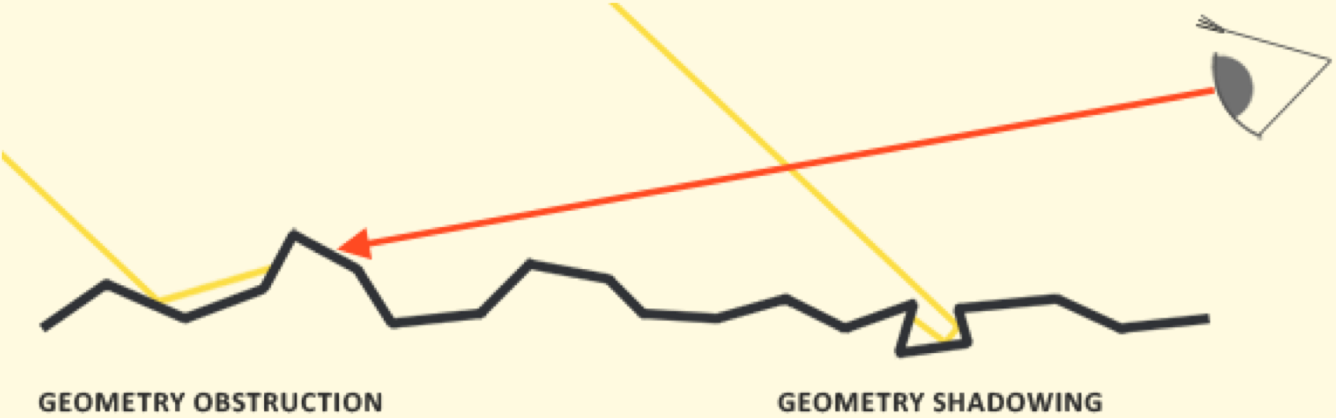

l
h
v

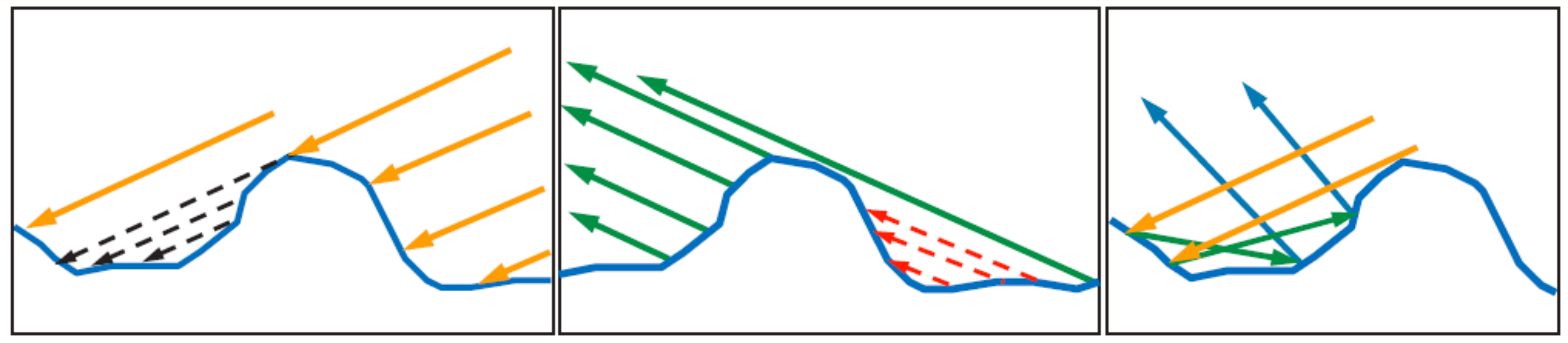




BRDF

Geometry function: The geometry function statistically approximates the relative surface area where its micro surface-details overshadow each other causing light rays to be occluded.





BRDFs

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

$$f_{cook-torrance} = \frac{DFG}{4(\omega_o \cdot n)(\omega_i \cdot n)}$$

$$k_{\text{spec}} = \frac{DFG}{4(V \cdot N)(N \cdot L)}$$