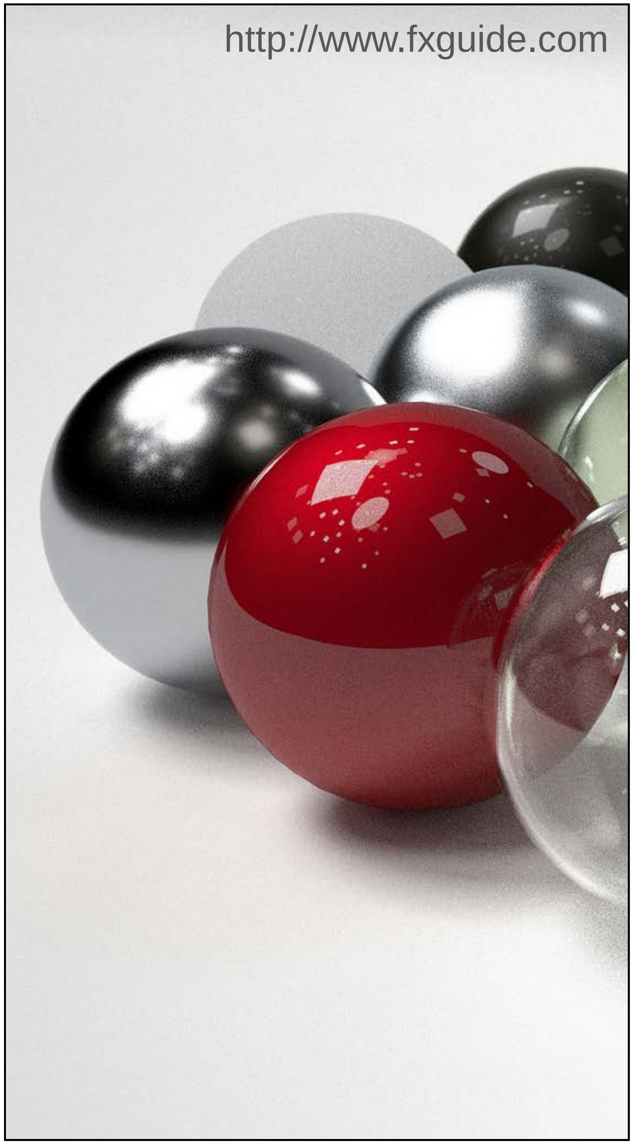
Appearance:

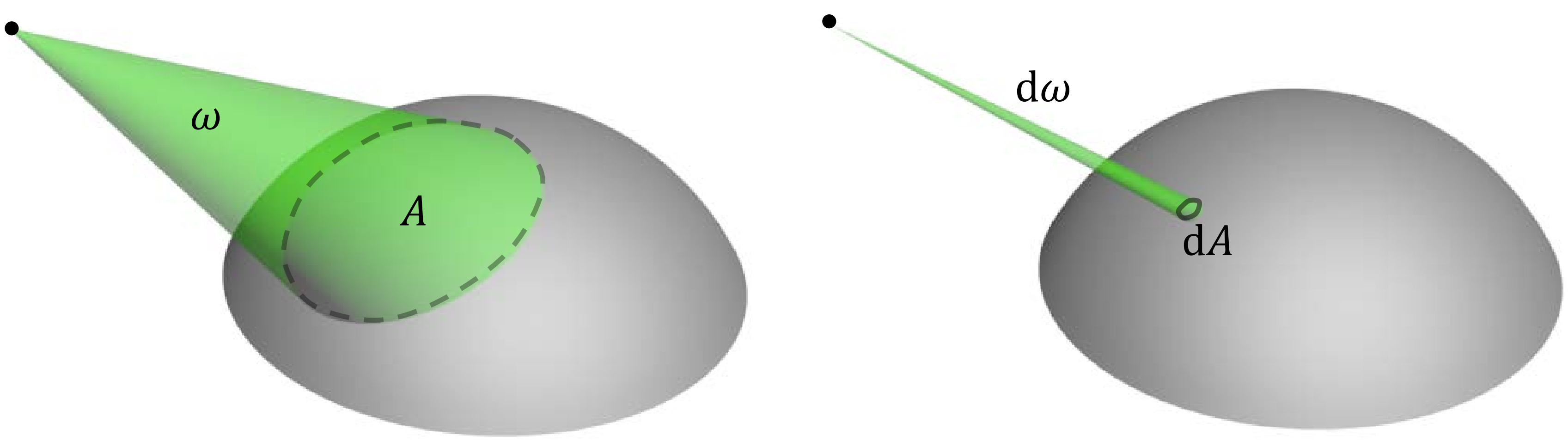
Local Shading



Georgios Papaioannou - 2014

Basic Concepts

- Central to the energy transport are two measures:
  - The surface area (and the differential surface area)
  - The solid angle (and of course the differential solid angle)

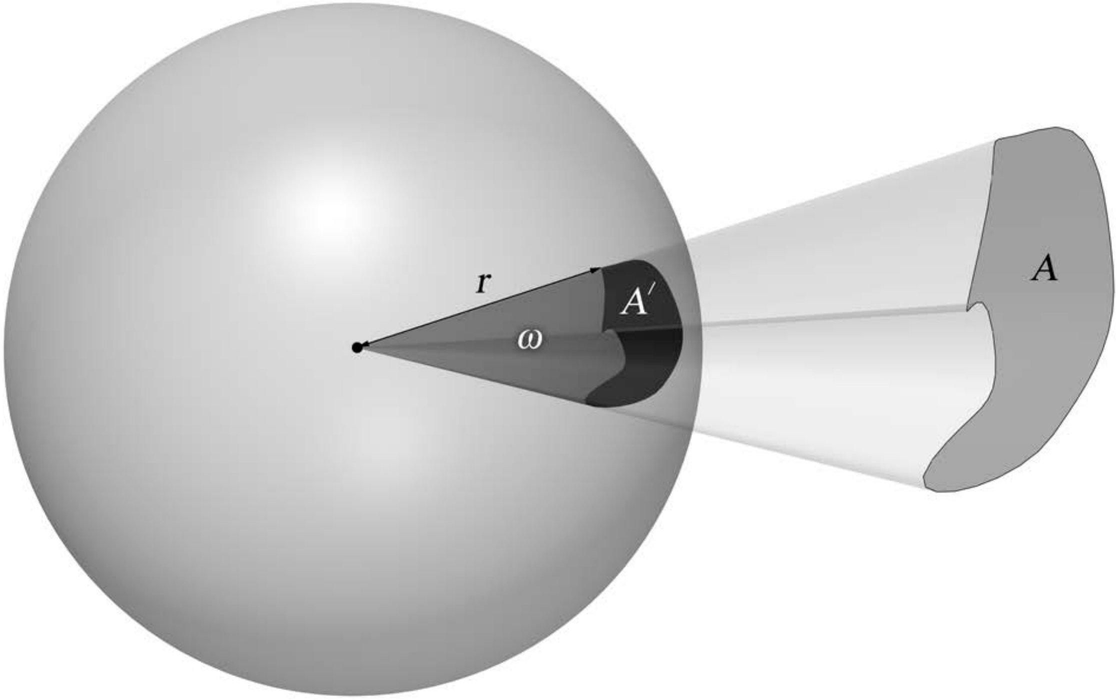


Solid Angles

- The solid angle ω subtended by a surface patch *A* is defined as the area of the projection of *A* on the surface of a sphere of radius r, divided by r^2
- Unit: steradian

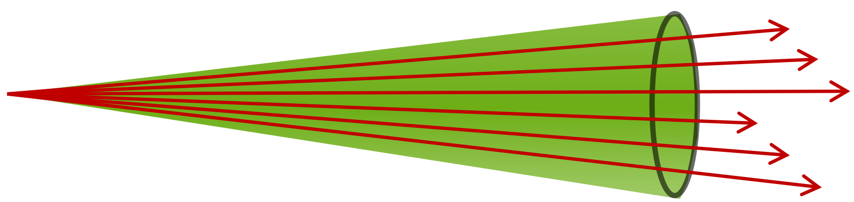
$$\omega = \frac{A'}{r^2}$$

$$\omega_{sphere} = 4\pi$$



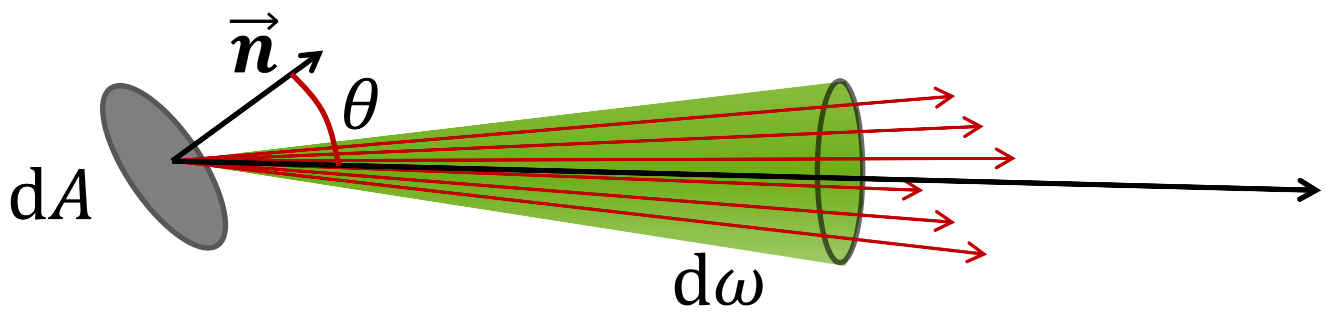
Basic Radiometric Quantities (1)

- Radiant energy $\boldsymbol{Q}$: the energy carried by photons emitted from a light source (Joules)
- Radiant power (flux) $\boldsymbol{\Phi}=dQ/dt$: Rate of energy (W)
- Radiant intensity $\boldsymbol{I}= \mathrm{d}\Phi/d\omega$: perceived light through a given solid angle in space (W/steradian)



Basic Radiometric Quantities (2)

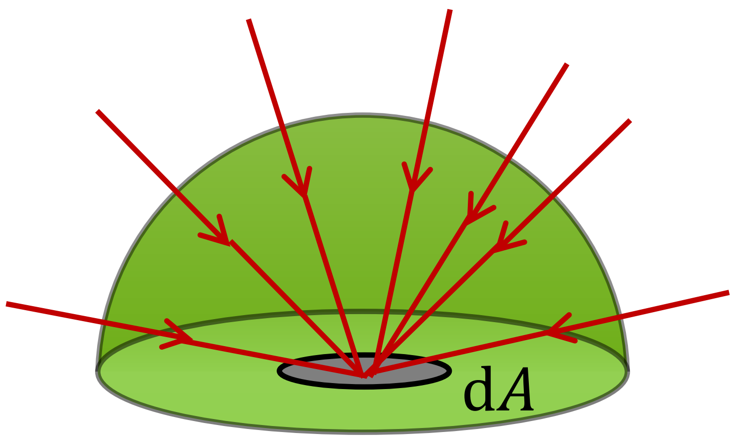
- Radiance $\boldsymbol{L}$: The flow of radiant power emitted through a solid angle that crosses a tilted differential surface dA (W/(steradians· m²))



$$L = \frac{\partial^2 \Phi}{\partial A \partial \omega \cos\theta}$$

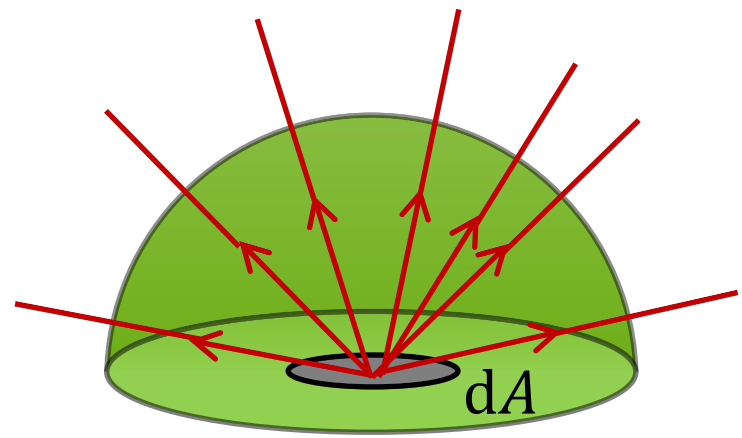
Basic Radiometric Quantities (3)

- Irradiance ***E***: Incident flux from all directions on a differential patch dA:
- Radiosity ***B***: Total flux exiting a differential patch dA:



irradiance

$$E = \frac{\mathrm{d}\Phi_i}{\mathrm{d}A}$$



radiosity

$$B = \frac{\mathrm{d}\Phi_o}{\mathrm{d}A}$$

Local Shading Models

- Local shading only regards the light interactions at a single point
- All geometry inter-reflections are omitted
- The same holds for shadowing (light blocking)

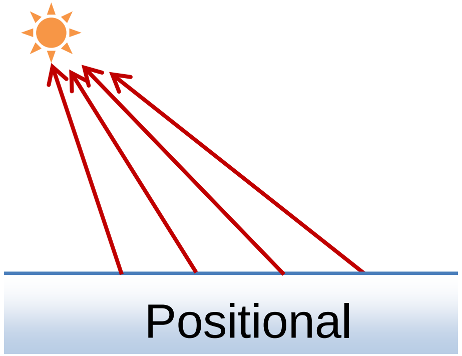
- Local shading models can be computed at isolated locations, without requiring knowledge about the entire scene → ideal for shader computations

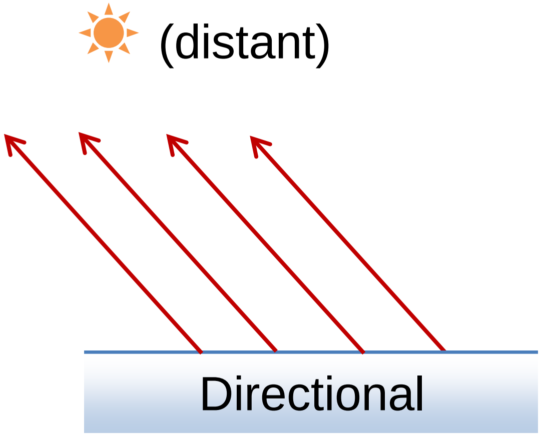
Light Sources

- For a local shading model to work we need emitting bodies
- In graphics, light emitters are frequently modelled separately as light sources
- For simplicity, proper luminaries with mass and surface can be approximated by punctual (point) light sources

Punctual Lights

- Infinitesimally small (point) sources
  - Infinite power density
  - Can explicitly define exitant radiance and intensity
- Can be:
  - Directional (distant compared to world scale)
  - Positional

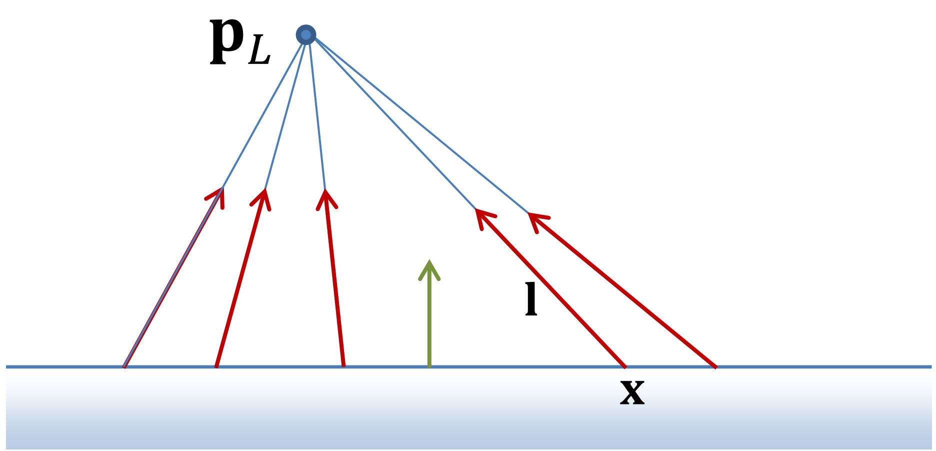




Punctual Lights - Positional

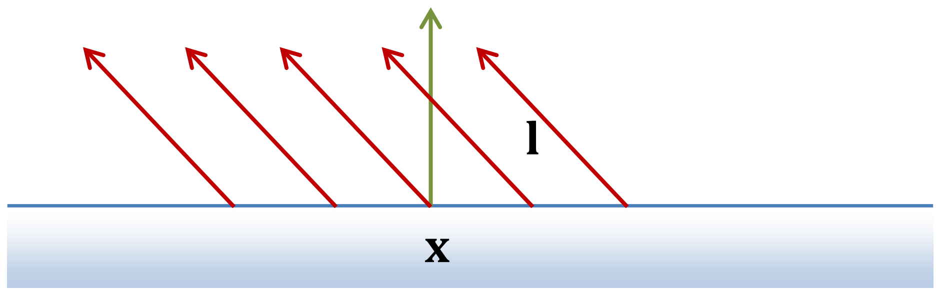
- We are given a light source position $\mathbf{p}_L$
- The direction towards the light is calculated per shaded point:

$$\mathbf{l} = \frac{\mathbf{p}_L - \mathbf{x}}{|\mathbf{p}_L - \mathbf{x}|}$$



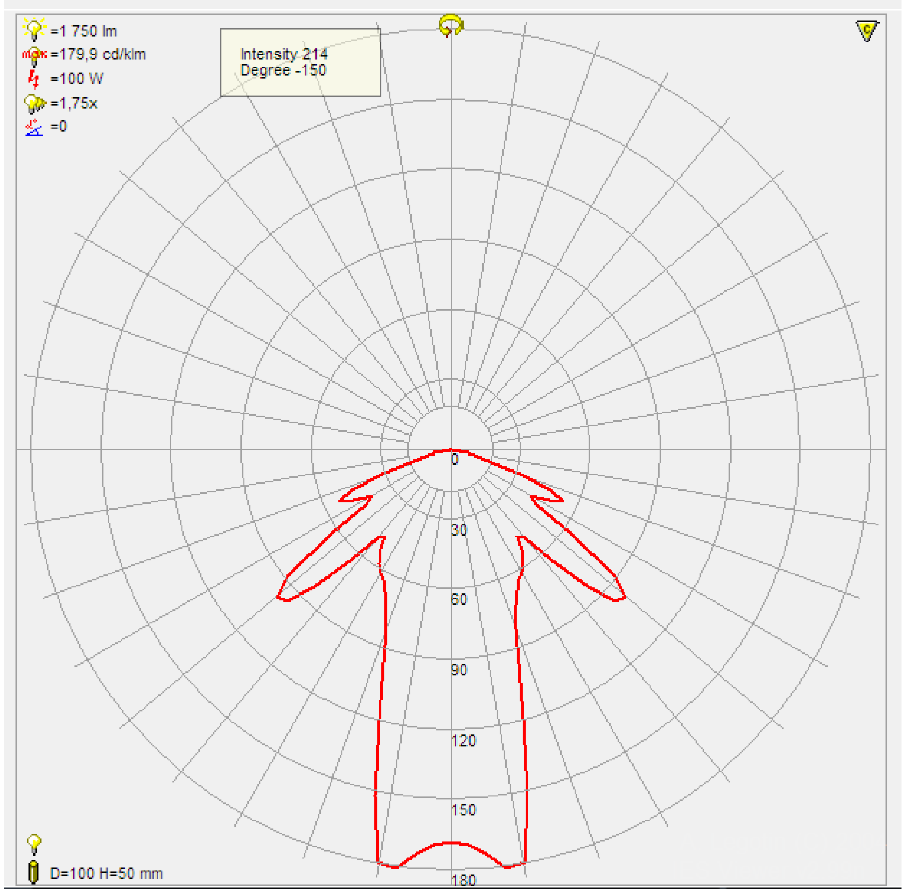
Punctual Lights - Directional

- We are given a light source direction $\mathbf{l}$ explicitly



Lighting Distribution (1)

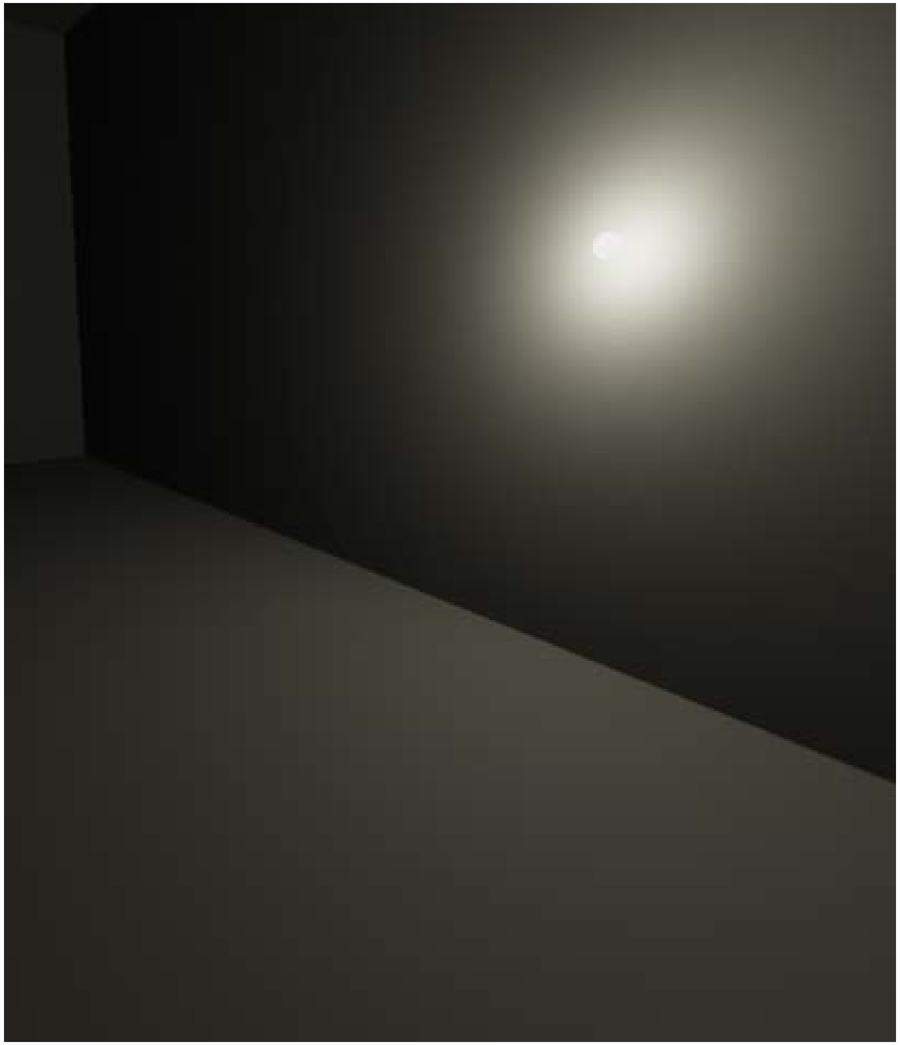
- Light sources practically emit a different amount of energy per direction
- We can model this as a distribution $f_e(\omega)$
- For convenience, we usually create punctual lights of constant emission



Screenshot from IES Viewer

Lighting Distribution (2)

Uniform



Custom

Lighting Distribution (3)

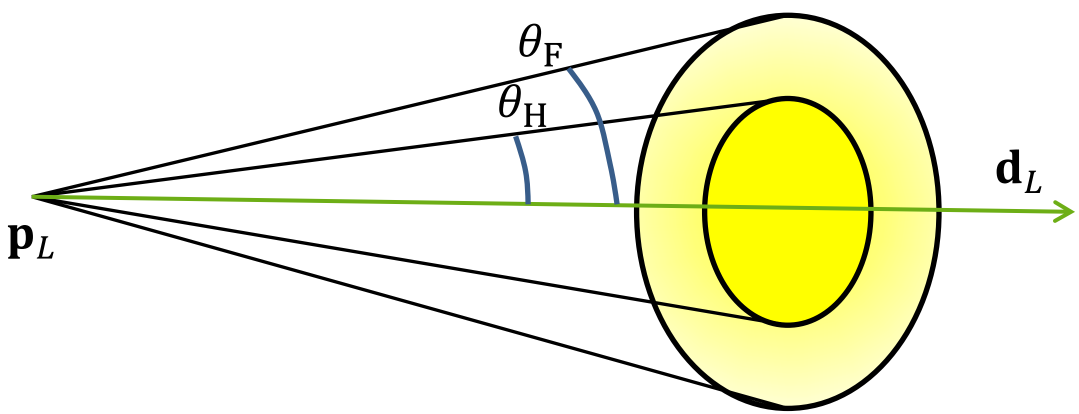
Examples

IES Lights

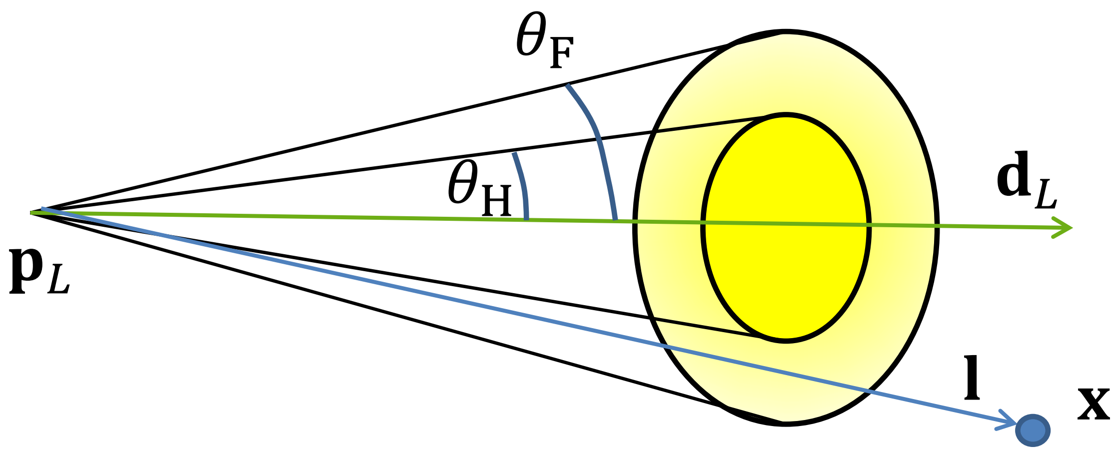
- There exists a standardization for defining the emissive properties of light sources
- IES Light description defines the emission of realistic (or measured) light sources for a given set of directions $\omega = (\theta, \varphi)$
  - Supports symmetrical luminaries, too

Light Sources – Spotlights (1)

- Very frequently, we use spotlights in computer graphics, as a procedural way to define a light source with tight emission cone
- Spotlights have 2 brightness zones:
  - Hotspot (full, maximum emission)
  - Fall-off zone (gradual dimming to zero emission)



Light Sources – Spotlights (2)



$$\mathbf{l} = \frac{\mathbf{x}-\mathbf{p}_L}{|\mathbf{x}-\mathbf{p}_L|}$$

$$f_L(\mathbf{l}) = \begin{cases} 1, & \mathbf{l}\cdot\mathbf{d}_L > \cos\theta_\mathrm{H} \\ 1-\dfrac{\cos\theta_\mathrm{H}-\mathbf{l}\cdot\mathbf{d}_L}{\cos\theta_\mathrm{H}-\cos\theta_\mathrm{F}}, & \cos\theta_\mathrm{H} \ge \mathbf{l}\cdot\mathbf{d}_L > \cos\theta_\mathrm{L} \\ 0, & otherwise \end{cases}$$

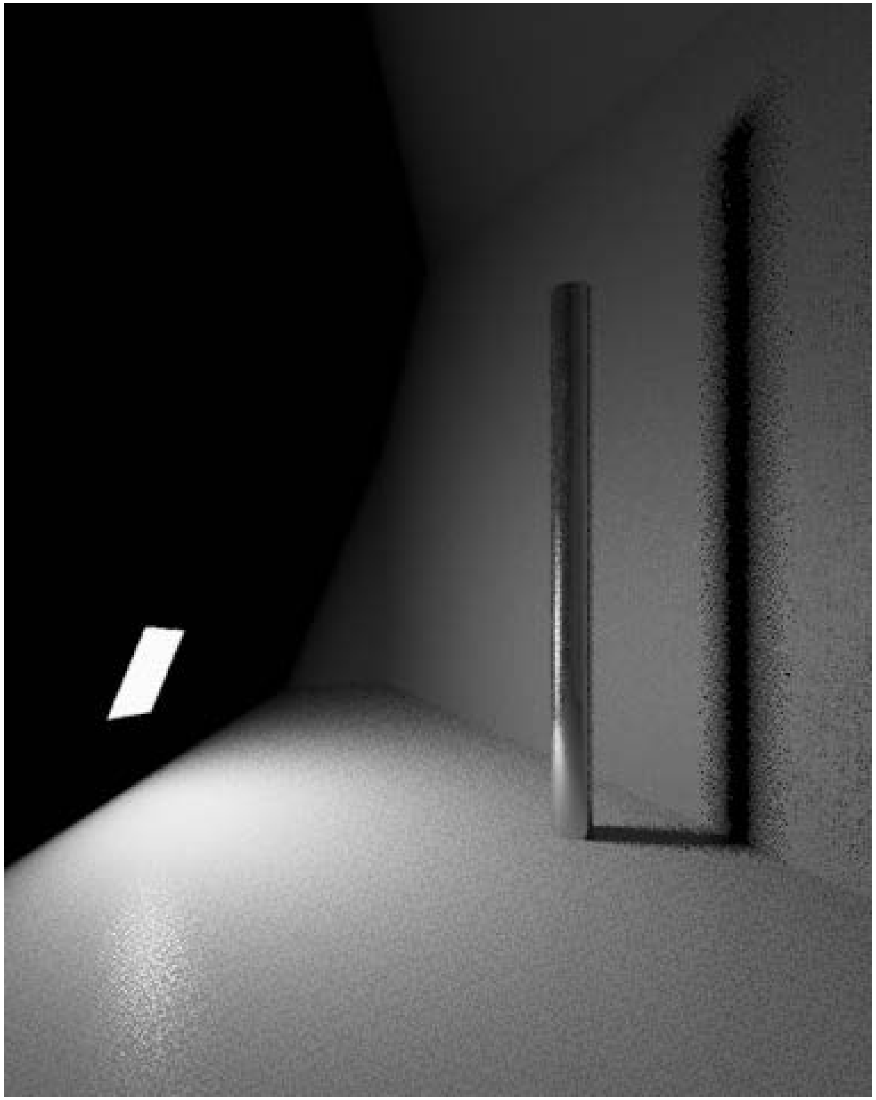
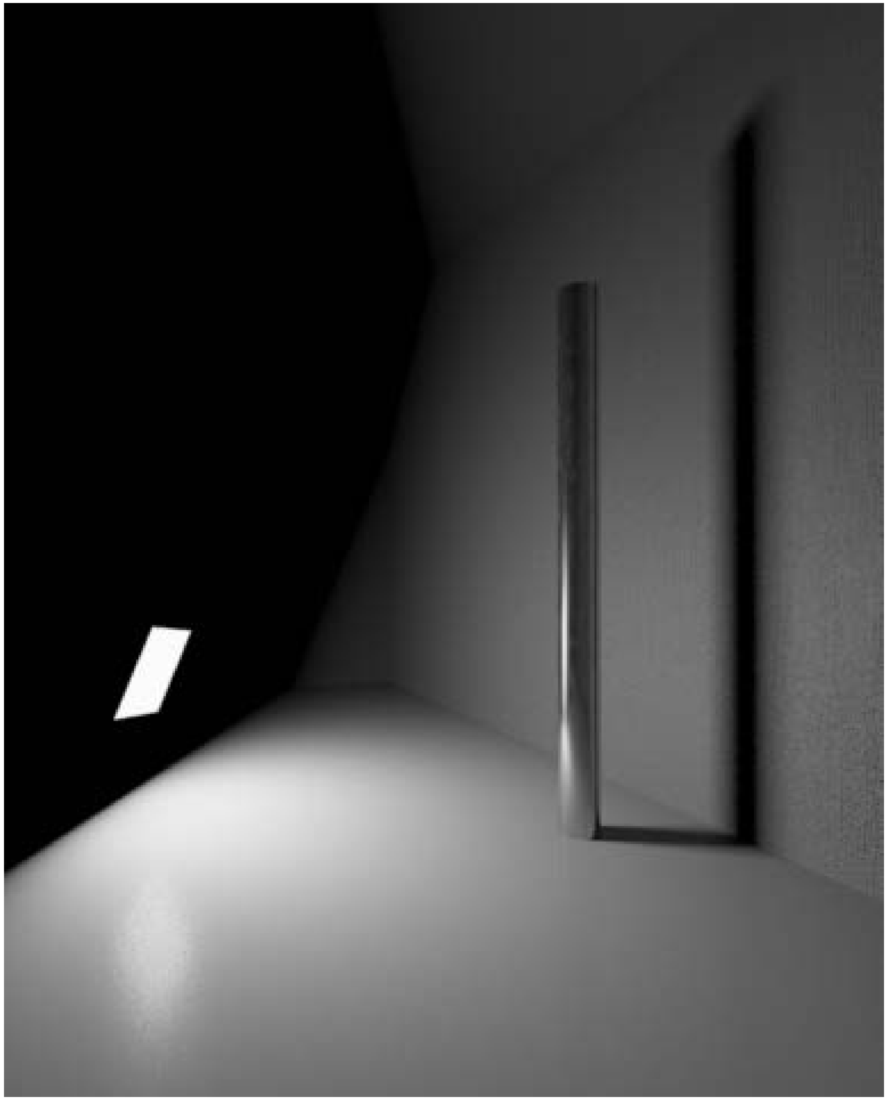
Area Lights

- In reality, there are no punctual light sources!
- Physical light sources are light emitting bodies
  - They have physical properties like surface area and volume

Light Contribution of Area Lights (1)

- Can be done analytically for certain light source geometry types (e.g. spheres, disks etc.)
  - Difficult to handle shadows (see shadowing presentation)
- However, usually area lights are point sampled
  - A number of point samples are chosen on them (see also Monte Carlo light sampling)
  - Each one is treated as a punctual light source
  - Each punctual light sample has its properties derived from the area light (radiance, flux etc.)
  - The sample configuration changes per shaded point to avoid patterns

Light Contribution of Area Lights (2)

Units for Lighting - Watts

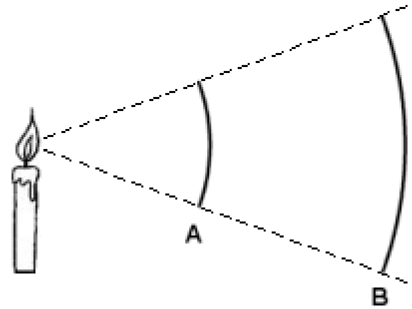
- Radiant flux is the total power that emanates from a light emitter (in Watts)
  - Caution: this is the actual produced power, not the consumed power (e.g. electrical)
  - Measured at the emitter surface
  - Over the entire spectrum
  - Our eyes are not equally sensitive to all wavelengths! A lot of energy is wasted (outside the visible spectrum)

Units for Lighting – Lumen

- Is the unit of luminous flux, i.e. the apparent (visible) flux (lm)
- It is related to the radiant power via the luminous efficacy, i.e the ability of source to produce usable lighting per Watt of produced energy
- Maximum possible efficacy: 683 lm/W (at λ=555nm)
- Example:
  - A 100W light bulb with an average efficacy of 30lm/W emits 3000lm

Units for Lighting – Candela

- Is a measure of light intensity, i.e. flux per solid angle
- We can obtain luminous flux by integrating the measured intensity over all emitting directions of the light source

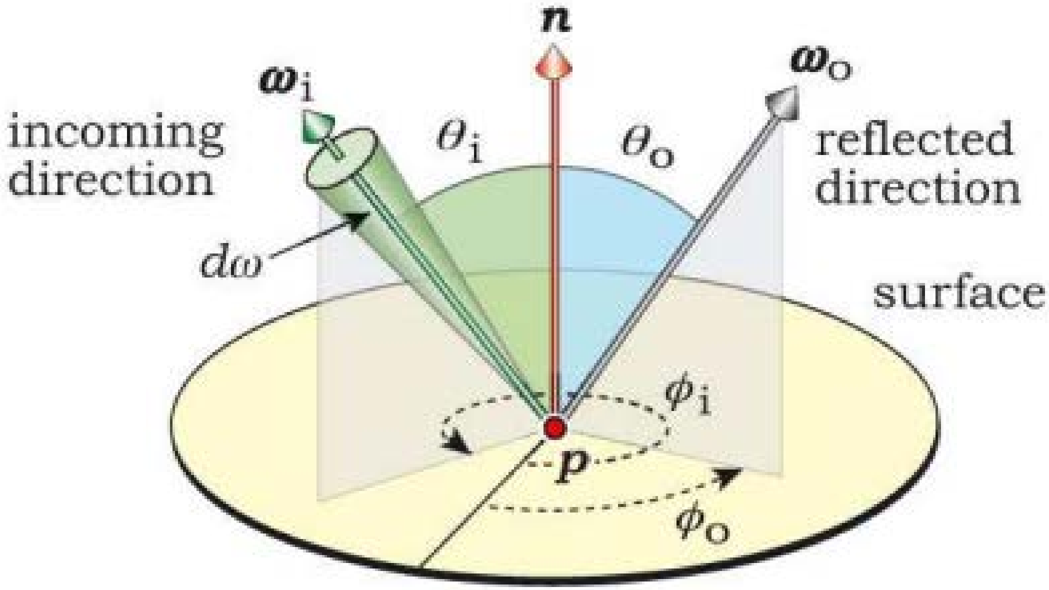


BRDF – The Reflectance Equation (1)

- What is the equilibrium of energy at a differential patch $\mathrm{d}A$?
- Energy leaving the surface in a direction ω_o is the result of:
  - Energy reflected from all incident directions ω_i
  - Energy scattered from all incident directions ω_i as a local effect (diffuse reflection)
  - Energy from all incident directions ω_i being absorbed

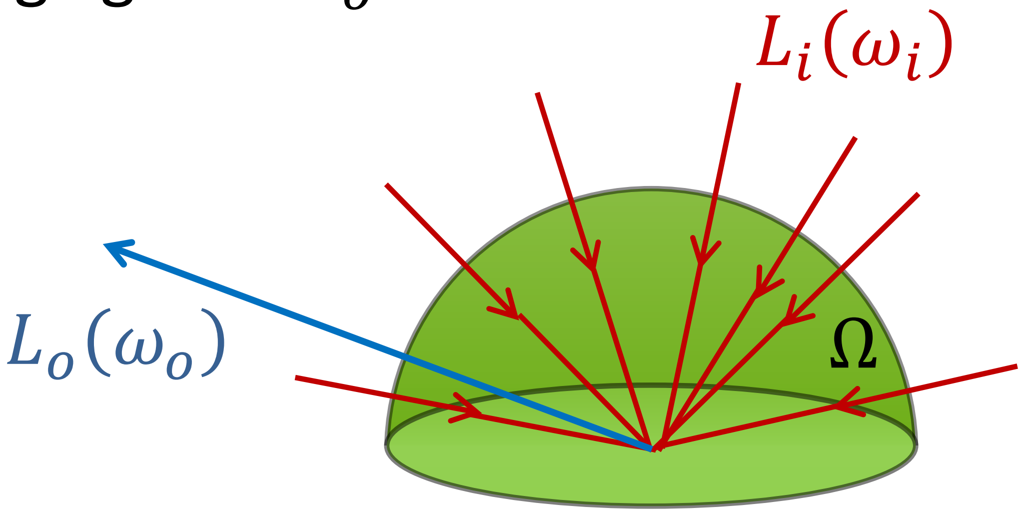
BRDF – The Reflectance Equation (2)

- The setup:



BRDF – The Reflectance Equation (3)

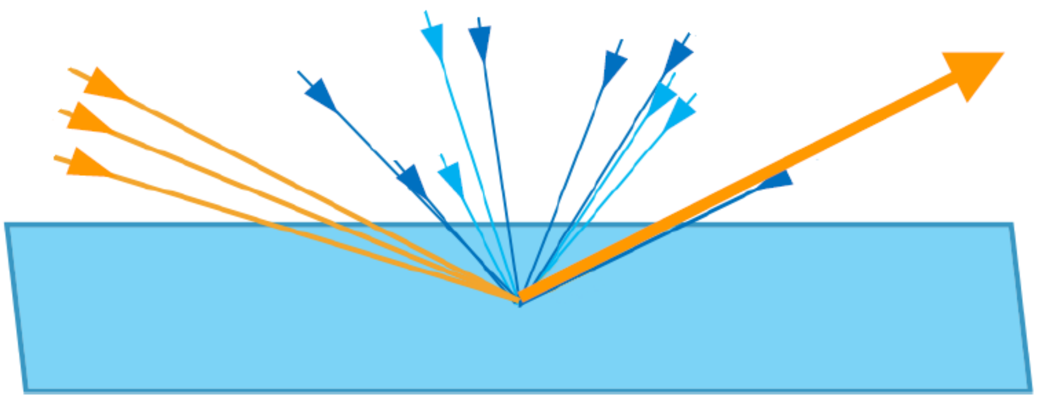
- Therefore, given a function $f(\omega_i, \omega_o)$ that indicates how much light from incident direction ω_i contributes to outgoing light in ω_o direction:



$$L_o(\omega_o) = \int_{\Omega} f(\omega_i, \omega_o) L_i(\omega_i) \cos\theta_i \, \mathrm{d}\omega_i$$

The BRDF (1)

- $f(\omega_i, \omega_o)$ is the Bidirectional Reflectance Distribution Function
- Provides the relative contribution of each incoming direction to the outgoing lighting in a given direction



$$f(\omega_i, \omega_o) = \frac{\mathrm{d}L_o(\omega_o)}{L_i(\omega_i)\cos\theta_i\,\mathrm{d}\omega_i}$$

The BRDF (2)

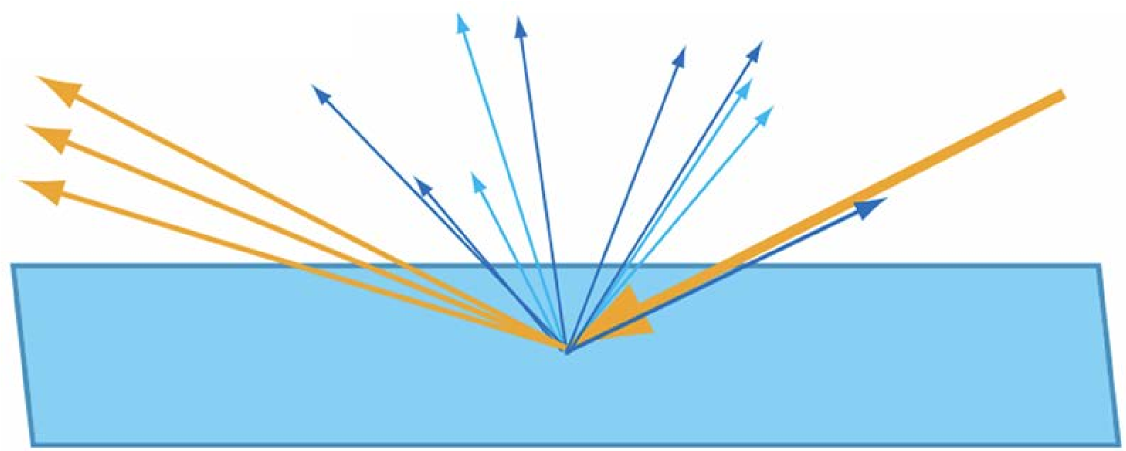
- The BRDF characterizes the **surface material**
- The BRDF is a function of:
  - In/out latitude and longitude
  - Wavelength (so it is different for each R,G,B channel)
- A BRDF can be measured for real materials and
- **Approximated by models** in most calculations

The BRDF (3)

- Properties:
  - Should be positively defined
  - Linear operator
  - The integral of the BRDF over the entire hemisphere should be ≤ 1 (it is a distribution of non-absorbed radiance)
  - Helmholtz reciprocity: For most materials $f(\omega_i, \omega_o) = f(\omega_o, \omega_i)$. Important property for many algorithms

The BRDF (4)

- Therefore, the BRDF also describes how incident light from a given direction is distributed w.r.t outgoing directions



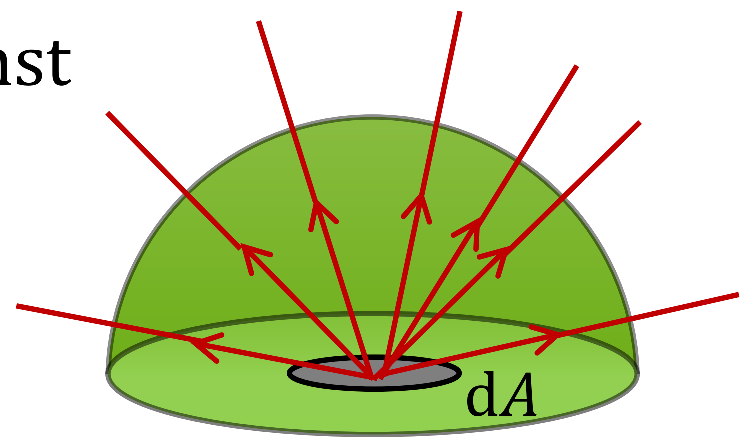
Specular and Diffuse BRDFs

- For the modeling of the BRDF, we typically regard the local scattering and reflection separately:
  - Diffuse BRDF
  - Specular BRDF
- We combine the contribution of both to the reflected color

Diffuse BRDF

- The most common modeling of the local scattering of light (diffuse reflection) is the uniform light scattering
- This BRDF is called a Lambertian BRDF

$$f_d(\omega_i, \omega_o) = f_d = \text{const}$$



Diffuse BRDF – Lambertian Surfaces (1)

Value?

- For ideally diffuse surfaces (pure white), the reflectance integral should be 1 using unit incoming energy:

$$1 = \int_{\Omega} f_d \cos\theta_i \,\mathrm{d}\omega_i \Rightarrow 1 = f_d \int_{\Omega} \cos\theta_i \,\mathrm{d}\omega_i = f_d \pi \Rightarrow$$

$$f_d = \frac{1}{\pi}$$

Diffuse BRDF – Lambertian Surfaces (2)

And accounting for absorption, we have loss of energy:

Replace 1 with the albedo ρ (or k_d) of the surface:

$$f_d = \frac{\rho}{\pi}$$

Specular BRDF – A Simple Model

- The commonest model for specular BRDFs is the Phong model
- It was later modified by Blinn (Blinn-Phong model)
- It is an empirical model, not a physically-based one
- Tries to model the specular highlight by using:
  - A specular color (the reflectance color K_s)
  - A specular exponent factor ("tightness" of the highlight)

The Phong Model for Specular BRDF (1)

- With the Phong model, outgoing radiance is directly given by a custom reflectance equation:

Diffuse reflection — Specular reflection

$$L_o(\vec{\mathbf{v}}) = \begin{cases} \left(k_d \vec{\mathbf{n}} \cdot \vec{\mathbf{l}} + k_s (\vec{\mathbf{r}} \cdot \vec{\mathbf{v}})^n\right) L_i(\vec{\mathbf{l}}), & \vec{\mathbf{n}} \cdot \vec{\mathbf{l}} > 0 \\ 0, otherwise \end{cases}$$

The Phong Model for Specular BRDF (2)

(should be at most) $\frac{\rho}{\pi}$

$\cos\theta_i$

Custom specular color

Specular exponent (tightness)

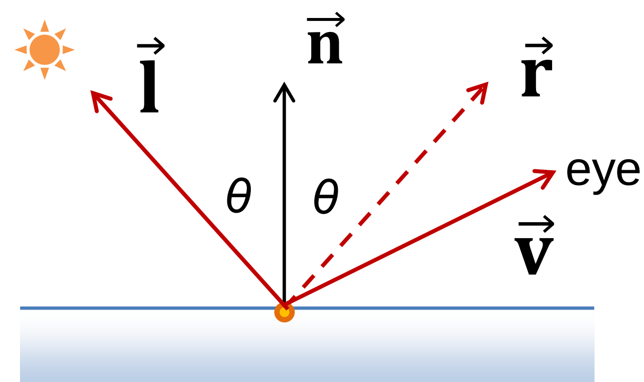
$$k_d \vec{\mathbf{n}} \cdot \vec{\mathbf{l}} + k_s (\vec{\mathbf{r}} \cdot \vec{\mathbf{v}})^n$$

l: Vector towards light source (ω_i)

n: Surface normal vector

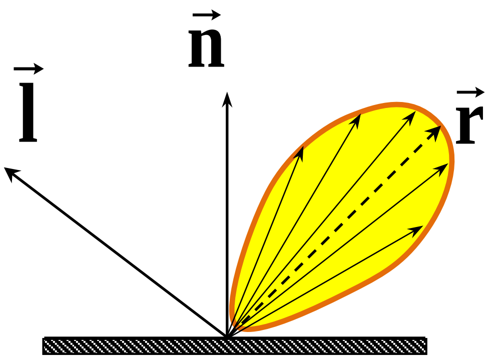
v: Vector towards the eye (ω_o)

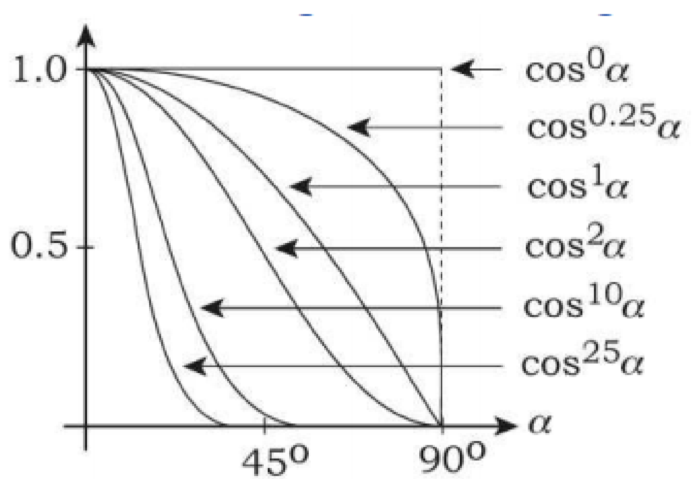
r: Direction of ideal reflection



The Phong Model for Specular BRDF (3)

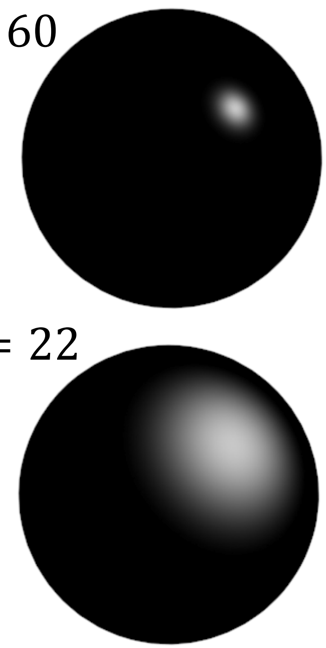
- Interpretation:
  - Outgoing directions near the ideal reflection direction receive more energy
  - The falloff of this distribution is controlled by the tightness of the highlight (exponent)





$n = 60$

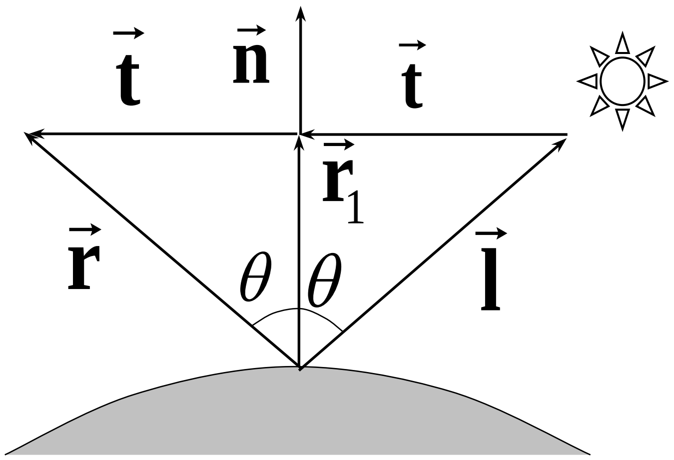
$n = 22$



Phong Model: The Reflection Vector

- If $\overrightarrow{\mathbf{r}_1}$ is the projection of $\vec{\mathbf{r}}$ on $\vec{\mathbf{n}}$, then $\overrightarrow{\mathbf{r}_1} = \vec{\mathbf{n}}\cos\theta = \vec{\mathbf{n}}(\vec{\mathbf{n}}\,\vec{\mathbf{l}})$
- Additionally, $\vec{\mathbf{t}} = \overrightarrow{\mathbf{r}_1} - \vec{\mathbf{l}}$, and $\vec{\mathbf{r}} = \vec{\mathbf{l}} + \mathbf{2}\vec{\mathbf{t}}$:

$$\vec{\mathbf{r}} = 2\vec{\mathbf{n}}(\vec{\mathbf{n}}\,\vec{\mathbf{l}}) - \vec{\mathbf{l}}$$

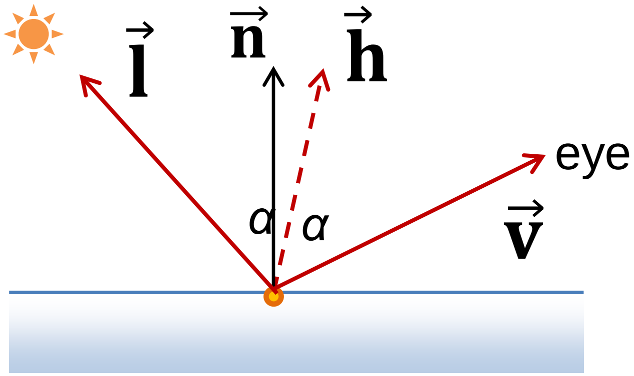


The Blinn Model (1)

- Similar to Phong
- Replaces the specular part with the following:

$$k_s(\vec{\mathbf{n}} \cdot \vec{\mathbf{h}})^n$$

- Where $\vec{\mathbf{h}}$ is the "halfway" vector between the incident and outgoing direction:



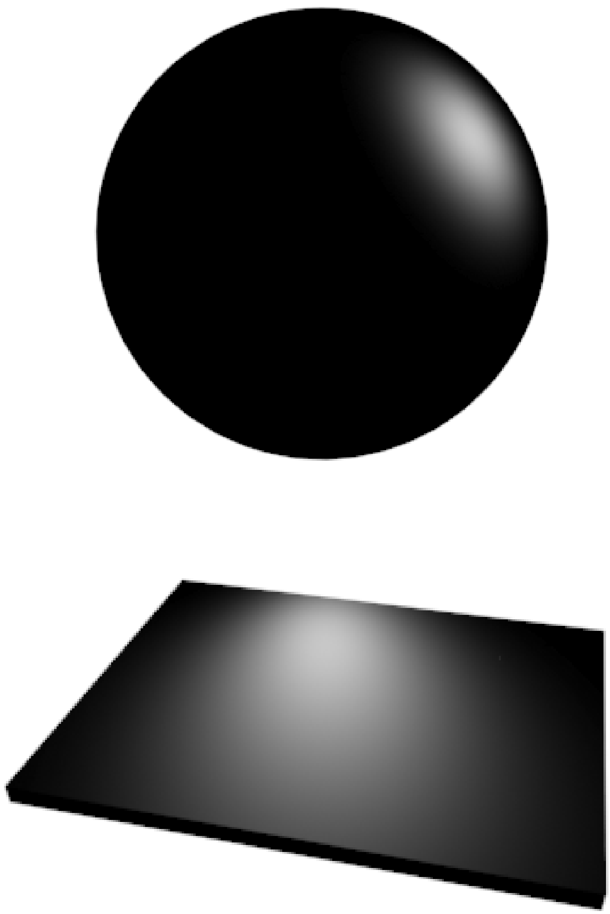
The Blinn Model (2)

- Why is the Blinn model better?
  - More consistent with the notion of "micro-facet" geometry at a microscopic level (see next)
  - Validated to be more accurate (compared to photos)
  - Faster to compute:

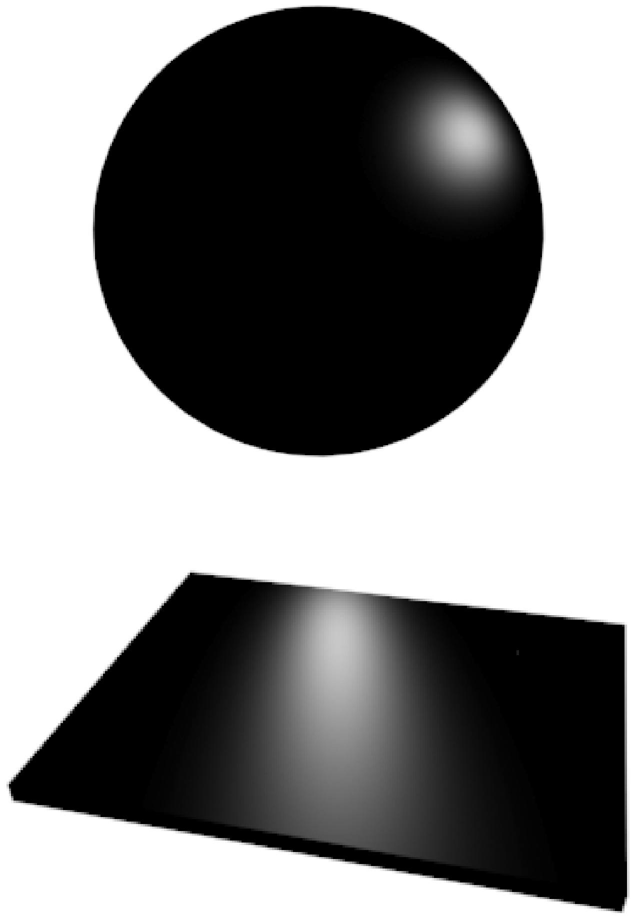
$$\vec{\mathbf{h}} = \frac{\vec{\mathbf{v}} + \vec{\mathbf{l}}}{\left|\vec{\mathbf{v}} + \vec{\mathbf{l}}\right|}$$

The Blinn Model (3)

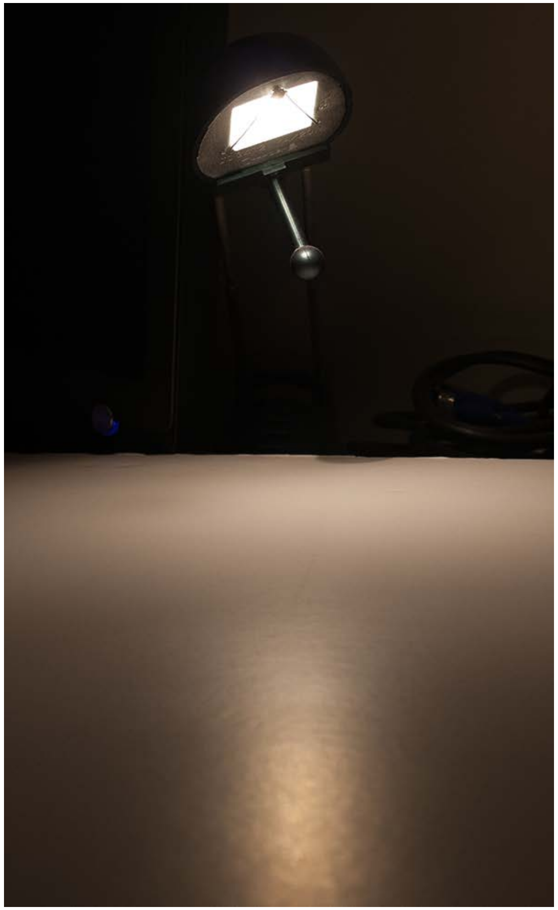
Phong



Blinn-Phong



Real glossy surface



Is the Phong-Blinn Model Realistic?

- It is not a physically-based shading model
- It could have been a “plausible” model, if it were not for the fact that it is not normalized
- It takes some manipulation to convert to a BRDF

The Importance of Being Normalized (1)

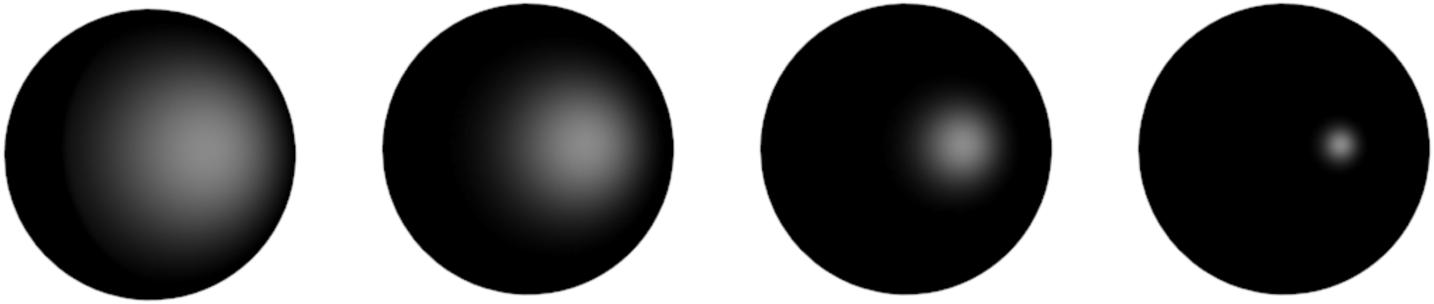
- Why is it important for the model to be normalized?
- Remember, the BRDF represents a distribution!
- For a fixed reflectivity, the total flux leaving the surface (i.e. the surface radiosity) must be constant wr.t. input energy

→Energy preserving

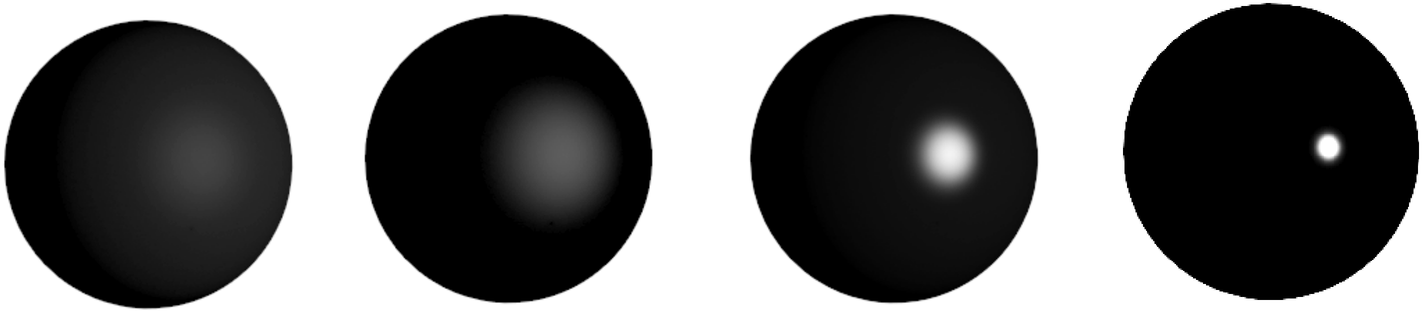
- So, we must normalize the BRDF so that the reflectance integral is ≤ 1

The Importance of Being Normalized (2)

- Clearly this is not the case here:

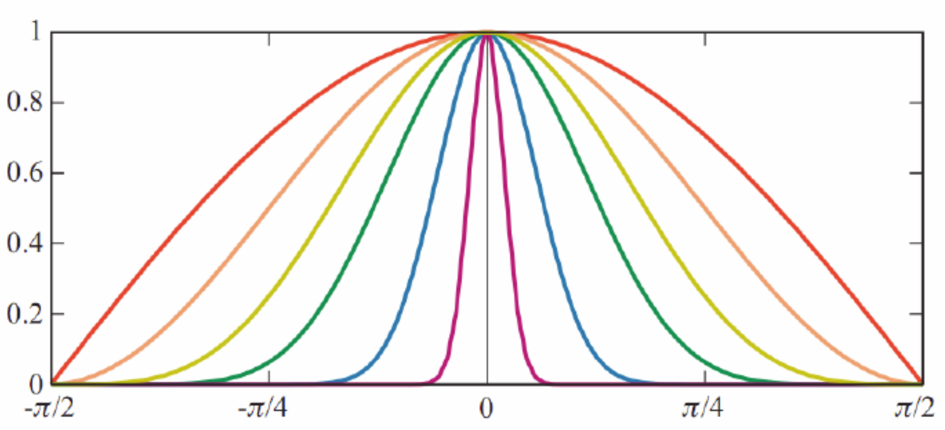


- Should be:

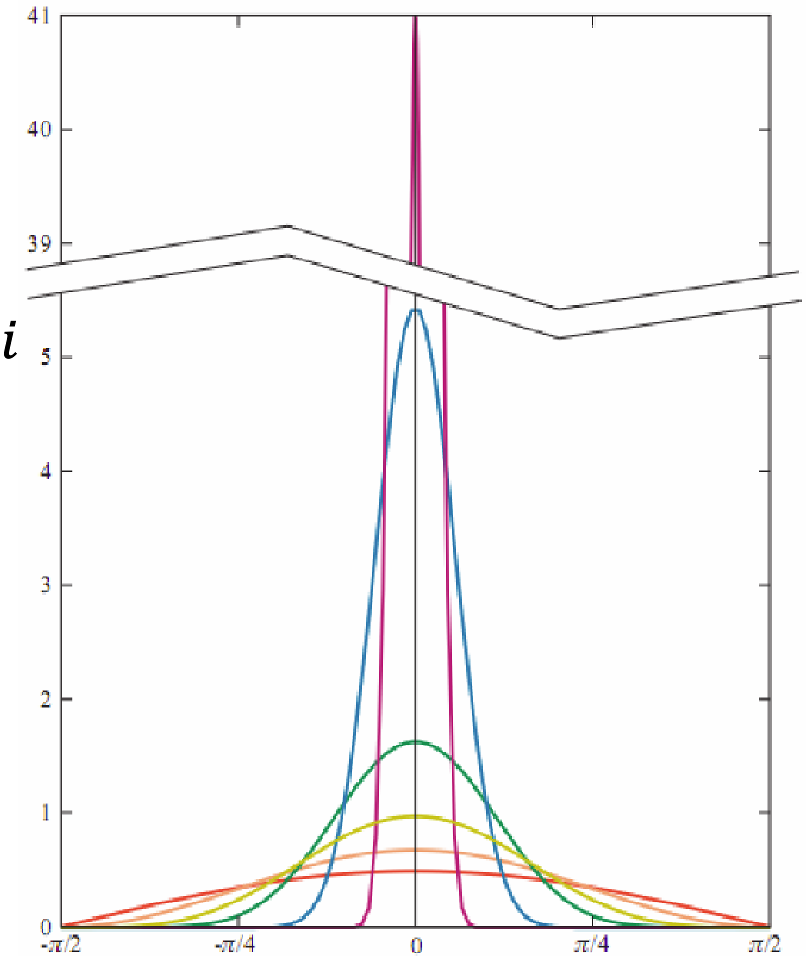


Normalized Blinn-Phong Model

$$L_{specular}(\vec{\mathbf{v}}) = \frac{n+2}{4\pi(n+2^{-n/2})} k_s (\vec{\mathbf{n}} \cdot \vec{\mathbf{h}})^n L_i$$



Unnormalized



Normalized
(area under the function plot is constant)

Converting the Blinn-Phong Model to BRDF

- When the Blinn-Phong model is used within the reflectance equation, the entire integral has to be normalized (for maximum reflectivity)
- Also, $k_s + k_d$ must equal 1 or less (reflected vs transmitted and scattered back)

Blinn-Phong BRDF (1)

- By requiring the specular BRDF integral to be 1 for $k_s = 1$ and maximum flow direction $\vec{\mathbf{v}} = \vec{\mathbf{n}}$,

$$1 = \int_{\Omega} \left(\vec{\mathbf{n}}\vec{\mathbf{h}}\right)^{n} \cos\theta \, \mathrm{d}\omega \xRightarrow{\vec{\mathbf{h}} = \frac{\vec{\mathbf{n}}+\vec{\mathbf{l}}}{\left|\vec{\mathbf{n}}+\vec{\mathbf{l}}\right|}} 1 = \int_{\Omega} cos^{n}\frac{\theta}{2} \cos\theta \, \mathrm{d}\omega$$

- the normalization factor f_n becomes:

$$f_n = \frac{(n+2)(n+4)}{8\pi\left(n + 2^{-\frac{n}{2}}\right)}$$

Blinn-Phong BRDF (2)

- Therefore, the complete BRDF becomes:

$$f_{Blinn}(\omega_o, \omega_i) = \frac{k_d}{\pi} + k_s \frac{(n+2)(n+4)}{8\pi(n+2^{-\frac{n}{2}})} \cos^n a$$

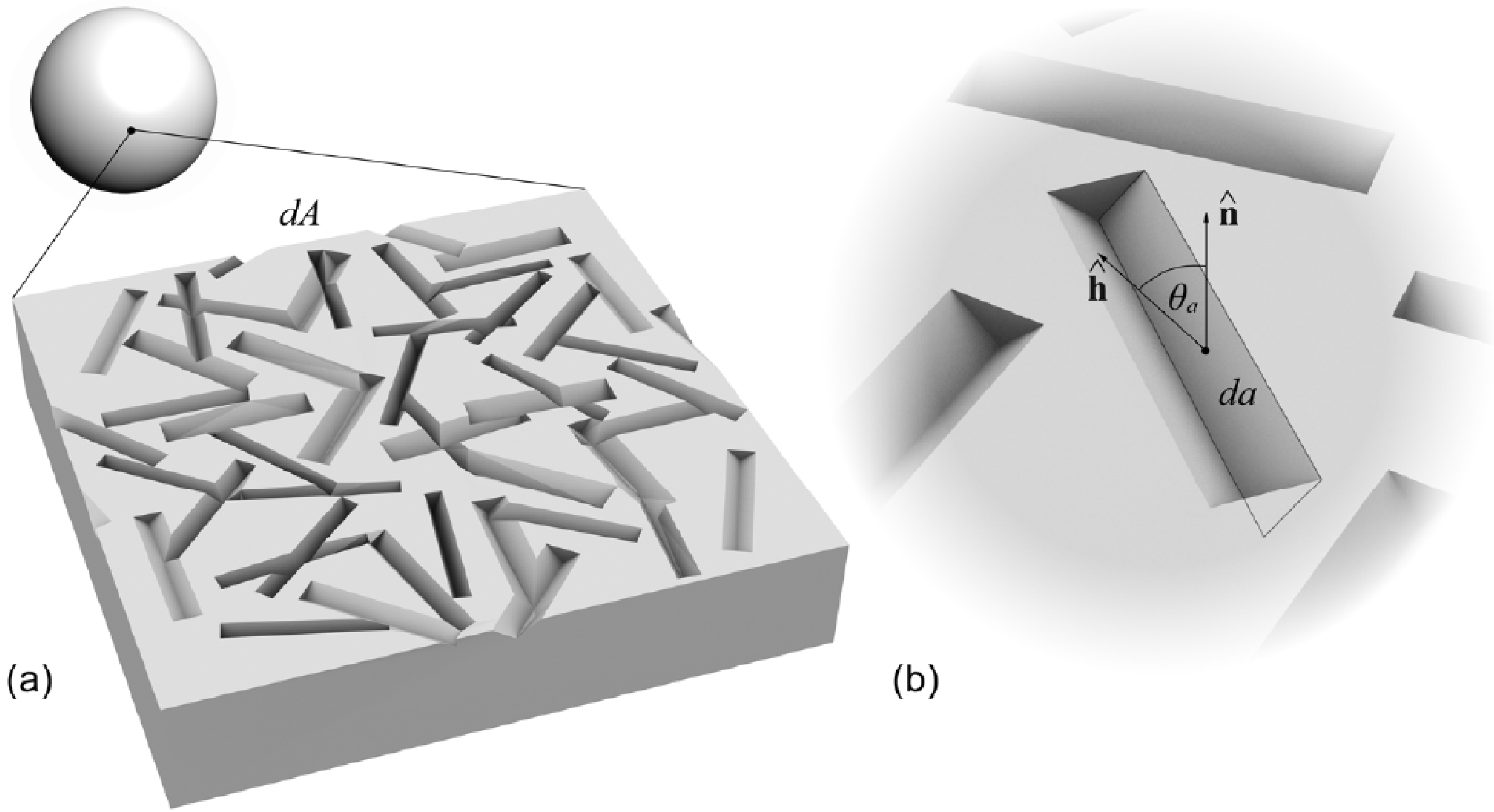
a being the angle between the halfway vector and the normal

Need for a Physically-based Reflectance Model

- The Blinn-Phong BRDF:
  - Requires the user to guess the coefficients k_s, k_d
  - These coefficients vary with angle of incidence
  - Cannot correctly model the behaviour of metals (different reflectivity at normal and grazing angles)
  - Is based on a counter-intuitive notion of an exponent to set the “glossiness” of a surface

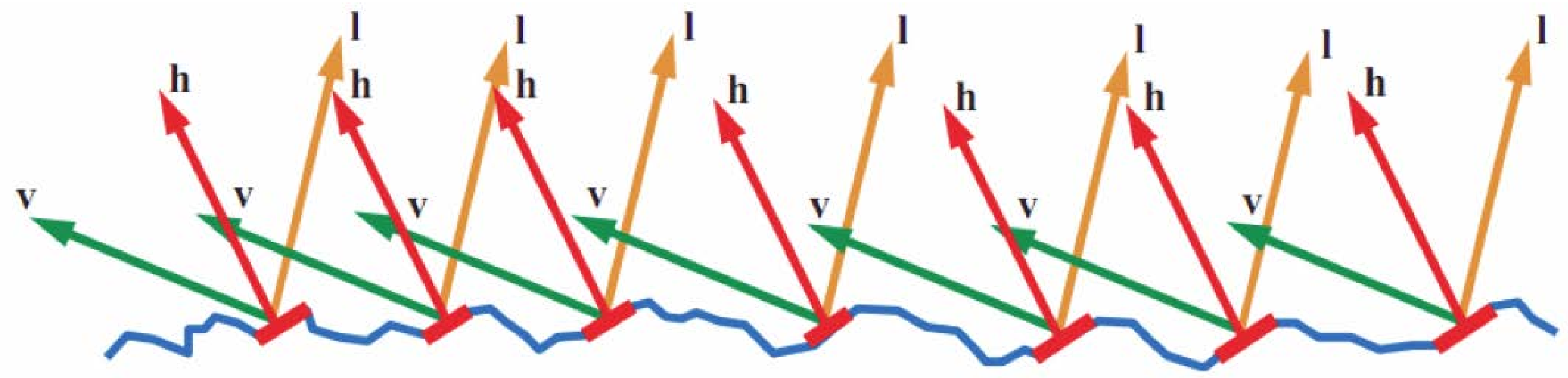
The Torrance – Sparrow Microfacet Model (1)

- Models arbitrarily "rough" surfaces
- Aggregation of V-shaped grooves



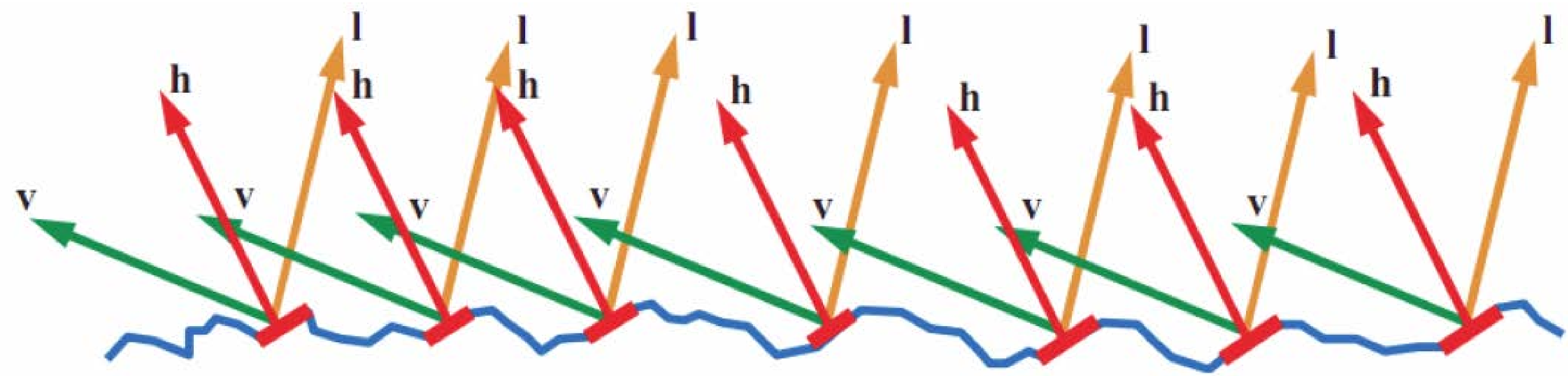
The Torrance – Sparrow Microfacet Model (2)

- Assumes surface is composed of many microfacets – individual optically flat surfaces too small to be seen
- Each microfacet reflects an incoming ray of light in only one outgoing direction (ideal reflector)
- Only those microfacets which happen to have their surface normal **m** oriented exactly halfway between $\mathbf{l}$ and $\mathbf{v}$ (i.e. $\mathbf{h}$)will reflect visible light



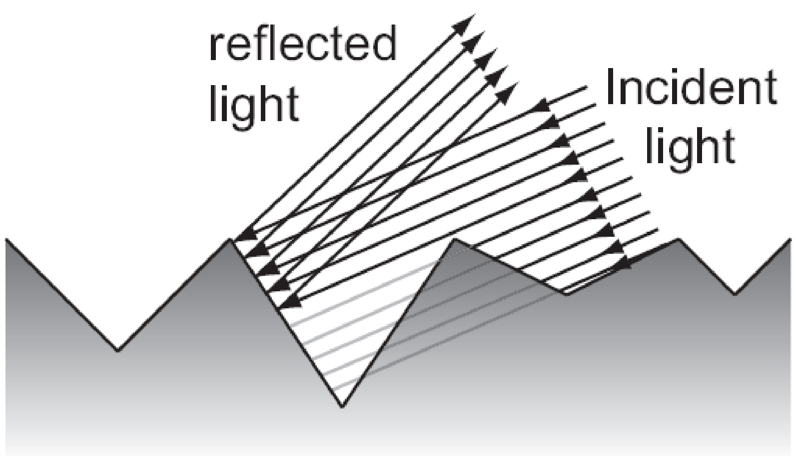
The Torrance – Sparrow Microfacet Model (3)

- Perfect mirror sides:
  - On/off contribution of micro-facets
  - Specular component proportional to fraction of facets facing in the **h** direction

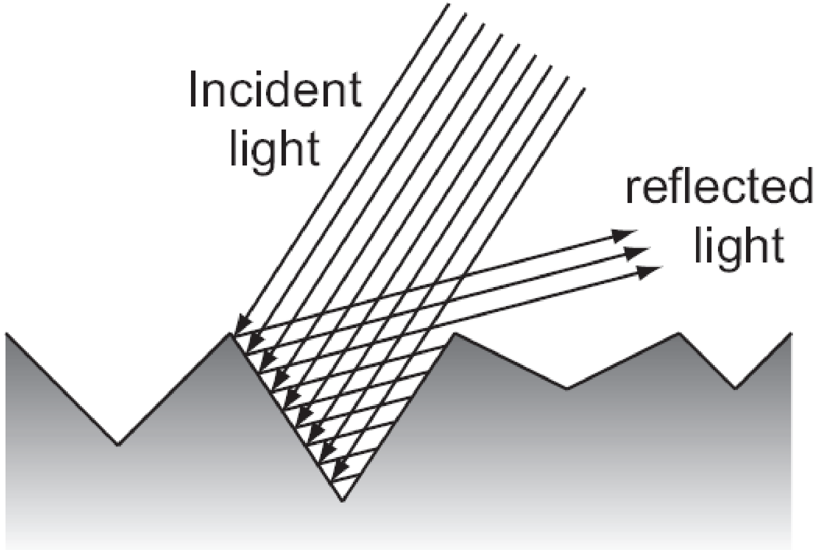


Shadowing and Masking

- Not all microfacets with $\mathbf{m} = \mathbf{h}$ will contribute
- Some will be blocked by other microfacets from either $\mathbf{l}$ (*shadowing*) or $\mathbf{v}$



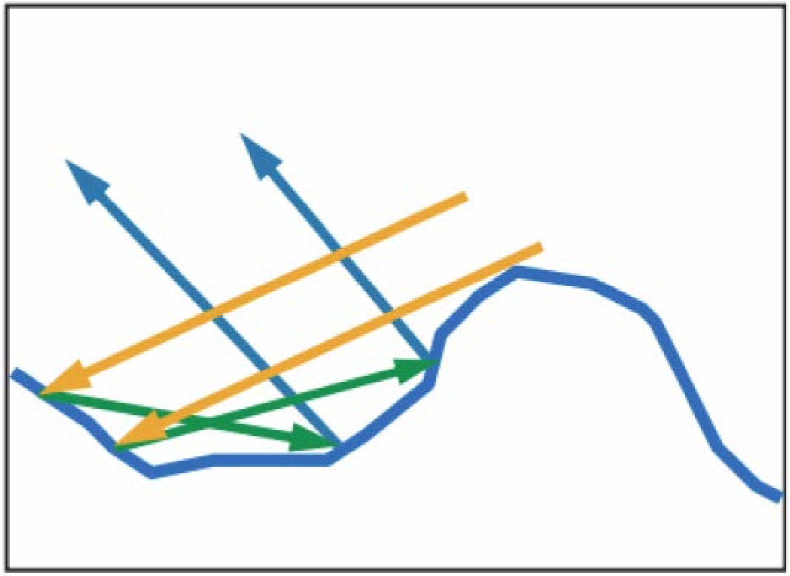
masking (shadow)



interception

Inter-reflections

- In reality, blocked light continues to bounce; some will eventually contribute to the BRDF
- Microfacet BRDFs ignore this – blocked light is lost (see Oren-Nayar model for inter-reflection contribution)



The Cook – Torrance Model (1)

- Uses the Torrance-Sparrow surface model
- Accounts for self-shadowing / masking light attenuation
- Accounts for directional reflectivity changes (Fresnel term)

The Cook – Torrance Model (2)

$$f_s = \frac{1}{\pi}\frac{DGF}{(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})}$$

- **D**istribution, **G**eometry, **F**resnel
- Saturates color to light source color with full brightness at grazing angles
- In the original model, maximum reflectivity if not attenuated (similar to Lambert diffuse scattering)

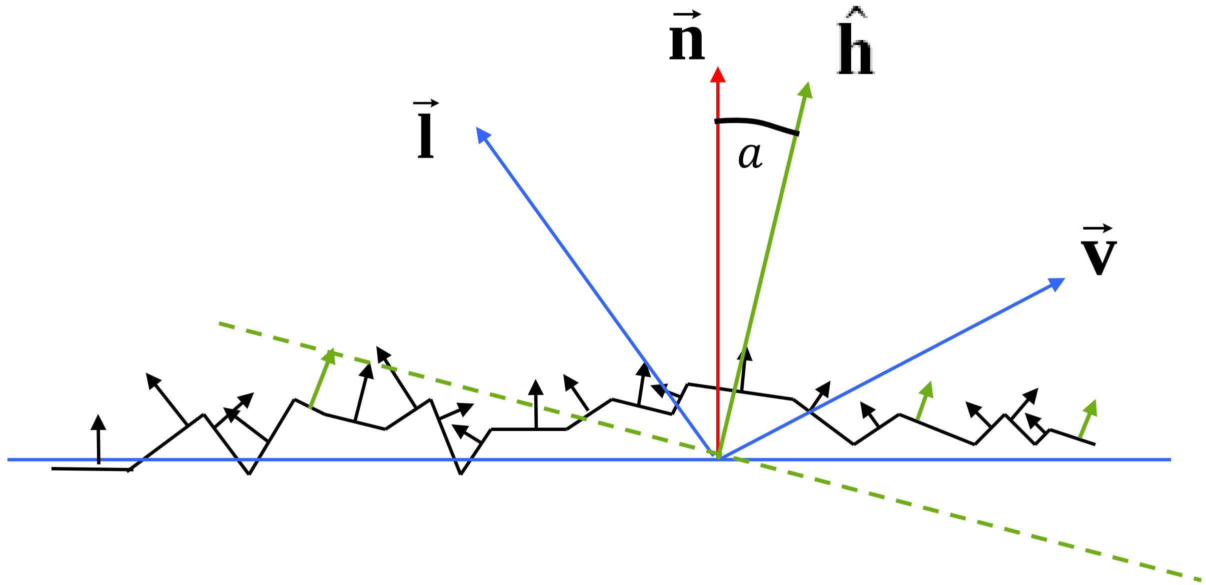
Cook – Torrance – Distribution Term (1)

- Represents the micro-facet density oriented along a direction $\mathbf{h}$
- It is a normalized term: expresses the fraction (probability) of facets turned towards $\mathbf{h}$
- Any distribution function can be used!
- Some reasonable ones though:
  - Gauss
  - Beckmann
  - Normalized Blinn-Phong

$$f_s = \frac{1}{\pi} \frac{DGF}{(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})}$$

Cook – Torrance – Distribution Term (2)

- An example:



$$D(a) = 3/21$$

Cook – Torrance – Distribution Term (2)

Beckmann Distribution:

- Typically used in BRDFs

$$D(a) = \frac{e^{-\frac{\tan^2 a}{m^2}}}{\pi m^2 \cos^4 a}, \qquad a = \mathrm{acos}(\mathbf{n} \cdot \mathbf{h})$$

- Physically-based: m represents the RMS slope of the micro-facets
  - $m \to 0$: polished materials (caution with near zero values)

Cook – Torrance – Distribution Term (3)

Beckmann Distribution:

- Relatively expensive (not preferred for RT graphics)
- A faster alternative (no acos(), no tan(), just dot products):

$$D(a) = \frac{e^{-\boxed{\frac{\tan^2 a}{m^2}}}}{\pi m^2 \cos^4 a}$$

$$\tan^2 a = \frac{\sin^2 a}{\cos^2 a} = \frac{1 - \cos^2 a}{\cos^2 a}, \qquad \cos a = \mathbf{n} \cdot \mathbf{h}$$

Cook – Torrance – Distribution Term (4)

Beckmann distribution example

No other factor apart from the $\mathbf{n} \cdot \mathbf{l}$ and the Beckmann distribution of micro-facets:

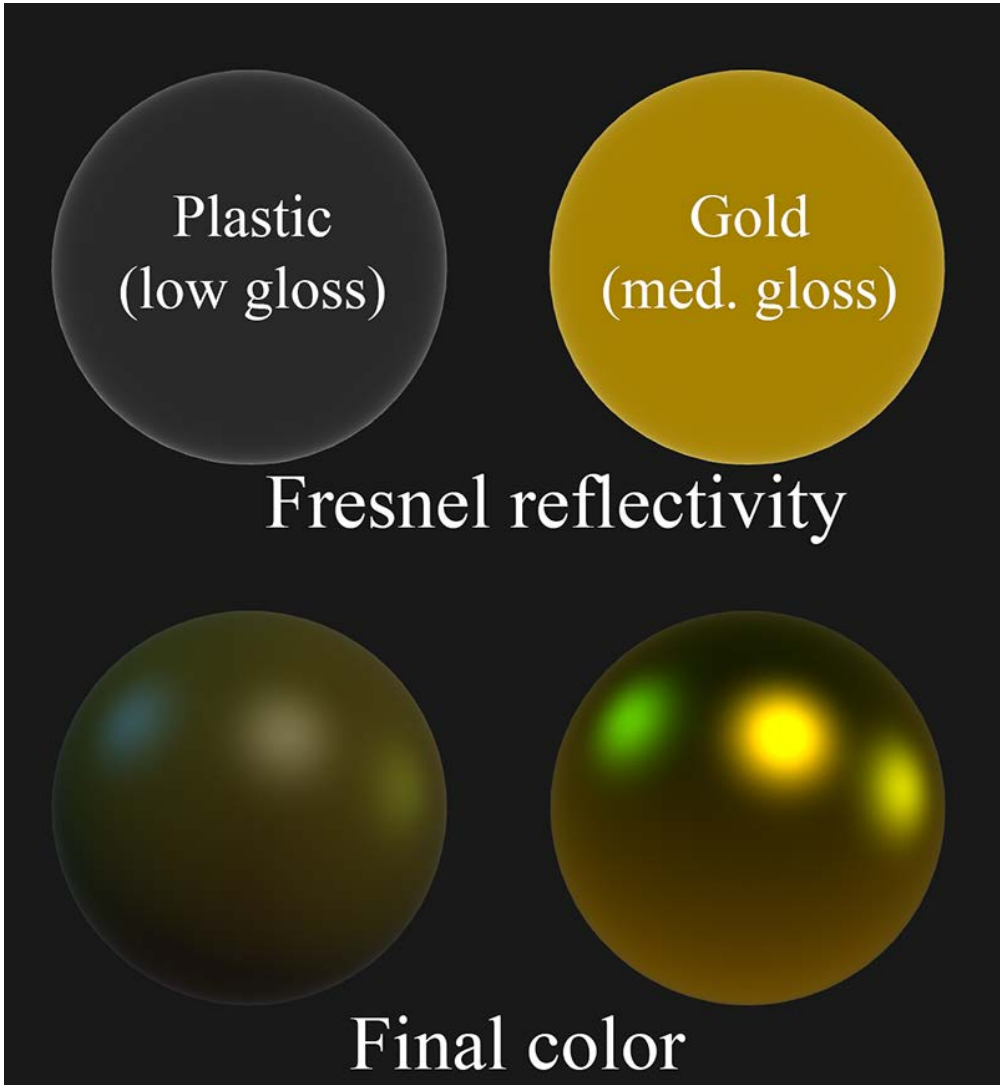
Cook – Torrance – Fresnel Term (1)

- Fraction of light reflected from optically flat surface given light direction $\mathbf{l}$ and surface normal $\mathbf{h}$
- Value range: 0 to 1, spectral (RGB)
- Transmitted light = 1 - reflected

$$f_s = \frac{1}{\pi}\frac{DG\boldsymbol{F}}{(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})}$$

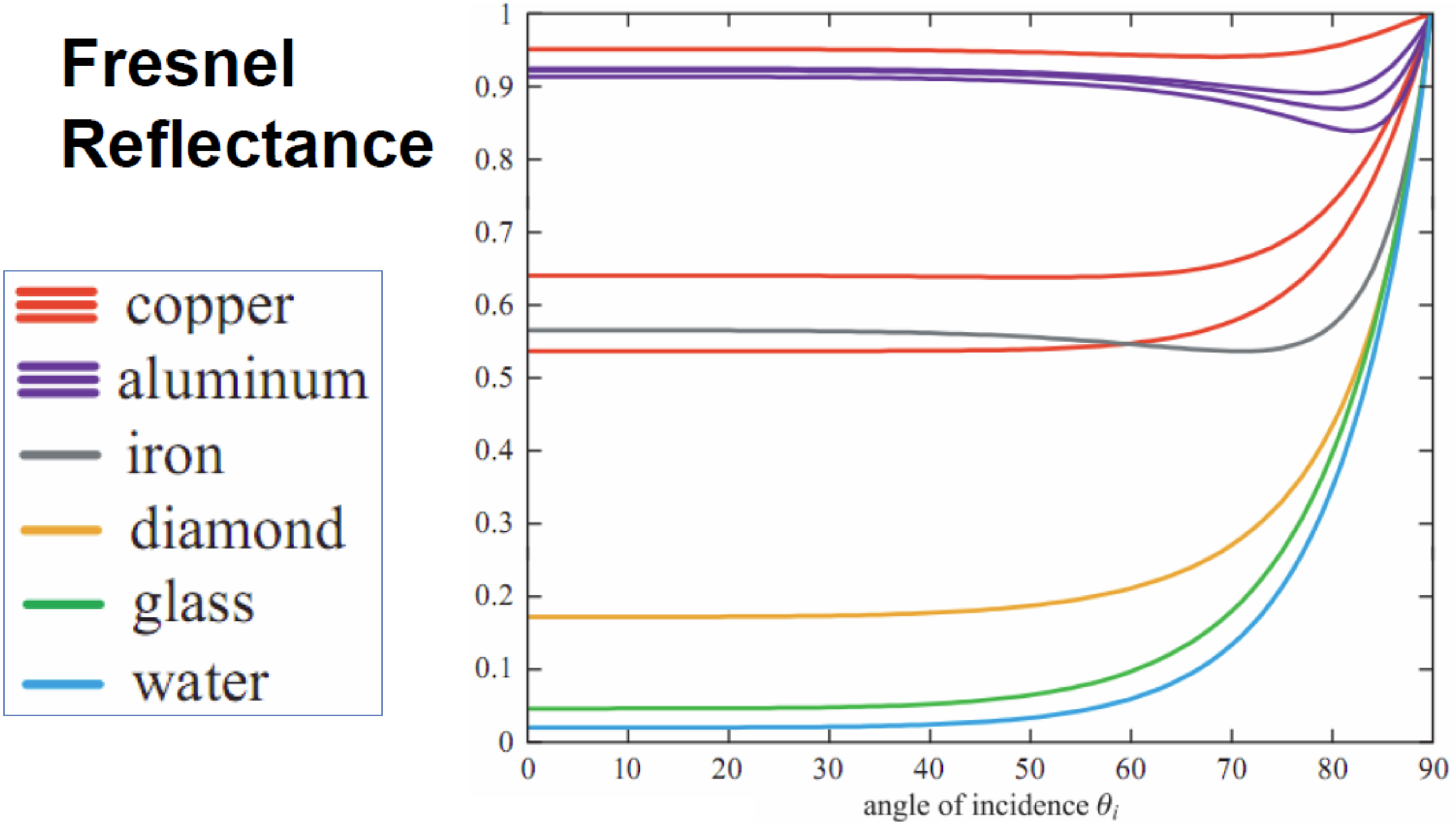
Cook – Torrance – Fresnel Term (2)

- Depends on refractive index and light angle
  - As angle increases, at first the reflectance barely changes, then for very glancing angles goes to 1 at all wavelengths



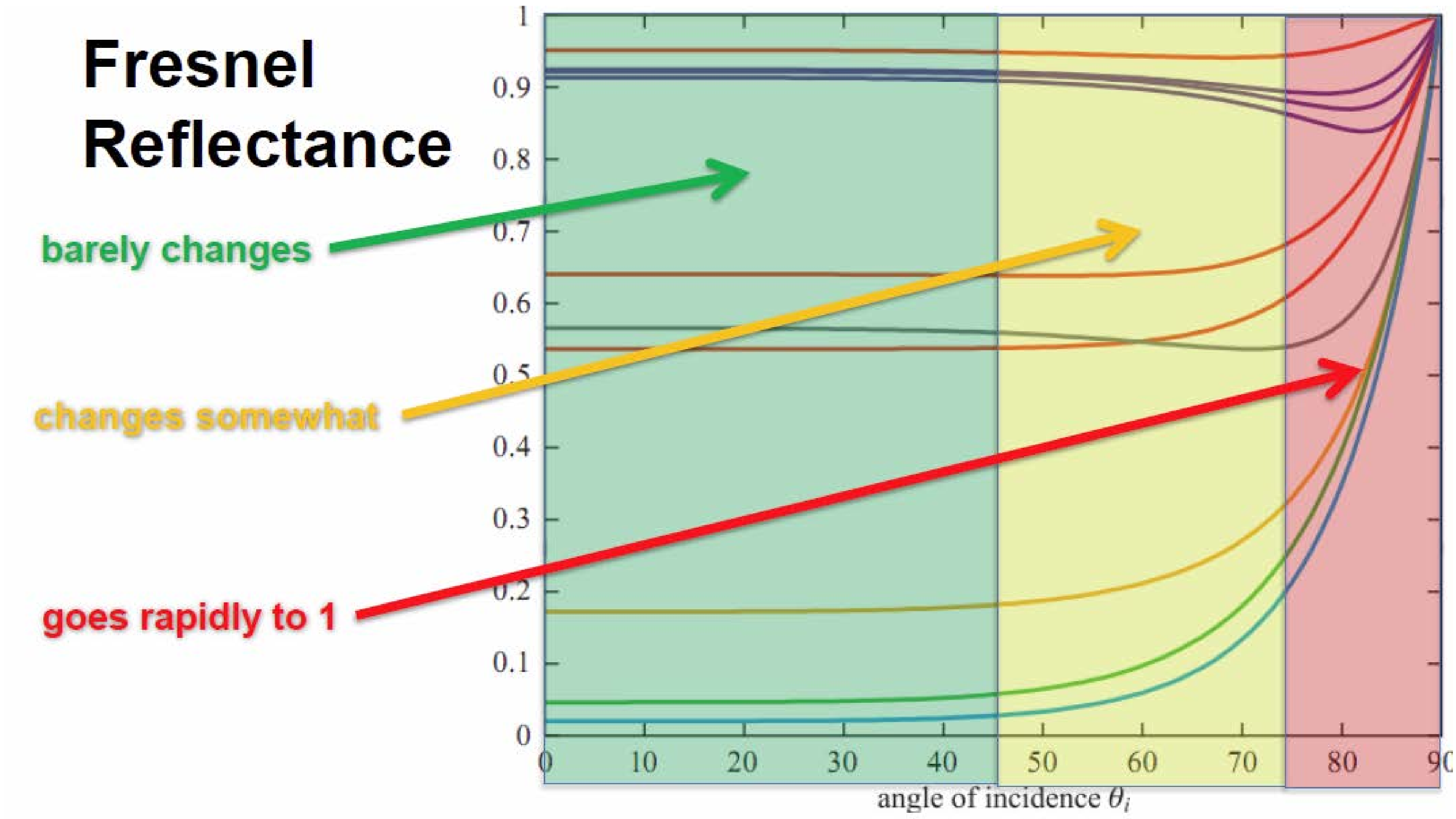
Cook – Torrance – Fresnel Term (3)

Fresnel Reflectance



Source: [PBSM]

Cook – Torrance – Fresnel Term (4)



Source: [PBSM]

Cook – Torrance – Fresnel Term (5)

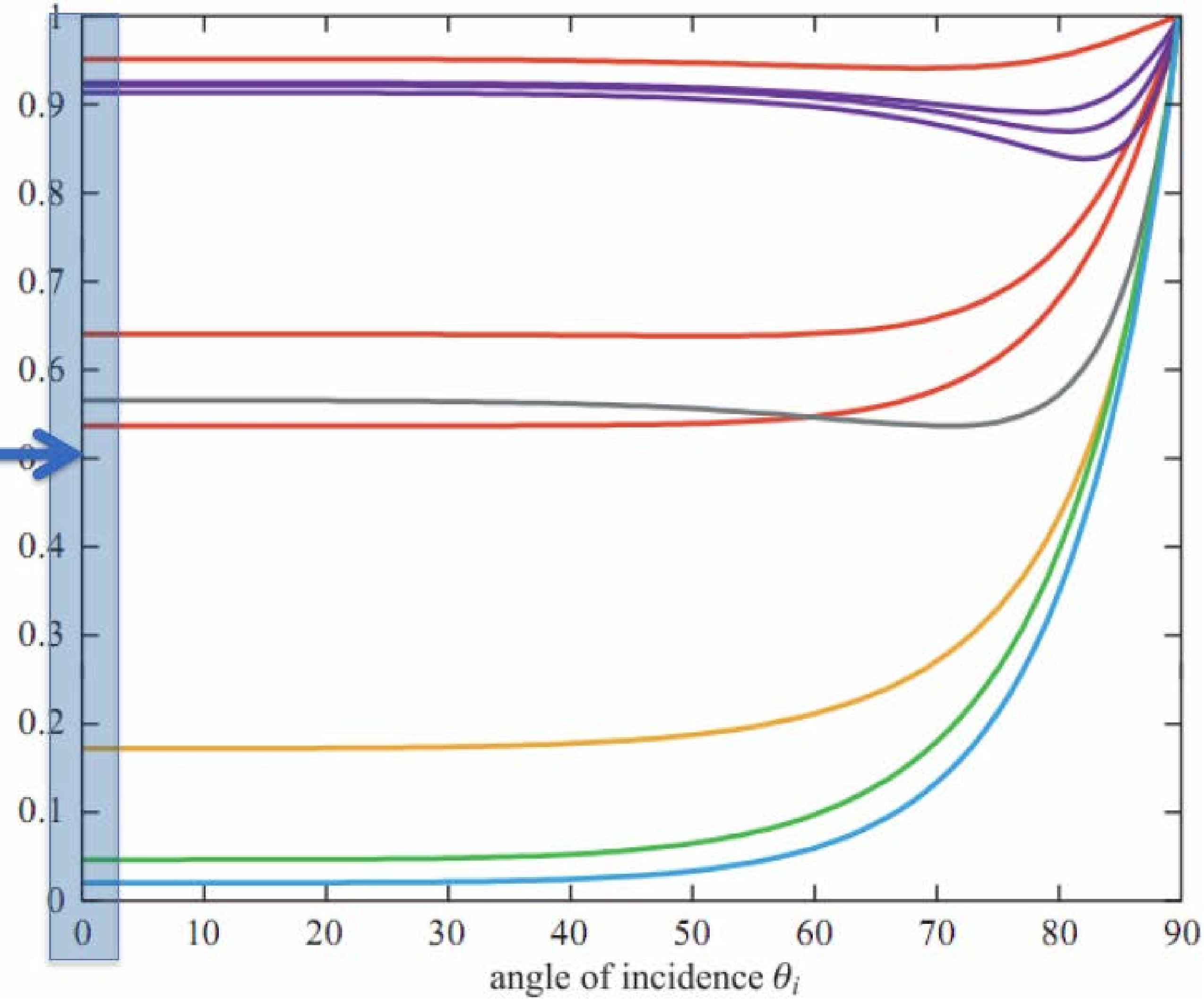
Fresnel Reflectance

The normal-incidence Fresnel reflectance:

$F(0°)$

Is the surface's characteristic specular color :

$\mathbf{c}_{spec}$



Source: [PBSM]

Cook – Torrance – Fresnel Term (6)

Normal-Incidence Fresnel for Metals

- No subsurface term; this is only source of color

Metal	$F(0°)$ (Linear)	$F(0°)$ (sRGB)	Color
Gold	1.00,0.71,0.29	1.00,0.86,0.57	
Silver	0.95,0.93,0.88	0.98,0.97,0.95	
Copper	0.95,0.64,0.54	0.98,0.82,0.76	
Iron	0.56,0.57,0.58	0.77,0.78,0.78	
Aluminum	0.91,0.92,0.92	0.96,0.96,0.97	

Source: [PBSM]

Cook – Torrance – Fresnel Term (7)

Normal-Incidence Fresnel for Non-Metals

- Subsurface term (diffuse) usually also present in addition to this Fresnel reflectance

Insulator	$F(0°)$ **(Linear)**	$F(0°)$ **(sRGB)**	**Color**
Water	0.02,0.02,0.02	0.15,0.15,0.15	
Plastic / Glass (Low)	0.03,0.03,0.03	0.21,0.21,0.21	
Plastic High	0.05,0.05,0.05	0.24,0.24,0.24	
Glass (High) / Ruby	0.08,0.08,0.08	0.31,0.31,0.31	
Diamond	0.17,0.17,0.17	0.45,0.45,0.45	

Cook – Torrance – Fresnel Term (8)

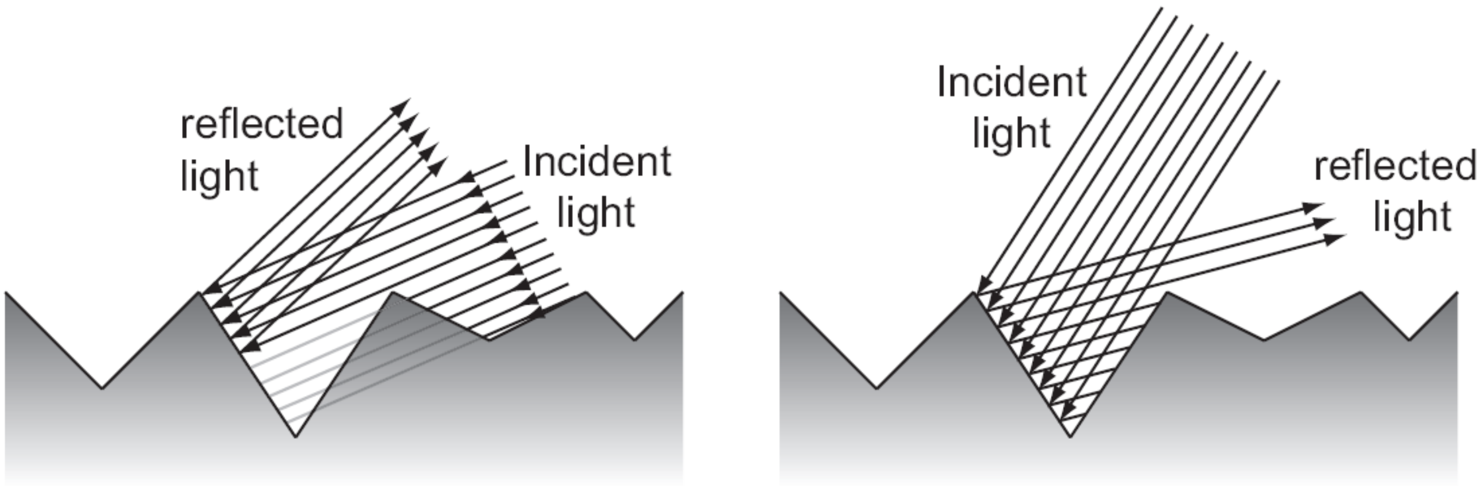
- Fresnel equations produce the reflectivity of polarized and unpolarized light
- A simple formula can approximate reasonably the reflectivity for unpolarized light (Schlick approximation formula):

$$F_{Schlick} = c_0 + (1 - c_0)(1 - \mathbf{l} \cdot \mathbf{h})^5$$

Cook – Torrance – Geometric Term (1)

- Accounts for the loss of light due to either light interception or shadowing

$$f_s = \frac{1}{\pi} \frac{DGF}{(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})}$$

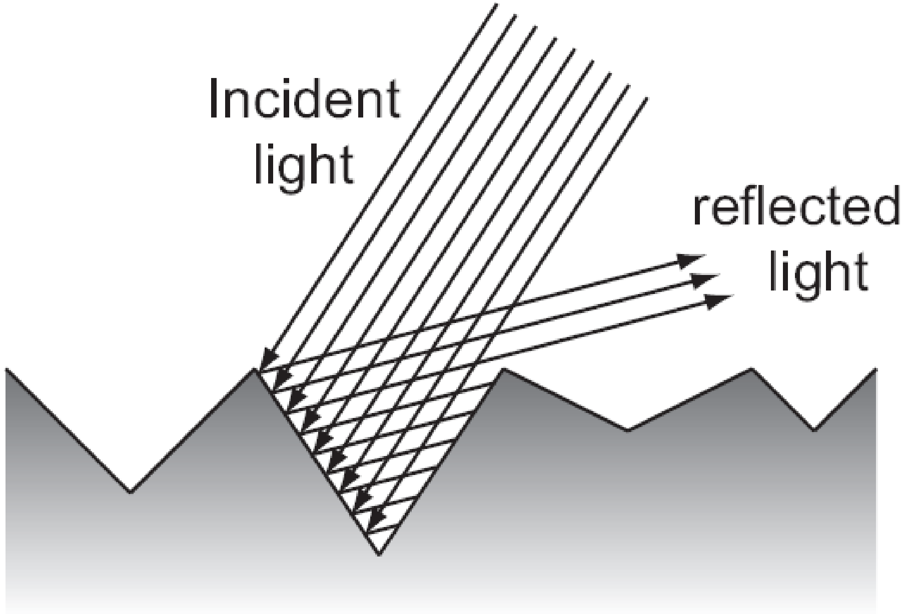


masking (shadow)

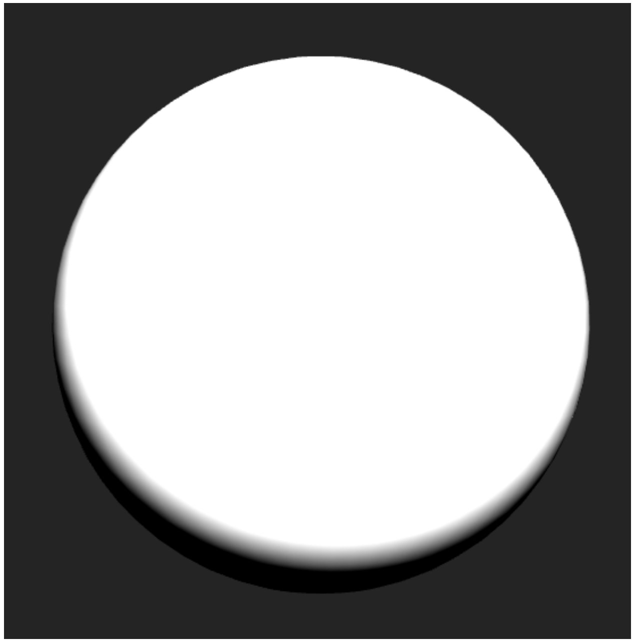
interception

Cook – Torrance – Geometric Term (2)

$$G_{\text{intercept}} = \frac{2(\hat{\mathbf{n}} \cdot \hat{\mathbf{h}})(\hat{\mathbf{n}} \cdot \hat{\mathbf{v}})}{\hat{\mathbf{v}} \cdot \hat{\mathbf{h}}}$$



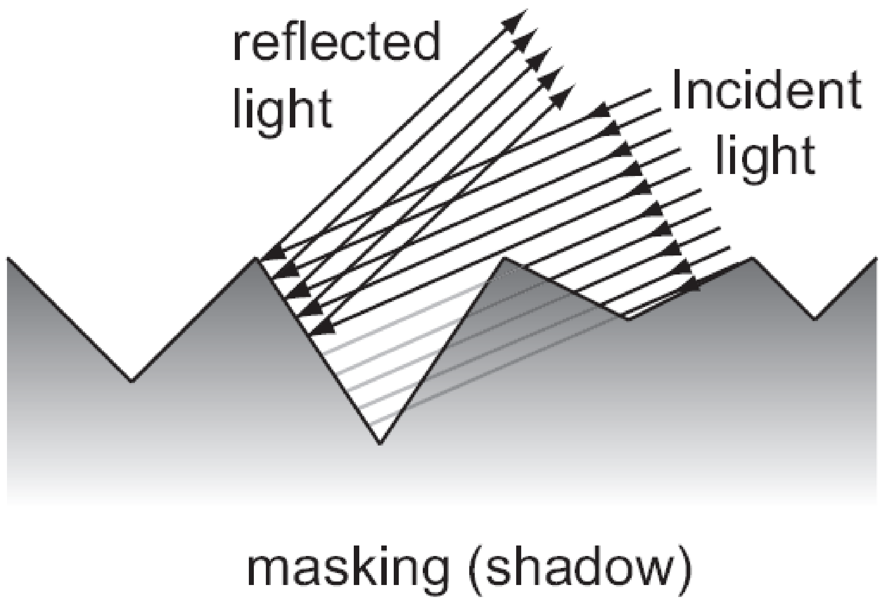
interception

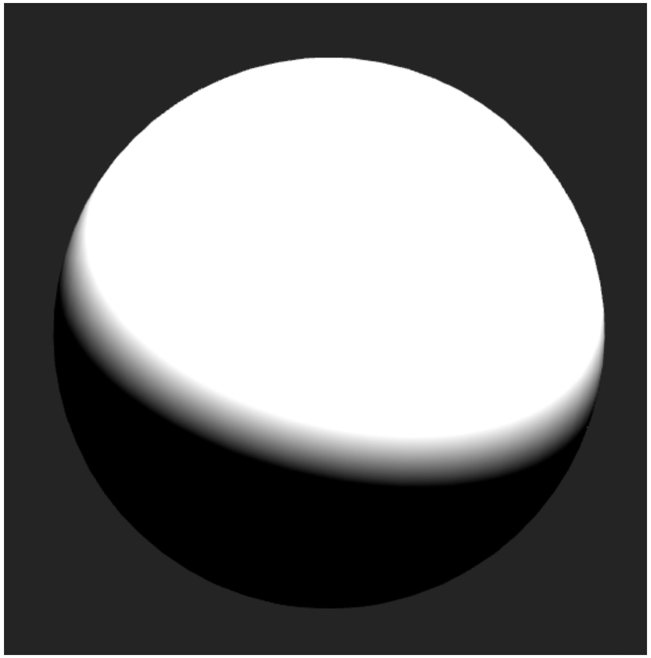


Cook – Torrance – Geometric Term (3)

- If we swap the roles of light and view direction:

$$G_{\text{shadow}} = \frac{2(\hat{\mathbf{n}} \cdot \hat{\mathbf{h}})(\hat{\mathbf{n}} \cdot \hat{\mathbf{l}})}{\hat{\mathbf{l}} \cdot \hat{\mathbf{h}}} = \frac{2(\hat{\mathbf{n}} \cdot \hat{\mathbf{h}})(\hat{\mathbf{n}} \cdot \hat{\mathbf{l}})}{\hat{\mathbf{v}} \cdot \hat{\mathbf{h}}}$$



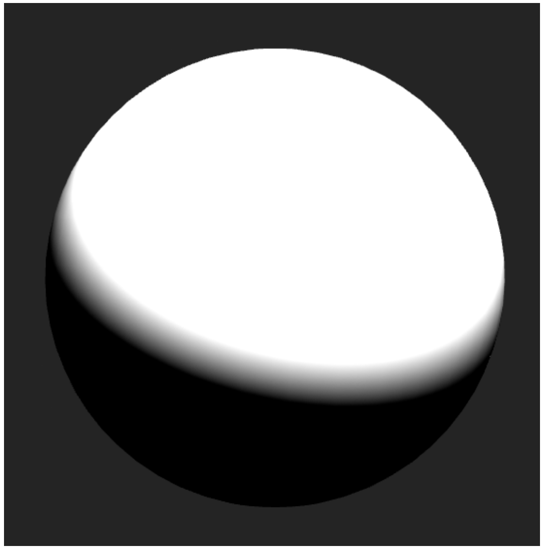


Cook – Torrance – Geometric Term (3)

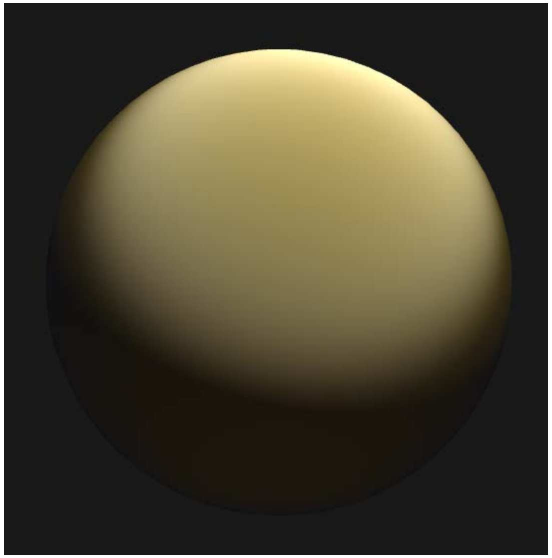
- Combining both and keeping the most dominant (smallest) factor:

$$G = \min\left\{1, \frac{2(\hat{\mathbf{n}}\cdot\hat{\mathbf{h}})(\hat{\mathbf{n}}\cdot\hat{\mathbf{v}})}{\hat{\mathbf{v}}\cdot\hat{\mathbf{h}}}, \frac{2(\hat{\mathbf{n}}\cdot\hat{\mathbf{h}})(\hat{\mathbf{n}}\cdot\hat{\mathbf{l}})}{\hat{\mathbf{v}}\cdot\hat{\mathbf{h}}}\right\}$$

Combined G

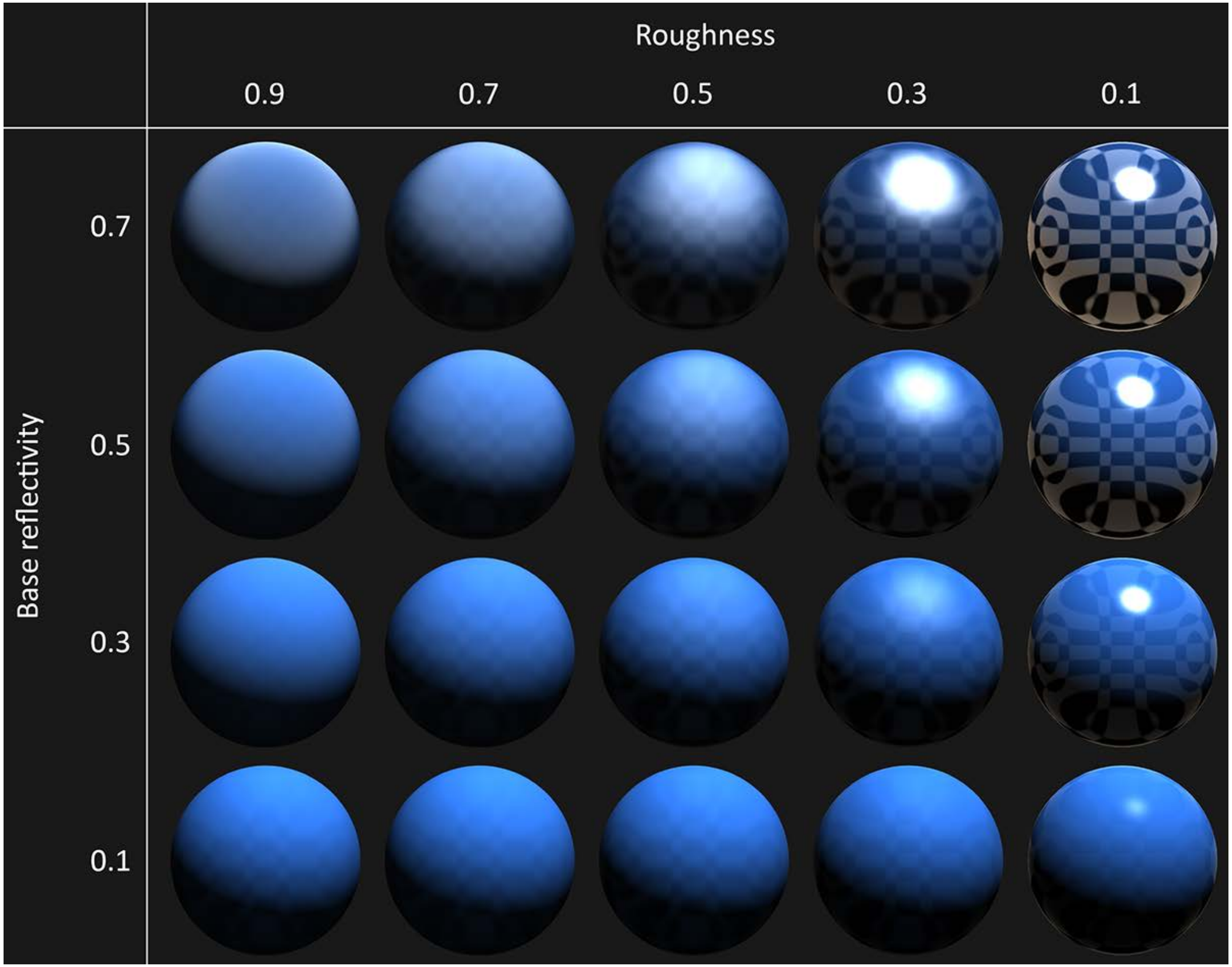


Without G



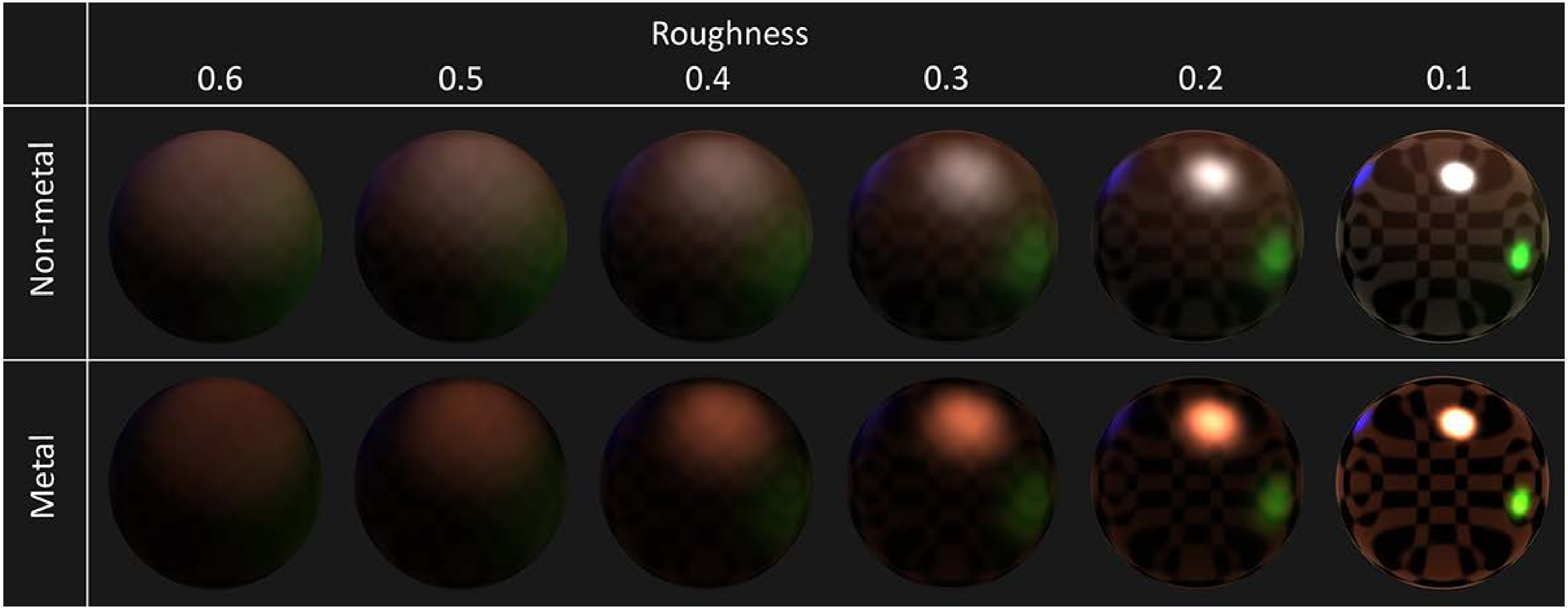
With G

Cook Torrance – Comparison (1)



Non-metal

Cook Torrance – Comparison (2)



Working with Shading Models

- Implementing a shading model (correctly) requires:
  - Understanding what quantities we handle within our rendering system (radiance, intensity, flux, irradiance etc)
  - A firm grasp of the conversions between the above
  - Understanding what the visible (fragment) geometry represents
  - Correct definition of light sources and their properties
  - Properly normalized (energy-conserving) models

Plausible Shading – Measuring Light

- For area lights, we typically sample radiance from points on their surface
- For point lights, the above process has no meaning
- We rather rely on the intensity of the source for that:
  - Given the total flux of the source Φ:
  - $\Phi = \int_{sphere} I(\omega)\,\mathrm{d}\omega \xrightarrow{uniform} \Phi = 4\pi I \Rightarrow I = \Phi/4\pi$
  - For point sources sufficiently far from a shaded point, $L_i \approx I/r^2$, r the distance to the light source

Plausible Shading – BRDFs

- Use energy conserving BRDFs
  - Make sure to balance the reflected vs transmitted (diffuse + sub. scattered + refracted) energy
  - Use the Fresnel terms for this
  - Take care of metallic surfaces (remember they do not transmit / scatter light from the surface substrate)

- See separate example shader (demo) for putting all these together

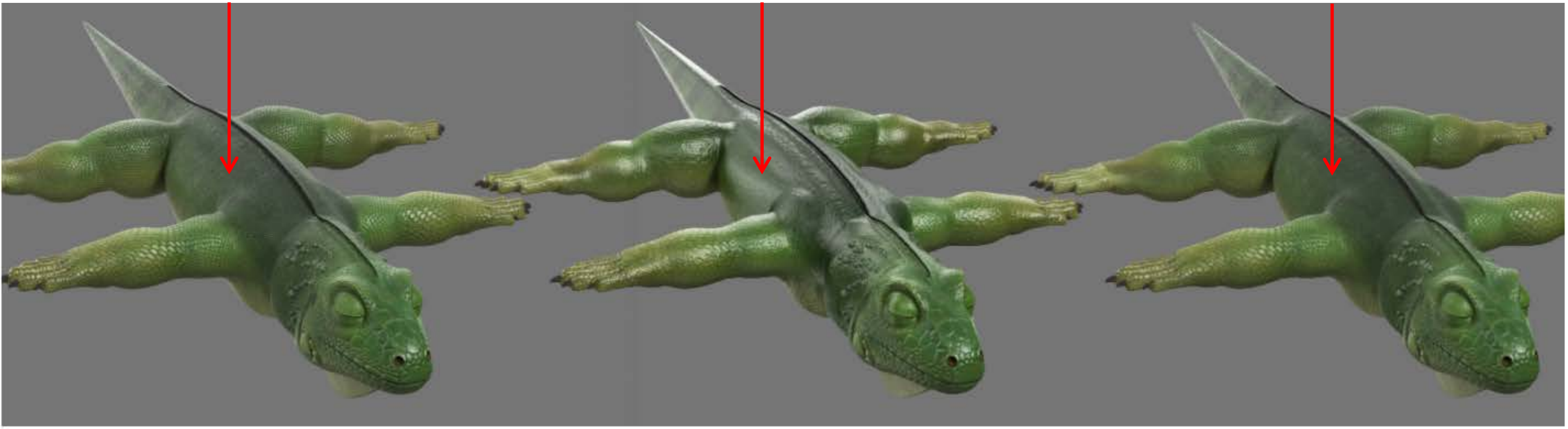
Plausible Shading – The Scale Effect

- Remember, micro-facet geometry behaves differently at different scales
  - You may need to introduce macro-scale irregularities into the BRDF roughness for distant objects

Ground truth

Incorrect shading: skin bumps now at micro-facet level!

Corrected



http://graphics.pixar.com/library/BumpRoughness/paper.pdf

Plausible Shading - Texturing

- Event the most perfect surfaces exhibit subtle details that vary spatially
- We provide texturing for important attributes of the surface to simulate reality (weathering, chaotic structure etc.)

Contributors

- Georgios Papaioannou

- Sources:
  - [PBSM] SIGGRAPH 2010 Course: Physically Based Shading Models in Film and Game Production
  - T. Theoharis, G. Papaioannou, N. Platis, N. M. Patrikalakis, Graphics & Visualization: Principles and Algorithms, CRC Press