COMPSCI 715 Part 2

Lecture 8 - Advanced Lighting and Materials

OpenGL Model

- Ambient illumination, diffuse reflection, and specular highlights
- Basic materials properties
- Uses combination of Phong and Gouraud
- Limited to particular types of materials
- *Phenomenological* model

OpenGL's Phong based Illumination

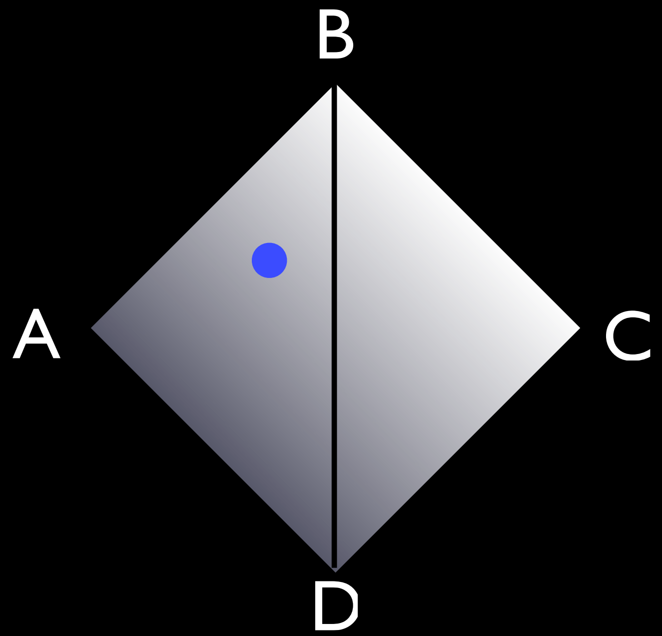
- Most common lighting model (taught in 372)
- $\text{Colour}_{pixel} = \text{Amb}_{mat} \times \text{Amb}_{scene}$

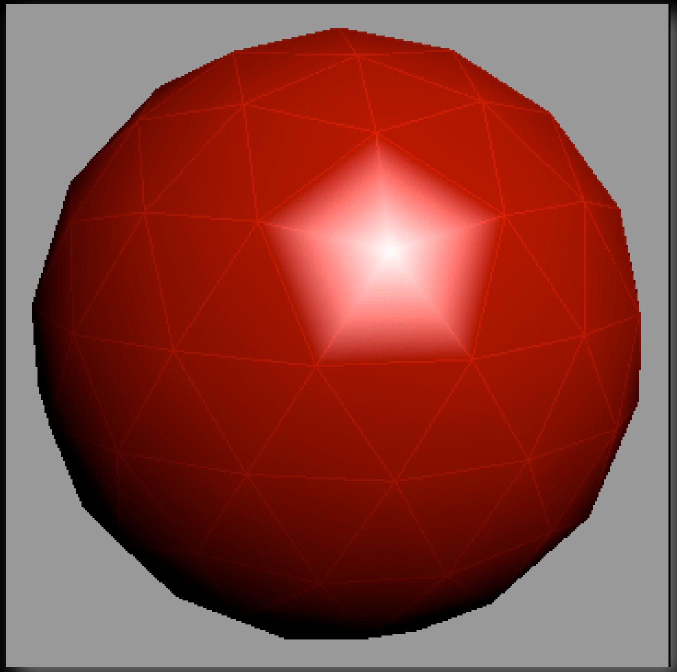
  $+ \max(L \cdot N, 0) \times \text{Diff}_{mat} \times \text{Diff}_{light}$

  $+ \max((L+E) \cdot N, 0)^{shine} \times \text{Spec}_{mat} \times \text{Spec}_{light}$
  - L+E is known as the 'half-angle vector'
- Attenuation = $1/(k_c + k_l d + k_q d^2)$

Gouraud Interpolation

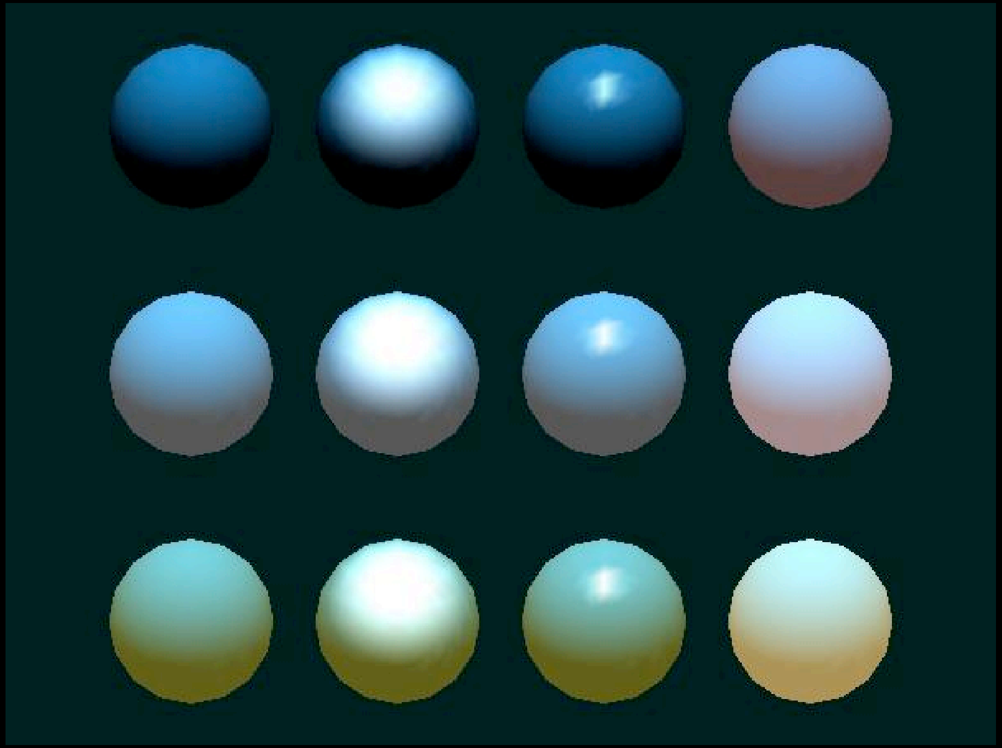
- Lighting calculation done per-vertex
- Interpolation across surface:
  - Rotationally independent (if triangles)





Material Properties

- OpenGL allows material properties to be specified as part of state:
  - ambient, diffuse, specular reflection coefficients
  - shininess factor



Material Properties

- Tables of commonly used properties exist:

Name	Ambient			Diffuse			Specular			Shininess
emerald	0.0215	0.1745	0.0215	0.07568	0.61424	0.07568	0.633	0.727811	0.633	0.6
jade	0.135	0.2225	0.1575	0.54	0.89	0.63	0.316228	0.316228	0.316228	0.1
obsidian	0.05375	0.05	0.06625	0.18275	0.17	0.22525	0.332741	0.328634	0.346435	0.3
pearl	0.25	0.20725	0.20725	1	0.829	0.829	0.296648	0.296648	0.296648	0.088
ruby	0.1745	0.01175	0.01175	0.61424	0.04136	0.04136	0.727811	0.626959	0.626959	0.6
turquoise	0.1	0.18725	0.1745	0.396	0.74151	0.69102	0.297254	0.30829	0.306678	0.1
brass	0.329412	0.223529	0.027451	0.780392	0.568627	0.113725	0.992157	0.941176	0.807843	0.21794872
bronze	0.2125	0.1275	0.054	0.714	0.4284	0.18144	0.393548	0.271906	0.166721	0.2
chrome	0.25	0.25	0.25	0.4	0.4	0.4	0.774597	0.774597	0.774597	0.6
copper	0.19125	0.0735	0.0225	0.7038	0.27048	0.0828	0.256777	0.137622	0.086014	0.1
gold	0.24725	0.1995	0.0745	0.75164	0.60648	0.22648	0.628281	0.555802	0.366065	0.4
silver	0.19225	0.19225	0.19225	0.50754	0.50754	0.50754	0.508273	0.508273	0.508273	0.4

BRDF

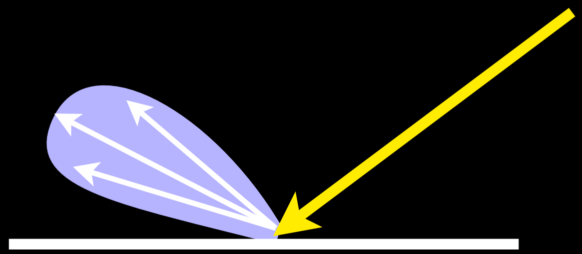
- *Bidirectional Reflectance Distribution Function*
- Given a normal (N) computes light reflected towards the eye (E) due to light from direction (L)
- Denoted BRDF(L,E;N, *params*)

BRDF Constraints

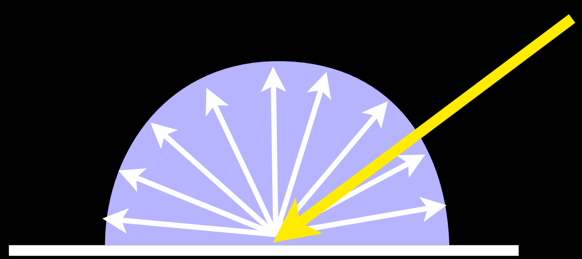
- Two constraints:
  - Reciprocity: BRDF(L,E;N) == BRDF(E,L;N)
  - Energy Conservation:
    - Incident Light = Reflected + Absorbed + Transmitted

BRDF Components

- Two components:
  - Glossy / specular



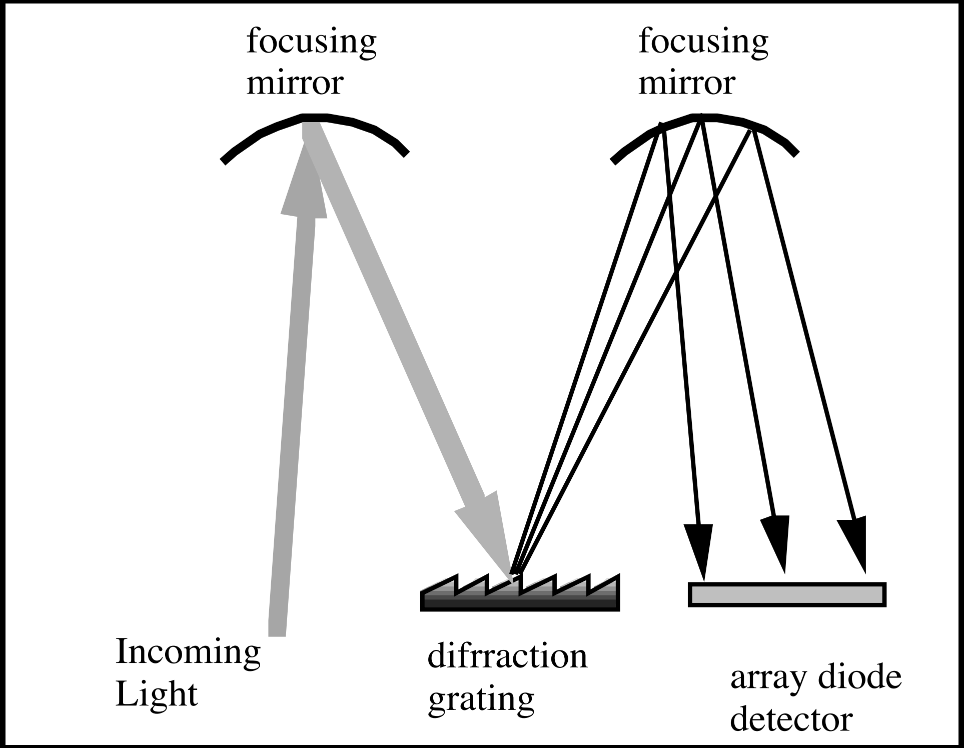
  - Diffuse / Lambertian

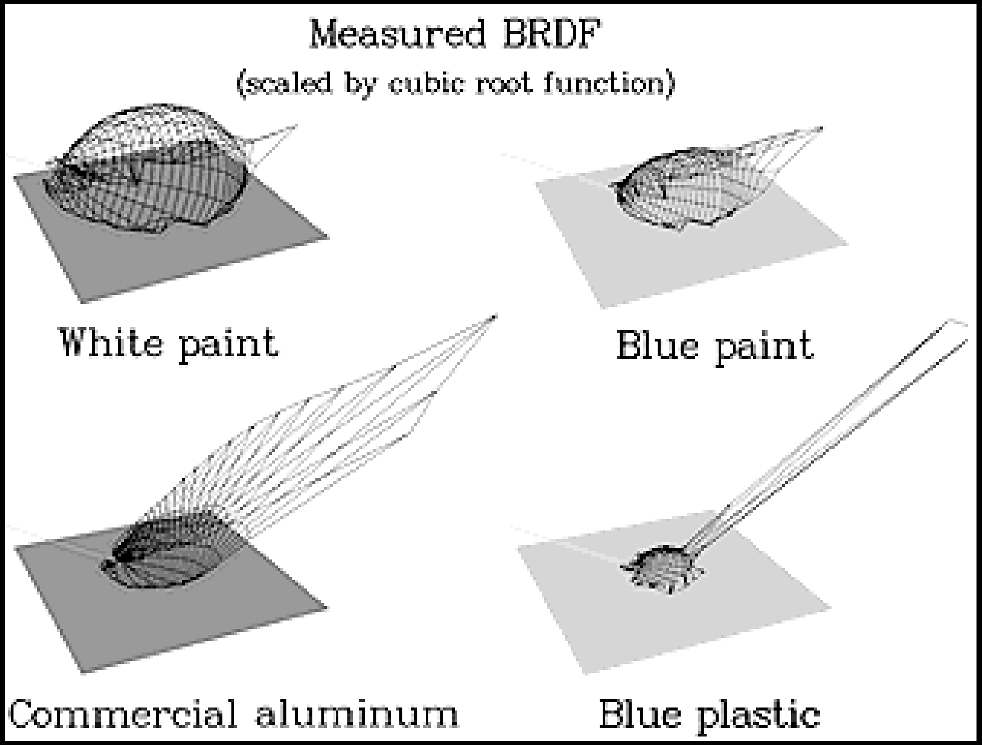


BRDF Types

- Creation Methods:
  - Analytical / Observation-based
  - Emperical / Physically-based
- Model Types:
  - Anisotropic
  - Isotropic

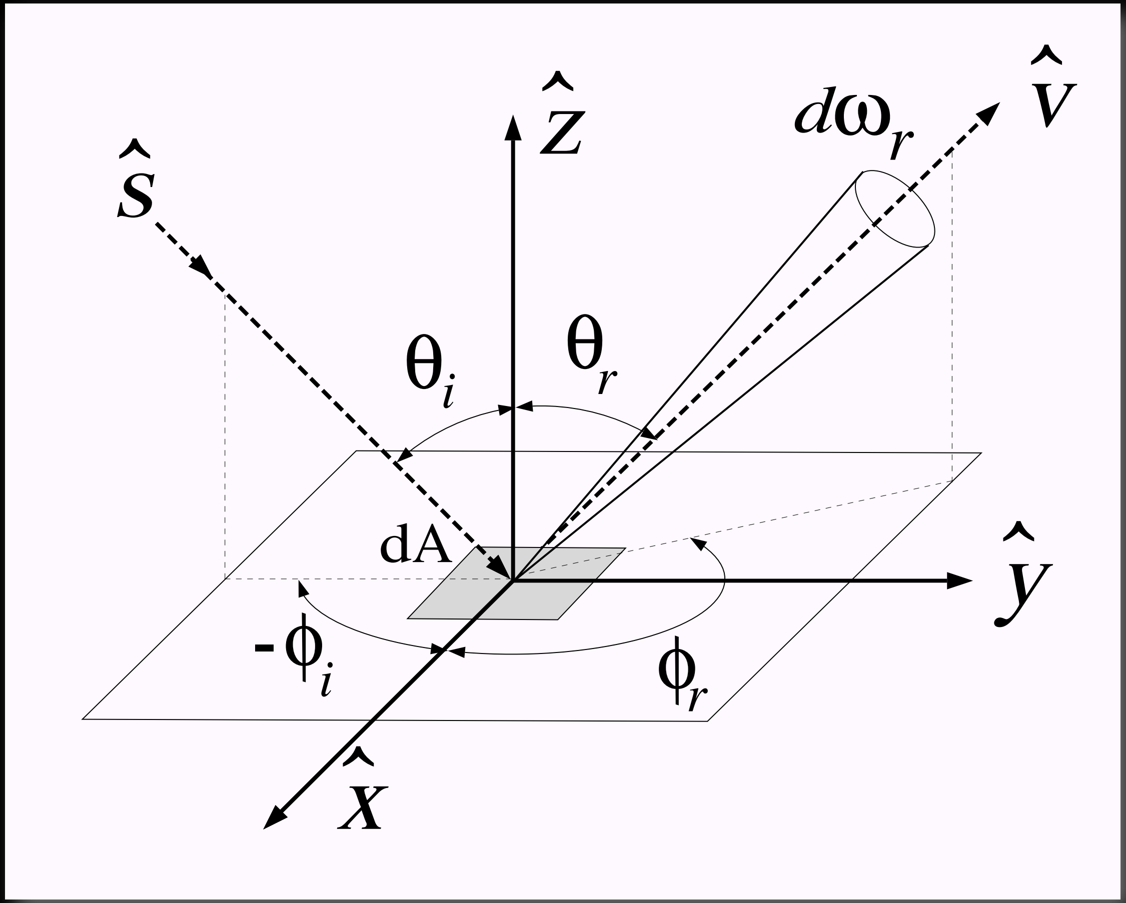
BRDF Measuring





Source: Greenberg et al.

BRDF



Lambertian

- Models perfectly diffuse surfaces
- Proportional to angle of incidence

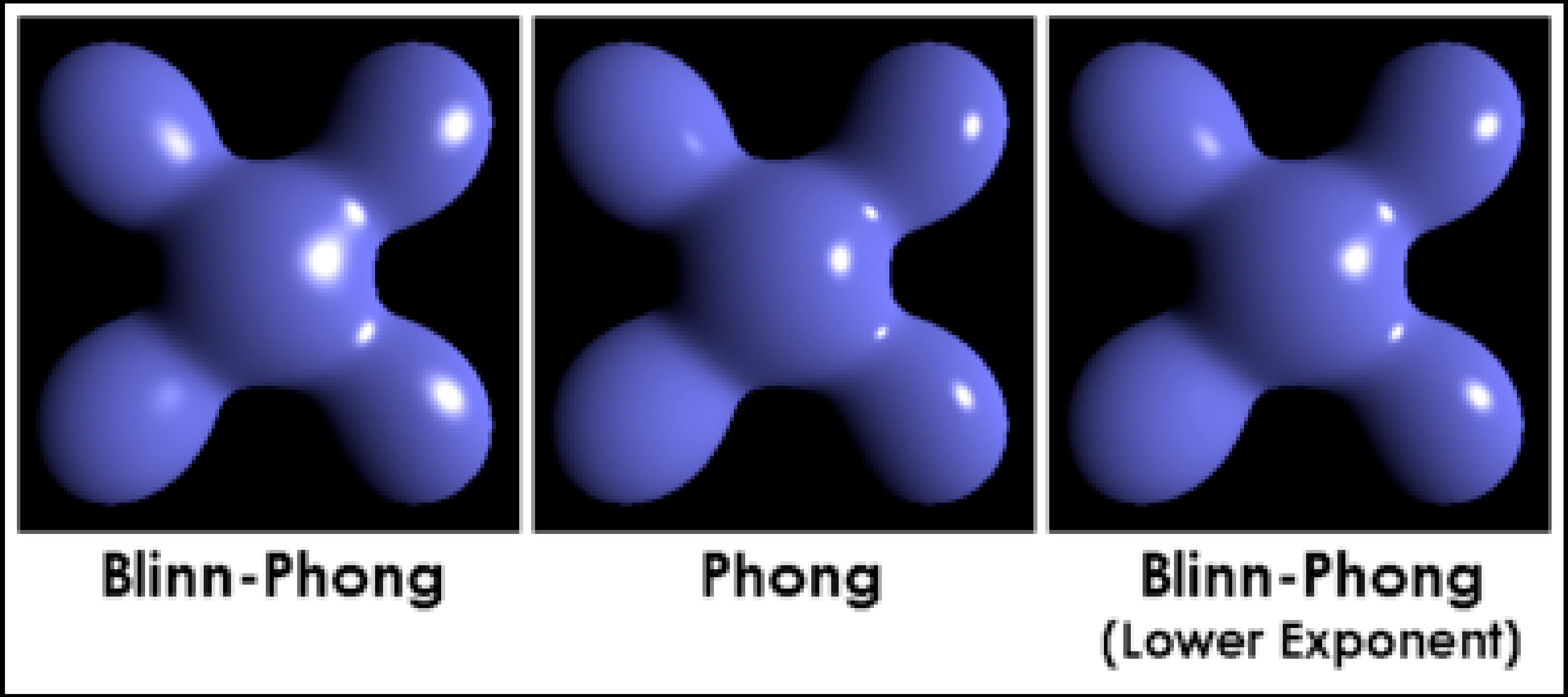
$$f_r(\lambda) = \frac{\cos\theta_i}{\pi} k_d(\lambda)$$

Blinn-Phong as BRDF

- Blinn-Phong is not reciprocal or energy conserving unless we reformulate:
  - $Colour_{pixel} = Diff_{light}$

    $+ \max((L+E) \cdot N, 0)^{shine} x Spec_{light}$
  - $Diff_{light} = (1 - Spec_{light})$

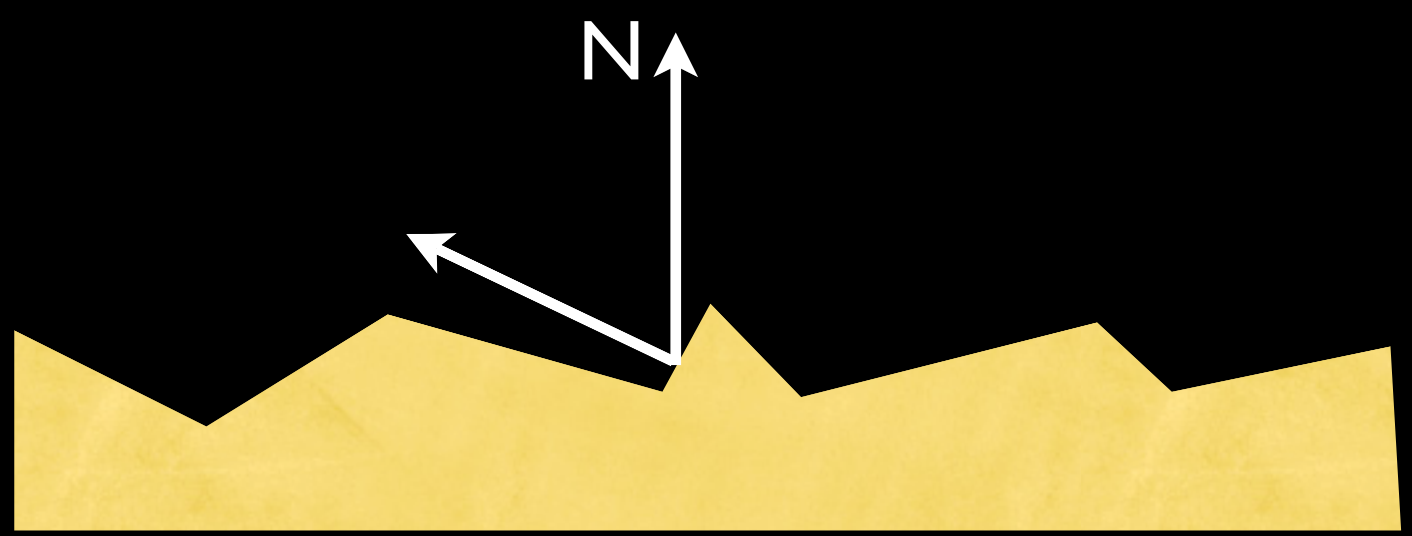
Phong vs. Blinn-Phong



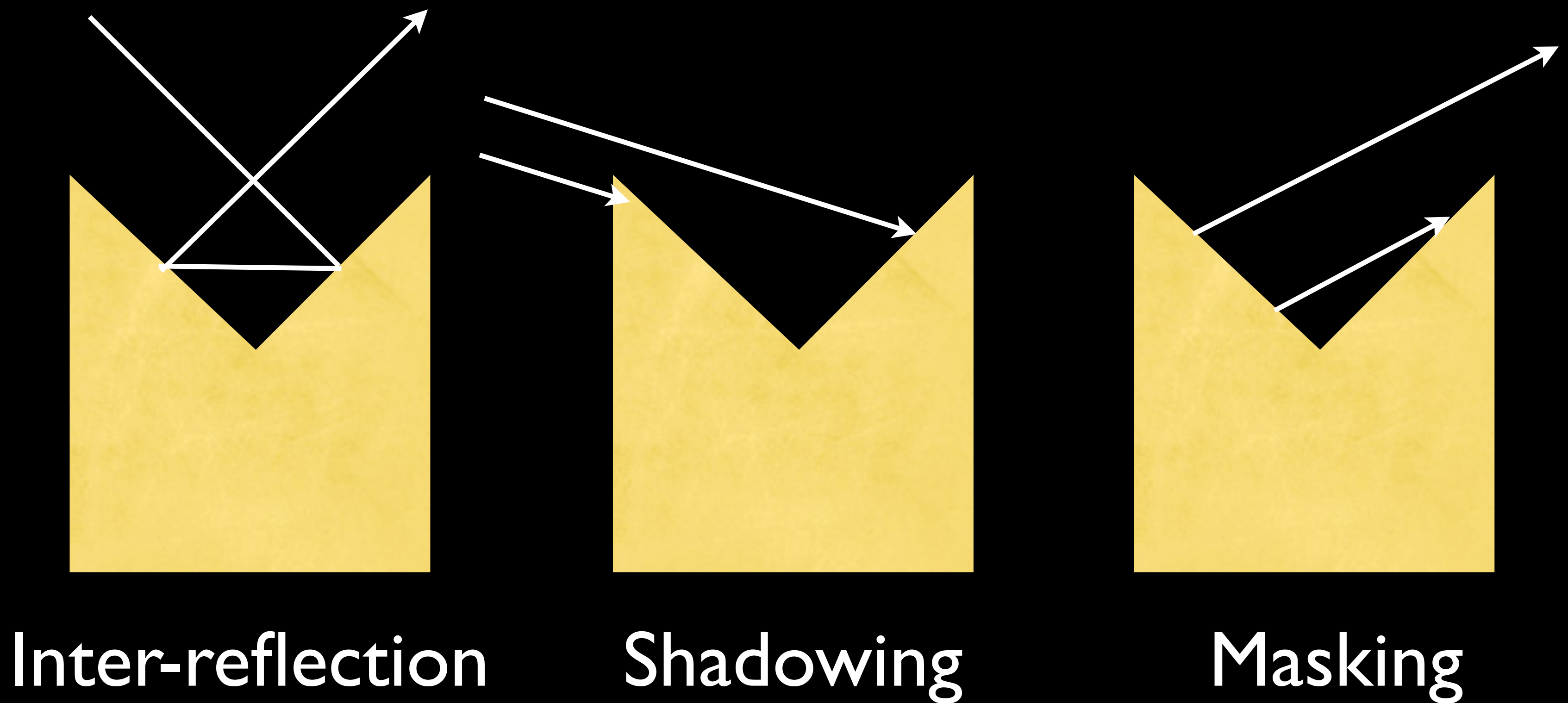
Source: Wikipedia

Microfacets

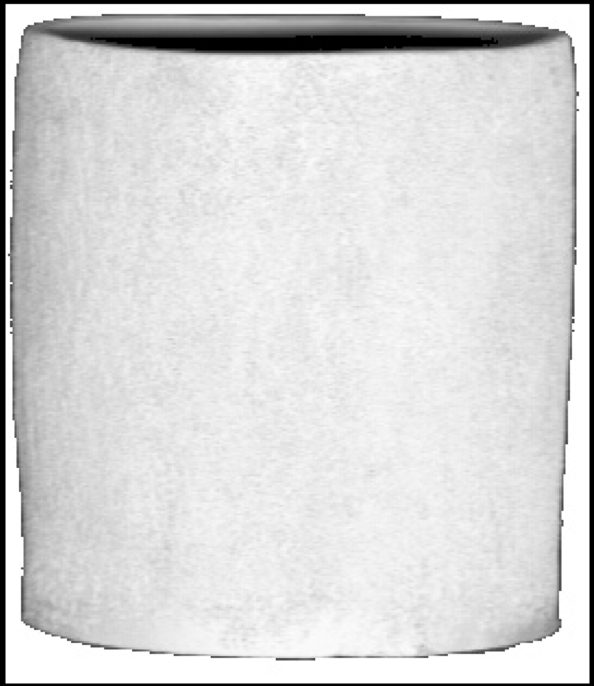
- Microfacets are tiny surface details modeled using bump-mapping
- Most models require facet size to be greater than the wavelength of the light reflected



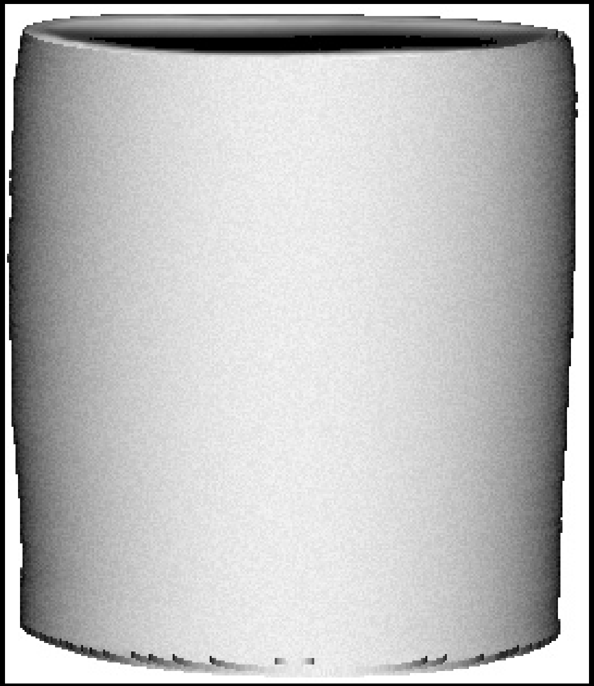
Light Interaction



Why use Microfacets?



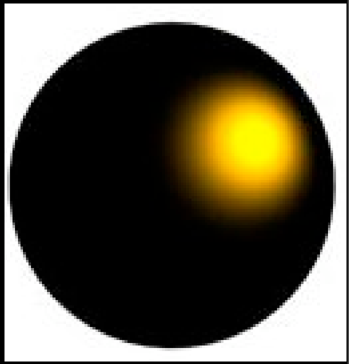
Real Vase



Phong Shading

Source: Oren-Nayar

Cook-Torrance



- Built on v-facet model of Torrance & Sparrow (1967)
- Has different functions for distribution of microfacets and models self-shadowing and masking
- Incorporated Blinn-Phong and Fresnel reflection
- Often used to model metallic surfaces

Cook-Torrance Facets

- Distributed around the Normal *N*
- Normally uses the Beckmann distribution:

$$D = \frac{1}{m^2 \cos^4 \alpha} e^{-\left(\frac{\tan \alpha}{m^2}\right)^2}$$

- Maximum variance α
- Mean difference m

Cook-Torrance Fresnel

- Fresnel Specular Reflections
  - Describes the interaction of light between materials of different refractive indexes

$$
\begin{aligned}
F &= \frac{1}{2}\frac{(g-c)^2}{(g+c)^2}\left(1+\frac{(c\,(c+g)-1)^2}{(c\,(c-g)-1)^2}\right) \\
c &= cos\theta = \vec{V}\cdot\vec{H} \\
g^2 &= n^2+c^2-1
\end{aligned}
$$

  - *n*: Refractive index

Cook-Torrance Attenuation

- Geometric Attenuation: Simulates self-shadowing and masking

$$
\begin{aligned}
G\left(\vec{N},\vec{V},\vec{L}\right) &= \min(1, G_{mask}, G_{shadow}) \\
G_{mask} &= \frac{2\left(\vec{N}\cdot\vec{H}\right)\left(\vec{N}\cdot\vec{V}\right)}{\left(\vec{V}\cdot\vec{H}\right)} \\
G_{shadow} &= \frac{2\left(\vec{N}\cdot\vec{H}\right)\left(\vec{N}\cdot\vec{L}\right)}{\left(\vec{L}\cdot\vec{H}\right)}
\end{aligned}
$$

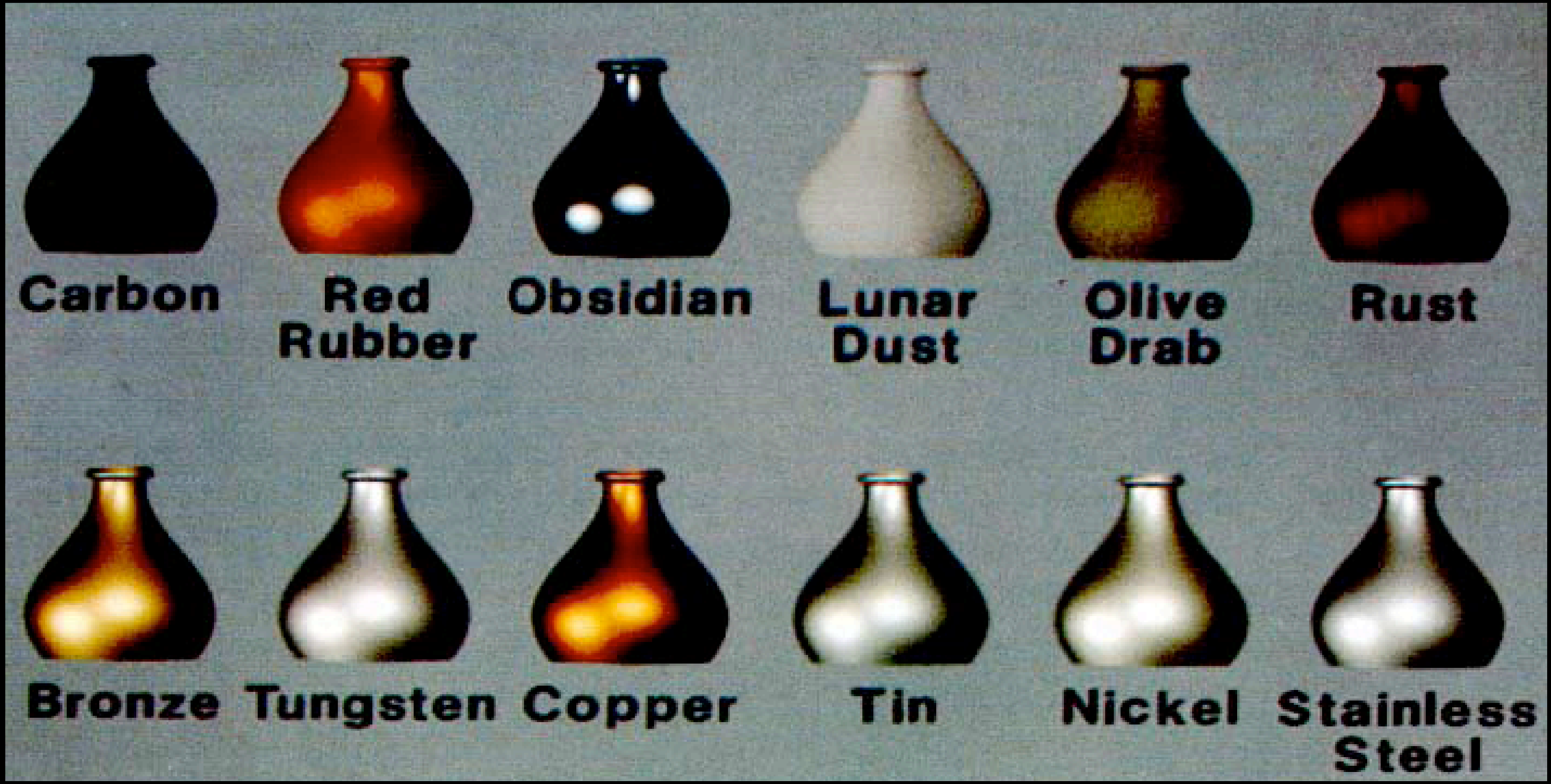
Cook-Torrance

- Putting together previously defined elements we can create the equation for the specular component of reflection:

$$\frac{F}{\pi}\frac{DG}{(\vec{N}\cdot\vec{L})(\vec{N}\cdot\vec{V})}$$

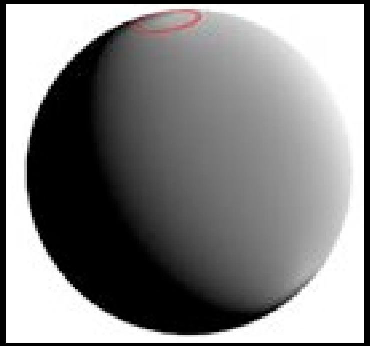
- Diffuse component is usually just Lambertian

Cook-Torrance Materials



Source:Cook-Torrance 1982

Oren-Nayar



- Diffuse model derived from real-world observations
- Statistical isotropic Gaussian distribution of orientations
- Attenuation factor accounting for light interactions

Oren-Nayar Parameters

- Parameters:
  - p: Roughness
  - E: Width of slope distribution
  - σ: Distribution of microfacets
- When σ is zero the model is identical to the lambertian

Oren-Nayar

$$ON(\theta_r,\theta_i,\varphi_r,\varphi_i) = \frac{\varrho}{\pi}E_0\cos\theta_i(A+B\max[0,\cos(\varphi_r-\varphi_i)]\sin\alpha\tan\beta)$$

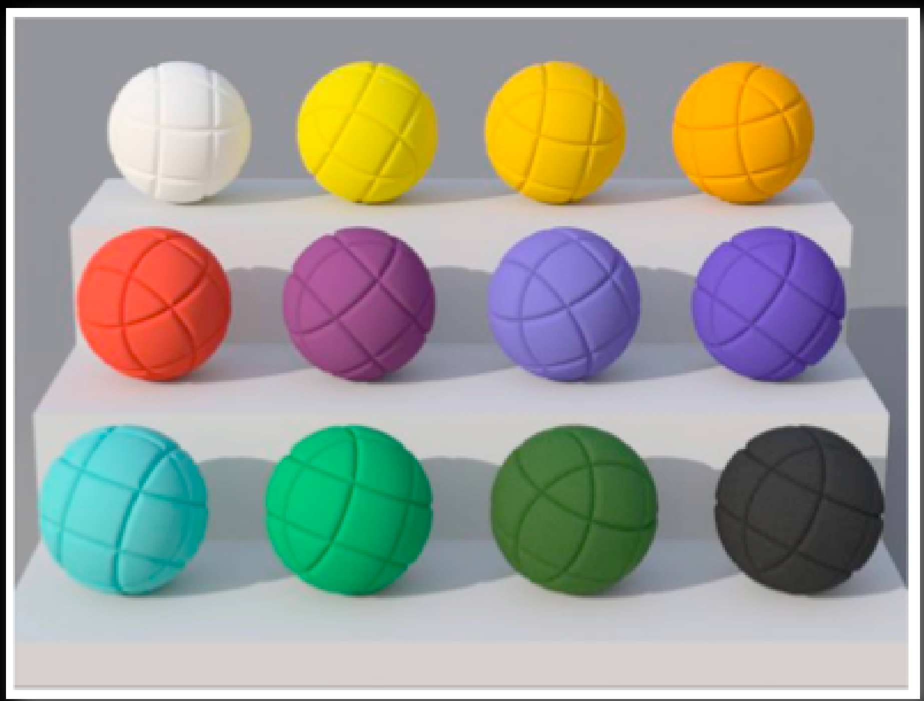
$$A=1.0-0.5\frac{\sigma^2}{\sigma^2+0.33}$$

$$B=0.45\frac{\sigma^2}{\sigma^2+0.09}$$

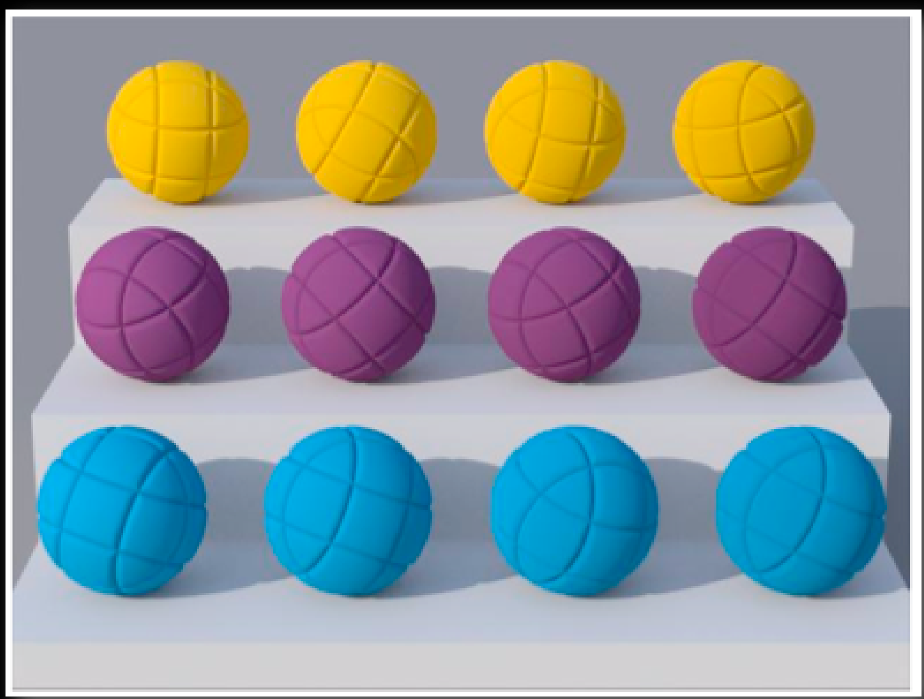
$$\alpha=\max(\theta_r,\theta_i)$$

$$\beta=\min(\theta_r,\theta_i)$$

Oren-Nayar Comparison



Lambertian



Oren-Nayar

More modern methods

- He-Torrance-Sillion-Greenberg (199)
  - Sub-surface scattering, directional diffusion
- Schlick (1994)
  - New microfacet models, anisotropy
- Ward (1992)
  - Very fast anisotropy, physically correct

Sources

- Astle, D (2006). More OpenGL Game Programming. Thompson Course Technology
- Greenberg, D et al (1997). A Framework For Realistic Image Synthesis. SIGGRAPH 1997
- Lobb, R (2003). Advanced Ray Tracing. COMPSCI 715 Lecture Notes
- Oren, M & Nayar, S (1994). Generalization of Lambert's Reflectance Model. SIGGRAPH 1994