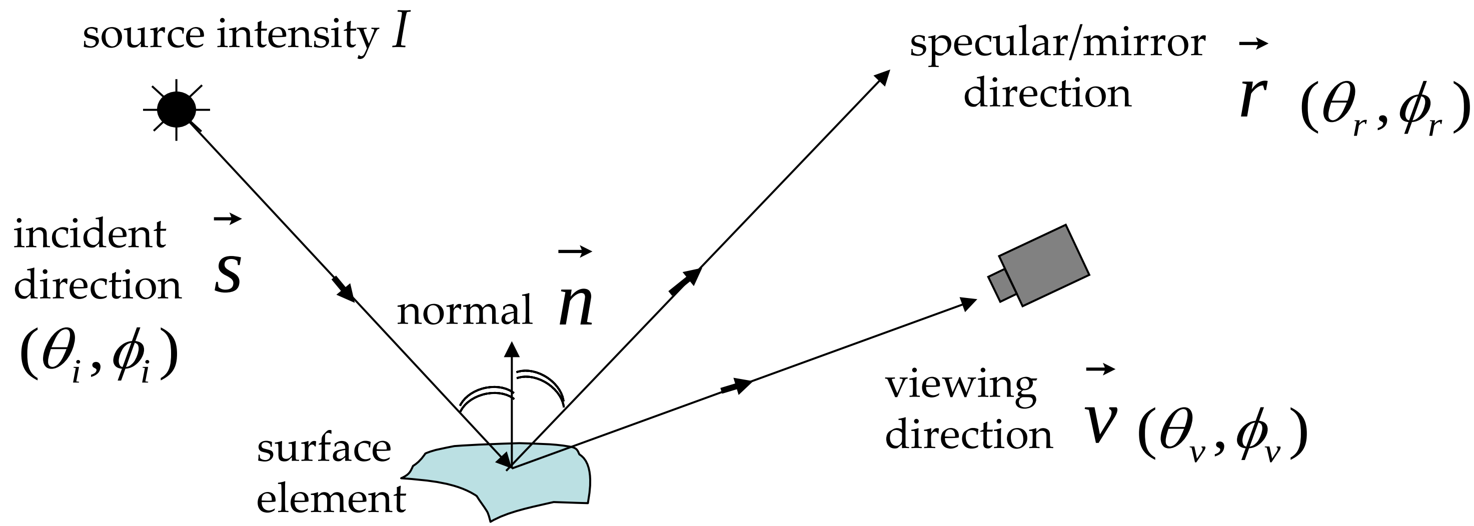
Specular Reflections from Rough Surfaces

Lecture #4

Thanks to Shree Nayar, Ravi Ramamoorthi, Pat Hanrahan

Specular Reflection and Mirror BRDF - RECAP



- **Very smooth surface.**
- All incident light energy reflected in a SINGLE direction. (only when $\vec{v} = \vec{r}$)
- Mirror BRDF is simply a double-delta function :

specular albedo

$$f(\theta_i, \phi_i; \theta_v, \phi_v) = \rho_s \; \delta(\theta_i - \theta_v) \; \delta(\phi_i + \pi - \phi_v)$$

- Surface Radiance : $L = I \; \rho_s \; \delta(\theta_i - \theta_v) \; \delta(\phi_i + \pi - \phi_v)$

Glossy Surfaces

- Delta Function too harsh a BRDF model
  (valid only for highly polished mirrors and metals).

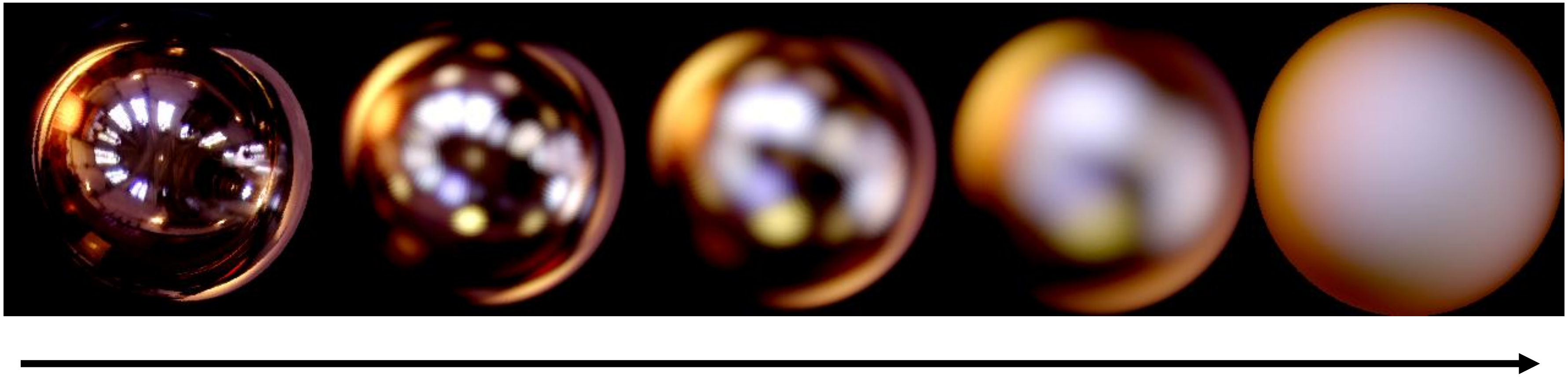
- Many glossy surfaces show broader highlights in addition to mirror reflection.

- Surfaces are not perfectly smooth – they show micro-surface geometry (roughness).

- Example Models : Phong model

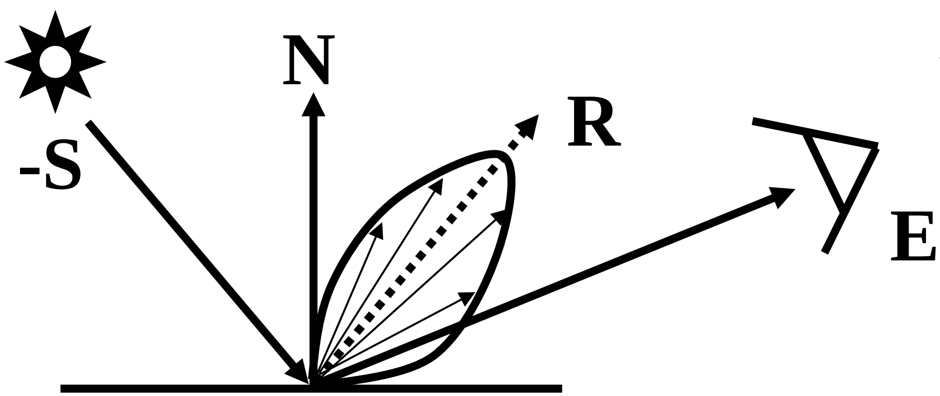
  Torrance Sparrow model

Blurred Highlights and Surface Roughness



Phong Model: An Empirical Approximation

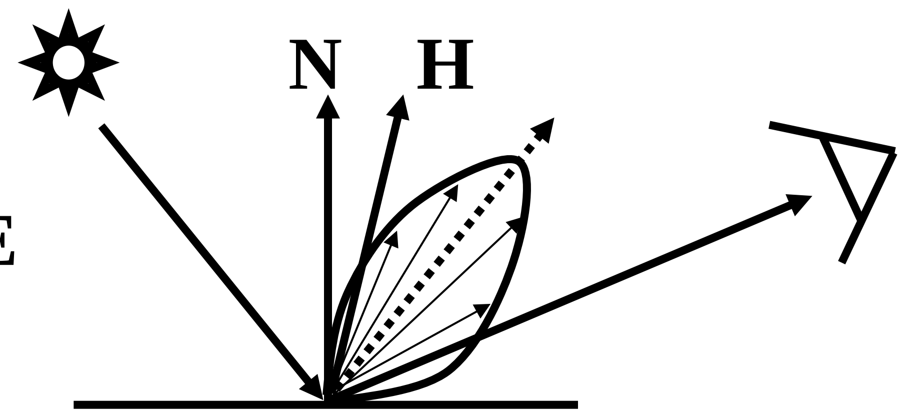
- How to model the angular falloff of highlights:



$$L = I\ \rho_s\ (R.E)^{n_{shiny}}$$

$$R = -S + 2(N.S)N$$

Phong Model



$$L = I\ \rho_s\ (N.H)^{n_{shiny}}$$

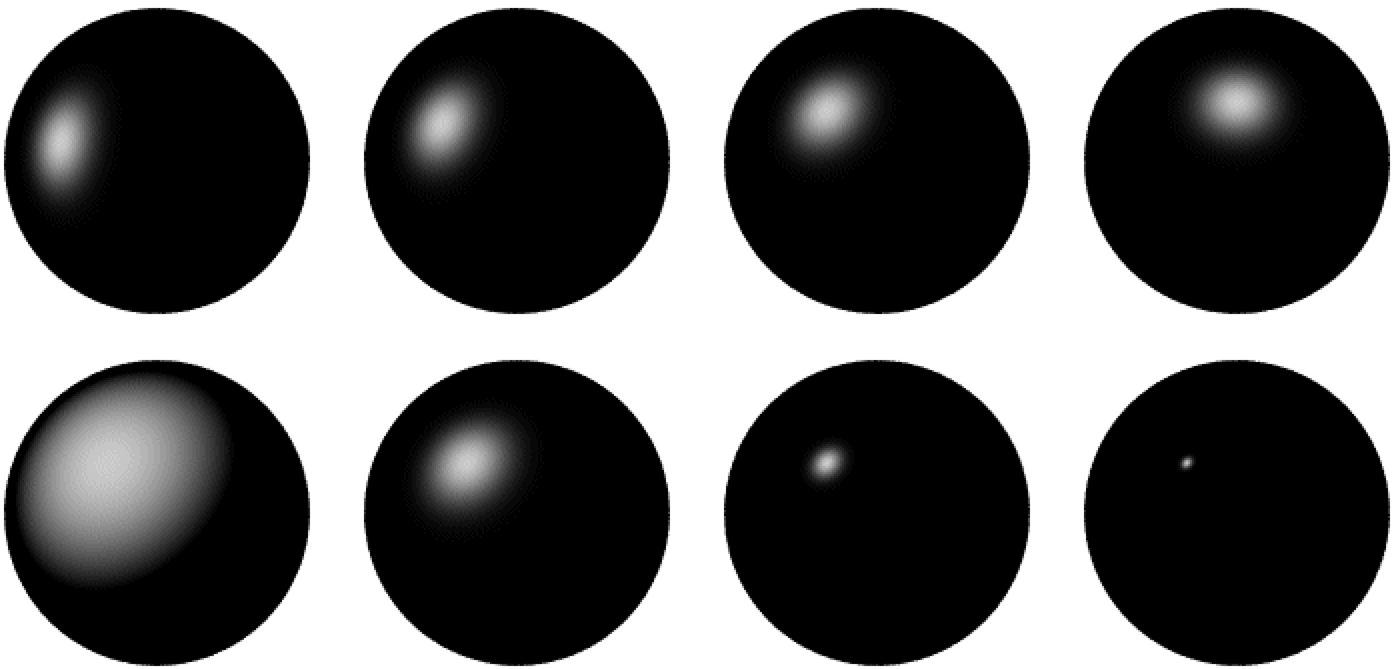
$$H = (E + S)/2$$

Blinn-Phong Model

- Sort of works, easy to compute
- But not physically based (no energy conservation and reciprocity).
- Very commonly used in computer graphics.

Phong Examples

- These spheres illustrate the Phong model as *lighting direction* and n_{shiny} are varied:



Those Were the Days

- "In trying to improve the quality of the synthetic images, we do not expect to be able to display the object exactly as it would appear in reality, with texture, overcast shadows, etc. We hope only to display an image that approximates the real object closely enough to provide a certain degree of realism."
  – Bui Tuong Phong, 1975

Torrance-Sparrow Model – Main Points

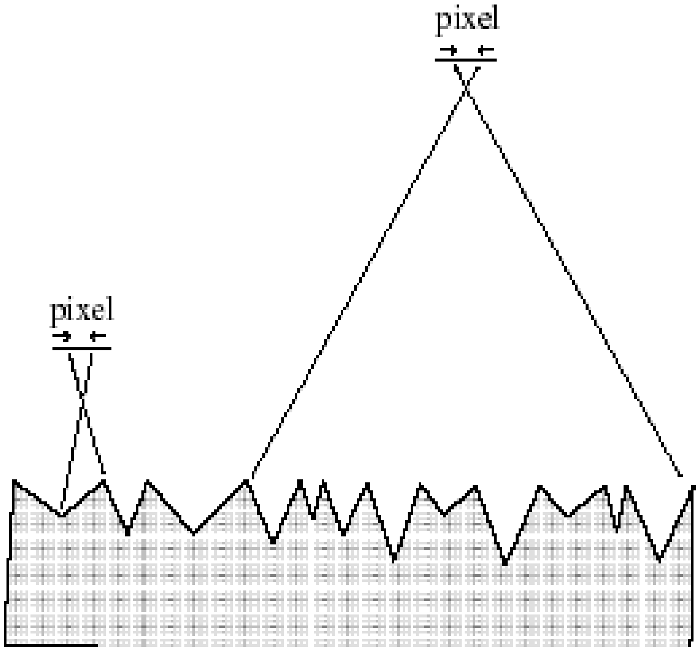
- Physically Based Model for Surface Reflection.
- Based on Geometric Optics.
- Explains off-specular lobe (wider highlights).
- Works for only rough surfaces.

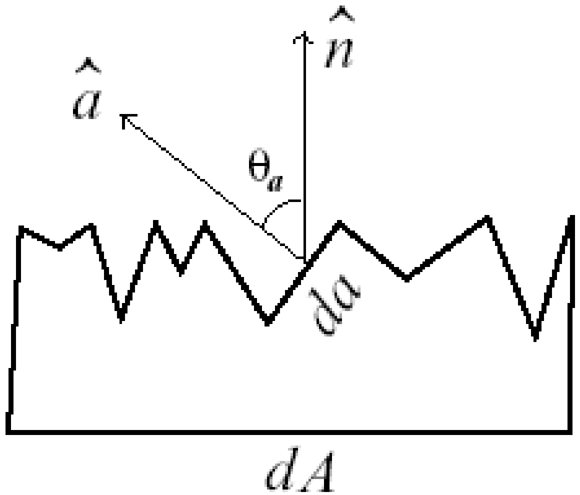
- For very smooth surfaces, electromagnetic nature of light must be used

  Beckmann-Spizzichinno model.

  Beyond the scope of this course.

Modeling Rough Surfaces - Microfacets





- Roughness simulated by Symmetric V-groves at Microscopic level.
- Distribution on the slopes of the V-grove faces are modeled.
- Each microfacet assumed to behave like a perfect mirror.

Torrance-Sparrow BRDF – Different Factors

Fresnel term: allows for wavelength dependency

Geometric Attenuation: reduces the output based on the amount of shadowing or masking that occurs.

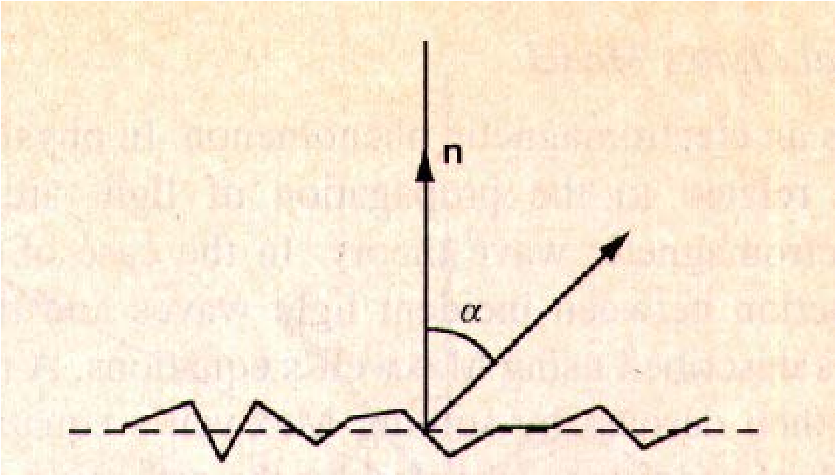
$$f = \frac{F(\theta_i)G(\omega_i, \omega_r)D(\theta_h)}{4\cos(\theta_i)\cos(\theta_r)}$$

Distribution: distribution function determines what percentage of microfacets are oriented to reflect in the viewer direction.

How much of the macroscopic surface is visible to the light source

How much of the macroscopic surface is visible to the viewer

Slope Distribution Model

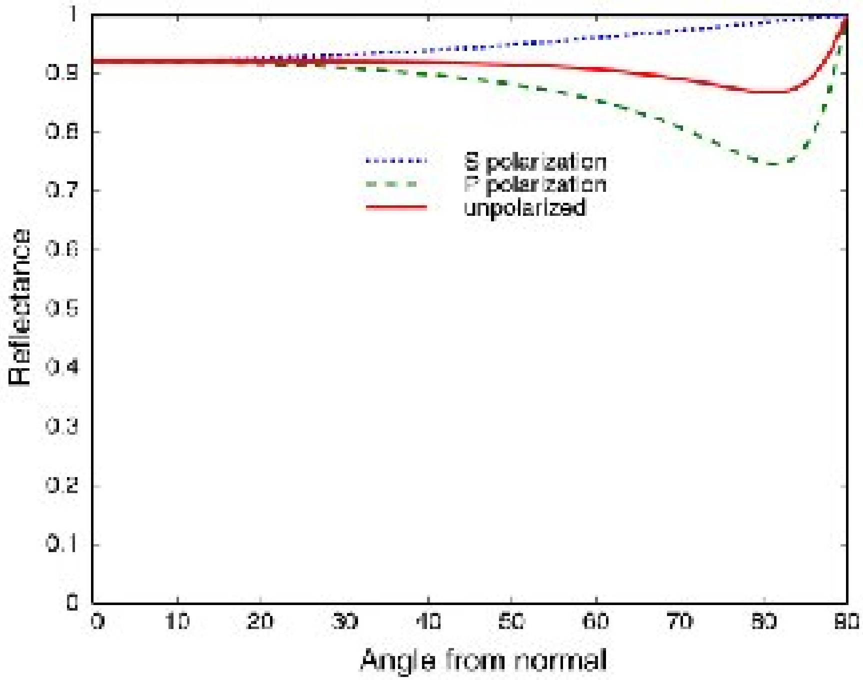


- Model the distribution of slopes as Gaussian.
- Mean is Zero, Variance represents ROUGHNESS.

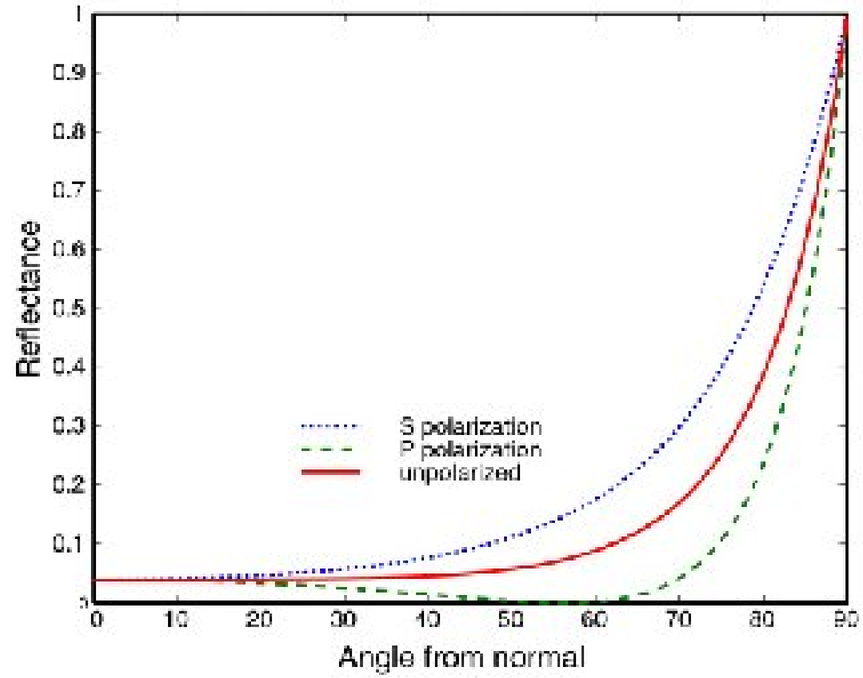
$$\rho_\alpha(\alpha) = \frac{1}{\sqrt{2\pi\sigma_\alpha}} e^{-\frac{\alpha^2}{2\sigma_\alpha{}^2}}.$$

Fresnel Reflectance

Metal (Aluminum)



Dielectric (N=1.5)



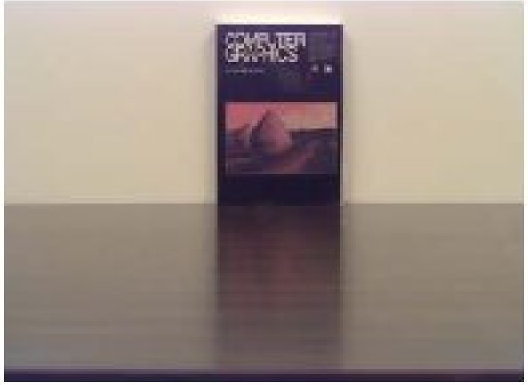
Gold F(0)=0.82
Silver F(0)=0.95

Glass n=1.5 F(0)=0.04
Diamond n=2.4 F(0)=0.15

Schlick Approximation $F(\theta) = F(0) + (1 - F(0))(1 - \cos\theta)^5$

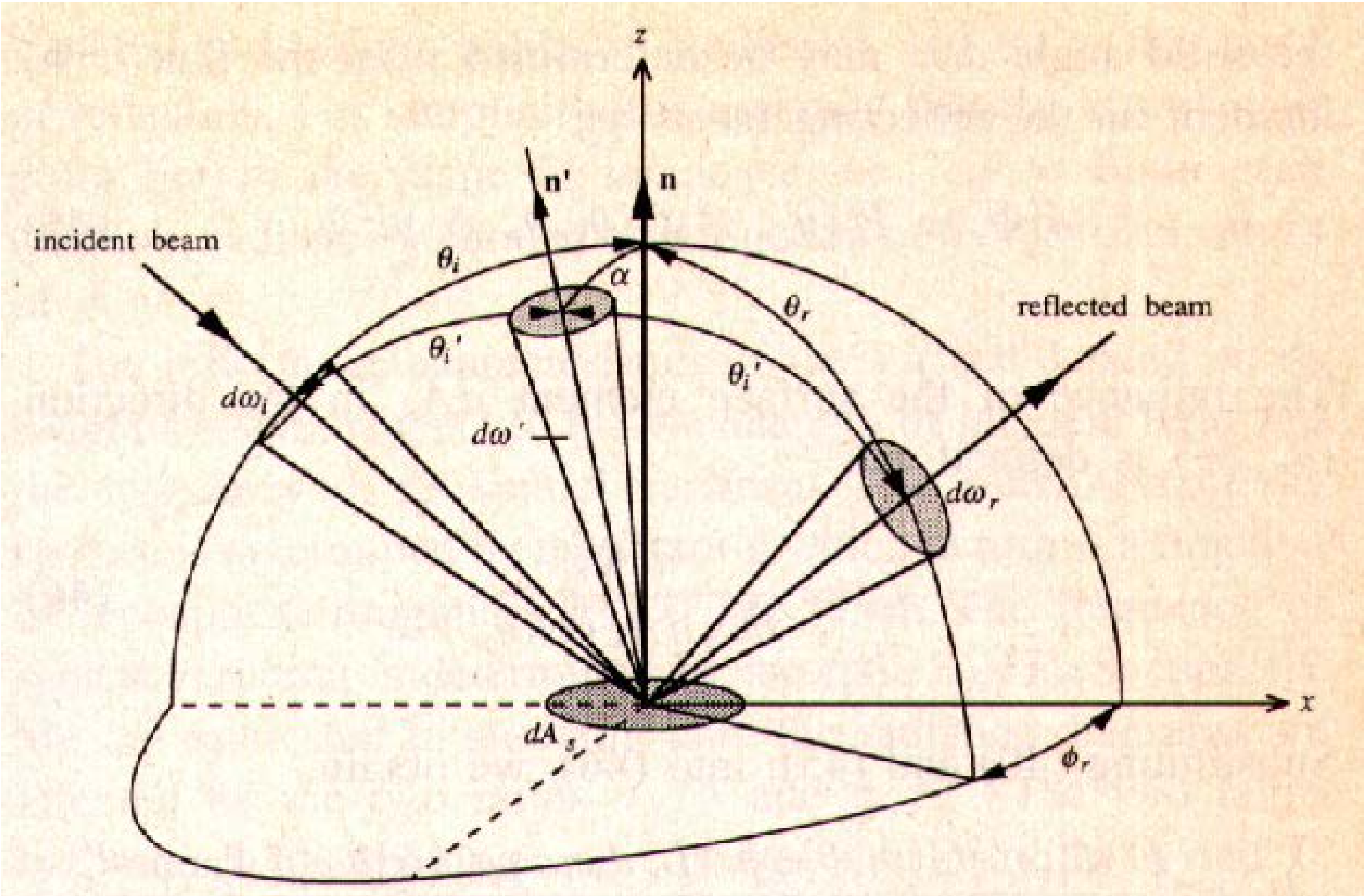
Experiment

Reflections from a shiny floor

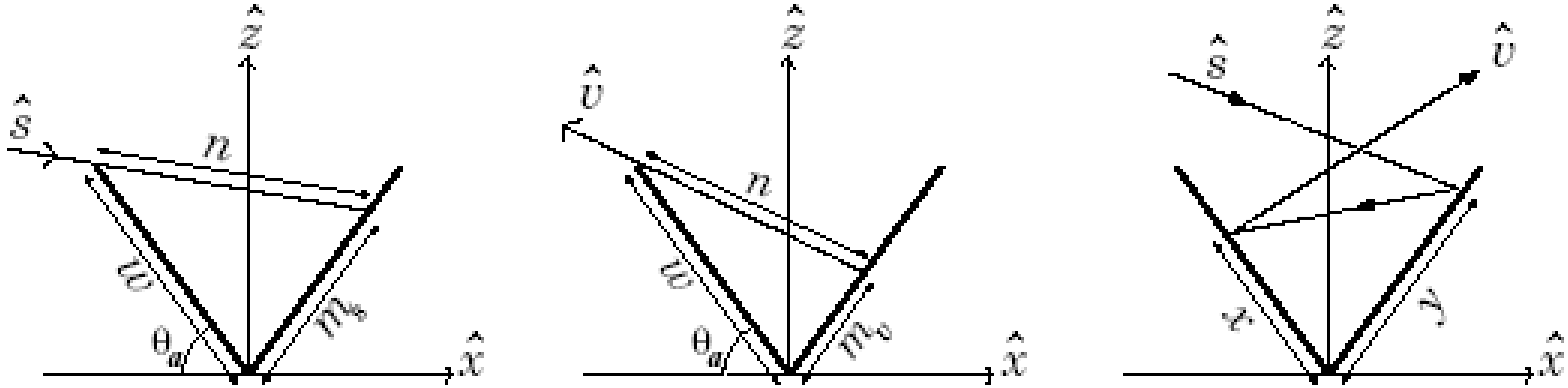


From Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 97

Coordinate System needed to derive T-S model



Geometric Attenuation Factor

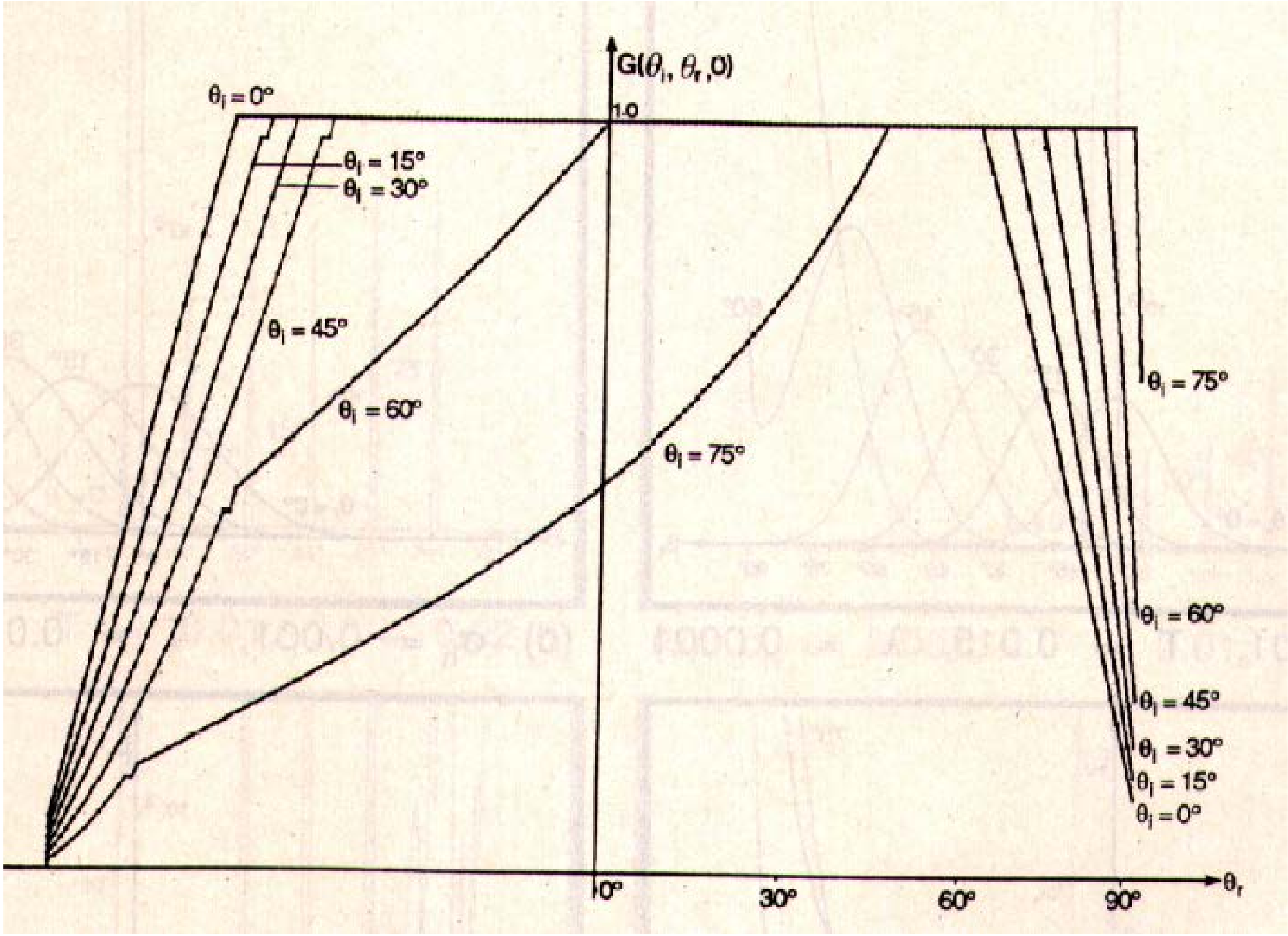


(a) Shadowing (b) Masking (c) Interreflection

$$G(\theta_i, \theta_r, \phi_r) = \min\left(1, \frac{2\cos\alpha\cos\theta_r}{\cos\theta_i'}, \frac{2\cos\alpha\cos\theta_i}{\cos\theta_i'}\right).$$

- No interreflections taken into account in above function.
- Derivation found in 1967 JOSA paper (read if interested).

Geometric Attenuation Factor



Torrance Sparrow Model - Final Expression

$$L_r = \kappa_{\text{spec}} \frac{L_i d\omega_i}{\cos\theta_r} e^{-\frac{\alpha^2}{2\sigma_\alpha{}^2}}$$

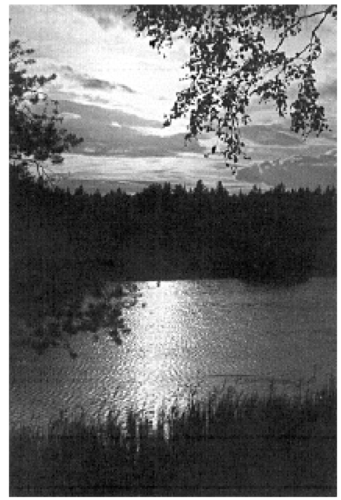
$$\kappa_{\text{spec}} = \frac{c a_f F'(\theta_i', \eta') G(\theta_i, \theta_r, \phi_r)}{4}.$$

- Does the expression blow-up at grazing viewing angles?

At grazing angles F is maximum, denominator is close to zero. Specular surfaces appear very bright at grazing angles.

At the same time, due to shadowing, the total brightness does not explode (G term at grazing angles is close to zero).

Reflections on water surfaces - Glittering

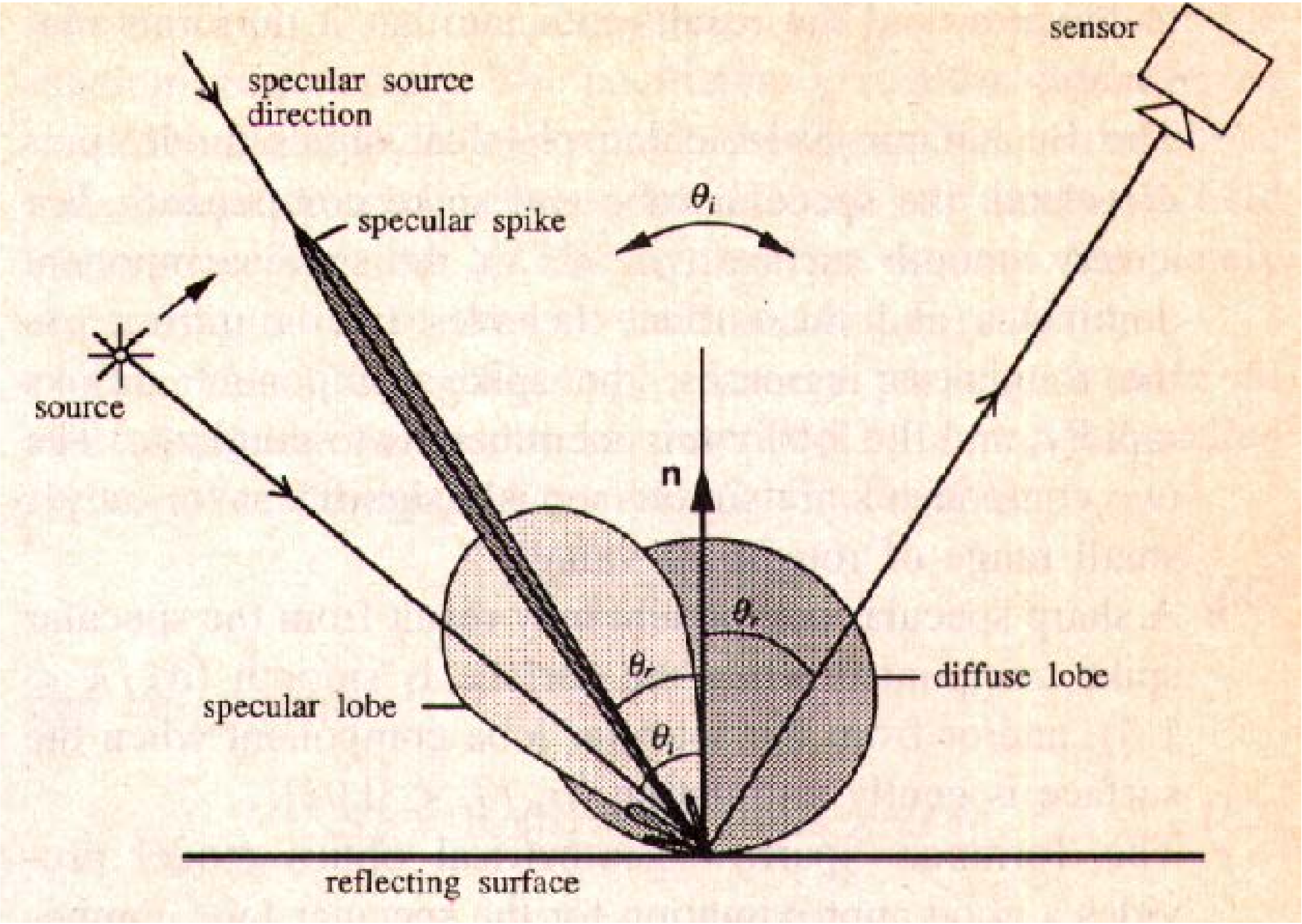


- **Possible Midterm Assignment:**

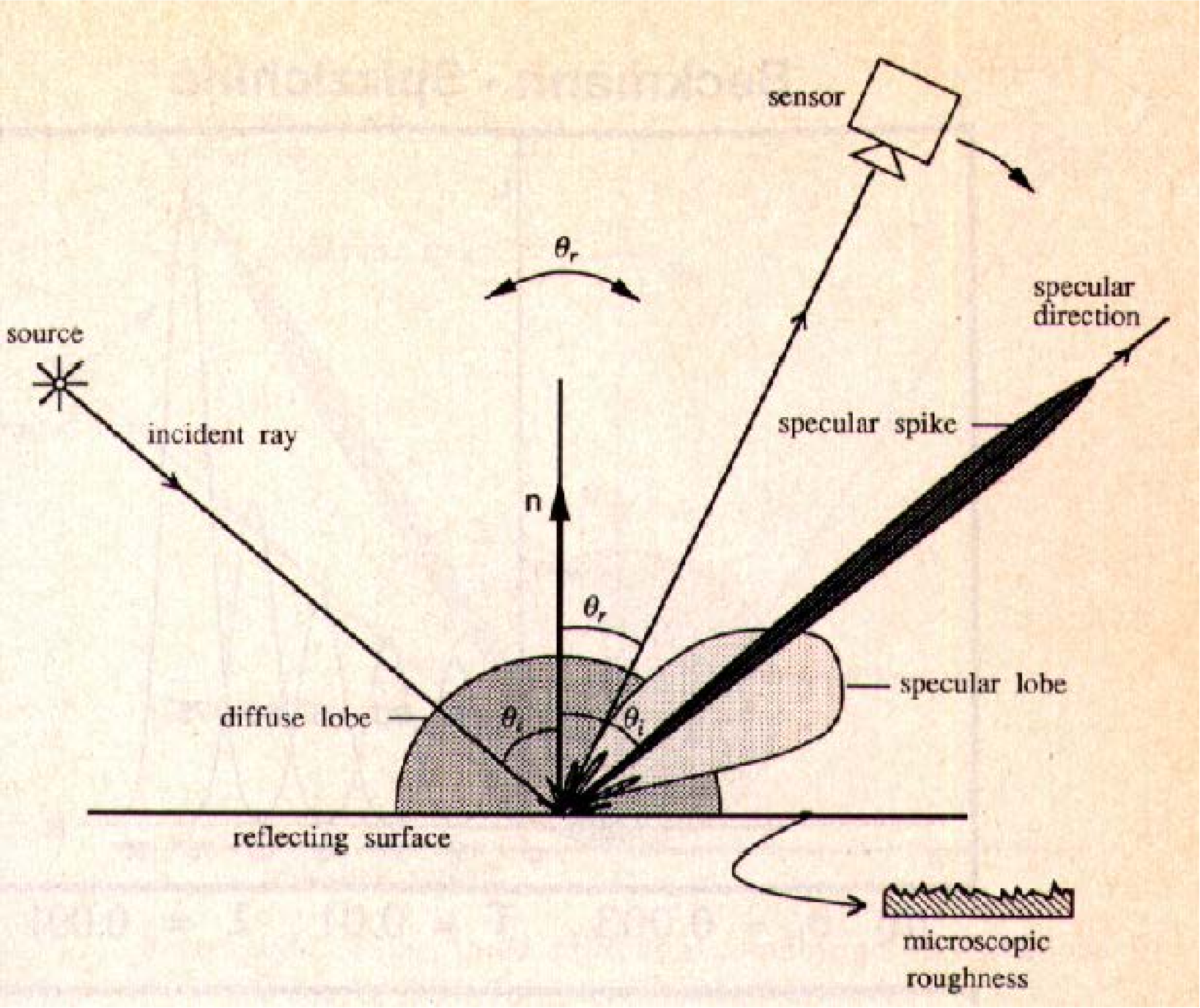
  Can the glittering be modeled by Torrance-Sparrow model?

  Explain the shape of the glittering as a function of viewing angle?

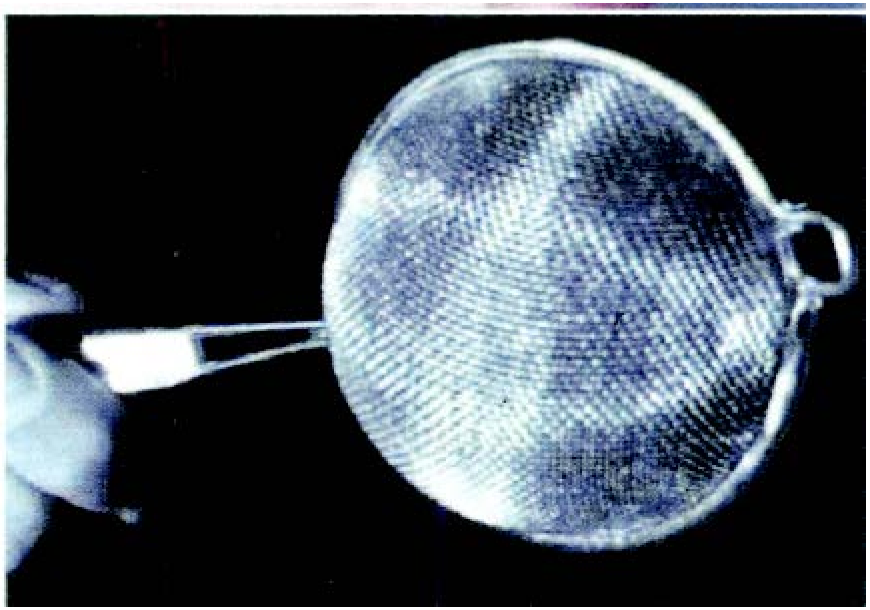
Components of Surface Reflection – Moving Light Source

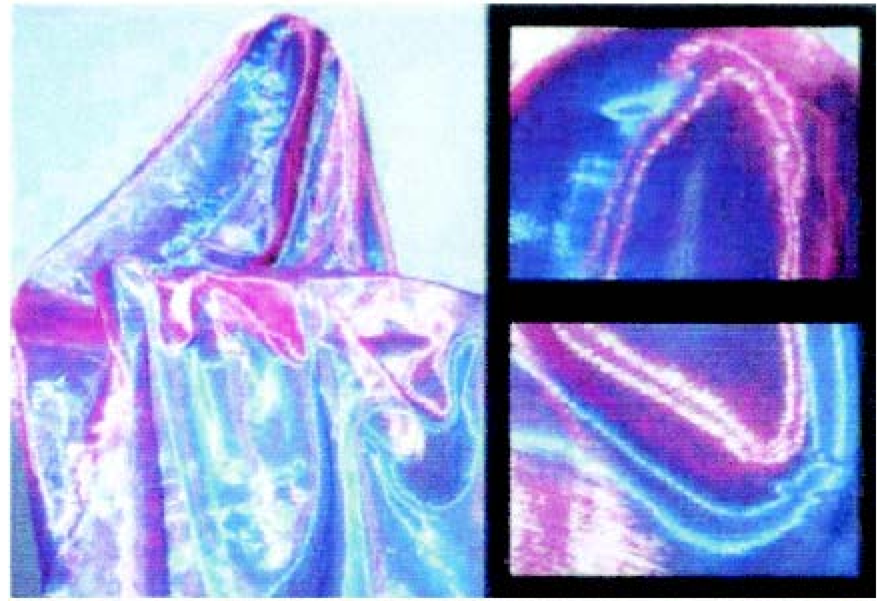


Components of Surface Reflection – Moving Camera



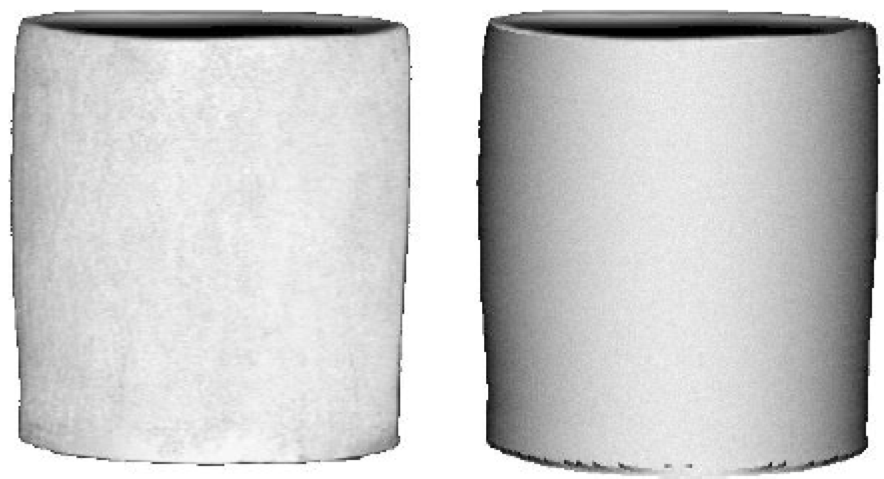
Split off-specular Reflections in Woven Surfaces





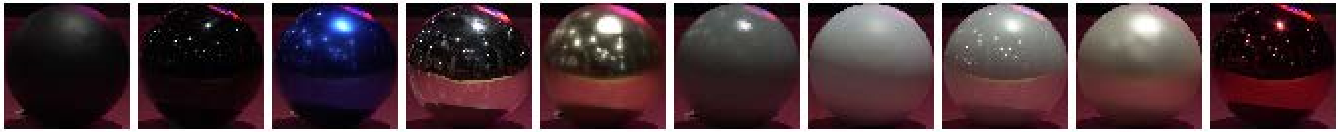
Next Class – Rough Diffuse Surfaces

Same Analysis of Roughness for Diffuse Objects – Oren Nayar Model



Illumination: Office scene

Illumination: Kendall Food Court



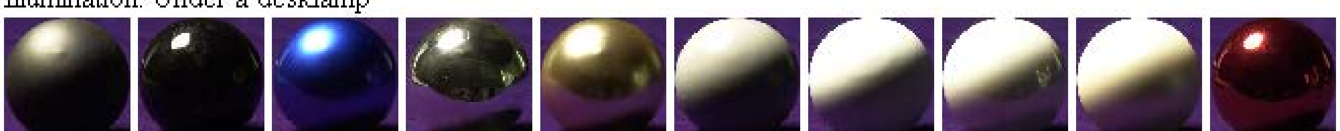
Illumination: Adelson Lab

Illumination: NE20 4th floor lobby

Illumination: Street scene

Illumination: By a window

Illumination: Under a desklamp

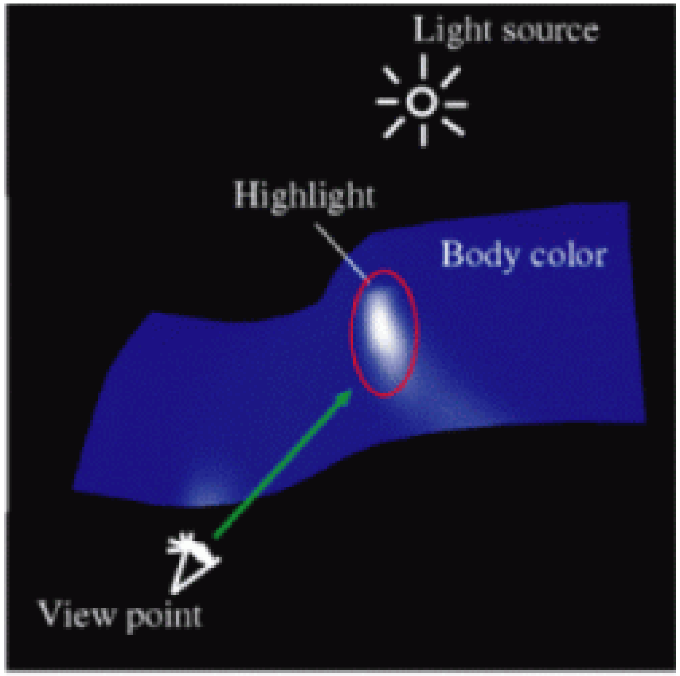


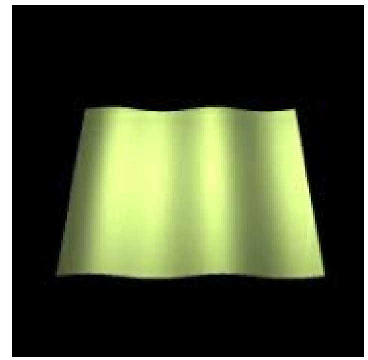
Dror, Adelson, Wilsky

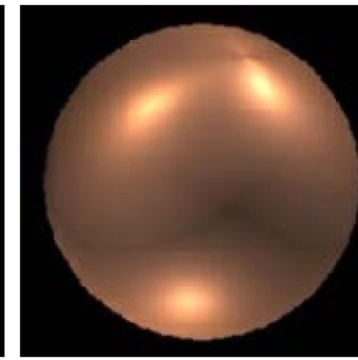
A Simple Reflection Model - Dichromatic Reflection

Observed Image Color = a x Body Color + b x Specular Reflection Color

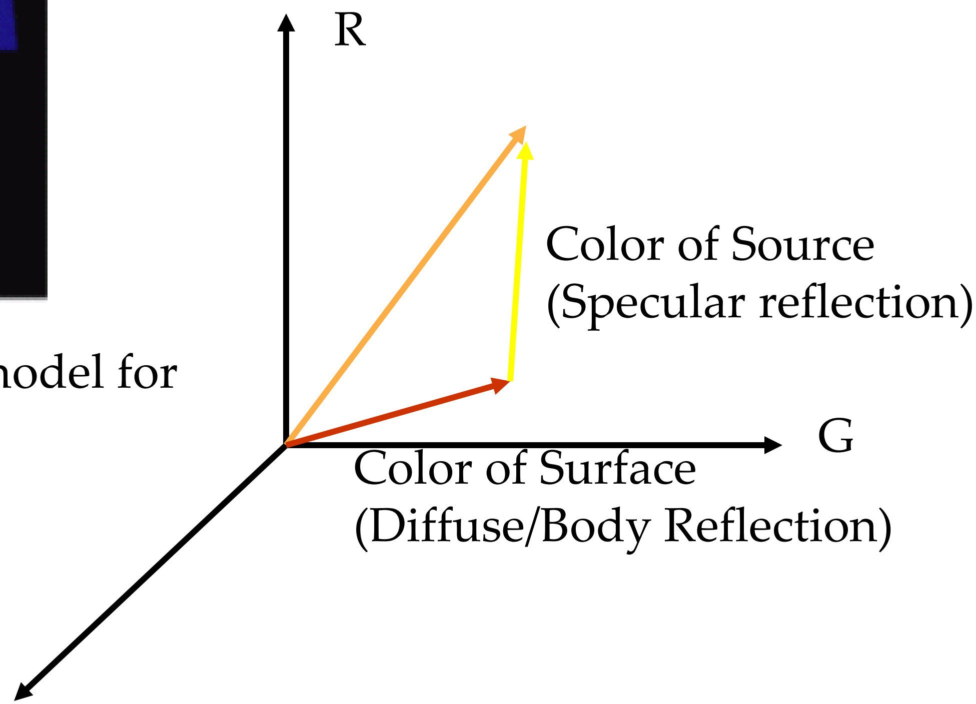
Klinker-Shafer-Kanade 1988







Does not specify any specific model for
Diffuse/specular reflection



Separating Diffuse and Specular Reflections

Observed Image Color = a x Body Color + b x Specular Reflection Color