Rendering
Light Reflection Models
Direct Illumination

Visual Imaging in the Electronic Age

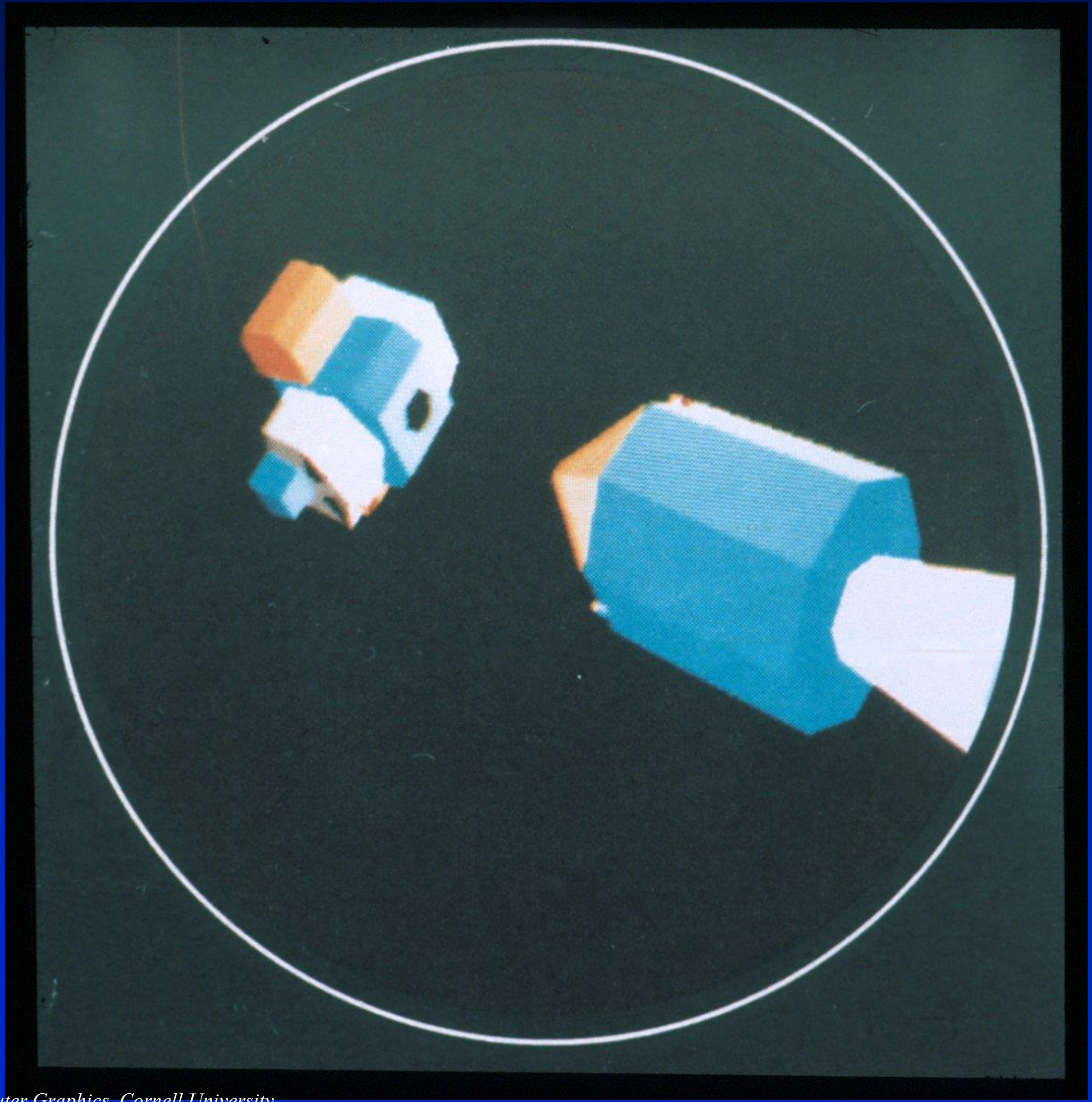
Donald P. Greenberg

October 20 , 2020

Lecture #14

Ivan Sutherland - 1963

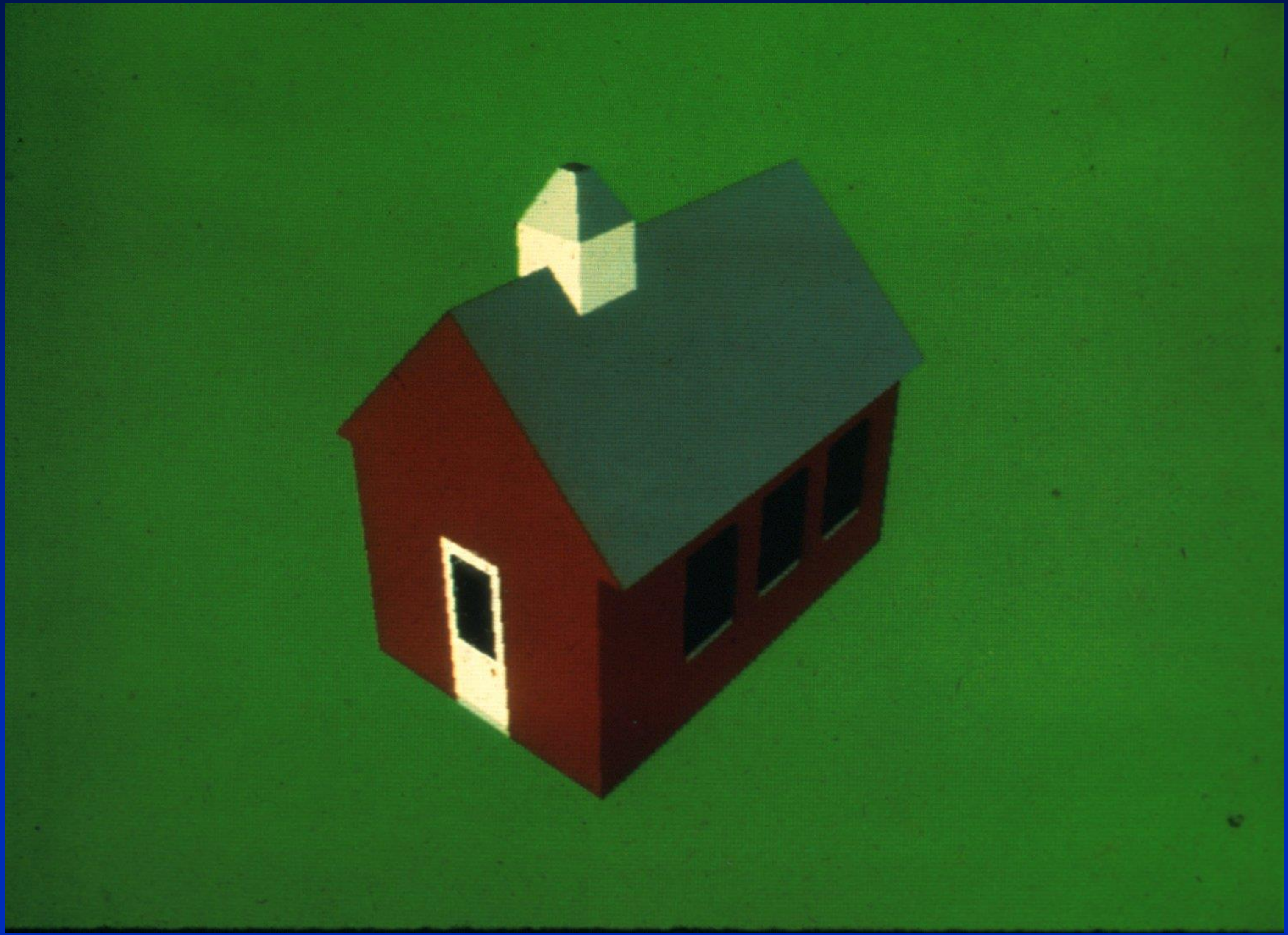
General Electric 1967



Program of Computer Graphics, Cornell University

Professors Office Janitor's Closet 1973

DPG 1967

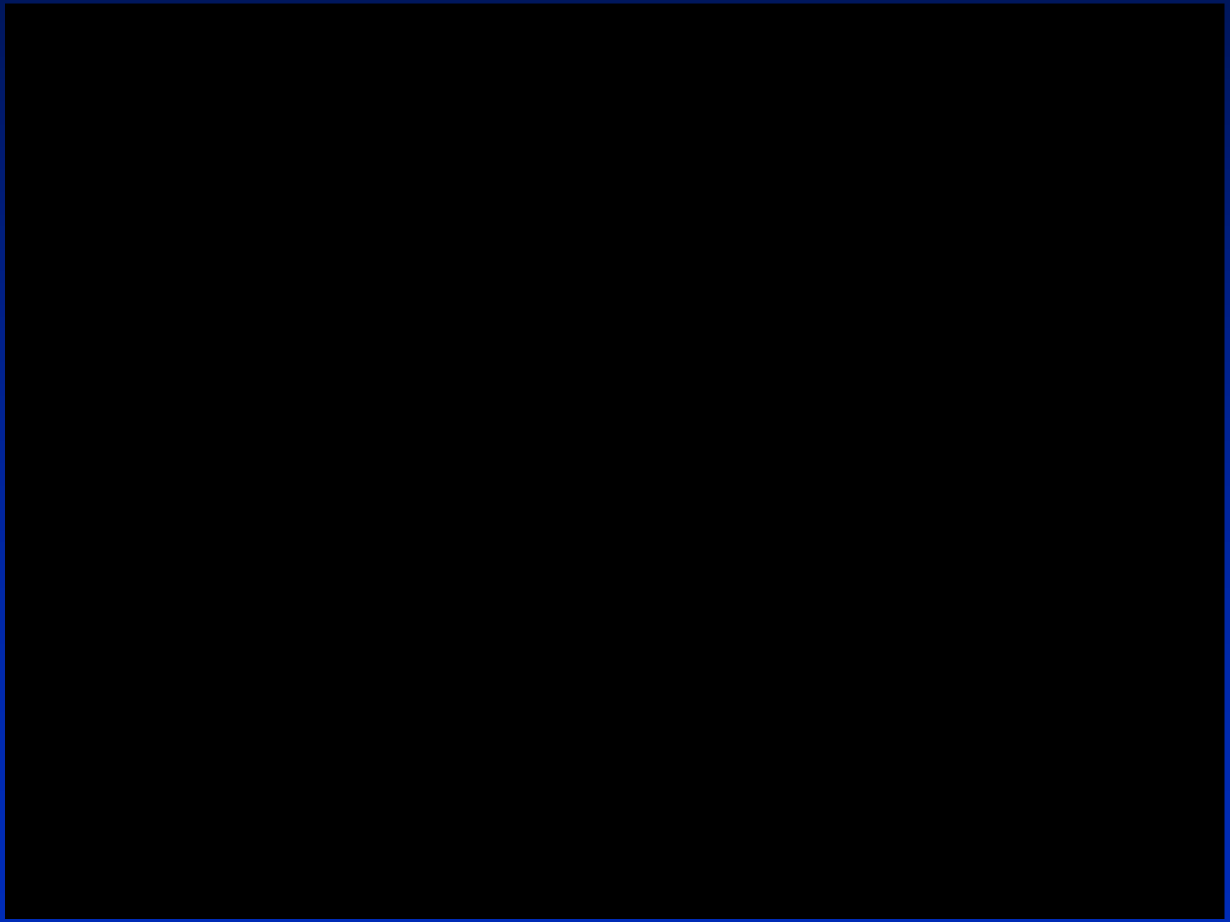


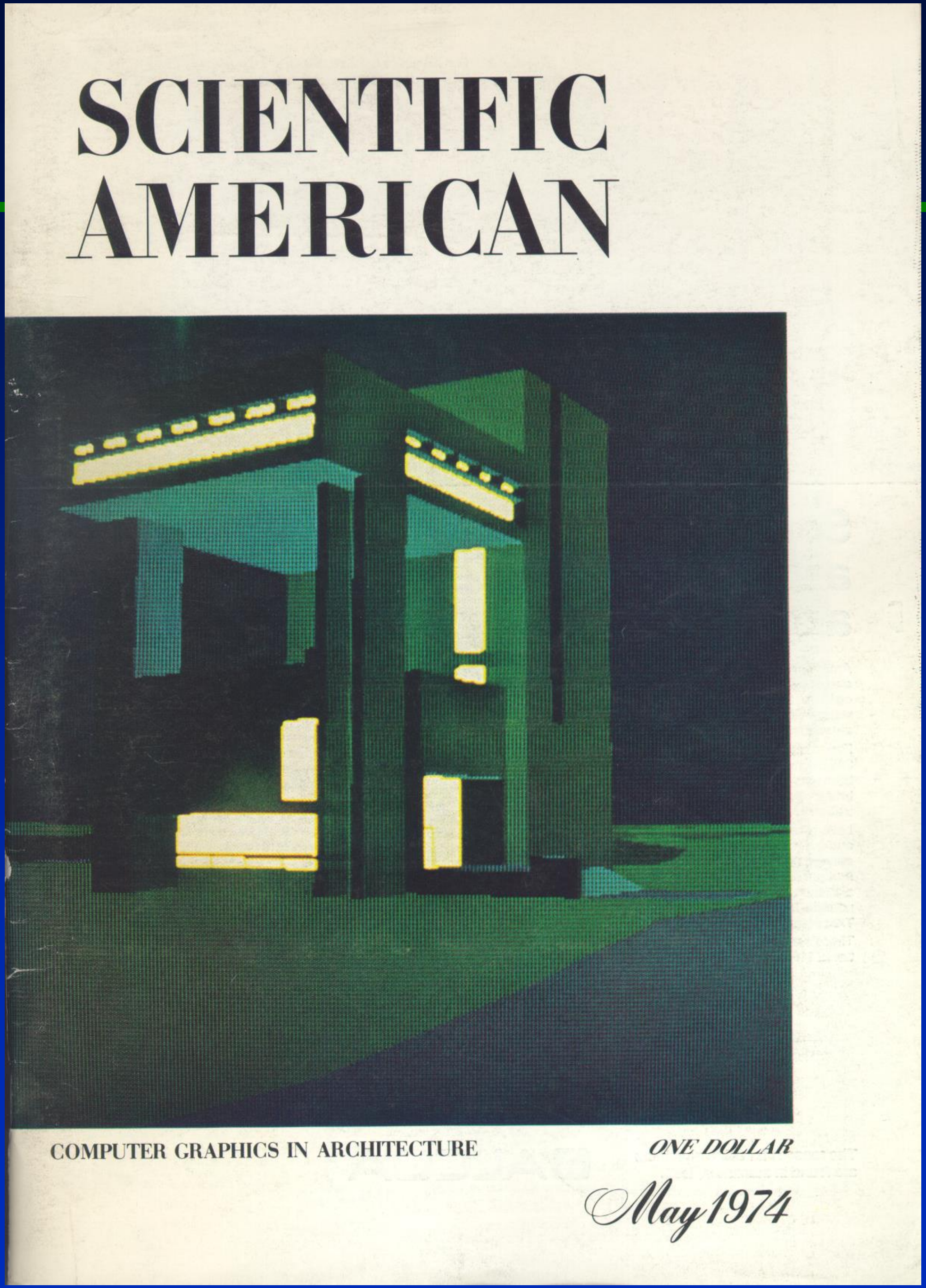
Program of Computer Graphics, Cornell University

Cornell in Perspective Film

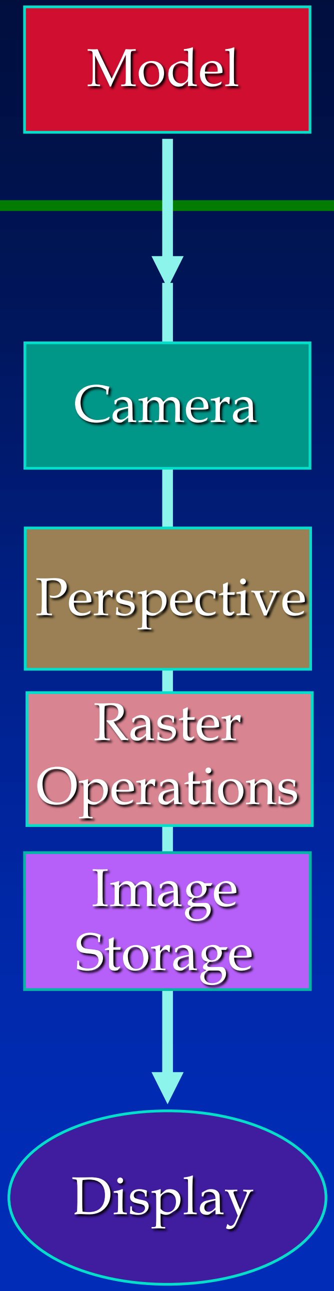
Program of Computer Graphics, Cornell University

Cornell in Perspective Film




SCIENTIFIC
AMERICAN
COMPUTER GRAPHICS IN ARCHITECTURE
ONE DOLLAR
May 1974

Direct Illumination



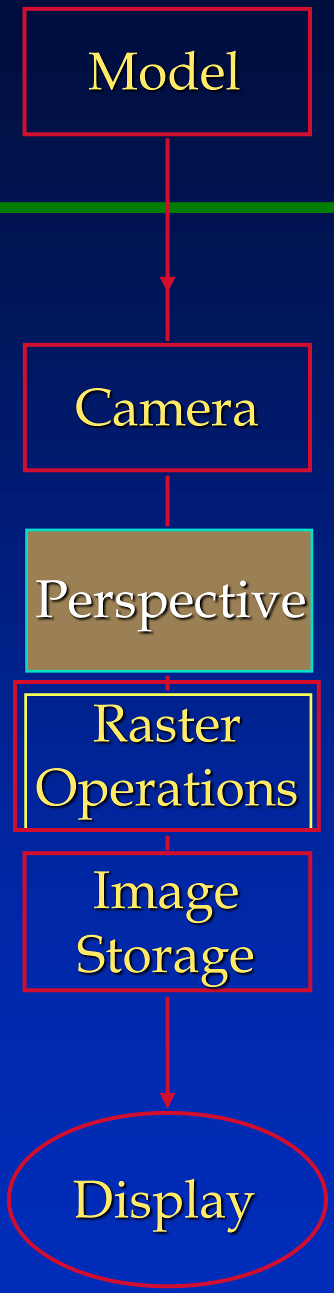
Perspective Transformation

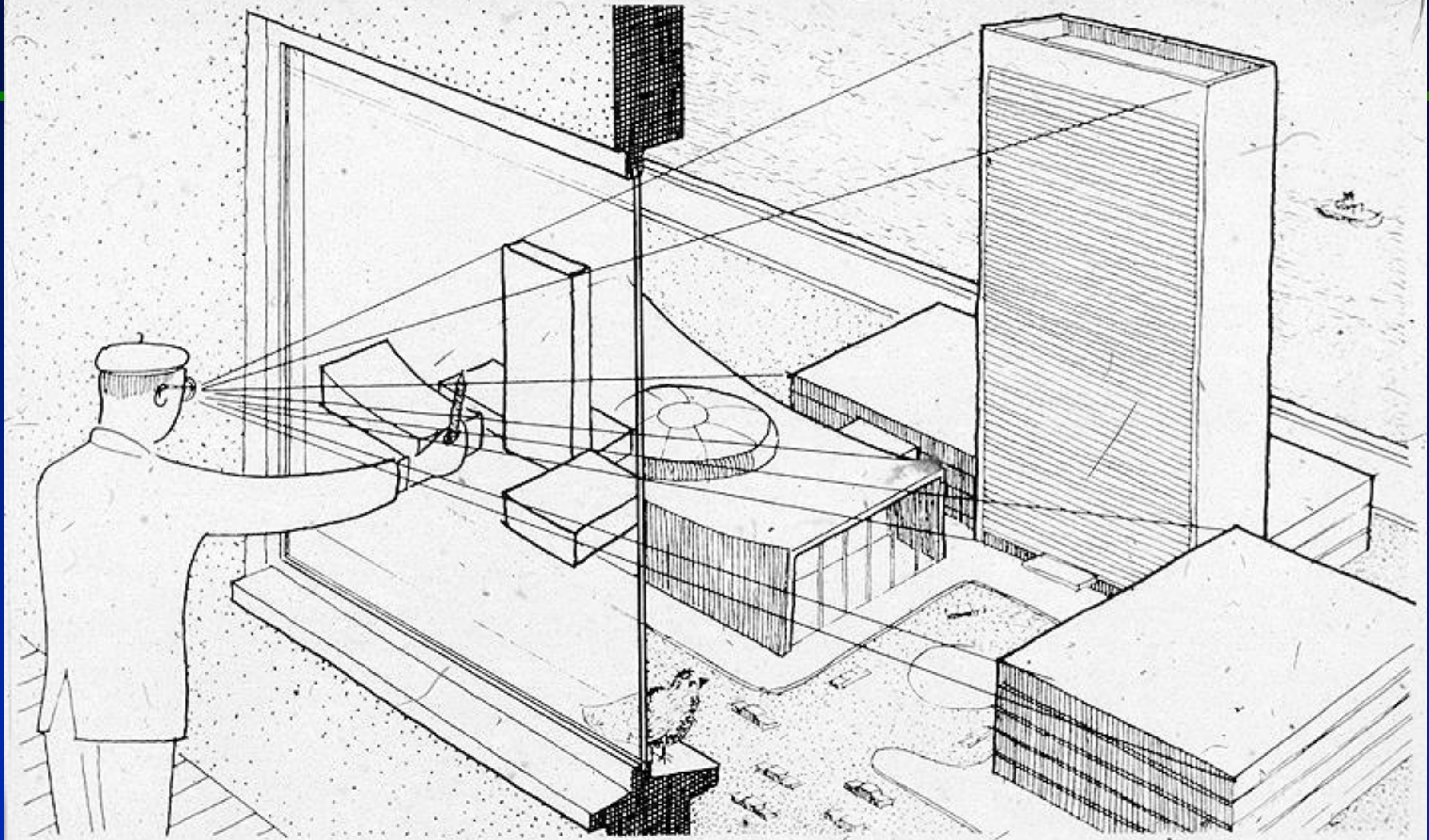
- Perspective transformation

  Matrix multiplication

- Clipping

- Culling



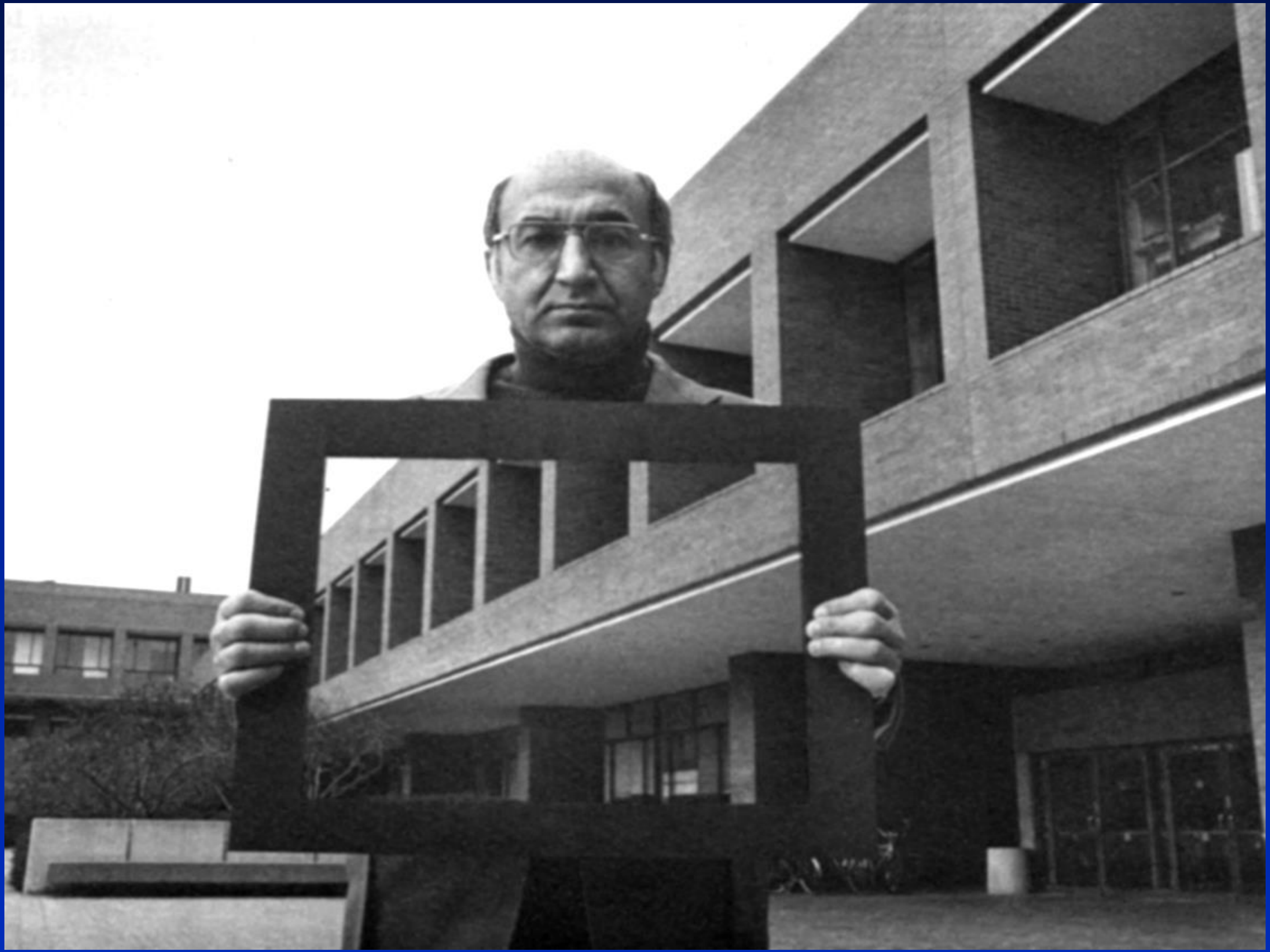


The concept of the picture plane may be better understood by looking through a window or other transparent plane from a fixed viewpoint. Your lines of sight, the multitude of straight lines leading from your eye to the subject, will all intersect this plane. Therefore, if you were to reach out with a grease pencil and draw the image of the subject on this plane you would be "tracing out" the infinite number of points of intersection of sight rays and plane. The result would be that you would have "transferred" a real three-dimensional object to a two-dimensional plane.

Goal of Realistic Imaging

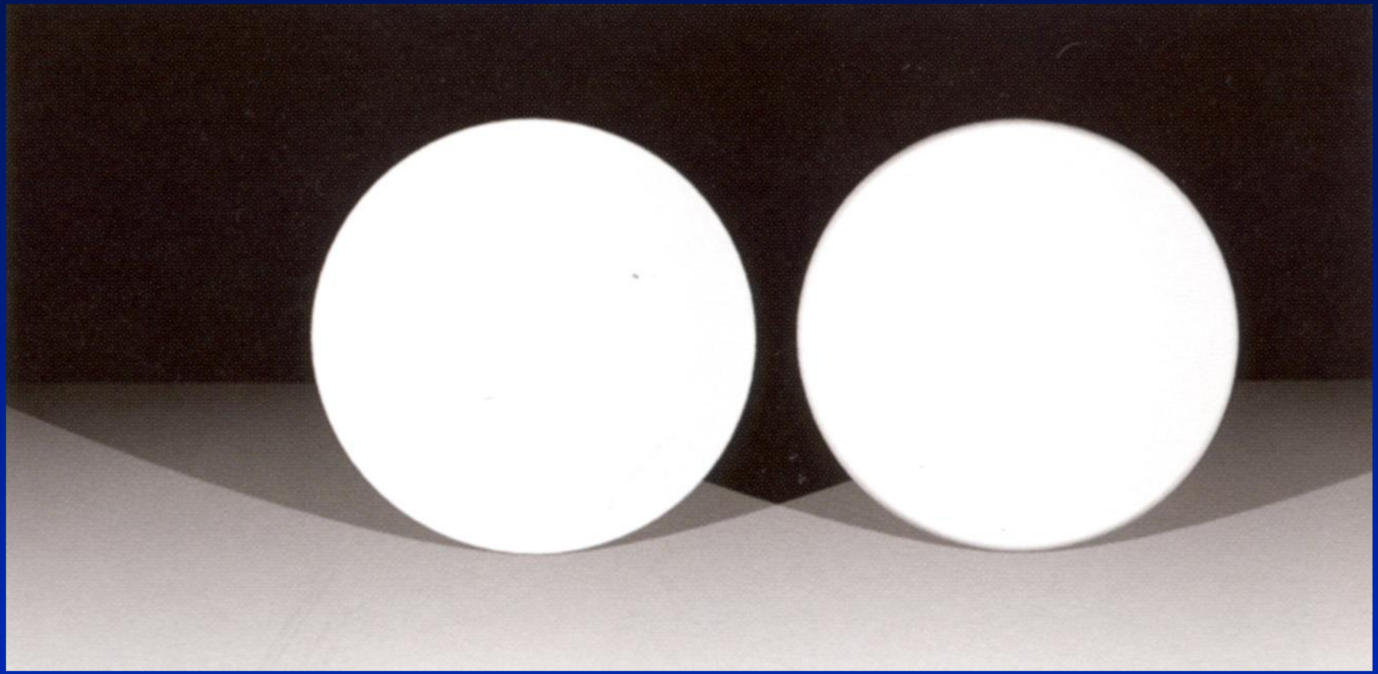
"The resulting images should be physically accurate and perceptually indistinguishable from real world scenes"

Goal of Realistic Imaging



From Strobel, Photographic Materials and Processes © Focal Press, 1986.

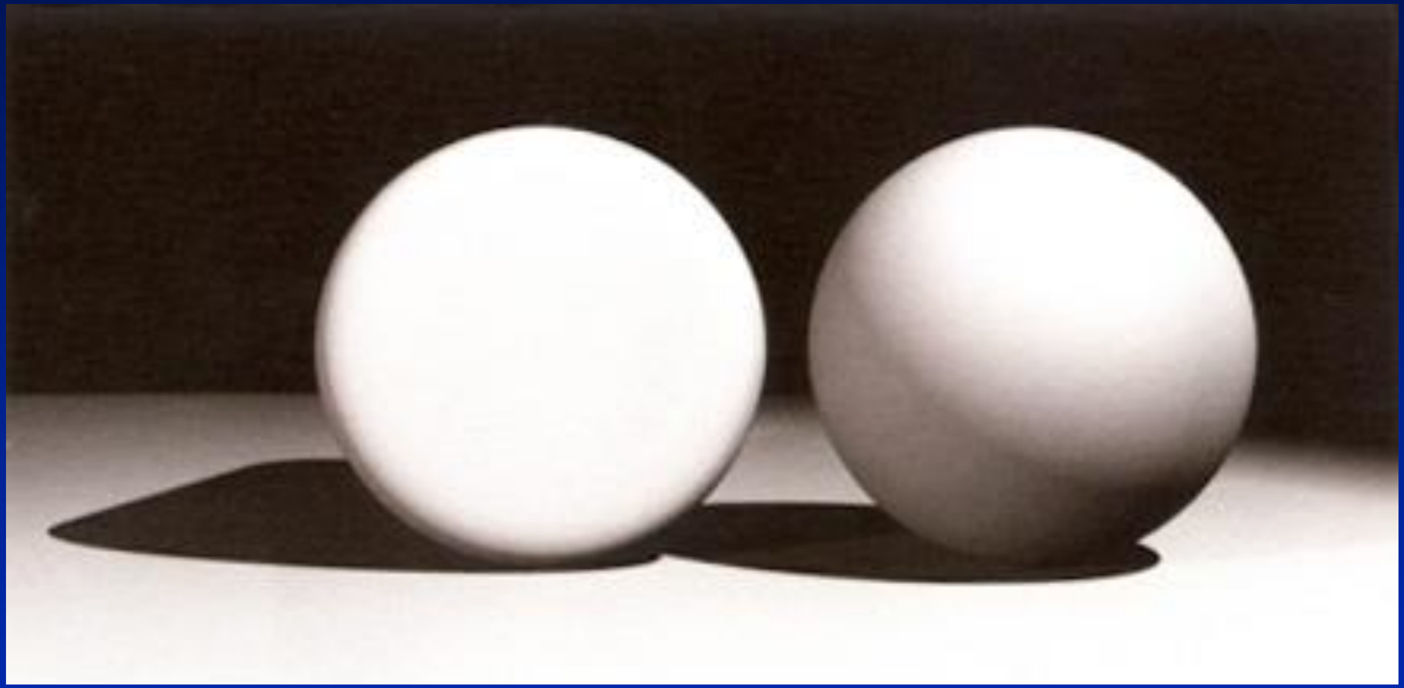
Lighting



Jeremy Birn, “[digital] Lighting & Rendering”, 2000 New Riders Publishers

The three dimensional shape is only inferred with this lighting.

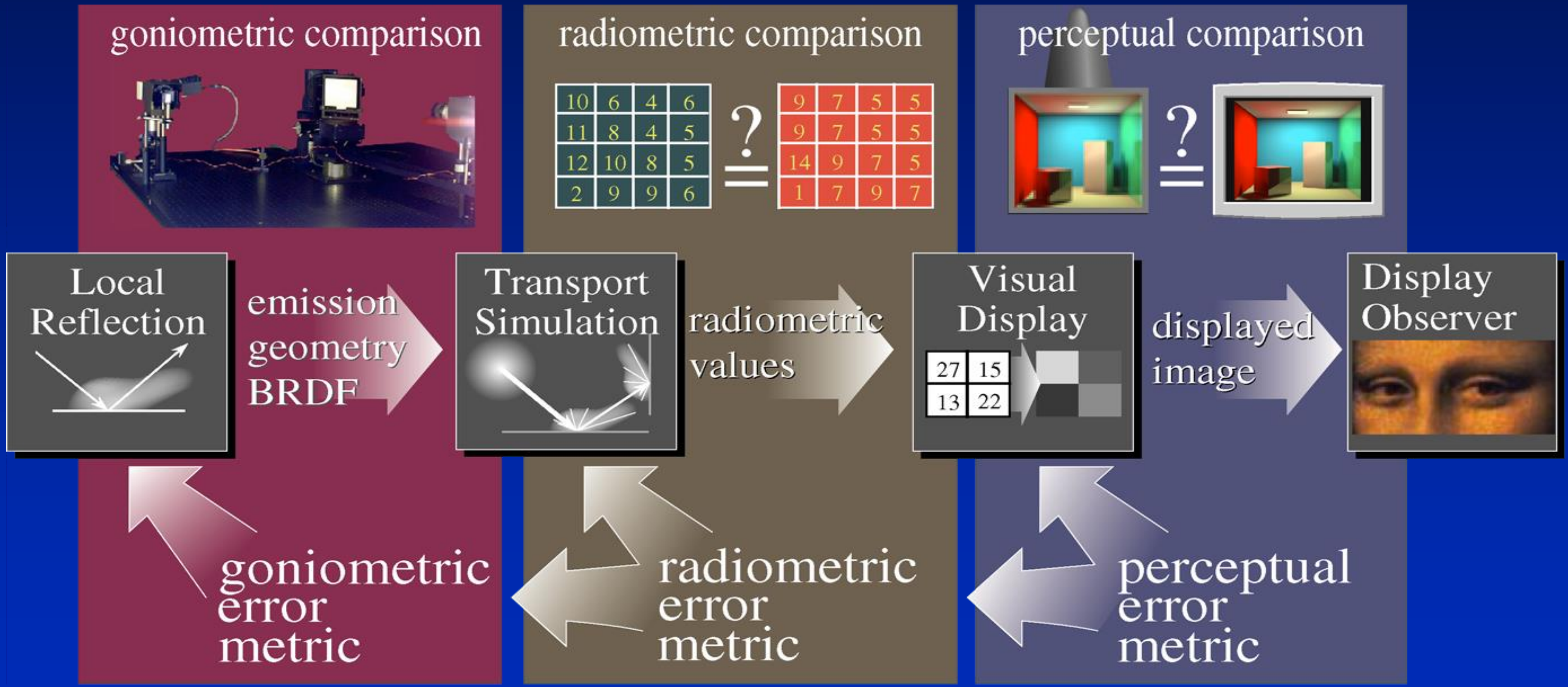
Lighting



Jeremy Birn, “[digital] Lighting & Rendering”, 2000 New Riders Publishers

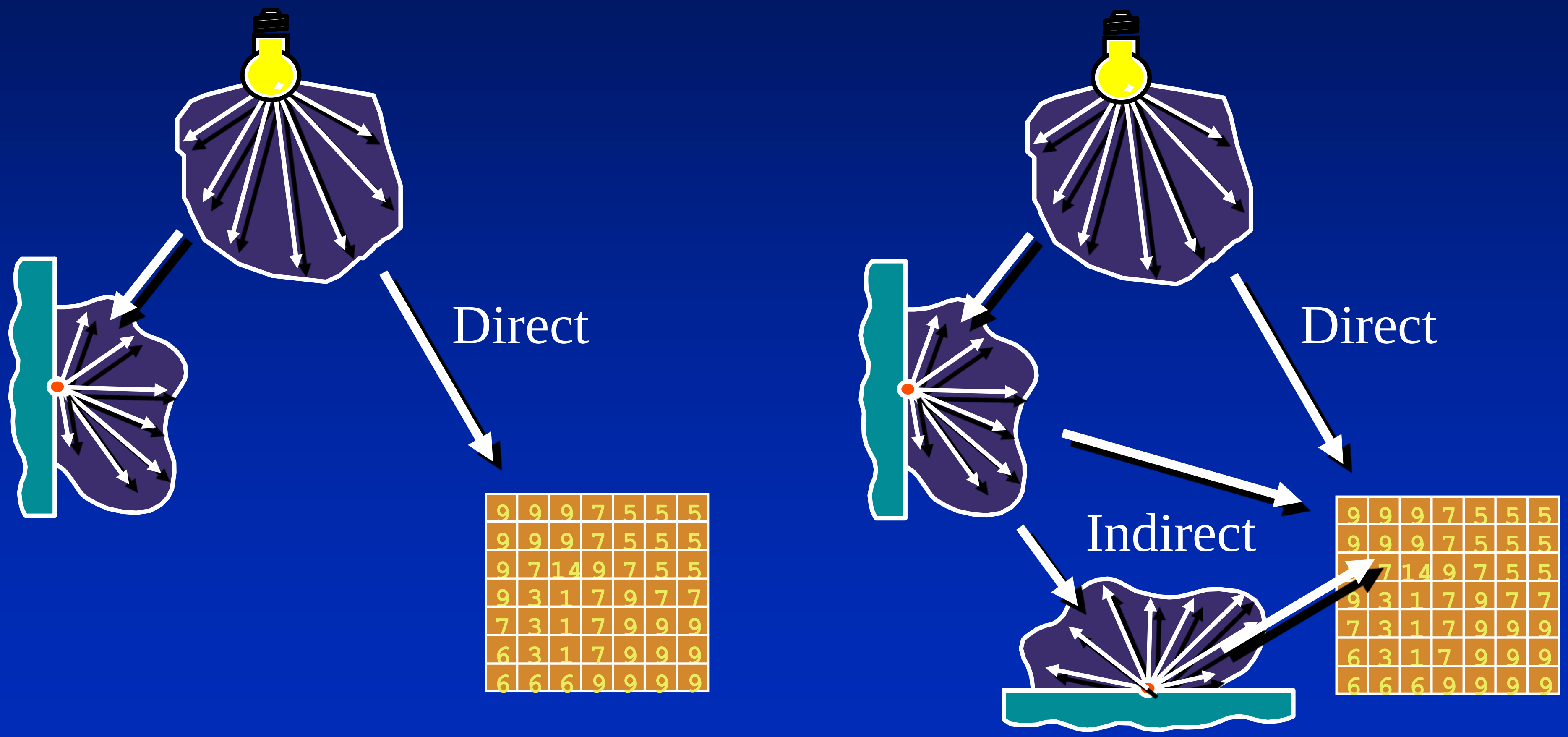
The geometry is better understood with correct lighting and shading.

Rendering Framework 1997

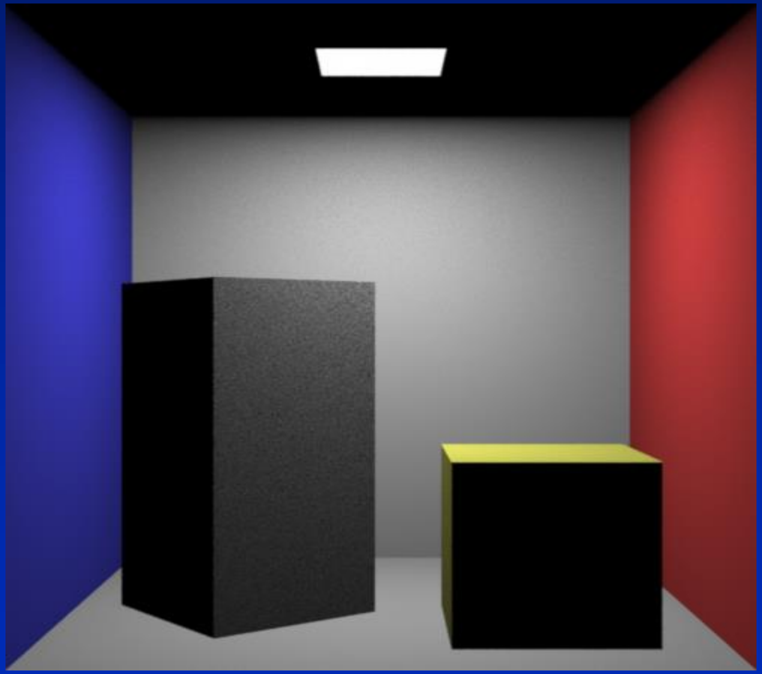


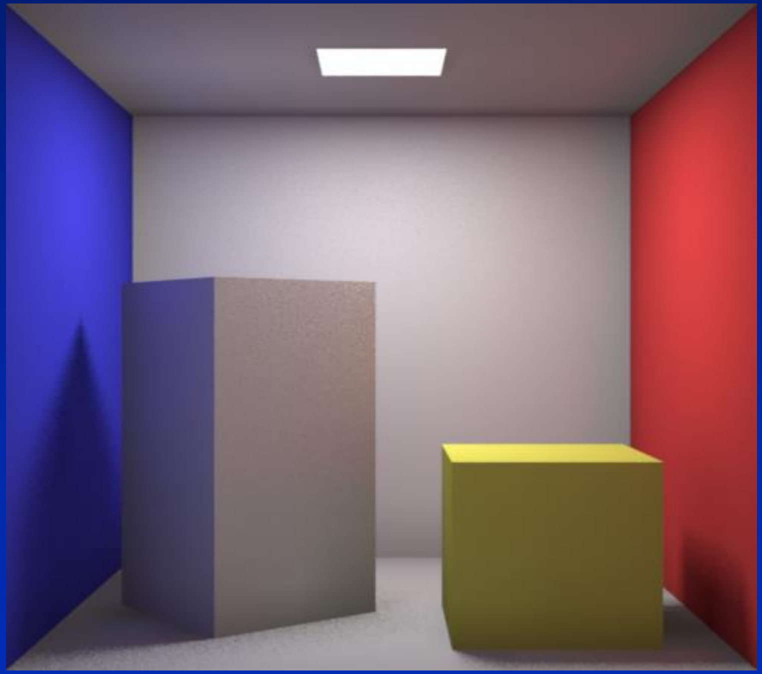
Cornell Box with Cameras

Direct Lighting and Indirect Lighting



Direct Lighting and Indirect Lighting





Assumptions In Direct Lighting

Light travels directly from light source to all object surfaces (no occlusion)
$\therefore$ no shadows

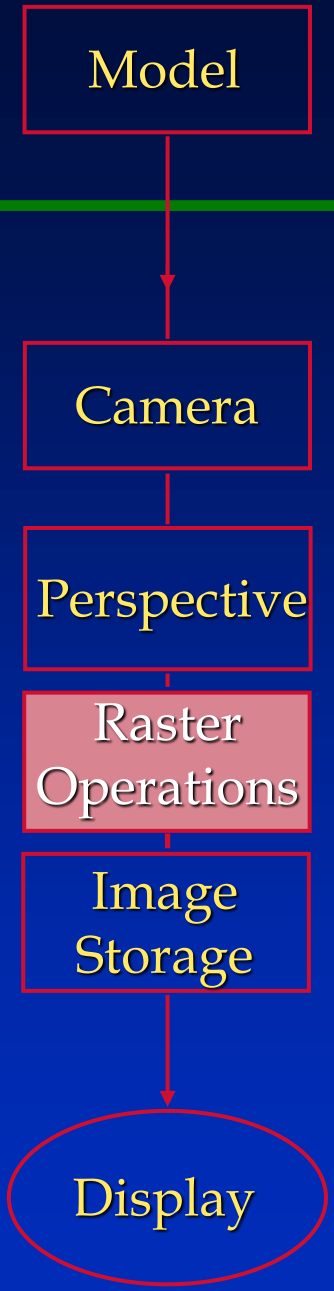
All light sources are point light sources
(no geometric area)

No interreflections from any surfaces

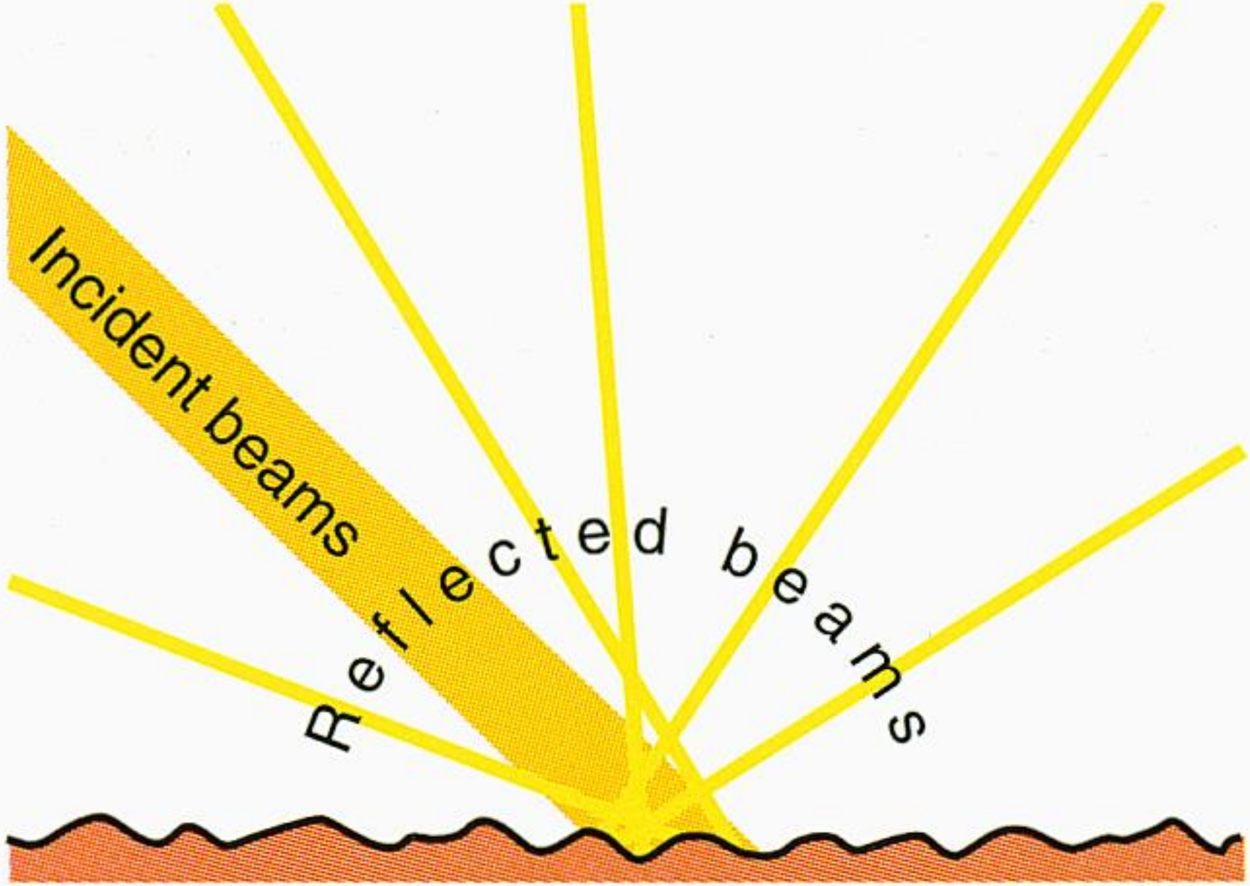
Lights maybe “directional”, “spot” or “omni lights”

Raster Operations

- Conversion from polygons to pixels
- Hidden surface removal (z-buffer)
- Incremental shading



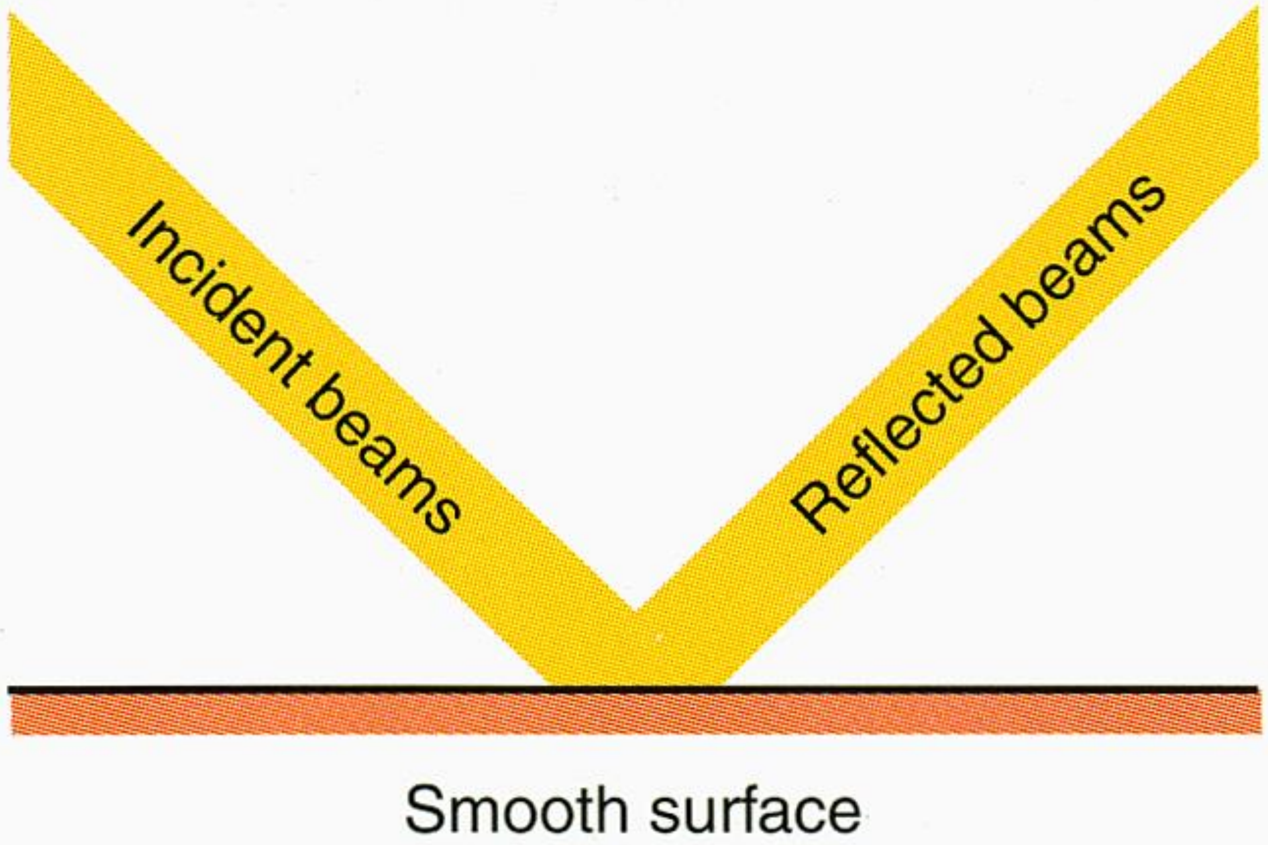
Diffuse Reflections



Diffuse reflection of light from a rough surface.

Roy S. Berns. “Billmeyer and Saltzman’s Principles of Color Technology, 3rd Ed. 2000, John Wiley & Sons, Inc. p. 12.

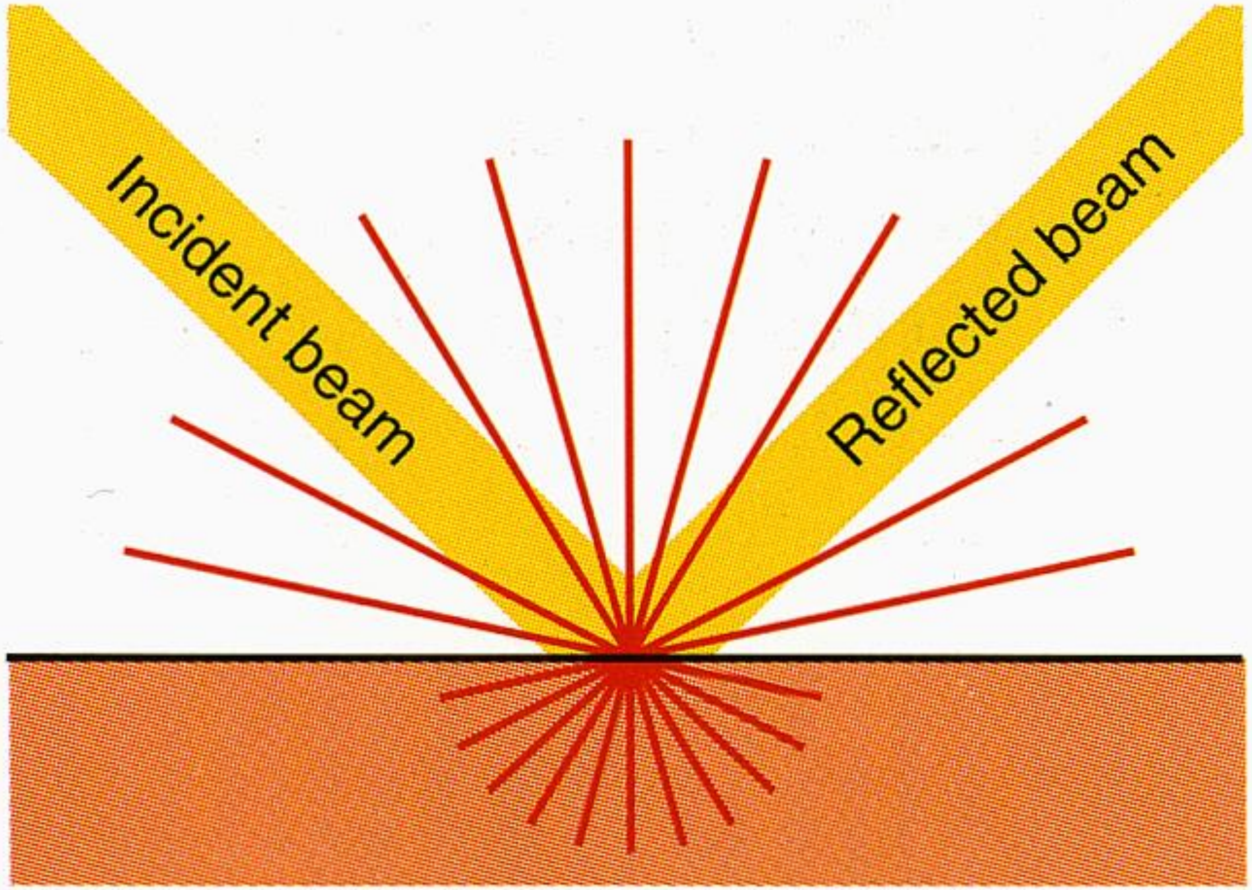
Specular Reflections



Specular reflection of light from a mirrorlike surface.

Roy S. Berns. “Billmeyer and Saltzman’s Principles of Color Technology, 3rd Ed. 2000, John Wiley & Sons, Inc. p. 12.

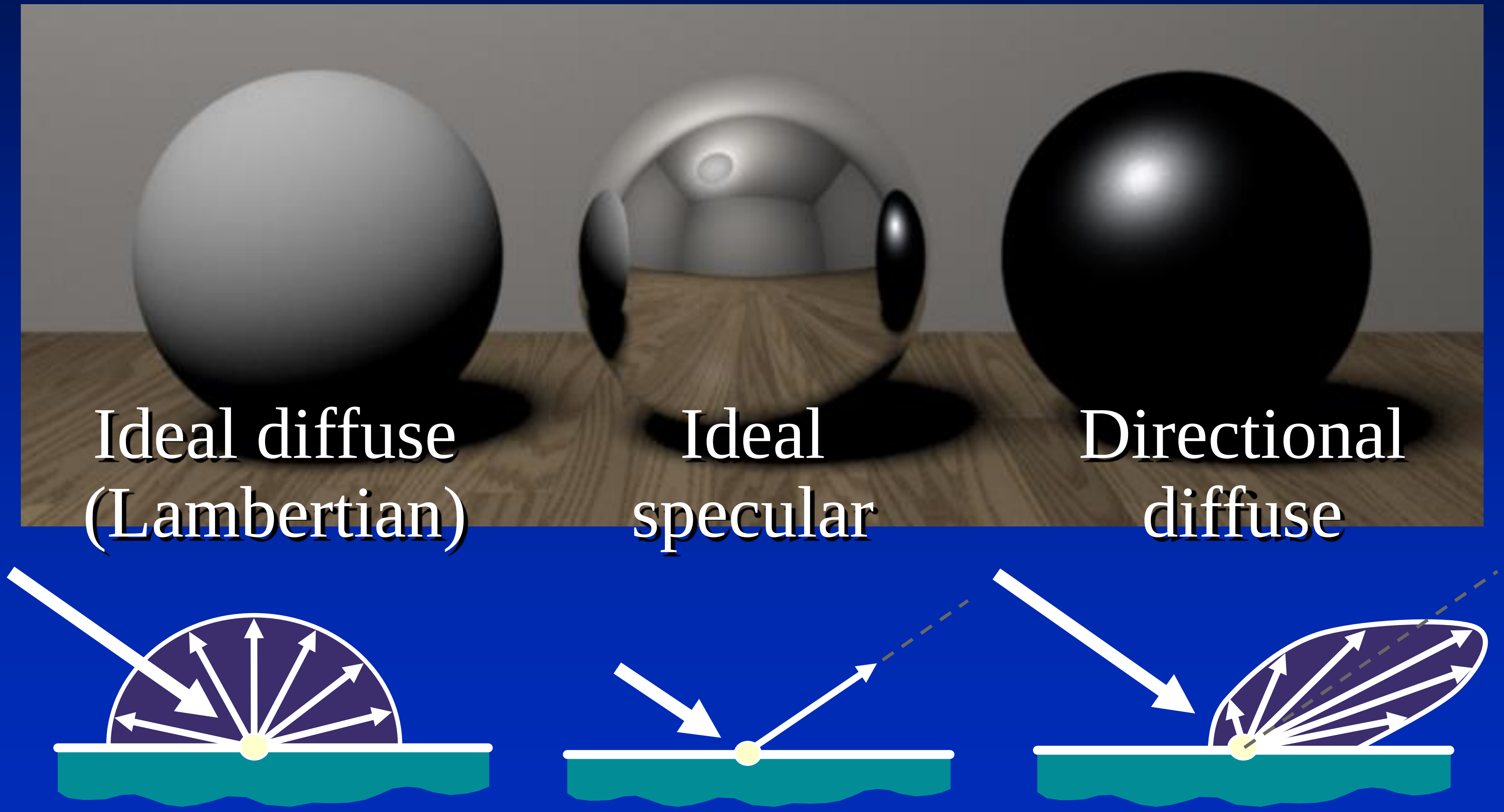
Glossy Reflections



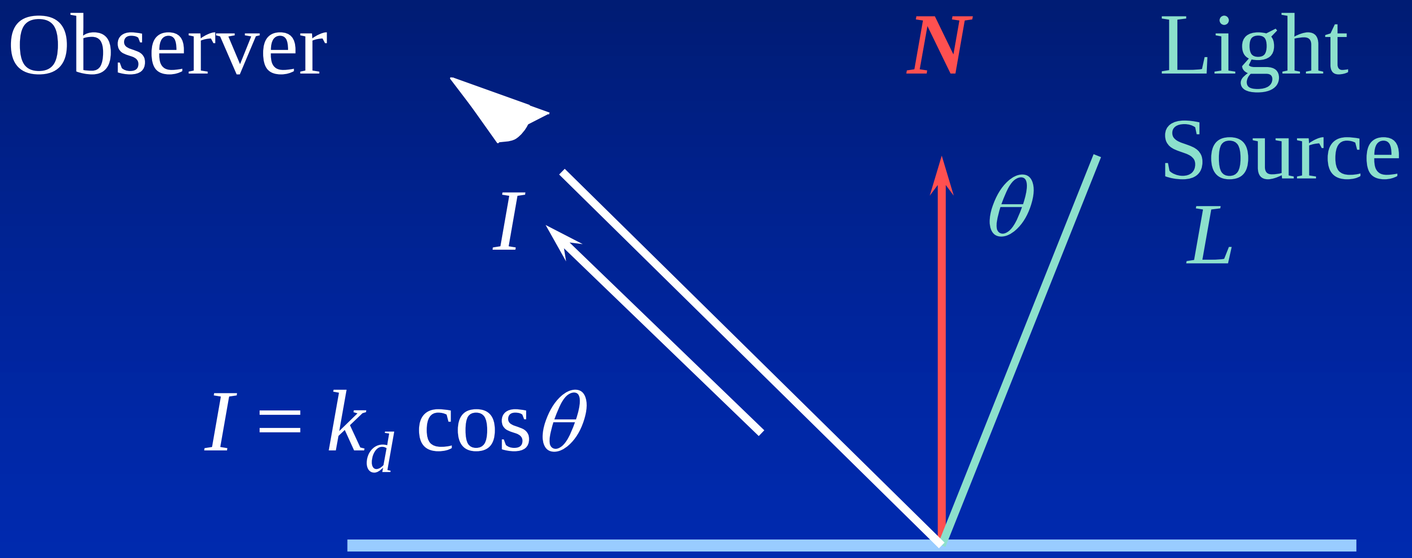
Combination of diffuse and specular reflection due to scattering from beneath, plus reflection from, a smooth surface.

Roy S. Berns. "Billmeyer and Saltzman's Principles of Color Technology, 3rd Ed. 2000, John Wiley & Sons, Inc. p. 12.

Reflectance - Three Forms

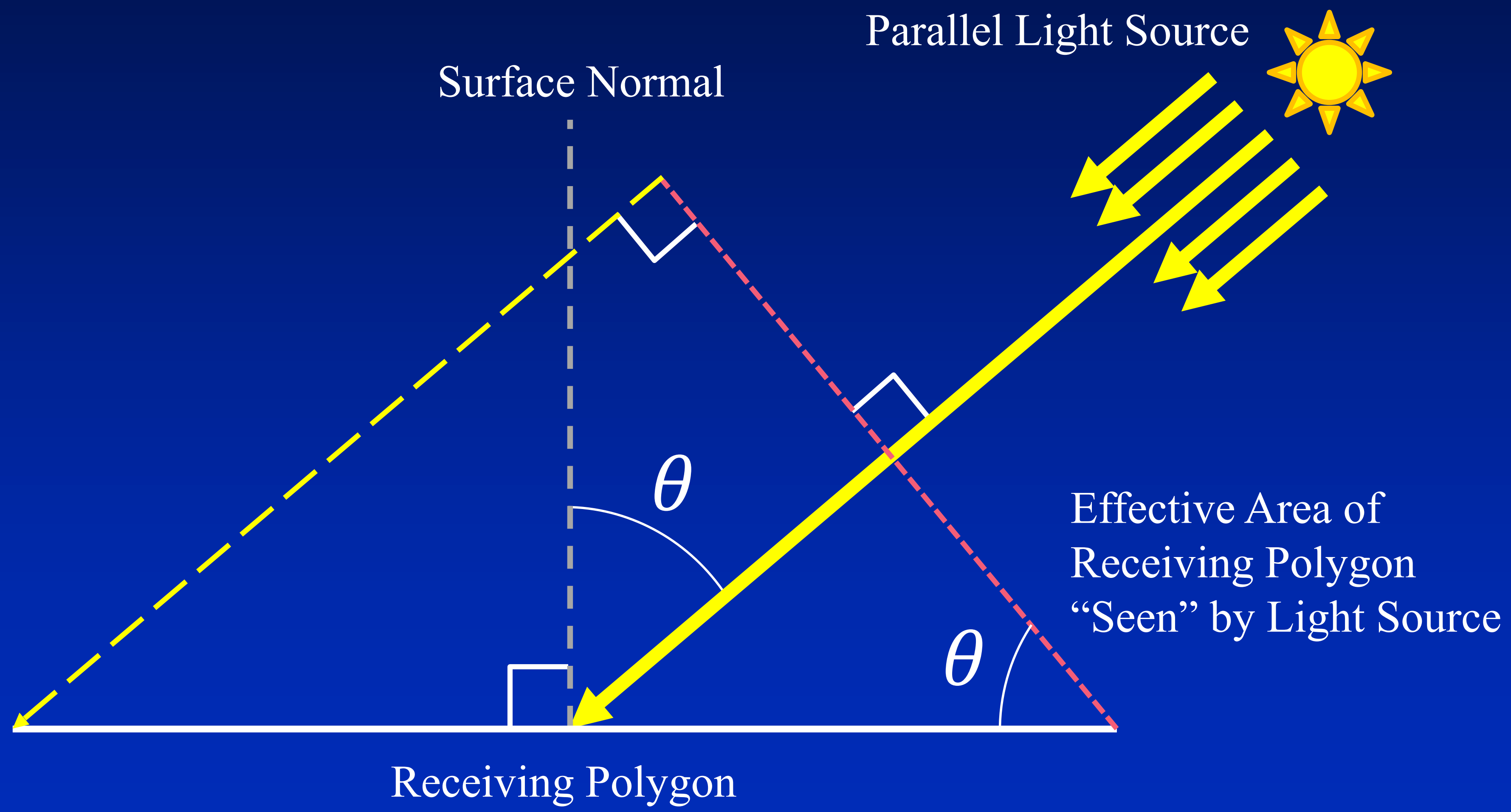


Diffuse Reflections

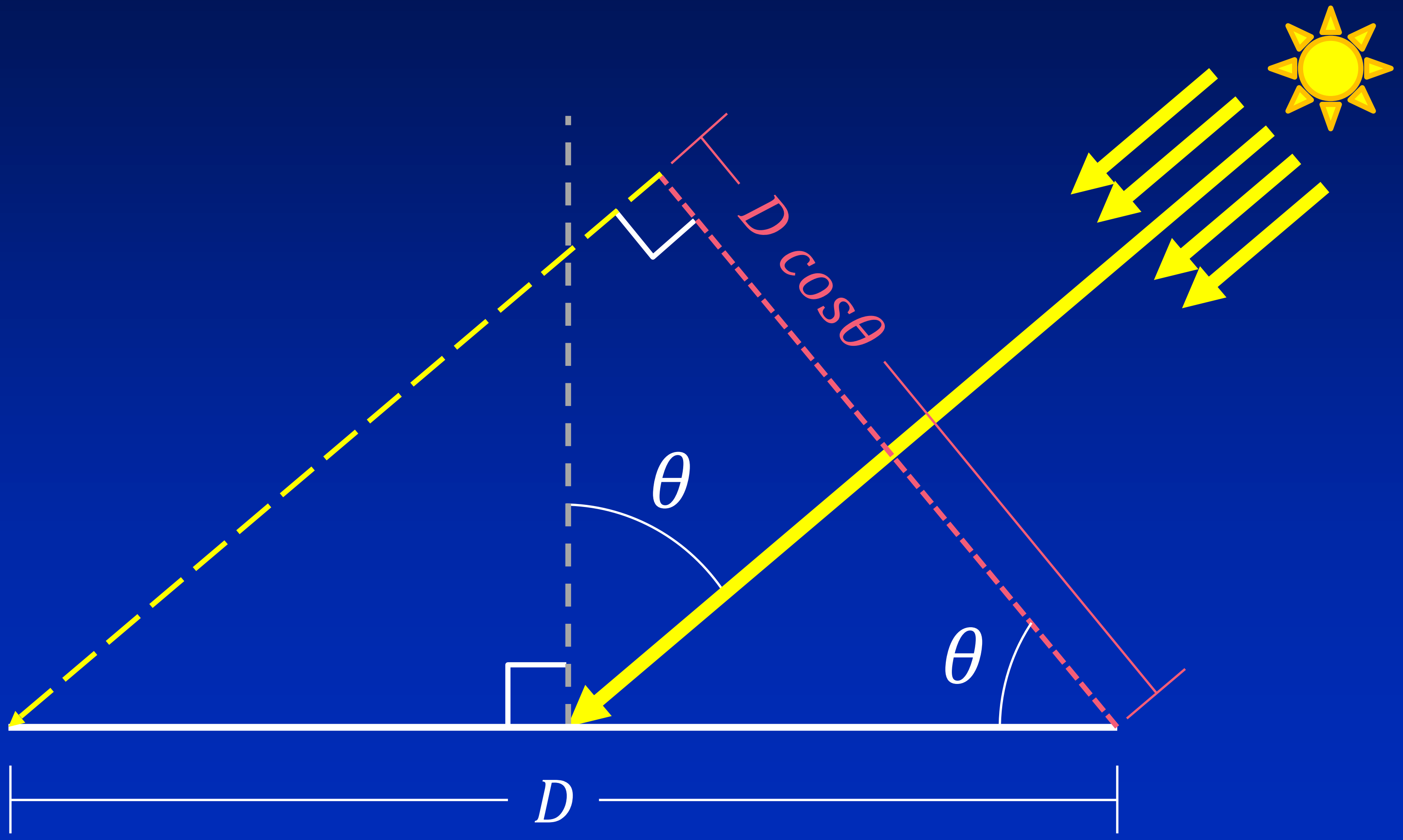


$$I = k_d \cos\theta$$

Diffuse Reflections



Diffuse Reflections



How do you find the angle θ?

- If you know the surface definition (it's planar equation), you can find it's normal direction $\vec{N}$. A unit normal in this direction is $\vec{N}/|\vec{N}|$
- If you know the location of the light source L, you can find the illumination direction $\vec{L}$. A unit normal in this direction is $\vec{L}/|\vec{L}|$

Cosine Calculations

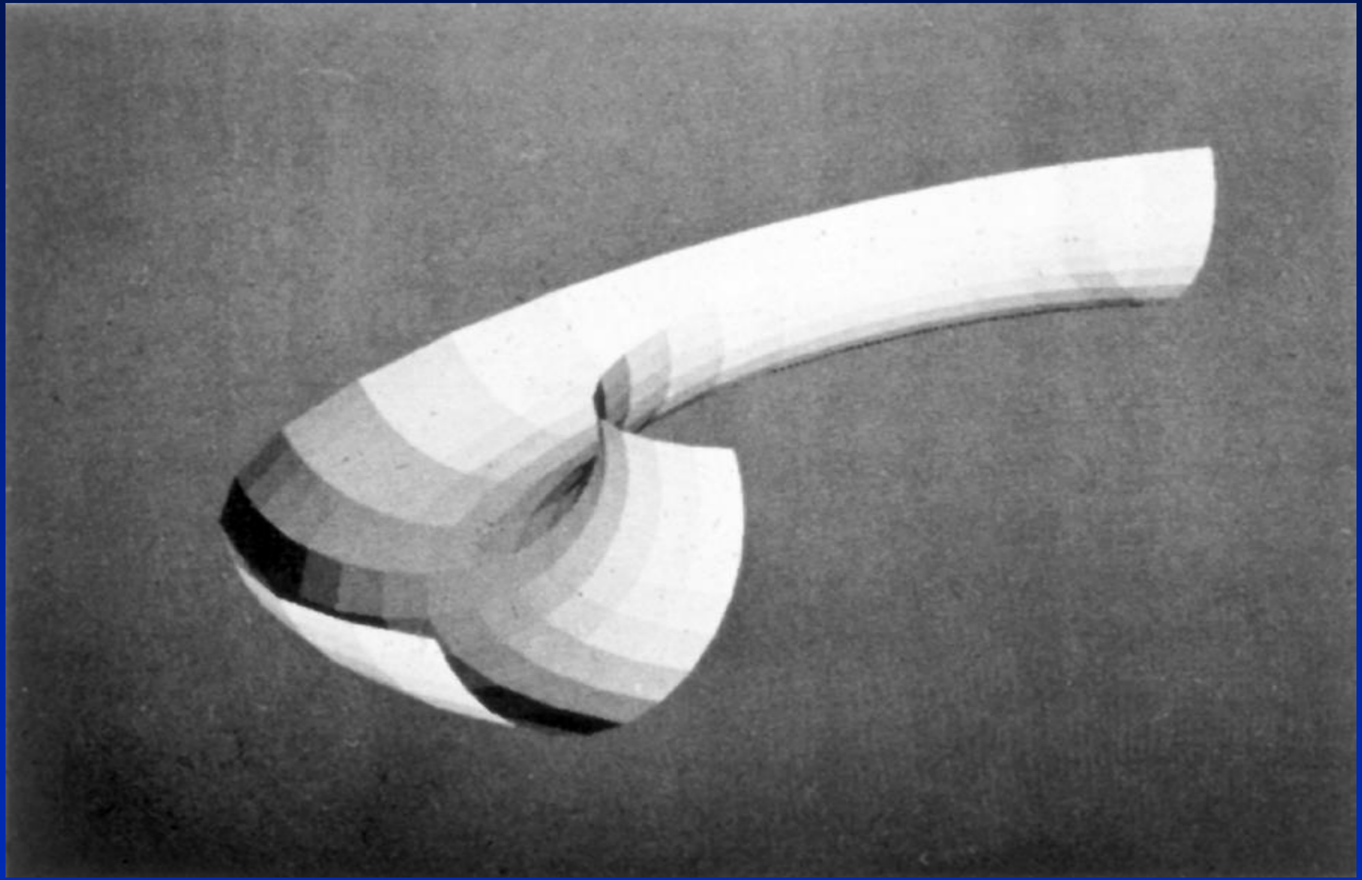
Dot Product Definition

$$\overline{N} \cdot \overline{L} = \left|\overline{N}\right|\left|\overline{L}\right| \cos\theta$$

$$\cos\theta = \frac{\overline{N} \cdot \overline{L}}{|N||L|} = \frac{\overline{N}}{|N|} \cdot \frac{\overline{L}}{|L|}$$

Usually, the normal and light source vector directions are given as unit normals.

Gouraud Flat Polygon Shading

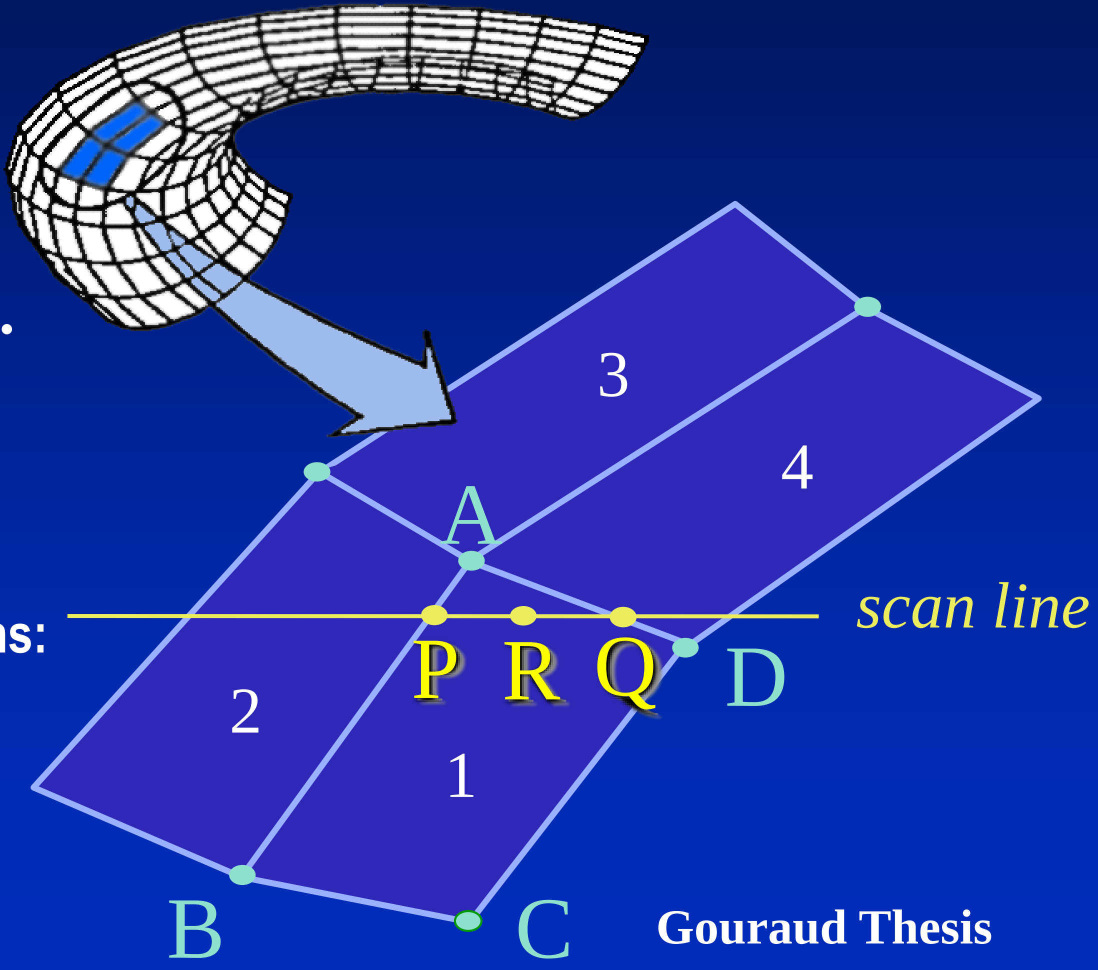


Each polygon is shaded based on a single normal.

Gouraud Thesis

Gouraud Smooth Shading

Four polygons
approximating a surface
in the vicinity of point A.



Gouraud Thesis

The shading at point R is computed as

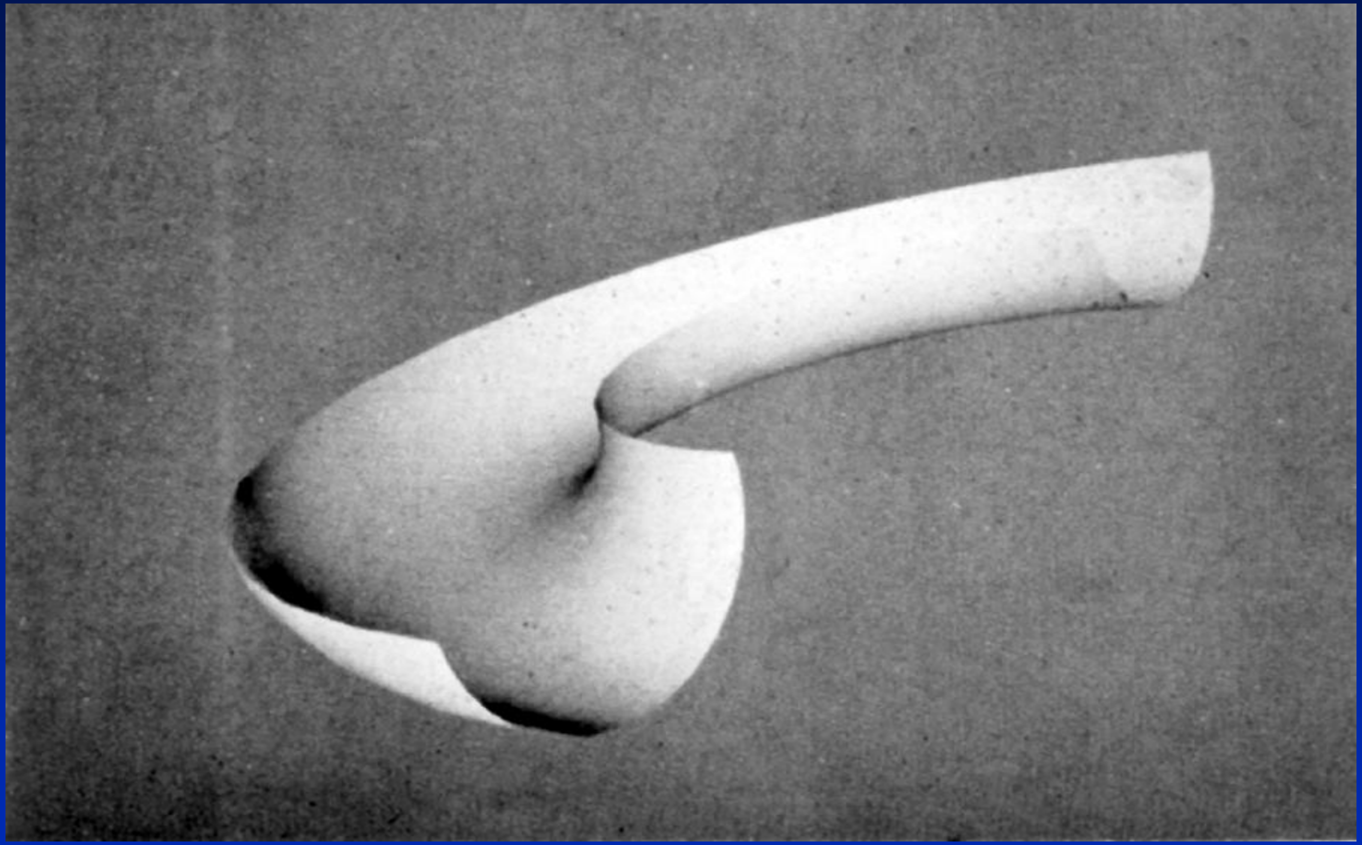
two types of successive linear interpolations:

across polygon edges: P between A and B,

Q between A and D;

across the scan line: R between P and Q.

Gouraud Smooth Shading



Each pixel is shaded by interpolating intensities computed at each of the polygon's vertices.

Gouraud Thesis

Steps in Gouraud Shading

- For each polygon
  - Compute vertex intensities (using any illumination model)
  - Compute slopes (linear interpolation) in spatial (image) domain (picture plane) and intensity domain (real environment)
  - Increment by scan line
- For each scan line
  - Compute slope in intensity domain (real environment)
  - Render each pixel

Note the intensity computations are based on object space data, but all interpolation is done in image space.

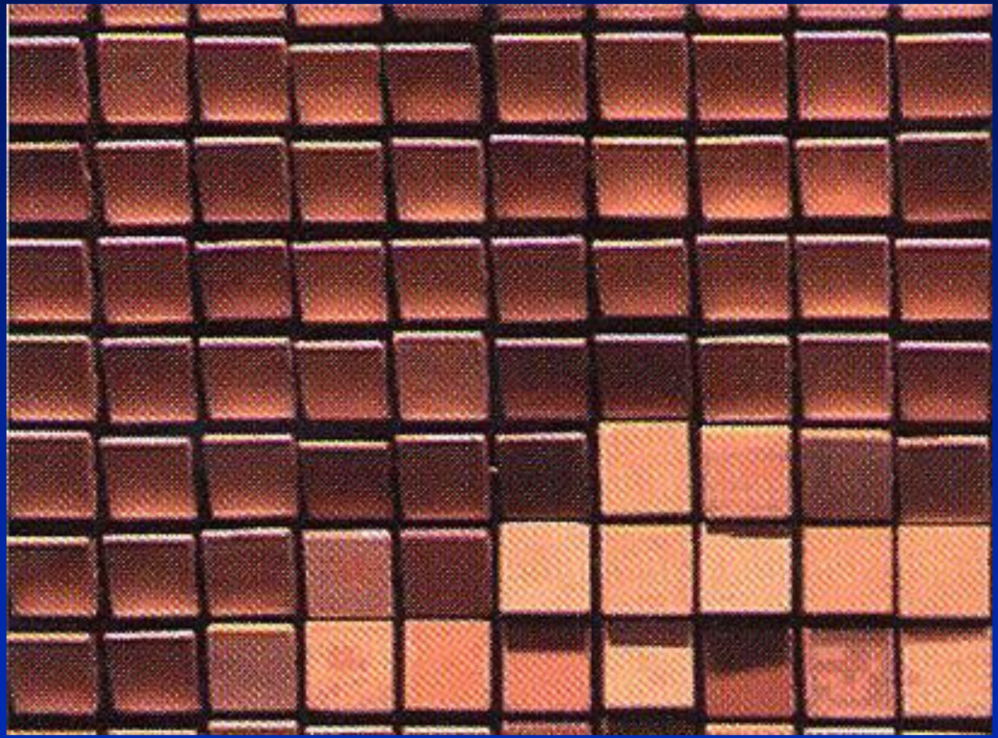
Diffuse Shading

Jeremy Birn. Digital Lighting & Rendering , p. 74.

Between Analogue and Digital

Daniel Rozin, “Wooden Mirror”

Daniel Rozin, “Wooden Mirror” close-up



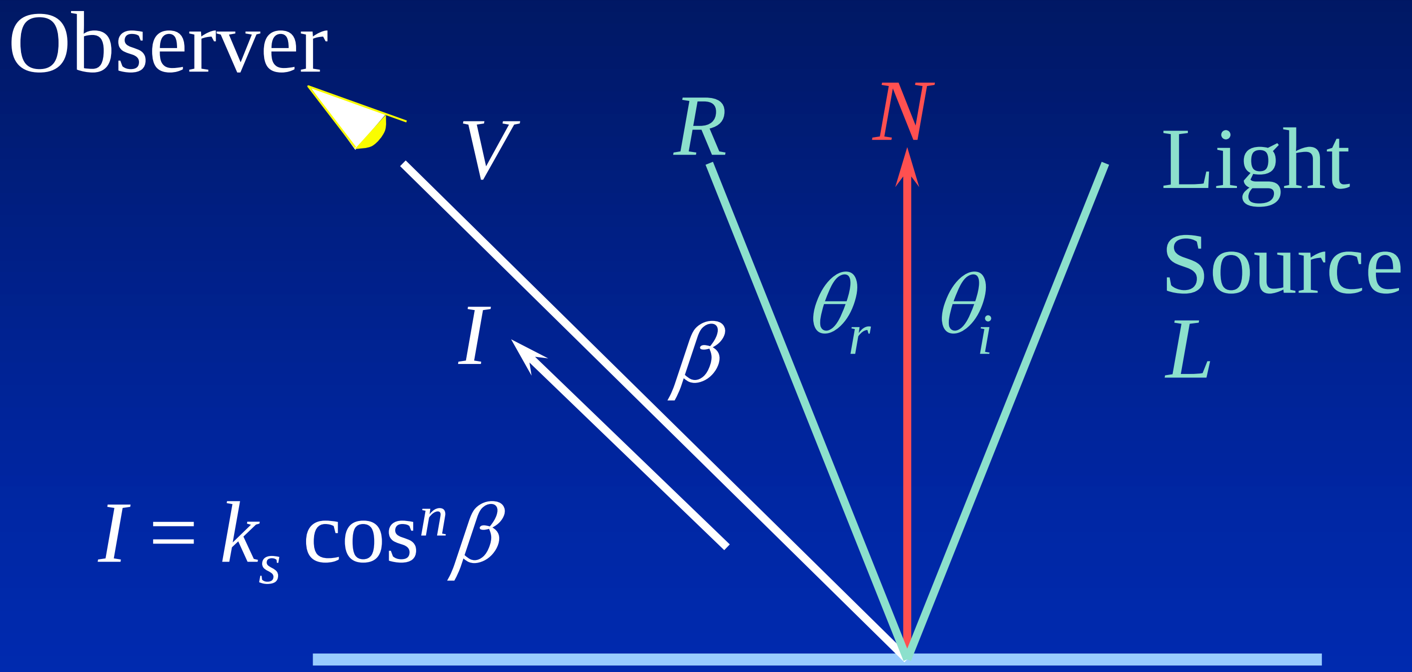
Specular Shading

Viennese Siler, Modern Design 1780-1918) Teapot, Jakob Krautauer, Vienna 1802 – Silver, fruitwood, H 14.8 cm/5.9 in.

Phong Model Assumptions

- The reflection function can be represented by three components: a constant ambient term, and diffuse and specular components
- Isotropic (rotationally symmetric)
- Point or parallel light source (one vector direction)
- Computationally simple

Phong Model Specular Reflection

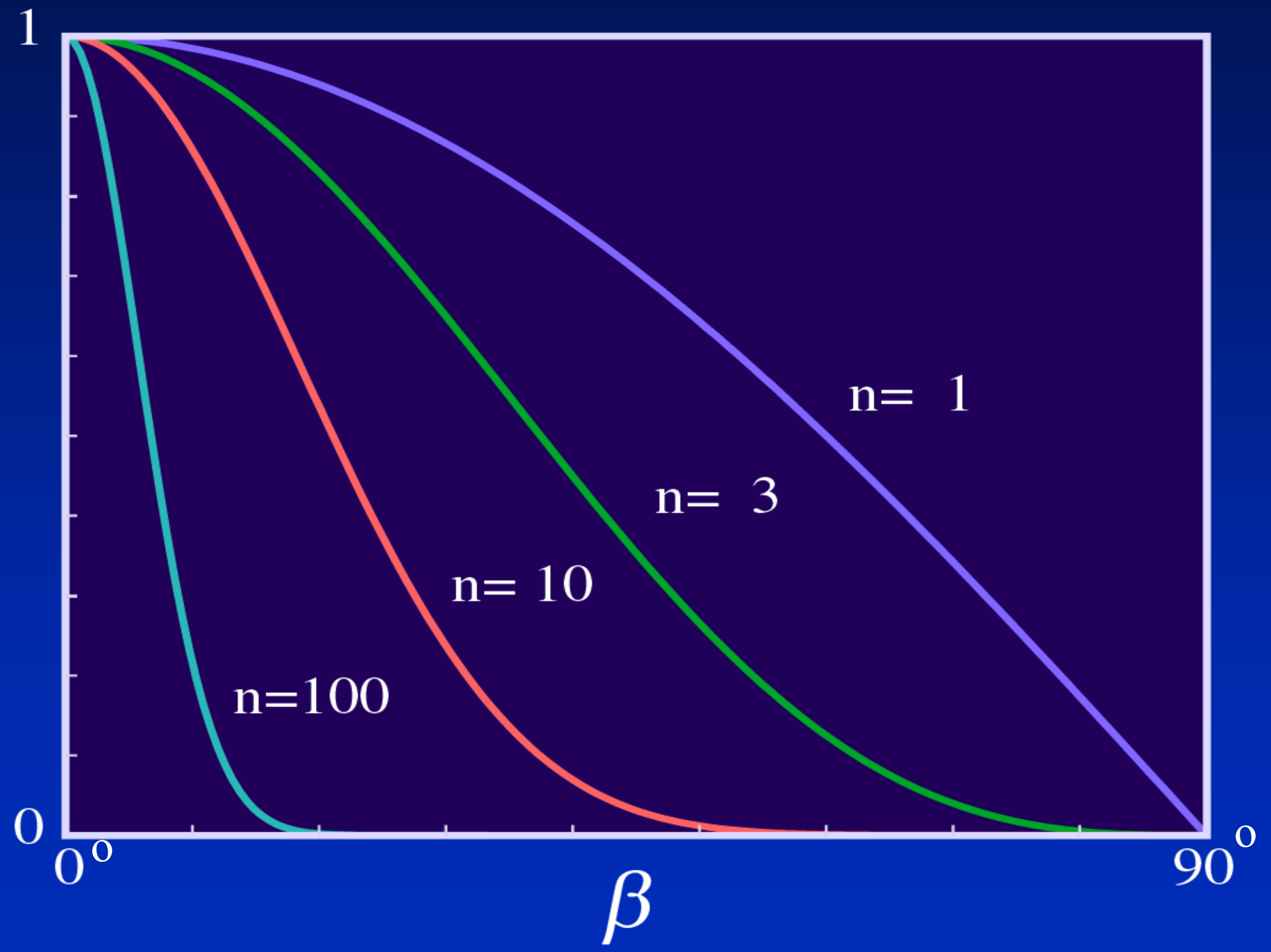


$$I = k_s \cos^n \beta$$

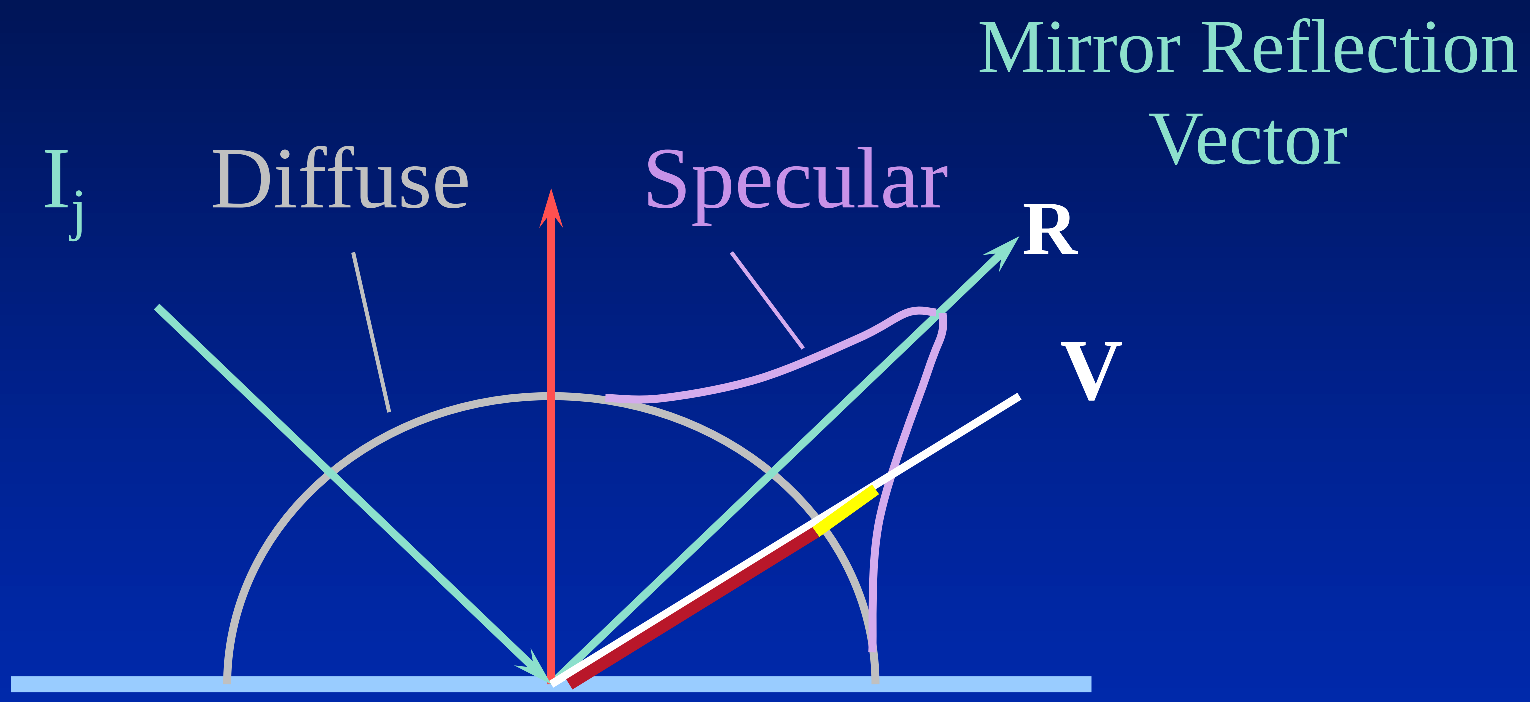
How do you find the angle β?

- If you know the illumination direction $\vec{L}$, you can find the reflection direction $\vec{R}$ (angle of reflection = angle of incidence)
- If you know the location of the observer, you can find the view direction $\vec{V}$
- The specular reflection component is a function of the angle $\boldsymbol{\beta}$, the angle between the view direction and the reflection vector

Variation of $\cos^n \beta$



Phong Reflection Model



$$\text{Diffuse} = \quad k_d(\overline{N} \cdot \overline{L})$$

$$\text{Specular} = \quad k_s(\overline{R} \cdot \overline{V})^n$$

Phong Goblet

Bui Toung Phong Thesis

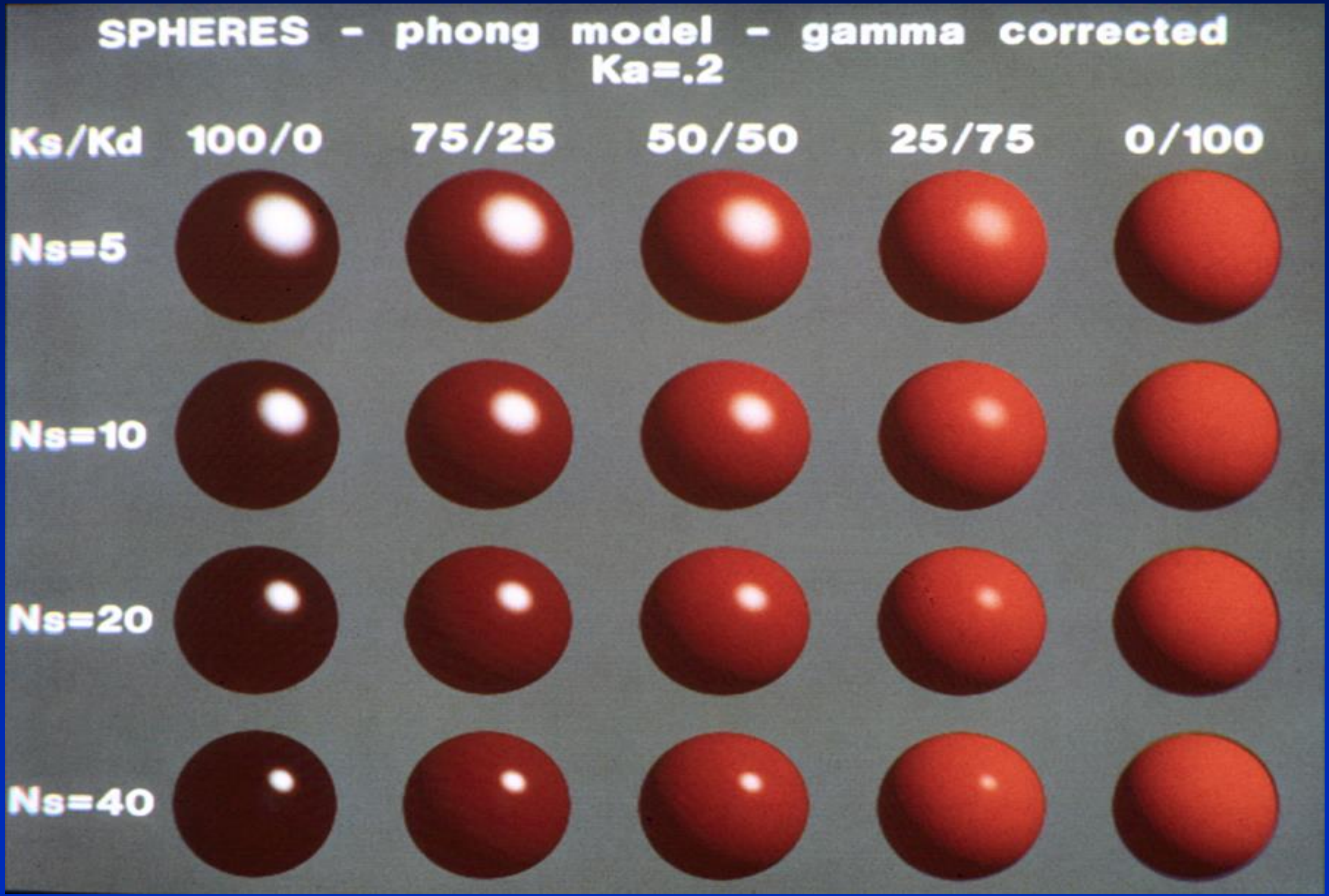
Phong Equation

$$I = I_a + I_d + I_s$$

$$= [k_a + k_d(\vec{N} \cdot \vec{L})](object\ color) + k_s(\vec{R} \cdot \vec{V})^n(light\ color)$$

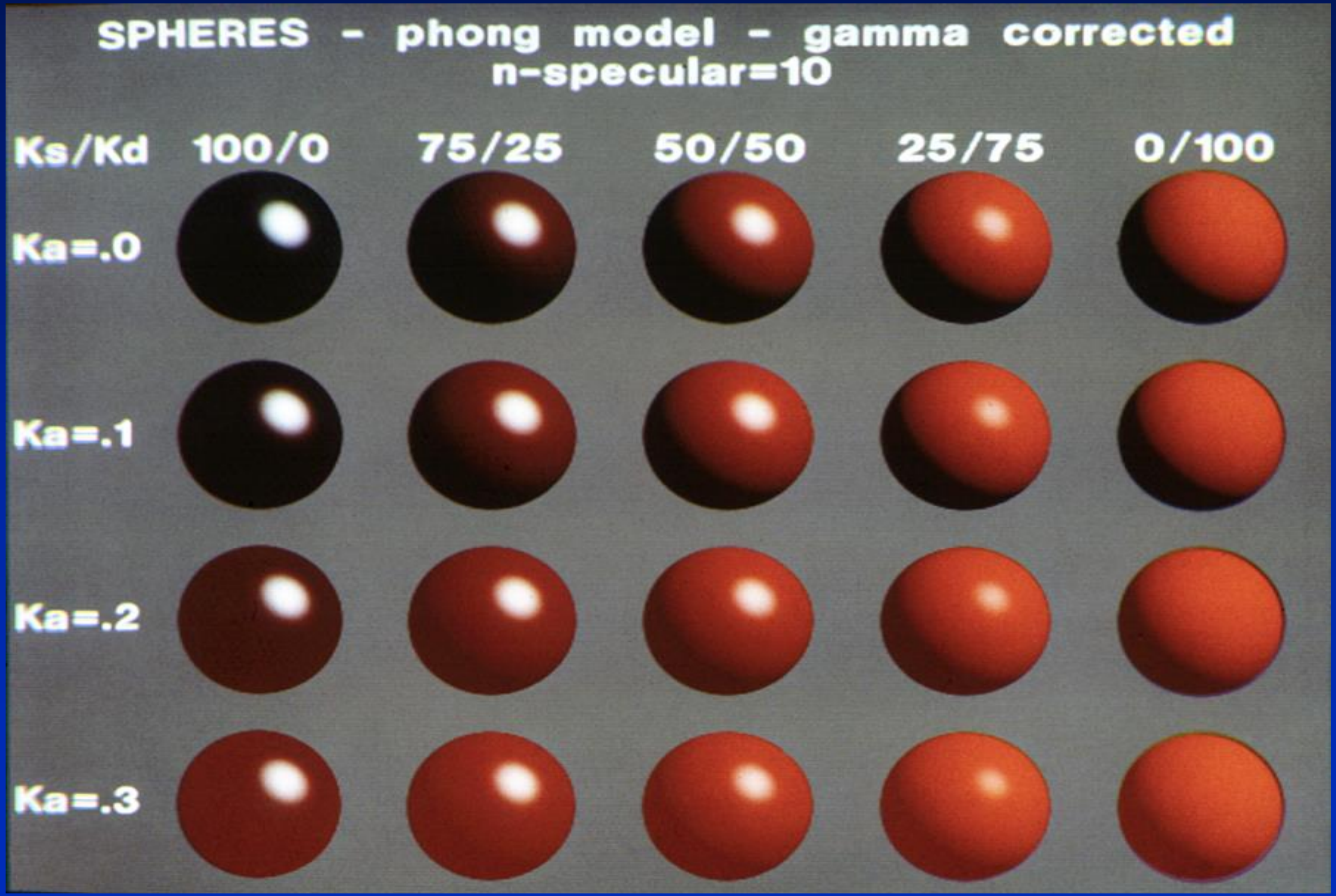
Where k_a= constant ambient term and $k_a + k_d + k_s = 1$

Phong Model with Constant Ambient Term and Variations of Specular Exponent



Roy Hall

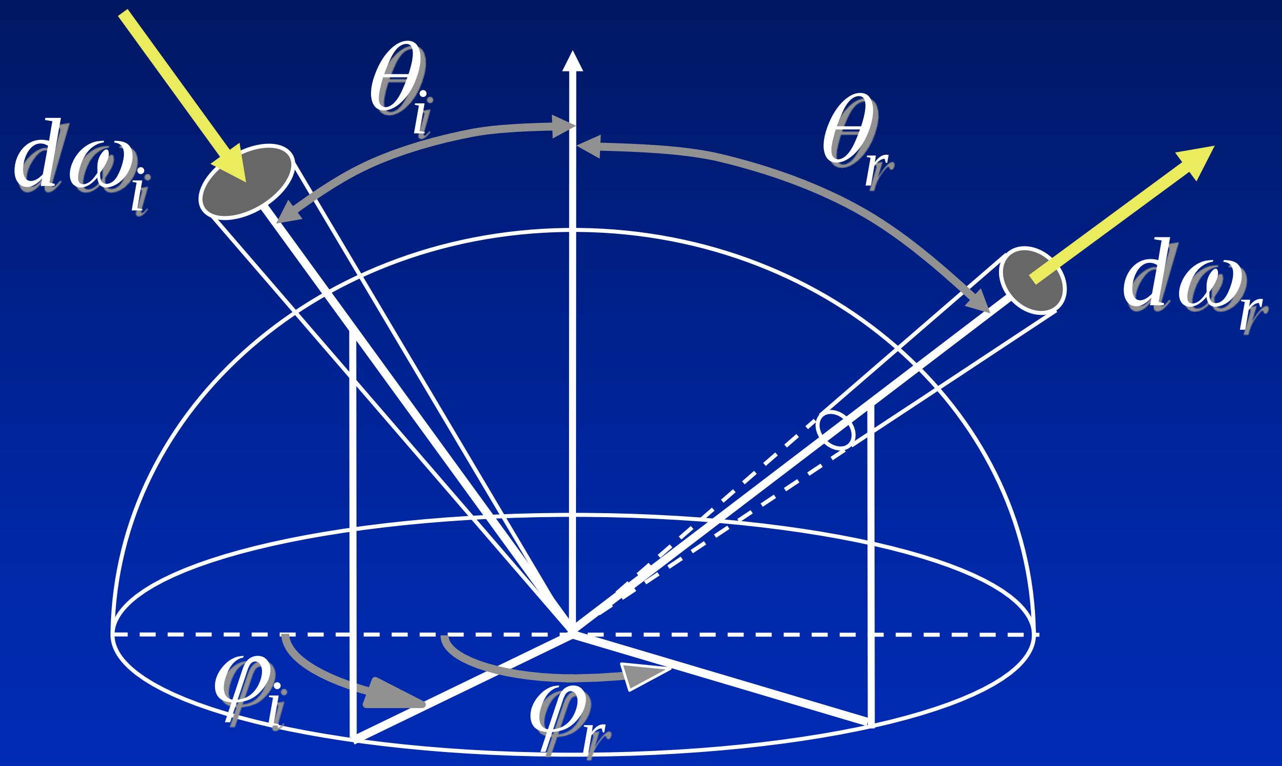
Phong Model with Constant Specular Exponent and Variation of Ambient Term



Roy Hall

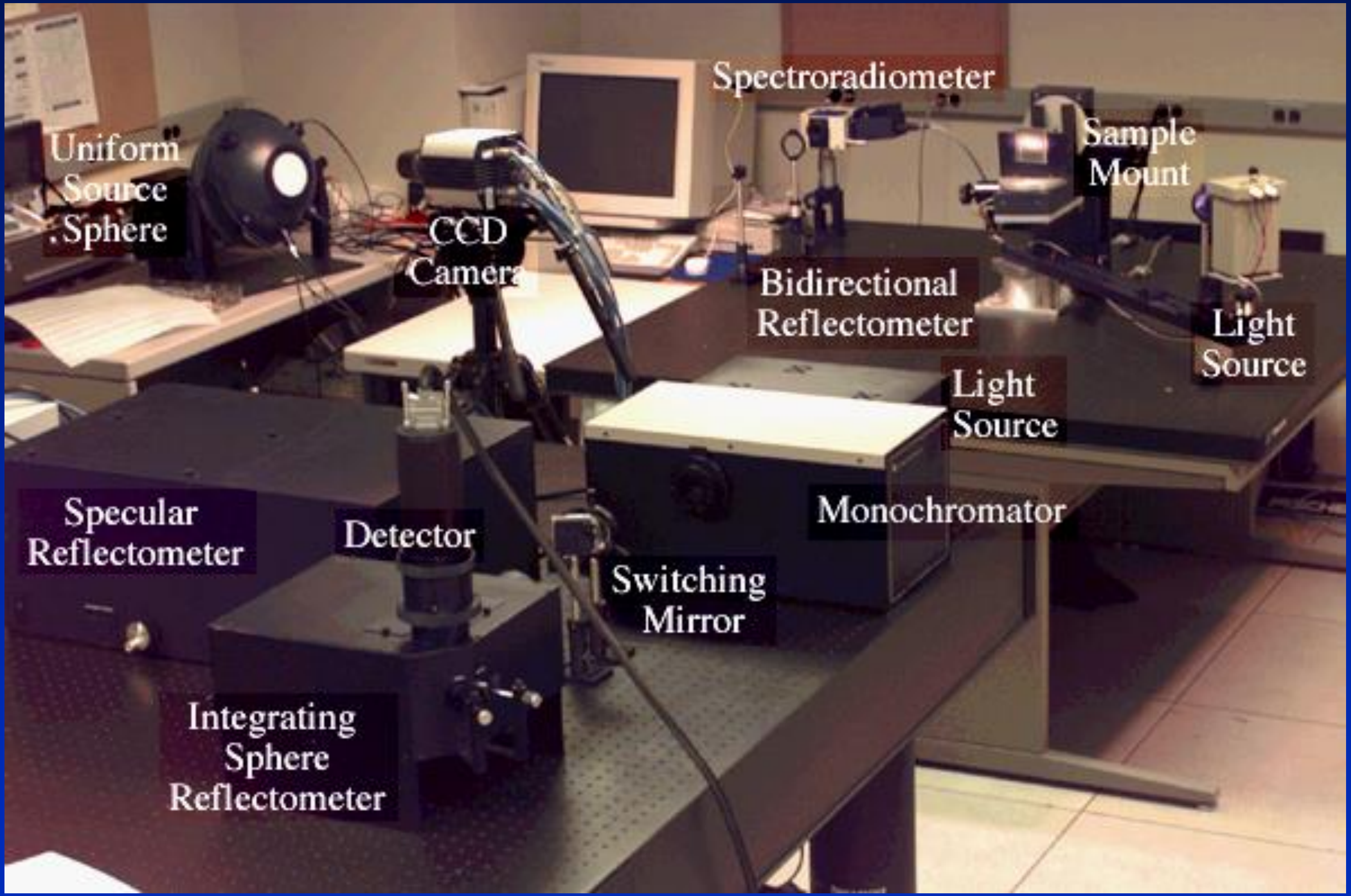
Bidirectional Reflection Distribution Function (BRDF)

Reflection Geometry (BRDF)

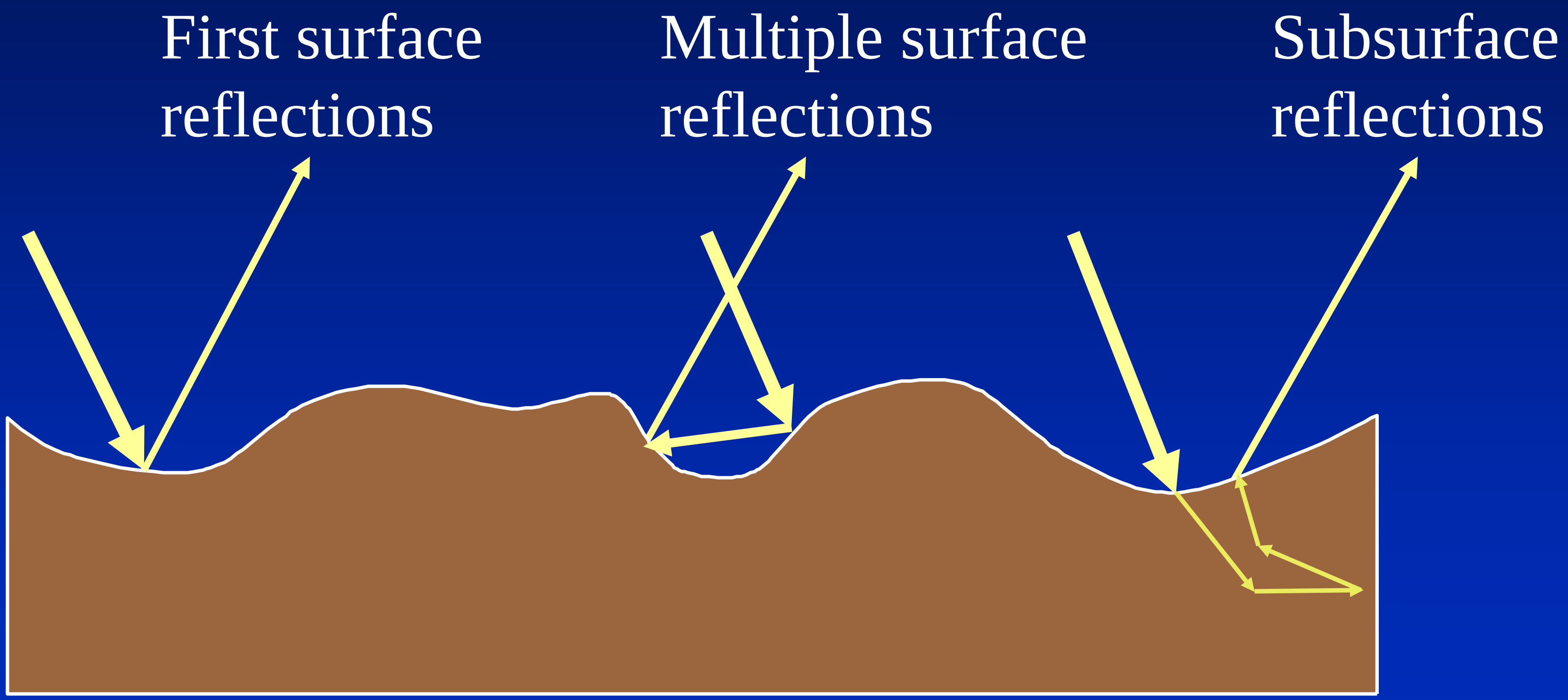


Bidirectional Reflection Distribution Function

Light Measurement Laboratory



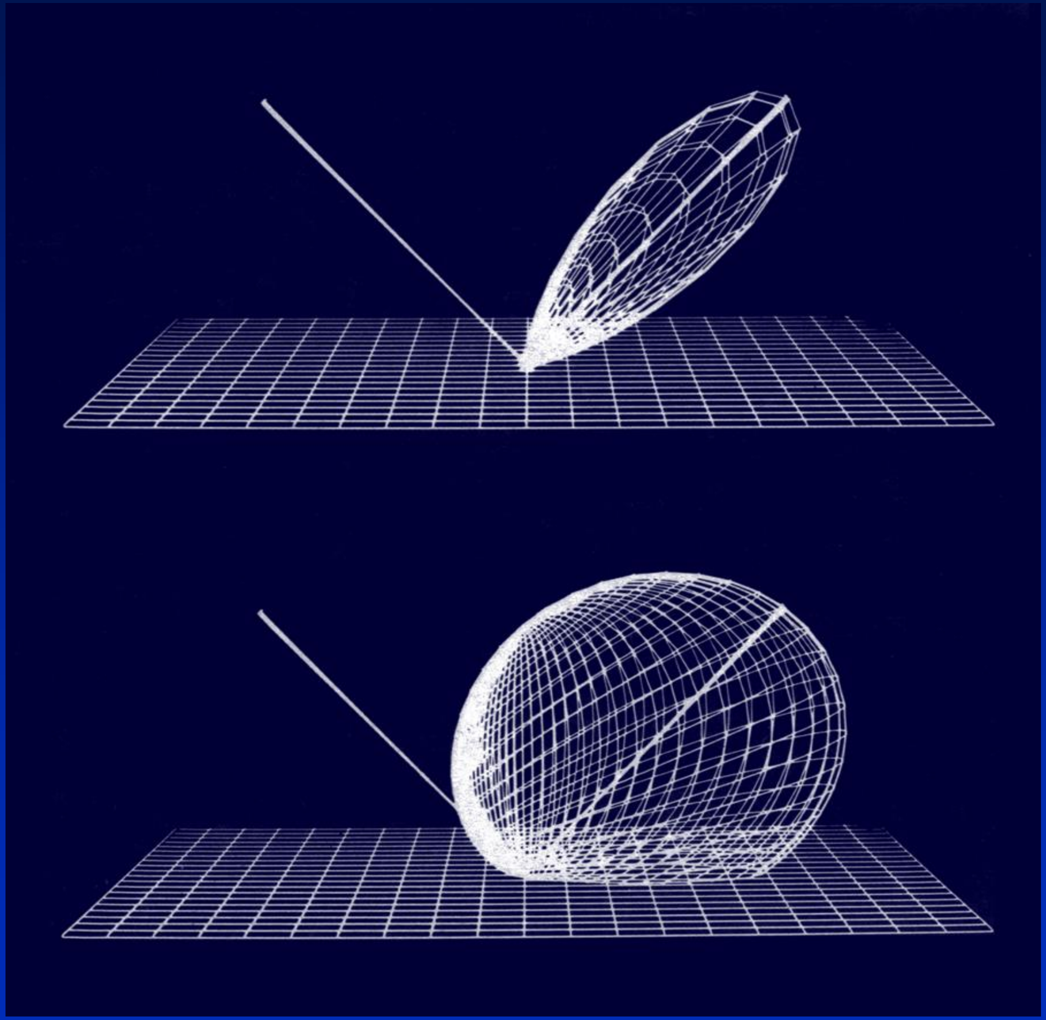
Reflection Processes



Gaussian Distribution

$m = 0.2$

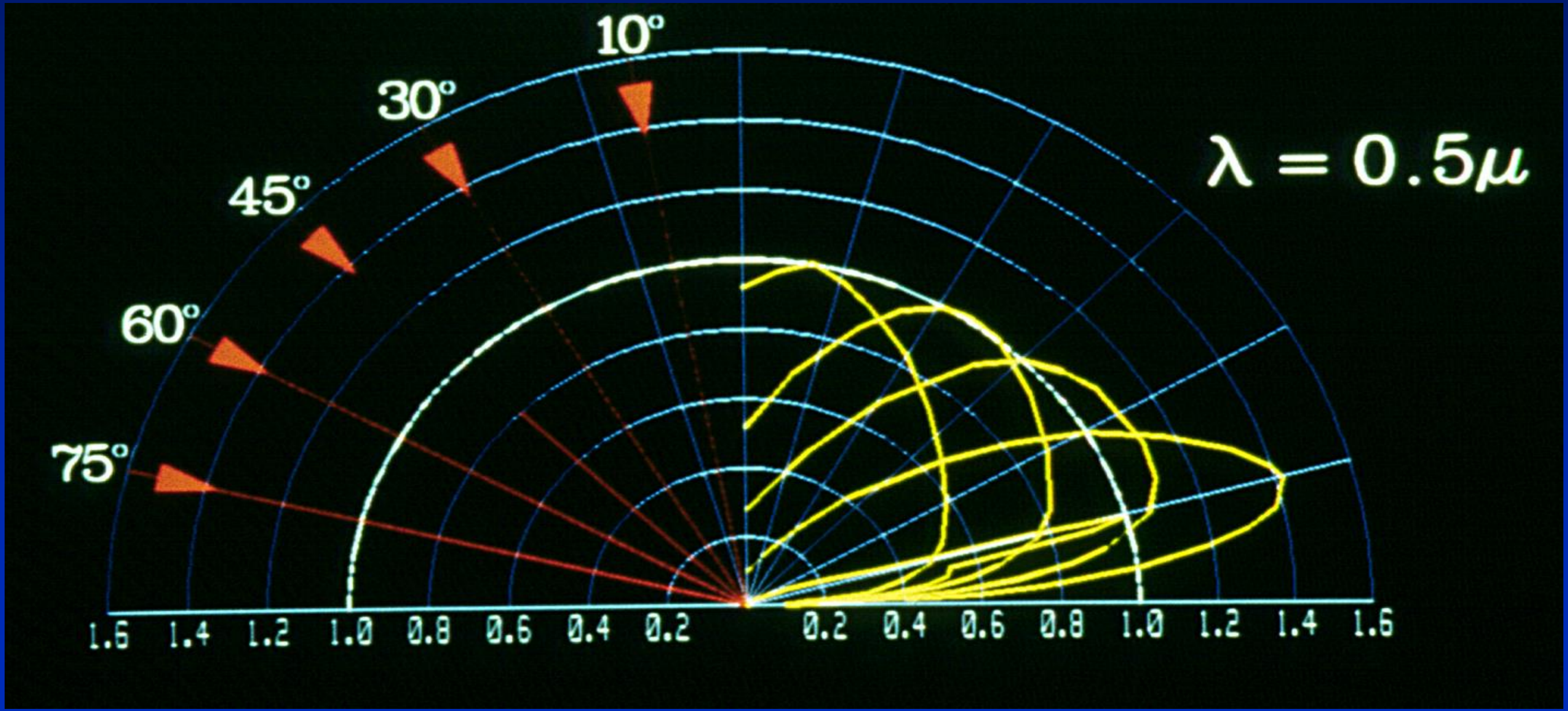
$m = 0.6$



Where m=root mean square slope of the microfacets

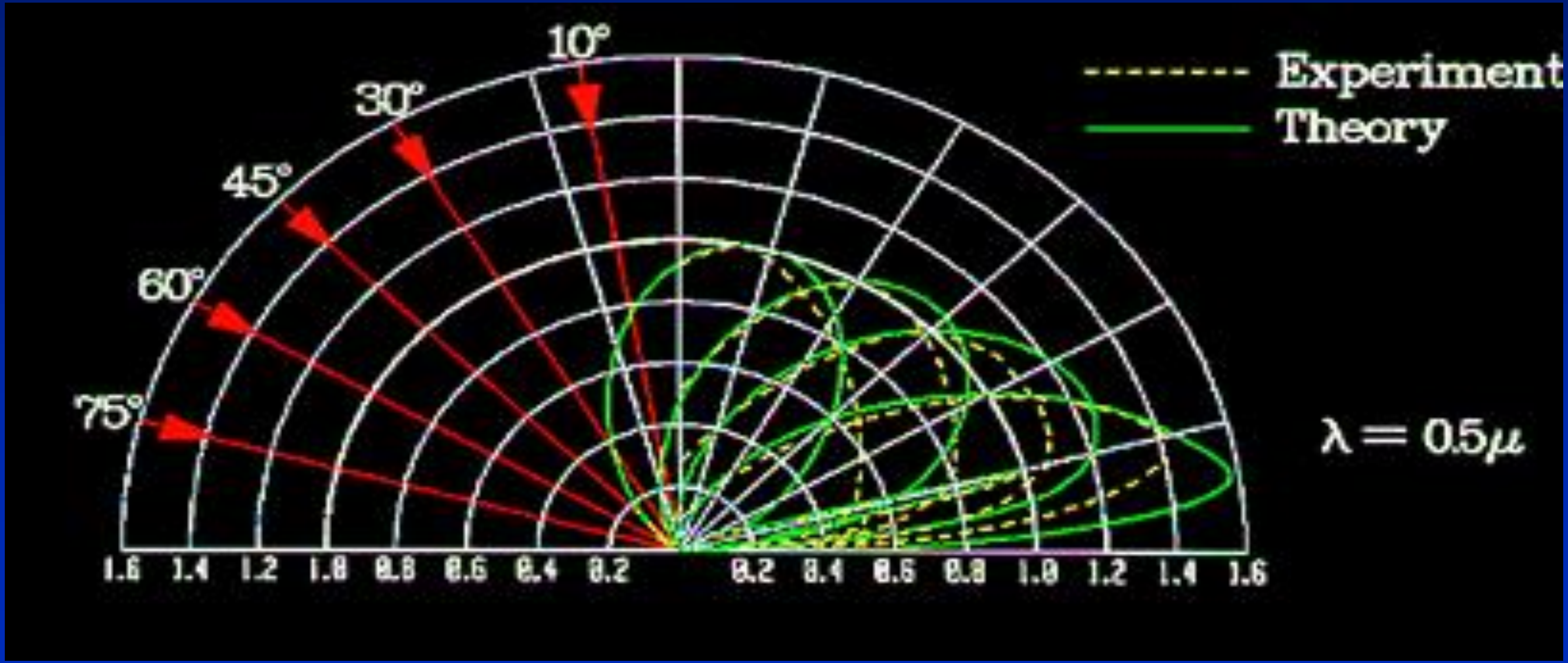
Experiment Data

Aluminum, σ_0=0.28μ

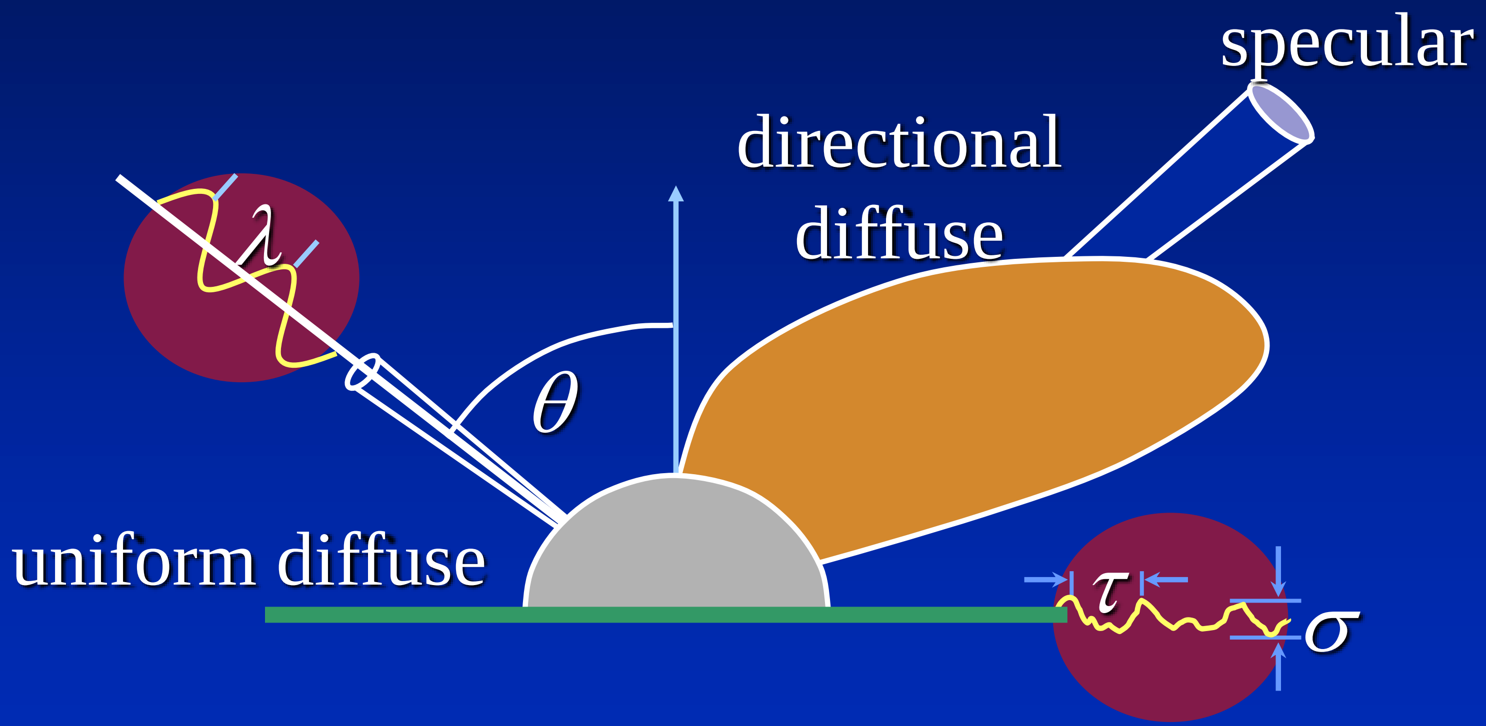


Comparison of experiment and theory

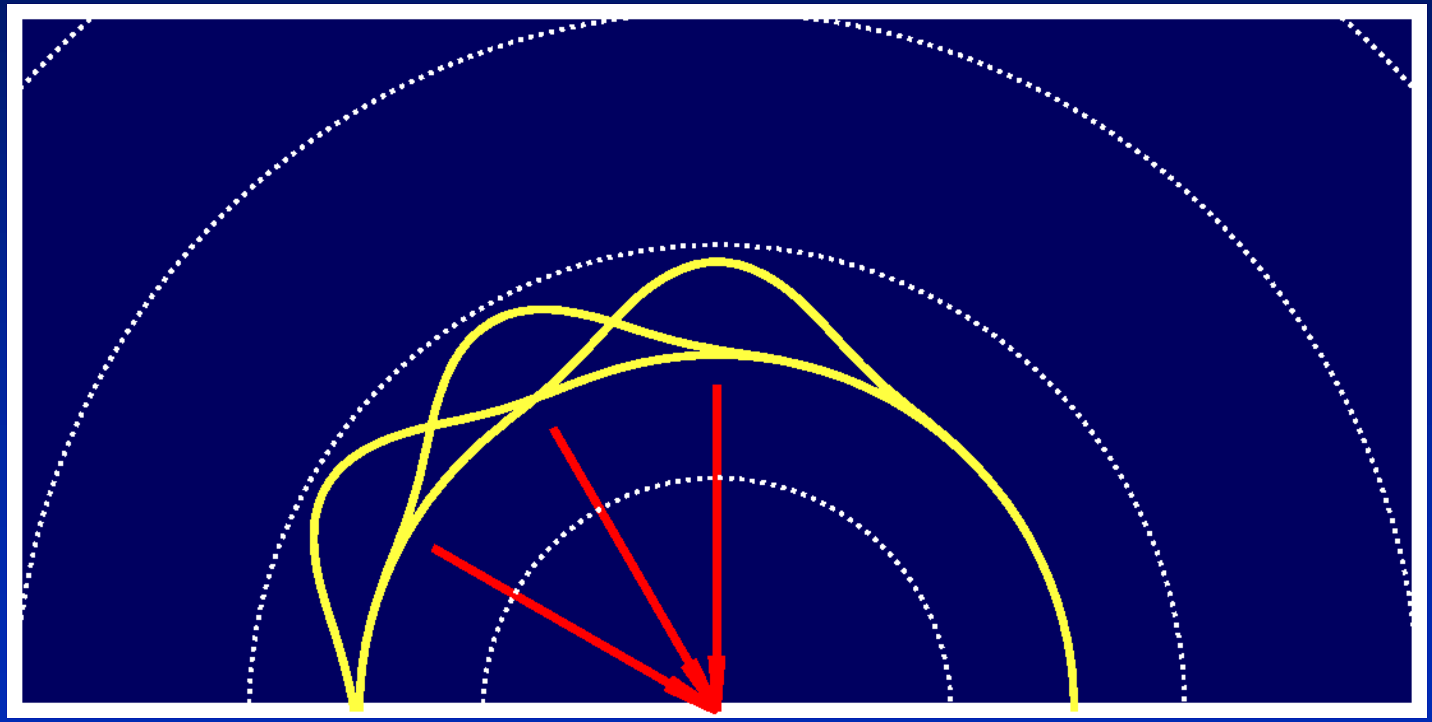
Aluminum $\sigma_0 = 0.28\mu, \quad \tau = 1.77\mu$



Bidirectional Reflectance (BRDF)



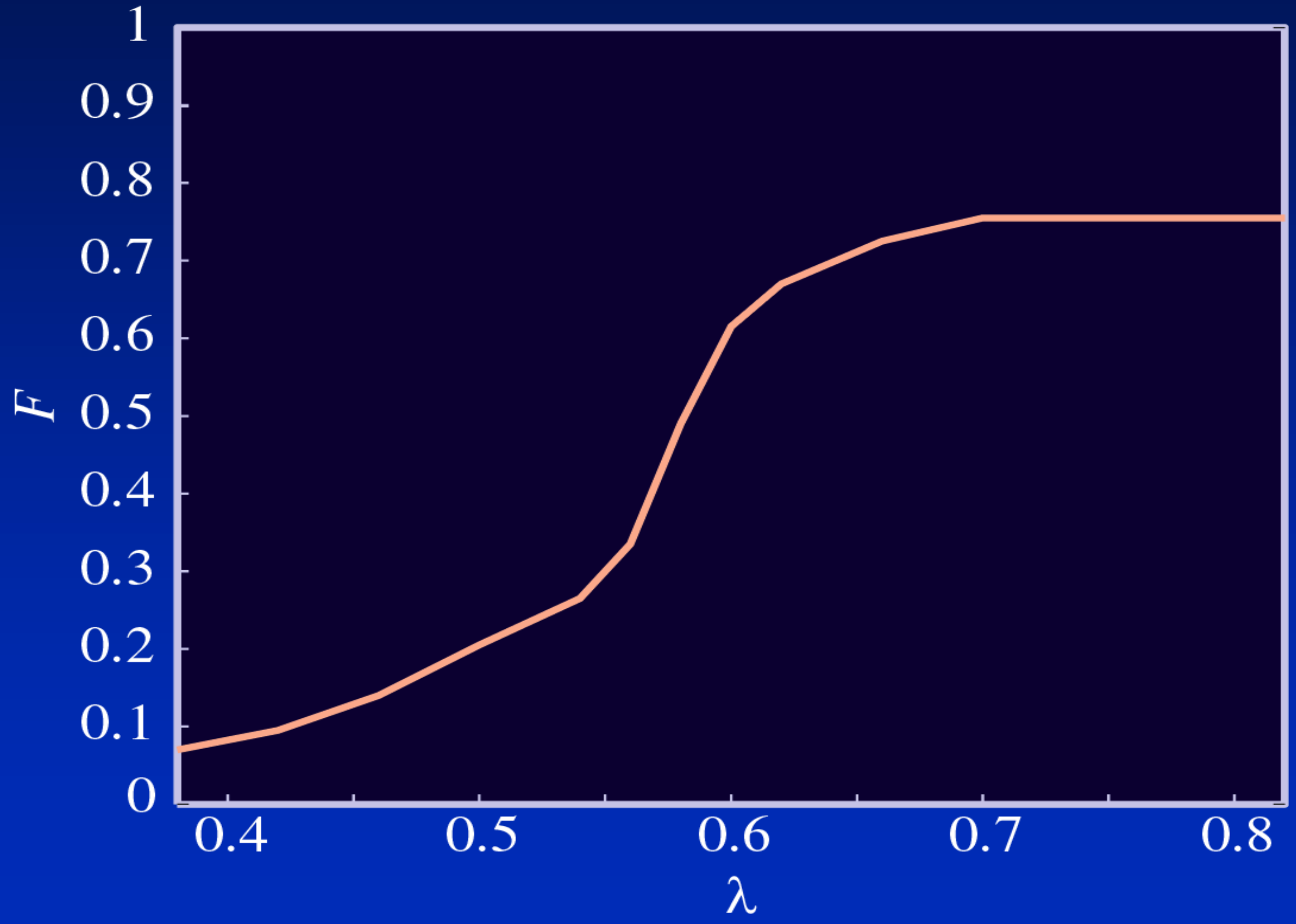
Retro-Reflection



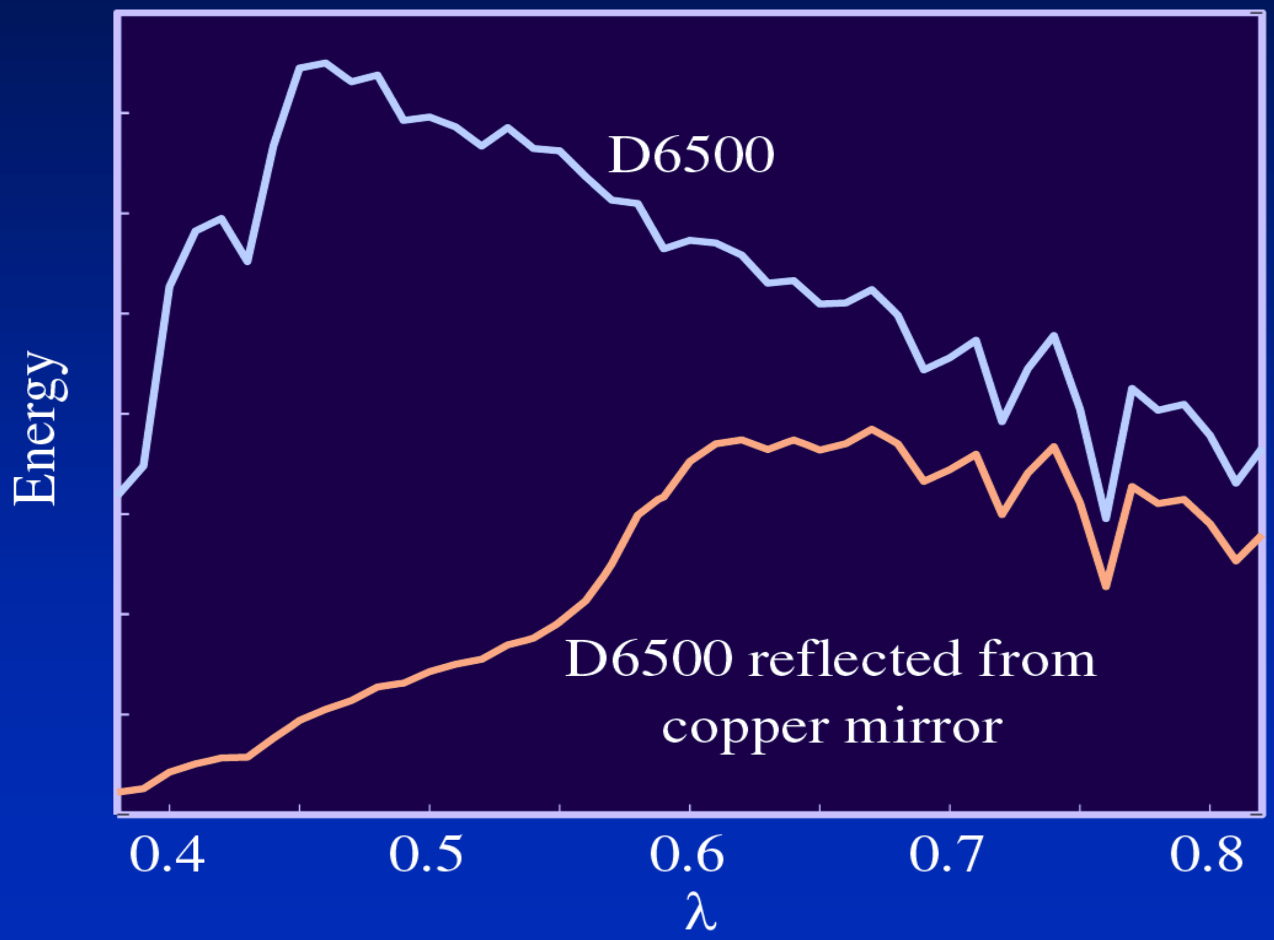
Retroreflection

Retroreflection

Reflectance of Copper Mirror

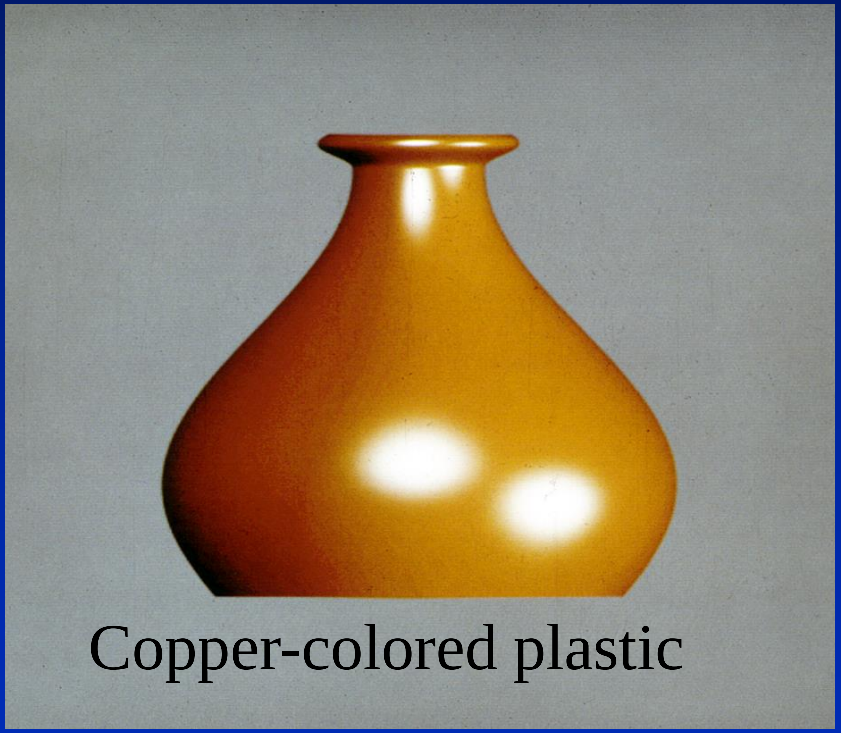


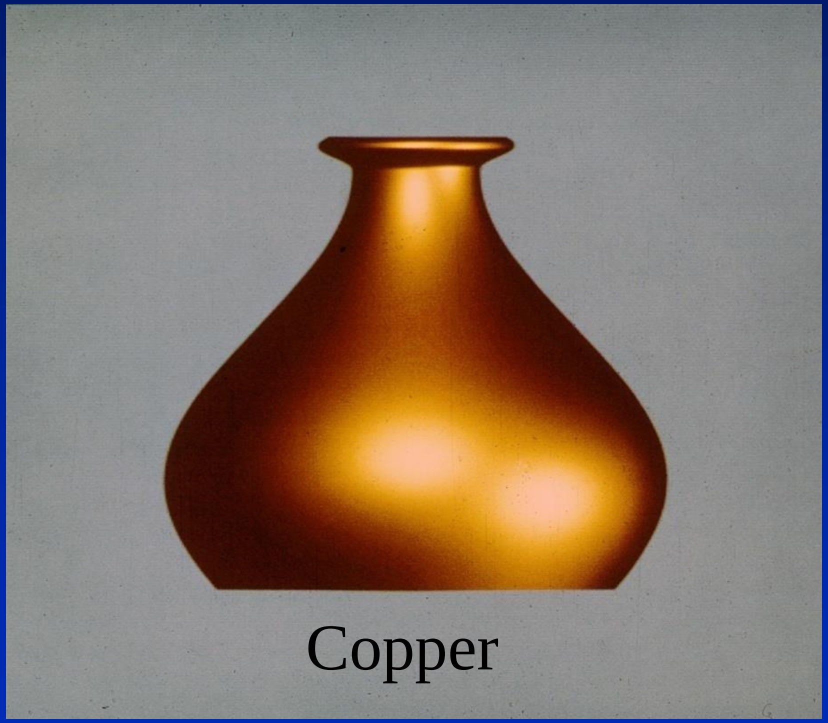
Light Reflected from Copper



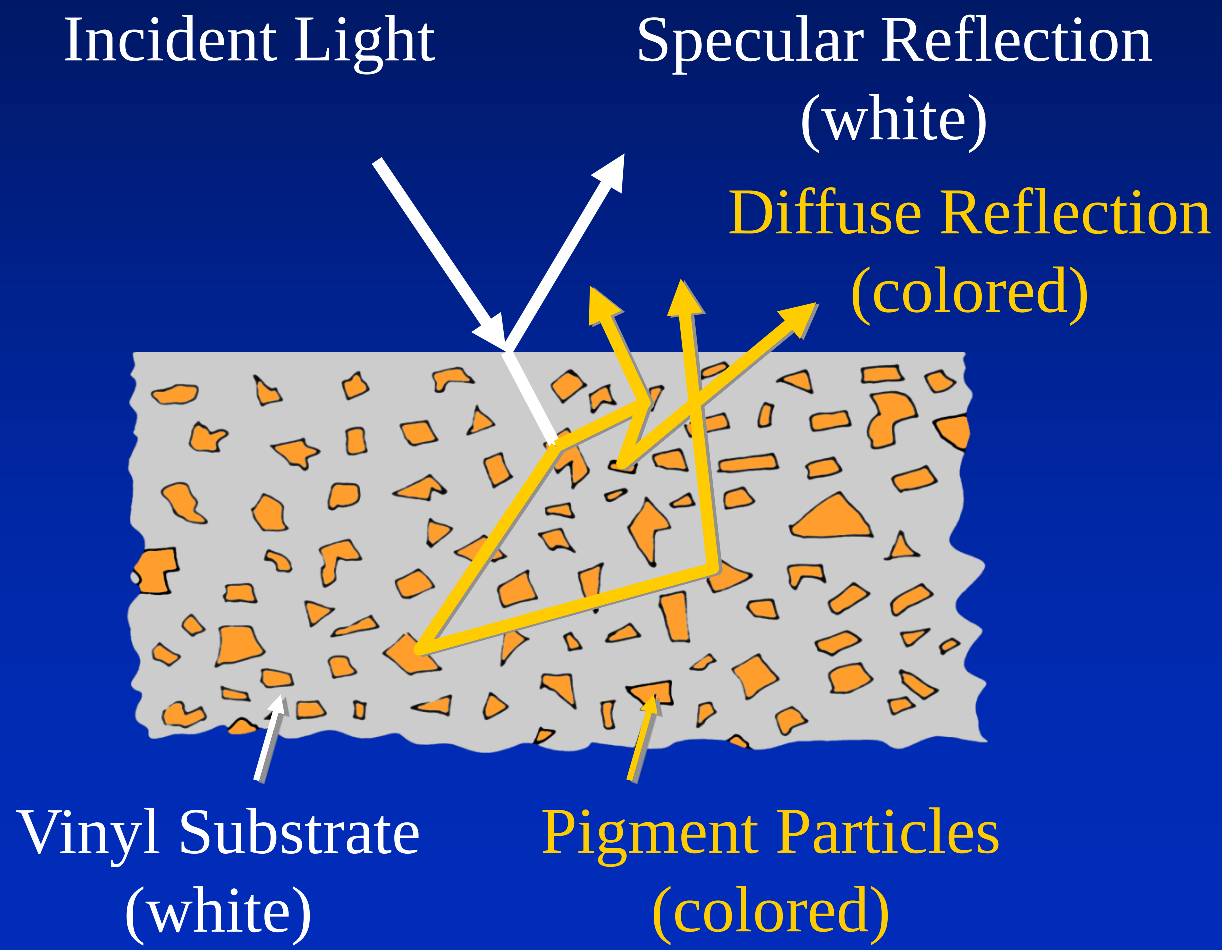
Cook-Torrance Renderings

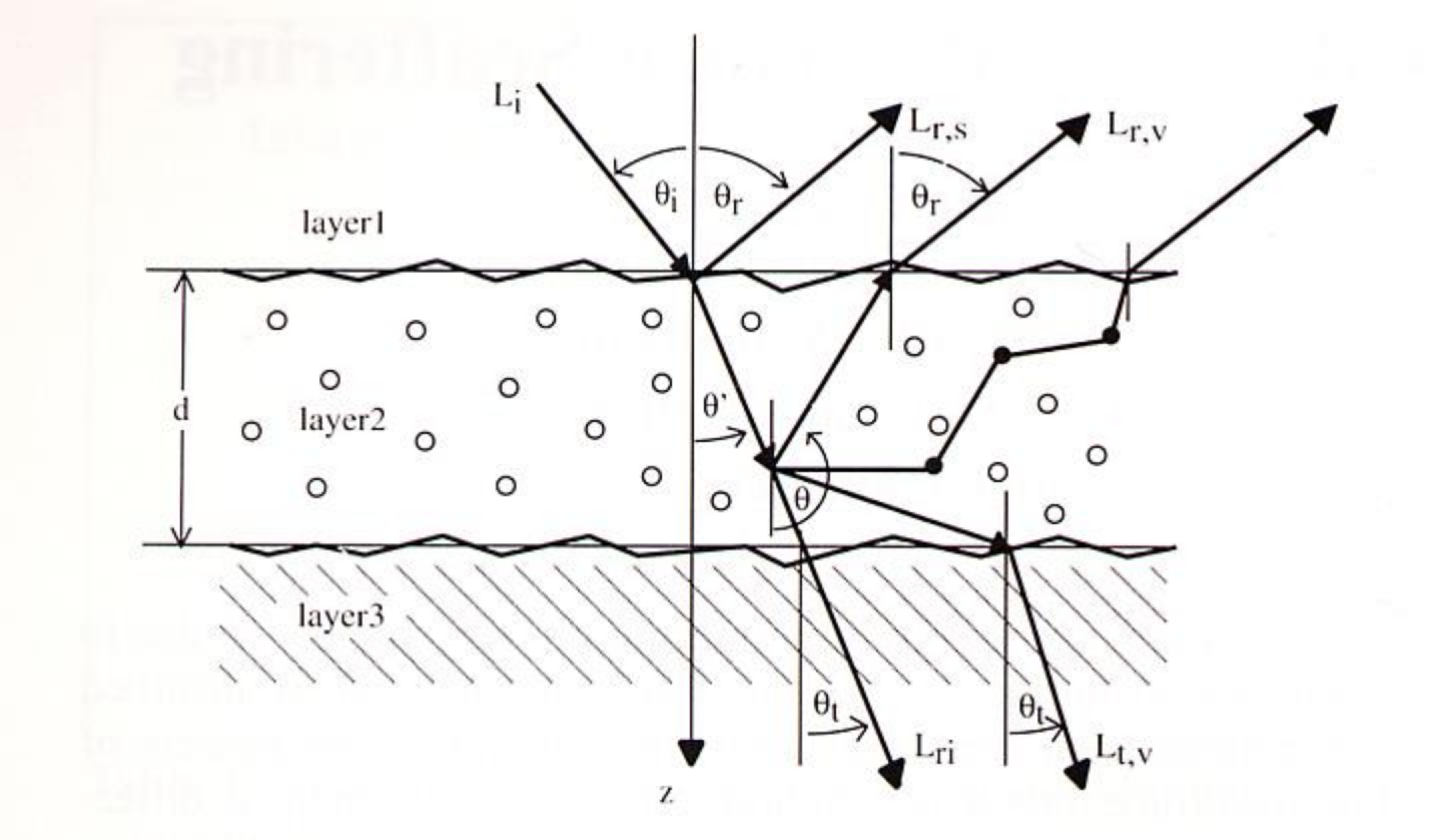
Copper Vase





Reflection from Plastic





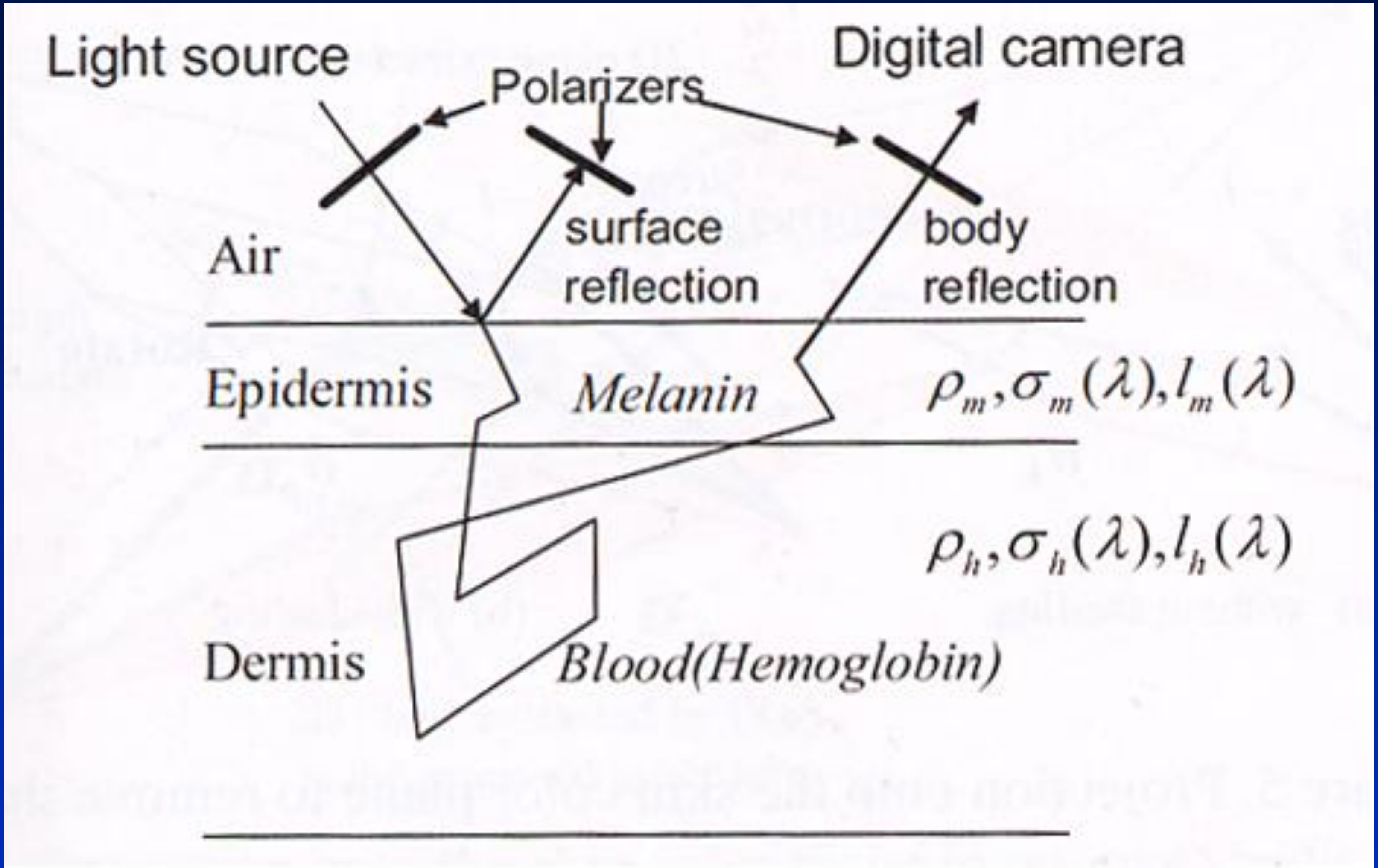
The geometry of scattering from a layered surface

Phong Goblet

Bui Toung Phong Thesis

Brushed Stainless Steel

Henrik Wann Jensen, Stephen R. Marschner, Marc Levoy, Pat Hanrahan. “A Practical Model for Subsurface Light Transport,” ACM Siggraph 2001, August 2001, Los Angeles, CA, pp. 511-518.

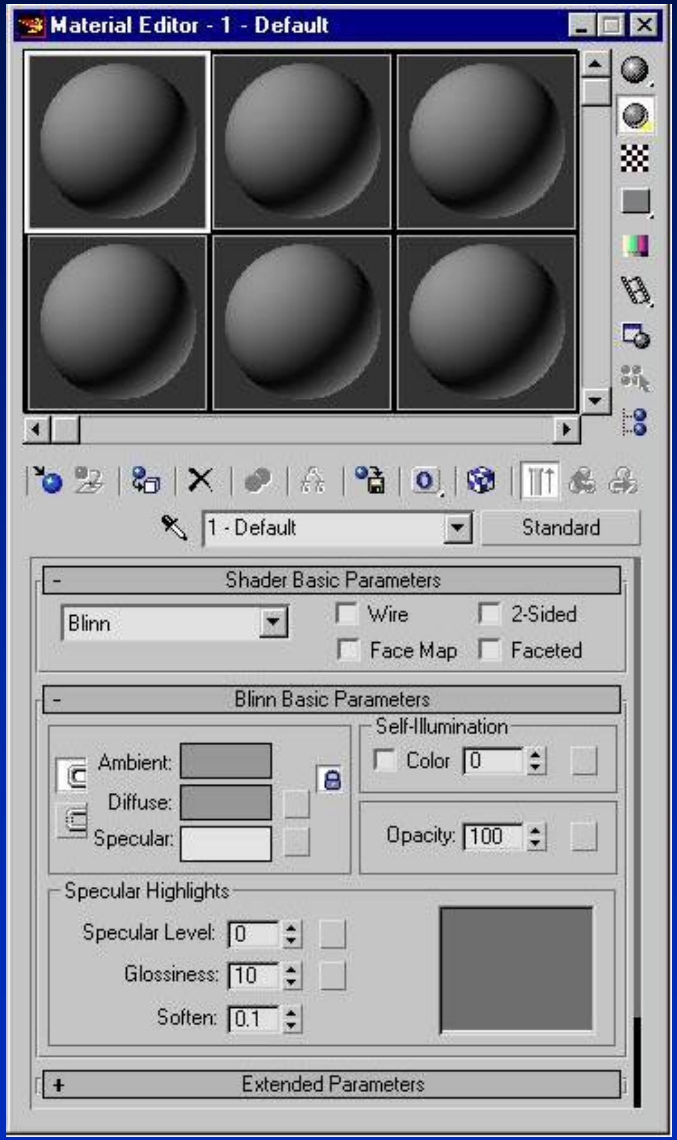


Schematic model of the image process

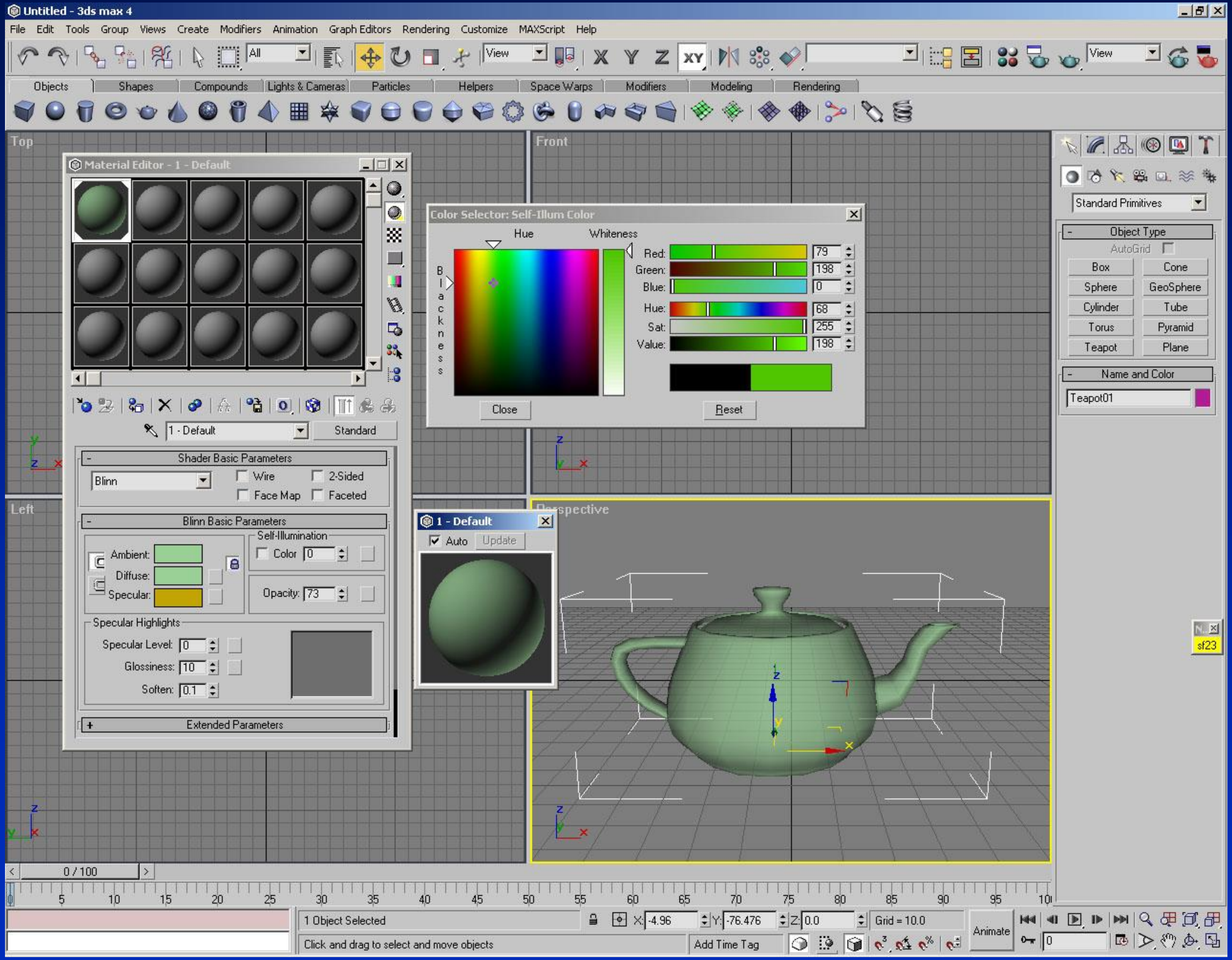
ACM Transactions on Graphics, SIGGRAPH 2003 p. 773

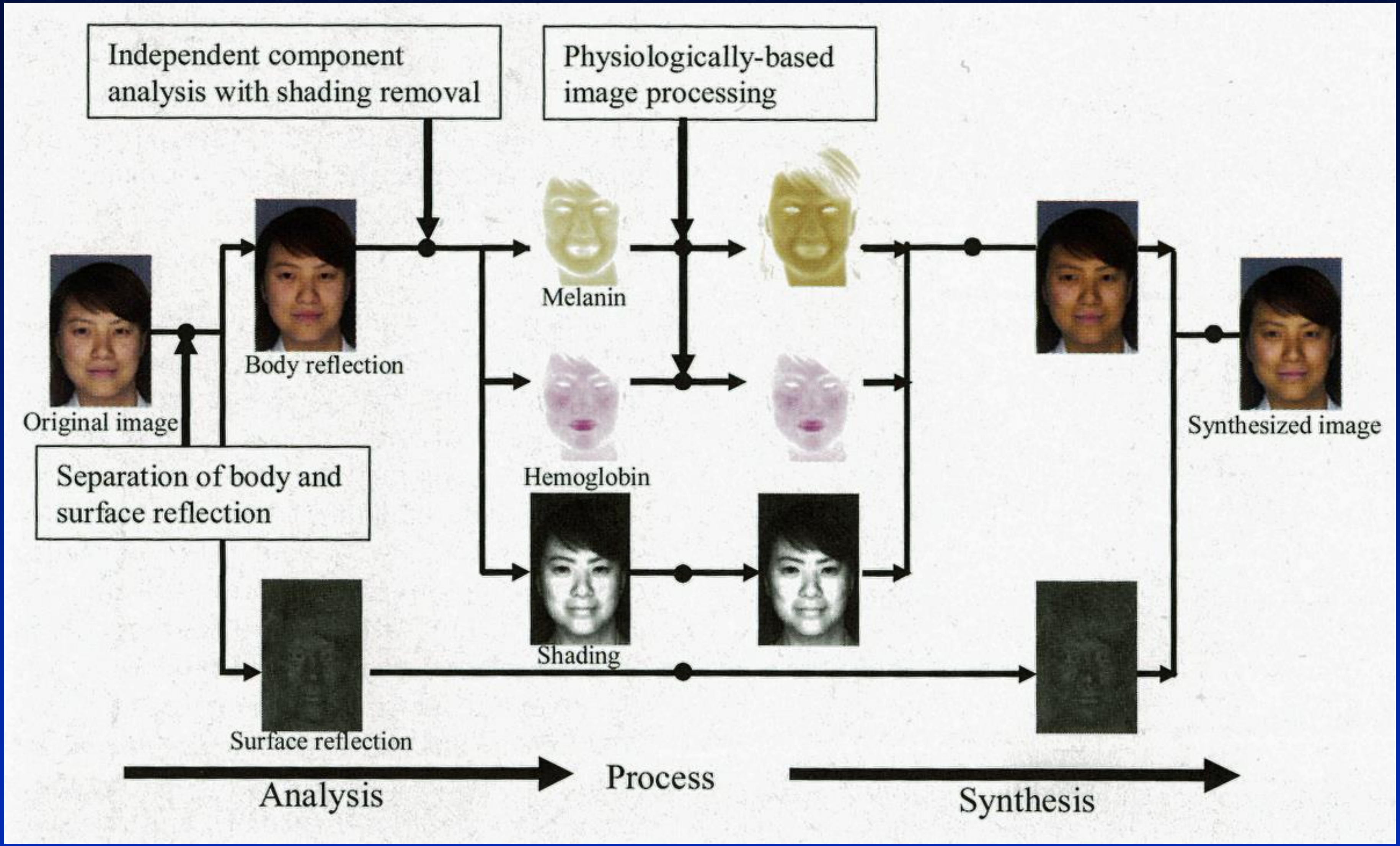
End. . .

3D Studio Max: Material Editor



3D Studio Max: Material Editor

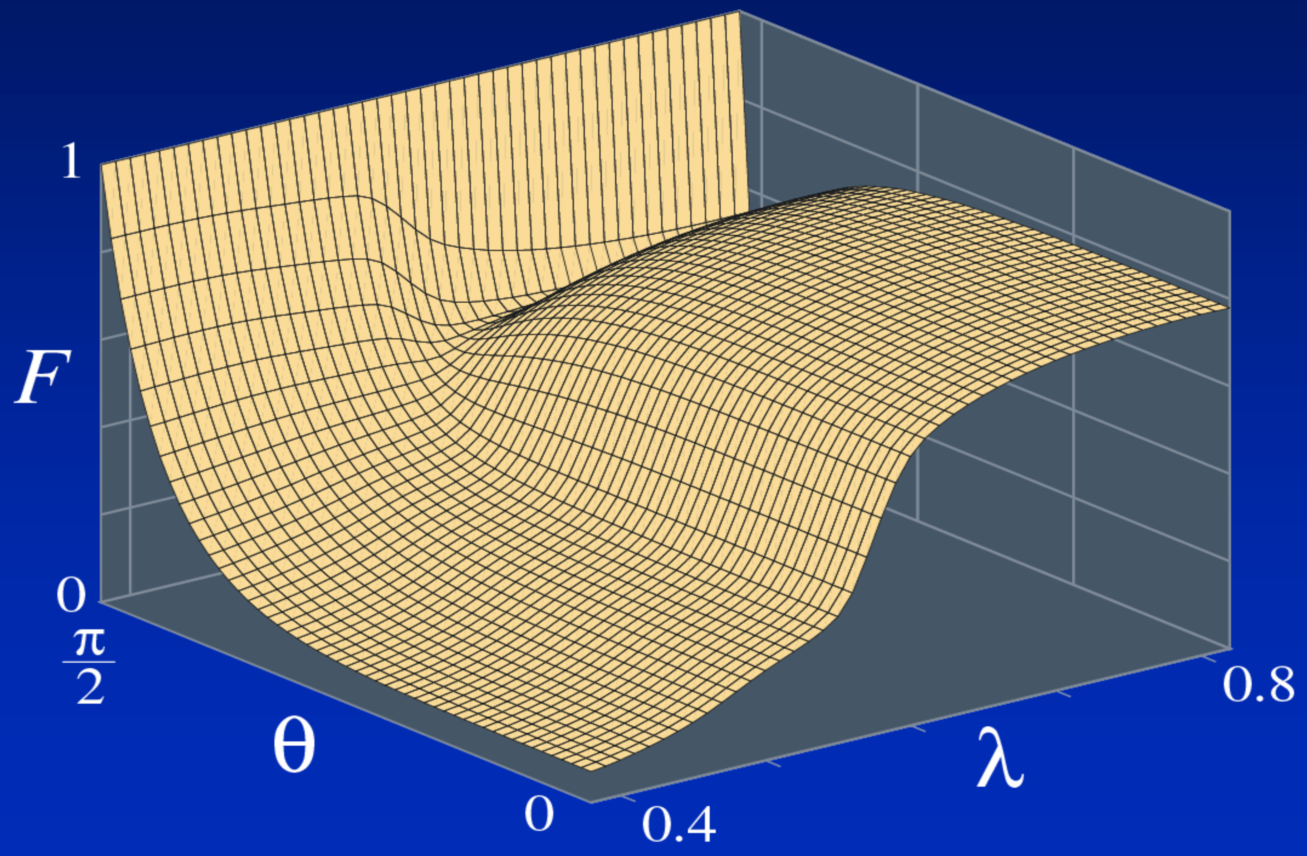




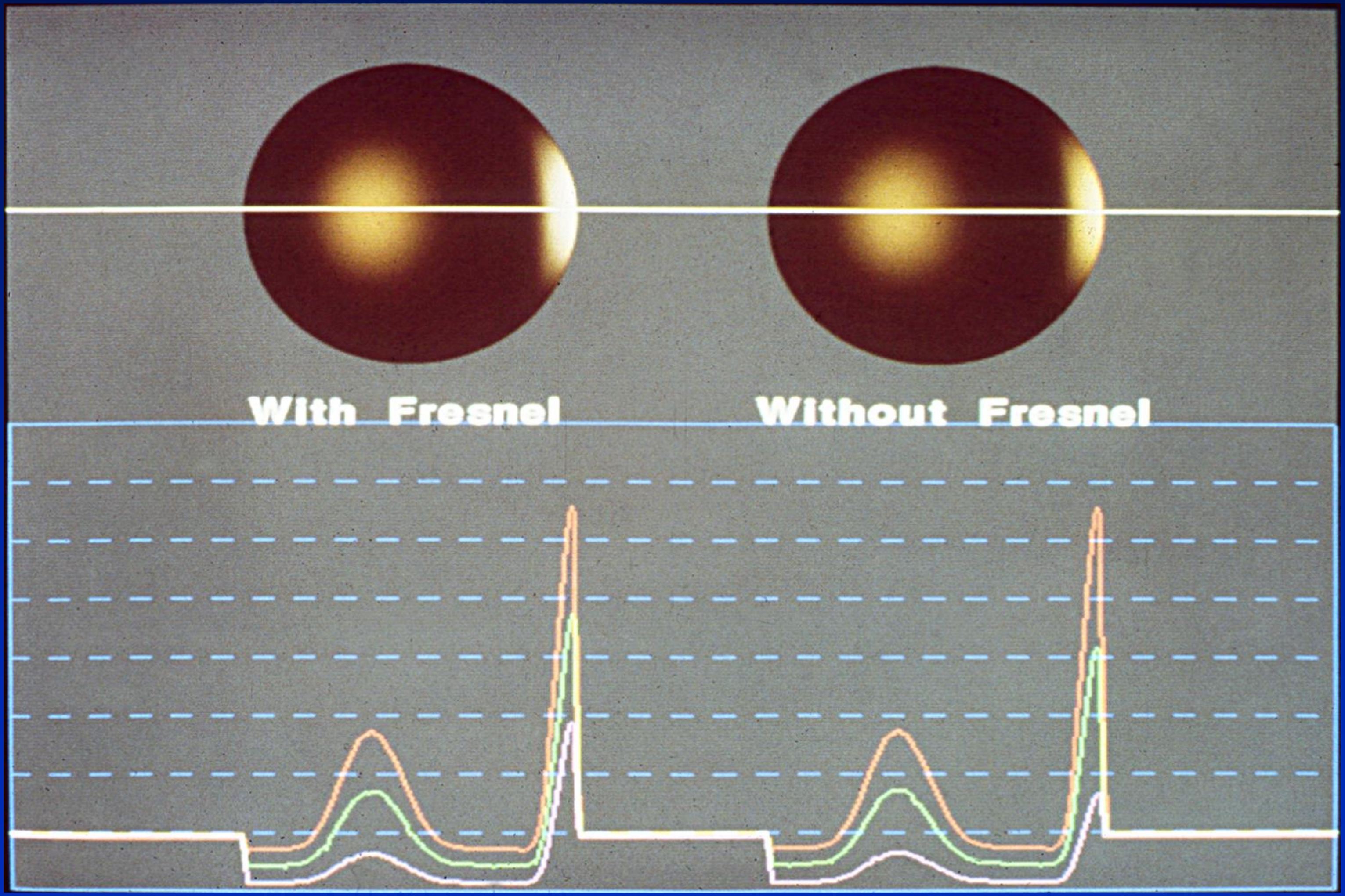
Schematic flow of the imaging process in proposed image-based skin color and texture analysis/synthesis

ACM Transactions on Graphics, SIGGRAPH 2003 p. 771

Cook's Fresnel Approximation



Cook's Copper Spheres



Cosine Calculations

Dot Product Definition

$$\overline{N} \cdot \overline{L} = \left|\overline{N}\right|\left|\overline{L}\right| \cos\theta$$

$$\cos\theta = \frac{\overline{N} \cdot \overline{L}}{|N||L|} = \frac{\overline{N}}{|N|} \cdot \frac{\overline{L}}{|L|}$$

Usually, the normal and light source vector directions are given as unit normals.

Dot Products to find Cosine of Angle θ

$$i \cdot i = 1$$

$$i \cdot j = 0$$

$$i \cdot k = 0$$

Dot Product to find the cosine of the angle β

This is the product of the reflection vector R and the view direction V

Cross Product to find Normal Vectors

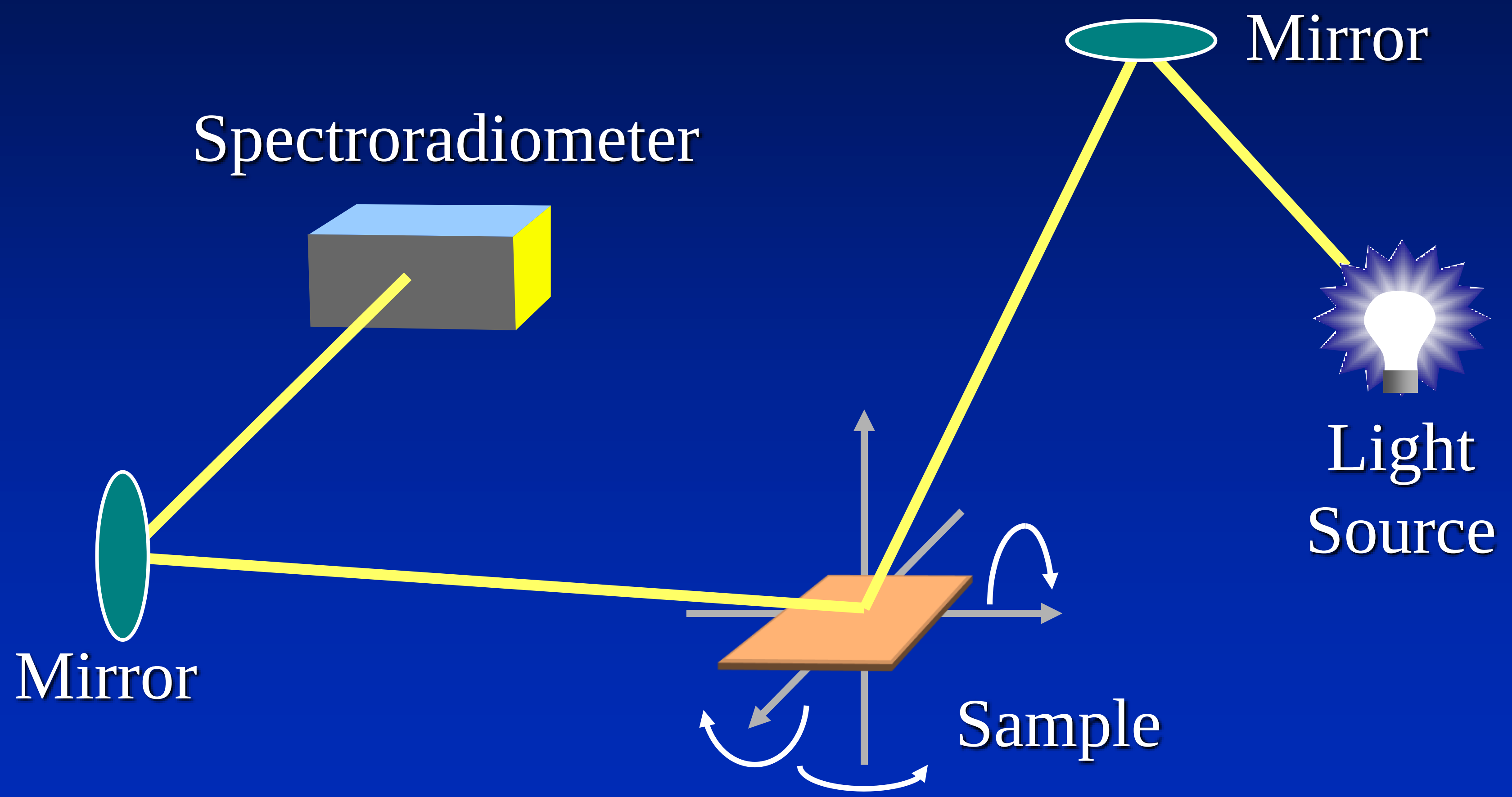
4x4 Transformations

Engineering Honors Section

Slides to explain the difference between the fast Phong algorithm, the change which varies by scan line, and the actual change which varies by pixel.

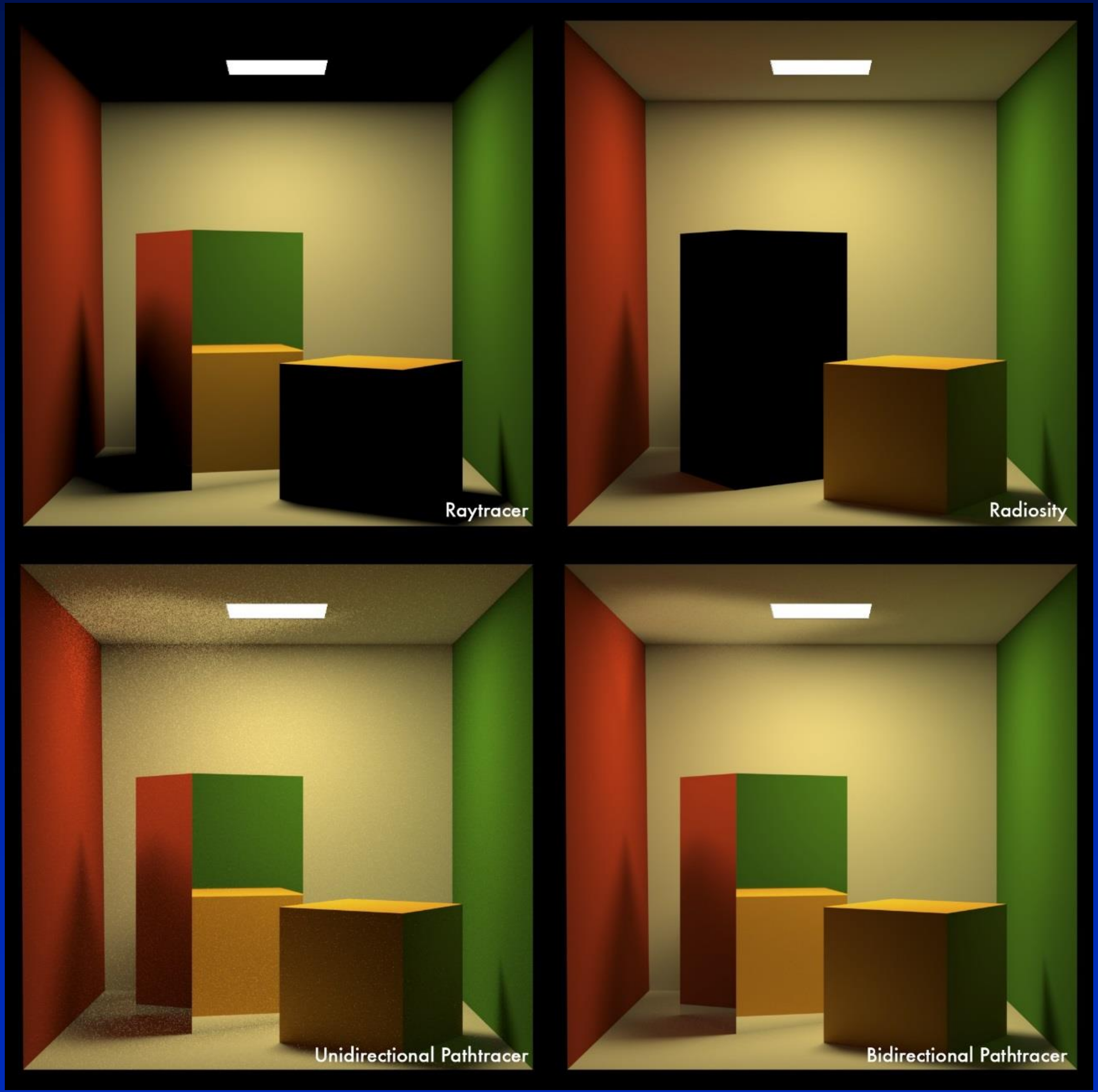
Also an explanation to change the shading based on the original geometry.

Gonioreflectometer

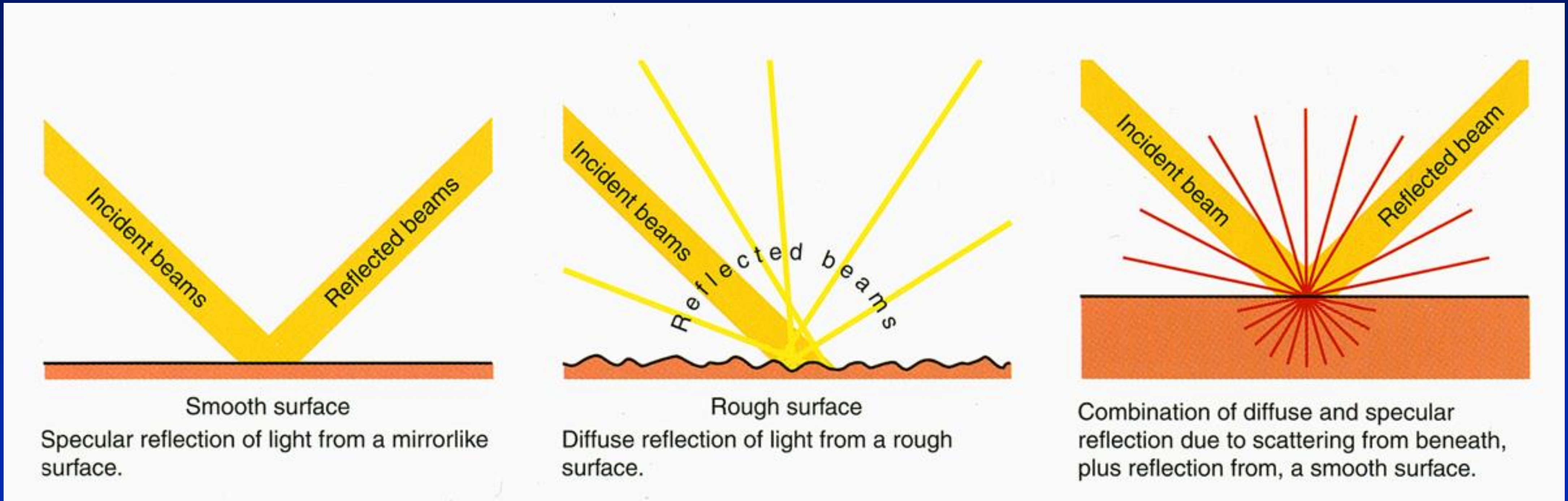


Bidirectional Reflectometer

Model Comparisons



Smooth Surface, Rough Surface, Combination



Roy S. Berns. "Billmeyer and Saltzman's Principles of Color Technology, 3rd Ed. 2000, John Wiley & Sons, Inc. p. 12.