Light Reflection Models

Visual Imaging in the Electronic Age

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Lecture #15
Goal of Realistic Imaging
Direct Lighting and Indirect Lighting
Direct Lighting and Indirect Lighting
The three dimensional shape is only inferred with this lighting.
The geometry is better understood with correct lighting and shading.
Assumptions In Direct Lighting

Light travels directly from light source to all object surfaces (no occlusion)  
\[ \therefore \text{ no shadows}\]

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

No interreflections from any surfaces

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

Rough surface

Diffuse reflection of light from a rough surface.
Specular Reflections

Specular reflection of light from a mirrorlike surface.
Glossy Reflections

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

Smooth surface
Specular reflection of light from a mirrorlike surface.

Rough surface
Diffuse reflection of light from a rough surface.

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

Reflectance - Three Forms

Ideal diffuse (Lambertian)

Ideal specular

Directional diffuse
Diffuse Reflections

$I = k_d \cos \theta$
How do you find the angle $\beta$?

• 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

\[ \mathbf{N} \cdot \mathbf{L} = |\mathbf{N}| |\mathbf{L}| \cos \theta \]

\[
\cos \theta = \frac{\mathbf{N} \cdot \mathbf{L}}{|\mathbf{N}| |\mathbf{L}|} = \frac{\mathbf{N} \cdot \mathbf{L}}{|\mathbf{N}| \cdot |\mathbf{L}|}
\]

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
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.

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

Each pixel is shaded by interpolating intensities computed at each of the polygon’s vertices.
Steps in Gouraud Shading

• For each polygon
  – Compute vertex intensities (using any illumination model)
  – Compute slopes in spatial (image) domain and intensity domain (linear interpolation)
  – Increment by scan line

• For each scan line
  – Compute slope in intensity domain
  – Render each pixel

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

Viennese Silver, 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

Observer

$V$

$I$

$N$

$R$

$\beta$

$\theta_r$

$\theta_i$

$I = k_s \cos^n \beta$

Light Source

$L$
How do you find the angle $\beta$?

- 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 $\beta$, the angle between the view direction and the reflection vector
Variation of $\cos^n \beta$
Phong Reflection Model

\[ \text{Diffuse} = k_d (\overrightarrow{N} \cdot \overrightarrow{L}) \]

\[ \text{Specular} = k_s (\overrightarrow{R} \cdot \overrightarrow{V})^n \]
Phong Goblet

Bui Young Phong Thesis
Phong Equation

\[ I = I_a + I_d + I_s \]

\[ = [k_a + k_d (\vec{N} \cdot \vec{L})](\text{object color}) + k_s (\vec{R} \cdot \vec{V})^2(\text{light color}) \]

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

SPHERES - phong model - gamma corrected
Ka=.2

Ks/Kd 100/0 75/25 50/50 25/75 0/100
Ns=5
Ns=10
Ns=20
Ns=40
Phong Model with Constant Specular Exponent and Variation of Ambient Term

Roy Hall
Reflection Geometry (BRDF)

Bidirectional Reflection Distribution Function
Light Measurement Laboratory
Gonioreflectometer

- Spectroradiometer
- Mirror
- Light Source
- Sample
Bidirectional Reflectometer
Reflection Processes

First surface reflections

Multiple surface reflections

Subsurface reflections
Gaussian Distribution

$m = 0.2$

$m = 0.6$

Where $m$ = root mean square slope of the microfacets
Comparison of experiment and theory

Aluminum $\sigma_0 = 0.28\mu$, $\tau = 1.77\mu$
Bidirectional Reflectance (BRDF)
Retro-Reflection
Retroreflection
Retroreflection
Reflectance of Copper Mirror
Light Reflected from Copper

![Graph showing light energy reflected from copper mirror](graph.png)
Cook’s Fresnel Approximation
Cook’s Copper Spheres
Cook-Torrance Renderings

Carbon  Red Rubber  Obsidian  Lunar Dust  Olive Drab  Rust
Bronze  Tungsten  Copper  Tin  Nickel  Stainless Steel
Copper Vase

Copper-colored plastic

Copper
Reflection from Plastic

Incident Light

Specular Reflection
(white)

Diffuse Reflection
(colored)

Vinyl Substrate
(white)

Pigment Particles
(colored)
The geometry of scattering from a layered surface
Schematic model of the image process
Schematic flow of the imaging process in proposed image-based skin color and texture analysis/synthesis
3D Studio Max: Material Editor
3D Studio Max: Material Editor
End...