Shading

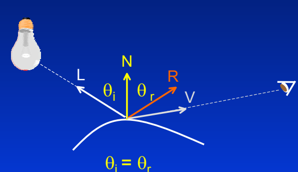
- Illumination Models
  - Local x Global
  - Ambient, Diffuse and Specular Terms in Local Models
  - Light Attenuation
- Shading Models
  - Flat, Gouraud and Phong
- Mach Band Effect
- Problems with Interpolated Shading

Illumination Model

- Also called Reflection Model or Lighting Model
- Describes the interaction of light with object surfaces
- Local versus Global
- Empiric versus Physically-Based
- In computer graphics we make use of fast tricks to obtain images that "look right"

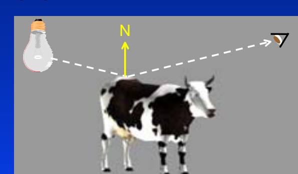
Light Reflection

- Light reflected at a surface point



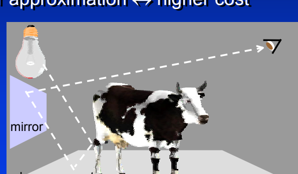
Local Illumination Model

- Shading of a surface point is computed independent of any other elements in the scene
- Assumption: light hits the surface once and is reflected towards the viewer



Global Illumination Model

- Shading of a surface point is computed taking into account all elements in the scene
- Light ray may hit several surfaces before it reaches the viewer: better approximation ↔ higher cost



Illumination Models in CG

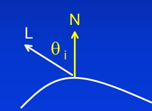
- Local illumination models are used to allow interactivity
- Global models are expensive to evaluate in real-time, but for diffuse surfaces they can be evaluated off-line
- All local models are non-physically based
- Some tricks are used in conjunction with local models to approximate a global solution
- Global illumination models are used to improve image quality

Diffuse Surfaces

- Diffuse (dull, matte) surfaces scatter incident light equally in all directions
- Such surfaces are characterized by being rough

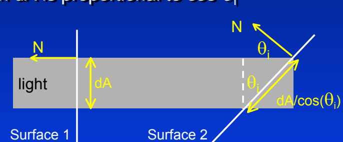
Diffuse Reflection

- Diffuse reflection is also called Lambertian reflection
- For a given surface, its brightness only depends on the angle between L and N and on its material properties



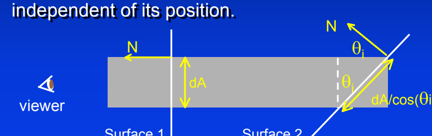
Diffuse Reflection (cont.)

- As θ_i increases, the same amount of energy (light) is distributed across a larger area → less brightness
- For a given light beam, the amount of light energy that falls on dA is proportional to cos θ_i



Diffuse Reflection (cont.)

- Lambert's law: the amount of light reflected from dA towards the viewer is directly proportional to the cosine of the angle between V and N
- But the area seen by the viewer is inversely proportional to the cosine of the same angle and the two terms cancel out: thus the viewer perceives the same intensity independent of its position.



Diffuse Reflection (cont.)

- Assuming that N and L have been normalized, the perceived intensity at the surface point is given by

$$I = I_l k_d (N \cdot L)$$

- I_l is the intensity of the point light source and k_d is diffuse reflection coefficient of the surface material
- $0 \leq k_d \leq 1$ tells how much of the incident light is diffusely reflected by the material
- This simple (local) model does not take into account light that reaches the surface indirectly

Ambient Light

- Approximates indirect light reaching the surface
- Some amount of diffuse light is added to the environment
- This is a trick that tries to achieve a global effect using a local model

$$A = I_a k_a$$

- I_a is the ambient intensity and $0 \leq k_a \leq 1$ describes how much of the ambient light is reflected by the surface material

$$I = I_a K_a + I_l k_d (N \cdot L)$$

Attenuation Factor

- The energy from a point light source *S* that reaches a given surface point *p* falls off as the inverse square of d_l = distance(*S*,*p*)
- In real life objects are usually not lit by point light sources

$1/d_l^2$ **$1/d_l$** **1**

Attenuation Factor in CG

- A function that allows wide range of effect by using user specified values c_1, c_2 and c_3

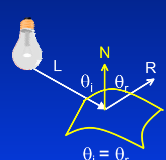
$$f_{att} = \min\left(\frac{1}{c_1 + c_2 d_L + c_3 d_L^2}, 1\right)$$

- The illumination model than becomes

$$I = I_a K_a + f_{att} I_l k_d (N \cdot L)$$

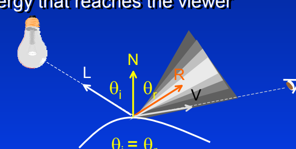
Specular Surfaces

- Specular (shiny) surfaces scatter incident light
- Such surfaces are characterized by being smooth
- On ideal specular surfaces, light is reflected only in the direction R



Specular Reflection

- If the surface is not a perfect mirror, light is reflected inside a cone of directions around ideal reflected direction R
- The bigger the angle of between R and V, the smaller the energy that reaches the viewer



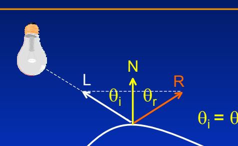
Phong Illumination Model

- Phong approximated the rapid fall off of the “specularly” reflected intensity as $\cos^n\alpha$, where α is the angle between R and V
- *n* determines the specularity of the surface
- For normalized R and V vectors, the resulting illumination model becomes

$$I = I_a K_a + f_{att} I_l \left(k_d (N \cdot L) + k_s (V \cdot R)^n\right)$$

- $0 \le k_s \le 1$ is the specular reflection coefficient

The Reflection Vector



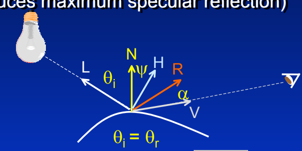
$$\frac{L + R}{2} = \rho N \qquad R = 2\rho N - L$$

- Since ρ is the length of the projection of L onto N

$\rho = N \cdot L$ and $R = 2(N \cdot L)N - L$

The Halfway Vector (H)

- Halfway vector between L and V (direction of the normal that produces maximum specular reflection)



$$\theta_i + \Psi = \theta_i - \Psi + \alpha \Rightarrow \Psi = \frac{\alpha}{2}$$

- One can use $(N \cdot H)^n$ instead of $(R \cdot V)^n$, but for the same value of *n* results are, of course, different

Colored Lights and Surfaces

- Light, object surface and reflection coefficients specified in terms of wavelength λ
- In computer graphics we use a trichromatic system (R,G,B)

$$I_\lambda = I_{a\lambda} K_{a\lambda} + f_{att} I_{l\lambda} \left(k_{d\lambda} (N \cdot L) + k_{s\lambda} (V \cdot R)^n \right)$$

- Compute I_λ for each of the values of λ = R, G and B

Multiple Light Sources

- The effect of multiple light sources are added

$$I_\lambda = I_{a\lambda} K_{a\lambda} + \sum_{l}^{lights} f_{att\,l} I_{l\lambda} \left(k_{d\lambda} (N \cdot L) + k_{s\lambda} (V \cdot R)^n \right)$$

Shading Model

- Determines when the illumination model is evaluated (e.g., once per polygon, once per vertex or once per pixel)
- Examples
  - Flat Shading
  - Gouraud Shading
  - Phong Shading

Flat Shading

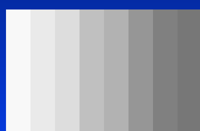
- Illumination model evaluated once per polygon (all pixels of the polygon are shaded with the same color)
- Introduces intensity discontinuities
- Mach band effect (discontinuities in intensity or in its first derivative)

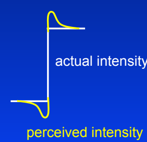
Flat Shading

- Valid only if
  - Light source at infinity: $N \cdot L$ is constant
  - Viewer at infinity: $N \cdot V$ is constant
  - Polygonal model represents the actual surface

Mach Band Effect

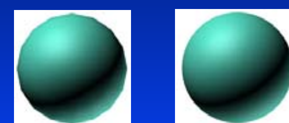
- The human visual system is very sensitivity to small differences in light intensity
- Caused by lateral inhibition of the receptors in the eye
- The more light a receptor receives, the more it inhibits the response of receptors adjacent to it.





Gouraud Shading

- Illumination model evaluated once per vertex
- Color in the interior of the polygon are obtaining from interpolation of the computed colors at the vertices
- Physically incorrect, but produces good results in the interior of the polygons and is computationally cheap

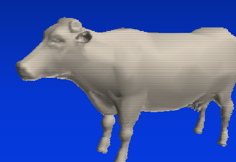


Gouraud Shading (cont.)

- Normal at a vertex computed as the average of the incident faces to the vertex
- Misses highlights in the interior of the polygons
- Does not completely solve Mach band artifacts (discontinuities in the first derivative of the intensity function remain)

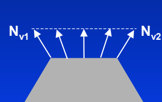
Gouraud Shading (cont.)

- Straightforward hardware implementation
- Results are far superior than the ones obtained with flat shading



Phong Shading

- Illumination model evaluated once per pixel
- Normal at the pixel is interpolated from the vertices' normals and used in the illumination model
- Capture highlights at any pixels
- Computationally more expensive than Gouraud shading



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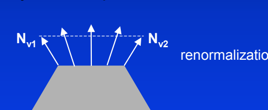
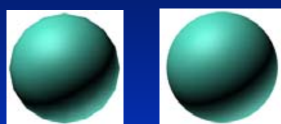


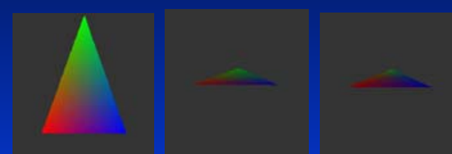
Interpolated Shading (problems)

- Polygonal silhouettes



Interpolated Shading (problems)

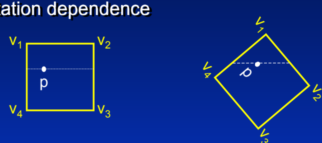
- Incorrect perspective



original triangle | incorrect rendering | correct rendering

Interpolated Shading (problems)

- Orientation dependence



- T-Vertices