Illumination and shading

Chapter 10

Illumination

- So…given a 3-D triangle and a 3-D viewpoint, we can set the right pixels
- But what color should those pixels be?
- If we’re attempting to create a realistic image, we need to simulate the *lighting* of the surfaces in the scene
  - Fundamentally simulation of *physics* and *optics*

Some definitions!

- Illumination model, lighting model, shading model, surface rendering, shading method, surface lighting effects......????
- Baker & Hearn took some heavy stuff while writing page 557!

Definitions

- Illumination: the transport of energy (luminous flux of visible light) from lightsources to surfaces, indirect and direct.
- Often a confusion between lighting and shading
- **Lighting**
  - The process of computing the luminous intensity (outgoing light) at a particular 3D point.
  - **Illumination model** (shading model!) (Hearn Baker)
- **Shading**
  - The process of assigning colors to pixels
  - **Surface-rendering** method (Hearn Baker)

Definitions

- Fundamentally:
  - CG is about modelling the interaction of electromagnetic energy within the objects of a scene.
  - What we see, is the light (electromagnetic energy in the spectrum of visual light) that hits the eyes.
  - Involves a number of things:
    - Material properties
    - Object position relative to lightsources and other objects
    - Feature of light sources

Illumination

- Empirical illumination model
  - Tries to formulate approximations of observed phenomenon
  - Phong illumination model (OpenGL), Raytracing
- Physically-based
  - Models based on the actual physics of light interacting with matter
  - Radiosity, Photonmapping

Components

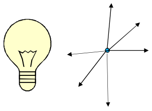
- Light sources
  - Emitters of radiant energy
  - Geometric attributes
    - Position
    - Direction
    - Shape
  - Spectrum of emittance , Color
  - Directional attenuation
- Surfaces
  - Reflecting spectrum (Color)
  - Geometry (position, orientation and micro structure)
  - Absorption
- Simplification
  - Only direct illumination from the emitters to the reflectors of the scene
  - Ignore Geometry of emitters

Ambient Light Source

- Due to reflections onto other objects, even object that are not directly lit by a lightsource are visible
- To model indirect illumination a hack called
  - Ambient light source is used
  - No position nor direction.
  - Constant for all surfaces in the scene
  - Can have color
  - Independent on objects orientation and position.
  - Surface properties are used to determine how much ambient light is reflected

Light sources

- Point light sources
  - Approximates a lightbulb



- Attributes
  - Position
  - Color
- Light are generated radially
- Reasonable approximation for sources that are small compared to objects in the scene

Light sources

? Infinitely Distant Light Sources

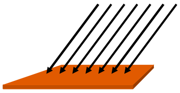
? Attributes

  – Direction

  – Color

? The SUN!

? Little variation in directional effects.



Lightsources

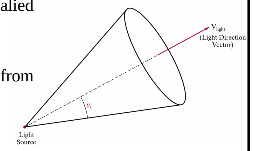
- Radial Intensity Attenuation
  - Light source is attenuated by a factor 1/d^2
  - A surface close lightsource recieves higher incident light intensity
  - 1/d^2 does not produce acceptal result
  - The problem: real lightsources are not infitesimal small! (point sources)
  - Solution:

$$f_{l,radatten} = \begin{cases} 1.0, & \text{If source is at infinity} \\ \dfrac{1}{a_0 + a_1 d_1 + a_2 d_l{}^2} & \text{If source is local} \end{cases}$$

Light source

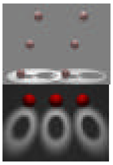
- Directional light sources
  - Requires the calculation of a normalied light direction: $\bar{d} = \dfrac{\bar{p} - \bar{l}}{\left\| \bar{p} - \bar{l} \right\|}$
  - The angular distance of the object from the light can be used:

$$V_{obj} \bullet V_{light} = \cos a$$



  - If we for example restrict the cone to 0 < ?$_1$ <= 90 and $V_{obj} \bullet V_{light} < \cos q_l$
  - Then the object is outside the cone of light

Light sources



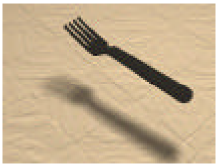
- Angular Intensity Attenuation
- **Spotlight**
- Attenuate the light intensity about the cone axis vector.
- Highest intensity in center of cone

$$f_{l,angatten} = \begin{cases} 1.0, & \text{If source is not a spotlight} \\ 0.0, & \text{If } \left(V_{obj} \bullet V_{light}\right) = \cos a < \cos q_l \\ \left(V_{obj} \bullet V_{light}\right)^{a_l}, & \text{otherwise} \end{cases}$$

Light sources

? Area Light Sources

- Occupies a 2D area
- Generates soft shadows, WHY?



Surface Lighting effects

? Surface properties

- Transparecy
- Reflectance coefficients
- Texture

- When light hits an opaque surface parts of it is reflected and parts is absorbed.
- For transparent surfaces some light are also transmitted through the material

Surface Lighting Effects

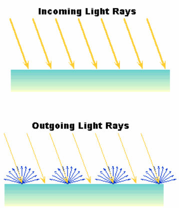
- Ambient Lighting model
  - Light coming from other objects
- Diffuse Lighting model
  - Light reflected equally in all directions
- Specular Lighting model
  - Light reflected in the area of the reflection vector between the view and light vector

Ambient lighting

- Not dependent on light, view or object direction, nor distance to anything else
- Surface parameter k_a - amount of reflected ambient light from surface.
- $I_{lambient} = k_a I_l$

Diffuse reflection

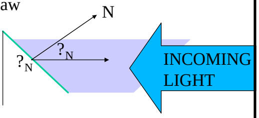
- Rough surfaces scatter reflected light many directions
- This is due to microscopic variations in the surface.
- An *IDEAL DIFFUSE REFLECTOR*
  - Will reflect incoming light equally in all outgoing directions independent from the view direction
- Chalk is an approximation for an ideal surface



Computing Diffuse reflection

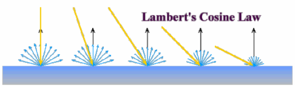
- Ideal diffuse surfaces
  - Also called Lambertian reflectors
  - Reflected radiant light energy from any point on the surface is calculated with Lamberts cosine law

$$\text{Intensity} = \frac{\text{radiant energy per unit time}}{\text{projected area}}$$



  - Amount of radiant energy coming from any small surface dA in a direction $?_N$ relative to the surface normal is proportional to $\cos ?_N$

Diffuse reflection



? We can model the amount of incident light on a surface with a source with intensity I_l such as:

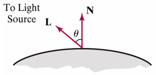
$I_{ldiffuse} = I_l \cos ?$

? With a surface property to control the amount of reflected diffuse light k_d we have:

$I_{ldiffuse} = k_d I_l \cos ?$

? Rember dot product,$V_1 * V_2 = \cos ?$, then we get:

$I_{ldiffuse} = k_d I_l N?L$, where N and L must be normalized (have length 1)



Error on page 565

Last paragraph!

Diffuse reflection

? An Illumination Modelleling example only considering diffuse reflection

Diffuse + Ambient lighting

- As we only consider angles in the range of 0 to 90 degrees.
- Greater angles, where N?L is below zero, the light is blocked by the surface and the reflected energy is 0
- So adding the Ambient (background) and the Diffuse lighting equation together results in:

$$I_{l,diff+amb} = \begin{cases} k_a I_a + k_d I_l \left(N \bullet L\right), & \text{if N} \bullet \text{L>0} \\ k_a I_a, & \text{if N} \bullet \text{L} \leq 0 \end{cases}$$

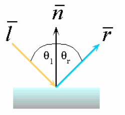
Specular reflection

- When we look at a shiny surface, polished metal, we see a highlight, or a bright spot.
- This spot is view-dependent, that is it is related to the viewers position in relation to the surface normal of the object and the lights incoming direction.
- An ideal mirror is a purely specular reflector.

Specular reflection

- Reflection behaves according to Snells laws which state:

  $n_l\sin ?_l=n_r\sin ?_r$



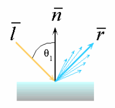
- The incoming ray, the surface normal, and the reflected ray all lie in a common plane.
- The angle that the reflected ray forms with the surface normal is determined by the angle that the incoming ray forms with the mediums (n_l,n_r) in which the incident and reflected rays propagate.
- Reflection is a special case, where the incidents light medium and the reflected rays medium is the same, which gives that: n_l=n_r -> $?_l$ = $?_r$

Specular reflection

? Snells law applies only to ideal mirror reflectors. Real materials deviates significantly from ideal reflectors.

? In general, we expect most of the reflected light to travel in the direction of the ideal reflection direction. But due to microscopic variations in the reflector (surface) the some of the reflected light scatters in different directions.

? As we as a viewer moves out from the reflection vector, we expect to see less light reflected.



Phong Bui Toung! Kiaaaa!

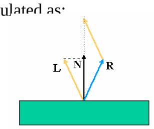
And other asian words i dont know shit about!

- A model for approximating the non ideal reflection is the Phong specular-reflection model where V is the unit vector in the direction of the viewer and R is the mirror reflection direction.

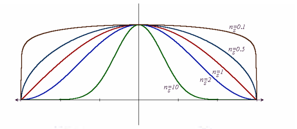
$$I_{l,spec} = \begin{cases} k_s I_l (V \bullet R)^{n_s}, & \text{if } V \bullet R > 0 \text{ and } N \bullet L > 0 \\ 0.0, & \text{if } V \bullet R < 0 \text{ or } N \bullet L \leq 0 \end{cases}$$

- The reflection vector R can be calculated as:

$$\bar{R} + \bar{L} = \left(2\left(\bar{N} \bullet \bar{L}\right)\right)\bar{N}$$



? n_s controlles the ”size” of the reflection lobe



n_s=5

n_s=30

Specular lighting

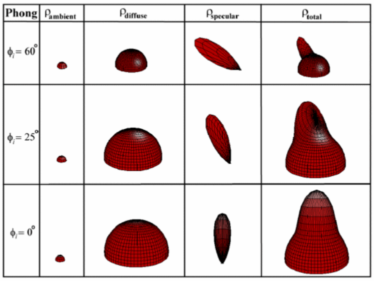
? Adding ambient, diffuse and specular together results in the following lighting equation:

$$I_{l,diff+amb+spec} = \begin{cases} k_a I_a + k_d I_l (N \bullet L) + k_s I_l (V \bullet R)^{n_s}, & \text{if } V \bullet R > 0 \text{ and } N \bullet L > 0 \\ k_a I_a, & \text{if } V \bullet R < 0 \text{ or } N \bullet L \leq 0 \end{cases}$$

? Which is the basic lighting equation for computer graphics.

? Its empirical, not physical!

Final result



Final result!

- What about colors then? Red, Blue, Green?
  - – One lighting equation per color...
- Several lightsources?
  - – Iterate over all lightsources and add the result, per color.

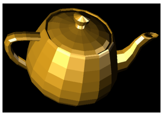
$$I_{l,diff+amb+spec} = k_a I_a + \sum_{i=1}^{nlights} I_l \left(k_d (N \bullet L) + k_s (V \bullet R)^{n_s} \right)$$

Shading

- Or surface rendering!
- Up to this point we have discussed how to compute the illumination model at a point on a surface. At which point should we apply the model? Where and how often it is applied has a noticable effect on the end result.
- Calculating the illumination model is costly, including several normalizations of vectors.

Flat Shading

- Applying the illumination calculation once per primitive (quad, triangle, ...)
- Constant intensity surface rendering (Hearn Baker)
- Issues:
  - For point light sources, the direction light varies over the primitive.
  - For specular reflections the direction to the eye varies over the primitive.
  - Illumination is usually calculated at the centroid of the primitive.

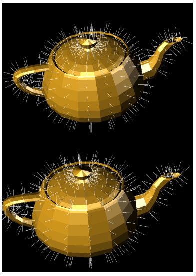


$$centroid = \frac{1}{numvertices}\sum_{i=1}^{numvertices} \bar{p}_i$$

Flat shading

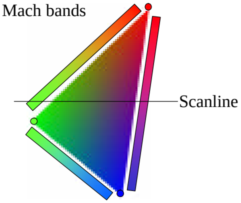
- Introducing normals on the surface
- Used for back face culling etc..
- One normal for each primitive is obviously not enough.
- Vertex normals can be calculated by averaging the normals sharing that vertex.

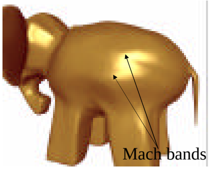
$$\bar{n}_v = \sum_{i=1}^{k} \frac{\bar{n}_i}{|\bar{n}_i|}$$



Goraud Shading

- Intensity-interpolation surface rendering
- The Goraud shading method applies the illumination model at several positions of a primitive, *usually per vertex.* The result is then interpolated over the facet (primitive).
- Still artefacts are present, highligts sometimes shows anomalies, Mach bands





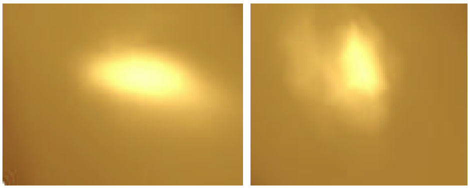
Phong Shading

- Not the same thing as Phong's illumination model! Shading ? Illumination
- Illumination model applied to every point on the primitives surface.
- Requires a normal per vertex (as Gouraud)
- Interpolates the normals over each point on the surface (Gouraud interpolates colors!)
- Drawbacks
  - Computational demanding

Phong Shading

- Up until for a couple of years ago, phong shading
- Was not possible in realtime for larger models.
- GPU enables that, (Graphics Processor Unit)
- A very short shader code snippet will do the phong shading for you...

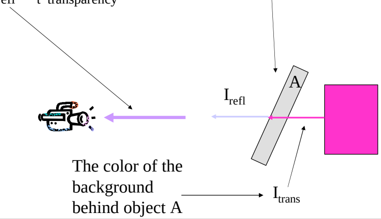
Comparison, where is the Phongie?



Other effects

- Transparent surfaces
  - Simple transparency equation:

$I = (1-k_t)I_{refl}+k_tI_{transparency}$


An object with transparency k_t
A
I_{refl}
I_{trans}
The color of the background behind object A

Other effects

- Transparent surfaces
  - When light enters a transparent surface, the direction of the light beam changes direction according to Snell's law: $n_l\sin?_l=n_r\sin?_r$
  - **Refraction** index *n* depends on temperatur, and the wavelength of the light. Therefore light can scatter into several rays of different color (prisma!)
  - For Air n=1, for water we have n=1.33, using those two refraction index we can calculate the refraction direction.
  - If we follow the refraction ray and get the color information which it contributes to the image, we could get something like:

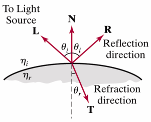
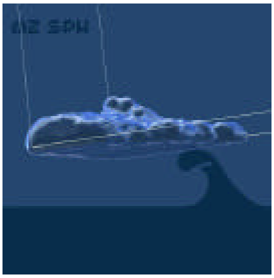


Figure 10-30



Is this all?

- So we can land on the moon, thinking of going to Mars, and the Phong illumination model is all we can do?
- No there are a lot more
- One exampel is **Cook-Torrance-Illumination**

$$I_{\lambda,r} = I_{\lambda,a}k_a + \sum_{i=1}^{lights} I_{\lambda,i}\left((1-k_a-k_s)\rho_\lambda(\bar{l}_i \cdot \bar{n}) + k_s \frac{DGF_\lambda(\theta_i)}{\pi(\bar{v} \cdot \bar{n})}\right)$$

- Takes into account, microfacet distribution, geometric attenuation, fresnel conductance term.