Now Playing:

Night Light
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from *Urban Renewal Program*
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Lighting and Shading

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COMP 575
September 20, 2007

Announcements

- Programming Assignment 1 is out today
  - Due next Thursday by 11:59pm
- ACM Programming Contest
  - Meeting tonight at 7pm in 011

Last Time

- Reviewed Homework 1
- Assigned / Demoed Programming Assignment 1
  - Due next Thursday (9/27) by 11:59pm
- Discussed different ways of representing geometric objects for computer graphics
  - Procedural
  - Tessellated polygons

Today

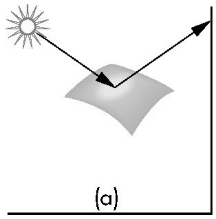
- Programming assignment 1 is out
  - Any questions?
- Talking about lighting and shading
  - Focusing on OpenGL

Light and Matter

- Review:
  - Materials do NOT have color
  - Light does
    - Material objects appear to have color because they reflect only certain wavelengths of light
- How does light interact with matter?

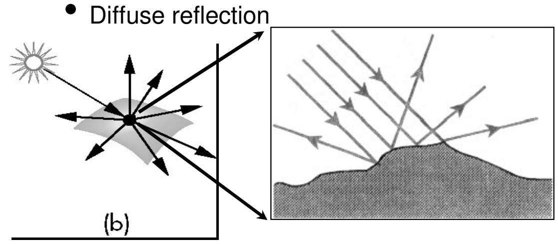
Light and Matter

- Specular reflection



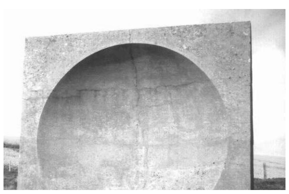
Light and Matter

- Diffuse reflection



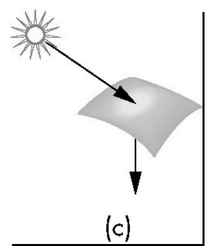
Light and Matter

- Diffuse Reflection



Light and Matter

- Translucency / Transparen

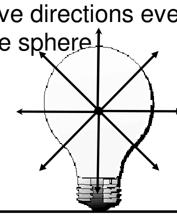


Lights

- So what are some properties of lights?
  - Wavelength (Color)
  - Position
  - Size
  - Intensity
  - Distribution of light

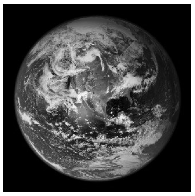
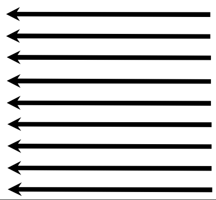
Point Lights

- Emit light evenly in all directions
  - That is, photons (rays) from a point light all originate from the same point, and have directions evenly distributed over the sphere



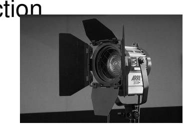
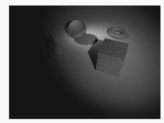
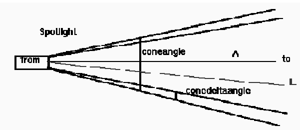
Directional Lights

- Point light sources at an infinite (or near infinite) distance
  - Can assume that all rays are parallel

Spot Lights

- Similar to point lights, but intensity of emitted light varies by direction
  - Can think of it as only emitting rays over a patch on the sphere

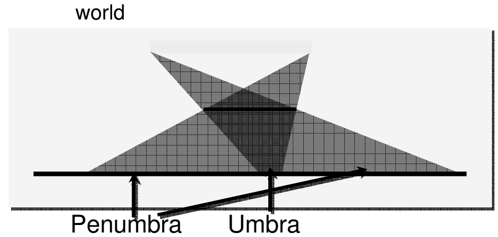




Area Lights

- Emits light in every direction from a surface
  - Can think of it as a set of point lights, or a patch on which every point is a point light

Area Lights

- Real lights have some area
  - That's why we have soft shadows in the real world



The Rendering Equation

Jim Kajiya, 1986

$$L_o(x,\vec{w}) = L_e(x,\vec{w}) + \int_\Omega f_r(x,\vec{w}',\vec{w}) L_i(x,\vec{w}') (\vec{w}' \cdot \vec{n}) d\vec{w}'$$

- In short, the light out from a point in a specific direction depends on:
  - The light it emits in that direction
  - The light incident on that point <u>from every direction</u>, affected by
    - How reflective the material is for that pair of directions
    - How close the incoming direction is to the surface normal

The Rendering Equation

- This is a theoretical model of light transport
- It's not actually solvable by conventional means
  - Radiosity and various ray-tracing methods attempt to approximate it's actual solution in various ways
  - OpenGL uses a simplified model

Light Simplifications

- We must simplify lights for real-time rendering:
  - Single RGB color instead of wavelength distribution (denoted L_m)
  - Intensity is rolled into L_m
  - No area lights
  - Distribution of light is uniform
    - Except for spot lights

Light Simplifications

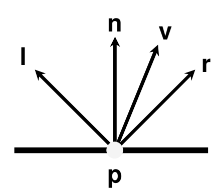
- We must simplify lights for real-time rendering: (cont'd)
  - No indirect light
    - Use an ambient light term
      - Really just a hack
  - Shadows are hard shadows, or are not included at all

Phong Reflection Model

- A simplification of the rendering equation
- Divided into 3 parts
  - Ambient
  - Diffuse
  - Specular
- The sum of these components describes the color at a point

Phong Reflection Model

- Uses 4 vectors to compute the color of an arbitrary point **p**
  - Normal (**n**)
  - Light (**l**)
  - Viewer (**v**)
  - Reflection (**r**)



Phong Reflection Model

Ambient Diffuse

- $I = I_a(R_a, L_a) + I_d(\mathbf{n}, \mathbf{l}, R_d, L_d, a, b, c, d) + I_s(\mathbf{r}, \mathbf{v}, R_s, L_s, n, a, b, c, d)$ Specular
- $R_{\text{something}}$ represents how reflective the surface is
- $L_{something}$ represents the intensity of the light
- In practice, these are each 3-vectors
- One each for R, G, and B

Phong Reflection Model: Ambient Term

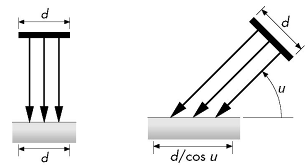
- Assume that ambient light is the same everywhere
  - Is this generally true?
- $I_a(R_a, L_a) = R_a * L_a$
  - The contribution of ambient light at a point is just the intensity of the light modulated by how reflective the surface is (for that color)

Phong Reflection Model: Diffuse Term

- $I_d(\mathbf{n}, \mathbf{l}, R_d, L_d, a, b, c, d) = (R_d / (a + bd + cd^2)) * max(\mathbf{l} \cdot \mathbf{n}, 0) * L_d$
- a, b, c : user-defined constants
- d : distance from the point to the light
- Let's consider these parts

Lambert's Cosine Law

- The incident angle of the incoming light affects its apparent intensity
  - Does the sun seem brighter at noon or 6pm?
- Why?



"Noon" "Evening"

Phong Reflection Model: Diffuse Term

- We already know how to get the cosine between the light direction and the normal
  - $\mathbf{n} \cdot \mathbf{l}$
- What happens if the surface is facing away from the light?
  - That's why we use $max(\mathbf{n} \cdot \mathbf{l}, 0)$
  - Why not just take $|\mathbf{n} \cdot \mathbf{l}|$?

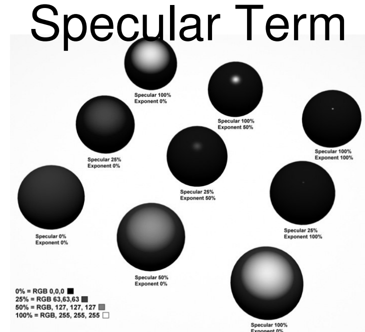
Phong Reflection Model: Diffuse Term

- In the real world, lights seem to get dimmer as they get further away
  - Intensity decreases with distance
- We can simulate that by adding an attenuation term
  - $(R_d / (a + bd + cd^2))$
  - User can choose the a,b,c constants to achieve the desired "look"

Phong Reflection Model: Specular Term

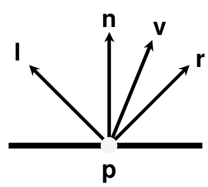
- $I_s(\mathbf{r}, \mathbf{v}, R_s, L_s, n, a, b, c, d) = (R_s / (a + bd + cd^2)) * max(\mathbf{r} \cdot \mathbf{v}, 0)^n * L_s$
- Why $\mathbf{r} \cdot \mathbf{v}$?
  - Reflection is strongest in the direction of the reflection vector
  - $\mathbf{r} \cdot \mathbf{v}$ is maximized when the viewpoint vector (or really the vector to the viewpoint) is in the same direction as $\mathbf{r}$
- What is n?

Phong Reflection Model: Specular Term



Phong Reflection Model

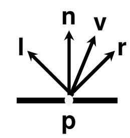
- So how do we compute these vectors?
  - Normal (**n**)
  - Light (**l**)
  - Viewer (**v**)
  - Reflection (**r**)



Where do vectors come from?

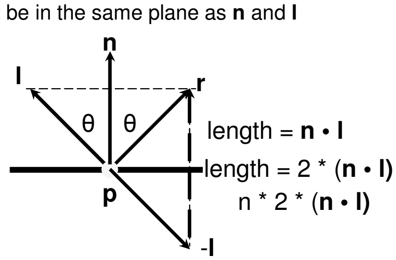
- So how do we compute these vectors?
  - Viewer (**v**) = normalize(*eyePos*$_{xyz}$ - **p**)
  - Light (**l**) = normalize(*lightPos*$_{xyz}$ - **p**)
  - Normal (**n**)
  - Reflection (**r**)

These are easy



Reflection Vector

- A reflection of **l** across **n**
  - Must be in the same plane as **n** and **l**



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  - Viewer (**v**) = normalize(*eyePos*$_{xyz}$ - **p**)
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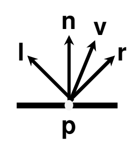
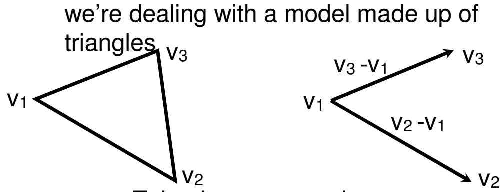
  - Normal (**n**)
  - Reflection (**r**) = -**l** + 2 * (**n • l**) * **n**



Normal Vector

- Can be stored with the model
- More likely (at least with OpenGL), we're dealing with a model made up of triangles



Take the cross product:
n = normalize(cross(v_2 - v_1, v_3 - v_1))

Where do vectors come from?

- So how do we compute these vectors?
  - Viewer (**v**) = normalize(*eyePos*$_{xyz}$ - **p**)
  - Light (**l**) = normalize(*lightPos*$_{xyz}$ - **p**)
  - Normal (**n**) = normalize(cross(v_2 - v_1, v_3 - v_1))
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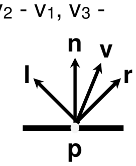


Summing up Lighting

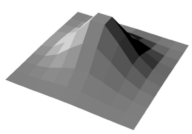
- So that's how we think about lighting
  - Computing the color of a single point on a surface
- Now we're going to talk about *shading*
  - Not shadows
  - Graphics term: Filling in a polygon with color

Types of Shading

- There are several well-known / commonly-used shading methods
  - Flat shading
  - Gouraud shading
  - Phong shading

Flat Shading

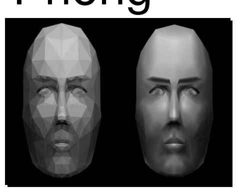
- Simplest type of shading
  - Treat the entire polygon as one point (usually the center)
  - Solve the Phong lighting equations once
  - Fill in the whole polygon with that color



Gouraud Shading

- A bit more complicated than flat shading
  - Compute normals at each vertex
  - Solve the Phong lighting equations at each vertex
  - Linearly interpolate color inside the triangle
- Gouraud shading is the default in OpenGL
  - Flat shading is also built i

Gouraud vs. Phong

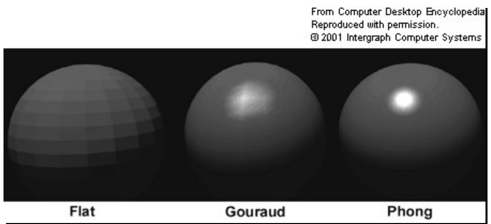


- Gouraud shading is:
  - Still very fast
  - MUCH nicer looking than flat shading
- However:
  - Specular highlights brighten/fade near vertices
  - The change in linear function is noticeable at triangle edges

Phong Shading

- Not the same as Phong *lighting*
  - Compute normals at each vertex
  - Linearly interpolate *normals* at each point inside the triangle
  - Solve the Phong lighting equations at each fragment (pixel)
- Not built into OpenGL
  - Can now be done in real-time with programmable shaders

Shading Comparison



Lighting in OpenGL

- Need to enable
  GL_LIGHTING
  GL_LIGHTN //(N = 0, 1, 2, 3, ...)
- Can use:
  - Point lights
  - Spot lights
  - Directional lights
  - Ambient lights

Lighting in OpenGL

- Can choose your shading model:
  - Flat (GL_FLAT)
  - Gouraud (GL_SMOOTH)
- Other functions you might need:
  - glLight{fv}
  - glLightModel
  - glMaterial
  - glColorMaterial
  - glNormal3f

We'll demo some of this on Tuesday

Next Time

- Continuing our discussion of lighting and shading
- OpenGL demo of lighting/shading functions
- Introducing stylized shading techniques