Computer Graphics

Prof. Feng Liu

Fall 2016

http://www.cs.pdx.edu/~fliu/courses/cs447/

11/07/2016

Last time

- Hidden Surface Removal

Today

- Lighting and Shading
- Project 2
- Will publicize several times in the final week of classes when you can get your project graded
  - Demo your program to the instructor in person
    - Bring your own laptop or on a CS Windows Lab Machine
  - Latest time to grade
    - 5:00 pm, Friday, December 2, 2015
  - No late submission!

Where We Stand

- So far we know how to:
  - Transform between spaces
  - Draw polygons
  - Decide what’s in front
- Next
  - Deciding a pixel’s intensity and color

Normal Vectors

- The intensity of a surface depends on its orientation with respect to the light and the viewer
- The *surface normal vector* describes the orientation of the surface at a point
  - Mathematically: Vector that is perpendicular to the tangent plane of the surface
  - Just “the normal vector” or “the normal”
  - Will use **n** or **N** to denote
- Normals are either supplied by the user or automatically computed

Transforming Normal Vectors

- Normal vectors are *directions*

  Normal vectors are perpedicular to tangent vectors: $\mathbf{n} \bullet (\mathbf{x} - \mathbf{p}) = 0$

  There is a matrix form of this: $\mathbf{n}^t(\mathbf{x} - \mathbf{p}) = \mathbf{0}$

  Consider the equation with a transformed tangent: $\mathbf{n}^t\mathbf{T}^{-1}\mathbf{T}(\mathbf{x} - \mathbf{p}) = \mathbf{0}$

  The right hand half is the transformed point.

  The new transpose normal must be equal to: $\mathbf{n}^t\mathbf{T}^{-1}$

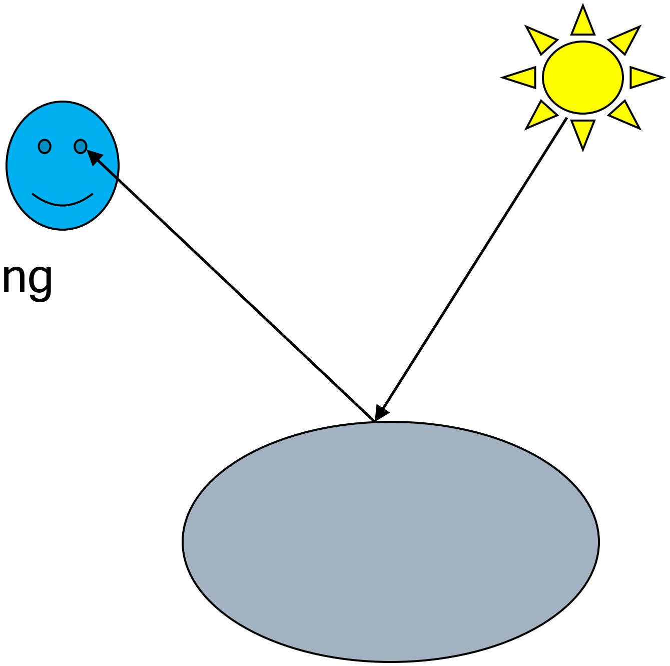
  The new normal must then be: $(\mathbf{n}^t\mathbf{T}^{-1})^t = (\mathbf{T}^{-1})^t\mathbf{n}$
- To transform a normal, multiply it by the inverse transpose of the transformation matrix
- Recall, rotation matrices are their own inverse transpose
- Don't include the translation! Use $(n_x, n_y, n_z, 0)$ for homogeneous coordinates

Local Shading Models

- *Local shading models* provide a way to determine the intensity and color of a point on a surface
  - The models are local because they **don't consider other objects**
  - We use them because they are fast and simple to compute
  - They do not require knowledge of the entire scene, only the current piece of surface.
- For the moment, assume:
  - We are applying these computations at a particular point on a surface
  - We have a normal vector for that point

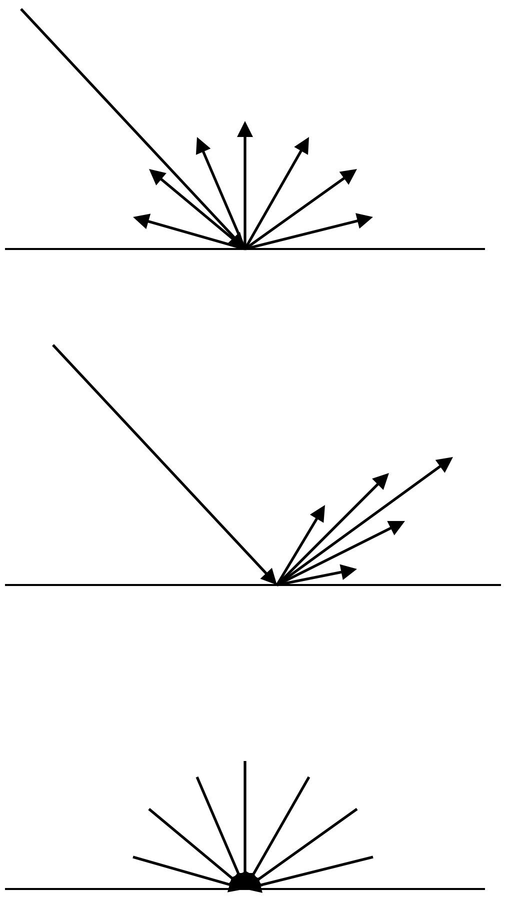
Local Shading Models

- What they capture:
  - Direct illumination from light sources
  - *Diffuse* and *Specular* reflections
  - (Very) Approximate effects of global lighting
- What they don't do:
  - Shadows
  - Mirrors
  - Refraction
  - Lots of other stuff …

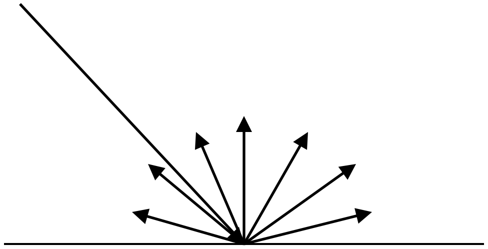


“Standard” Lighting Model

- Consists of three terms linearly combined:
  - *Diffuse* component for the amount of incoming light from a point source reflected equally in all directions
  - *Specular* component for the amount of light from a point source reflected in a mirror-like fashion
  - *Ambient* term to approximate light arriving via other surfaces



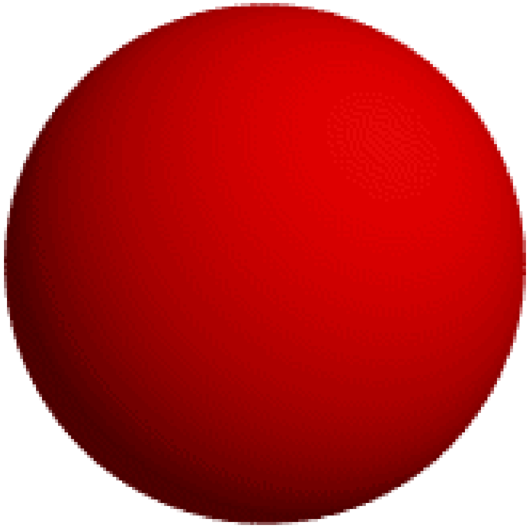
Diffuse Illumination



$$k_d I_i (\boldsymbol{L} \bullet \boldsymbol{N})$$

- Incoming light, I_i, from direction L, is reflected equally in all directions
  - **No dependence on viewing direction**
- Amount of light reflected depends on:
  - Angle of surface with respect to light source
    - Actually, determines how much light is collected by the surface, to then be reflected
  - Diffuse reflectance coefficient of the surface, k_d
- Don't want to illuminate back side. Use $k_d I_i \max(\boldsymbol{L} \bullet \boldsymbol{N}, 0)$

Diffuse Example



Diffuse Lighting

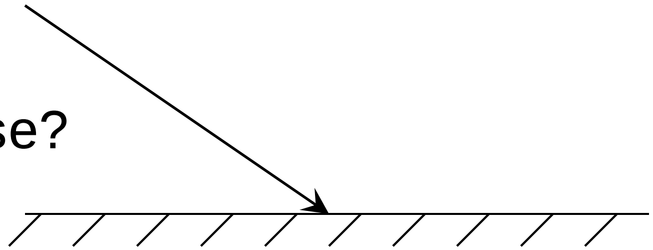
Where is the light?

Which point is brightest (how is the normal at the brightest point related to the light)?

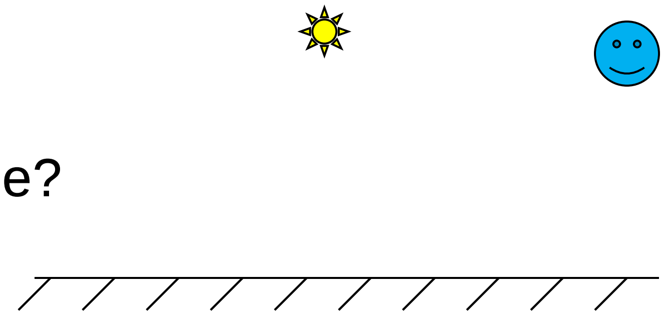
Illustrating Shading Models

- Show the polar graph of the amount of light leaving for a given incoming direction:

Diffuse?

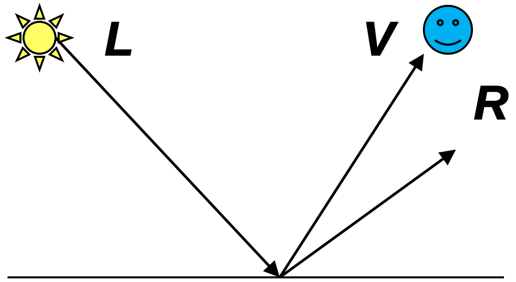


- Show the intensity of each point on a surface for a given light position or direction



Diffuse?

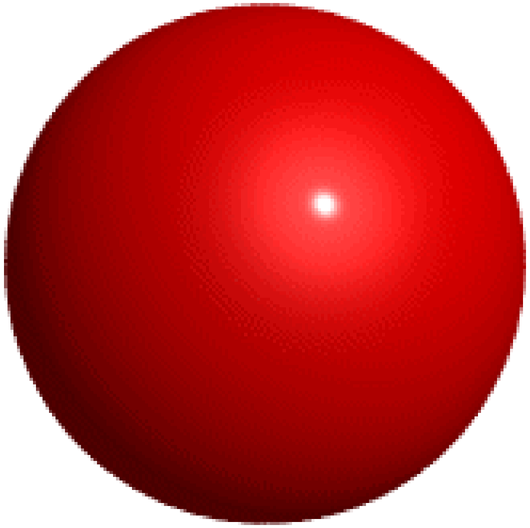
Specular Reflection
(Phong Reflectance Model)



$$k_s I_i (\mathbf{R} \bullet \mathbf{V})^p$$

- Incoming light is reflected primarily in the mirror direction, *R*
  - Perceived intensity depends on the relationship between the viewing direction, *V*, and the mirror direction
  - Bright spot is called a *specularity*
- Intensity controlled by:
  - The specular reflectance coefficient, k_s
  - The *Phong Exponent*, *p*, controls the apparent size of the specularity
    - Higher *p*, smaller highlight

Specular Example

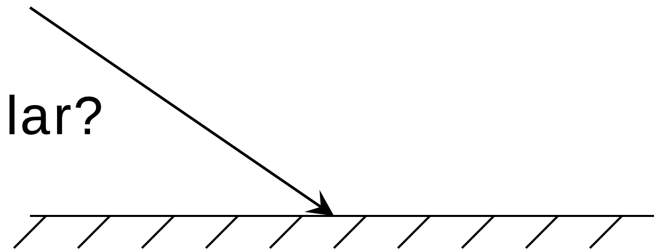


Plus Specular Highlight

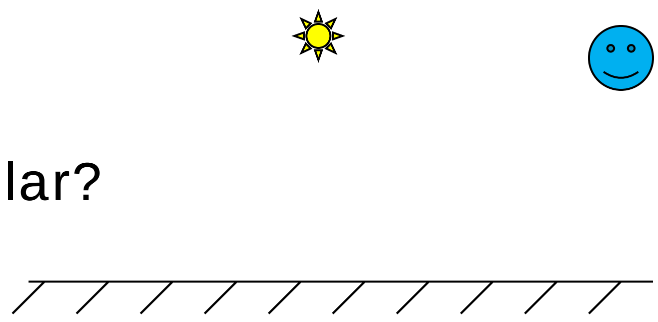
Illustrating Shading Models

- Show the polar graph of the amount of light leaving for a given incoming direction:

Specular?



- Show the intensity of each point on a surface for a given light position or direction

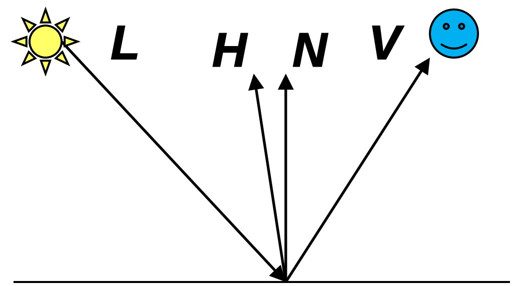


Specular?

Alternative Specular Reflection Model

$$\mathbf{H} = (\mathbf{L} + \mathbf{V}) / \|\mathbf{L} + \mathbf{V}\|$$

$$k_s I_i (\mathbf{H} \bullet \mathbf{N})^p$$



- Compute based on normal vector and “halfway” vector, *H*

Putting It Together

$$I = k_a I_a + I_i \left(k_d (\mathbf{L} \bullet \mathbf{N}) + k_s (\mathbf{H} \bullet \mathbf{N})^p \right)$$

- Global ambient intensity, I_a:
  - Gross approximation to light bouncing around of all other surfaces
  - Modulated by ambient reflectance k_a
- Just sum all the terms
- If there are multiple lights, sum contributions from each light
- Several variations, and approximations …

Color

$$I_r = k_{a,r} I_{a,r} + I_{i,r}\left(k_{d,r}(\boldsymbol{L} \bullet \boldsymbol{N}) + k_{s,r}(\boldsymbol{H} \bullet \boldsymbol{N})^n\right)$$

- Do everything for three colors, r, g and b
- Note that some terms (the expensive ones) are constant
- Using only three colors is an approximation, but few graphics practitioners realize it
  - *k* terms depend on wavelength, should compute for continuous spectrum

Approximations for Speed

- The viewer direction, *V*, and the light direction, *L*, depend on the surface position being considered, ***x***
- Distant light approximation:
  - Assume *L* is constant for all ***x***
  - Good approximation if light is distant, such as sun
- Distant viewer approximation
  - Assume *V* is constant for all ***x***
  - Rarely good, but only affects specularities

Distant Light Approximation

- Distant light approximation:
  - Assume ***L*** is constant for all ***x***
  - Good approximation if light is distant, such as sun
  - Generally called a *directional light source*
- What aspects of surface appearance are affected by this approximation?
  - Diffuse?
  - Specular?

Distant Viewer Approximation

- Specularities require the viewing direction:
  - $V(x) = ||c\text{-}x||$
  - Slightly expensive to compute
- Distant viewer approximation uses a global *V*
  - Independent of which point is being lit
  - Use the view plane normal vector
  - Error depends on the nature of the scene
- Is the diffuse component affected?

Describing Surfaces

- The various parameters in the lighting equation describe the appearance of a surface
- $(k_{d,r}, k_{d,g}, k_{d,b})$: The *diffuse color*, which most closely maps to what you would consider the “color” of a surface
  - Also called *diffuse reflectance coefficients*
- $(k_{s,r}, k_{s,g}, k_{s,b})$: The specular color, which controls the color of specularities
  - Some systems do not let you specify this color separately
- $(k_{a,r}, k_{a,g}, k_{a,b})$: The ambient color, which controls how the surface looks when not directly lit
  - Normally the same as the diffuse color

OpenGL Commands (1)

- `glMaterial{if}(face, parameter, value)`
  - Changes one of the coefficients for the front or back side of a face (or both sides)
- `glLight{if}(light, property, value)`
  - Changes one of the properties of a light (intensities, positions, directions, etc)
  - There are 8 lights: `GL_LIGHT0, GL_LIGHT1, …`
- `glLightModel{if}(property, value)`
  - Changes one of the global light model properties (global ambient light, for instance)
- `glEnable(GL_LIGHT0)` enables `GL_LIGHT0`
  - You must enable lights before they contribute to the image
  - You can enable and disable lights at any time

OpenGL Commands (2)

- `glEnable(GL_LIGHTING)` turns on lighting
  - **You must enable lighting explicitly** – it is off by default
- Don't use specular intensity if you don't have to
  - It's expensive - turn it off by giving 0,0,0 as specular color of the **lights**
- **Don't forget normals**
  - If you use scaling transformations, must enable GL_NORMALIZE to keep normal vectors of unit length
- Many other things to control appearance

Light Sources

- Two aspects of light sources are important for a local shading model:
  - Where is the light coming from (the *L* vector)?
  - How much light is coming (the *I* values)?
- Various light source types give different answers to the above questions:
  - *Point light source*: Light from a specific point
  - *Directional*: Light from a specific direction
  - *Spotlight*: Light from a specific point with intensity that depends on the direction
  - *Area light*: Light from a continuum of points (later in the course)

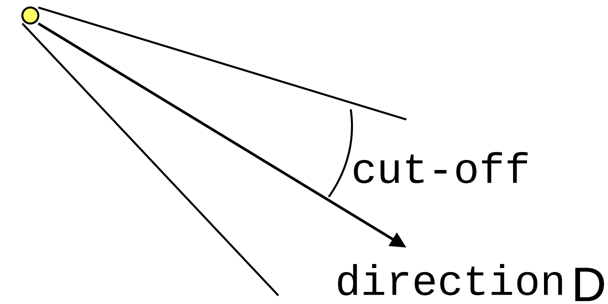
Point and Directional Sources

- Point light: $L(x) = \frac{p_{light} - x}{\left\| p_{light} - x \right\|}$
  - The **L** vector depends on where the surface point is located
  - Must be normalized - slightly expensive
  - To specify an OpenGL light at 1,1,1:

```
Glfloat light_position[] = { 1.0, 1.0, 1.0, 1.0 };
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```

- Directional light: $L(x) = L_{light}$
  - The *L* vector does not change over points in the world
  - OpenGL light traveling in direction 1,1,1 (*L* is in opposite direction):

```
Glfloat light_position[] = { 1.0, 1.0, 1.0, 0.0 };
glLightfv(GL_LIGHT0, GL_POSITION, light_position);
```



Spotlights

- Point source, but intensity depends on *L*:
  - Requires a position: the location of the source

    ```
    glLightfv(GL_LIGHT0, GL_POSITION, light_posn);
    ```

  - Requires a direction: the center axis of the light

    ```
    glLightfv(GL_LIGHT0, GL_SPOT_DIRECTION, light_dir);
    ```

  - Requires a cut-off: how broad the beam is

    ```
    glLightfv(GL_LIGHT0, GL_SPOT_CUTOFF, 45.0);
    ```

  - Requires and exponent: how the light tapers off at the edges of the cone
    - Intensity scaled by $(L \cdot D)^n$

    ```
    glLightfv(GL_LIGHT0, GL_SPOT_EXPONENT, 1.0);
    ```

Shading so Far

- So far, we have discussed illuminating a single point

$$I = k_a I_a + I_i \left(k_d (\mathbf{L} \bullet \mathbf{N}) + k_s (\mathbf{H} \bullet \mathbf{N})^p \right)$$

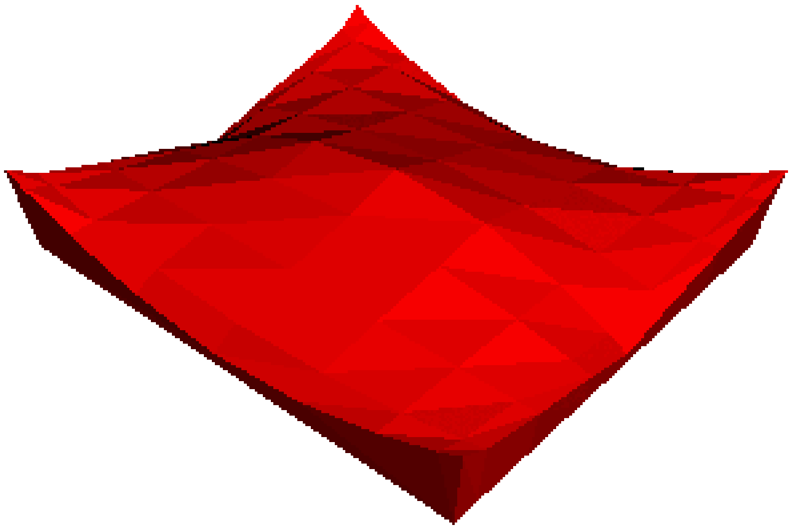
- We have assumed that we know:
  - The point
  - The surface normal
  - The viewer location (or direction)
  - The light location (or direction)
- But commonly, normal vectors are only given at the vertices
- It is also expensive to compute lighting for every point

Shading Interpolation

- Take information specified or computed at the vertices, and somehow propagate it across the polygon (triangle)
- Several options:
  - Flat shading
  - Gouraud interpolation
  - Phong interpolation

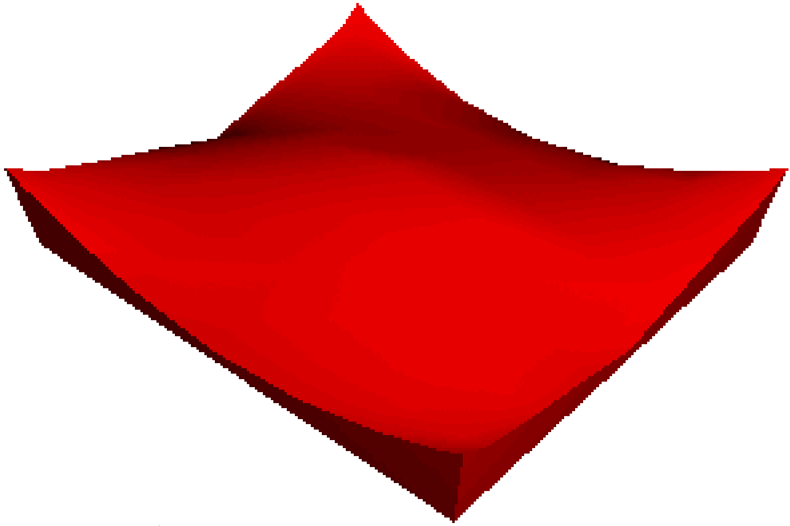
Flat shading

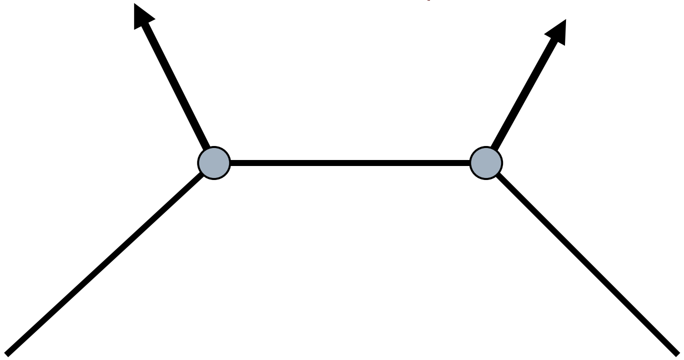
- Compute shading at a representative point and apply to whole polygon
  - OpenGL uses one of the vertices
- Advantages:
  - Fast - one shading computation per polygon
- Disadvantages:
  - Inaccurate
  - What are the artifacts?



Gouraud Shading

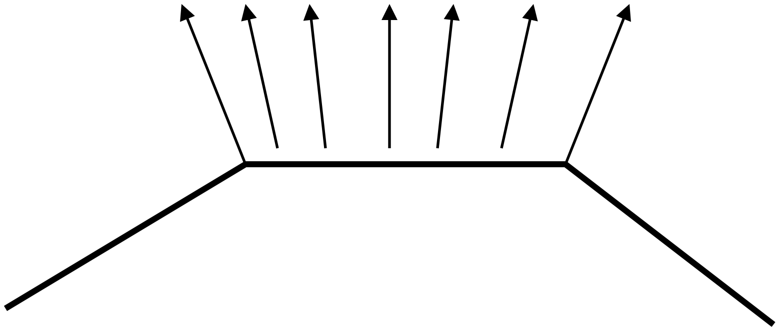
- Shade each *vertex* with it's own location and normal
- *Linearly interpolate* the color across the face
- Advantages:
  - Fast: incremental calculations when rasterizing
  - Much smoother - use same normal every time a vertex is used for a face
- Disadvantages:
  - What are the artifacts?
  - Is it accurate?



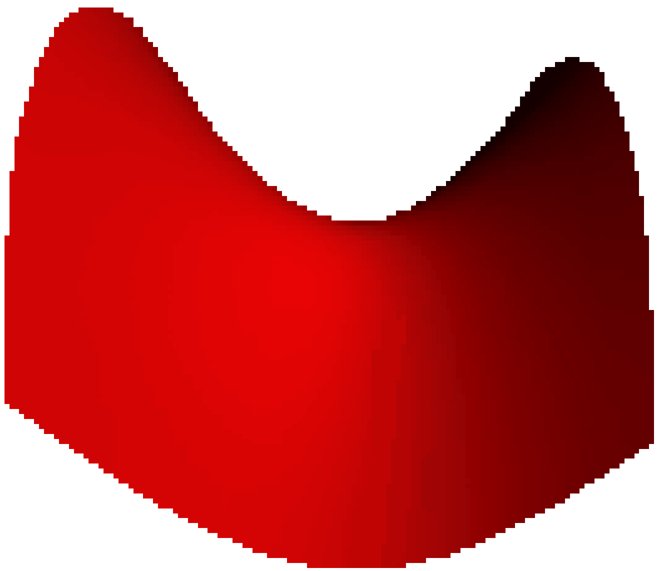


Phong Interpolation

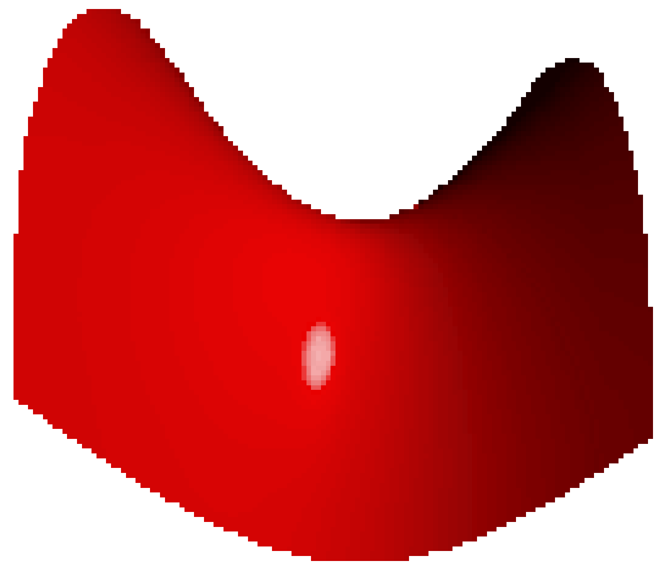
- Interpolate normals across faces
- Shade each pixel individually
- Advantages:
  - High quality, narrow specularities
- Disadvantages:
  - Expensive
  - Still an approximation for most surfaces
- Not to be confused with Phong's specularity model



Gouraud



Phong



Shading and OpenGL

- OpenGL defines two particular shading models
  - Controls how colors are assigned to pixels
  - `glShadeModel(GL_SMOOTH)` interpolates between the colors at the vertices (the default, Gouraud shading)
  - `glShadeModel(GL_FLAT)` uses a constant color across the polygon
- Phong shading requires a significantly greater programming effort – beyond the scope of this class
  - Also requires *fragment shaders* on *programmable graphics hardware*

Next Time

- Texture mapping