Shading so Far

- So far, we have discussed illuminating a single point

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

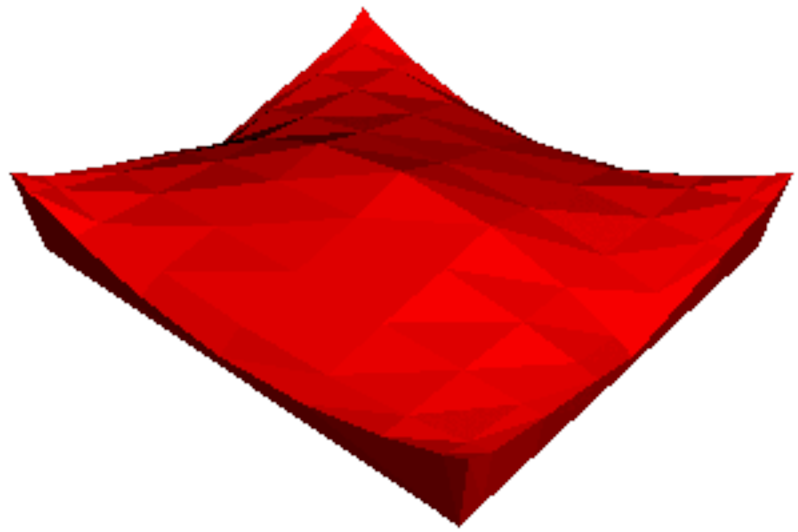
- We have assumed that we know:
  - The point
  - The surface normal
  - The viewer location (or direction)
  - The light location (or direction)
- But commonly, normal vectors are only given at the vertices
- It is also expensive to compute lighting for every point

Shading Interpolation

- Several options:
  - Flat shading
  - Gouraud interpolation
  - Phong interpolation
- New hardware provides other options

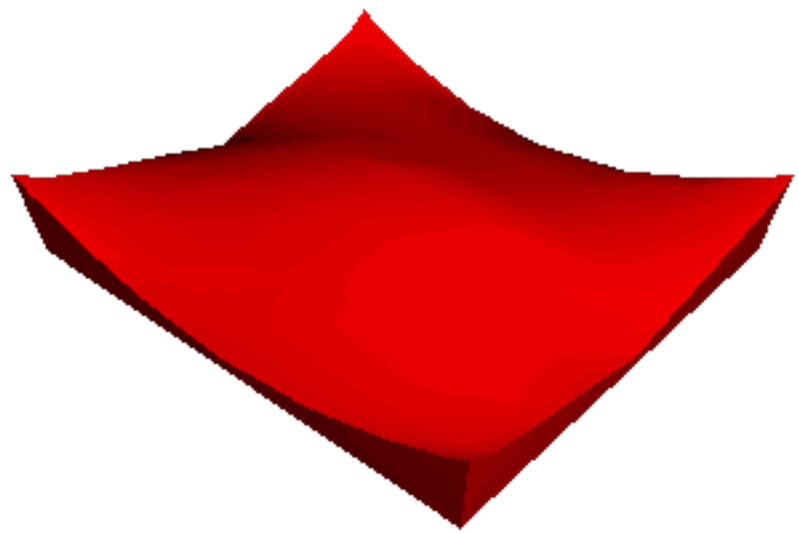
Flat shading

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



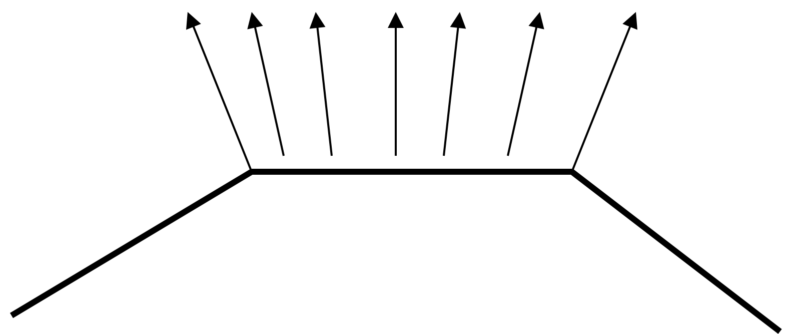
Gouraud Shading

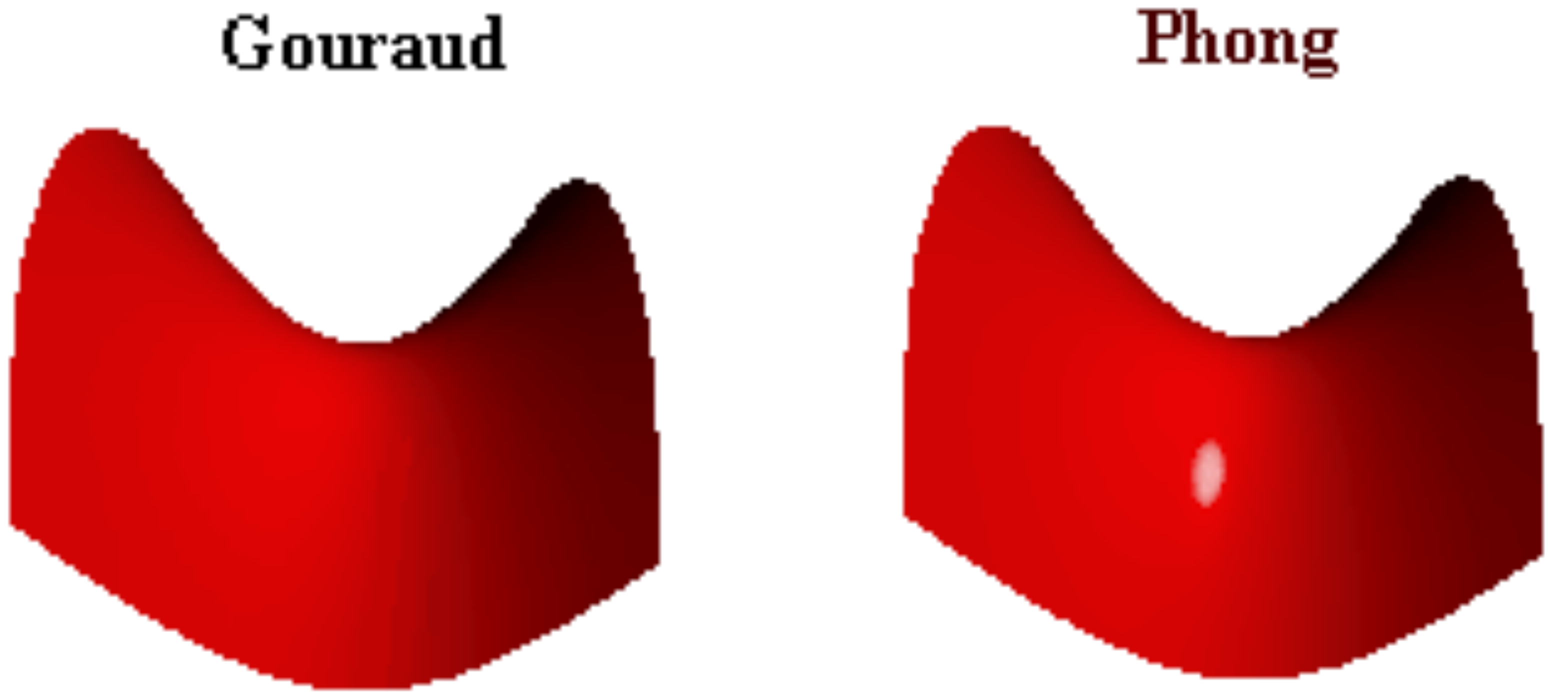
- Shade each *vertex* with it's own location and normal
- *Linearly interpolate* the color across the face
- Advantages:
  - Fast - incremental calculations when rasterizing
  - Much smoother - use one normal per shared vertex to get continuity between faces
- Disadvantages:
  - What are the artifacts?
  - Is it accurate?



Phong Interpolation

- Interpolate normals across faces
- Shade each pixel
- 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

The Current Generation

- Current hardware allows you to break from the standard illumination model
- *Programmable Vertex Shaders* allow you to write a small program that determines how the color of a vertex is computed
  - Your program has access to the surface normal and position, plus anything else you care to give it (like the light)
  - You can add, subtract, take dot products, and so on

The Full Story

- We have only touched on the complexities of illuminating surfaces
  - The common model is hopelessly inadequate for accurate lighting (but it's fast and simple)
- Consider two sub-problems of illumination
  - Where does the light go? *Light transport*
  - What happens at surfaces? *Reflectance models*
- Other algorithms address the transport or the reflectance problem, or both
  - Much later in class, or a separate course

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

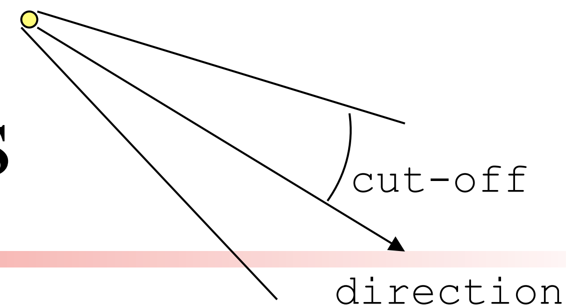
- Point light: $\boldsymbol{L}(x) = ||\boldsymbol{p}_{light} - \boldsymbol{x}||$
  - The **L** vector depends on where the surface point is located
  - Must be normalized - slightly expensive
  - To specify an OpenGL light at 1,1,1:

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

- Directional light: $\boldsymbol{L}(x) = \boldsymbol{L}_{light}$
  - 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 $(\boldsymbol{L}\cdot\boldsymbol{D})^n$

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