Shading
(Part 2)

Brian Curless

CSEP 557

Winter 2013

Reading

Required:

- Angel chapter 5.

Optional:

- OpenGL red book, chapter 5.

Gouraud vs. Phong interpolation

Now we know how to compute the color at a point on a surface using the Blinn-Phong lighting model.

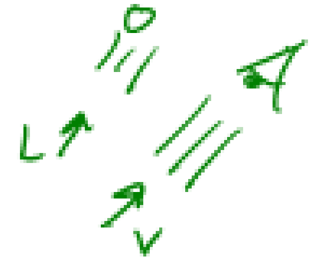
Does graphics hardware do this calculation at *every* point? Not by default...

Smooth surfaces are often approximated by polygonal facets, because:

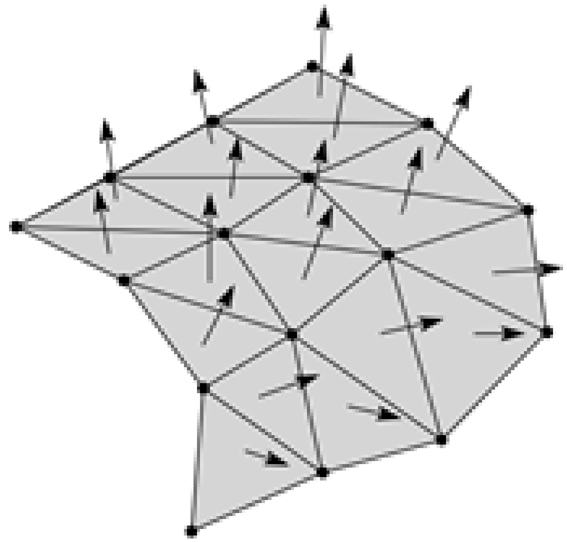
- Graphics hardware generally wants polygons (esp. triangles).
- Sometimes it easier to write ray-surface intersection algorithms for polygonal models.

How do we compute the shading for such a surface?

Faceted shading



Assume each face has a constant normal:



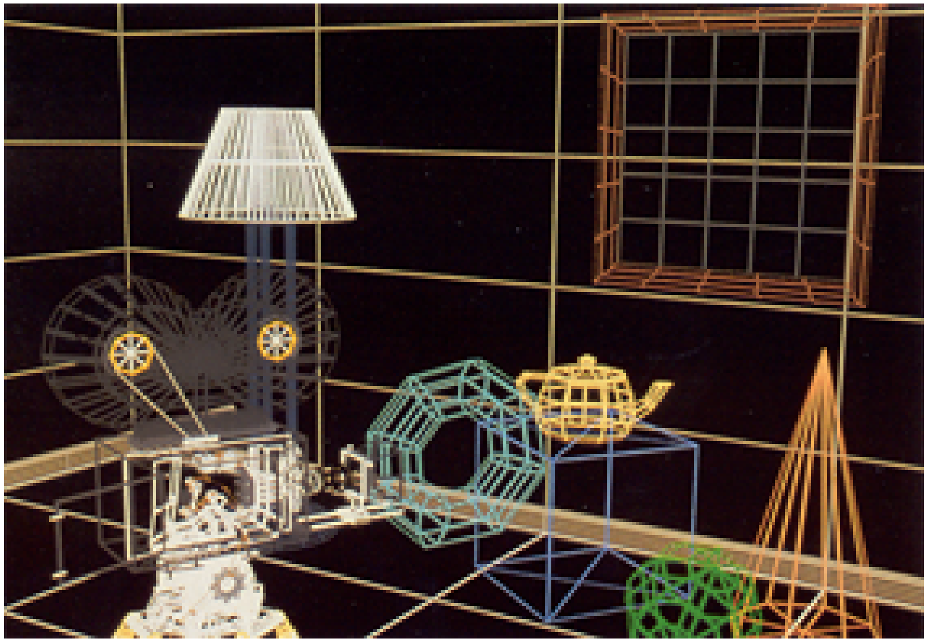
$= \ldots (N \cdot L) \ldots (N \cdot H)$

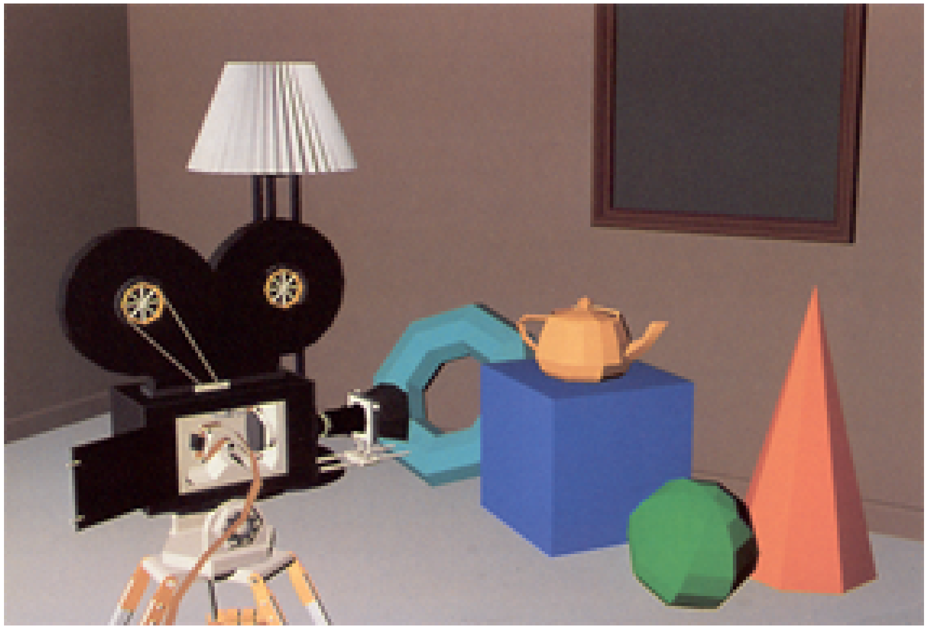
$H = \frac{L+V}{\|L+V\|}$

For a distant viewer and a distant light source and constant material properties over the surface, how will the color of each triangle vary?

Result: faceted, not smooth, appearance.

Faceted shading (cont'd)





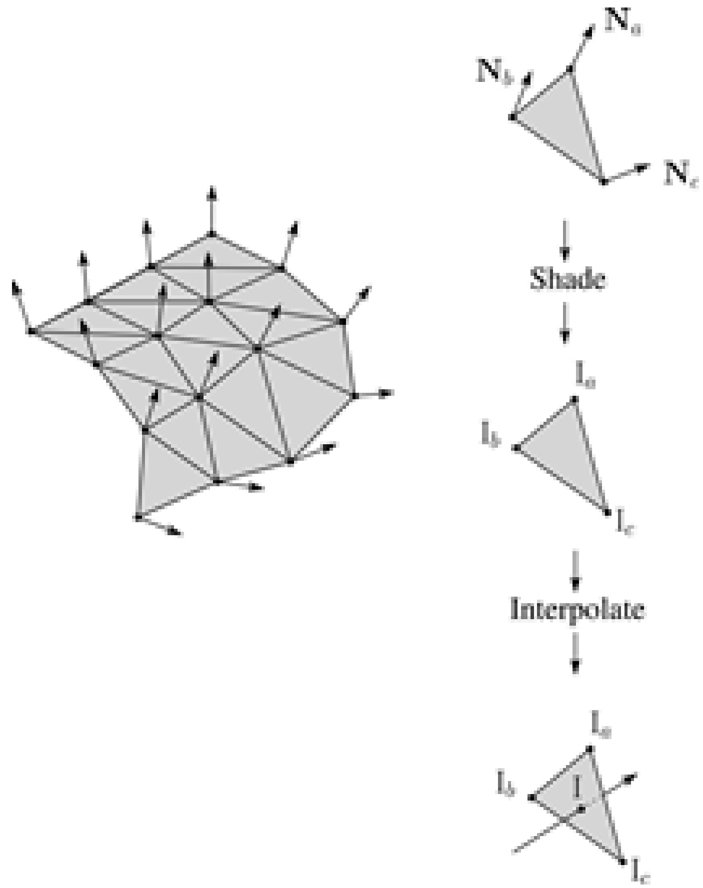
[Williams and Siegel 1990]

Gouraud interpolation

To get a smoother result that is easily performed in hardware, we can do **Gouraud interpolation**.

Here's how it works:

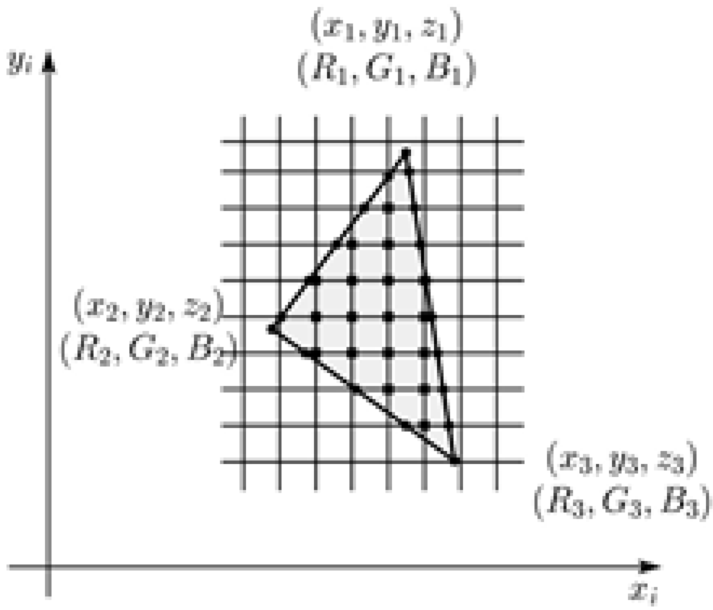
1. Compute normals at the vertices.
2. Shade only the vertices.
3. Interpolate the resulting vertex colors.



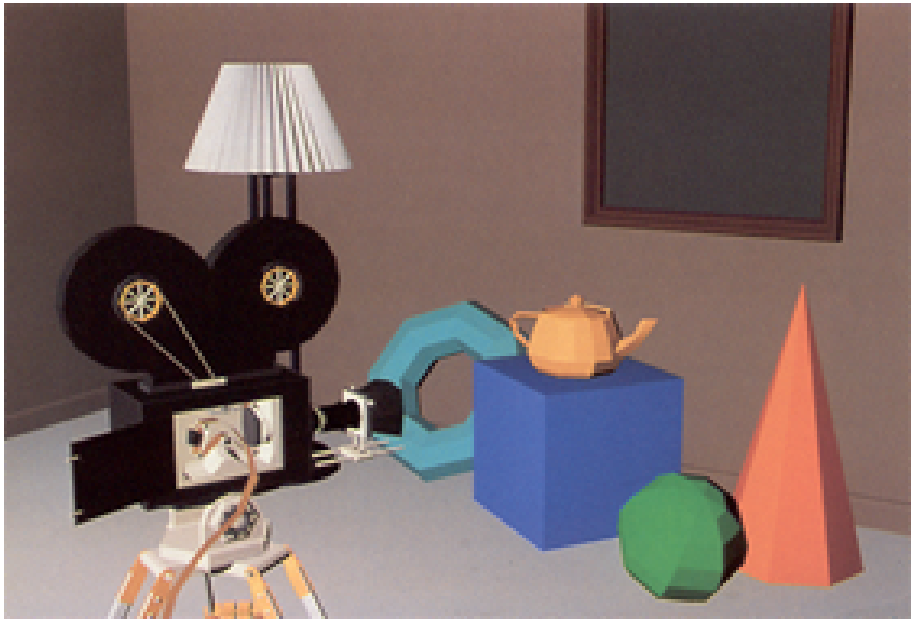
Rasterization with color

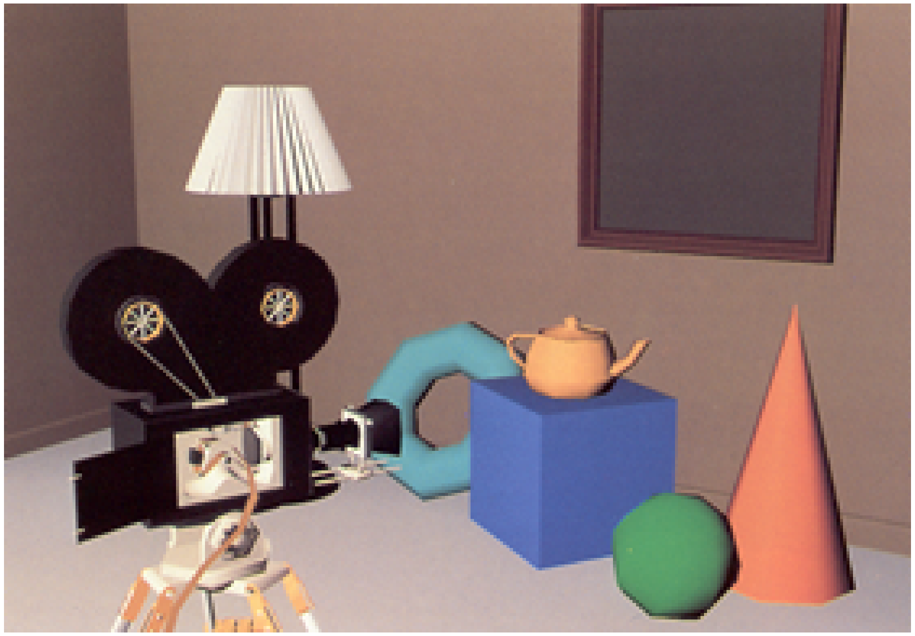
Recall that the z-buffer works by interpolating z-values across a triangle that has been projected into image space, a process called rasterization.

During rasterization, colors can be smeared across a triangle as well:



Facted shading vs. Gouraud interpolation



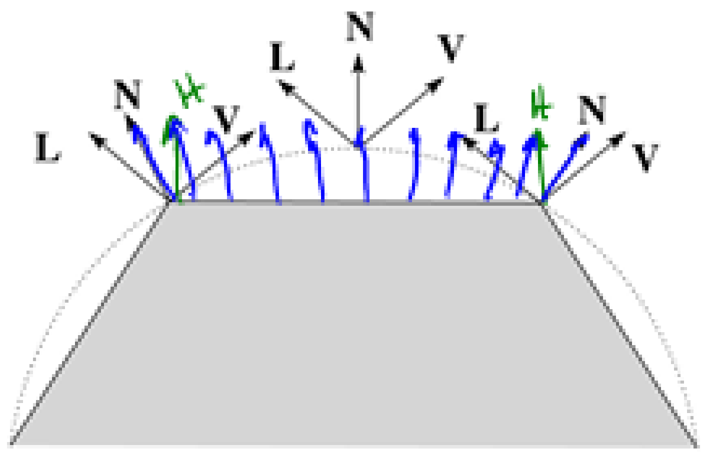


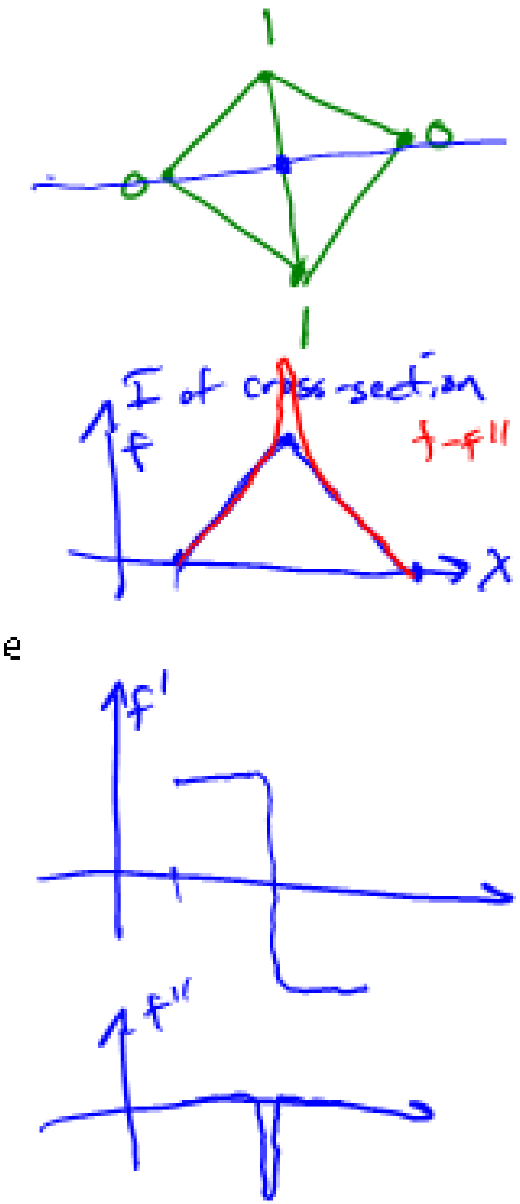
[Williams and Siegel 1990]

Gouraud interpolation artifacts

Gouraud interpolation has significant limitations.

1. If the polygonal approximation is too coarse, we can miss specular highlights.





2. We will encounter **Mach banding** (derivative discontinuity enhanced by human eye).

This is what graphics hardware does by default.

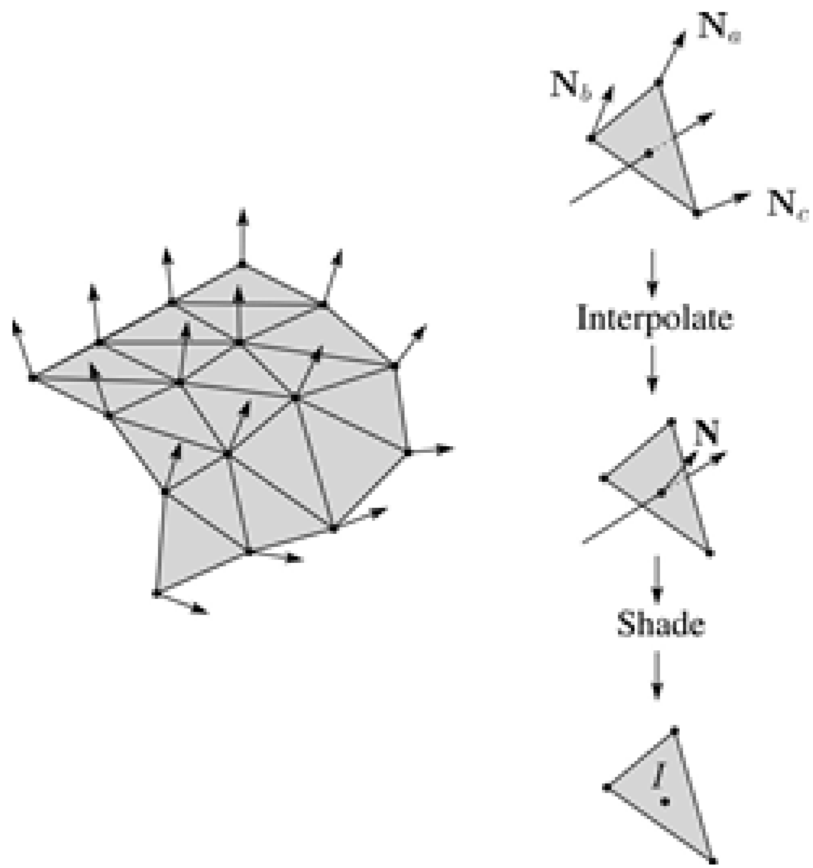
A substantial improvement is to do...

Phong interpolation

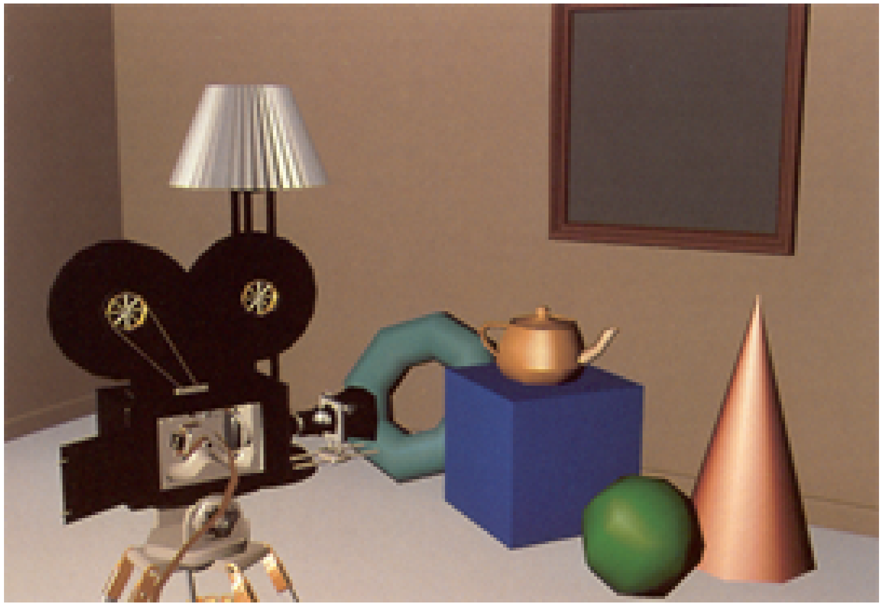
To get an even smoother result with fewer artifacts, we can perform **Phong *interpolation***.

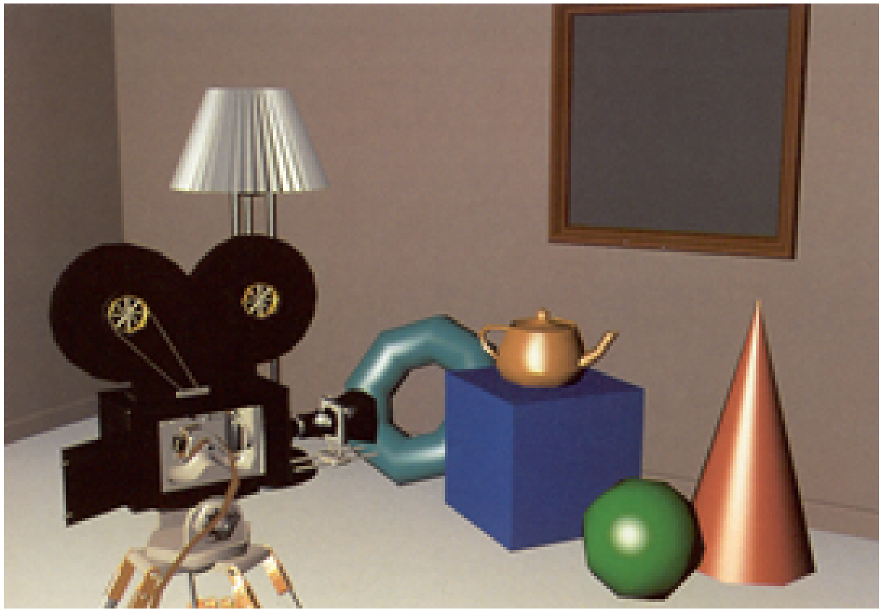
Here's how it works:

1. Compute normals at the vertices.
2. Interpolate normals and normalize.
3. Shade using the interpolated normals.



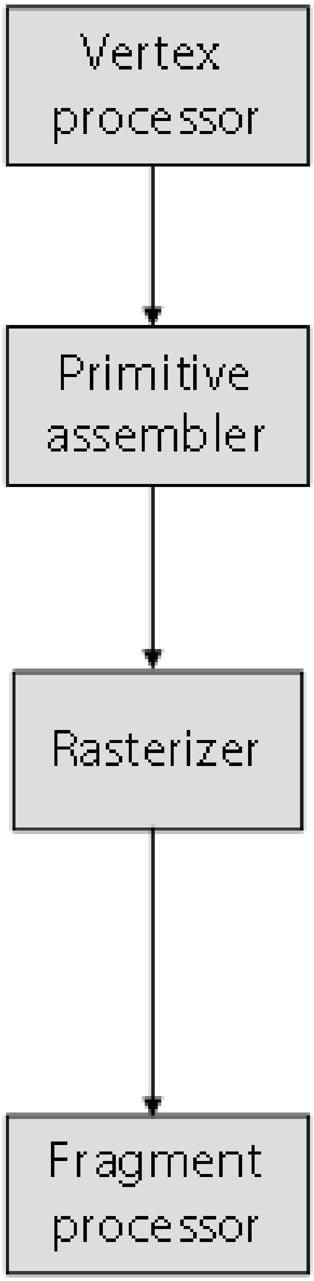
Gouraud vs. Phong interpolation





[Williams and Siegel 1990]

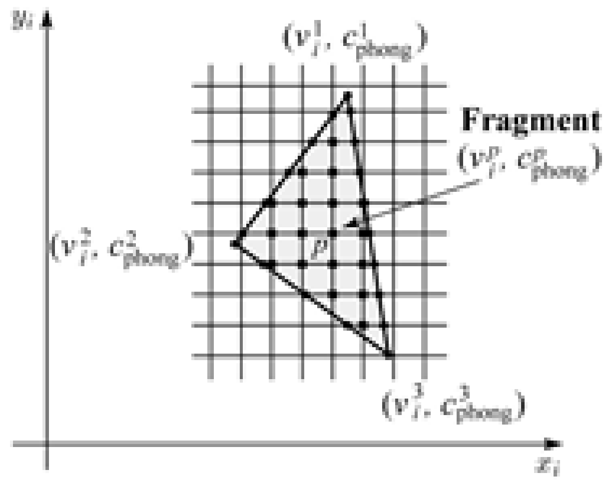
Default pipeline: Gouraud interpolation



Default vertex processing:

$L \leftarrow$ determine lighting direction
$V \leftarrow$ determine viewing direction
$N \leftarrow$ normalize(n_v)
$c_{phong} \leftarrow$ shade with L, V, N, k_d, k_s, n_s
attach c_{phong} to vertex as "varying"
$v_i \leftarrow$ project v to image

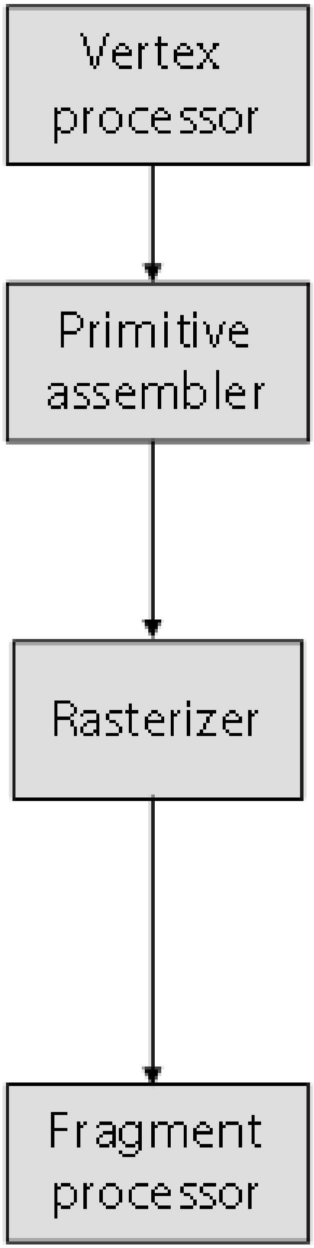
$v_i^1, v_i^2, v_i^3 \rightarrow$ triangle



Default fragment processing:

color $\leftarrow c_{phong}^p$

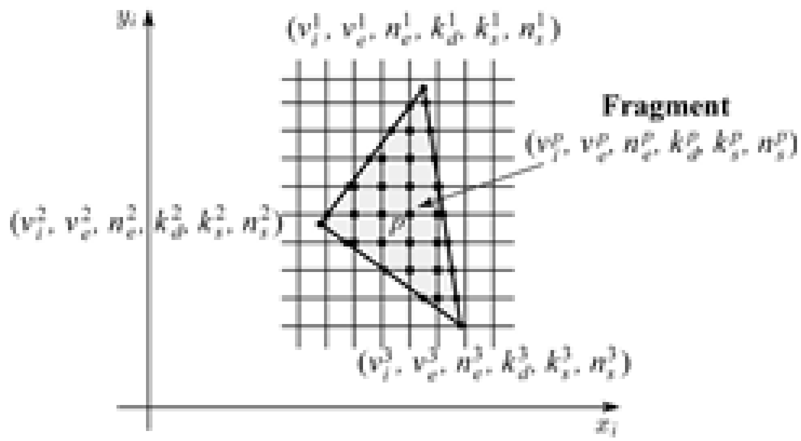
Programmable pipeline: Phong-interpolated normals!



Vertex shader:

attach n_e to vertex as "varying"
attach v_e to vertex as "varying"
$v_i \leftarrow$ project v to image

$v_i^1, v_i^2, v_i^3 \rightarrow$ triangle

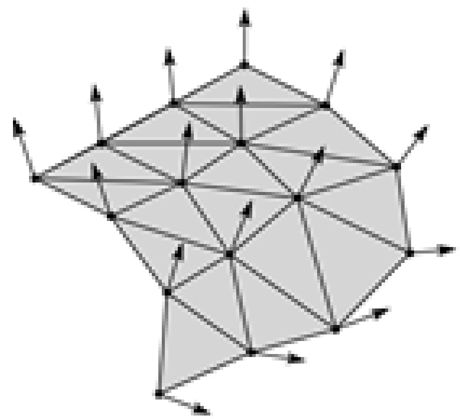


Fragment shader:

$L \leftarrow$ determine lighting direction
$V \leftarrow$ determine viewing direction
$N \leftarrow$ normalize(n_e^p)
color $\leftarrow$ shade with $L, V, N, k_d^p, k_s^p, n_s^p$

Surface normals

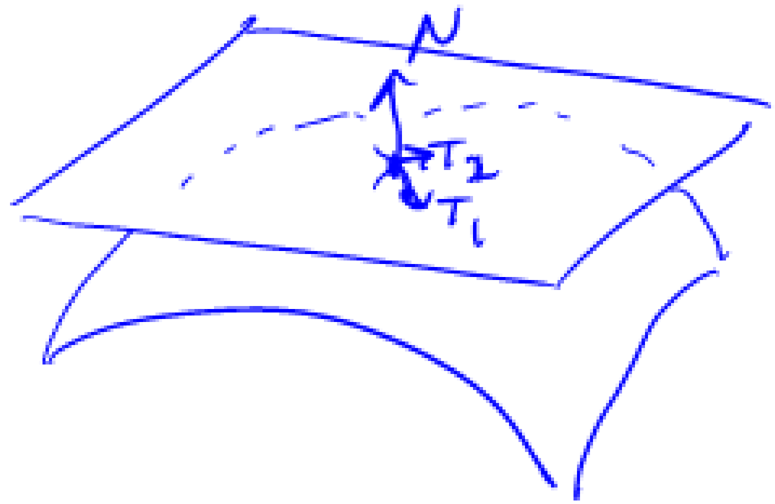
How can we compute the normal to a surface at a given point?



Tangent vectors and tangent planes

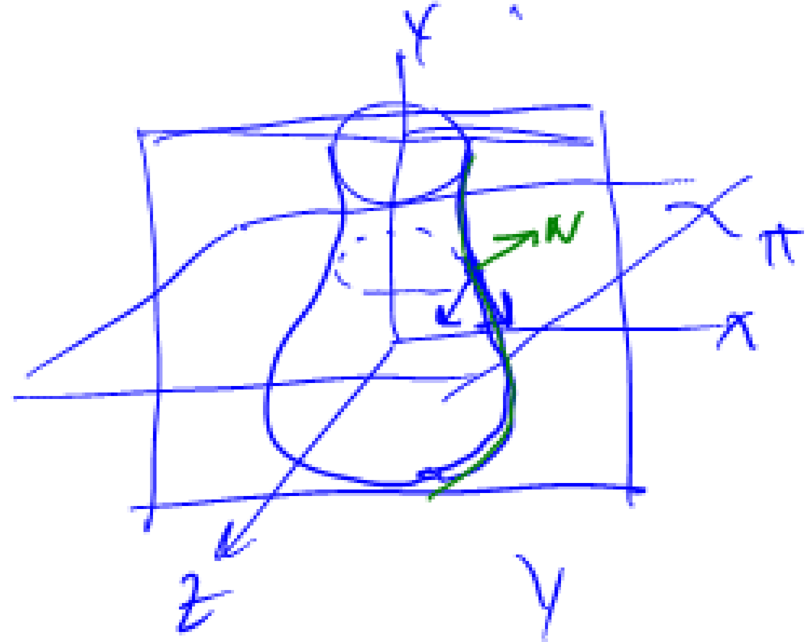
$$T \approx Q - P$$

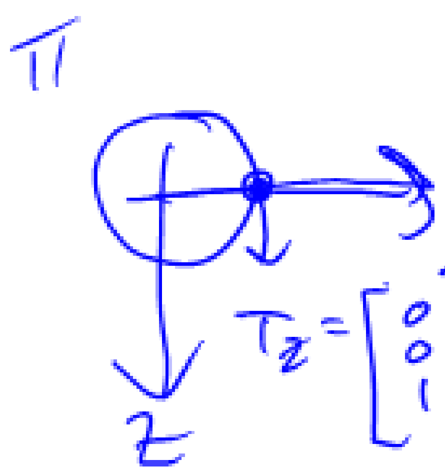
$$T \approx Q - R$$



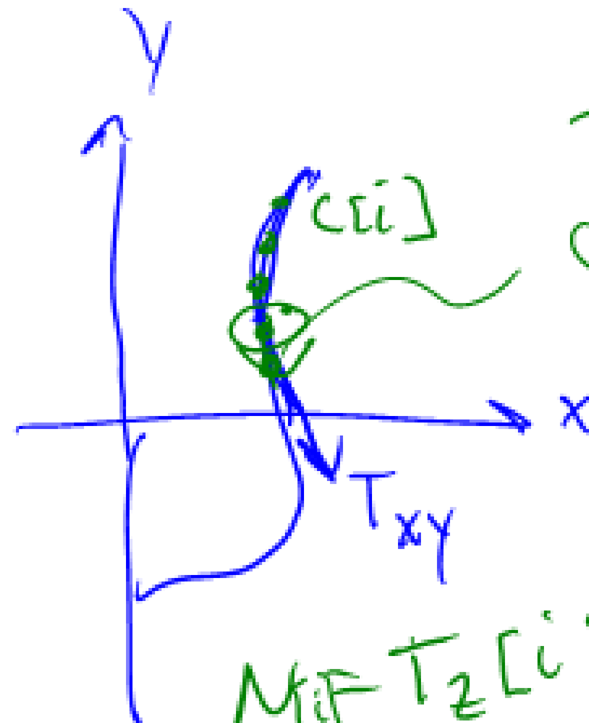
$$N \approx T_1 \times T_2$$

Normals on a surface of revolution





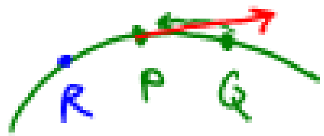
$T_z = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$



$T_{xy}[i] = C[i-1] - C[i]$

$N[i] = T_z[i] \times T_{xy}[i]$

This is normal to the surface for points in xy-plane. Can rotate to get others:
$N[i,j] = R_y(\theta_j)\, N[i]$



Finite diff.

$$T \approx Q - P$$

$$T = \lim_{Q \to P} \frac{Q - P}{\|Q - P\|}$$

Central difference

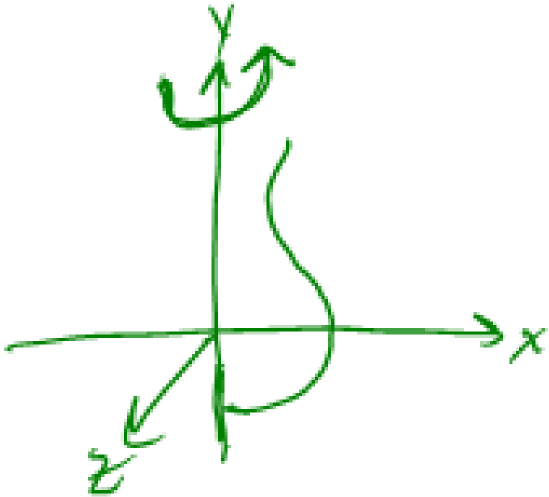
$$T \approx Q - R$$

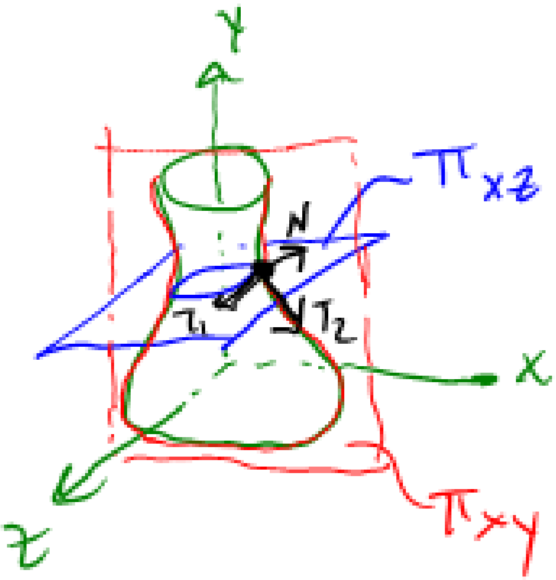
$$T = \lim_{Q, R \to P} \frac{Q - R}{\|Q - R\|}$$

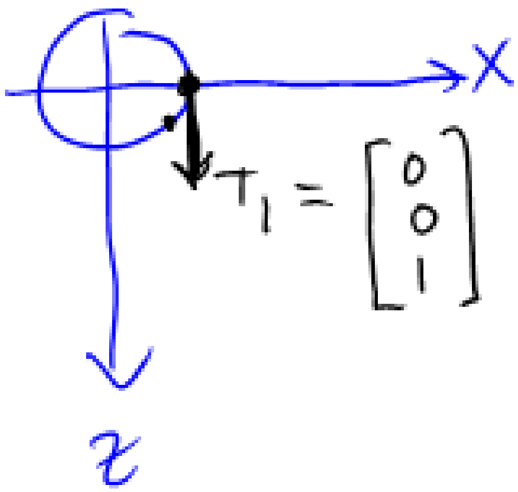
$$T_1 \approx Q_1 - P$$

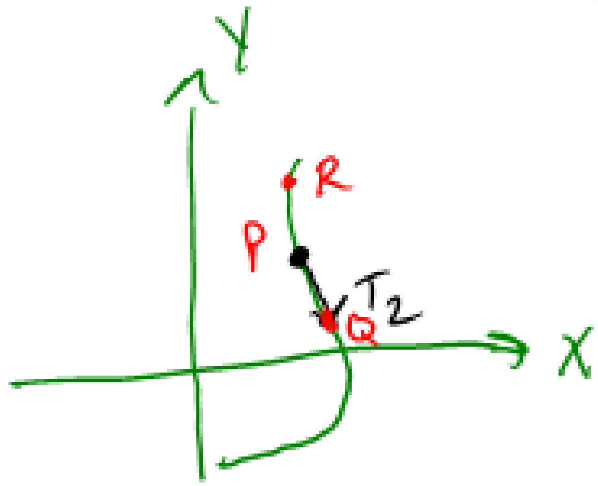
$$T_2 \approx Q_2 - P$$

$$N = \frac{T_2 \times T_1}{\|T_2 \times T_1\|}$$









Can rotate when creating points on surface of rev.

$$N = \frac{T_1 \times T_2}{\|T_1 \times T_2\|}$$

Summary

You should understand the equation for the Blinn-Phong lighting model described in the "Iteration Four" slide:

- What is the physical meaning of each variable?
- How are the terms computed?
- What effect does each term contribute to the image?
- What does varying the parameters do?

You should also understand the differences between faceted, Gouraud, and Phong *interpolated* shading.

And you should understand how to compute the normal to a surface of revolution.