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Scan Conversion & Shading

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Princeton University
C0S 426, Fall 2001

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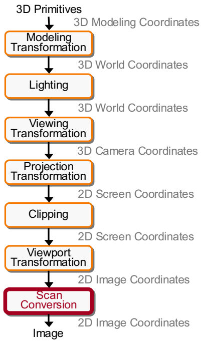
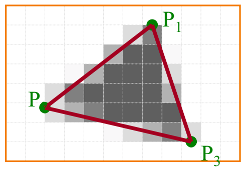
3D Rendering Pipeline (for direct illumination)





Scan Conversion & Shading

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Overview

- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel

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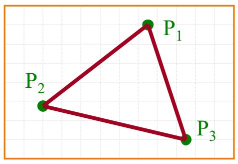
Scan Conversion

- Render an image of a geometric primitive by setting pixel colors

```
void SetPixel(int x, int y, Color rgba)
```

- Example: Filling the inside of a triangle



5

Scan Conversion

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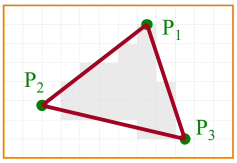
- Example: Filling the inside of a triangle



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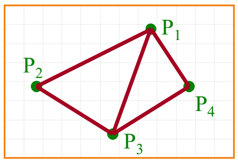
Triangle Scan Conversion

- Properties of a good algorithm
  - Symmetric
  - Straight edges
  - Antialiased edges
  - No cracks between adjacent primitives
  - MUST BE FAST!



Triangle Scan Conversion

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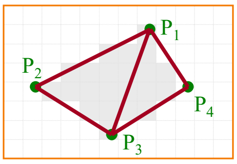
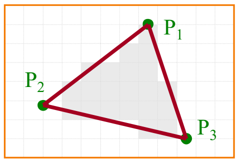


Simple Algorithm

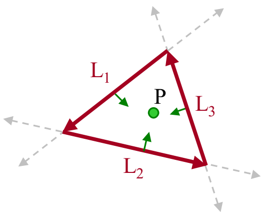
- Color all pixels inside triangle

```
void ScanTriangle(Triangle T, Color rgba){
   for each pixel P at (x,y){
      if (Inside(T, P))
         SetPixel(x, y, rgba);
   }
}
```



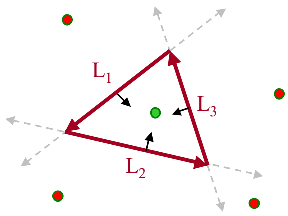
Inside Triangle Test

- A point is inside a triangle if it is in the positive halfspace of all three boundary lines
  - Triangle vertices are ordered counter-clockwise
  - Point must be on the left side of every boundary line



Inside Triangle Test

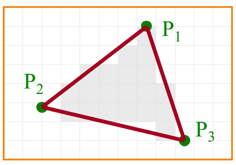
```
Boolean Inside(Triangle T, Point P)
{
   for each boundary line L of T {
      Scalar d = L.a*P.x + L.b*P.y + L.c;
      if (d < 0.0) return FALSE;
   }
   return TRUE;
}
```



Simple Algorithm

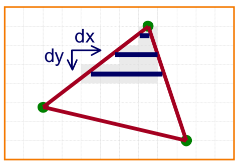
- What is bad about this algorithm?

```
void ScanTriangle(Triangle T, Color rgba){
   for each pixel P at (x,y){
      if (Inside(T, P))
         SetPixel(x, y, rgba);
   }
}
```



Triangle Sweep-Line Algorithm

- Take advantage of spatial coherence
  - Compute which pixels are inside using horizontal spans
  - Process horizontal spans in scan-line order
- Take advantage of edge linearity
  - Use edge slopes to update coordinates incrementally



Triangle Sweep-Line Algorithm

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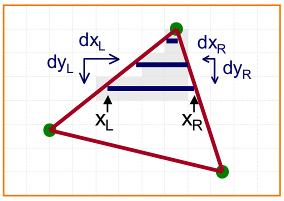
```
void ScanTriangle(Triangle T, Color rgba){
  for each edge pair {
    initialize xL, xR;
    compute dxL/dyL and dxR/dyR;
    for each scanline at y
      for (int x = xL; x <= xR; x++)
        SetPixel(x, y, rgba);
    xL += dxL/dyL;
    xR += dxR/dyR;
  }
}
```



Polygon Scan Conversion

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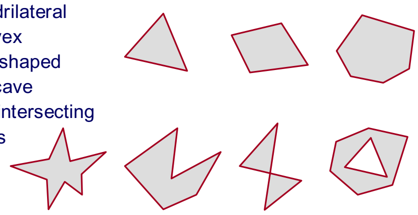
- Fill pixels inside a polygon
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes



What problems do we encounter with arbitrary polygons?

Polygon Scan Conversion

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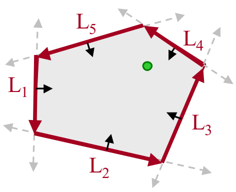
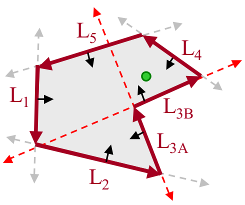
- Need better test for points inside polygon
  - Triangle method works only for convex polygons



Convex Polygon



Concave Polygon

Inside Polygon Rule

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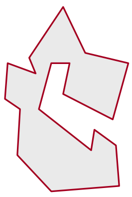
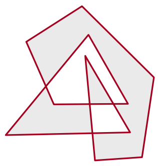
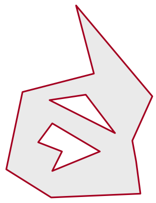
- What is a good rule for which pixels are inside?



Concave



Self-Intersecting



With Holes

Inside Polygon Rule

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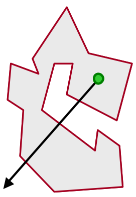
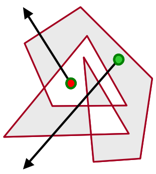
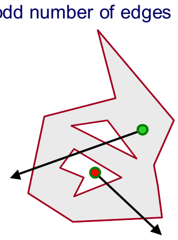
- Odd-parity rule
  - Any ray from P to infinity crosses odd number of edges



Concave



Self-Intersecting



With Holes

Polygon Sweep-Line Algorithm

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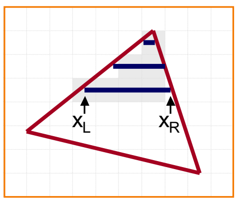
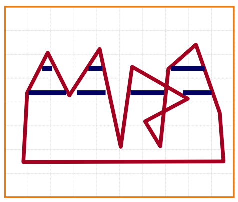
- Incremental algorithm to find spans, and determine insideness with odd parity rule
  - Takes advantage of scanline coherence



Triangle



Polygon

Polygon Sweep-Line Algorithm

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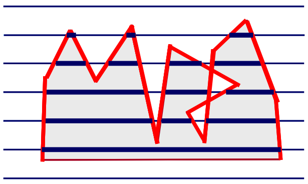
```
void ScanPolygon(Triangle T, Color rgba){
   sort edges by maxy
   make empty "active edge list"
   for each scanline (top-to-bottom) {
       insert/remove edges from "active edge list"
       update x coordinate of every active edge
       sort active edges by x coordinate
       for each pair of active edges (left-to-right)
           SetPixels(xi, xi+1, y, rgba);
       }
}
```



Hardware Scan Conversion

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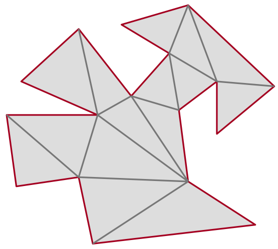
- Convert everything into triangles
  - Scan convert the triangles



Hardware Antialiasing

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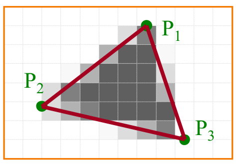
- Supersample pixels
  - Multiple samples per pixel
  - Average subpixel intensities (box filter)
  - Trades intensity resolution for spatial resolution



Overview

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- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel

Shading

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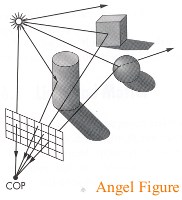
- How do we choose a color for each filled pixel?
  - Each illumination calculation for a ray from the eyepoint through the view plane provides a radiance sample
    - » How do we choose where to place samples?
    - » How do we filter samples to reconstruct image?

Emphasis on methods that can be implemented in hardware



Angel Figure 6.34

Ray Casting

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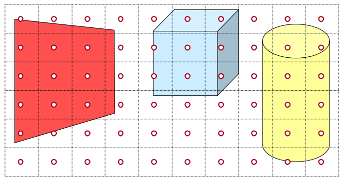
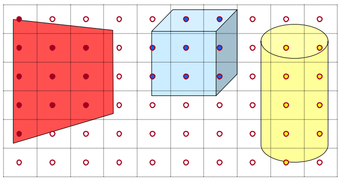
- Simplest shading approach is to perform independent lighting calculation for every pixel
  - When is this unnecessary?



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Polygon Shading

- Can take advantage of spatial coherence
  - o Illumination calculations for pixels covered by same primitive are related to each other



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Polygon Shading Algorithms

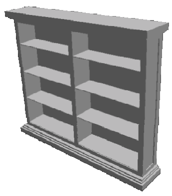
- Flat Shading
- Gouraud Shading
- Phong Shading

Polygon Shading Algorithms

- **Flat Shading**
- Gouraud Shading
- Phong Shading

Flat Shading

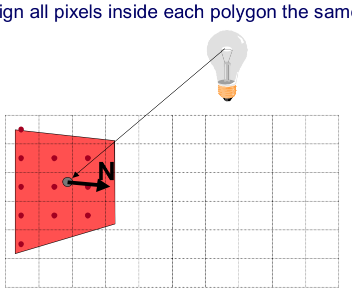
- What if a faceted object is illuminated only by directional light sources and is either diffuse or viewed from infinitely far away



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

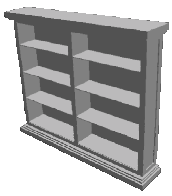
Flat Shading

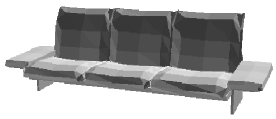
- One illumination calculation per polygon
  - o Assign all pixels inside each polygon the same color



Flat Shading

- Objects look like they are composed of polygons
  - o OK for polyhedral objects
  - o Not so good for ones with smooth surfaces





Polygon Shading Algorithms
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- Flat Shading
- **Gouraud Shading**
- Phong Shading

Gouraud Shading
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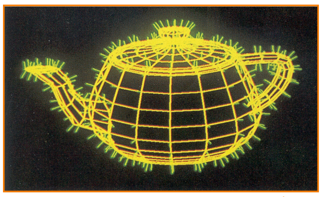
- What if smooth surface is represented by polygonal mesh with a normal at each vertex?



Watt Plate 7

$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

Gouraud Shading
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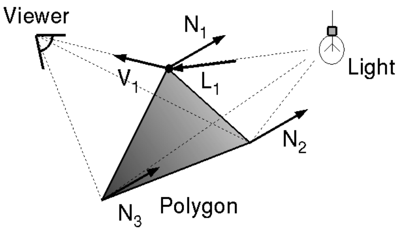
- Method 1: One lighting calculation per vertex
  - o Assign pixels inside polygon by interpolating colors computed at vertices



Gouraud Shading
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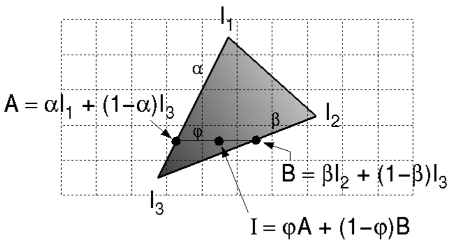
- Bilinearly interpolate colors at vertices down and across scan lines



Gouraud Shading
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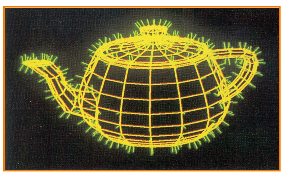
- Smooth shading over adjacent polygons
  - o Curved surfaces
  - o Illumination highlights
  - o Soft shadows



Mesh with shared normals at vertices

Watt Plate 7

Gouraud Shading
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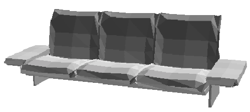
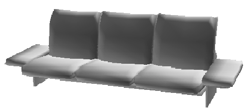
- Produces smoothly shaded polygonal mesh
  - o Piecewise linear approximation
  - o Need fine mesh to capture subtle lighting effects



Flat Shading



Gouraud Shading

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Polygon Shading Algorithms

- Flat Shading
- Gouraud Shading
- **Phong Shading**

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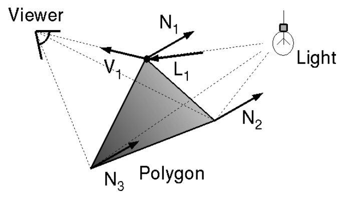
Phong Shading

- What if polygonal mesh is too coarse to capture illumination effects in polygon interiors?



$$I = I_E + K_A I_{AL} + \sum_i (K_D (N \bullet L_i) I_i + K_S (V \bullet R_i)^n I_i)$$

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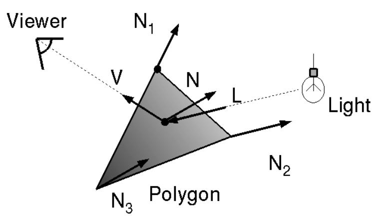
Phong Shading

- Method 2: One lighting calculation per pixel
  - o Approximate surface normals for points inside polygons by bilinear interpolation of normals from vertices



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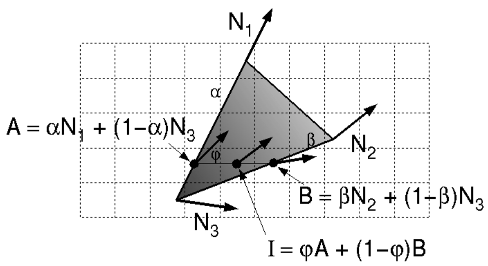
Phong Shading

- Bilinearly interpolate surface normals at vertices down and across scan lines



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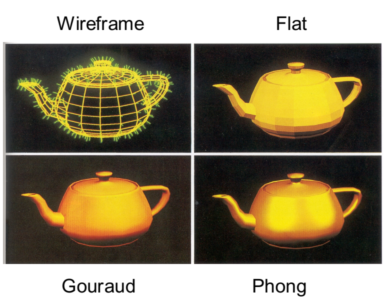
Polygon Shading Algorithms



Watt Plate 7

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Shading Issues

- Problems with interpolated shading:
  - o Polygonal silhouettes
  - o Perspective distortion
  - o Orientation dependence (due to bilinear interpolation)
  - o Problems at T-vertices
  - o Problems computing shared vertex normals

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Summary

- 2D polygon scan conversion
  - Paint pixels inside primitive
  - Sweep-line algorithm for polygons
- Polygon Shading Algorithms
  - Flat
  - Gouraud
  - Phong
  - Ray casting

  Less expensive

  More accurate
- Key ideas:
  - Sampling and reconstruction
  - Spatial coherence