Scan Conversion & Shading

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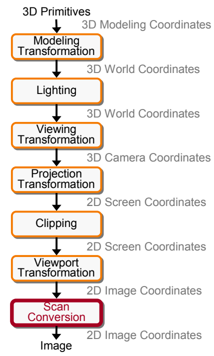
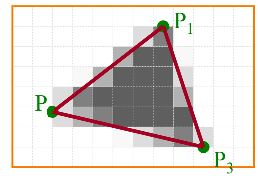
3D Rendering Pipeline (for direct illumination)





Scan Conversion & Shading

Overview

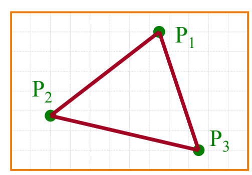
- Scan conversion
  - Figure out which pixels to fill
- Shading
  - Determine a color for each filled pixel

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



Scan Conversion

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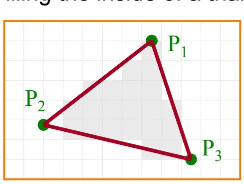
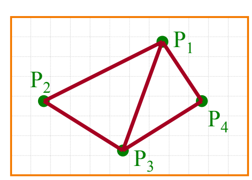
- Example: Filling the inside of a triangle



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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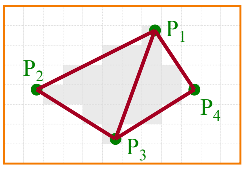
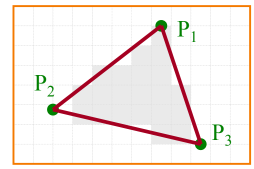


Simple Algorithm

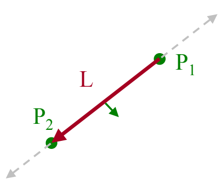
- Color all pixels inside triangle

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



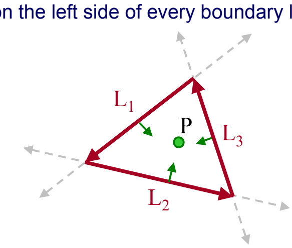
Line defines two halfspaces

- Implicit equation for a line
  - On line: $ax + by + c = 0$
  - On right: $ax + by + c < 0$
  - On left: $ax + by + c > 0$



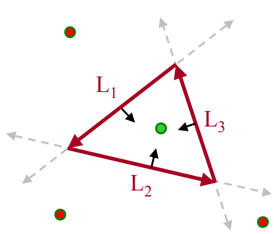
Inside Triangle Test

- 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

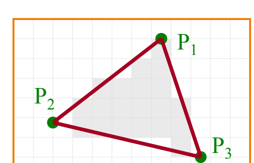
```
Boolean Inside(Triangle T, Point P)
{
  for each boundary line L of T {
     Scalar d = L.a*P.x + L.b*P.y + L.c;
     if (d < 0.0) return FALSE;
  }
  return TRUE;
}
```



Simple Algorithm

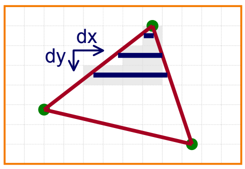
- What is bad about this algorithm?

```
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

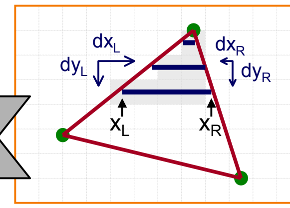
- Take advantage of spatial coherence
  - Compute which pixels are inside using horizontal spans
  - Process horizontal spans in scan-line order
- Take advantage of edge linearity
  - Use edge slopes to update coordinates incrementally



Triangle Sweep-Line Algorithm

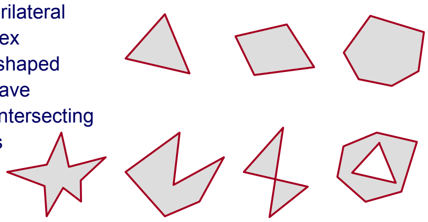
```
void ScanTriangle(Triangle T, Color rgba){
  for each edge pair {
     initialize x_L, x_R;
     compute dx_L/dy_L and dx_R/dy_R;
     for each scanline at y
        for (int x = x_L; x <= x_R; x++)
           SetPixel(x, y, rgba);
     x_L += dx_L/dy_L;
     x_R += dx_R/dy_R;
  }
}
```

Bresenham's algorithm works the same way, but uses only integer operations!



Polygon Scan Conversion

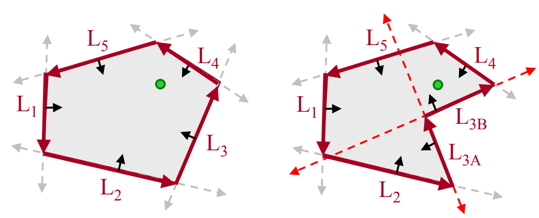
- Fill pixels inside a polygon
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes



What problems do we encounter with arbitrary polygons?

Polygon Scan Conversion

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

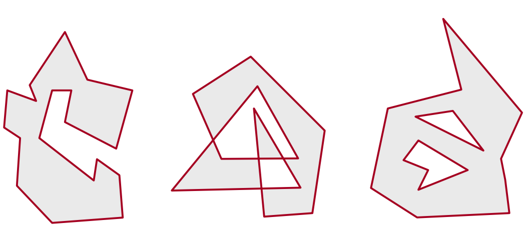


Convex Polygon

Concave Polygon

Inside Polygon Rule

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



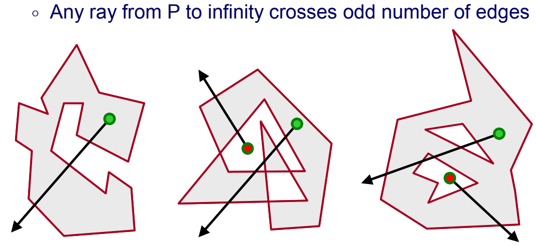
Concave

Self-Intersecting

With Holes

Inside Polygon Rule

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



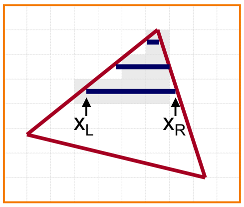
Concave

Self-Intersecting

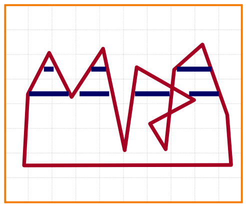
With Holes

Polygon Sweep-Line Algorithm

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



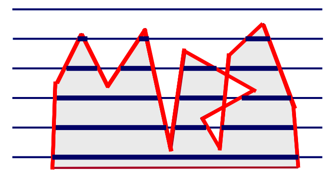
Triangle



Polygon

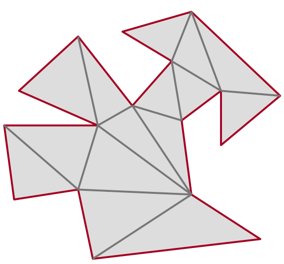
Polygon Sweep-Line Algorithm

```
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(x_i, x_i+1, y, rgba);
     }
}
```



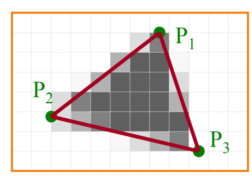
Hardware Scan Conversion

- Convert everything into triangles
  - Scan convert the triangles



Hardware Antialiasing

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



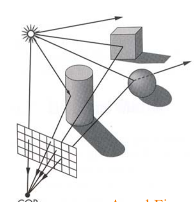
Overview

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

Shading

- 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?

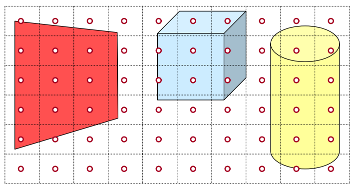
Emphasis on methods that can be implemented in hardware



Angel Figure 6.34

Ray Casting

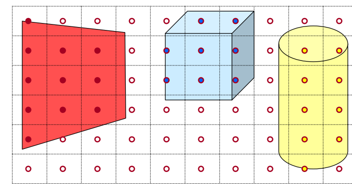
- Simplest shading approach is to perform independent lighting calculation for every pixel
  - When is this unnecessary?



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

Polygon Shading

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



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Polygon Shading Algorithms

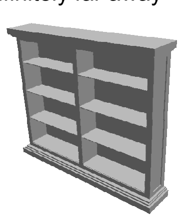
- Flat Shading
- Gouraud Shading
- Phong Shading

Polygon Shading Algorithms

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

Flat Shading

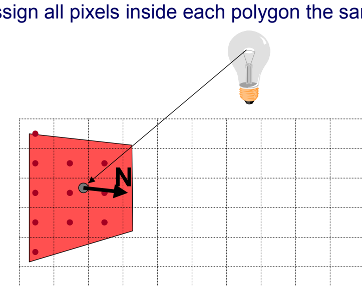
- What if a faceted object is illuminated only by directional light sources and is either diffuse or viewed from infinitely far away



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

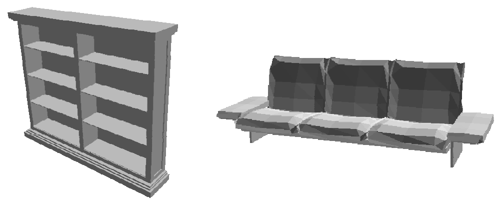
Flat Shading

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



Flat Shading

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

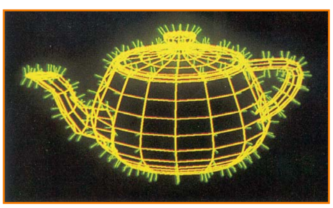


Polygon Shading Algorithms

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

Gouraud Shading

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

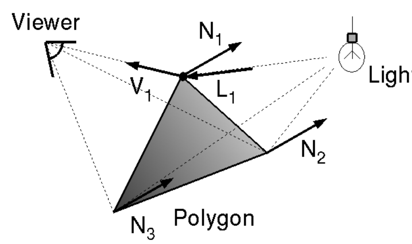


Watt Plate 7

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

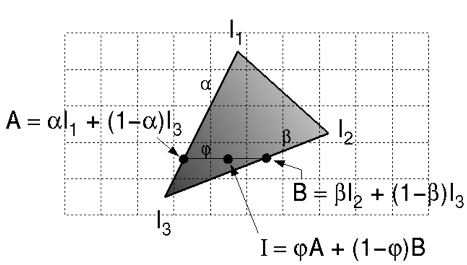
Gouraud Shading

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



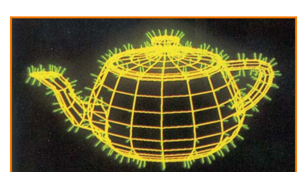
Gouraud Shading

- Bilinearly interpolate colors at vertices down and across scan lines



Gouraud Shading

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

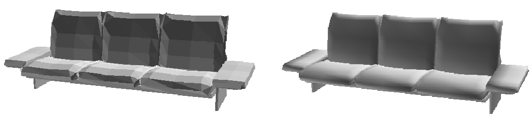


Mesh with shared normals at vertices

Watt Plate 7

Gouraud Shading

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



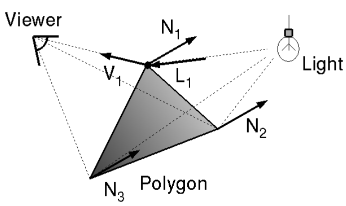
Flat Shading   Gouraud Shading

Polygon Shading Algorithms

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

Phong Shading

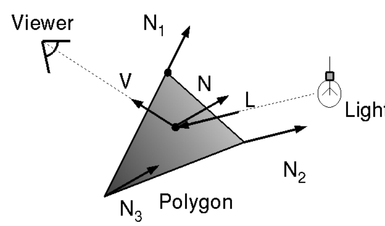
- What if polygonal mesh is too coarse to capture illumination effects in polygon interiors?



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

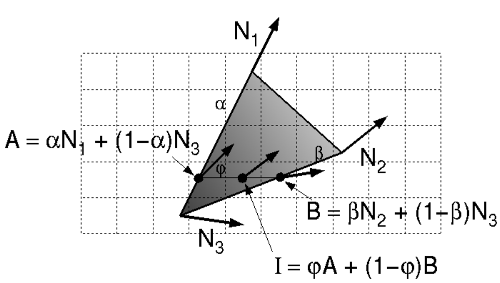
Phong Shading

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



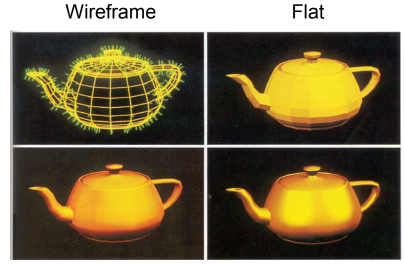
Phong Shading

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



Polygon Shading Algorithms

Wireframe   Flat

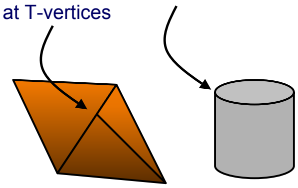


Gouraud   Phong

Watt Plate 7

Shading Issues

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



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