Lecture Set 4

Scan Conversion

CS5600 *Computer Graphics*

Spring 2013

Review

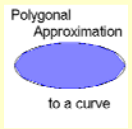
- Line rasterization
  - Basic Incremental Algorithm
  - Digital Differential Analyzer
    - Rather than solve line equation at each pixel, use evaluation of line from previous pixel and slope to approximate line equation
  - Bresenham
    - Use integer arithmetic and midpoint discriminator to test between two possible pixels (over vs. over-and-up)

Rasterizing Polygons

- In interactive graphics, polygons rule the world
- Two main reasons:
  - Lowest common denominator for surfaces
    - Can represent any surface *with arbitrary accuracy*
    - Splines, mathematical functions, volumetric isosurfaces…
  - Mathematical simplicity lends itself to simple, regular rendering algorithms
    - Like those we're about to discuss…
    - Such algorithms embed well in hardware

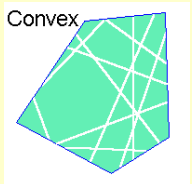
Rasterizing Polygons

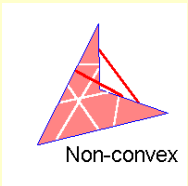
- Triangle is the *minimal unit* of a polygon
  - All polygons can be broken up into triangles
    - Convex, concave, complex
  - Triangles are guaranteed to be:
    - Planar
    - Convex
  - *What exactly does it mean to be convex?*



Convex Shapes

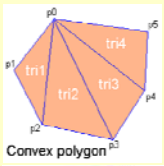
- A two-dimensional shape is *convex* if and only if every line segment connecting two points on the boundary is entirely contained.



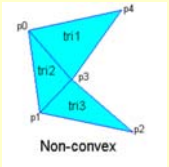


Triangularization

- Convex polygons easily triangulated



- Concave polygons present a challenge



Rasterizing Triangles

- Interactive graphics hardware sometimes uses *edge walking* or *edge equation* techniques for rasterizing triangles
- Interactive graphics hardware more commonly uses barycentric coordinates for rasterizing triangles

Scan Conversion

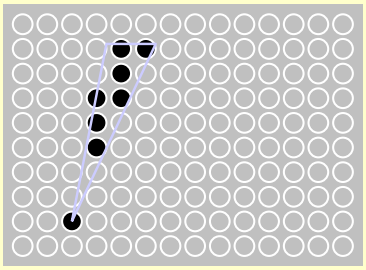
- In scanline rendering surfaces are projected on the screen and space filling 'rasterizing' algorithms are used to fill in the color.
- Color values from light are approximated.

Triangle Rasterization Issues

- *Exactly which pixels should be lit?*
- A: Those pixels inside the triangle edges
- *What about pixels exactly on the edge?*
  - Draw them: order of triangles matters (it shouldn't)
  - Don't draw them: gaps possible between triangles
- We need a consistent (if arbitrary) rule
  - Example: draw pixels on left and bottom edge, but not on right or top edge

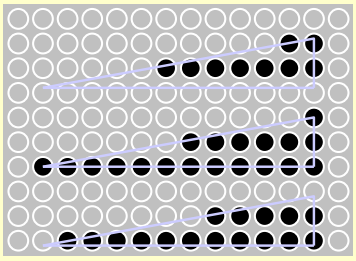
Triangle Rasterization Issues

- Sliver



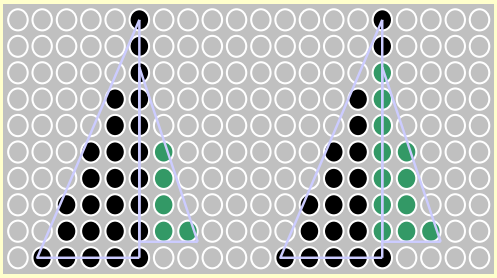
Triangle Rasterization Issues

- Moving Slivers



Triangle Rasterization Issues

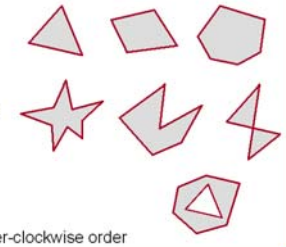
- Shared Edge Ordering



2D Polygon

- Area "inside" a sequence of points
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes

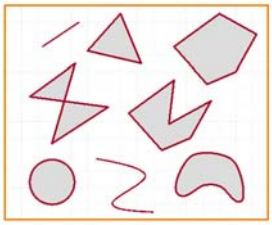
```
typedef struct {
    Point *points;
    int npoints;
} Polygon;
```



Points are in counter-clockwise order

2D Rendering

- Create an image from a set of 2D geometric primitives

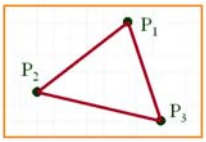


Scan Conversion

- 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



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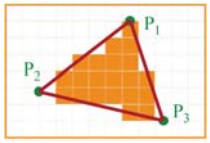
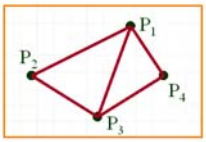


Triangle Scan Conversion

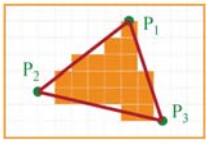
- Properties of a good algorithm
  - Symmetric
  - Straight edges
  - Antialiased edges
  - No cracks between adjacent primitives
  - MUST BE FAST!



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);
  }
}
```

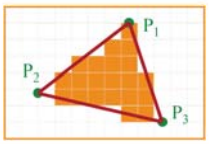


Simple Algorithm

- 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);
   }
}
```

How do we know if it's 'inside'?

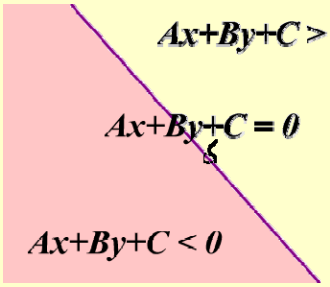


Edge Equations

- An edge equation is simply the equation of the line defining that edge
  - Q: *What is the implicit equation of a line?*
  - A: $Ax + By + C = 0$
  - Q: *Given a point (x,y), what does plugging x & y into this equation tell us?*
  - A: Whether the point is:
    - On the line: $Ax + By + C = 0$
    - "Above" the line: $Ax + By + C > 0$
    - "Below" the line: $Ax + By + C < 0$

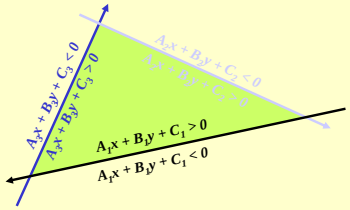
Edge Equations

- Edge equations thus define two *half-spaces*:



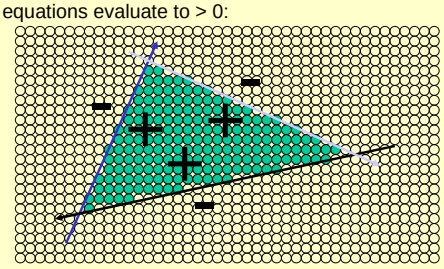
Edge Equations

- And a triangle can be defined as the intersection of three positive half-spaces:



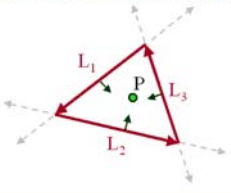
Edge Equations

- So…simply turn on those pixels for which all edge equations evaluate to > 0:



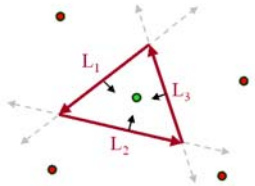
Inside Triangle Test

- 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

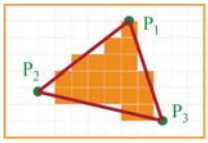
```
Boolean Inside(Triangle T, Point P)
{
   for each boundary line L of T {
      Scalar d = L.a*P.x + L.b*P.y + L.c;
      if (d < 0.0) return FALSE;
   }
   return TRUE;
}
```



Simple Algorithm

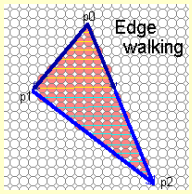
- What is bad about this algorithm?

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



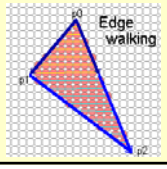
Sweep-line

- Basic idea:
  - Draw edges vertically
    - Interpolate colors up/down edges
  - Fill in horizontal **spans** for each scanline
    - At each scanline, interpolate edge colors across span



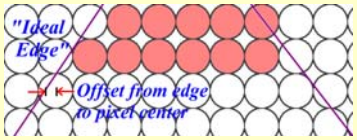
Sweep-line: Notes

- Order three triangle vertices in x and y
  - Find middle point in y dimension and compute if it is to the left or right of polygon. Also could be flat top or flat bottom triangle
- We know where left and right edges are.
  - Proceed from top scanline downwards (and other way too)
  - Fill each span
  - Until bottom/top vertex is reached
- Advantage: can be made very fast
- Disadvantages:
  - Lots of finicky special cases



Sweep line: Disadvantages

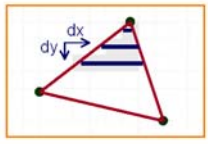
- Fractional offsets:



- Be careful when interpolating color values!
- Beware of gaps between adjacent edges
- Beware of duplicating shared edges

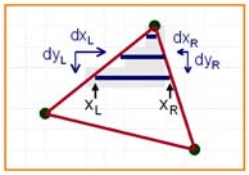
Triangle Sweep-Line Algorithm

- 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



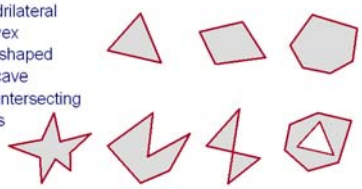
Triangle Sweep-Line Algorithm

```
void ScanTriangle(Triangle T, Color rgba){
  for each edge pair {
     initialize 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

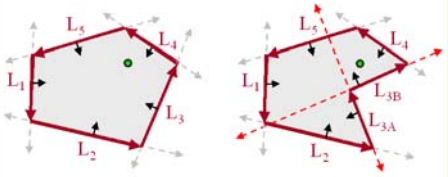
- Fill pixels inside a polygon
  - Triangle
  - Quadrilateral
  - Convex
  - Star-shaped
  - Concave
  - Self-intersecting
  - Holes



What problems do we encounter with arbitrary polygons?

Polygon Scan Conversion

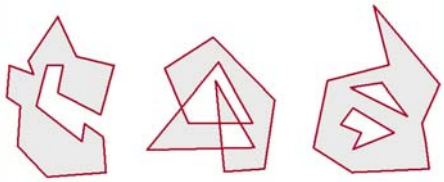
- Need better test for points inside polygon
  - Triangle method works only for convex polygons



Convex Polygon Concave Polygon

Inside Polygon Rule

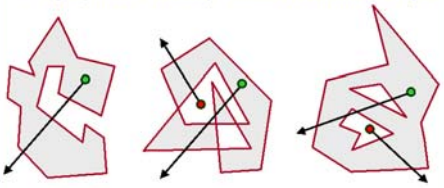
- What is a good rule for which pixels are inside?



Concave Self-Intersecting With Holes

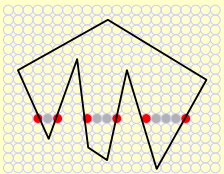
Inside Polygon Rule

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



Concave Self-Intersecting With Holes

Polygon Scan Conversion

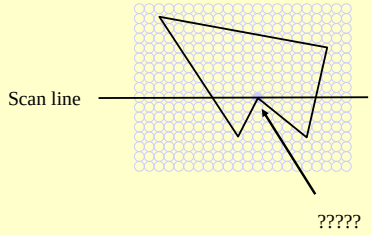


- Intersection Points
- Other points in the span

Determining Inside vs. Outside

- Use the odd-parity rule
  - Set parity even initially
  - Invert parity at each intersection point
  - Draw pixels when parity is odd, do not draw when it is even
- How do we count vertices, i.e., do we invert parity when a vertex falls exactly on a scan line?

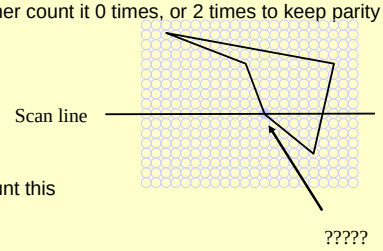
Vertices and Parity



- How do we count the intersecting vertex in the parity computation?

Vertices and Parity

- We need to either count it 0 times, or 2 times to keep parity correct.
- What about:

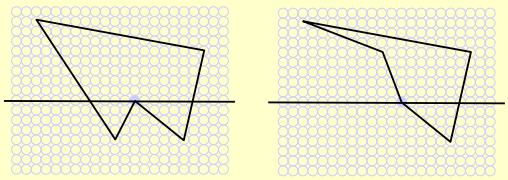


- We need to count this vertex once

Vertices and Parity

- If we count a vertex as one intersection, the second polygon gets drawn correctly, but the first does not.
- If we count a vertex as zero or two intersections, the first polygon gets drawn correctly, but the second does not.
- How do we handle this?
  - Count only vertices that are the y_{min} vertex for that line

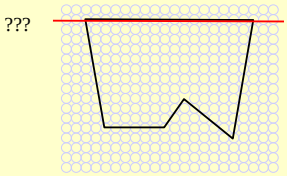
Vertices and Parity



- Both cases now work correctly

Horizontal Edges

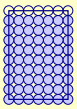
- How do we deal with horizontal edges?



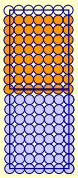
Don't count their vertices in the parity calculation!

Top Spans of Polygons

- Effect of only counting y_{min} :
  - Top spans of polygons are not drawn



  - If two polygons share this edge, it is not a problem.

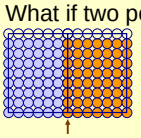


  - What about if this is the only polygon with that edge?

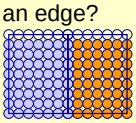
Shared Polygon Edges

Draw → Last polygon wins

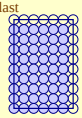
- What if two polygons share an edge?



Orange last



Blue last

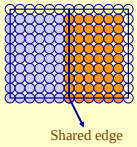


- Solution:
  - Span is closed on left and open on right ($x_{min} \le x < x_{max}$)
  - Scan lines closed on bottom and open on top ($y_{min} \le y < y_{max}$)

General Pixel Ownership Rule

- Half-plane rule:

  A boundary pixel (whose center falls exactly on an edge) is not considered part of a primitive if the half plane formed by the edge and containing the primitive lies to the left or below the edge.



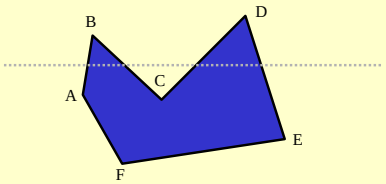
Shared edge

Applies to arbitrary polygons as well as to rectangles....

- Consequences:
  - Spans are missing the right-most pixel
  - Each polygon is missing its top-most span

General Polygon Rasterization

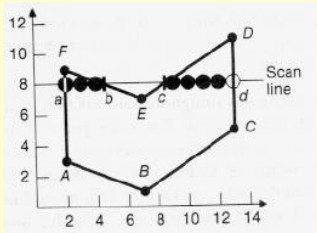
- Consider the following polygon:



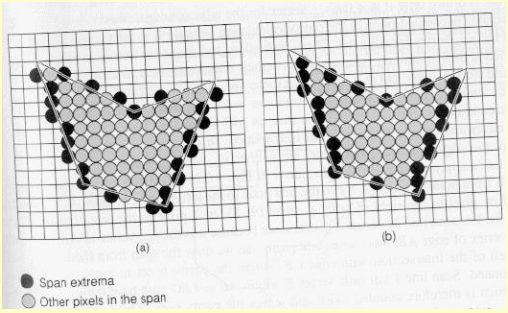
- How do we know whether a given pixel on the scanline is inside or outside the polygon?

Polygon Rasterization

- Inside-Outside Points



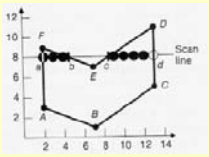
Polygon Rasterization



General Polygon Rasterization

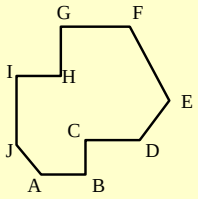
- Basic idea: use a *parity test*

```
for each scanline
    edgeCnt = 0;
    for each pixel on scanline (l to r)
        if (oldpixel->newpixel crosses edge)
            edgeCnt ++;
        // draw the pixel if edgeCnt odd
        if (edgeCnt % 2)
            setPixel(pixel);
```



General Polygon Rasterization

- Count your vertices carefully



Faster Polygon Rasterization

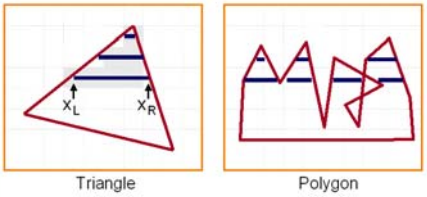
- *How can we optimize the code?*

```
for each scanline
    edgeCnt = 0;
    for each pixel on scanline (l to r)
        if (oldpixel->newpixel crosses edge)
            edgeCnt ++;
        // draw the pixel if edgeCnt odd
        if (edgeCnt % 2)
            setPixel(pixel);
```

- Big cost: testing pixels against each edge
- Solution: *active edge table (AET)*

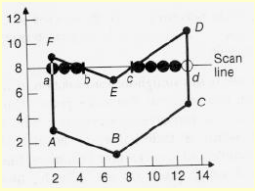
Polygon Sweep-Line Algorithm

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



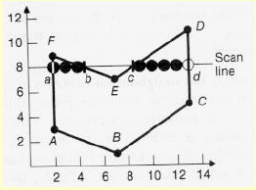
Active Edge Table

- Idea:
  - Edges intersecting a given scanline are likely to intersect the next scanline
  - The order of edge intersections doesn't change much from scanline to scanline



Active Edge Table

Preprocess: Sort on Y

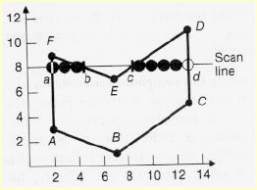


Edge Table

Y_{max},$x_{at\ y\ min}$,slope

Active Edge Table

Preprocess: Sort on Y

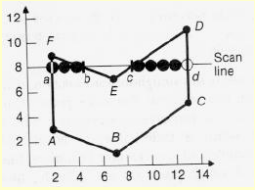


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:			

Active Edge Table

Preprocess: Sort on Y

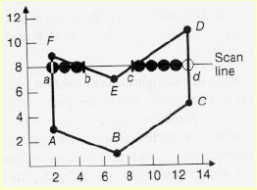


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:			

Active Edge Table

Preprocess: Sort on Y

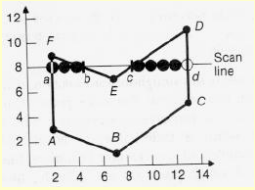


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:			

Active Edge Table

Preprocess: Sort on Y

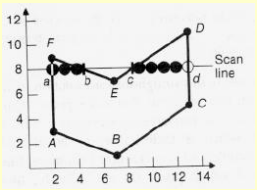


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:	11	13	0
DE:			

Active Edge Table

Preprocess: Sort on Y

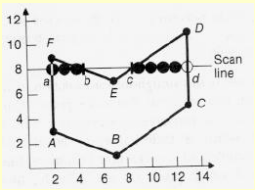


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:	11	13	0
DE:	11	7	6/4
EF:			

Active Edge Table

Preprocess: Sort on Y

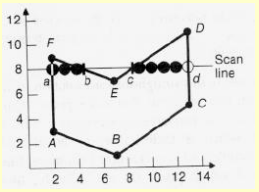


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:	11	13	0
DE:	11	7	6/4
EF:	9	7	-5/2
FA:			

Active Edge Table

Preprocess: Sort on Y

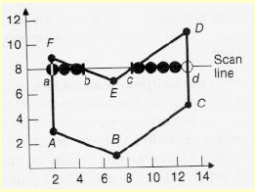


Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:	11	13	0
DE:	11	7	6/4
EF:	9	7	-5/2
FA:	9	2	0

Active Edge Table

Preprocess: Sort on Y



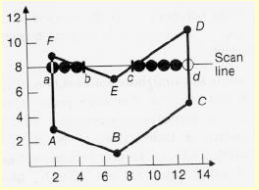
Edge Table

	Y_{max}	$x_{at\ y\ min}$	slope
AB:	3	7	-5/2
CB:	5	7	6/4
CD:	11	13	0
DE:	11	7	6/4
EF:	9	7	-5/2
FA:	9	2	0

What about Y_{min}?

Active Edge Table

Preprocess: Sort on Y



Edge Table

Y_{max}, x_{min}, slope

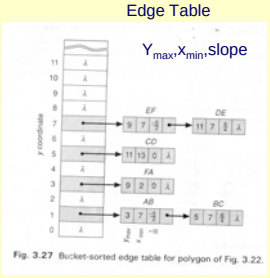


Fig. 3.27 Bucket-sorted edge table for polygon of Fig. 3.22.

Active Edge Table

- Algorithm: scanline from bottom to top…
  - Sort all edges by their minimum y coord (last slide)
  - Starting at smallest Y coord with in entry in edge table
  - For each scanline:
    - Add edges with Y_{min} = Y (move edges in edge table to AET)
    - Retire edges with Y_{max} < Y (completed edges)
    - Sort edges in AET by x intersection
    - Walk from left to right, setting pixels by parity rule
    - Increment scanline
    - Recalculate edge intersections (*how?*)
  - Stop when Y > Y_{max} for edge table and AET is empty

Active Edge Table

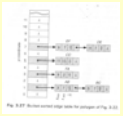
- Algorithm: scanline from bottom to top…
  - Sort all edges by their minimum y coord (last slide)
  - Starting at smallest Y coord with in entry in edge table
  - For each scanline:
    1. Add edges with Y_{min} = Y (move edges in edge table to AET)
    2. Retire edges with Y_{max} < Y (completed edges)
    3. Sort edges in AET by x intersection
    4. Walk from left to right, setting pixels by parity rule
    5. Increment scanline
    6. Recalculate edge intersections (*how?*)

    For every non-vertical edge in the AET update *x* for the new *y* (calculate the next intersection of the edge with the scan line).
  - Stop when Y > Y_{max} for edge table and AET is empty

Active Edge Table Example

Example of an AET containing edges {FA, EF, DE, CD} on scan line 8:

1. **: (*y* = 8) Get edges from ET bucket *y* (none in this case, *y* = 8 has no entry)**
2. **: Remove from the AET any entries where *ymax* = *y* (none here)**
3. **: sort by X**
4. **: Draw scan line. To handle multiple edges, group in pairs: {FA,EF}, {DE,CD}**
5. **: *y* = *y*+1 (*y* = 8+1 = 9)**
6. **: Update *x* for non-vertical edges, as in simple line drawing.**



Scanline 8

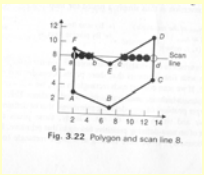


Fig. 3.22 Polygon and scan line 8.

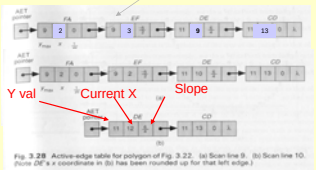


Fig. 3.28 Active-edge table for polygon of Fig. 3.22. (a) Scan line 9. (b) Scan line 10. (Note DE's x coordinate in (b) has been rounded up for that left edge.)

(FvDFH pages 92, 99)

Active Edge Table Example (cont.)

1. : (*y* = 9) Get edges from ET bucket *y* (none in this case, *y* = 9 has no entry in ET)
   – "Scan line 9" shown in fig 3.28 below
2. : Remove from the AET any entries with *ymax* = *y* (remove FA, EF)
3. : Sort by X
4. : Draw scan line between {DE, CD}
5. : *y* = *y*+1 = 10
6. : Update x in {DE, CD}
7. : (*y* = 10) (Scan line 10 shown in fig 3.28 below)

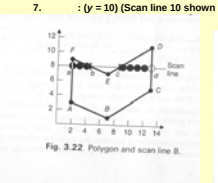


Fig. 3.22 Polygon and scan line 8.

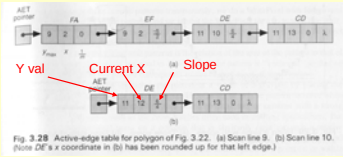


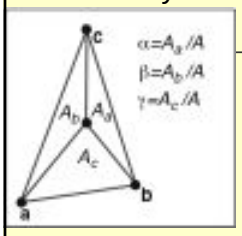
Fig. 3.28 Active-edge table for polygon of Fig. 3.22. (a) Scan line 9. (b) Scan line 10. (Note DE's x coordinate in (b) has been rounded up for that left edge.)

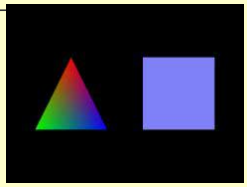
(FvDFH pages 92, 99)

Triangles (cont.)

- Rasterization algorithms can take advantage of triangle properties
- Graphics hardware is optimized for triangles
- Because triangle drawing is so fast, many systems will subdivide polygons into triangles prior to scan conversion

Why are Barycentric coordinates useful?



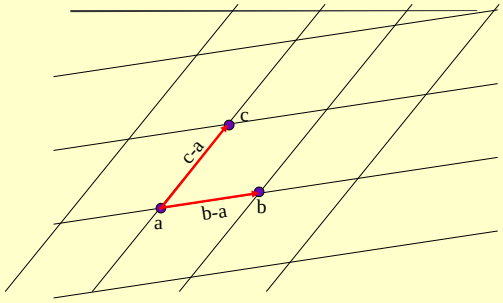


- For any point *x*, if the barycentric representation of that point: $x_\alpha x_\beta$, $x_\gamma < 1$
- Also α,β,γ can be used as a mass function across the surface of a triangle to be used for interpolation.
- This is used to interpolate normals across the surface of a triangle to make polygon surfaces look rounder.

Barycentric Coordinates

- Consider a triangle defined by three points **a, b,** and **c**.
- Define a new coordinate system in which **a** is the origin, **b** and **c** define the coordinate system basis vectors
- Note that the coordinate system will be non-orthogonal.

Barycentric Coordinates



Barycentric Coordinates

- With this new coordinate system, any point can be written as:

$$p = a + \beta(b-a) + \gamma(c-a)$$

- rearranging terms, we get:

$$p = (1-\beta-\gamma)a + \beta b + \gamma c$$

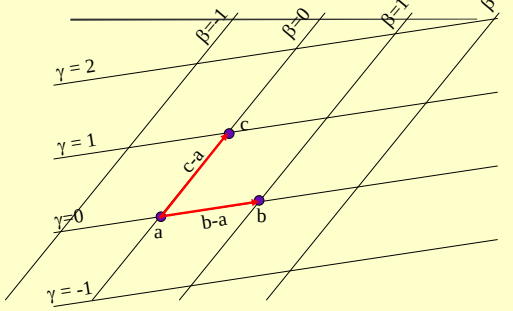
- let

$$\alpha = (1-\beta-\gamma)$$

- then

$$p = \alpha a + \beta b + \gamma c$$

Barycentric Coordinates



Barycentric Coordinates

- Now any point in the plane can be represented using its barycentric coordinates

$$p = \alpha a + \beta b + \gamma c$$

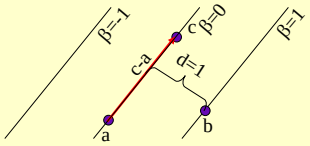
- If

$$\alpha + \beta + \gamma = 1$$
$$0 < \alpha < 1$$
$$0 < \beta < 1$$
$$0 < \gamma < 1$$

- then the point lies somewhere in the triangle

Barycentric Coordinates

- If one of the coordinates is zero and the other two are between 0 and 1, the point is on an edge
- If two coordinates are zero and the other is one, the point is at a vertex.
- The barycentric coordinate is the signed scaled distance from the point to the line passing through the other two triangle points



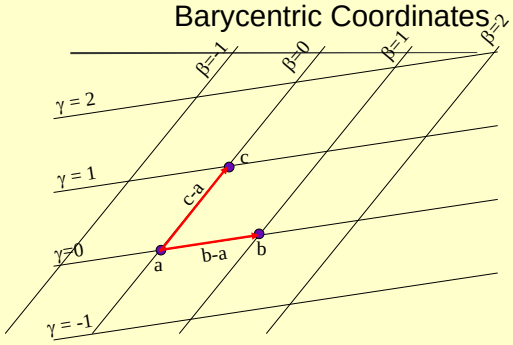
Computing Barycentric Coordinates

- Implicit form between two points (a,b) and (a,c)

$$f(a,b) = (y_a - y_b)x + (x_b - x_a)y + x_a y_b - x_b y_a$$

$$f(a,c) = (y_a - y_c)x + (x_c - x_a)y + x_a y_c - x_c y_a$$

Barycentric Coordinates



PDF Slides

Computing Barycentric Coordinates

- To compute the barycentric coordinates of a point:

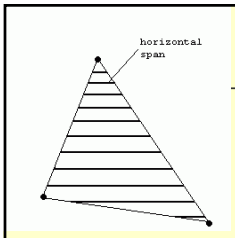
$$\gamma = \frac{(y_a - y_b)x + (x_b - x_a)y + x_a y_b - x_b y_a}{(y_a - y_b)x_c + (x_b - x_a)y_c + x_a y_b - x_b y_a}$$

$$\beta = \frac{(y_a - y_c)x + (x_c - x_a)y + x_a y_c - x_c y_a}{(y_a - y_c)x_b + (x_c - x_a)y_b + x_a y_c - x_c y_a}$$

$$\alpha = 1 - \beta - \gamma$$

Barycentric Coordinate Applet

http://i33www.ira.uka.de/applets/mocca/html/noplugin/inhalt.html



Rasterize This!

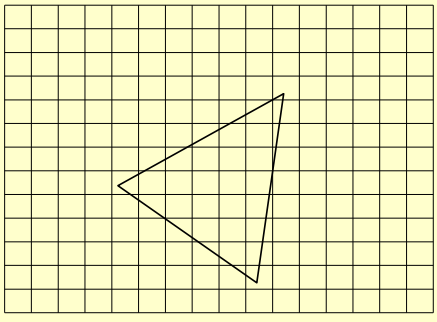
(Rasterization intuition)

- When we render a triangle we want to determine if a pixel is within a triangle. (barycentric coords)
- Calculate the color of the pixel (use barycentric coors).
- Draw the pixel.
- Repeat until the triangle is appropriately filled.

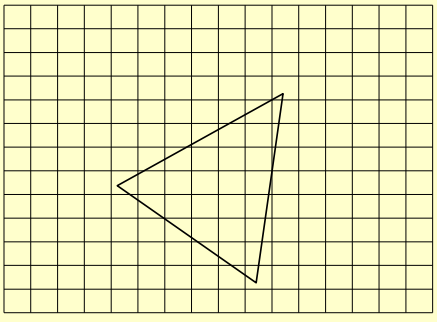
Rasterization Pseudo Code

```
drawTriangle2D(x_a, y_a, x_b, y_b, x_c, y_c)
{
   for all x in screen_x
      for all y in screen_y
         compute(α, β, γ) for (x, y)
            if(α ∈ [0,1] and β ∈ [0,1] and γ ∈ [0,1])
               color = compute_color(...)
               put_pixel(x, y, color)
}
```

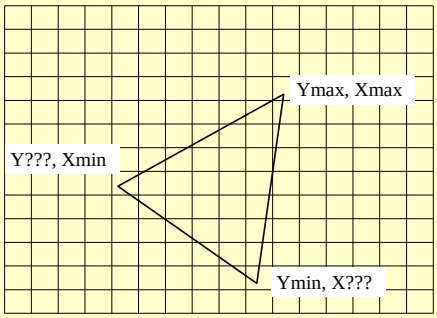
Rasterization



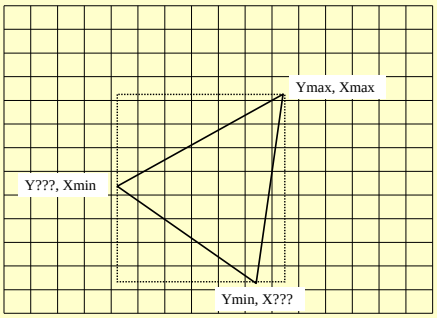
Rasterization



Rasterization



Bounding Box

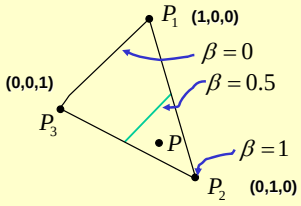


Barycentric Coordinates

- weighted combination of vertices

$$P = \alpha \cdot P_1 + \beta \cdot P_2 + \gamma \cdot P_3$$
$$\alpha + \beta + \gamma = 1$$
$$0 \le \alpha, \beta, \gamma \le 1$$

"convex combination of points"



Barycentric Coordinates for I nterpolation

- how to compute α, β, γ ?
  - use bilinear interpolation or plane equations

interpolate α, β, γ

$$\alpha = a \cdot x + b \cdot y + c \cdot z + d$$
$$\beta = \ldots$$

  - once computed, use to interpolate any # of parameters from their vertex values

$$x = \alpha \cdot x_1 + \beta \cdot x_2 + \gamma \cdot x_3$$
$$r = \alpha \cdot r_1 + \beta \cdot r_2 + \gamma \cdot r_3$$
$$g = \alpha \cdot g_1 + \beta \cdot g_2 + \gamma \cdot g_3$$

etc.

Interpolatation: Gouraud Shading

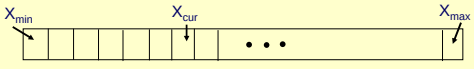
- need linear function over triangle that yields original vertex colors at vertices
- use barycentric coordinates for this
  - every pixel in interior gets colors resulting from mixing colors of vertices with weights corresponding to barycentric coordinates
  - color at pixels is affine combination of colors at vertices

$$Color(\alpha \cdot \mathbf{x}_1 + \beta \cdot \mathbf{x}_2 + \gamma \cdot \mathbf{x}_3) :=$$
$$\alpha \cdot Color(\mathbf{x}_1) + \beta \cdot Color(\mathbf{x}_2) + \gamma \cdot Color(\mathbf{x}_3)$$

Gouraud Shading Scanline Alg

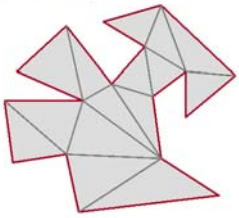
- algorithm
  - modify scanline algorithm for polygon scan-conversion :
    - linearly interpolate colors along edges of triangle to obtain colors for endpoints of span of pixels
    - linearly interpolate colors from these endpoints within the scanline

$$\frac{X_{max} - X_{cur}}{X_{max} - X_{min}} * C_{min} + \left(1 - \frac{X_{max} - X_{cur}}{X_{max} - X_{min}}\right) * C_{max}$$



Hardware Scan Conversion

- Convert everything into triangles
  - Scan convert the triangles

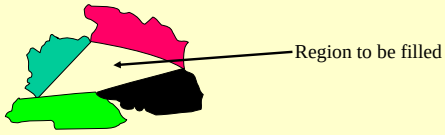


Filling Techniques

- Another approach to polygon fill is using a filling technique, rather than scan conversion
- Pick a point inside the polygon, then fill neighboring pixels until the polygon boundary is reached
- Boundary Fill Approach:
  - Draw polygon boundary in the frame buffer
  - Determine an interior point
  - Starting at the given point, do
    - If the point is not the boundary color or the fill color
      Set this pixel to the fill color
      Propagate to the pixel's neighbors and continue

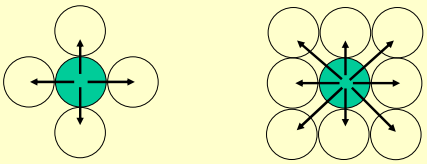
Filling Techniques

- Flood Fill Approach:
  - Set all interior pixels to a certain color
  - The boundary can be any other color
  - Pick an interior point and set it to the polygon color
  - Propagate to neighbors, as long as the neighbor is the interior color
- This is used for regions with multi-colored boundaries



Propagating to Neighbors

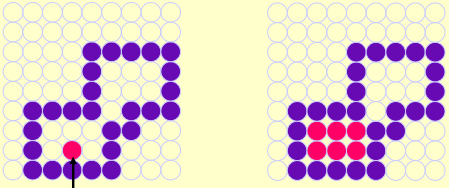
- Most frequently used approaches:
  - 4-connected area
  - 8-connected area



4-connected 8-connected

Fill Problems

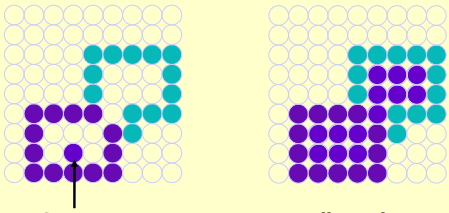
- Fill algorithms have potential problems
- E.g., 4-connected area fill:



Starting point Fill complete

Fill Problems

- Similarly, 8-connected can "leak" over to another polygon



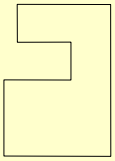
Starting point Fill complete

- Another problem: the algorithm is highly recursive
  - Can use a stack of spans to reduce amount of recursion

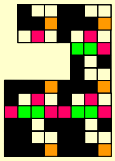
Pattern Filling

- Often we want to fill a region with a pattern, not just a color
- Define an n by m pixmap (or bitmap) that we wish to replicate across the region

5x4 pixmap



Object to be patterned



Final patterned object

Pattern Filling

- How do you determine the anchor point
  - A point on the polygon
    - Left-most point?
    - The pattern will move with the polygon
    - Difficult to decide the right anchor point
  - Screen (or window) origin
    - Easier to determine anchor point
    - The pattern does not move with the object

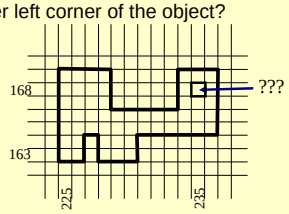
Pattern Filling

- How do we determine which color to color a point in the object?
- Use the MOD function to tile the pattern across the polygon
- For point (x, y)
  - Use the pattern color located at (x MOD m, y MOD n)

Pattern Example

- For the pattern shown, what color does the pixel at location (235, 168) get colored, assuming the pattern is anchored at the lower left corner of the object?

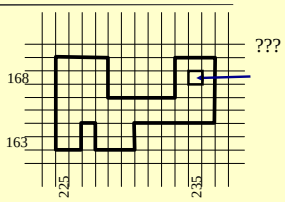
Pattern



Pattern Example

Pattern

The pattern is 5x4



Need to find the relative distance to the point to draw:
X = (235 – 225) = 10
Y = (168 – 163) = 5

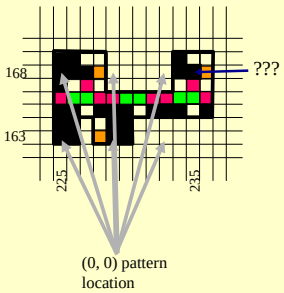
Next figure out which pattern pixel corresponds to this screen pixel:
$X_{pattern}$ = 10 MOD 4 = 2
$Y_{pattern}$ = 5 MOD 5 = 0

Pattern Example

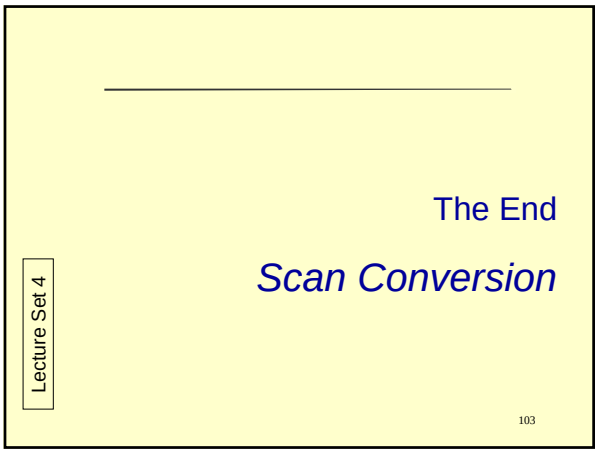
- The pattern pixel (2, 0) should map to screen location (235, 168)

(2, 0)

Let's map the pattern onto the polygon and see



(0, 0) pattern location


The End
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