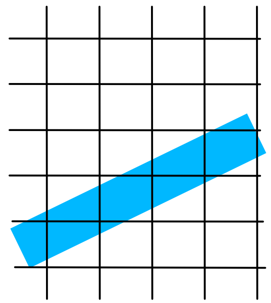
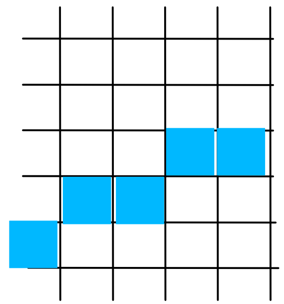
Filled Area Primitives





CEng 477
Introduction to Computer Graphics
METU, 2007

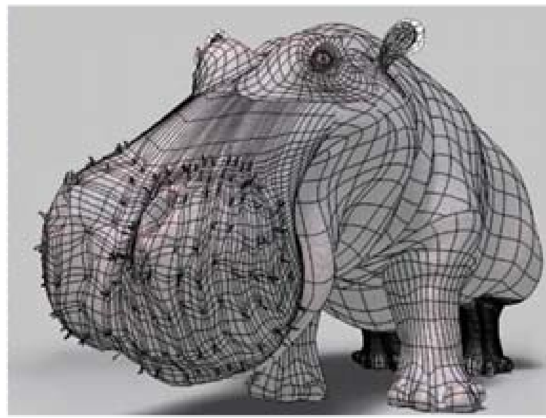
Filled Area Primitives

- Two basic approaches to area filling on raster systems:
  - Determine the overlap intervals for scan lines that cross the area (scan-line)
  - Start from an interior position and point outward from this point until the boundary condition reached (fill method)
- Scan-line: simple objects, polygons, circles,..
- Fill-method: complex objects, interactive fill.

Polygon Fill Areas

- Most library routines require that a fill area be specified as a polygon
  - OpenGL only allows ***convex*** polygons
- Non-polygon (curved) objects can be approximated by polygons
  - Surface tessellation, polygon mesh, triangular mesh

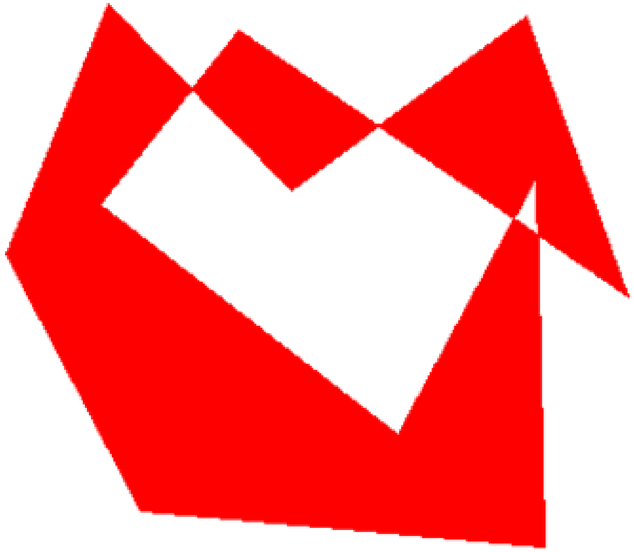




Polygon types

- Simple polygon:
  - all vertices are on the same plane and no edge crosses, no holes

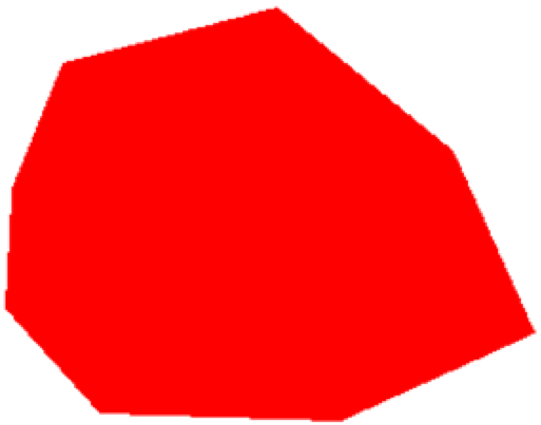
simple polygon



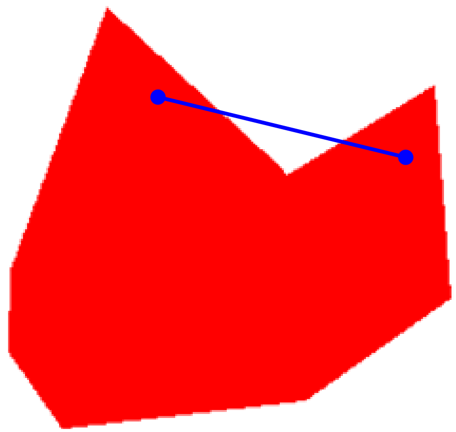
not a simple polygon

Polygon types

- Simple polygons are either ***convex*** or ***concave***:
  - Convex polygon: All interior angles < 180°, or any line segment combining two points in the interior is also in the interior



convex polygon



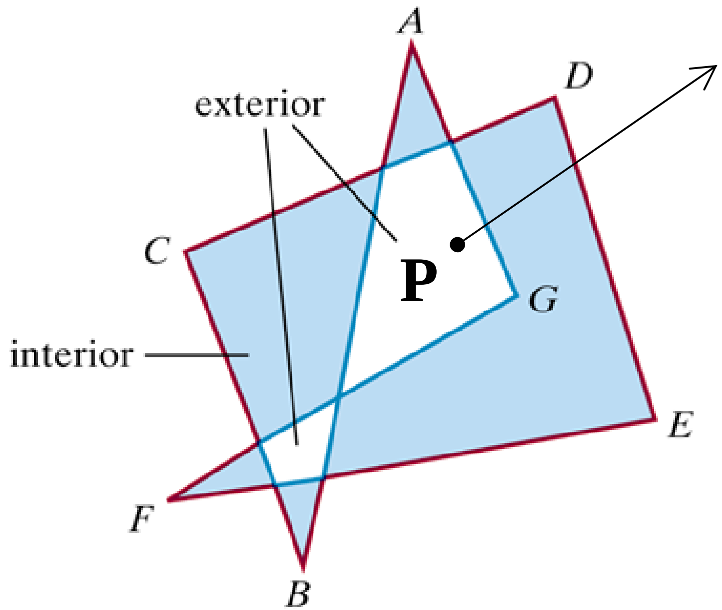
concave polygon

can be split into a number of convex polygons

Inside-Outside Tests

- Identifying the interior of a polygon (simple or complex) is important to identify the region to be filled

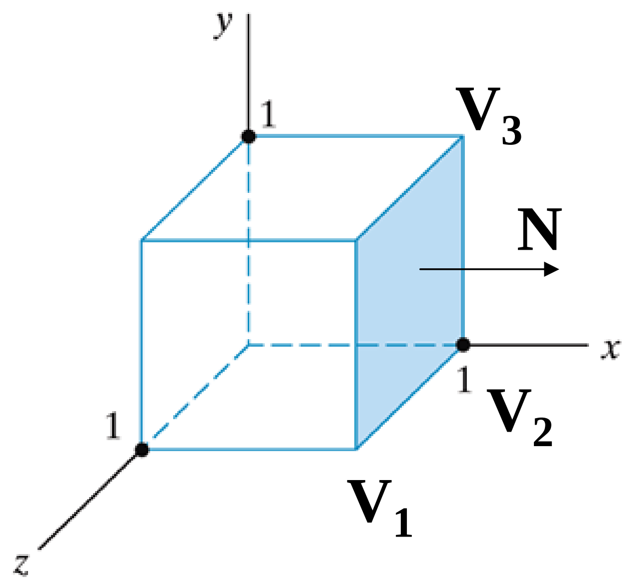
- Odd-even rule: To determine whether point **P** is inside or not. Draw a line starting from P to a distant position. Count the number of edges that crosses this line. If the count is **odd** then the point is **inside**, otherwise it is outside.



Odd-Even Rule

Front and Back Face of a Polygon

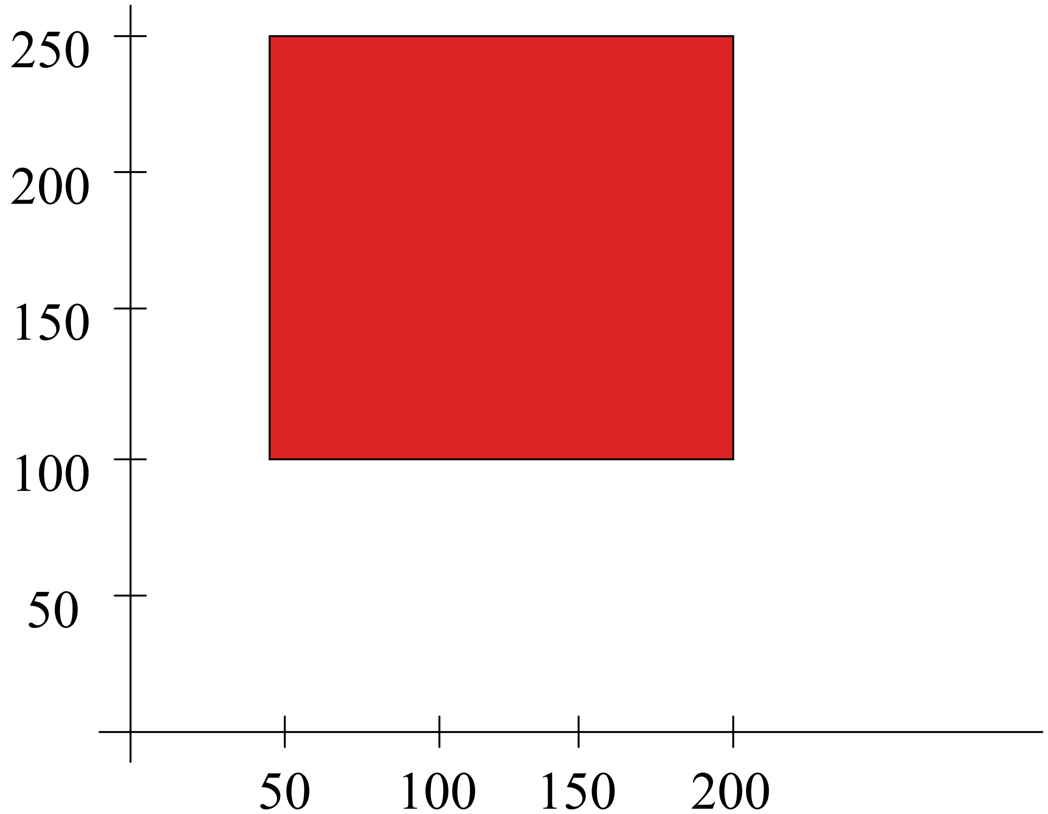
- The normal vector points in a direction from the back face of the polygon to the front face
- Normal vector is the cross product of the two edges of the polygon in counter-clockwise direction



$$\mathbf{N} = (\mathbf{V}_2 - \mathbf{V}_1) \times (\mathbf{V}_3 - \mathbf{V}_2)$$

OpenGL Polygon Fill-Area Functions

- glRecti(50, 100, 200, 250)



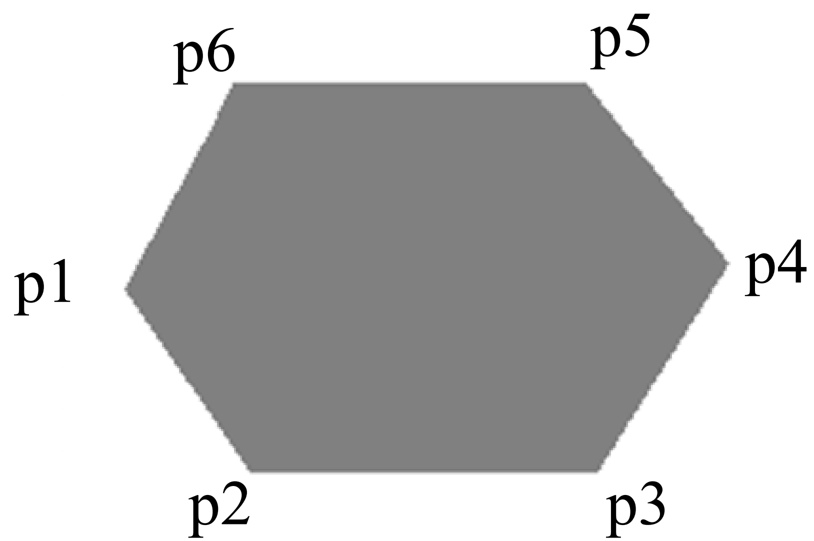
OpenGL primitives

- GL_POLYGON
- GL_TRIANGLES
- GL_TRIANGLE_STRIP
- GL_TRIANGLE_FAN
- GL_QUADS
- GL_QUAD_STRIP

OpenGL primitives

- GL_POLYGON

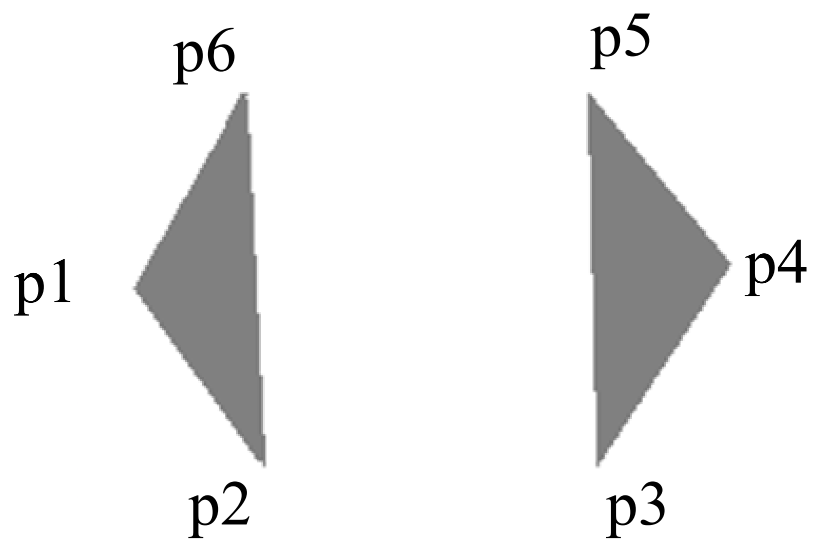
```
glBegin (GL_POLYGON);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p3);
        glVertex2iv (p4);
        glVertex2iv (p5);
        glVertex2iv (p6);
glEnd ( );
```



OpenGL primitives

- GL_TRIANGLES

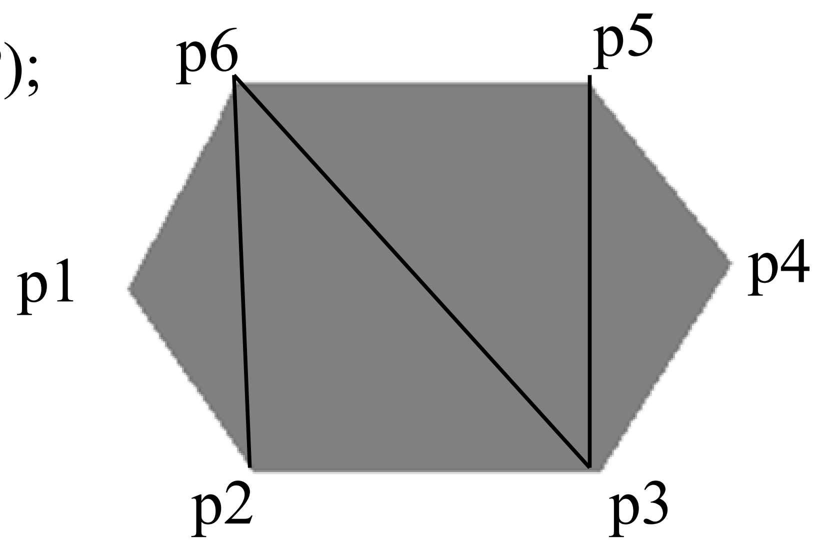
```
glBegin (GL_TRIANGLES);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p6);
        glVertex2iv (p3);
        glVertex2iv (p4);
        glVertex2iv (p5);
glEnd ( );
```



OpenGL primitives

- GL_TRIANGLE_STRIP

```
glBegin (GL_TRIANGLE_STRIP);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p6);
        glVertex2iv (p3);
        glVertex2iv (p5);
        glVertex2iv (p4);
glEnd ( );
```

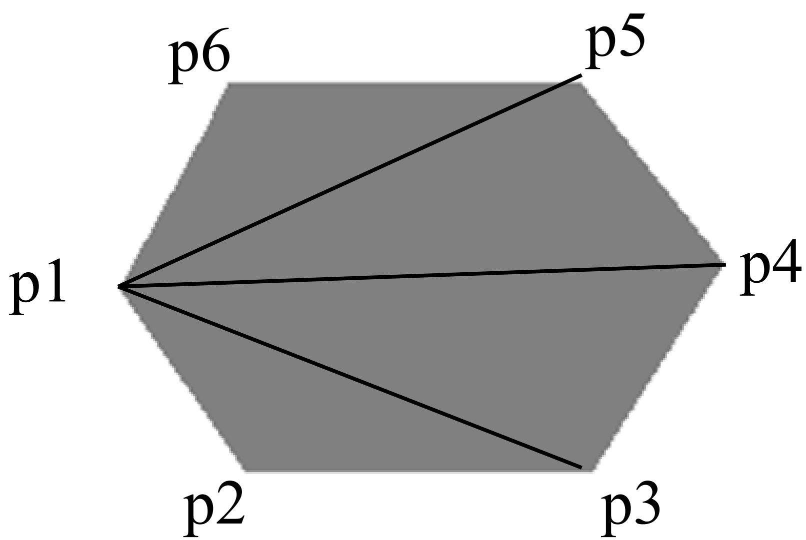


N vertices→N-2 triangles
order of triangles: n, n+1, n+2 (if n is odd)
n+1, n, n+2 (if n is even) (n from 1 to N-2)

OpenGL primitives

- GL_TRIANGLE_FAN

```
glBegin (GL_TRIANGLE_FAN);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p3);
        glVertex2iv (p4);
        glVertex2iv (p5);
        glVertex2iv (p6);
glEnd ( );
```

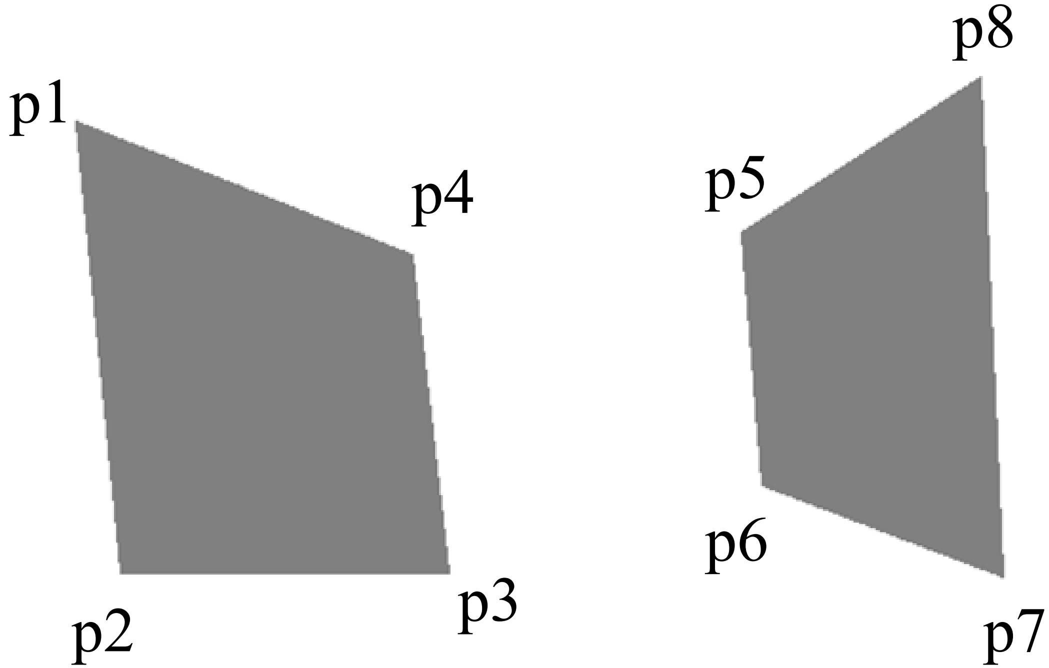


N vertices $\rightarrow$ N-2 triangles
order of triangles: 1, n+1, n+2
(n from 1 to N-2)

OpenGL primitives

- GL_QUADS

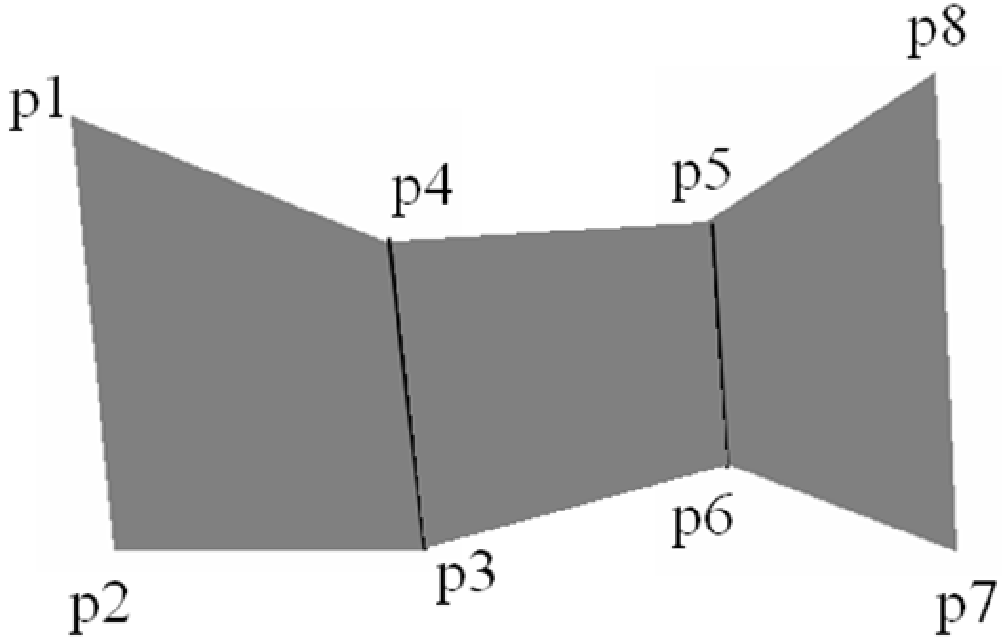
```
glBegin (GL_QUADS);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p3);
        glVertex2iv (p4);
        glVertex2iv (p5);
        glVertex2iv (p6);
        glVertex2iv (p7);
        glVertex2iv (p8);
glEnd ( );
```



OpenGL primitives

- GL_QUAD_STRIP

```
glBegin (GL_QUAD_STRIP);
        glVertex2iv (p1);
        glVertex2iv (p2);
        glVertex2iv (p4);
        glVertex2iv (p3);
        glVertex2iv (p5);
        glVertex2iv (p6);
        glVertex2iv (p8);
        glVertex2iv (p7);
glEnd ( );
```



N vertices→N/2-1 quads

order of quads: 2n-1,2n,2n+2,2n+1

(n from 1 to N/2-1)

OpenGL vertex arrays

- Complex scenes may require many glVertex() calls
- OpenGL provides vertex arrays to reduce function calls
- Drawing a cube:

```
glEnableClientState (GL_VERTEX_ARRAY);
GLint pt[8][3] = {{0,0,0},{0,1,0},{1,0,0},{1,1,0},
                  {0,0,1},{0,1,1},{1,0,1},{1,1,1}};
glVertexPointer (3, GL_INT, 0, pt);
GLubyte vertIndex[24] ={6,2,3,7,5,1,0,4,7,3,1,5,4,0,2,6,2,0,1,3,7,5,4,6};
glDrawElements (GL_QUADS, 24, GL_UNSIGNED_BYTE, vertIndex);
```

OpenGL Display Lists

- Allows modular description of object components. Using display lists you can reference a set of OpenGL drawing commands multiple times

```
listID = glGenLists(1); // (number of list numbers to generate)
glNewList (listID, GL_COMPILE_AND_EXECUTE); // or GL_COMPILE
.....
.....
glEndList ( );

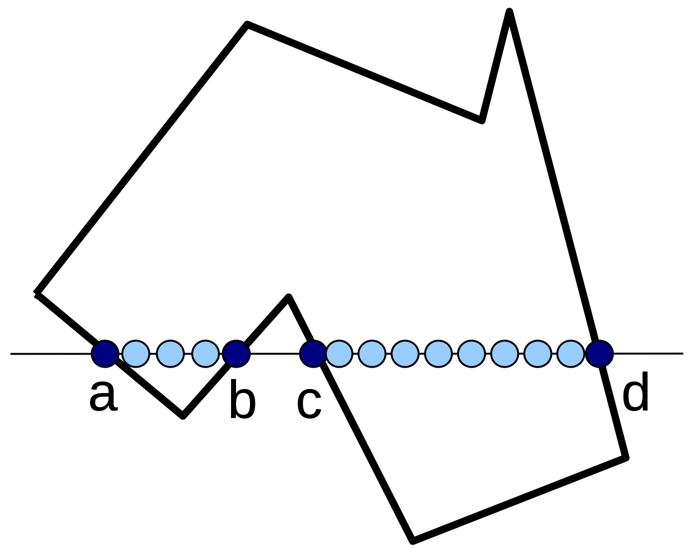
glCallList(listID);
glDeleteLists(listID,1); // (startID, number of lists)
```

Fill Algorithms

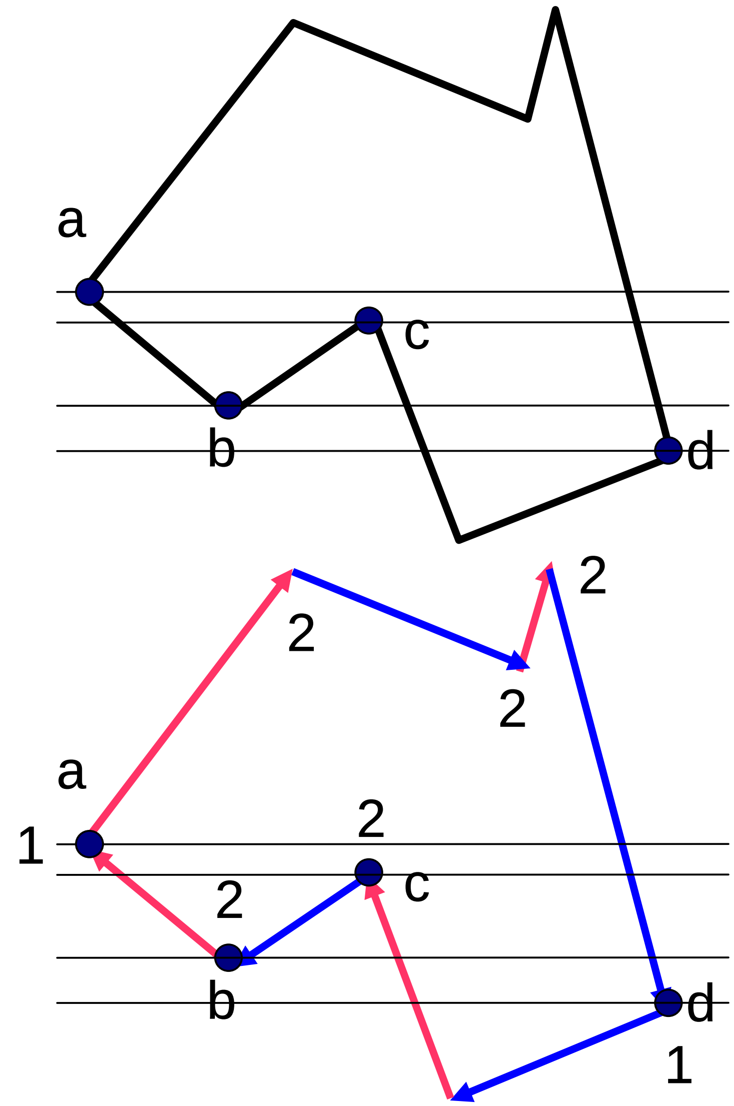
- General Scan-Line Polygon fill algorithm
  - to fill convex and concave polygons
- Boundary-Fill and Flood-Fill algorithms
  - to fill arbitrary complex, irregular boundaries
- For now, assume that we fill the interior with a *single* color with no fill-pattern applied
- Application of fill-patterns is explained in sections 4-9 and 4-14 of your textbook

Scan-line Polygon Fill

- For each scan-line:
  - Locate the intersection of the scan-line with the edges ($y=y_s$)
  - Sort the intersection points from left to right.
  - Draw the interiors intersection points pairwise. (a-b), (c-d)
- Problem with corners. Same point counted twice or not?



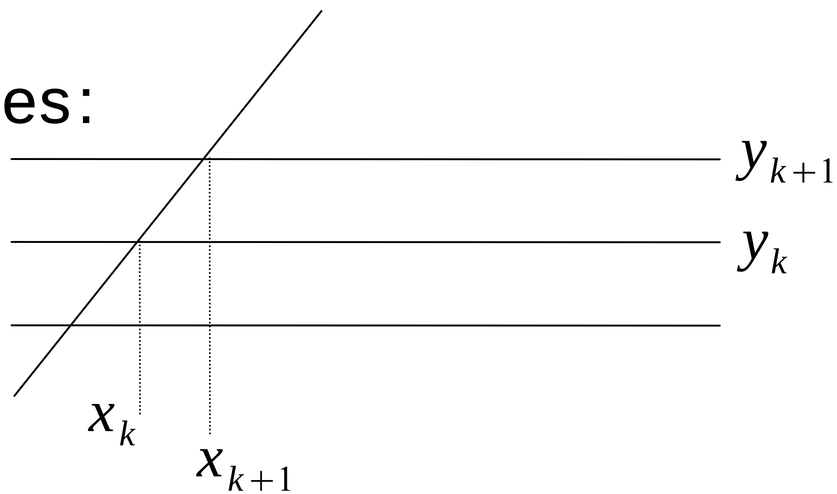
- *a*,*b*,*c* and *d* are intersected by 2 line segments each.
- Count *b*,*c* twice but *a* and *d* once. Why?
- Solution:
  Make a clockwise or counter-clockwise traversal on edges. Check if y is monotonically increasing or decreasing.
  If direction changes, double intersection, otherwise single intersection.



Scan-line Polygon Filling (coherence)

- **Coherence**: Properties of one part of a scene are related with the other in a way that can it be used to reduce processing of the other.
- Scan-lines adjacent to each other:
  The intersection points of edges with adjacent scan-lines are close to each other (like scan conversion of a line)
- Intersection points with scan lines:

$$x_{k+1} = round\left(x_k + \frac{1}{m}\right)$$



- Instead of floating point operations, use integer operations:

$$m = \frac{\Delta y}{\Delta x} \qquad x_{k+1} = x_k + \frac{\Delta x}{\Delta y}$$

$counter \leftarrow 0$
for each scan-line
    $counter \leftarrow counter + \Delta x$
    while $counter \geq \Delta y$
        $x \leftarrow x+1$
        $counter \leftarrow counter - \Delta y$

- Example:
  m = 8/5

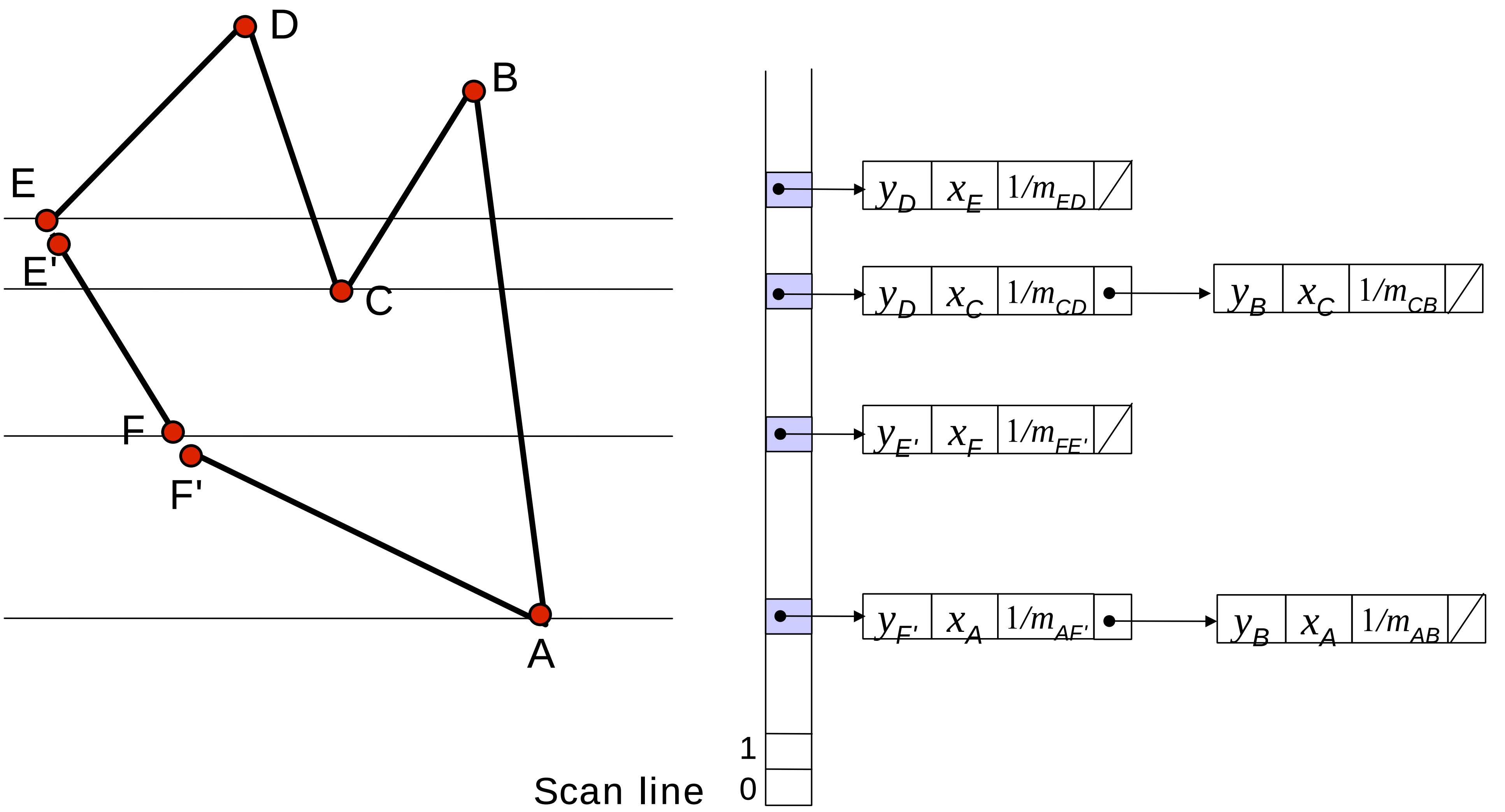
scanline	counter	x
0	0	0
1	5	0
2	10 (2)	1
3	7	1
4	12 (4)	2
5	9 (1)	3

This algorithm truncates $x+1/m$. To achieve rounding, we should compare the counter with $\Delta y/2$. Modification of the algorithm left as an exercise.

Efficient Polygon Fill

- Make a (counter) clockwise traversal and shorten the single intersection edges by one pixel (so that we do not need to re-consider single/double edges).
- Generate a sorted edge table on the scan-line axis. Each edge has an entry in smaller y valued corner point (vertex).
- Each entry keeps a linked list of all connected edges:
  - x value of the point
  - y value of the end-point
  - Slope of the edge

Sorted edge table



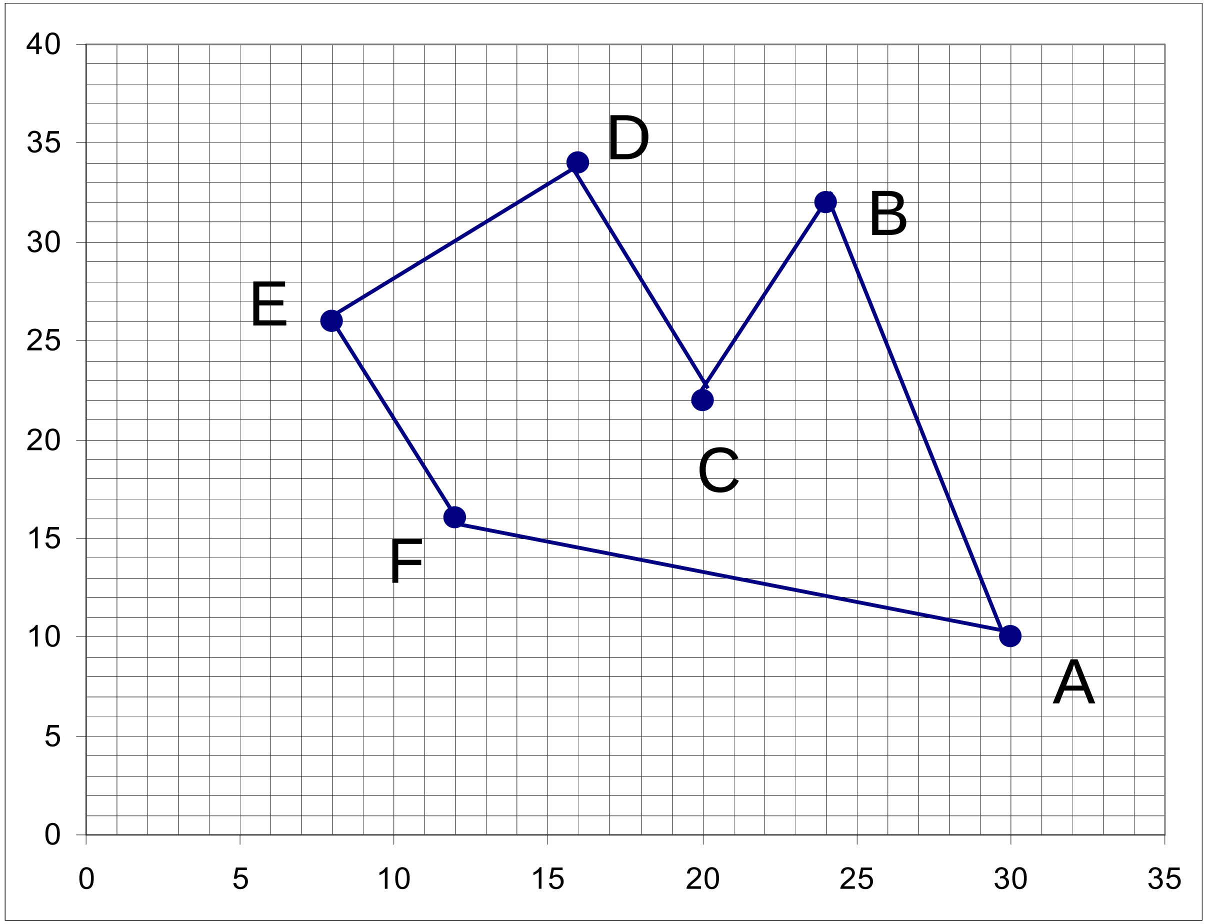
- Start with the smallest scan-line
- Keep an **active edge list**:
  - Update the current *x* value of the edge based on *m* value
  - Add the lists in the current table entry based on their *x* value
  - Remove the completed edges
  - Draw the intermediate points of pairwise elements of the list.

Example

- Example:
  A: (30,10),B: (24,32),C: (20,22), D: (16,34)
  E: (8,26), F: (12,16)

- Define the polygon with

  A,B,C,D,E,F,A



Example

- Example:
  A: (30,10),B: (24,32),C: (20,22), D: (16,34)
  E: (8,26), F: (12,16)

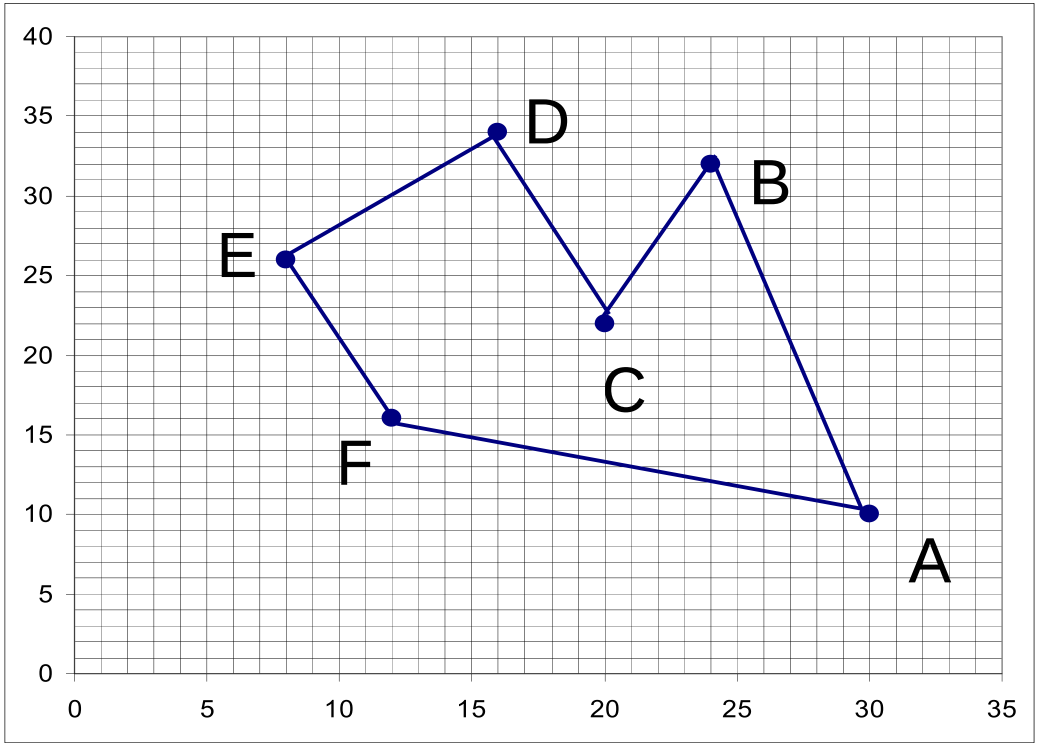
- Define the polygon with

  A,B,C,D,E,F,A

- E'=(20,25), F'=(12,15)

  Sorted Edge Table:

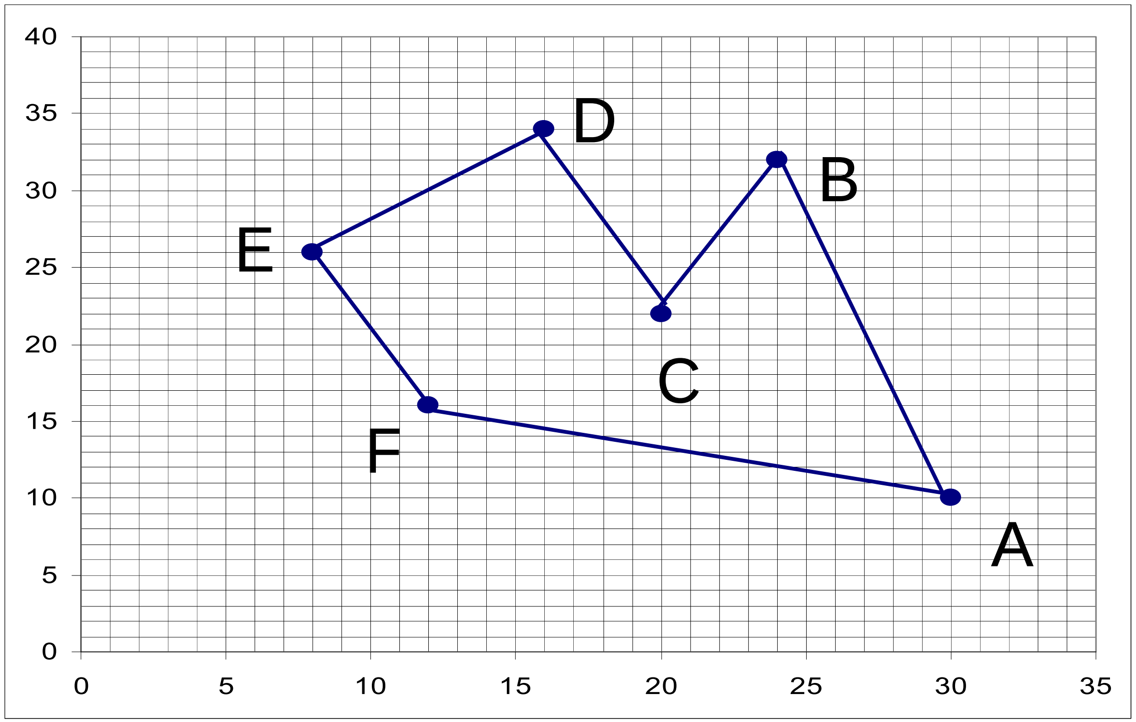
Y	E1	E2
10	[15,30,-3]	[32,30,-3/11]
16	[25,12,-2/5]	
22	[34,20,-1/3]	[32,20,2/5]
26	[34,8,1]	



Example

- Sorted Edge Table:

Y	E1	E2
10	[15,30,-3]	[32,30,-3/11]
16	[25,12,-2/5]	
22	[34,20,-1/3]	[32,20,2/5]
26	[34,8,1]	



Active Edge List

Y	S1	S1	S2	S2
10	30	30		
11	27	29.73		
12	24	29.45		
13	21	29.18		
14	18	28.91		
15	15	28.64		
16	12	28.36		
17	11.6	28.09		
18	11.2	27.82		
19	10.8	27.55		
20	10.4	27.27		
21	10	27		
22	9.6	20	20	26.73
23	9.2	19.67	20.4	26.45
24	8.8	19.33	20.8	26.18
25	8.4	19	21.2	25.91
26	8	18.67	21.6	25.64
27	9	18.33	22	25.36
28	10	18	22.4	25.09
29	11	17.67	22.8	24.82
30	12	17.33	23.2	24.55
31	13	17	23.6	24.27
32	14	16.67	24	24
33	15	16.33		
34	16	16		

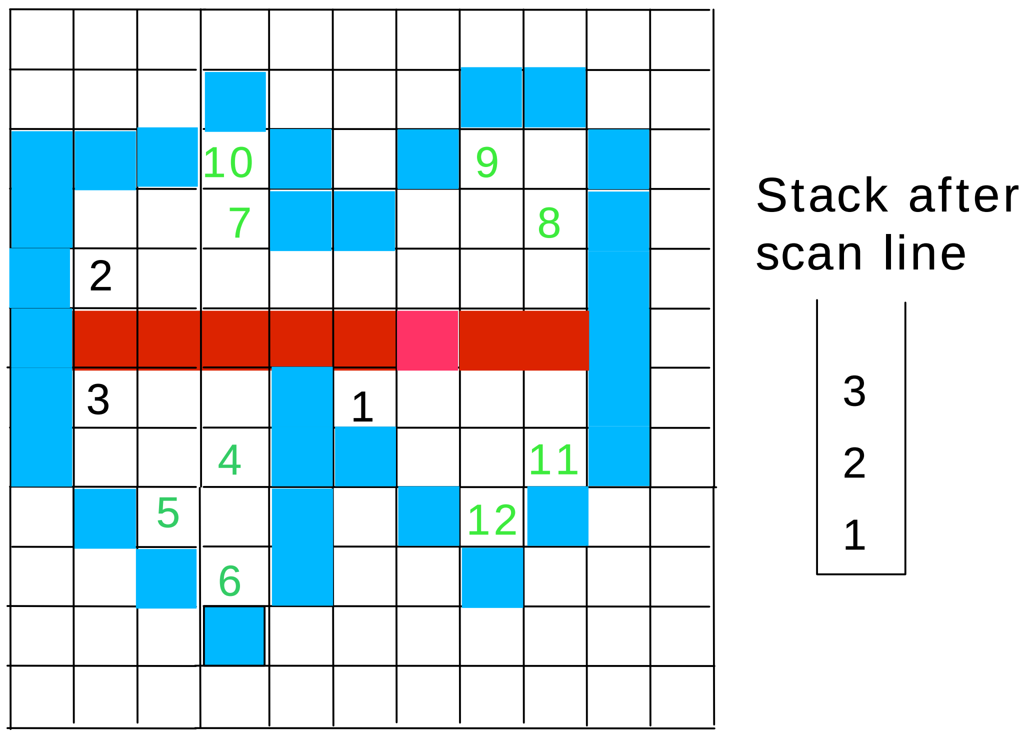
Boundary Fill Algorithm

- Start at a point inside a continuous arbitrary shaped region and paint the interior outward toward the boundary. Assumption: boundary color is a single color
- (x,y): start point; b:boundary color, fill: fill color

```
void boundaryFill4(x,y,fill,b) {
  cur = getpixel(x,y)
  if (cur != b) AND (cur != fill) {
       setpixel(x,y,fill);
       boundaryFill4(x+1,y,fill,b);
       boundaryFill4(x-1,y,fill,b);
       boundaryFill4(x,y+1,fill,b);
       boundaryFill4(x,y-1,fill,b);
  }
}
```

- 4 neighbors vs 8 neighbors: depends on definition of continuity.
  8 neighbor: diagonal boundaries will not stop
- Recursive, so slow. For large regions with millions of pixels, millions of function calls.
- Stack based improvement: keep neighbors in stack
- Number of elements in the stack can be reduced by filling the area as pixel spans and pushing only the pixels with pixel transitions.

- Check the neighbor pixels as filling the area line by line
- If pixel changes from null to boundary or null when scan-line finishes, push the pixel information on stack.
- After a scan-line finishes, pop a value from stack and continue processing.



Flood-Fill

- Similar to boundary fill. Can be used for cases when the boundary is not single-color. Algorithm continues while the neighbor pixels have the same color.

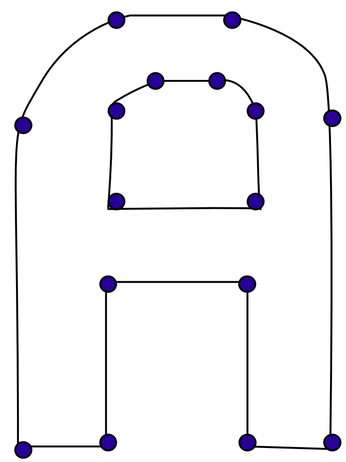
- ```
   void FloodFill4(x,y,fill,oldcolor) {
    cur = getpixel(x,y)
    if (cur == oldcolor) {
          setpixel(x,y,fill);
          FloodFill4(x+1,y,fill,oldcolor);
          FloodFill4(x-1,y,fill,oldcolor);
          FloodFill4(x,y+1,fill,oldcolor);
          FloodFill4(x,y-1,fill,oldcolor);
    }
  }
  ```
  ```

Character Generation

- Typesetting fonts:
  - Bitmap fonts: simple, not scalable.
  - Outline fonts: scalable, flexible, more complex to process
-

```
0 0 0 0 0 0 0 0
0 0 0 1 1 1 0 0
0 0 1 1 0 1 1 0
0 1 1 0 0 0 1 1
0 1 1 0 0 0 1 1
0 1 1 1 1 1 1 1
0 1 1 1 1 1 1 1
0 1 1 0 0 0 1 1
0 1 1 0 0 0 1 1
0 1 1 0 0 0 1 1
0 1 1 0 0 0 1 1
0 0 0 0 0 0 0 0
```

Pixelwise on/of information



Points and tangents of the boundary