## Scan-line area fill

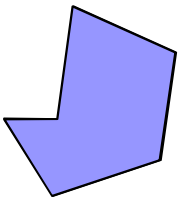
The algorithm
Applications

## Scan-line algorithms

- Essential in rendering, i.e. conversion of geometric entities into image pixels
- Used, for example, in
  - Display of polygons
  - Hidden surface removal
  - Texture mapping

## Scan-line algorithm

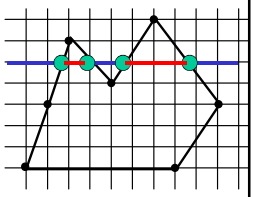
- **Purpose**: given a set of (2D) vertex coordinates for a polygon, fill the area surrounded by the polygon
- Polygons can be filled with a uniform colour or texture
- The algorithm is efficient because it incorporates some coherence properties of the polygons (i.e. direction and slope of each edge)



## Scan-line algorithm - outline

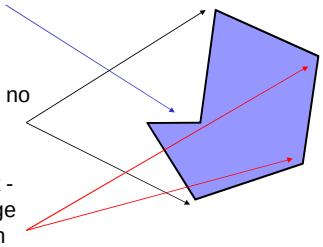
For each scan line (each y-coordinate)

- Compute x coordinates of the intersections of the current scan line with all edges
- Sort these edge intersections by increasing x value
- Group the edge intersections by pairs (vertex intersections require special processing)
- Fill in the pixels on the scan line between pairs of values



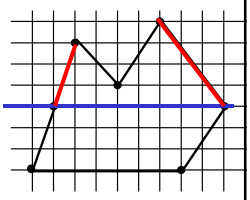
## Vertex considerations

- do not include edges with zero slope
- an extremum vertex - no additional processing
- non-extremum vertex - shorten a second edge by 1 unit in y direction



## Computational structures

- Edge table - list of buckets, one per line
- Each bucket contains edges whose minimum y coordinate (**ymin**) starts at the bucket's line
- Each entry is a record containing:
  **ymax** **xmin** **increment**
- The array of buckets sorted according to **ymin**
- Records in a bucket sorted according to **xmin**



## Polygon Data Structure

Edge record

| xmin | ymax | 1/m | |
|---|---|---|---|
| 1 | 6 | 8/4 | |

(9, 6)

(1, 2)

xmin = x value at lowest y

ymax = highest y

Why 1/m?

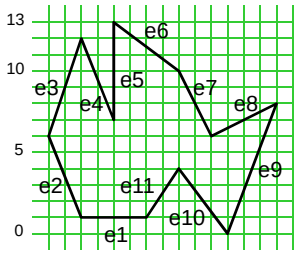
If y = mx + b, x = (y-b)/m.

x at y+1 = (y+1-b)/m = (y-b)/m + 1/m.

## Polygon Data Structure

13
12
11
10 → e6
9
8
7 → e4 → e5
6 → e3 → e7 → e8
5
4
3
2
1 → e2 → e1 → e11
0 → e10 → e9

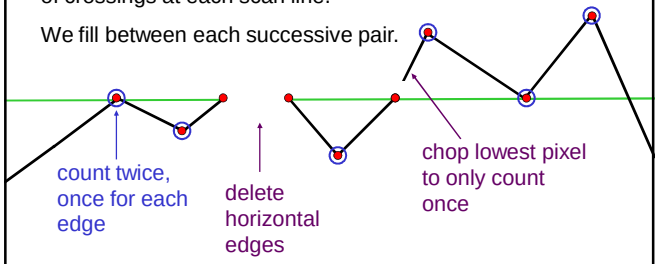
Edge Table (ET) has a list of edges for each scan line.




## Preprocessing the edges

For a closed polygon, there should be an even number of crossings at each scan line.

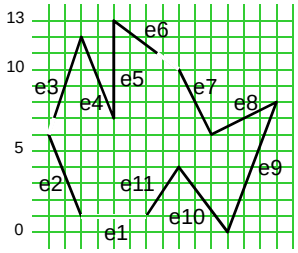
We fill between each successive pair.




## Polygon Data Structure
**after preprocessing**

13
12
11 → e6
10
9
8
7 → e3 → e4 → e5
6 → e7 → e8
5
4
3
2
1 → e2 → e11
0 → e10 → e9

Edge Table (ET) has a list of edges for each scan line.




## Algorithm

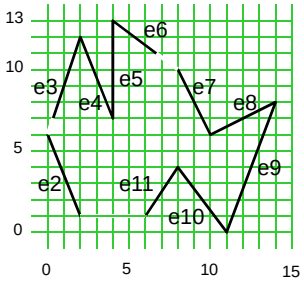
1 Build edge table
  Initialise scan-line list
2 Find first non-empty bucket **(ymin)** in the edge table
3 While the current **ymin** not greater than topmost y coordinate of the polygon
  3.1 merge the edge table for the current **ymin** with scan-line list, sort on increasing **xmin**
  3.2 fill pixels between pairs of rounded **xmin**-s
  3.3 Remove from the scan-line list the edges whose **ymax** = current scanline
  3.4 increment **xmin** by the **increment** (1/m) for remaining edges in the scan list
  3.5 re-sort scan line list on increasing **xmin**
  3.6 increment current scanline **ymin** to give next scanline

ET

11 → e6
7 → e3 → e4 → e5
6 → e7 → e8
1 → e2 → e11
0 → e10 → e9

| | xmin | ymax | 1/m |
|---|---|---|---|
| e2 | 2 | 6 | -2/5 |
| e3 | 1/3 | 12 | 1/3 |
| e4 | 4 | 12 | -2/5 |
| e5 | 4 | 13 | 0 |
| e6 | 6 2/3 | 13 | -4/3 |
| e7 | 10 | 10 | -1/2 |
| e8 | 10 | 8 | 2 |
| e9 | 11 | 8 | 3/8 |
| e10 | 11 | 4 | -3/4 |
| e11 | 6 | 4 | 2/3 |

## Running the Algorithm



## Running the Algorithm

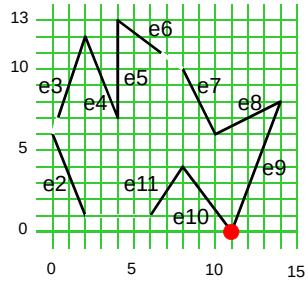
y=0

SCB→ | 10 1/4 | 4 | -3/4 | •

e10

e9

| 11 3/8 | 8 | 3/8 | • |




## Running the Algorithm

y=1

SLB→ | 1 3/5 | 6 | -2/5 | •

e2

e11

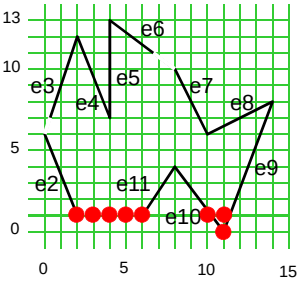
| 6 2/3 | 4 | 2/3 | •

e10

| 9 1/2 | 4 | -3/4 | •

e9

| 11 6/8 | 8 | 3/8 | •




## Running the Algorithm

y=2

SLB→ | 1 1/5 | 6 | -2/5 | •

e2

e11

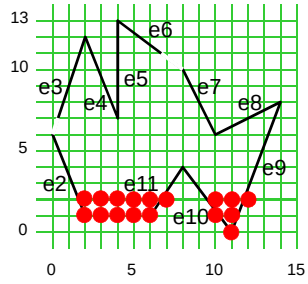
| 7 1/3 | 4 | 2/3 | •

e10

| 8 3/4 | 4 | -3/4 | •

e9

| 12 1/8 | 8 | 3/8 | •




## Running the Algorithm

y=3

SLB→ | 4/5 | 6 | -2/5 | •

e2

e11

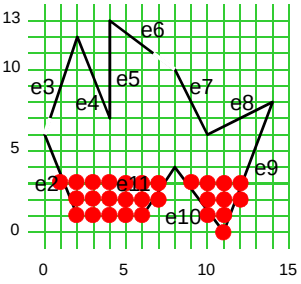
| 8 | 4 | 2/3 | •

e10

| 8 | 4 | -3/4 | •

e9

| 12 4/8 | 8 | 3/8 | •




## Running the Algorithm

y=4

SLB→ | 4/5 | 6 | -2/5 | •

e2

e11

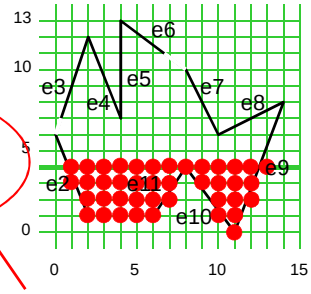
| 8 | 4 | 2/3 | •

e10

| 8 | 4 | -3/4 | •

e9

| 12 4/8 | 8 | 3/8 | •




Remove these edges.

## Running the Algorithm

y=4

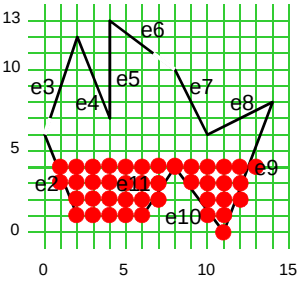
SLB→ | 2/5 | 6 | -2/5 | •

e2

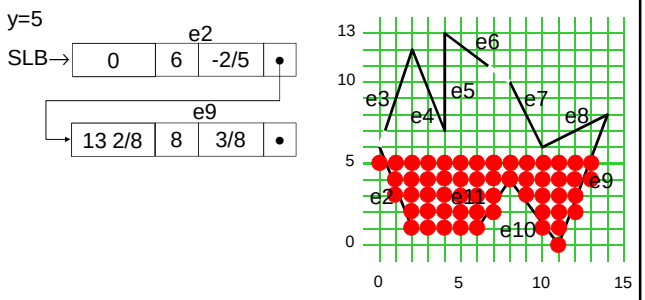
e9

| 12 7/8 | 8 | 3/8 | •

e11 and e10 are removed.



## Running the Algorithm

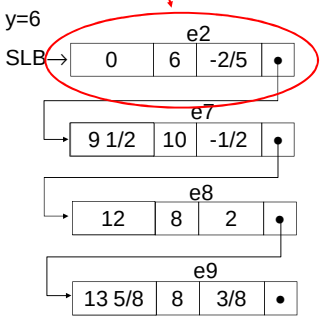


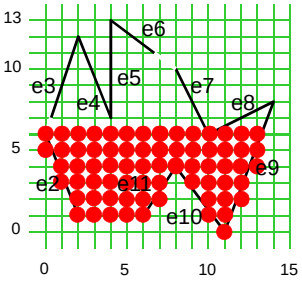




Remove this edge.

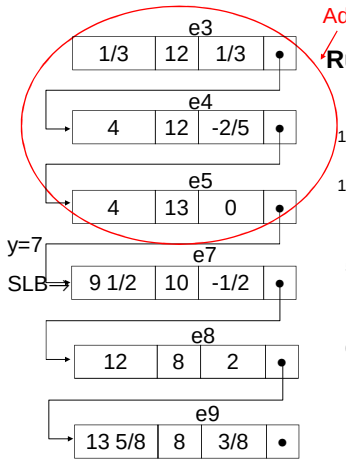
## Running the Algorithm

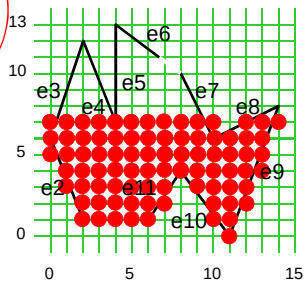



Add these edges.

## Running the Algorithm




## Scan line algorithm

- The algorithm provides a method for computing **locations** of individual pixels in a 2D display
  - E.g. hidden surface removal methods
- The pixel **colours** are computed using other algorithms, e.g.
  - Shading (flat, Gouraud, Phong)
  - Texturing

## Polygon display

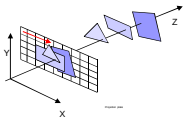
Flat shading

Phong shading

## Hidden surface removal

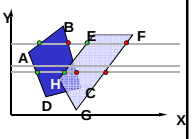
**Z-buffer algorithm**

```
for x increments, along each
scan line x+1, y):
   z' = z - A/C
for y increments,
for each new scan line (x, y+1):
   z" = z + B/C
```

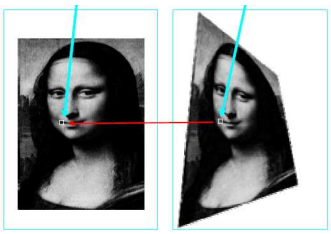



**Scan-line method**

•Each scan line is processed
•list of edges (of **ALL** polygons) crossing a current line sorted in order of increasing x
• ...



## Texture mapping



Backward mapping algorithm:

for (r,c) = polygon pixel

$u = (a_{11}r+a_{12}c+a_{13})/(a_{31}r+a_{32}c+1)$

$v = (a_{21}r+a_{22}c+a_{23})/(a_{31}r+a_{32}c+1)$

copy pixel at source (u,v)
to destination (r,c)

## Credits

The animations copied from Prof. Harriet Fell's lecture slides, College of Computer and Information Science, Northeastern University

## Next lecture

Hidden surface removal