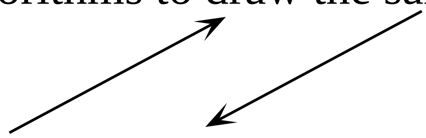
# 2D Graphics Primitives II

## Additional issues in scan converting lines

### 1)Endpoint order

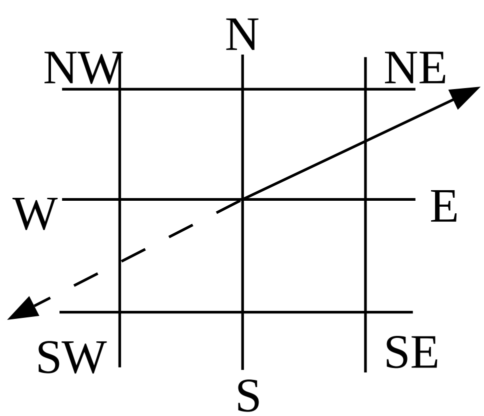
Want algorithms to draw the same pixels for each line



How handle?

a) draw only in one order - switch endpoints

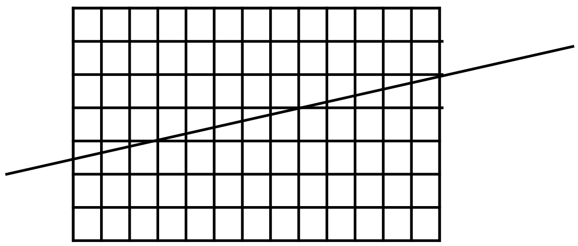
b) algorithm to draw in both directions
only problem is for error = 1/2 pixel
e.g.: if choose E then when going in one direction,
choose SW when going in opposite direction




Solution (a) can be a problem when drawing a patterned line - want pattern to start at specified start end point

e.g. 001100110011 versus 110011001100

2) Starting at the edge of a clip rectangle

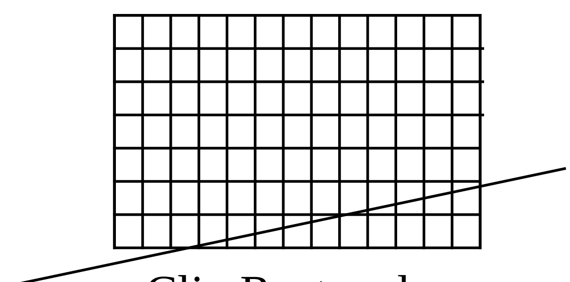


Line to be clipped

Clip Rectangle

To clip line:

can analytically clip with the sides of the clip rectangle
on right - get integer coordinates
on left - get non integer y
can't draw lines with non integer coordinates
could use closest pixel
Now scan-converted clipped line has different slope!
Correct by initializing decision variable to midpoint of next two points



Clip Rectangle

Problem for lines intersecting horizontals:
Which pixels closest?
Multiple pixels lie on bottom scanline

If find intersection of line and y =ymin and then round x, don't get all the pixels

Thus intersect y = ymin - 0.5 with line, and round up the x

3) Varying intensity of line as a function of slope

Diagonal lines have less intensity than horizontals and verticals

If bi-level display - no solution

If multilevel display - can vary intensity of each point as function of average distance between points (thus of slope)

4) Outline primitives composed of lines

shared vertices should be drawn only once

Why:

a) if write in XOR mode (sometimes done) then
if background color initially set
write pixel once and sets to foreground color
write pixel twice and sets to background color

| | | | | |
|---|---|---|---|---|
| Source | 0 | 0 | 1 | 1 |
| Dest | 0 | 1 | 0 | 1 |
| | | | | |
| or | 0 | 1 | 1 | 1 |
| xor | 0 | 1 | 1 | 0 (draw & undraw) |
| copy | 0 | 0 | 1 | 1 (default) |
| invert | 1 | 0 | 1 | 0 |
| clear | 0 | 0 | 0 | 0 |

b) reduce number of memory accesses (writes)

# Scan Conversion of Polygons

Rectangles

Polygons in general

How draw polygon?

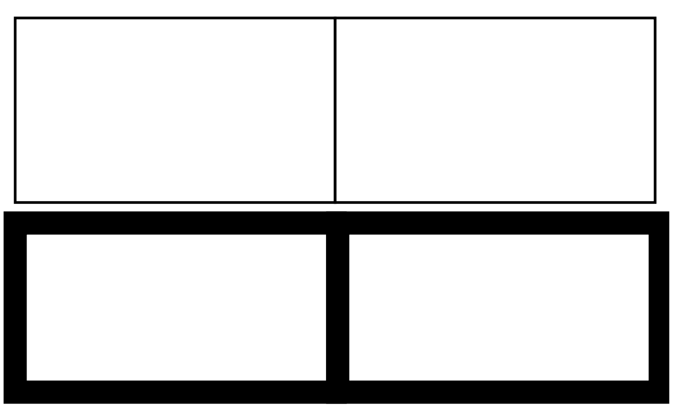
Do we need a special point plotting routine for polygons?
What is OpenGL's point plotting function for a line?
(GL_Lines)
Would you use this to draw a polygon?
Why GL_LINE_STRIP rather than GL_LINES?

How to draw a filled polygon

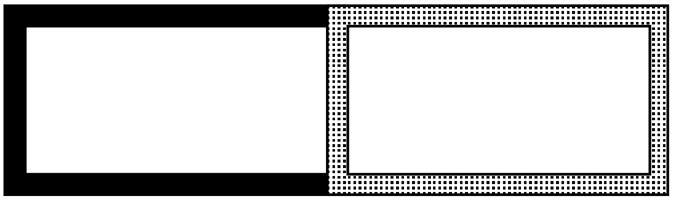
1) Draw polygon boundary (scan-conversion of lines)
Then fill the boundary
2) Draw a filled polygon (scan-conversion of polygons)

Issues:

1) Edge adjacent polygons
Example: Rectangles
How specify?
two opposite corners: (0,0) (20,10)
upper left corner, width, height: 0, 0, 20, 10
(easier to move)
If have two rectangles: 0, 0, 20, 10
20, 0, 20, 10



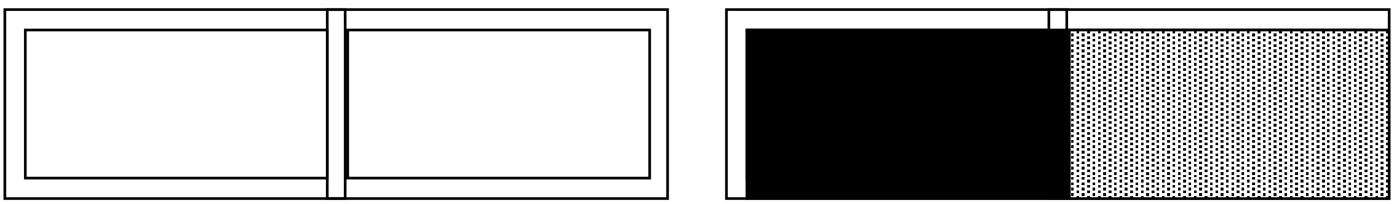
Discretization Problem
Shared edge
Continuous
Discrete



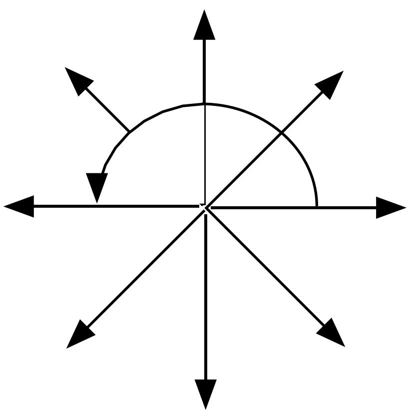
Define which pixels belong to a primitive

Interior pixels obviously belong
What about boundary pixels?
Problem above, as middle column could belong to both
Don't want to scan convert twice
Need to decide what color to display

Solution:
Left and bottom edges drawn and belong to rectangle
Right and top edges not drawn and not belong

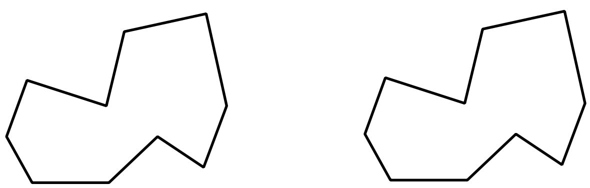


Applies to rectangles and to any other polygon
How apply to any polygon?
Go round polygon in counter clockwise direction
and assign directions to edges



0 <= angle < pi
draw and include

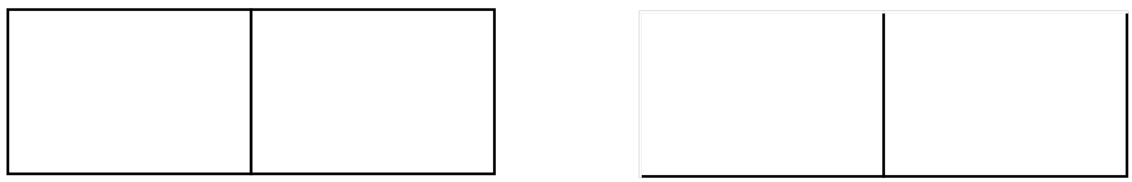
pi <= angle < 2 pi
don't draw or include



Drawing Rule

Still draws some points twice
    Which points?

Can apply rule to filled and unfilled polygons
    When would you apply it to unfilled?



Each span misses it's rightmost pixel
Each rectangle misses it's topmost span

Scan converting rectangles

Write rectangle a scan-line at a time
    a span at a time
    $y = y_C$; $xmin < x <= xmax$

Exploits Spatial Coherence
    Nearby pixels generally have the same value
        When not true?

Exploits Span Coherence
    All pixels on a span have the same value
    Neighboring spans generally have the same value
        Is this true for all polygons?

Edge Coherence
    All pixels on an edge have the same value

Can bundle pixels together into words to reduce memory access

# Draw and then fill Algorithms

Pixel defined filling versus polygon defined filling

Define pixel connectivity

## Neighbors

4-neighbors

| | | |
|---|---|---|
| | [i, j-1] | |
| [i-1, j] | [i, j] | [i+1, j] |
| | [i, j+1] | |

8-neighbors

| | | |
|---|---|---|
| [i-1, j-1] | [i, j-1] | [i+1, j-1] |
| [i-1, j] | [i, j] | [i+1, j] |
| [i-1, j+1] | [i, j+1] | [i+1, j+1] |

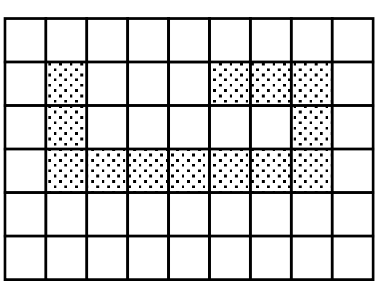
6-neighbors

| | | |
|---|---|---|
| [i-1, j-1] | [i, j-1] | |
| [i-1, j] | [i, j] | [i+1, j] |
| | [i, j+1] | [i+1, j+1] |

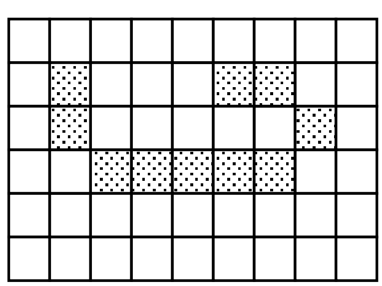
| | | |
|---|---|---|
| | [i, j-1] | [i+1, j-1] |
| [i-1, j] | [i, j] | [i+1, j] |
| [i-1, j+1] | [i, j+1] | |

## Path

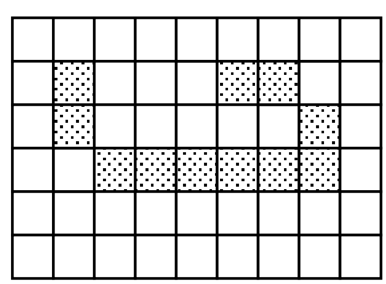
A *path* from the pixel at $[i_0, j_0]$ to the pixel at $[i_n, j_n]$ is a sequence of pixel indices $[i_0, j_0], [i_1, j_1], \ldots, [i_n, j_n]$ s.t. the pixel at $[i_k, j_k]$ is a neighbor of the pixel at $[i_{k+1}, j_{k+1}]$ for all k with $0 <= k <= n-1$.



4? 8? 6?



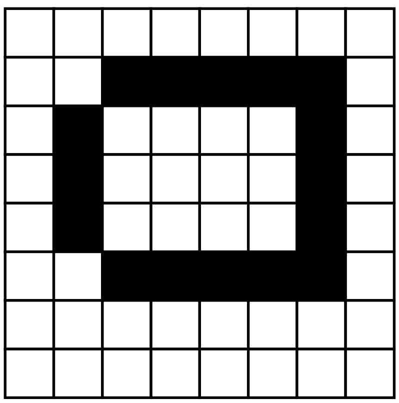
4? 8? 6?



4? 8? 6?

A region (polygon) is n-connected if there exists an n-path between every pair of points in the region.

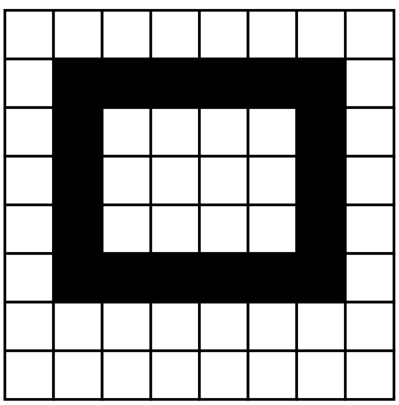
Define different connectivities for boundary and interior pixels



If boundary is 8 connected and interior is 8 connected, then interior of polygon is connected to background

If boundary is 4 connected, then two boundary regions

If boundary is 8 connected and interior is 4 connected, then okay

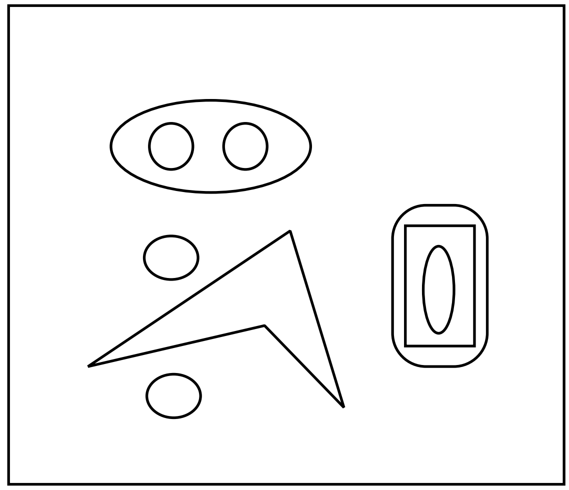


Here okay to have 4 connected boundary and 8 connected interior

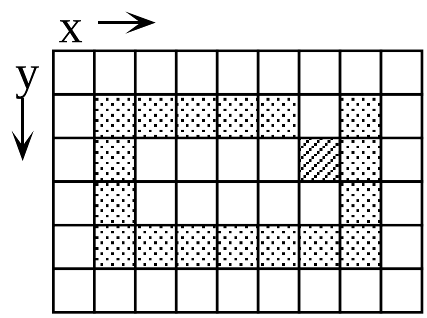
Must use opposite connectivity for boundary and interior in general

Recursive Flood Fill:

```
Label (x, y, interior, new: Integer) ;
Begin
        If (pixel(x,y) == interior) Then
                pixel(x,y) = new;
                Label(x+1, y, interior, new);
                Label(x-1, y, interior, new);
                Label(x, y+1, interior, new);
                Label(x, y-1, interior, new);
        End;
End Label;
```



Elegance versus Efficiency?



# Scan Conversion of Filled Polygons

Uses spatial coherence

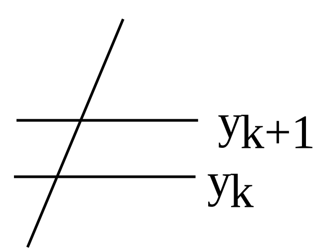
For each scan line crossing a polygon:
- Locate intersections of scan lines with polygon edges
- Sort intersections by x
- Fill horizontal regions using pairs of intersections

(see Figure 1)

Scan lines passing through vertices
- add the intersection twice

(see Figure 2)
- okay for y', not for y
- so add the intersection twice only if end points of two edges don't monotonically increase or decrease
  - (add both only if a local extrema)
  - now okay for both
- OR
- Shorten one edge at vertex where not extrema
  - If monotonically decreasing, then shorten top of next segment such that y = y-1
  - If monotonically increasing, then shorten top of current segment such that y - y-1
  - (see Figure 3)

Use scan coherence to calculate intersections
- express slope in terms of coordinates of scan line intersection points
- $m = (y_{k+1} - y_k) /(x_{k-1} - x_k)$
- $m = 1/(x_{k+1} - x_k)$
- $x_{k+1} = x_k + 1/m$



to avoid using fractions

$x_{k+1} = x_k + \Delta x / \Delta y$

now initialize counter to 0

increment counter by $\Delta x$ as go up a scan line

when counter >= $\Delta y$, then increment current x intersection
and decrease counter by $\Delta y$

Example:

slope = 7/3

counter inc = 3

counter = 0

$x = x_0 = 5$

$y = y_0 = 4$

| intercepts | counter |
|---|---|
| 5,4 | 0 |
| 5,5 | 3 |
| 5,6 | 6 |
| 6,7 | 9 reset to 2 |
| 6,8 | 5 |
| 7,9 | 8 reset to 1 |

etc. This in essence truncates instead of rounding

Can increment by $2\Delta x$, and decrement by $2\Delta y$ and compare to $\Delta y$

This rounds

How avoid multiplication?

Using a sorted edge table

Going clockwise around polygon, use bucket sort to store edges sorted by smallest y value of edge, and x intercept of low pt

Don't store horizontal edges

Do edge shortening at monotonic vertices

Each entry:

max y value of edge

x intercept for lower vertex of edge

inverse of the slope of edge

($\Delta x$ and $\Delta y$) (see Figure)

Start at scan line at bottom of polygon and generate active edge list
- of all lines crossed by the scanline
  - Add new edges from sorted edge table
  - Remove edges if y > ymax of edge
- If new entry in active edge list then compute scanline intersection
  - else incrementally compute scanline intersection
- Store intersections in same sorted order
- Read off pairs of intersections and fill between them

Example:

| ScanLine | Active List |
|---|---|
| 1 | AE, AB |
| 2 | AE, AB |
| 3 | CD, DE, AE, AB |
| 4 | CD, AB |
| 5 | CD, AB |
| 6 | CB, AB |
| 7 | CB, AB |
| 8 | CB, AB |
| 9 | none |

Inside/Outside Tests

- Different Filling Rules
  - Odd-even rule
  - Nonzero winding rule