Implementation III

Objectives

- Survey Line Drawing Algorithms
  - DDA
  - Bresenham

Rasterization

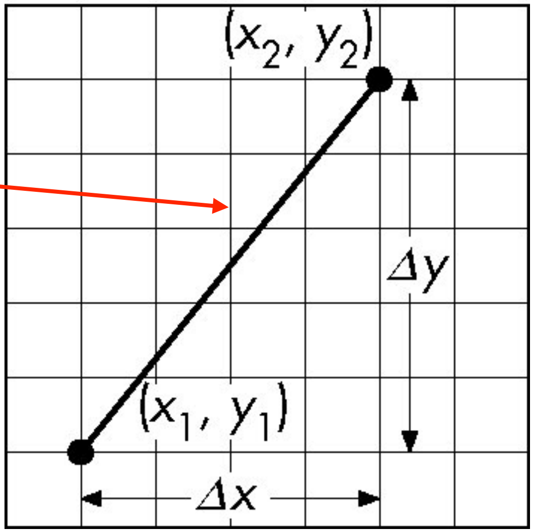
- Rasterization (scan conversion)
  - Determine which pixels that are inside primitive specified by a set of vertices
  - Produces a set of fragments
  - Fragments have a location (pixel location) and other attributes such color and texture coordinates that are determined by interpolating values at vertices
- Pixel colors determined later using color, texture, and other vertex properties

Scan Conversion of Line Segments

- Start with line segment in window coordinates with integer values for endpoints
- Assume implementation has a **`write_pixel`** function

$$y = mx + h$$

$$m = \frac{\Delta y}{\Delta x}$$



DDA Algorithm

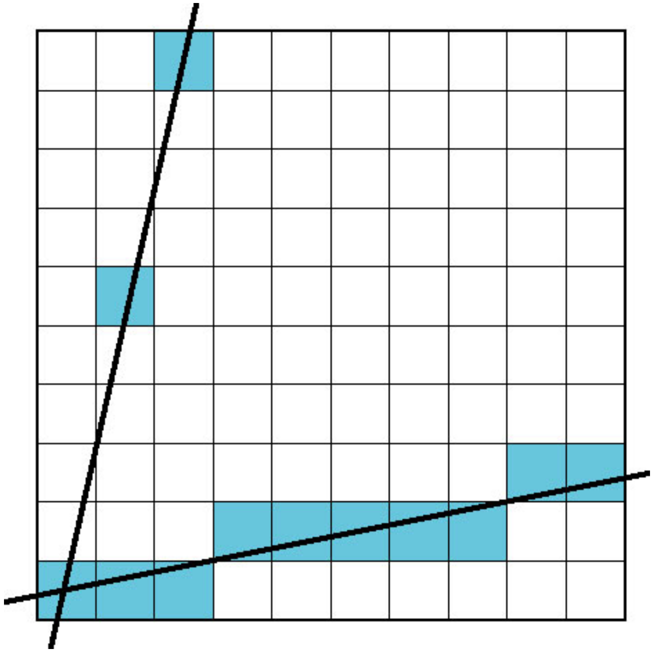
- Digital Differential Analyzer
  - DDA was a mechanical device for numerical solution of differential equations
  - Line $y=mx+h$ satisfies differential equation

    $dy/dx = m = \Delta y/\Delta x = y_2-y_1/x_2-x_1$
- Along scan line $\Delta x = 1$

```
For(x=x1; x<=x2,ix++) {
    y+=m;
   write_pixel(x, round(y), line_color)
}
```

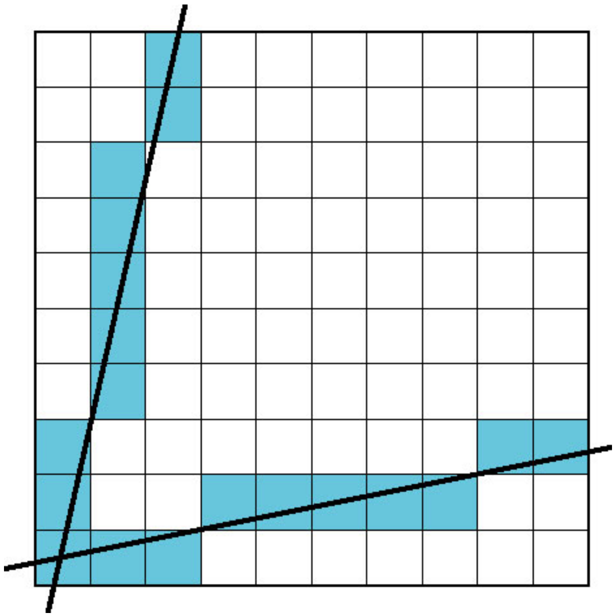
Problem

- DDA = for each x plot pixel at closest y
  - Problems for steep lines



Using Symmetry

- Use for $1 \geq m \geq 0$
- For $m > 1$, swap role of x and y
  - For each y, plot closest x

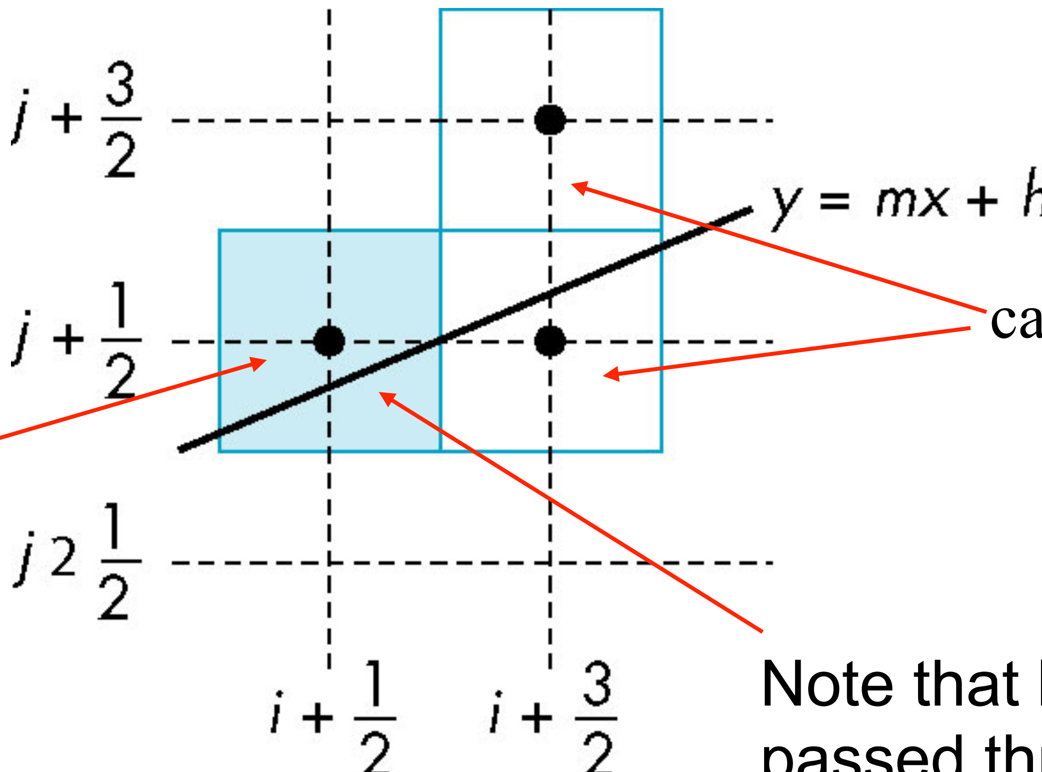


Bresenham's Algorithm

- DDA requires one floating point addition per step
- We can eliminate all fp through Bresenham's algorithm
- Consider only $1 \geq m \geq 0$
  - Other cases by symmetry
- Assume pixel centers are at half integers
- If we start at a pixel that has been written, there are only two candidates for the next pixel to be written into the frame buffer

Candidate Pixels

$1 \geq m \geq 0$



candidates

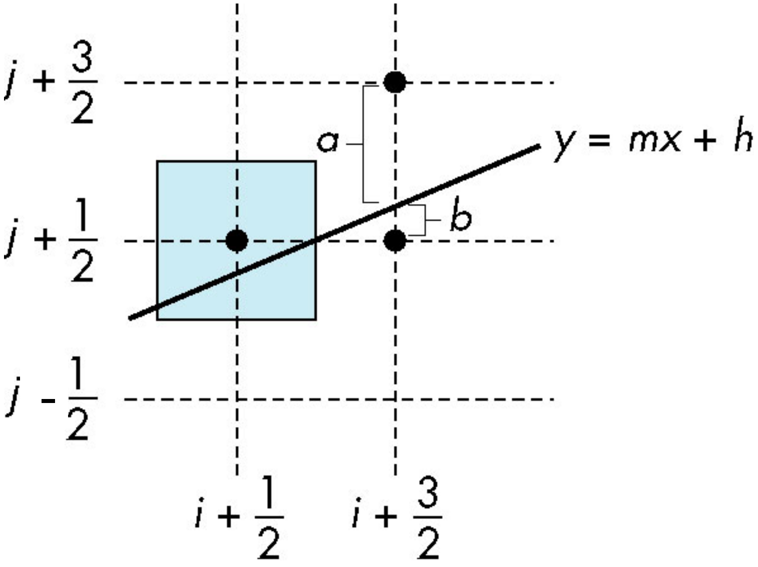
last pixel

Note that line could have passed through any part of this pixel

Decision Variable

$d = \Delta x(b-a)$

d is an integer
d > 0 use upper pixel
d < 0 use lower pixel



Incremental Form

- More efficient if we look at d_k, the value of the decision variable at $x = k$

$$d_{k+1} = d_k + 2\Delta y, \quad \text{if } d_k < 0$$
$$d_{k+1} = d_k + 2(\Delta y - \Delta x), \quad \text{otherwise}$$

- For each x, we need do only an integer addition and a test
- Single instruction on graphics chips

Example

- Consider line from (20,10) to (30,18)

  $\Delta x = 10$,

  $\Delta y = 8$,

  $2\Delta y = 16$

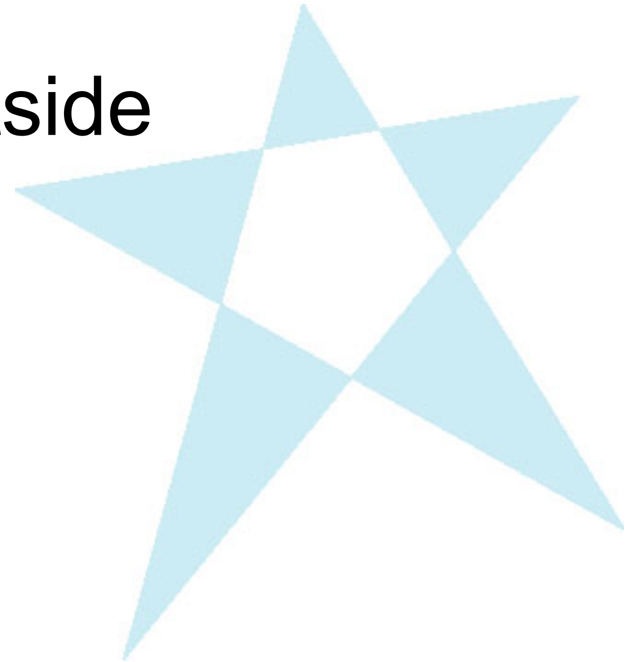
  $2(\Delta y - \Delta x) = -4$

  $d = 2\Delta y - \Delta x = 6$

d	x	y
6	21	11
2	22	12
-2	23	12
14	24	13
10	25	14
6	26	15
2	27	16
-2	28	16
14	29	17
10	30	18

Polygon Scan Conversion

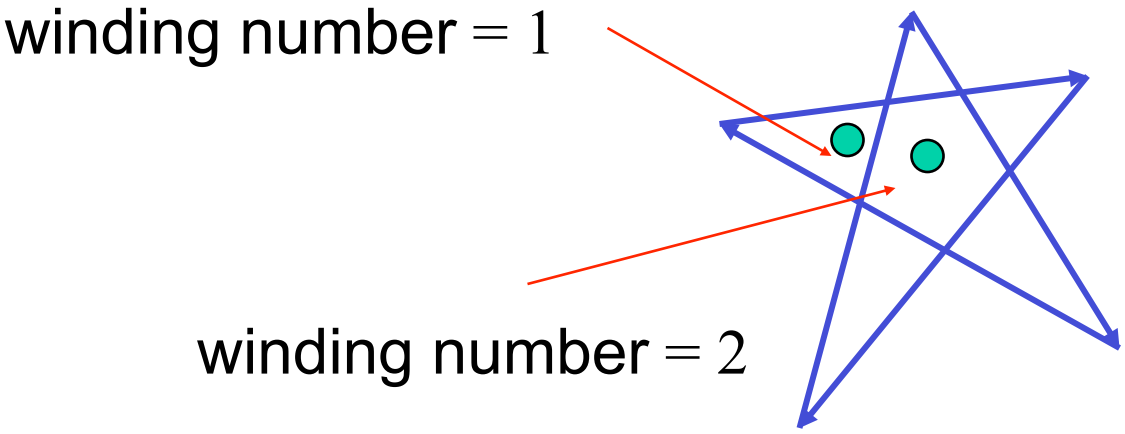
- Scan Conversion = Fill
- How to tell inside from outside
  - Convex easy
  - Nonsimple difficult
  - Odd even test
    - Count edge crossings
  - Winding number



odd-even fill

Winding Number

- Count clockwise encirclements of point



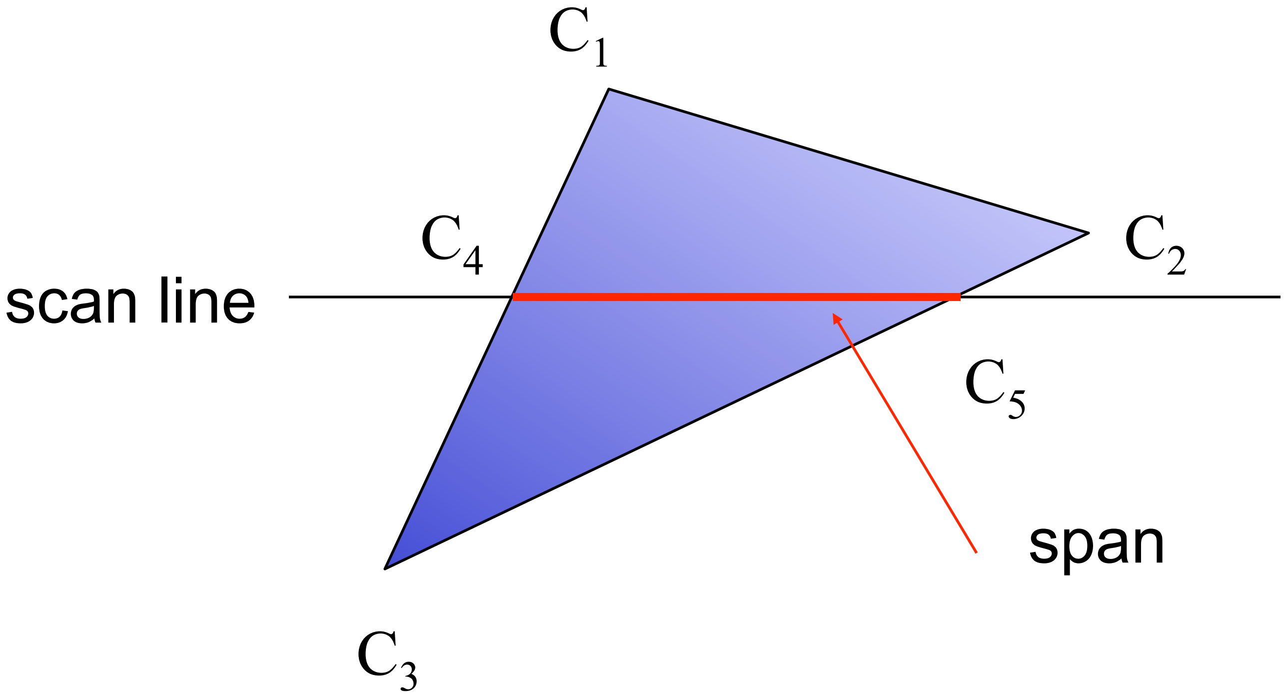
- Alternate definition of inside: inside if winding number $\neq 0$

Filling in the Frame Buffer

- Fill at end of pipeline
  - Convex Polygons only
  - Nonconvex polygons assumed to have been tessellated
  - Shades (colors) have been computed for vertices (Gouraud shading)
  - Combine with z-buffer algorithm
    - March across scan lines interpolating shades
    - Incremental work small

Using Interpolation

C_1 C_2 C_3 specified by **`glColor`** or by vertex shading
C_4 determined by interpolating between C_1 and C_2
C_5 determined by interpolating between C_2 and C_3
interpolate between C_4 and C_5 along span



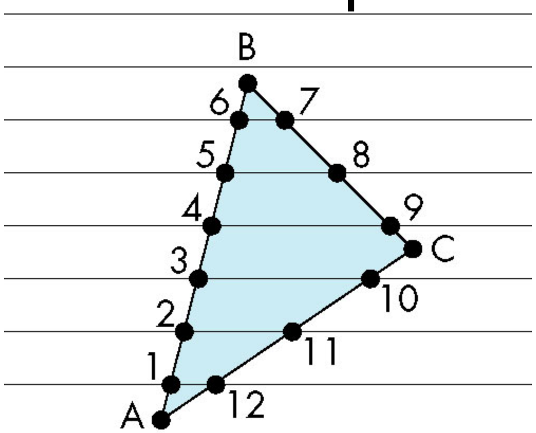
Flood Fill

- Fill can be done recursively if we know a seed point located inside (WHITE)
- Scan convert edges into buffer in edge/inside color (BLACK)

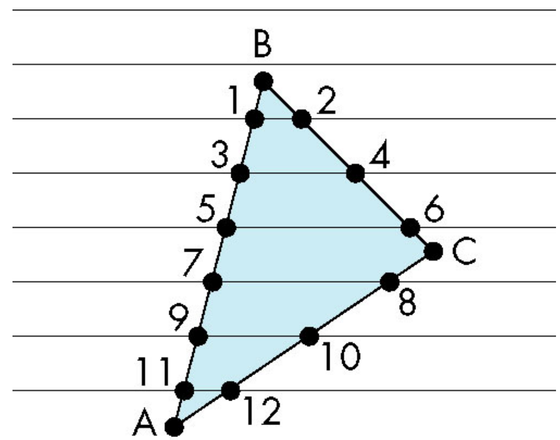
```
flood_fill(int x, int y) {
    if(read_pixel(x,y)= = WHITE) {
        write_pixel(x,y,BLACK);
        flood_fill(x-1, y);
        flood_fill(x+1, y);
        flood_fill(x, y+1);
        flood_fill(x, y-1);
}   }
```

Scan Line Fill

- Can also fill by maintaining a data structure of all intersections of polygons with scan lines
  - Sort by scan line
  - Fill each span

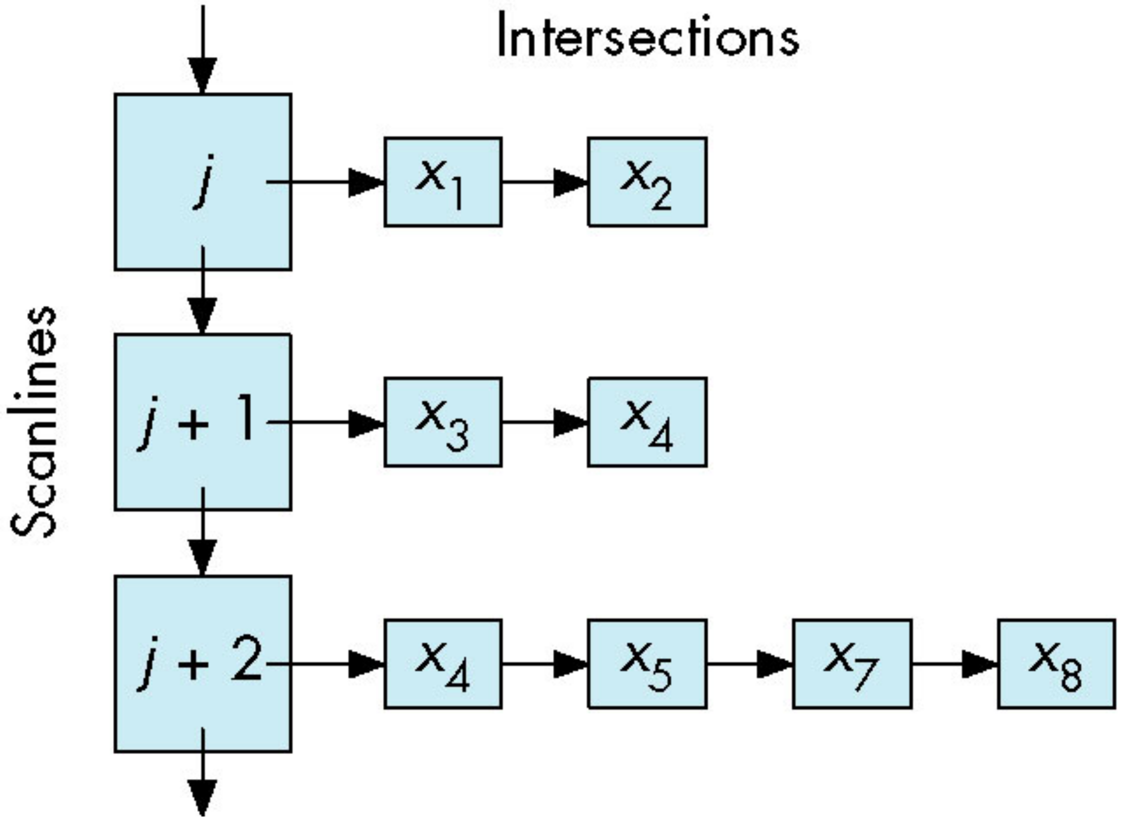


vertex order generated by vertex list



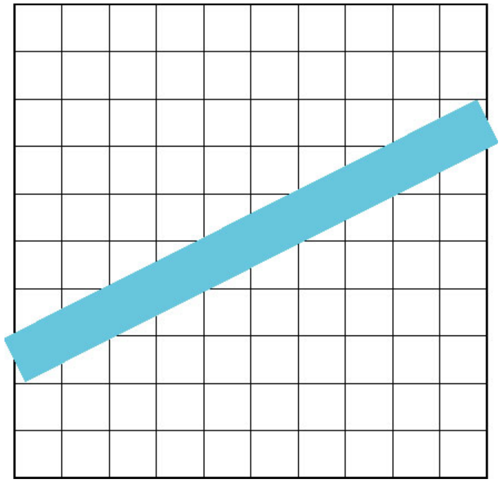
desired order

Data Structure



Aliasing

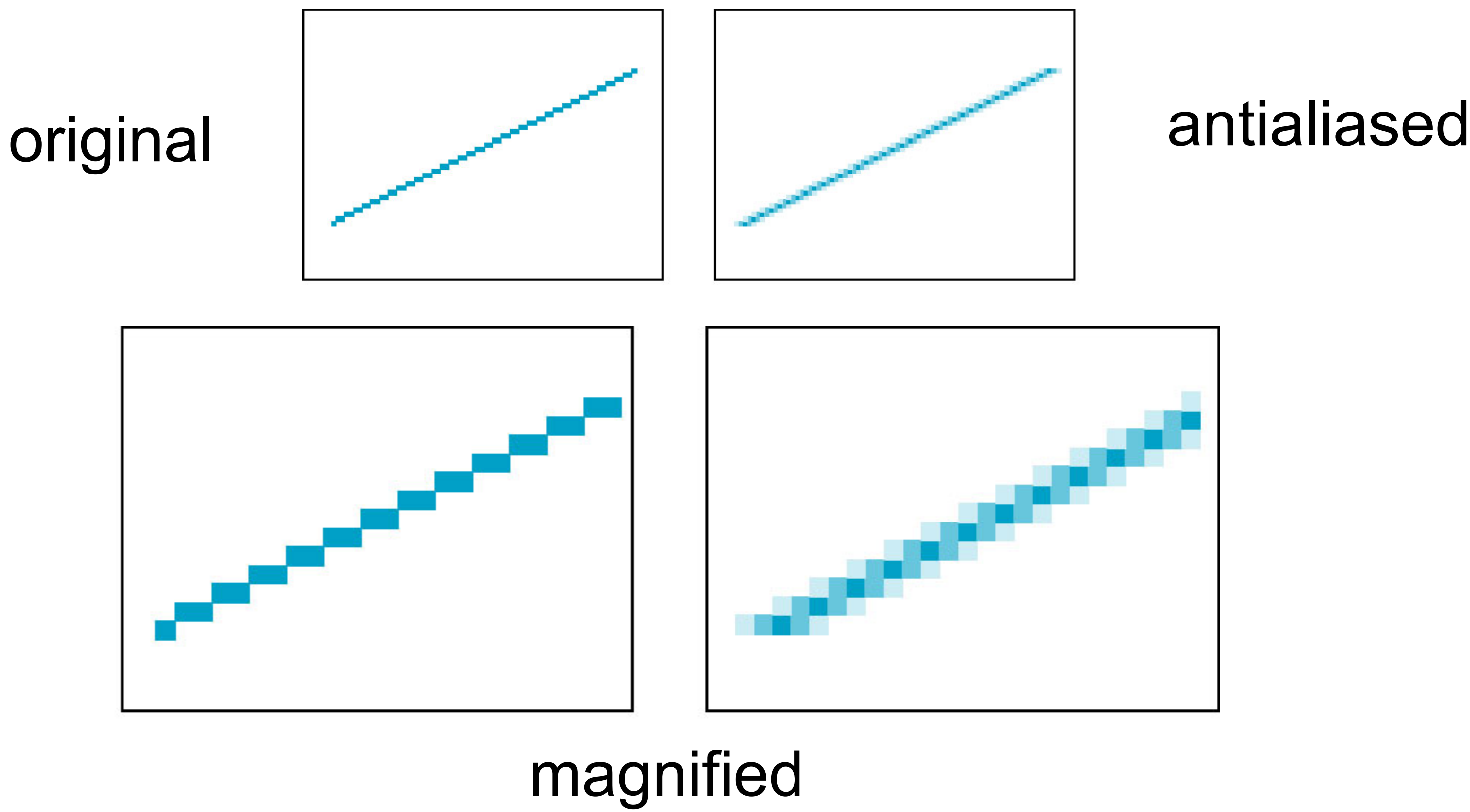
- Ideal rasterized line should be 1 pixel wide



- Choosing best y for each x (or visa versa) produces aliased raster lines

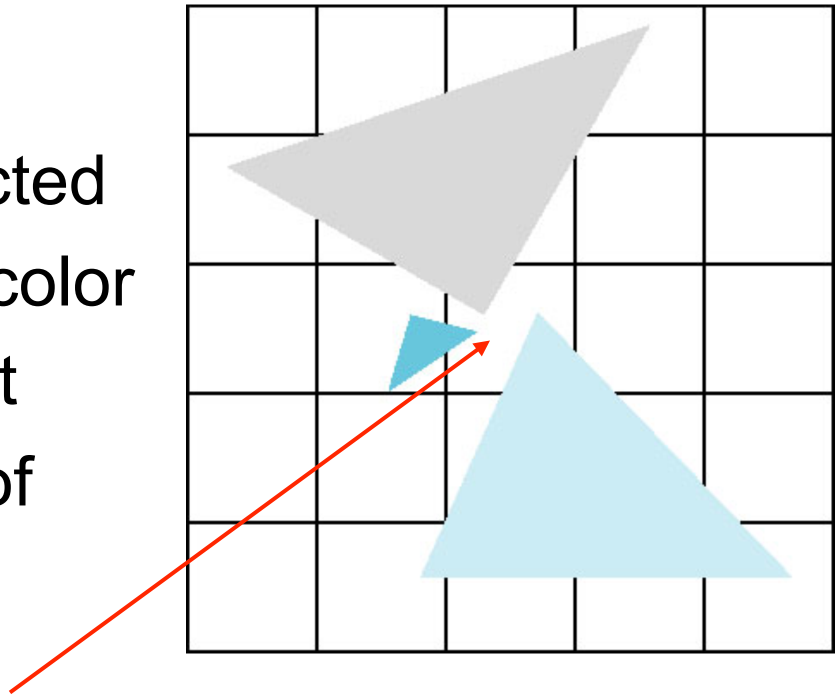
Antialiasing by Area Averaging

- Color multiple pixels for each x depending on coverage by ideal line



Polygon Aliasing

- Aliasing problems can be serious for polygons
  - Jaggedness of edges
  - Small polygons neglected
  - Need compositing so color of one polygon does not totally determine color of pixel



All three polygons should contribute to color