

## Rasterization

Scan Conversion  
Antialiasing  
[Ch 7.8-7.11, 8.9-8.12]

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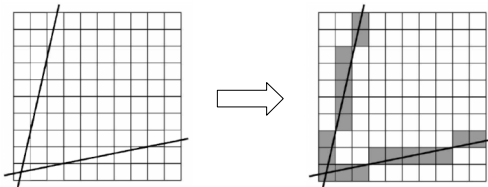
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## Rasterization (scan conversion)

- Final step in pipeline: rasterization
- From screen coordinates (float) to pixels (int)
- Writing pixels into frame buffer
- Separate buffers:
  - depth (z-buffer),
  - display (frame buffer),
  - shadows (stencil buffer),
  - blending (accumulation buffer)

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## Rasterizing a line



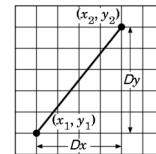
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## Digital Differential Analyzer (DDA)

- Represent line as

$$y = mx + h \quad \text{where} \quad m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\Delta y}{\Delta x}$$

- Then, if  $\Delta x = 1$  pixel, we have  $\Delta y = m \Delta x = m$



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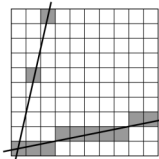
## Digital Differential Analyzer

- Assume `write_pixel(int x, int y, int value)`

```
for (i = x1; i <= x2; i++)
{
    y += m;
    write_pixel(i, round(y), color);
}
```

- Problems:

- Requires floating point addition
- Missing pixels with steep slopes: slope restriction needed

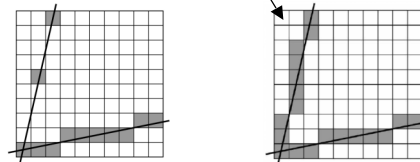


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## Digital Differential Analyzer (DDA)

- Assume  $0 \leq m \leq 1$
- Exploit symmetry
- Distinguish special cases

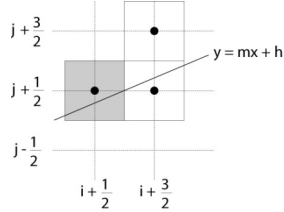
But still requires floating point additions!



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### Bresenham's Algorithm I

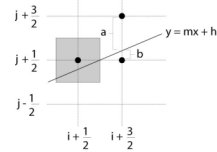
- Eliminate floating point addition from DDA
- Assume again  $0 \leq m \leq 1$
- Assume pixel centers halfway between integers



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### Bresenham's Algorithm II

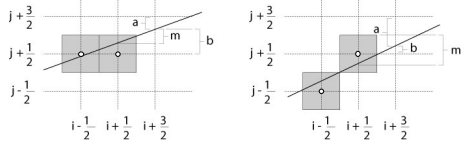
- Decision variable  $a - b$ 
  - If  $a - b > 0$  choose lower pixel
  - If  $a - b \leq 0$  choose higher pixel
- Goal: avoid explicit computation of  $a - b$
- Step 1: re-scale  $d = (x_2 - x_1)(a - b) = \Delta x(a - b)$
- $d$  is always integer



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### Bresenham's Algorithm III

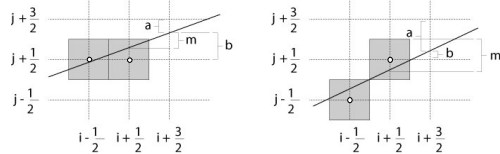
- Compute  $d$  at step  $k + 1$  from  $d$  at step  $k!$
- Case:  $j$  did not change ( $d_k > 0$ )
  - $a$  decreases by  $m$ ,  $b$  increases by  $m$
  - $(a - b)$  decreases by  $2m = 2(\Delta y / \Delta x)$
  - $\Delta x(a - b)$  decreases by  $2\Delta y$



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### Bresenham's Algorithm IV

- Case:  $j$  did change ( $d_k \leq 0$ )
  - $a$  decreases by  $m - 1$ ,  $b$  increases by  $m - 1$
  - $(a - b)$  decreases by  $2m - 2 = 2(\Delta y / \Delta x - 1)$
  - $\Delta x(a - b)$  decreases by  $2(\Delta y - \Delta x)$



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### Bresenham's Algorithm V

- So  $d_{k+1} = d_k - 2\Delta y$  if  $d_k > 0$
- And  $d_{k+1} = d_k - 2(\Delta y - \Delta x)$  if  $d_k \leq 0$
- Final (efficient) implementation:

```
void draw_line(int x1, int y1, int x2, int y2) {
    int x, y = y0;
    int dx = 2*(x2-x1), dy = 2*(y2-y1);
    int dydx = dy-dx, D = (dy-dx)/2;

    for (x = x1; x <= x2; x++) {
        write_pixel(x, y, color);
        if (D > 0) D -= dy;
        else {y++; D -= dydx;}
    }
}
```

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### Bresenham's Algorithm VI

- Need different cases to handle  $m > 1$
- Highly efficient
- Easy to implement in hardware and software
- Widely used

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## Outline

- Scan Conversion for Lines
- Scan Conversion for Polygons
- Antialiasing

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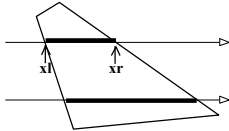
## Scan Conversion of Polygons

- Multiple tasks:
  - Filling polygon (inside/outside)
  - Pixel shading (color interpolation)
  - Blending (accumulation, not just writing)
  - Depth values (z-buffer hidden-surface removal)
  - Texture coordinate interpolation (texture mapping)
- Hardware efficiency is critical
- Many algorithms for filling (inside/outside)
- Much fewer that handle all tasks well

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## Filling Convex Polygons

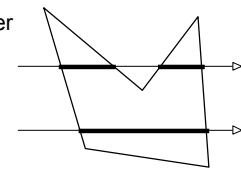
- Find top and bottom vertices
- List edges along left and right sides
- For each scan line from bottom to top
  - Find left and right endpoints of span,  $x_l$  and  $x_r$
  - Fill pixels between  $x_l$  and  $x_r$
  - Can use Bresenham's alg. to update  $x_l$  and  $x_r$



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## Concave Polygons: Odd-Even Test

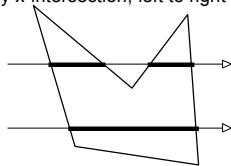
- Approach 1: odd-even test
- For each scan line
  - Find all scan line/polygon intersections
  - Sort them left to right
  - Fill the interior spans between intersections
- Parity rule: inside after an odd number of crossings



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## Edge vs Scan Line Intersections

- Brute force: calculate intersections explicitly
- Incremental method (Bresenham's algorithm)
- Caching intersection information
  - Edge table with edges sorted by  $y_{min}$
  - Active edges, sorted by x-intersection, left to right
- Process image from smallest  $y_{min}$  up



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## Concave Polygons: Tessellation

- Approach 2: divide non-convex, non-flat, or non-simple polygons into triangles
- OpenGL specification
  - Need accept only simple, flat, convex polygons
  - Tessellate explicitly with tessellator objects
  - Implicitly if you are lucky
- Most modern GPUs scan-convert only triangles

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## Flood Fill

- Draw outline of polygon
- Pick color seed
- Color surrounding pixels and recurse
- Must be able to test boundary and duplication
- More appropriate for drawing than rendering



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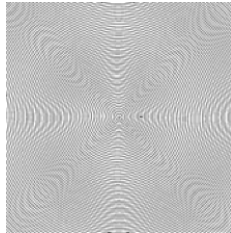
## Outline

- Scan Conversion for Lines
- Scan Conversion for Polygons
- Antialiasing

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## Aliasing

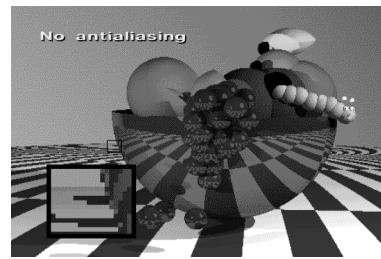
- Artifacts created during scan conversion
- Inevitable (going from continuous to discrete)
- Aliasing (name from digital signal processing): we sample a continuous image at grid points
- Effect
  - Jagged edges
  - Moire patterns



Moire pattern from sandlotscience.com

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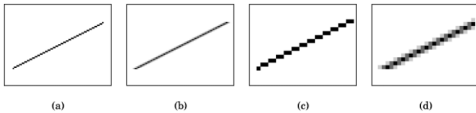
## More Aliasing



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## Antialiasing for Line Segments

- Use area averaging at boundary

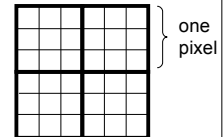


- (c) is aliased, magnified
- (d) is antialiased, magnified
- Warning: these images are sampled on screen!

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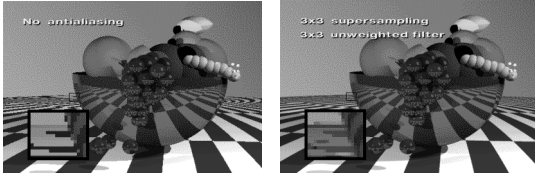
## Antialiasing by Supersampling

- Mostly for off-line rendering (e.g., ray tracing)
- Render, say, 3x3 grid of mini-pixels
- Average results using a filter
- Can be done adaptively
  - Stop if colors are similar
  - Subdivide at discontinuities



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## Supersampling Example

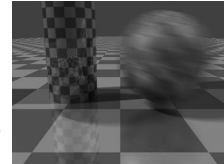


- Other improvements
  - Stochastic sampling (avoiding repetition)
  - Jittering (perturb a regular grid)

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## Temporal Aliasing

- Sampling rate is frame rate (30 Hz for video)
- Example: spokes of wagon wheel in movie
- Possible to supersample and average
- Fast-moving objects are blurred
- Happens automatically with real hardware (photo and video cameras)
  - Exposure time (shutter speed)
  - Memory persistence (video camera)
  - Effect is motion blur



Motion blur

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## Wagon Wheel Effect



Source: YouTube

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## Motion Blur Example

Achieve by stochastic sampling in time



T. Porter, Pixar, 1984  
16 samples / pixel / timestep

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## Summary

- Scan Conversion for Polygons
  - Basic scan line algorithm
  - Convex vs concave
  - Odd-even rules, tessellation
- Antialiasing (spatial and temporal)
  - Area averaging
  - Supersampling
  - Stochastic sampling

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