

Rasterization

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

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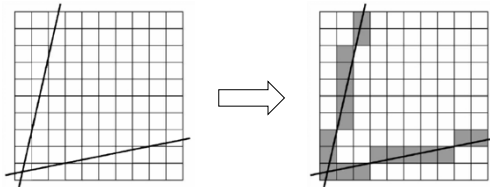
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Rasterization (scan conversion)

- 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



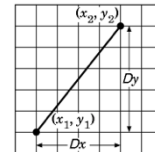
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Digital Differential Analyzer (DDA)

- 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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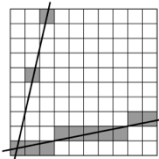
Digital Differential Analyzer

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

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

- Problems:

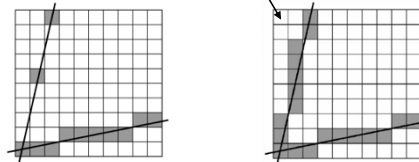
- Requires floating point addition
- Missing pixels with steep slopes: slope restriction needed



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Digital Differential Analyzer (DDA)

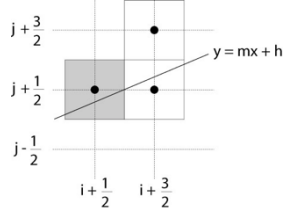
- Assume $0 \leq m \leq 1$
 - Exploit symmetry
 - Distinguish special cases
- But still requires floating point additions!



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Bresenham's Algorithm I

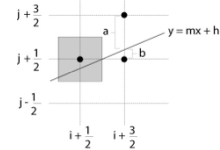
- Eliminate floating point addition from DDA
- Assume again $0 \leq m \leq 1$
- Assume pixel centers halfway between integers



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Bresenham's Algorithm II

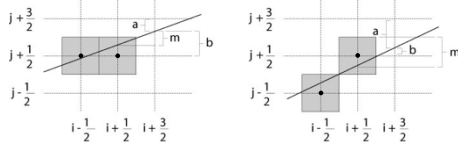
- Decision variable $a - b$
 - If $a - b > 0$ choose lower pixel
 - If $a - b \leq 0$ choose higher pixel
- Goal: avoid explicit computation of $a - b$
- Step 1: re-scale $d = (x_2 - x_1)(a - b) = \Delta x(a - b)$
- d is always integer



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Bresenham's Algorithm III

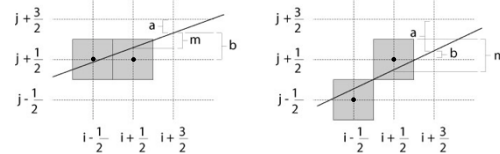
- Compute d at step $k + 1$ from d at step k !
- Case: j did not change ($d_k > 0$)
 - a decreases by m , b increases by m
 - $(a - b)$ decreases by $2m = 2(\Delta y / \Delta x)$
 - $\Delta x(a - b)$ decreases by $2\Delta y$



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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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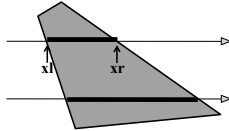
Scan Conversion of Polygons

- 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

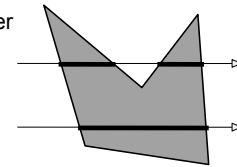
- Find top and bottom vertices
- List edges along left and right sides
- For each scan line from bottom to top
 - Find left and right endpoints of span, x_l and x_r
 - Fill pixels between x_l and x_r
 - Can use Bresenham's algorithm to update x_l and x_r



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Concave Polygons: Odd-Even Test

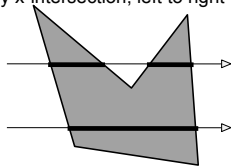
- Approach 1: odd-even test
- For each scan line
 - Find all scan line/polygon intersections
 - Sort them left to right
 - Fill the interior spans between intersections
- Parity rule: inside after an odd number of crossings



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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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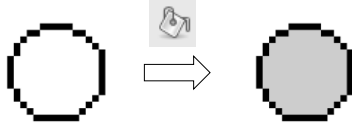
Concave Polygons: Tessellation

- 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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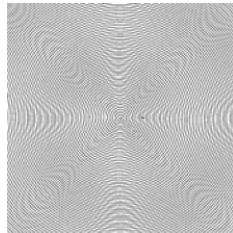
Outline

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

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Aliasing

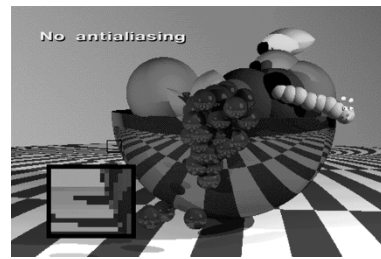
- Artifacts created during scan conversion
- Inevitable (going from continuous to discrete)
- Aliasing (name from digital signal processing): we sample a continuous image at grid points
- Effect
 - Jagged edges
 - Moire patterns



Moire pattern from sandlotscience.com

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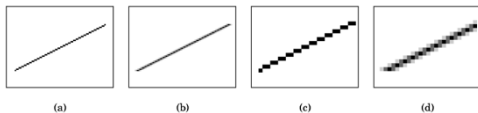
More Aliasing



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Antialiasing for Line Segments

- Use area averaging at boundary

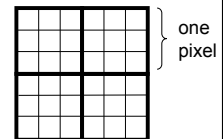


- (c) is aliased, magnified
- (d) is antialiased, magnified

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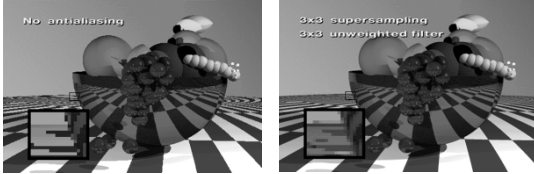
Antialiasing by Supersampling

- 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

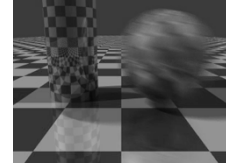


- Other improvements
 - Stochastic sampling: avoid sample position repetitions
 - Stratified sampling (jittering) : perturb a regular grid of samples

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Temporal Aliasing

- Sampling rate is frame rate (30 Hz for video)
- Example: spokes of wagon wheel in movies
- Solution: supersample in time and average
 - Fast-moving objects are blurred
 - Happens automatically with real hardware (photo and video cameras)
 - Exposure time is important (shutter speed)
 - Effect is called 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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