CSCI 420 Computer Graphics
Lecture 14

Rasterization

Scan Conversion
Antialiasing
[Angel Ch. 6]

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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)
Rasterizing a line
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 \( \Delta y = m \Delta x = m \)
Digital Differential Analyzer

• Assume write_pixel(int x, int y, int value)

```c
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
Digital Differential Analyzer (DDA)

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

But still requires floating point additions!
Bresenham’s Algorithm I

- Eliminate floating point addition from DDA
- Assume again $0 \leq m \leq 1$
- Assume pixel centers halfway between integers
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
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 $2\Delta y$
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 \(2(\Delta y - \Delta x)\)
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:

```c
void draw_line(int x1, int y1, int x2, int y2) {
    int x, y = y0;
    int twice_dx = 2 * (x2 - x1), twice_dy = 2 * (y2 - y1);
    int twice_dy_minus_twice_dx = twice_dy - twice_dx;
    int d = twice_dx / 2 - twice_dy;

    for (x = x1 ; x <= x2 ; x++) {
        write_pixel(x, y, color);
        if (d > 0) d -= twice_dy;
        else {y++; d -= twice_dy_minus_twice_dx ;}
    }
}
```
Bresenham’s Algorithm VI

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

• Scan Conversion for Lines
• Scan Conversion for Polygons
• Antialiasing
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
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 $x_r$
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
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
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
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
Outline

• Scan Conversion for Lines
• Scan Conversion for Polygons
• Antialiasing
Aliasing

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

Moire pattern from sandlotscience.com
More Aliasing
Antialiasing for Line Segments

• Use area averaging at boundary

• (c) is aliased, magnified
• (d) is antialiased, magnified
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
Supersampling Example

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

Source: YouTube
Motion Blur Example

Achieve by stochastic sampling in time

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