

CSCE 441 Computer Graphics

scan conversion of lines

- horizontal, vertical lines are easy
- for general lines, assume $0 < slope < 1$ (flat to diagonal)
 - you can transform any line to fit this
- naive algorithm would just use floating point and round off
 - floating point is sometimes slow (especially back when not every computer did it in hardware)
- slope from two points:

$$m = \frac{y_H - y_L}{x_H - x_L} a$$

- $s \frac{a}{b}$
- intercept from two points: $b = y_L - m * x_L$
- **Simple Algorithm**
 - start from (xL, yL) and draw to (xH, yH)
 - * where $xL < xH$
 - ```
def draw_line(xL, yL, xH, yH):
 x, y = (xL, yL)
 for i in range(0, xH - xL):
 draw_pixel(x, round(y))
 x = x + 1
 y = m * x + b # simplifies to
 y = y + m
```
  - problem: uses floating point math
  - problem: rounding
- **Midpoint Algorithm**
  - given a point, we just need to know whether we will move right or up and right on the next step (N or NE)
  - we can simplify this to whether the actual line travels above or below the point  $(x + 1, y + 1/2)$ 
    - \* so we derive formula from  $y = m * x + b$
  - formula:  $f(x, y) = c * x + d * y + e$ 
    - \*  $c = yL - yH$
    - \*  $d = xL - xH$
    - \*  $e = b * (xL - xH)$
    - \*  $f(x, y) = 0$ :  $(x, y)$  is on the line
    - \*  $f(x, y) < 0$ :  $(x, y)$  below line
    - \*  $f(x, y) > 0$ :  $(x, y)$  above line
  - don't want to recalculate formula at every step, so do it iteratively
    - \* that is, use  $f(x + 1, y + 1/2)$  to calculate  $f(x + 2, y + 1/2)$  or  $f(x + 2, y + 3/2)$  depending on right or up-right choice last time
  - went right last time, now calculate  $f(x + 2, y + 1/2)$

- \*  $f(x + 2, y + 1/2) = c + f(x + 1, y + 1/2)$
- went up-right last time, now calculate  $f(x + 2, y + 1/2)$ 
  - \*  $f(x + 2, y + 3/2) = c + d + f(x + 1, y + 1/2)$
- starting value:  $f(x + 1, y + 1/2) = f(xL, yL) + c + (1/2)d = c + (1/2)d$ 
  - \* we can eliminate  $f(xL, yL)$  because we know it is on the line
  - \* furthermore, we can use  $f(x + 1, y + 1/2) = 2 * c + d$  because multiplying by 2 does not change the sign of  $f$ . Also, this saves an expensive division
- full algorithm:
 

```
def midpoint_algorithm_line(xL, yL, xH, yH):
 x = xL
 y = yL
 d = xH - xL
 c = yL - yH
 sum = 2*c + d
 draw_pixel(x,y)
 while x < xH:
 if sum < 0:
 sum += 2*d
 y += 1
 x += 1
 sum += 2*c
 draw_pixel(x,y)
```
- pro:
  - \* only integer operations
  - \* extends to other kinds of shapes, just need formula to tell if inside/outside shape (called implicit formula)
- same as Bresenham's algorithm (more common algorithm)

## scan conversion of polygons

- to deal with overlap, we do not draw the top and right of a polygon
  - this means artifacts are possible. This doesn't really matter since pixels are very small
- rectangles (aligned with axes) are easy
- scan line: one row of pixels
- general polygons: basic idea (**scanline method**)
  - intersect scan lines with edges of polygon
  - this means you must keep track of which edges intersect with which scan lines
    - \* this is easy to do: just look at the y coordinate
  - consecutive scan lines will usually intersect with a similar set of edges
    - \* so we can use coherence to speed stuff up
  - we can throw out horizontal lines. They are implicitly represented by

- start and end, connecting to the other edges
- data structures
  - \* edge: maxY, currentX, xIncr (increment)
    - calculate these from the two points
    - xIncr is inverse of slope, but you can't calculate the slope and invert it, because divide by 0
    - maxY: y value of higher point
    - currentX: x value of lower point
  - \* active edge table
    - has entry for every scanline on the screen
    - initialize with edges by indexing by minY of edge
  - \* active edge list
    - stores edges that intersect with the current scan line being processed
    - edges must always be sorted by current x value
- at each step of the algorithm, you must update the active edge list
  - \* remove edges where maxY is less than or equal to the current scan line
    - less or equal because we don't draw the top and right of the polygon
  - \* add edges from the current scan line to the edge list
  - \* sort all edges by currentX
- then draw the scan line
  - \* take pairs of edges and fill in between their currentX values
    - do not include the right point (because we don't draw the top and right of the polygon)
  - \* if you ever have an odd number of edges in the active edge list, you made a mistake
- disadvantages
  - \* does not handle long, thin polygons well
  - \* incremental updates are not suitable for massively parallel GPUs
- boundary fill
  - draw the boundary of the polygon, then fill in interior
    - \* fill in interior wherever it is not the same color as you are drawing
  - need to be sure filling can't escape out from an edge or corner
  - need to be able to choose arbitrary interior point to start from
- flood fill
  - starting at point, recursively replace one color with another
  - paint bucket tool

## openGL data CPU to GPU

- openGL can accept data various ways, with different speed impacts
- speed depends on driver implementation

- GPUs only render triangles, and triangles usually share vertexes with other triangles, so saving lots of bandwidth is possible
- fastest is usually vertex buffer objects?
  - stores data directly on GPU?

## clipping lines

- it's not really possible to draw things that are outside of the viewing area
- clipping points is easy (when comparing to rectangular window)
- clipping lines:
  - if both end points are inside window, draw it
- window intersection method:
  - if either or both is outside, intersect line with each window border in sequence
  - $(x_1, y_1), (x_2, y_2)$  intersect with vertical edge at  $x_{right}$ :  
 $y_{intersect} = y_1 + m * (x_{right} - x_1)$ , where  $m = (y_2 - y_1) / (x_2 - x_1)$
  - $(x_1, y_1), (x_2, y_2)$  intersect with horizontal edge at  $y_{bottom}$ :  
 $x_{intersect} = x_1 + (y_{bottom} - y_1) / m$ , where  $m = (y_2 - y_1) / (x_2 - x_1)$
  - all these intersections are costly to compute
    - \* we would like to efficiently handle trivial accepts and trivial rejects
- cohen-sutherland algorithm
  - classify two points  $p_1, p_2$  using 4-bit codes **c0** and **c1**
  - if **c0** & **c1** != 0: trivial reject
    - \* bitwise AND
    - \* both points are outside one of the boundaries
  - if **c0** | **c1** == 0: trivial accept
    - \* bitwise OR
    - \* none of the coordinates of either point is outside any boundary  
=> line is entirely within window
  - otherwise split line until it is a trivial case
  - bits: | **top** | **bottom** | **right** | **left**
    - \* doesn't matter as long as you're consistent? TODO
    - \* you can determine each of these by just comparing one coordinate with the axes
    - \* thus the comparison is fast
  - disadvantages
    - \* repeated clipping is expensive
  - advantages
    - \* considers all possible trivial accept/reject
- laing-barsky algorithm
  - use parametric form of line for clipping
    - \* means that lines are oriented (have a direction)
  - need to classify lines as moving into or out of the window

- since lines are parametric, we will be finding the parameter value of the intersection
  - \* we can put that back into the formula to get the actual point
- parametric lines
  - \*  $x(t) = x_0 + (x_1 - x_0) * t$
  - \*  $y(t) = y_0 + (y_1 - y_0) * t$
  - \*  $0 \leq t \leq 1$
  - \* solve 2d matrix to intersect lines:
 
$$\begin{bmatrix} x_1 - x_0 & x_2 - x_3 \end{bmatrix} \begin{bmatrix} t \\ s \end{bmatrix} = \begin{bmatrix} x_2 - x_0 \\ y_2 - y_0 \end{bmatrix}$$
- algorithm:
  - \* start with  $t$  on range  $[0, 1]$ 
    - this is  $t_{min}, t_{max}$
  - \* iteratively intersect each line with each edge
    - find intersection at  $t$
    - if line is moving in to out:  $t_{max} = \min(t_{max}, t)$
    - else:  $t_{min} = \max(t_{min}, t)$
    - if  $t_{min} > t_{max}$ : reject line
- moving out vs moving in can be determined by looking at coordinates
  - \* different for each boundary
  - \* e.g. for right boundary,  $x_1 < x_2$  is moving in
  - \* does not depend on where either point is, or whether either point is inside/outside window boundary, just relative positions of the points
- disadvantages
  - \* does not consider trivial accept/reject
- advantages
  - \* computation of  $(x, y)$  is done only once at the end
  - \* computation of parametric intersections is fast (only one division)
- note: clipping line and then rounding to integer coordinates may not produce the correct result, due to round-off error
  - can account for this by calculating sum for use in midpoint algorithm

## clipping polygons

- clipping a polygon can change the number of sides it has
  - minimum number of sides is 3 (triangle)
  - maximum number of sides is  $2n + 1$ ? TODO
  - e.g. maximum number of sides of triangle after clipping is 7 sides
- when clipping convex polygons, you could end up with multiple polygons
- sutherland hodgman clipping
  - clip polygon vs each edge of window individually
  - is not guaranteed to handle convex polygons correctly
    - \* does not split into multiple polygons

\* but usually looks about right

**transformations in 2D**

**fractals and iterated function systems**

**transformations in 3D**

**color**

**lighting**