Scan Conversion

Wolfgang Heidrich

Course News

Assignment 2

- Due Monday, Feb 28

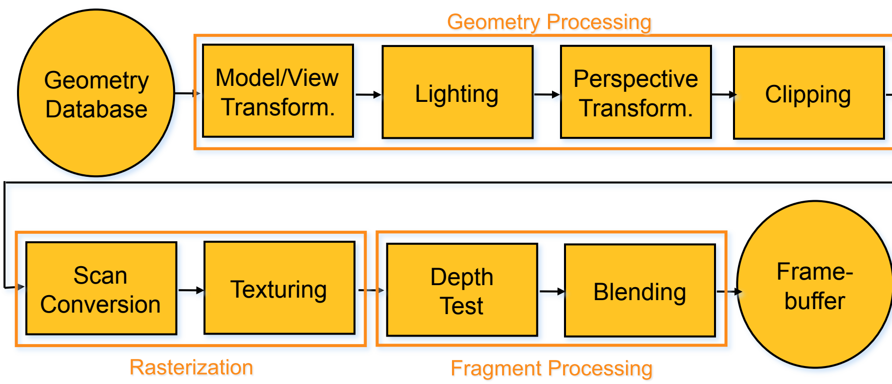
Homework 3

- Discussed in labs next wee

Reading

- Chapter 3 (this week)
- Chapter 8 (next week)

The Rendering Pipeline



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Course News

Assignment 2

- Due March 2

Homework 3

- Discussed in labs next week

Reading

- Chapter 3

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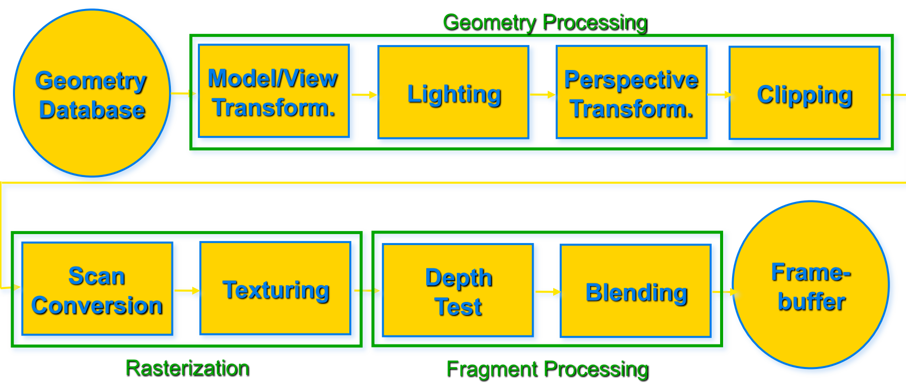
The Rendering Pipeline



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Scan Conversion - Rasterization

Convert continuous rendering primitives into discrete fragments/pixels

- Lines
  - *Midpoint/Bresenham*
- Triangles
  - *Flood fill*
  - *Scanline*
  - *Implicit formulation*
- Interpolation

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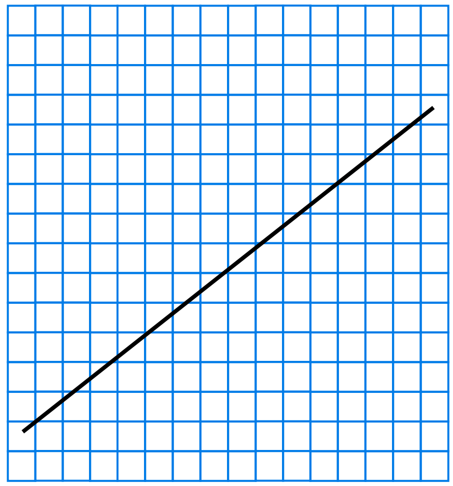
Scan Conversion - Lines



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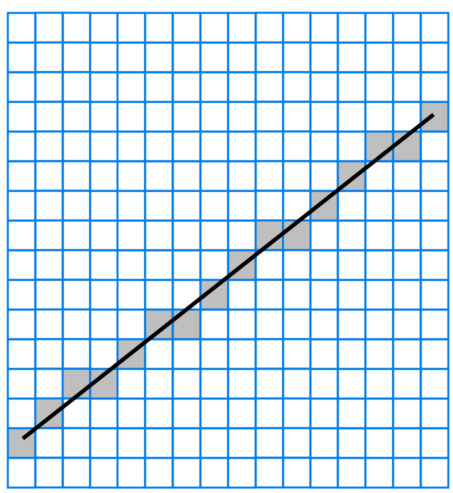
Scan Conversion - Lines



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Scan Conversion - Lines

First Attempt:

- Line (s,e) given in device coordinates
- Create the thinnest line that connects start point and end point without gap

Assumptions for now:

- Start point to the left of end point: xs< xe
- Slope of the line between 0 and 1 (I.e. elevation between 0 and 45 degrees:

$$0 \le \frac{ye - ys}{xe - xs} \le 1$$

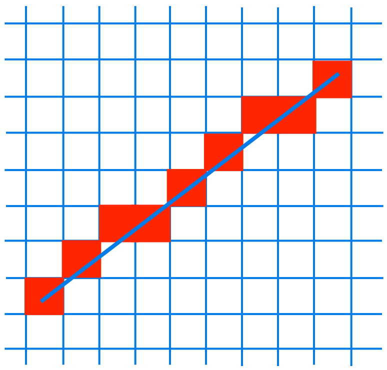
Scan Conversion of Lines - Digital Differential Analyzer

First Attempt:

```
dda( float xs, ys, xe, ye ) {
  // assume xs < xe, and slope m between 0 and 1
  float m= (ye-ys)/(xe-xs);
  float y= round( ys );
  for( int x= round( xs ) ; x<= xe ; x++ ) {
    drawPixel( x, round( y ) );
    y= y+m;
  }
}
```

Scan Conversion of Lines

DDA:



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Scan Conversion of Lines
Midpoint Algorithm

Moving horizontally along x direction

- Draw at current y value, or move up vertically to y+1?
  - *Check if midpoint between two possible pixel centers above or below line*

Candidates

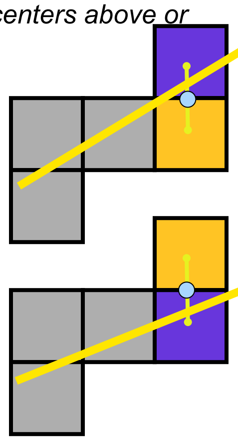
- Top pixel: (x+1,y+1)
- Bottom pixel: (x+1, y)

Midpoint: (x+1, y+.5)

Check if midpoint above or below line

- Below: top pixel
- Above: bottom pixel

Key idea behind Bresenham Alg.



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Scan Conversion of Lines

Idea: decision variable

```
dda( float xs, ys, xe, ye ) {
    float d= 0.0;
    float m= (ye-ys)/(xe-xs);
    int y= round( ys );
    for( int x= round( xs ) ; x<= xe ; x++ ) {
        drawPixel( x, y );
        d= d+m;
        if( d>= 0.5 ) { d= d-1.0; y++; }
    }
}
```

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Scan Conversion of Lines Bresenham Algorithm ('63)

- Use decision variable to generate purely integer algorithm
- Explicit line equation:

$$y = \frac{(y_e - y_s)}{(x_e - x_s)}(x - x_s) + y_s$$

- Implicit version:

$$L(x, y) = \frac{(y_e - y_s)}{(x_e - x_s)}(x - x_s) - (y - y_s) = 0$$

- In particular for specific x, y, we have
  - *L(x,y)>0 if (x,y) below the line, and*
  - *L(x,y)<0 if (x,y) above the line*

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Scan Conversion of Lines
Bresenham Algorithm

- Decision variable: after drawing point (x,y) decide whether to draw
  - $(x+1,y)$: *case E (for "east")*
  - $(x+1,y+1)$: *case NE (for "north-east")*
- Check whether $(x+1,y+1/2)$ is above or below line

$$d = L(x+1, y+\frac{1}{2})$$

- Point above line if and only if $d<0$

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Scan Conversion of Lines

Bresenham Algorithm

- Problem: how to update d?
- Case E (point above line, $d <= 0$)
  - *x= x+1;*
  - d= L($x+2$, $y+1/2$)= $d+ (y_e-y_s)/(x_e-x_s)$
- Case NE (point below line, $d> 0$)
  - *x= x+1; y= y+1;*
  - d= L($x+2$, $y+3/2$)= $d+ (y_e-y_s)/(x_e-x_s)$ -1
- Initialization:
  - d= L(x_s+1, $y_s+1/2$)= $(y_e-y_s)/(x_e-x_s) - 1/2$

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Scan Conversion of Lines

Bresenham Algorithm

- This is still floating point
- But: only sign of d matters
- Thus: can multiply everything by $2(x_e-x_s)$

Scan Conversion of Lines

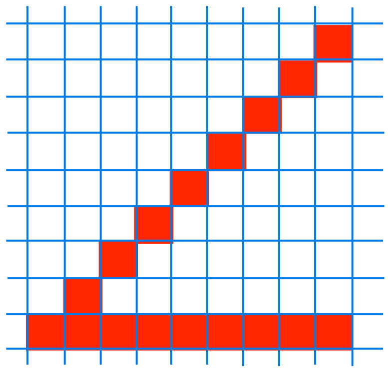
Bresenham Algorithm

```
Bresenham( int xs, ys, xe, ye ) {
    int y= ys;
    incrE= 2(ye - ys);
    incrNE= 2((ye - ys) – (xe-xs));
    for( int x= xs ; x<= xe ; x++ ) {
        drawPixel( x, y );
        if( d<= 0 ) d+= incrE;
        else { d+= incrNE; y++; }
    }
}
```

Scan Conversion of Lines

Discussion

- Bresenham sets same pixels as DDA
- Intensity of line varies with its angle!



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Scan Conversion of Lines

Discussion

- Bresenham
  - *Good for hardware implementations (integer!)*
- DDA
  - *May be faster for software (depends on system)!*
  - *Floating point ops higher parallelized (pipelined)*
    - E.g. RISC CPUs from MIPS, SUN
  - *No if statements in inner loop*
    - More efficient use of processor pipelining

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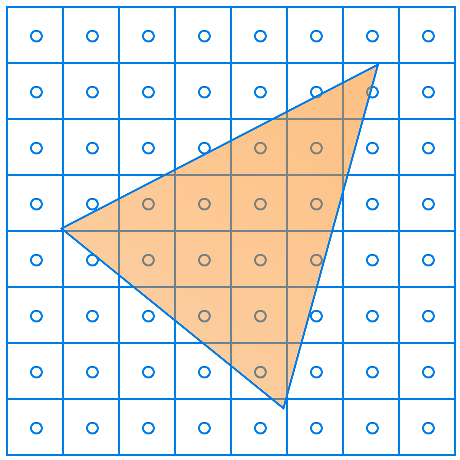
Scan Conversion of Polygons



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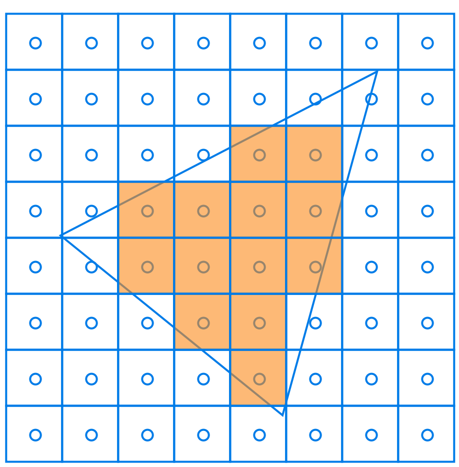
Scan Conversion of Polygons

One possible scan conversion



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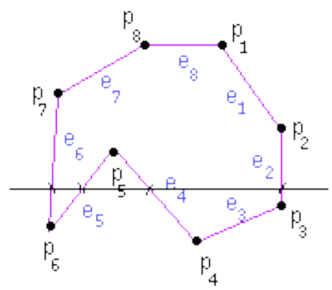
Scan Conversion of Polygons

A General Algorithm

- Intersect each scanline with all edges
- Sort intersections in x
- Calculate parity to determine in/out
- Fill the 'in' pixels



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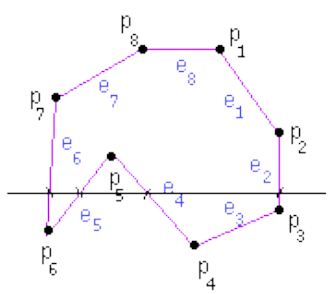
Scan Conversion of Polygons

- Works for arbitrary polygons
- Efficiency improvement:
  - *Exploit row-to-row coherence using "edge table"*



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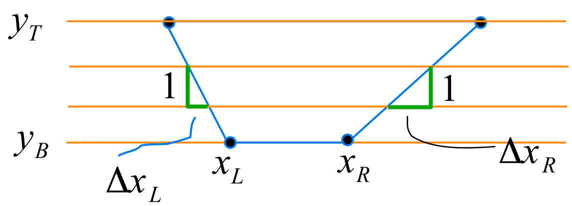
Edge Walking

Past graphics hardware

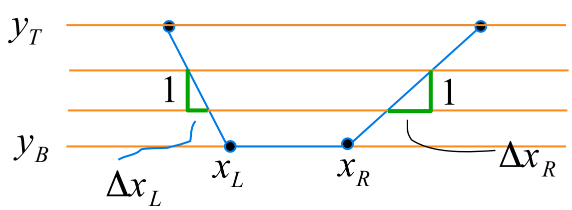
- Exploit continuous L and R edges on trapezoid

scanTrapezoid($x_L, x_R, y_B, y_T, \Delta x_L, \Delta x_R$)



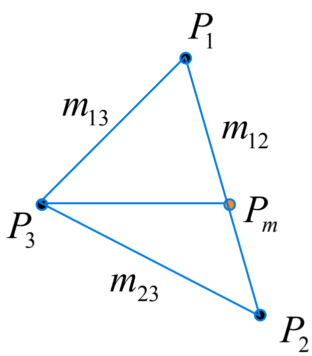
Edge Walking

```
for (y=yB; y<=yT; y++) {
 for (x=xL; x<=xR; x++)
     setPixel(x,y);
 xL += DxL;
 xR += DxR;
}
```



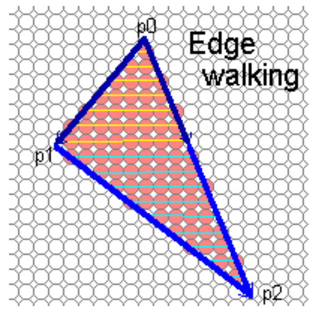
Edge Walking Triangles

- Split triangles into two regions
  with continuous left and right edges



scanTrapezoid($x_3, x_m, y_3, y_1, \frac{1}{m_{13}}, \frac{1}{m_{12}}$ **)**

scanTrapezoid($x_2, x_2, y_2, y_3, \frac{1}{m_{23}}, \frac{1}{m_{12}}$ **)**



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Edge Walking Triangles

Issues

- Many applications have small triangles
  - *Setup cost is non-trivial*
- Clipping triangles produces non-triangles
  - *This can be avoided through re-triangulation, as discussed*

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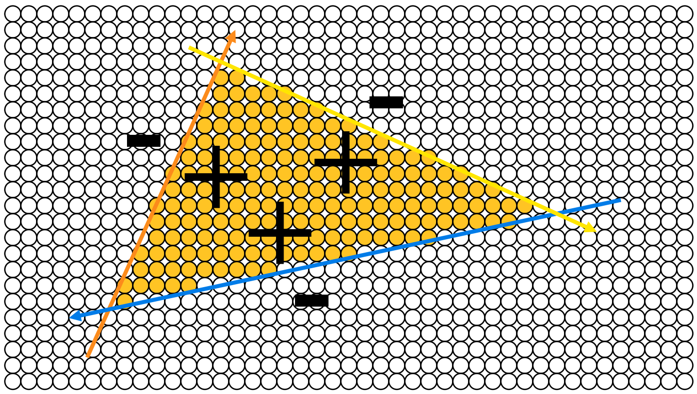
Modern Rasterization: Edge Equations

Define a triangle as follows:



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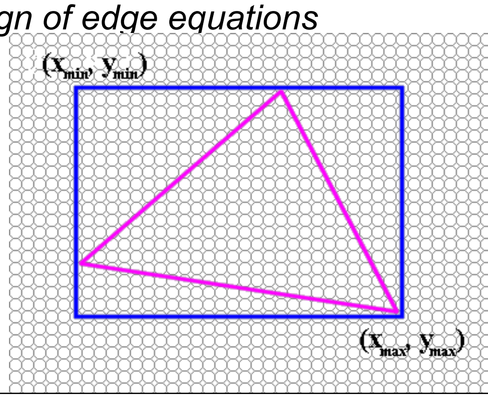
Using Edge Equations

Usage:

- Go over each pixel in bounding rectangle
- Check if pixel is inside/outside of triangle
  - *Using sign of edge equations*



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Computing Edge Equations

Implicit equation of a triangle edge:

$$L(x,y) = \frac{(y_e - y_s)}{(x_e - x_s)}(x - x_s) - (y - y_s) = 0$$

(see Bresenham algorithm)

- L(x,y) positive on one side of edge, negative on the other

Question:

- What happens for vertical lines?

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Edge Equations

Multiply with denominator

$$L(x,y) = (y_e - y_s)(x - x_s) - (y - y_s)(x_e - x_s) = 0$$

- Avoids singularity
- Works with vertical lines

What about the sign?

- Which side is in, which is out?

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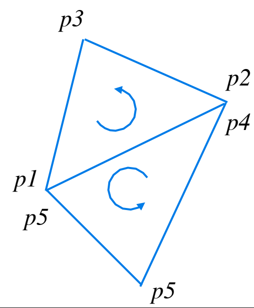
Edge Equations

Determining the sign

- Which side is "in" and which is "out" depends on order of start/end vertices…
- Convention: specify vertices in counter-clockwise order



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Edge Equations

Counter-Clockwise Triangles

- The equation L(x,y) as specified above is *negative inside, positive outside*
  - *Flip sign:*

$$L(x,y) = -(y_e - y_s)(x - x_s) + (y - y_s)(x_e - x_s) = 0$$

Clockwise triangles

- *Use original formula*

$$L(x,y) = (y_e - y_s)(x - x_s) - (y - y_s)(x_e - x_s) = 0$$

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Discussion of Polygon Scan Conversion Algorithms

On old hardware:

- Use first scan-conversion algorithm
  - *Scan-convert edges, then fill in scanlines*
  - *Compute interpolated values by interpolating along edges, then scanlines*
- Requires clipping of polygons against viewing volume
- Faster if you have a few, large polygons
- Possibly faster in software

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Discussion of Polygon Scan Conversion Algorithms

Modern GPUs:

- Use edge equations
  - *And plane equations for attribute interpolation*
  - *No clipping of primitives required*
- Faster with many small triangles

Additional advantage:

- Can control the order in which pixels are processed
- Allows for more memory-coherent traversal orders
  - *E.g. tiles or space-filling curve rather than scanlines*

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Triangle Rasterization Issues (Independent of Algorithm)

Exactly which pixels should be lit?

- A: Those pixels inside the triangle edge (of course)

But what about pixels exactly on the edge?

- Draw them: order of triangles matters (it shouldn't)
- Don't draw them: gaps possible between triangles

We need a consistent (if arbitrary) rule

- Example: draw pixels on left or top edge, but not on right or bottom edge

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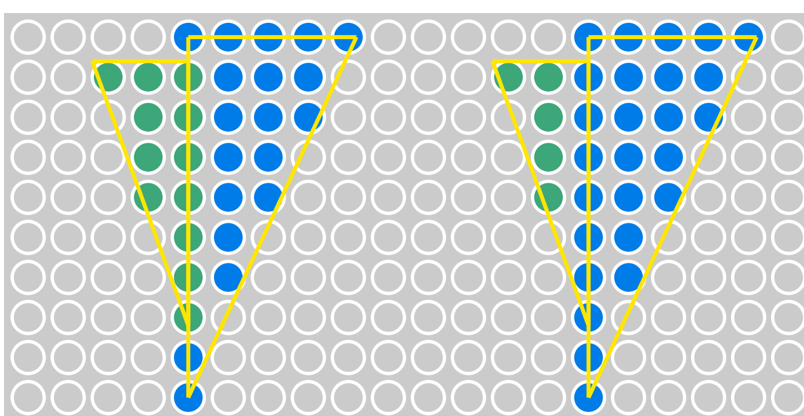
Triangle Rasterization Issues

Shared Edge Ordering



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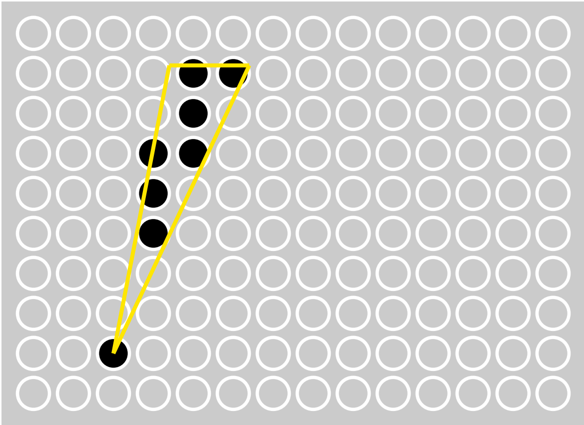
Triangle Rasterization Issues

Sliver



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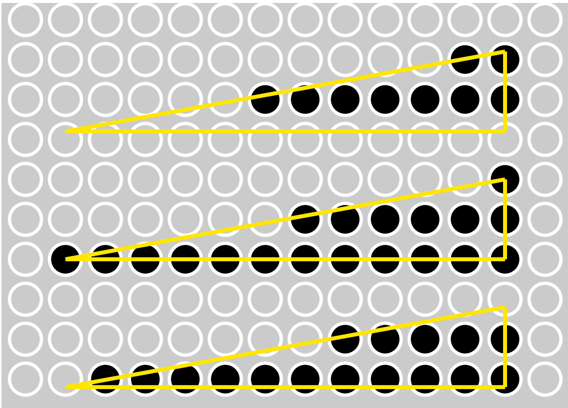
Triangle Rasterization Issues

Moving Slivers



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Triangle Rasterization Issues

These are ALIASING Problems

- Problems associated with representing continuous functions (triangles) with finite resolution (pixels)
- More on this problem when we talk about sampling…

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Coming Up:

Monday

- Scan conversion / shading

Wednesday/Friday

- Clipping, hidden surface removal

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