CS-184: Computer Graphics

Lecture #10: Scan Conversion

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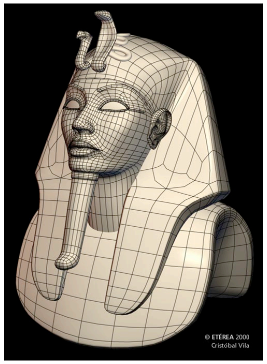
With additional slides based on those of Maneesh Agrawala

Today

- 2D Scan Conversion
  - Drawing Lines
  - Drawing Curves
  - Filled Polygons
  - Filling Algorithms

Drawing a Line

- Basically, its easy... but for the details
- Lines are a basic primitive that needs to be done well...



Drawing a Line

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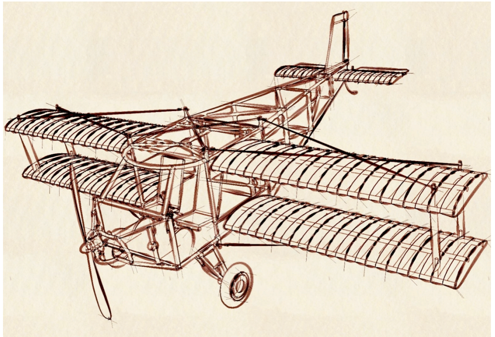
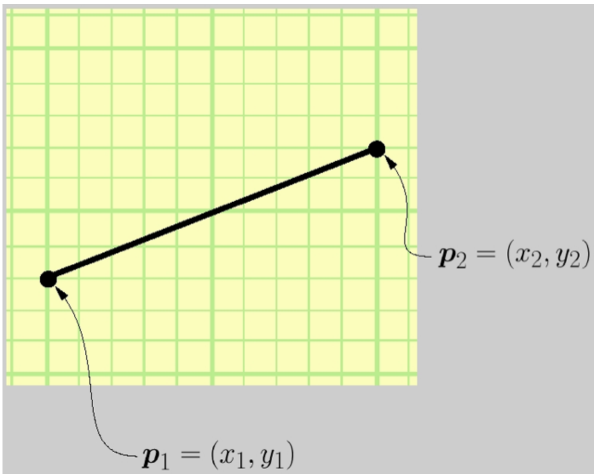
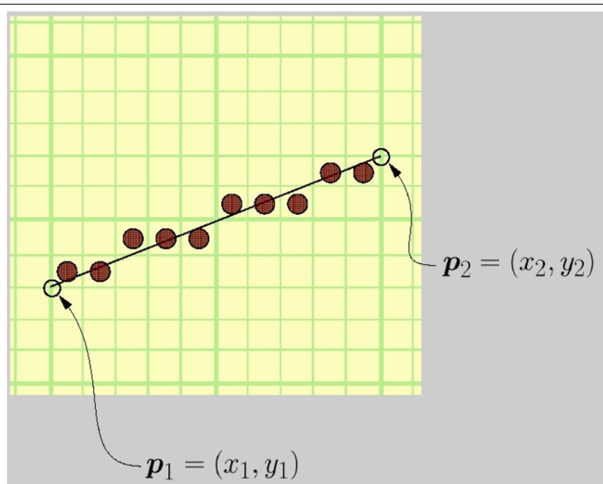


From "A Procedural Approach to Style for NPR Line Drawing from 3D models," by Grabli, Durand, Turquin, Sillion

Drawing a Line



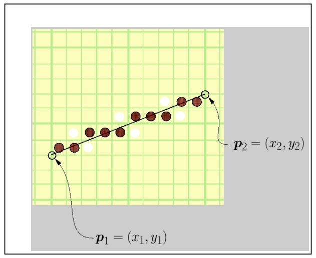
Drawing a Line



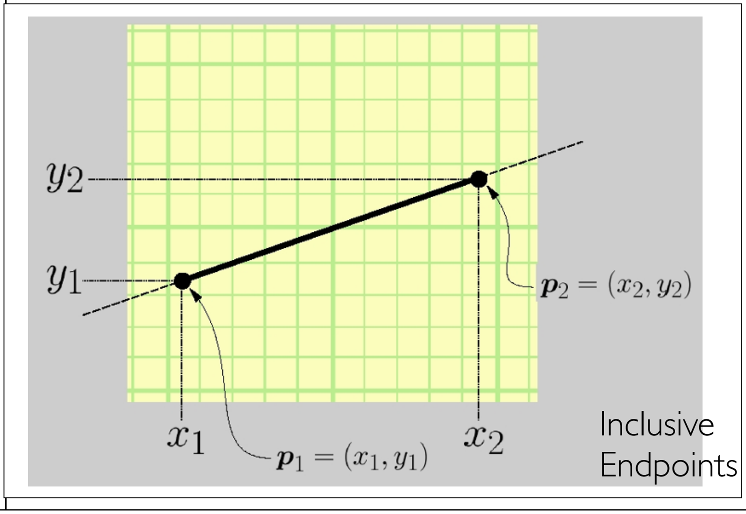
Drawing a Line

- Some things to consider
  - How thick are lines?
  - How should they join up?
  - Which pixels are the right ones?

For example:



Drawing a Line



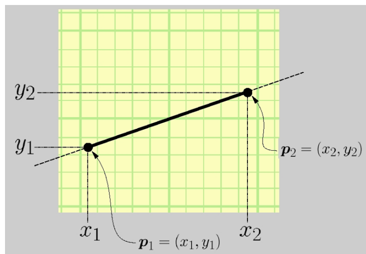
Inclusive Endpoints

Drawing a Line

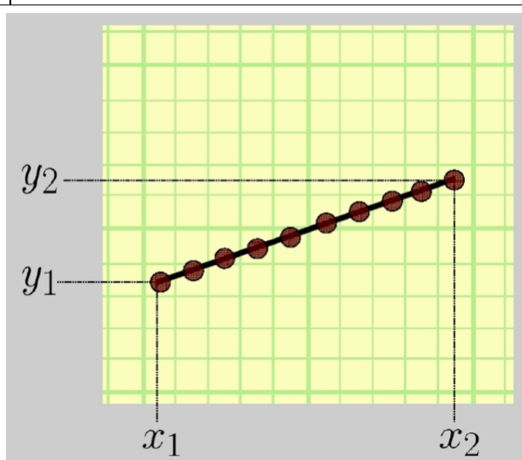
$$y = m \cdot x + b, x \in [x_1, x_2]$$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$b = y1 - m \cdot x_1$$



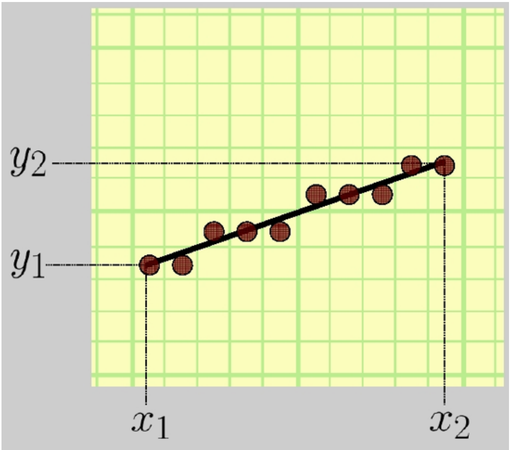
Drawing a Line



$$\Delta x = 1$$
$$\Delta y = m \cdot \Delta x$$

```
x=x1
y=y1
while(x<=x2)
  plot(x,y)
  x++
  y+=Dy
```

Drawing a Line

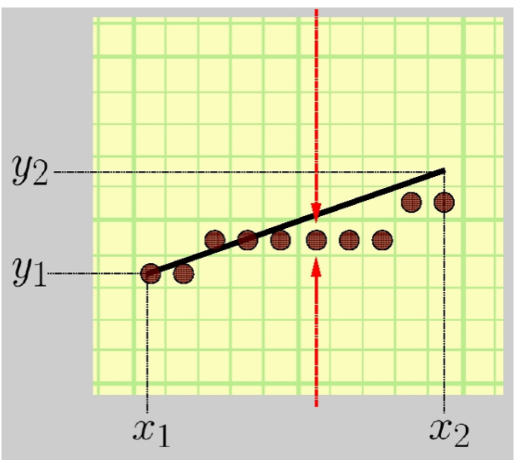


$\Delta x = 1$

$\Delta y = m \cdot \Delta x$

After rounding

Drawing a Line



$\Delta x = 1$

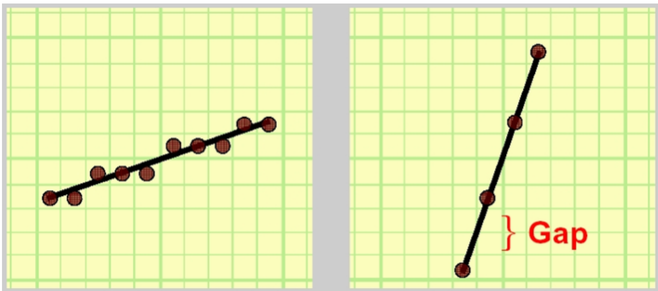
$\Delta y = m \cdot \Delta x$

$y += \Delta y$

Accumulation of roundoff errors

How slow is float-to-int conversion?

Drawing a Line



$|m| \leq 1$ $|m| > 1$

Drawing a Line

```
void drawLine-Error1(int x1,x2, int y1,y2)

  float m = float(y2-y1)/(x2-x1)
  int x = x1
  float y = y1

  while (x <= x2)

    setPixel(x,round(y),PIXEL_ON)

    x += 1
    y += m
```

Not exact math

Accumulates errors

Drawing a Line

```
void drawLine-Error2(int x1,x2, int y1,y2)

  float m = float(y2-y1)/(x2-x1)
  int x = x1
  int y = y1
  float e = 0.0

  while (x <= x2)

    setPixel(x,y,PIXEL_ON)

    x += 1
    e += m
    if (e >= 0.5)
      y+=1
      e-=1.0
```

No more rounding

Drawing a Line

```
void drawLine-Error3(int x1,x2, int y1,y2)

  int x = x1
  int y = y1
  float e = -0.5

  while (x <= x2)

    setPixel(x,y,PIXEL_ON)

    x += 1
    e += float(y2-y1)/(x2-x1)
    if (e >= 0.0)
      y+=1
      e-=1.0
```

Drawing a Line

```
void drawLine-Error4(int x1,x2, int y1,y2)

  int x = x1
  int y = y1
  float e = -0.5*(x2-x1)        // was -0.5

  while (x <= x2)

    setPixel(x,y,PIXEL_ON)

    x += 1
    e += y2-y1                  // was /(x2-x1)
    if (e >= 0.0)               // no change
      y+=1
      e-=(x2-x1)                // was 1.0
```


Drawing a Line

```
void drawLine-Error5(int x1,x2, int y1,y2)

  int x = x1
  int y = y1
  int e = -(x2-x1)              // removed *0.5

  while (x <= x2)

    setPixel(x,y,PIXEL_ON)

    x += 1
    e += 2*(y2-y1)              // added 2*
    if (e >= 0.0)               // no change
      y+=1
      e-=2*(x2-x1)              // added 2*
```

Drawing a Line

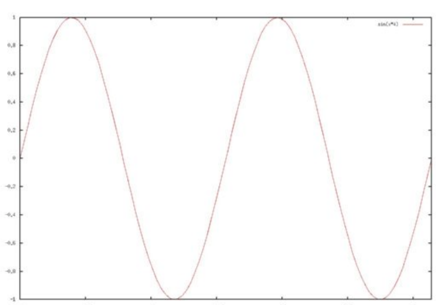
```
void drawLine-Bresenham(int x1,x2, int y1,y2)

  int x = x1
  int y = y1
  int e = -(x2-x1)

  while (x <= x2)

    setPixel(x,y,PIXEL_ON)

    x += 1
    e += 2*(y2-y1)
    if (e >= 0.0)
      y+=1
      e-=2*(x2-x1)
```

Faster
Not wrong

$$|m| \leq 1$$

$$x_1 \leq x_2$$

Drawing Curves



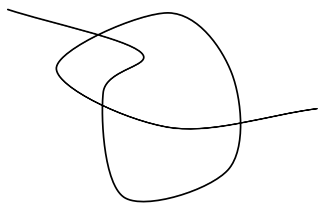
$$y = f(x)$$

Only one value of y for each value of x...

Drawing Curves

- Parametric curves
  - Both x and y are a function of some third parameter

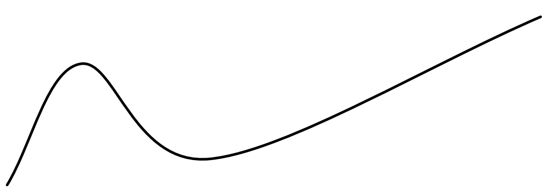
$$x = f(u)$$
$$y = f(u)$$



$$\mathbf{x} = \mathbf{f}(u)$$

$$u \in [u_0 \ldots u_1]$$

Drawing Curves



$$\mathbf{x} = \mathbf{f}(u) \qquad u \in [u_0 \ldots u_1]$$

Drawing Curves

- Draw curves by drawing line segments
  - Must take care in computing end points for lines
  - How long should each line segment be?

$$\mathbf{x} = \mathbf{f}(u) \qquad u \in [u_0 \ldots u_1]$$

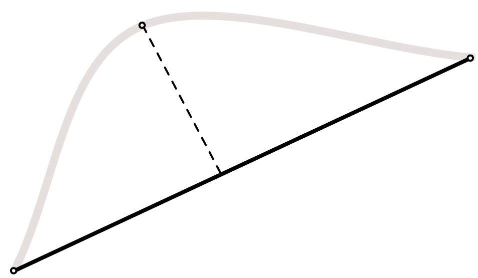
Drawing Curves

- Draw curves by drawing line segments
  - Must take care in computing end points for lines
  - How long should each line segment be?
  - Variable spaced points

$$\mathbf{x} = \mathbf{f}(u) \qquad u \in [u_0 \ldots u_1]$$

Drawing Curves

• Midpoint-test subdivision



$$|\mathbf{f}(u_{mid}) - \mathbf{l}(0.5)|$$

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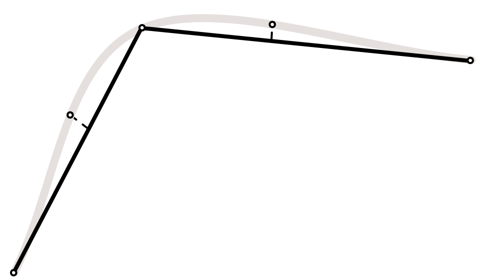
Drawing Curves

• Midpoint-test subdivision



$$|\mathbf{f}(u_{mid}) - \mathbf{l}(0.5)|$$

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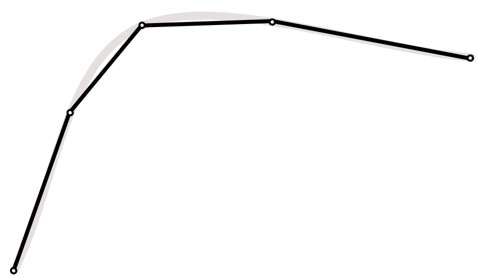
Drawing Curves

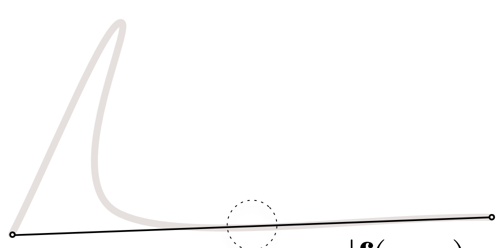
- Midpoint-test subdivision



$$|\mathbf{f}(u_{mid}) - \mathbf{l}(0.5)|$$

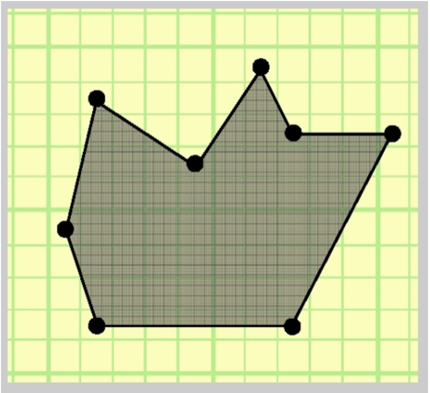
Drawing Curves

- Midpoint-test subdivision
  - Not perfect
  - We need more information for a guarantee...

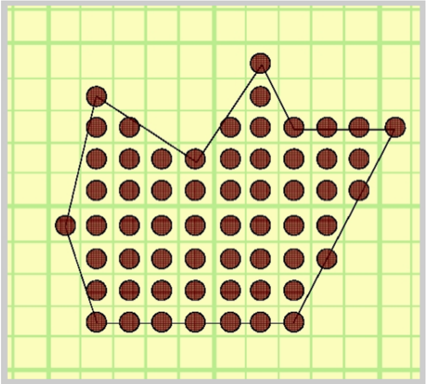


$$|\mathbf{f}(u_{mid}) - \mathbf{l}(0.5)|$$

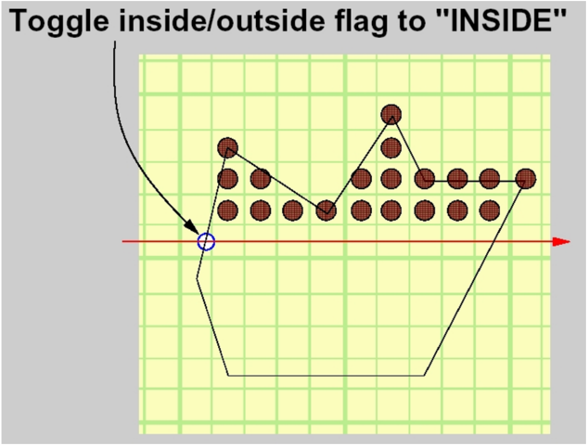
Filled Polygons



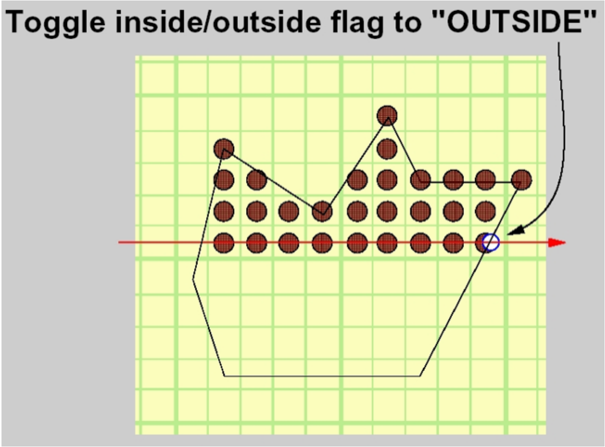
Filled Polygons



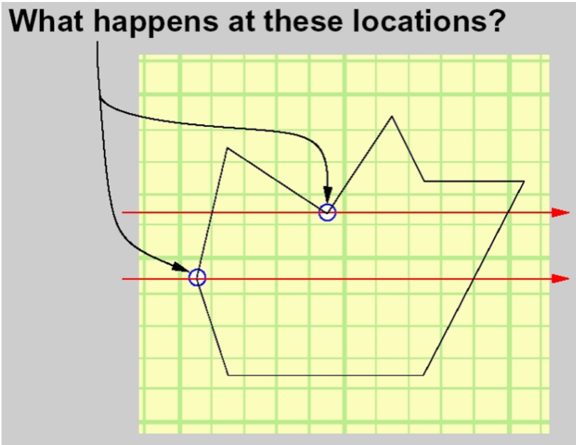
Filled Polygons



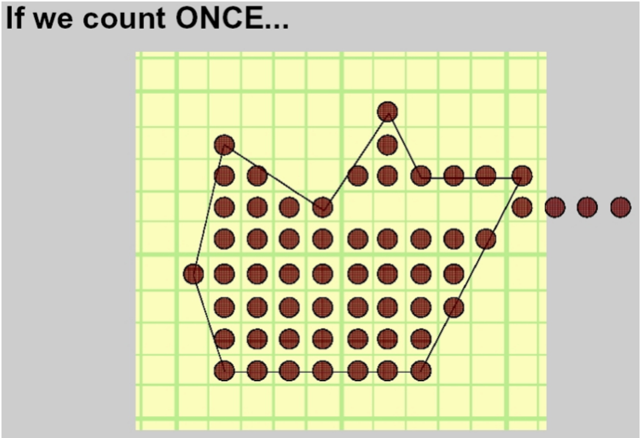
Filled Polygons



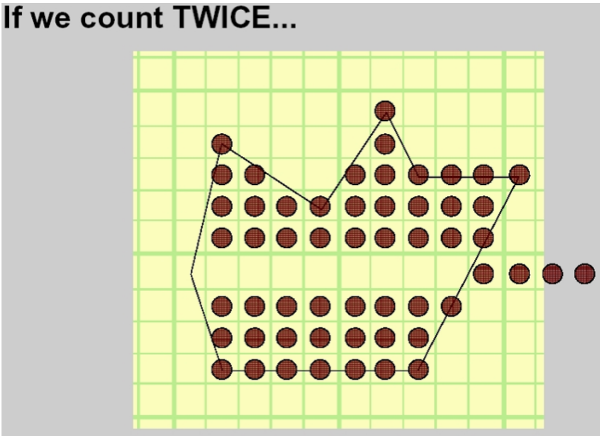
Filled Polygons



Filled Polygons

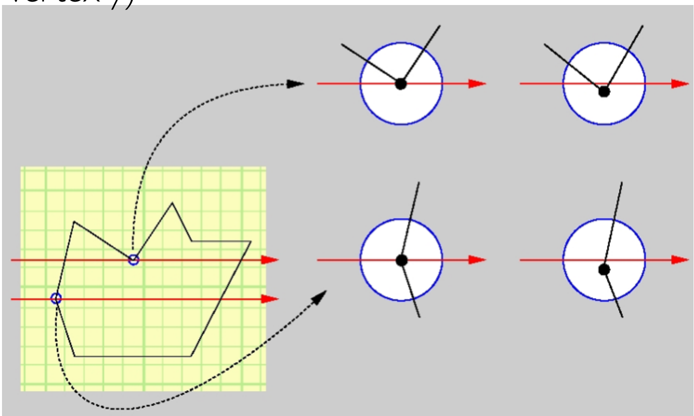


Filled Polygons



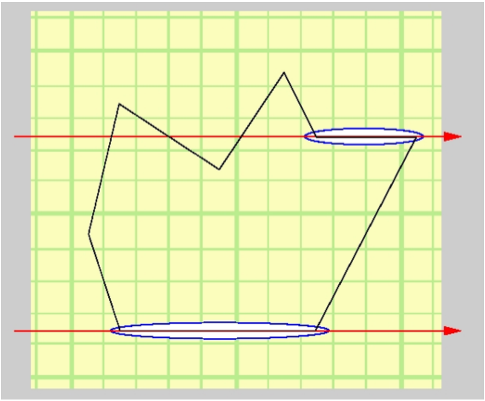
Filled Polygons

Treat (scan y = vertex y) as (scan y > vertex y)



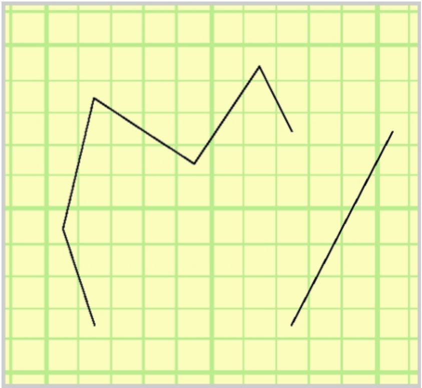
Filled Polygons

Horizontal edges



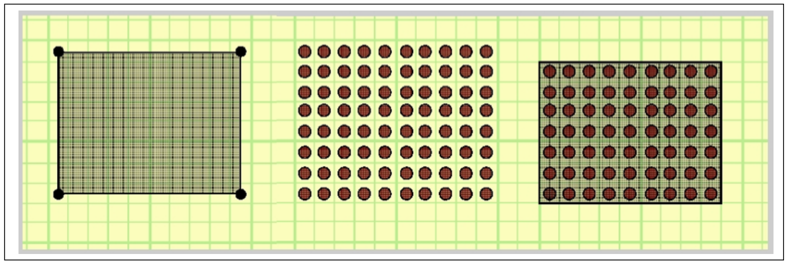
Filled Polygons

Horizontal edges



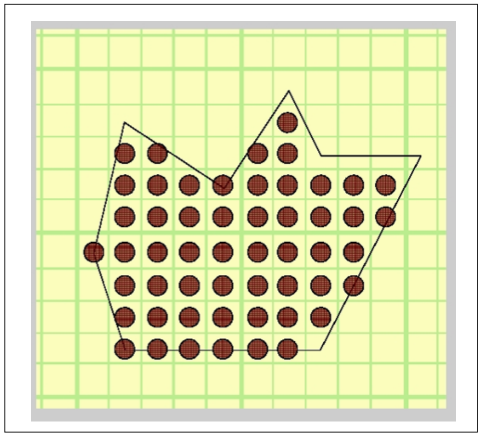
Filled Polygons

- "Equality Removal" applies to all vertices
- Both x and y coordinates



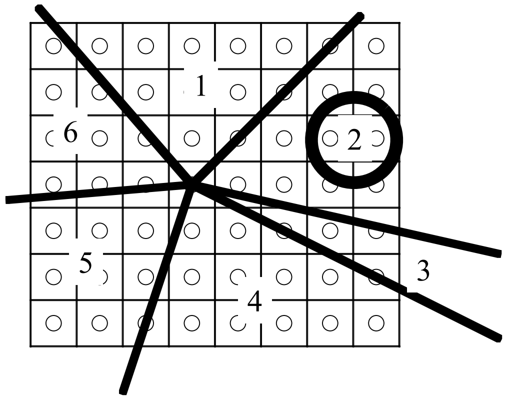
Filled Polygons

- Final result:



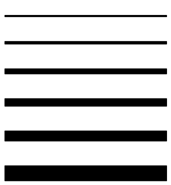
Filled Polygons

- Who does this pixel belong to?

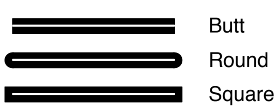


Drawing a Line

- How thick?

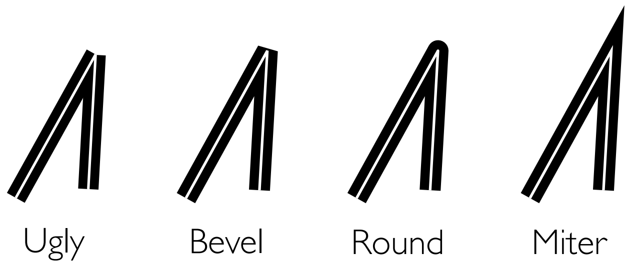


- Ends?

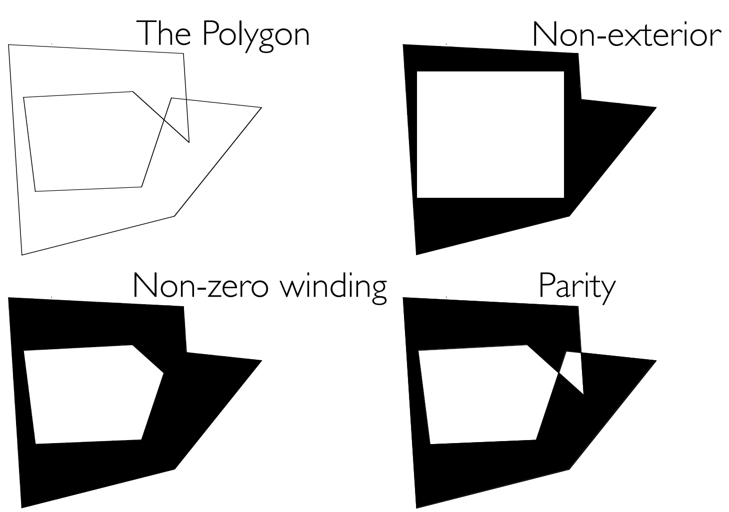


Drawing a Line

• Joining?

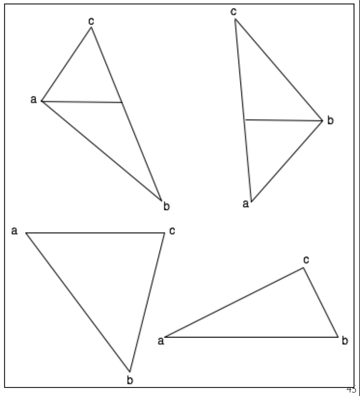


Inside/Outside Testing

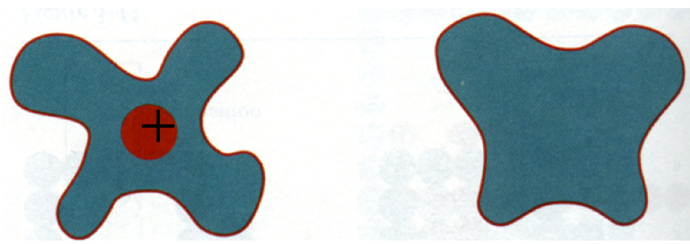


Optimize for Triangles

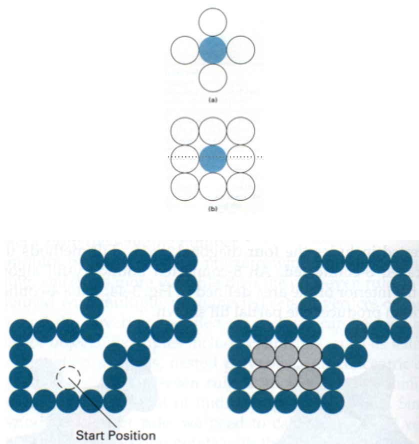
- Spilt triangle into two parts
  - Two edges per part
  - Y-span is monotonic
- For each row
  - Interpolate span
- Interpolate barycentric coordinates

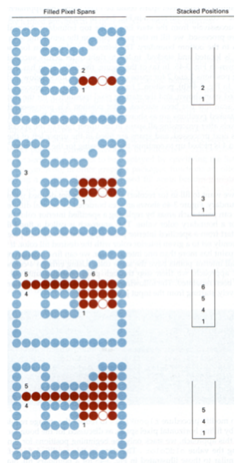


Flood Fill



Flood Fill





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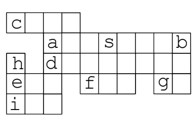
Span-Based Algorithm

Definition: a ***run*** is a horizontal span of identically colored pixels



1. Start at pixel "s", the seed.
2. Find the run containing "s" ("b" to "a").
3. Fill that run with the new color.
4. Search every pixel above run, looking for pixels of interior color
5. For each one found,
6. Find left side of that run ("c"), and push that on a stack.
7. Repeat lines 4-7 for the pixels below ("d").
8. Pop stack and repeat procedure with the new seed

The algorithm finds runs ending at "e", "f", "g", "h", and "i"