CS-184: Computer Graphics

Lecture #2: Scan Conversion

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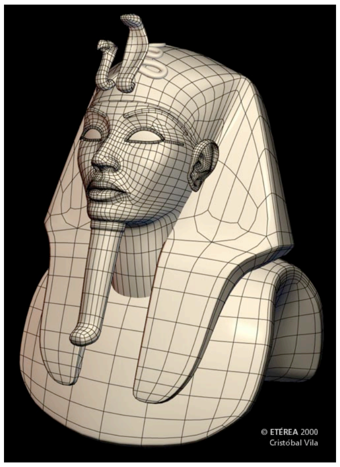
Today

- 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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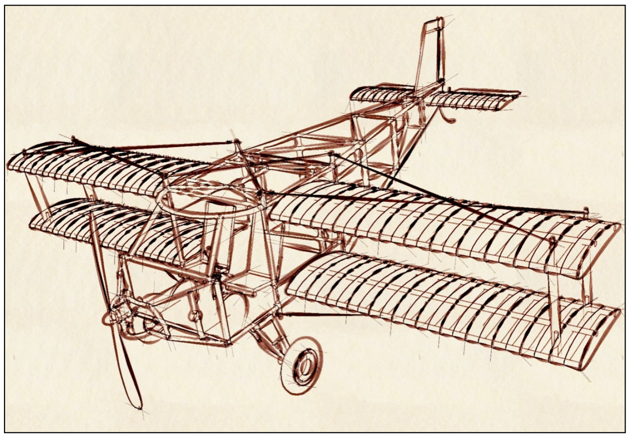
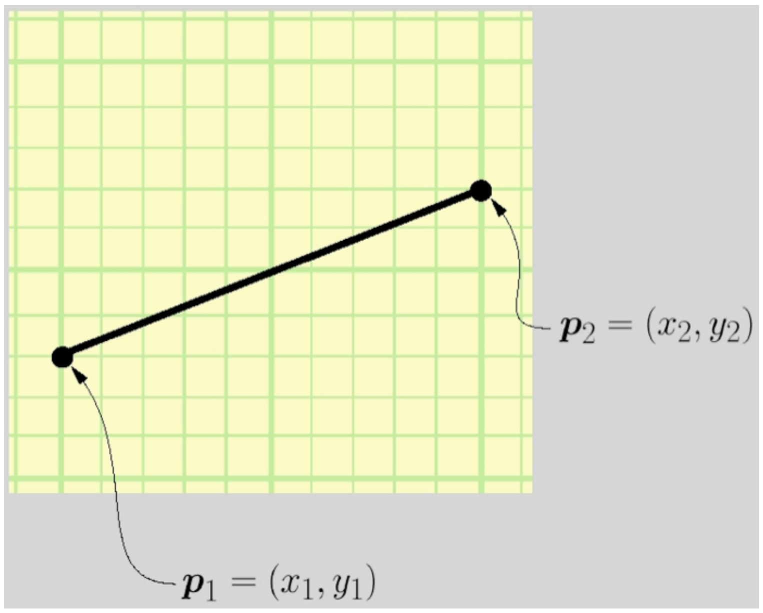
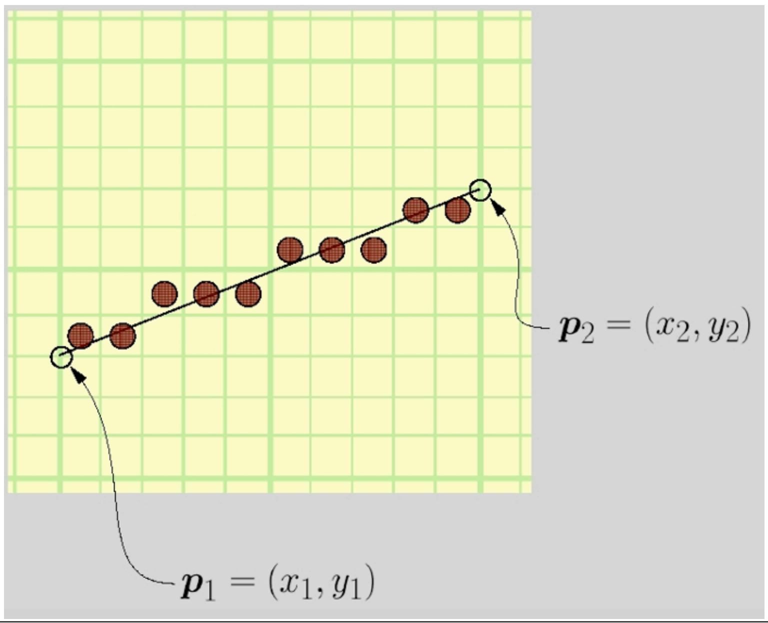
- Lines are a basic primitive that needs to be done well...


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

Drawing a Line


$\boldsymbol{p}_2 = (x_2, y_2)$
$\boldsymbol{p}_1 = (x_1, y_1)$

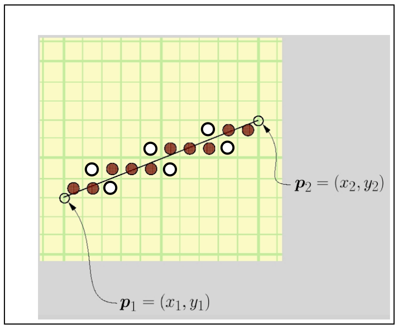
Drawing a Line


$\boldsymbol{p}_2 = (x_2, y_2)$
$\boldsymbol{p}_1 = (x_1, y_1)$

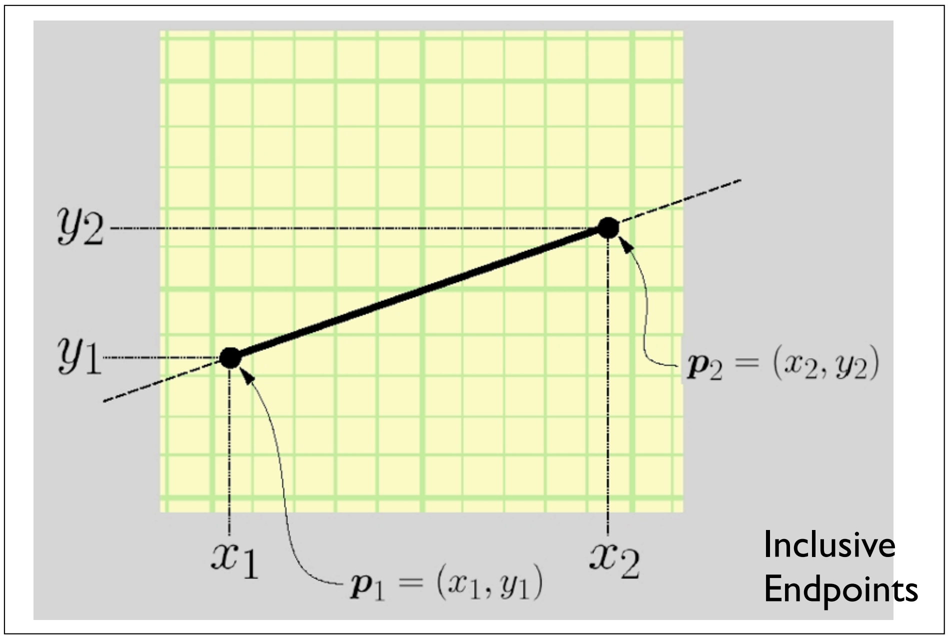
Drawing a Line

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

For example:



Drawing a Line



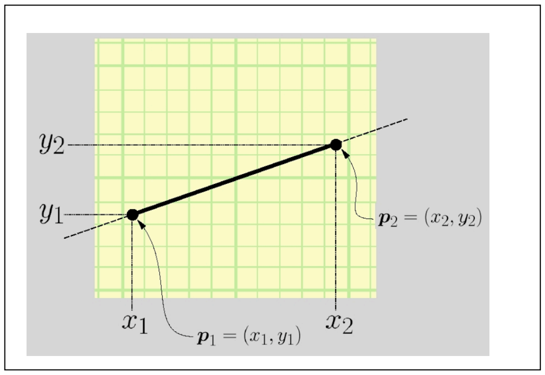
Inclusive Endpoints

Drawing a Line

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

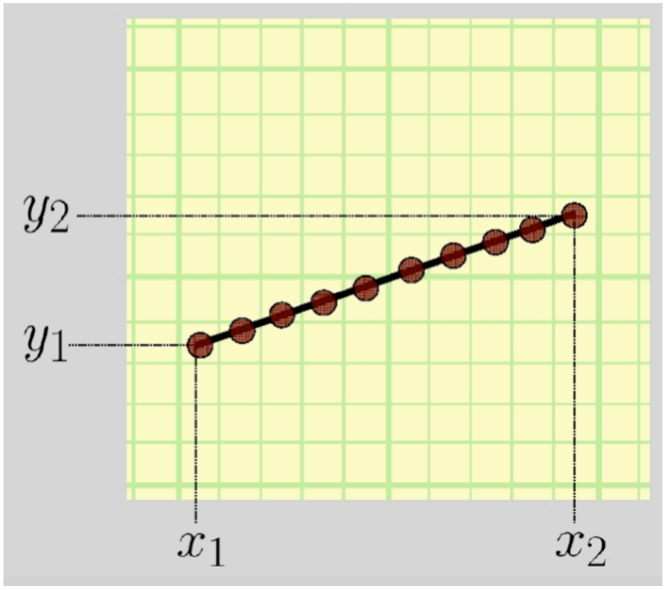
$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

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



y_2
y_1
$\boldsymbol{p}_2 = (x_2, y_2)$
x_1
$\boldsymbol{p}_1 = (x_1, y_1)$
x_2

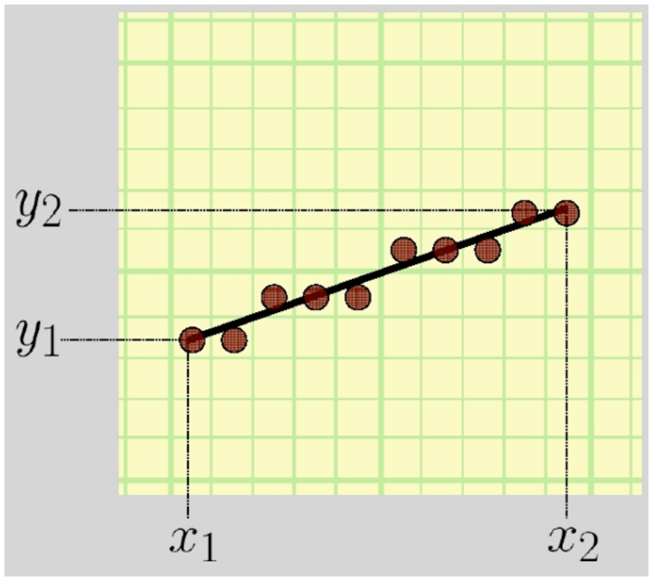
Drawing a Line



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

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

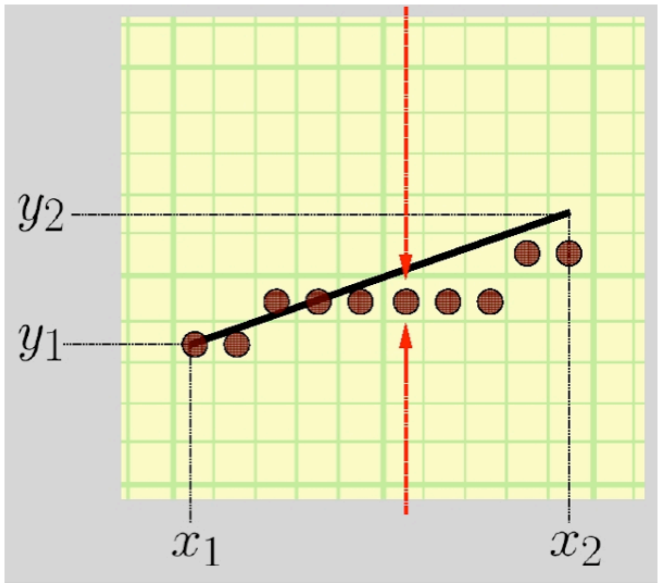
Drawing a Line



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

After rounding

Drawing a Line

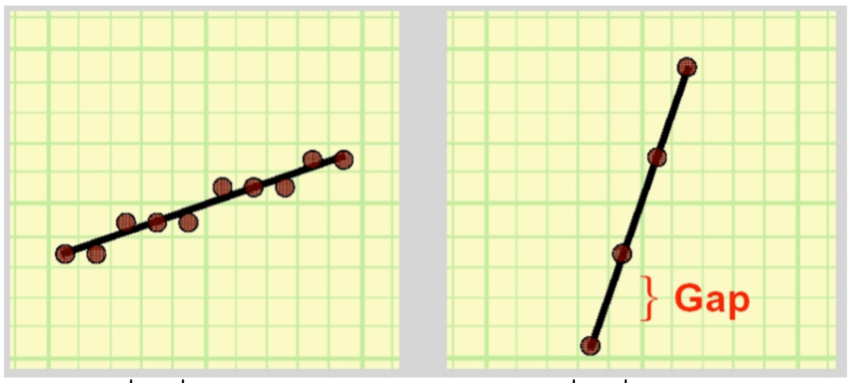


$\Delta x = 1$
$\Delta y = m \cdot \Delta x$
$y += \Delta y$

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

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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
```

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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

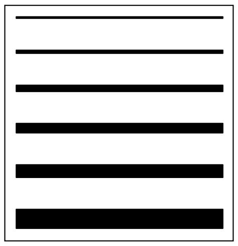
```
void drawLine-Bresenham(int x1,x2, int y1,y2)

  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

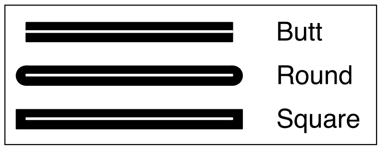
$$|m| \leq 1$$
$$x_1 \leq x_2$$

Drawing a Line

- How thick?

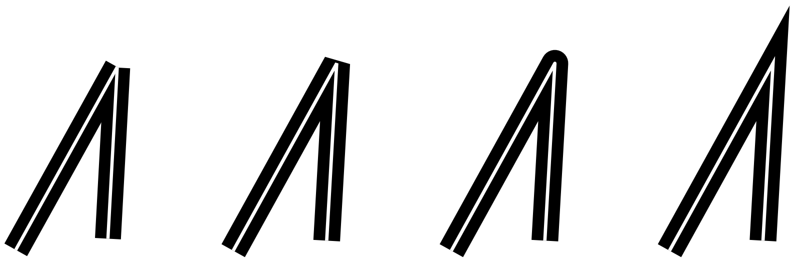


- Ends?

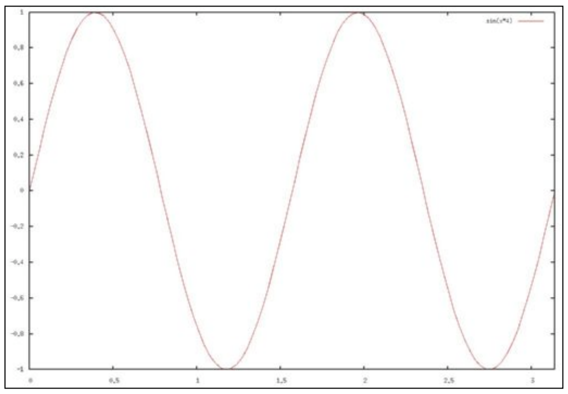


Drawing a Line

- Joining?



Drawing Curves



$$y = f(x)$$

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

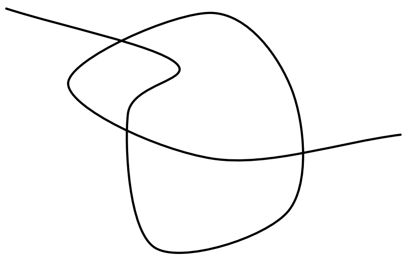
Drawing Curves

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

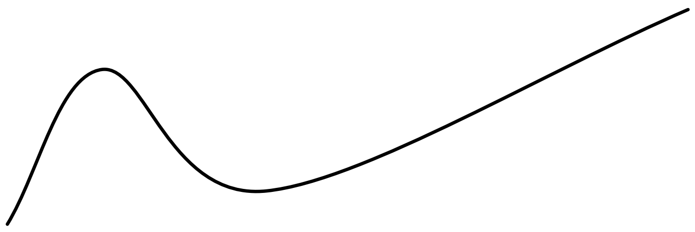
$$x = f(u)$$
$$y = f(u)$$

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

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



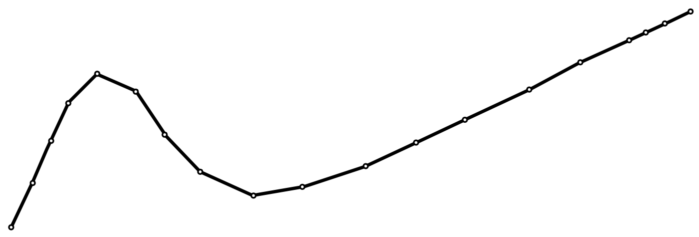
Drawing Curves



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

Drawing Curves

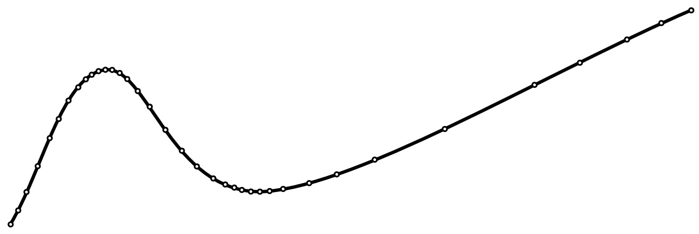
- Draw curves by drawing line segments
  - Must take care in computing end points for lines
  - How long should each line segment be?



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

Drawing Curves

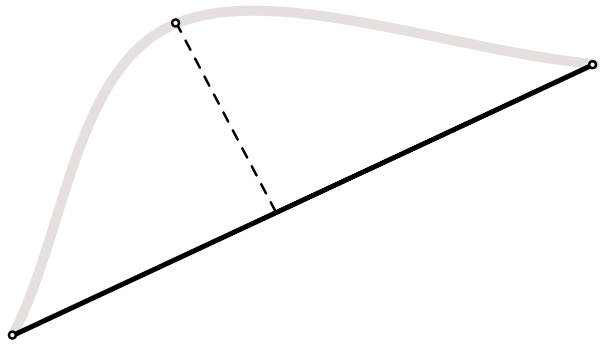
- Draw curves by drawing line segments
  - Must take care in computing end points for lines
  - How long should each line segment be?
  - Variable spaced points



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

Drawing Curves

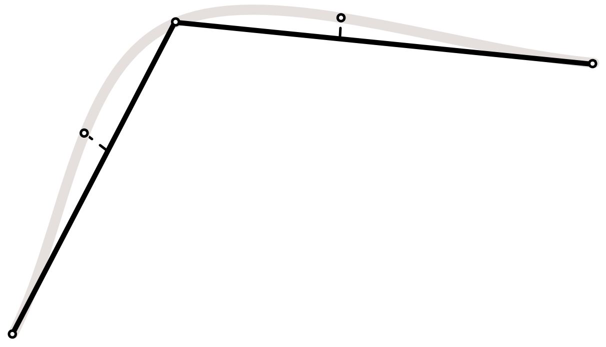
- Midpoint-test subdivision



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

Drawing Curves

- Midpoint-test subdivision



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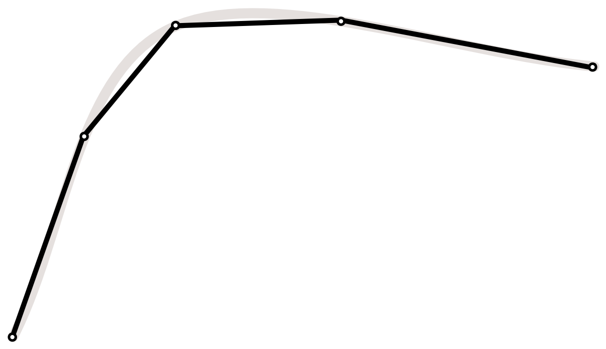
Drawing Curves

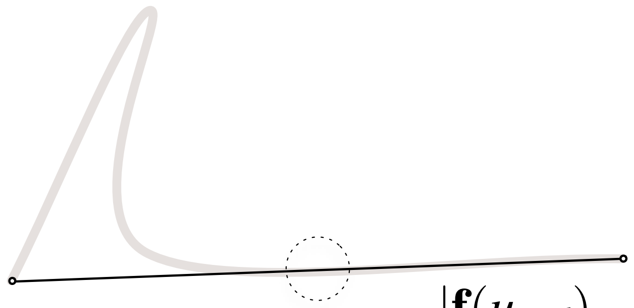
- Midpoint-test subdivision



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

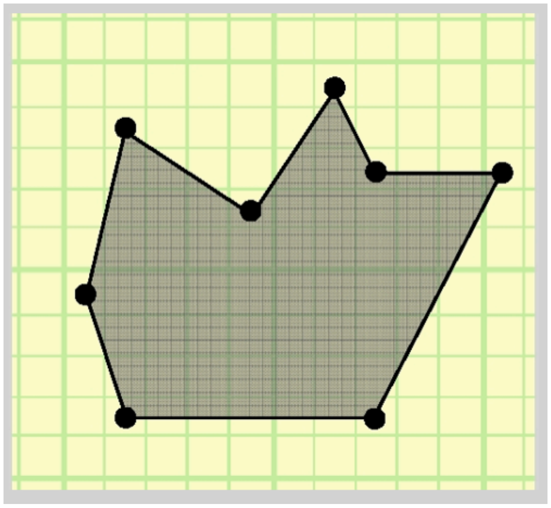
Drawing Curves

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

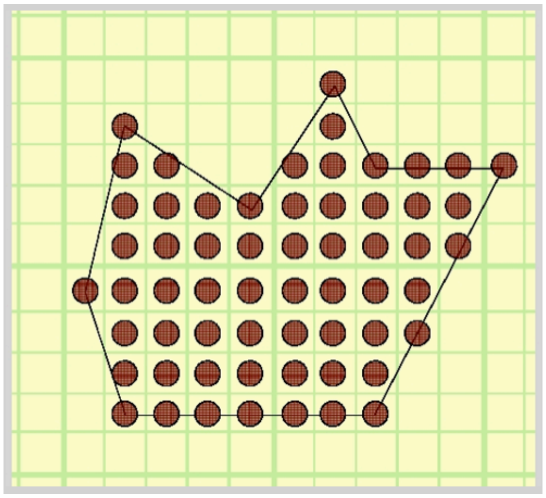


$$|\mathbf{f}(u_{mid}) - \mathbf{l}(0.5)|$$

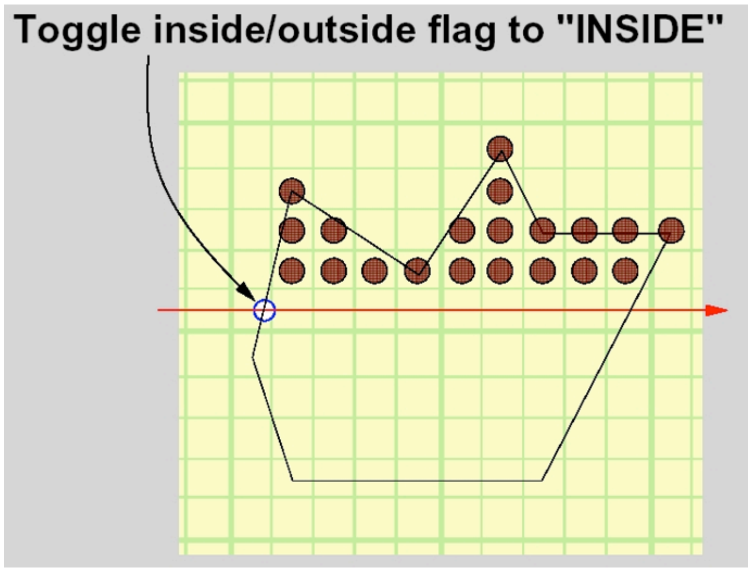
Filled Polygons



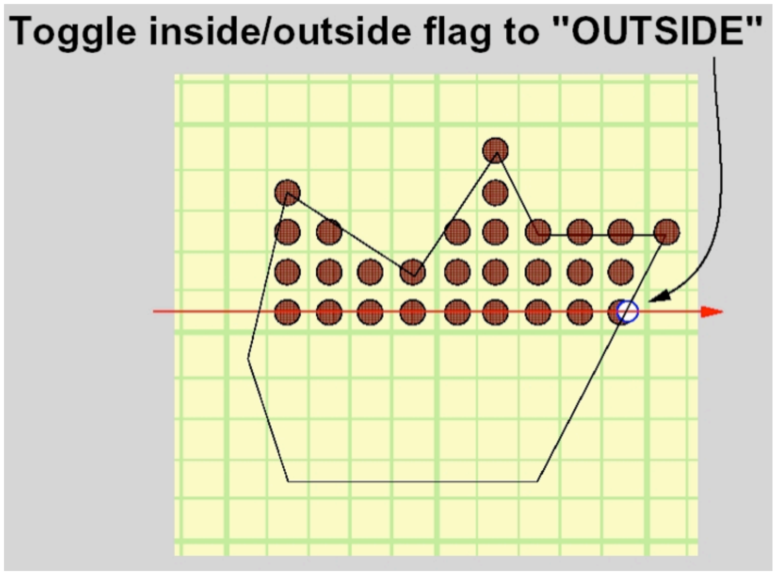
Filled Polygons



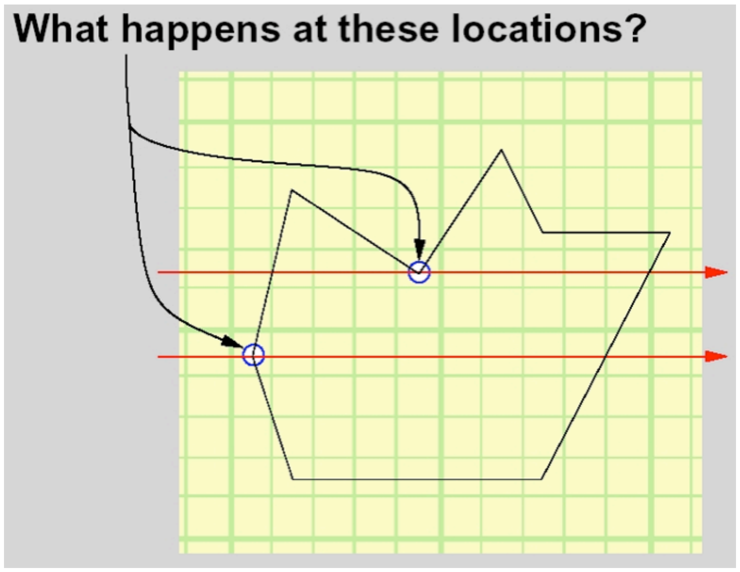
Filled Polygons



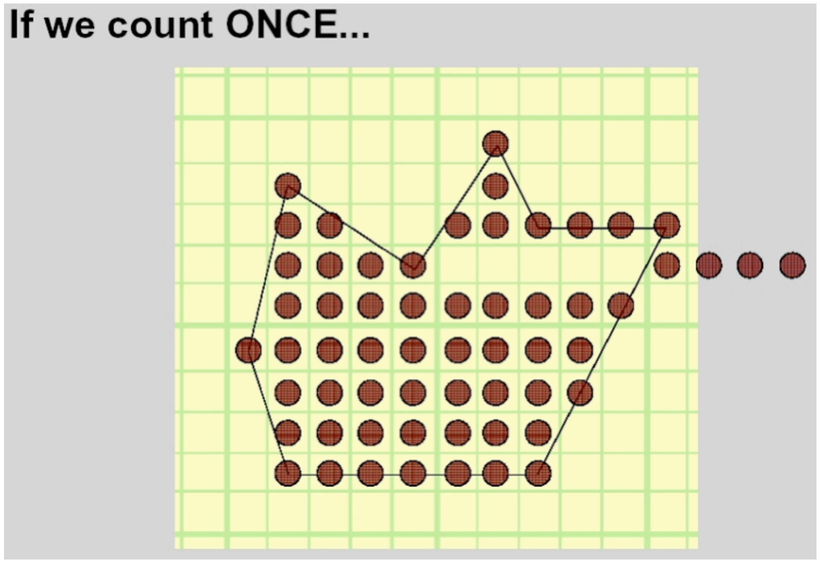
Filled Polygons



Filled Polygons

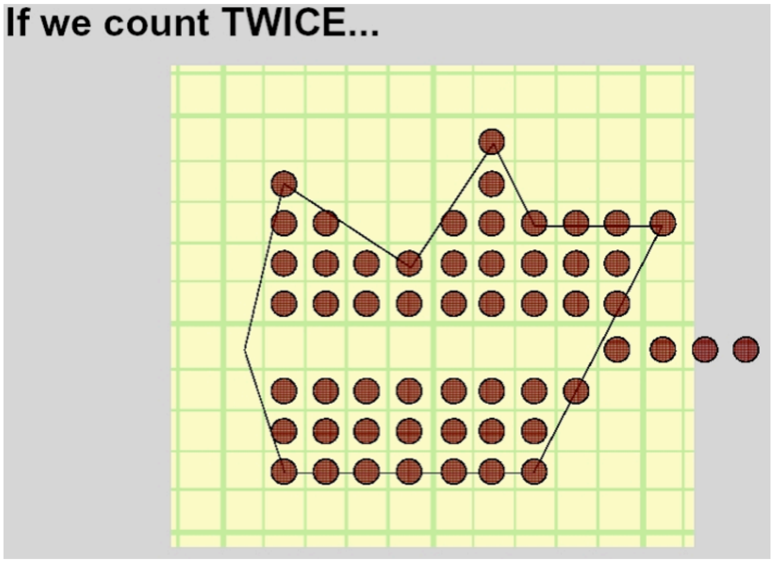


Filled Polygons



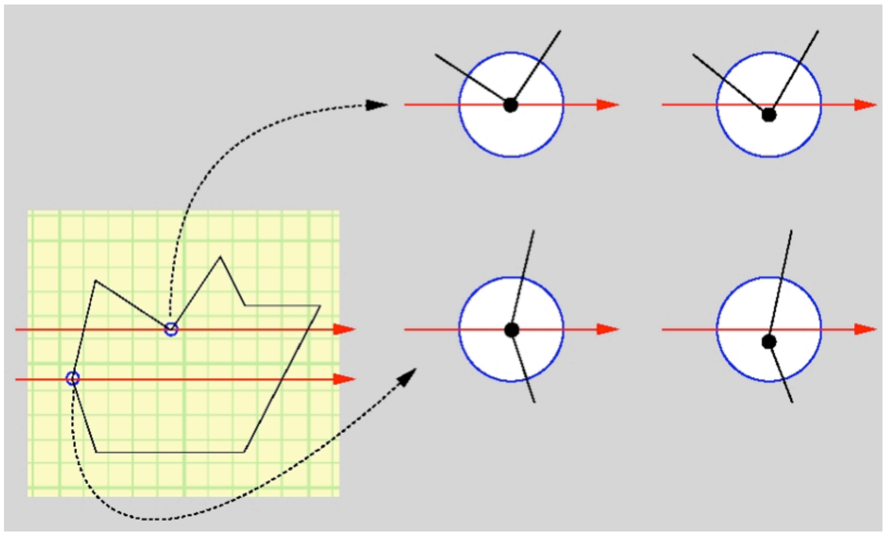
Filled Polygons

If we count TWICE...



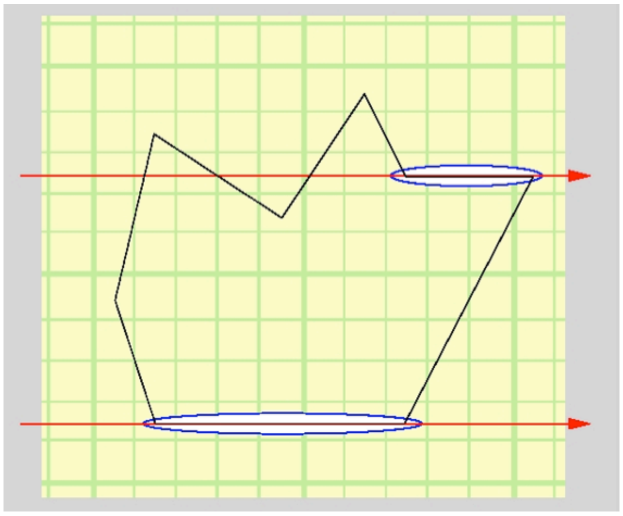
Filled Polygons

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



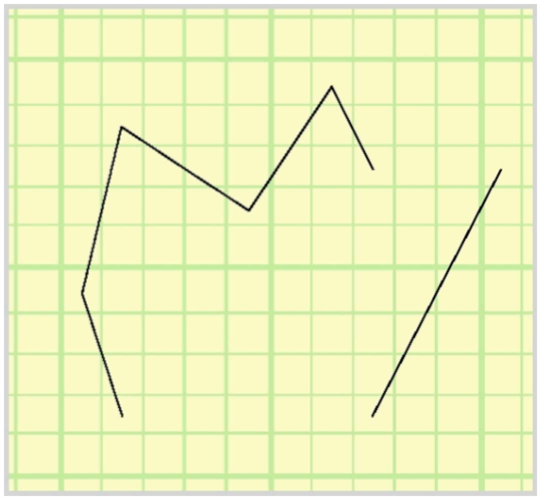
Filled Polygons

Horizontal edges



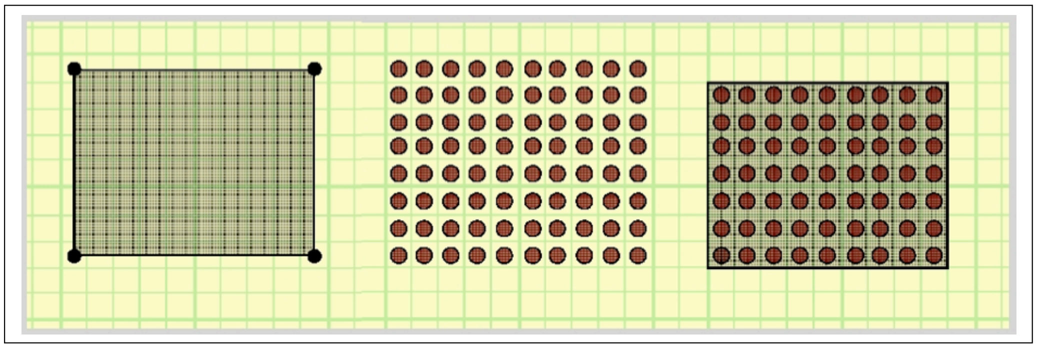
Filled Polygons

Horizontal edges



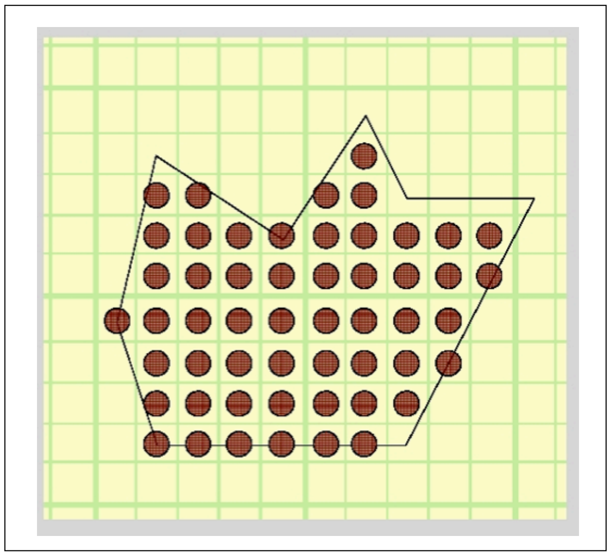
Filled Polygons

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



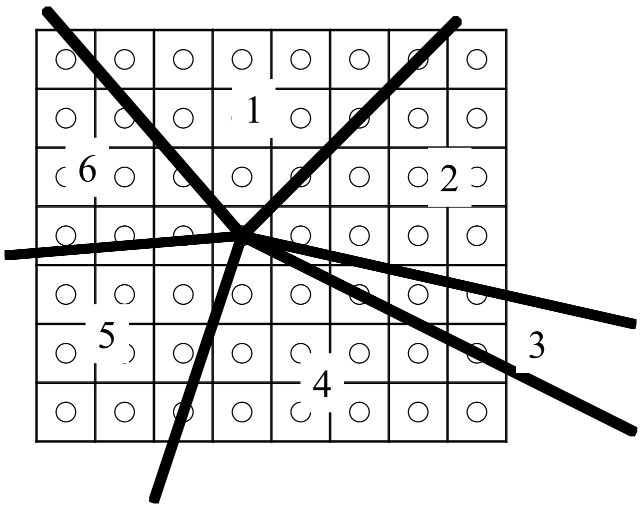
Filled Polygons

- Final result:

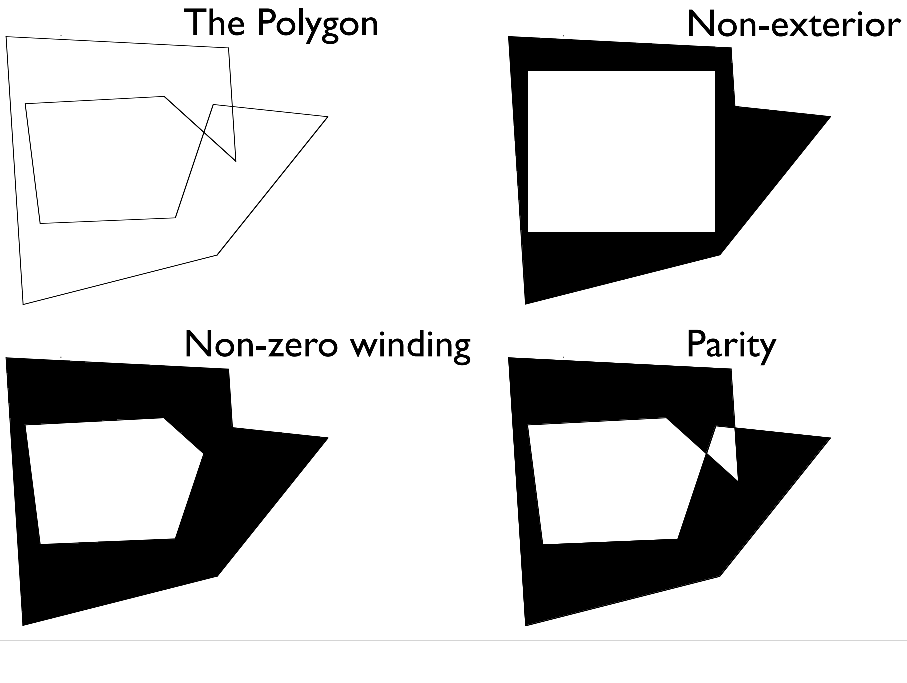


Filled Polygons

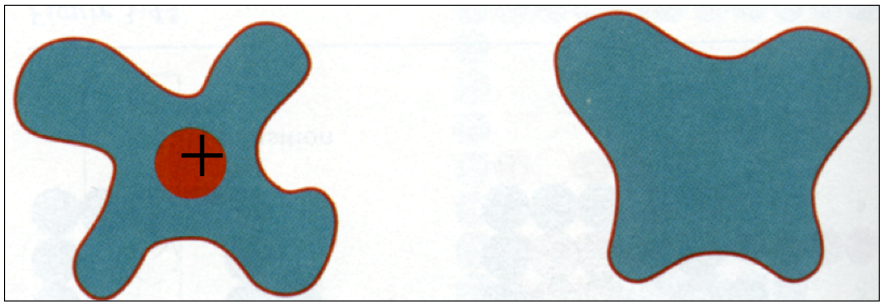
- Who does this pixel belong to?



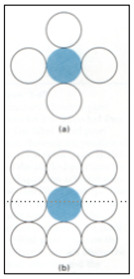
Inside/Outside Testing

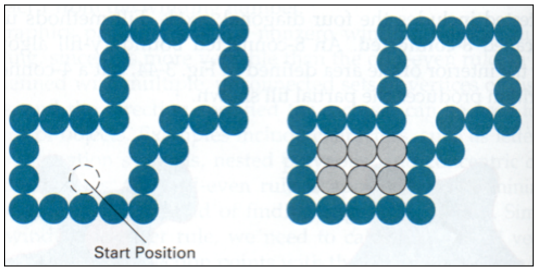


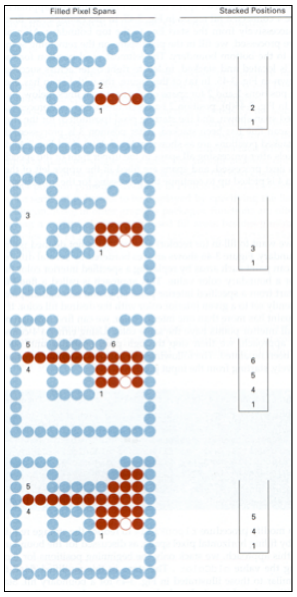
Flood Fill



Flood Fill




Start Position


Filled Pixel Spans
Stacked Positions