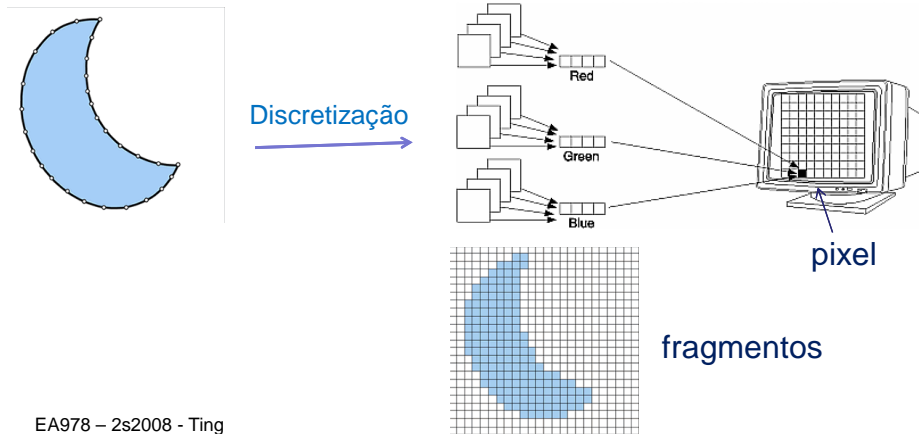


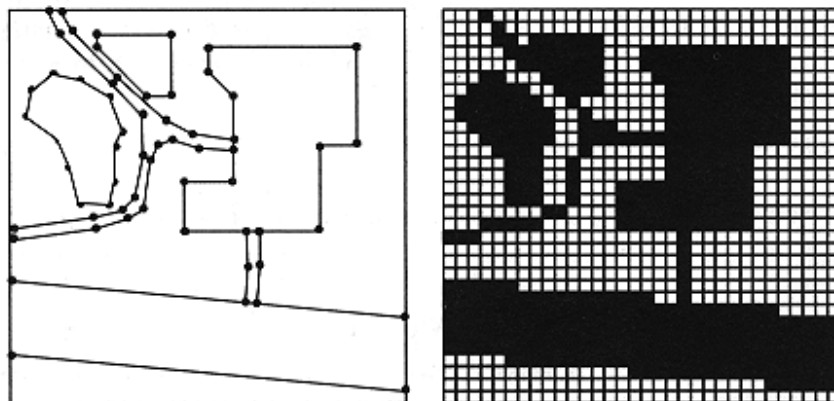
Rasterização: Fragmentos

Conversão de informações vetoriais em fragmentos



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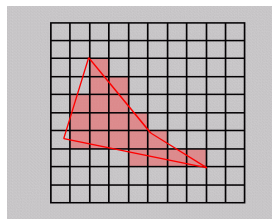
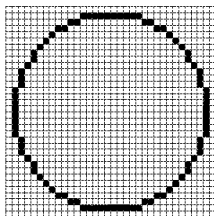
Rasterização



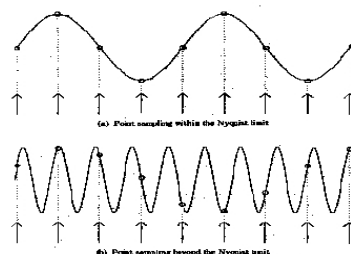
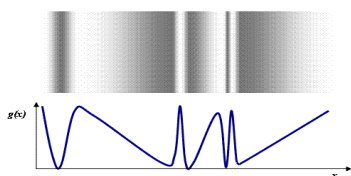
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Duas Abordagens

Geométrica (Rasterização): *pixels* que sobrepõem os objetos vetoriais

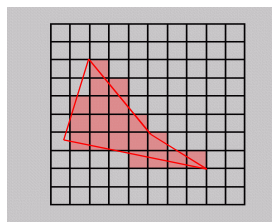
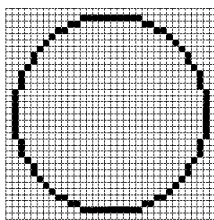


Espectral (Amostragem): amostragem da função de intensidade definida no domínio espacial

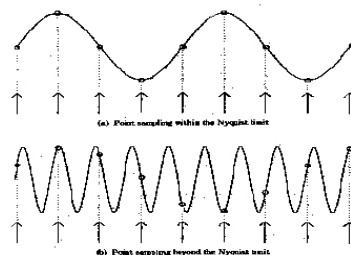
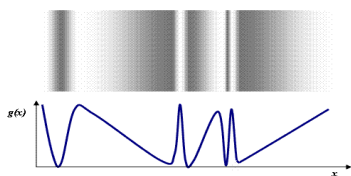


Duas Abordagens

Geométrica (Rasterização): *pixels* que sobrepõem os objetos vetoriais



Espectral (Amostragem): amostragem da função de intensidade definida no domínio espacial

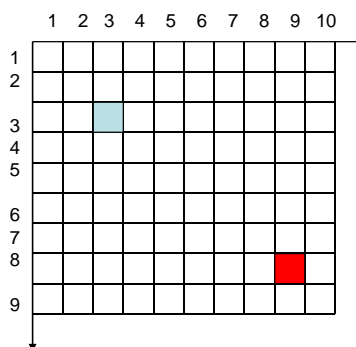


Amostragem

Rasterização de Pontos Truncamento ou Arredondamento

Pontos:
 (2.75,3.1)
 (3.1,2.8)
 (3.0,3.0)

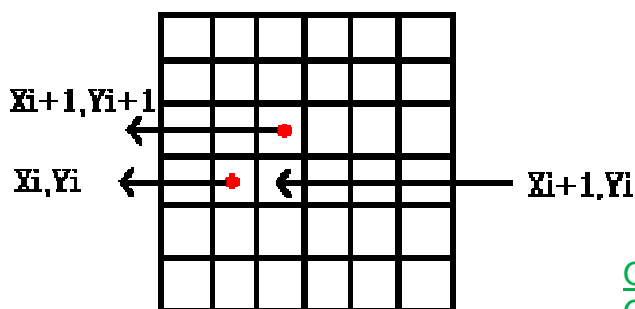
 (7.6,9.3)
 (7.8,9.0)
 (8.3,8.7)



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Rasterização de Segmentos

DDA (Digital Differential Analyzer)



$$Y = (\Delta y / \Delta x) X + b$$

$$m = \Delta y / \Delta x = (Y_{i+1} - Y_i) / (X_{i+1} - X_i);$$

$m \leq 1$ (X cresce +): $Y_{i+1} = Y_i + m$

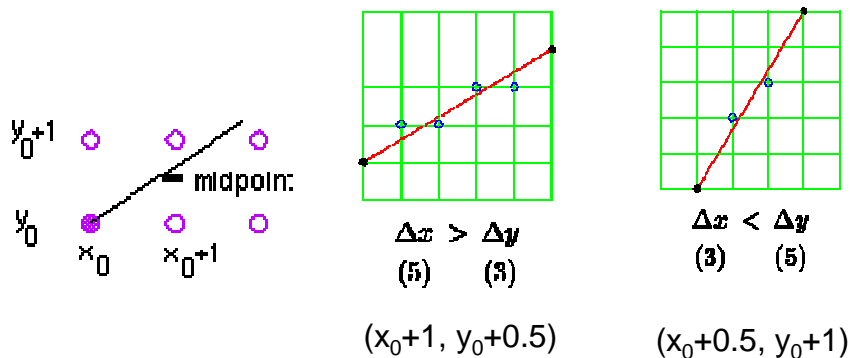
$m > 1$ (Y cresce +): $X_{i+1} = X_i + 1/m$

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Observação:
 O menor
 incremento da
 coordenada que
 cresce mais
 rápido é 1!

Rasterização de Segmentos Algoritmo de Bresenham

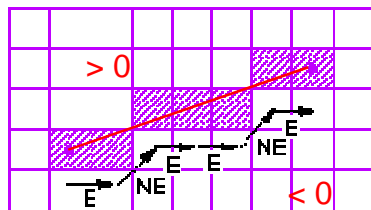
$$f(x,y) = (y_1 - y_0)x + (x_1 - x_0)y + C = -\Delta y x + \Delta x y + C = 0$$



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Rasterização de Segmentos Algoritmo de Bresenham

$$f(x,y) = (y_1 - y_0)x + (x_1 - x_0)y + C = -\Delta y x + \Delta x y + C = 0$$



Se $(y_1 - y_0) < (x_1 - x_0)$, ou $\Delta y < \Delta x$,

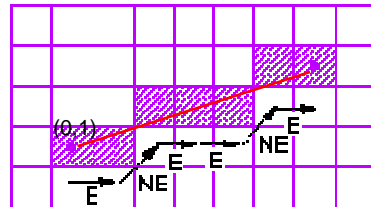
Função de Decisão

$f(x_0+1, y_0+0.5) \geq 0 \rightarrow f(x_0+1, y_0+0.5)$ acima da reta $f(x,y) \rightarrow E$
 $f(x_0+1, y_0+0.5) < 0 \rightarrow f(x_0+1, y_0+0.5)$ abaixo da reta $f(x,y) \rightarrow NE$

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Rasterização de Segmentos

Algoritmo de Bresenham



$$y = (1/3)x + 1 \longrightarrow f(x,y) = y - (1/3)x - 1; \quad x_0 = 0; \quad y_0 = 1:$$

$$\begin{aligned} f(0+1, 1+0.5) &> 0 \longrightarrow f(1, 1.5) = 1/6 \text{ acima da reta } f(x,y) \longrightarrow E \\ f(1+1, 1+0.5) &< 0 \longrightarrow f(2, 1.5) = -1/6 \text{ abaixo da reta } f(x,y) \longrightarrow NE \\ f(2+1, 2+0.5) &< 0 \longrightarrow f(3, 2.5) = 0.5 \text{ acima da reta } f(x,y) \longrightarrow E \end{aligned}$$

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Rasterização de Segmentos

Algoritmo de Bresenham

Como obter $f(x_0+2, y_{i+2})$ de forma eficiente?

➤ Se a direção E for escolhida $y_{i+1} = y_i$:

$$\begin{aligned} f(x_{i+2}, y_{i+2}) &: f(x_i+2, y_i+0.5) \\ f(x_i+2, y_i+0.5) &= -\Delta y (x_i+2) + \Delta x (y_i+0.5) + C \\ &= -\Delta y (x_i+1) - \Delta y + \Delta x (y_i+0.5) + C \\ &= f(x_i+1, y_i+0.5) - \Delta y \\ \mathbf{f(x_i+2, y_i+0.5) = f(x_i+1, y_i+0.5) - \Delta y} \end{aligned}$$

➤ Se a direção NE for escolhida $y_{i+1} = y_i + 1$:

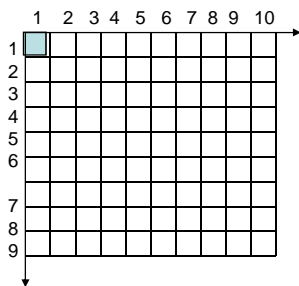
$$\begin{aligned} f(x_{i+2}, y_{i+2}) &: f(x_i+2, y_i+1.5) \\ f(x_i+2, y_i+1.5) &= -\Delta y (x_i+2) + \Delta x (y_i+1.5) + C \\ &= -\Delta y (x_i+1) - \Delta y + \Delta x (y_i+0.5) + \Delta x + C \\ &= f(x_i+1, y_i+0.5) - \Delta y + \Delta x \\ \mathbf{f(x_i+2, y_i+1.5) = f(x_i+1, y_i+0.5) - \Delta y + \Delta x} \end{aligned}$$

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Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição

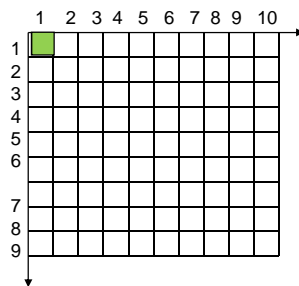


$$y = 0.5x + 0.5$$

$$y = 0.5(2) + 0.5 = 1.5$$

Arredonda para 1.0 ou
para 2.0?

DDA

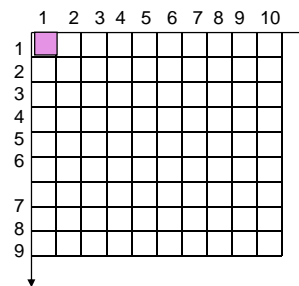


$$m = \Delta y / \Delta x = 0.5$$

$$y_1 = y_0 + m = 1.5$$

Arredonda para 1.0 ou
para 2.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

$$f(x,y) = y - 0.5x - 0.5$$

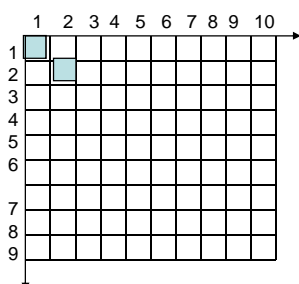
$$d_0 = f(1+1, 1+0.5) = 0$$

$$d_0 \geq 0 \rightarrow y_1 = y_0$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

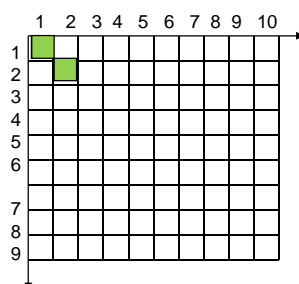
Substituição



$$y = 0.5x + 0.5$$

$$y = 0.5(3) + 0.5 = 2.0$$

DDA

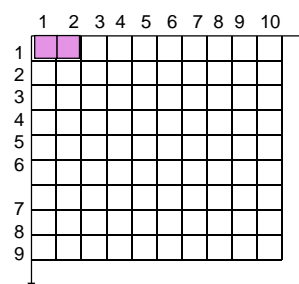


$$m = \Delta y / \Delta x = 0.5$$

$$y_2 = y_1 + m = 2.5$$

Arredonda para 2.0 ou
para 3.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

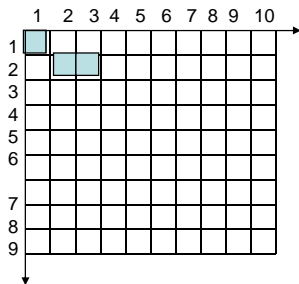
$$y_1 = y_0 \rightarrow d_1 = d_0 - \Delta y = -2$$

$$d_1 < 0 \rightarrow y_2 = y_1 + 1$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição

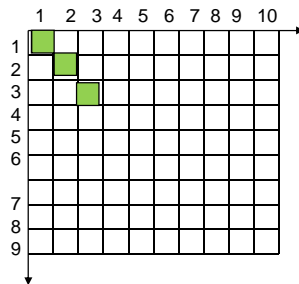


$$y = 0.5x + 0.5$$

$$y = 0.5(4) + 0.5 = 2.5$$

Arredonda para 2.0 ou
para 3.0?

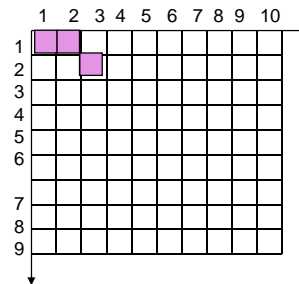
DDA



$$m = \Delta y / \Delta x = 0.5$$

$$y_3 = y_2 + m = 3.0$$

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

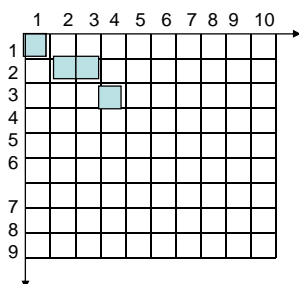
$$y_2 = y_1 + 1 \rightarrow d_2 = d_1 - \Delta y + \Delta x = 0$$

$$d_2 \geq 0 \rightarrow y_3 = y_2$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

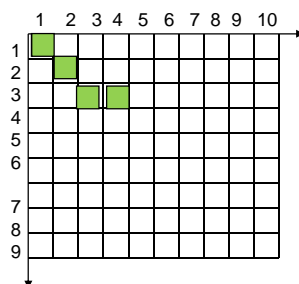
Substituição



$$y = 0.5x + 0.5$$

$$y = 0.5(5) + 0.5 = 3.0$$

DDA

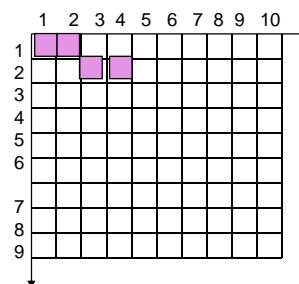


$$m = \Delta y / \Delta x = 0.5$$

$$y_4 = y_3 + m = 3.5$$

Arredonda para 3.0 ou
para 4.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

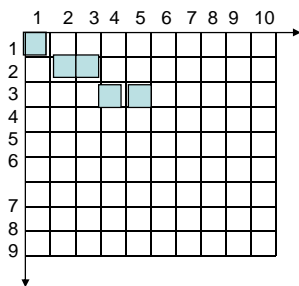
$$y_3 = y_2 \rightarrow d_3 = d_2 - \Delta y = -2$$

$$d_3 < 0 \rightarrow y_4 = y_3 + 1$$

Exemplo 1

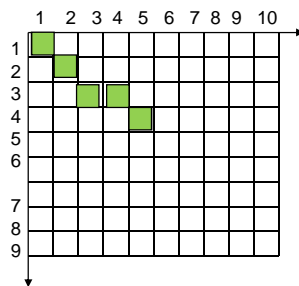
Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição



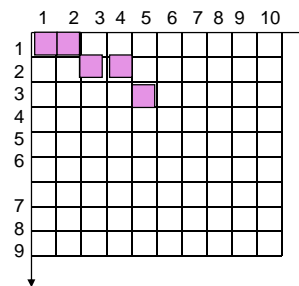
$$y = 0.5x + 0.5$$

DDA



$$m = \Delta y / \Delta x = 0.5$$

Bresenham



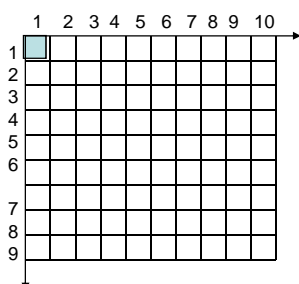
$$\Delta y = 2 \quad \Delta x = 4$$

Não chegou no ponto final!!!!

Exemplo 2

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(3,5)$
 $(\Delta x = 2) < (\Delta y = 4) \rightarrow y$ "anda" em passo unitário

Substituição

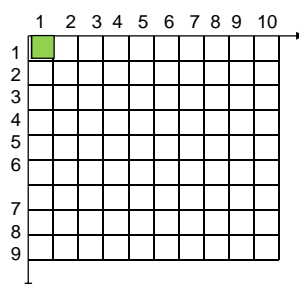


$$x = 0.5y + 0.5$$

$$x = 0.5(2) + 0.5 = 1.5$$

Arredonda para 1.0 ou
para 2.0?

DDA

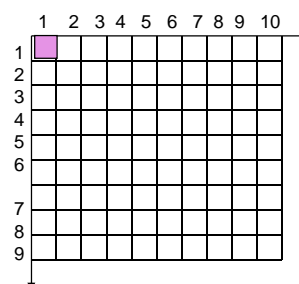


$$1/m = \Delta x / \Delta y = 0.5$$

$$x_1 = x_0 + m = 1.5$$

Arredonda para 1.0 ou
para 2.0?

Bresenham



$$\Delta y = 4 \quad \Delta x = 2$$

$$f(x,y) = y - 0.5x - 0.5$$

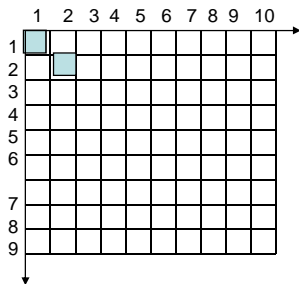
$$d_0 = f(1+0.5, 1+1) = 0$$

$$d_0 \geq 0 \rightarrow x_1 = x_0$$

Exemplo 2

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(3,5)$
 $(\Delta x = 2) < (\Delta y = 4) \longrightarrow x$ "anda" em passo unitário

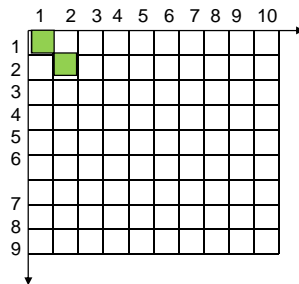
Substituição



$$x = 0.5y + 0.5$$

$$y = 0.5(3) + 0.5 = 2.0$$

DDA

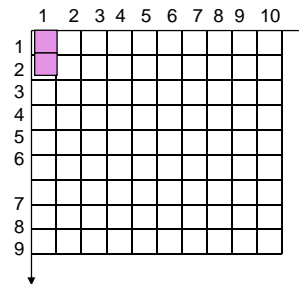


$$1/m = \Delta x / \Delta y = 0.5$$

$$x_2 = x_1 + m = 2.5$$

Arredonda para 2.0 ou
para 3.0?

Bresenham



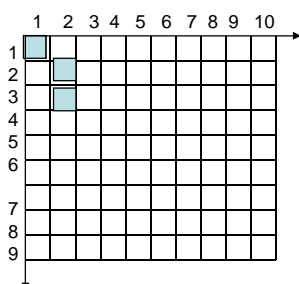
$$\Delta y = 4 \quad \Delta x = 2$$

$x_1 = x_0 \rightarrow d_1 = d_0 - \Delta x = -2$
 $d_1 < 0 \rightarrow x_2 = x_1 + 1$

Exemplo 2

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(3,5)$
 $(\Delta x = 2) < (\Delta y = 4) \longrightarrow x$ "anda" em passo unitário

Substituição

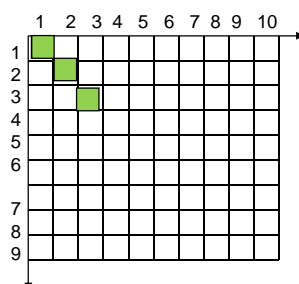


$$x = 0.5y + 0.5$$

$$x = 0.5(4) + 0.5 = 2.5$$

Arredonda para 2.0 ou
para 3.0?

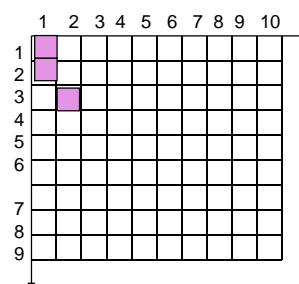
DDA



$$1/m = \Delta x / \Delta y = 0.5$$

$$x_3 = x_2 + m = 3.0$$

Bresenham



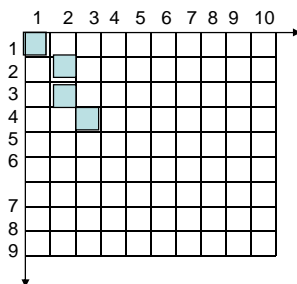
$$\Delta y = 4 \quad \Delta x = 2$$

$x_2 = x_1 + 1 \rightarrow d_2 = d_1 - \Delta x + \Delta y = 0$
 $d_2 \geq 0 \rightarrow x_3 = x_2$

Exemplo 2

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(3,5)$
 $(\Delta x = 2) < (\Delta y = 4) \rightarrow$ x "anda" em passo unitário

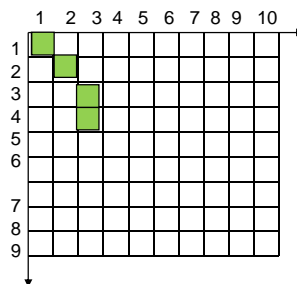
Substituição



$$x = 0.5y + 0.5$$

$$y = 0.5(5) + 0.5 = 3.0$$

DDA

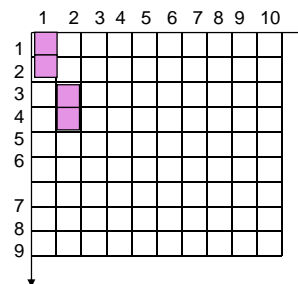


$$1/m = \Delta x / \Delta y = 0.5$$

$$x_4 = x_3 + m = 3.5$$

Arredonda para 3.0 ou
para 4.0?

Bresenham



$$\Delta y = 4 \quad \Delta x = 2$$

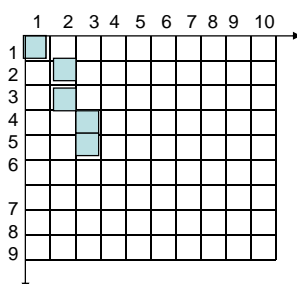
$$y_3 = y_2 \rightarrow d_3 = d_2 - \Delta y = -2$$

$$d_3 < 0 \rightarrow x_4 = x_3 + 1$$

Exemplo 2

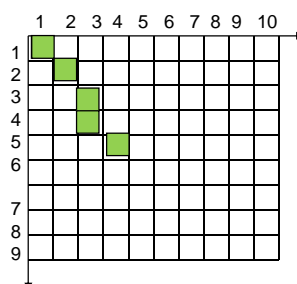
Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(3,5)$
 $(\Delta x = 2) < (\Delta y = 4) \rightarrow$ x "anda" em passo unitário

Substituição



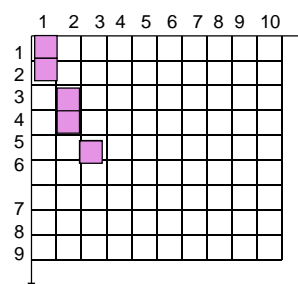
$$x = 0.5y + 0.5$$

DDA



$$1/m = \Delta y / \Delta x = 0.5$$

Bresenham

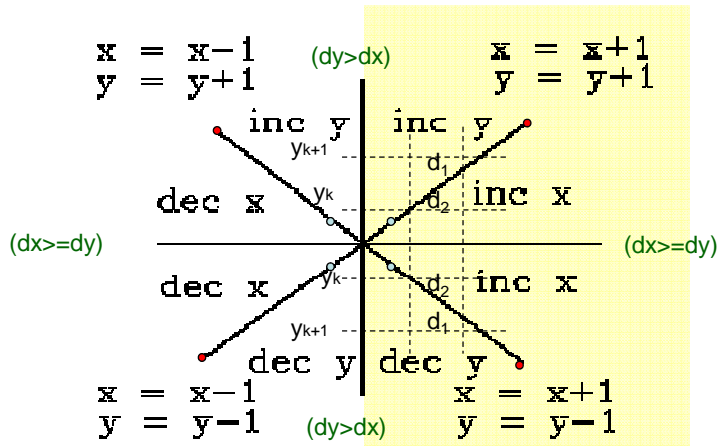


$$\Delta y = 4 \quad \Delta x = 2$$

Não chegou no ponto final!!!!

Rasterização de Segmentos

Linhas: Todos os possíveis casos



Se invertermos os pontos extremos adequadamente, reduzimos em 4 casos

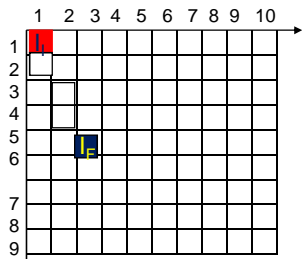
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Rasterização de Segmentos

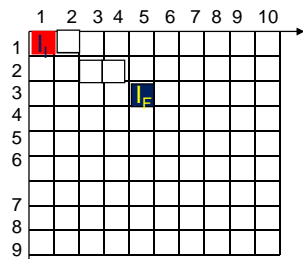
Cor em cada pixel

Interpolação linear

$$I_{i+1} = I_i + 1/(\text{maior variação}) (I_F - I_i)$$



$$I_{i+1} = I_i + 1/(\Delta y) (I_F - I_i)$$



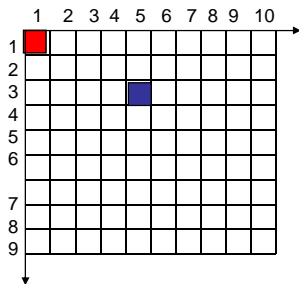
$$I_{i+1} = I_i + 1/(\Delta x) (I_F - I_i)$$

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Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição



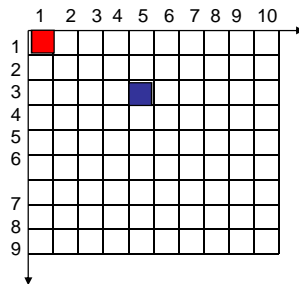
$$y = 0.5x + 0.5$$

$$y = 0.5(2) + 0.5 = 1.5$$

$$I = (1,0,0) + 0.25(-1,0,1)$$

Arredonda para 1.0 ou para 2.0?

DDA



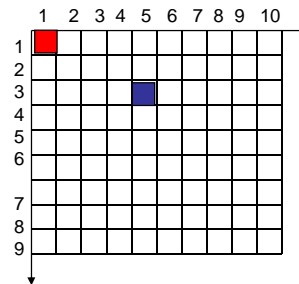
$$m = \Delta y / \Delta x = 0.5$$

$$y_1 = y_0 + m = 1.5$$

$$I_1 = I_0 + (-0.25, 0, 0.25)$$

Arredonda para 1.0 ou para 2.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

$$f(x,y) = y - 0.5x - 0.5$$

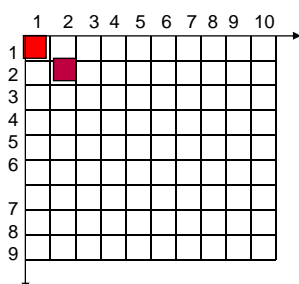
$$d_0 = f(1+1, 1+0.5) = 0$$

$$d_0 \geq 0 \rightarrow y_1 = y_0$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição

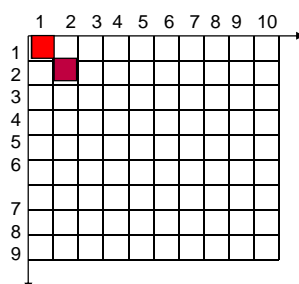


$$y = 0.5x + 0.5$$

$$y = 0.5(3) + 0.5 = 2.0$$

$$I = (1,0,0) + 0.5(-1,0,1)$$

DDA



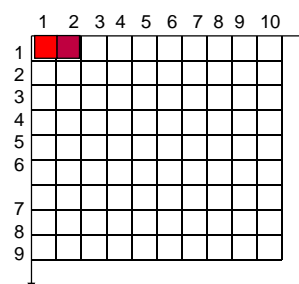
$$m = \Delta y / \Delta x = 0.5$$

$$y_2 = y_1 + m = 2.5$$

$$I_2 = I_1 + (-0.25, 0, 0.25)$$

Arredonda para 2.0 ou para 3.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

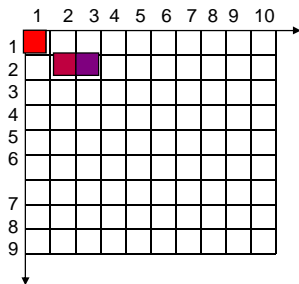
$$y_1 = y_0 \rightarrow d_1 = d_0 - \Delta y = -2$$

$$d_1 < 0 \rightarrow y_2 = y_1 + 1$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição



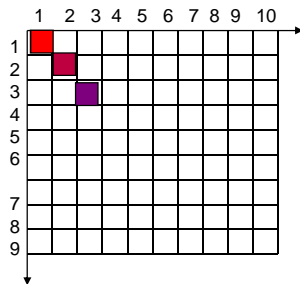
$$y = 0.5x + 0.5$$

$$y = 0.5(4) + 0.5 = 2.5$$

$$I = (1,0,0) + 0.75(-1,0,1)$$

Arredonda para 2.0 ou para 3.0?

DDA

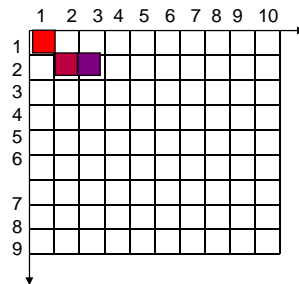


$$m = \Delta y / \Delta x = 0.5$$

$$y_3 = y_2 + m = 3.0$$

$$I_3 = I_2 + (-0.25, 0, 0.25)$$

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

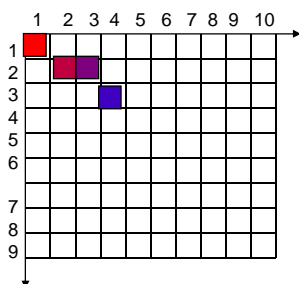
$$y_2 = y_1 + 1 \rightarrow d_2 = d_1 - \Delta y + \Delta x = 0$$

$$d_2 \geq 0 \rightarrow y_3 = y_2$$

Exemplo 1

Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição

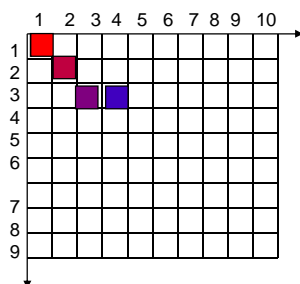


$$y = 0.5x + 0.5$$

$$y = 0.5(5) + 0.5 = 3.0$$

$$I = (1,0,0) + 1.0(-1,0,1)$$

DDA



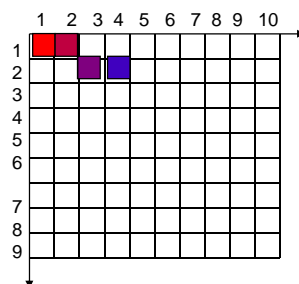
$$m = \Delta y / \Delta x = 0.5$$

$$y_4 = y_3 + m = 3.5$$

$$I_4 = I_3 + (-0.25, 0, 0.25)$$

Arredonda para 3.0 ou para 4.0?

Bresenham



$$\Delta y = 2 \quad \Delta x = 4$$

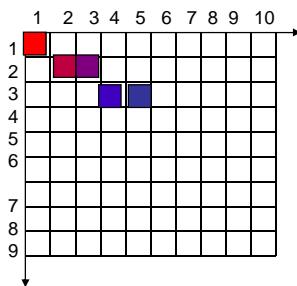
$$y_3 = y_2 \rightarrow d_3 = d_2 - \Delta y = -2$$

$$d_3 < 0 \rightarrow y_4 = y_3 + 1$$

Exemplo 1

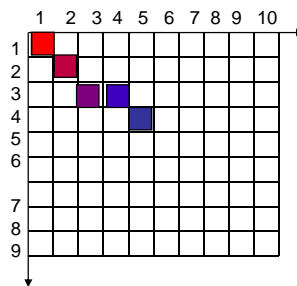
Rasterize o segmento definido pelos pontos $P_I=(1,1)$ e $P_F=(5,3)$
 $(\Delta x = 4) \geq (\Delta y = 2) \rightarrow x$ "anda" em passo unitário

Substituição



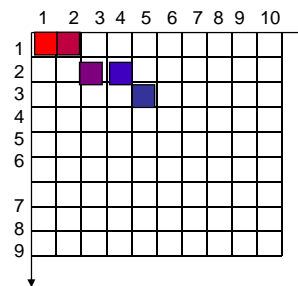
$$y = 0.5x + 0.5$$

DDA



$$m = \Delta y / \Delta x = 0.5$$

Bresenham



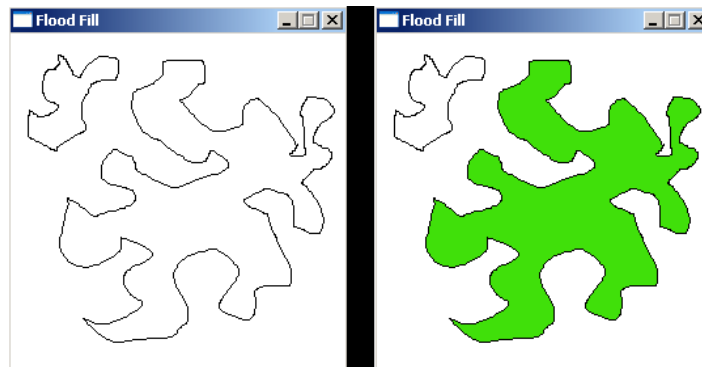
$$\Delta y = 2 \quad \Delta x = 4$$

Não chegou no ponto final!!!!

Rasterização de Polígonos

Princípio de Preenchimento

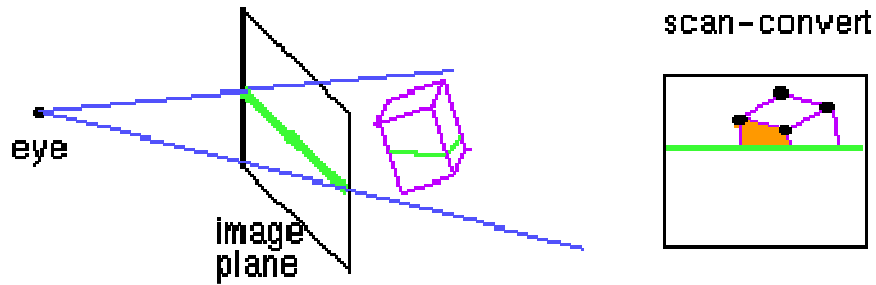
```
flood_fill(x,y) {
  enquanto (pixel(x,y) = branco) {
    mudar cor de (x,y);
    flood_fill(x-1,y);
    flood_fill(x+1,y);
    flood_fill(x,y-1);
    flood_fill(x,y+1);
  }
}
```



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Rasterização de Polígonos

Princípio de *Scanline*

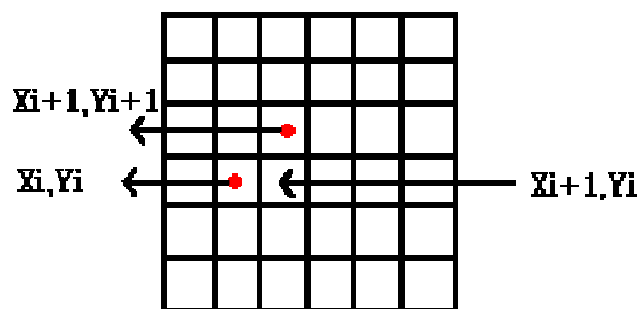


1. Rasterizar borda com DDA
2. Utilizar coerência para preenchimento de linhas

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Rasterização de Segmentos

DDA



$$Y = (\Delta y / \Delta x) X + b$$

$$m = \Delta y / \Delta x = (Y_{i+1} - Y_i) / (X_{i+1} - X_i);$$

$$m \leq 1 : Y_{i+1} = Y_i + m$$

$$m > 1 : X_{i+1} = X_i + 1/m$$

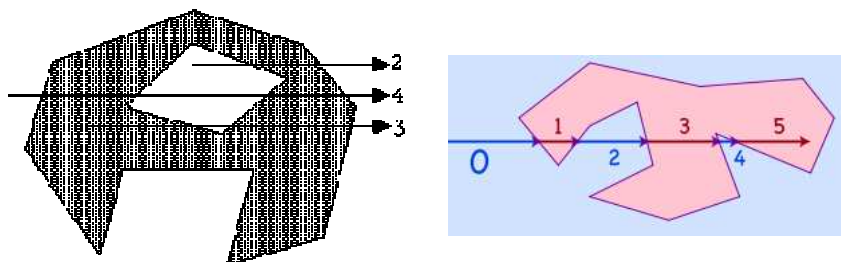
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Como uniformizar o arredondamento/truncamento?

Rasterização de Polígonos

Teste de Pertinência

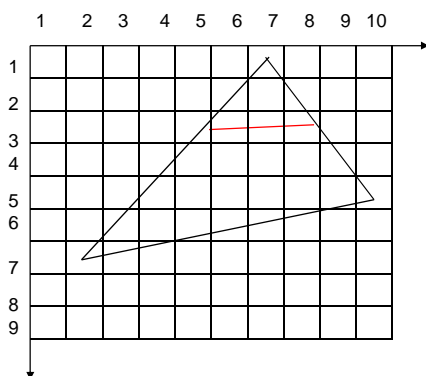
Ray Casting



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Rasterização de Polígonos

Scanline



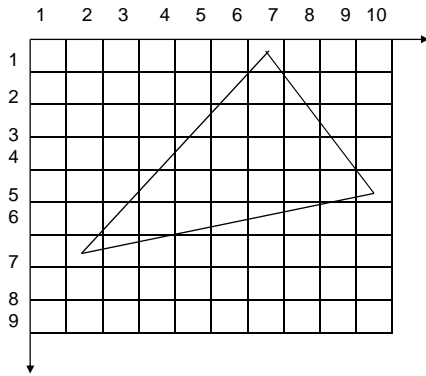
Varredura por linha

Para cada linha:

1. Determinar os pontos de interseção
2. Ordenar os pontos de interseção
3. Preencher o interior

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Rasterização de Polígonos Scanline



1. Inserir as arestas na tabela de arestas (ET);

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Rasterização de Polígonos Scanline

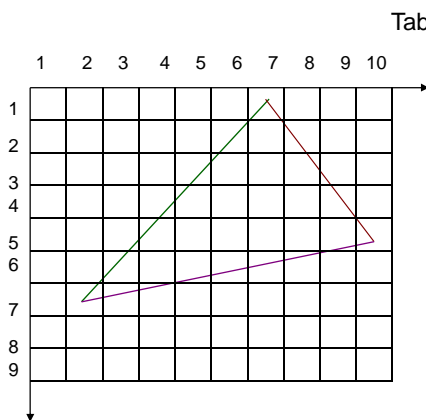
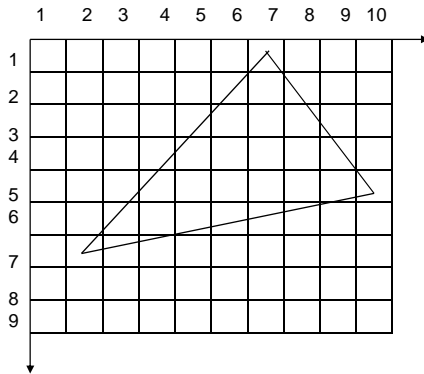


Tabela de Arestas

	y_{max}	x	$1/m$	
→	7	7	3/4	→
	5	7	-5/6	
→	7	10	-4	

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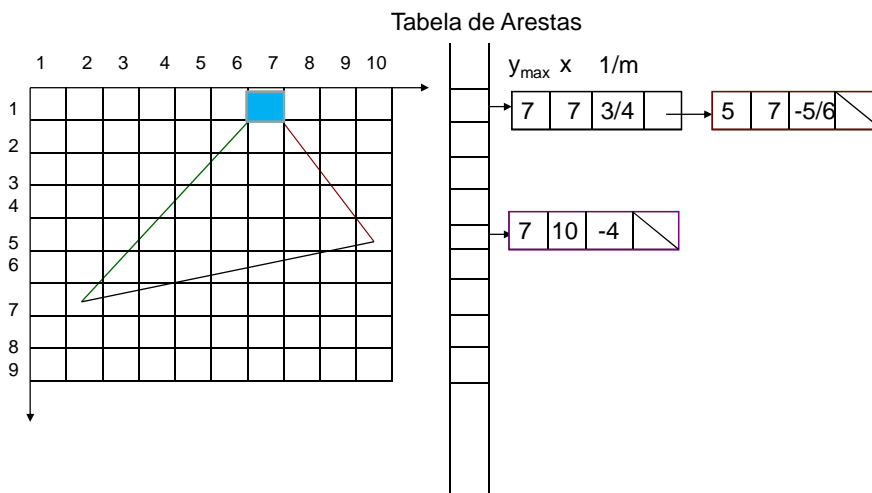
Rasterização de Polígonos Scanline



1. Inserir as arestas na tabela de arestas (ET);
2. Setar a linha $y=1$ como ativa;
3. Inicializar a tabela de arestas ativa (AET) para linha ativa, ordenando as células em relação à coordenada x
4. Preencher os intervalos

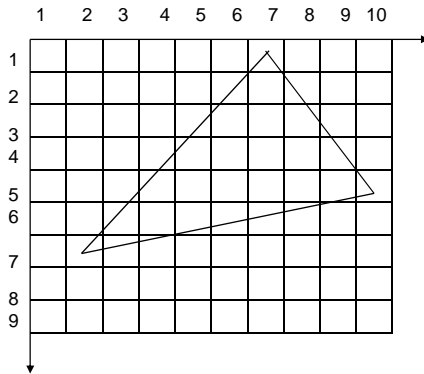
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Rasterização de Polígonos Scanline



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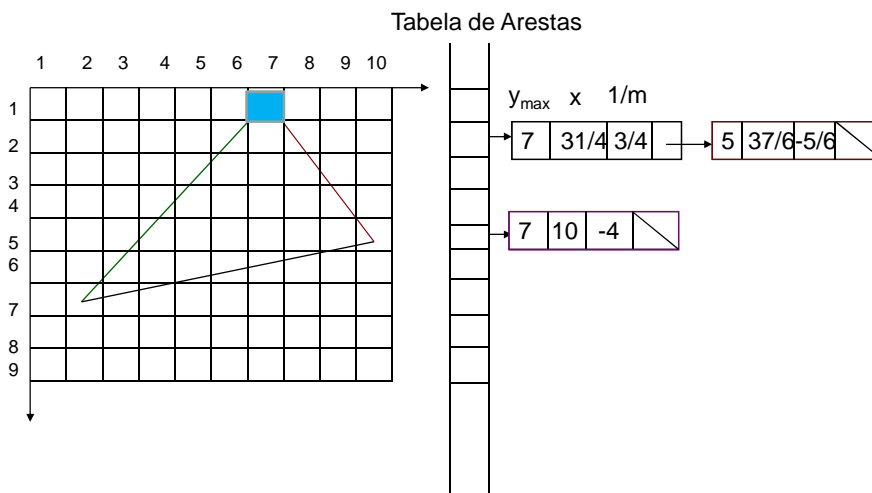
Rasterização de Polígonos Scanline



1. Inserir as arestas na tabela de arestas (ET);
2. Setar a linha $y=1$ como ativa;
3. Inicializar a tabela de arestas ativa (AET) para linha ativa, ordenando as células em relação à coordenada x
4. Preencher os intervalos
5. Se a próxima linha é menor que y_{max} , atualize x e transfere a célula para a próxima linha

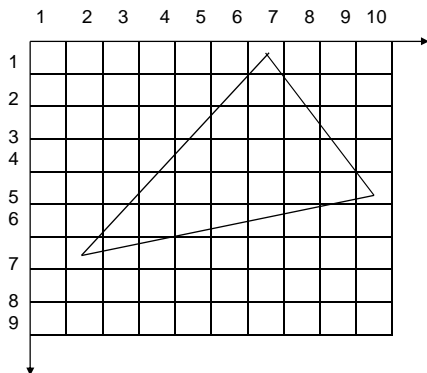
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Rasterização de Polígonos Scanline



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Rasterização de Polígonos Scanline



1. Inserir as arestas na tabela de arestas (ET);
2. Setar a linha $y=1$ como ativa;
3. Inicializar a tabela de arestas ativa (AET) para linha ativa, ordenando as células em relação à coordenada x
4. Preencher os intervalos
5. Se a próxima linha é maior que y_{max} , atualize x e transfere a célula para a próxima linha
6. Se há arestas na ET, ir para (3).

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Rasterização de Polígonos Scanline

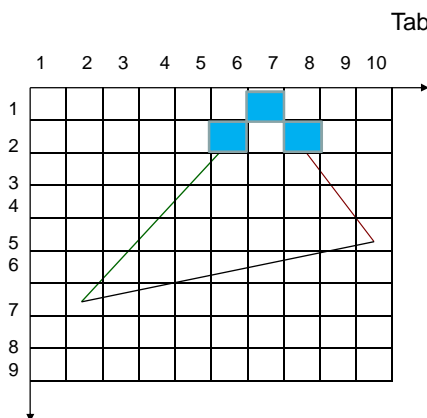
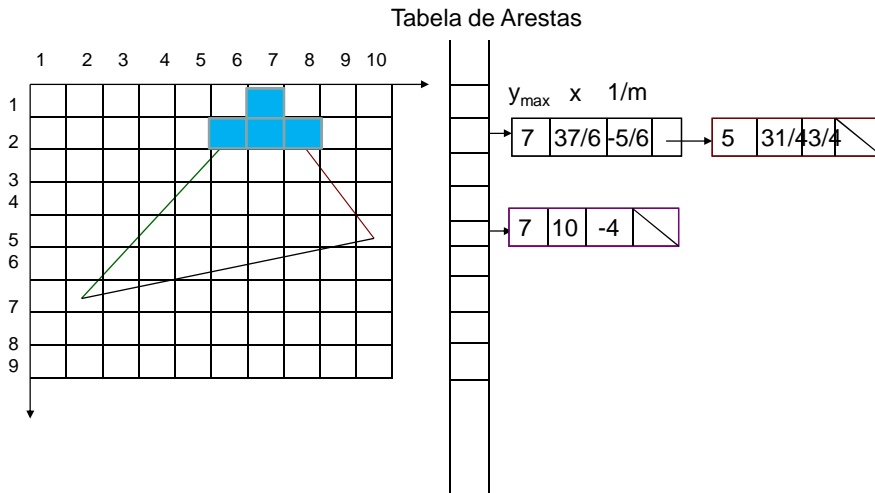


Tabela de Arestas

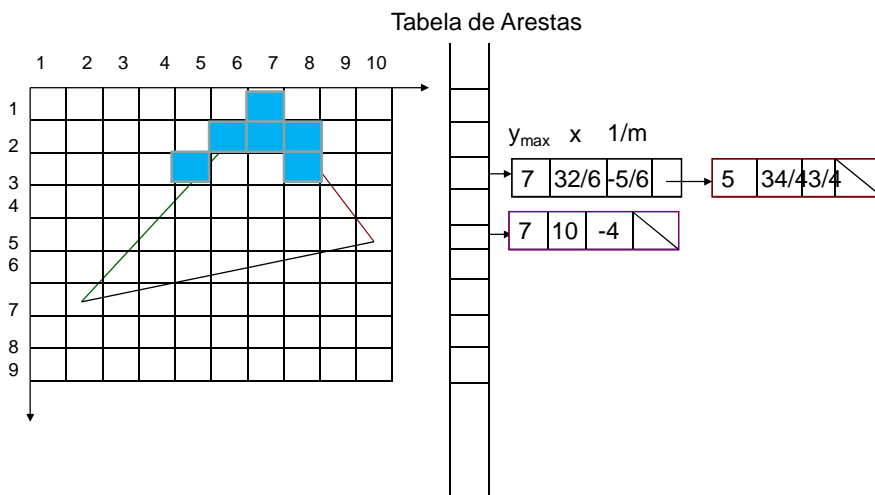
	y_{max}	x	$1/m$			
→	7	37/6	-5/6	→	5	31/43/4
→	7	10	-4			

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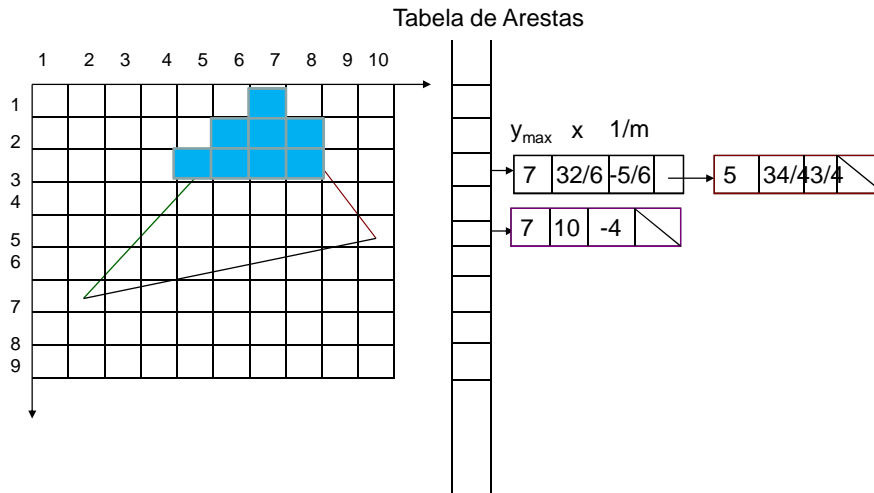
Rasterização de Polígonos Scanline



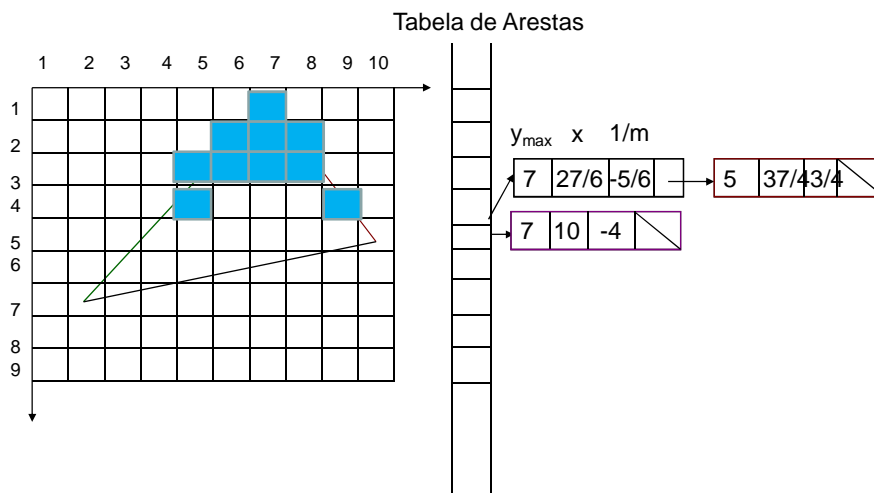
Rasterização de Polígonos Scanline



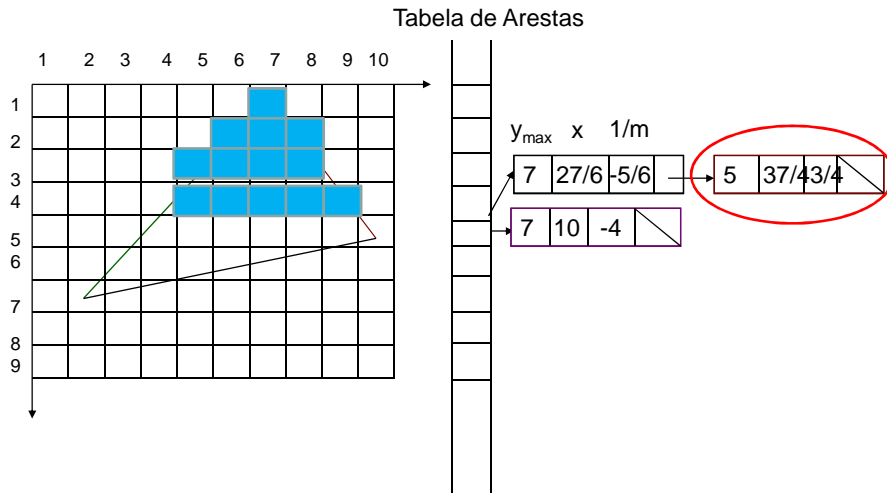
Rasterização de Polígonos Scanline



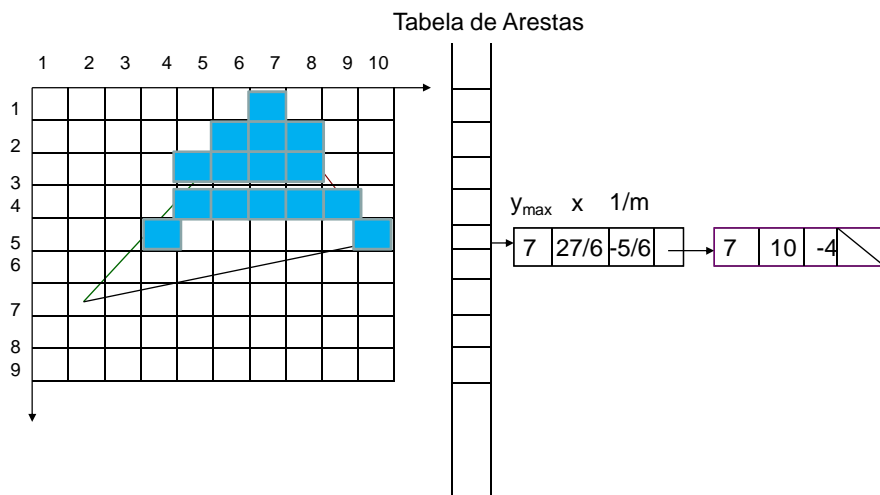
Rasterização de Polígonos Scanline



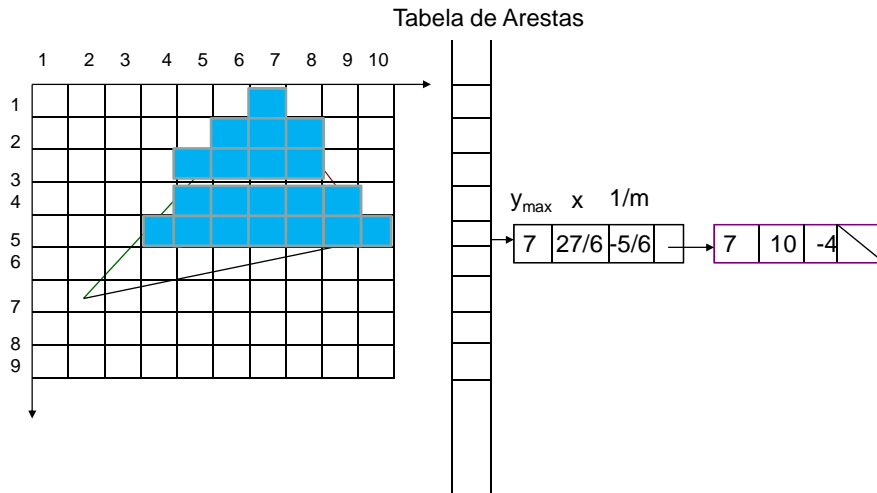
Rasterização de Polígonos *Scanline*



Rasterização de Polígonos *Scanline*

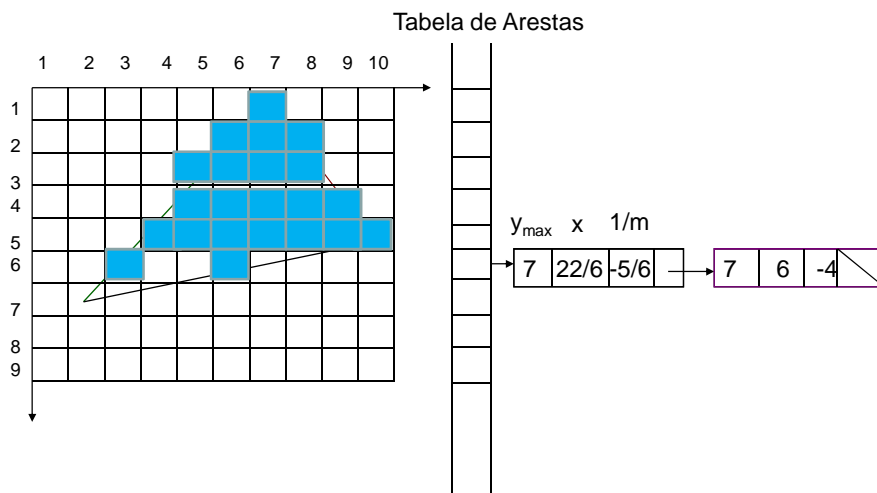


Rasterização de Polígonos *Scanline*



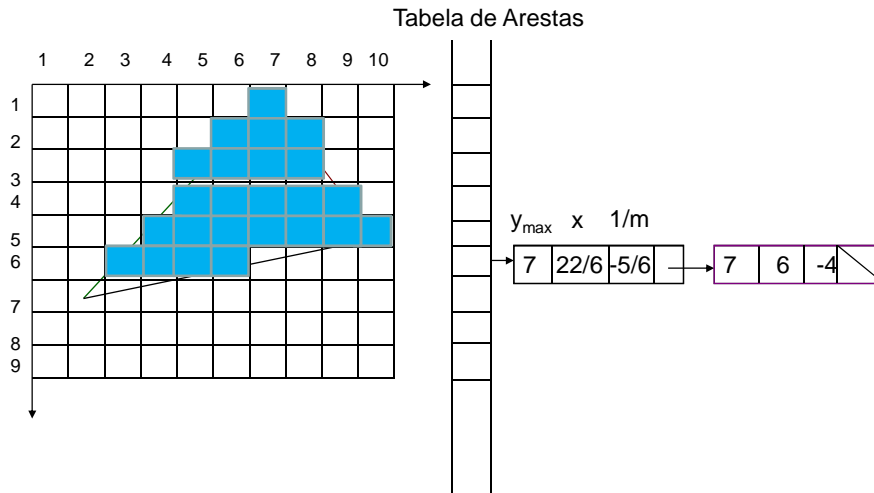
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Rasterização de Polígonos *Scanline*



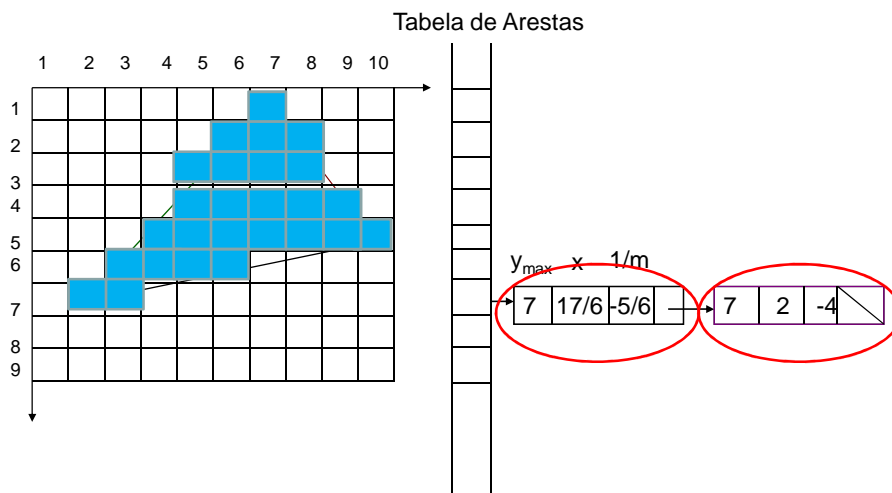
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Rasterização de Polígonos Scanline



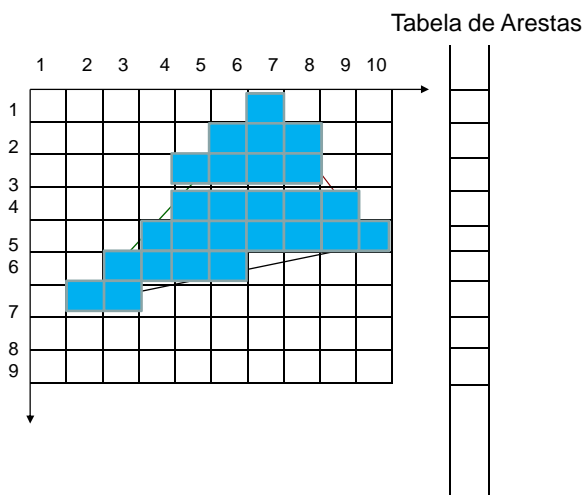
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Rasterização de Polígonos Scanline

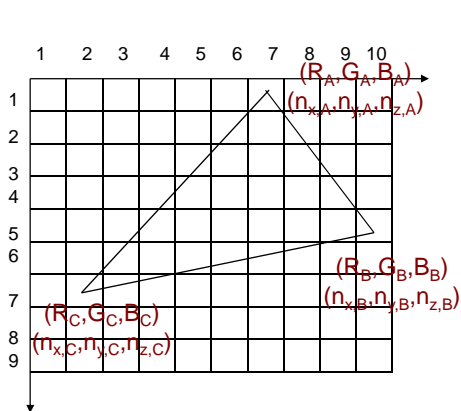


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Rasterização de Polígonos Scanline



Rasterização de Polígonos Scanline - Variações



Tonalização de Gouraud:

A intensidade nos vértices é computada e a intensidade dos restantes pixels, interpolada linearmente.

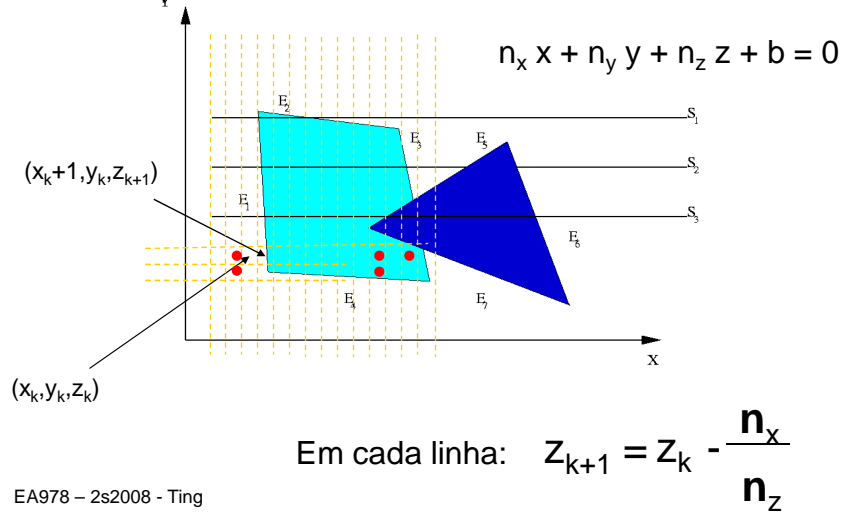
Tonalização de Phong:

O vetor normal nos vértices é computado e o vetor normal dos restantes pixels, interpolado linearmente.

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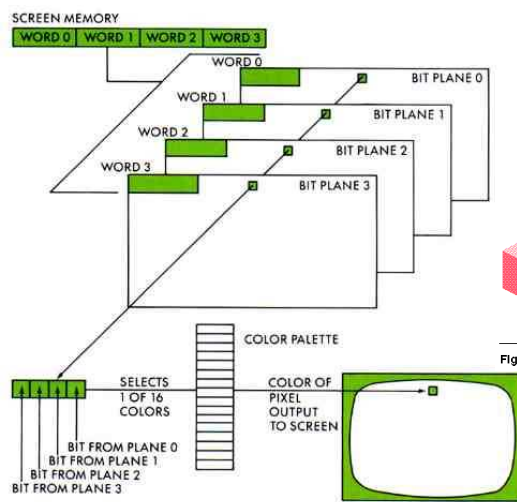
Rasterização de Polígonos Scanline - Variações

- Valor de profundidade obtido incrementalmente



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Tecnologia Raster Frame Buffer



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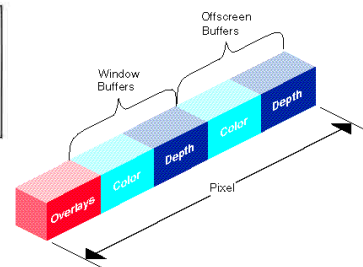


Figure 5. Frame Buffer Pixel Memory Including Offscreen Buffers

Operações sobre Frame Buffer Transferência de Blocos

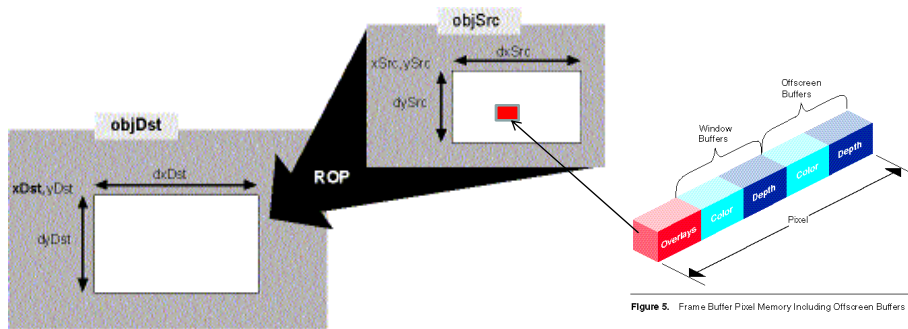


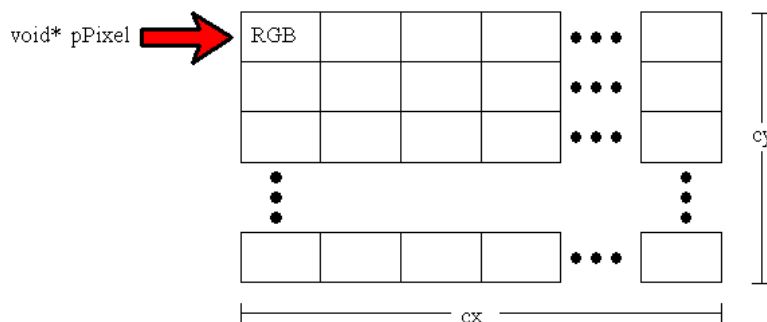
Figure 5. Frame Buffer Pixel Memory Including Offscreen Buffers

```
objDst.PaintPicture objSrc, xDst, yDst[, dxDst, dyDst, _
                    xSrc, ySrc, dxSrc, dySrc, ROP]
f = BitBlt(objDst.hDC, xDst, yDst, dxDst, dyDst, _
           objSrc.hDC, xSrc, ySrc, ROP)
* dxSrc and dySrc understood to be dxDst and dyDst
f = StretchBlt(objDst.hDC, xDst, yDst, dxDst, dyDst, _
              objSrc.hDC, xSrc, ySrc, dxSrc, dySrc, ROP)
```

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Armazenamento de Imagens

Formato de Dados
Arranjo de valores RGB em cada *pixel*
(bmp, OpenGL)

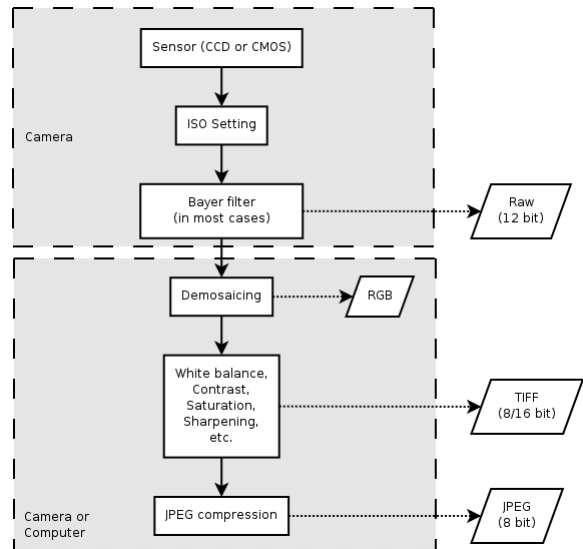


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Armazenamento de Imagens

Formato de Dados com Compressão

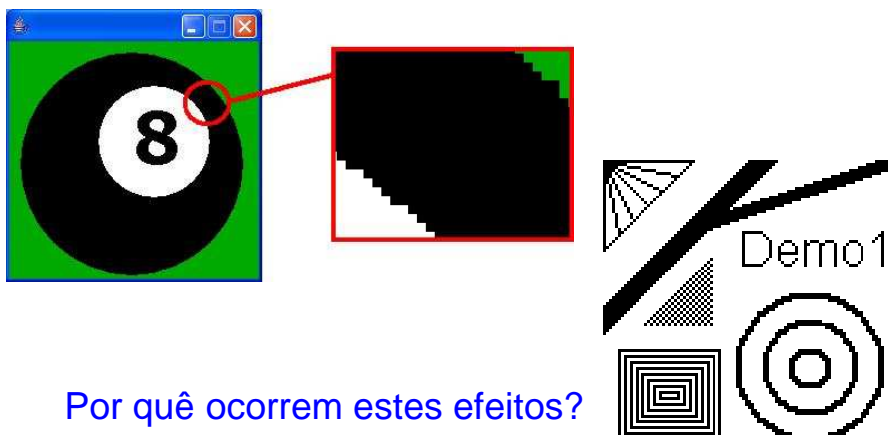
- Com perda (*lossy*): gif, jpeg
- Sem perda (*lossless*): tiff, ppm, png



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Rasterização de Polígonos

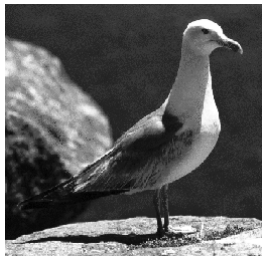
Efeito de Borda Serrilhada



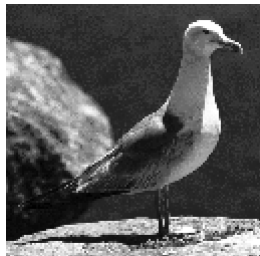
Por quê ocorrem estes efeitos?

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Rasterização



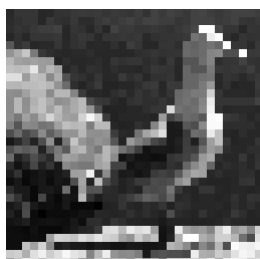
256 x 256



128 x 128



64 x 64



32 x 32



16 x 16

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