

CC222 – Visão Computacional

Descrição e Feições

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Tópicos da aula

- Detecção de cantos
- Detecção de contornos
- Regiões binárias – caracterização
- Descrição de formas geométricas

Livro para acompanhar essa aula

Gonzalez e Woods

Shapiro e Stockman

Horn (regiões binárias)

Ballard (descrição)

Trucco (detecção de cantos)

Detecção de cantos

$$C = \begin{bmatrix} \sum E_x^2 & \sum E_x E_y \\ \sum E_x E_y & \sum E_y^2 \end{bmatrix}$$

Realizar os somatórios sobre uma região centrada no pixel investigado.

Obter os autovalores de C.

Se o menor autovalor de C for maior que um valor limite, detectou-se um canto.

Detectando contorno por máscaras de convolução

Seja S um sinal unidimensional amostrado num vetor $S[i]$.

$S'[i]$ é o sinal correspondente às diferenças de primeira ordem.

$S''[i]$ é o sinal correspondente às diferenças de segunda ordem.

A máscara M' é a máscara de convolução que produz as diferenças entre pixels consecutivos

$$S'[i] = -S[i-1] + S[i]$$

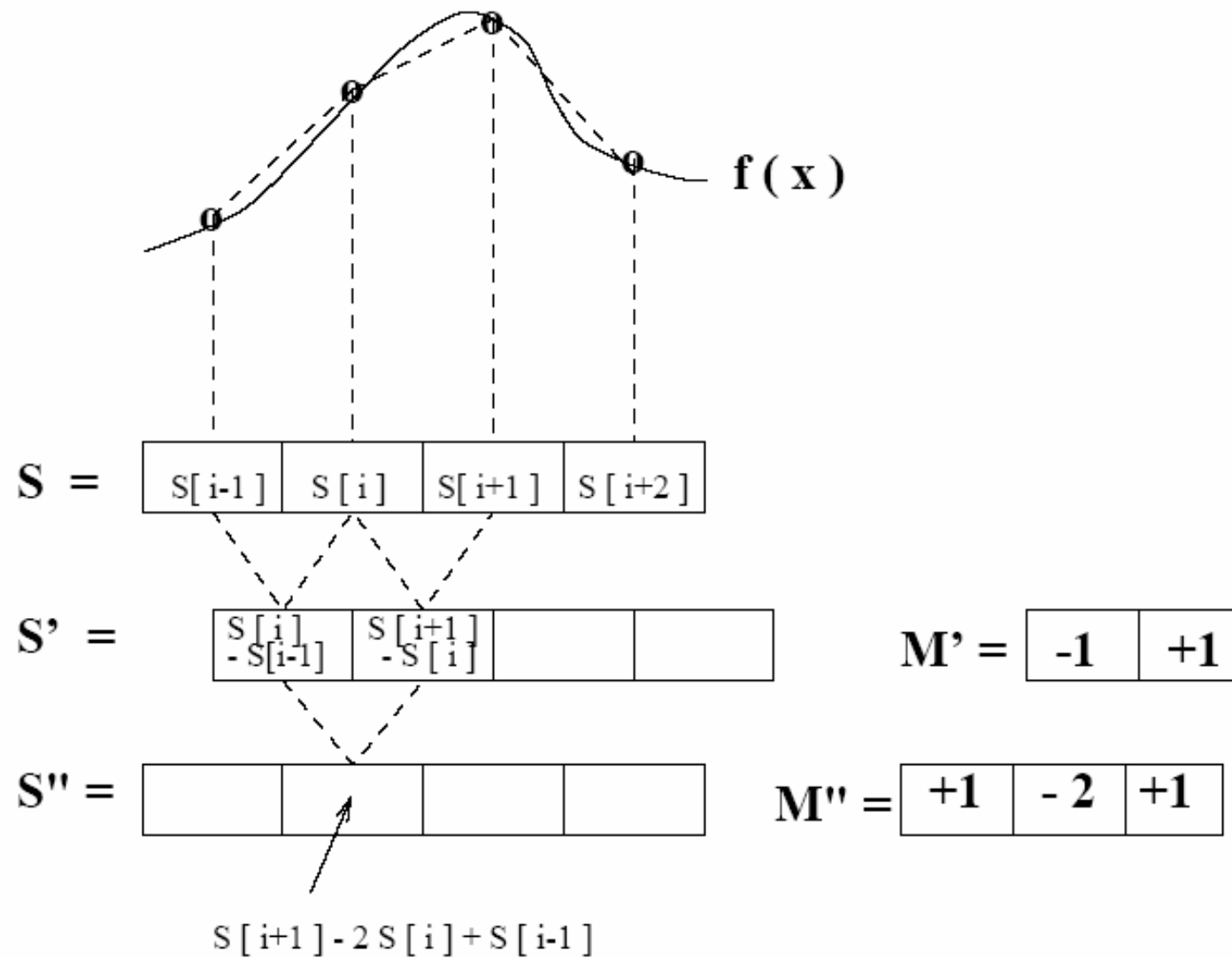
$$\text{mask } M' = [-1, +1]$$

$$S''[i] = -S'[i] + S'[i+1]$$

$$= -(S[i] - S[i-1]) + (S[i+1] - S[i])$$

$$= S[i-1] - 2S[i] + S[i+1]$$

$$\text{mask } M'' = [1, -2, 1]$$



$$\text{mask } \mathbf{M} = [-1, 0, 1]$$

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_1 | | | 12 | 12 | 12 | 12 | 12 | 24 | 24 | 24 | 24 | 24 |
| S_1 | \otimes | M | 0 | 0 | 0 | 0 | 12 | 12 | 0 | 0 | 0 | 0 |

(a) S_1 is an upward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|-----|-----|----|----|----|----|
| S_2 | | | 24 | 24 | 24 | 24 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_2 | \otimes | M | 0 | 0 | 0 | 0 | -12 | -12 | 0 | 0 | 0 | 0 |

(b) S_2 is a downward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_3 | | | 12 | 12 | 12 | 12 | 15 | 18 | 21 | 24 | 24 | 24 |
| S_3 | \otimes | M | 0 | 0 | 0 | 3 | 6 | 6 | 6 | 3 | 0 | 0 |

(c) S_3 is an upward ramp

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|-----|----|----|----|----|
| S_4 | | | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_4 | \otimes | M | 0 | 0 | 0 | 12 | 0 | -12 | 0 | 0 | 0 | 0 |

(d) S_4 is a bright impulse or “line”

exemplos de convolução

Filtros Gaussianos

Os coeficientes da máscara são dados pela função

$$g(x, y) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{d^2}{2\sigma^2}}$$

Onde

$$d = \sqrt{(x - x_c)^2 + (y - y_c)^2}$$

Utilizado para remoção de ruído (smoothing ou suavização).

Aplicando a convolução com uma máscara derivativa, obtemos uma máscara derivativa mais robusta (evita o ruído)

box smoothing mask $M = [1/3, 1/3, 1/3]$

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_1 | | | 12 | 12 | 12 | 12 | 12 | 24 | 24 | 24 | 24 | 24 |
| S_1 | \otimes | M | 12 | 12 | 12 | 12 | 16 | 20 | 24 | 24 | 24 | 24 |

(a) S_1 is an upward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_4 | | | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_4 | \otimes | M | 12 | 12 | 12 | 16 | 16 | 16 | 12 | 12 | 12 | 12 |

(d) S_4 is a bright impulse or “line”

Gaussian smoothing mask $M = [1/4, 1/2, 1/4]$

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_1 | | | 12 | 12 | 12 | 12 | 12 | 24 | 24 | 24 | 24 | 24 |
| S_1 | \otimes | M | 12 | 12 | 12 | 12 | 15 | 21 | 24 | 24 | 24 | 24 |

(a) S_1 is an upward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_4 | | | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_4 | \otimes | M | 12 | 12 | 12 | 15 | 18 | 15 | 12 | 12 | 12 | 12 |

(d) S_4 is a bright impulse or “line”

Some properties of derivative masks follow:

- Coordinates of derivative masks have opposite signs in order to obtain a high response in signal regions of high contrast.
- The sum of coordinates of derivative masks is zero so that a zero response is obtained on constant regions.
- First derivative masks produce high absolute values at points of high contrast.
- Second derivative masks produce zero-crossings at points of high contrast.

For comparison, smoothing masks have these properties:

- Coordinates of smoothing masks are positive and sum to one so that output on constant regions is the same as the input.
- The amount of smoothing and noise reduction is proportional to the mask size.
- Step edges are blurred in proportion to the mask size.

Operadores diferenciais em imagens

$$\begin{aligned} \partial f / \partial x \equiv f_x \approx & \frac{1}{3} [(I[x + 1, y] - I[x - 1, y])/2 \\ & + (I[x + 1, y - 1] - I[x - 1, y - 1])/2 \\ & + (I[x + 1, y + 1] - I[x - 1, y + 1])/2)] \end{aligned}$$

$$\begin{aligned} \partial f / \partial y \equiv f_y \approx & \frac{1}{3} [(I[x, y + 1] - I[x, y - 1])/2 \\ & + (I[x - 1, y + 1] - I[x - 1, y - 1])/2 \\ & + (I[x + 1, y + 1] - I[x + 1, y - 1])/2)] \end{aligned}$$

$$\text{mask } M = [-1, 2, -1]$$

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|-----|----|----|----|----|----|
| S_1 | | | 12 | 12 | 12 | 12 | 12 | 24 | 24 | 24 | 24 | 24 |
| S_1 | \otimes | M | 0 | 0 | 0 | 0 | -12 | 12 | 0 | 0 | 0 | 0 |

(a) S_1 is an upward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|-----|----|----|----|----|
| S_2 | | | 24 | 24 | 24 | 24 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_2 | \otimes | M | 0 | 0 | 0 | 0 | 12 | -12 | 0 | 0 | 0 | 0 |

(b) S_2 is a downward step edge

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|----|----|----|----|----|----|----|
| S_3 | | | 12 | 12 | 12 | 12 | 15 | 18 | 21 | 24 | 24 | 24 |
| S_3 | \otimes | M | 0 | 0 | 0 | -3 | 0 | 0 | 0 | 3 | 0 | 0 |

(c) S_3 is an upward ramp

| | | | | | | | | | | | | |
|-------|-----------|-----|----|----|----|-----|----|-----|----|----|----|----|
| S_4 | | | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 12 | 12 |
| S_4 | \otimes | M | 0 | 0 | 0 | -12 | 24 | -12 | 0 | 0 | 0 | 0 |

(d) S_4 is a bright impulse or “line”

Máscaras 2D

Prewitt: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$

Sobel: $M_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$

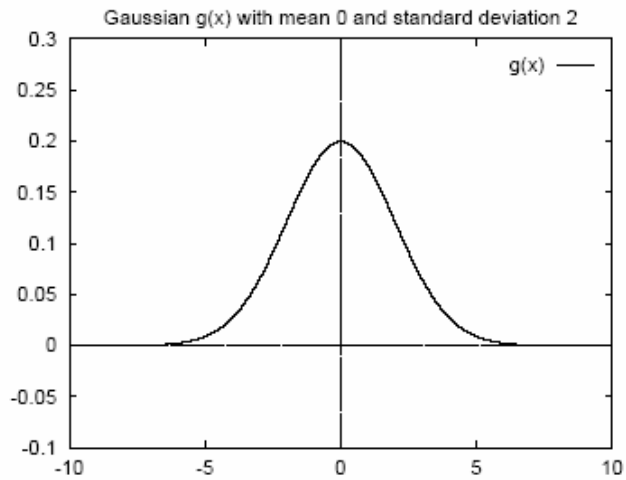
Roberts: $M_x = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$; $M_y = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

diferenciais

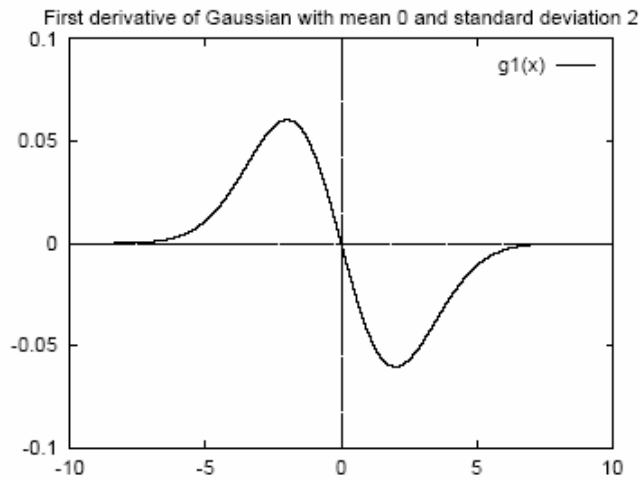
$G_{3 \times 3} = \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$;

$G_{7 \times 7} = \begin{bmatrix} 1 & 3 & 7 & 9 & 7 & 3 & 1 \\ 3 & 12 & 26 & 33 & 26 & 12 & 3 \\ 7 & 26 & 55 & 70 & 55 & 26 & 7 \\ 9 & 33 & 70 & 90 & 70 & 33 & 9 \\ 7 & 26 & 55 & 70 & 55 & 26 & 7 \\ 3 & 12 & 26 & 33 & 26 & 12 & 3 \\ 1 & 3 & 7 & 9 & 7 & 3 & 1 \end{bmatrix}$

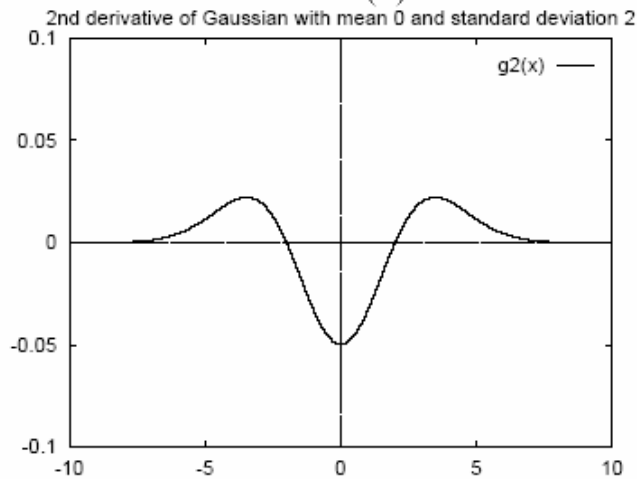
gaussianas



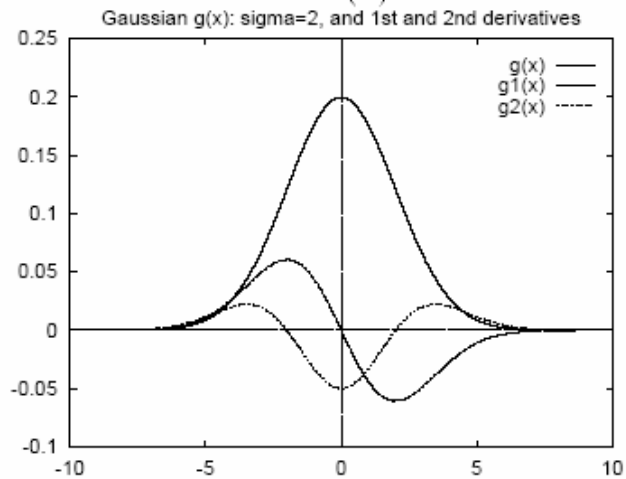
(a)



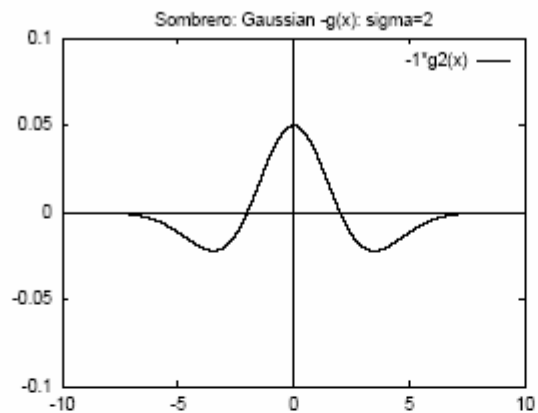
(b)



(c)



(d)



| | | |
|----|----|----|
| 0 | -1 | 0 |
| -1 | 4 | -1 |
| 0 | -1 | 0 |

| | | | | | |
|---|---|----|----|----|----|
| 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 5 | 5 | 5 | 5 |
| 5 | 5 | 10 | 10 | 10 | 10 |
| 5 | 5 | 10 | 10 | 10 | 10 |
| 5 | 5 | 5 | 10 | 10 | 10 |
| 5 | 5 | 5 | 5 | 10 | 10 |

| | | | | | |
|---|----|-----|----|----|---|
| - | - | - | - | - | - |
| - | 0 | -5 | -5 | -5 | - |
| - | -5 | 10 | 5 | 5 | - |
| - | -5 | 10 | 0 | 0 | - |
| - | 0 | -10 | 10 | 0 | - |
| - | - | - | - | - | - |

laplaciano de gaussianas

Notar os zero-crossings

| | | | | | | | | | | |
|----|----|-----|-----|-----|-----|-----|-----|-----|----|----|
| 0 | 0 | 0 | -1 | -1 | -2 | -1 | -1 | 0 | 0 | 0 |
| 0 | 0 | -2 | -4 | -8 | -9 | -8 | -4 | -2 | 0 | 0 |
| 0 | -2 | -7 | -15 | -22 | -23 | -22 | 15 | -7 | -2 | 0 |
| -1 | -4 | -15 | -24 | -14 | -1 | -14 | -24 | -15 | -4 | -1 |
| -1 | -8 | -22 | -14 | 52 | 103 | 52 | -14 | -22 | -8 | -1 |
| -2 | -9 | -23 | -1 | 103 | 178 | 103 | -1 | -23 | -9 | -2 |
| -1 | -8 | -22 | -14 | 52 | 103 | 52 | -14 | -22 | -8 | -1 |
| -1 | -4 | -15 | -24 | -14 | -1 | -14 | -24 | -15 | -4 | -1 |
| 0 | -2 | -7 | -15 | -22 | -23 | -22 | 15 | -7 | -2 | 0 |
| 0 | 0 | -2 | -4 | -8 | -9 | -8 | -4 | -2 | 0 | 0 |
| 0 | 0 | 0 | -1 | -1 | -2 | -1 | -1 | 0 | 0 | 0 |

laplaciano 11x11

$$\begin{aligned}
 G[x, y] &= F[x, y] \otimes H[x, y] \\
 &= \sum_{i=-w/2}^{w/2} \sum_{j=-h/2}^{h/2} F[x+i, y+j] H[i, j]
 \end{aligned}$$

(construção das convoluções com máscara centrada em um pixel)

Vizinhança

| | | |
|---|---|---|
| | N | |
| W | * | E |
| | S | |

vizinhança 4

| | | |
|----|---|----|
| NW | N | NE |
| W | * | E |
| SW | S | SE |

vizinhança 8

Regiões conexas

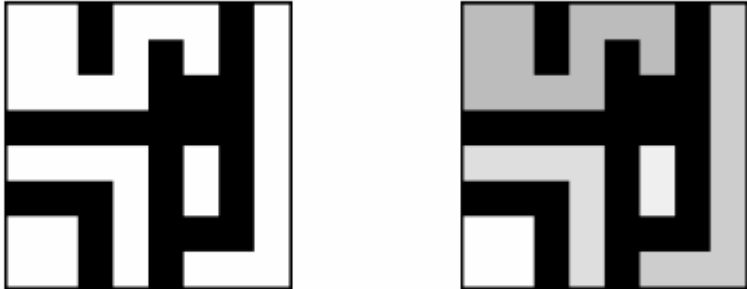
Rotulação de regiões

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |

a) binary image

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | 2 |
| 1 | 1 | 0 | 1 | 0 | 1 | 0 | 2 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 2 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 3 | 3 | 3 | 3 | 0 | 4 | 0 | 2 |
| 0 | 0 | 0 | 3 | 0 | 4 | 0 | 2 |
| 5 | 5 | 0 | 3 | 0 | 0 | 0 | 2 |
| 5 | 5 | 0 | 3 | 0 | 2 | 2 | 2 |

b) connected components labeling



c) binary image and labeling, expanded for viewing

```
function bim=lbl_label(im)

% bim=lbl_label(im)
%
% Labeling of image im.
% The labels are sorted by area.
% Label 1 is usually the background.
%

lut=1:10000; % look-up table
bim=zeros(size(im)); % image of the labels

%primeiro elemento
bim(1,1)=1;
lbl=2;
```

```
% primeira linha
for j=2:size(im,2)
    if(im(1,j)==im(1,j-1))
        bim(1,j)=bim(1,j-1);
    else
        bim(1,j)=lbl;
        lbl=lbl+1;
    end
end

%demais linhas
for i=2:size(im,1)
    cline=0;
    %primeira coluna
    if im(i,1)==im(i-1,1)
        bim(i,1)=bim(i-1,1);
    else
```

```

        bim(i,1)=lbl;
        lbl=lbl+1;
end
%demais colunas
for j=2:size(im,2)
    if(im(i,j)==im(i,j-1))
        bim(i,j)=bim(i,j-1);
        if (im(i,j)==im(i-1,j))
            lut(bim(i,j))=bim(i-1,j);
            bim(i,j)=bim(i-1,j);
            cline=1;
        end
    elseif (im(i,j)==im(i-1,j))
        bim(i,j)=bim(i-1,j);
    else
        bim(i,j)=lbl;
        lbl=lbl+1;
    end
end

```

```

        end
    end
    if cline
        for j=1:size(im,2)
            bim(i,j)=lut(bim(i,j));
        end
    end
end

end

%compactar lut
plut=zeros(1,lbl);
nlbl=1;
for i=1:size(plut,2)
    p=i;
    q=lut(p);
    while p~=q
        p=q;
    end
end

```

```

        q=lut(p);
    end
    lut(i)=p;
    if plut(p)==0
        plut(p)=nlbl;
        nlbl=nlbl+1;
    end
end
end

for i=1:size(im,1)
    for j=1:size(im,2)
        bim(i,j)=plut(lut(bim(i,j)));
    end
end

%newpack
mlut=zeros(size(plut));

```

```

mlbl=1;
for i=1:size(im,1)
    for j=1:size(im,2)
        if mlut(bim(i,j))==0
            mlut(bim(i,j))=mlbl;
            bim(i,j)=mlbl;
            mlbl=mlbl+1;
        else
            bim(i,j)=mlut(bim(i,j));
        end
    end
end

% sort by area
lb=bim;
h=hist(lb(1:end),max(max(lb)));
[y,ilut]=sort(-h);

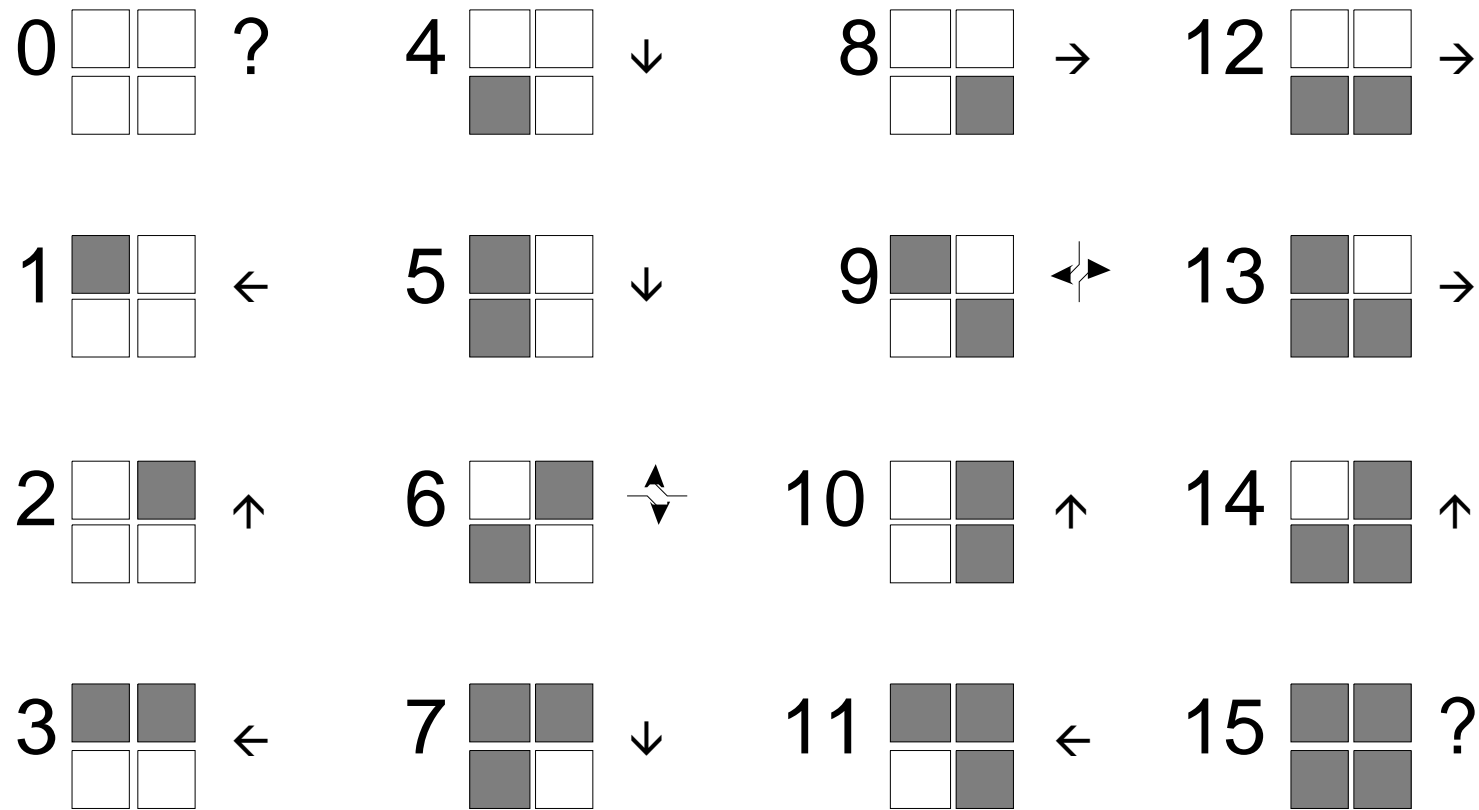
```

```
ylut=ilut;
for i=1:size(ilut,2)
    ylut(i)=find(ilut==i);
end

for i=1:size(lb,1)
    for j=1:size(lb,2)
        lb(i,j)=ylut(lb(i,j));
    end
end
lbimg=lb;
bim=lb;
```

Para obter a região de rótulo 3 use `bim==3`. Para obter o inverso `bim~=3`.

Traçando o contorno de uma região binária



Descrição de Regiões Binárias

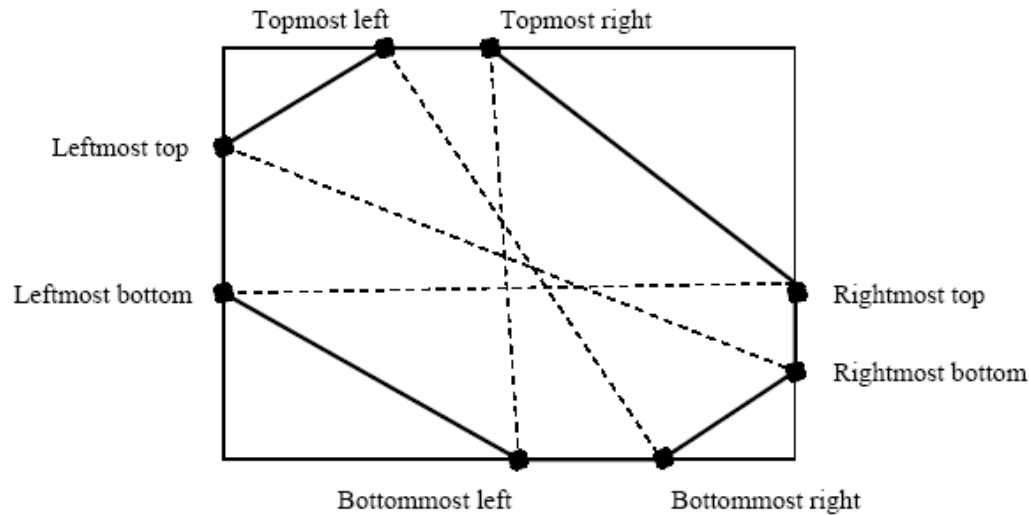
Área $A = \sum_{(r,c) \in R} 1$

Centróide $\bar{r} = \frac{1}{A} \sum_{(r,c) \in R} r$
 $\bar{c} = \frac{1}{A} \sum_{(r,c) \in R} c$

Perímetro $|P| = |\{k | (r_{k+1}, c_{k+1}) \in N_4(r_k, c_k)\}|$
 $+ \sqrt{2} |\{k | (r_{k+1}, c_{k+1}) \in N_8(r_k, c_k) - N_4(r_k, c_k)\}|$

Circularidade $C_1 = \frac{|P|^2}{A}$

Bounding box



Distribuição da distância ao centróide

mean radial distance:

$$\mu_R = \frac{1}{K} \sum_{k=0}^{K-1} \|(r_k, c_k) - (\bar{r}, \bar{c})\|$$

standard deviation of radial distance:

$$\sigma_R = \left(\frac{1}{K} \sum_{k=0}^{K-1} [\|(r_k, c_k) - (\bar{r}, \bar{c})\| - \mu_R]^2 \right)^{1/2}$$

Momentos centrais de segunda ordem

second-order row moment:

$$\mu_{rr} = \frac{1}{A} \sum_{(r,c) \in R} (r - \bar{r})^2$$

second-order mixed moment:

$$\mu_{rc} = \frac{1}{A} \sum_{(r,c) \in R} (r - \bar{r})(c - \bar{c})$$

second-order column moment:

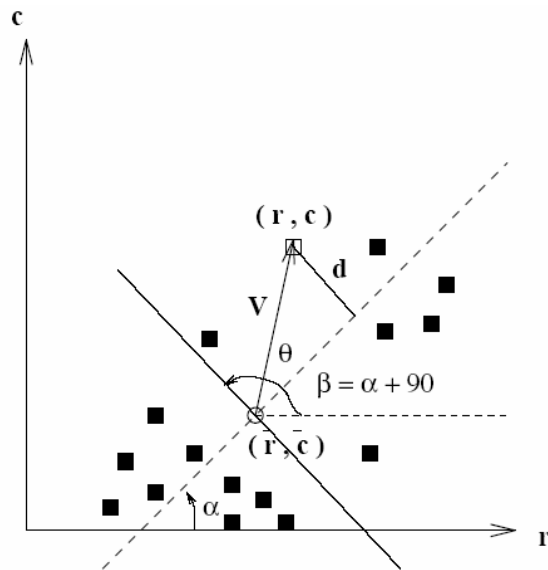
$$\mu_{cc} = \frac{1}{A} \sum_{(r,c) \in R} (c - \bar{c})^2$$

Estão relacionados aos coeficientes de uma elipse com centro na origem

$$R = \{(r, c) \mid dr^2 + 2erc + fc^2 \leq 1\}$$

$$\begin{pmatrix} d & e \\ e & f \end{pmatrix} = \frac{1}{4(\mu_{rr}\mu_{cc} - \mu_{rc}^2)} \begin{pmatrix} \mu_{cc} & -\mu_{rc} \\ -\mu_{rc} & \mu_{rr} \end{pmatrix}$$

Eixo de mínima dispersão



* second moment about axis:

$$\begin{aligned}
 \mu_{\bar{r}, \bar{c}, \alpha} &= \frac{1}{A} \sum_{(r, c) \in R} d^2 \\
 &= \frac{1}{A} \sum_{(r, c) \in R} (\bar{V} \circ (\cos \beta, \sin \beta))^2 \\
 &= \frac{1}{A} \sum_{(r, c) \in R} ((r - \bar{r}) \cos \beta + (c - \bar{c}) \sin \beta)^2
 \end{aligned}$$

where $\beta = \alpha + \pi/2$.

* axis with least second moment:

$$\begin{aligned}\tan 2\hat{\alpha} &= \frac{2 \sum (r - \bar{r})(c - \bar{c})}{\sum (r - \bar{r})(r - \bar{r}) - \sum (c - \bar{c})(c - \bar{c})} \\ &= \frac{\frac{1}{A} 2 \sum (r - \bar{r})(c - \bar{c})}{\frac{1}{A} \sum (r - \bar{r})(r - \bar{r}) - \frac{1}{A} \sum (c - \bar{c})(c - \bar{c})} \\ &= \frac{2 \mu_{rc}}{\mu_{rr} - \mu_{cc}}\end{aligned}$$

Obtendo imagens binárias de imagens de escala de cinza

Thresholding

$$b_{ij} = \begin{cases} 1, & \text{se } E_{ij} > \textit{threshold} \\ 0, & \text{caso contrário} \end{cases}$$



a) original image



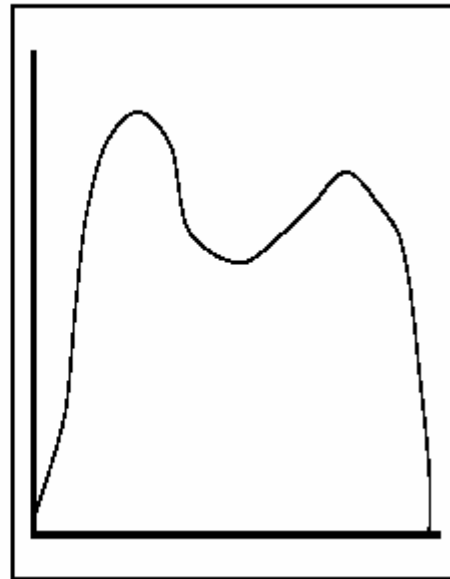
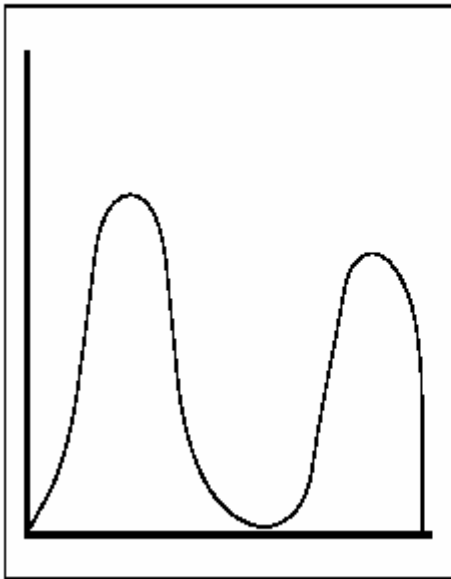
b) pixels below 93



c) pixels above 93

Histograma

$$h(m) = |\{(r, c) \mid I(r, c) = m\}|,$$



O valor de threshold deve ser escolhido para separar a distribuição bi-modal.

Construção do fecho convexo em 2D

Dados vértices ordenados em y

Insira o primeiro vértice e o segundo vértice nas listas esquerda e direita.

Para cada outro vértice V

Percorrer lista da esquerda inversamente removendo vértices até garantir que o ângulo das arestas em relação à horizontal é sempre decrescente.

Percorrer a lista da direita inversamente removendo vértices até garantir que o ângulo das arestas em relação à horizontal é sempre crescente.

Insira V nas duas listas.

Fim

