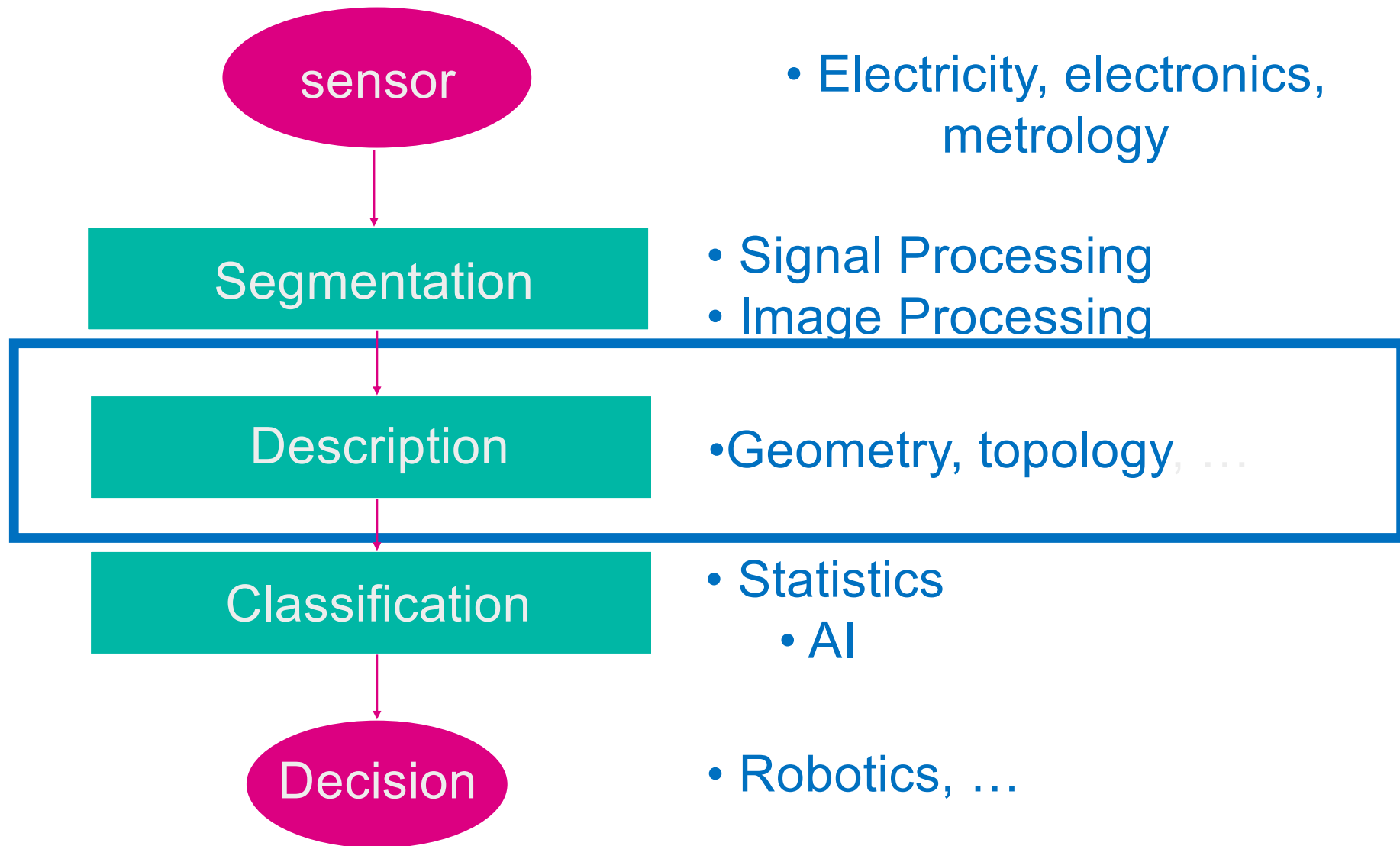


Image analysis and Pattern Recognition

Lecture 3 : object description

Prof. Jean-Philippe THIRAN
JP.Thiran@epfl.ch



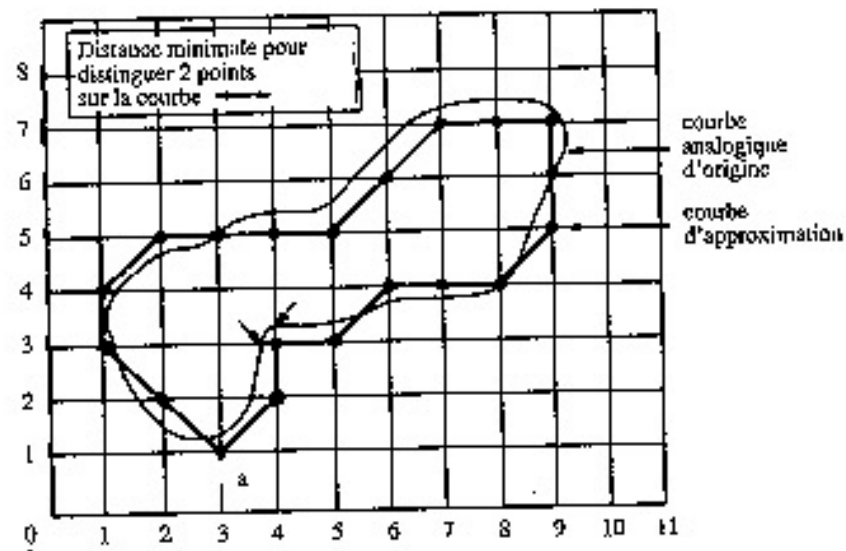
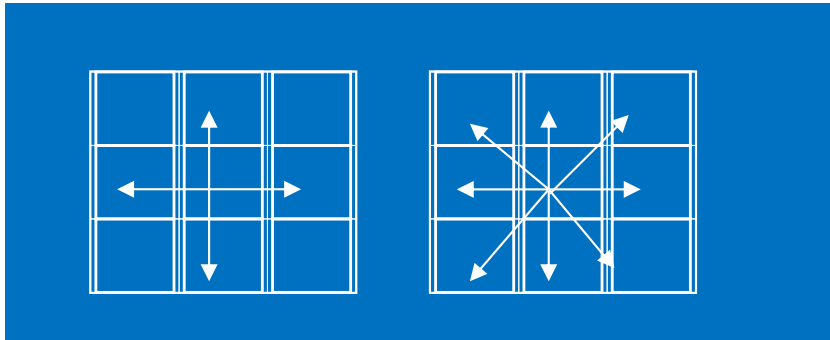


- **Goal:** present some of the main methods allowing describing a 2D shape by a set of adequate parameters
 - The 2D shape is provided as a binary image as the result of a segmentation task
 - There is a large variety of representations, ranging from “lossless” to very “elementary” ones.
 - The elements of a representation are called **features**
 - Reference : « Reconnaissance des formes et analyse de scènes », Murat KUNT, éditeur, chapitre 2.

- Pattern recognition approach: object classification:
 - The features to extract should ideally respond to the following requirements:
 - *Small intra-class variance*
 - *Large inter-class variance*
 - *Small number of features*
 - *Independence in translation-rotation (and scaling some times)*
- Twp types of representations:
 - **External** : description based on the contours of the shape
 - **Internal** : description based on the inner part



- There are mainly two approaches in contour-based description:
 - **Local** methods: point-to-point description
 - **Global** methods: description by features calculated globally on the whole contour
- Notice that we treat contours on a discrete grid
 - 4 or 8 connectivity

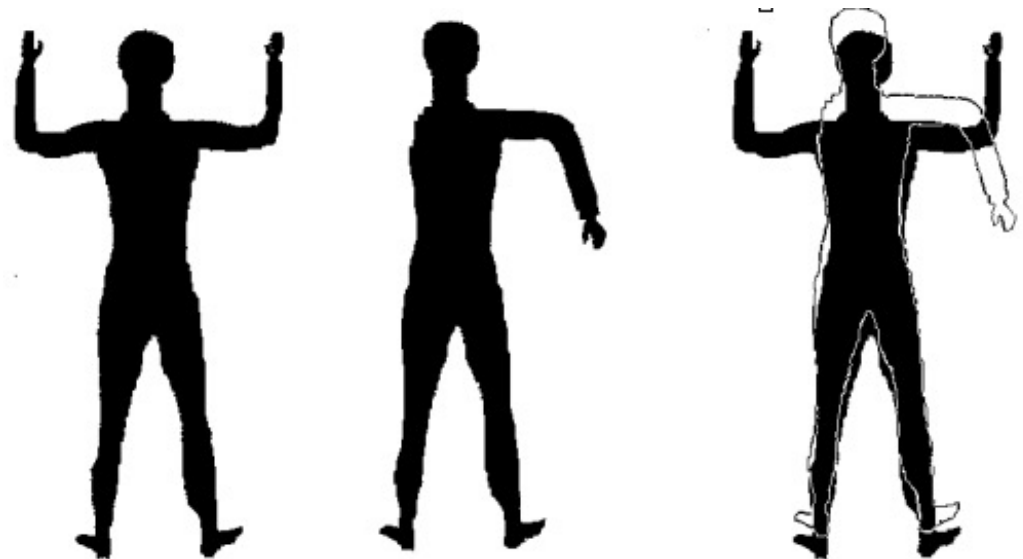


- The most simple feature is the **contour itself**: the set of border points
 - Not very compact, not easy to handle
 - Subject to noise => smoothing is needed (by mathematical morphology for instance)
- To classify a shape based on its contour, we need to define the **similarity between contours**, e.g. a notion of distance between a contour and a reference shape of different classes
 - The feature used for classification is then the **distance between the shape and the reference shape** of the different classes

- Distance between two contours = distance between two sets of points
 - Usual definition of the distance between two sets **A** and **B** : mean distance between each point of **A** and the closest point of **B**

Problems :

- $n*m$ operations
- Euclidean Distance : floating number

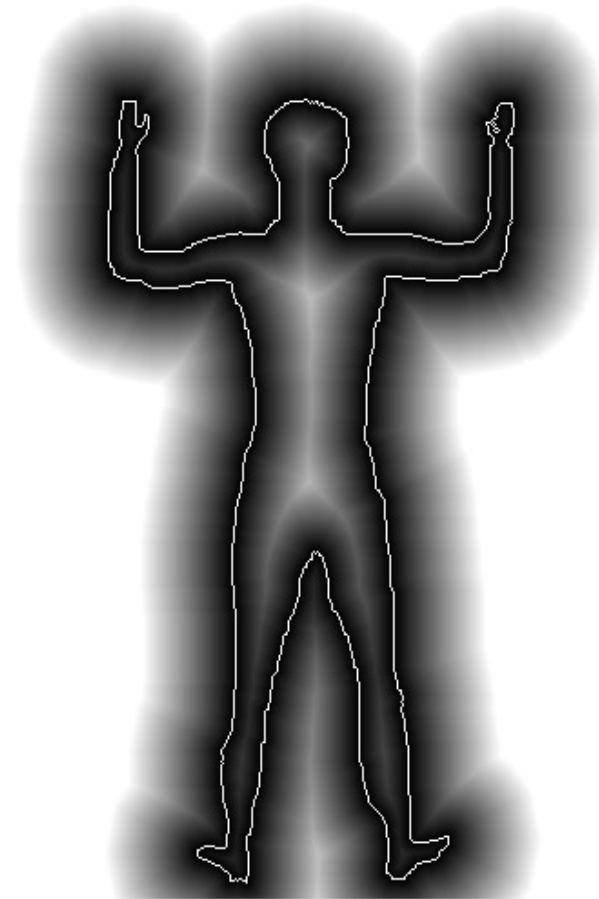


- Simplification 1 :

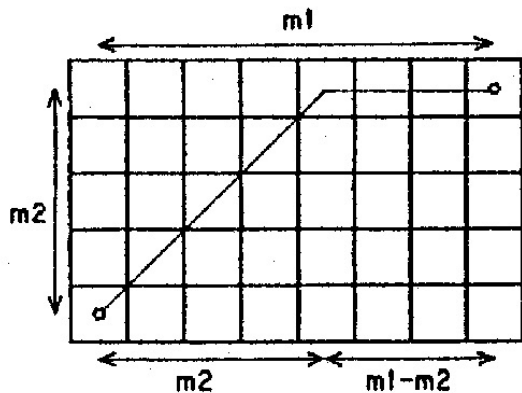
- distance map**

- To calculate the distance between two sets A and B, we can create a distance map of one of the two sets (say A)
 - $v =$ **distance map of A** : image where each point has a value that is the distance between that point and the closest point in A
 - Distance between A and B :

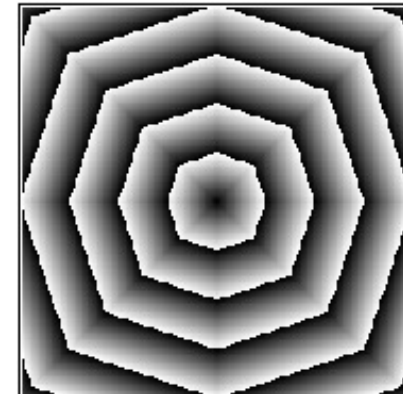
$$d_{A,B} = \sqrt{\frac{1}{n} \sum_{(i,j) \in B} v_{i,j}^2}$$



- Simplification 2 : approximation of the Euclidean distance: *chamfer distance* (distance du chanfrein)
 - Approx of the Euclidean distance



4	3	4
3	0	3
4	3	4



- **Fast algorithm** : two passes on the image:

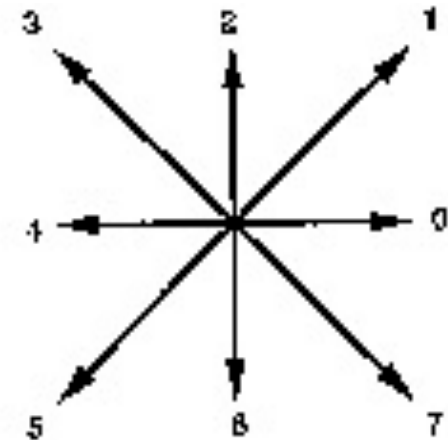
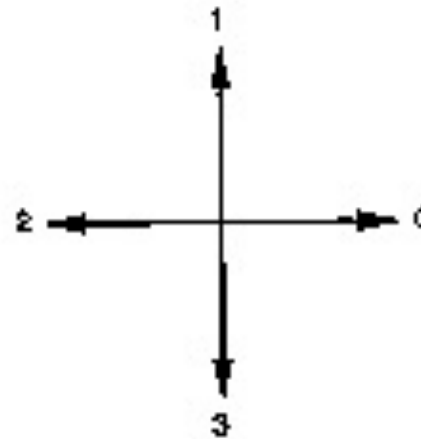
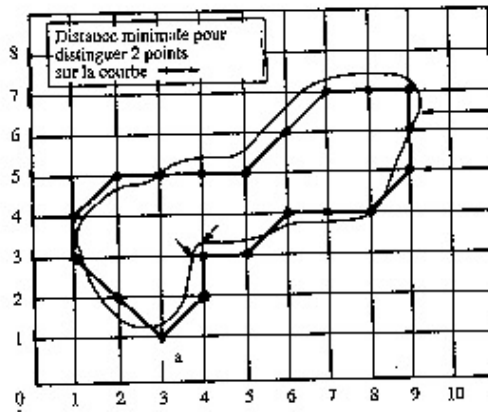
Initialisation : $v(i,j) = 0$ for all the points in the object
= $+\infty$ elsewhere

Direct : $v(i,j) = \min\{v(i-i,j-1)+4, v(i,-1j)+3, v(i-1,j+1)+4, v(i,j-1)+3, v(i,j)\}$,
for $i=2 \dots nl, j=2 \dots nc$

Inverse : $v(i,j) = \min\{v(i,j+1)+3, v(i+1,j-1)+4, v(i+1,j)+3, v(i+1,j+1)+4, v(i,j)\}$,
for $i=nl-1 \dots 1, j=nc-1 \dots 1$

- Then, to calculate the similarity between two objects A and B, we can
 - Define the **transformation** we want to be invariant to (rotation, translation, scaling, perspective, ...)
 - Search the **optimal transformation** of B that minimizes the distance between A and B
 - This minimal distance is the features used to classify the object B

- Chain code or **Freeman code**
 - Let us define a starting point
 - *E.g. the top left point of the contour*
 - The **position of the next point** is defined with respect to the position of the previous point, in a given connectivity definition (4 or 8), using a **code** defined on 2 or 3 bits



- Example : starting point : a
 - $C_8 = 12010012244554445677$ (i.e. 60 bits)

- Interest : chain handling: known problem (in OCR)
- Cfr. Search similar words in a dictionary
 - Detection of sub-parts of an object that have a given shape = detection of sub-chains in a long chain of characters
 - Notion of distance between two chains : **edition distance**
 - Specification :
 - Should reflect the **difference in length** between two chains
 - Should reflect the **number of different characters** between two chains appearing in corresponding positions
 - Thus, should reflect the **minimum number of elementary operation** (insert, suppress, substitute) necessary to transform one chain to the other

- Example :
 - $x = \text{« ababa »}$ and $y = \text{« abba »}$
 - Replace the « a » in the middle by « b » and suppress the next « b » : 2 operations
 - Suppress the « a » in the middle : 1 operation
 - Thus the edition distance: $\delta(x,y) = 1$
- Definition : The edition distance $\delta(x,y)$ two chains x and y is the **minimum number of elementary operations** (insertion, suppression or substitution) necessary to transform x into y

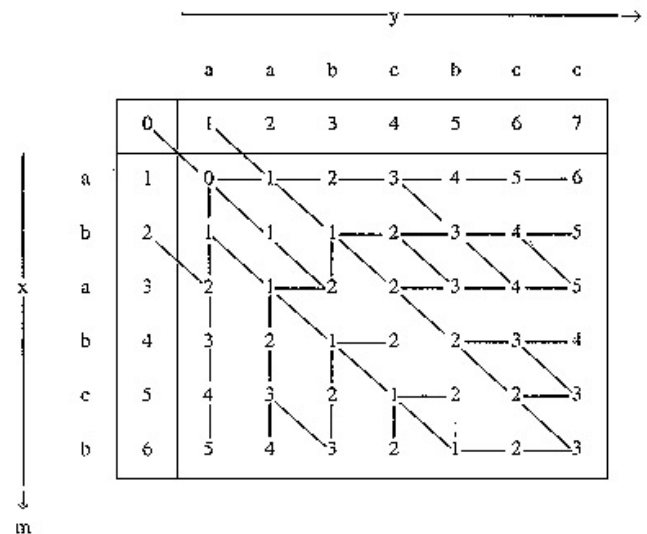
- There are variants of this definition, that penalizes more some operations:
 - Example : replace **b** by **d** or **rn** by **m**
- Computing of the edition distance:
 - Combinatory search: prohibitive cost
 - Algorithm of **Fisher-Wagner** : recursive
 - *Let $x(1...m)$ and $y(1...n)$ be the initial parts, of lengths m and n , of the chains x and y*
 - $D(m,n) = \delta(x(1...m), y(1...n))$

- Fisher-Wagner algorithm:**

$$D(m,n) = \min \{ D(m-1,n-1) + \delta(x(m),y(n)), D(m-1,n) + 1, D(m,n-1) + 1 \}$$

With $d(x(m),y(n)) = 0$ if $x(m) = y(n)$ and
 $d(x(m),y(n)) = 1$ otherwise

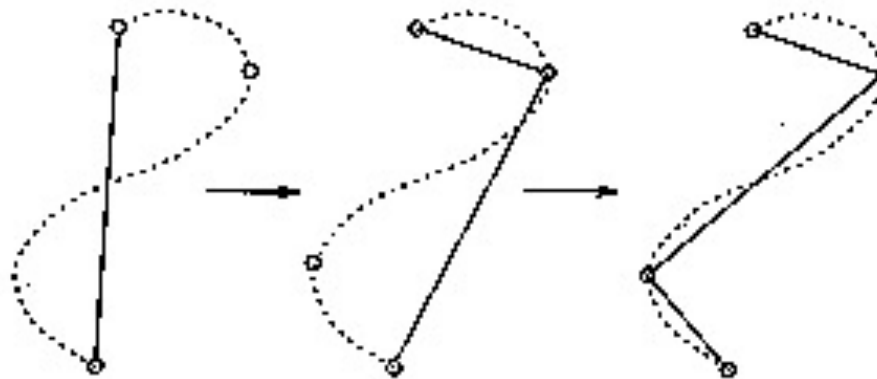
Finally $d(x,y) = D(\text{length}(x), \text{length}(y))$



- Curve Polygonalisation
- Morphological skeleton
- Fourier descriptors



- Approximate the curve by a polygon
 - Recursive method by dichotomy
 - Choice of a starting point
 - Look for the most distant point of the curve
 - Look of the most distant point to that line
 - Etc.

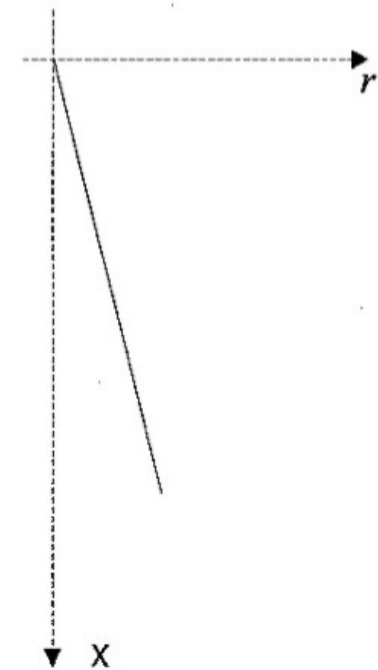
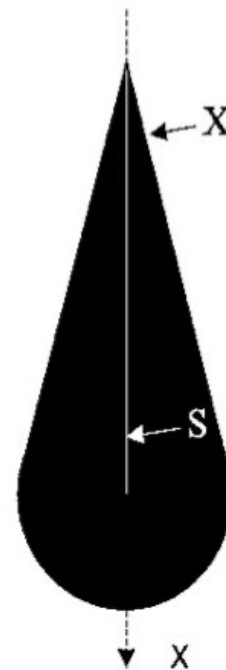


- Interest :
 - Progressive description (i.e with losses)
 - Few parameters (coord of the points, etc.)

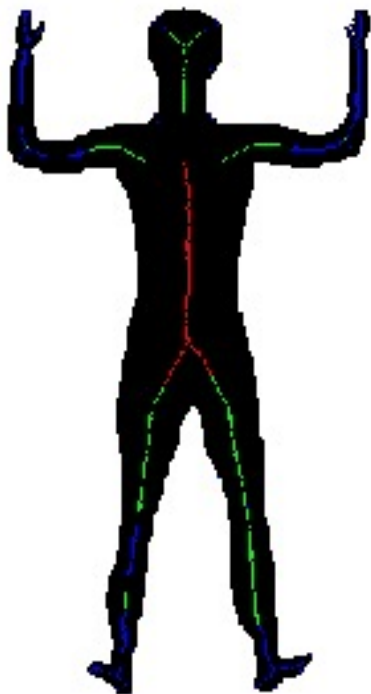
- The morphological skeleton

$$S(X) = \bigcup_{r=0}^N S_r(X) \quad \text{with} \quad S_r(X) = (X \ominus rB) - (X \ominus rB) \circ B$$

$$X = \bigcup_{r=0}^N S_r(X) \oplus rB$$



- Medial axis
- Multi-scale approach



(a)



(b)



(c)



(d)



(e)



(f)



(g)



(h)

- Invariance in rotation

- Based on the choice of the structuring element :

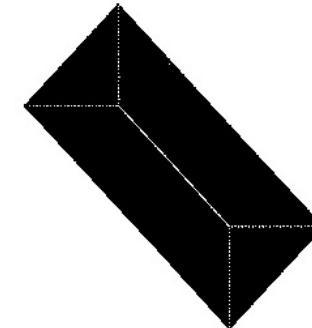
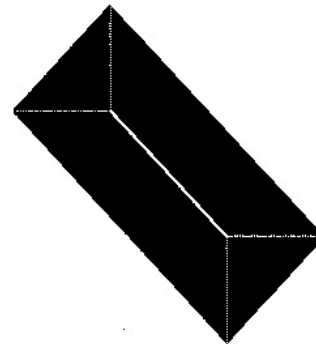
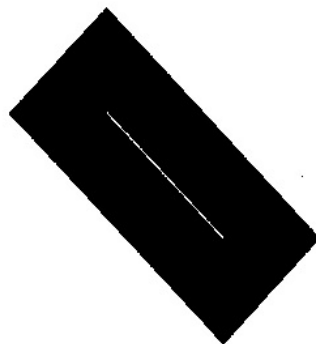
cross 3x3



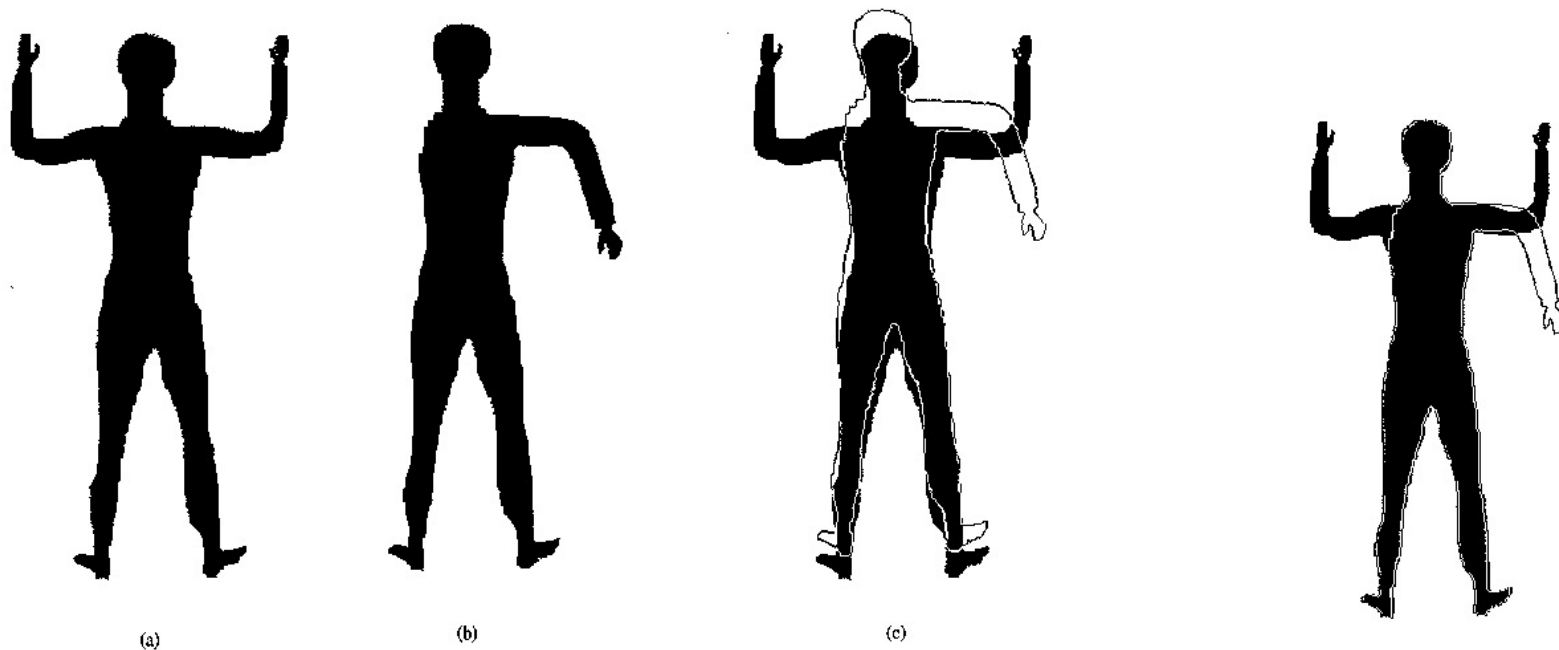
square 3x3



combinaison



- **Similar objects :**
 - Main parts should be similar
 - What are the « main parts »??
 - Related to the scale of the object → multi-scale description



- **Idea** : Fourier transform of the contours: decomposition in « frequencies » : fundamental frequency + high frequency details
- Different descriptions
 - **Complex Definition**
 - Angular Definition
- Let (x_k, y_k) , $k=0 \dots N-1$, be the coordinates of the N successive points of a contour. For each of those points, we define them as complex numbers:

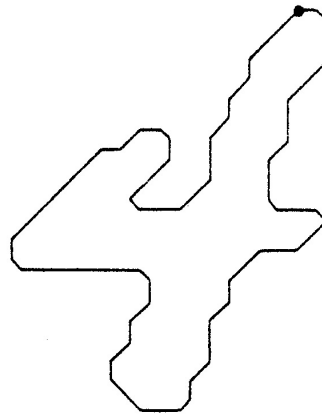
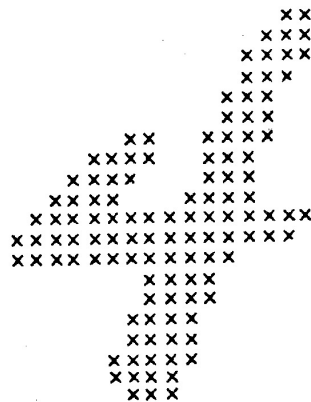
$$u_k = x_k + jy_k$$

- With those N points u_k , we can calculate their DFT:

$$f_l = \sum_{k=0}^{N-1} u_k e^{-\frac{j2\pi kl}{N}}$$

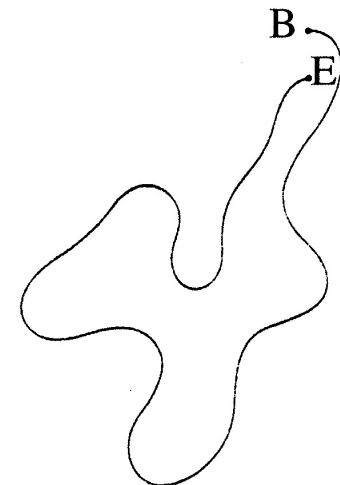
- The f_l are the **Fourier descriptors** of the contour. They are complex numbers
- By inverse DFT, we can recover the original contour.

- The **first descriptors** contain the majority of the shape information of the object



i	A_i	α_i
1	.347	.698
2	.371	5.687
3	1.001	4.989
4	.384	3.279
5	.575	4.588
6	.423	1.084
7	.422	.004
8	.128	4.283
9	.240	4.084
10	.081	4.708

$\mu_0 = -0.75$



Effect of a translation, a rotation or a scaling

- Translation :

$$x'_k = x_k + \Delta x$$

$$y'_k = y_k + \Delta y \quad \text{thus} \quad u'_k = u_k + (\Delta x + j\Delta y) = u_k + \Delta u'$$

$$f'_l = \sum_{k=0}^{N-1} u'_k e^{-\frac{j2\pi kl}{N}} = f_l + \sum_{k=0}^{N-1} \Delta u e^{-\frac{j2\pi kl}{N}} = f_l + \Delta u N \delta(l)$$

– A translation affect only f'_0

- Rotation :

$$u'_k = u_k e^{j\theta}$$

$$f'_l = \sum_{k=0}^{N-1} u'_k e^{-\frac{j2\pi kl}{N}} = e^{j\theta} \sum_{k=0}^{N-1} u_k e^{-\frac{j2\pi kl}{N}} = f_l e^{j\theta}$$

- A rotation affect the phase of all the descriptors by the same amount, and does not modify their amplitude

- **Scaling:**

$$u'_k = a u_k$$

$$f'_l = \sum_{k=0}^{N-1} u'_k e^{-\frac{j2\pi kl}{N}} = a \sum_{k=0}^{N-1} u_k e^{-\frac{j2\pi kl}{N}} = a f_l$$

– A **scaling** does not change the ratio $\frac{f_i}{f_j}$

- Choice of u_0 :

$$u'_k = u_{k-k_0}$$

$$\begin{aligned} f'_l &= \sum_{k=0}^{N-1} u'_k e^{-\frac{j2\pi kl}{N}} = \sum_{k=0}^{N-1} u_{k-k_0} e^{-\frac{j2\pi kl}{N}} \\ &= \sum_{m=0}^{N-1} u_m e^{-\frac{j2\pi(m+k_0)l}{N}} = f_l e^{-\frac{j2\pi k_0 l}{N}} \end{aligned}$$

- The choice of the **starting point** only affect the **phase** of the descriptors

- Example of normalization : choice of u_0

$$u'_k = u_{k-k_0} \Rightarrow f'_l = f_l e^{-\frac{j2\pi k_0 l}{N}}$$

thus

$$f'_1 = f_1 e^{-\frac{j2\pi k_0}{N}} \Rightarrow f'_1 = |f_1| e^{-j\phi_1} e^{-\frac{j2\pi k_0}{N}} = |f_1| e^{-j(\phi_1 + \frac{2\pi k_0}{N})} = |f_1| e^{-j(\phi'_1)}$$

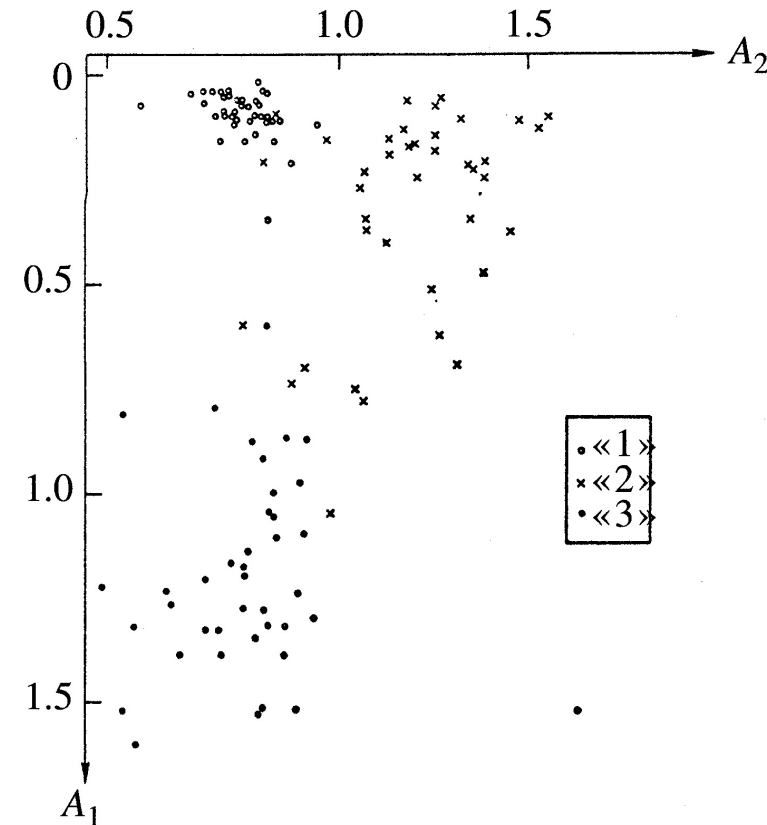
By defining the normalised descriptors by:

$$\hat{f}_l = f_l e^{jl\phi_1},$$

we get

$$\hat{f}'_l = f'_l e^{jl\phi'_1} = f'_l e^{j(l\phi_1 + \frac{2\pi k_0 l}{N})} = f_l e^{jl\phi_1} = \hat{f}_l$$

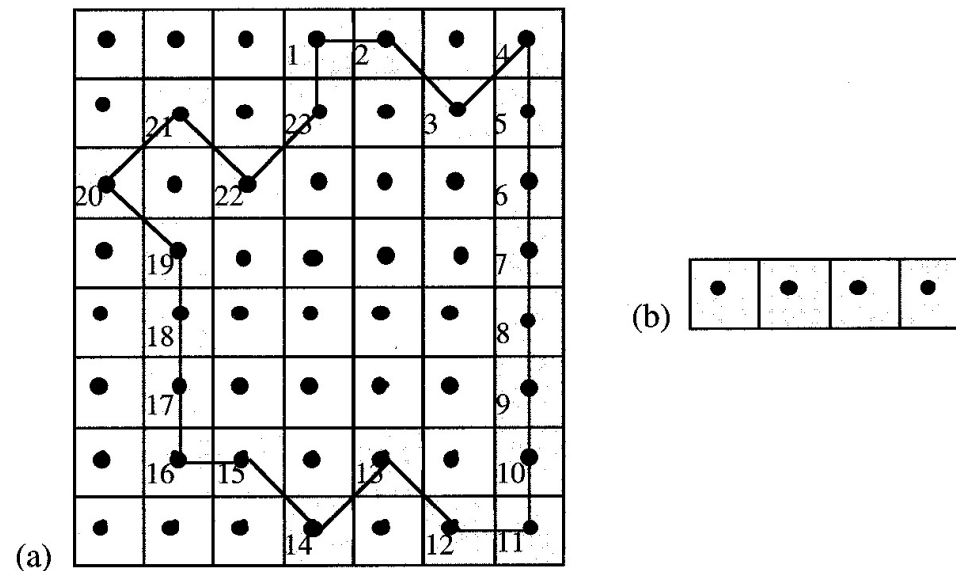
- By the fact the energy is concentrated in the low frequencies, the **Fourier descriptors** are powerful features for classification
 - Ex : **amplitude of the two first Fourier descriptors**



- If we consider the object as a whole, there are many descriptors, **more or less complete**. Let us describe some of them.
- The **surface A**
 - $A_1 = n \cdot \varepsilon^2$,
 - *n is the number of points of the object*
 - *ε is the size of a pixel*
 - Does not vary much w.r.t ε and of the orientation of the shape, because of the cancellation effect of the error

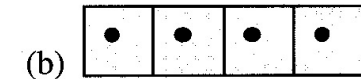
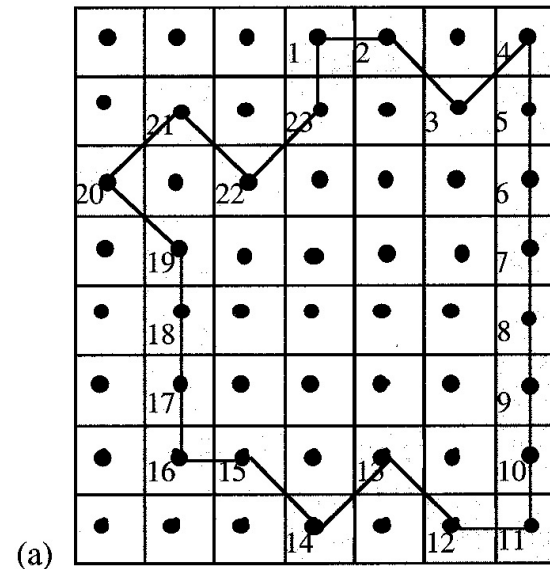
Shape ($\varepsilon=0.2\text{cm}$)	Area	A1	erreur
Circle (d=5.44cm)	23.24	23.63 and 23.65	+1.75% et +1.75%
Circle (d=2.50cm)	4.91	4.85 and 4.76	-1.2% et -3%
Square (a=2.54cm)	6.45	6.58 and 6.40	+2% et -0.8%
Rectangle (a=5.08 cm and b = 2.62 cm)	38.71	39.89	+3%
Triangle (5.1 cm, 2.07 cm et 5.1 cm)	13.01	12.98	-0.2%

- Other possibility: area in the polygon connecting the contour points
 - $A_2 = \varepsilon^2 (b/2 + i - 1)$
 - b : number of contour points
 - i : number of points inside the contour

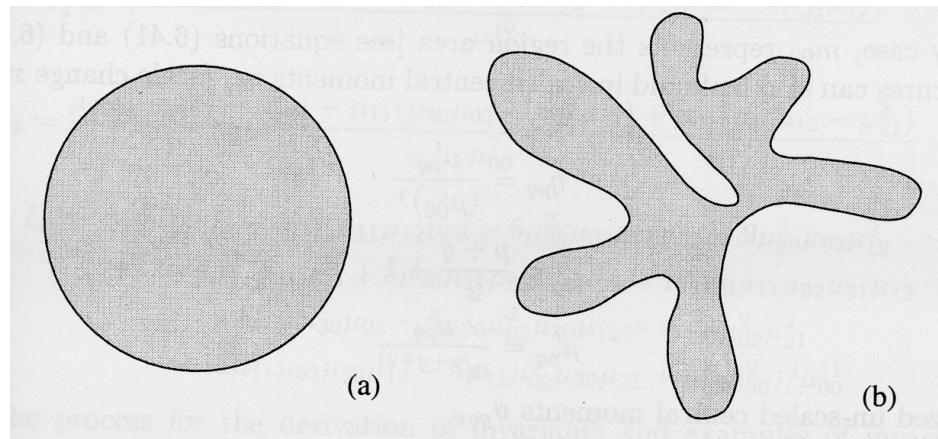


• Perimeter

- Very variable w.r.t. the size of the pixel and the orientation!
- P_1 : surface of the contour points
 - *Ex : (a) $P_1=23$ and (b) $P_1=4$*
- P_2 : follow the contour with +1 and +1.414
 - *Ex : (a) $P_2=26.2$ and (b) $P_2=6$*
- P_3 : length of the polygon connecting the contour points
 - *Ex : (a) $P_3=26.2$ and (b) $P_3=3$*

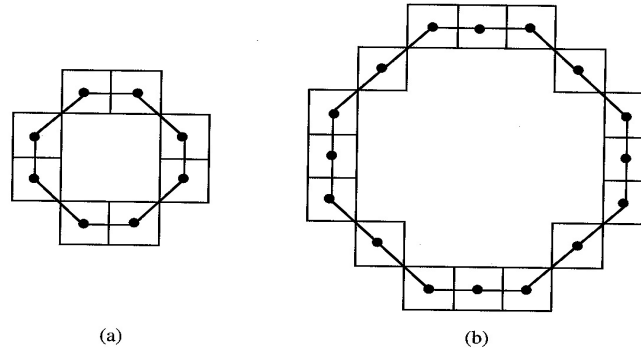


- **Compacity** $C = \frac{P^2}{A} \geq 4\pi$

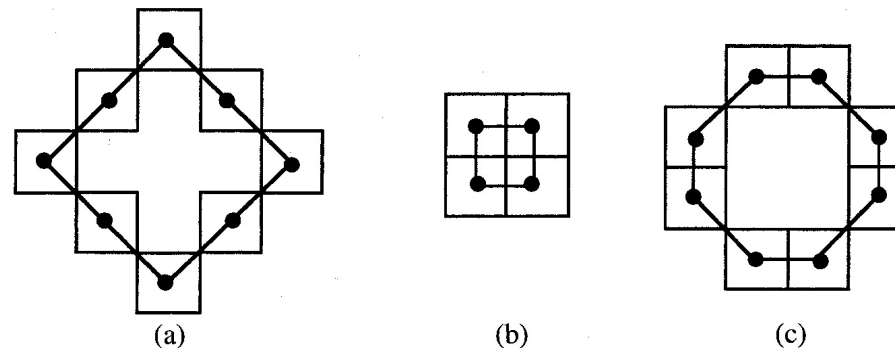


- **Invariant** in translation, rotation and scaling

- But sensitive to the definition of A and P



$4\pi=12.56$. with A_1 and P_3 : (a) : $C=7.77$, (b) : $C=11.64$
 – However with A_2 and P_3



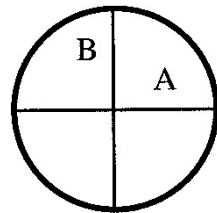
(a) $C=16$, (b) $C=16$, (c) $C=13.3$

- **Rectangularity** : ratio between the surface of the object and that of the circumscript rectangle

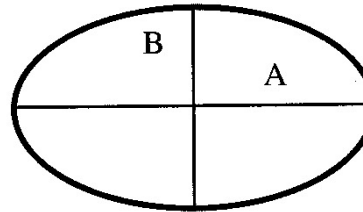
$$\text{rectangularity} = \max_k \left(\frac{A}{A_{\text{rect}_k}} \right)$$

A_{rect_k} : area of the circumscript rectangle of orientation k

- **Elongation** : ratio between the maximum diameter of the object and its minimum diameter perpendicular to it.



(a)



(b)

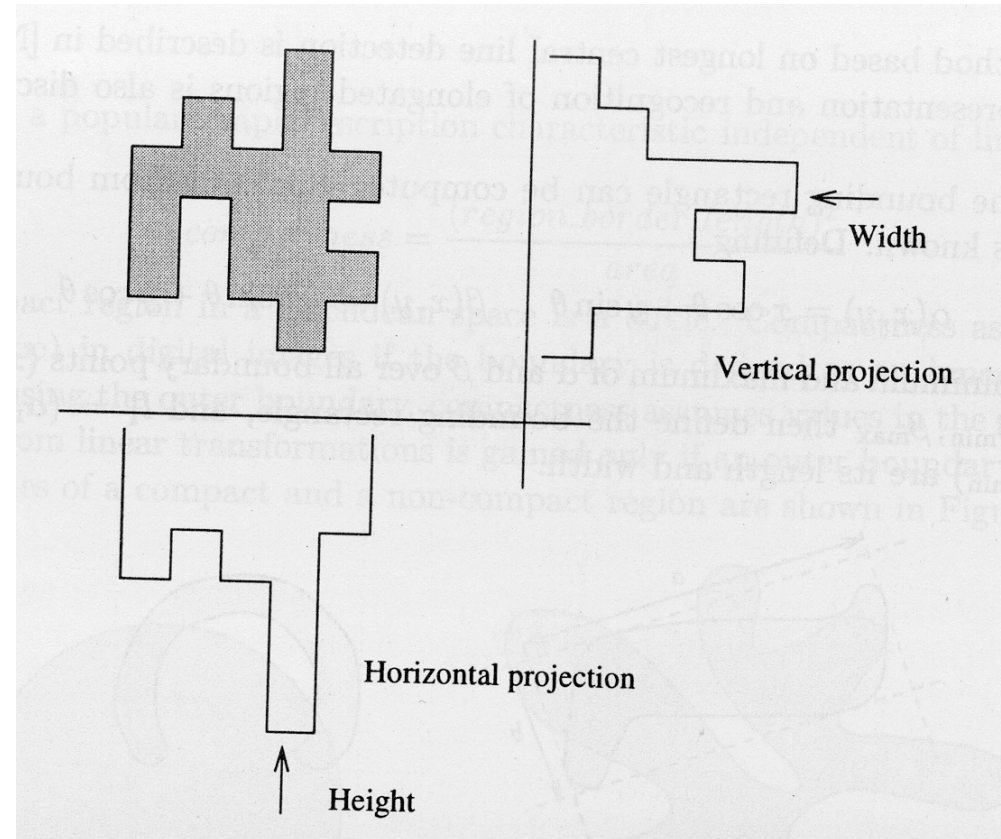
- Can also be defined as the square root of the ratio of the eigenvalues of the matrix of inertia (see later)

- Projections :

$$p_h(i) = \sum_j f(i, j)$$

$$p_v(j) = \sum_i f(i, j)$$

- Good basis for a classification
 - *Width and length*
 - *Number of maxima/minima*



- **Moments**: used in physics to describe the mass repartition of a body
- For an image :
 - Repartition of the grey levels $f(k,l)$
 - Binary image ($f(k,l) = 0$ or 1): description of the shape
- **Moments** : $M_{i,j} = \sum_k \sum_l k^i l^j f(k,l)$
- **Centre of gravity** :

$$\bar{k} = \frac{M_{1,0}}{M_{0,0}} \quad \bar{l} = \frac{M_{0,1}}{M_{0,0}}$$

- In order to make them invariant to **translation**, we can choose the center of gravity as origin, and define **centered moments**:

$$\mu_{i,j} = \sum_k \sum_l (k - \bar{k})^i (l - \bar{l})^j f(k, l)$$

$$\mu_{0,0} = M_{0,0}$$

$$\mu_{1,0} = \mu_{0,1} = 0$$

$$\mu_{1,1} = M_{1,1} - (M_{0,0} \cdot \bar{k} \cdot \bar{l})$$

- In order to make them **invariant to rotation**, we can define :

$$M_1 = \mu_{2,0} + \mu_{0,2}$$

$$M_2 = (\mu_{2,0} - \mu_{0,2})^2 + 4\mu_{1,1}^2$$

$$M_3 = (\mu_{3,0} - 3\mu_{1,2})^2 + (3\mu_{2,1} - \mu_{0,3})^2$$

$$M_4 = (\mu_{3,0} + \mu_{1,2})^2 + (\mu_{2,1} + \mu_{0,3})^2$$

etc. (see page 43 in the book of M. Kunt)

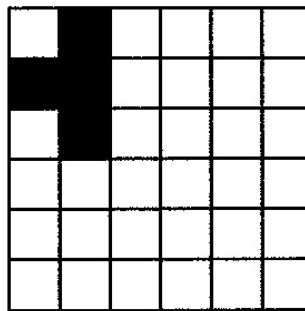
- In order to make them invariant to **scaling**, we define standard centered moments:

$$\eta_{i,j} = \frac{\mu_{i,j}}{(\mu_{0,0})^\gamma}$$

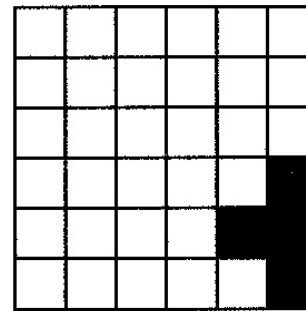
$$\text{avec } \gamma = \left\lfloor \frac{i+j}{2} \right\rfloor + 1$$

- By using the standard centered moments with the definition of M_i , we obtain moments M_i' **invariant in translation, rotation et scaling**

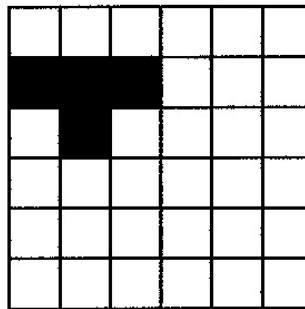
- Example : see page 45 in the book of M. Kunt



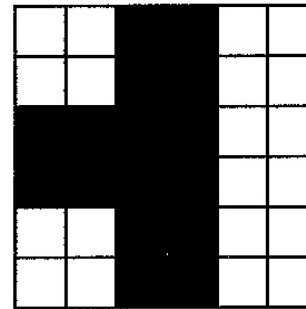
(a)



(b)



(c)



(d)

- **Axes of inertia:** an system of axes that minimizes the variance of the shape projected on the axes
- The variance of a shape S w.r.t. an axis \mathbf{u} is given by

$$\begin{aligned} V(S, \mathbf{u}) &= \sum_{x \in S} [\mathbf{u}^T (\mathbf{x} - \bar{\mathbf{x}})]^2 \\ &= \sum_{x \in S} [\mathbf{u}^T (\mathbf{x} - \bar{\mathbf{x}})] [(\mathbf{x} - \bar{\mathbf{x}})^T \mathbf{u}] \\ &= \mathbf{u}^T \sum_{x \in S} [(\mathbf{x} - \bar{\mathbf{x}})(\mathbf{x} - \bar{\mathbf{x}})^T] \mathbf{u} \end{aligned}$$

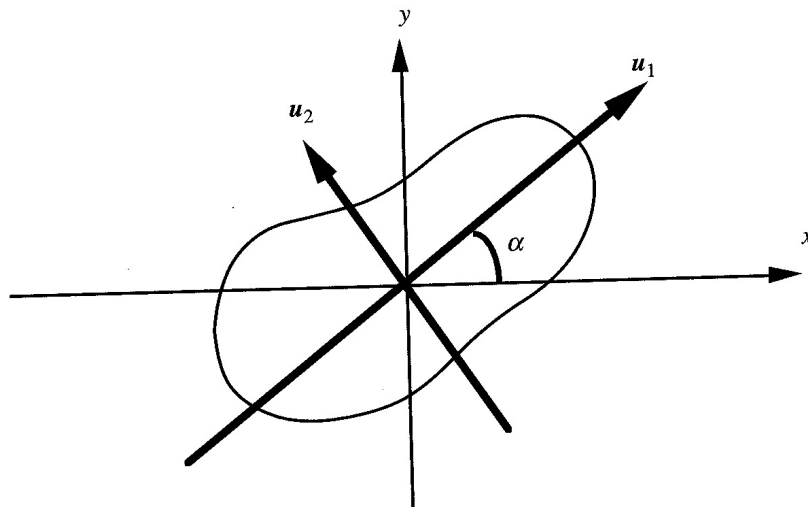
- By developing the central term, we get

$$T = \begin{pmatrix} x_1 - \bar{x} & x_2 - \bar{x} & \dots & x_N - \bar{x} \\ y_1 - \bar{y} & y_2 - \bar{y} & \dots & y_N - \bar{y} \end{pmatrix} \begin{pmatrix} x_1 - \bar{x} & y_1 - \bar{y} \\ x_2 - \bar{x} & y_2 - \bar{y} \\ \dots & \dots \\ x_N - \bar{x} & y_N - \bar{y} \end{pmatrix}$$

$$= \begin{pmatrix} \sum_{i=1}^N (x_i - \bar{x})^2 & \sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y}) \\ \sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y}) & \sum_{i=1}^N (y_i - \bar{y})^2 \end{pmatrix} = \begin{pmatrix} \mu_{2,0} & \mu_{1,1} \\ \mu_{1,1} & \mu_{0,2} \end{pmatrix}$$

- This is the **Covariance Matrix** of the object

- We have thus $V(S, \mathbf{u}) = \mathbf{u}^T T \mathbf{u}$
- The axes of inertia are the **eigenvectors** of T
- The **eigenvalues** express the variance of the shape projected on the axes of inertia



and

$$\alpha = \frac{1}{2} \arctg \frac{2\mu_{1,1}}{\mu_{2,0} - \mu_{0,2}}$$

- Objects can be described
 - By their **contours**
 - *Perimeter*
 - *Freeman Codes*
 - *Polygon approximating the contour*
 - *Distance to an object of reference*
 - By **morphological skeletons**
 - *Multi-scale approach*
 - By **region descriptor**
 - *Surface, capacity, etc.*
 - *Moments et axes of inertia*

- Pattern recognition consists in choosing **good descriptors** for a given application and in using a **classification** algorithm for recognizing the object.

