LABORATORIO DI VISIONE ARTIFICIALE
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Tecniche e Strumenti per l'Elaborazione di Immagini ed il Riconoscimento di Forme

Parte II: Livello Alto e Strumenti Disponibili

8.

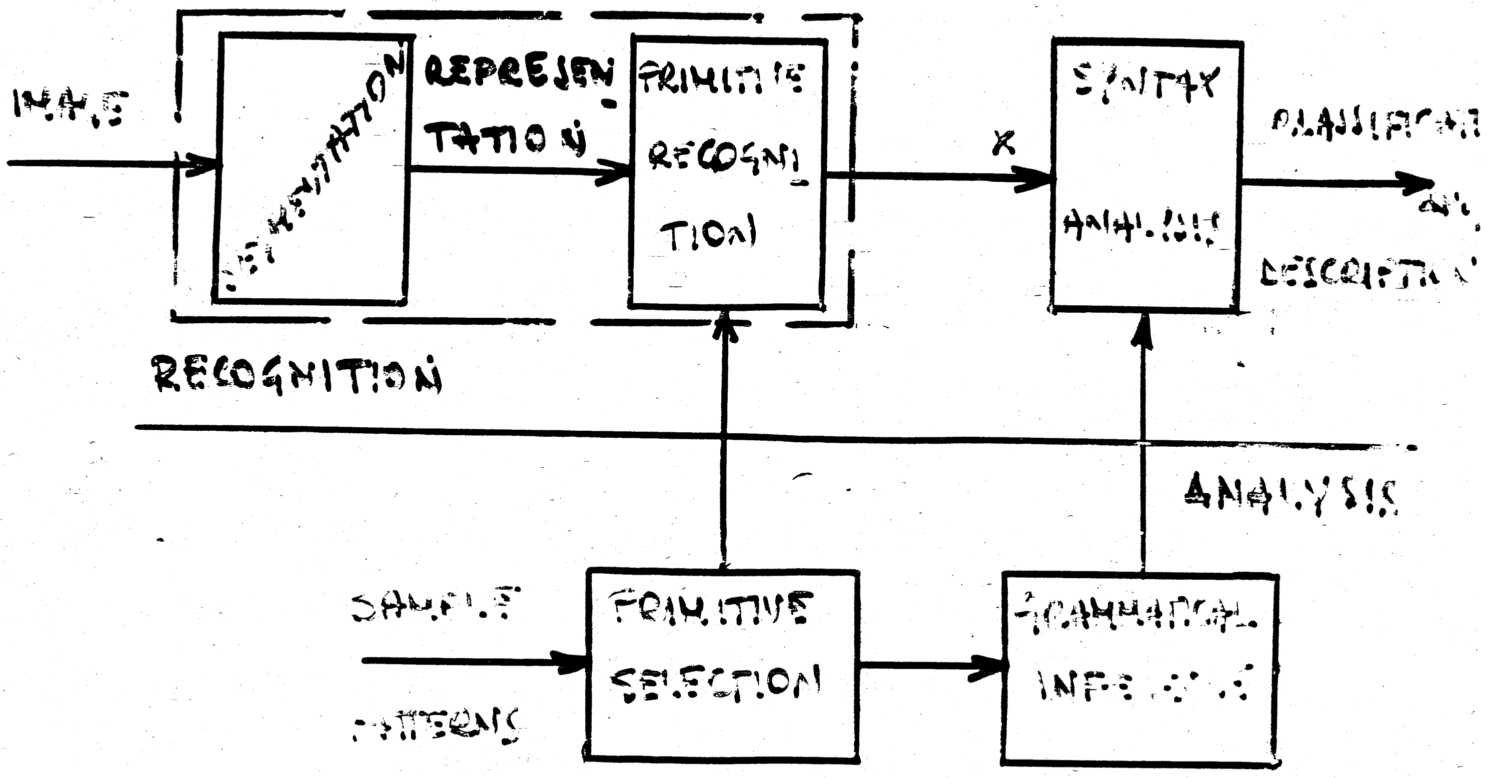
27 Novembre 1989
c/o SPERONI Spa, Spessa Po

V. Cantoni:

Riconoscimento di Forme:
Approccio Sintattico-Linguistico ed
Approccio Strutturale.

Dipartimento di Informatica e Sistemistica, Università degli Studi di Pavia

BLOCK DIAGRAM OF [illegible] SHAPE RECOGNITION



SYNTAX ANALYSIS : PRELIMINARY CONSIDERATIONS

- THERE ARE APPLICATIONS IN WHICH THE STUCTURE OF A SHAPE PLAYS AN IMPORTANT ROLE IN CLASSIFICATION PROCESS. THE SYNTACTIC APPROACH TO SHAPE RECOGNITION POSSESSES THE STRUCTURE HANDLING CAPABILITY REQUIRED. IT IS BASED ON CONCEPTS FROM FORMAL LANGUAGE THEORY.

- BASIC TO THE SYNTACTIC SHAPE RECOGNITION APPROACH IS THE DECOMPOSITION OF SHAPE INTO <u>SUBPATTERNS</u> OR <u>PRIMITIVES</u>

- EACH PRIMITIVE IS USED AS A POSSIBLE SYMBOL OF A <u>GRAMMAR</u>, WHERE A GRAMMAR IS A SET OF RULES OF SYNTAX FOR THE GENERATION OF SENTENCES FROM THE GIVEN SYMBOLS

- GIVEN A SENTENCE REPRESENTING AN INPUT SHAPE THE PROBLEM IS THAT OF DECIDING IN WHICH <u>LANGUAGE</u> (WHICH GRAMMAR) THE SENTENCE IS <u>VALID</u>

$$G = (V_N, V_T, P, \Sigma)$$

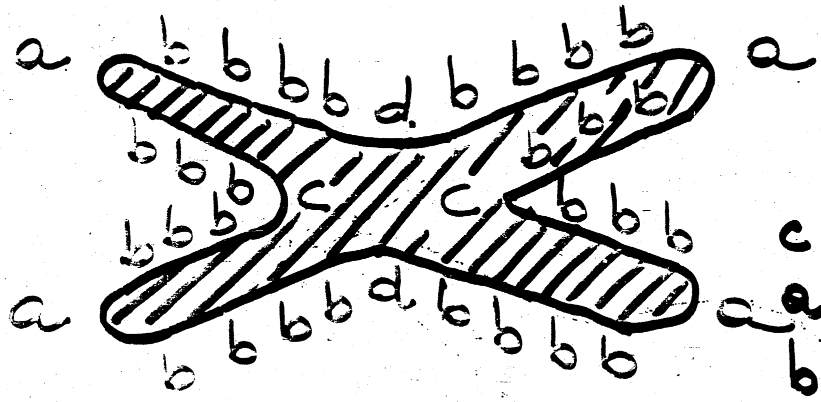
V_N : [illegible] terminal symbols

V_T : [illegible] terminal "

P : " " production rules

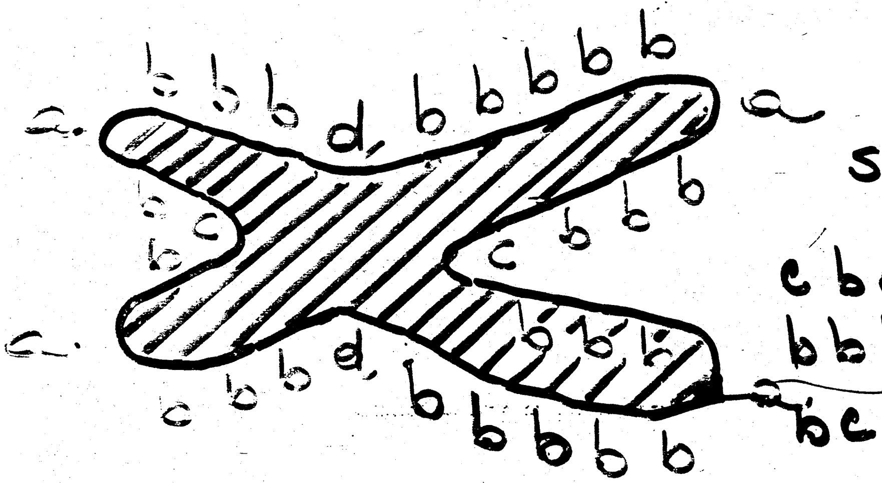
Σ : [illegible]

CROMOSOME CLASIFICATION



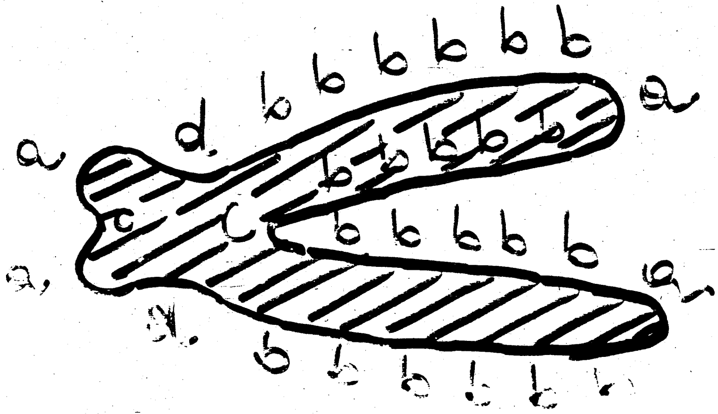
MEDIAN

c b b b a b b b b d b b b
a b b b c b b b a b b b
b b b b a b b b



SUBMEDIAN

c b a b b b d b b b b b
b b b c b b b a b b b b
b c



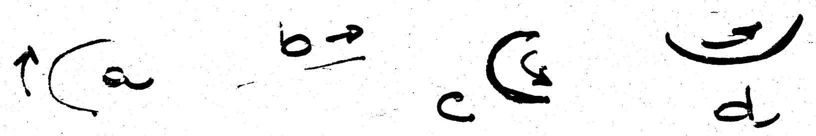
ACROCENTRIC

c a d b b b b b b a b b b
b c b b b b b a b b b b
d a

LINGUISTIC APPROACH TO CROMOSOME CLASSIFICATION

THREE CONTEXT-FREE GRAMMARS HAVE BEEN DEVELOPED, EACH DESCRIBING ONE CLASS OF CROMOSOME : MEDIAN SUBMEDIAN ACROCENTRIC.

TERMINAL SET : V_T



MEDIAN :

P: $S \to AA$ $\quad A \to cB$ $\quad B \to FBE$ $\quad B \to HDJ$

$D \to FDE$ $\quad D \to d$ $\quad F \to b$ $\quad E \to b$

$H \to a$ $\quad J \to a$

SUBMEDIAN :

P: $S \to AA$ $\quad A \to cM$ $\quad B \to FBE$ $\quad B \to FL$

$B \to RE$ $\quad D \to FDE$ $\quad D \to FG$ $\quad D \to WE$

$L \to FL$ $\quad R \to RE$ $\quad G \to FG$ $\quad W \to WE$

$F \to b$ $\quad E \to b$ $\quad H \to a$ $\quad M \to FBE$

$J \to a$ $\quad L \to HNJ$ $\quad R \to HNJ$ $\quad G \to d$

$W \to d$ $\quad N \to FDE$

ACROCENTRIC

P: $S \to AA$ $\quad A \to cB$ $\quad B \to FL$ $\quad B \to RE$

$D \to FG$ $\quad D \to WE$ $\quad L \to FL$ $\quad R \to RE$

$G \to FG$ $\quad W \to WE$ $\quad L \to HDJ$ $\quad H \to a$

$R \to HDJ$ $\quad G \to d$ $\quad W \to d$ $\quad J \to a$

$E \to b$ $\quad F \to b$

ATTRIBUTED GRAMMAR.

AN ATTRIBUTED GRAMMAR IS A GRAMMAR WHERE:

- EACH PRIMITIVE OR NONTERMINAL HAS A SYMBOL PART AND A VALUE PART WHICH MAY HAVE SEVERAL ATTRIBUTES
- EACH SYMBOLIC PRODUCTION RULE HAS A CORRESPONDING SET OF ATTRIBUTE RULES WHICH PRODUCE THE ATTRIBUTE RELATED TO THE PRODUCTION RULE IN PARSING
- INTRODUCTION OF A METRIC

AS AN EXAMPLE WE CONSIDER THE TOTAL CURVE LENGHT TO BE AN ATTRIBUTE IN THE CROMOSOME CLASSIFICATION

PRODUCTION RULES:

$S \to Q_1^1 \; Q_1^2 \qquad l_{S1} \leftarrow l_{Q_1^1} ; \; l_{S2} \leftarrow l_{Q_1^2}$

$S \to Q_1 \; Q_2 \qquad l_{S1} \leftarrow l_{Q1} ; \; l_{S2} \leftarrow l_{Q2}$

$S \to Q_1 \; Q_2 \qquad l_{S1} \leftarrow l_{Q2} ; \; l_{S2} \leftarrow l_{Q1}$

$Q_1 \to D R_1 \qquad l_{Q1} \leftarrow l_{R1}$

$Q_2 \to D R_2 \qquad l_{Q2} \leftarrow l_{R2}$

$R_1 \to M_1^1 C M_1^2 \qquad l_{R1} \leftarrow (l_{M_1^1} + l_{M_1^2})/2$

$R_2 \to M_2 C M_2 \qquad l_{R2} \leftarrow 0$

$M_1 \to B^1 A B^2 \qquad l_{M1} \leftarrow (l_{B1} + l_{B2})/2$

$M_2 \to A$

$A \to a$

$B \to b \qquad l_B \leftarrow \,!$

$C \to c$

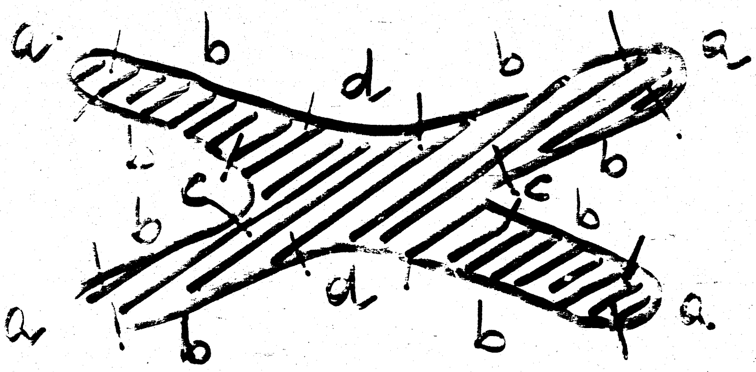
$D \to d.$

Q_1 coppia di (R_1) propaggini mediane o sottomediane

Q_2 Coppia di (R_2) propaggini acrocentriche

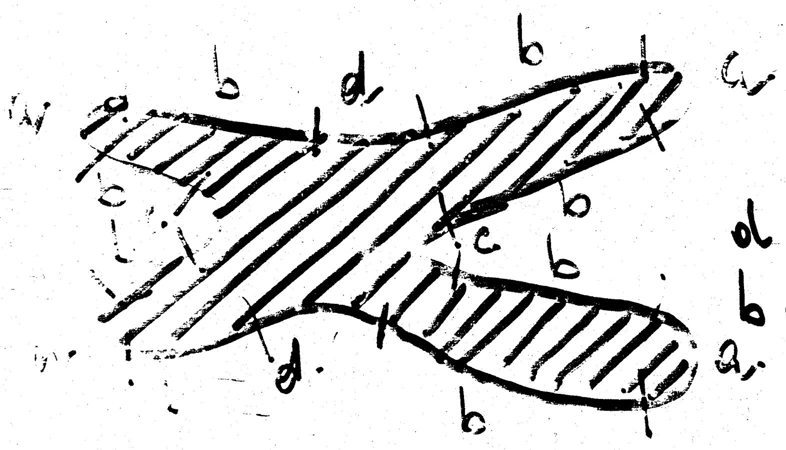
M propaggine singola

ATTRIBUTED GRAMMAR EXAMPLE



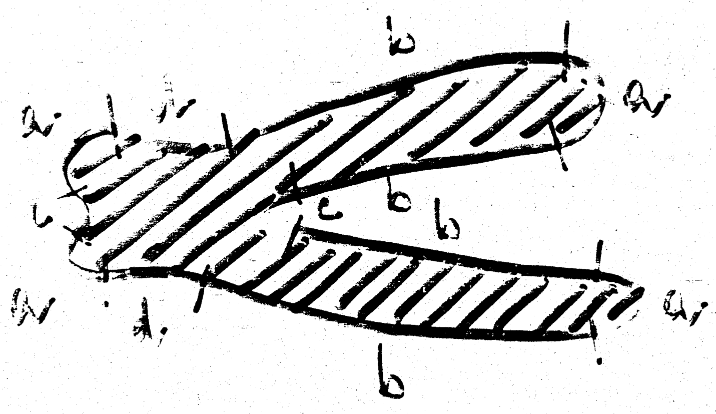
MEDIAN

dbabcbabd
babcbab



SUBMEDIAN

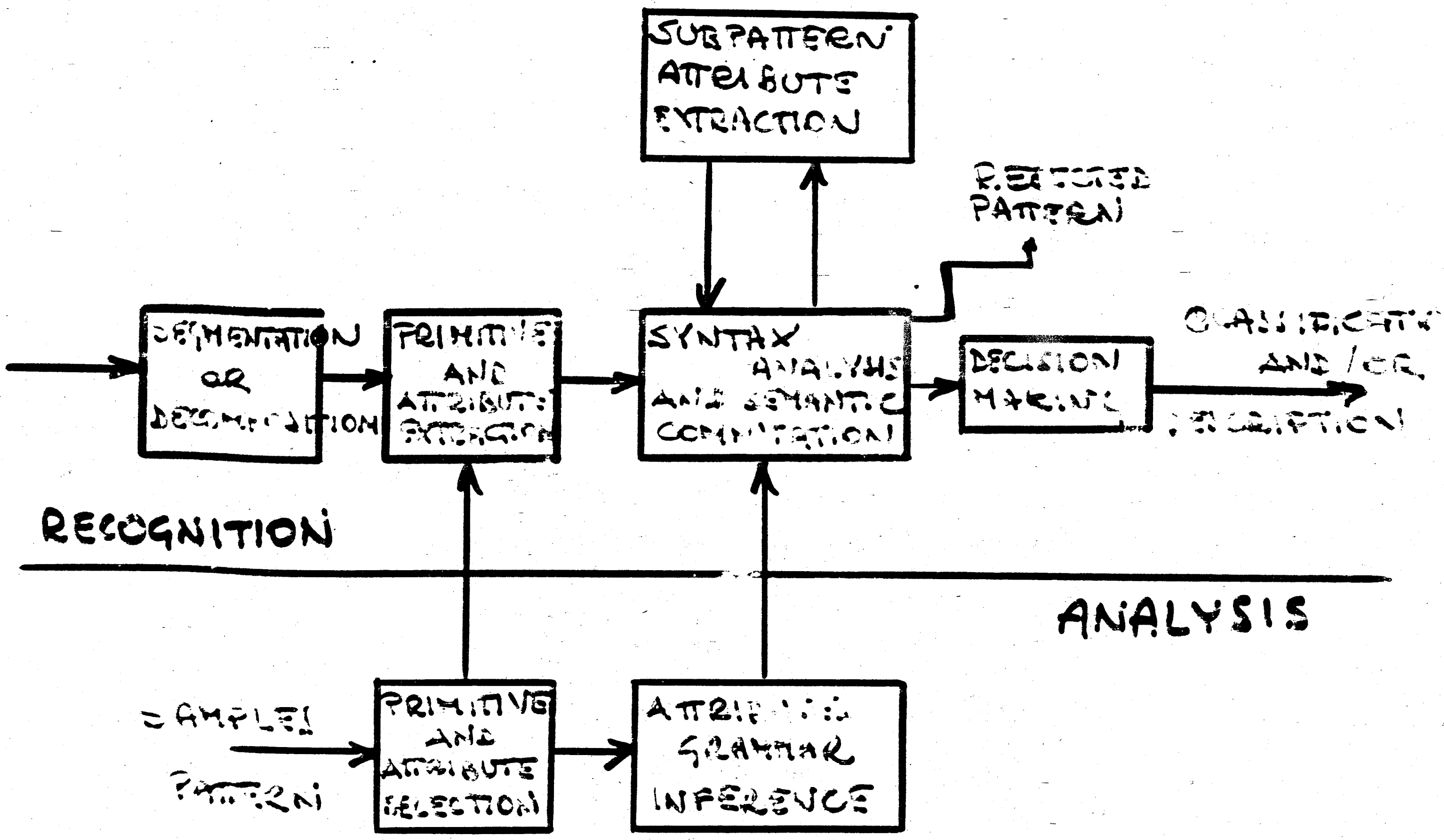
dbabcbabd
babcbab



ACROCENTRIC

dbabcbabd
aca

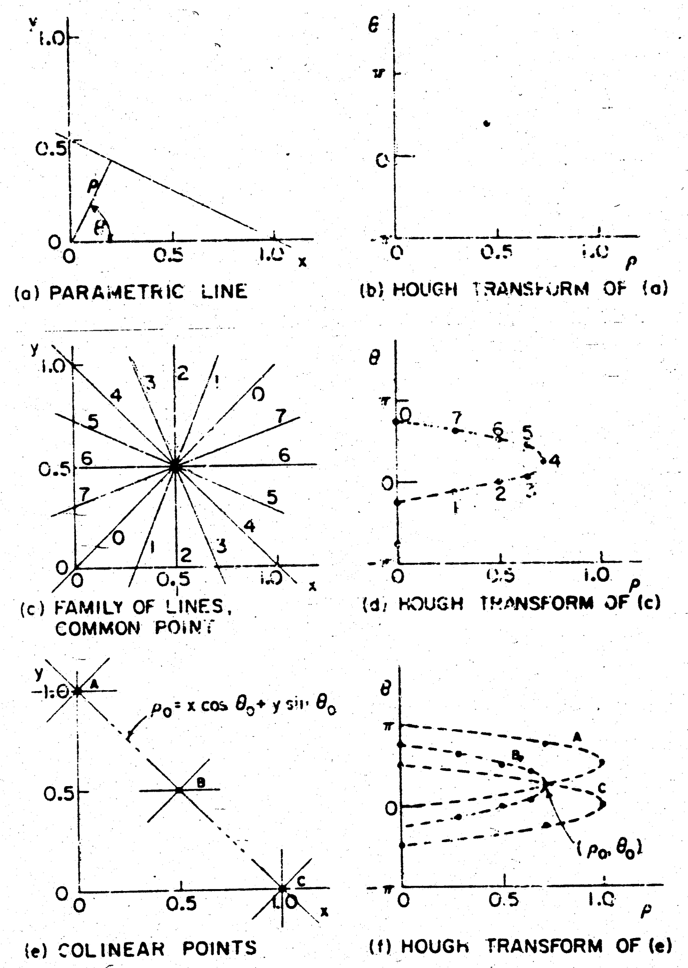
SHAPE ANALYSIS SYSTEM USING ATTRIBUTED GRAMMARS



THE HOUGH TRANSFORM

P. V. C. HOUGH : METHOD AND MEANS FOR RECOGNIZING COMPLEX PATTERNS - 1962 - U. S. PATENT 3.069.654

LINE TO POINT TRANSFORM $\rho = x\cos\theta + y\sin\theta$



$C_i = \{(x,y)\} \mid f(x,y,\{a_{ik}\})=0$ $\qquad P = \langle a_1,\dots,a_k, i\rangle$

$$H : C_i \to p_i \in P$$

$$\forall : e \in C_i \rightarrow \Gamma(e) \subset P$$

Such that $$\boxed{\bigcap_{e \in C_i} \Gamma(e) = p_i \in P}$$

EXAMPLE

$Z \equiv R^2 \qquad i=2 \qquad k=2 \qquad P = < a_1 , a_2 , i >$

$$\begin{cases} y = a_1 x + a_2 x^{-1} \\ i = 1 \end{cases} \qquad \begin{cases} y = a_1 x^2 + a_2 \\ i = 2 \end{cases}$$

- for each element $e \equiv (x', y')$:

$$\begin{cases} a_2 = y'x' - a_1 x'^2 \\ i = 1 \end{cases} \qquad \begin{cases} a_2 = y' - a_1 x'^2 \\ i = 2 \end{cases}$$

- for each element $e \equiv (x', y', \theta)$:

$$\begin{cases} i = -1 \\ a_1 = \dfrac{y' + \lambda x'}{2x'} \\ a_2 = \dfrac{(x'y' - \lambda x')}{2} \end{cases} \qquad \begin{cases} i = 2 \\ a_1 = \dfrac{\lambda}{2x'} \\ a_2 = y' - \dfrac{\lambda}{2} x' \end{cases}$$

where $\lambda = tg\ \theta$

------ THE GENERALIZED HOUGH TRANSFORM ------

Let us consider a subset of points C^* which defines a model of arbitrary, non analytic shapes. We assume that all the subset of points C_i which can be produced by translating, rotating, and uniformly scaling the model C^* have the same "shape", that is belong to the family C.

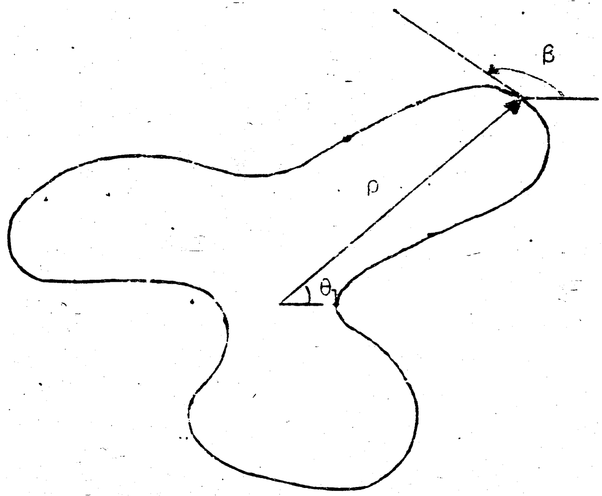
C_i is represented by a point in the four dimensional space P:

$$P = \langle x, y, \theta, s \rangle$$

where:

> x, y measure the translation, θ the rotation, and s is the scaling factor.

------ MODEL DESCRIPTION ------



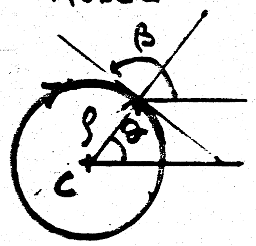
MODEL

R TABLE

θ_1	ρ_1	$\beta_1 - \theta_1$
θ_2	ρ_2	$\beta_2 - \theta_2$
θ_3	ρ_3	$\beta_3 - \theta_3$
$\vdots$	$\vdots$	$\vdots$

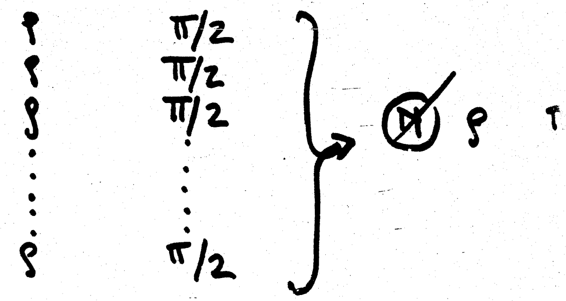
EXAMPLE

MODEL



C ≡ REFERENCE POINTS

R - TABLE



MAPPING RULE

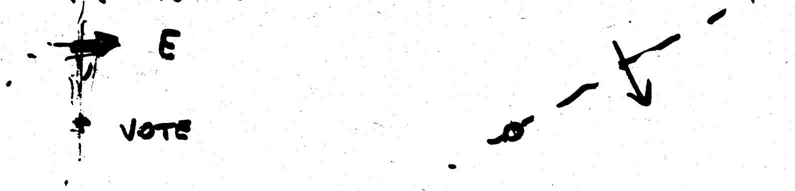
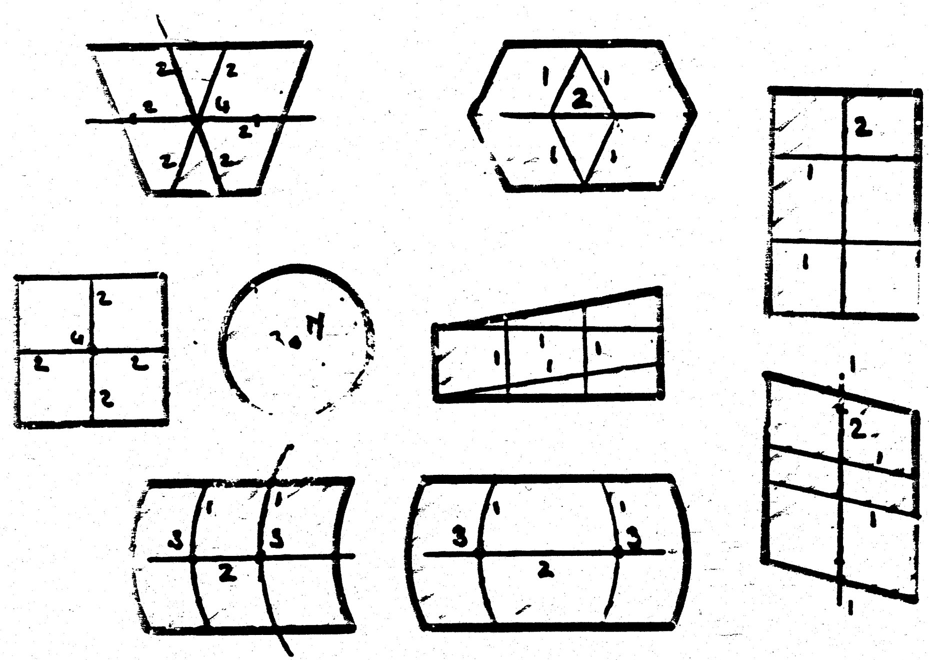


IMAGE AND PARAMETER SPACE



------ EXAMPLE ------

S = 1
ROTATION NOT MEASURED

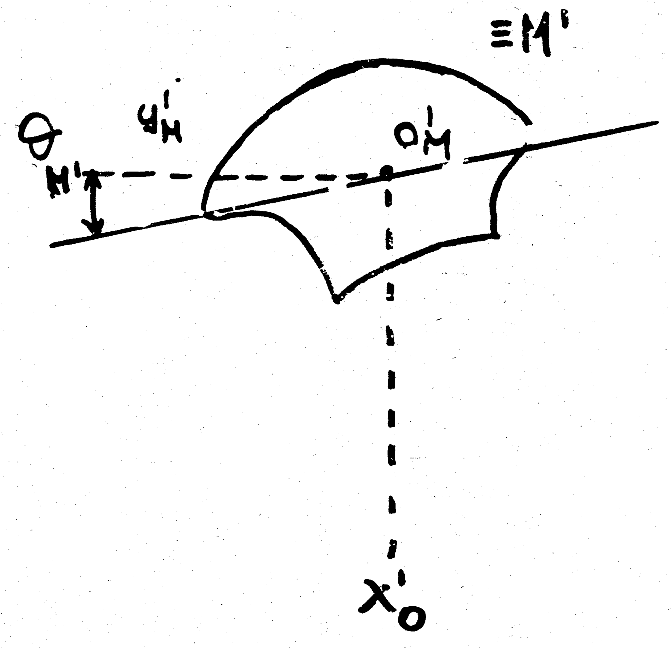
Mapping function:

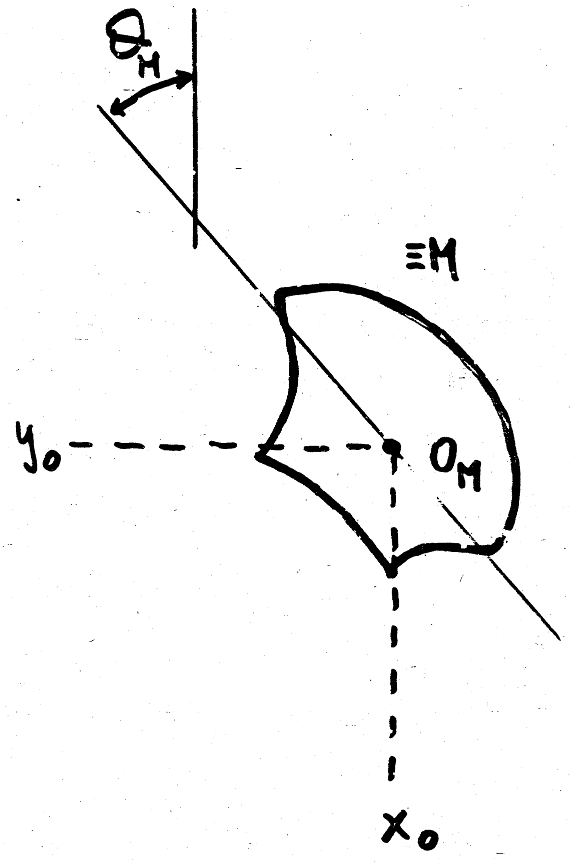
$$X_r = X_e - \rho(\theta) \cos\{\theta + \Psi_e - \beta(\theta)\}$$

$$Y_r = Y_e - \rho(\theta) \sin\{\theta + \Psi_e - \beta(\theta)\}$$

where:

(x_e, y_e)	are the picture edge element coordinates
θ	is the independent variable
$\rho(\theta)$	is the model description in polar coordinates
$\beta(\theta)$	is the tangent direction of the model in the point $\rho\ \theta$
Ψ_e	is the gradient direction in e.

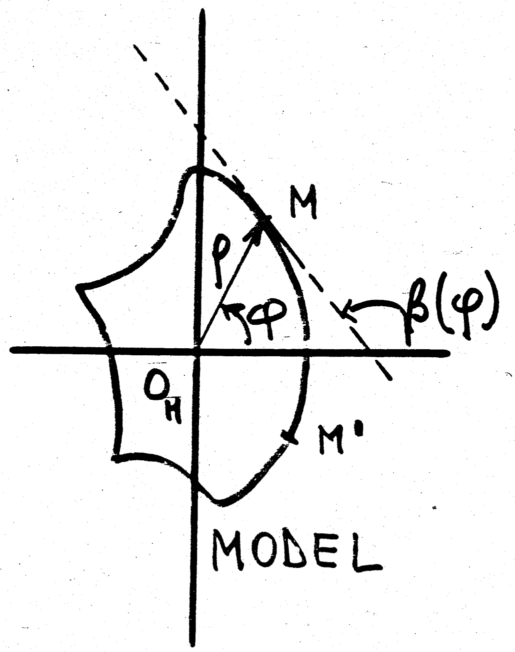

≡M'
θ
M'
y'M
O'M
X'0

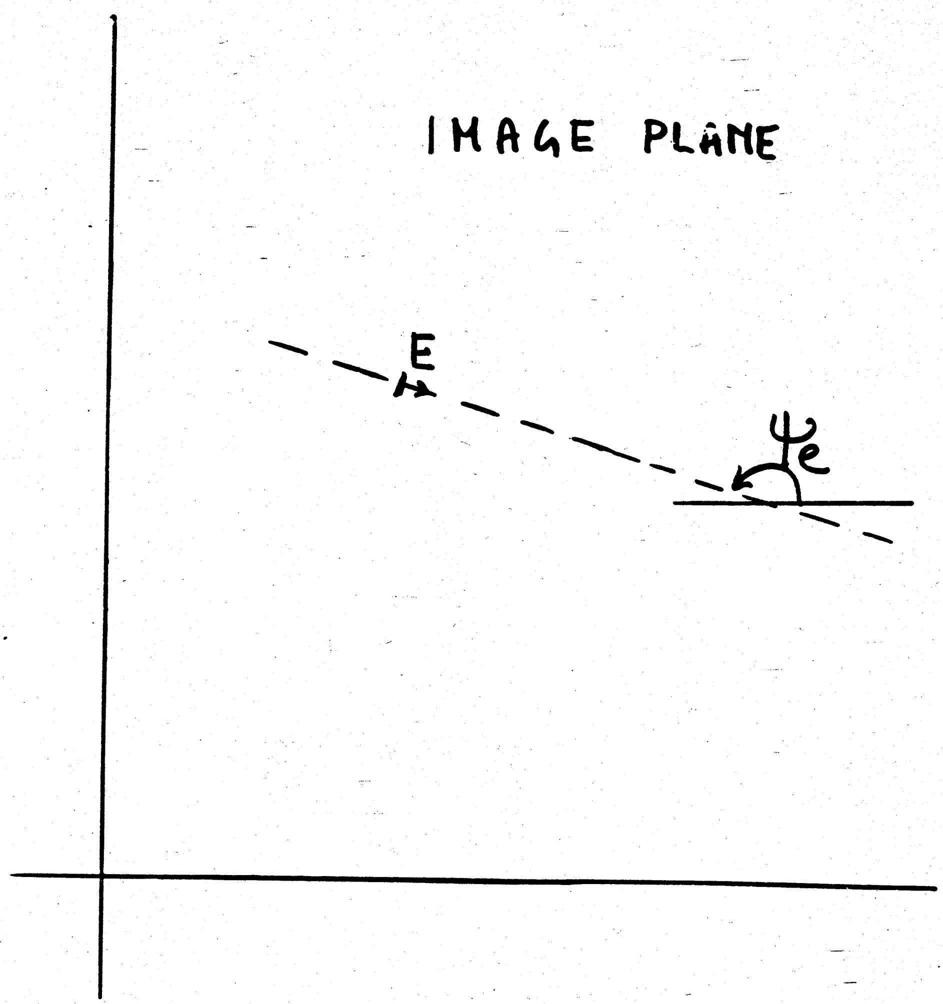


θ_M
ΞM
y_0
O_M
x_0

GENERALIZED HOUGH TRANFORM

DETECTION AND LOCATION





$$E = (x_e, y_e, \Psi_e)$$

$$\begin{cases} x_0 = x_e - s \cdot \rho(\varphi) \cos[\theta + \varphi] \\ y_0 = y_e - s \cdot \rho(\varphi) \sin[\theta + \varphi] \\ \theta = \Psi_e - \beta(\varphi) \end{cases}$$

THE HOUGH TECHNIQUE

BASIC ELEMENTS:

A) A LOCAL EDGE-DETECTOR ELEMENT, E

B) AN N-DIMENSIONAL PARAMETER SPACE, P, QUANTIZED AND REPRESENTED BY AN N-DIMENSIONAL ACCUMULATOR ARRAY, AA

C) A MAPPING, M , FROM THE INFORMATION PROVIDED BY E INTO P (AND THUS AA)

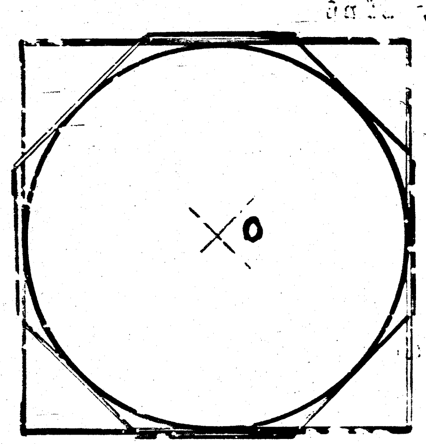
D) A VOTING RULE, V , SPECIFYING HOW A PARTICULAR EDGE-ELEMENT AFFECTS THE VALUES OF AA

E) A DETECTION RULE, D, SPECIFYING THE CONDICTIONS UNDER WHICH A PARTICULAR SHAPE HAS BEEN DETECTED.

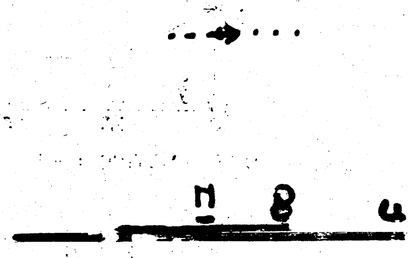
GENERALIZED HOUGH TECHNIQUE

SELECTION OF THE REFERENCE POINT

REGULAR POLYGONS:



MAPPING RULES

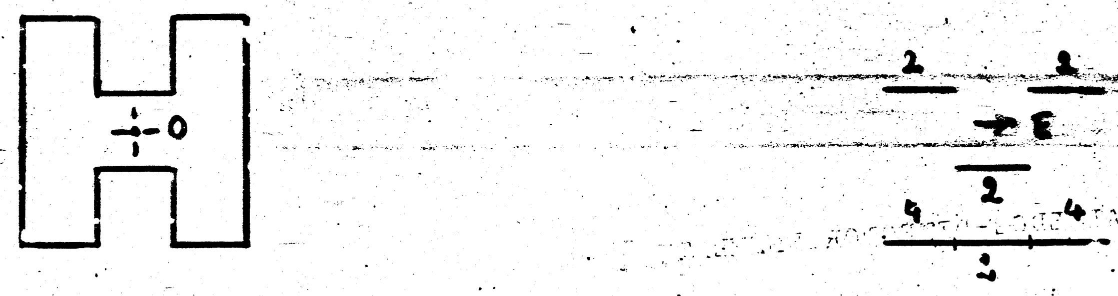


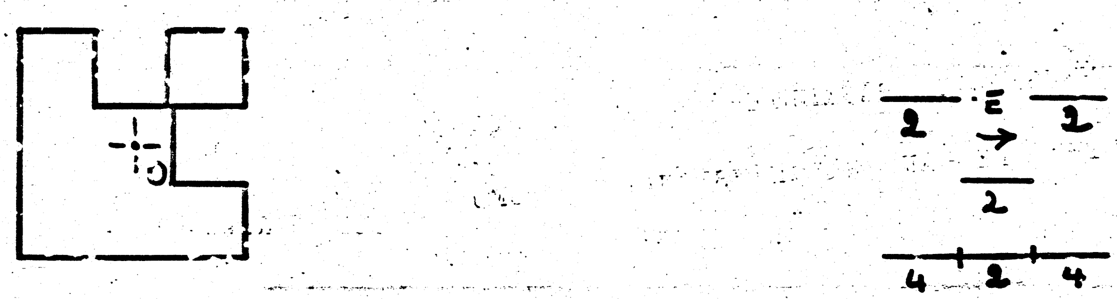
SHAPE	LOCUS Γ
SEGMENT	SEGMENT
EQUILATERAL TRIANGLE SQUARE REGULAR POLYGON	SIDE
RECTANGLE RHOMBUS PARALLELOGRAM	COUPLE OF SIDES
CIRCLE	POINT
POINT SYMMETRIC FIGURE	HALF SHAPE

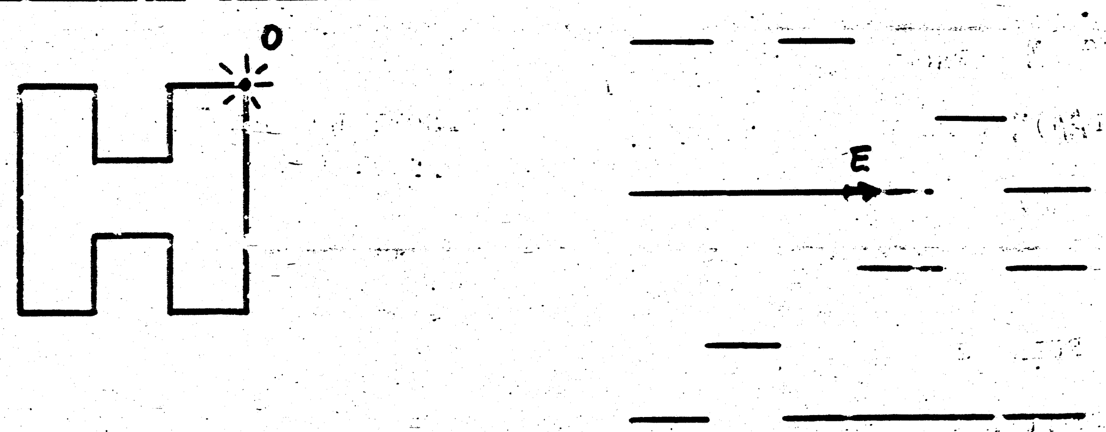
GENERALIZED HOUGH TRANSFORM

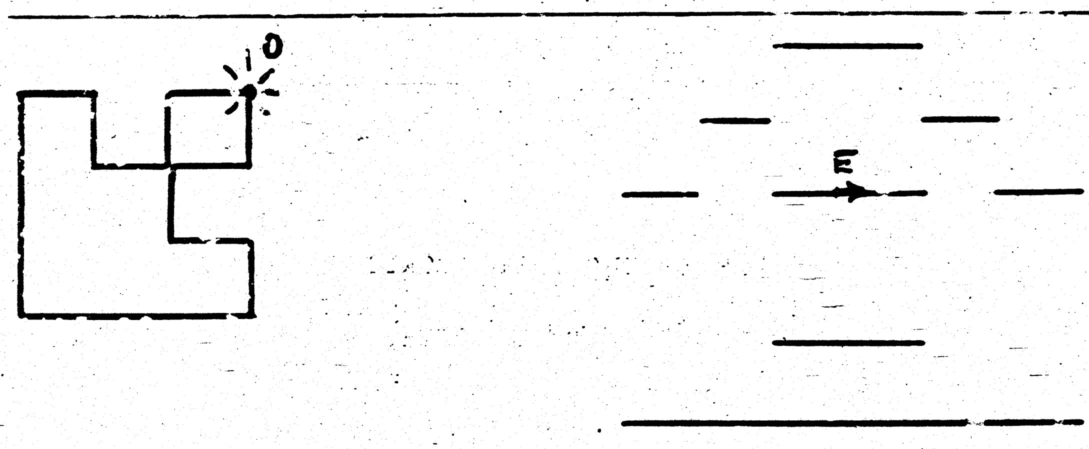
SELECTION OF THE REFERENCE POINT

MODEL | MAPPING RULE



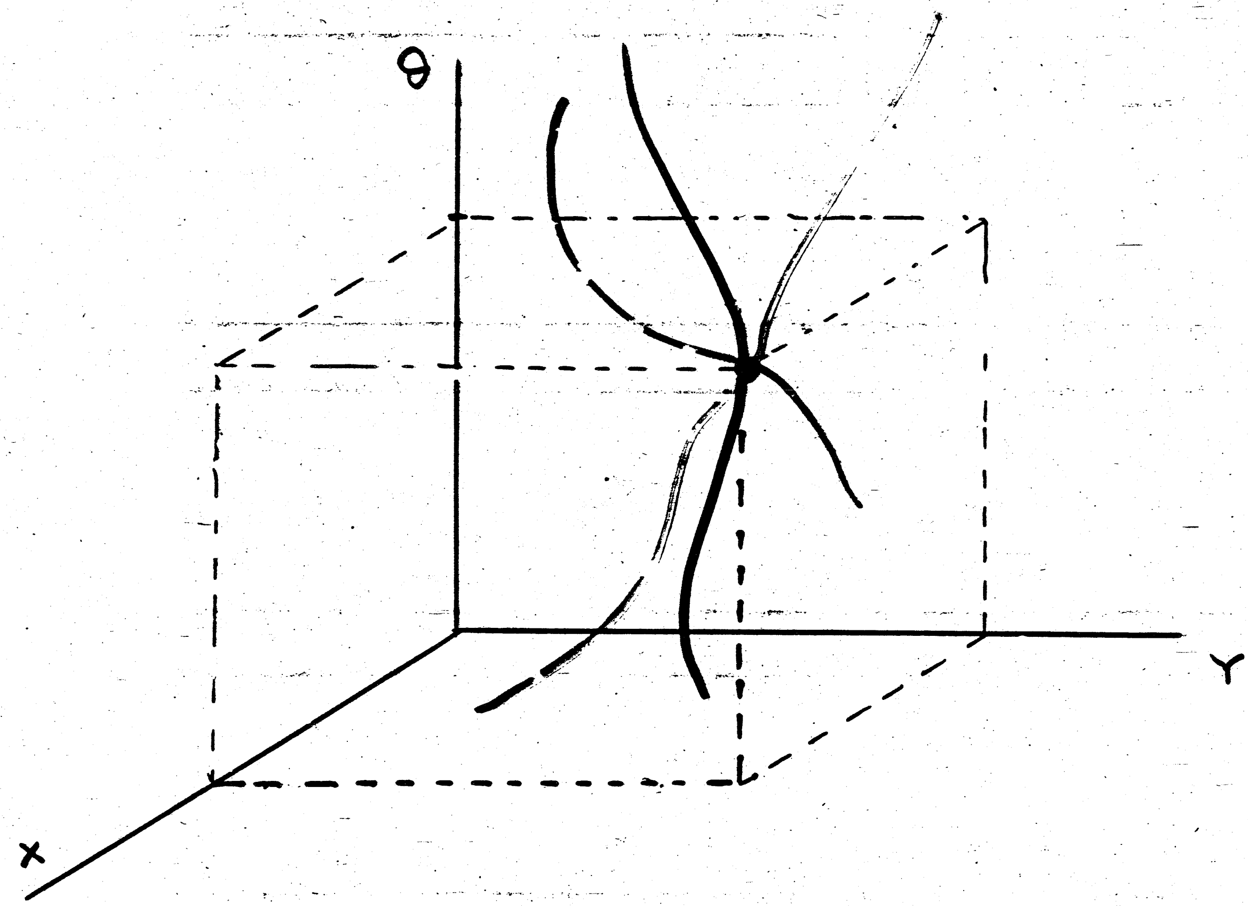






ORIENTATION DETECTION

$$x_o = x_e - \rho(\varphi)\cos[\psi_e - \beta(\varphi) + \varphi]$$
$$y_o = y_e - \rho(\varphi)\sin[\psi_e - \beta(\varphi) + \varphi]$$
$$\theta = \psi_e - \beta(\varphi)$$



ORIENTATION DETECTION

3D METHOD

$$x_0 = x_e - \rho(\varphi) \cos\left[\psi_e - \beta(\varphi) + \varphi\right]$$
$$y_0 = y_e - \rho(\varphi) \sin\left[\psi_e - \beta(\varphi) + \varphi\right]$$
$$\vartheta = \psi_e - \beta(\varphi)$$

ALL VOTES DERIVED FROM THE MAPPING OPERATION WILL BE STORED UP IN THE LOCATION OF THIS 3D SPACE

- THE INDEX PROCESS IS COMPLEX
- IT IS NECESSARY TO SEEK THE PEAK IN A 3D SPACE
- THE ALLOCATION MEMORY IS VERY HIGH

2D AND $2\frac{1}{2}$ METHOD

a) USING SEVERAL R-TABLES OBTAINED REFERRING THE MODEL TO DIFFERENT REFERENCE POINTS

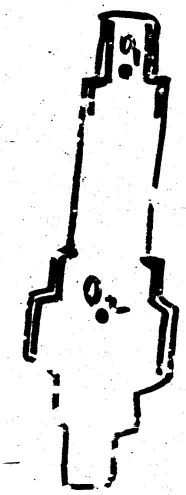
b) USING SEVERAL SUBSHAPES MODELS AND SEVERAL R TABLES REFERRING EACH SUBMODEL TO ITS OWN REFERENCE POINT

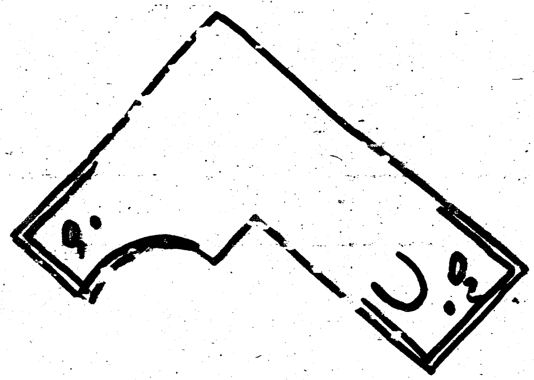
THESE TWO METHODS GIVE IN THE PARAMETER SPACE AS MANY PEAKS AS THE REFERENCE CENTRES USED, AT THE SAME RELATIVE POSITION OF THE CORRESPONDENT CENTER IN THE ORIGINAL MODEL

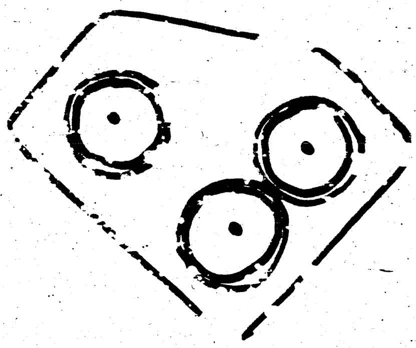
- THE POSSIBILITY OF WORKING IN A MULTIPROCESSING ENVIRONMENT ALLOWS TO ALLOCATE EACH R TABLE IN DIFFERENT PROCESSORS
- THE KNOLEDGE OF THE SPATIAL RELATIONS AMONG THE REFERENCE POINTS OF THE SUBSHAPES PERMITS

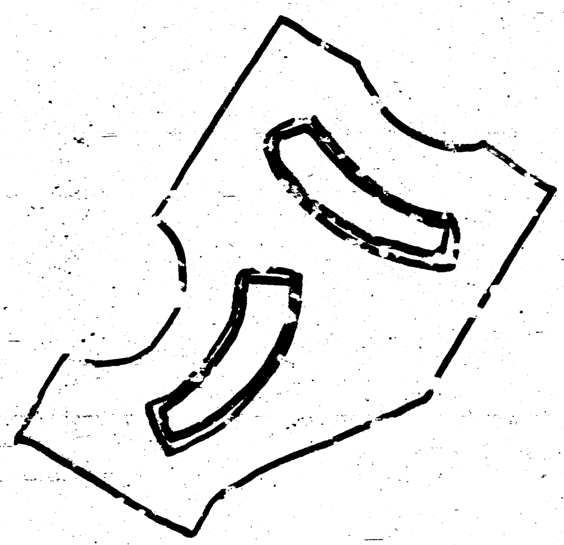
ORIENTATION DETECTION

O_1 reference point of the 1st subshap
O_2 reference point of the 2nd subshap









In a 2D Accumulator we look for more than one maximum points

LABELING OF LOCAL INSTANCES

ADVANTAGES

- EXPLOITATION OF THE INFORMATION OF THE "CRITICAL" POINTS (SIDE, CORNER, CONCAVE AND CONVEX PARTS, ETC)

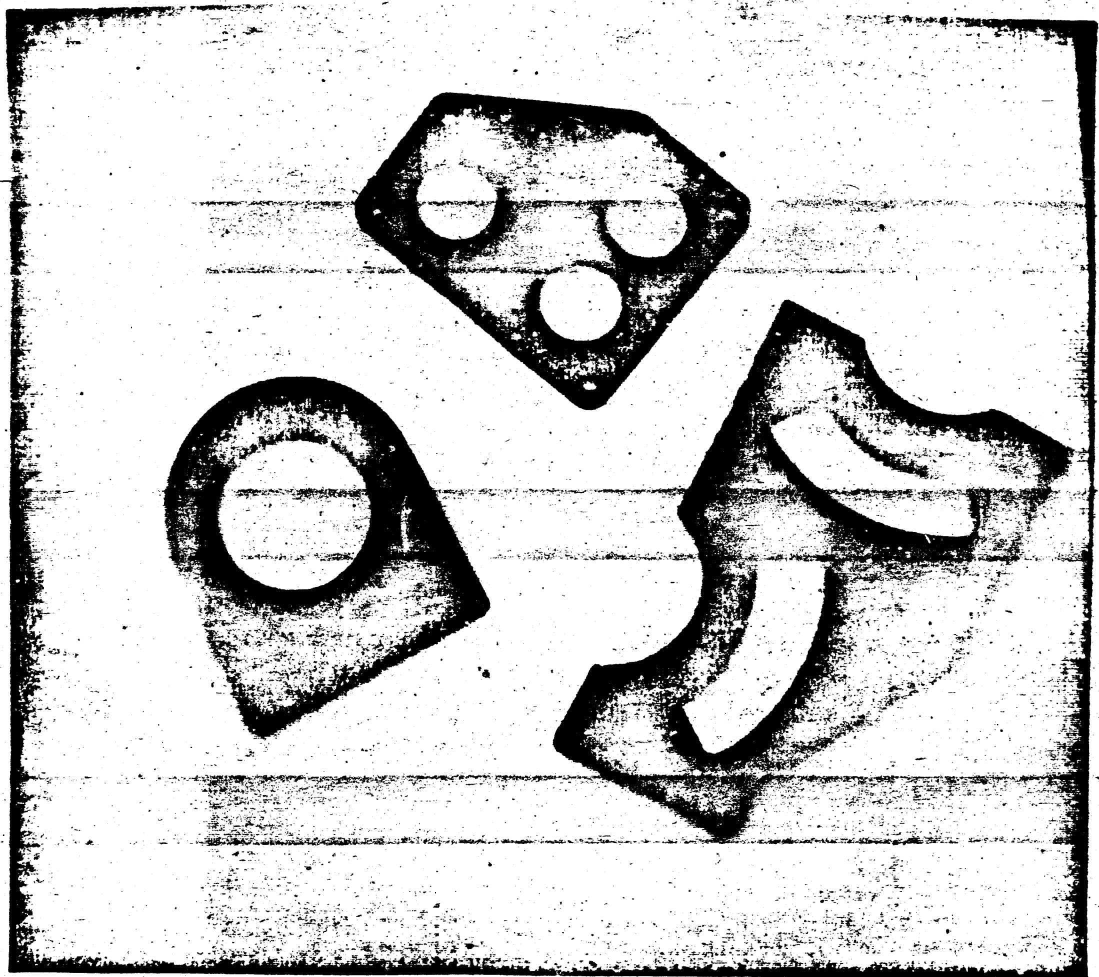
- SPEED UP OF COMPUTATION (EACH POINT FOR THE INSTANCES HAVING THE SAME LABEL IN THE MODEL)

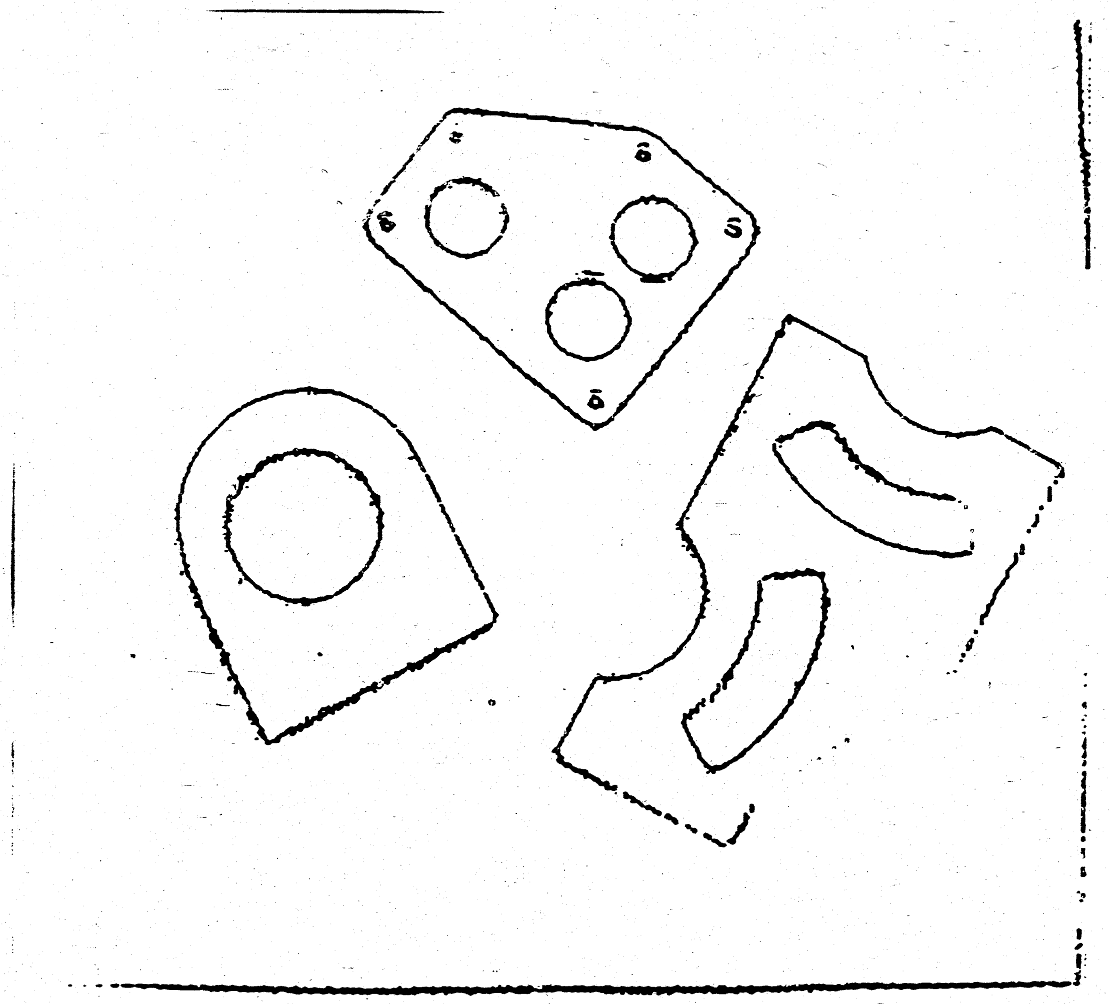
  - THE ANALYSIS OF THE LOCAL CONTEXT IS EASILY IMPLEMENTED IN PARALLEL MACHINES

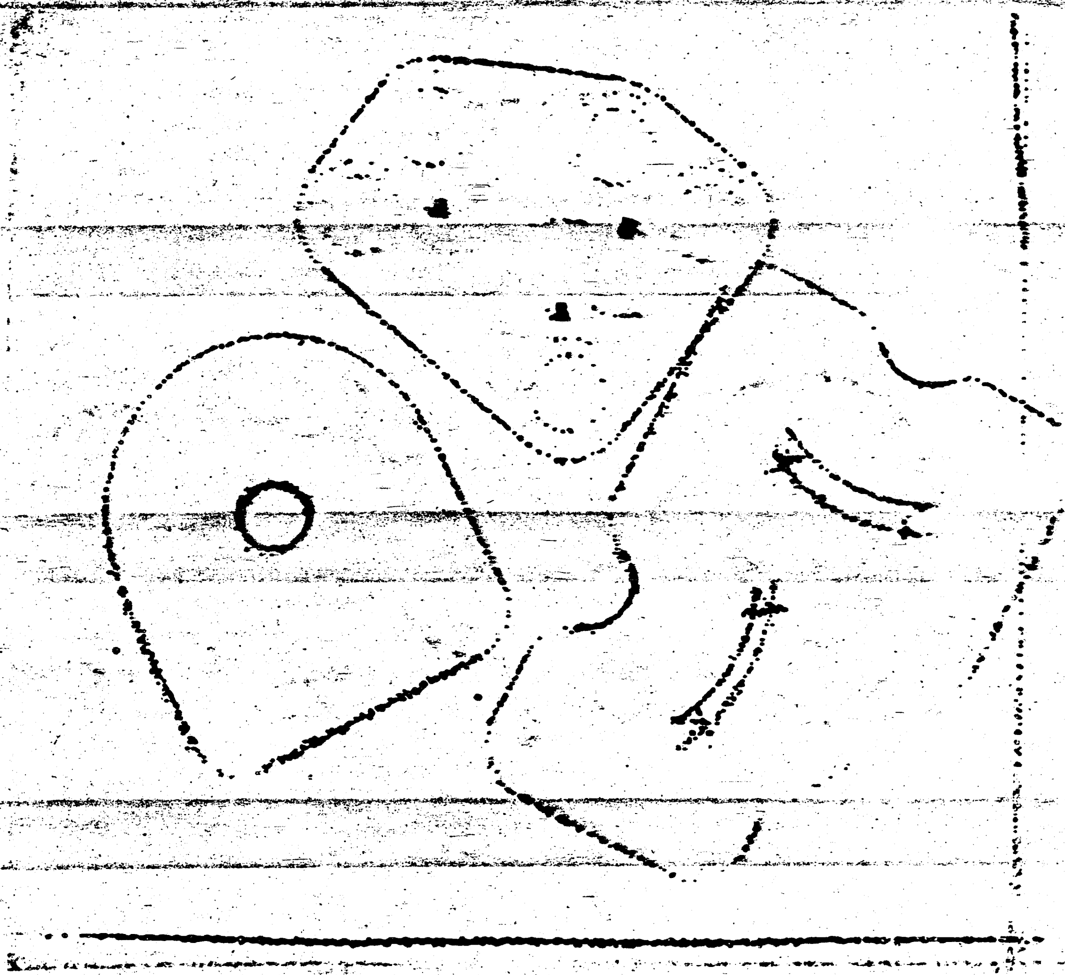
REQUIREMENTS

- ANALYSIS IN A SUBARRAY LARGER THAN 3x3

- SEVERAL REFERENCE-TABLES (ONE FOR EACH LABEL)

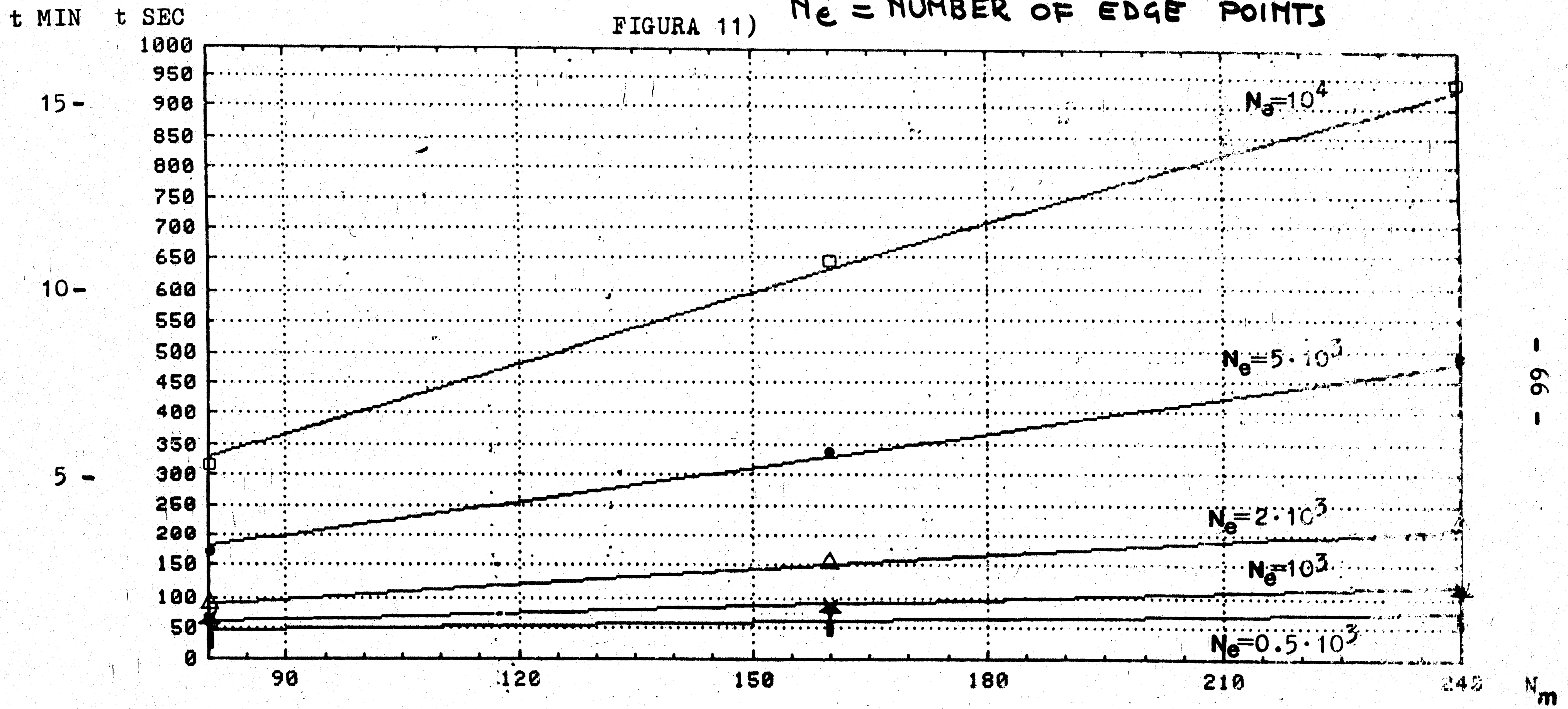






COMPUTATION TIME VERSUS RTABLE CARDINALITY

FIGURA 11) N_e = NUMBER OF EDGE POINTS



Tempi di elaborazione per immagine da 256x256 pixels del sistema HP1000F

N_e = Numero pixels sede di lato

N_m = Numero punti del modello

Valore di t stimato:

$t \simeq 30 + 3.75\cdot10^{-4} N_m N_e$ Sec.

Valori di t sperimentali:

□ $N_e = 10^4$; ● $N_e = 5\cdot10^3$; △ $N_e = 2\cdot10^3$

★ $N_e = 10^3$; ▮ $N_e = 0.5\cdot10^3$

MULTIRESOLUTION IMPLEMENTATION

- THE CARDINALITY OF THE REFERENCE TABLE LINEARLY DEPENDS ON THE IMAGE RESOLUTION

- IMPLEMENTING THE HOUGH TRANSFORM IN A PYRAMID DATA STRUCTURE THE HIGHER IS THE PROCESSING LEVEL PLANE THE LOWER IS THE COMPUTATION REQUESTED

$$\left(M' = M / 2^{\ell-\ell'} \right)$$

- USING THE LABELING APPROACH THE COMPUTATION IS PERFORMED AT THE HIGHER RESOLUTION LEVELS ONLY FOR THE ANALYSIS OF POINTS THAT HAVE "COMPLEX" LOCAL CONTEXT

ALTO-DESTRA