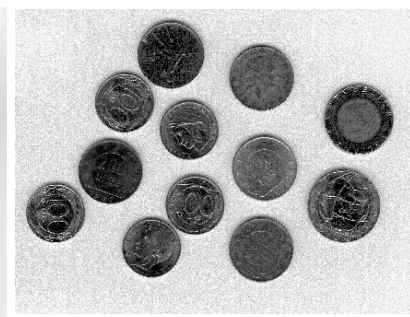


Artificial visual search and Hough Transform

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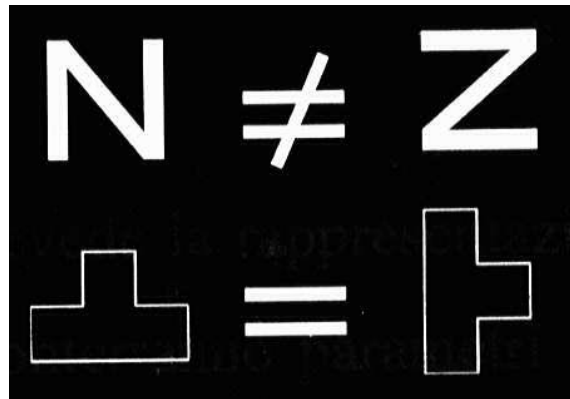
Artificial visual search

- Given an unknown input image segment and the basic properties (template) of the object-target, the problem is to determine if the segment belongs to the target class
- Difficulties can arise when large variations and distortions are expected in this segment. In general this is the case because objects appears:
 - roto-translated and with a scaling factor
 - with shading, luminance and color changes
 - overlapped, occluded and noisy
 - rigid, semi rigid or even flexible



Model definition

- The real world contains, in general, high variability and variety levels for mathematical and statistical models to describe it completely. The components outside such descriptions are commonly termed noise. An automatic system - and maybe the human mind itself - is necessarily endowed with models to interpret reality - where the so called context is part of.
- In computer vision *context* can be described through a particular configuration of internal parameters and pragmatically a context is valid if the automatic interpretations, in the current scenario, correspond to an acceptable extent, to the target goals.

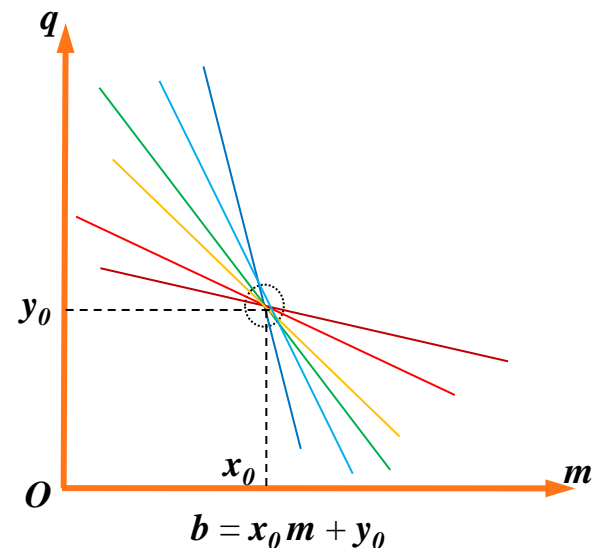
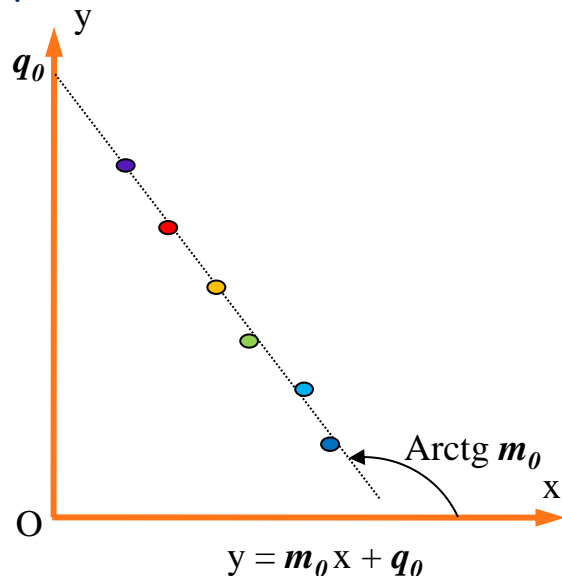


Visual search approaches

ARTIFICIAL VISUAL SEARCH	OBJECT REPRESENTATION	DECISION POLICY
Direct Matching Track	Template or prototype shape	Correlation
Statistical Theoretic Track	Features set, features vector	Decision function, e.g. maximum likelihood, minimum risk, etc.
Linguistic/Syntactic Track	Grammar	String parsing
Structural track Hough Transform	Reference Table	Statistic – Search of max in parameter space
Hybrid	Combination of previous method	Multi-classifier, e.g. AdaBoost

Hough Transform

- The Hough transform has been introduced in 1962 by Paul Hough for the detection of straight lines. Each contour point identified in an image can support the existence of the set of straight lines crossing its location. If a straight line is present in the image, and N of its points are detected, N sets of lines receive a contribution but only the common single straight line receives N contributions. An edge detector may also provide the contour orientation; in this case the possible detection is more effective with less spurious artifacts.



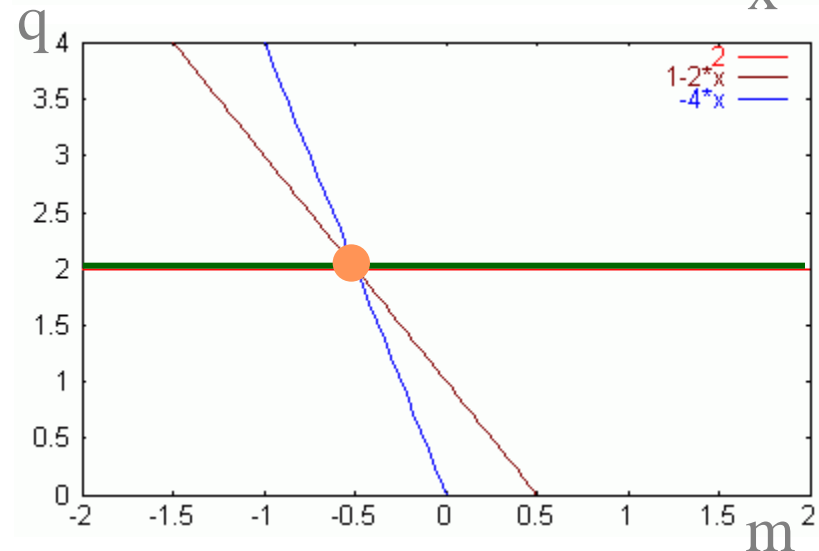
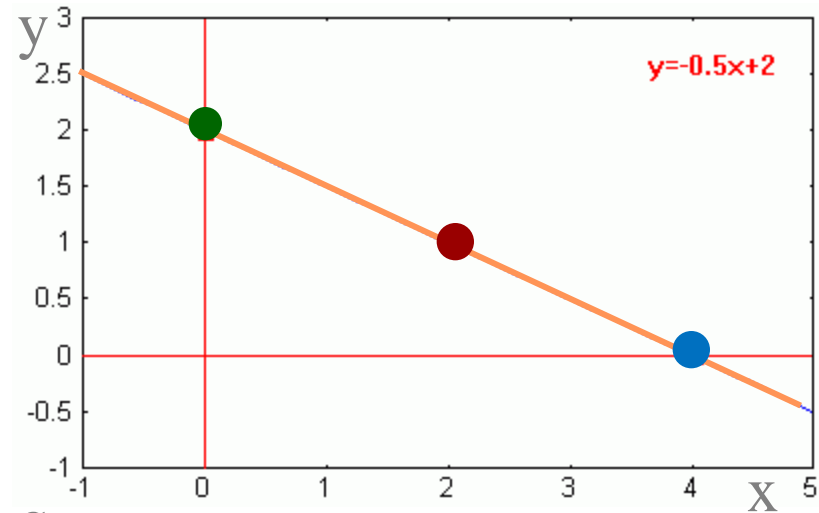
HT: searching straight lines

- Classical straight line equation:

$$y = mx + q$$

$$f((x,y), (m,q)) = y - mx - q = 0$$

- Given a point (x_i, y_i) in the image space (IS) the equation $q = y_i - mx_i$ describes the locus of points of the parameter space (PS) representing the set of straight line crossing (x_i, y_i)
- Knowing the orientation ($dy_i/dx_i = m_i$) the locus is limited to just one point: (m_i, q_i)



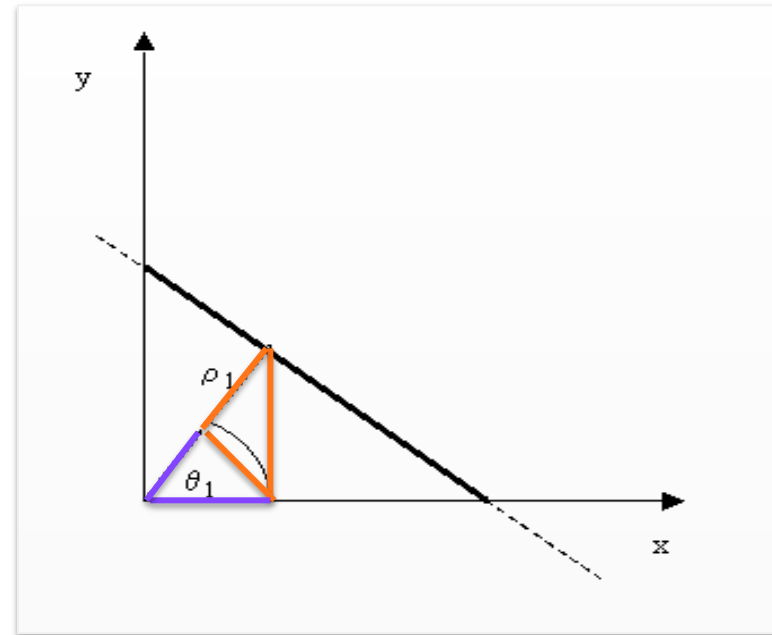
HT: searching straight lines

- In the classic equation the parameters are not limited:
 $-\infty < m, q < +\infty.$
- For this reason Paul Hough adopted a different straight line representation introducing the a PS (ρ, θ) :

$$\rho = x \cos(\theta) + y \sin(\theta).$$

- In this case the PS is limited to:

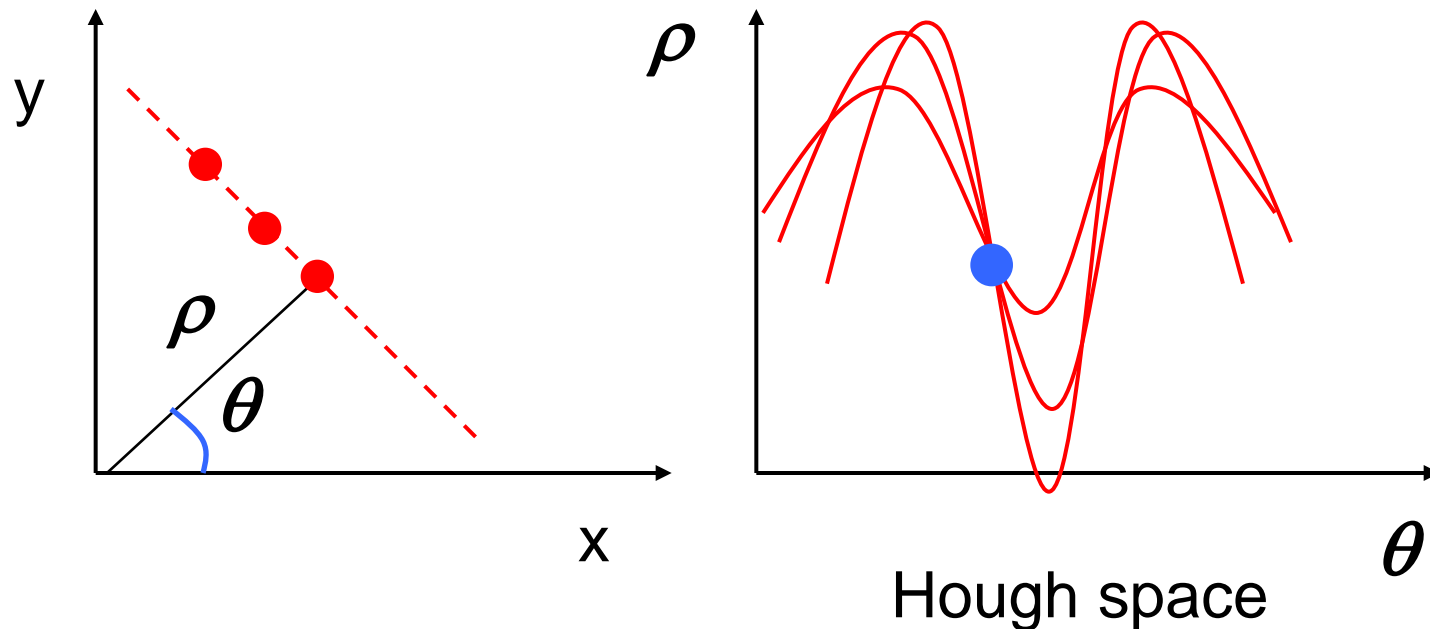
$$0 < \rho < L\sqrt{2}; -\pi \leq \theta \leq \pi.$$



Hough transform

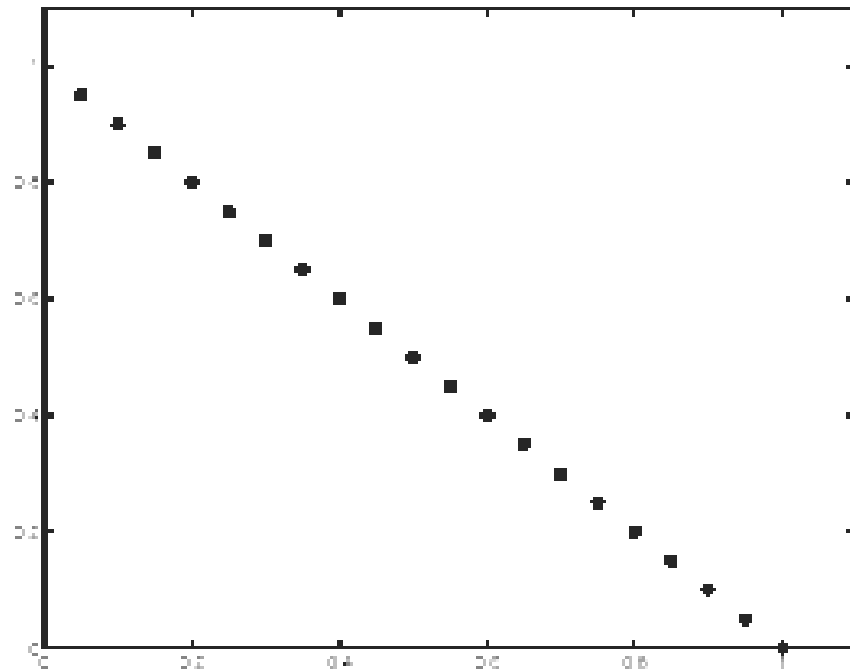
P.V.C. Hough, *Machine Analysis of Bubble Chamber Pictures*, Proc. Int. Conf. High Energy Accelerators and Instrumentation, 1959

- Issue : parameter space $[m,b]$ is unbounded...
- Use a polar representation for the parameter space

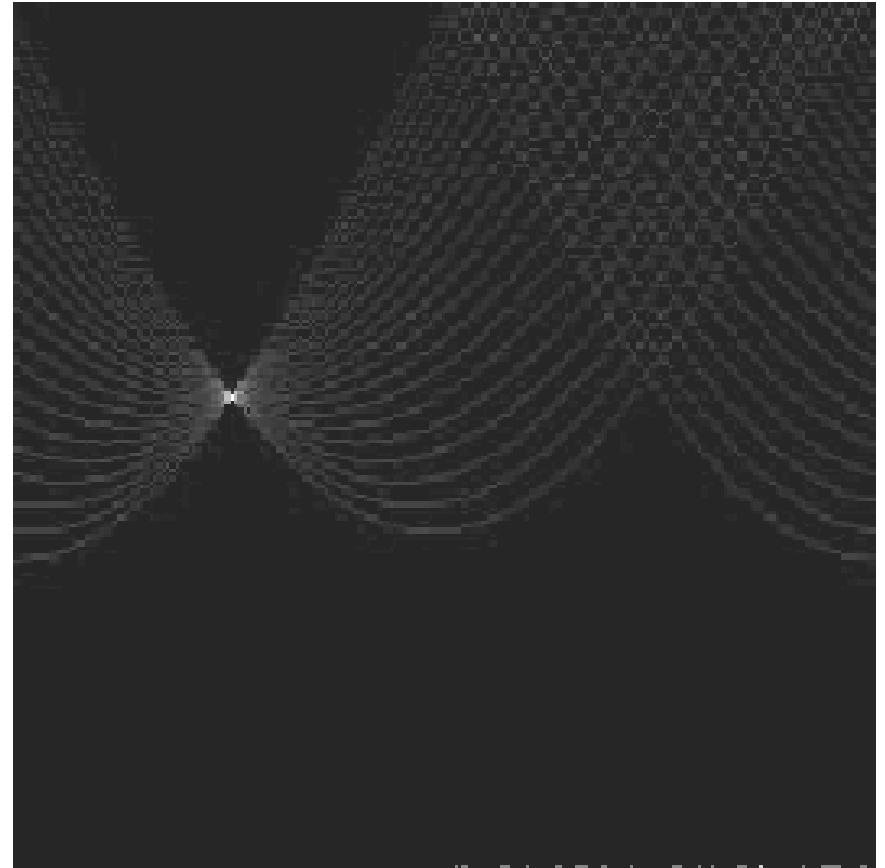


$$x \cos \theta + y \sin \theta = \rho$$

Hough transform - experiments

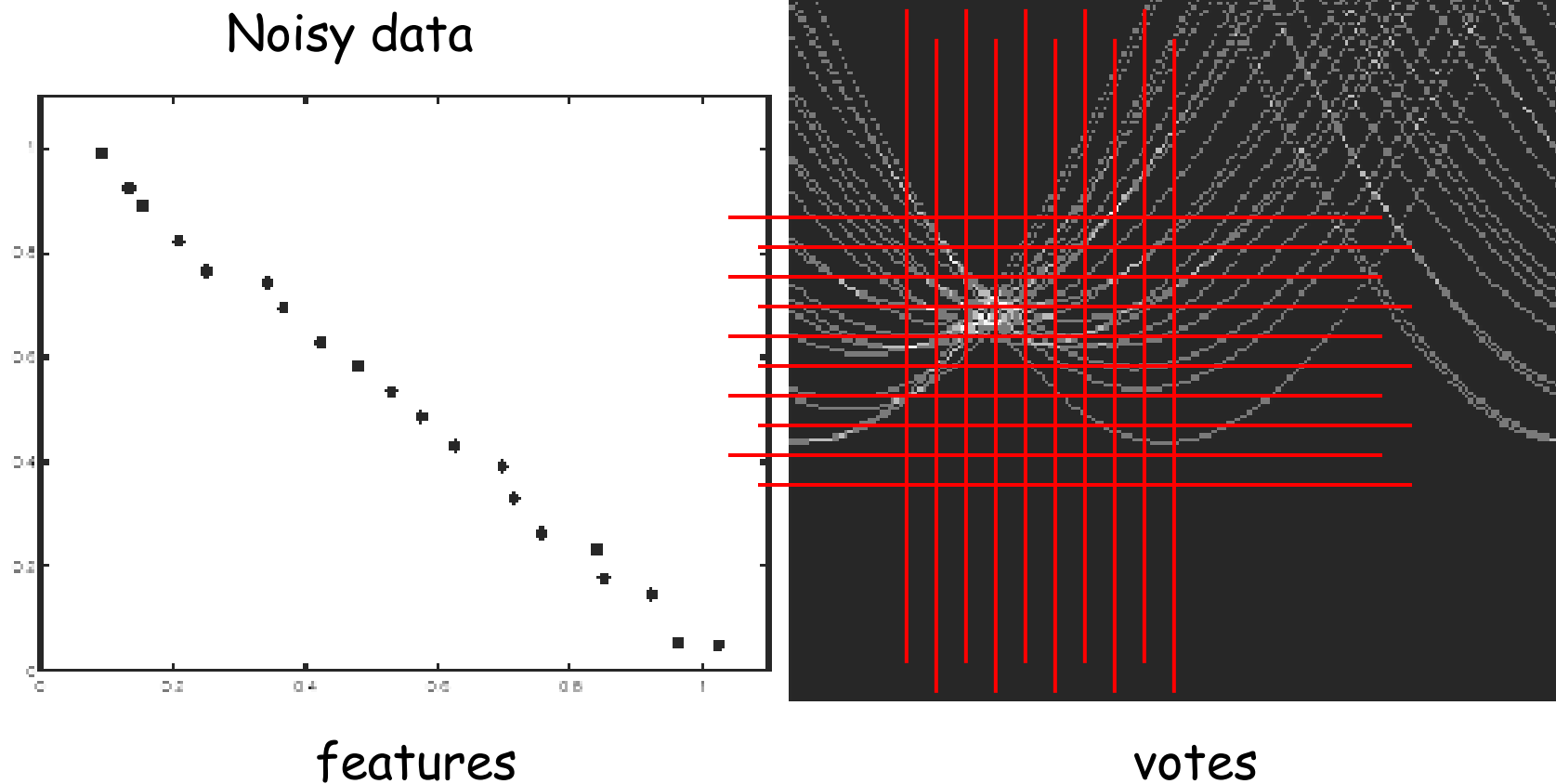


features



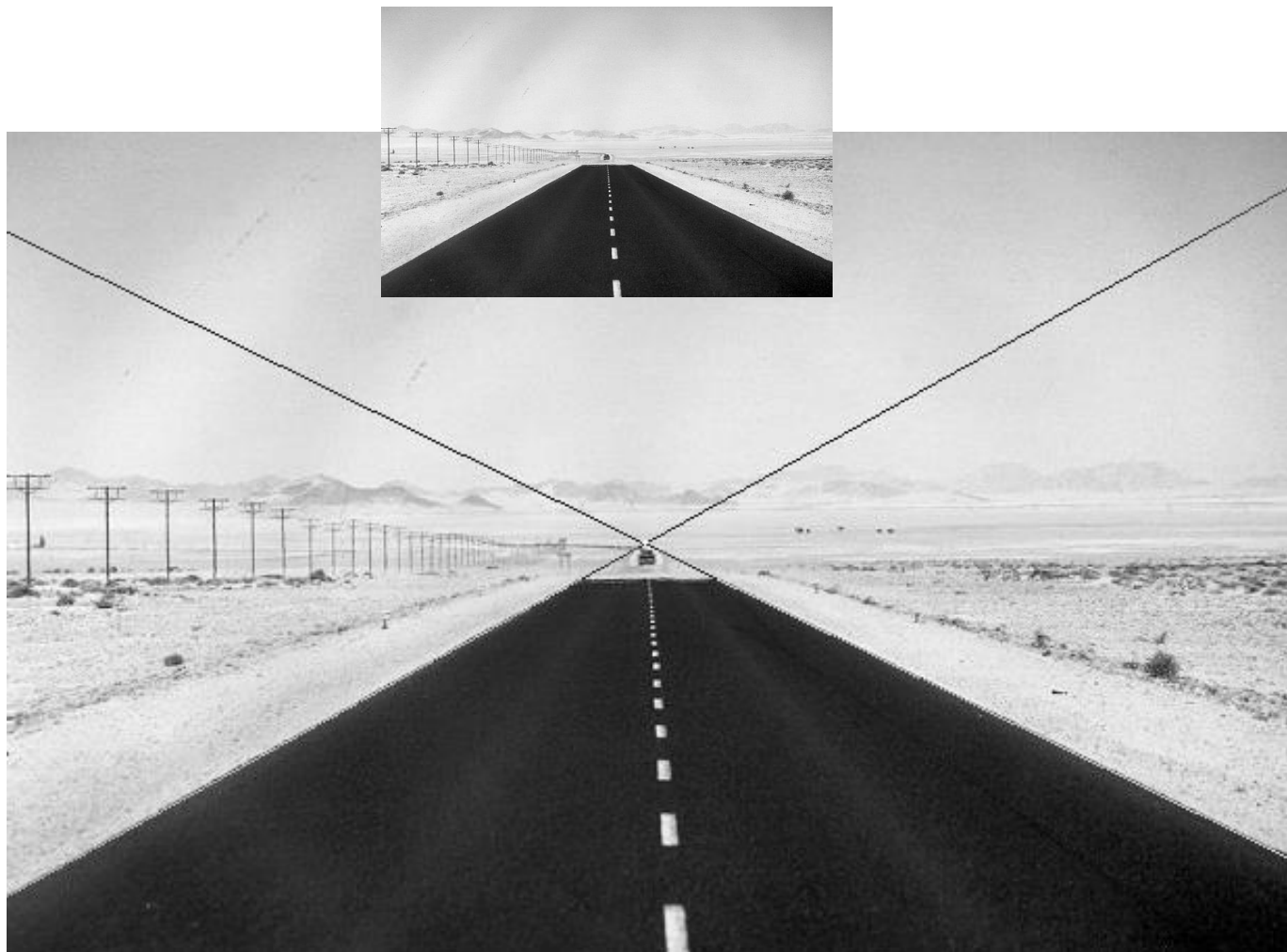
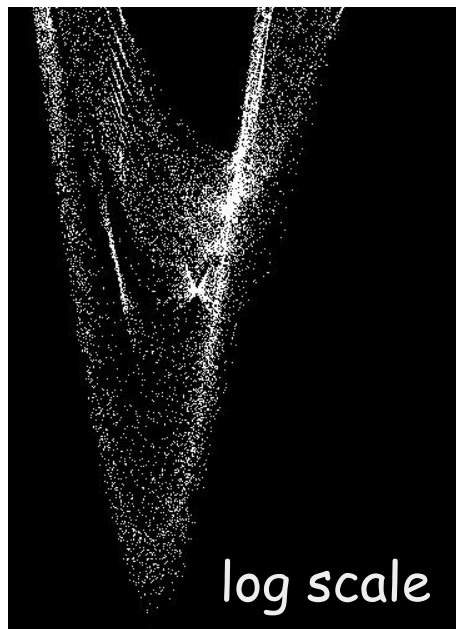
votes

Hough transform - experiments



Need to adjust grid size or smooth

Esempio di voto



Esempio di voto



Esempio di voto



HT: searching analytical curves

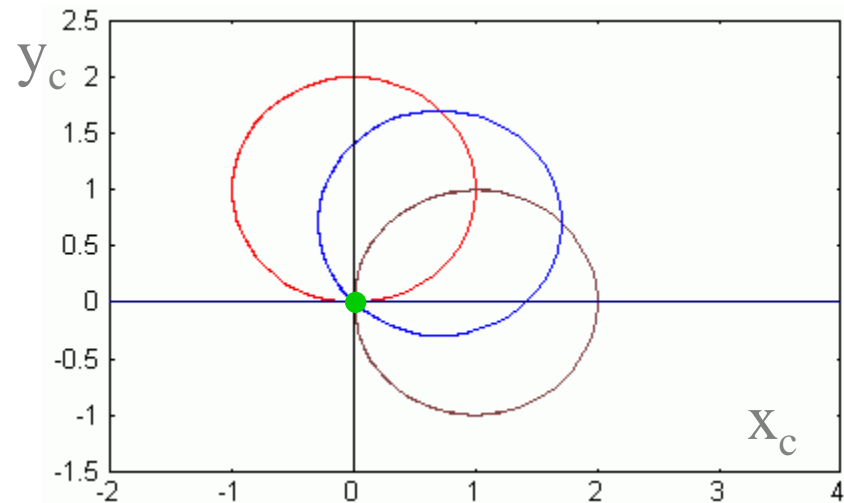
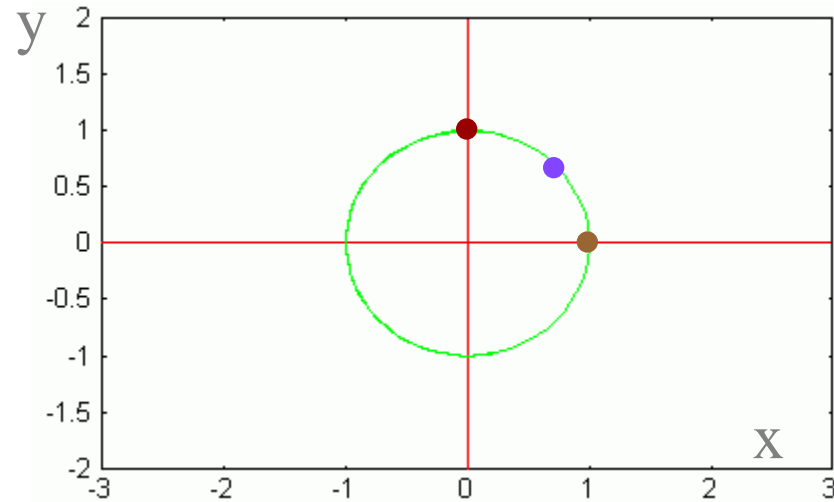
- From the very first Hough transform version, many extensions were developed along the years. It ranges from more complex analytical curves (with a higher number of parameters), e.g. circles:

$$(y-y_c)^2+(x-x_c)^2=r^2$$

- First approach: search circle with a given radius. In this case we have a 2D PS and the mapping rule (locus of compatible points) is also a circle with the given radius.

Note that it is not always true that searched curves and mapping rule are equal

- The PS represents the circle center coordinates (x_c, y_c)
- Also in this case, knowing the orientation (dy_i/dx_i) the mapping rule is reduced to one point: (x_c, y_c) at distance r from (x_i, y_i) in \perp direction

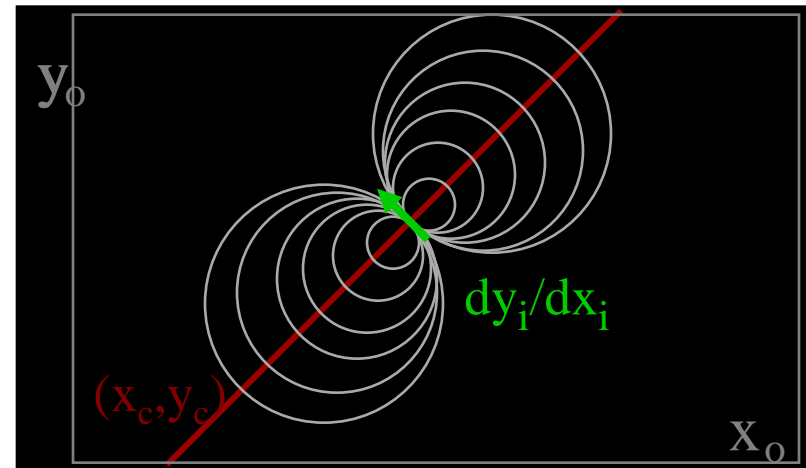
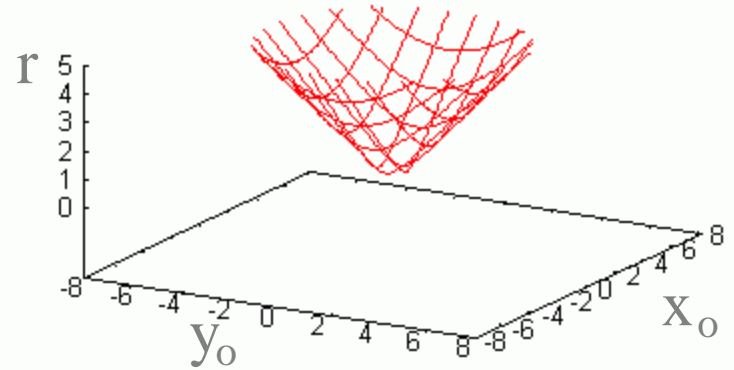


HT: searching for circles

- If also the radius is unknown the PS is 3D:

$$f((x,y),(x_c,y_c),r) = (y-y_c)^2+(x-x_c)^2-r^2=0$$

- The mapping rule in this case is a cone.
- If the orientation is known (dy_i/dx_i) the mapping rule is reduced to a straight line: $y_c = -1/m_i x_c + (y_i - m_i x_i)$.
- If also the curvature is known (e.g. is known r) the mapping rule, as shown previously is reduced to a point: x_c, y_c



Implementation of the HT

- The original approach of the HT is based on these elements:
 - an enriched edge detector to find contour pixels and some local properties as the gradient angle or local curvature (concavity and convexity);
 - an array (in a parameter space) working as an accumulator of the contributions. Each element of the parameter space represents a possible instance of the searched object (in the GHT each element corresponds to the parameters of the rigid motion that moves the reference point of the object on that location);
 - a mapping rule which defines the contributions of the detected instance on the accumulator array. The simplest solution is to increment all the elements, corresponding to the pattern, compatible with the detected instance. A weighted contribution can be introduced on the basis of both the estimated precision (e.g. the further the location the lower the contribution because of the edge detection orientation bias) and/or of the saliency of the detected instance;
 - a discriminant criterion for the evaluation of the resulting final contribution in the parameter space. Knowing the expected maximum contribution, the common solution is by means of a threshold (local maxima over the threshold identify the presence of the pattern), so taking care of possible occlusions, noise, etc.

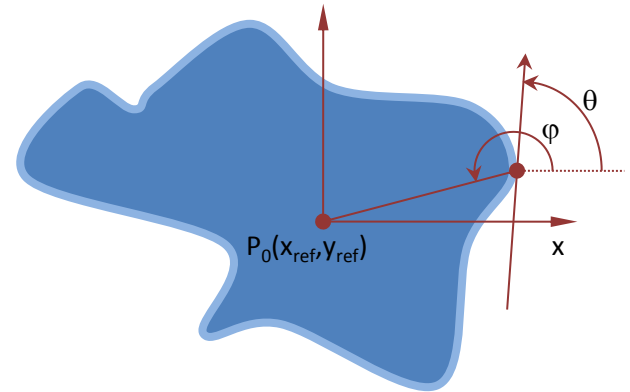
The Generalized Hough Transform

- With the *Generalized Hough Transform (GHT)*, under the assumption of rigid motion, any pattern can be represented and recognized.
- Let us first consider the case of a pattern given as silhouette at fixed scale
- Let us select a reference point $P_{ref}(x_{ref}, y_{ref})$, non necessarily the baricenter even if its centrality is often advantageous
- Each boundary point $P(x,y)$ can be referred to P_0 as:

$$\rho = \sqrt{(x_{ref} - x)^2 + (y_{ref} - y)^2}$$

$$x_{ref} = x + \rho \cos(\varphi - \theta) \quad y_{ref} = y + \rho \sin(\varphi - \theta)$$

- The object contour can be described by a Reference Table (RT) with the illustrated geometry



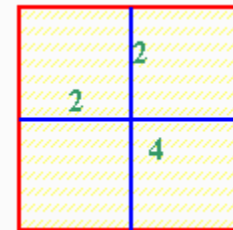
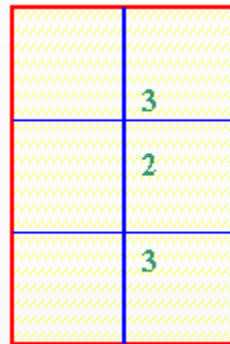
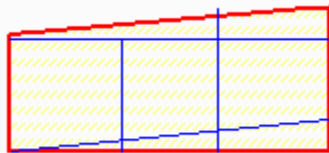
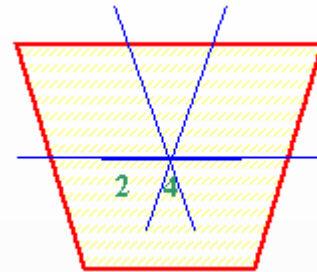
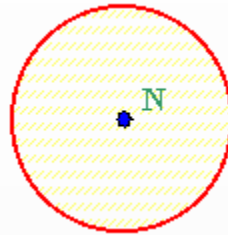
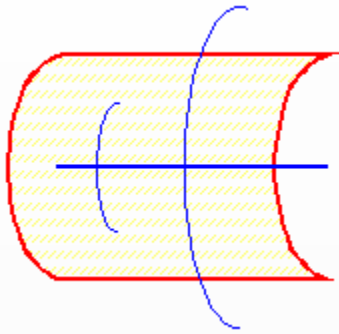
...
$P(x,y)$	ρ	$\varphi - \theta$	other peculiarities
...

Reference Table

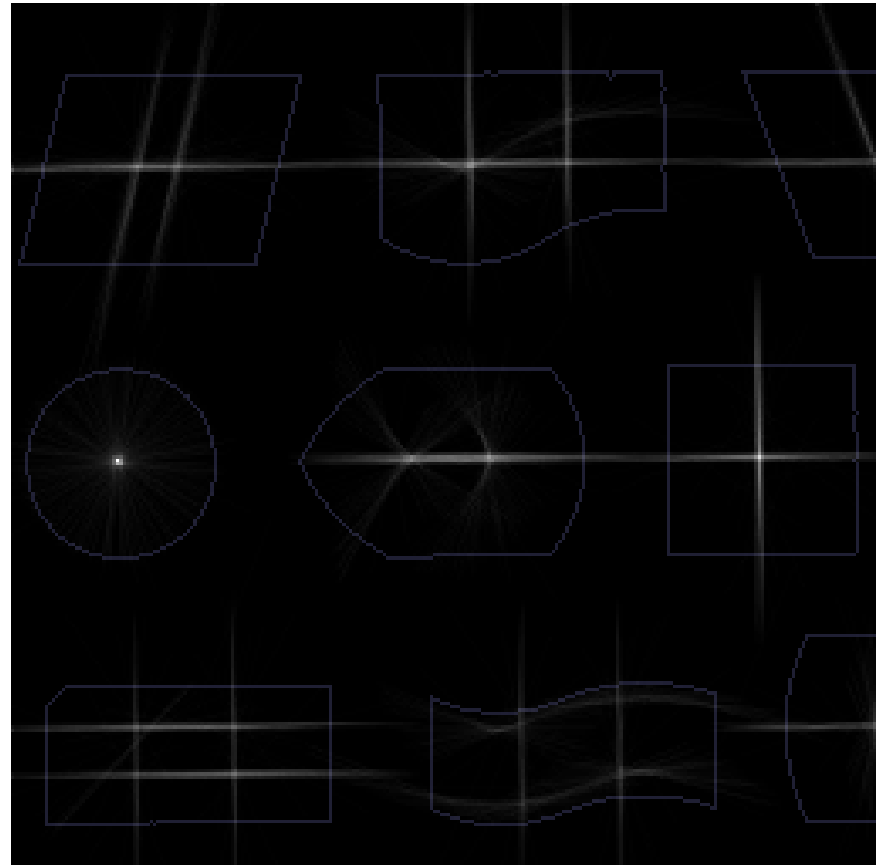
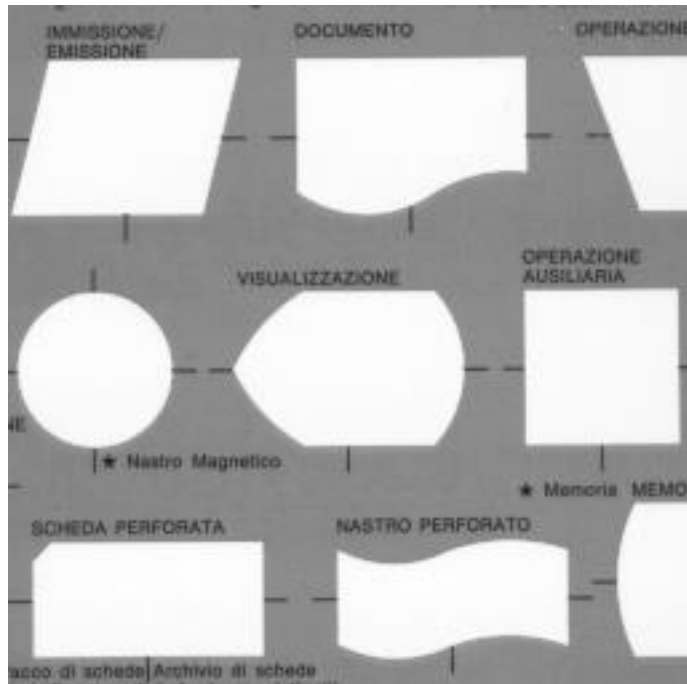
The Generalized Hough Transform

- For a given point $P(x,y)$ obtained by an edge detector on the image under analysis, the set of compatible points of the PS (which here represent the positions of the of the P_{ref} compatible with the contour crossing P) are given by the equation above (that represents the mapping rule).
- For each contour point detected on the image, the number of contributions onto PS is N , the cardinality of the RT .
- If all the contour points of a searched pattern, effectively present in the image, are detected a peak of value N will appear in the P_{ref} position of PS (corresponding to the model roto-traslation)
- Considering the case of unknown scale factor s , to the image describing the position of the P_{ref} in the image, an extra dimension must be introduced in the PS for the parameter s . It become a 3D PS (replicating the image for each value of s) and in the above equation ρ must be multiplied by the correspondent scale factor s .
- In a similar way, if we want to detect directly the object orientation all the process must be realized in a 4D PS: $(x_{ref}, y_{ref}, s, \phi)$. As we will see later a more convenient solution is to choose a couple of P_{ref} .


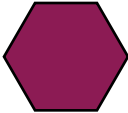
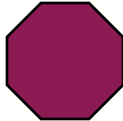
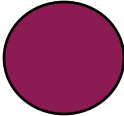

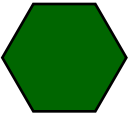
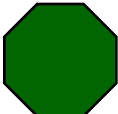
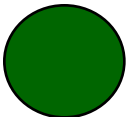
Example



Example: looking for a square

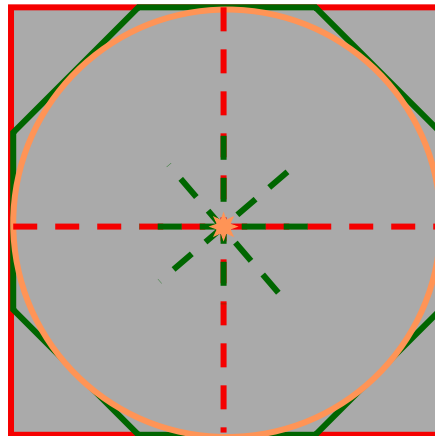


HT: search for regular polygons

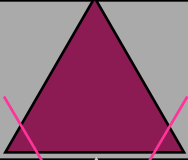


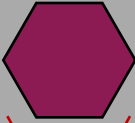
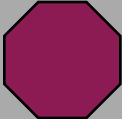

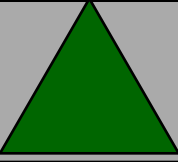
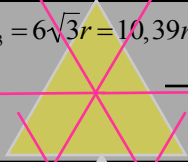

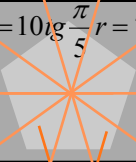
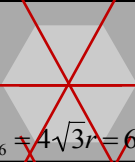



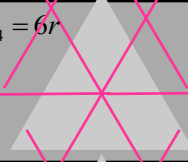

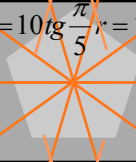

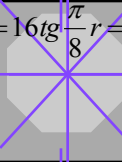


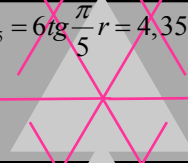
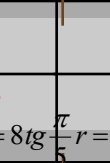
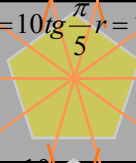
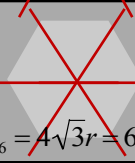

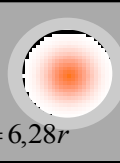
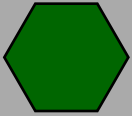
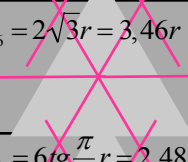
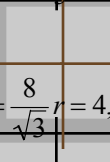
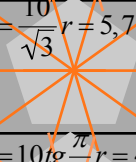
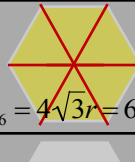
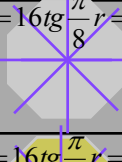
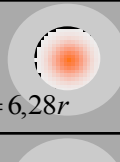
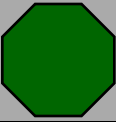
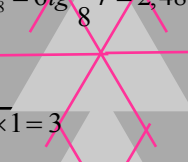
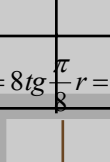
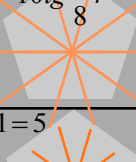
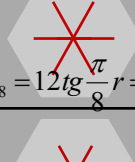
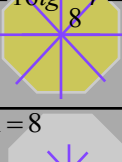
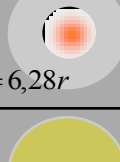
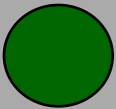

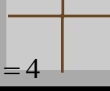

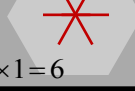

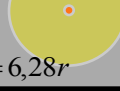
Present Searched				
				
				
				
				

Regular polygons

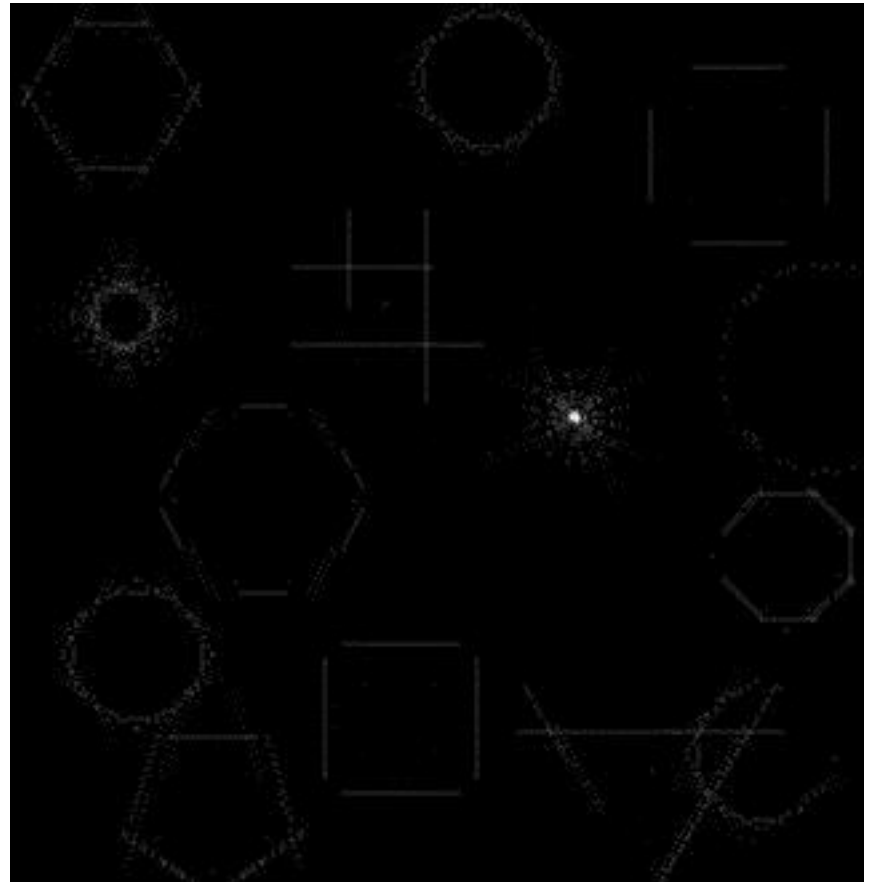
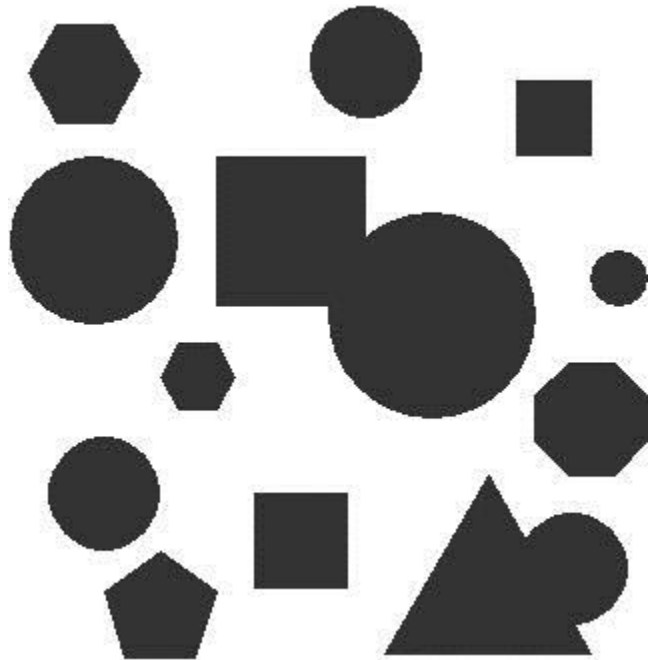
- Regular polygons have a mapping rule consisting in a side distant from the center as the apothem
- The mapping rule of a regular polygon of order n contains all the mapping rules of regular polygons of higher order having the same apothem
- Looking for a regular polygon of order n , it will gather a number of votes V equal to its perimeter: $V = n L_n$
- If another regular polygon of order m with the same apothem is present it will gather a number of votes V equal to: $V = m L_n$ if $m \leq n$, $V = m L_m$ if $m > n$ but note that in this case $n L_n > m L_m$



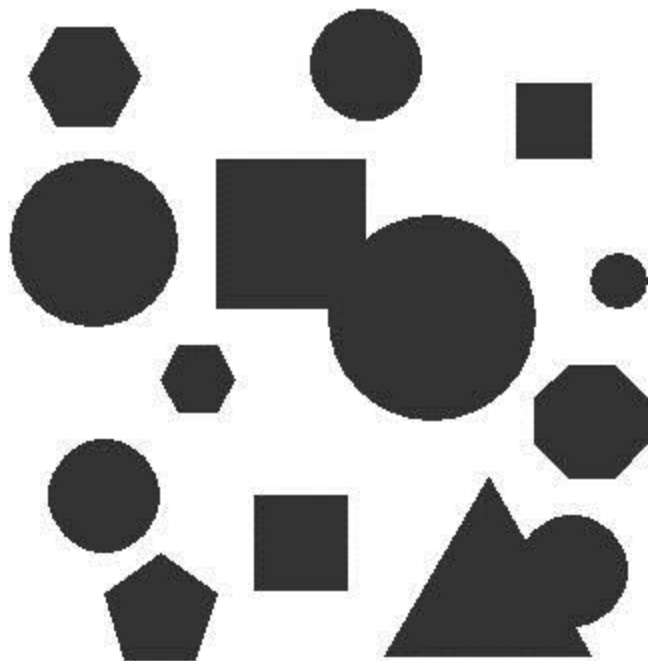
HT: search for regular polygons

Present Searched						
	$3l_3 = 6\sqrt{3}r = 10,39r$ 	$4l_4 = 8r$ 	$5l_5 = 10tg\frac{\pi}{5}r = 7,27r$ 	$6l_6 = 4\sqrt{3}r = 6,93r$ 	$8l_8 = 16tg\frac{\pi}{8}r = 6,63r$ 	$2\pi r = 6,28r$ 
	$3l_4 = 6r$ 	$4l_4 = 8r$ 	$5l_5 = 10tg\frac{\pi}{5}r = 7,27r$ 	$6l_6 = 4\sqrt{3}r = 6,93r$ 	$8l_8 = 16tg\frac{\pi}{8}r = 6,63r$ 	$2\pi r = 6,28r$ 
	$3l_5 = 6tg\frac{\pi}{5}r = 4,35r$ 	$4l_5 = 8tg\frac{\pi}{5}r = 5,81r$ 	$5l_5 = 10tg\frac{\pi}{5}r = 7,27r$ 	$6l_6 = 4\sqrt{3}r = 6,93r$ 	$8l_8 = 16tg\frac{\pi}{8}r = 6,63r$ 	$2\pi r = 6,28r$ 
	$3l_6 = 2\sqrt{3}r = 3,46r$ 	$4l_6 = \frac{8}{\sqrt{3}}r = 4,62r$ 	$5l_6 = \frac{10}{\sqrt{3}}r = 5,78r$ 	$6l_6 = 4\sqrt{3}r = 6,93r$ 	$8l_8 = 16tg\frac{\pi}{8}r = 6,63r$ 	$2\pi r = 6,28r$ 
	$3l_8 = 6tg\frac{\pi}{8}r = 2,48r$ 	$4l_8 = 8tg\frac{\pi}{8}r = 3,34r$ 	$5l_8 = 10tg\frac{\pi}{8}r = 4,14r$ 	$6l_8 = 12tg\frac{\pi}{8}r = 4,97r$ 	$8l_8 = 16tg\frac{\pi}{8}r = 6,63r$ 	$2\pi r = 6,28r$ 
	$3 \times 1 = 3$ 	$4 \times 1 = 4$ 	$5 \times 1 = 5$ 	$6 \times 1 = 6$ 	$8 \times 1 = 8$ 	$2\pi r = 6,28r$ 

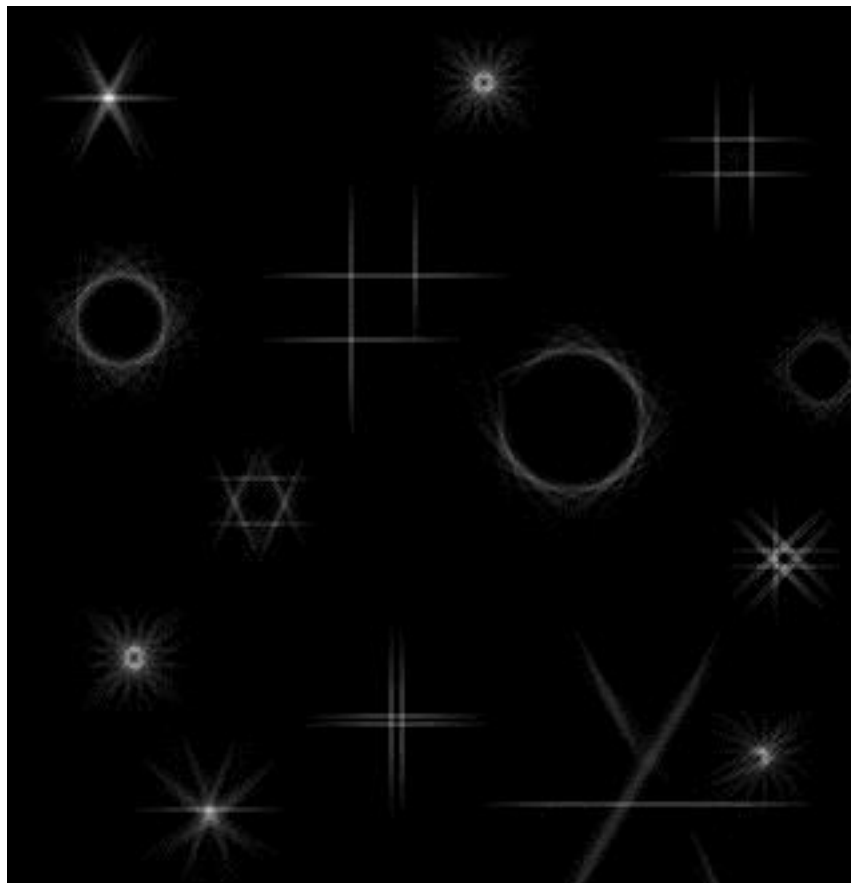
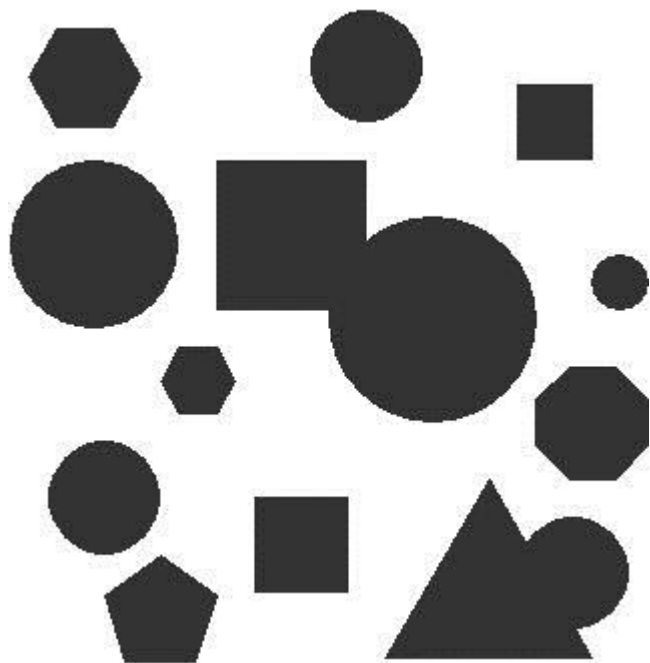
Example: looking for a circle



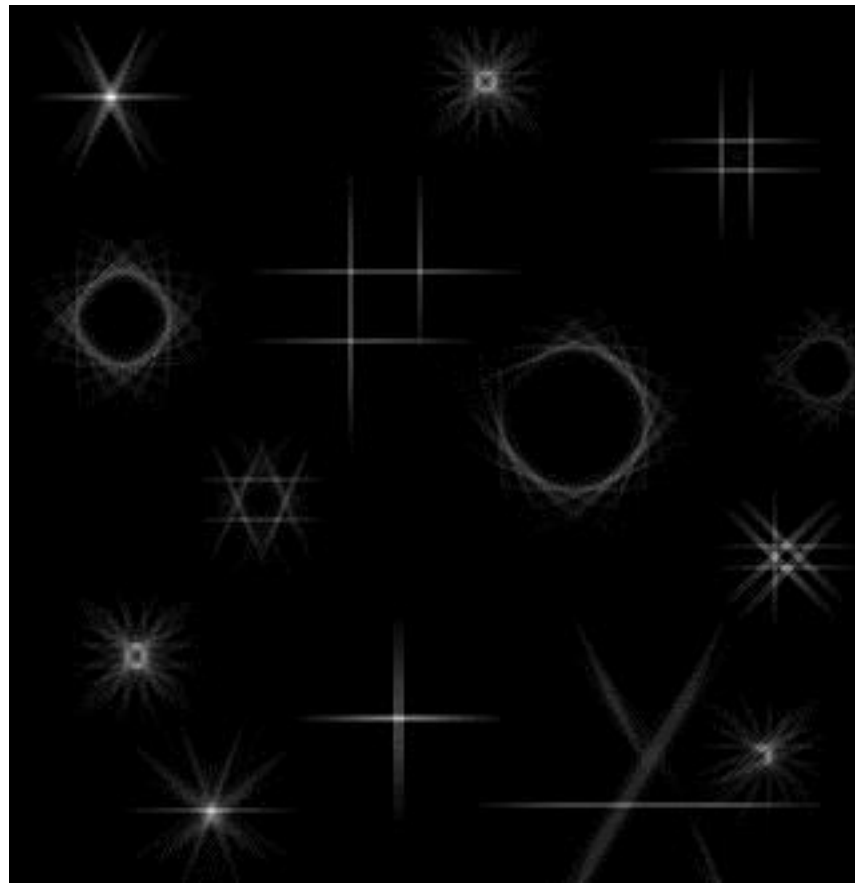
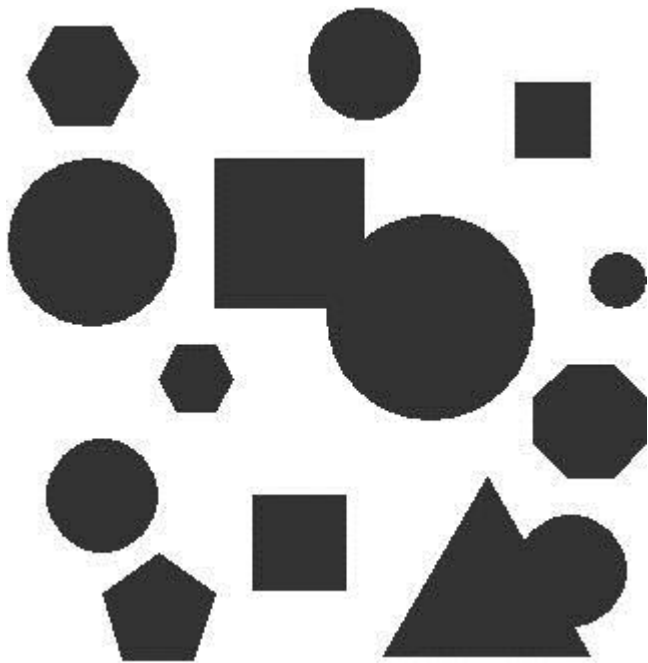
Example: looking for a octagon



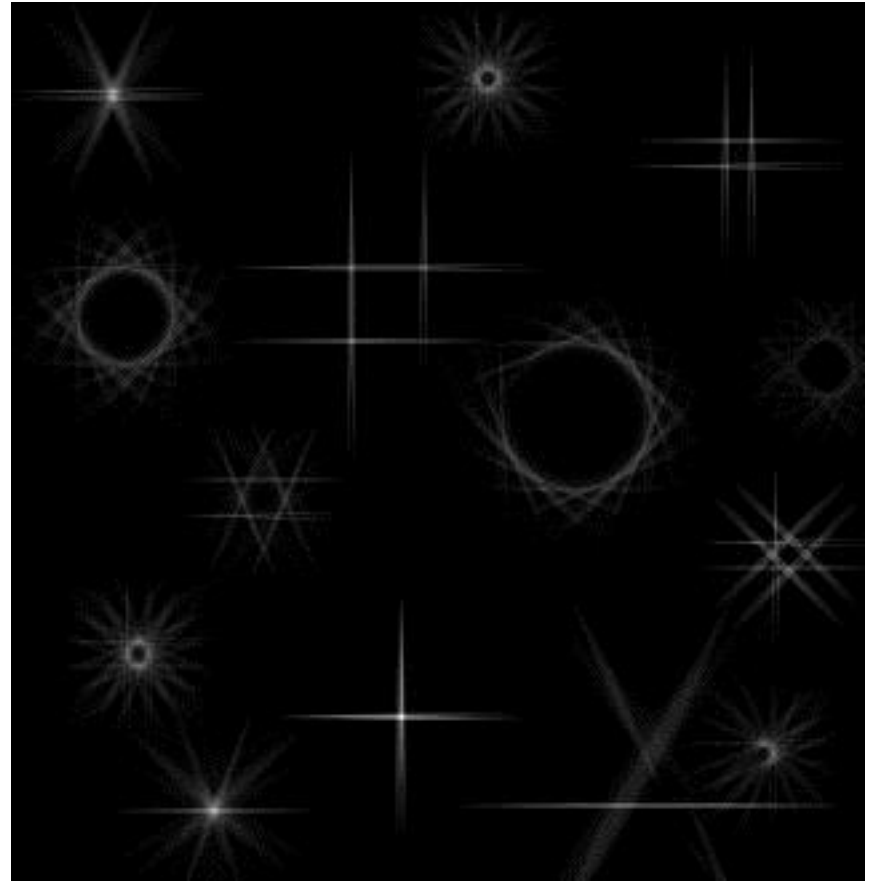
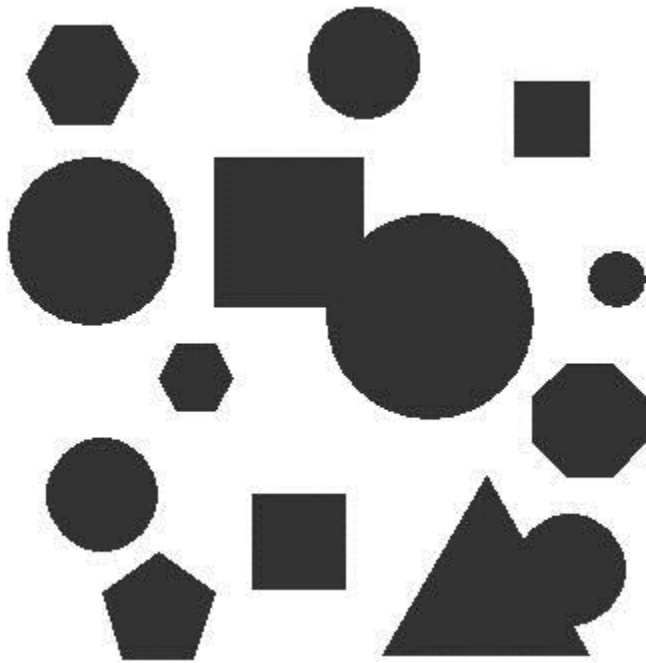
Example: looking for a hexagon



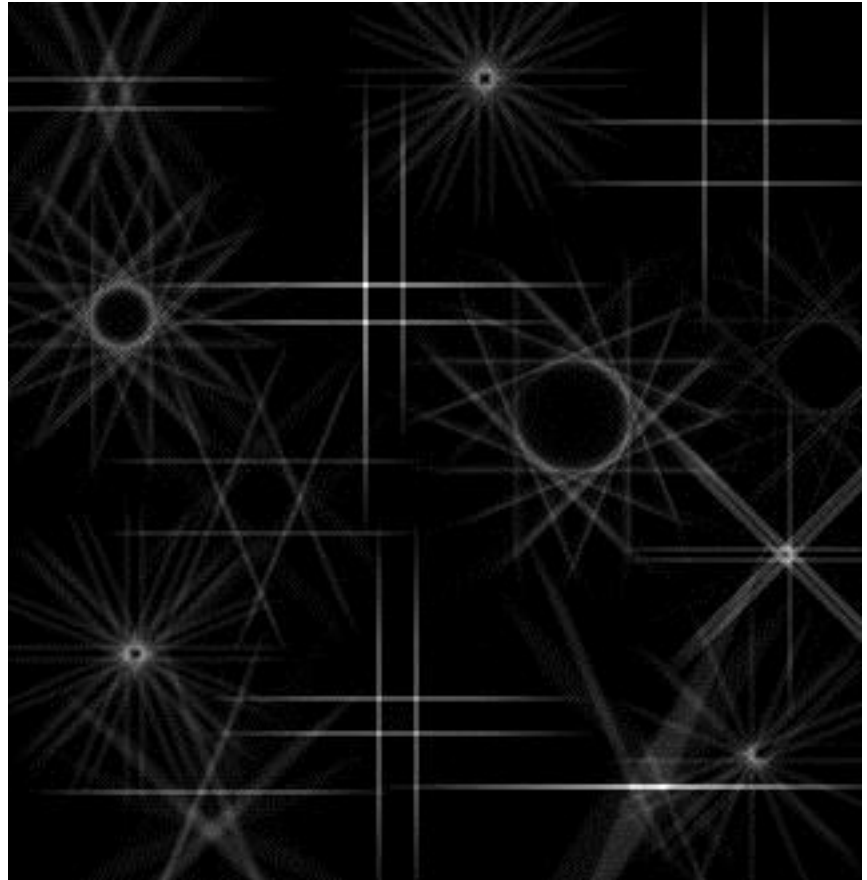
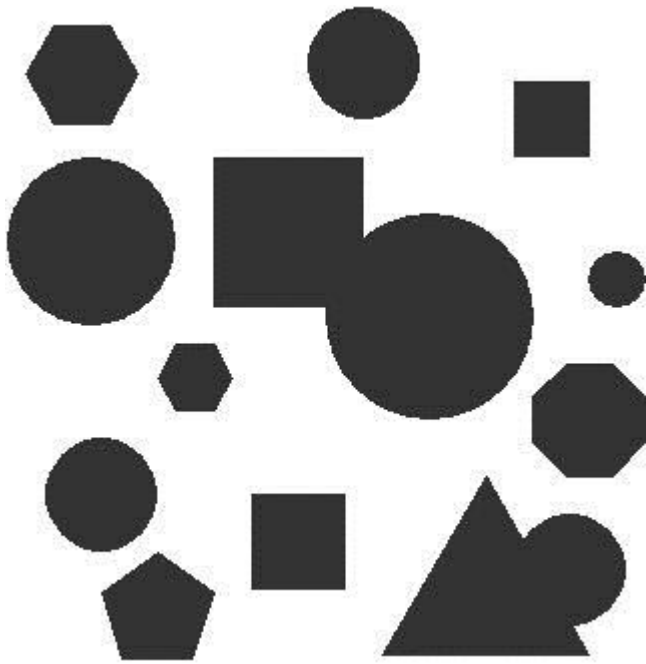
Example: looking for a pentagon



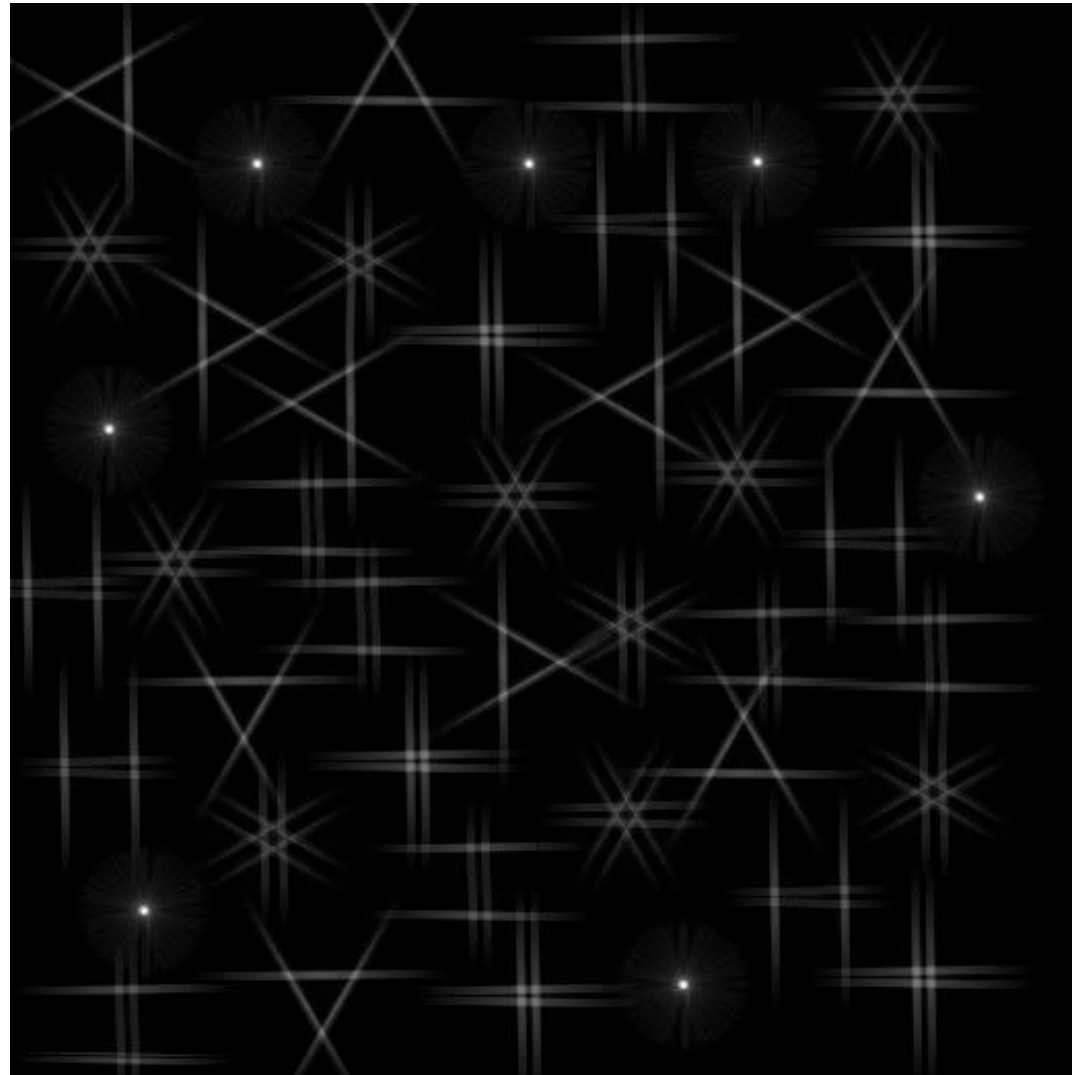
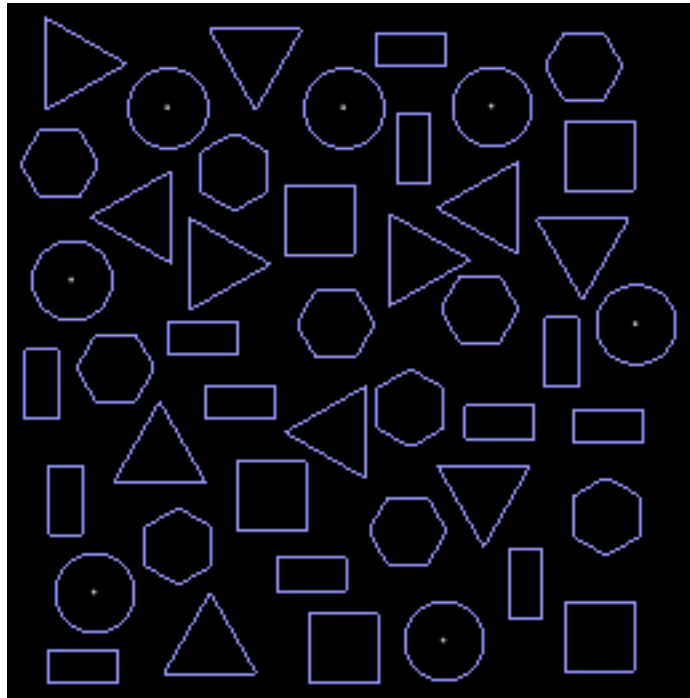
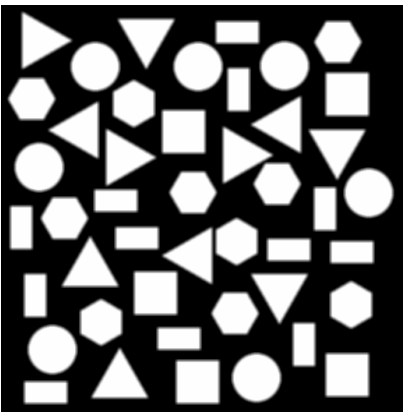
Example: looking for a square



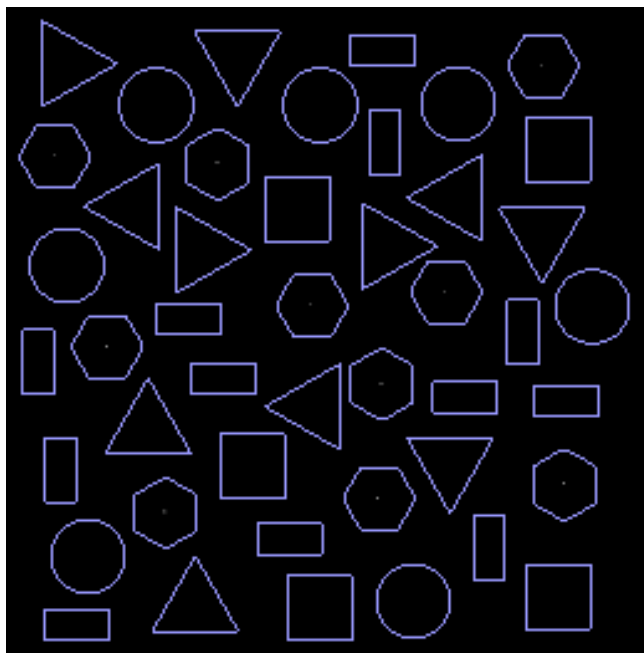
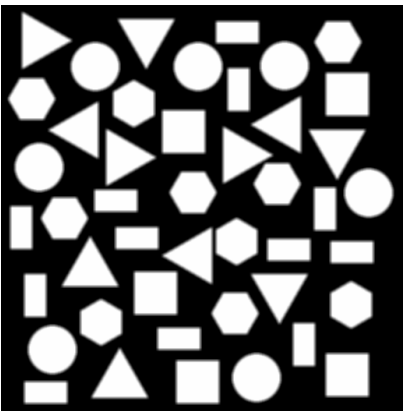
Example: looking for a triangle



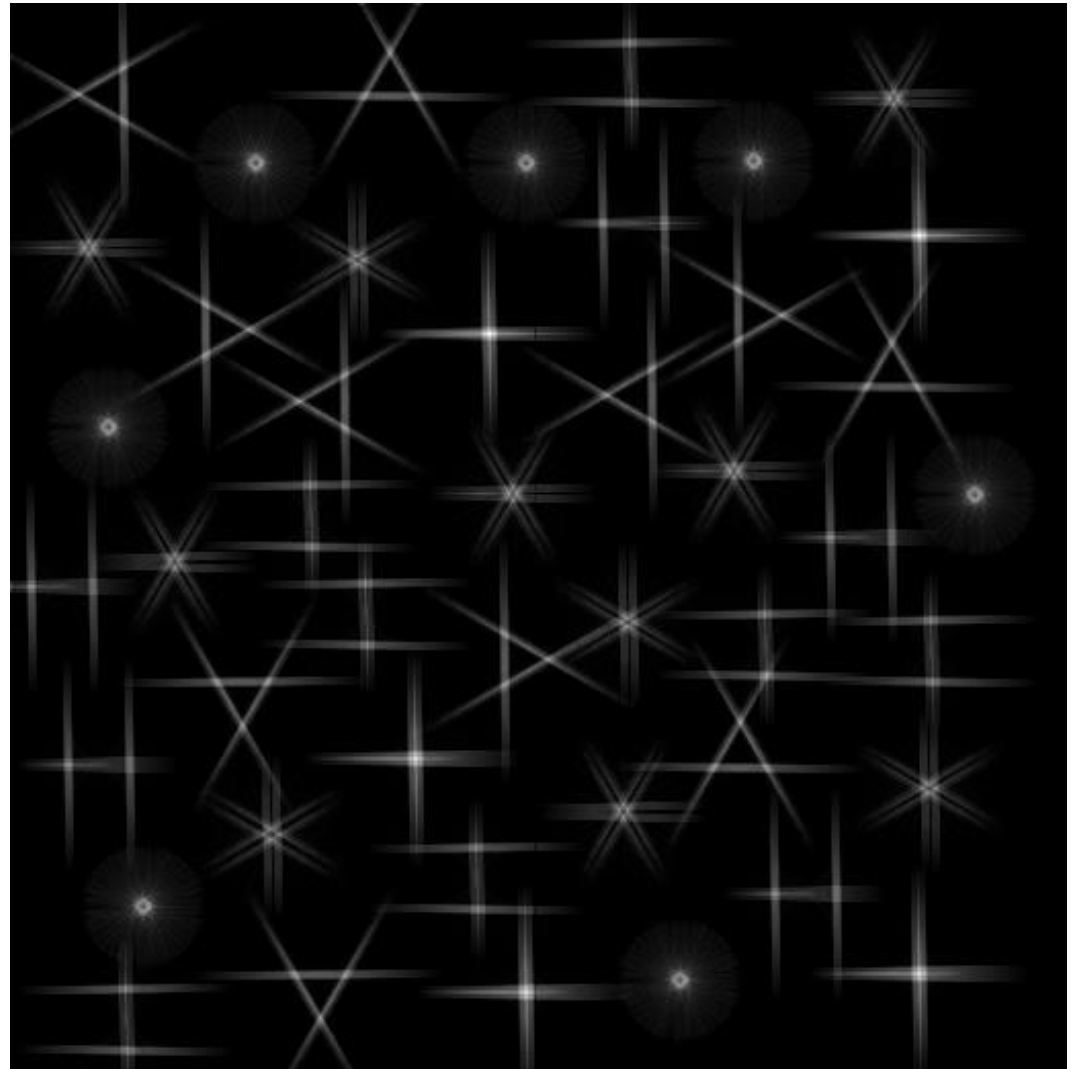
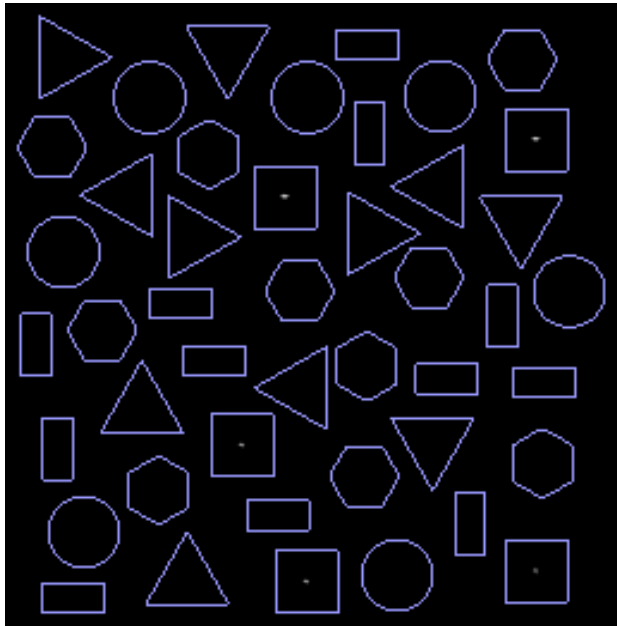
looking for a circle



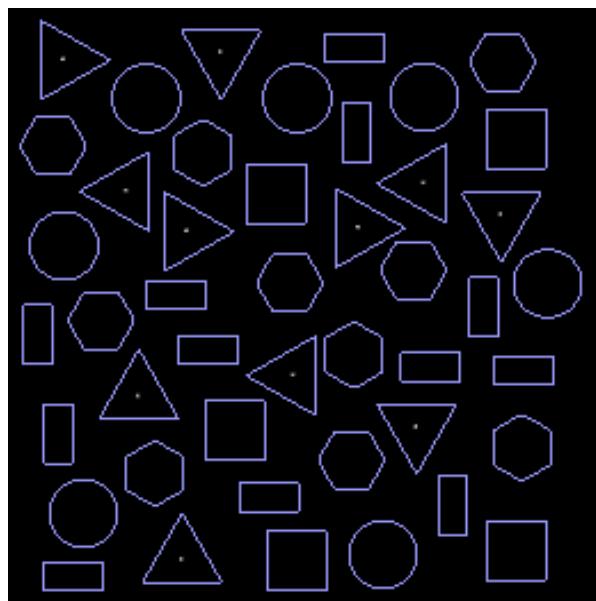
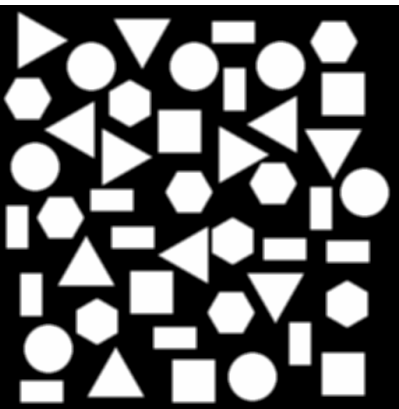
looking for a hexagon

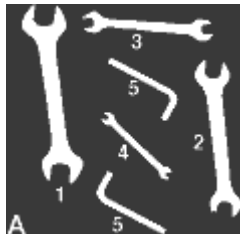


looking for a square

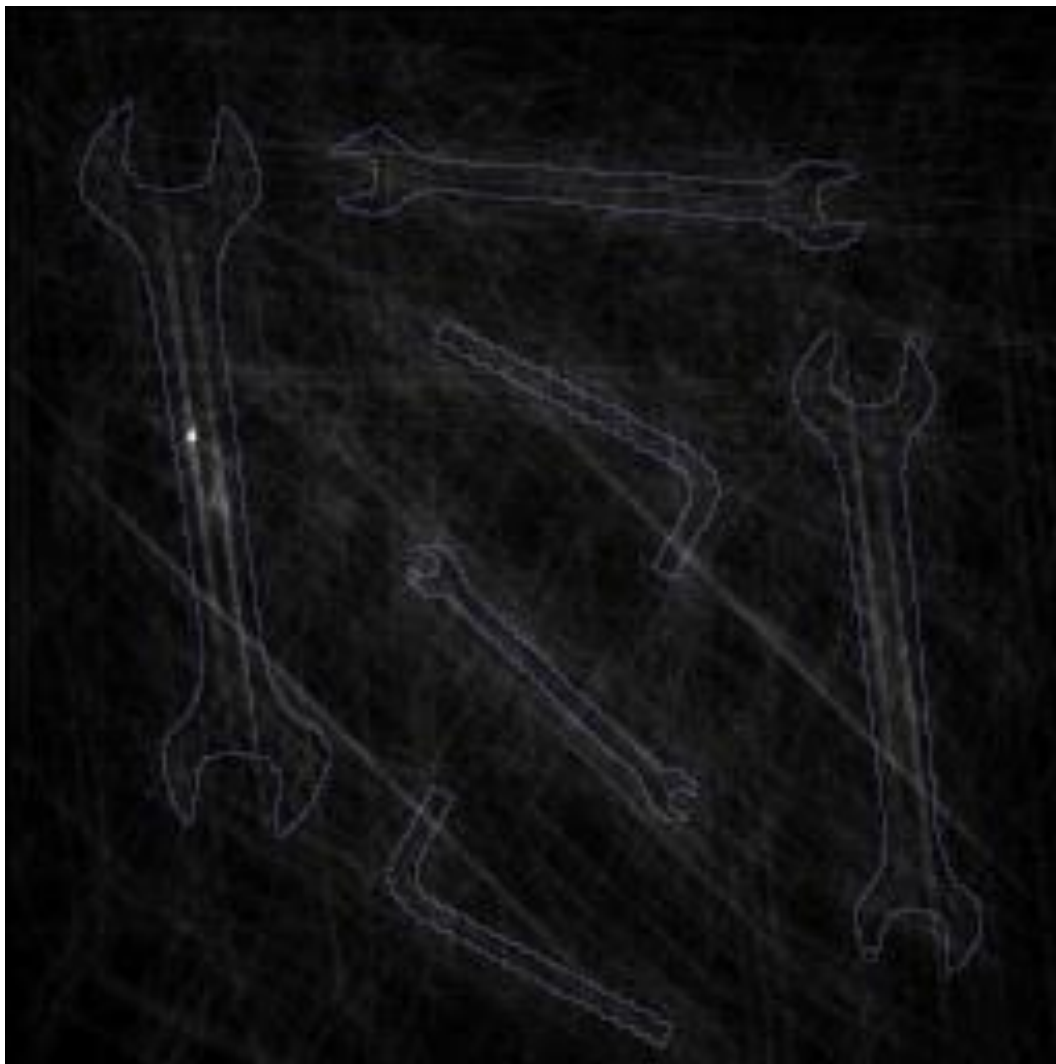
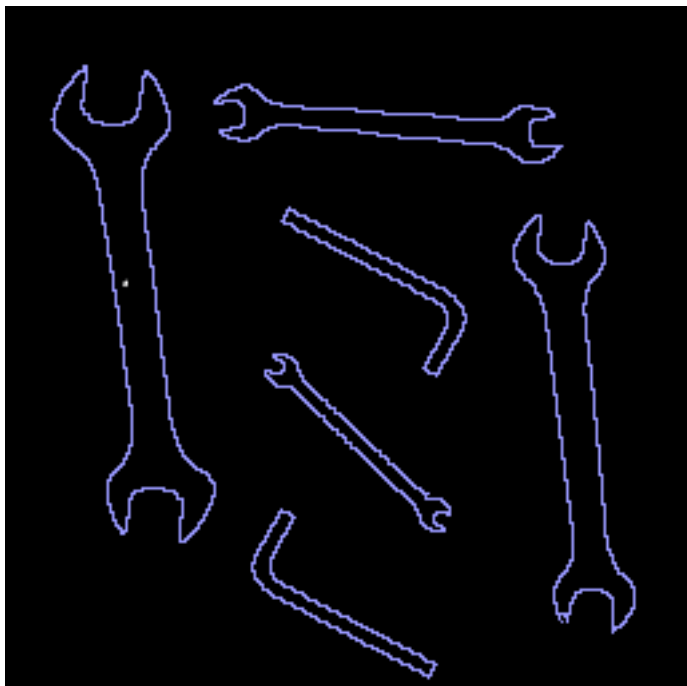


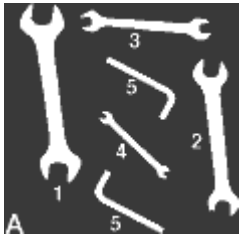
looking for a triangle



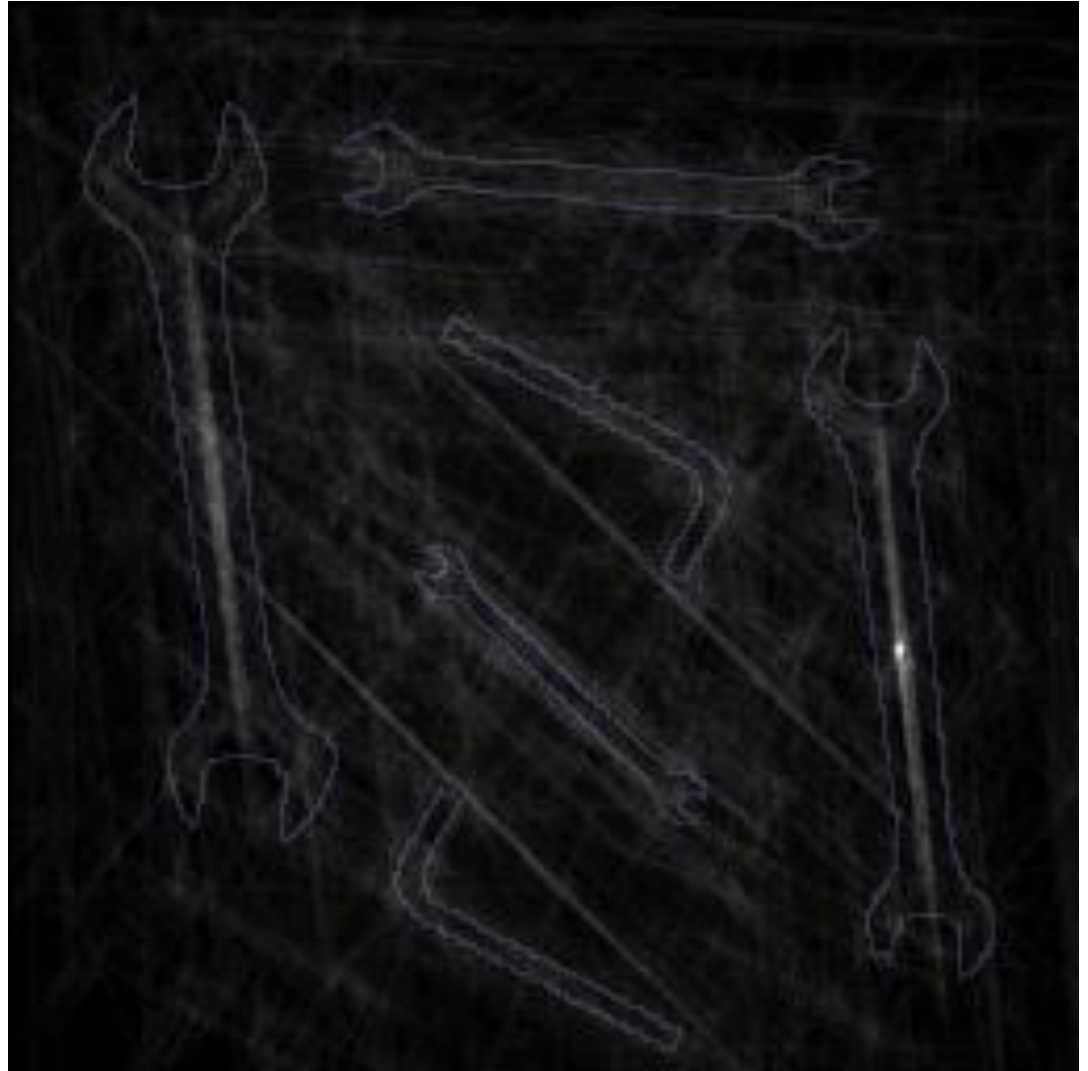
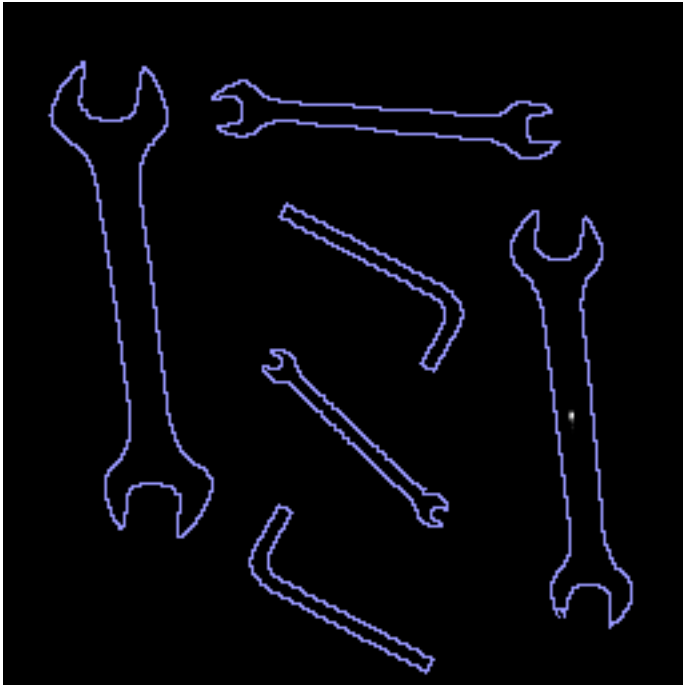


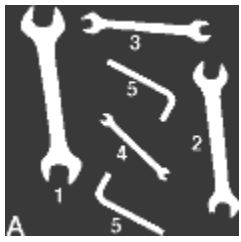
Example: wrench 1



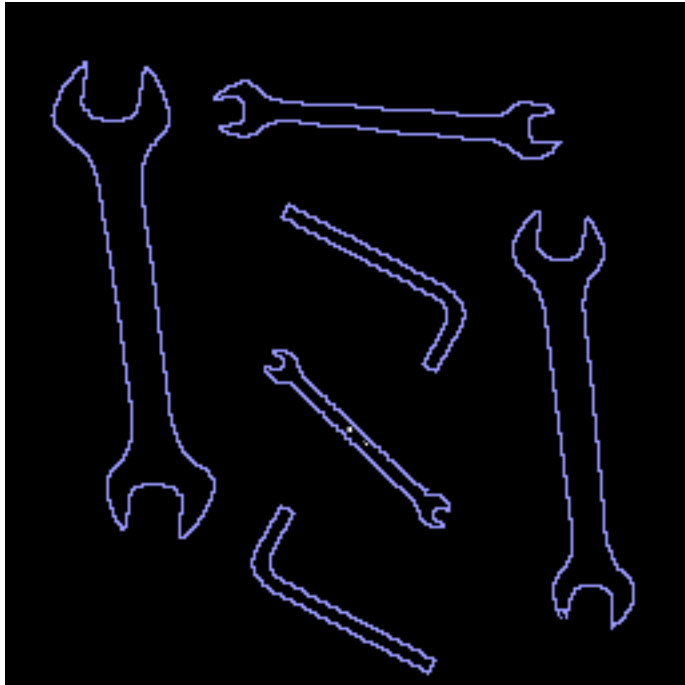


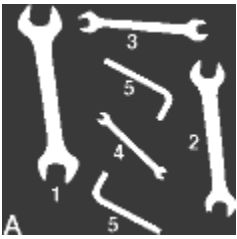
Example: wrench 2



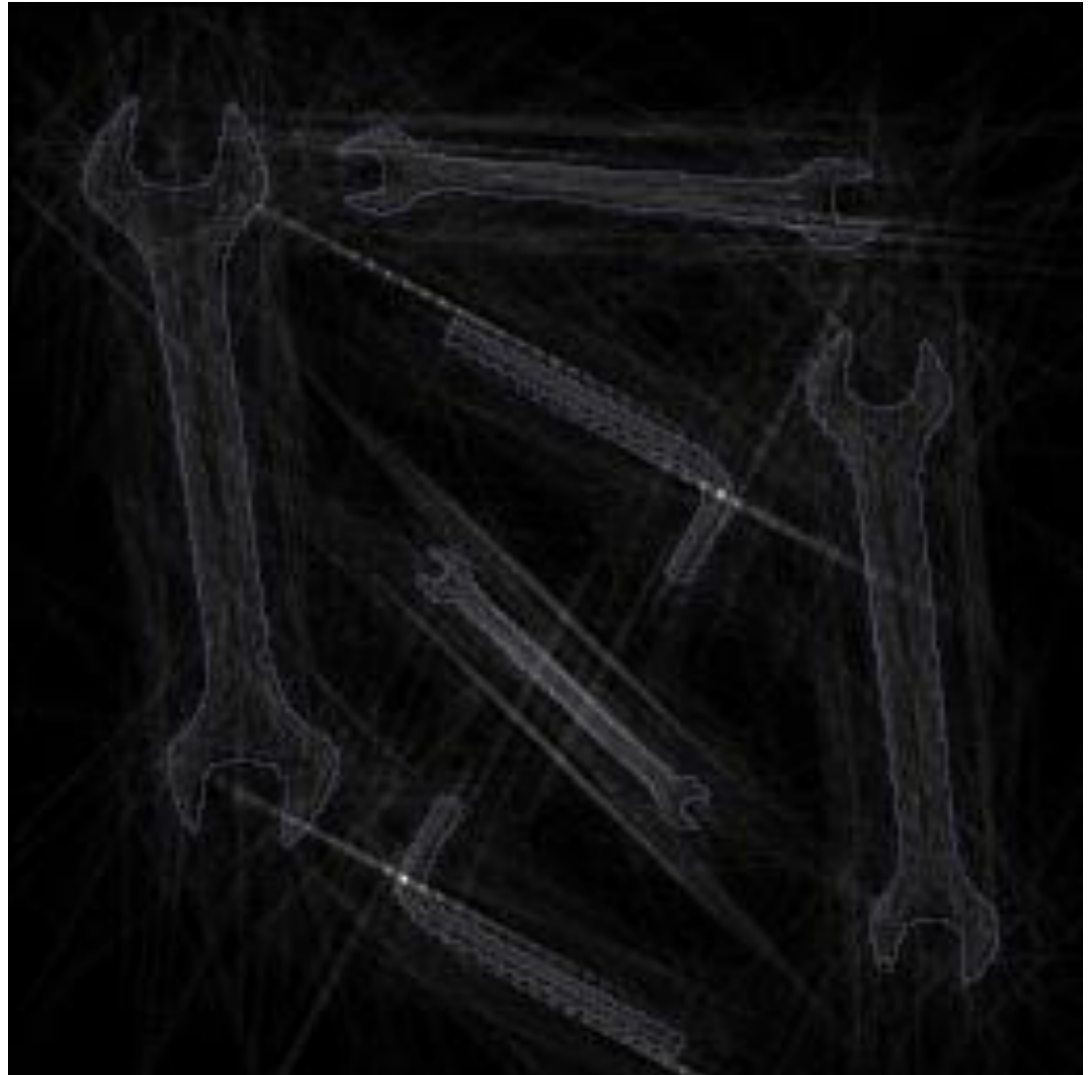
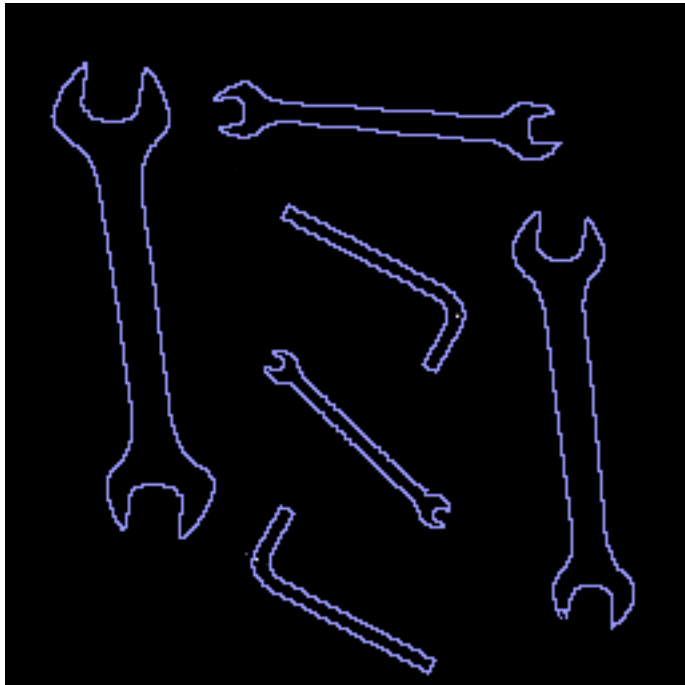


Example: wrench 4

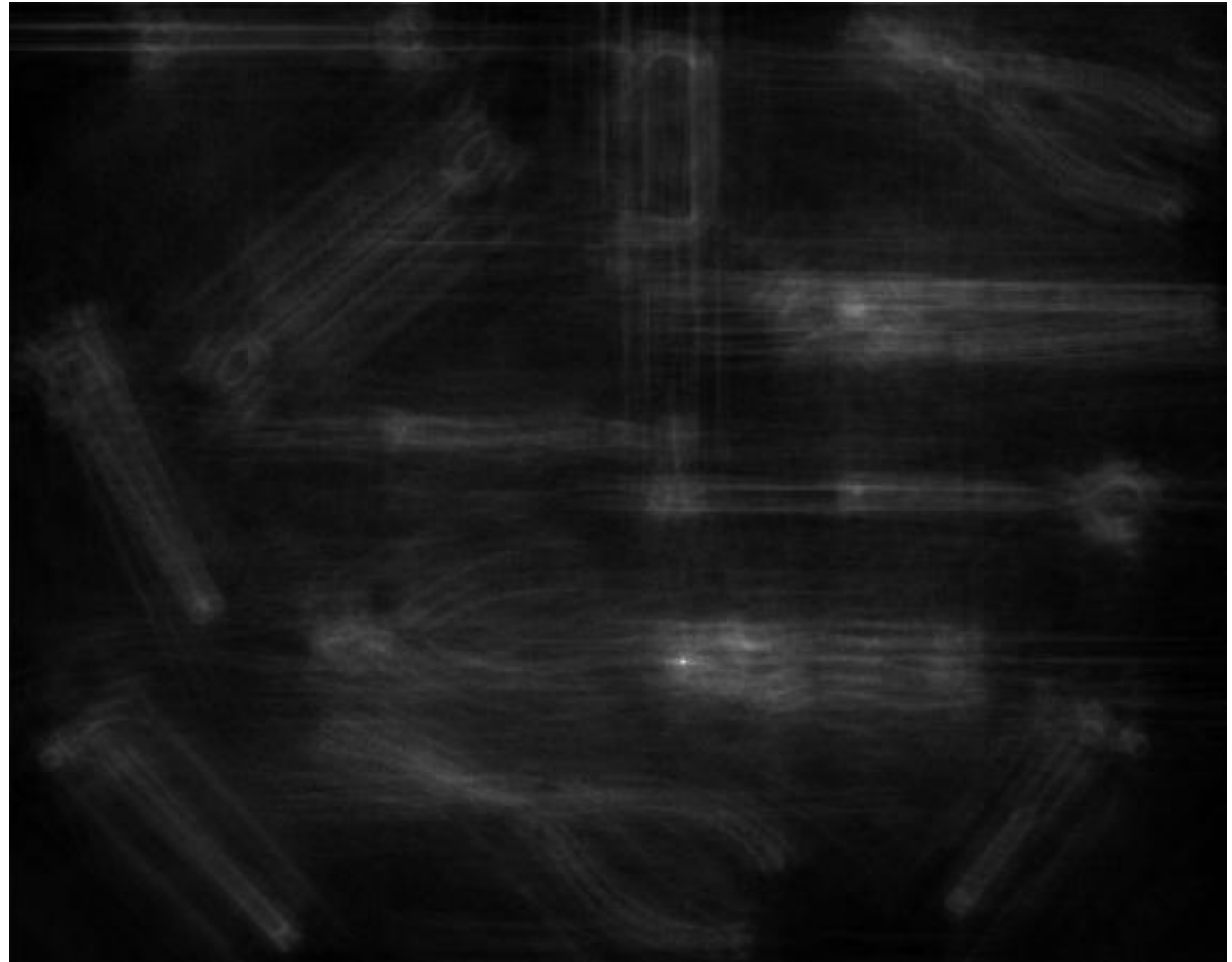
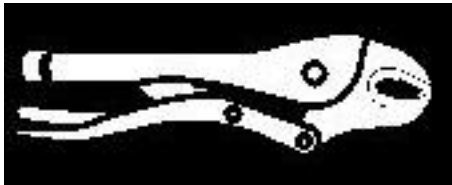




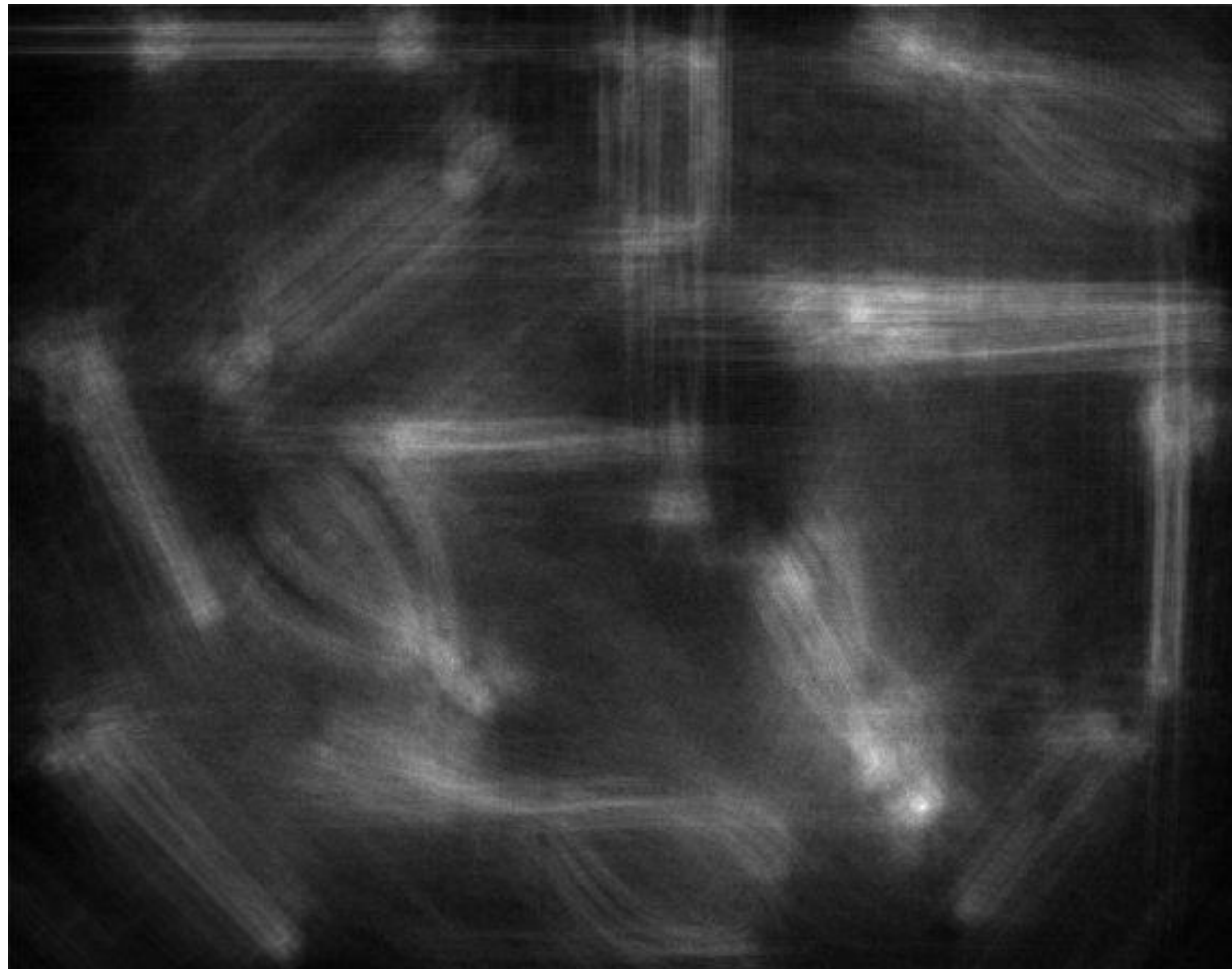
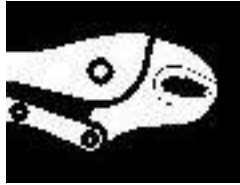
Example: hex key 5



HT: arbitrary pattern



HT: segmented arbitrary pattern



Implementation aspects

- The RT can be decomposed in many subtable (possibly overlapped) on the bases of a label encoding some peculiarities (e.g. a taxonomy of concavities and convexities)
- In the image plane, for each evidence, a subtable is selected and only this subtable is involved in the voting process
- The peak intensity remains the same, but it is reduced the number of scattered contributions: increases the signal to noise ratio of the PR

Computation performances

- The computation time is linear with the product of the number of edge points in the image N_E with N_{RF} , the cardinality of the RF
- In the case of labeled RT the computation time is given by the weighted sum the subtable cardinality by the number of occurrences of the correspondent labels
- The algorithm is completely parallelizable both over the image (PEs taking care of different image blocks) and over the RT (PEs taking care of different object segment)

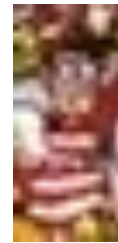
Perspective effects



Where's Waldo?



Scene



Template

Where's Waldo?



Scene

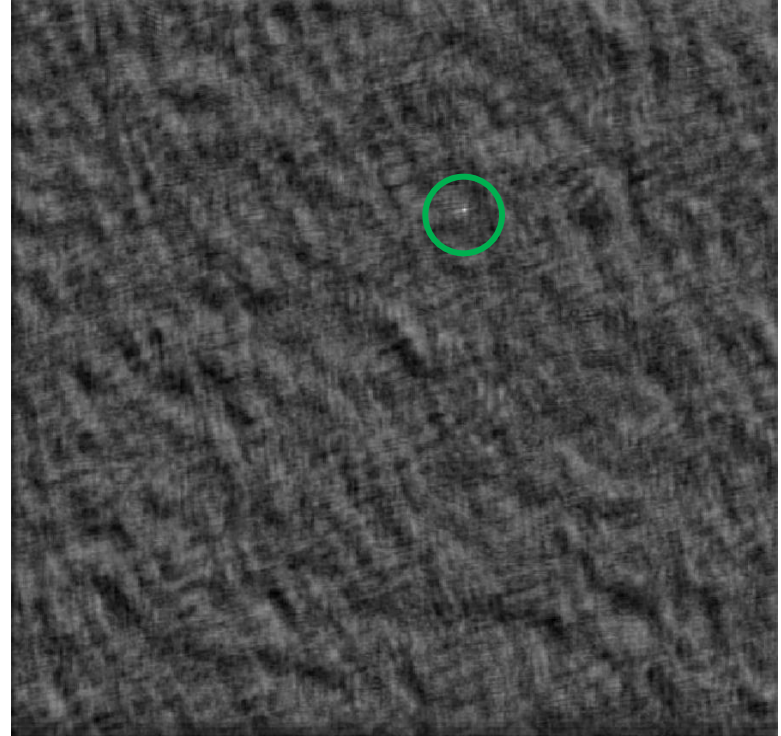


Template

Where's Waldo?



Detected template



Correlation map