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The Algorithms of Adjustment of Reflection Symmetry Axis Found by the Skeleton Primitive Sub-chains Comparison Method

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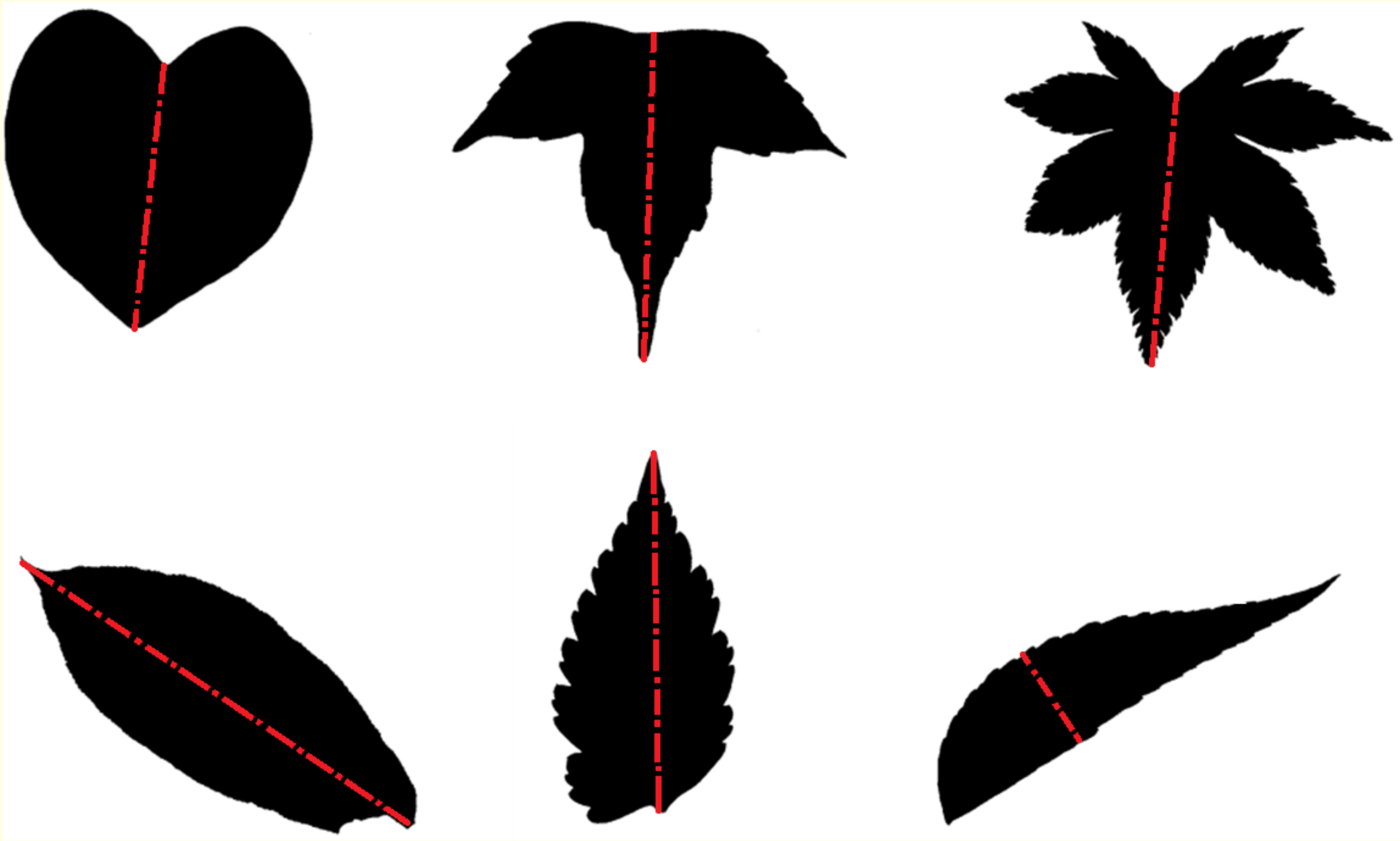
Reflection Symmetry



Analysing binary images it is easy to notice that many objects, both artificial and natural, have intrinsic reflection symmetry property. It is obvious that real-world images could rarely be absolute reflection symmetric. So, it is valuable to detect approximate reflection symmetry and evaluate the measure of approximate reflection symmetry of shape.

Methods for Solving Approximate Symmetry Detection Problem

Approximate symmetry detection problem applying to binary images is well known but there are not so many effective methods for solving it. The main ones are based on:

1) Fourier series expansion of parametric contour representation,
2) contour representation by turning function,
3) contour representation by critical points and computation of similarity measure for two sub-contours via vectors of geodesic distances,
4) skeleton primitive sub-chains comparison.

All mentioned methods exploit known algorithms of shapes dissimilarity (or similarity) evaluation.

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1. **van Otterloo P. J.** A Contour-Oriented Approach to Digital Shape Analysis. PhD thesis, Delft University of Technology, Delft, The Netherlands (1988).

2. **Sheynin S., Tuzikov A., Volgin D.** Computation of Symmetry Measures for Polygonal Shapes. Computer Analysis of Images and Patterns. Springer Berlin Heidelberg. P. 183-190 (1999).

3. **Yang, X., Adluru, N., Latecki, L. J., Bai, X., Pizlo, Z.** Symmetry of shapes via selfsimilarity. Advances in Visual Computing. Springer Berlin Heidelberg. P. 561-570 (2008).

4. **Kushnir O., Fedotova S., Seredin O., Karkishchenko A.** Reflection Symmetry of Shapes Based on Skeleton Primitive Chains // Fifth International Conference, AIST 2016, Yekaterinburg, Russia, April 7-9, 2016, Revised Selected Papers, CCIS, Springer International Publishing Switzerland (2016)

Evaluation of Approximate Reflection Symmetry Detection

Jaccard (Tanimoto) similarity as symmetry measure

$$\mu_T(B) = \frac{|S(B) \cap S(B_r)|}{|S(B) \cup S(B_r)|} \qquad 0 \le \mu_T(B) \le 1$$

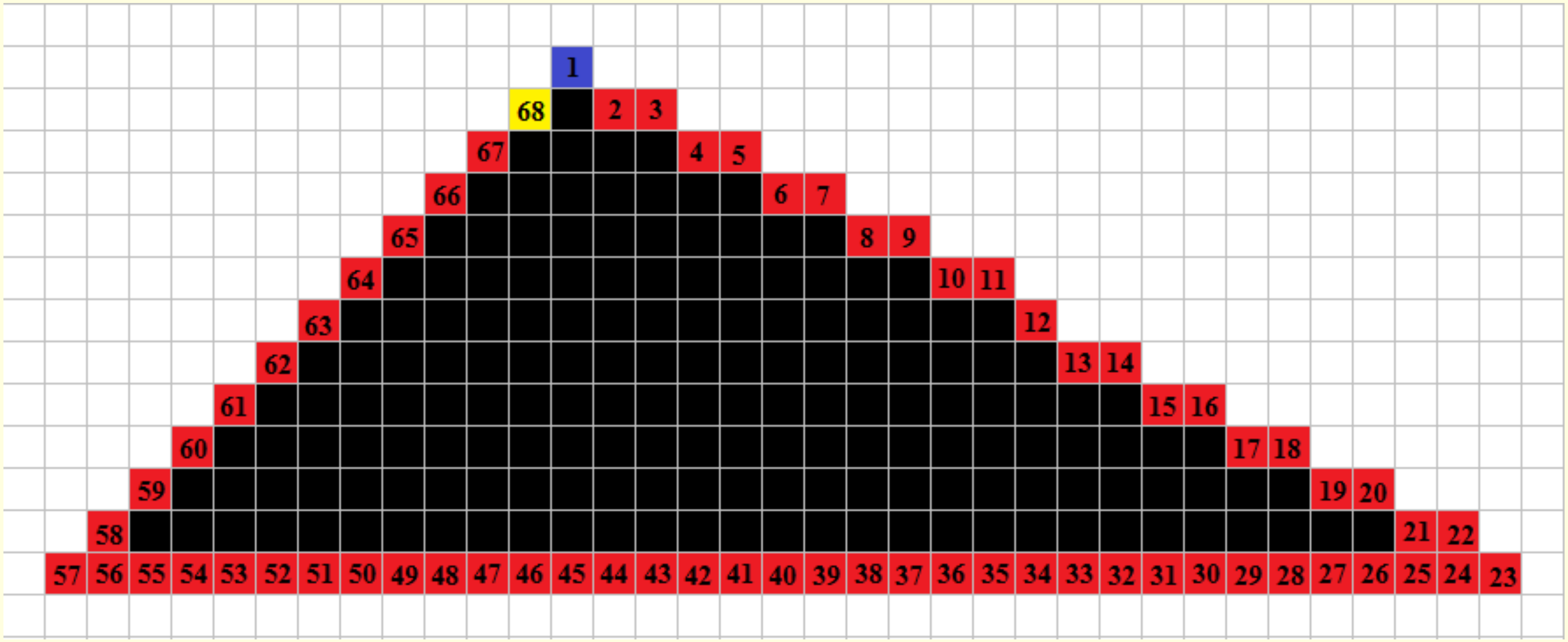
B - the binary image,

B_r - image obtained by refection of binary image B relative to straight line

$S(B)$ - set of pixels of image B, the brightness of which is equal to 1

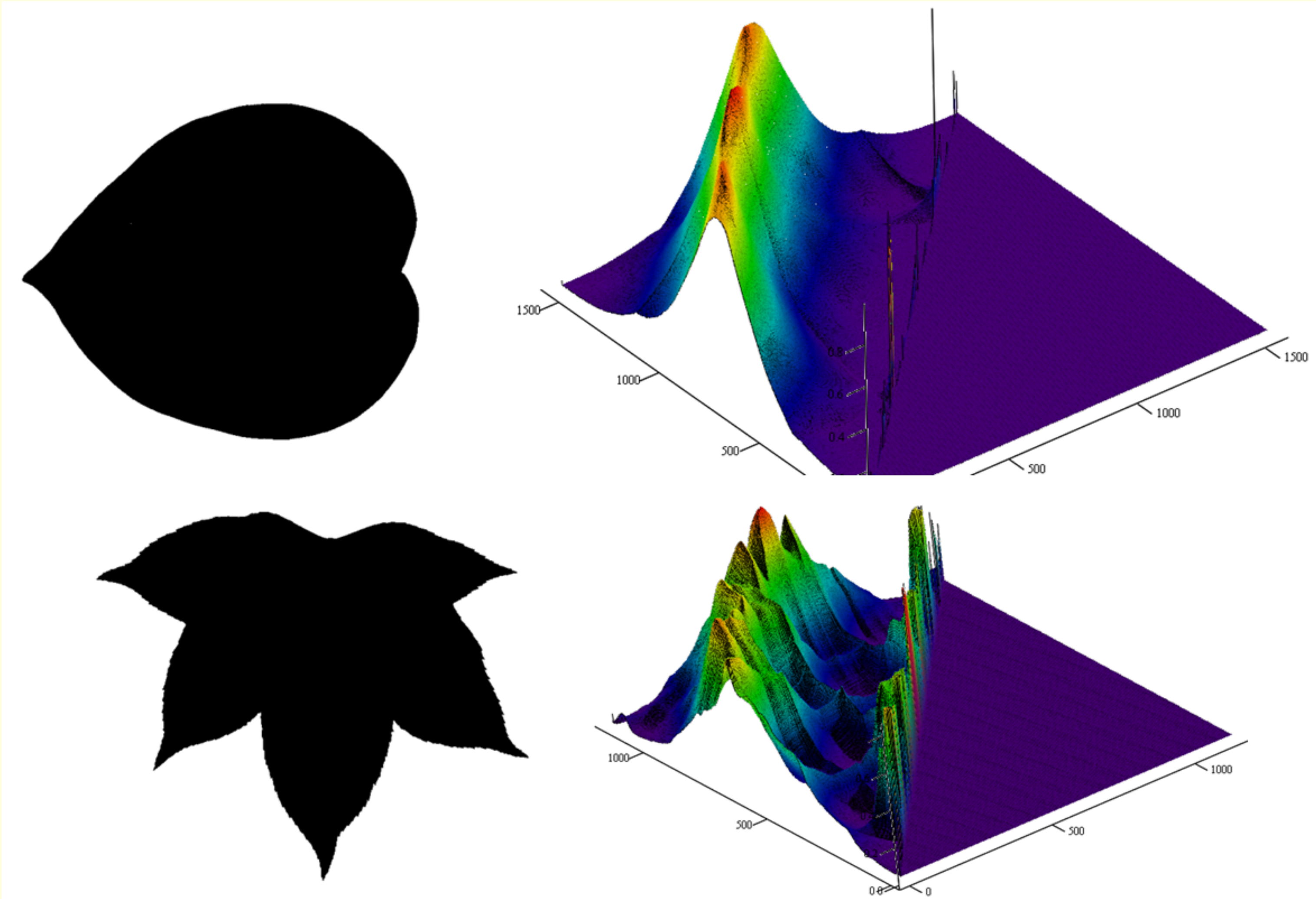
i.e. $S(B) = \{(i,j) \mid B(i,j) = 1\}$

The Exact Algorithm Based on Brute-Force Search



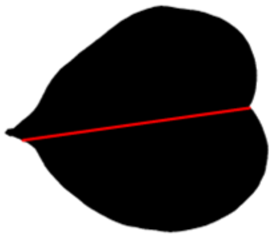
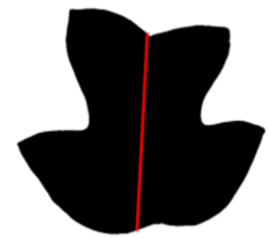
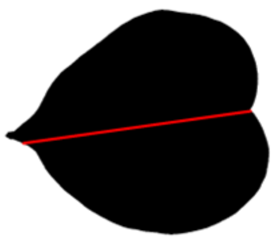
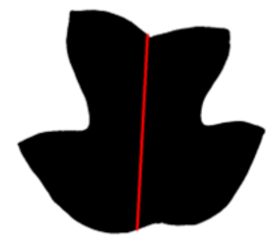
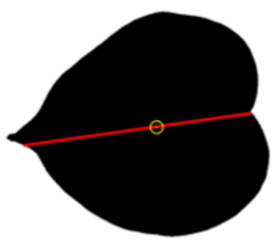
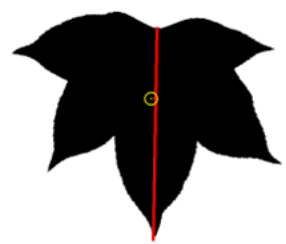
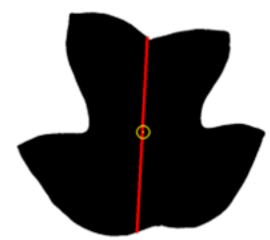
Kushnir O., Fedotova S., Seredin O., Karkishchenko A. Reflection Symmetry of Shapes Based on Skeleton Primitive Chains // Fifth International Conference, AIST 2016, Yekaterinburg, Russia, April 7-9, 2016, Revised Selected Papers, CCIS, Springer International Publishing Switzerland (2016)

Analysis of the Symmetry Function



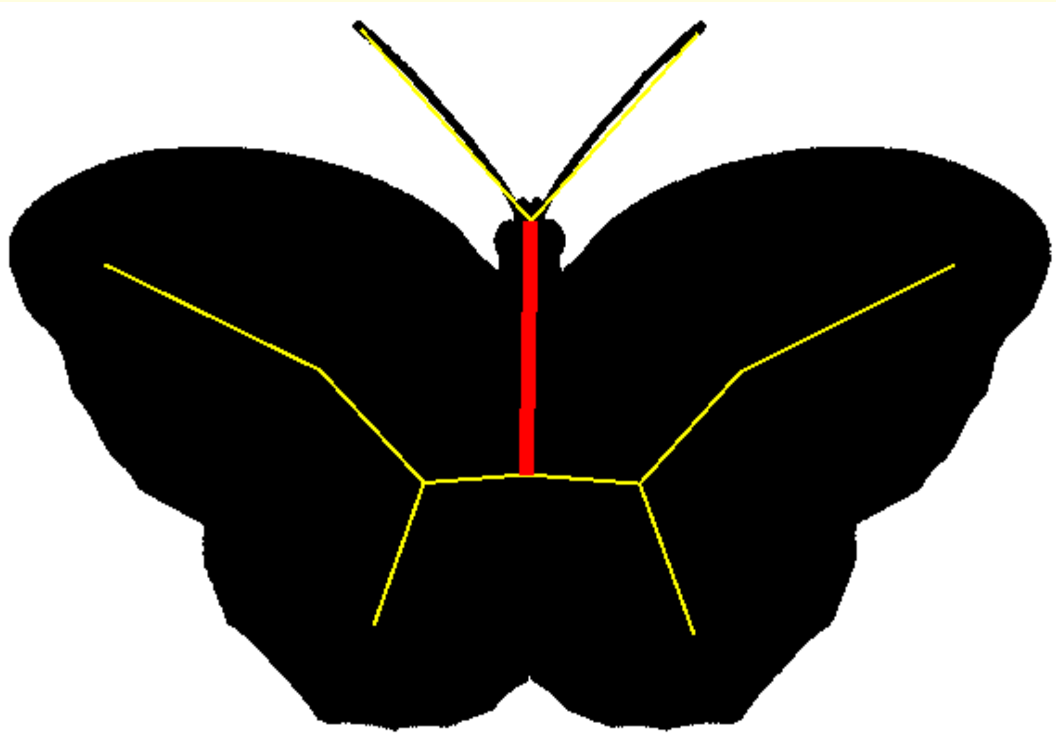
Examples of images and the corresponding values of symmetry functions for all pairs of contour points.

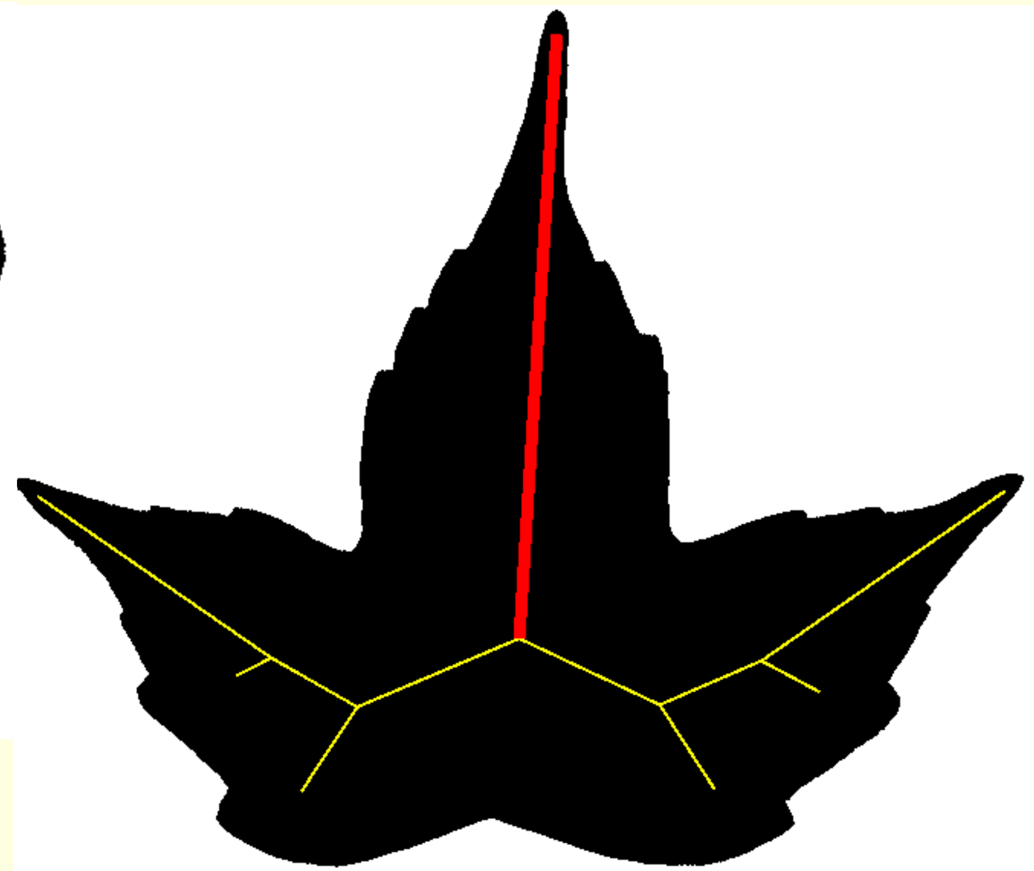
The Ground-Truth Found by Brute-Force Algorithm, Semi-Perimeter Algorithm and Algorithm with Center of Mass

	Image 1	Image 2	Image 3
Base algorithm (brute force), time in hours	 0.950 2.66 h	 0.837 5.25 h	 0.844 3.33 h
Algorithm semi perimeter (ε = 25)	 0.950 386.86	 0.837 451.94	 0.844 371.19
Algorithm center of mass (ε = 15)	 0.950 395.34	 0.837 651.98	 0.844 622.47

Reflection Symmetry Detection Based on a Skeleton of a Shape

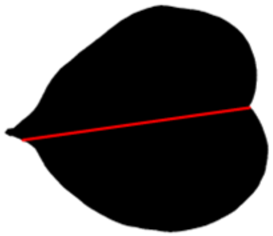
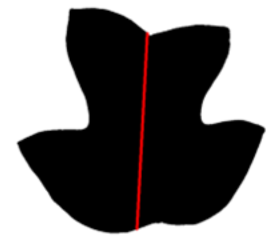
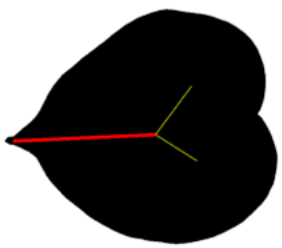
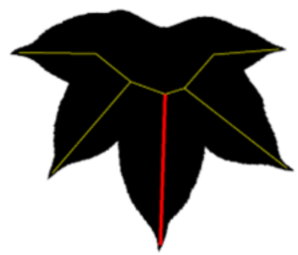
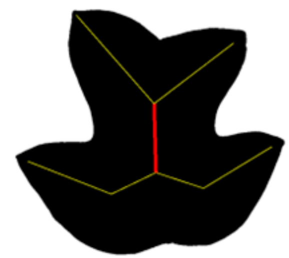
Symmetry axis of the shape (and its skeleton):



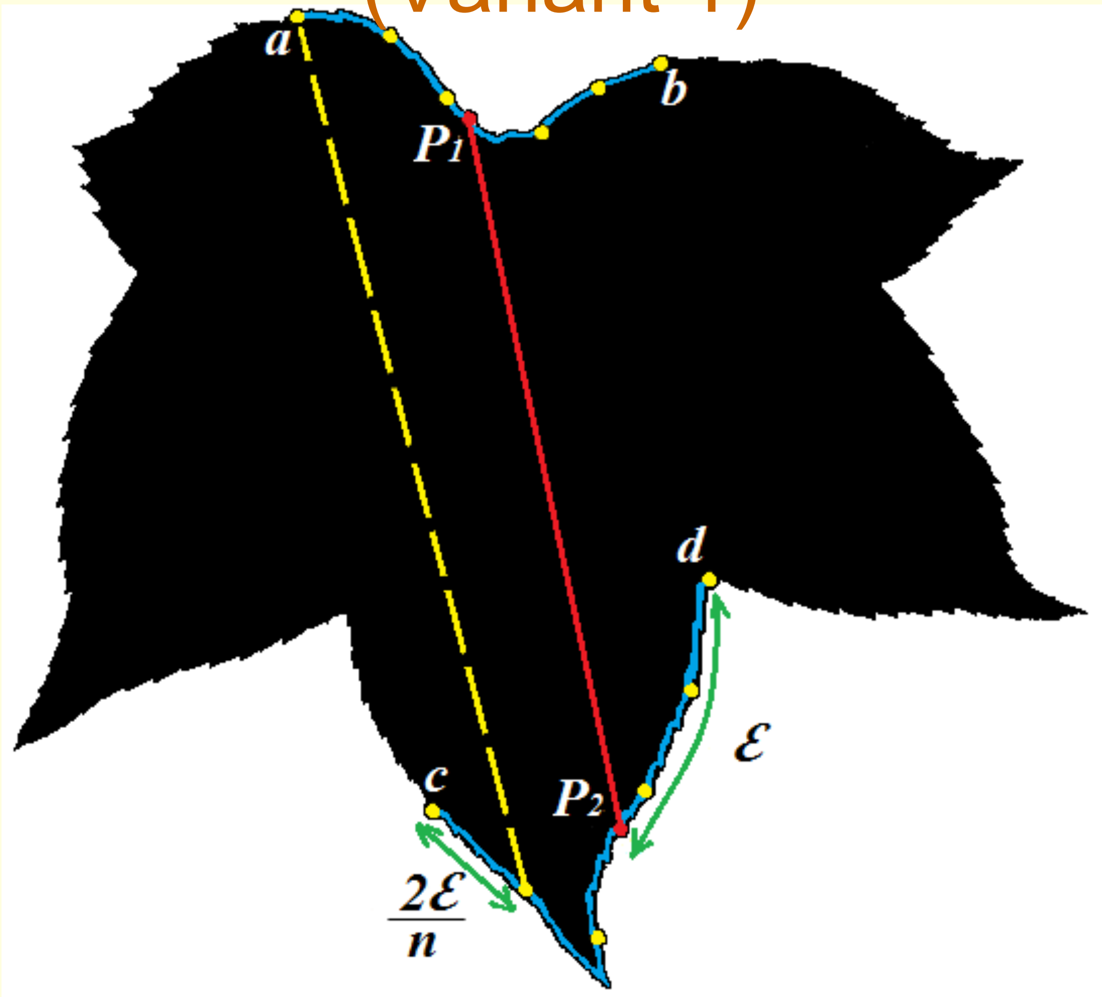


How to find the symmetry axis:
it needs to find maximum of similarity between two sub-skeletons

Comparison of Experimental Results Achieved by the Skeleton Algorithm with the Ground-Truth

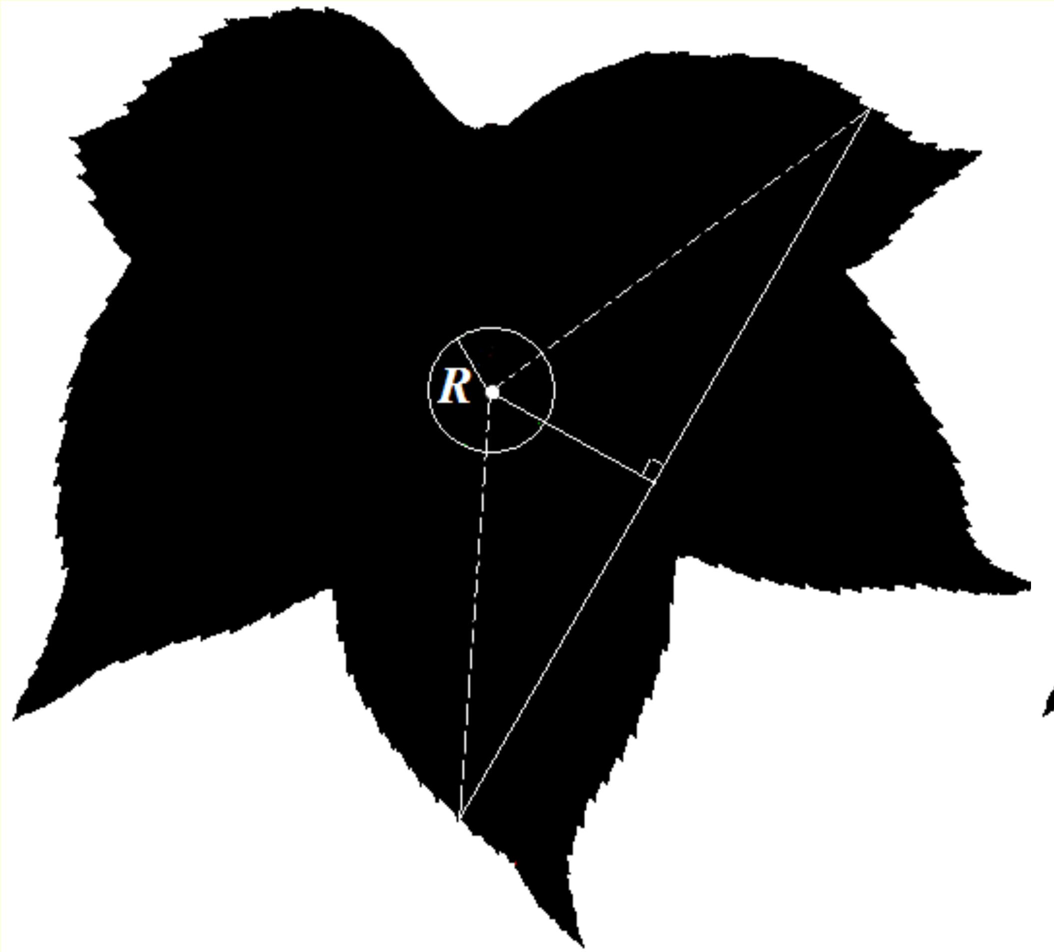
	Image 1	Image 2	Image 3
Base algorithm (brute force), time in hours	 **0.950** **2.66 h**	 **0.837** **5.25 h**	 **0.844** **3.33 h**
Algorithm based on **sub-skeletons**	 **0.859** **0.2**	 **0.784** **1.49**	 **0.834** **0.84**

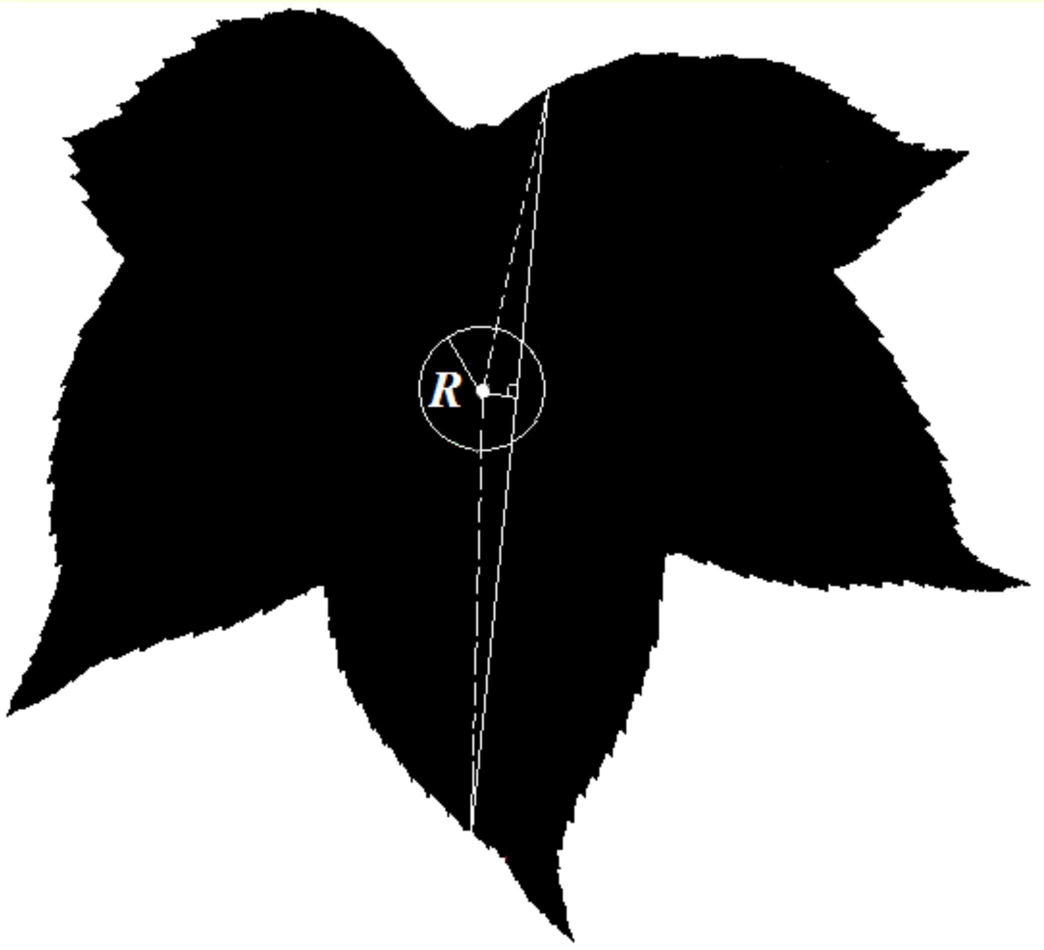
Adjustment Algorithm of Reflection Symmetry Axis (Variant 1)



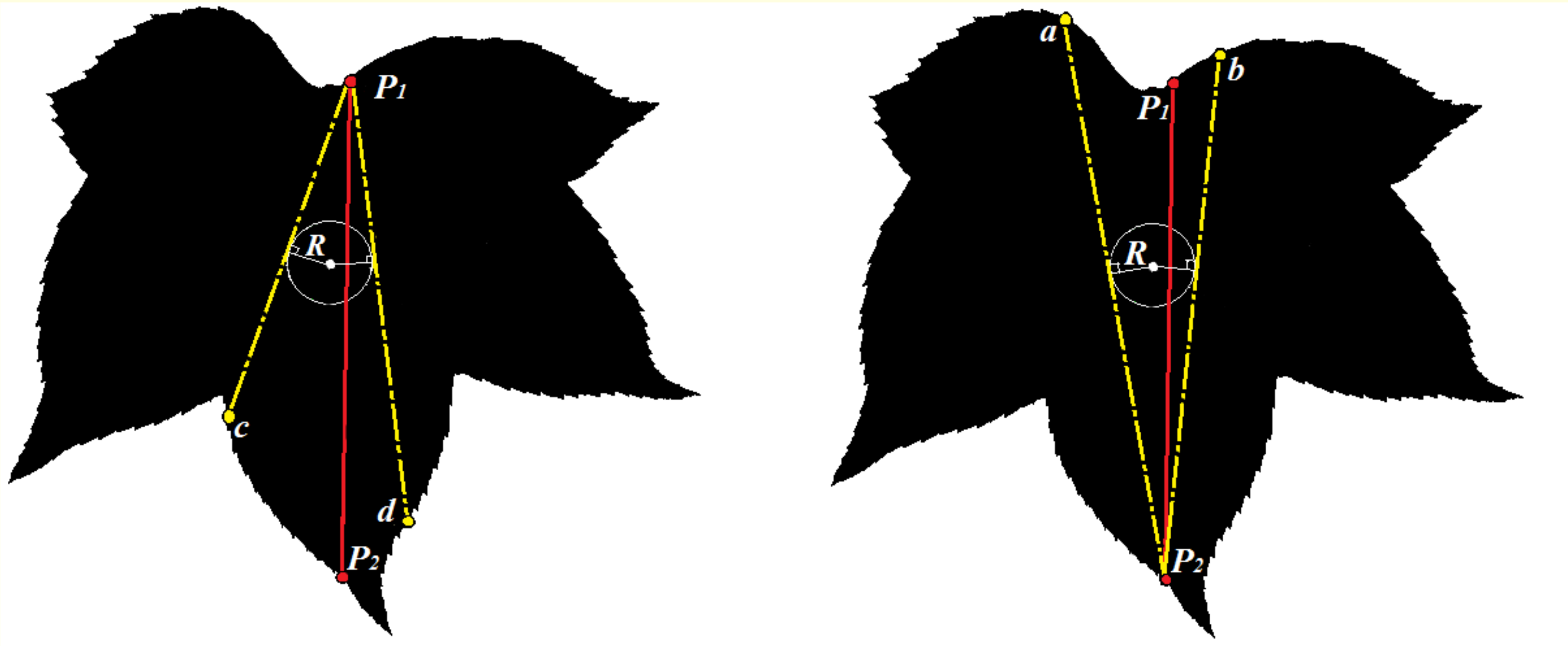
The red axis was obtained by skeleton method. Yellow points - two sets of equidistant points chosen according to *p1* and *p2* which belong to the skeleton axis and contour of the image. Yellow dashed - one of the test axes.

Adjustment Algorithm Considering the Center of Mass of a Figure (Variant 2)



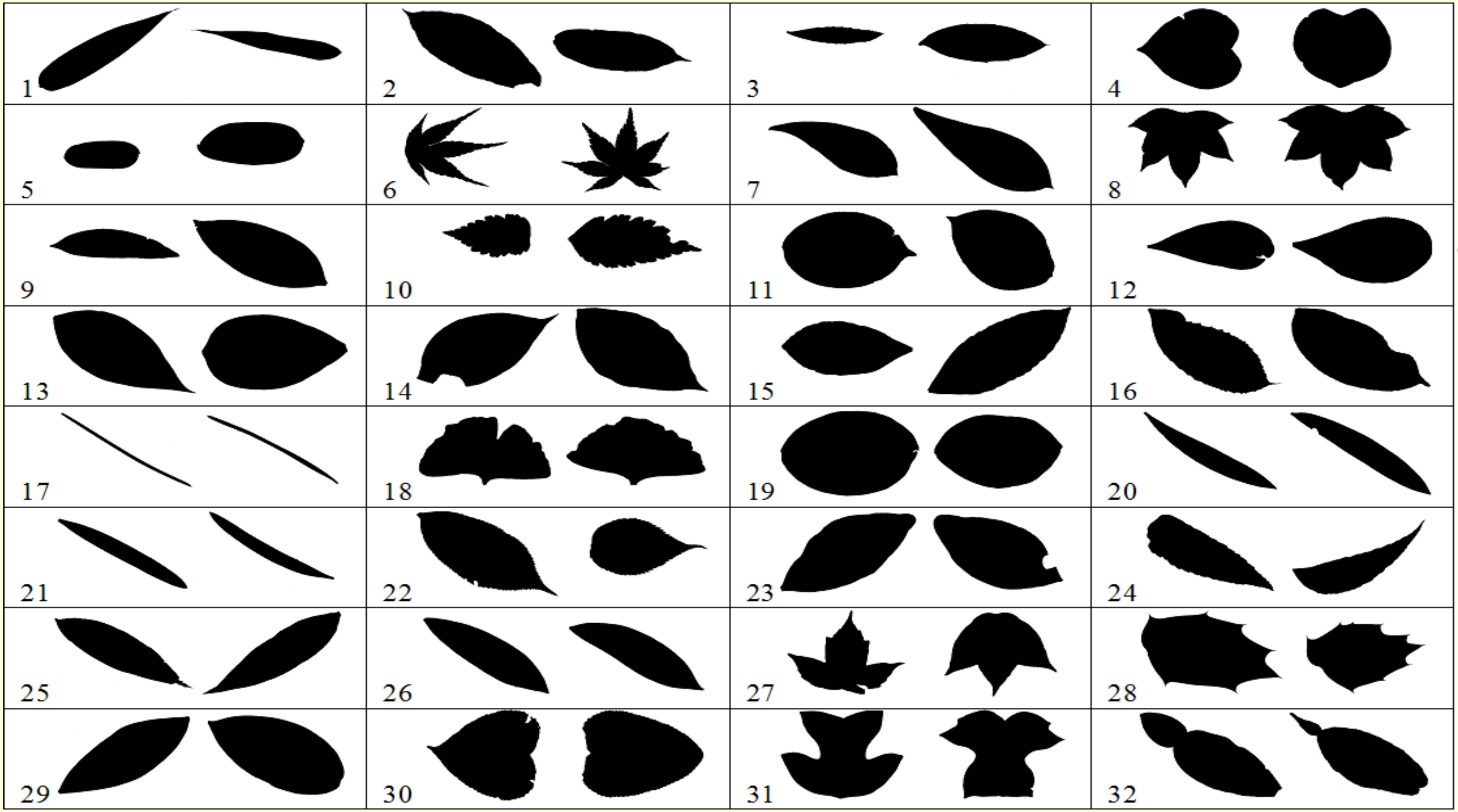


Adjustment Algorithm with Flexible Choice of the Search Intervals (Variant 3)



Construction of tangents to the circle that allows flexible choice of the search intervals for the 3-rd variant of the algorithm.

Flavia Dataset



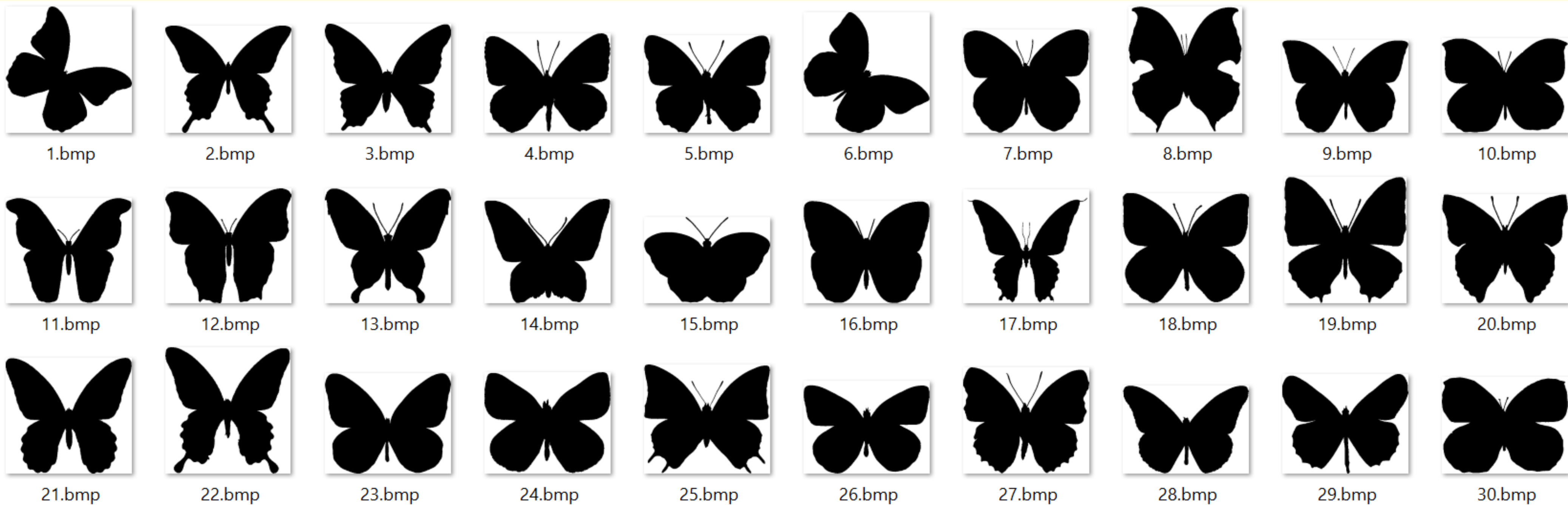
Number of classes: 32

Objects per class: 50 - 77

Total num of objects 1907

S. Wu, F. Bao, E. Xu, Y.-X. Wang, Y.-F. Chang, Q.-L. Xiang. A leaf recognition algorithm for plant classification using probabilistic neural network, in: IEEE International Symposium on Signal Processing and Information Technology, 2007, pp. 11–16.

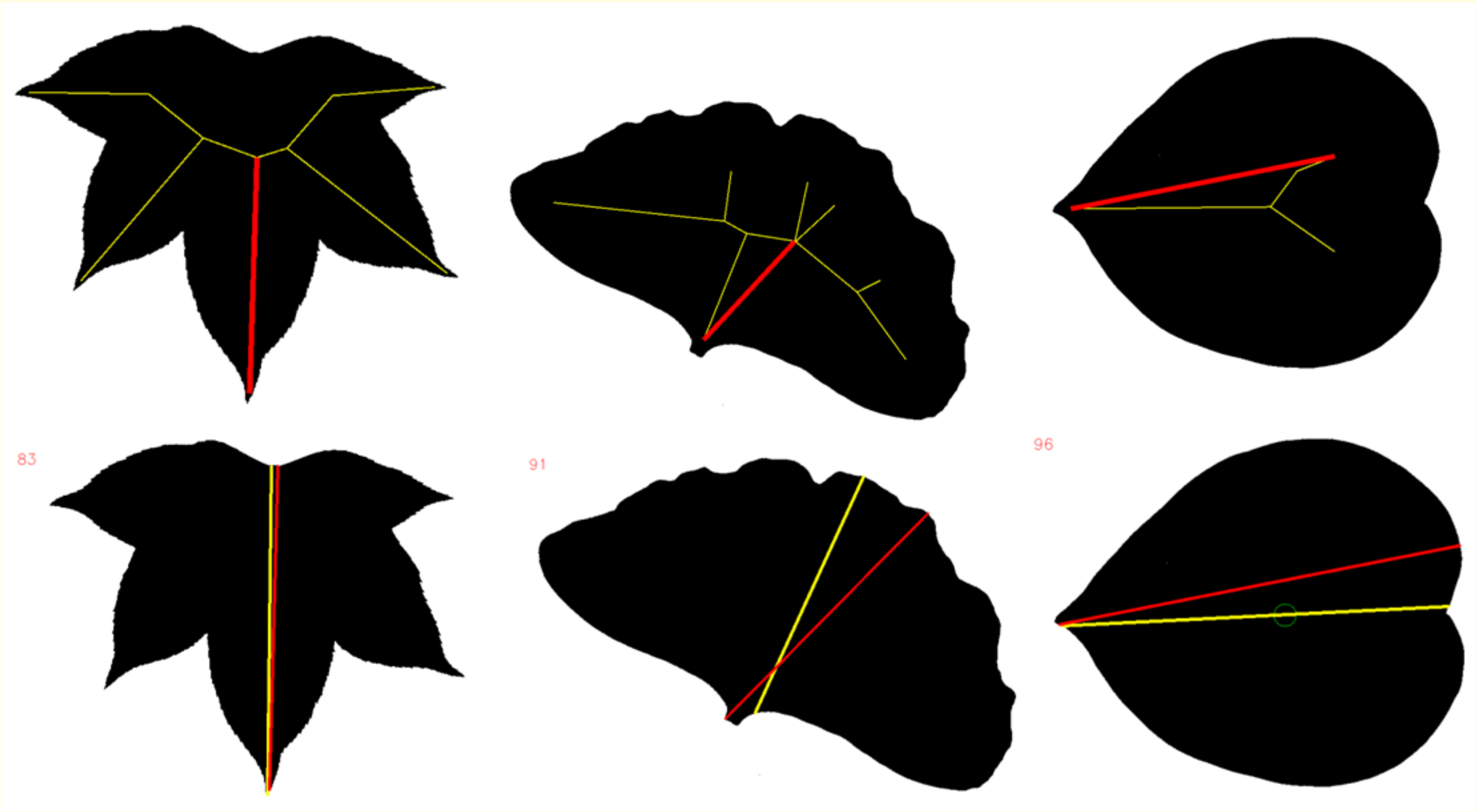
Butterfly Dataset



Experimental Results

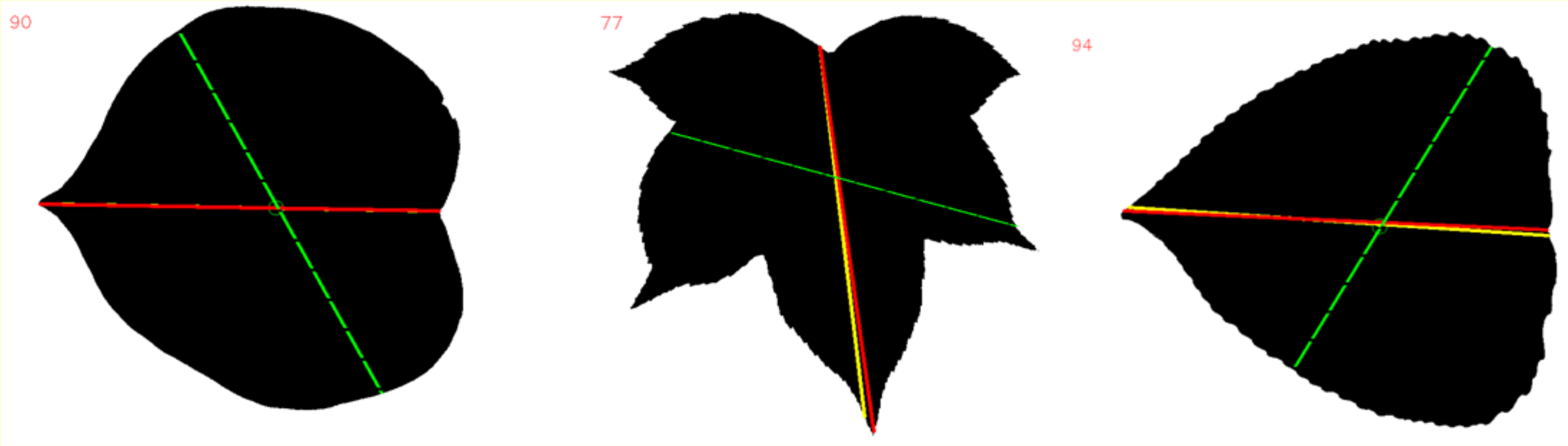
Class icon	Characteristics	Variant 1			Variant 2				Variant 3		
		$\varepsilon=1/4$	$\varepsilon=1/8$	$\varepsilon=1/16$	$\varepsilon=1/4$		$\varepsilon=1/8$		$k_R=0{,}03$	$k_R=0{,}05$	$k_R=0{,}1$
Objects, num					$k_R=0{,}03$	$k_R=0{,}05$	$k_R=0{,}03$	$k_R=0{,}05$			
	s.d. (σ)	0,022	0,007	0,018	0,023	0,022	0,007	0,007	0,022	0,007	0,019
	max deviation	0,105	0,048	0,077	0,105	0,105	0,048	0,048	0,179	0,048	0,160
	num. greater 3σ	3	2	4	4	3	2	2	1	2	1
72	average time, sec	3,727	3,048	2,973	2,037	0,238	1,894	2,021	1,938	2,131	2,743
	s.d. (σ)	0,021	0,028	0,059	0,028	0,021	0,028	0,028	0,062	0,060	0,053
	max deviation	0,121	0,148	0,233	0,150	0,121	0,148	0,148	0,204	0,197	0,187
	num. greater 3σ	1	3	2	2	1	3	3	2	2	1
64	average time, sec	4,161	3,005	3,163	2,276	2,579	1,552	1,921	2,144	2,453	2,564
	s.d. (σ)	0,020	0,091	0,093	0,067	0,049	0,092	0,091	0,121	0,124	0,109
	max deviation	0,097	0,280	0,290	0,228	0,226	0,280	0,280	0,387	0,352	0,296
	num. greater 3σ	3	1	1	3	3	1	1	1	0	0
62	average time, sec	4,993	3,805	3,915	2,715	3,226	2,000	2,366	1,812	2,255	2,536
	s.d. (σ)	0,000	0,002	0,000	0,000	0,000	0,002	0,002	0,026	0,050	0,074
	max deviation	0,002	0,008	0,001	0,002	0,002	0,008	0,008	0,102	0,181	0,284
	num. greater 3σ	2	3	1	2	2	3	3	2	2	2
56	average time, sec	3,669	2,743	2,901	2,237	2,513	1,659	2,056	1,438	1,379	1,375
	s.d. (σ)	0,011	0,015	0,024	0,020	0,021	0,012	0,015	0,041	0,039	0,024
	max deviation	0,043	0,067	0,140	0,125	0,125	0,060	0,067	0,228	0,228	0,141
	num. greater 3σ	3	2	1	1	1	2	2	2	2	1
52	average time, sec	5,651	5,886	4,638	3,089	3,801	3,609	4,344	3,669	4,296	4,227
	s.d. (σ)	0,029	0,021	0,104	0,058	0,050	0,021	0,021	0,117	0,089	0,113
	max deviation	0,112	0,099	0,365	0,298	0,228	0,099	0,099	0,478	0,470	0,467
	num. greater 3σ	2	1	2	1	1	1	1	2	1	1
30	average time, sec	3,092	3,404	2,453	2,014	2,399	2,659	2,930	2,307	2,597	2,169

Examples of the Symmetry Axis Adjustment



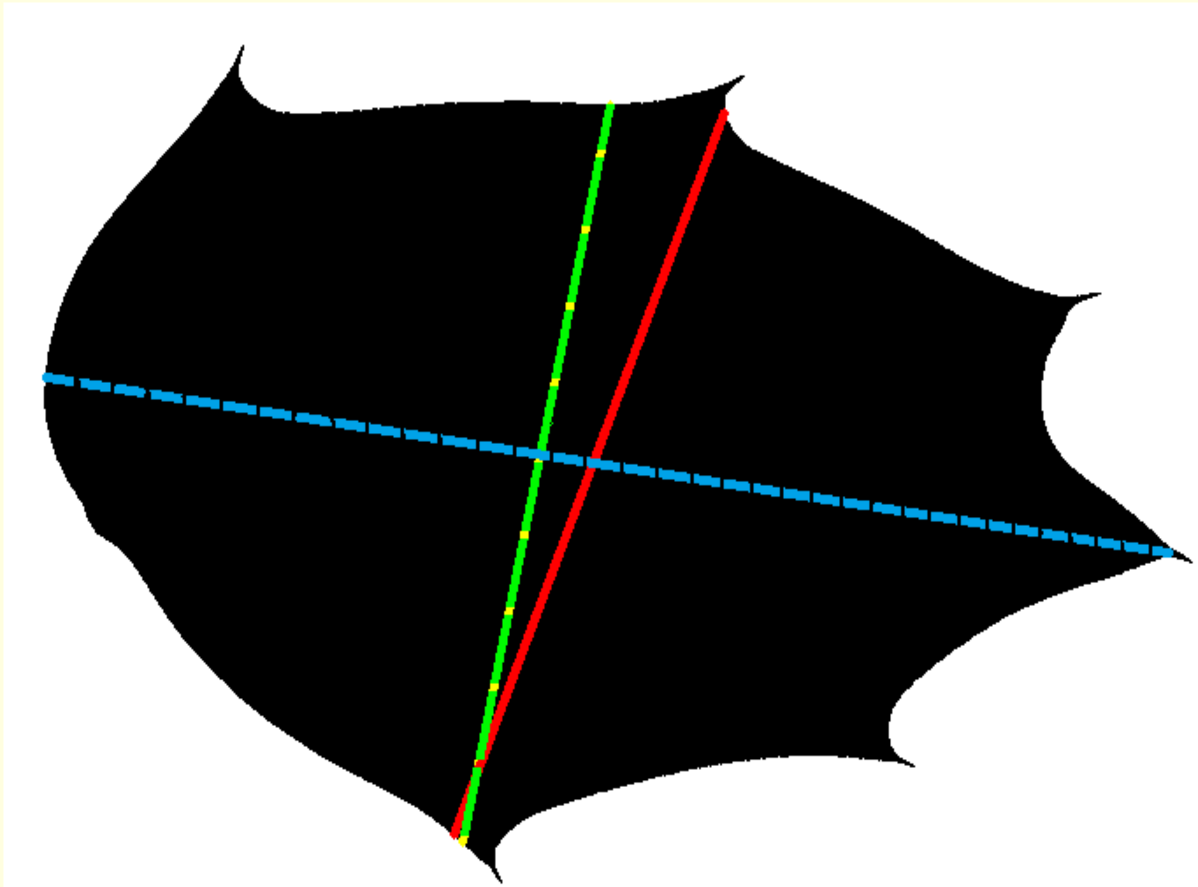
The top row - an axis obtained by skeleton method (red); bottom row - adjusted axis (yellow). In all cases, adjusted axis coincides with the ground-truth axis.

Discussion of Jaccard Similarity for Symmetry Evaluation



There are some examples of images for which the best axis according to Jaccard similarity (green dashed line) does not coincide with the axis obtained by skeleton method

Discussion of Jaccard Similarity for Symmetry Evaluation



The example of image for which the symmetry axis obtained by skeleton method (red) and brute-force (green dashed line) significantly differ from the axis drawn by the expert (blue dotted line)

Further Work

- Further efforts will be made to explore the possibility to speed up the procedure to tens of milliseconds, that will allow to use the algorithm in real time.
- Develop new ways of ground-truth reflection symmetry axis detection combining measures calculated on subsets of pixels, with the contour methods.

Thank you for your attention!