THE PATH-BASED DISTANCE SKELETON: A FLEXIBLE TOOL TO ANALYSE SILHOUETTE SHAPE

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Abstract
The path-based distance skeleton is used to analyse the shape of a digital silhouette, perceived as the superposition of elongated regions. The skeleton is suitably decomposed and the resulting components are used to represent and describe the corresponding regions.

1. Introduction

The description of a digital silhouette perceived as the superposition of ribbon-like regions(1) can be facilitated by decomposing a suitable representation of the silhouette into a number of components, each of which representing one of the constituting ribbon-like regions(2-5). A ribbon-like region is characterised by one spine and a disc: the disc sweeps out the shape by moving along the spine, changing size as it moves. Its shape can be conveniently analysed by using the path-based distance skeleton(6-11). In fact, the label of any pixel p of the skeleton, i.e. the distance of p from the complement of the pattern, can be interpreted as the radius of the sweeping disc centred on p. The shape of the disc depends on the adopted distance function. The discs are more rounded if a quasi Euclidean metric is adopted.

In this paper, the skeletonization algorithm(11) will be employed to provide the silhouette representation. This algorithm equally runs whichever distance is used, among the city block distance d_1, the chessboard distance $d_{1,1}$, the 2-weight distance $d_{3,4}$, and the 3-weight distance $d_{5,7,11}$. Thus, the distance function can be selected according to the problem domain.

The skeleton is interpreted as a curve in the 3D space, where the co-ordinates of any pixel are the planar co-ordinates and the (normalised) distance label. The 3D skeleton is divided into rectilinear segments, which are interpreted as the spines of elementary regions, characterised by linearly changing width and orientation. Then, skeleton segments unnecessary for shape description are annihilated, while contiguous segments constituting the spines of sufficiently similar elementary regions are merged. The merging step reduces the number of regions into which the pattern is decomposed, so that the obtained results are more in accordance with human intuition. In particular, it allows to alleviate the distortions generally affecting geometry and labels of the skeleton in correspondence of region crossings.

2. Spine identification

Let B and S be respectively the silhouette and its skeleton; S can be interpreted as a concatenation of skeleton branches. These are the subsets of S delimited by end points and branch points.

Let R be the region obtained by applying the reverse distance transformation to a subset of a skeleton branch (the spine of R). R is an elementary region if : 1) the local thickness of R (measured along the normal to the skeleton branch) changes monotonically and linearly; 2) the contour subsets shared by R and B are straight line segments.

R can be approximated by the envelope of the discs associated with the extremes of the spine. Note that recovery of R is not indispensable to compute geometric features (e.g., area, perimeter) and shape features (e.g., orientation, rectangularity) of the region, since these features can be directly derived starting from the 3D co-ordinates of the two spine vertices.

Every skeleton branch is interpreted as a 3D arc, the three co-ordinates of any skeletal pixel being the planar co-ordinates and the normalised label. Then, a polygonal approximation is computed; vertices are placed wherever non linear changes (in curvature or label) occur along the 3D arc, as they reflect non linear shape changes (in curvature or thickness) of the corresponding pattern subset. A split type algorithm is used to compute the polygonal approximation(12), so that the obtained set of vertices is not influenced by the order in which the skeletal pixels are processed along the arc.

Pairs of successive vertices identifiy the spines of the elementary regions constituting the decomposition of B. The value of the threshold θ used during the polygonal approximation, is fixed depending on the tolerance regarded as acceptable for the specific task. It should be rather small to favour a quite faithful representation of B by means of the found regions. In our experiments, the value $\theta = 1.5$ has been revealed as adequate. In Figure 1, the vertices found on the $d_{5,7,11}$ skeleton of a test pattern are shown as black dots.

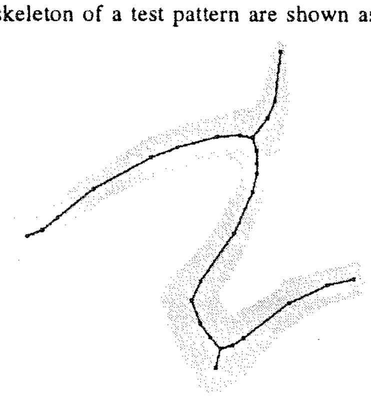

Figure 1. The vertices found on the $d_{5,7,11}$ skeleton, after the polygonal approximation with $\theta = 1.5$.

3. Spine annihilation

Some elementary regions may be (almost completely) overlapped by adjacent regions and should be disregarded while describing the shape of B. To this purpose, the corresponding spines should be identified and ignored. Among these spines, those delimited by branch points cannot be completely ignored, though having no region representation power. These spines, play the role of linking elements among significant spines and are necessary to illustrate the spatial relations among the significant regions of the decomposition of B.

3.1 Short spine case

Spines with length less than 4, in pixel unit, are associated with generally disregardable regions. These short spines are ignored, if they are delimited by end points and/or branch points. In turn, short spines which are embedded in between two non short spines (i.e., isolated short spines) are annihilated. Annihilation of an isolated short spine s_i is done by moving its extremes (shared by s_i with the contiguous spines s_{i-1} and s_{i+1}) towards a common point in the 3D space. This is the barycentre of s_i or the intersection between s_{i-1} and s_{i+1}, depending on the angle between s_{i-1} and s_{i+1}. See Figure 2.

Annihilation causes s_i to disappear, and s_{i-1} and s_{i+1} to be modified and possibly merged into a unique spine. Merging is done, if the two modified spines result aligned, in the limits of the tolerance adopted when performing the polygonal approximation.

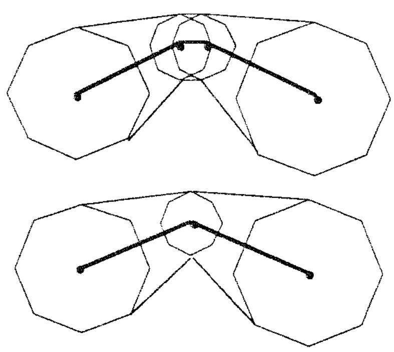

Figure 2. After the intermediate spine, a), is annihilated, a more significant decomposition is obtained, b).

3.2 Superfluous spine case

Also non short spines may correspond to regions almost completely overlapped by adjacent regions, and are superfluous for pattern representation and description.

In general, a spine can be considered superfluous if the envelope of the discs centred on its extremes does not significantly differ from the union of the two discs, as it is the case if the two discs partially overlap. The distance d between the extremes of the spine and the value of their labels, say l_1 and l_2, can be used to evaluate the overlapping degree. A spine is regarded as superfluous if the overlapping condition is satisfied, i.e. if it results $l_1 + l_2 \geq d$. A superfluous spine is annihilated if i) its extremes are normal points, and ii) the contiguous spines are not superfluous.

Superfluous spines delimited by branch points play the role of linking elements. Let $b_1, b_2, \ldots, b_n$ be the skeleton branches sharing the branch point v_b, and let v_i (i=1, n) be the first vertex along b_i. The subset of b_i, delimited by v_b and v_i, is regarded as rid of region representation power if any of the following cases occurs:

i) a vertex v_j, located on b_j ($j \neq i$), exists such that the overlapping condition is satisfied by the discs centred on v_j and v_i.

ii) the overlapping condition is satisfied by the discs centered on v_b and v_i

As an example, refer to Figure 3.

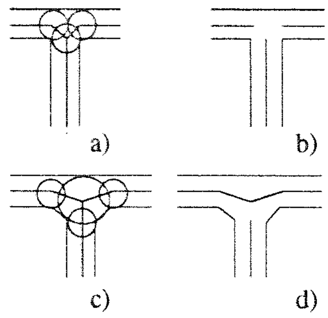

Figure 3. Skeleton segments rid of region representation power are suppressed in b) and d).

4. Spine merging

Although the spines remaining at this stage of the process all significantly contribute to pattern recovery, merging some of them could be useful to reduce the number of regions into which the pattern is interpreted as decomposed. Reducing the number of regions generally increases the stability of the decomposition and produces results more in accordance with human intuition.

Elementary regions having sufficiently similar width and orientation could be merged by concatenating the corresponding spines. A merged region, though no longer an elementary region, can still be simply described starting from the 3D co-ordinates of the vertices of the corresponding concatenation. By employing different merging tolerances, different concatenations of merged spines are possible, which produce different pattern decompositions. The decompositions have all the same global representation power, since any merged region is the union of the corresponding elementary regions. (This would not be the case, if different thresholds were adopted during the polygonal approximation of the skeleton).

Two contiguous regions are merged if their spines, represented in the 3D space, are aligned in the limits of the adopted tolerance, τ. To avoid a propagation effect that could cause excessive spine merging, we proceed as follows.

Each pair of successive spines, on the same skeleton branch, is examined. Let (v_{i-1}, v_i), and (v_i, v_{i+1}) be the vertices delimiting the current pair of spines. Let L_i and D_i be respectively the Euclidean length of the segment joining v_{i-1} and v_{i+1}, and the 3D Euclidean distance of v_i from the segment. A flag F, initially equal to "0", is set to "1" in correspondence of each vertex v_i, such that D_i/L_i is less than the merging threshold τ. Let $v_1, v_2, \ldots, v_n$ be a sequence of successive vertices in correspondence of which it is F=1. Moreover, let v_0 and v_{n+1} be the two vertices immediately preceding v_1 and immediately following v_n.

If n=1, the two spines (v_0, v_1) and (v_1, v_{n+1}) are merged.

If n>1, for every $i=\{1,2,...,n\}$ the distance D_i of v_i from the straight line segment joining v_0 with v_{n+1} is divided by the length L of the segment. If for every vertex, it is $D_i/L < \tau$, all the spines are merged. Otherwise, the sequence $v_2, v_3, ..., v_{n-1}$ is considered and for each of its vertices the merging ratio D_i/L is checked with reference to the straight line segment joining v_1 and v_n. The process is repeated until for the sequence $v_k, v_{k+1}, ..., v_j$ ($k=1+i$, $j=n-i$, $i>0$) the merging condition is verified by all vertices. The corresponding spines are merged. Then, the merging condition is recursively checked on the two sub-sequences $v_1, v_2, ..., v_{k-1}$ and $v_{j+1}, v_{j+2}, ..., v_n$.

The vertices delimiting the set of the concatenation of spines are taken as the extremes of the resulting complex spine. Note that the remaining vertices still maintain their region representation power, since the region associated with a complex spine is the union of the elementary regions associated with the merged spines.

The value of the merging threshold τ depends on the desired merging tolerance. Large values favour merging. An example referring to the $d_{5,7,11}$ skeleton is shown in Figure 4, where two different values ($\tau=0.15$ and $\tau=0.25$) have been used for the merging threshold. The decompositions are obtained starting from the polygonal approximation of the skeleton, performed with $\theta=1.5$.

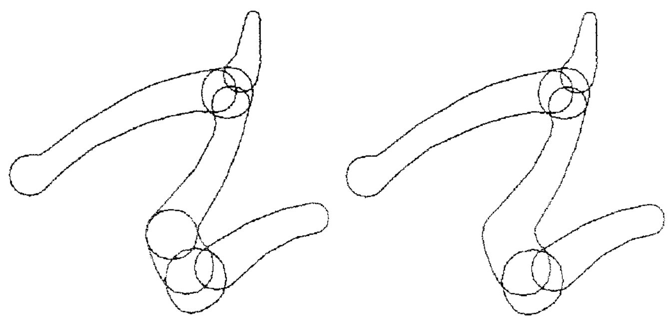

Figure 4. Different decompositions of a pattern represented by the $d_{5,7,11}$ skeleton, obtained by using different values for the merging threshold: $\tau=0.15$, left, $\tau=0.25$, right.

Figure 5 shows the decompositions obtained for the same pattern, respectively represented by the d_1, $d_{1,1}$, and $d_{3,4}$ skeleton, by using $\tau=0.25$.

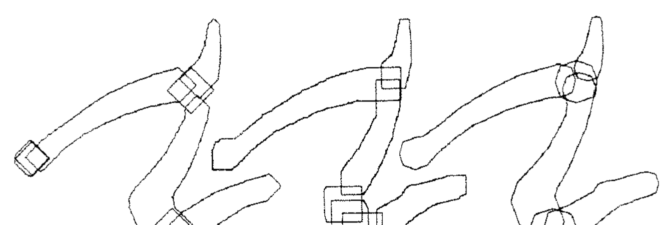

Figure 5. From left to right, the decompositions obtained starting from the d_1, $d_{1,1}$, and $d_{3,4}$ skeleton, for $\tau=0.25$.

The possibility of merging spines sharing a branch point as a common vertex could also be taken into account, in order the final pattern decomposition be not conditioned by the preliminary decomposition of the skeleton into its constituting branches. Work in this respect is currently in progress.

5. Conclusion

We have illustrated a method for decomposing a digital pattern through the decomposition of its path-based distance skeleton. The method is adequate for patterns that can be perceived as constituted by the union of elongated (ribbon-like) regions. Stability of the decomposition under pattern rotation is favoured by the annihilation and merging steps, which reduce the skeleton decomposition components to the most significant ones. A relevant feature of the proposed decomposition method is the possibility to obtain decompositions at different resolution levels, by changing the threshold used during the merging step. The decompositions differ from each other for the number and shape of the constituting regions, but all have the same global representative power.

The computational burden of the process is rather modest, because all the computations are performed on a small amount of data (the skeletal pixels and, afterwards, the vertices of the polygonal approximation), which are stored in vector form.

References

1 A. Rosenfeld, Axial representation of shape, *CVGIP*, **33**, 156-173 (1986).

2 H. Blum, and R.N. Nagel, Shape description using weighted symmetric axis features, *Pattern Recognition*, **10**, (167-180) 1978.

3 P.P. Cortopassi and T.C. Rearick, A computationally efficient algorithm for shape decompsition, *Proc. 2nd Int. Conf. on Computer Vision*, Ann Arbor, 597-601 (1988).

4 C. Arcelli, R. Colucci and G. Sanniti di Baja, On the description of digital strips, *Proc. Int. Conf. on Artificial Intelligence Applications and Neural Networks*, Zurich, 193-196 (1990).

5 E. Thiel and A. Montanvert, Shape splitting from medial lines using the 3-4 chamfer distance, in *Visual Form Analysis and Recognition*, C.Arcelli et al., Eds., Plenum, New York, 537-546 (1992).

6 L. Dorst, Pseudo-Euclidean skeletons, *Proc. 8th Int. Conf. on Pattern Recognition*, Paris, 286-288 (1986).

7 C. Arcelli and G. Sanniti di Baja, A width-independent fast thinning algorithm, *IEEE PAMI*, **7**, 463-474, (1985).

8 C. Arcelli and G. Sanniti di Baja, A one-pass two-operations process to detect the skeletal pixels on the 4-distance transform, *IEEE PAMI*, **11**, 411-414 (1989).

9 C. Arcelli and M. Frucci, Reversible skeletonization by (5,7,11)-erosion, in *Visual Form Analysis and Recognition*, C.Arcelli et al. Eds., Plenum, New York, 21-28 (1992).

10 G. Sanniti di Baja, Well-shaped, stable and reversible skeletons from the (3,4)-distance transform, *Journal of Visual Communication and Image Representation*, **5**, 107-115 (1994).

11 G. Sanniti di Baja and E. Thiel, "Extracting and Comparing distance driven skeletons", Proc. 2nd Int. Workshop on Visual Form, Capri, May 1994. (in press)

12 T. Pavlidis, Structural pattern recognition, Springer Verlag, New York, chapter 7, (1977).