Integrated Skeleton and Boundary Shape Representation for Medical Image Interpretation*

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Abstract. We propose a method of extracting and describing the shape of features from medical images which provides both a skeleton and boundary representation. This method does not require complete closed boundaries nor regularly sampled edge points. Lines between edge points are connected into boundary sections using a measure of proximity. Alternatively, or in addition, known connectivity between points (such as that available from traditional edge detectors) can be incorporated if known. The resultant descriptions are object-centred and hierarchical in nature with an unambiguous mapping between skeleton and boundary sections.

1 Introduction

We are currently developing an improved shape representation for use in the Guy's Computer vision system for medical image interpretation [RC1]. The requirement is for an efficient method of shape representation which can be used to store information about the expected anatomical structure in the model, and also represent information about the shape of features present in the image. In this paper we present an integrated approach to shape representation which also addresses the problem of grouping dot pattern and disconnected edge sections to form perceptual objects. The method of shape representation is based on the dual of the Voronoi diagram and the Delaunay triangulation of a set of points. For each object, the boundary and the skeleton are represented hierarchically. This reduces sensitivity to small changes along the object boundary and also facilitates coarse to fine matching of image features to model entities.

2 Previous work

Many approaches to shape representation have been proposed, and more extensive reviews can be found in reference [Ma1]. Boundary representation of the shape of objects such as those described in references [Fr1] and [Ay1] tend to be sensitive to small changes along the object boundaries, hierarchical representation is often difficult, as is the sub-division of objects into their sub-parts. The hierarchical approach of the curvature primal

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sketch [AB1] is an improvement on boundary representations, but the use of multiple Gaussian scales may cause problems especially when primitives are close together.

Skeleton representations such as proposed in [Bl1] allows the shape of objects to be represented in terms of the relationships between their sub-parts. Spurious skeleton branches can be generated by small protrusions on the object boundary. Nackman & Pizer [NP1] propose an approach to overcoming the problems of these spurious branches by generating the skeleton of an object at multiple Gaussian scales, and Arcelli [Ar1] proposes a hierarchy of skeletons in terms of the object's boundary curvature.

Grouping dot-patterns to form perceptual objects has been attempted by a number of authors. We are concerned with grouping together dots which are considered to form the boundary of objects (in a similar manner to a child's dot-to-dot game). Ahuja et al [AH1] and [AT1] propose the use of the Voronoi diagram and the properties of the individual Voronoi cells to classify points as boundary points, interior points, isolated points, or points on a curve.

Fairfield [Fa1], like ourselves, is concerned with both the detection of the boundary of objects from dots, and also the segmenting of these objects into their sub-parts. He uses the Voronoi diagram to detect areas of internal concavity and replaces Voronoi diagram sides with the corresponding Delaunay triangulation sides to produce both the object boundary and sub-parts. This work is dependent on a user defined threshold and does not differentiate between object boundaries and the sub-part boundaries.

Ogniewicz et al [Ol1] use the Voronoi diagram of a set of points to produce a medial axis description of objects. This method requires that the points making up the boundary have known connectivity, and a threshold is used to prune the skeleton description.

The method we propose does not require connected boundaries as input, merely a set of points (dots) which are believed to be edge points of objects. Our method produces distinct objects from these potential edge points, and concurrently generates both a skeleton and a boundary representation of the shape of these objects.

3 Defining boundary/skeleton and objects

The Delaunay triangulation of the candidate edge points is calculated, and from this the Voronoi diagram. We must then select from the Delaunay triangulation those sides that make up the perceived object boundaries, and from the Voronoi diagram those sides that make up the perceived object skeleton. This selection is refined to the exclusive decision of whether to keep a Delaunay side as a boundary section or the corresponding Voronoi side as a skeleton section. The decision is based purely on proximity, and the shorter of the Delaunay triangle side and corresponding Voronoi side is kept as a boundary section or skeleton section respectively. If connectivity between any two specific points is known this can be easily incorporated by overriding the selection criteria for the Delaunay triangle side connecting the two points. If no such triangle side exists then a new connection is formed, while still preserving the Delaunay triangulation using the method of Boissonnat [Bo1].

Objects can now be defined by stretches of unbroken and possibly branching skeletons. Each branch in a skeleton has associated with it two properties. Firstly, the mean direction of the skeleton branch, and secondly the area of the object corresponding to that branch. Fig. 1a shows an example set of points corresponding to the bodies of the lateral cerebral ventricles, extracted via a DOG from a transverse MR image. These points are shown as a series of crosses which are unfortunately drawn so close that they partially overlap. Fig. 1b-c show the Delaunay triangulation and Voronoi diagram of these points respectively. Fig 1d shows the result of the proximity based selection criterion.

4 Defining the intra-object hierarchy

Objects are decomposed into sub-parts by examining the area and direction associated with each skeleton branch. These two measures are combined to locate small branches meeting a more significant part of the object. Where these less significant branches occur, "*virtual boundaries*" are constructed from the Delaunay triangle side corresponding to the Voronoi side emanating from the branch. Each sub-object has an associated area which is the total area of the object within the real or virtual boundaries surrounding that sub-part.

An intra-object hierarchy is then generated by ordering the sub-objects in decreasing size and starting a new level in the hierarchy where there is a significant change in area between sub-parts which are adjacent in the list. Fig. 2a shows the object corresponding to the lateral ventricles with the boundaries of these sub-parts shown with dotted lines. Fig. 2b shows a low-level in the intra-object hierarchy, and fig. 2c shows the remaining fine detail in the intra-object hierarchy. Figures 3a-c show the same information as figures 2a-c for the small portion of the object indicated in figure 2a.

5 Using the skeleton/boundary unification

The unified nature of the representation that comes from the duality of the Delaunay triangulation and the Voronoi diagram allows simple changes in the data structure to change the perceived number of objects. For example, considering the lateral ventricles in figs 1-2, we may wish to further divide the object into left and right ventricles. This can be easily achieved by simply forcing the connection between the two bodies. This requires only a local change in the data structure, but generates two new objects. Fig. 4b shows the effect of this simple change.

The converse of this can be just as easily achieved (merging two objects into one) by forcing a boundary section to become a skeleton section.

6 Concluding Remarks

We have defined a hierarchical, object-centred shape description. The algorithm for computing this description works on both connected and disconnected edge points. The technique is based on a scale invariant proximity measure and so requires no user defined thresholds.

We are extending our technique to make use of criteria other than proximity, for example gradient magnitude at edge points, and directional continuity of edge sections.

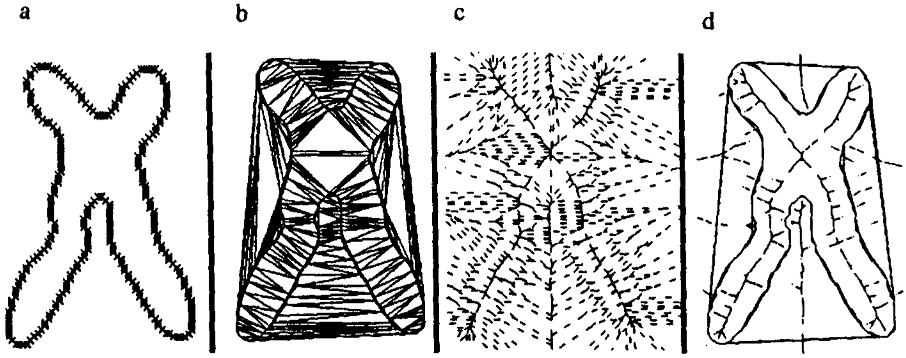

Fig. 1. a) Discrete edge points, shown partially overlapping; **b)** Delaunay triangulation (solid lines); **c)** Voronoi diagram (dashed lines); **d)** Result of selection criterion.

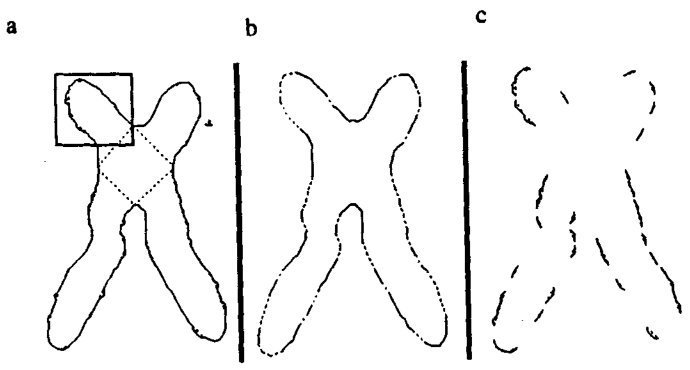

Fig. 2. a) Boundary and sub part of lateral bodies; **b)** low-level in object hierarchy; **c)** fine detail of the object hierarchy. Dotted lines are Delaunays forming the virtual boundaries.

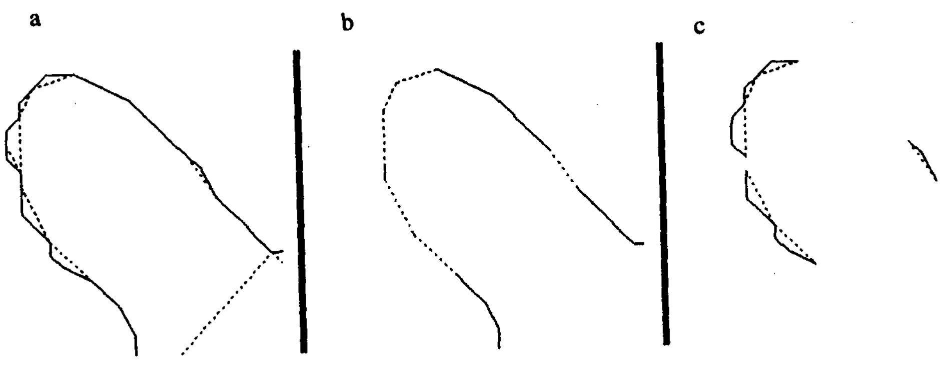

Fig. 3. a)-c) same features as fig. 2 for the small area indicated in fig. 2a.

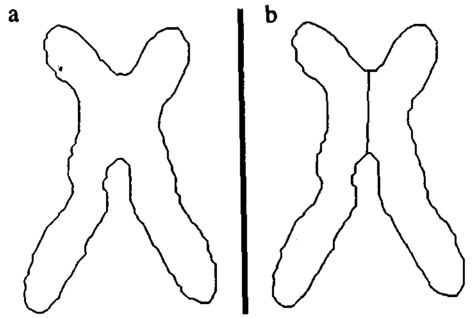

Fig. 4. a) Lateral bodies of figs. 2-3; **b)** result of splitting the object in two.

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