Alternative waterfall

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There are many applications for image segmentation in the world of medical imaging, for example, feature identification and classification, 3D visualisation, and volume estimation. All these help when working with CAT scans and each require knowledge of where key anatomical features are found in the image.

In order to locate any such features, the image needs to be segmented. That is, pixels of similar greyscale values get grouped together in one region. Most algorithms tend to over-segment images significantly, leading to far more regions than can be handled sensibly. This effect is partly due to problems such as indistinct boundaries between features and the variation present between different images, and partly due to the algorithms not having any knowledge of the context in which the segmentation takes place.

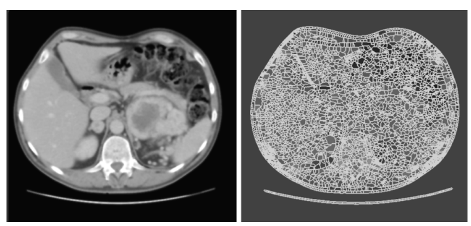

Fig. 1. Example of oversegmented image

Figure 1 illustrates (on a CAT scan) the results of a common segmentation algorithm, the watershed. The image is clearly over-segmented and hence not much more useful than the original for the purposes mentioned earlier.

This over-segmented image can be processed further by grouping together those regions that feature similar grey values. This technique is known as the waterfall algorithm. It yields a hierarchy called a partition forest, which is a more comprehensive data structure that can be used subsequently in the process of feature identification. The waterfall algorithm is widely used and can produce good results.

Figure 2 illustrates the various layers that result from applying the waterfall algorithm repeatedly to the segmentation shown in Figure 1.

Both the watershed and the waterfall algorithms are based on a geographical metaphor. The image is regarded as a landscape, with each grey value being associated to a terrain height. The valleys are in the darker areas, whereas the lighter areas are regarded as peaks.

The waterfall algorithm [1, 2] can be imagined as a flooding process. The water falls into (low) catchment basins and gradually fills them up to the nearest boundaries. When two adjacent basins have been filled up to the boundary between them, they get joined (and the boundary gets removed). This process continues until the whole image becomes a single basin. The intermediate stages of the process can be regarded as intermediate segmentations of the image, with each basin representing a region, and each inter-basin peak representing a boundary between regions.

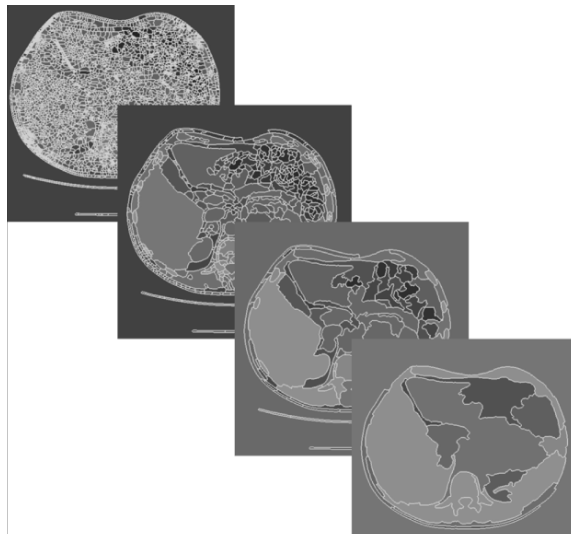

Fig. 2. Hierarchy of segmentations

The traditional implementation of this algorithm [2] involves the construction of a Minimum Spanning Tree (MST) and the gradual elision of some of its edges. Its nodes are the local minima and maxima of the plateaus in the landscape, whereas its edges are the relative difference in height between these. (In actual fact it is the landscape formed by the gradient of the original image that is used, rather than the raw image.)

The collection of regional minimum edges of a graph G is a connected subgraph of G whose edges have the same weight as each other, and whose adjacent edges in G have strictly higher weights. The waterfall algorithm relies heavily on finding these regional minimum edges, eliding them and rebuilding the MST – a process which not only requires careful implementation of the MST but, more importantly, is relatively complex and hard to implement.

In this paper we present a new data structure for the waterfall algorithm that simplifies the process and improves efficiency compared to current implementations. It is based on a recursive-tree data structure and a recursive relation on the nodes rather than the conventional iterative transformations.

[some details about the new data structure]

Production of partition forests has many applications outside of the field of medical imaging, for instance, binary space partitioning in 3D map rendering for games.

[some results, and possibly something about validation]

References

1. Serge Beucher. *Watershed, hierarchical segmentation and waterfall algorithm*. In Mathematical Morphology and its Applications to Image Processing, Proc. ISMM 94, pages 69-76, Fontainebleau, France, 1994. Kluwer Ac. Publ.
2. Beatriz Marcotegui and Serge Beucher, *Fast Implementation of Waterfall Based on Graph*. In Mathematical Morphology: 40 Years On, Springer Netherlands, 2005.