A simpler approach to waterfall

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Most applications of image segmentations of CAT scans require knowledge of where key anatomical features are found in the image. In order to locate any such features, pixels of similar greyscale values need to have been 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 due to problems such as indistinct boundaries between features, the variation present between different images, but mostly due to the algorithms not having any knowledge of the context in which the segmentation takes place.

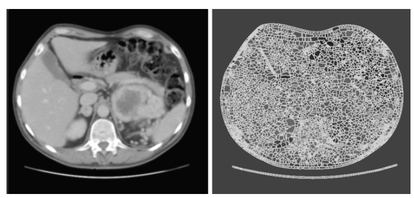

Fig. 1. Example of oversegmented image

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 regions featuring similar grey values. This technique is known as the *waterfall* algorithm. It yields a partition forest hierarchy, which is a comprehensive data structure which can be used subsequently in the process of feature identification. Figure 2 illustrates the various layers that result from applying the waterfall algorithm repeatedly to the segmentation shown in Figure 1.

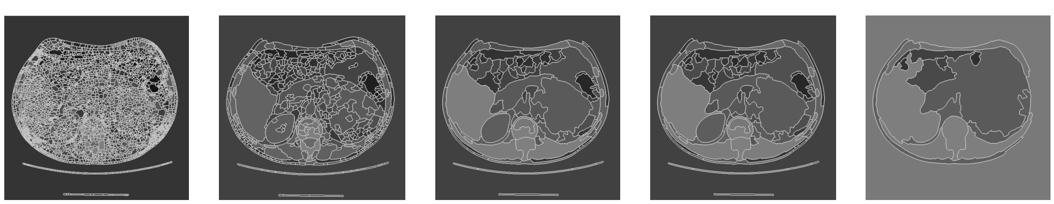

Fig. 2. Hierarchy of segmentations

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 proportional to the terrain height. The valleys are in the darker areas, whereas the lighter areas are regarded as peaks.

The waterfall algorithm [1, 2] can then be imagined as a flooding process. The water falls into (low) catchment basins and gradually fills them up to the nearest boundaries, sometimes spilling into adjacent regions. 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.

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.

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.

The main advantage of our approach to the waterfall problem is that the algorithm uses a single data structure (the MST) and a single loop to walk it, which can be written in pure functional style. It walks (bottom-up) the MST and, in a single pass, merges regions that belong together. The waterfall algorithm, thus improved, produces similar layers of segmented images, combined in a hierarchical structure that can be processed for feature identification.

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

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.