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Graph-Based Vertebra Segmentation Using a Cubic Template

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Purpose

The current development of the population's structure leads to a growing part of older patients with a more frequent insistence for surgical treatment like lumbar spinal stenosis (LS), which is the most common cause of spinal surgery in individuals older than 65 years of age [1]. For the assessment of spinal structures such as nerve roots, intervertebral discs and ligamentary constitution, Magnetic Resonance Imaging (MRI) is in general suitable. However, certain changes of the vertebra due to osteoporosis, fractures or osteophytes, require an evaluation of the bone structures via Computed Tomography (CT)-scans, which include radiation exposure [2]. In this contribution, we want to illustrate the capability of MRI-segmentation to reconstruct the vertebral body without x-ray examination, leading to less pre-operative examinations and therefore affecting radiation exposure costs and time-management.

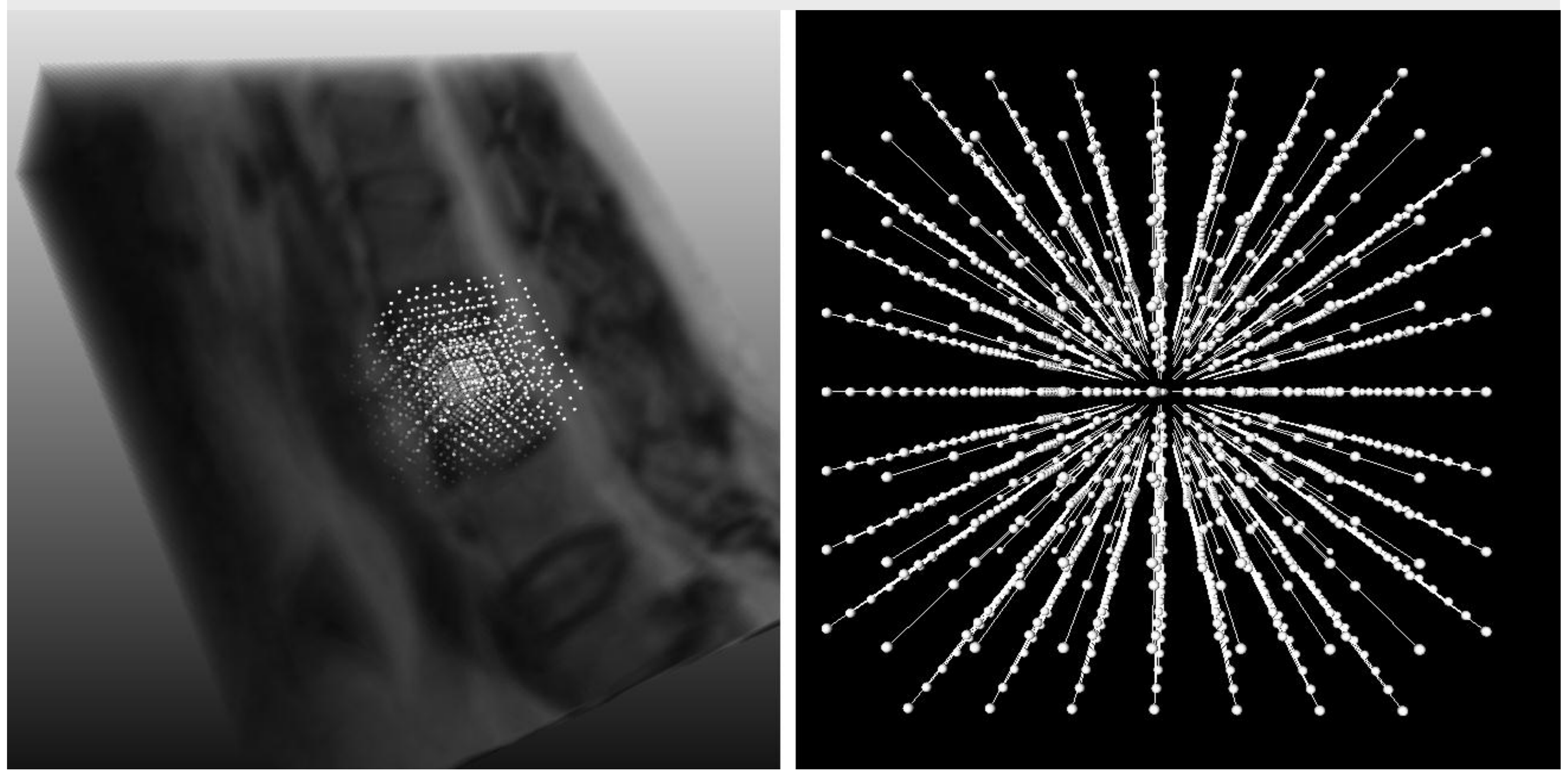

Figure 1: Left: Distribution of vertices. Right: Visualization of z-edges.

Methods

The presented approach is an extension of our previously introduced strategy [3, 4] to a third dimension. It starts by setting up a directed, weighted, two-terminal 3D-graph G = (V,E) (an s-t-network). After its construction, the minimal closed set on the graph is calculated via a polynomial time s-t-cut [5], creating a 3D segmentation of the vertebral body. The vertices $v \in V \setminus \{s,t\}$ are distributed along several rays that extend from a user-defined seed point inside the vertebra and intersect with the vertebral body's outer boundaries. All rays are made up of the same number of vertices and each layer forms a cube shape (see figure 1). There are two types of edges $e \in E$. *n-links* connect all vertices to a virtual source s and a virtual sink t and the n-links' capacities reflect a node's affiliation with either the source (vertebra) or the sink (background). A set of infinity-weighted *i-links* connects the vertices on the rays with each other. The i-links are further subdivided into *z-edges* (see figure 1) and *xy-edges* (see figure 2). The z-edges ensure that each ray is cut exactly one time, while the xy-edges allow the user to impose a smoothness constraint Δ on the segmentation result [6]. A Δ-value of zero results in a regular, cubic shape, whereas a Δ-value greater zero allows a corresponding deviation (see figure 3).

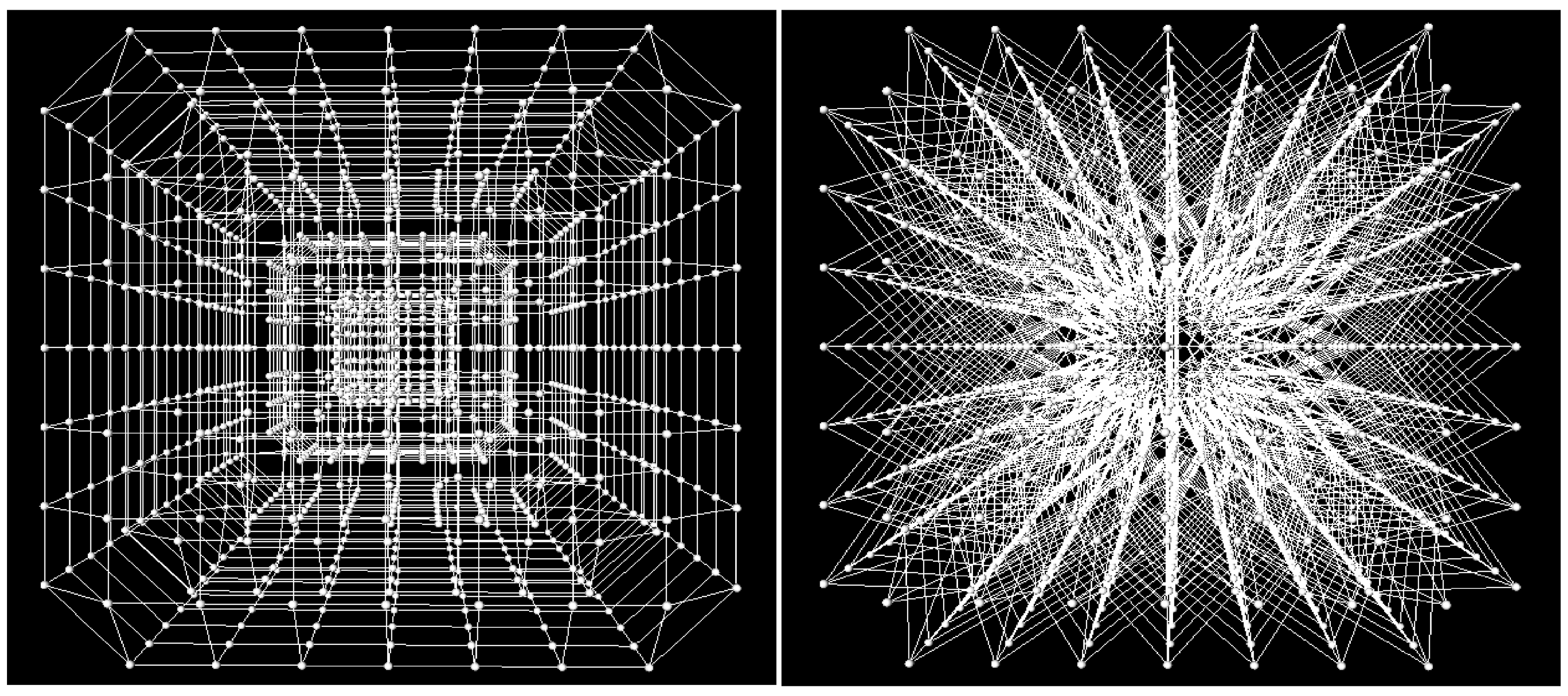

Figure 2: Topology of xy-edges. Left: Smoothness constraint $\Delta = 0$. Right: $\Delta = 1$.

Results

For testing the presented segmentation method we used a C++ implementation within the medical prototyping platform MeVisLab (see http://www.mevislab.de). The overall segmentation – sending rays, graph construction and mincut computation – in our implementation took about twenty seconds on an Intel 2.1 GHz CPU, 4 GB RAM, Windows 7 Home Premium x64 Version, SP 1. We carried out an initial evaluation, segmenting 5 vertebrae: The average DSC was 83%.

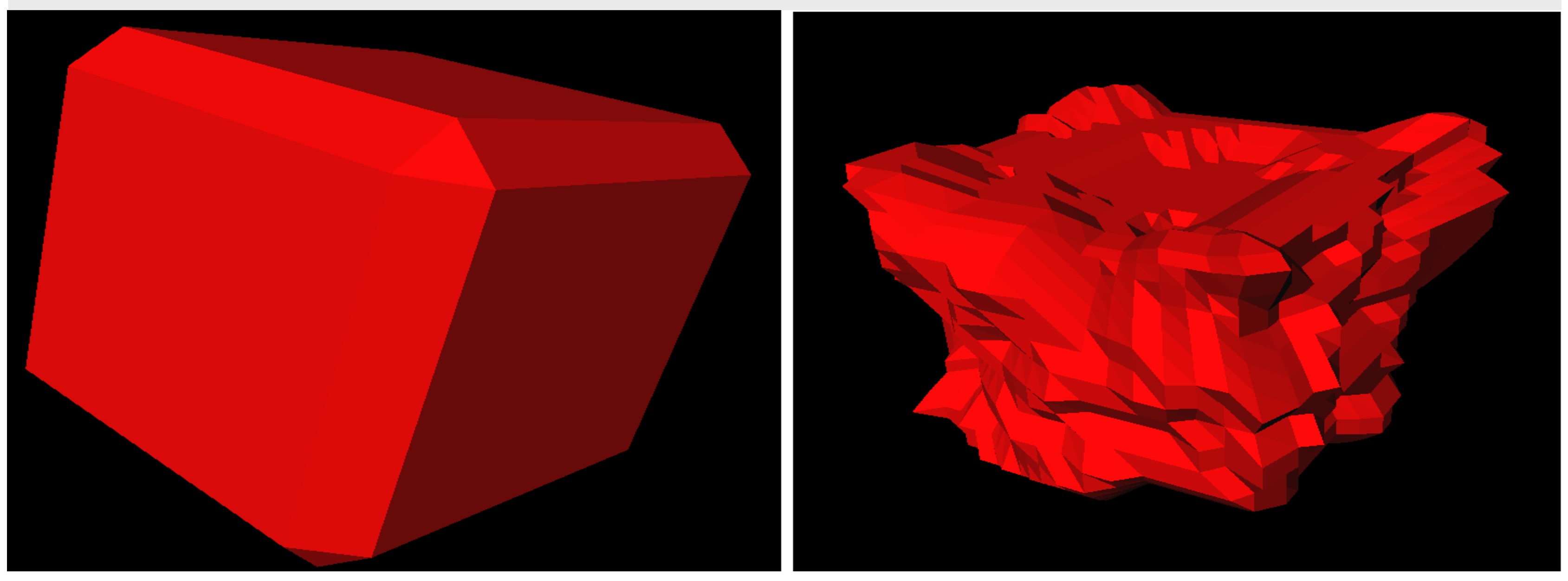

Figure 3: Left: Segmentation result for $\Delta = 0$. Right: Segmentation result for $\Delta = 2$.

Conclusions

In this contribution, we presented the initial results for a novel vertebra 3D segmentation method. The method enhances our recently developed algorithm to a third dimension. Whereas the previously introduced algorithm allowed the calculation of a vertebral area (2D), the method presented here determines the volume of a vertebra (3D) (see figure 4). It constructs an s-t-network within a cubic-shaped template and allows the user to impose a smoothness constraint on the segmentation result which determines the result's deviation from a regular cube shape. The segmentation result is computed by a polynomial s-t-cut, creating an optimal segmentation of the vertebra's outer boundaries. A first evaluation led to an average DSC of 83 %.

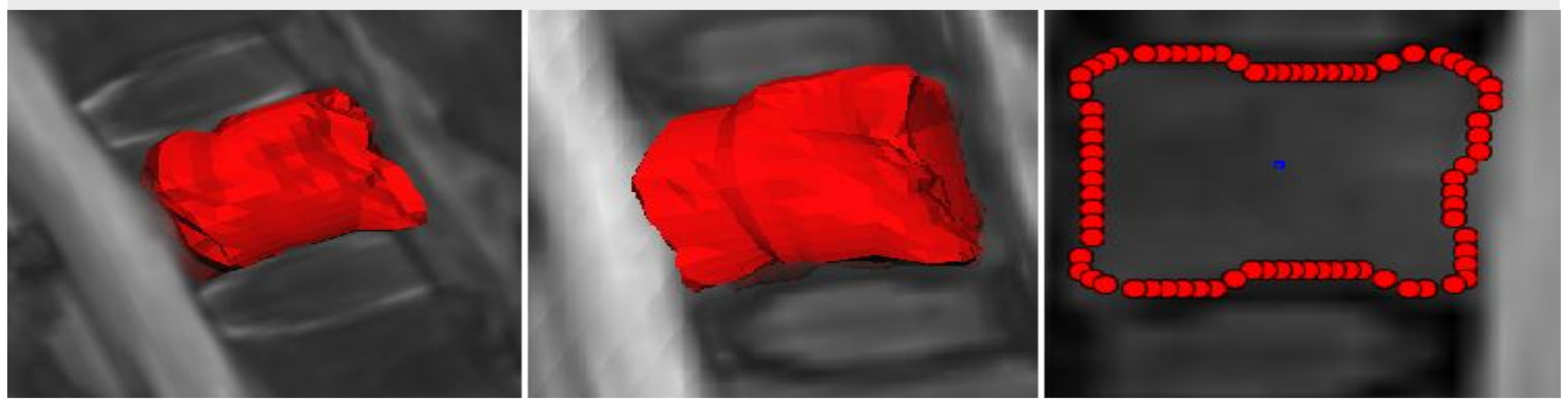

Figure 4: Left and middle: 3D segmentation results. Right: 2D Segmentation result.

References

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