Chapter 9

Conclusion

In this work we have developed efficient methods and algorithms related to the generation of geometrical models from three dimensional image data. This includes visualization of the primary data and the resulting models as well as image segmentation, extraction of line-like structures and triangulation of labelings for the final surface generation.

Our primary motivation has been to create a practically usable working environment for researchers in neurobiology, in particular for our cooperation partners investigating insect brains. In the course of this work we have verified the generality of the methods by utilizing them in many other applications areas as well.

We have described previous work in the diverse fields relevant for our goal and have adopted existing algorithms whenever suitable. We have identified problems in existing algorithms, as well as algorithmic gaps in our targeted work-flow and have modified and improved existing as well as developed new algorithms, where necessary.

In detail we have worked in the following fields:

Visualization: We have implemented visualization techniques for the primary data types occurring in our application: three dimensional image data, polygonal surfaces, and polyline trees, as well as arbitrary combinations of these. Specifically, we have implemented different slicing techniques (Section 3.2.1), which can be combined with the color mapping techniques (Section 3.2.2), thereby providing a powerful tool for image data and general scalar field visualization. Additionally, we have discussed and implemented isosurfacing and volume rendering algorithms, and explained how modern graphics hardware can be used to make such methods work at interactive speed (Sections 3.2.4 and 3.2.5). We have shown how maximum intensity projections can be applied to efficiently visualize sparse data sets like neuronal dendritic trees (Section 3.2.3) and used this as the visual basis for our interactive line extraction tool. In Section 3.3 we have presented a new technique for effective shading of line-structures, which can be implemented with hardware acceleration on current graphics workstations. In Section 3.4 we derive and propose a transparency model which significantly enhances the shape perception and indicate how it can be implemented in a hardware accelerated way.

Image Segmentation: We have designed and implemented a complete interactive image segmentation tool (Section 4.2). We have discussed why efficient interactive and semi-automatic segmentation tools are essential for practical applications and discussed how they can be complemented with interpolation and extrapolation methods (Section 4.3). We have proposed new distance map based interpolation schemes and shown results.

Line Extraction: We have developed an interactive method for the extraction of line-like structures based on maximum intensity projections, and a two-step shortest path finding algorithm 5.1. Furthermore we have discussed and tested existing methods for the automatic extraction of line-like structures, mainly developed for angiography analysis (Section 5.2). We propose a method to overcome limitations of these methods, when applied to dendritic trees (Section 5.2.4). We have shown how skeletonization followed by a graph extraction method can be used to turn the results of these algorithms into thin poly-line trees.

Geometry Reconstruction: Based on H.C.-Hege's idea to generalize the Marching Cubes algorithm to non-binary configurations [142], we have proposed a new method for the generation of consistent, intersection free, and closed surfaces from non-binary labelings (Section 6.1). This is complemented with our new algorithm to compute sub-voxel positions for the intersection points, which lead to smooth surfaces, which are still consistent with the given labeling (Section 6.3). Furthermore we have proposed a flexible and easy-to-implement method to create polygonal models from thickness-annotated graph structures for high quality rendering (Section 6.4).

Registration and Averaging: We have discussed, implemented, and used existing methods for correlation based and landmark based registration methods, and explained how they can be used in the context of our application for integration, comparison, and averaging (Chapter 7). We have proposed a non-affine registration procedure based on a per-structure rigid alignment combined with an interpolation scheme derived from the heat-transfer equation (Section 7.1.3); we have shown average intensity maps generated with this method (Section 8.2).

Applications: In Chapter 8, we have presented biological applications based on our results and methods and shown how each of the individual steps is used to investigate biological questions and how the different algorithms are linked to each other. We also give an outlook to future applications, that can now be attacked.

The described methods have been implemented within in a user-friendly frame-work [148], which is used by numerous research groups worldwide now. I hope to have contributed to open the door for further progress in computer aided neuro-biology, and beyond that in the other disciplines that rely on three dimensional image data, like medical diagnosis, surgery planning, seismic and geoscience research, or material science.