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Summary and conclusions

Image segmentation, i.e. the partitioning of an image into semantically meaningful regions, is often a necessary prerequisite to perform clinically relevant quantitative measurements in medical images. Due to the differences in image content, quality, organ shape and organ appearance in medical imagery, many low-level segmentation methods rely on a human observer to perform an initial image interpretation step. The main objective of this thesis is to investigate different approaches to represent high-level anatomical knowledge, which can be used to automate this segmentation initialization step, with particular application to segmentation of cardiovascular MR images.

The methods described in this work have been designed to equip the computer with a notion of 'the general picture' of thoracic anatomy as it commonly appears in three-dimensional MR volumes of the human thorax, where a tradeoff has been made between generality and accuracy in favor of generality. A critical design requirement for the methods described in this thesis was that the models encompass shape knowledge of multiple organ shapes in their three-dimensional spatial context, as opposed to shape knowledge of single organs without considering surrounding organs.

Chapter 2 reviews the different anatomical modeling techniques and their applications as described in the literature, where three application fields are addressed: visualization and education, functional analysis and image segmentation. Anatomical models for segmentation purposes are discussed in detail following a common subdivision of image segmentation into a number of abstraction levels in an image interpretation pyramid.

In Chapter 3, a novel application of a knowledge representation called Voronoi arrangement is described, which is suitable to express the notion of 'tomographic similarity' in a graph representation of the spatial embedding of a set of objects. The original formulation of Voronoi arrangements is extended with a computationally feasible graph matching method, which enables the calculation of a label isomorphism between an example image and a target image. The method is applied to labeling of the major vessels in aortic MR flow images, and it is demonstrated that the arrangement metric is a powerful representation for the content of images, in which objects differ in size, shape and location, but of which the spatial embedding is similar.

Chapter 4 describes the development of a novel, three-dimensional anatomical shape model, by which the three-dimensional boundary surfaces of the heart and lungs can be localized automatically in thoracic MR sets. The major organs in the thorax are described in a compact, closed form mathematical model by combining a set of fuzzy implicit surfaces by means of a solid modeling technique named Constructive Solid Geometry (CSG). The resulting mathematical shape description captures both the single organ shapes and their spatial context in a boundary potential function. This 'model potential' enables an automated model-image registration step in which the model is fitted to an image set of a different subject, where anatomical and pathological variations are expressed as differences in size, position and orientation of the different thoracic organs with respect to each other. The matching method was tested in phantom simulations and on 15 clinical thoracic MR scans from 13 different subjects. In 13 cases, the matching converged to a semantically correct solution, where the lung and epicardial surfaces were localized within a 10 mm margin. The matching method demonstrated to be applicable to thoracic MR data irrespective of its planar orientation, provided that a major part of the thorax is present in the image volume.

In Chapter 5, an important improvement is presented of the anatomical model matching method described in Chapter 4. By weighting gradient information based on a comparison between the local image gradient direction and the local model surface normal, prior knowledge about the expected gradient polarity is incorporated in the matching energy function. This increases the robustness of the matching algorithm considerably. The improved method has been quantitatively validated against a manually defined independent standard in a study based on twenty image volumes that were acquired in two centers from 17 patients and 3 normal subjects. This study demonstrated that on average, 90% (worst case 77%) of the computer detected borders of the heart and lungs was localized with sufficient accuracy (average 6 mm positional error) to automatically provide the initial conditions for a subsequently applied locally accurate segmentation method.

Chapter 6 presents a novel application of the anatomical thorax model developed in Chapters 4 and 5, which involves the automated acquisition planning of short-axis cardiac MR images directly from a set of scout views. In routine clinical practice, the planning of the optimal view of the left ventricle requires subjective user interaction and the acquisition of auxiliary scans. By applying the automated model matching method to a set of thoracic scout views as acquired prior to every cardiac MR examination, the position and orientation of the left ventricular long axis can be estimated automatically; these two scanning parameters are required to define the short-axis image volume. In a study including 20 patients suffering from various cardiac pathologies, it is demonstrated that the automatically generated scanning grids are defined with a comparable accuracy as in the manual scan planning procedure, even in the presence of cardiac shape deformations.

In conclusion, in this thesis different ways to integrate prior knowledge into image segmentation methods are explored. This work demonstrates that a set of coarse models of multiple organ shapes combined with a description of their spatial embedding provides an excellent starting point for subsequent, more accurate segmentation algorithms.