1 Introduction

Medical imaging techniques play an essential role in medicine for diagnostic, treatment planning and patient monitoring purposes. Over the last century, imaging modalities such as X-ray imaging and much later ultrasound imaging have become available to the clinician to examine a patient's condition and the changes therein over time (either with or without an intervention). The last two decades have shown a significant increase in the development and use of three-dimensional imaging techniques like Computed X-ray Tomography (CT) and Magnetic Resonance Imaging (MRI). Particularly MRI has rapidly become very popular for its flexibility and clinical versatility, as anatomical information can be acquired in combination with functional data. A number of specialized MR acquisition methods is available to depict vessel structures like peripheral and coronary vessels (Magnetic Resonance Angiography, MRA), measure blood flow velocities (Magnetic Resonance Velocity Mapping), examine metabolic processes (MR Spectroscopy) or measure myocardial wall contraction properties (MR tagging, MR velocity imaging, multi-slice multi-phase imaging). Especially in cardiology, MRI may potentially replace different types of other imaging modalities; for that reason MRI is increasingly referred to as the 'one-stop shop' approach for cardiac imaging.

The human observer plays a pivotal role in the processing and analysis of medical image data. In performing an image interpretation task, the human eye draws from a battery of intellectual resources in the form of prior knowledge, experience or expectation. As a result of this, a human observer is superbly capable of localizing organs in a medical image, analyzing organ dimensions and distinguishing normal from abnormal anatomical features. Unfortunately, the human eye is not fit to perform accurate measurements in medical images, and in clinical practice many diagnostic and treatment decisions are taken on the basis of visual estimates of the severity of a condition.

In general, such visual estimates suffice to formulate a diagnosis or treatment plan. With the ever-expanding spectrum of treatment and diagnostic options however, there is an increasing demand for more objective, quantitative measures. Over the last two decades, the computer has become an indispensable tool to satisfy this demand, where a computer is supplementary to the human eye in the sense that it can provide accurate quantitative measures based on local image information.

To derive measurements from image data, it is often necessary to outline the structure(s) of interest in the data, a process referred to as image segmentation. In many clinical applications, this is performed manually or semi-automatically, simply because the computer is not capable of interpreting an image scene autonomously. Therefore, computer-aided measurements are generally performed under human supervision, where an observer performs the complex task of image interpretation and the computer provides quantitative measurements. Furthermore, the human operator evaluates the computer output, and intervenes in case the automated segmentation results contradict human perception and common sense.

With the advent of tomographic imaging techniques like MRI and CT, which generally provide three- or higher dimensional image data, the amount of data per examination has increased to such an extent that manual analysis has become inpractical. For example, a cardiac MR examination provides the radiologist or cardiologist with a fully three-dimensional visualization of the heart in various stages in the cardiac cycle (typically 10 slices x 20 phases at each stage, totaling ± 200 images per examination). The time required to accurately analyze such image sets manually (2-3 hours) is a major obstacle for the widespread use of MRI as a routine diagnostic tool to quantitatively assess cardiac function. Secondly, manual contour drawing is a significant source of inter- and intra observer variabilities in clinical practice. These two factors have created a great demand for reliable tools to further automate the segmentation and functional quantification of medical image data.

A vast body of work has been described on image segmentation and its applications in medicine, where many automated segmentation methods merely utilize low-level image data. Unfortunately, the success rate of such data-driven segmentation methods greatly depends on the application domain. In MR images of the brain, the image conditions and tissue contrasts are such that a fully automatic segmentation is within reach purely based on low-level image features. However, most imaging protocols and modalities are susceptible to variations in image quality, where information may be unreliable or missing. In many cases, the human eye is still capable of tracking a particular organ in the image data based on experience and prior knowledge, where a data driven segmentation method clearly fails. There is a growing consensus in the medical imaging community that the integration of prior knowledge into data driven approaches is of critical importance to improve the robustness of automated segmentation methods.

The human visual system is capable of looking at an image at different levels of abstraction. When a human perceives an image, a first impression of the 'general picture' is combined with prior knowledge, and based on this information mix an observer is able to reason about the location of an object. From there on, the human observer can seamlessly focus his/her attention to those parts of the image of interest. The highest level in this image interpretation process involves a coarse localization of the object of interest amongst a number of other objects, whereas the second stage is aimed at accurately examining its shape. In each stage a tradeoff between generality and accuracy is made, where in the first stage emphasis lies on generality and in the second stage on accuracy.

The scope of the work described in this thesis is the development of knowledge representations suitable to further automate the highest level in the image interpretation chain for cardiovascular MR-images. By providing the computer with a *coarse* model of what different organs look like in their spatial context in cardiac MR-images, a segmentation problem can be approached in a similar coarse-to-fine manner as occurs in the process of human perception. The anatomical models developed in this work provide the computer with knowledge about 'the general picture' of thoracic anatomy as it appears in two types of cardiovascular MR-images with an emphasis on generality. They are intended to automatically provide the initial conditions for locally accurate segmentation methods, and are therefore not intended to be accurate in itself.

The thesis is further outlined as follows. In Chapter 2, an overview is provided of current anatomical modeling methods and their applications in medical image analysis. Chapter 3 describes a novel application of a topological representation for pictorial content called Voronoi arrangement, which is aimed at interpreting an image scene by merely utilizing knowledge about the spatial embedding of the objects in an image scene. Chapter 4 describes the development of a three-dimensional anatomical scene model of the thorax, with which a thoracic MR volume can be coarsely segmented into semantically meaningful regions. In Chapter 5, an important improvement in robustness of this modeling and matching technique is described, along with a quantitative assessment of the accuracy of the method. Chapter 6 describes the application of this thorax model to automate a part of the scan planning procedure for short-axis cardiac MR-images. Chapter 7 concludes this thesis with a summary.