Chapter 4.5
Methods and Applications for Segmenting 3D Medical Image Data

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ABSTRACT

In this chapter, we will give an intuitive introduction to the general problem of 3D medical image segmentation. We will give an overview of the popular and relevant methods that may be applicable, with a discussion about their advantages and limits. Specifically, we will discuss the issue of incorporating prior knowledge into the segmentation of anatomic structures and describe in detail the concept and issues of knowledge-based segmentation. Typical sample applications will accompany the discussions throughout this chapter. We hope this will help an application developer to improve insights in the understanding and application of various computer vision approaches to solve real-world problems of medical image segmentation.

INTRODUCTION

The advances in medical imaging equipment have brought efficiency and high capability to the screening, diagnosis and surgery of various diseases. The 3D imaging modalities, such as multi-slice computer tomography (CT), magnetic resonance imaging (MRI) and ultrasound scanners, produce large amounts of digital data that are difficult and tedious to interpret merely by physicians. Computer aided diagnosis (CAD) systems will therefore play a critical role, especially in the visualization, segmentation, detection, registration and reporting of medical pathologies. Among these functions, the segmentation of objects, mainly anatomies and pathologies from large 3D volume data, is more fundamental, since the results often become the basis of all other quantitative analysis tasks.

The segmentation of medical data poses a challenging problem. One difficulty lies in the large volume of the data involved and the on-time requirement of medical applications. The time constraints vary among applications, ranging from several tens of milliseconds for online surgical monitoring, to seconds for interactive volumetric measures, to minutes or hours for off-line processing on a PACS server. Depending on the application, this puts a limit on the types of methods that may be used. Another major hurdle is the high variation of image properties in the data, making it hard to construct a general model. The variations come from several aspects. First, the complexity of various anatomies maps to the large variation of their images in the medical data. Second, the age, gender, pose and other conditions of the patient lead to high inter-patient variability. Last, but not the least, are the almost infinite variations in an anatomy due to pathology or in the pathological structures. On the other hand, medical applications usually have a strong requirement of robustness over all variations. Beside the above challenges, system issues exist for the major modalities, such as noise, partial volume effects, non-isotropic voxel, variation in scanning protocols, and so forth. These all lead to more difficulties for the medical segmentation problem.

Knowledge-Based Segmentation

Medical image segmentation has the advantage of knowing beforehand what is contained in the image. We also know about the range of size, shape, and so forth, which is extracted from expert statements. In other fields of computer vision, such as satellite image analysis, the task of segmentation sometimes contains a recognition step. Bottom-up strategy is usually used, which starts with the low-level detection of the primitives that form the object boundaries, followed by merging. One sophisticated development is Perceptual Organization (Sarkar & Boyer, 1994; Guy & Medioni, 1996; Mohan & Nevatia, 1989), which attempts to organize detected primitives into structures. It is regarded as the "middle ground" between low-level and high-level processing. In 3D medical data, grouping is much more difficult due to the complexity of medical shapes. Because of this, top-down strategies prevail in 3D medical image analysis.

Knowledge-based segmentation makes strong assumptions about the content of the image. We use prior knowledge to find and tailor a general segmentation method to the specific application. Global priors are applied when the local information is incomplete or of low quality. It is a top-down strategy that starts with knowledge or models about high-level object features and attentively searches for their image counterparts.

The past several decades witnessed dramatic advances in the fields of computer vision and image analysis, from which the area of medical image analysis is derived. Various methods and frameworks for segmentation have been proposed, and many are driven by the needs of medical image analysis. These provide valuable theoretical thoughts as the basis of knowledge-based segmentation, but only at a high level. Typically, such a method is shown to be generic as it works on a number of cases from various applications with reasonable successes. This is quite different from the requirement of medical image segmentation in the real world, which depend heavily on the specific application—the workflow of the medical procedure, the anatomy and pathology of interest, the performance and accuracy requirements and the user inputs. Given all the priors and conditions of a medical application, we need to design the algorithm that will be the best compromise between accuracy, speed, robustness and user inputs. The resulting system will be specific to the given application; not only the algorithm, but also the parameter settings. A medical image analysis algorithm will be put to tests on thousands of data sets before it can be made into a clinical product. Hence, even if it is application specific, such an algorithm is general in that it has to cover all possible variations of the application.

A developer in this field not only needs to master the various methods in computer vision,

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