An Ontology for Knowledge-based Segmentation of Organs at Risk in Radiation Therapy Planning

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Abstract

Radiation therapy planning is based on three-dimensional image data, mainly acquired by computer tomography imaging. According to patient's anatomy, raw image data is used to derive an individual, three-dimensional organ model. It comprises radiation target volumes and adjacent organs at risk. Therapy relevant structures need to be segmented therefore in medical image data. When done manually, it turns into a time-consuming task that cannot be repeated for every session of a fractionated radiation treatment. As a consequence, automatic segmentation is in the focus of research to accelerate segmentation processes and support treatment planners. Fast and accurate segmentation would allow physicians to replan radiation session more often. This contribution presents an ontology to parameterize semi-automatic segmentation algorithms in a knowledge-based segmentation context. It is applied to semi-automatic segmentation algorithms in different body regions. As a result, incorporating only general knowledge can remain insufficient to deal with strong inter-patient variations. Case-dependent knowledge acquisition methods are additionally required.

Introduction

Radiation therapy with linear accelerators is often applied from different directions in a fractionated therapy course. The prescribed dose is not applied in one single treatment, but in a 4-6 weeks treatment course. Repair mechanisms of cells are utilized to compensate DNA damage in healthy tissue while neoplastic tissue is continuously exposed to therapeutic radiation. Extensive treatment planning and simulation based on three-dimensional image data (mainly acquired by computer tomography (CT) imaging) is a time-consuming process. An individually given, three-dimensional patient model is crucial to enable quantitative treatment planning, simulation and optimization on a computer before the actual treatment takes place. Treatment relevant volumes of interest (VOIs) are segmented in the image data, to derive the three-dimensional organ model. This is often done manually on a slice by slice basis with simple graphical tool. It turns into a time-consuming task, although treatment planners are supported with semi-automatic segmentation algorithms. Semi-automatic segmentation algorithms need to be parameterized carefully. Otherwise, false segmentation will be the result. It is often not simple to understand complex semi-automatic segmentation algorithms in detail and therefore finding an appropriate parameterization can easily turn into trial-and-error trails. As a consequence, it is a knowledge-intensive task that could be supported by knowledge-based systems. Appropriate parameterization for various segmentation algorithms and different VOIs draws on expert knowledge that is not always available. An ontology is therefore presented as a form of knowledge representation that incorporates image processing algorithms and an anatomical model.

Material and Methods

Knowledge-based systems explicitly distinguish domain knowledge from inference mechanism. An inference mechanism applies given rules as long as given facts fulfill their premises and lead to new knowledge. Ontologies are used in different contexts in medical applications, artificial intelligence, the semantic web and other computer sciences as form of knowledge representation.

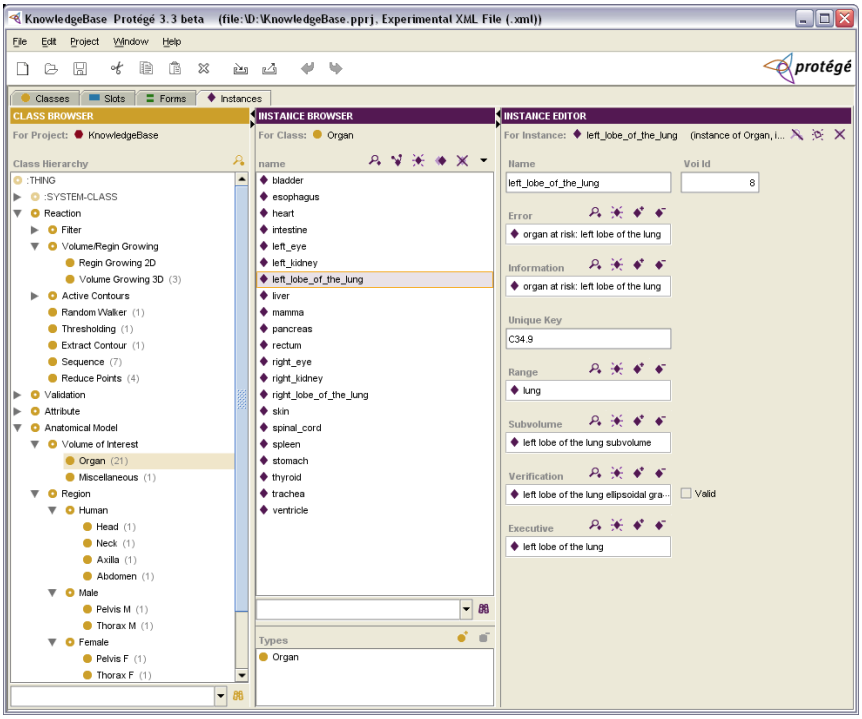

Figure 1: Knowledge base for automatic segmentation tasks.

Fig. 1 gives an overview of the knowledge base for automatic segmentation tasks in radiation therapy planning. Four main classes are shown, two of which are explained in more detail. Class *reaction* contains segmentation algorithms (e.g. volume growing, active contours, random walks, etc.), image filter and contour post-processing algorithms. Class *anatomical model* represents the human anatomy. It is divided into six body regions (*head*, *neck*, *axilla*, *thorax, abdomen* and *pelvis*). Each body region comprises certain organs at risk (OARs). For instance *left lobe of the lung* is displayed for the thorax. According to the international commission on radiation units (ICRU), each OAR has a name and a unique key. In CT imaging, lung parenchyma comprises certain Hounsfield units [-850, -500] HU and only a sub-volume that encloses the left lobe of the lung is appropriate for organ specific image analysis and segmentation tasks. In total, 21 OAR instances exist; however not all of them are connected with automatic segmentation algorithms yet. It turned out that representing only general knowledge, can remain insufficient to deal with large inter-patient variability. Additionally, patients can have severe preconditions like metal implants or resections. Therefore patient specific knowledge acquisition should be incorporated into a knowledge-based segmentation application.

Results

Four different methods of pattern recognition (k-nearest neighbor classification, linear and quadratic discriminate analysis, support vector machines and a perceptron) are investigated for patient specific knowledge acquisition on raw CT image data. They are applied to classify single transversal CT slices into one of six body region. Precise knowledge about a body region and its associated transversal slices allow expecting particular OARs, estimating their location and as a consequence adapting the general knowledge base to an individual case.

Discussion

Segmentation of organs at risk is a time-consuming and knowledge-intensive task. Time and knowledge are not always available for segmentation tasks in radiation therapy planning. Therefore knowledge-based systems are in the focus of research to provide expert knowledge for semi-automatic segmentation algorithms. A domain specific ontology is presented. As a result, only providing general knowledge turned out to be insufficient to deal with large inter-patient variability. Knowledge acquisition methods are necessary to adapt anatomical knowledge to individual conditions.