Image Analysis Software Prototype for the Segmentation and Quantification of Lung Nodules based on the Cognition Network Technology®

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Abstract. We present a software prototype for semi-automatic segmentation and quantification of lung nodules. The system is based on an image analysis platform, which enables users to develop different image analysis solutions for different data modalities. The technology behind the platform is the Definiens Cognition Network Technology®, which is a context-driven approach based on objects and knowledge. The presented system quantifies the diameters required by the Response Evaluation Criteria in Solid Tumors (RECIST) criteria and calculates the volume of the lung nodules.

Keywords: semi-automatic segmentation, objects, context, knowledge, volume.

1 Introduction

For Computer Aided Detection and Diagnosis systems (CAD) the image analysis is an important component. Fields of applications, which need extensive image data analysis, are for example automated tumor quantification by using CT, MRI, ultrasound data for mammography, detection of polyps in colonoscopy, detection and localization of ischemic areas in the brain, detection and volumetric measurements for liver and lung tumors, measurement of aneurisms in blood vessels [8]. Using analysis and reconstruction of 3D image data, three dimensional reconstructions of organs, vessels, muscles, and bones can be achieved. 3D data sets may be used for the reconstruction of individual anatomical models. The development of algorithms and methods for “multiorgan-extraction” is the goal of actual research and development [3, 4, and 7]. Most of the methods which are used for the development of the appropriate image analysis solutions are pixel based. Therefore they show strong limitations in using context and domain knowledge. The standard for performing quantification of lung nodules is RECIST [5]. The RECIST evaluation criteria require the measurement of nodule diameters. There are several initiatives like the Quantitative Imaging Biomarkers Alliance (QIBA), which evaluate the quantification of volumetric changes of nodules in CT data sets as a *standard* for the assessment of therapy response. There are also several works, which focus on the assessment of volumetric changes of lunge nodules (e.g., [9]). Some of them are using semi automated algorithms to calculate tumor volume and other parameters [6].

The software we present enables the measurement of the volume of lung nodules. The aim of the software demonstration is to show the advantages of context driven, object and knowledge based versus pixel based algorithms concerning lesion measurements in CT series. For doing that, we use as example the quantification of lung nodules in such data sets.

2 Materials and Methods

The Cognition Network Technology® is a context-based approach based on objects and knowledge. The technology incorporates elements from semantic networks, description logics, and functional programming. It can be applied to different kinds of data [1, 2]. Such data are for example images of different dimensionality, magnification and resolution and from different acquisition modalities.

In pixel-based image analysis algorithms, objects of interest are extracted through a series of filters, including intensity thresholds, proximity, gradients, and edges. These mathematical filters are generally applied to a whole image or to "regions of interest" in images, evaluating pixels or pixel fields in relation to neighboring pixels. New images are produced, transforming "regions of interest" from the images into "objects of interest" that can be extracted with a simple threshold. Contents of biomedical image data are often very complex. In general, such problems cannot be solved with conventional procedures of applying a sequence of pixel filters combined with thresholds.

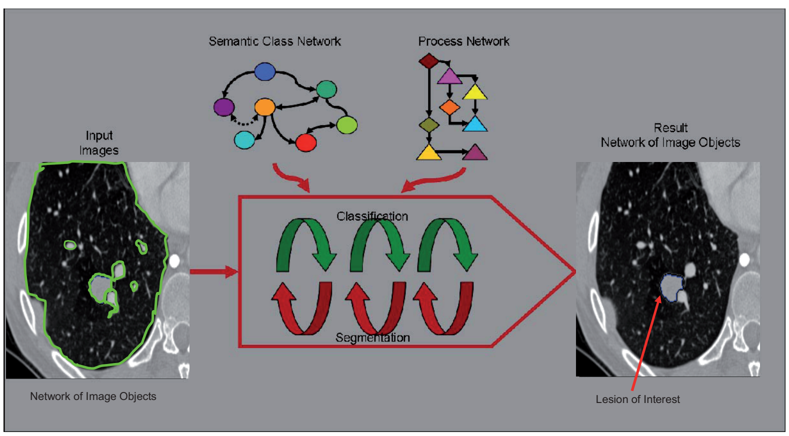

Fig. 1. Schematic representation of the Definiens Cognition Network Technology for image data analysis.

In contrast to such pixel-based approaches, Definiens Cognition Network Technology® creates not only the final product (objects of interest) but also automates the intermediate steps involved in the process. The process evolves during segmentation, rather than being predefined. Thus, semantic relationships are generated by classifying all image objects, including the intermediate objects. This image analysis technology invokes an evolutionary process comprised of alternating classification and segmentation which may be applied to different data modalities synchronously (Fig. 1). Information about the image objects and their relationships gathered *during* the course of segmentation can then be used effectively for future purposes. Alternating segmentation processes may take place in a single image or image modality by using contextual information about objects drawn from the segmentation and classification of additional images or image modalities. Finally, a *network of objects* in the same or in different images of the same or of different modalities is created in order to understand the overall system. Subsequent data analysis relies on the development of these "*Cognition Networks*", consisting of objects and their mutual links. "*Cognition Network Language*" (CNL) is the corresponding Graphical User Interface meta language that allows efficient development of rule-based algorithms to create and process Cognition Networks (Fig. 1). CNL consists of four basic data structures: *Processes, Domains, Image Objects* and *Image Object Classes*. By selecting and parameterizing the Processes the particular processing algorithms are specified for a given programming step, whereas through the definition of a Domain the system is guided to the data structure that is going to be processed. The Processes define "what" and the Domains "where" processing takes place. The most important Domains are Pixel Level Domains for filtering and initial segmentation operations; Image Object Domains that specify objects based on location in the network, their classification, and/or its specific attributes for the object-oriented processing, and Image Object Relation Domain which allows the navigation in the image object network. Through the formulation of domains and semantics, CNL supports the modeling and usage of specific expert domain knowledge within rule sets. The platform allows for the analysis of an arbitrary number of image layers (channels) simultaneously.

By operating over the presentation of the structures of interest on different scales in the object network, measurements, such as morphology, embedding, distribution, composition, structure, intensities, relative location and co-localization are possible.

Therefore features are defined that describe the individual properties of objects, the relationships of objects to their neighborhoods, the mutual relationships of groups of objects in the same or in different images, image sets and modality related features and metadata, and image modality properties. The technology defines context-neutral and context-sensitive features.

Based on this technology an image analysis platform has been developed (Definiens Developer XD). The platform uses the concept of "maps". These maps may contain copies of the same or of different data modalities, such as X-ray images and excel tables [7]. Algorithms for segmentation and classification of data can be applied to different maps with the same image data in order to achieve the best segmentation results. Multiple data modalities may be stored and analyzed in maps synchronously. While each map can be analyzed independently, the system utilizes image analysis results from one image or from multiple images and image modalities to provide context for the analysis of objects in other images in an alternating, iterative process. In this way intermediate analysis results of objects in an image or in data of a certain modality may be used in the next analysis steps as context for the analysis of data in the same or in other data as image data of the same or different modalities. In this way, analysis of different objects of interest can be done in multiple images and image modalities simultaneously.

At the beginning of this analysis process, simple, knowledge-based "seed objects" are automatically segmented and classified for use in the initial data processing. These seed objects are then utilized in subsequent analysis steps in order to provide context for the detection, segmentation and classification of other objects in the same image or in other images. As the technology enables multi-scale data analysis, multiple levels of information can be extracted from image data. They can also be analyzed in isolation from other objects, or in the context of other objects. Objects can be linked on demand and placed into object networks. Semantic objects, such as a lung lesion or the lungs itself, that are represented by multiple images may be linked to each other in multidimensional objects.

3 Results

We used Definiens Developer XD to develop a software prototype dedicated to the segmentation and quantification of lung nodules in CT image stacks. This “lung nodule” software prototype comprises a CNL Rule Set. As the CNL enables the automated measurement of object properties by using predefined and user defined object features, a detailed quantification of the nodule properties is made. Such features measure for example signal intensity, surface, volume, diameters, both as absolute and relative values. The system enables at least a detailed quantification of the nodules properties.

The major steps of the developed CNL Rule Set are the following: In the first step, the upper and lower threshold for the intensity of the lung nodule are calculated based on (a) the window settings and (b) the intensity distribution in the neighborhood of a seed point. Both the window settings and the seed point are provided by the user. Using the threshold values, an Image Object is created by region growing. If it is not isolated (touching the pleural wall or a vessel), the segmentation process is refined by using context Image Objects for the pleural wall and/or vessels.

Figure 2 shows three examples from the public database of the Lung Image Database Consortium (LIDC) with screen-shots of the annotation by a radiologist (left) and the segmentation result (right). Three types of lung nodules are depicted: isolated (top), juxtavascular (middle), and juxtapleural (bottom). The results of the volume quantification are stated below the corresponding screen-shots.

4 Discussion

The software prototype shows the ability of the Definiens Cognition Network Technology, the ability of CNL and the flexibility of the concerning image analysis

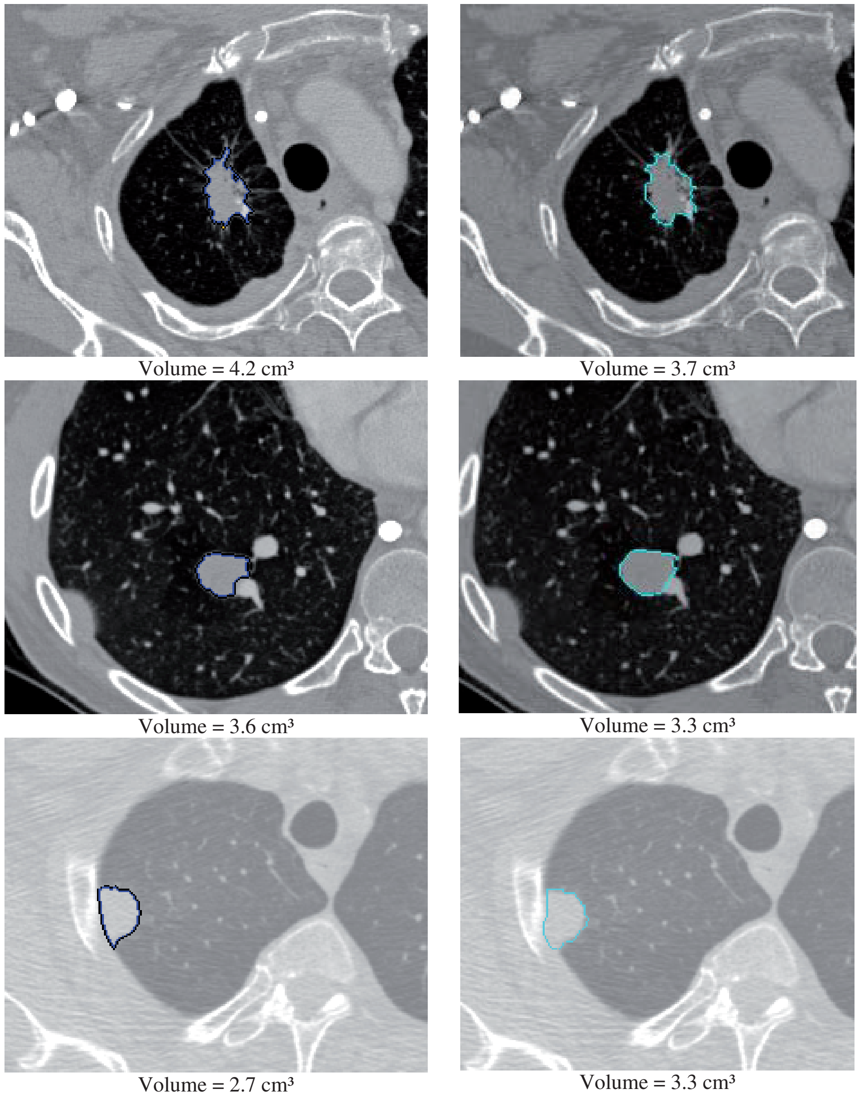

Fig. 2. Segmentation results for three examples from the LIDC database. The annotation of a radiologist and the corresponding segmentation result are shown on the left and the right, respectively.

platform for the development of tailored image analysis solutions. Such solutions can further be developed in order to fulfill the needs of the domain experts. Especially the solution for the lung nodules can be further developed in a CAD system and can support radiologists in their daily work. Although further evaluation of the system is needed, the first results are very promising. This kind of CAD prototype development may be used as an educational example for the development of further CAD systems as they are needed in different domains like radiology, pathology etc..

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