Description of a Fully Automatic Lung Segmentation Algorithm Based on the Cognition Network Technology

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Abstract. Accurate and fully automated segmentation and quantification of organs are prerequisites towards operational computer aided diagnosis and therapy control systems. The Definiens Cognition Network Technology presented in this paper provides a framework for rapid development and scalable execution of image analysis solutions. The Cognition Network Technology combines pixel-processing techniques with iterative, context-based object or segment generation and classification processes using a semantic knowledge base. We applied this technology to identify automatically left and right lungs in 3D CT data.

1 Methods

1.1 Cognition Network Technology

The Cognition Network Technology [1] is implemented in the software platforms Definiens Enterprise Image Intelligence Suite and Definiens XD, the latter being the platform used for the analysis of the present study. Both platforms feature an environment where scripts written in the Cognition Network Language, described in detail below, can be developed and executed. This environment allows the user to load image data, and generate, execute and edit graphically the analysis script. Results can be visualized, and properties and overall statistics of the resulting three dimensional image objects (segments) can be exported. The interactive mode allows for rapid script development with a steep learning and progress curve. Medical expert knowledge can be modeled using a class hierarchy (ontology) with fuzzy classifier functions to accommodate uncertainties in the description accuracy and to increase classification robustness in the presence of biological variations. During solution development, the model structure and its parameters are iteratively improved to converge to the required classification and segmentation accuracy, enabling easy integration of new knowledge. The execution environment uses a workspace concept in which the user may process many images offline and - if needed - in parallel on a computer cluster. Definiens XD

is a newly developed platform that is specifically designed for multi-dimensional image data [4]. In particular, it facilitates development and deployment of a wide range of multidimensional image analysis applications within areas such as medical imaging and preclinical small animal imaging.

1.2 Cognition Network Language

The Cognition Network Language (CNL) [1] is an object-based procedural computer language which is specifically designed to enable automated and semiautomated implementation of complex, context dependent image analysis tasks. It consists of four basic data structures: processes, domains, image objects and image object classes. The language was designed to provide an easy to learn but powerful approach to specify a complex image analysis task through the combination of less complex tasks. Each language element representing the dynamic of the analysis is called a process. There are processes to manage image objects, object features, classes, and variables, file input/output, image filters, segmentation, object linkage and classification operations, and control structures such as conditional execution commands and loops. The processes are organized in a process tree hierarchy. The process execution engine recursively executes a root process and then subsequently its entire child processes in a depth-first order. 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 specify where processing takes place. The most important domains are pixel level domains for filtering and initial segmentation operations, the image object domain for processes, which operate on image objects (segments) with specific classifications and properties, and the image object relation domain, which allows the navigation in the image object network. Navigation is particularly useful to process the neighbors or sub-objects of a given image object in the current process with the algorithms in its sub-processes. An image object represents a group of voxels or a group of image objects. An image object comprises methods to calculate its properties such as shape, position, mean spectral values or texture. Since image objects may be linked to other image objects using specific processes, relational properties such as relative surface contact area or relative brightness can be easily computed and used in the processing. Image objects are generated either by basic segmentation (e.g., multi-resolution segmentation [2]) or by grouping existing image objects on a higher image object level. The Cognition Network Language provides operations to re-segment and to re-classify image objects with specific, potentially context dependent properties. Each image object may be classified according to the fuzzy membership functions defined in the image object classes. Image object classes describe the kind of objects to be searched for in a given image. The classes may be grouped in a class hierarchy to enable the execution of process operations on groups of classes. Each class carries a name, a visualization color and optionally a logical expression of fuzzy membership functions. The membership functions are piecewise linear functions which describe the contribution of

each specified image object property (e.g., area, brightness, distance to another image object with a given classification) to the overall class member membership. Image object classes without membership function may be used as labels, which can be assigned to an image object using a class assignment process.

1.3 Lung Segmentation Algorithm

Overview The segmentation algorithm presented here identifies the left and right lungs. It runs fully automatically, using a region growing approach based on contextual as well as density, geometry and shape information. It is based on the Definiens Cognition Network Technology described above. It consists of the following parts:

(a) Initial Segmentation
(b) Refinement of Lung Boundary
(c) Trachea and Bronchi Context Object Segmentation
(d) Refinement of Left and Right Lung Separation.

The initial segmentation is based on the preprocessing of the semiautomated approach for volumetric analysis of lung tumors by Bendtsen et al. [3]. It returns an approximate segmentation of pathological and non pathological lungs (a). In the second step, the border to neighboring organs (such as liver and spleen) as well as the tips of the lungs is refined (b). Third, trachea and bronchi are classified (c) in order to avoid wrong classification as lungs and to use them as additional context to finally improve the separation of left and right lung (d).

Algorithm

Initial Segmentation The initial segmentation is based on the preprocessing of Bendtsen et al. [3] and performs automated organ segmentation with the main goal of segmenting the aerated lung. To this end intensity, object size, context, and geometry constraints are applied. For a detailed description of the individual steps see [3]. Figure 1 shows exemplary results of the initial segmentation.

Refinement of Lung Boundary In order to refine the initial segmentation the following steps are applied:

(a) Grow into image objects enclosed by lung in 3D
(b) Remove false positive high intensity structures at the lung border
(c) Grow into objects partially enclosed by lung in 3D
(d) Grow lungs in Z into low density voxels

Figure 2. shows exemplary results of the refinement step.

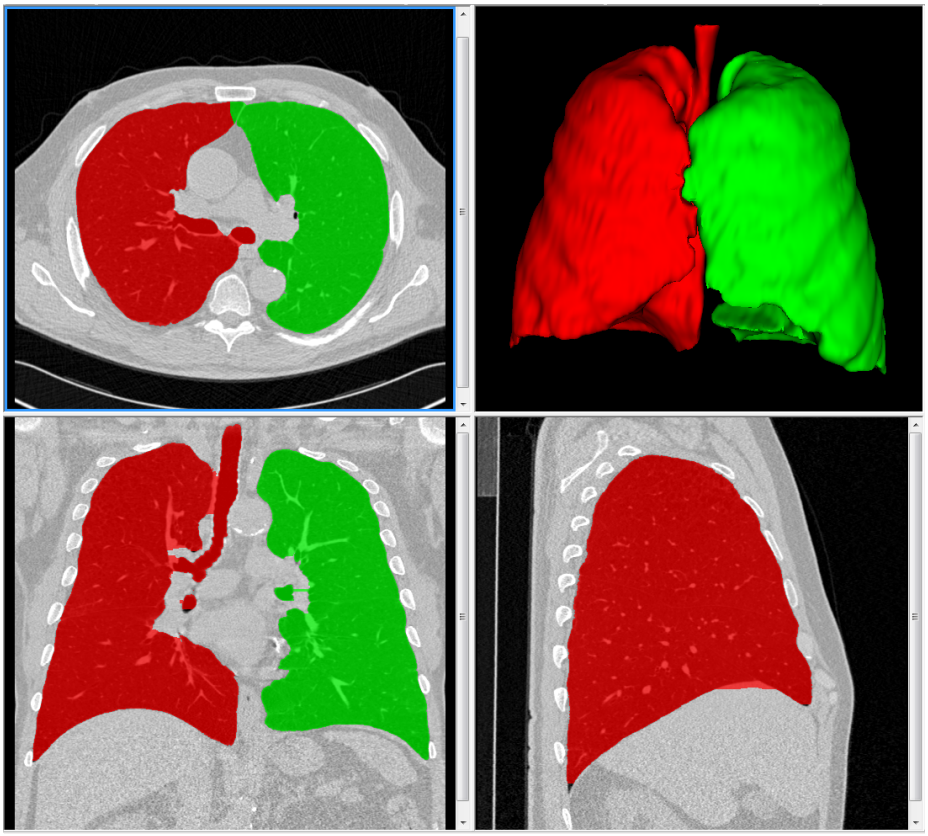

Fig. 1. MPR view of the initial segmentation of left (green) and right (red) lung. Please note that the trachea and bronchi are classified as lung; separation of the left and right lung is not perfect; and the lower tip of the left lung is missing.

Trachea and Bronchi Context Object Segmentation In order to segment the trachea and bronchi as additional context object the following steps are applied:

(a) Define a trachea region based on the existing lung segmentation
(b) Create 2D candidates based on trachea region
(c) Identify trachea seed based on fuzzy membership function, exploiting context, shape, and size information of the 2D candidates
(d) Grow trachea seed into neighboring candidates
(e) Grow into lung objects above trachea

Figure 3. shows exemplary results of the trachea and bronchi segmentation.

Refinement of Left and Right Lung Separation In order to improve the separation of left and right lung the following steps are applied:

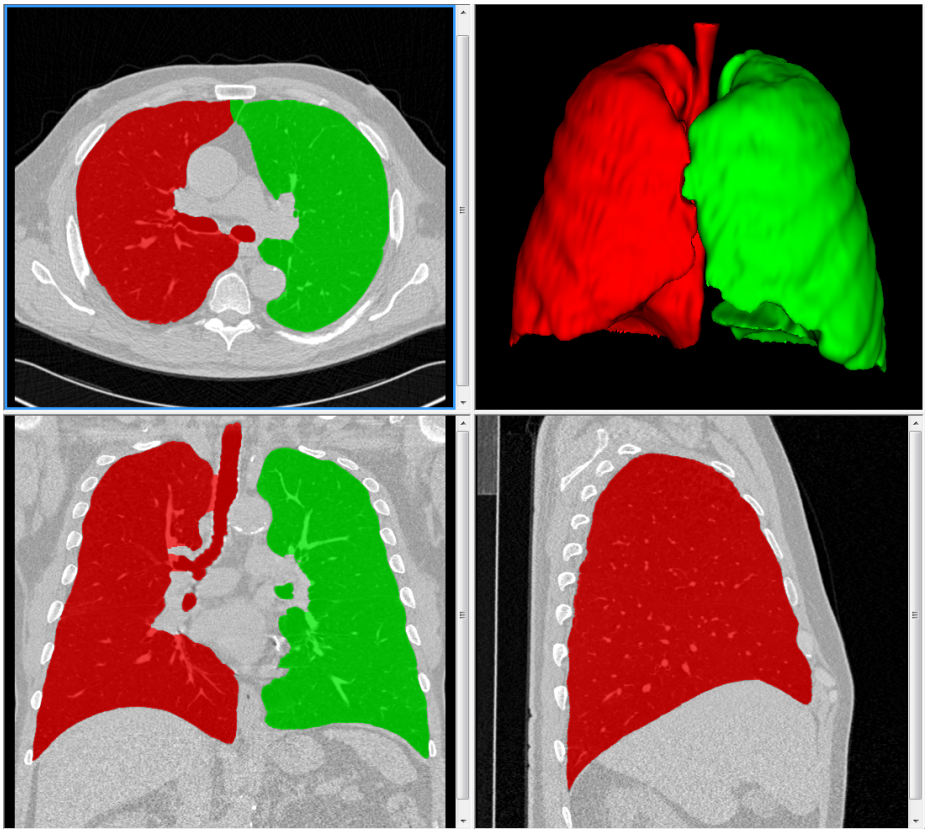

Fig. 2. MPR view of the refined left (green) and right (red) lung segmentation. Please note that the lower tip of the left lung is now classified correctly.

(a) Separate touching lungs by shrink based on intensity
(b) Create separation candidate segmentation of lungs
    (i) Identify high intensity voxels within lung segmentation
    (ii) Grow high intensity voxels in Z
    (iii) Remove high intensity objects enclosed by lung
    (iv) Grow remaining lung objects into high intensity objects
(c) Identify slices with reclassification candidates
(d) Define bounding box around left and right lung in remaining slices
(e) Validate candidates according to bounding box
(f) Reclassify candidates in 2D according to relative border to left or right lung
(g) Reclassify candidates in 3D according to relative border to left or right lung
(h) Separate touching lungs by shrink based on intensity

Figure 4. shows exemplary results of the refined separation of left and right lung.

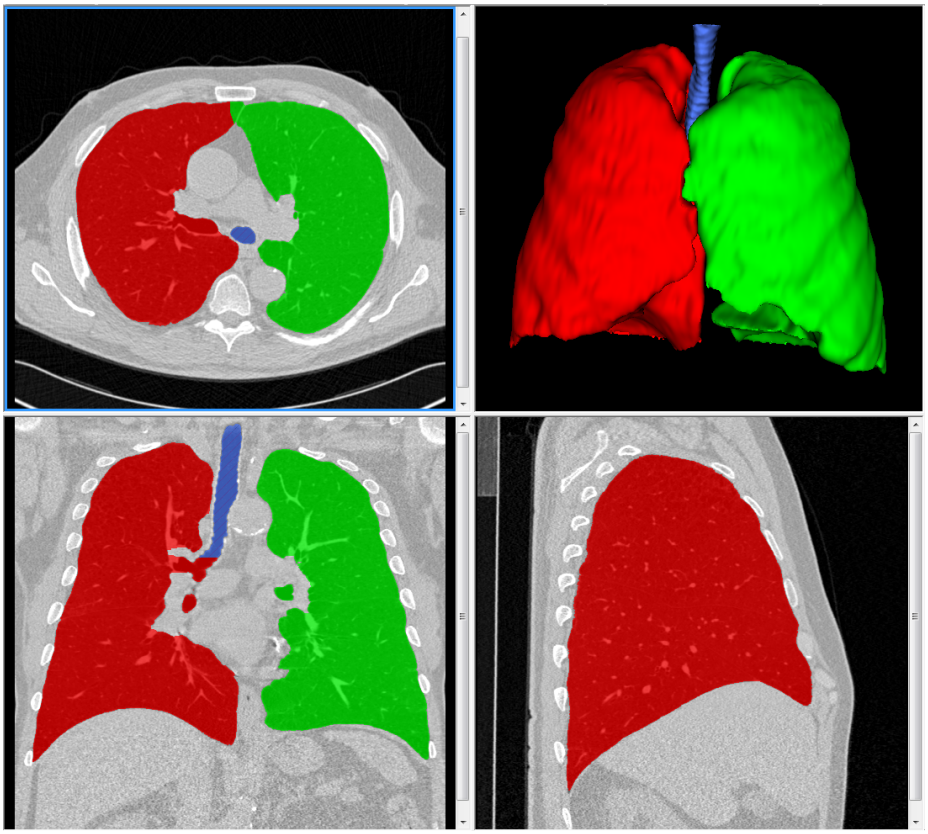

Fig. 3. MPR view of the trachea and bronchi segmentation. Please note that the trachea and bronchi are now displayed in blue (left lung: green; right lung: red).

1.4 Training Data

CT scans used for training contained pathological and non pathological cases. Slice distances, or reconstruction intervals, varied between 1 and $5mm$. The slice thickness generally was equal to the slice distance (range 1 to $7mm$).

2 Results

2.1 Segmentation accuracy

The segmentation algorithm was evaluated using the LOLA11 test data set which contains 55 CT scans. Table 1 shows the mean, standard deviation (SD), minimum, first quartile (Q1), median, third quartile (Q3), and maximum overlap for the left and the right lung, respectively. For details of the evaluation protocol, refer to the LOLA11 website [5].

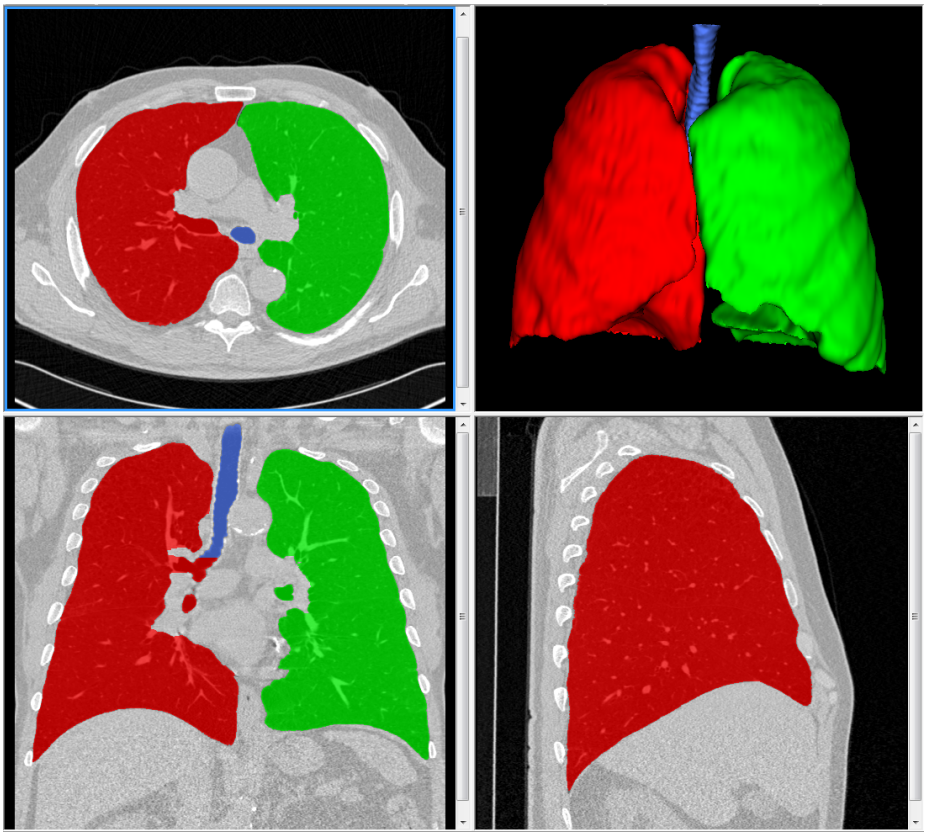

Fig. 4. MPR view of the final segmentation result (trachea and bronchi in blue, left lung in green and right lung in red). Please note the improved separation of left and right lung.

2.2 Runtime

The mean runtime of 12.6 minutes per CT scan of the LOLA11 test data was achieved on a Dell E6500 laptop with an Intel Core2 Duo CPU T9600 @ $2.80GHz$; $4.00GB$ RAM running Win7 Professional $64bit$ SP1.

3 Discussion

The segmentation algorithm is optimized for thick slice CT scans. Still, the results for the LOLA11 test data set (slice distance between 0.3 and $1.5mm$) are satisfactory, as can be seen in Table 1 (see columns median, Q1 and Q3). The outliers (see Table 1, column *min*) were to be expected, because two CT scans (IDs 44 and 45) contain non-aerated lungs. The segmentation of this type

Table 1. Results of lung segmentation for the 55 scans in LOLA11.

	mean	SD	min	Q1	median	Q3	max
left lung	0.950	0.172	0.000303	0.98	0.987	0.993	0.998
right lung	0.949	0.187	0	0.984	0.99	0.993	0.998
score	0.949						

of lungs, as well as the segmentation of lobes, is planned for a future extension of the algorithm.

4 Conclusion

In summary we presented a fully automated algorithm for the segmentation of left and right lungs in 3D data that uses contextual information and is based on the Definiens Cognition Network Technology.

References

1. Athelogou, M., Schmidt, G., Schäpe, A., Baatz, M., Binnig, G.: Definiens Cognition Network Technology - A Novel Multimodal Image Analysis Technique for Automatic Identification and Quantification of Biological Image Contents. In: Shorte, S.L., Frischknecht, F. (eds.) Imaging Cellular and Molecular Biological Functions, pp. 407–421. Springer-Verlag, Berlin Heidelberg (2007)
2. Baatz, M., Schäpe, A.: Object-Oriented and Multi-Scale Image Analysis in Semantic Networks. In: Proc. 2nd International Symposium on Operationalization of Remote Sensing. Enschede (August 16–20 1999)
3. Bendtsen, C., Kietzmann, M., Korn, R., Mozley, P.D., Schmidt, G., Binnig, G.: X-ray computed tomography: semiautomated volumetric analysis of late-stage lung tumors as a basis for response assessments. Int J Biomed Imaging 2011, 361589–361589 (2011), http://www.hubmed.org/display.cgi?uids=21747819
4. Definiens AG: Definiens XD. http://www.definiens.com
5. van Rikxoort, E., van Ginneken, B., Kerkstra, S.: Lobe and Lung Analysis 2011 (LOLA11). http://www.lola11.com (2011)