Knowledge-Driven 3D Medical Image Interpretation: A Few Examples

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The complexity of the human body and its understanding through medical imaging techniques require the development of image processing and interpretation methods that cope with this complexity. Recently, significant advances both in image acquisition techniques and in image processing have been achieved. In particular, advanced and sophisticated image processing methods find in medical imaging a privileged field of applications. The major aims concern help in diagnosis, therapy planning, surgical planning, patient's follow-up, morphometry, variability assessment, modelling, support for neuroscience applications, etc. This covers both clinical and research applications. To these aims, methods have to be developed to improve image quality, to perform segmentation and recognition of organs, pathologies, etc., to provide quantitative measures, to fuse multi-modal image data, to provide numerical models and to improve 3D visualization. In this paper, we present a few examples, developed recently in our group at ENST. More details can be found in the references mentioned.

1. Modelling and Knowledge Representation

Models constitute an important source of information that provides generic knowledge, complementary to the actual patient's data and images. On the one hand, biological, anatomical or biomechanical models can be used to guide image interpretation. On the other hand, medical images can be exploited in order to build models of the human body, from an anatomical or functional point of view. Such models have been developed for specific organs, or for some functions such as breathing.

Let us here consider more specifically the first aspect. Iconic representations of anatomical knowledge can be found, as anatomical atlases. Although their use for normal structure recognition is well acknowledged, they remain difficult to exploit in pathological cases. Anatomical knowledge is also available in textbooks or dedicated web sites, and expressed mainly in linguistic form. These models involve concepts that correspond to anatomical objects, their characteristics, or the spatial relations between them. Human experts use intensively such concepts and knowledge to recognize visually anatomical structures in images. This motivates their use in computer aided image interpretation. Some attempts to formalize this knowledge have been recently performed, in particular in the form of ontologies (e.g. the Foundational Model of Anatomy). In our work, we concentrate mainly on spatial relations, which are strongly involved in linguistic descriptions. They constitute a very important information to guide the recognition of structures embedded in a complex environment, and are more stable and less prone to variability (even in pathological cases) than object characteristics such as shape or size. We proposed mathematical models of several spatial relations, in the framework of fuzzy sets theory, which prove useful to recognize thoracic and brain structures. These fuzzy representations can enrich anatomical ontologies and contribute to fill the semantic gap between symbolic concepts, as expressed in the ontology, and visual percepts, as extracted from the images. These ideas were used in particular in our segmentation and recognition methods.

2. Segmentation and Recognition of Normal and Pathological Structures

The methods we develop for segmentation and recognition of 3D structures in medical images can be seen as spatial reasoning processes. Two main components of this domain are spatial knowledge representation and reasoning. In particular spatial relationships constitute an important part of the knowledge we have to handle, as explained before. Imprecision is often attached to spatial reasoning in images, and can occur at different levels, from knowledge to the type of question we want to answer. The reasoning component includes fusion of heterogeneous spatial knowledge, decision-making, inference, and recognition. Two types of questions are raised when dealing with spatial relationships:

1. given two objects (possibly fuzzy), assess the degree to which a relation is satisfied;
2. given one reference object, define the area of space in which a relation to this reference is satisfied (to some degree).

In order to answer these questions and address both representation and reasoning issues, we rely on three different frameworks and their combination:

- mathematical morphology, which is an algebraic theory that has extensions to fuzzy sets and to logical formulas, and can elegantly unify the representation of several types of relationships;
- fuzzy set theory, which has powerful features to represent imprecision at different levels, to combine heterogeneous information and to make decisions;

- formal logics and the attached reasoning and inference power.

The association of these three frameworks for spatial reasoning is an original contribution of our work.

The first recognition approach, called global, uses the first type of question (1). The idea is to represent all available knowledge about the objects to be recognized. A typical example consists of graph-based representations. The model is represented as a graph where nodes are objects and edges represent links between these objects. Both nodes and edges are attributed. Node attributes are characteristics of the objects, while edge attributes quantify spatial relationships between the objects. A data graph is then constructed from each image where the recognition has to be performed. Each region of the image (obtained after some processing) constitutes a node of this data graph, and edges represent spatial relationships between regions, as for the model graph. The comparison between representations is performed through the computation of similarities between model graph attributes and data graph attributes.

The second type of approach relies on the second type of question (2) and is called here progressive or sequential. In this approach, objects are recognized sequentially and their recognition makes use of knowledge about their relations with respect to other objects. Relations with respect to previously obtained objects can be combined at two different levels of the procedure. First, fusion can occur in the spatial domain, using spatial fuzzy sets. The result of this fusion allows us to build a fuzzy region of interest in which the search of a new object will take place, in a process similar to focalization of attention. In a sequential procedure, the amount of available spatial relations increases with the number of processed objects. Therefore, the recognition of the most difficult structures, usually treated in the last steps, will be focused in a more restricted area. Another level of fusion occurs during the final decision step, i.e. segmentation and recognition of a structure. For this purpose, spatial relations are introduced in the evolution scheme of a deformable model, in which they are combined with other types of numerical information, usually edge and regularity constraints.

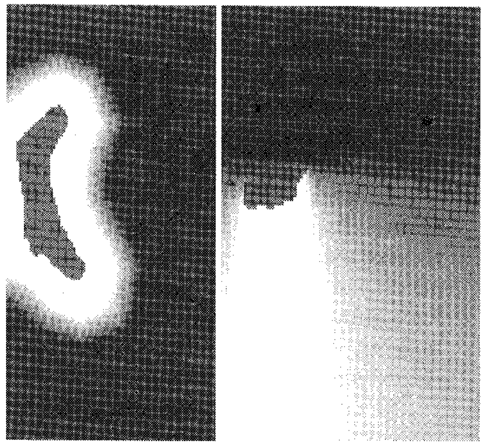


Fig. 1: Fuzzy representations of spatial relations: (a) close to the lateral ventricle and (b) below the lateral ventricle.

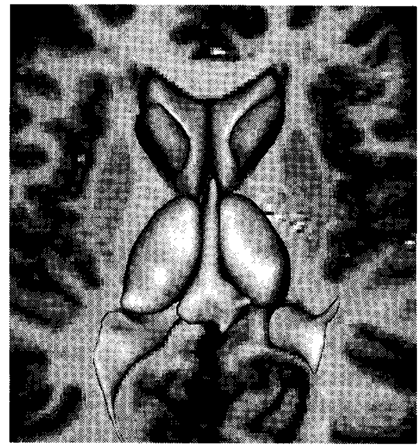


Fig. 2: Segmentation result superimposed on one axial slice.

3. Some Illustrations

Fuzzy representation examples of spatial relations close to and below the lateral ventricle are shown in Fig. 1.

A few segmented and recognized structures in 3D MRI using spatial relations and deformable models (3D views superimposed on one slice of the original MRI volume) are shown in Fig. 2 in a normal case and in Fig.3 in two pathological cases. The use of spatial relations allows us to obtain good segmentation and recognition results, although the objects are strongly deformed.

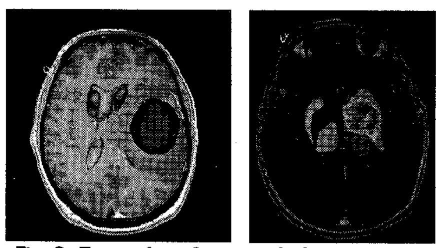


Fig. 3: Examples of two pathological cases.

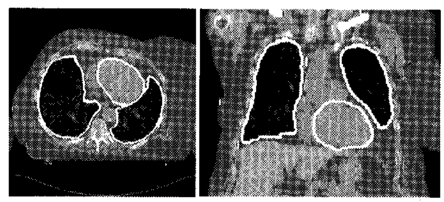
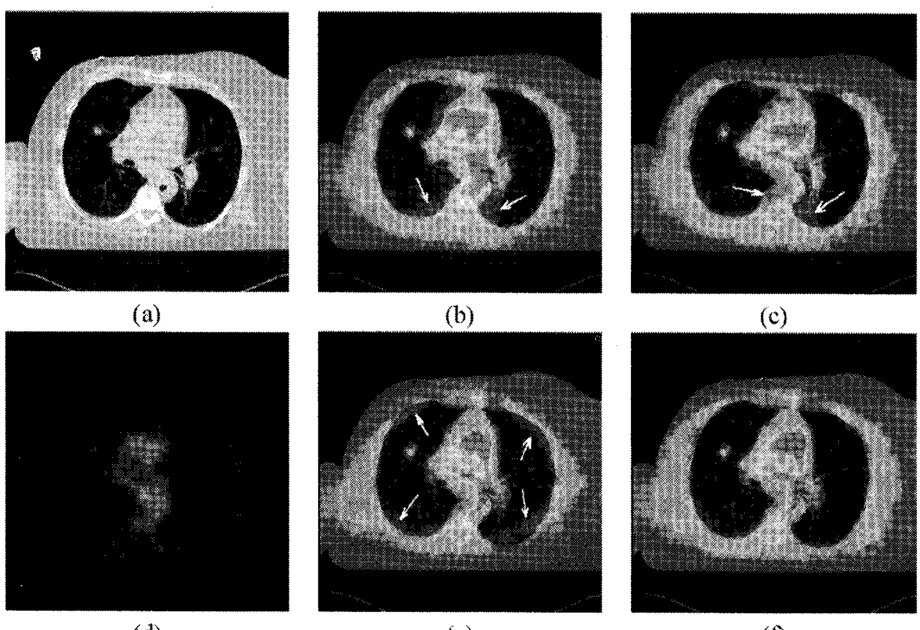


Fig. 4: (a) Segmentation of the lungs and (b) the heart in thoracic CT images

Segmentation of the lungs and the heart in thoracic CT images, using the information on the position of the heart (between the lungs) is shown in Fig. 4. One axial slice and one thoracic slice are shown.



This segmentation is then used in a non-linear registration procedure between CT and PET images, including a breathing model. A slice of the original data is shown in (a) (CT) and (d) (PET). (b, c, e) show non satisfactory registration results (problems are indicated by arrows) while (f) shows a good registration, as obtained using a non-linear technique and exploiting the segmentation results.

4. Current Work

Our current work consists of developing further methods for pathological cases, including quantification and patient's follow-up. Other applications such as heart imaging, high-resolution vascular imaging, foetal imaging are also under study. On a more methodological point of view, complex spatial relations as well as spatial reasoning schemes are still being developed.

References

J. Atif, C. Hudelot, G. Fouquier, I. Bloch, and E. Angelini. From Generic Knowledge to Specific Reasoning for Medical Image Interpretation using Graph-based Representations. In International Joint Conference on Artificial Intelligence IJCAI'07, Hyderabad, India, January 2007.

E. Bengoetxea, P. Larranaga, I. Bloch, A. Perchant, and C. Boeres. Inexact Graph Matching by Means of Estimation of Distribution Algorithms. Pattern Recognition, 35:2867--2880, 2002.

I. Bloch. Fuzzy Spatial Relationships for Image Processing and Interpretation: A Review. Image and Vision Computing, 23(2):89--110, 2005.

I. Bloch. Spatial Reasoning under Imprecision using Fuzzy Set Theory, Formal Logics and Mathematical Morphology.International Journal of Approximate Reasoning, 41:77--95, 2006.

I. Bloch, O. Colliot, O. Camara, and T. Géraud. Fusion of Spatial Relationships for Guiding Recognition. Example of Brain Structure Recognition in 3D MRI. Pattern Recognition Letters, 26:449--457, 2005.

I. Bloch, T. Géraud, and H. Maître. Representation and Fusion of Heterogeneous Fuzzy Information in the 3D Space for Model-Based Structural Recognition - Application to 3D Brain Imaging. Artificial Intelligence, 148:141--175, 2003.

O. Colliot, O. Camara, and I. Bloch. Integration of Fuzzy Spatial Relations in Deformable Models - Application to Brain MRI Segmentation. Pattern Recognition, 39:1401--1414, 2006.

C. Hudelot, J. Atif, and I. Bloch. Fuzzy Spatial Relation Ontology for Image Interpretation. Fuzzy Sets and Systems, 2008.

H. Khotanlou, O. Colliot, J. Atif, and I. Bloch. 3D Brain Tumor Segmentation in MRI Using Fuzzy Classification, Symmetry Analysis and Spatially Constrained Deformable Models. Fuzzy Sets and Systems, 2007.

A. Moreno, C.M. Takemura, O. Colliot, O. Camara, and I. Bloch. Using Anatomical Knowledge Expressed as Fuzzy Constraints to Segment the Heart in CT Images. Pattern Recognition, 2008.

A. Moreno, S. Chambon, A. Santhanam, R. Brocardo, P. Kupelian, J. Rolland, E. Angelini, and I. Bloch. Thoracic CT-PET Registration Using a 3D Breathing Model. In MICCAI 2007, LNCS 4791, pages 626--633, Brisbane, Australia, 2007.

O. Nempont, J. Atif, E. Angelini, and I. Bloch. Combining Radiometric and Spatial Structural Information in a New Metric for Minimal Surface Segmentation. In Information Processing in Medical Imaging (IPMI 2007), LNCS 4584, pages 283--295, Kerkrade, The Netherlands, July 2007.

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Isabelle Bloch is Professor at ENST (Signal and Image Processing Department). Her research interests include 3D image and object processing, 3D and fuzzy mathematical morphology, decision theory, information fusion, fuzzy set theory, belief function theory, structural and graph-based pattern recognition, spatial reasoning, and medical imaging.