VoxLogicA: a Spatial-Logic Based Tool for Declarative Image Analysis

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Glioblastomas are among the most common malignant intracranial tumours. Neuroimaging protocols are used before and after treatment to evaluate its effect and to monitor the evolution of the disease. In clinical studies and routine treatment, magnetic resonance images (MRI) are evaluated, largely manually, and based on qualitative criteria such as the presence of hyper-intense tissue in the image. VoxLogicA is an image analysis tool, designed to perform tasks such as identifying brain tumours in 3D magneto-resonance scans. The aim is to have a system that is portable, predictable and reproducible, and requires minimal computing expertise to operate.

VoxLogicA is a new tool to perform image analysis in a declarative way, based on the latest developments in the theory of spatial logics [L1]. The tool was developed as part of a collaboration between the "Formal Methods and Tools" group of ISTI-CNR and the Department of Medical Physics of the Azienda Ospedaliera Universitaria Senese (AOUS).

VoxLogicA can be used for 2D (general-purpose) imaging, and for analysing 3D medical images, which has so far been the most promising application scenario. VoxLogicA has been designed with an emphasis on simplicity, and with a focus on producing explainable and implementation-independent results. A VoxLogicA session consists of a textual specification of image analysis, employing a combination of spatial features (distance between regions, or inter-reachability) with texture similarity, statistical, and imaging primitives.

VoxLogicA is publicly distributed, free and open source software (see link). At its heart lies a "model checker"; a very efficient computation engine for logical queries, exploiting advanced techniques, such as memoization and multi-threading, to deliver top-notch performance.

VoxLogicA sessions are written using a declarative logical language, “Image Query Language” (ImgQL), inspired by the very successful "Structured Query Language" (SQL) for databases, but with strong mathematical foundations rooted in the area of spatial logics for topological (closure) spaces. When used in the context of medical imaging, this approach admits very concise, high level specifications (in the order of ten lines of text) that can delineate, with high accuracy, the contours of a glioblastoma tumour in a 3D Magneto-Resonance scan within eight seconds, on a standard laptop. In comparison, it takes an expert radiotherapist about half an hour to perform this task.

The same procedure has been applied to circa 200 cases (the well-known "Brain Tumour Segmentation (BraTS) challenge" dataset). Accuracy of the obtained results can be measured; the new procedure scores among the top-ranking methods of the BraTS challenge in 2017 - the state of the art in the field, dominated by machine-learning methods - and it is comparable to manual delineation by human experts. Figure 1 shows the results of segmentation of a tumour for one of those cases, where the top row shows the MRI image, the middle row the result of manual segmentation by independent experts, and the bottom row the result performed with VoxLogicA.

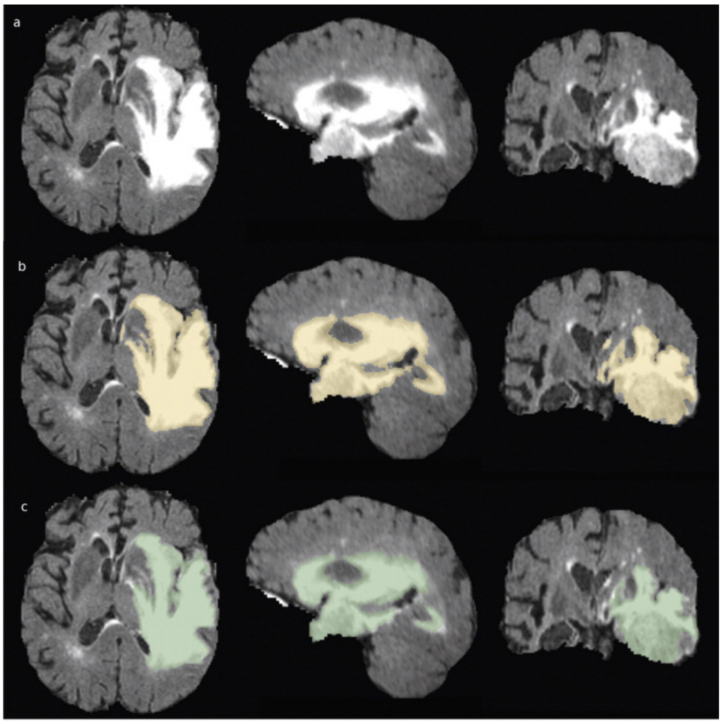

Figure 1: Results of segmentation of GTV for TCIA 471 patient: a) FLAIR acquisition b) Manual segmentation (BRATS 17 dataset) c) Segmentation result performed with VoxLogicA.

In the near future we plan to enhance this work, both in the direction of clinical case studies and to embrace other computational approaches that can be coordinated and harmonised using high-level logical specifications. Furthermore, the approach is very versatile, and its application is not limited to a single specific type of tumour or region in the body, paving the way for the analysis of other types of cancer and segmentation of various kinds of brain tissue such as white and grey matter.

A recent publication introducing the tool and its application to glioblastoma segmentation can be found in [1]. The source code and binaries of VoxLogicA are available at the link below together with a simple example of a 2D background removal task, intended as a mini tutorial for the tool. The theoretical foundations of spatial model checking can be found in [2] and an earlier study on glioblastoma segmentation performed with the general purpose spatial-temporal model checker "topochecker" can be found in [3].

Link:
[L1] https://kwz.me/hyy

References:

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[2] V. Ciancia, et al.:"Model Checking Spatial Logics for Closure Spaces", Logical Methods in Computer Science Vol. 12, Nr. 4, 2016. DOI: 10. 2168/LMCS-12(4:2)2016
[3] F. Banci Buonamici, et al.: "Spatial Logics and Model Checking for Medical Imaging", STTT, Online first, 2019. DOI: 10.1007/s10009-019-00511-9

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New Directions for Recognizing Visual Patterns in Medical Imaging

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New study directions are focused on the extraction and recognition of visual patterns from different types of medical images.

Various methods have been developed to recognise visual patterns in medical imaging [1]. Some techniques are used for classification of medical images; the automatic recognition of the pathology associated with the given image. Others are adopted for clustering medical image repositories, whose aim is to detect the different pathologies characterising the image repository. Pattern recognition is also used for segmenting or clustering medical images in uniform regions which can correspond to high-risk areas. Finally, medical image registration exploits pattern recognition methods for comparing body part images captured in different conditions and detecting the optimal alignment among them in order to monitor the evolution of the disease. All these approaches are important for multiple reasons: (i) quick identification of a given disease through visualisation and recognition of elements to further investigate with accurate medical exams, (ii) supporting the physician in the diagnosis process, and (iii) monitoring the patient's conditions over time.

When it comes to medical image registration, different methods, based mainly on magnetic resonance (MR) images of the brain, have been proposed for monitoring the temporal evolution of a stroke. These methods have limitations, however, given that acquisition costs are high and availability of MR imaging is sometimes low. Other studies are focused on monitoring the temporal evolution of a stroke in its acute phase.

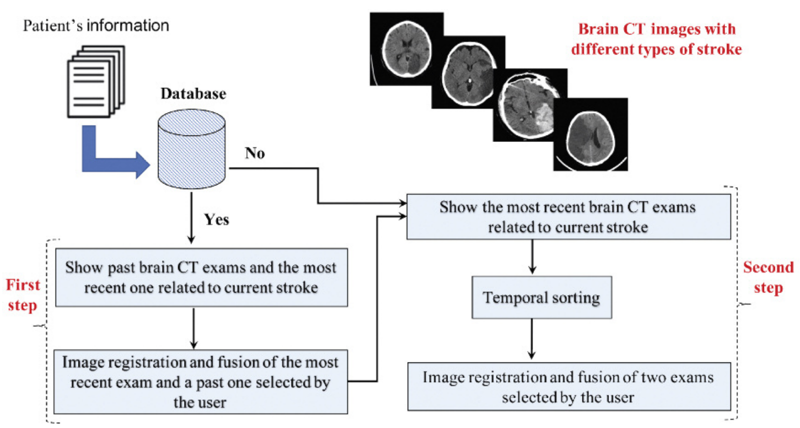

Figure 1: Flowchart of the proposed system [2].

To overcome these limitations, we propose a new system based on image registration techniques applied on computed tomography (CT) exams of the patient's brain for monitoring the temporal evolution of stroke lesions [2]. The system operates in two phases: (i) it evaluates past lesions which are not related to stroke through comparison of past CT exams with the most recent one related to stroke event; (ii) then it evaluates the trend of the lesion over time through comparison of recent CT exams related to the current stroke. Comparison of source and target CT exams is performed using image registration with a new introduced pattern-based similarity measure in 3D. The registration task aims to compute a transformation function maximizing the similarity between the source CT exam and a transformation of the target CT exam. The similarity function is a 3D extension of the "approximate average common submatrix" measure (A-ACSM). It computes the similarity between two CT exams as the average volume of the largest sub-cubes matching, to less than