Topologically-based segmentation of brain structures from T1 MRI

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1. Introduction

Cerebral structure segmentation from 3D MRI data is an important task for several medical applications. Brain segmentation methods can focus on specific structures such as the cortical surface [1], or intend to detect the principal parts of the brain [2]. Independently of their final purpose, they are primarily based on the classification of the intracranial volume into classes corresponding to the main cerebral tissues: cerebrospinal fluid (CSF), grey matter (GM), and white matter (WM). These classes present complex geometrical properties. However, they can be discriminated thanks to their distinct signal in modalities such as T1 or T2 MRI; moreover, they can be discriminated thanks to their distinct signal in modalities such as T1 or T2 MRI; moreover, they both present thin details near the cortex. The initial presegmentation C0 is composed of a simply connected volume corresponding to Cg, surrounded by three “thick” closed surfaces, modelling Cw, Cg and Cw, their thickness corresponding to a coherent anatomical approximation (Figure 1, 3rd picture).

2. Method

2.1 Input/output

The method takes as input a T1 MRI of the brain, I : E → N (with E = [0, d2 −1]×[0, d2 −1]×[0, d2 −1], generally [0, 255]3), from which the intracranial volume E′ ⊂ E has been extracted. (Figure 1, 2nd picture), and two threshold values µ1 < µ2 ∈ N de-limiting the T1 signal intensity between CSF/GM, and GM/WM, respectively. The method output is a partition C = {Cg, Cw, Cw, Cw} of E′, where Cg, Cw, Cw, and Cw correspond to the sulcal CSF, GM, WM, and ventricular CSF classes, respectively.

2.2 Initialization

The method starts from a presegmentation C0 of E′ having the desired topology: Cg is simply connected (1 connected component, 0 hole, 0 cavity), and successively surrounded by Cw, Cw, and Cw which are topological hollow spheres (1 connected component, 0 hole, 1 cavity), hierarchically organised, as illustrated in a 2D fashion in Figure 1 (1st picture). In Z3, such a model implies to choose dual adjacencies for the successive classes. The 6-adjacency has been considered for Cw (and thus Cw), since GM is geometrically organised as a “thick” ribbon, while the 26-adjacency has been considered for Cw, Cw, since they both present thin details near the cortex. The initial presegmentation C0 is composed of a simply connected volume corresponding to Cg, surrounded by three “thick” closed surfaces, modelling Cw, Cw and Cw, their thickness corresponding to a coherent anatomical approximation (Figure 1, 3rd picture).

2.3 Deformable process

From a topological point of view, C0, although composed of four distinct classes, can be considered as a binary image constituted of an object X = C0 ∪ Cg and of the background X = C0 ∪ Cg in a (26, 6)-adjacency framework. Based on this assumption, the segmentation process consists in modifying the frontier between X and X in a topology-preserving fashion, under photometric constraints. This discrete deformable model process is algorithmically formalised at the end of the section. It firstly modifies the classification of the points which are, from a photometric point of view, the “most misclassified”. In order to preserve the topology of the initial model, only simple points [6] can be switched from a class to another. For simplicity’s sake, the algorithm is presented using set-based notations. However, it was implemented using efficient data structures (ordered FIFO lists), enabling to reach an optimal algorithmic complexity O(|E′|), linear w.r.t. the size of the intracranial volume, since each point can be switched from one class to another only twice (the classification only depending on two threshold values).
The deformation process is only guided by photometric constraints, neglecting high-level anatomical knowledge such as volumetric or thickness information. Moreover, the initial topological model does perfectly take into account structures such that the brainstem and the cerebellum, providing good results on the superior part of the brain (cortex region), but less correct ones on its inferior part.

A more sophisticated version of the method, involving a presegmentation topologically and anatomically closer from the reality, and using both photometric and geometric constraints to guide the deformable model process is under development and will be further submitted for publication.

References


