Evaluation of Pairwise and Groupwise Templates-based Approaches for Automated Segmentation of Structures in Brain MR Images

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Synopsis

This work presents a detailed investigation of two multiple-templates based fusion approaches for automated segmentation of structures in the brain MR images: (i) fusion based on direct pairwise registrations between each template and the target image, and (ii) fusion based on an intermediate groupwise template, requiring only a single onsite registration. The key finding from these evaluations is that, if computational time for automated segmentations is a major concern, then groupwise-template based registration followed by fusion is an optimal choice; if time is not a major constraint, then multiple pairwise registrations followed by fusion provides more accurate segmentations.

Purpose

Multiple-templates (i.e., atlases) based methods are empirically proven to provide more accurate segmentations than single template-based methods. The commonly used approach in fusion requires 'N' onsite pairwise registrations for merging segmentations coming from 'N' templates. Such an approach could however be computationally unaffordable, particularly in the clinical scenarios where processing-time is a critical issue.

An alternative approach to overcome this limitation is to construct an intermediate groupwise template from 'N' templates, and register those templates to that groupwise template. As all this process can be performed offsite, to propagate segmentations from 'N' templates, only a single onsite registration between the groupwise template and the target image needs to be performed. Thus, unlike multiple pairwise registrations based fusion, groupwise template based fusion requires only a single onsite registration.

Although the groupwise template-based fusion is computationally fast compared to multiple pairwise registration-based fusion, the efficiency of it in capturing the anatomical variability from multiple MR brain templates is not very clear. Such study was performed earlier for automated segmentation in the cardiac MR data[1].

However, no such detailed study has been performed for automated segmentation of structures in brain MR images, and that is the main objective of this work.

Methods

(A) Groupwise Template Construction Method: ANTS tool[2] was used for simultaneously building the intermediate groupwise template, and registering the original templates to the groupwise template.

(B) Registration Methods: For direct pairwise registration-based approach, each template was aligned to the target image by first performing rigid registration, and it was followed by affine and diffeomorphic registrations[3] respectively. Same procedure are parameters are used for both groupwise-template and direct pairwise registrations.

(C) Fusion Method: Local Weighted Voting (LWV) is among the best fusion methods in various clinical applications[4]. Hence, LWV fusion was used in the current evaluations also.

Results

Evaluations are performed on the publicly available OASIS dataset[5] of 20 normal human brain MR images. Fifteen brain structures are considered for the evaluation, and the details of those structures are listed in Fig. 2. "Dice Similarity Metric" (DSM) is used for computing the overlap between ground truth and automated segmentations.
For completeness, pairwise and groupwise registration approaches are evaluated for both 'with' and 'without' fusion step. For "pairwise registrations without fusion" approach, each image in the dataset is registered to the remaining images in a leave-one-out manner; thus, results from 380 (=20x19) label-propagations are averaged for pairwise registration without fusion. For "groupwise registration without fusion" approach, to avoid any bias, 10 out of 20 images are randomly selected for template construction, and that groupwise template is used for segmenting the remaining 10 images in the dataset. Furthermore, the

aforementioned template-selection and label-propagation procedure is repeated 4 times to avoid any bias attributed to the random template selection. Thus, segmentation results from 400 (=10x10x4) label propagations are averaged for this approach.

In order to make a fair comparison between "pairwise registration with fusion," and "groupwise registration with fusion" approaches, the results from the same templates that are randomly selected for groupwise template construction are merged together in pairwise registration also. Since the template selection procedure is repeated 4 times, each of these two approaches are thus evaluated based on results from 40 (=4x10) fusions.

Figure 1 presents a qualitative illustration of segmentations obtained from all aforementioned approaches. Figure 2 presents the DSM based structure-wise quantitative evaluation of all methods. Among the simple pairwise and simple groupwise based segmentations without any fusion, groupwise based approach has given better segmentation results, both in terms of average and standard deviation. Hence, when segmentations are performed without any fusion, it is better to propagate the labels through an intermediate template rather than performing a direct pairwise registration. On the contrary, when results from multiple pairwise and groupwise registrations are merged using LWV fusion method, groupwise template-based approach has provided superior segmentation results. Notice that while groupwise template based methods are faster than the multiple pairwise registration methods, fusion on pairwise registrations provided more accurate segmentations.

Conclusions

A systematic and detailed performance evaluation of the pairwise and groupwise templates-based approaches for automated segmentation of structures in brain MR images is presented in this work. The key conclusion arising from these evaluations is that, if computational time taken for performing automated segmentations of brain structures is a major concern, then groupwise-template based registration followed by fusion is an optimal choice; if computational time is not a major

constraint, then multiple pairwise registrations followed by fusion provides more accurate segmentations than the groupwise template based approaches.

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References

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Figures

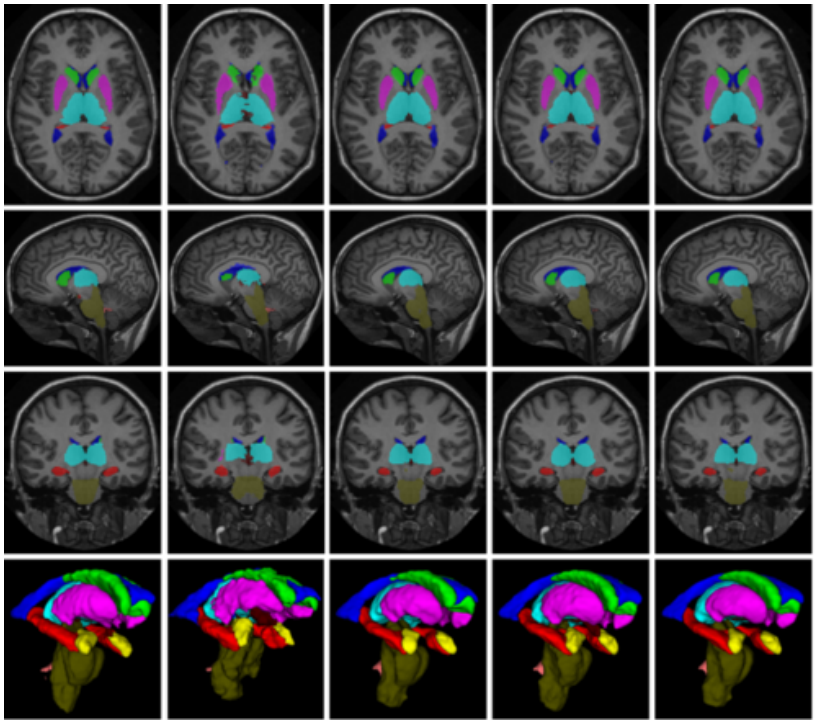

Fig 1: Qualitative illustration of segmentations results. Segmentations in

axial, sagittal, coronal slices and their volumes are shown in rows 1, 2, 3, and 4 respectively. Columns 1, 2, 3, 4, and 5 respectively show ground truth, results from pairwise registration, groupwise registration, fusion results on pairwise and groupwise registrations.

Structure Name	Pairwise Registration	Groupwise Registration	Fusion on Pairwise Registrations	Fusion on Groupwise Registration
1. Hippocampus-L	71.63%	76.41%	81.23%	78.71%
2. Hippocampus-R	71.06%	75.23%	81.14%	78.04%
3. Lateral Ventricle-L	77.93%	82.36%	86.68%	84.16%
4. Lateral Ventricle-R	76.24%	80.32%	85.75%	83.02%
5. Caudate–L	77.90%	79.99%	85.96%	82.15%
6. Caudate-R	77.85%	79.88%	86.37%	82.79%
7. Amygdala-L	61.36%	66.42%	72.94%	68.97%
8. Amygdala-R	59.37%	65.49%	73.37%	67.82%
9. Putamen-L	79.62%	79.48%	87.70%	80.40%
10. Putamen-R	79.02%	79.84%	88.17%	80.93%
11. Thalamus-L	83.43%	85.71%	89.70%	87.14%
12. Thalamus-R	82.69%	84.91%	89.03%	86.20%
13. Brainstem	85.03%	87.65%	90.05%	88.62%
14. 3rd ventricle	64.78%	56.65%	75.95%	62.49%
15. 4th ventricle	67.51%	69.71%	78.60%	70.98%
Average	74.36%	76.67%	**83.51%**	78.83%
Standard Deviation	9.2%	6.7%	**4.3%**	6.2%
Onsite registrations required	1	1	N	**1**

Fig 2: Average Dice Similarity Metric (DSM) computed on the automated segmentations obtained from (i) simple pairwise registration, (ii) simple groupwise registration, (iii) fusion on pairwise registrations, and (iv) fusion on groupwise registrations. The parameter 'N' in the table represents number of templates.