

Automatic Extraction of Left and Right Hemispheres from MRI Brain Volumes Using a Refined Registration Method

Kelly Rehm¹, Vina Goghari², David Rottenberg^{1,3}, Roger Woods⁴

¹Departments of Radiology, ²Psychology, and ³Neurology, University of Minnesota, Minneapolis, USA. ⁴Department of Neurology, University of California, Los Angeles, USA.



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This work was supported by NIH grant EB002013.

Introduction

Segmentation of MRI brain volumes into anatomical regions, e.g., left cerebral hemisphere (LCH), right cerebral hemisphere (RCH), cerebellum (CB) and brain stem (B), is important for many biomedical and neuroscience applications. In this work we focus on methods of forming spatial compartment masks that classify CSF as well as grey and white matter tissues. Estimates of both tissue and cerebral spinal fluid (CSF) volume are relevant for morphological analysis of patient populations, e.g., siblings of schizophrenic patients have been shown to exhibit significant reductions in cortical grey matter volume and significant increases in sulcal CSF volume compared with controls [1].

We here present a fully automatic method (*SpatCom*) based on registration to a template volume that has a corresponding spatial-compartment mask. We evaluate the accuracy of automatic spatial compartment labelling with respect to expert labelling for 81 T1-weighted MRI scans and compare *SpatCom* results to those of two public software packages: *BrainSuite* [2], and *SurfRelax* [3] that also partition CSF.

Methods

SpatCom

The necessary template dataset was prepared from a T1-weighted MRI brain volume. That volume was stripped (non-brain tissue excluded), and a spatial-compartment mask (LCH, RCH, CB, B) was prepared (in our case, manually). Each subject volume was stripped – but the stripping need not have been perfect. However, *SpatCom* can not distinguish brain tissue from blood vessels and dura and assigns such voxels to their neighboring compartment.

Step 1. A fourth-order polynomial warp is computed using AIR [4] to align the template MRI volume to the subject volume. The warp transform is then independently applied to each of the template volume's four spatial compartments using trilinear interpolation. Subject voxels "claimed" by two or more compartments are designated "contested" (Figure 1).

Step 2. The initial spatial compartments are refined. For each coronal slice a perimeter is computed for each spatial compartment from the uncontested boundary and the skeleton (approximating the midline) of any contested boundary. Subsequently the boundaries undergo "wiggling" within their local neighborhoods to settle into positions of low image intensity – presumed to be CSF-weighted (See Figure 1, column 3). Wiggling is restricted to remain within the area occupied by the original contested voxels and to maintain a face-connection between boundary voxels.

Step 3. On completion of step 2 global (3D) filling operations ensure that all voxels in the subject-volume mask receive a label and that each mask compartment is a single simply-connected region – eliminating any small voids or isolated pods of labels.

Methods

BrainSuite

BrainSuite is a Windows-based multi-function package with a graphical user interface. The package computes compartments based on alignment of a template volume to a subject volume to create a labelled volume. To get a spatial compartment volume we input a stripped brain volume and used the "Cerebrum" tool. The program computes a label volume with 6 values: left and right cerebellum +brainstem, left and right cerebrum, and left and right corpus callosum, ventricles, putamen, etc. For the purposes of this evaluation we collapsed the labels to LCH, RCH, CBB (cerebellum plus brainstem).

SurfRelax

SurfRelax is a Linux-based multi-function package with a Tcl GUI and command-line access to most modules. *SurfRelax* initially performs a white-matter segmentation, then divides the white-matter into LCH, RCH, and CB, and finally grows a surface for each compartment to enclose all the tissue. We input a stripped brain and used the "Intensity Normalizer", "Fill White Matter" and "Segment Hemispheres" modules to create closed surfaces for the LCH, RCH, and CBB. Author KR wrote software to fill inside each surface; voxels where surfaces competed (overlapped) were assigned to compartments based on the median label value in a 3x3x3 voxel neighborhood.

Methods

Dataset 1. Twenty 1 x 1 x 1 mm MR images of one normal subject were acquired in two sessions on a 1.5T Siemens Sonata scanner using two different pulse sequences: 5 MPRAGE (turboFLASH) and 5 SPGR (gradient echo) per session. The images underwent rigid-body alignment to correct for motion in each session, and the second session volumes were aligned to those of the first. We created a "gold standard" brain by averaging all scans and a brainmask for the gold standard was created by an expert operator (using *McStrip* [5] with manual touch-up). An anatomist drew divisions on the gold standard brain to define three spatial compartments (LCH/RCH/CBB).

Dataset 2. Forty-three 3T SPGR MR images of controls and healthy relatives of schizophrenics were acquired at 0.9375 x 0.9375 x 1.5 mm voxel resolution. [Images courtesy of Dr. Angus MacDonald and Vina Goghari – see also poster #41.] The volumes were stripped with *McStrip* (with manual correction where needed). Spatial compartment masks were estimated using *SpatCom* and subsequently corrected manually under author VG's supervision; we verified that every manually-corrected mask differed from the original.

Dataset 3. Eighteen volumes were downloaded from the Internet Brain Segmentation Repository. The MR brain data sets and their manual segmentations were provided by the Center for Morphometric Analysis at Massachusetts General Hospital and are available at <http://www.cns.nyu.edu/~jonnas/ibsr/>. The volumes were acquired coronally with 1.5 mm slice thickness and in-plane resolutions ranging from 0.837 mm² to 1.0 mm². The multi-value segmentations were collapsed to form a brain mask for each subject and LCH/RCH/CBB compartment labels.

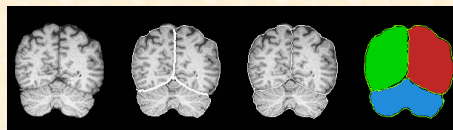


Figure 1. *SpatCom* processing stages. Left to right: original slice, contested voxels marked in white (step 1 processing), step 2 with thin boundary wiggled into position, spatial compartments after boundary adjustment – note the voids near the lines. Voids are filled in step 3.

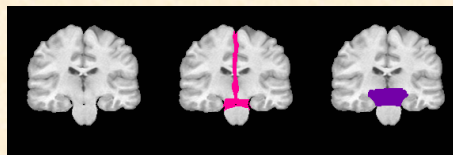


Figure 2. Evaluation regions. From left to right: an original slice from Dataset 3, slice with region A (near-boundary) marked in pink, slice with so-called transition region marked in purple.



Figure 3. Spatial compartment results for the volume shown in Figure 2. From left to right: *SpatCom*, *BrainSuite* and *SurfRelax*.

Results

Four accuracy metrics were computed for each instance of algorithm and MR volume. We expected that most labelling errors would occur in the immediate vicinity of the "true" boundaries, therefore we identified volume locations within a 5x5x5 voxel neighborhood of the true boundaries (Test region A), and all other voxels as Test region B. Because the transition between brainstem and cerebrum is not standardized, we identified a "transition" region superior and anterior to the superior colliculus. Test regions C and D excluded the transition region. Figure 2 illustrates region A and the transition region. Figure 3 presents a typical result from the three algorithms, demonstrating the need for generosity in evaluating some brainstem boundaries.

Test regions and errors are reported in terms of cubic centimeters of tissue. Run time per volume for *SpatCom* was on the order of 1 hour on a 3GHz processor, while *SurfRelax* and *BrainSuite* took approximately 9 minutes and 40 seconds, respectively.

Table 1. Dataset 1 (Twenty repeats); volumes and errors are reported in cubic centimeters of tissue.

Region	A	B	C	D
Test region	124.60	1423.38	118.74	1421.55
BrainSuite error	21.50 +/- 1.84	5.35 +/- 2.27	17.60 +/- 2.33	3.65 +/- 1.47
SurfRelax error	25.46 +/- 8.87	1.18 +/- 0.58	24.16 +/- 8.72	1.17 +/- 0.57
SpatCom error	15.61 +/- 1.92	2.78 +/- 1.87	13.19 +/- 2.29	2.41 +/- 0.88

Table 2. Dataset 2 (Healthy relatives and controls); volumes and errors are reported in cubic centimeters.

Region	A	B	C	D
Test region	121.02	1289.19	118.64	1289.05
BrainSuite error	22.78 +/- 3.80	5.14 +/- 2.40	21.10 +/- 3.36	5.00 +/- 2.33
SurfRelax error	38.61 +/- 9.91	54.86 +/- 17.58	37.36 +/- 9.57	54.82 +/- 17.58
SpatCom error	6.68 +/- 2.11	0.91 +/- 2.36	5.33 +/- 1.64	0.86 +/- 1.81

Table 3. Dataset 3 (IBSR volumes); volumes and errors are reported in cubic centimeters.

Region	A	B	C	D
Test region	82.84	1283.03	77.03	1274.25
BrainSuite error	15.67 +/- 2.50	14.04 +/- 1.57	55.35 +/- 2.66	4.32 +/- 1.57
SurfRelax error	19.41 +/- 5.03	6.50 +/- 2.75	15.91 +/- 4.75	2.87 +/- 2.49
SpatCom error	11.45 +/- 1.52	3.96 +/- 1.54	9.04 +/- 1.53	2.52 +/- 1.53

Conclusions

Eighty-one T1-weighted brain volumes from various sites were processed by *SpatCom*, *BrainSuite*, and *SurfRelax* to produce spatial compartment masks. Semi-expert to expert compartment labellings for each volume were obtained to test the accuracy of each algorithm. *SpatCom* consistently posted the lowest classification error in the region close to the true boundaries, regardless of the choice of a strict (region A) or transition (region C) boundary test. For errors occurring away from the true boundaries (presumably indicating a severe failure), best performance varied across datasets, although *SpatCom* errors remained low overall.

SpatCom refines 2D slice boundaries rather than 3D volume boundaries – which leads to compartmental boundaries that are seldom smooth in all slice views. However, though our method relies heavily on the quality of the registration and is computationally expensive, it produces consistent results across MRI volumes from different sites, subjects and scanning protocols.

References and Acknowledgements

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We are grateful to Ms. Kristi Boesen for preparing the brainmask and to Dr. Jill Huang for creating the manual spatial compartments for Dataset 1.