Evaluation of Open-Access, Automated Brain Extraction Methods on Multi-Site Multi-Disorder Data

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Introduction

Motivation: Brain extraction is a critical step in neuroimage processing pipelines. Precisely delineated cortex increases the interpretability of functional, perfusion, and structural MRI and PET, and is required before three-tissue cerebrum segmentation. Many theoretically distinct methods are available.
However, few comparison studies are reported [see Boesen HBM 2003 and Fennema-Notestine 2006].
This study may be the first to use both open-access methods and open-access data to perform a repeatable evaluation of contemporary brain extraction methods.

Methodology contribution:
Brain extraction may be formulated as a hybrid image registration and segmentation problem. Here, we evaluate the registration and segmentation steps for a new method, *Atropos*, that is adaptable to a variety of brain classification problems, and in this case incorporates both topology constraints and anatomical priors.

Atropos uses registration to initialize a GMM-MRF multi-class brain extraction model. The *N*-tissue model (*Atropos1*) uses Atropos and post-processing steps to classify brain and non-brain structures into known cerebral and extra-cerebral tissue categories. The three-tissue model (*Atropos2*) uses geometric constraints on topology and tissue-connectivity to isolate the brain from extraneous structures.

Community and clinical significance:
This project blends prior neuroanatomical knowledge with engineering to address the challenges of reliable brain extraction in clinically diverse medical imaging data. Contributions include a large-scale evaluation, general strategic suggestions for reliable brain extraction and an openly available and adaptable, dataset-specific strategy.

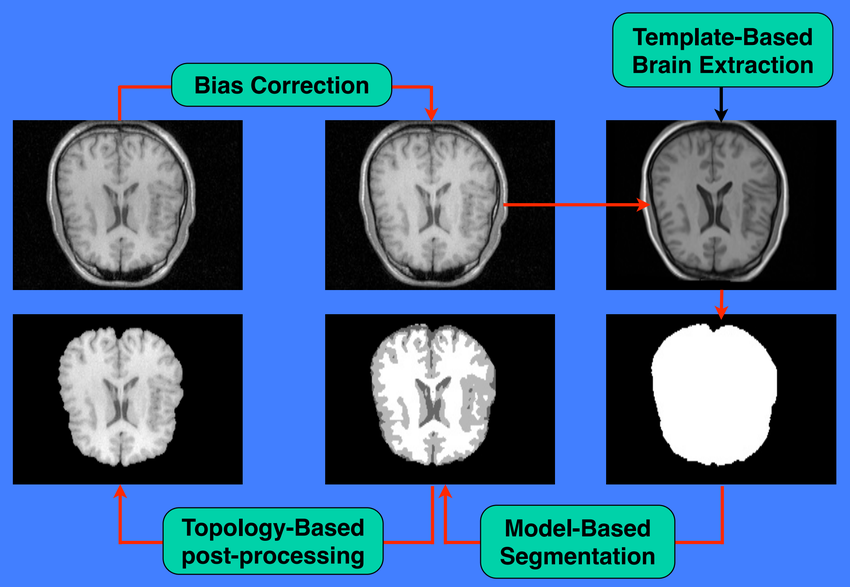


Fig. 1. The *Atropos* brain extraction algorithm.

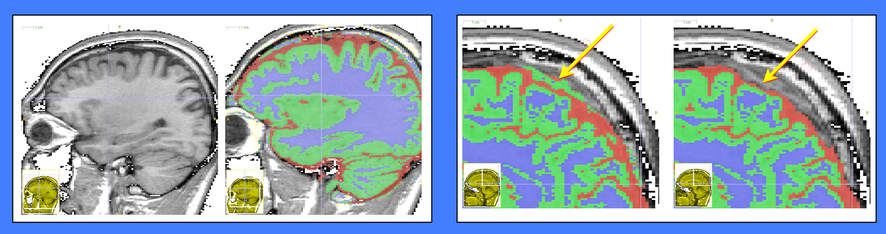


Fig. 2. Detail of alternatives for both segmentation (N-tissue at left) and topology processing.

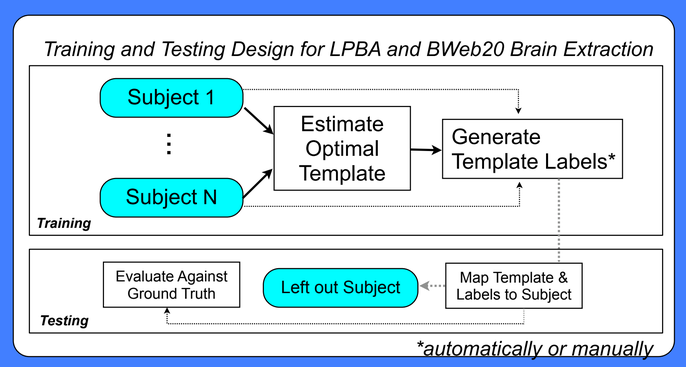


Fig. 3. The evaluation pipeline and sensitive parameters.

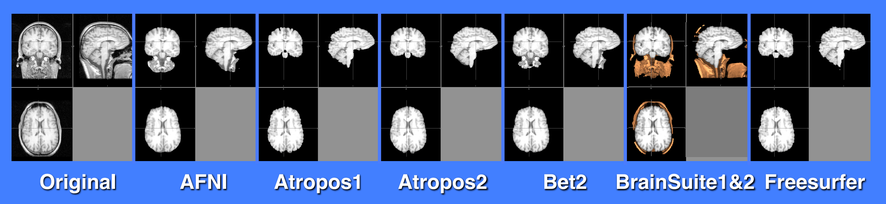


Fig. 4 Visual comparison of the *N* methods' output on LPBA40 data.

Study Aims

1. Evaluate impact of initial registration choices on Atropos brain extraction:
To determine the most appropriate similarity metrics for affine and nonlinear image registration steps, we evaluate registrations by the overlap of manually extracted brain images with each other.

2. Evaluate Atropos performance with best registration and freely available brain extraction tools:
We use best-case settings from step *1* conducted on LPBA40 data to initialize multi-class brain extraction models for LPBA40 and NVM40 data, and compare the results with those generated by BET2, AFNI, FreeSurfer, BrainSuite and BrainSuite with tuned parameters.

Evaluation data: We evaluate automated brain extractions by degree of overlap with manually extracted data: LPBA40 (N=40), BrainWeb20 (N=20), and the NVM40 (N=40, provided by Neuromorphometrics). Repeatability on the Oasis longitudinal data is reported in the abstract.

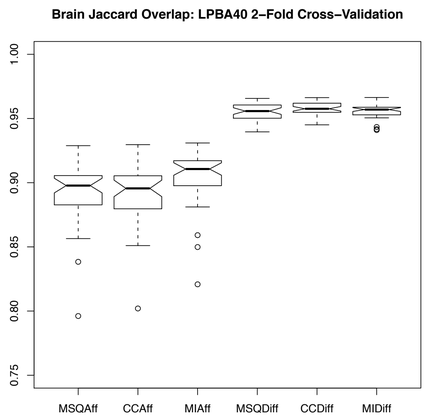
Conclusions

FreeSurfer and *Atropos2* provide the best overall performance as determined by indifference-zone ranking. If we set delta to a fraction of the voxels on the surface of the manually extracted brain (as in Klein, et al., 2009), then we obtain the following top ranks (within 1 SD of the top mean rank):

LPBA data:	δ=1/3: Atropos1&2, BrainSuite-tuned, FreeSurfer δ=1/6: Atropos2, BrainSuite-tuned
NVM data:	δ=1/3: Atropos1&2, FreeSurfer

Results

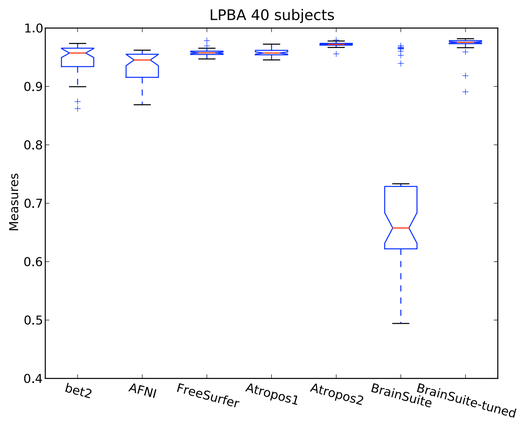
Evaluation of initial deformable registration



MI-based affine and CC-based diffeomorphic registration led to the best performance on purely template-based brain extraction.

The results of this initial study dictate registration parameters for the *Atropos GMM-MRF* model.

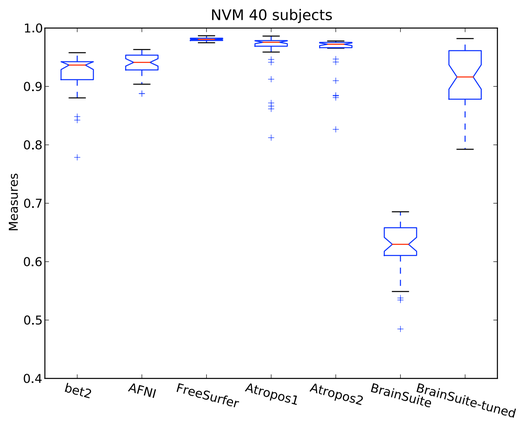
Evaluation of LPBA40 Brain Extraction



FreeSurfer results would likely improve via a template that is specific to the LPBA40 dataset.

Note: Atropos and BrainSuite-tuned were developed with LPBA40 evaluation data.

Evaluation of NVM Dataset Brain Extraction



Atropos results would improve by using an age-specific or elderly template. Outliers are due to limited affine performance.

Note: Freesurfer was trained on data from the same set as the NVM40 (Oasis) data.

Relevant articles

Avants, B. B.; Epstein, C. L.; Grossman, M. & Gee, J. C. "Symmetric diffeomorphic image registration with cross-correlation: Evaluating automated labeling of elderly and neurodegenerative brain" *Med Image Anal,,* **2008**

Klein, A.; Andersson, J.; Ardekani, B. A.; Ashburner, J.; Avants, B., et al. "Evaluation of 14 nonlinear deformation algorithms applied to human brain MRI registration" *Neuroimage,* **2009**

Funding sources

NIBIB grant EB006266
NIMH R01 MH084029

Web resources

Atropos is publicly available on the ANTS website:
http://www.picsl.upenn.edu/ANTS