Multi-Phase Three-Dimensional Level Set Segmentation of Brain MRI

[1]Elsa D. Angelini, [2]Ting Song, [3]Brett D. Mensh, [2]Andrew F. Laine

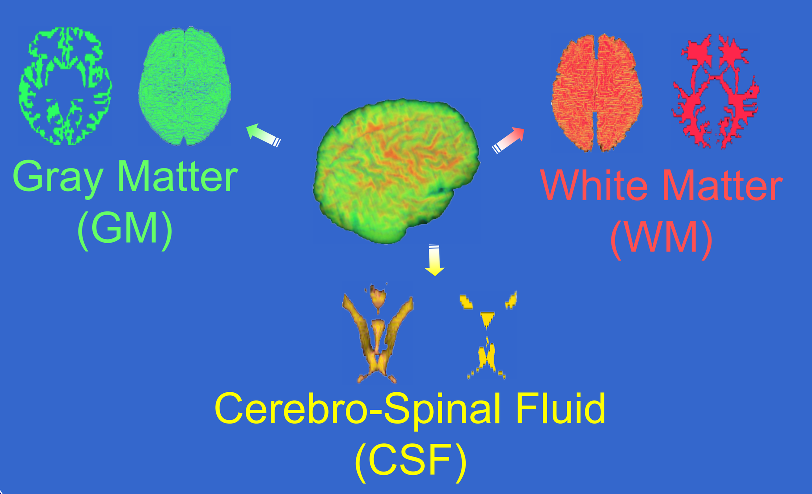
[1]Ecole Nationale Supérieure des Télécommunications, Département Traitement du Signal et des Images, Paris, France

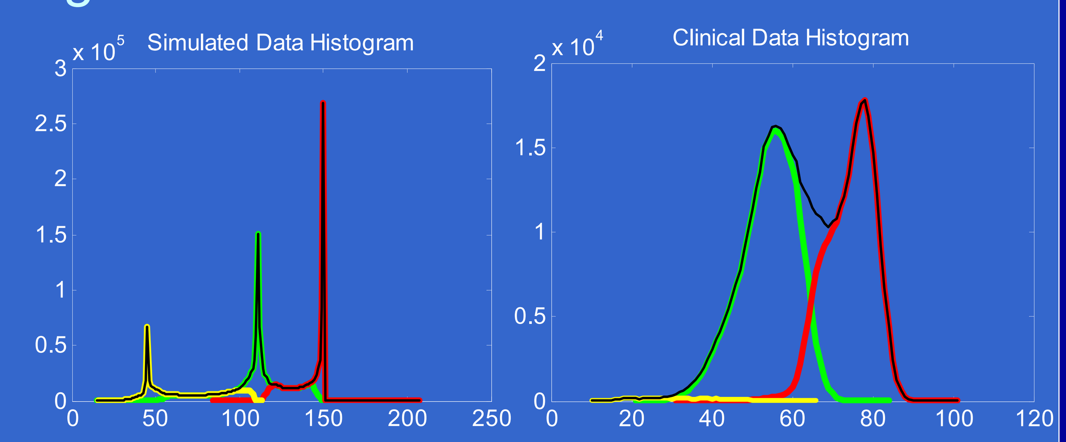
[2]Columbia University, The Heffner Biomedical Imaging Laboratory, Department of Biomedical Engineering, New York, NY, USA

[3]Columbia University, Department of Biological Psychiatry, College of Physicians and Surgeons, New York, NY, USA

1. INTRODUCTION

- Segmentation of cortical structures on clinical brain MRI data is applied for clinical study of depression on elderly subjects.
- Segmentation of clinical MRI data is more challenging than with simulated data due to intensity overlap among cortical structures and non-homogeneity within each tissue.





Histogram of simulated data (BrainWeb) and clinical data.

2. METHODOLOGY

2.1 Homogeneity-Based Energy Functional

- An active contour model proposed by Chan and Vese [1] derived from the Mumford-Shah functional with regularizing terms defined for a curve C as:

$$E = \mu\left(length(C)\right) + \upsilon\left(area\left(inside\,C\right)\right) + \lambda_1 \int_{inside(C)} \left|u_0 - c_1\right|^2 dx + \lambda_2 \int_{outside(C)} \left|u_0 - c_2\right|^2 dx$$

c_1, c_2: mean values of the image inside and outside the curve C.
$\mu, \nu, \lambda_1, \lambda_2$: fixed parameters.

- This energy functional can be extended to the segmentation of multiple homogeneous objects in the image by using several curves $\{C_1, C_2, \dots, C_i\}$. In the case of two curves, the energy functional is defined as:

$$E = \lambda_1 \int_{\substack{inside C_1 \\ inside C_2}} |u_0 - c_{11}| d\Omega + \lambda_2 \int_{\substack{inside C_1 \\ outside C_2}} |u_0 - c_{10}| d\Omega + \lambda_3 \int_{\substack{outside C_1 \\ inside C_2}} |u_0 - c_{01}| d\Omega + \lambda_4 \int_{\substack{outside C_1 \\ outside C_2}} |u_0 - c_{00}| d\Omega + \mu_1 length(C_1) + \mu_2 length(C_2) + \upsilon_1 area(inside\, C_1) + \upsilon_2 area(inside\, C_2)$$

2.2 Level Set Formulation of Optimization Problem

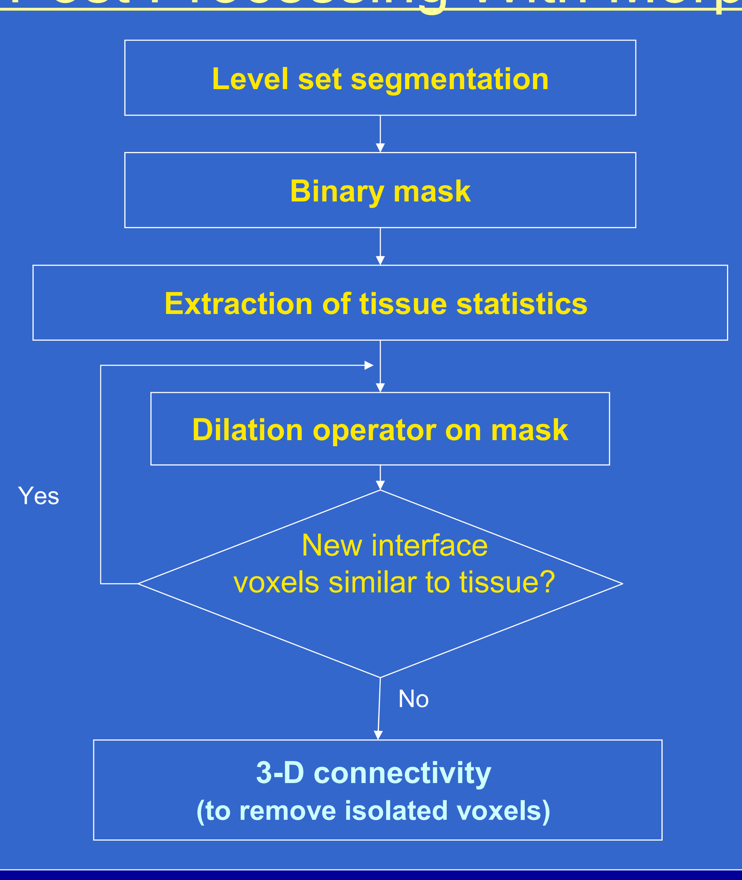
- The curve C is embedded in a level set function ϕ, with its associated Heaviside function H and Dirac function δ defined.
- The Euler-Lagrange system for the two level set functions is:

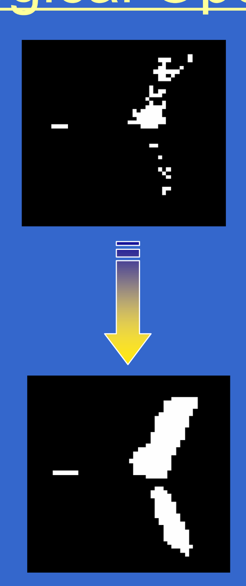
$$\frac{\partial \phi_1}{\partial t} = \delta(\phi_1)\left\{ \begin{array}{l} \mu div\left(\frac{\nabla \phi_1}{|\nabla \phi_1|}\right) - \upsilon + \lambda_1 (u_0 - c_{11})^2 H(\phi_2) + \lambda_2 (u_0 - c_{10})^2 (1 - H(\phi_2)) \\ -\lambda_3 (u_0 - c_{01})^2 H(\phi_2) - \lambda_4 (u_0 - c_{00})^2 (1 - H(\phi_2)) \end{array} \right\}$$

$$\frac{\partial \phi_2}{\partial t} = \delta(\phi_2)\left\{ \begin{array}{l} \mu div\left(\frac{\nabla \phi_2}{|\nabla \phi_2|}\right) - \upsilon + \lambda_1 (u_0 - c_{11})^2 H(\phi_1) - \lambda_2 (u_0 - c_{10})^2 H(\phi_1) \\ +\lambda_3 (u_0 - c_{01})^2 (1 - H(\phi_1)) - \lambda_4 (u_0 - c_{00})^2 (1 - H(\phi_1)) \end{array} \right\}$$

- Initialization: Two sets of 64 cylinders centered at regularly spaced seed locations, slightly shifted. Such initialization does not use any *a priori* information, is fully automated and provides robustness of the iterative optimization to local minima.

2.3 Post Processing With Morphological Operators

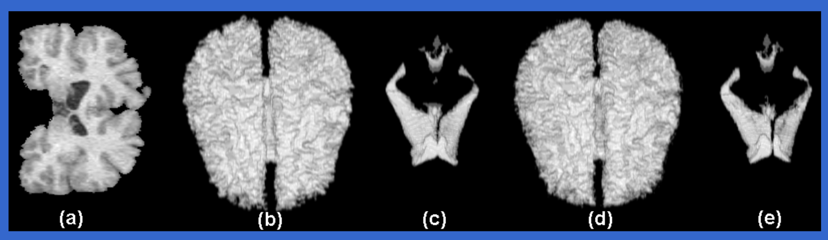




This post processing scheme is applied to:
1. The GM/WM interface.
2. The CSF/GM interface.

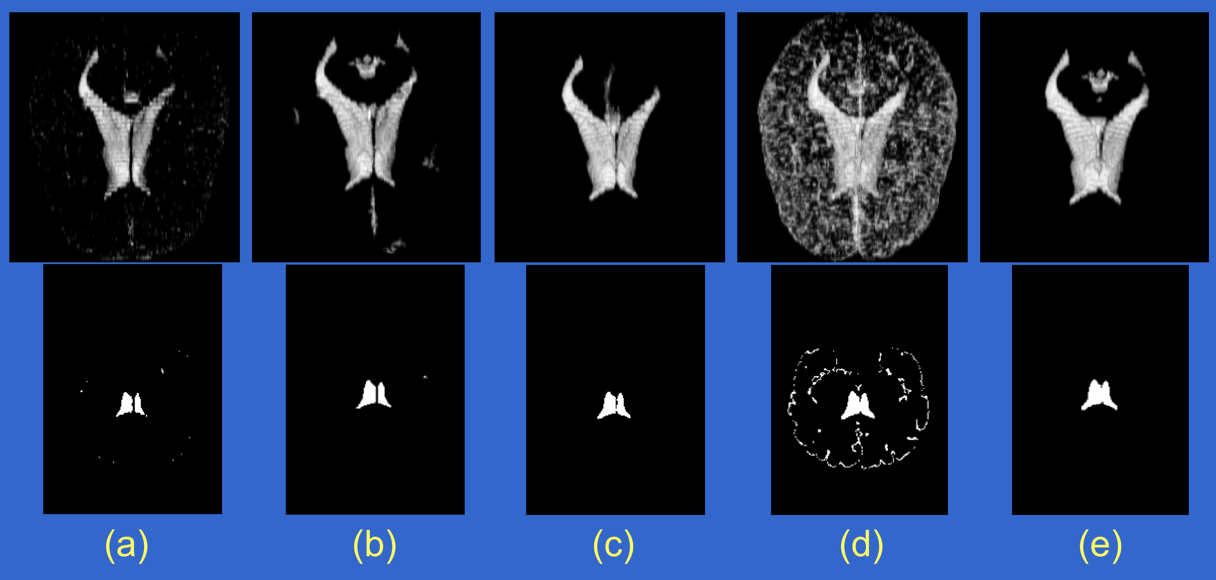
3. EXPERIMENTS AND RESULTS

- The segmentation method was applied to ten T1-weighted MRI data sets of healthy young volunteers, of size 256x256x73 with a 3mm slice thickness and 0.86mm in-plane resolution.

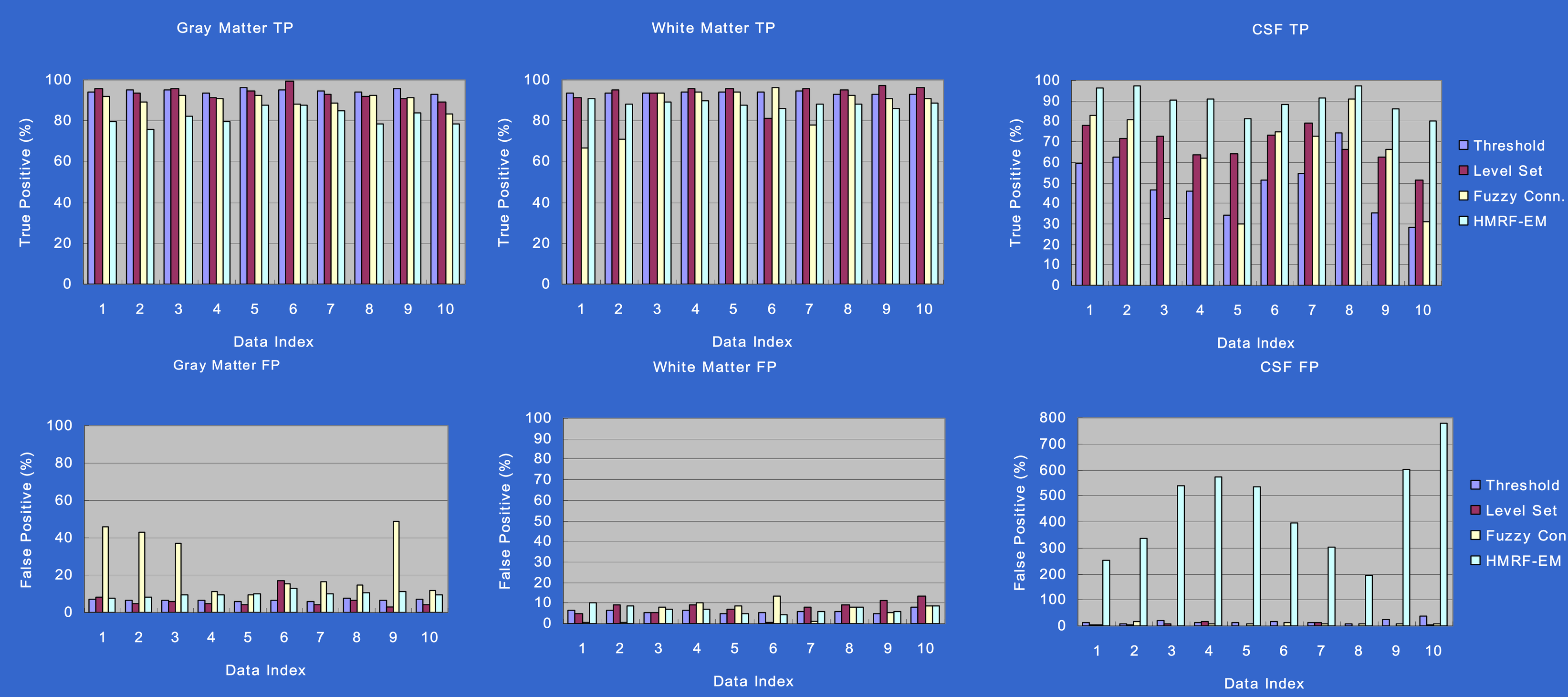


(a) MRI data. (b-e) Rendering of WM and CSF structures: (b-c) with manual labeling, (d-e) with multi-phase level set segmentation.

- Accuracy of the multi-phase level set segmentation was compared to histogram thresholding, fuzzy connectedness, and HMRF-EM segmentation methods using the methodology from Udupa *et al.* [2]. Detailed results of this study are reported in [3].



Segmentation of the CSF. (a) Histogram Thresholding, (b) Level set, (c) Fuzzy Connectedness, (d) HMRF-EM, (e) Manual labeling.



True positive and false positive bar plots of the four segmentation methods for GM, WM and CSF.

4. CONCLUSIONS

- Multi-phase level set segmentation framework was applied to clinical brain MRI for segmentation of cortical structures.
- A post processing scheme, based on morphological operators, was applied.
- A clinical study on 10 healthy cases was performed comparing the performance of four segmentation methods to manual labeling.
- Superiority of the proposed multi-phase level set and post processing method was observed using a simple computational set up.

5. REFERENCES

1. L. A. Vese and T. F. Chan, "A multiphase level set framework for image segmentation using the Mumford and Shah model," International Journal of Computer Vision, vol. 50, No. 3, pp. 271-293, 2002.
2. J. Udupa, V. LeBlanc, H. Schmidt, C. Imielinska, P. Saha, G. Grevera, Y. Zhuge, P. Molholt, Y. Jin, and L. Currie, "A methodology for evaluating image segmentation algorithm," SPIE Conference on Medical Imaging, San Diego CA, USA, pp. 266-277, 2002.
3. T. Song, E. D. Angelini, B. D. Mensh, A. Laine, "Comparison Study of Clinical 3D MRI Brain Segmentation Evaluation," 26th Annual International Conference IEEE Engineering in Medicine and Biology Society (EMBS), San Francisco, CA, USA. September 1-5, 2004.