Comparison Study of Clinical 3D MRI Brain Segmentation Evaluatio

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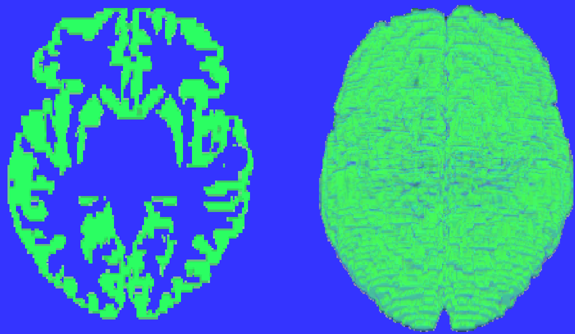
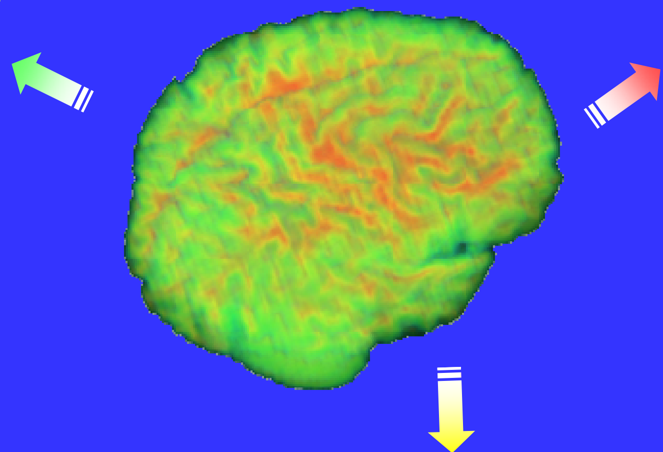
Overview

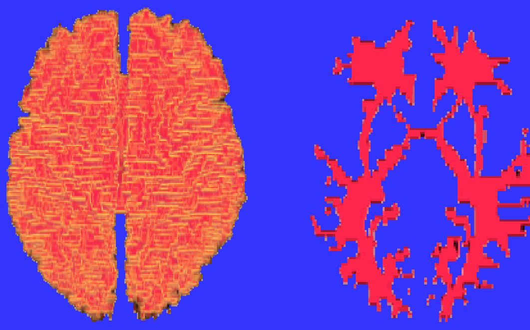
- Introduction
- Segmentation Methods
  - Histogram Thresholding.
  - Multi-phase Level Set.
  - Fuzzy Connectedness.
  - Hidden Markov Random Field Model and the Expectation-Maximization (HMRF-EM).
- Results & Comparison of Methods
- Conclusions

Introduction



Gray Matter (GM)





White Matter (WM)

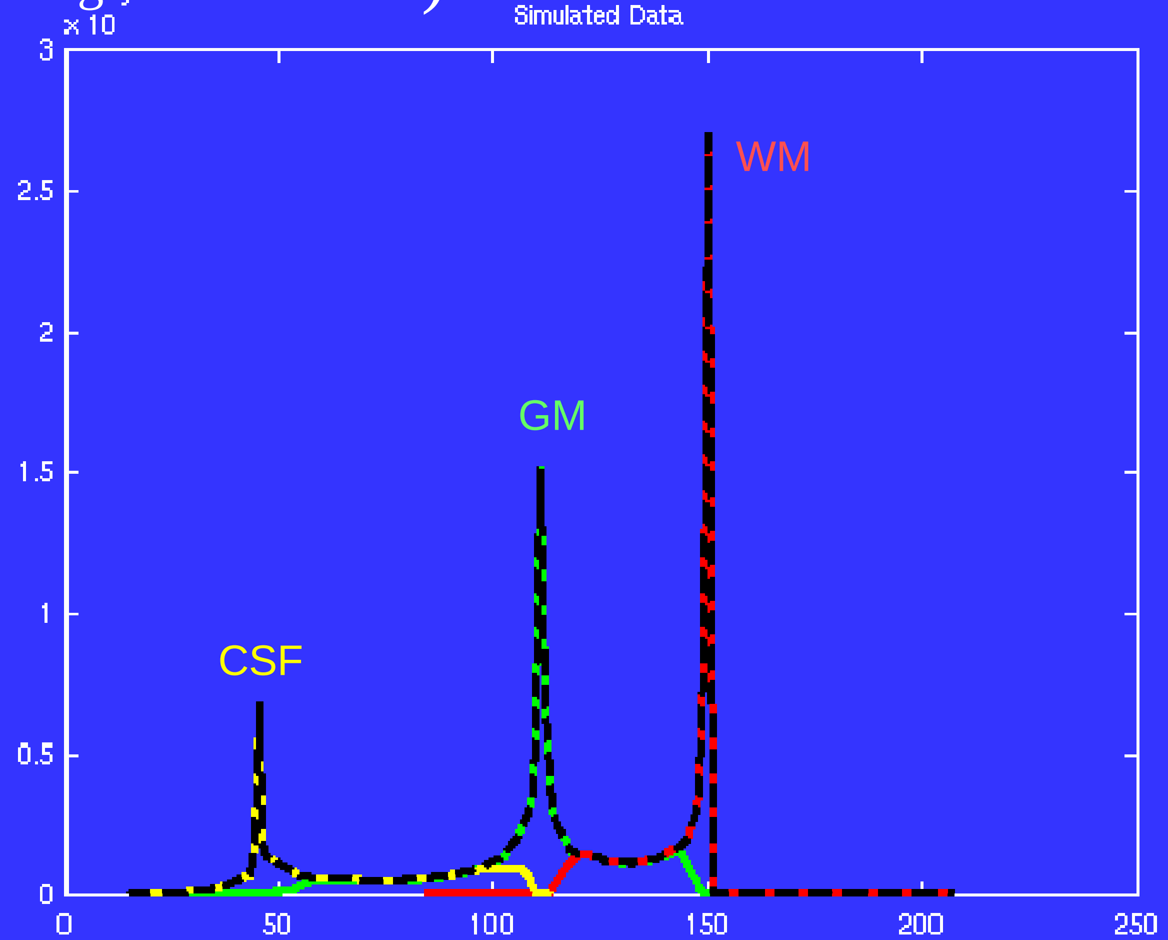
Cerebro-Spinal Fluid (CSF)

Motivation

- Segmentation of clinical brain MRI data is critical for functional and anatomical studies of cortical structures.
- Little work has been done to evaluate and compare the performance of different segmentation methods on clinical data sets, especially for the CSF.
- The performance of four different methods was quantitatively assessed according to manually labeled data sets (“ground truth”).

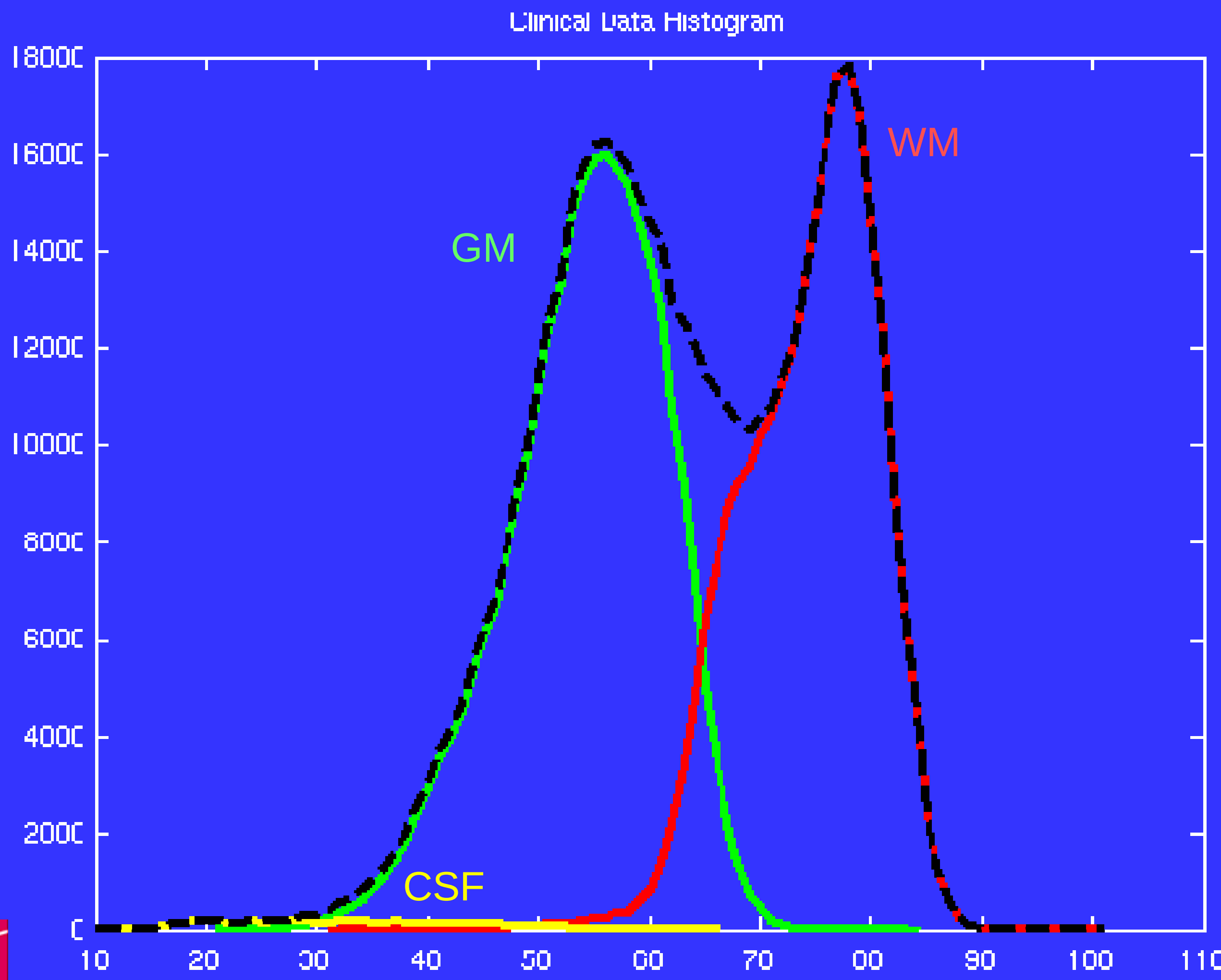
Motivation

Homogeneity of cortical tissues on simulated MRI data.
(source: BrainWeb simulated brain database, www.bic.mni.mcgill.ca/brainweb)



Motivation

Homogeneity of cortical tissues on clinical T1-weighted MRI data.



Methodology

Methods evaluated:

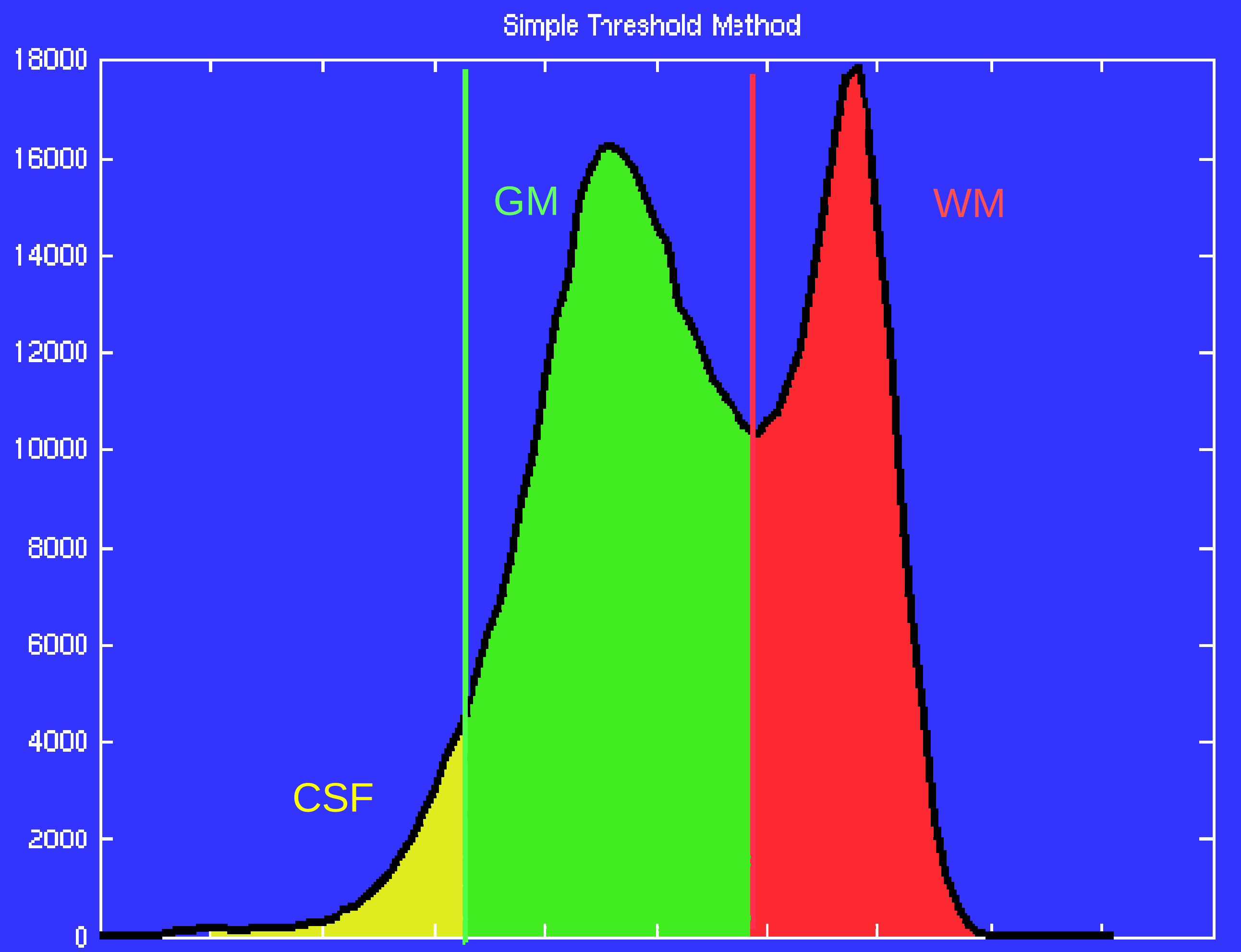
1. Histogram thresholding (Method A)

2. Multi-phase level set (Method B)

3. Fuzzy connectedness (Method C)

4. Hidden Markov Random Field Model and Expectation-Maximization (HMRF-EM) (Method D)

1. Histogram Thresholding



1. Histogram Thresholding

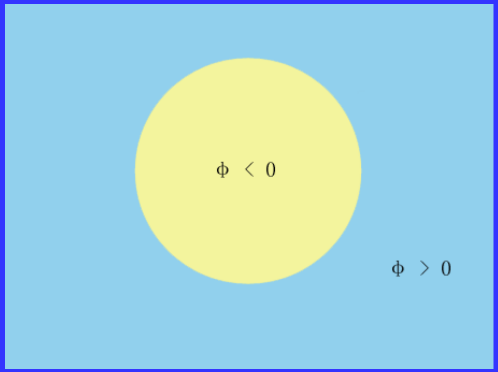
- Characteristics:
  - Initialization with two threshold values.
  - Simple set up & fast computation.
- Set up for "optimal" performance:
  - Tuning of threshold values for maximization of the Tanimoto index (TI) for the three tissues.
  - Manually labeled data used as the reference.
  - Simplex optimization for co-segmentation of the three tissues.

$$TI = \frac{TP}{1 + FP}$$

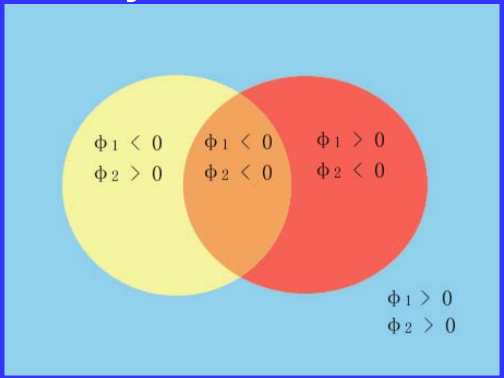
2. Multi-Phase Level Set

'Active Contours Without Edges' [Chan-Vese IEEE TMI 2001]

- Method:
  - 3D deformable model based on Mumford-Shah functional.
  - Homogeneity-based external forces.
  - Multiphase framework with 2 level set functions to segment 4 homogeneous objects simultaneously.



One ϕ function
=> Two phases



Two ϕ functions
=> Four phases

2. Multi-Phase Level Set

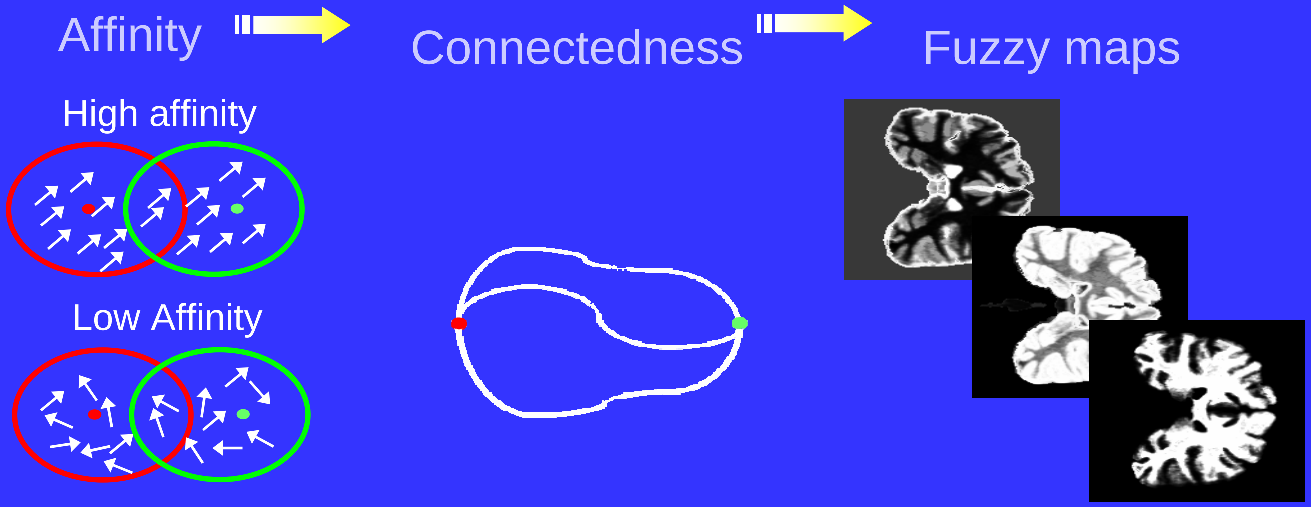
- Characteristics:
  - Automatic initialization.
  - No *a priori* information required.
- Set up:
  - Details provided in:

E. D. Angelini, T. Song, B. D. Mensh, A. Laine, "Multi-phase three-dimensional level set segmentation of brain MRI," *International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI),* Saint-Malo, France, September 2004.

3. Simple Fuzzy Connectedness

'Fuzzy Connectedness and Object Definition: Theory, Algorithms, and Applications in Image Segmentation', J. Udupa *et al.*, GMIP, 1996.

- Method:
  - Computation of a fuzzy connectedness map to measure similarities between voxels.



  - Thresholding of each tissue fuzzy map to obtain a final segmentation.

3. Simple Fuzzy Connectedness

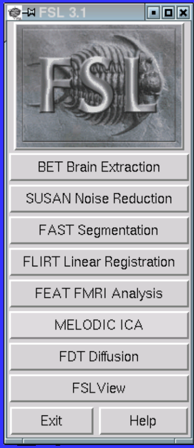
- Characteristics:
  - Initialization with seed points and prior statistics.
  - Implementation from the National Library of Medicine Insight Segmentation and Registration Toolkit (ITK). (www.itk.org)
- Set up for "optimal" performance:
  - The threshold value for fuzzy maps was optimized using the Simplex scheme to obtain the segmentation with best accuracy (from the computed fuzzy connectedness map).

4. HMRF-EM

'Segmentation of Brain MR Images Through a Hidden Markov Random Field Model and the Expectation-Maximization Algorithm '

[Y. Zhang, M. Brady, S. Smith, IEEE Transactions on Medical Imaging, 2001]

- Method
  - Statistical classification method based on Hidden Markov random field models.
  - Class labels, tissue parameters and bias fields are updated iteratively.
- Characteristics:
  - The method was implemented in the FSL-FMRIB Software Library (http://www.fmrib.ox.ac.uk/fsl).



Results

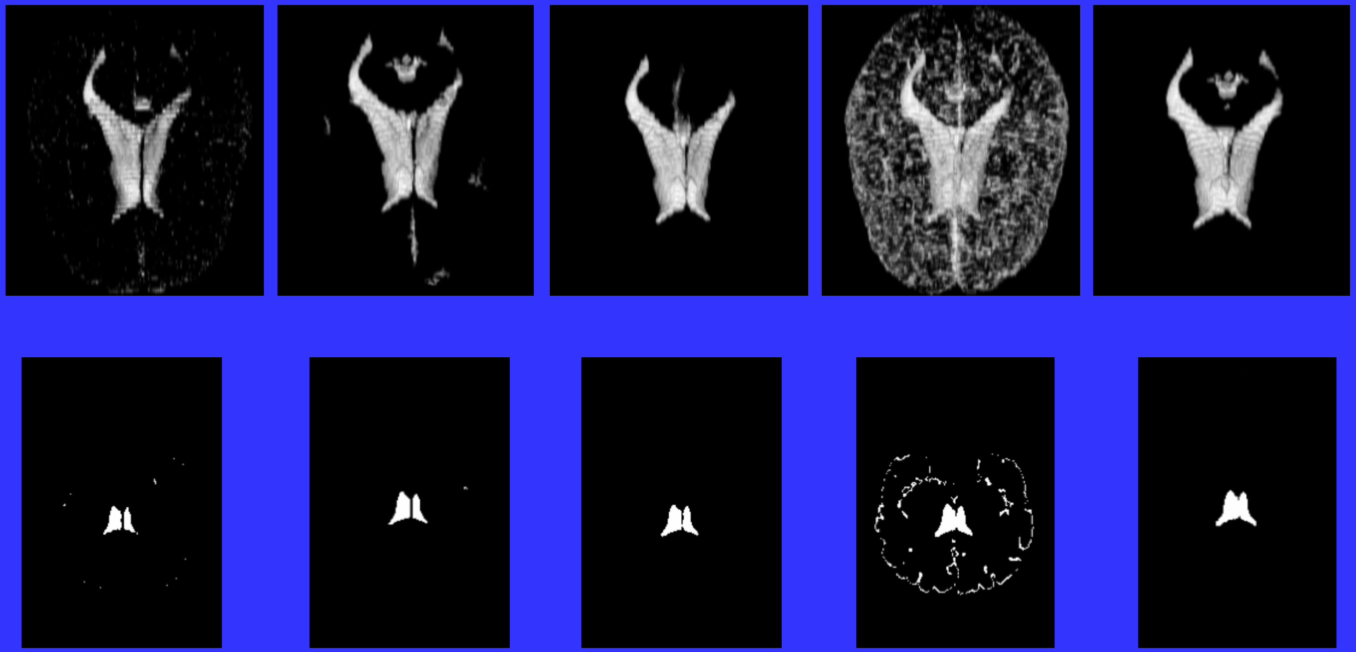
- **Data**
  - Ten T1-weighted MRI data sets from healthy young volunteers.
  - Data sets size = (256x256x73) with 3mm slice thickness and 0.86mm in-plane resolution.
  - Manual labeling available (manual protocol requiring 40 hours per brain).

Results

- Evaluation protocol
  - Measurements of organ’s volume.
  - True positive, false positive voxel fractions and the Tanimoto index for the each tissue.
  - Analysis of variance (ANOVA) performed to evaluate the differences between the four segmentation methods.

Results

Segmentation of CSF

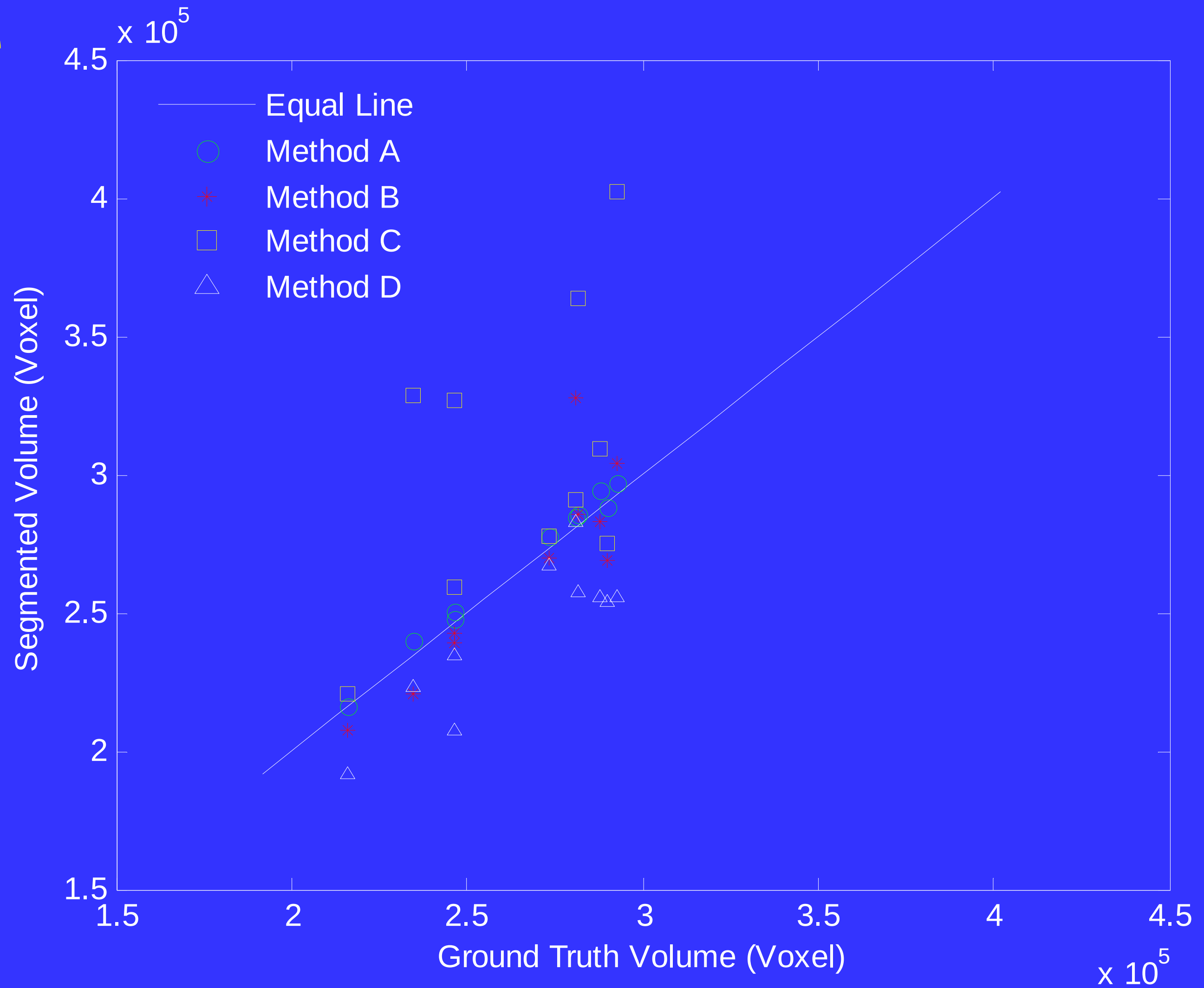


(a) (b) (c) (d) (e)

(a) Histogram thresholding, (b) Level set, (c) Fuzzy connectedness, (d) HMRFs, (e) Manual labeling.

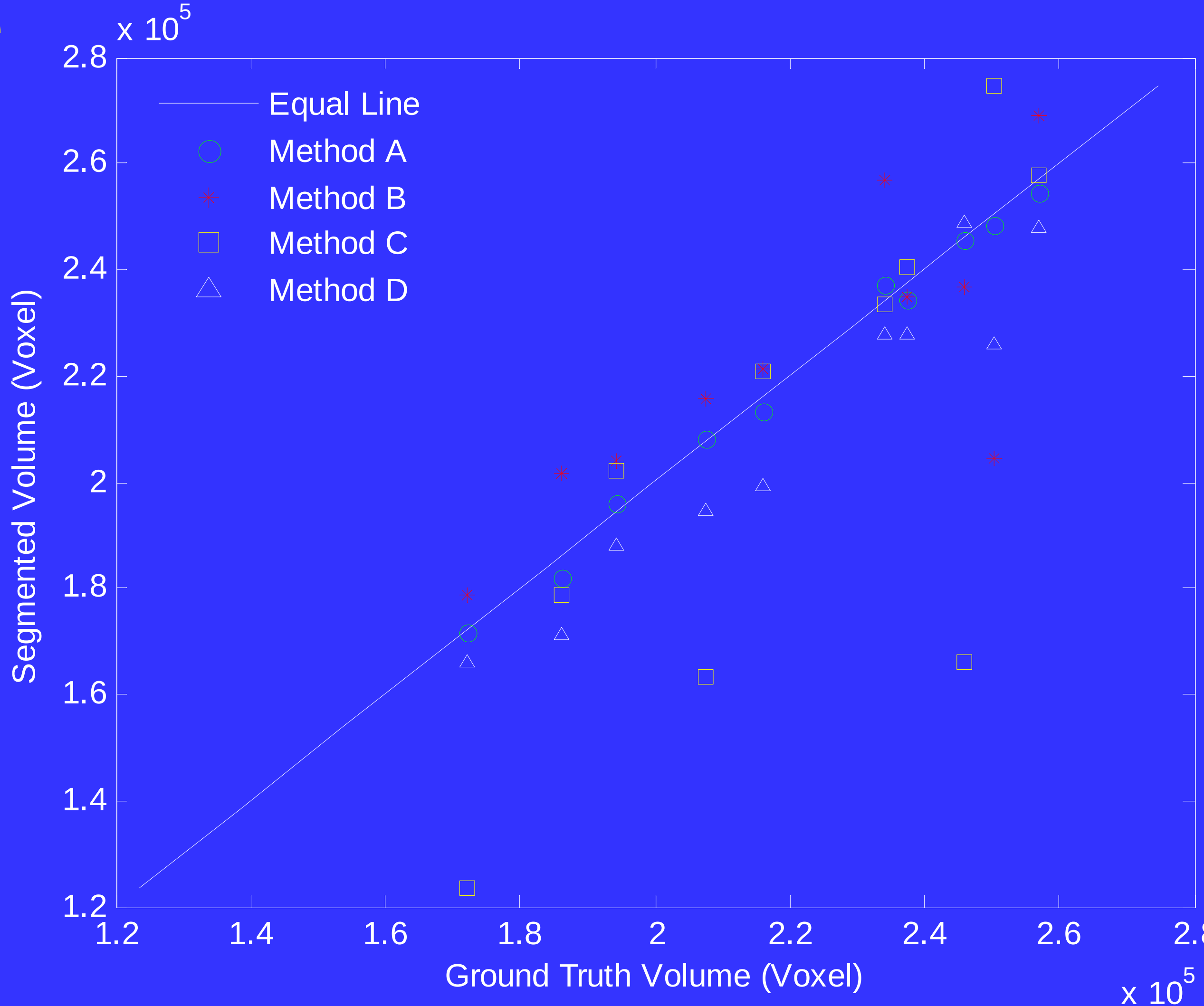
Results

GM volume



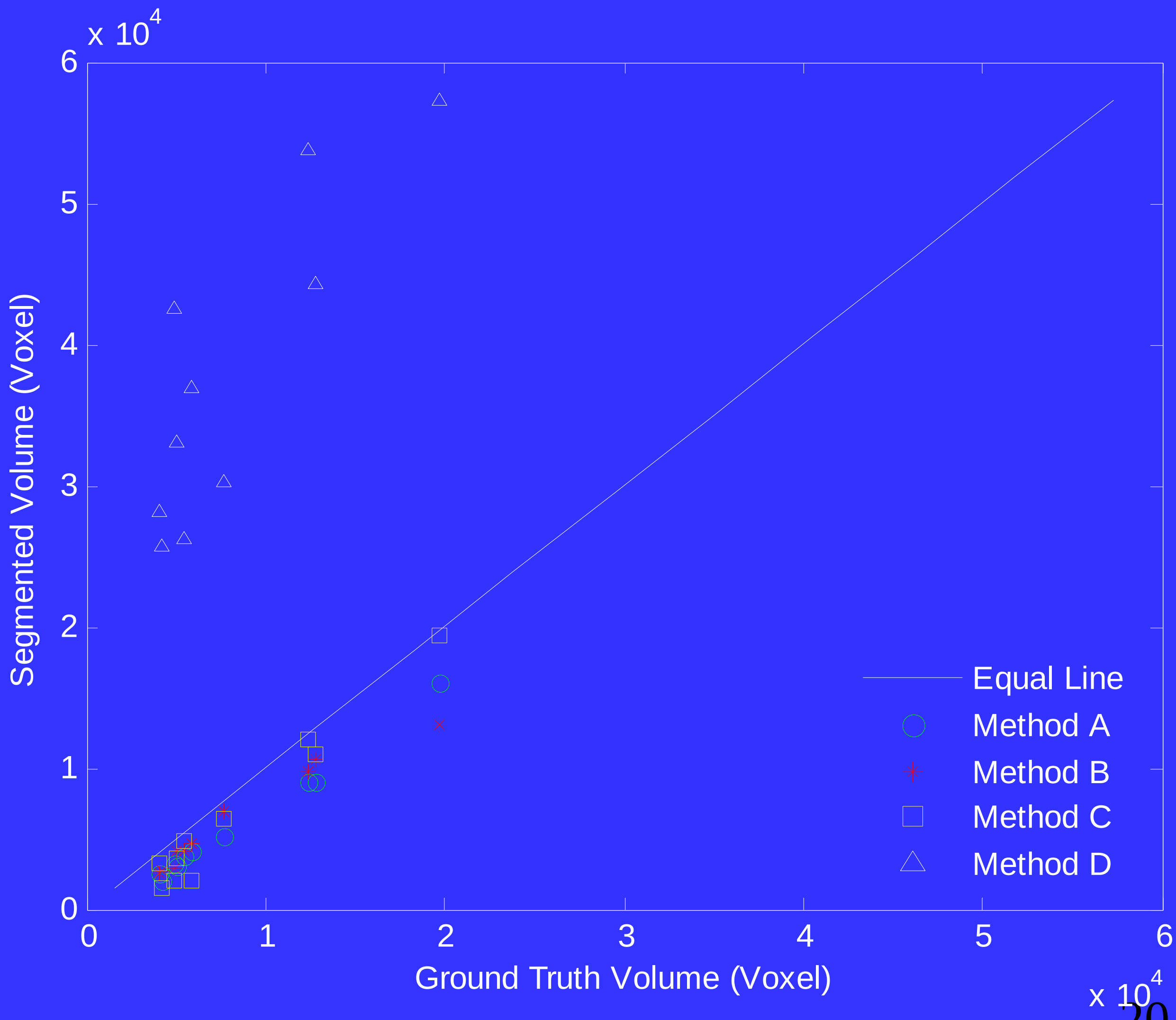
Results

WM volume



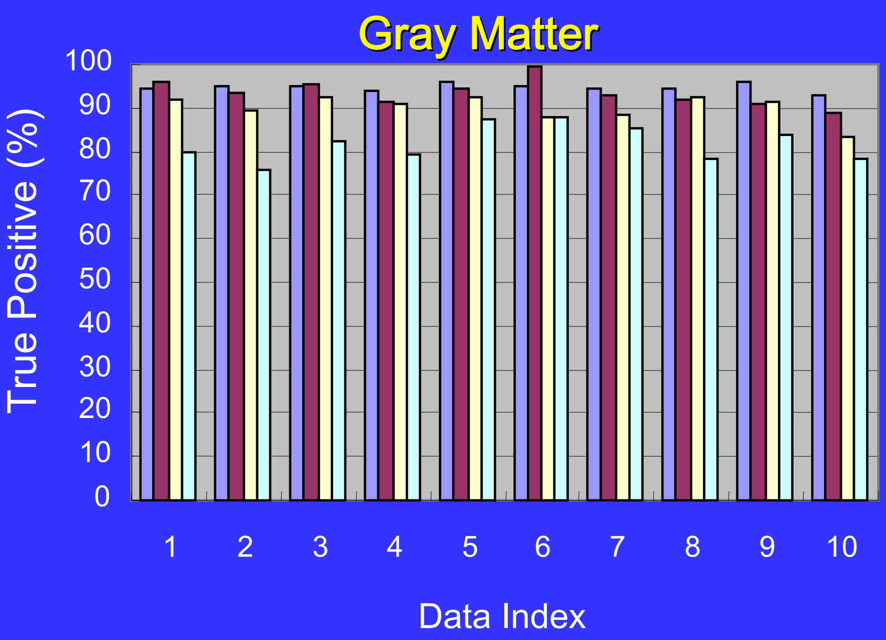
Results

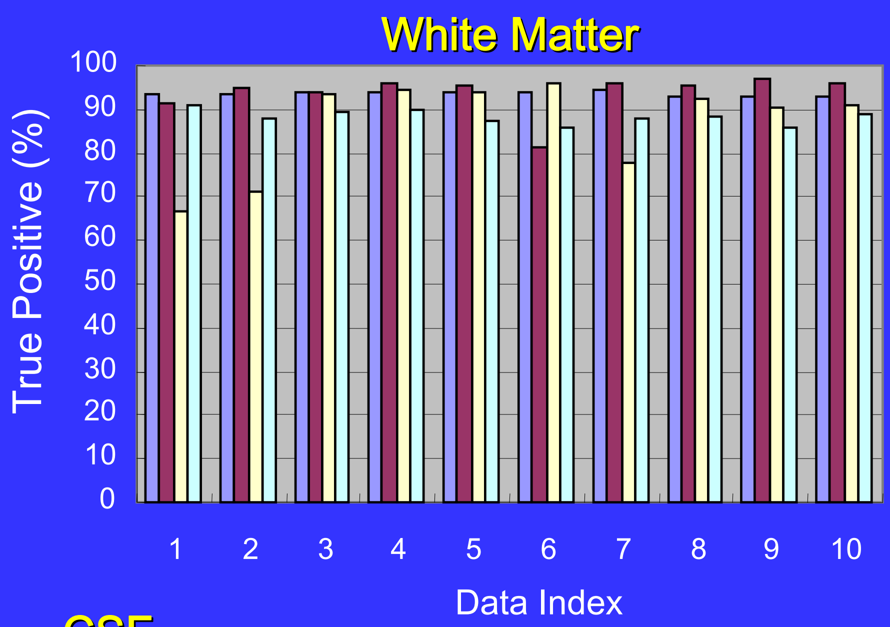
CSF volume

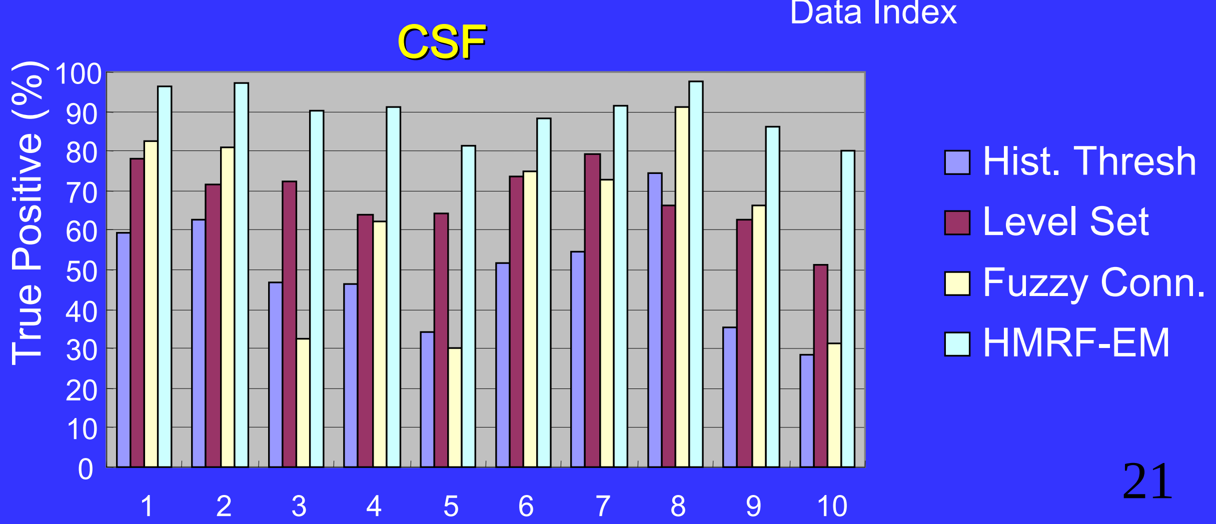


Results

Accuracy Evaluation: True Positive

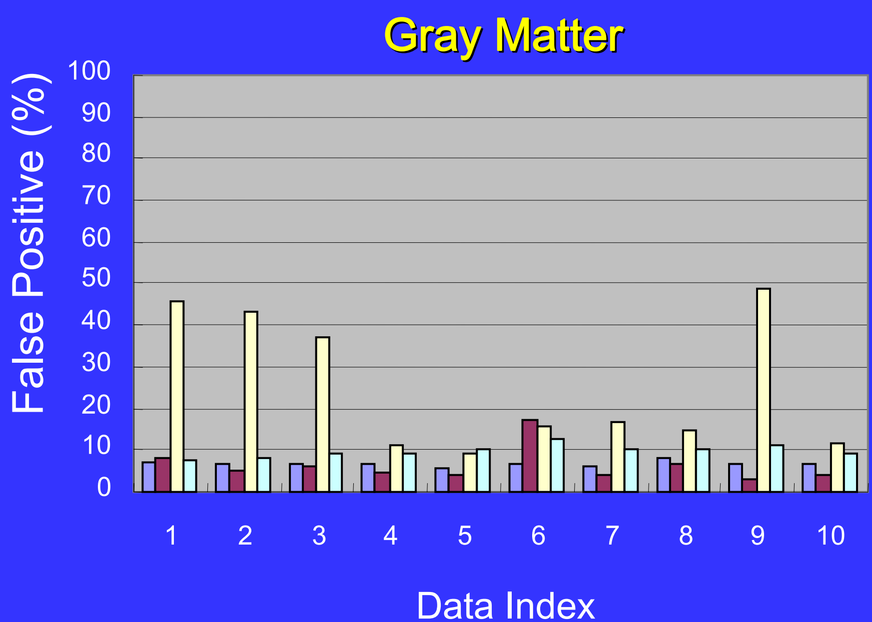


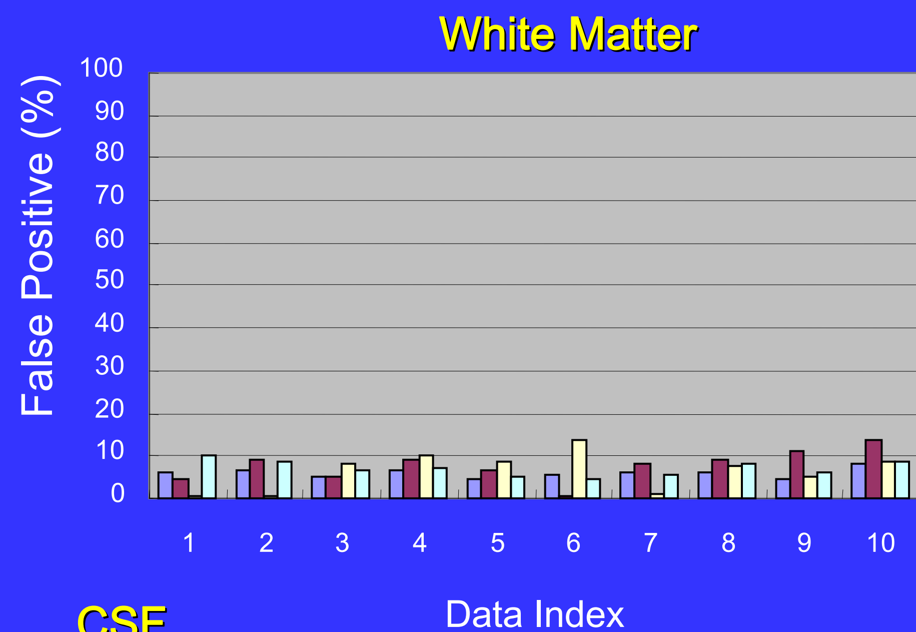


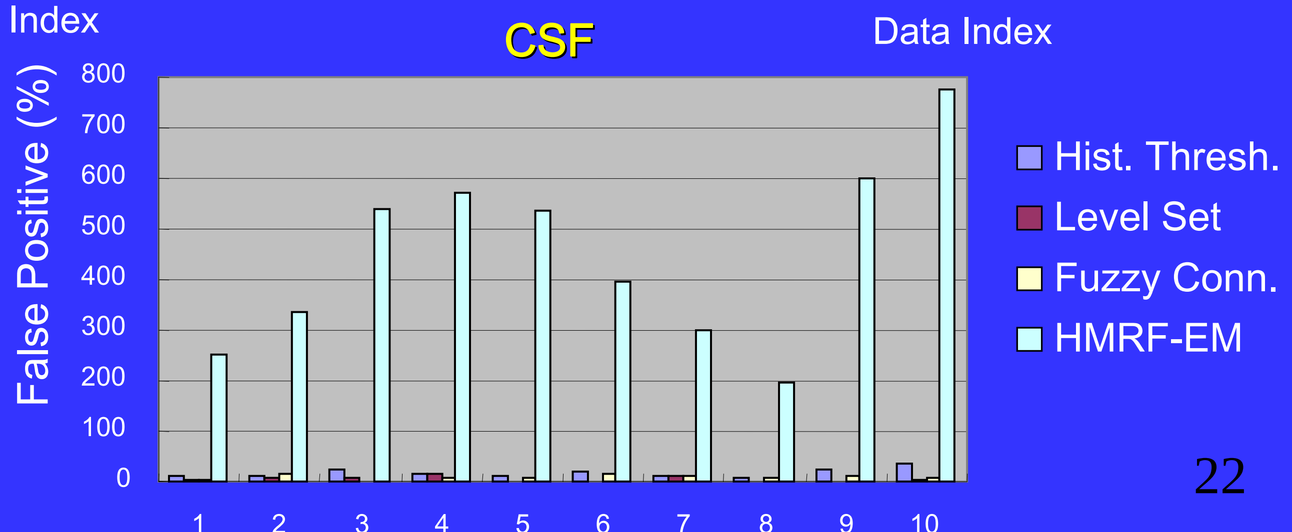


Results

Accuracy Evaluation: False Positives

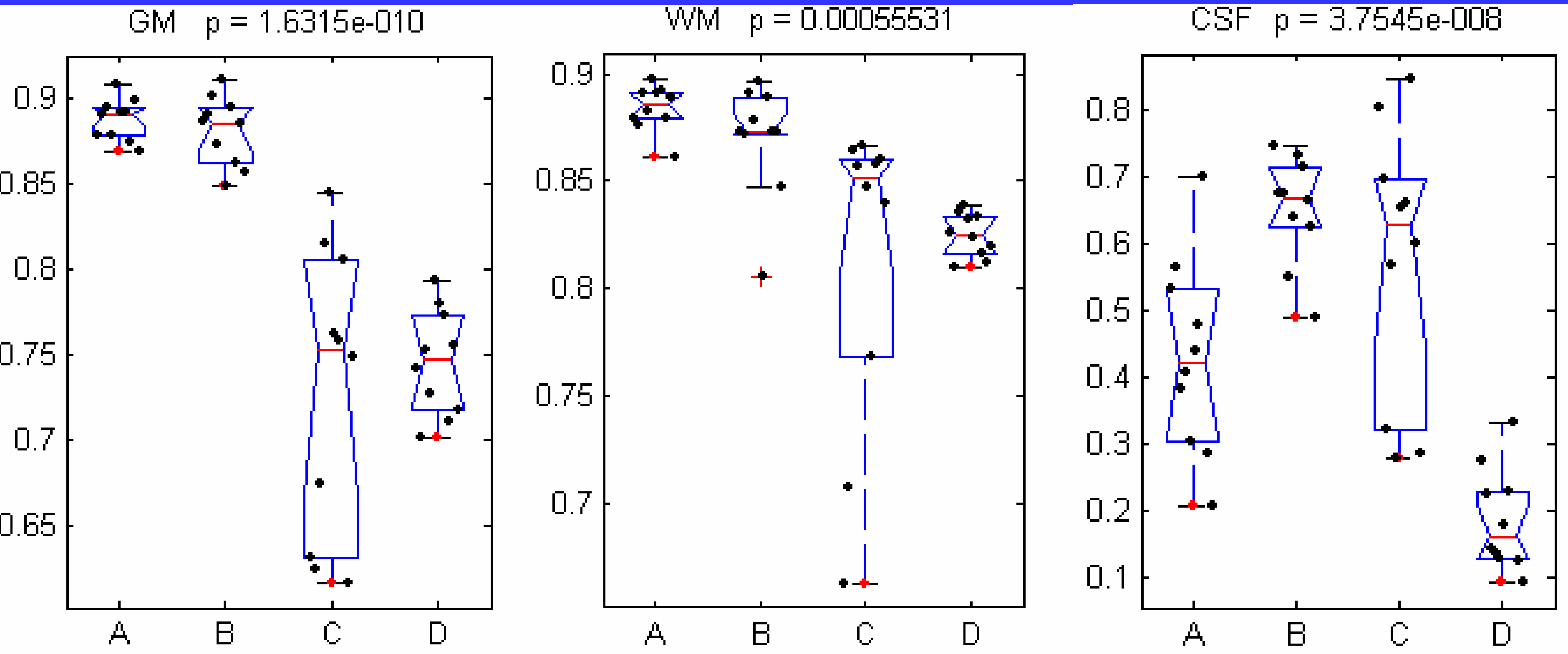






Results

- Analysis of variance: ANOVA
  - *Inter-method variance* / *Intra-method variance* of the TI index.
  - Statistical difference between methods confirmed for $p < 0.005$.



Discussion

- Segmentation of WM & GM
  - All methods reported high TI values.
  - Superior performance of methods A and B.
- Segmentation of CSF
  - Superiority of methods B and C (cf. TI values).
  - Highest variance for method C.
  - Significant under segmentation of CSF (i.e. high FN errors) due to very low resolution at the ventricle borders.
  - Difference between methods for sulcal CSF:
    - Different handling of partial volume effects
    - Manual labeling eliminates sulcal CSF. Arbitrary choice and no ground truth available for these voxels.
  - Manual labeling of the ventricles and sulcal CSF can vary up to 15% between experts as reported in the literature.

A. Hist. Thresh.
B. Level Set
C. Fuzzy Conn.
D. HMRF-EM

Conclusions

- A. Hist. Thresh.
- B. Level Set
- C. Fuzzy Conn.
- D. HMRF-EM

- Four different methods were compared using clinical data.
- Statistical difference of methods was assessed.
- Difference of performance focused on the extraction of CSF structures.
  - Method A and B have strong correlations with manual tracing.
  - Method C tends to over segment the GM structure in several cases.
  - Method D tends to over segment the CSF structures.
- Combining all results, the level set three-dimensional deformable model (Method B) provides the best performance for high accuracy and low variance of performance index.

References

1. E. D. Angelini, T. Song, B. D. Mensh, A. Laine, “Multi-phase three-dimensional level set segmentation of brain MRI,"
   MICCAI (Medical Image Computing and Computer-Assisted Intervention) International Conference 2004, Saint-Malo, France, September 26-30, 2004.

2. E. D. Angelini, T. Song, B. D. Mensh, A. Laine, “Segmentation and quantitative evaluation of brain MRI data with a multi-phase three-dimensional implicit deformable model,"
   SPIE International Symposium, Medical Imaging 2004, San Diego, CA USA, Vol. 5370, pp. 526-537, 2004.

3. Heffner Biomedical Imaging Lab
   http://hbil.bme.columbia.edu