The impact of processing workflow in performance of automatic white matter lesion segmentation in Multiple Sclerosis

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Summary

- Introduction
- STREMv1
- STREMv2
- Workflow
  - Intensity inhomogeneity correction
  - Denoising
- Results
- Conclusions

Introduction

- There is many algorithms for MS lesion segmentation
  - Little information available about the preprocessing algorithms employed
- Evaluate the need of denoising and intensity inhomogeneity correction

STREMv1

- Method introduced by (Ait-Ali et Al., MICCAI 2005)
- Model-based segmentation
  - Lesions are considered outliers to the model
- Three steps:
  1. Robust estimation of NABT parameters
  2. Refinement of outliers detection
  3. Application of lesion rules

Estimation NABT

- 3-class Finite Multivariate Gaussian Mixture Model
- Modified Expectation-Maximization algorithm (mEM)
  - Trimmed Likelihood (Neikov et al. 2006)

$$TL = \sum_{i=1}^{n-h} f(x_{\nu(i)};\Theta)$$

    - Ordering function

$$f(x_{\nu(1)};\Theta) \geq f(x_{\nu(2)};\Theta) \geq \ldots \geq f(x_{\nu(n)};\Theta)$$

  - In our experiments h=n/10

Outliers detection

- mEM gives a fixed number of outliers (h)
- h can contain voxels that fit the NABT model
- Compute Mahalanobis distance:

$$d_{i,j} = (\mathbf{y_i} - \mu_\mathbf{j})^T \Sigma_j^{-1} (\mathbf{y_i} - \mu_\mathbf{j})$$

- Mahalanobis distance follow a X^2 law with m d.o.f
  - m is the number of sequences
  - A threshold is defined by the X^2 law for a given p-value

Application of lesion rules

- Outliers have different sources:
  - Lesions
  - Registration errors, vessels, noise, etc.
- Rules to select lesions

(compared to WM)	T1-w	T2-w	PD-w	FLAIR
T2-w lesions	Isointensity or Hypointensity	Hyperintensity	Hyperintensity	Hyperintensity

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STREMv2

- STREMv1
  - Atlas registration for initialization:
    - Time consuming
    - Problems with tissue atrophy in samples with huge lesion loads
  - Segmentation only based on MR intensity
- STREMv1.5
  - Improve initialization of mEM
- STREMv2
  - STREMv1.5 + Reduction of false positives

Initialization of mEM

- Multiple random initializations
  - Computationally time expensive
  - No guarantee for global convergence
  - No general agreement on how many initializations are necessary, but they are growing with the number of dimensions

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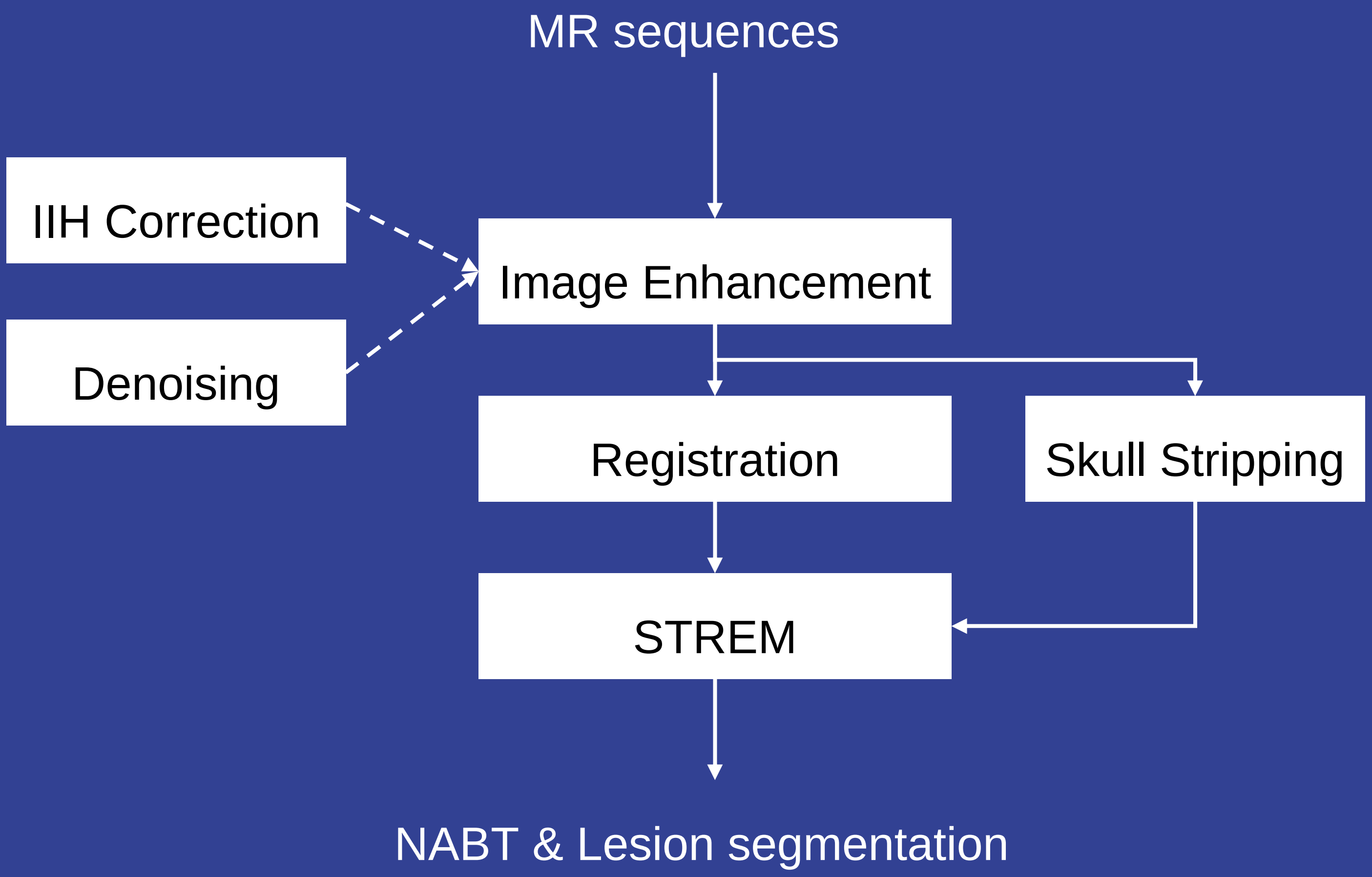
Initialization of mEM

- Hierarchical multiple initializations on T1-w only:
  1. n_0 random initializations
  2. Use mEM with $iter_0$ iterations using these initializations
  3. Keep n_1 best solutions
  4. Use mEM with n_1 partial solutions until convergence
  5. Keep best solution
  - n_0=300, $iter_0$=10 and n_1=10
- Expansion to multidimensional mEM
  - Probabilities at the end of E-step in T1-w are applied in the multidimensional M-Step

Spatial Constraints

- Detection of false positives:
  - Isolated hyperintensity voxels due to image noise are misclassified
  - In the cortex and CSF, voxels can have the same MR intensity as WML
- Two rules are added:
  - Minimal size of WM lesion is defined as $3mm^3$
  - MS lesions have to be contiguous to white matter

Workflow


MR sequences
IIH Correction
Denoising
Image Enhancement
Registration
Skull Stripping
STREM
NABT & Lesion segmentation

Workflow

- Skullstripping
  - Use BET (Smith 2002)
  - Manually corrected
- Rigid registration
  - Use Mutual Information with NEWUOA optimizer (Wiest-Daesle et al., 2007)
  - Use of FLAIR as reference sequence

Intensity Inhomogeneity Correction

- IIH is a small spatial variation of intensity in an homogeneous tissue
  - Caused by the imperfection of the magnetic field
- Does not affect "human" radiological assessments
  - But: Reduces performance of many algorithms
- Method applied (Mangin MMBIA 2000)
  - Entropy minimization method
  - No assumptions of MR sequence or number of tissues

Denoising

- Image additive noise in hardware acquisition
- Method employed
  - (Coupe et al.,TMI 2008)
  - Non-Local Means method

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Evaluation

	Scanner	T1-w	T2-w	FLAIR
Subject1	3T Siemens	Isotropic 1 mm	3 mm axial slice	3 mm axial slice
Subject2	3T Philips	Isotropic 1 mm	3 mm axial slice	3 mm axial slice
Subject3	3T Siemens	Isotropic 1 mm	Isotropic 1 mm	Isotropic 1 mm

Five different Workflows:

- Basic : No preprocessing before registration.
- NLM : Denoising before registration.
- IIH : Intensity correction before registration.
- IIH+NLM: Intensity correction and then denoising before registration.
- NLM+IIH: Denoising and then intensity correction before registration.

Experiments

- Preprocessing workflows:
  - With STREMv1, all workflows are tested for the three patients
- STREMv1 vs. STREMv1.5 vs. STREMv2
  - Applying best workflow we compare the different versions of STREM
- Metrics:
  - DSC with a manually delineated segmentation
  - Execution time

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Results

	Subj1	Subj2	Subj3
Basic(v1)	0.31	0.20	0.42
NLM(v1)	0.33	0.29	0.42
IIH(v1)	0.31	0.49	0.53
IIH+NLM(v1)	0.30	0.46	0.48
NLM+IIH(v1)	0.31	0.49	0.56
NLM+IIH(v1.5)	0.31	0.49	0.56
NLM+IIH(v2)	0.38	0.66	0.64

	IIH	NLM.	Reg.	Atl.	STREM	Total
Basic(v1)	0	0	339	99	2741	3179
NLM(v1)	0	429	347	136	2486	3398
IIH(v1)	68	0	387	186	1082	1723
IIH+NLM(v1)	68	424	355	48	911	1806
NLM+IIH(v1)	80	429	362	140	923	1934
NLM+IIH(v1.5)	80	429	362	0	584	1455
NLM+IIH(v2)	80	429	362	0	588	1459

- Left: DSC of different subjects and workflows
- Right: Processing time for subject 2

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- Performing IIH is more important than denoising
- Sequential association of NLM+IIH better than IIH+NLM

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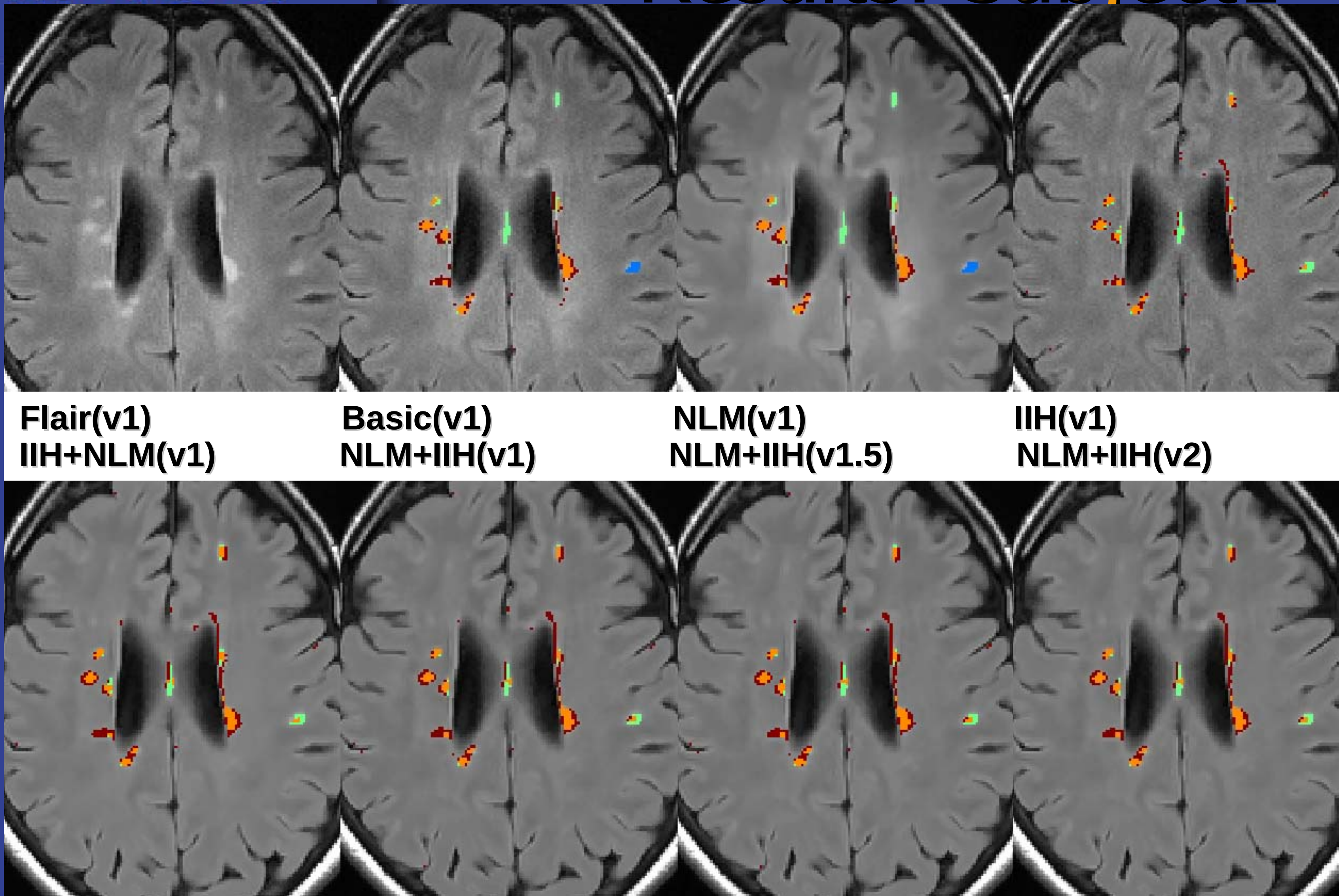
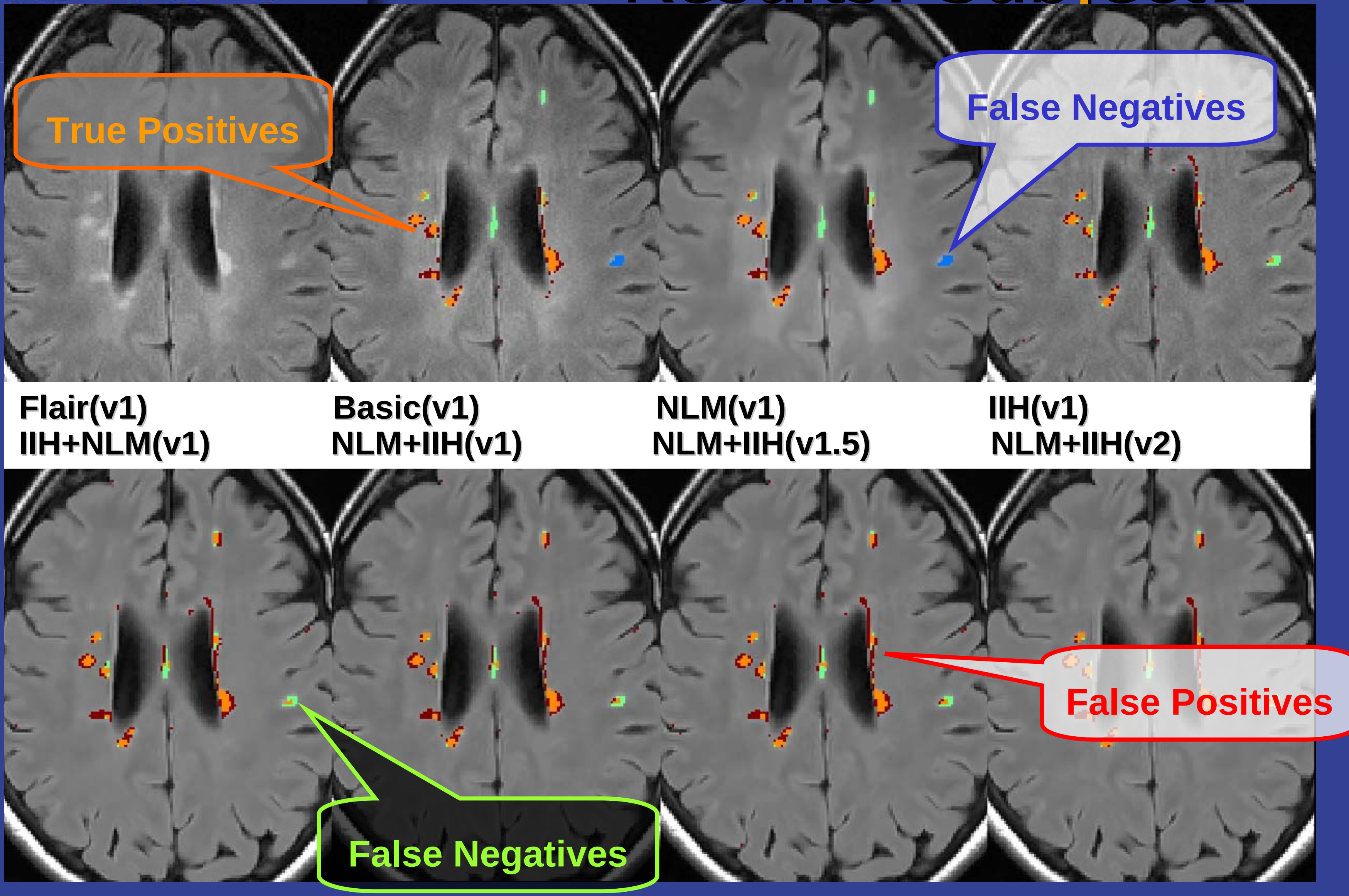
- New initialization has same solution as atlas based but the workflow is faster
- New rules reduce the number of false positives

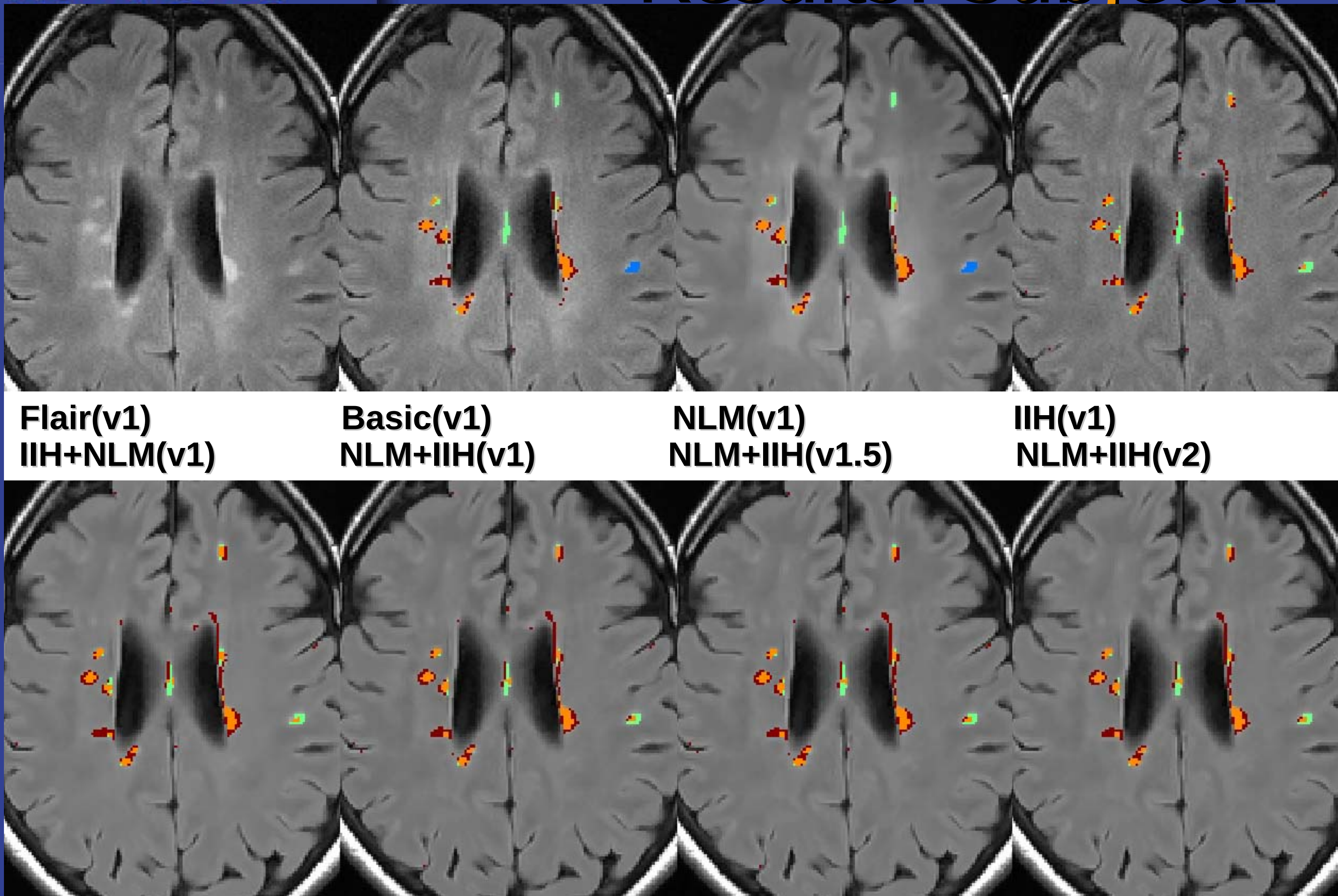
Results: Subject1



Results: Subject1



Results: Subject1



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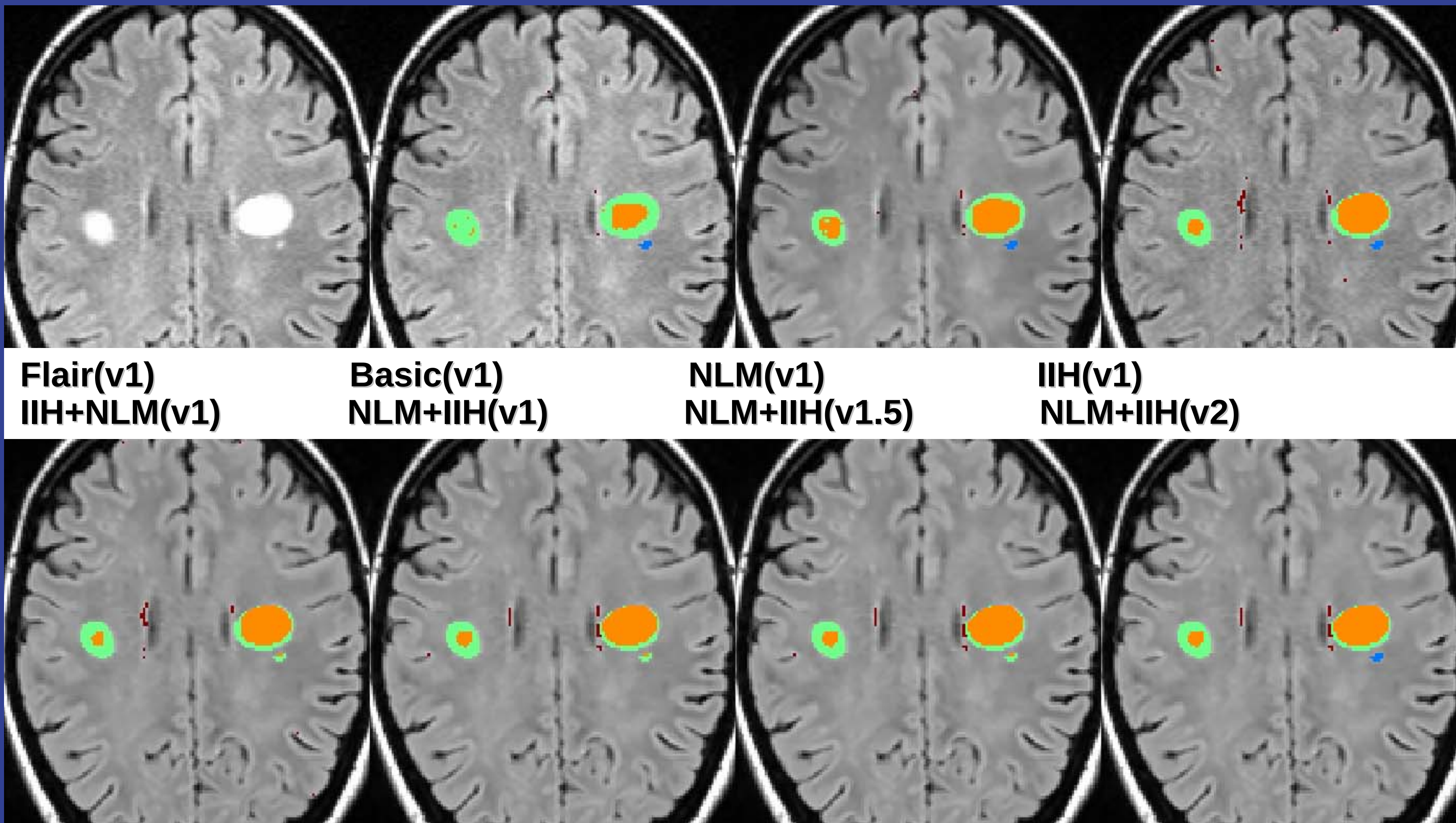
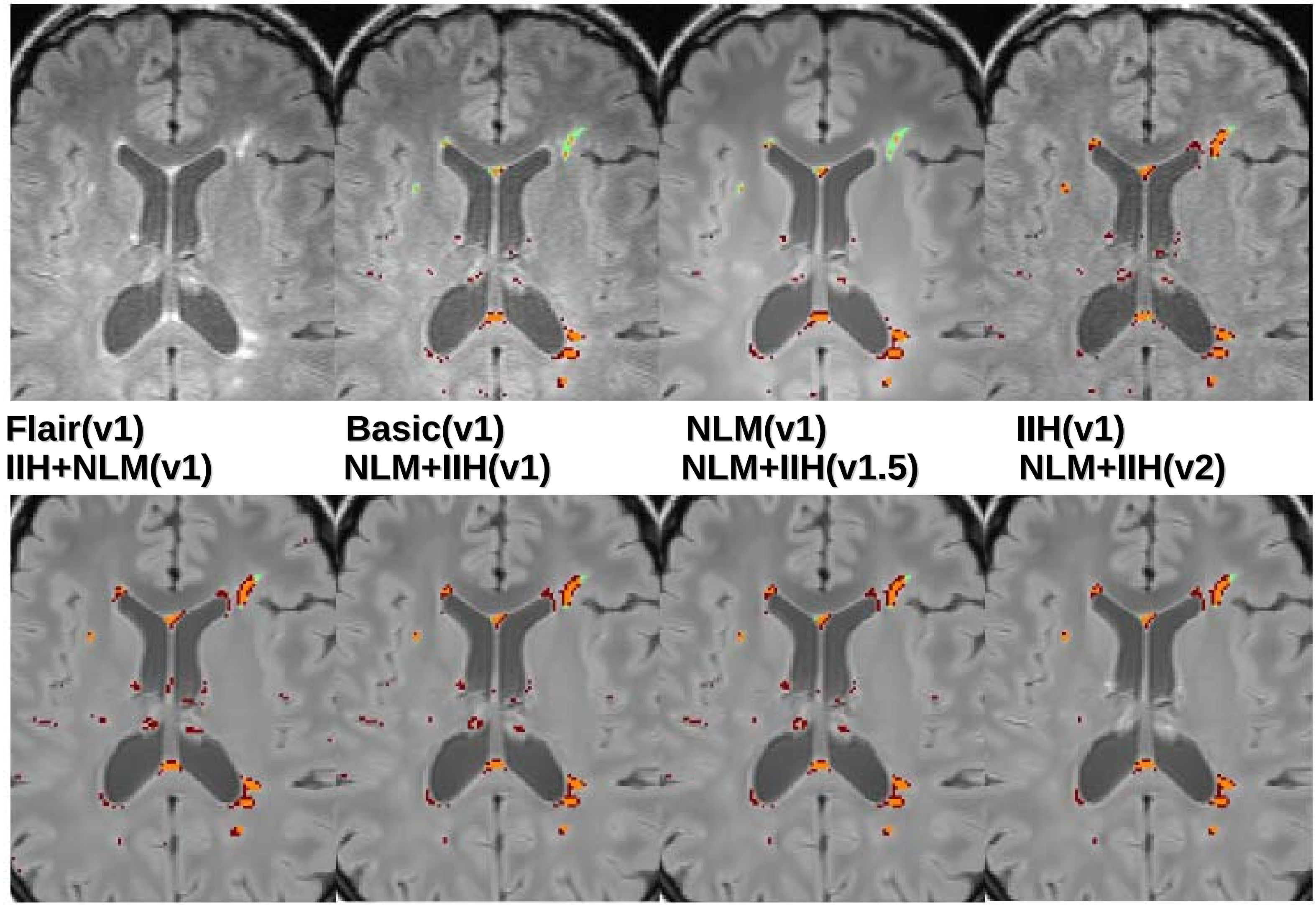
Results: Subject2



Results: Subject3



Conclusions

- Segmentation methods have to be evaluated looking at the whole preprocessing workflow
- We presented our WML and NABT segmentation workflow and showed its impact on the final segmentation result
- Future work:
  - To increase patient number
  - To compare more methods for each preprocessing step

Thank you very much for your attention

Supported by Arsep