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Automated DTI Analysis of MS Lesions and their contralateral regions of interest using the mid-sagittal plane as a reference

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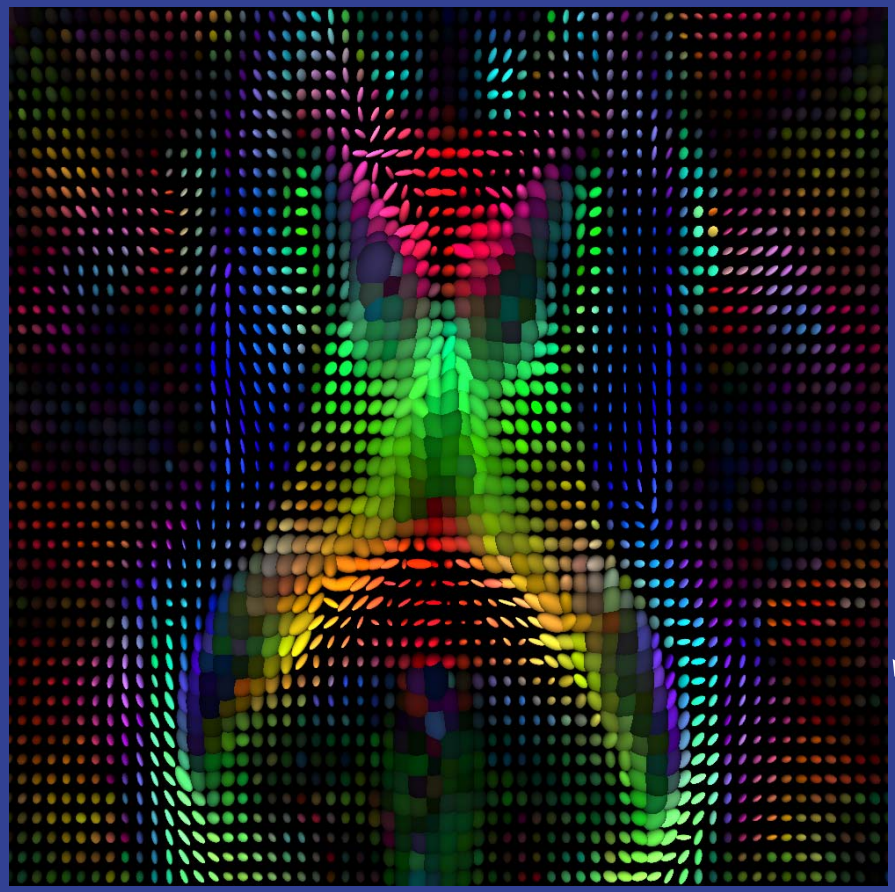
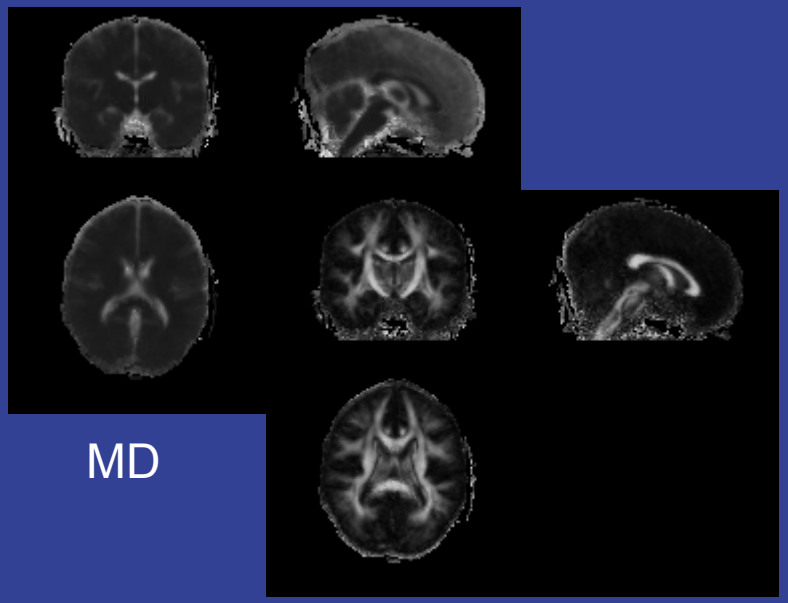
Introduction
Diffusion Tensor Imaging

- Diffusion Tensor MRI (DT-MRI)
- Non-invasive technique for analysis of the connectivity and structure of the brain
- Measure for diffusivity of water in the brain
- Brain water is constrained by the various fibrous cells
- Diffusion Tensor is a model of the water diffusivity

Introduction
Diffusion Tensor Imaging

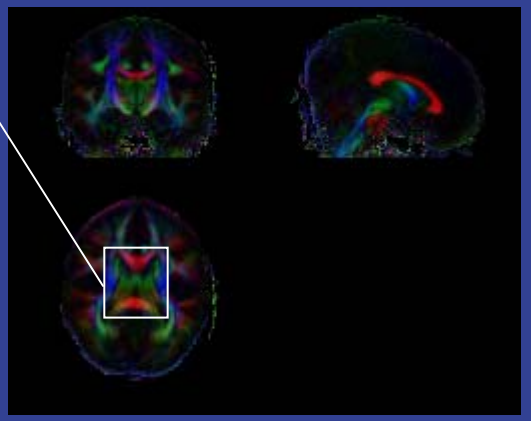


Ellipsoidal representation of a tensor field



MD

FA



Colored FA

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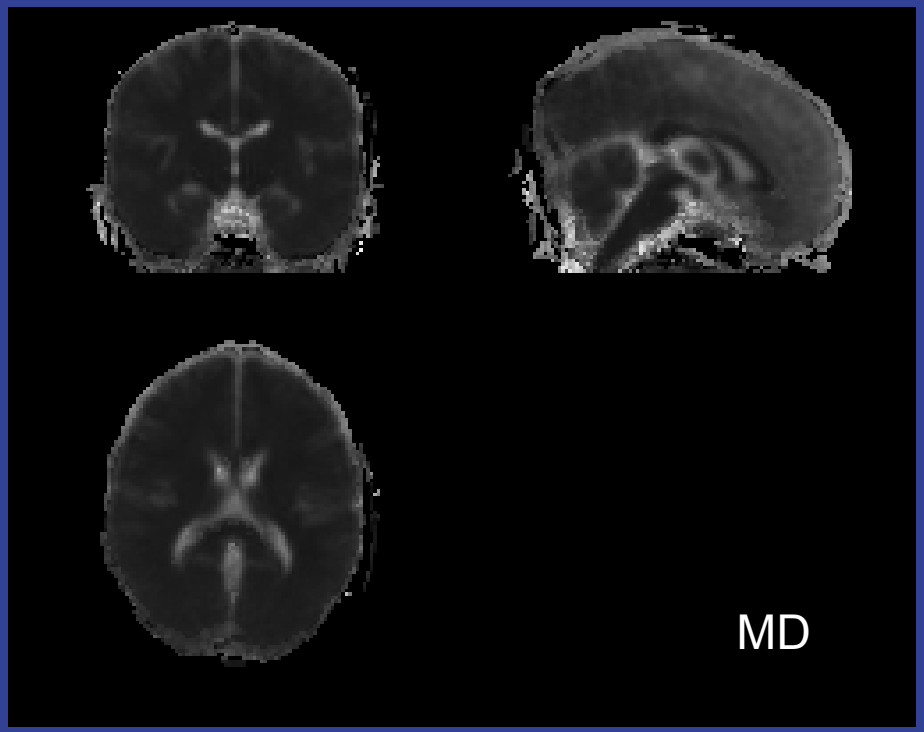
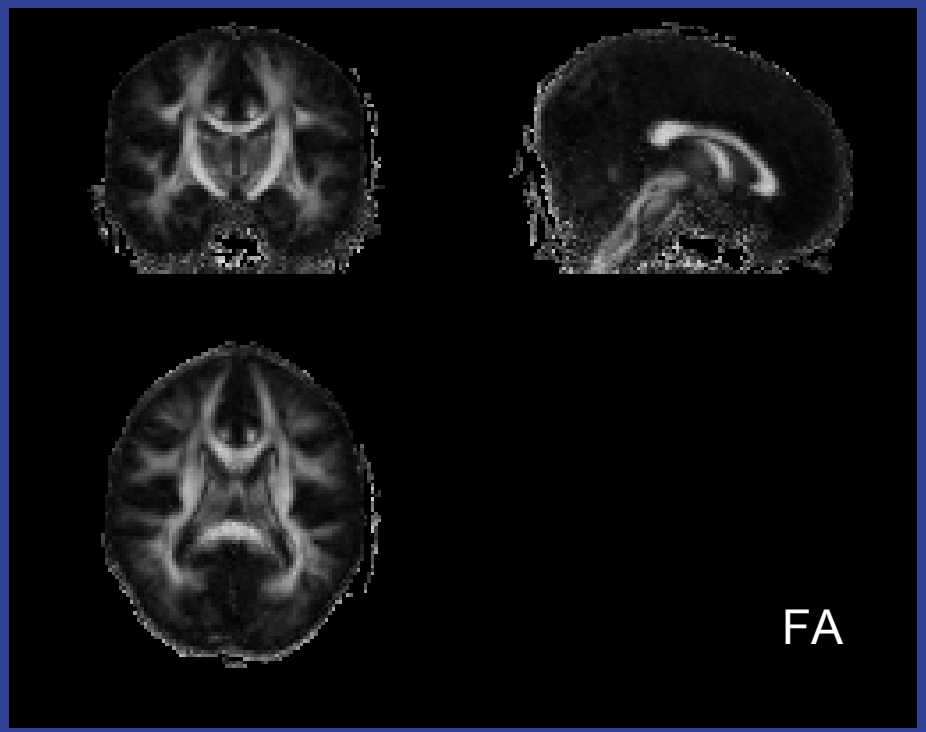
Introduction Diffusion Tensor Imaging

- FA quantifies the degree of anisotropy
- MD quantifies the average of diffusivity





Introduction

- DTI Analysis in MS (traditional approach):
  - Histogram analysis of whole brain
  - Histogram analysis of manually delineated ROI
- Results in MS Lesions (MSL), NAWM and NAGM:
  - Overall: Increase in MD - Loss of FA - Loss of RA
- Questions:
  - How does state-of-the-art Tensor estimation impact on results ?
  - How does correction of artefacts impact on results ?
- Objective :
  - DTI analysis of the white mater pathology in MS lesions in comparison with its contralateral NAWM region

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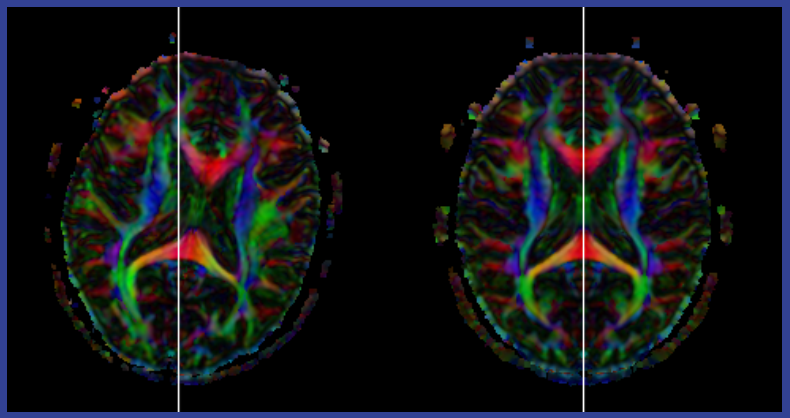
Patients and Methods

- 5 MS patients
- 5 age and sex matched controls

- DT-MRI acquisition on 3T scanner (Philips)
  - 15 directions of diffusion sensitization
  - 2mm slice thickness

Method

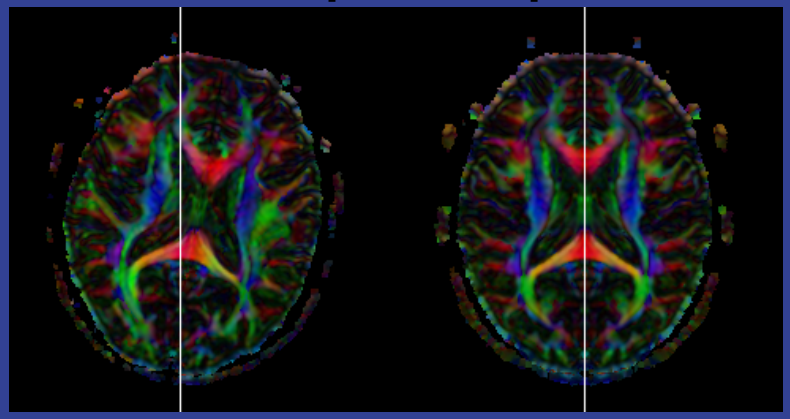
- Segmentation of MS Lesions
- Computation of the Mid-sagittal Plane (MSP)



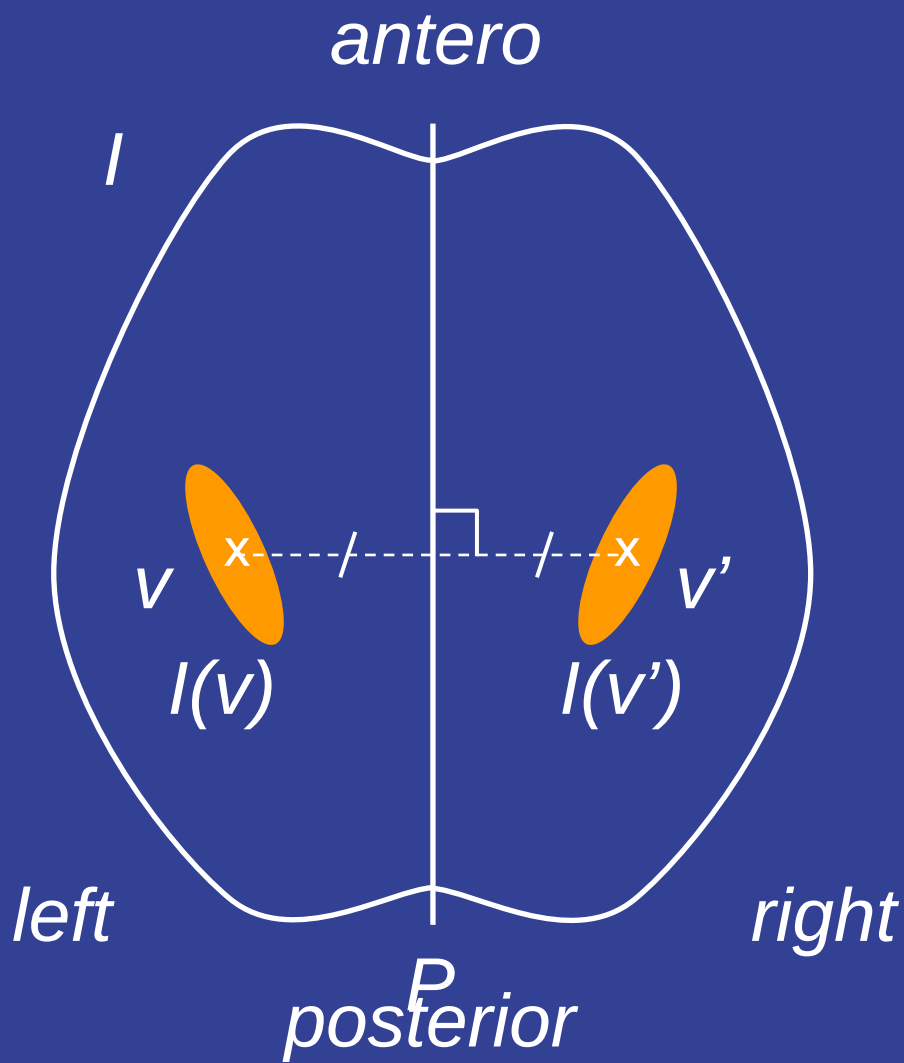
- Creation of NAWM mask by flipping MSL with respect to the MSP

Computation of the MSP

- Definition of the MSP:
  - The plane that best superposes the two hemispheres of the brain by reflection symmetry.
- Performed using automated minimisation of a correlation type criterion on tensor image
- Computation of the plane parameters



Illustrative sketch



- *I:* DT-MR image of the brain
- $v' = S_P(v)$
- $I(v') = S_P(I(v))$

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Mathematical formulation

- Perfect symmetry:

$$v' = S_P(v)$$

$$I(v') = S_P(I(v)) \Leftrightarrow I(v) = S_P(I(v'))$$

- Imperfect symmetry:

$$P = \arg\min \sum_{v} \Delta\left(I(v), S_P(I(v'))\right)$$

  - Δ is a metric on tensors

Optimisation using NEWUOA

- NEW Unconstrained Optimisation Algorithm
  - Compute a quadratic approximation of the function to maximise using a set of initial points (parameters), typically (n+1)(n+2)/2 for a problem of dimension n
  - Compute the maximum of the approximation within a “trust region” defined by the initial points
  - Replace the “worst” parameter of the initial set with this newly estimated value and update the trust region
  - Iterate

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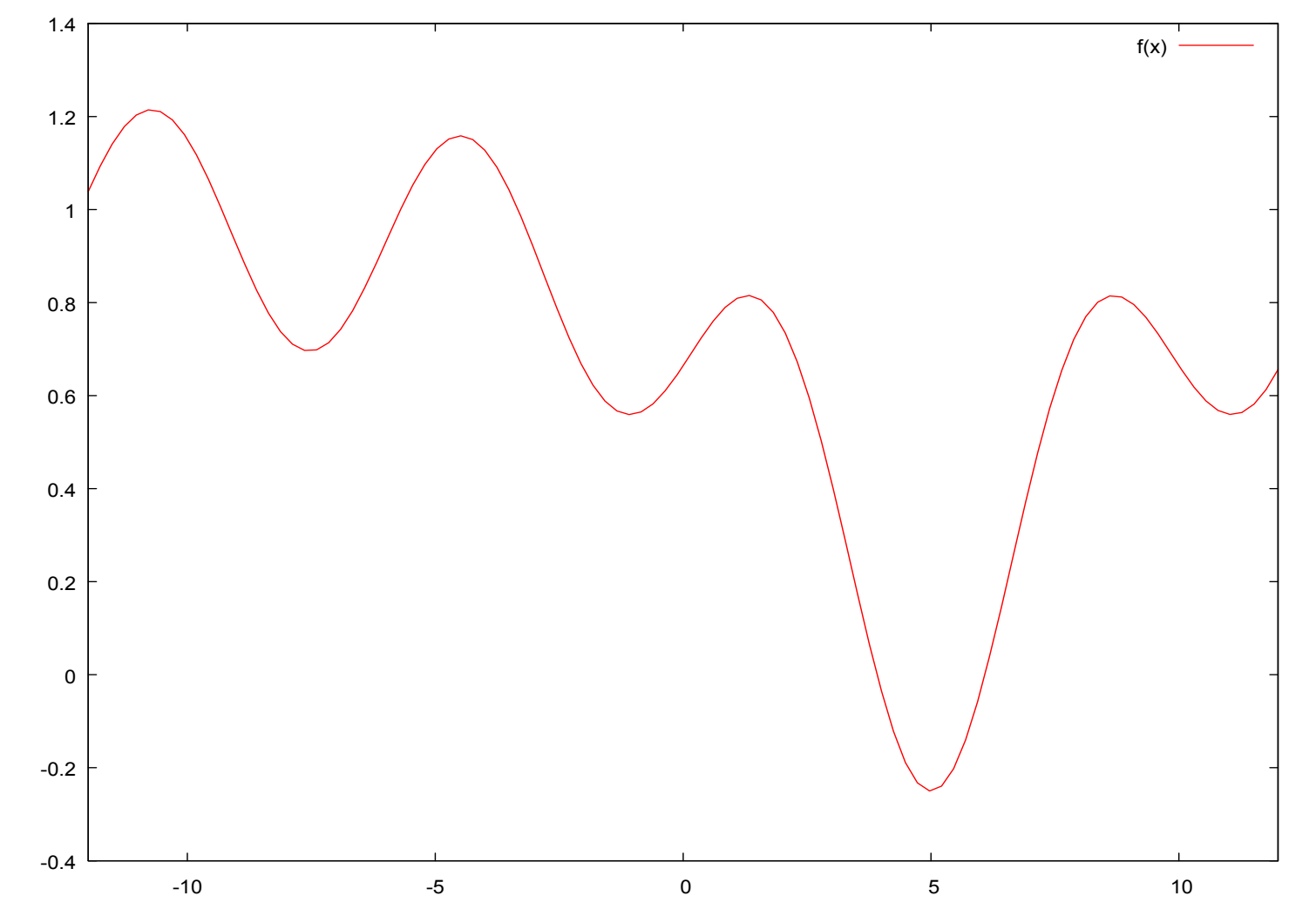
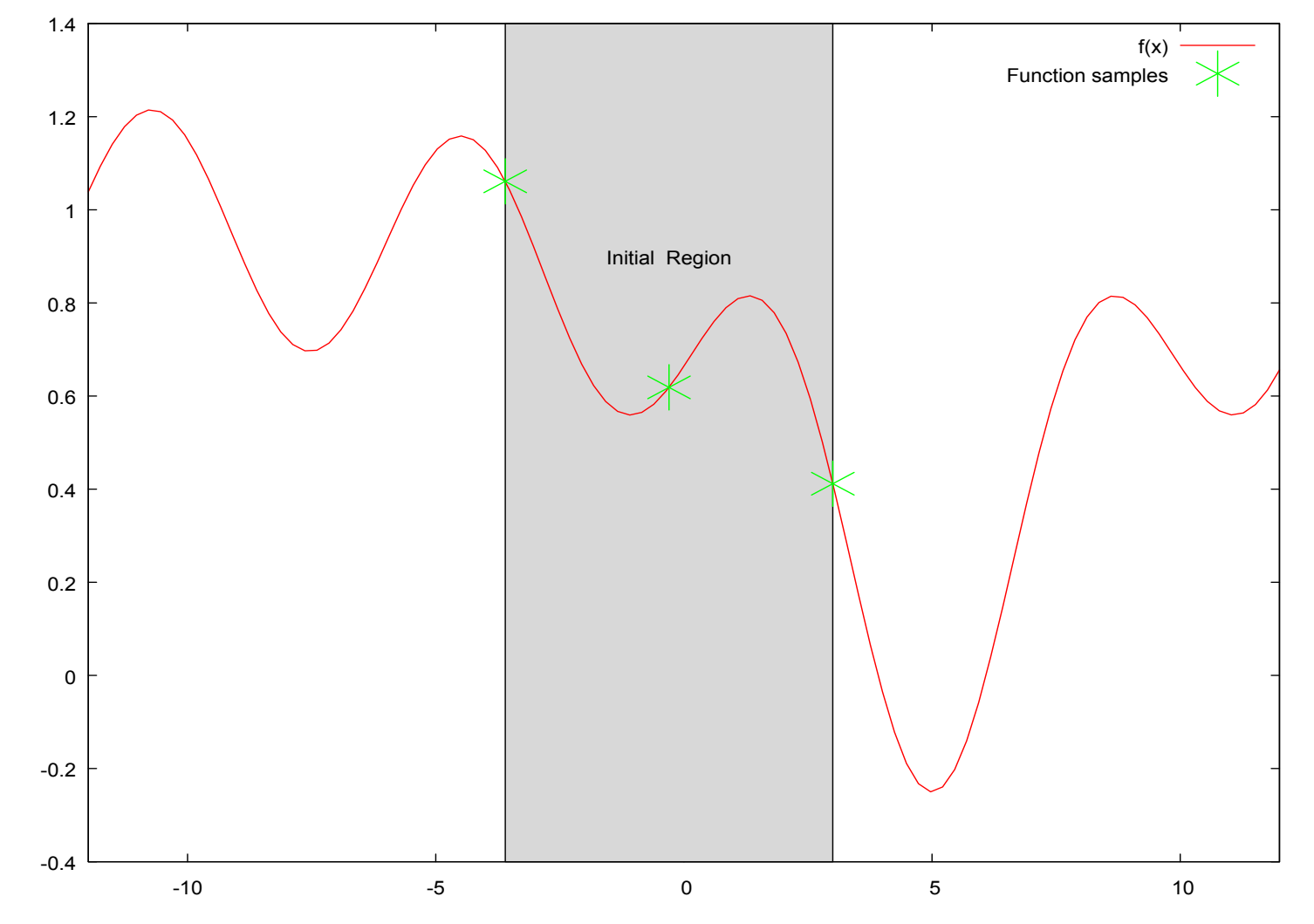
NEWUOA Iterations Example Function



NEWUOA Iterations Sampled Function



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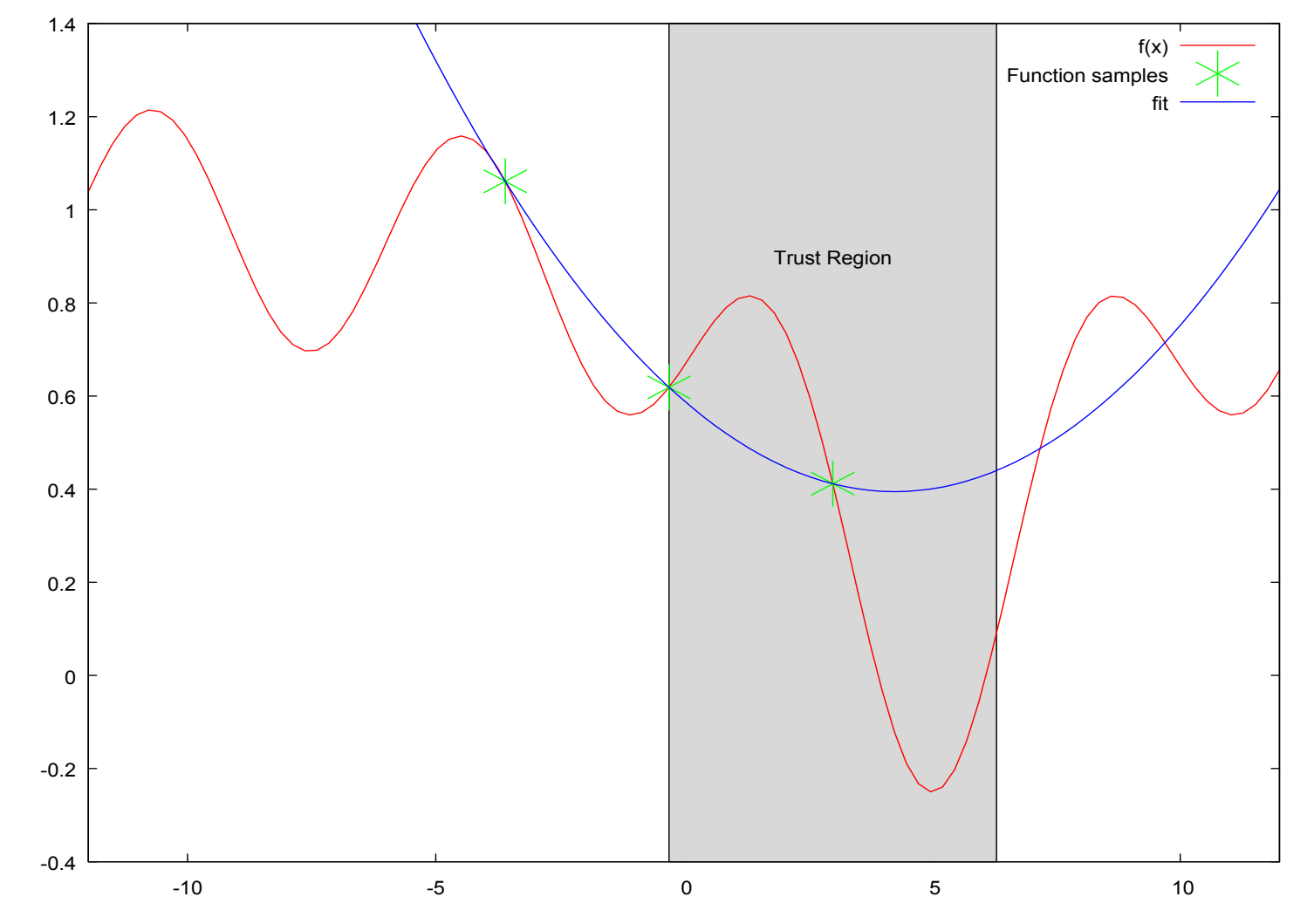
NEWUOA Iterations Quad Approx.



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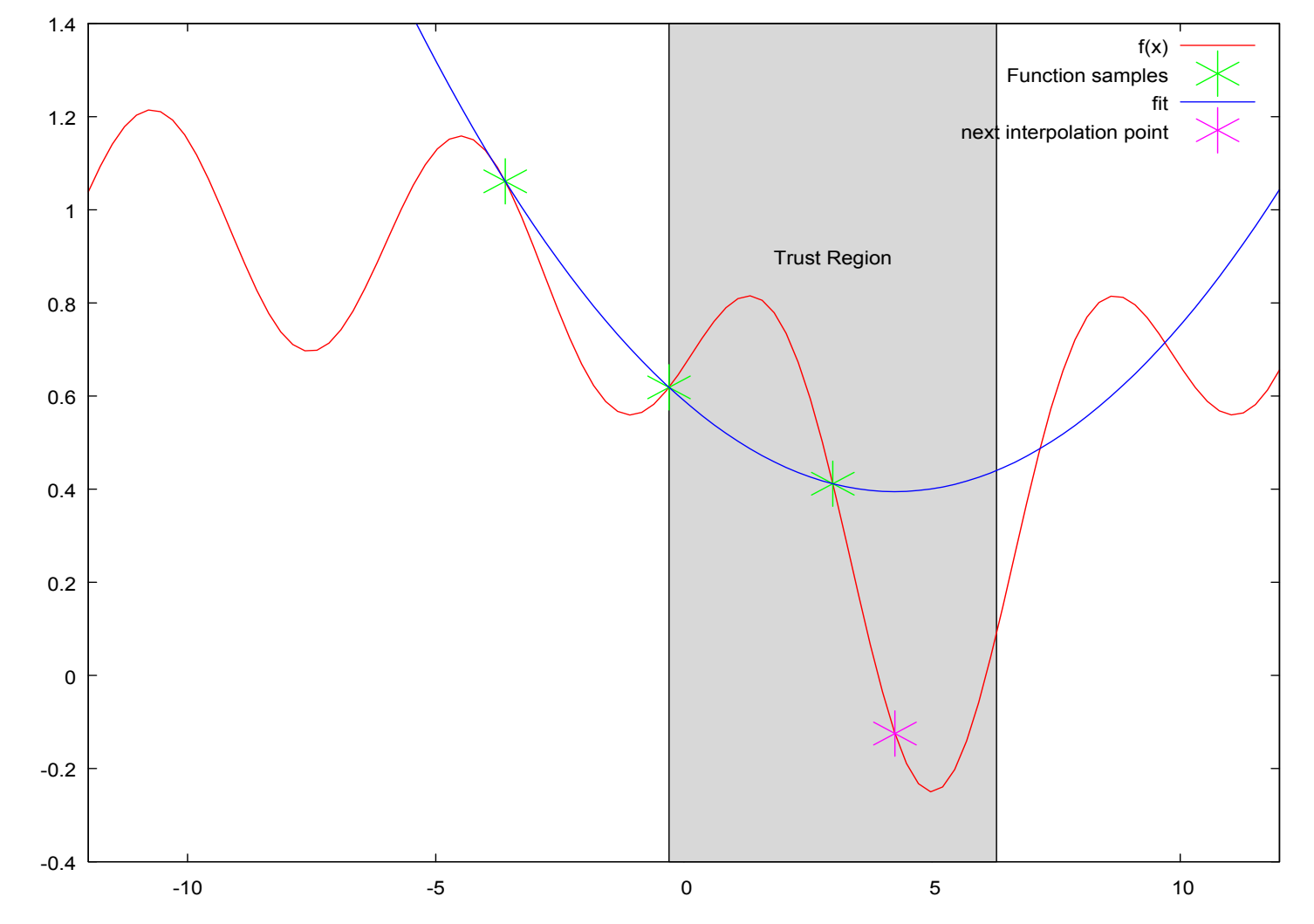
NEWUOA Iterations adding a new point



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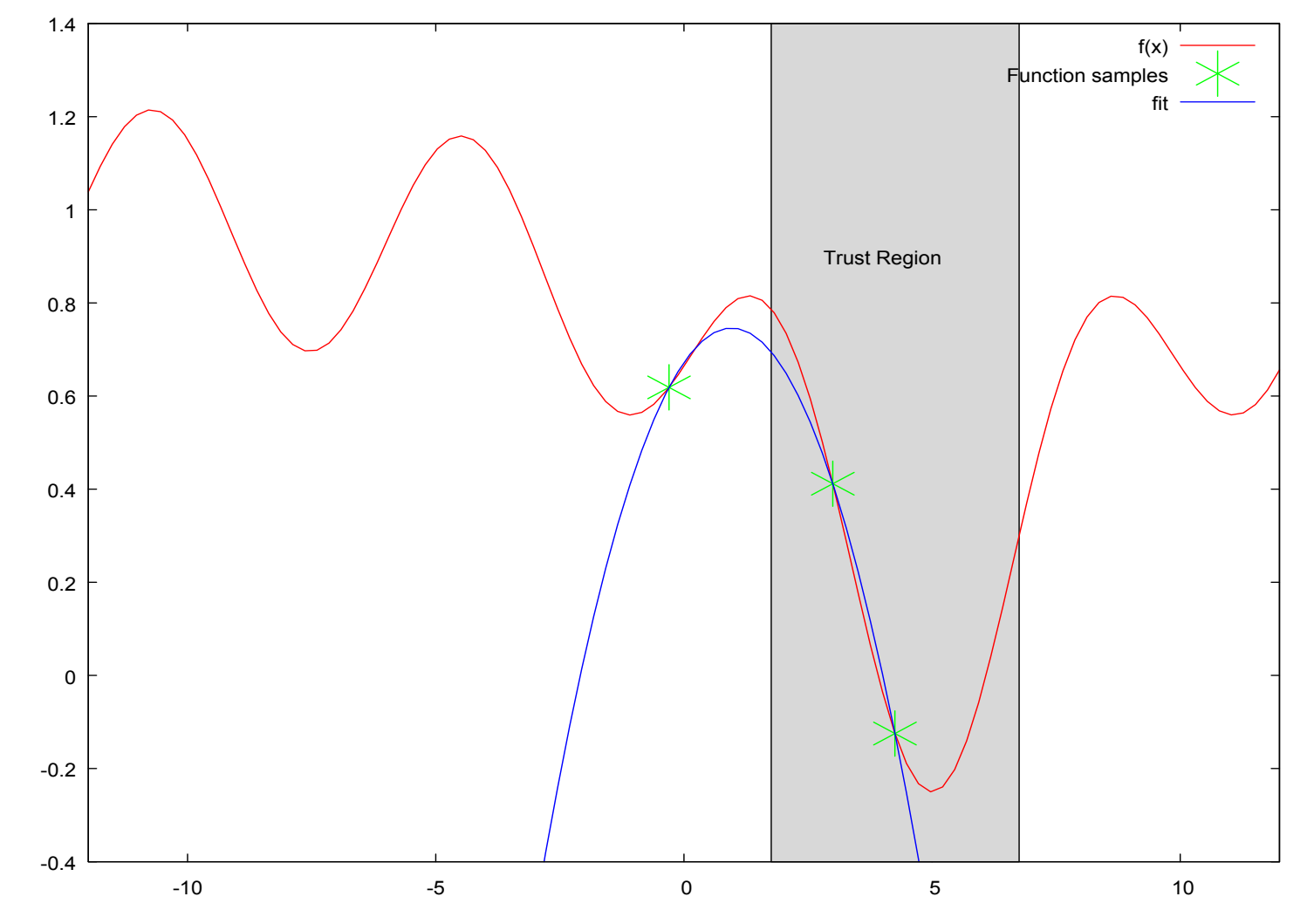
NEWUOA Iterations Quad Approx.



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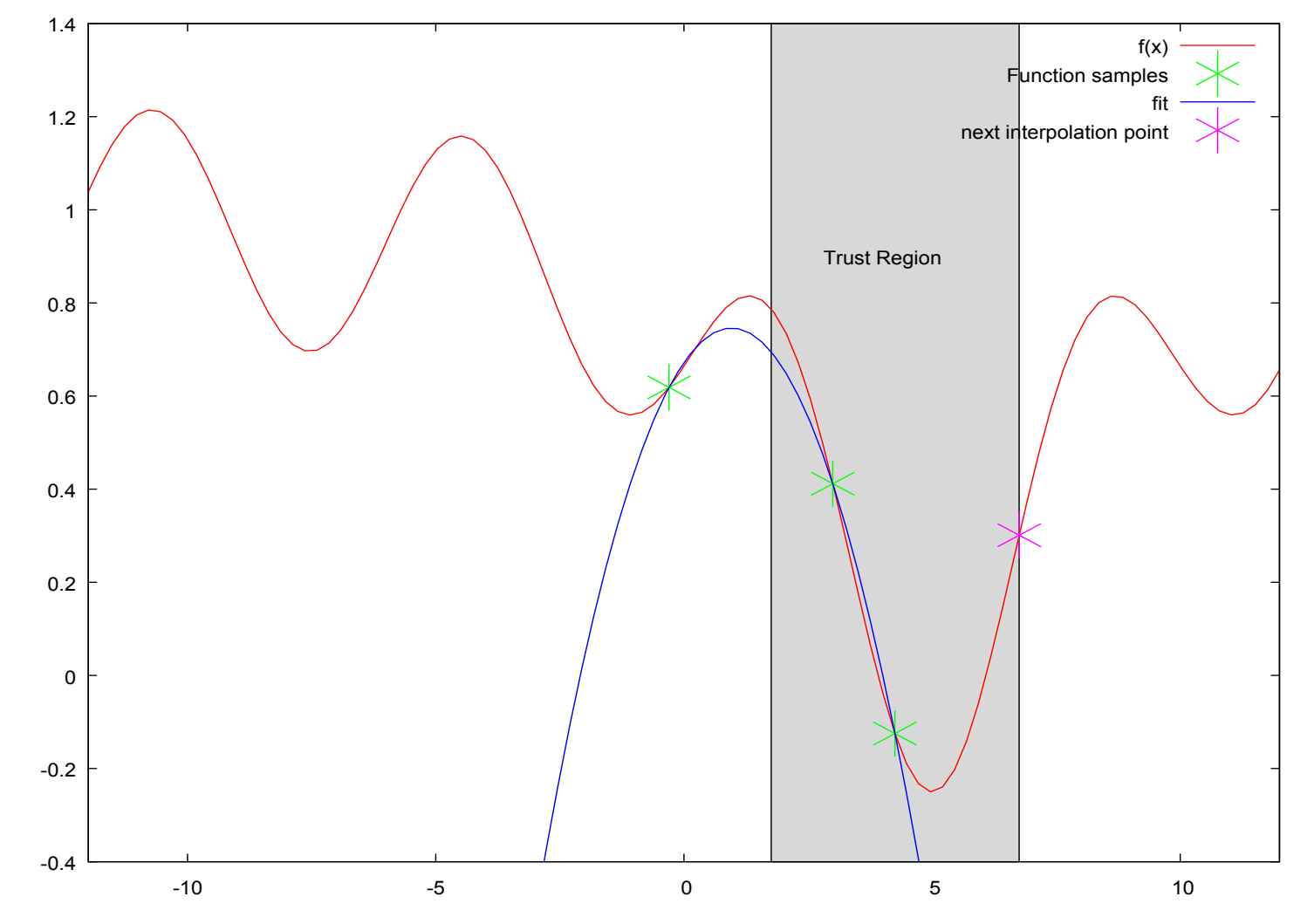
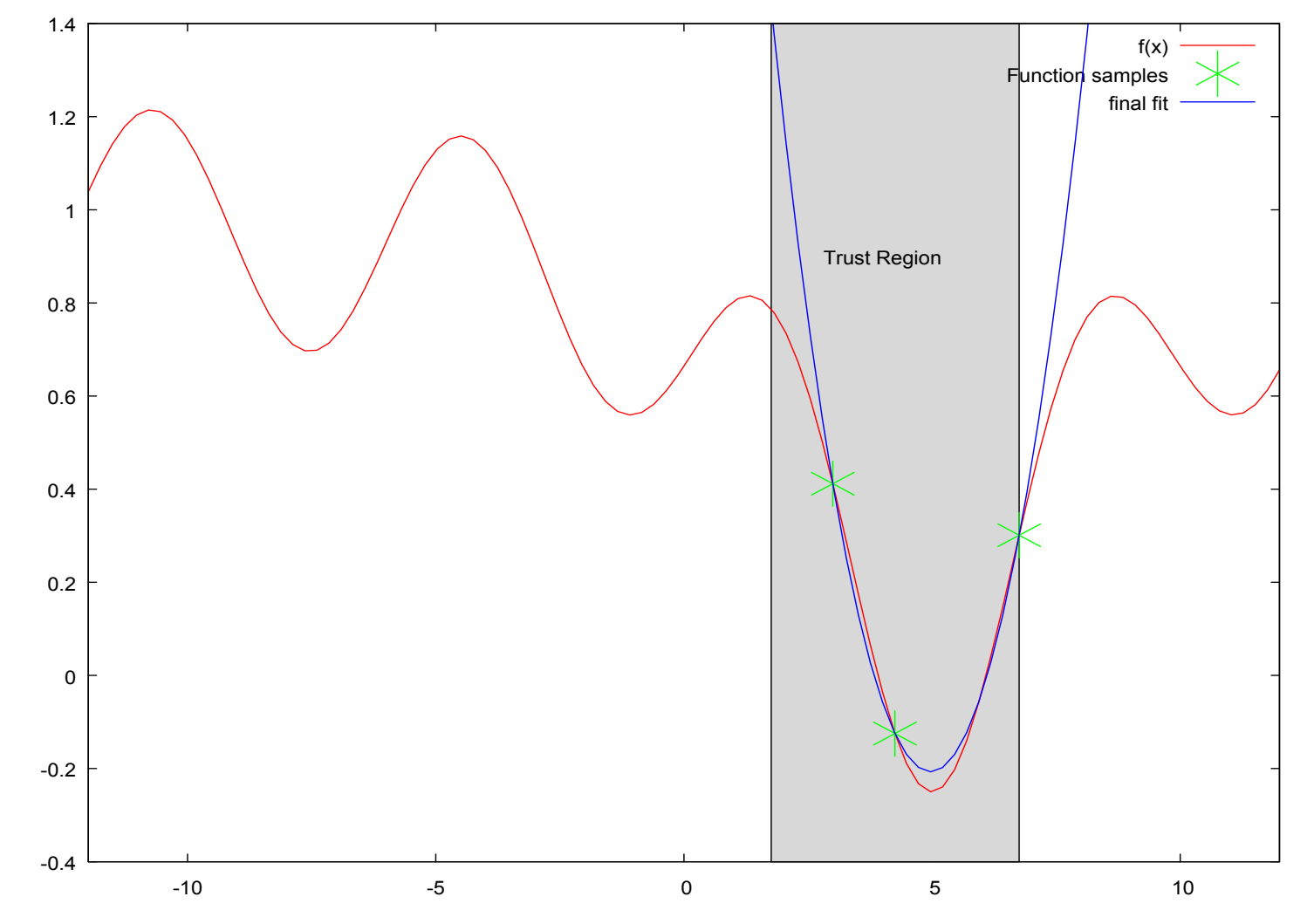
NEWUOA Iterations Repeating



NEWUOA Iterations Sampled Function



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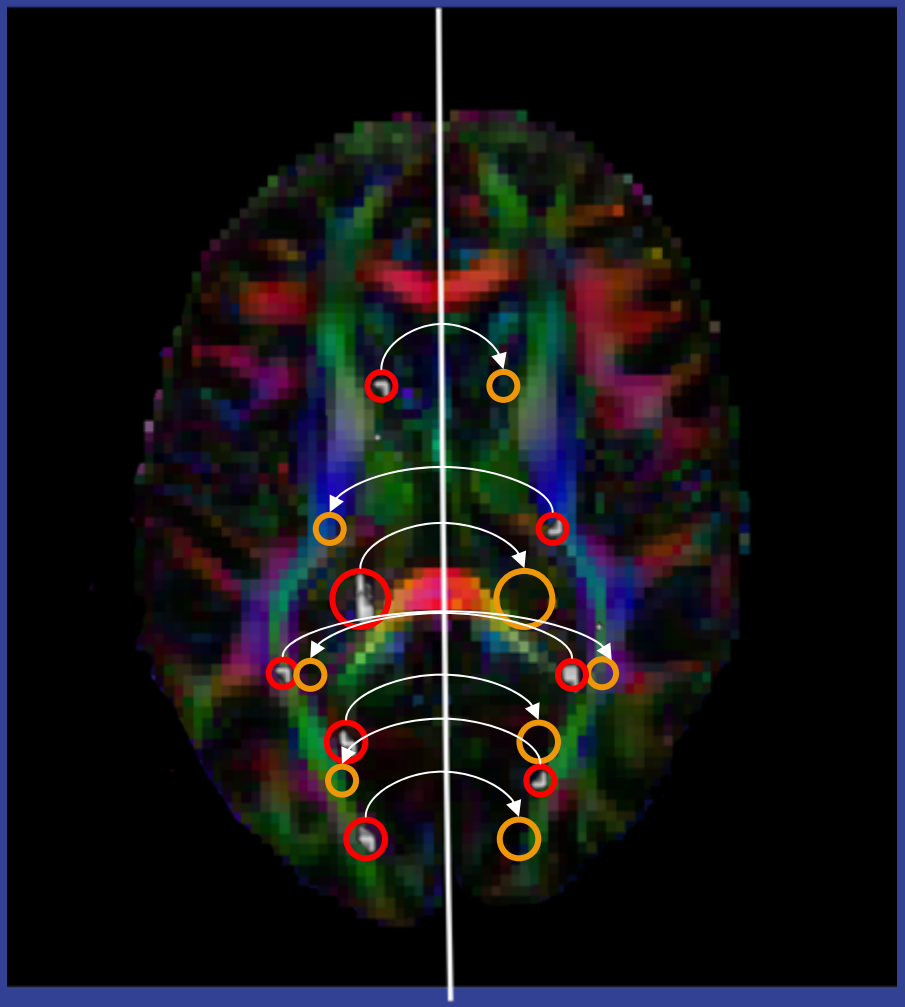
Method



MS Lesion

Contralateral NAWM region

Method on Controls

- Registration of MS patients to controls
  - Affine registration
  - Mutual Information
  - Optimisation using NEWUOA Algorithm
- Transformation of each MSL and NAWM masks in each controls reference

A Comparison of Methods

- State of the art tensor estimation :
  1. Least Squares (LS) estimation serves as a reference
     - Classical tensor estimation in litterature
  2. Weighted Least Squares (wLS) estimation
  3. Constrained Non Linear Least Squares
- Correction of Distortions
  1. No Correction
  2. Affine Transformation
  3. Polynomial second order Transformation
  4. Polynomial Third order Transformation
- ANOVA followed by a multiple comparison procedure analysis on FA and MD

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Data Generation

- For each MS subject and controls
  - Perform corrections of distortions
  - Perform tensor estimations
- This results in 12 volumes for each subject and controls
- Then: Extract Tensor Invariant features in MSL and contralateral NAWM

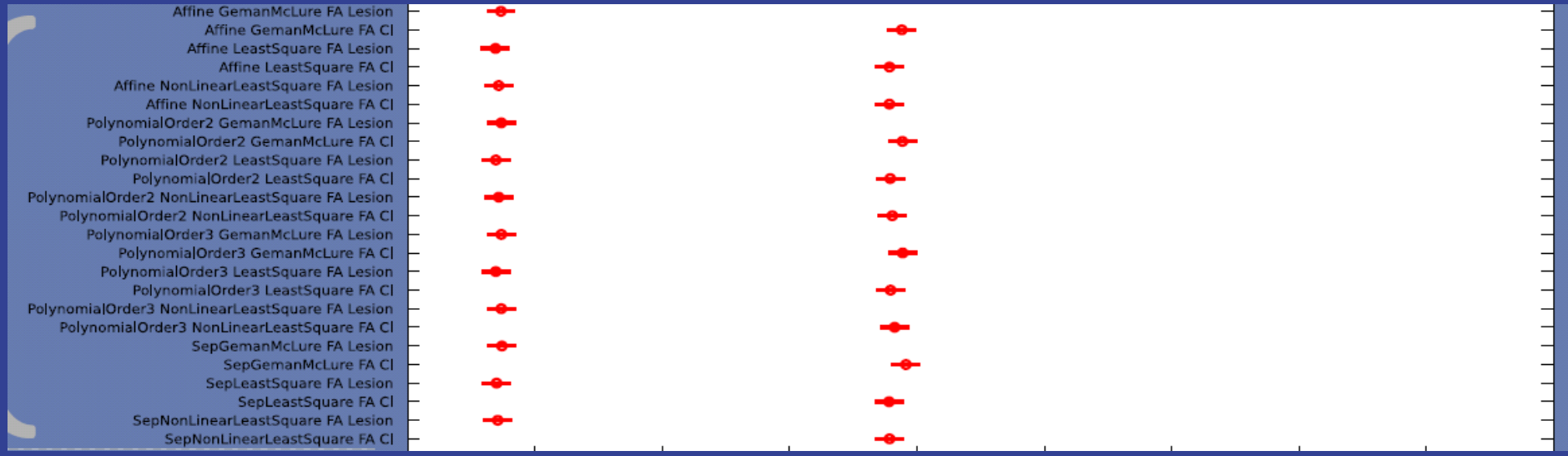
Results of Statistical FA Analysis

Controls

In controls, FA of ‘MSL’ and FA of ‘NAWM’ are identical

Results of Statistical FA Analysis

MS Patients



In controls, FA of ‘MSL’ and FA of ‘NAWM’ are identical
In MS Patients, FA of MSL is lower than FA of NAWM
FA of controls is higher than both MSL and NAWM of MS patients

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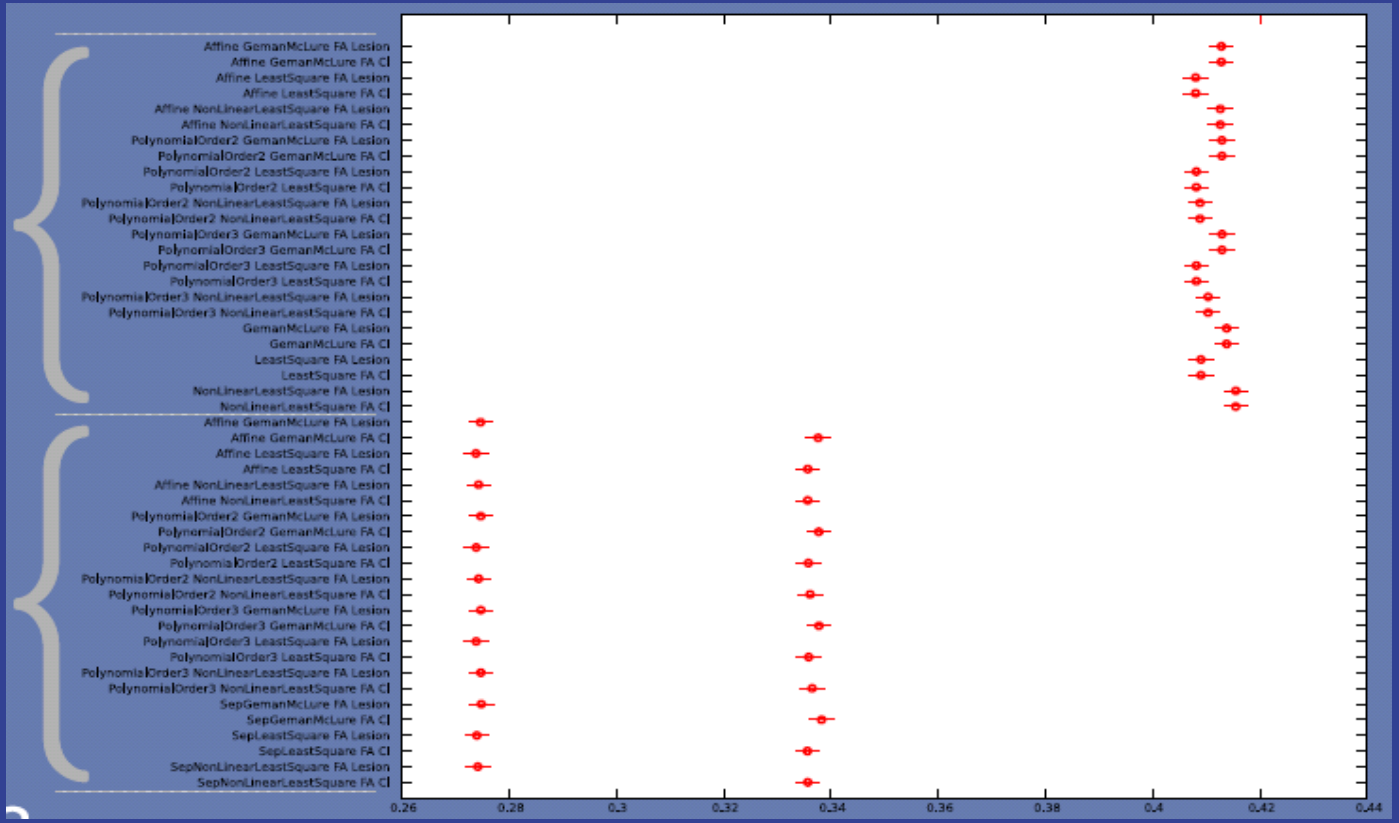
Results of Statistical FA Analysis

Controls

MS Patients

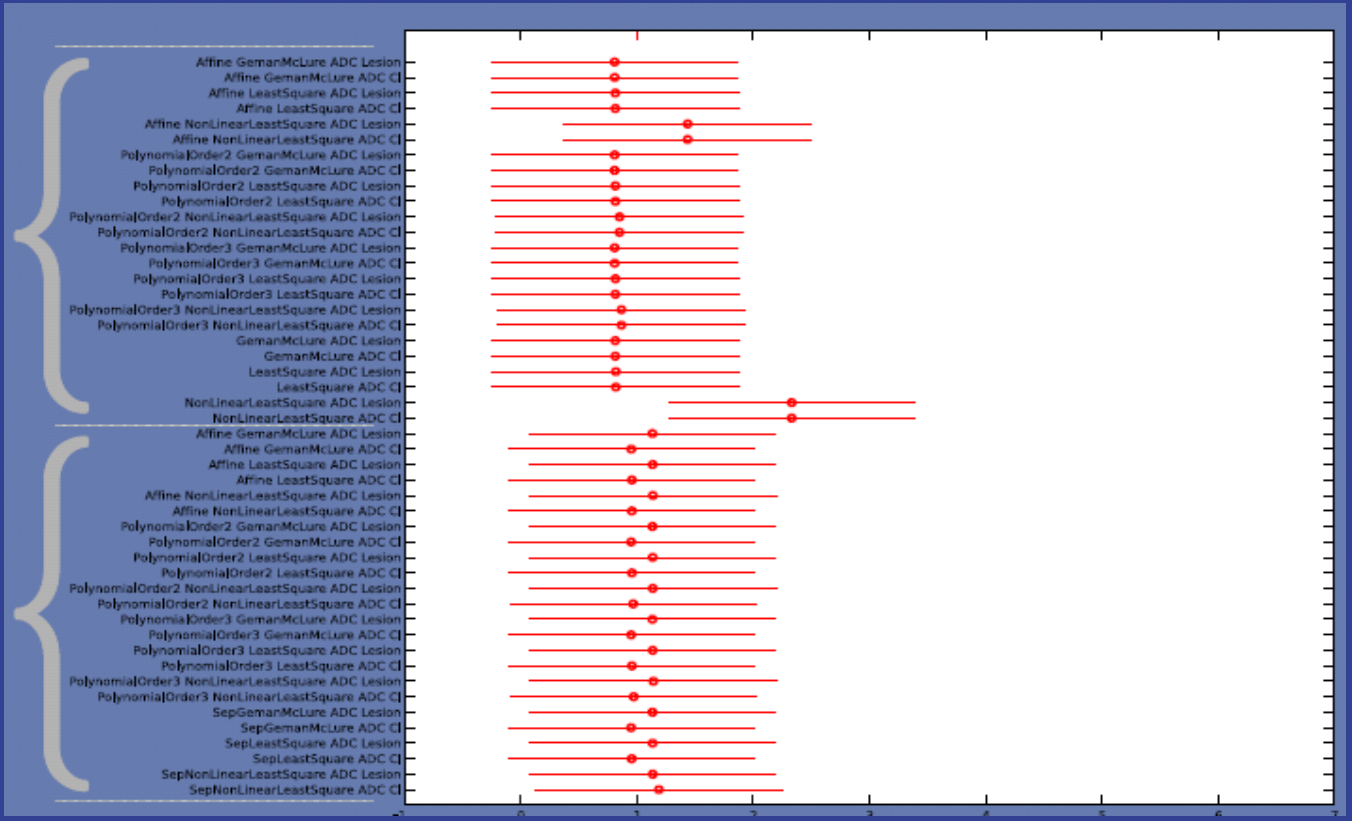


In controls, FA of ‘MSL’ and FA of ‘NAWM’ are identical
In MS Patients, FA of MSL is lower than FA of NAWM
FA of controls is higher than both MSL and NAWM of MS patients

Results of Statistical MD Analysis

Controls

MS Patients



MD differences are not statistically significant,
But in MS patients the average of MD in MSL is slightly different than in NAWM

Conclusions

- Outcomes matching results found in literature
- Advantages of our method:
  - Automatic approach
  - Better accuracy, reproducibility and robustness
- In MS patients statistical differences are present between MS lesions and their contralateral NAWM region which is not the case in normal controls.
- Current DTI Processing pipeline has little impact on results.