Centre for Medical Image Computing

Dementia Research Centre

Medical Image Registration Challenges and Validation

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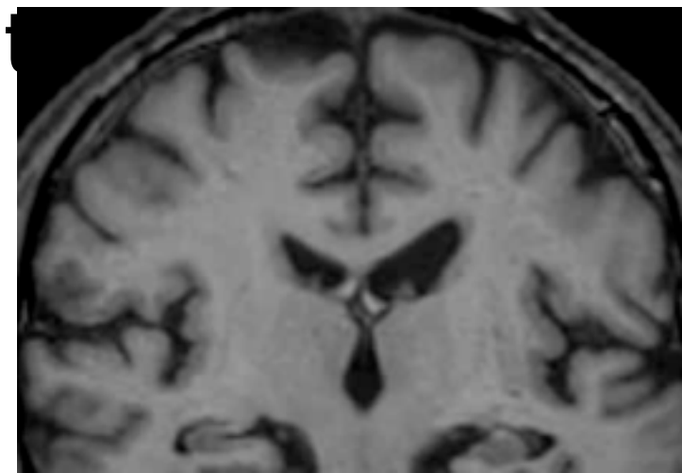


Non-Rigid Registration - Challenges

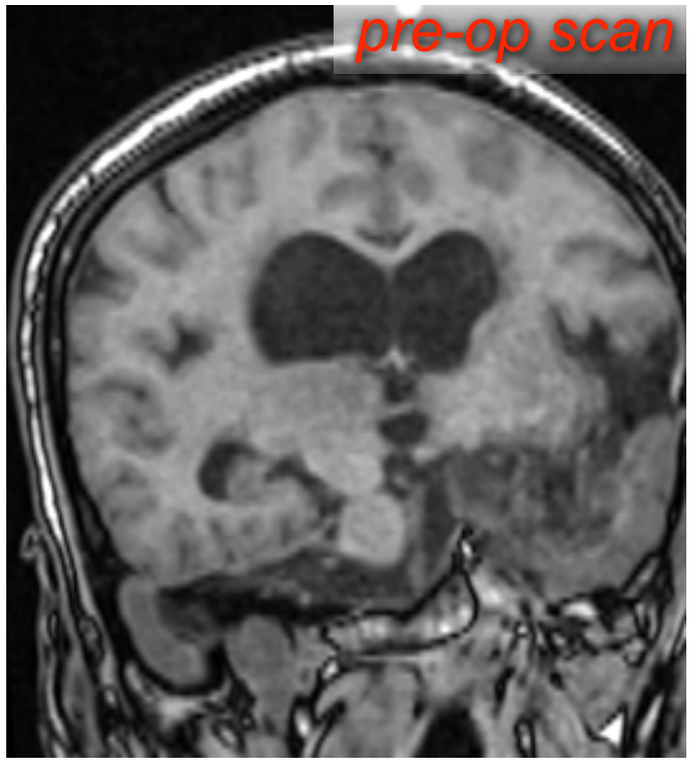
- There are no magic registration algorithm working with all applications. Registration is an ill-posed problem with no ground true.

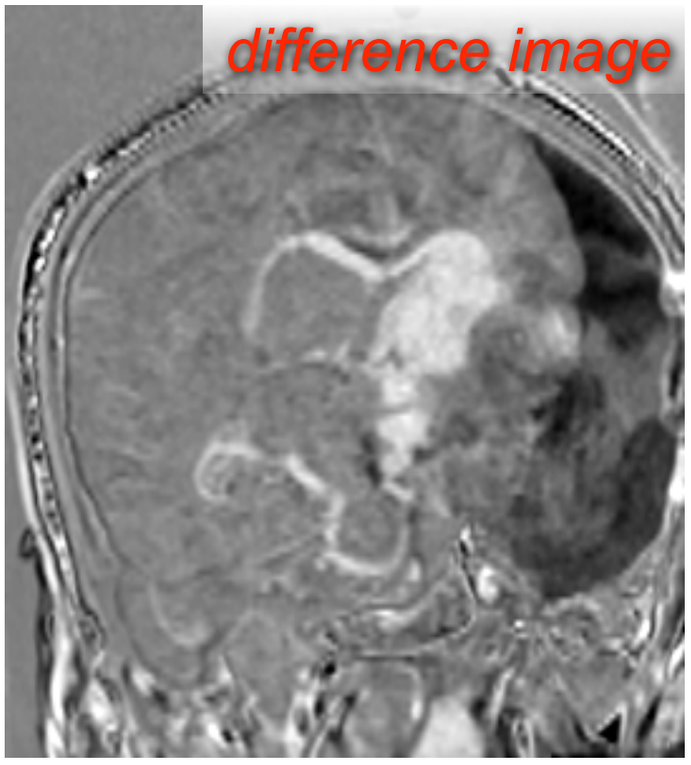
- Several challenges have to be considered
  - Efficiency
  - Topology conservation and invertibility
  - Different information
  - Data corruption
  - Symmetry
  - Plausibility
  - Associativity

Challenge: Computation time

- Efficiency
  - Large cohort - Clinical trials

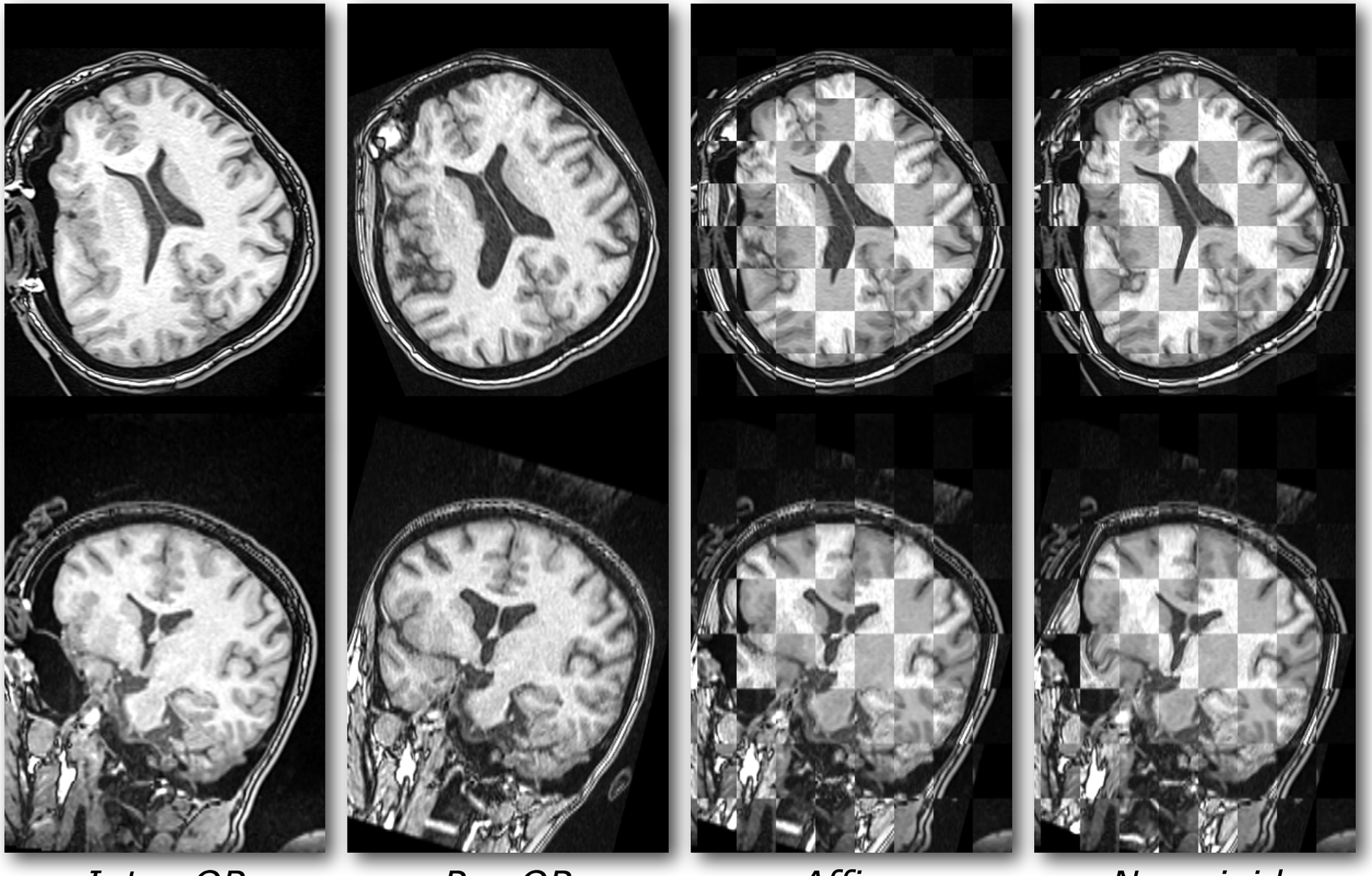
  - Real-time requirement - Brain shift





Challenge: Computation time

- Brain shift - illustration



Intra-OR *Pre-OR* *Affine checkerboard* *Non-rigid checkerboard*

Challenge: Computation time

- Segmentation propagation example
  - 181x217x181 - 256x124x256 - CPU 8 cores

Asymmetric
Euclidean parametrisation
300 iterations at most
NMI as a measure of similarity
(64 bins per image)

Symmetric
Velocity field parametrisation
10.000 iterations at most
LNCC as a measure
(Gaussian with a 5 vox. stdev)

Challenge: Computation time

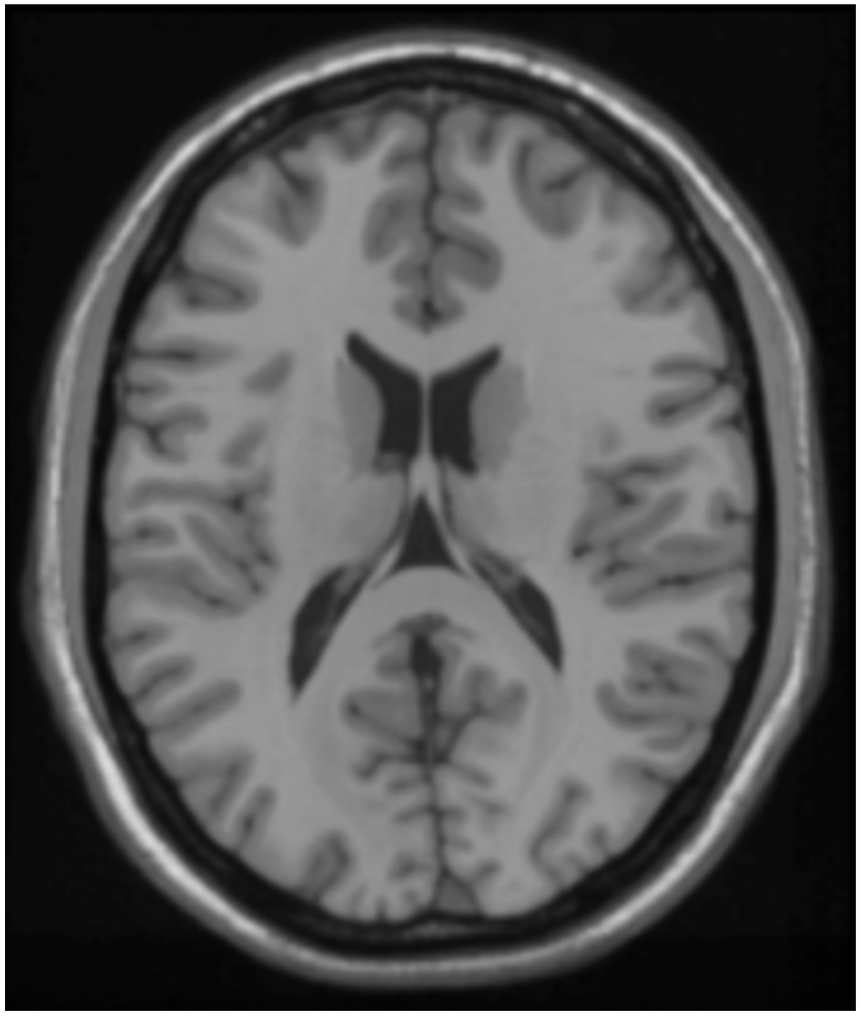
- Segmentation propagation example
  - 181x217x181 - 256x124x256 - CPU 8 cores

1’49”

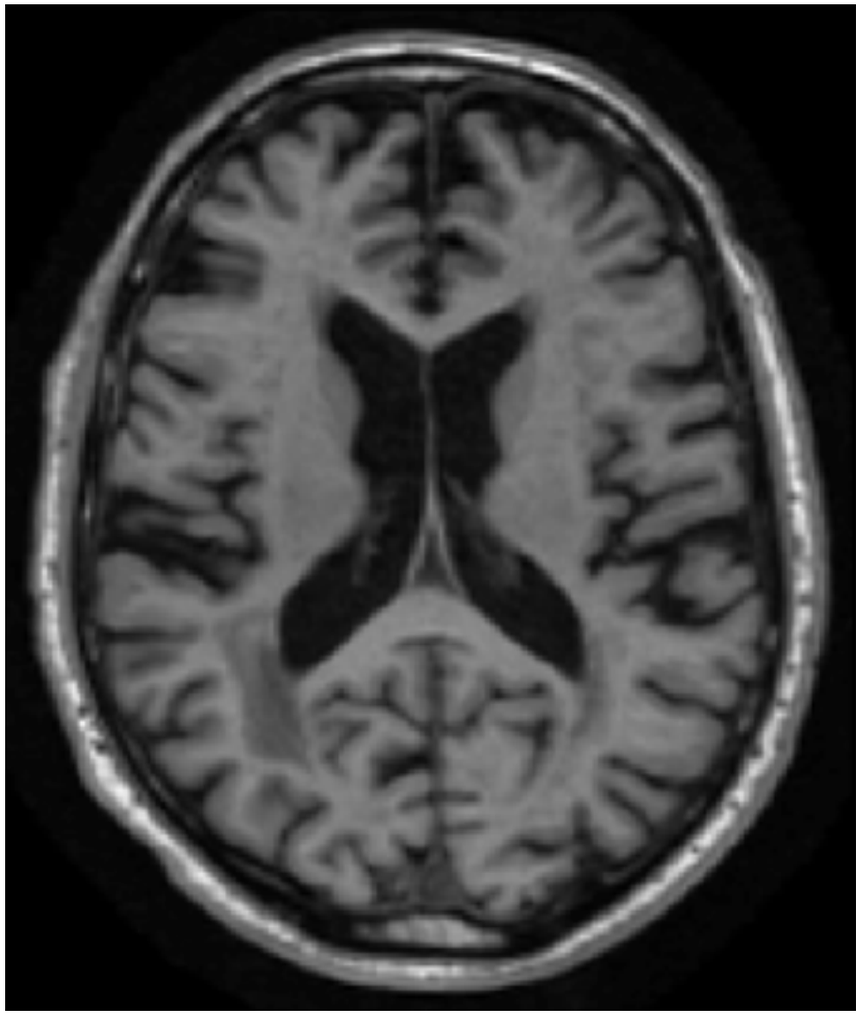
32’17”

Challenge: Topology conservation

- Inter-subject registration - Morphometric analysis



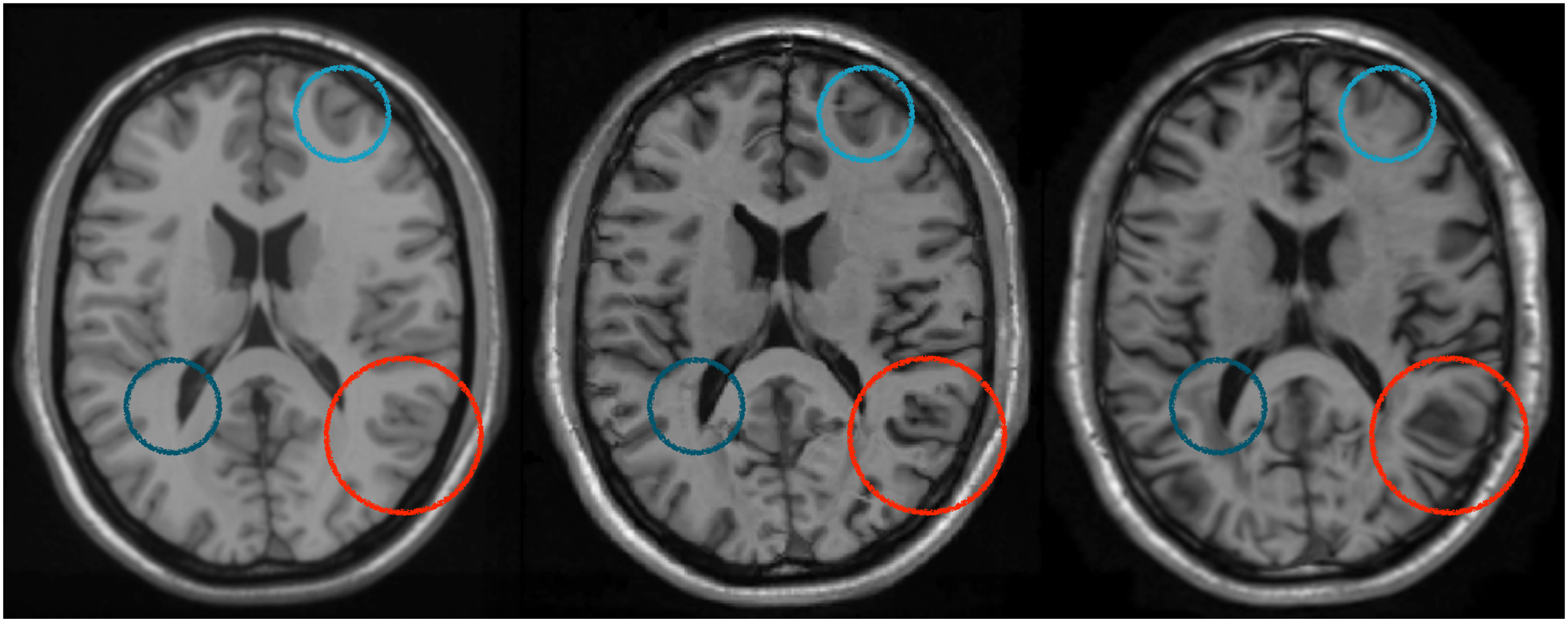
Reference Image



Floating Image

Challenge: Topology conservation

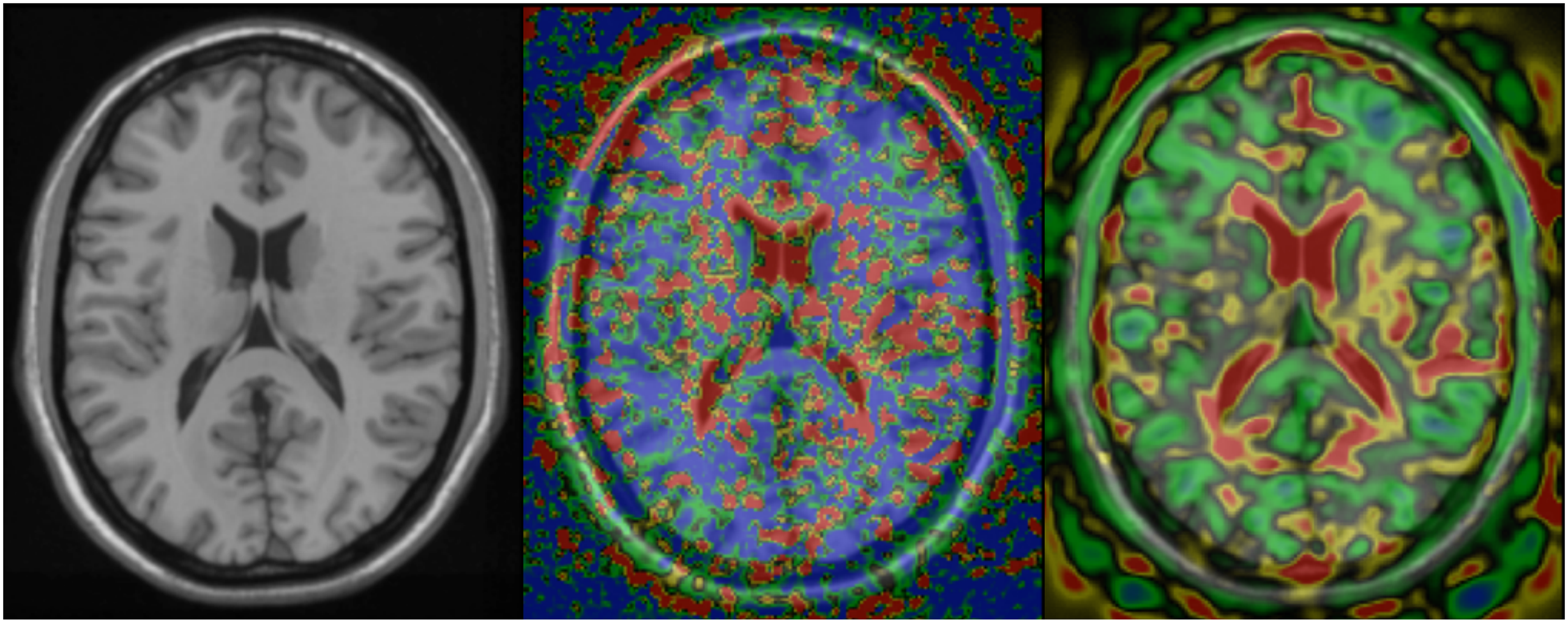
- Inter-subject registration - Morphometric analysis



Reference Image *Warped Image 1* *Warped Image 2*

Challenge: Topology conservation

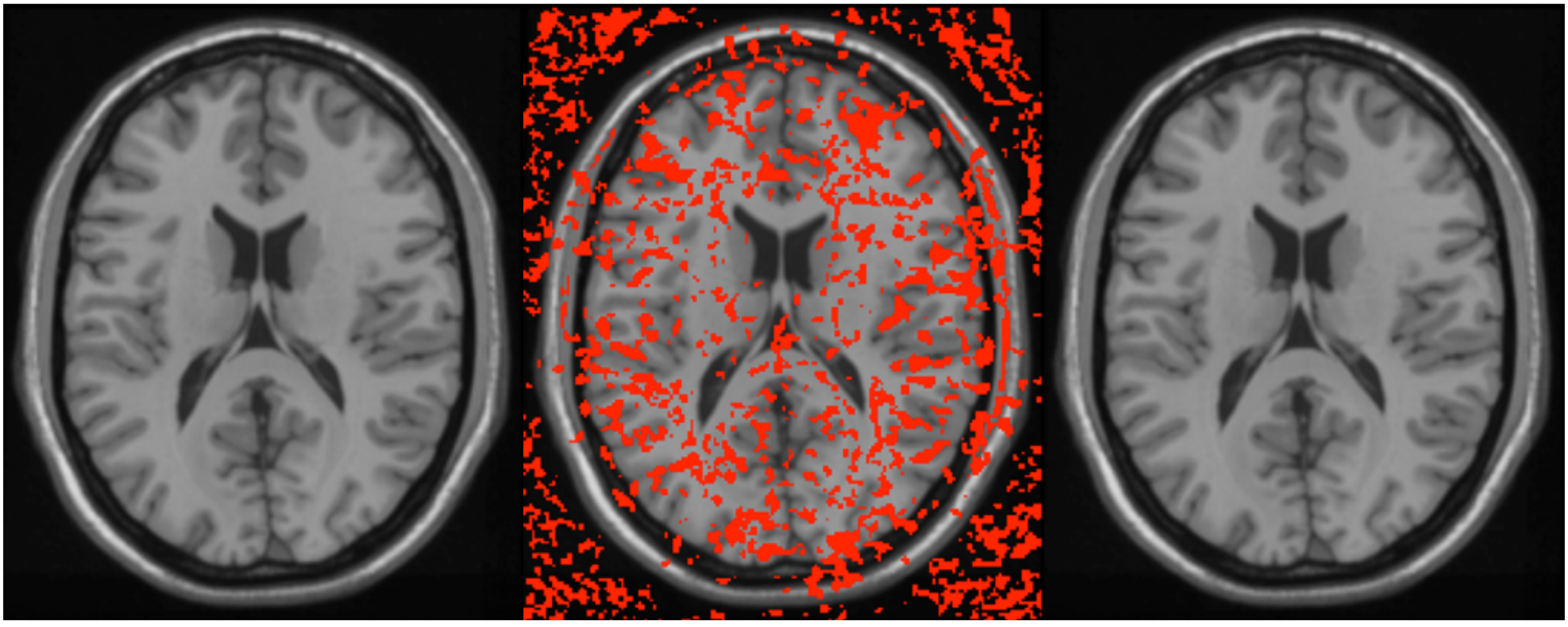
- Inter-subject registration - Morphometric analysis



Reference Image *Jacobian map 1* *Jacobian map 2*

Challenge: Topology conservation

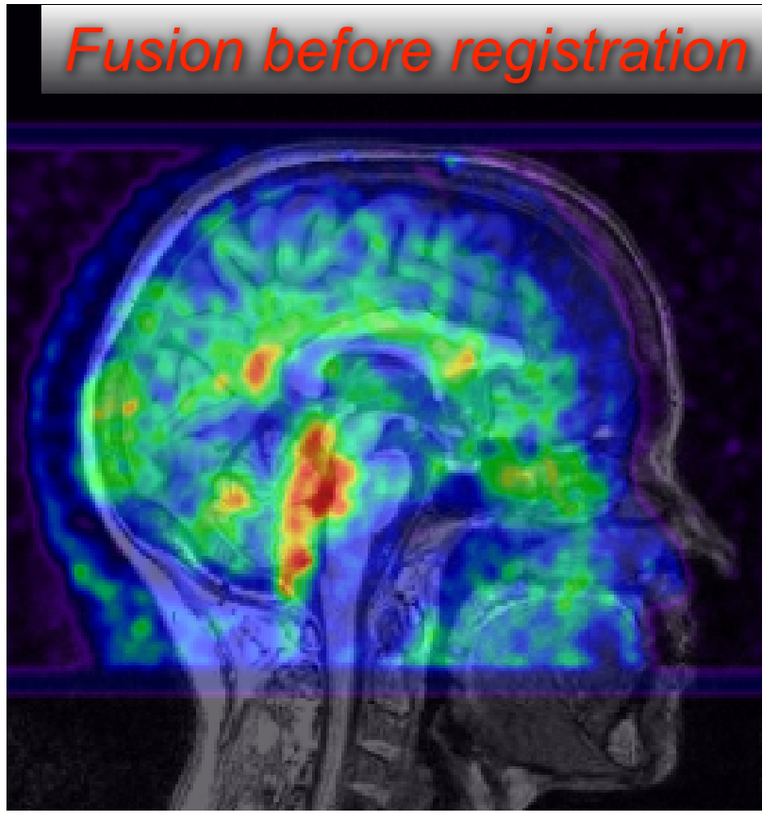
- Inter-subject registration - Morphometric analysis



Reference Image *Folded area 1* *Folded area 2*

Challenge: Different information

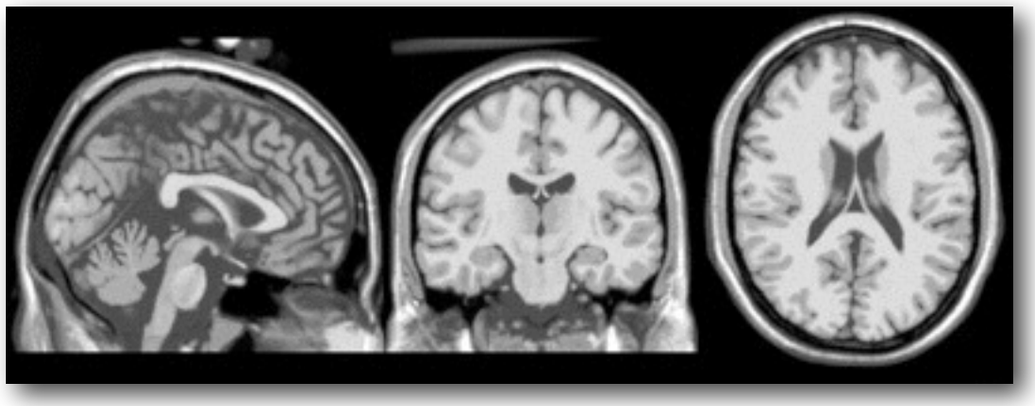
- Multi-modal case:
  - No “real” structural relationship



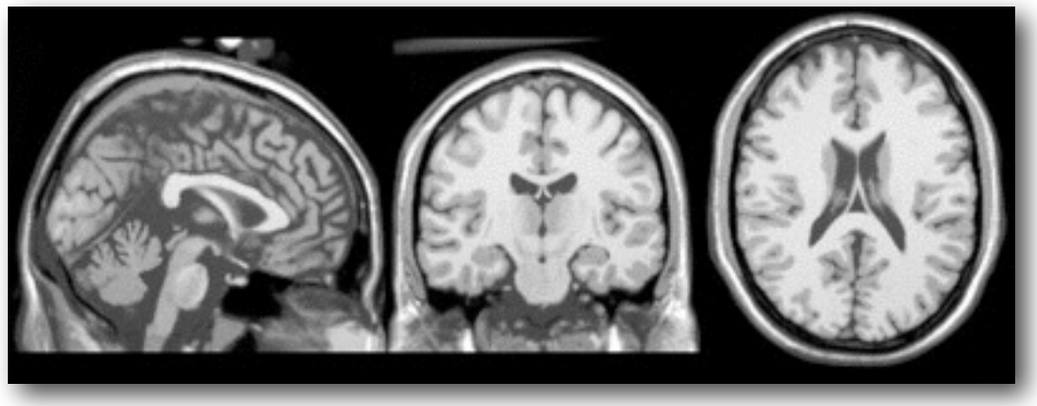
Challenge: Artefact

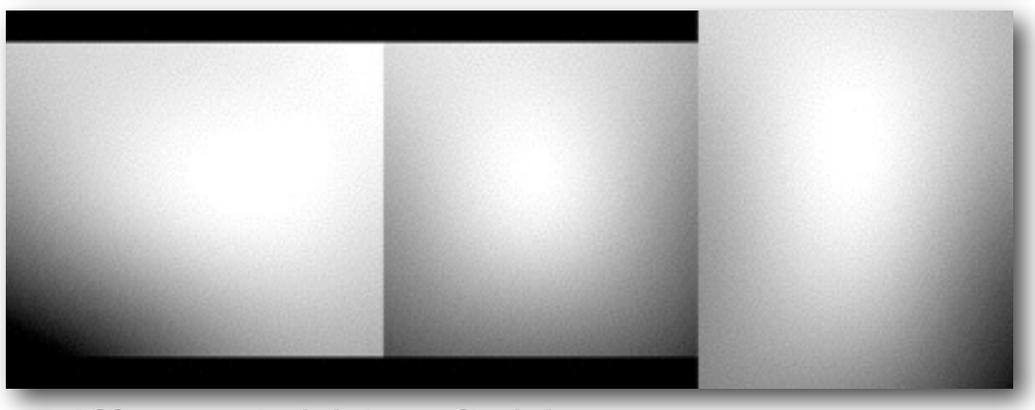
- Longitudinal registration
  - Influence of intensity non-uniformity (bias field)

BrainWeb - bias free

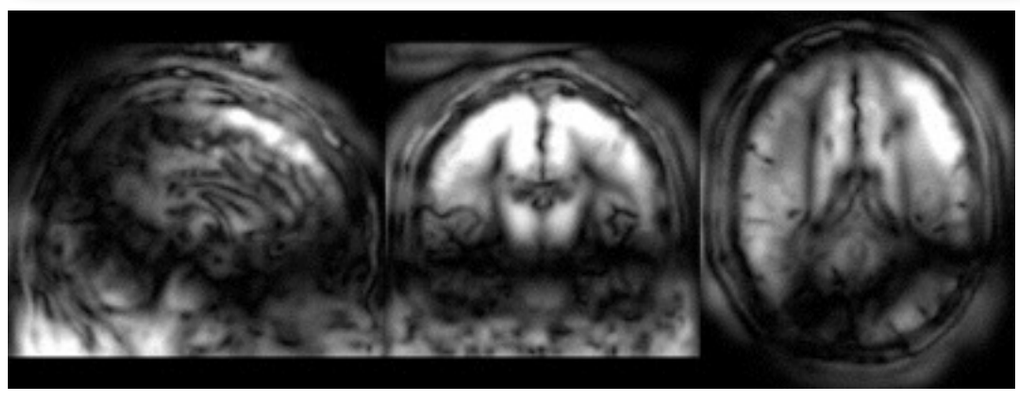


BrainWeb - with bias





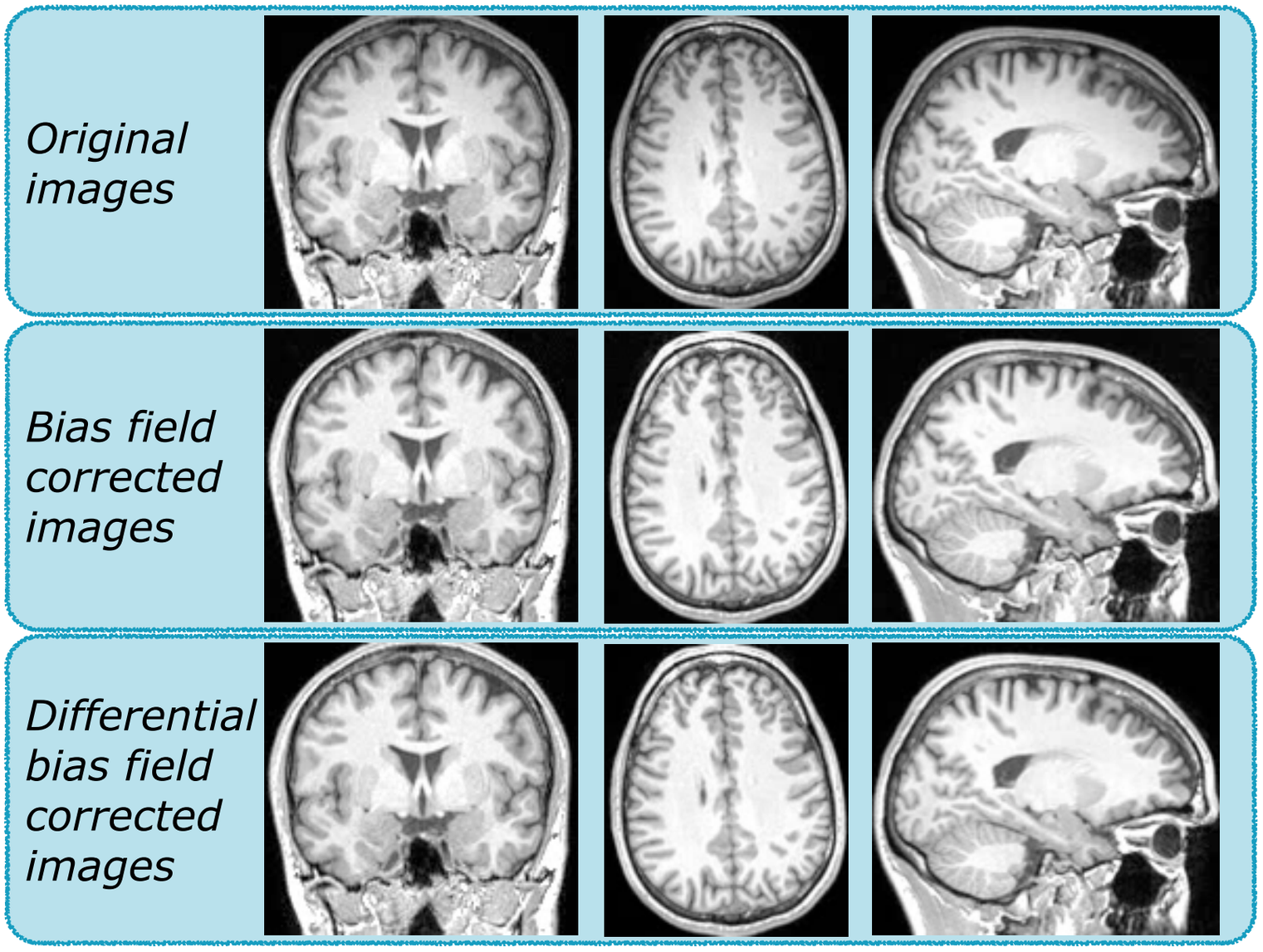
Differential bias field



Euclidean displacement [0 , 0.9[

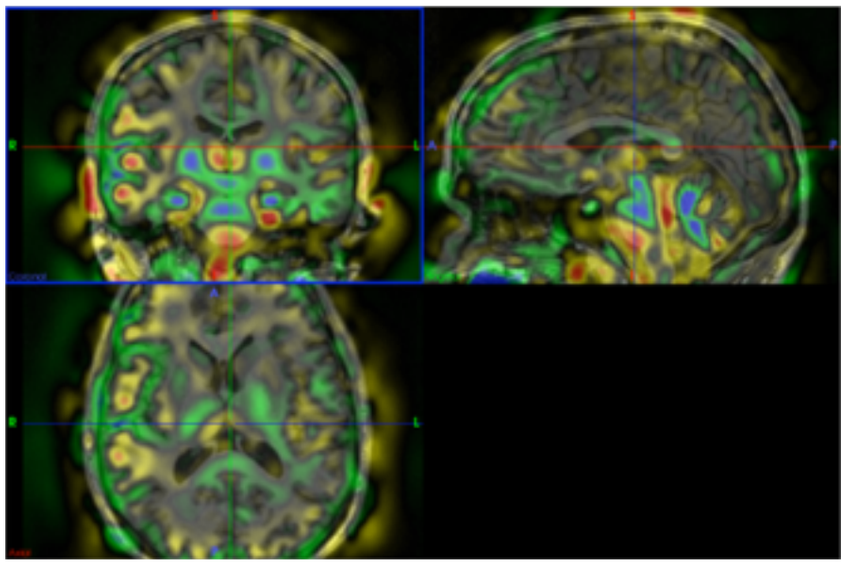
Challenge: Artefact

- Longitudinal registration
  - Influence of intensity non-uniformity (bias field)

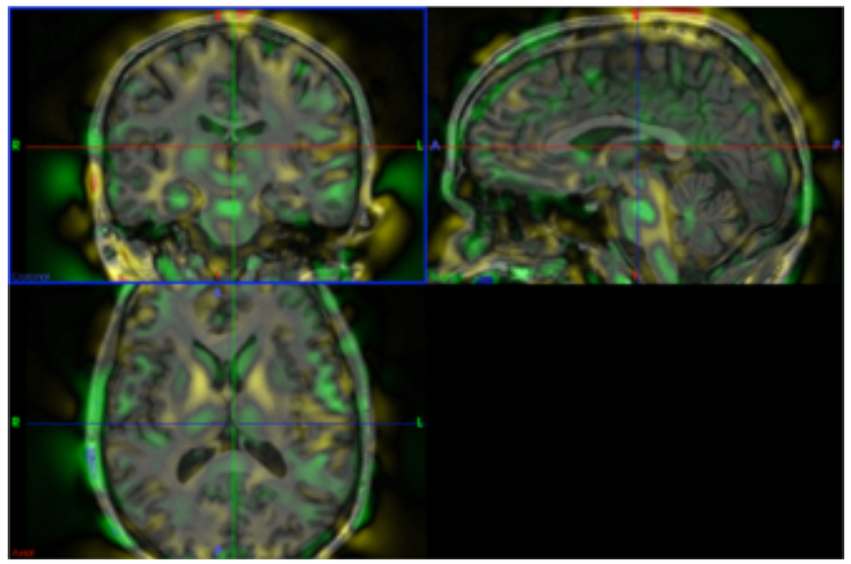


Challenge: Artefact

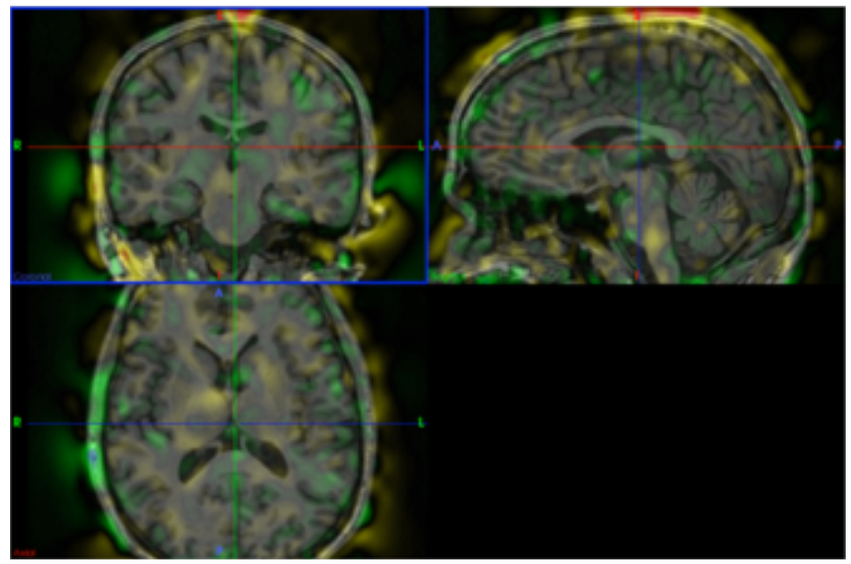
- Longitudinal registration
  - Influence of intensity non-uniformity (bias field)



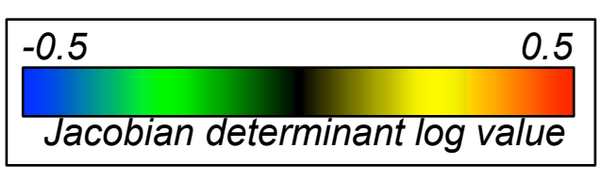
Jacobian det. map
Original images



Jacobian det. map
N3 corrected images

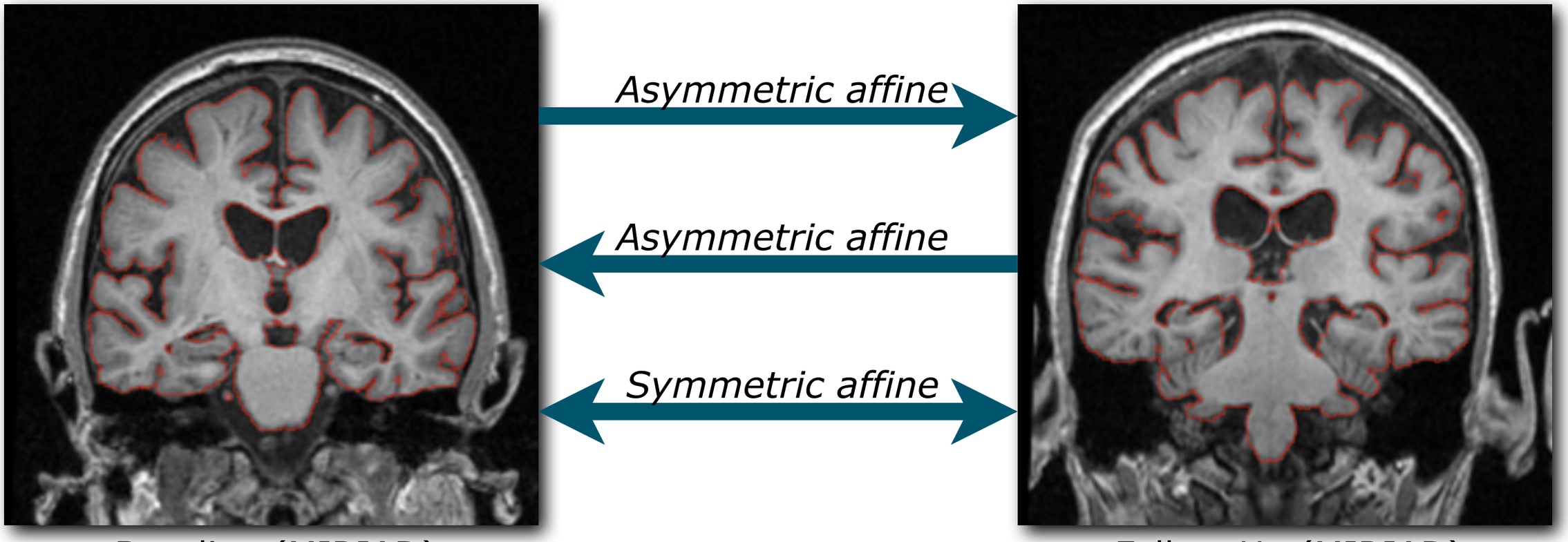


Jacobian det. map
DBC corrected images



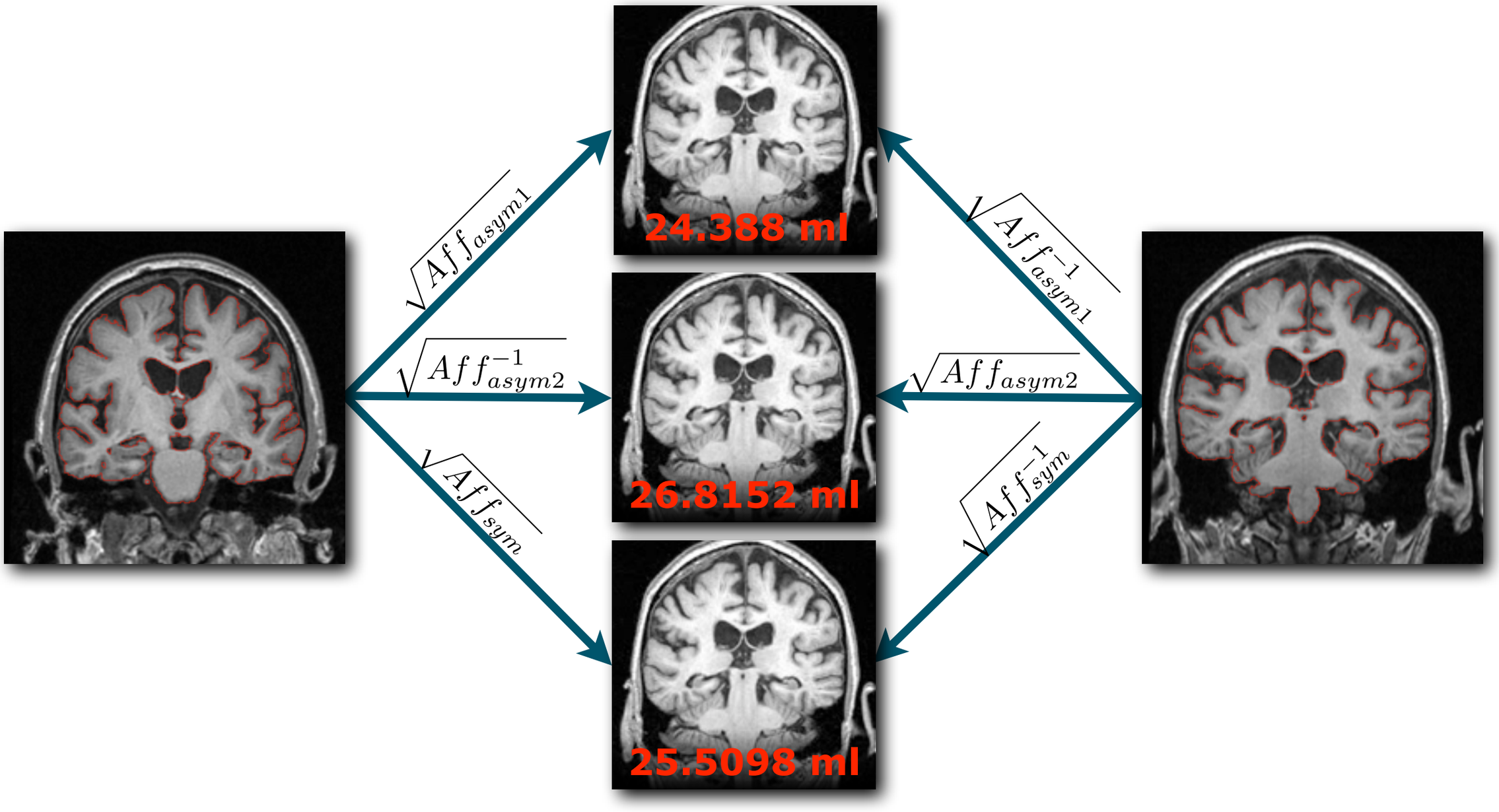
Challenge: Symmetry

- Boundary Shift Integral example



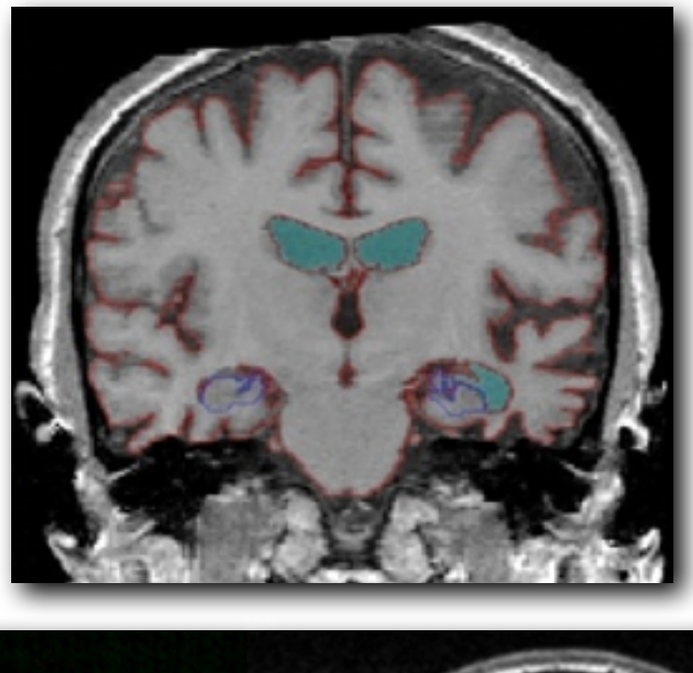
Challenge: Symmetry

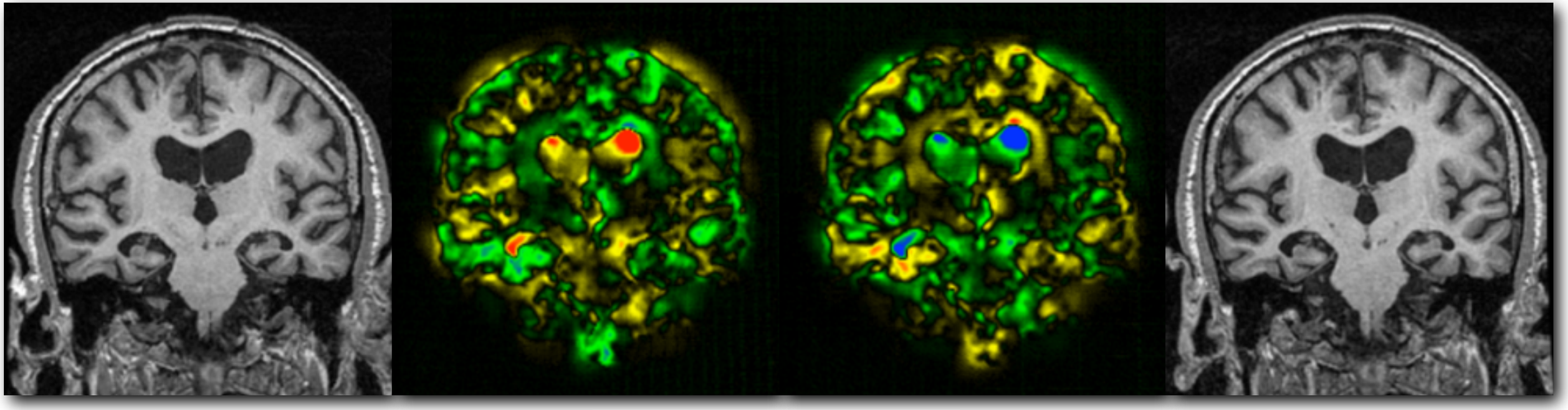
- Boundary Shift Integral example



Challenge: Symmetry

- Jacobian Integration
  - two asymmetric registrations (BL→FU and FU→BL)
  - one symmetric registration



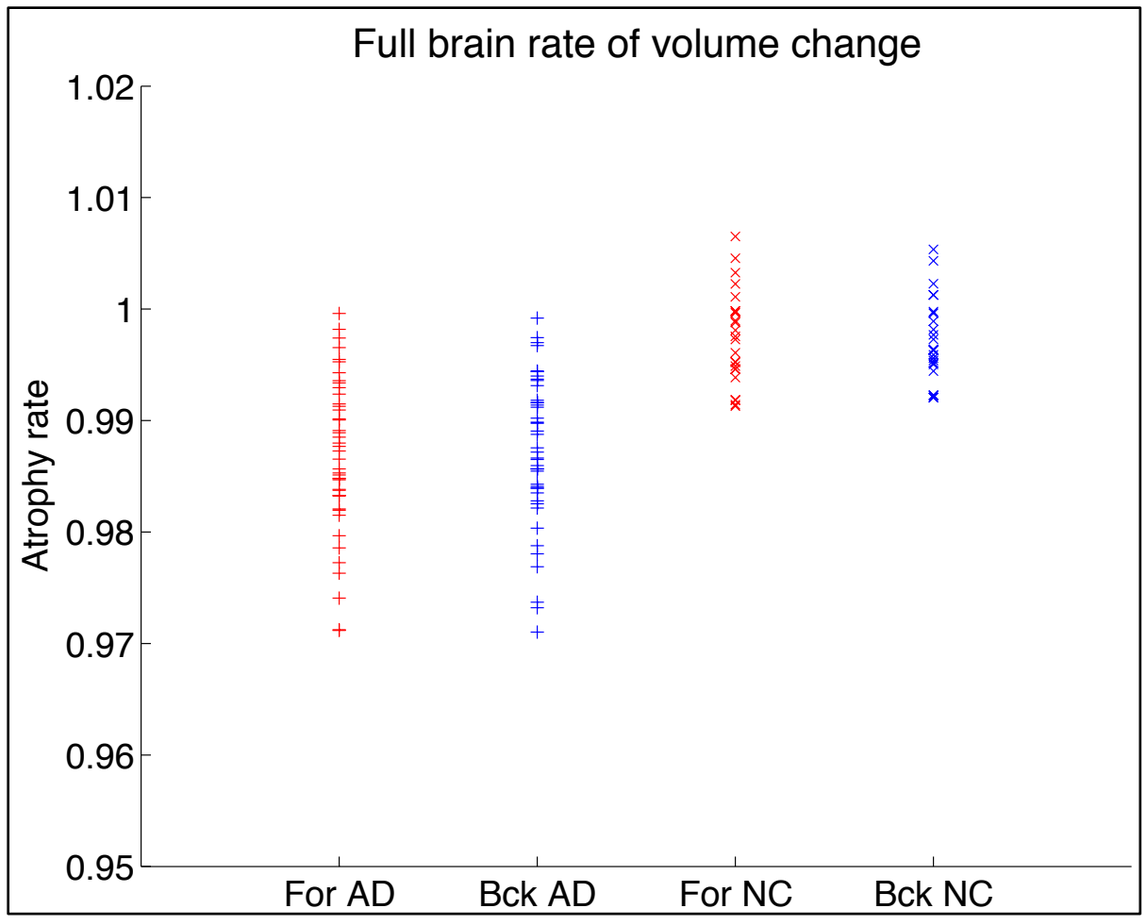


Baseline image

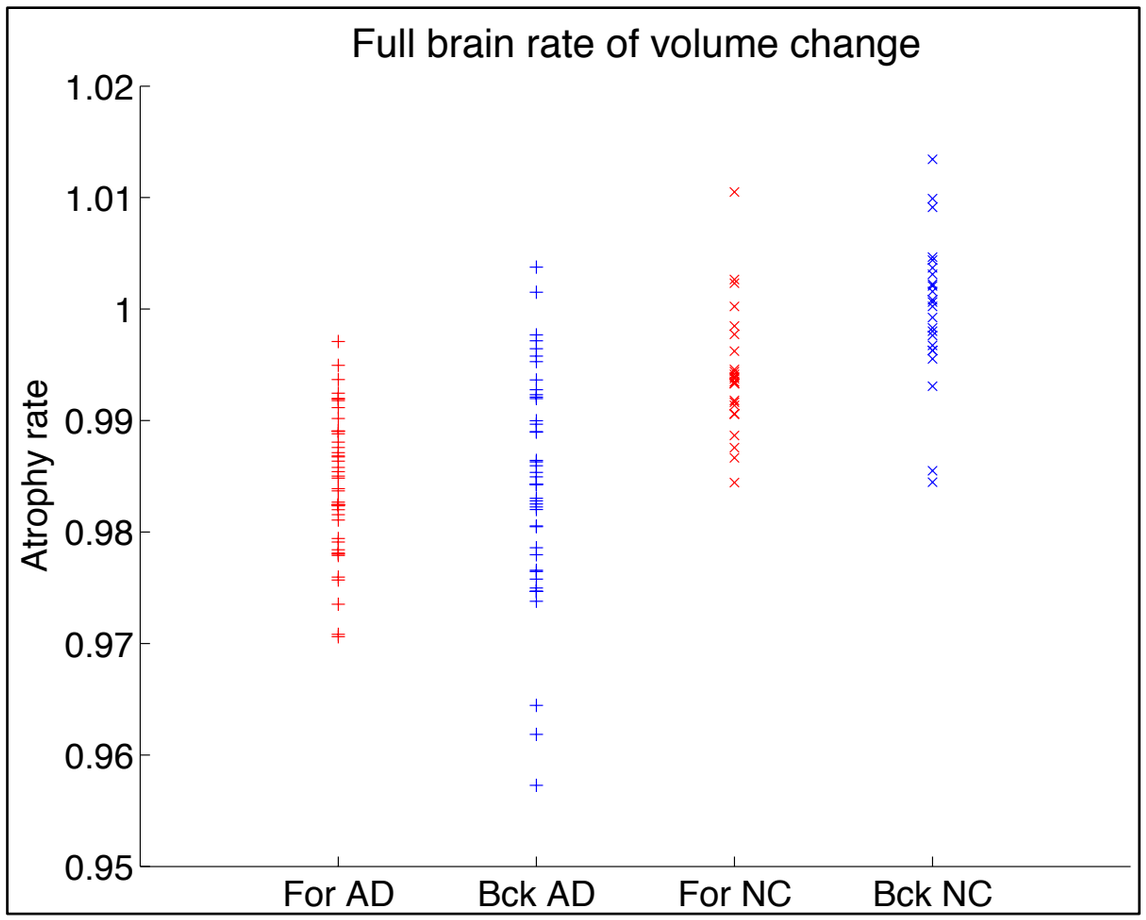
Follow-up image

Challenge: Symmetry

- Jacobian Integration
  - Full brain rate of volume change



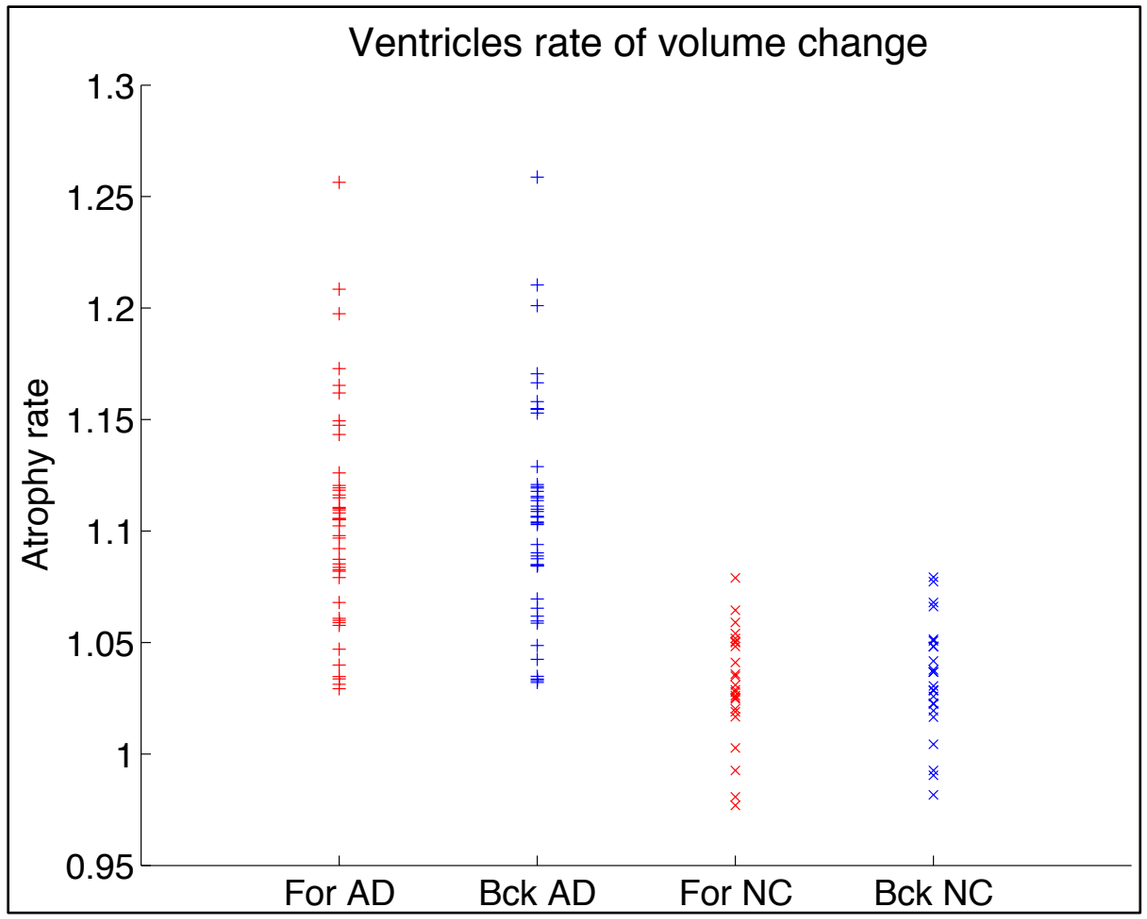
Symmetric



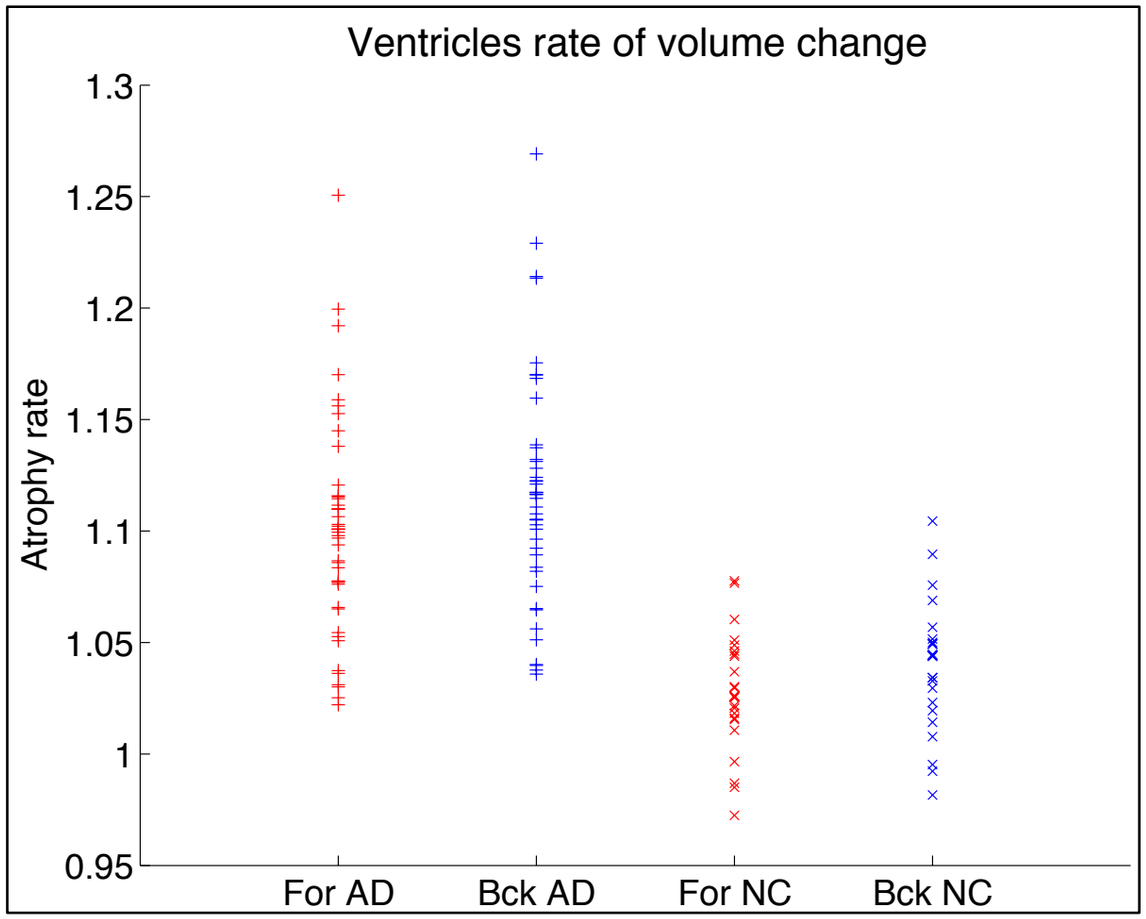
Asymmetric

Challenge: Symmetry

- Jacobian Integration
  - Ventricles rate of volume change



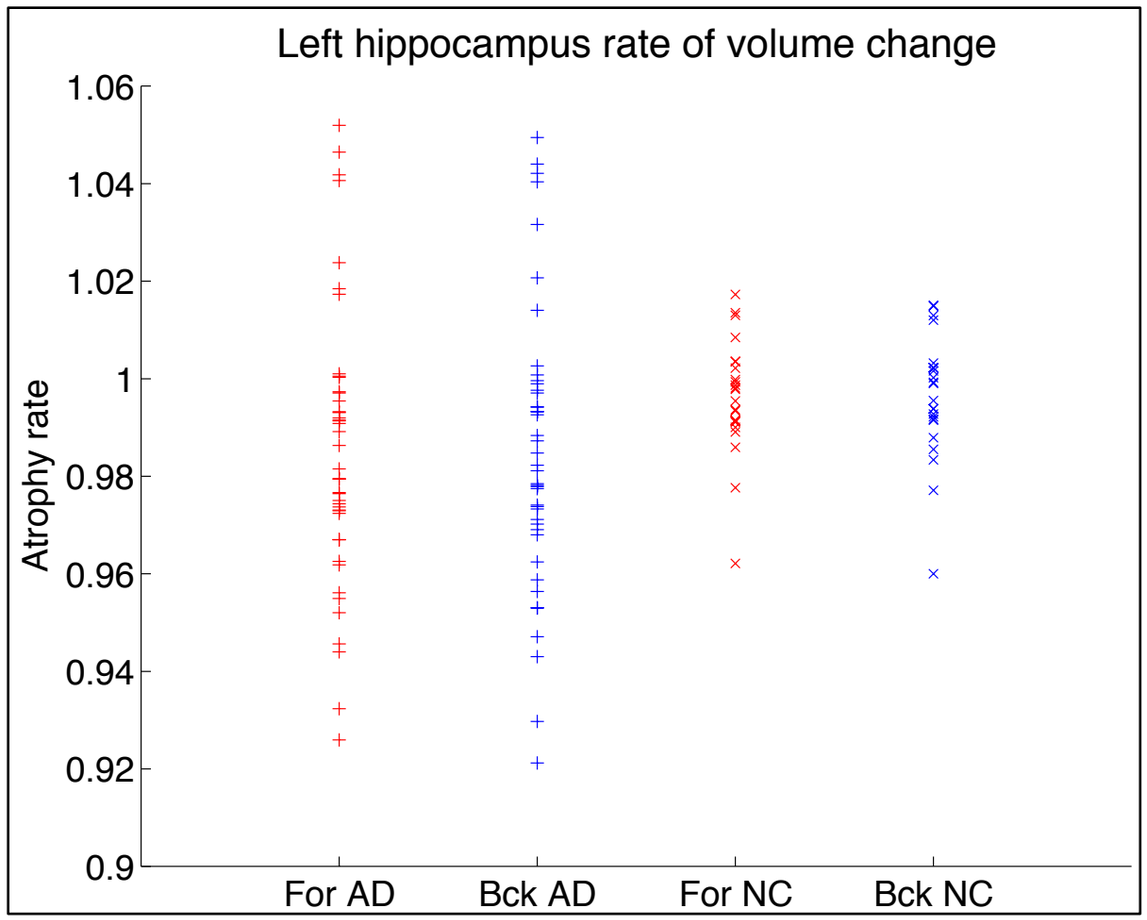
Symmetric



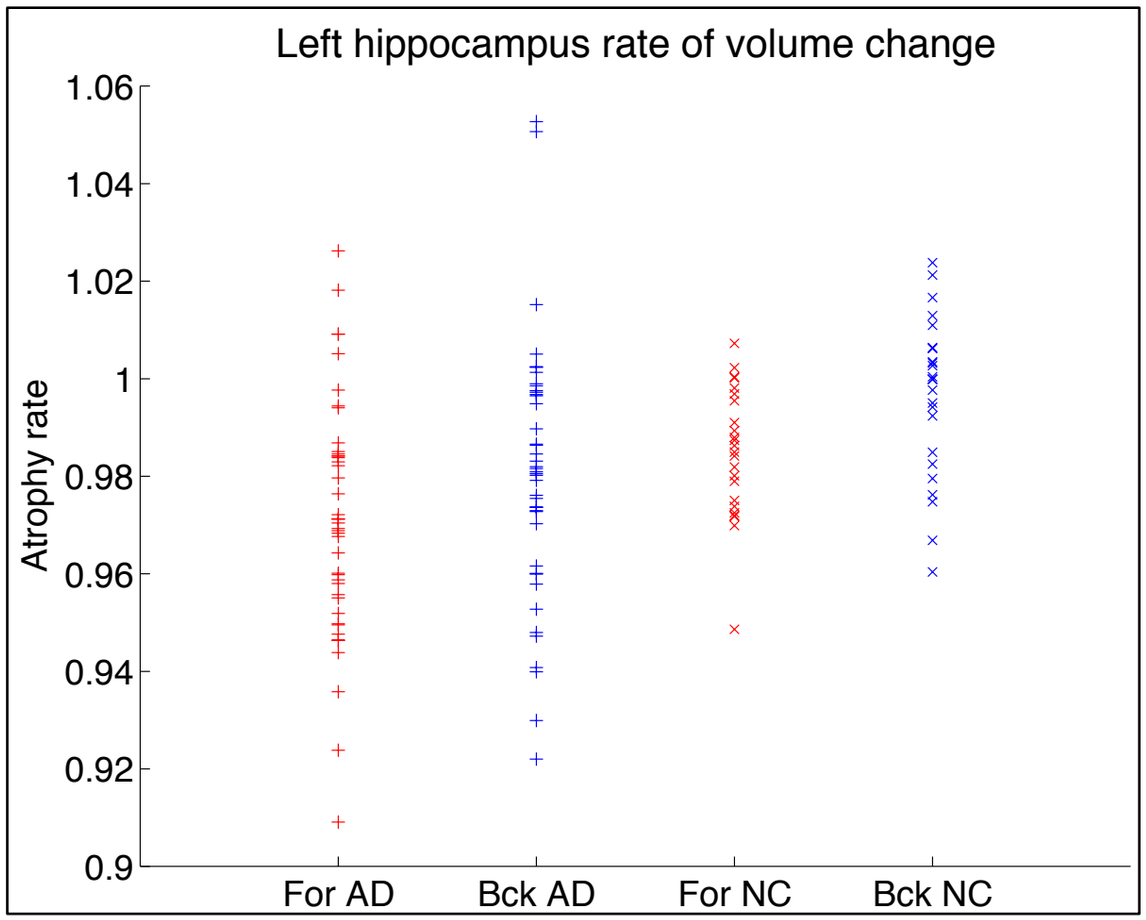
Asymmetric

Challenge: Symmetry

- Jacobian Integration
  - Left hippocampus rate of volume change



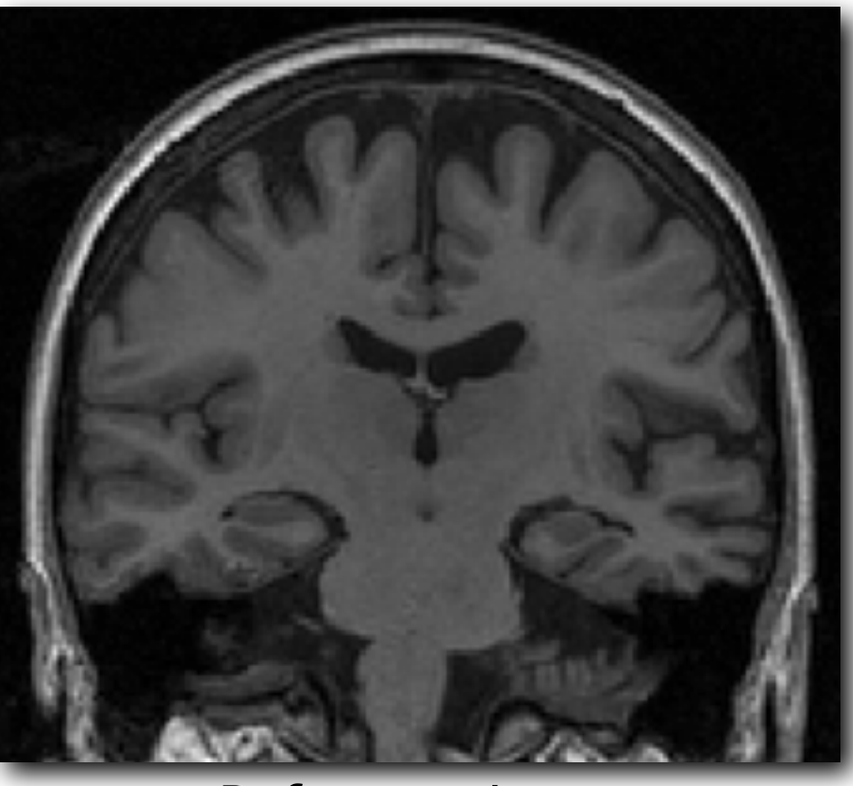
Symmetric



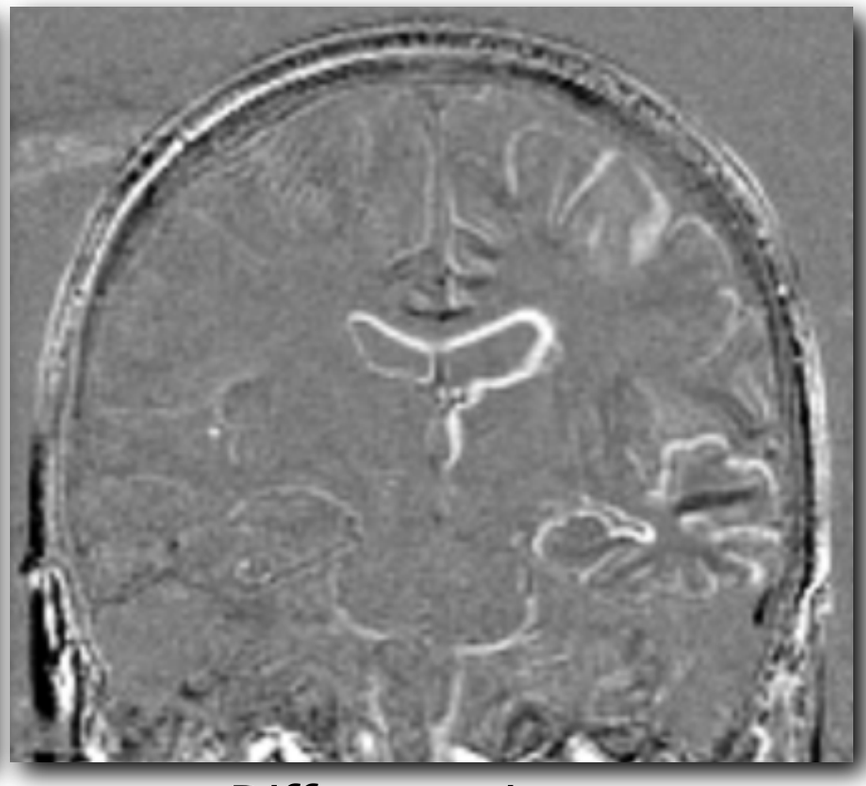
Asymmetric

Challenge: Plausibility

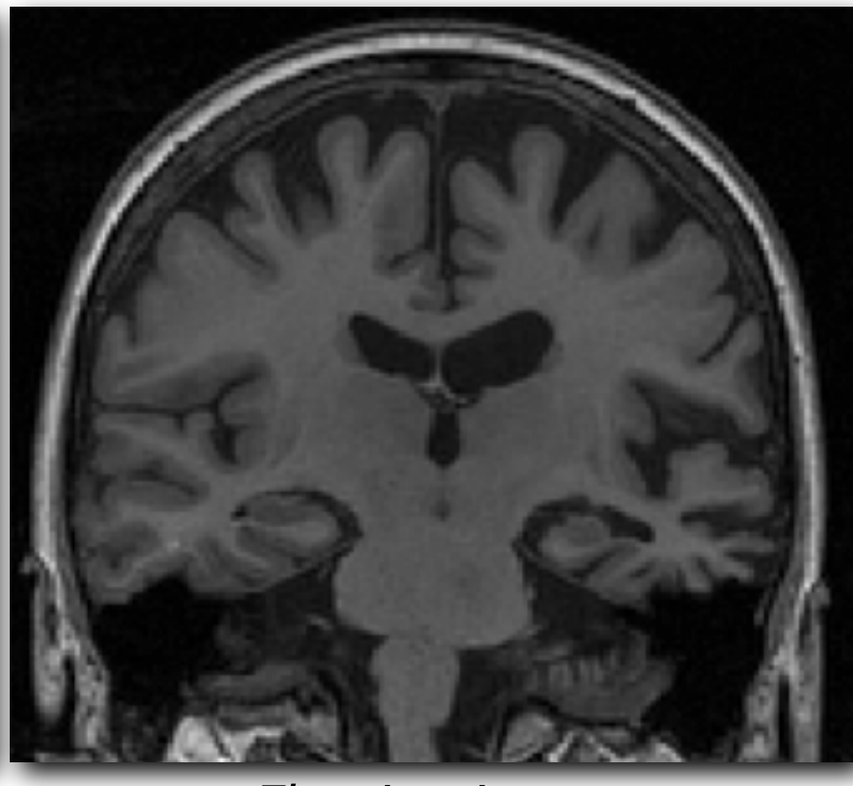
- Longitudinal registration example



Reference image



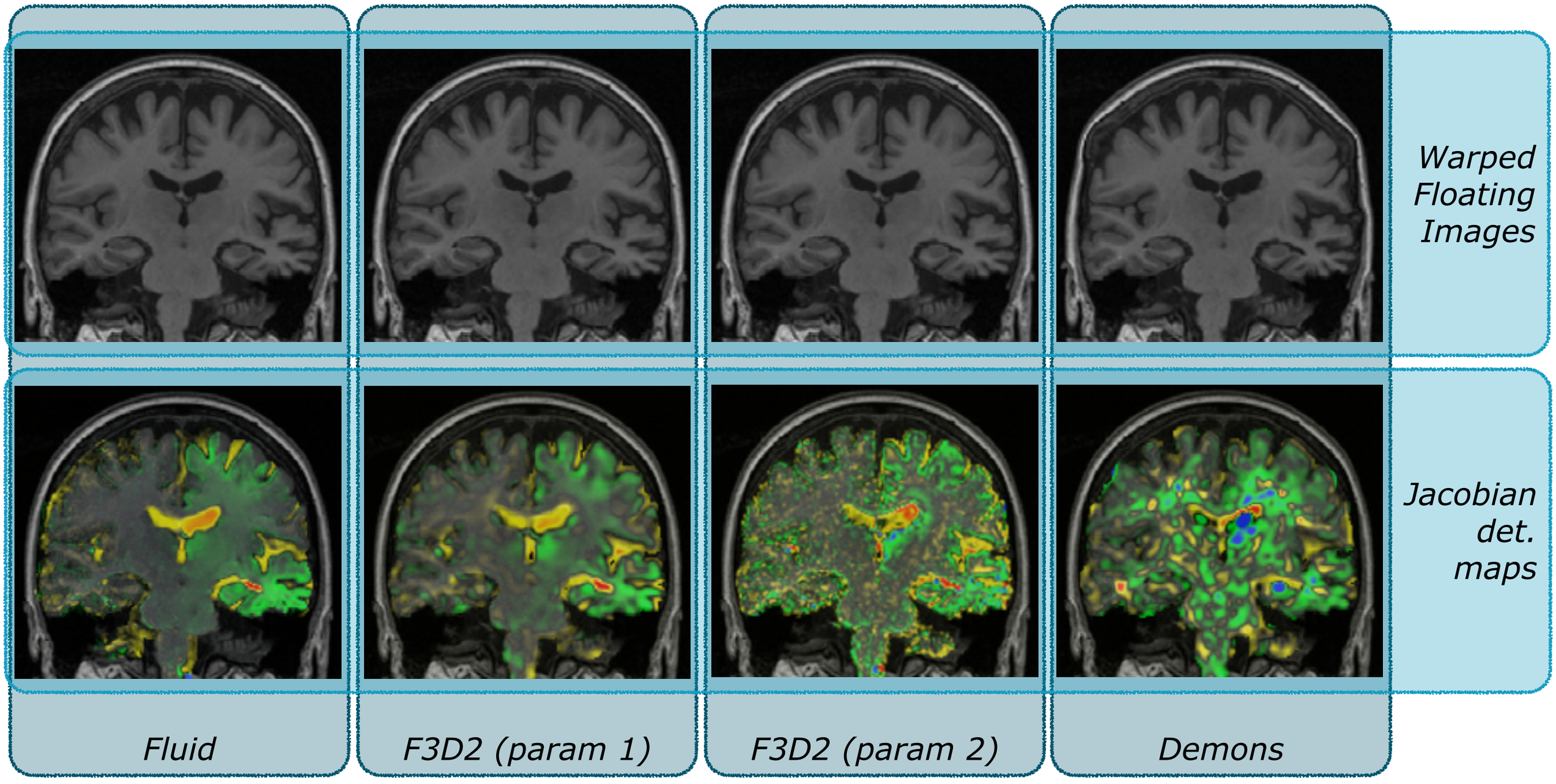
Difference image



Floating image

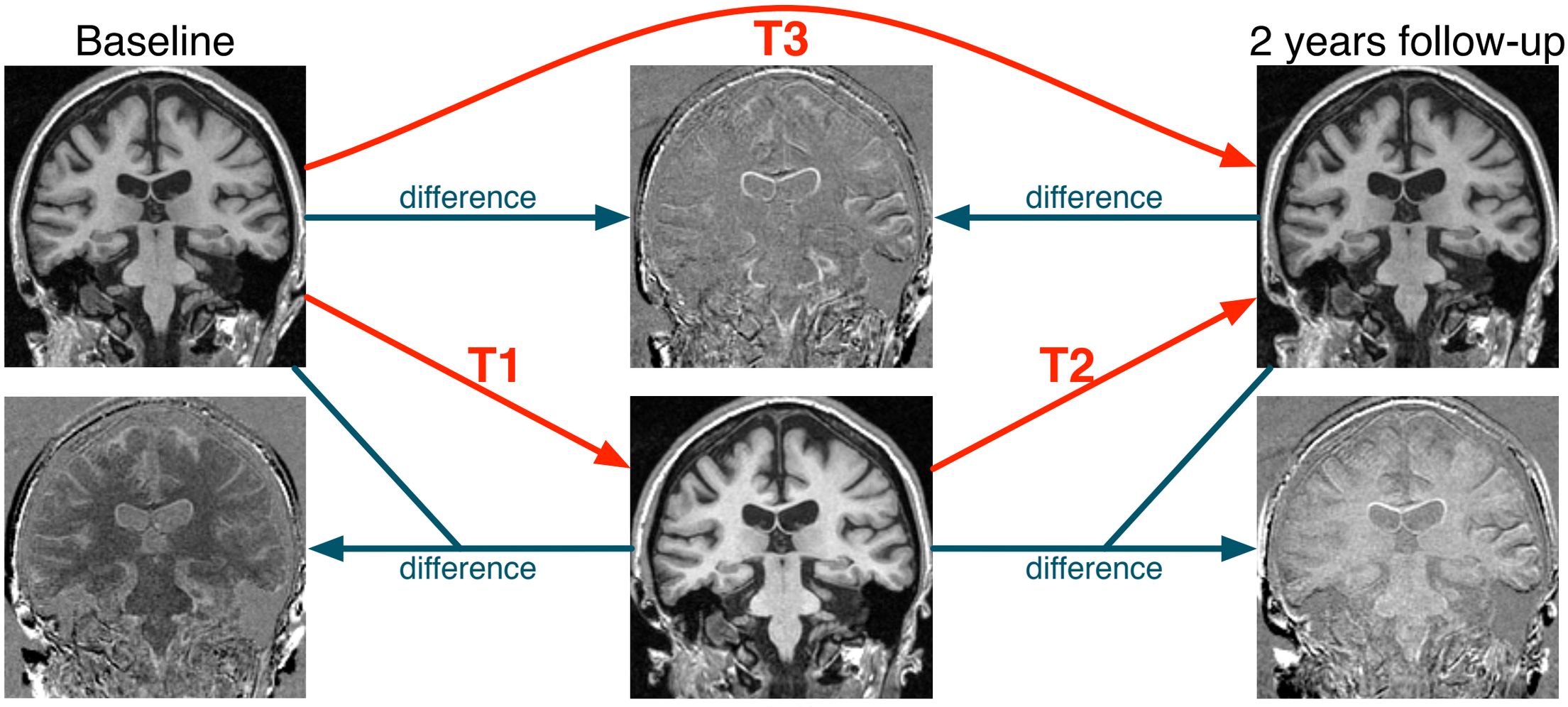
Challenge: Plausibility

- Longitudinal registration example



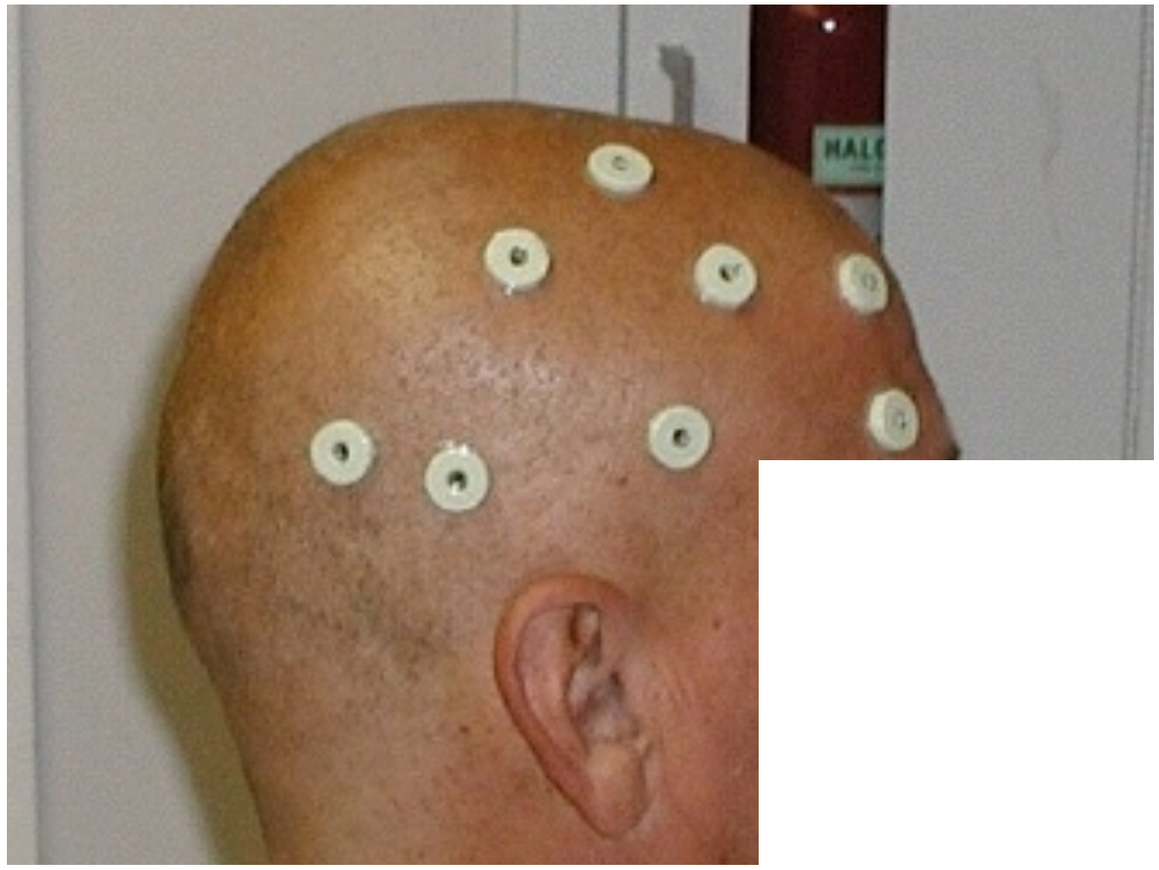
Challenge: Associativity

- Associativity (consistency)
  - is T3 = T2(T1) ?



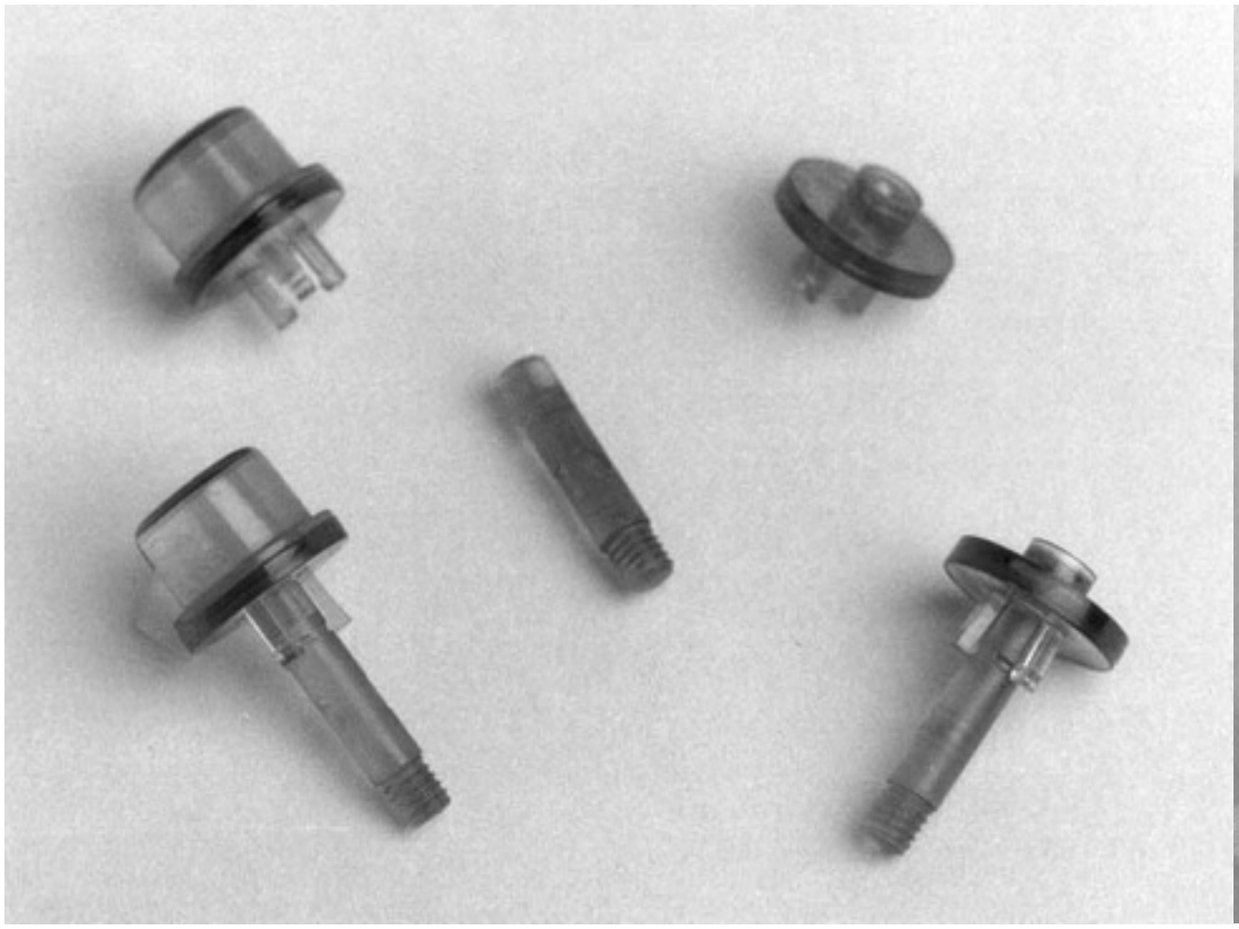
Gold Standards in Rigid Registration

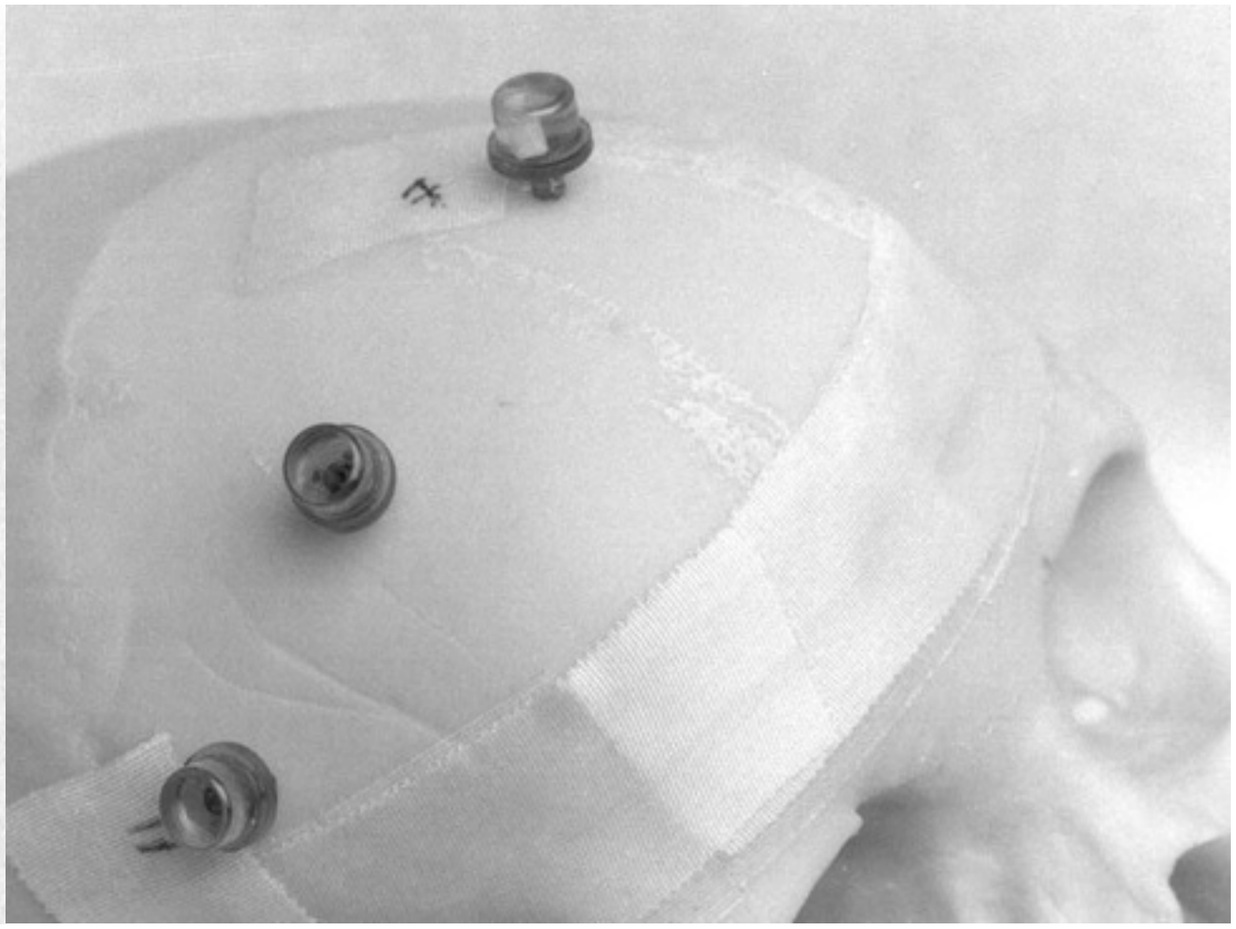
- Special evaluation case:
  - Use firmly attached markers visible in resulting scans.
  - NB markers may need to be designed for multiple modalities.
- Skin-fixed markers:
  - Relatively non-invasive but prone to movement or slippage.



Gold Standards in Rigid Registration

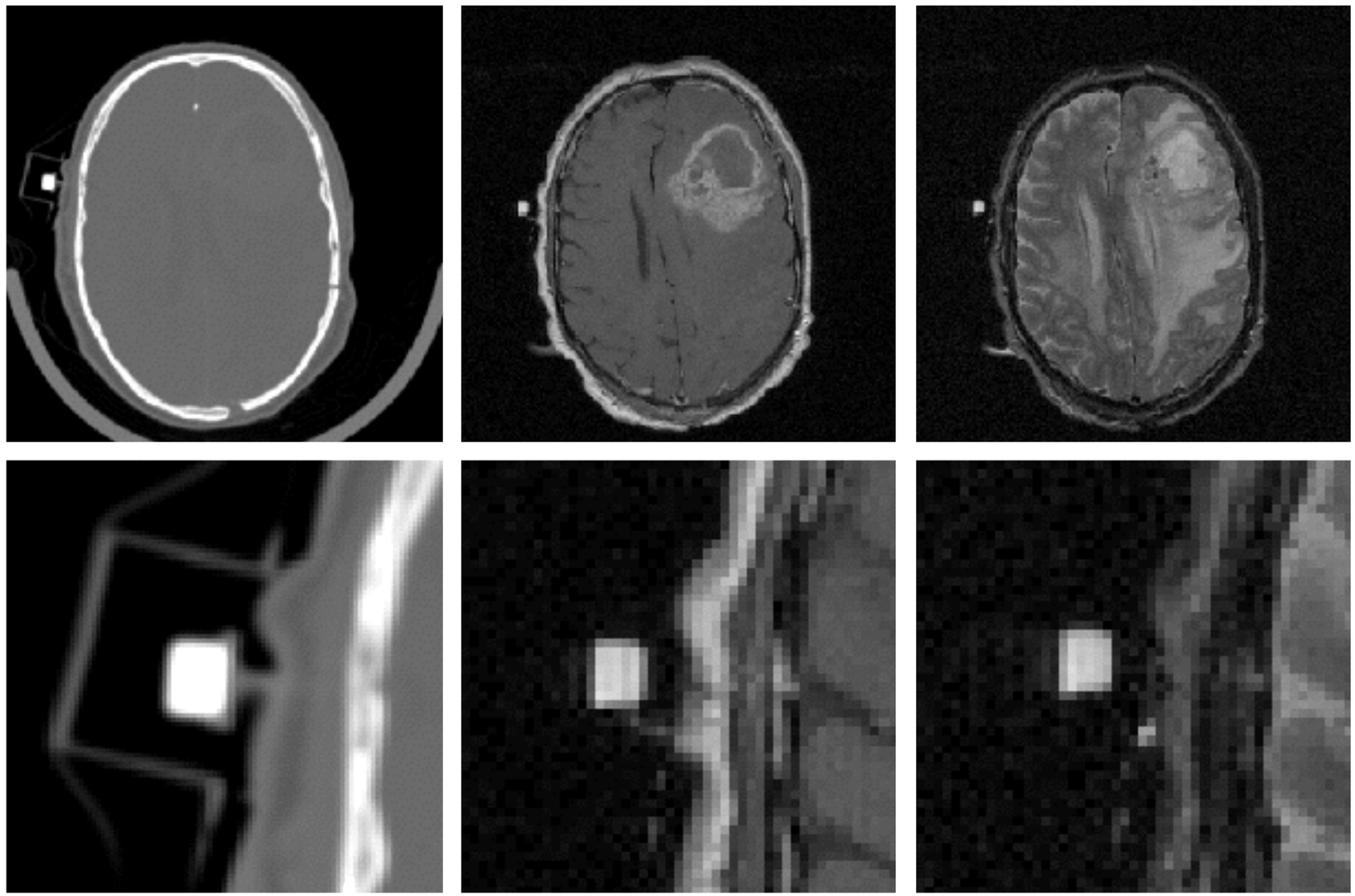
- Bone-fixed markers:
  - Invasive but robust.
  - Markers can be incorporated into stereotactic frames.





Gold Standards in Rigid Registration

- Bone-fixed markers:
  - Markers must be visible in each modality.
  - E.g. Vitamin-E - MR, Iodine solution - CT, Isotope - PET



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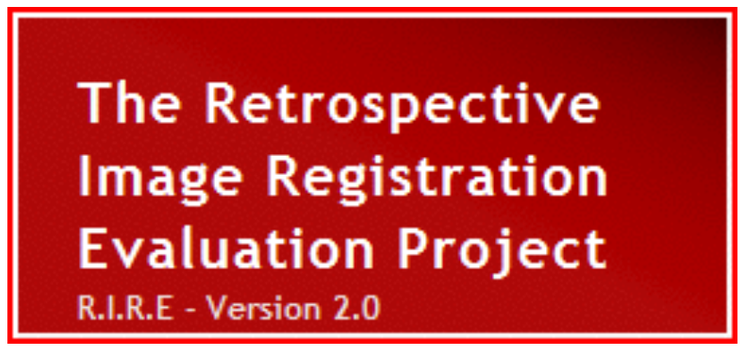
Gold Standards in Rigid Registration

- Fiducial-Localisation-Error (FLE)
  - error in the identified position of the marker

- Fiducial-Registration-Error (FRE)
  - mean displacement between corresponding markers

- Target-Registration-Error (TRE)
  - displacement between two arbitrary corresponding points (usually excluding fiducials if used to obtain registration)



http://insight-journal.org/rire/

Validation: CURT

- Validation commonly presented in the literature:
  - An increase in image similarity?
  - Improved overlap of image segmentations (Dice score)?
  - Any volume change in the deformation field?
  - Inverse consistency?
  - Improved alignment of independent fiducial markers?
  - Simulation/recovering of deformation field?

  - We can assess the relevance of these using one nonsense algorithms: the CURT

Validation: CURT

- CURT
  - "We introduce a new nonrigid registration algorithm based on a closed-form solution to maximizing the Rank Correlation criterion. The new algorithm produces more accurate registrations than two state-of-the-art methods as judged by image similarity and tissue overlap scores. It is also two to three orders of magnitude faster, requires no affine pre-registration, and has no tunable parameters."

Validation: CURT

- The algorithm is simple: to compute the transformation from a fixed image to a moving image, the Nf pixels in the fixed image and the Nm pixels in the moving image are independently sorted by increasing intensity values. The nfth pixel (as counted by increasing intensity) in the fixed image then maps to the nmth pixel in the moving image, which is computed as follows:

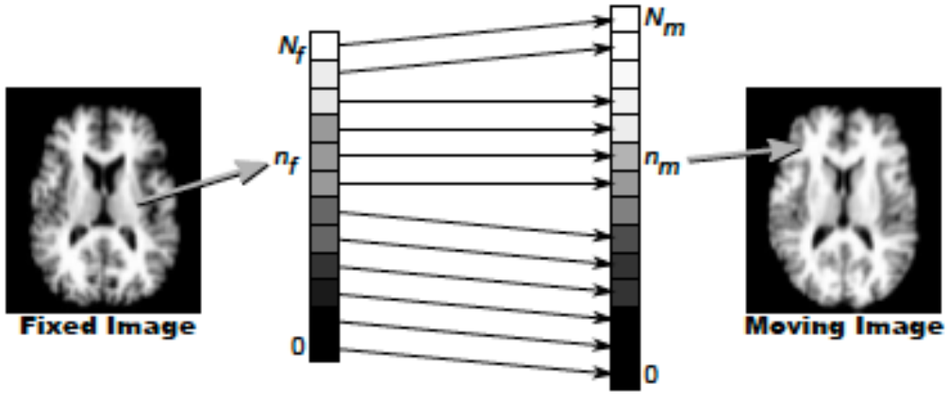
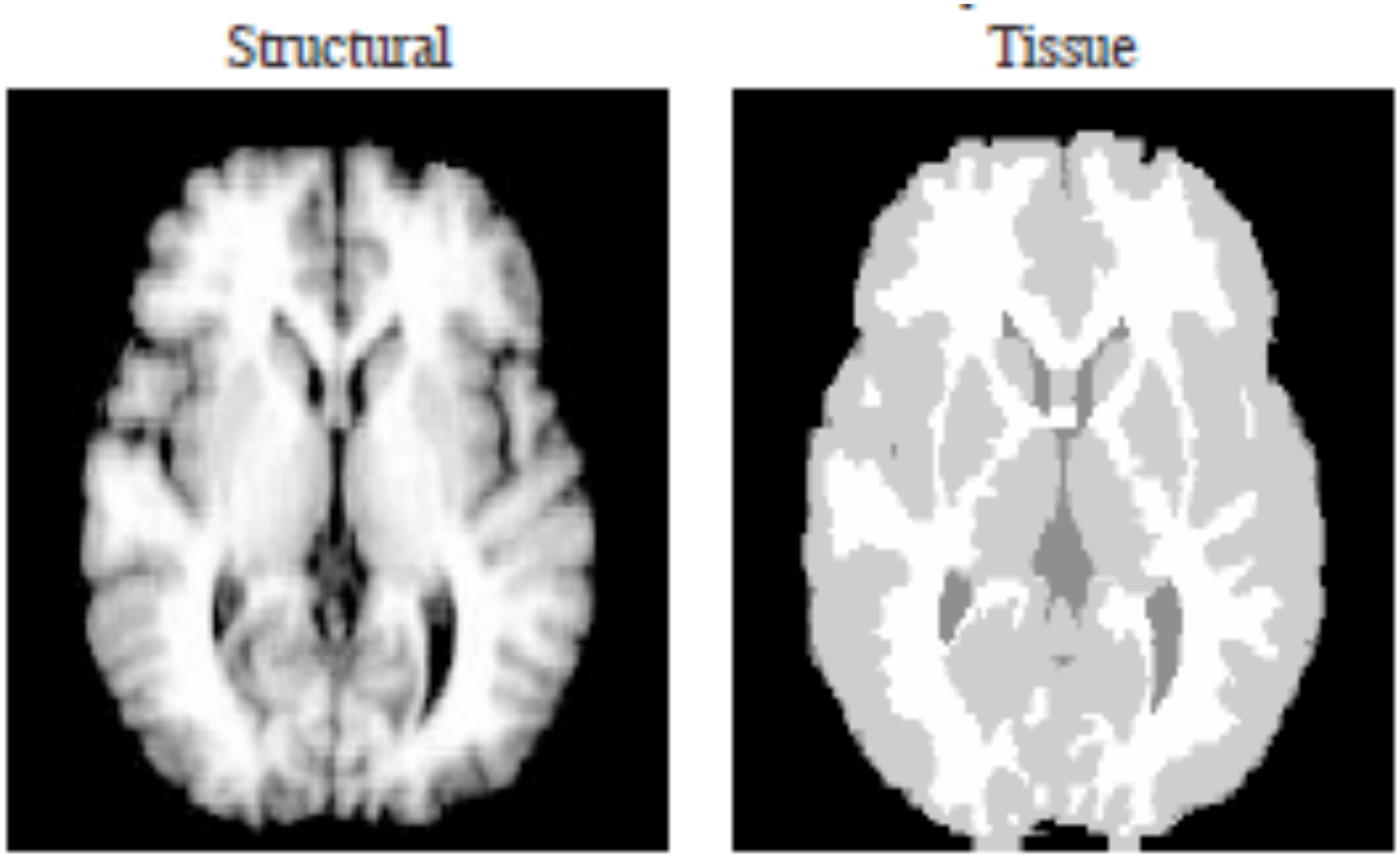


Fig. 2. Schematic illustration of rank order-based mapping of a pixel from the fixed image (*left*) to the moving image (*right*) via correspondence of pixels sorted by increasing intensities. See text for details and notation.

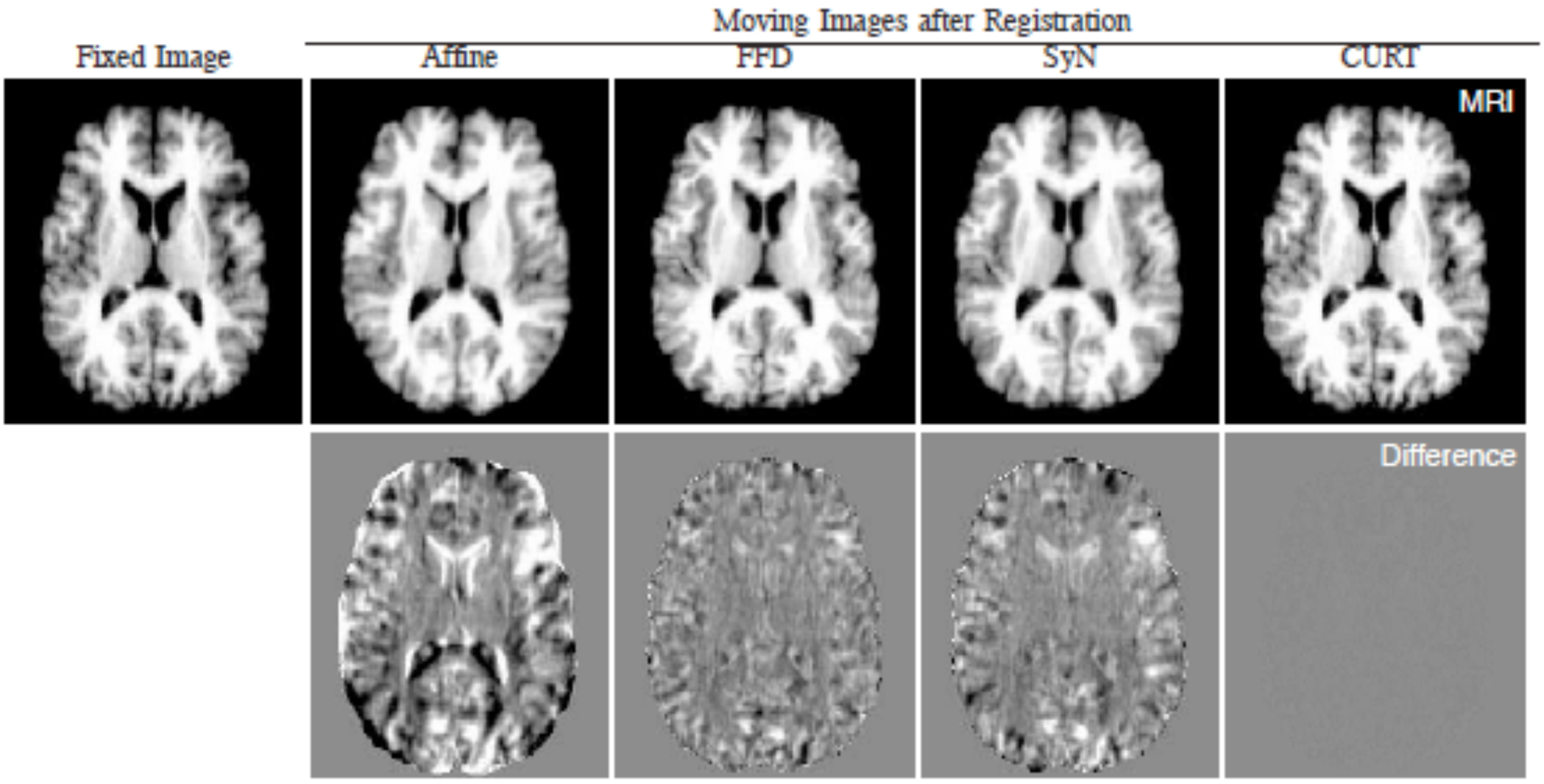
$$n_m = \lfloor N_m \frac{n_f}{N_f} \rfloor$$

- One way to interpret the algorithm is as a geometrically unconstrained, closed-form optimization of the rank correlation criterion.

Validation: CURT

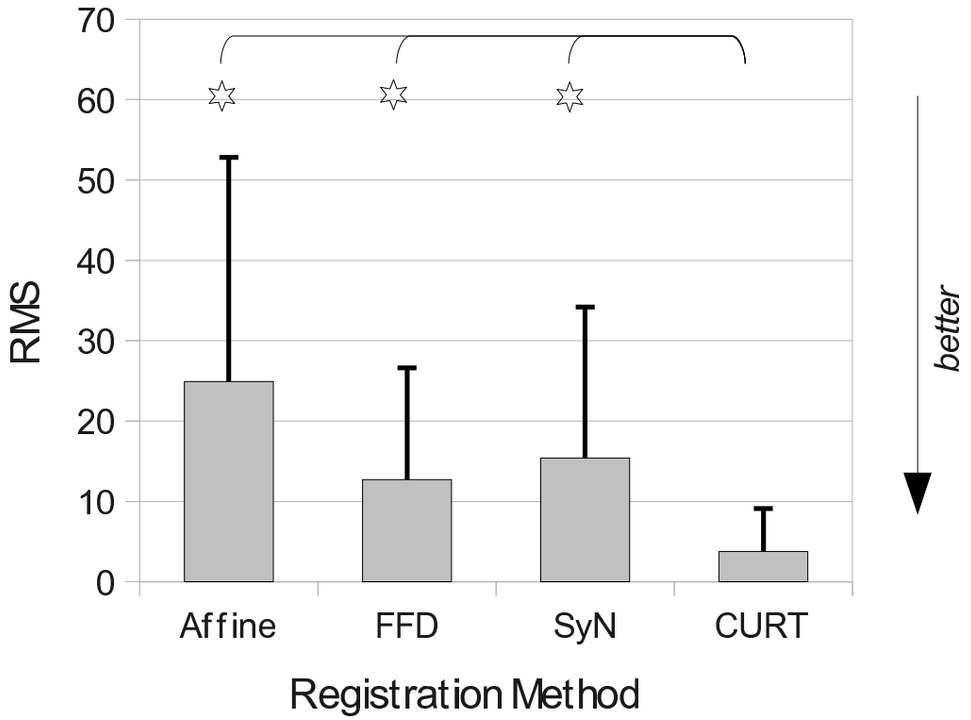


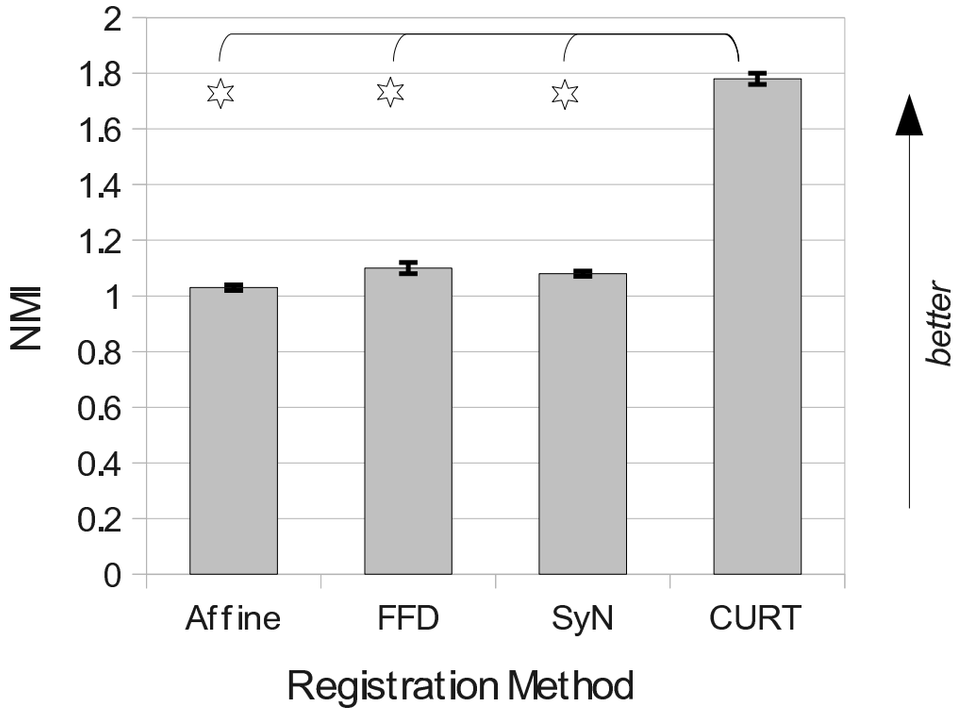
Validation: CURT



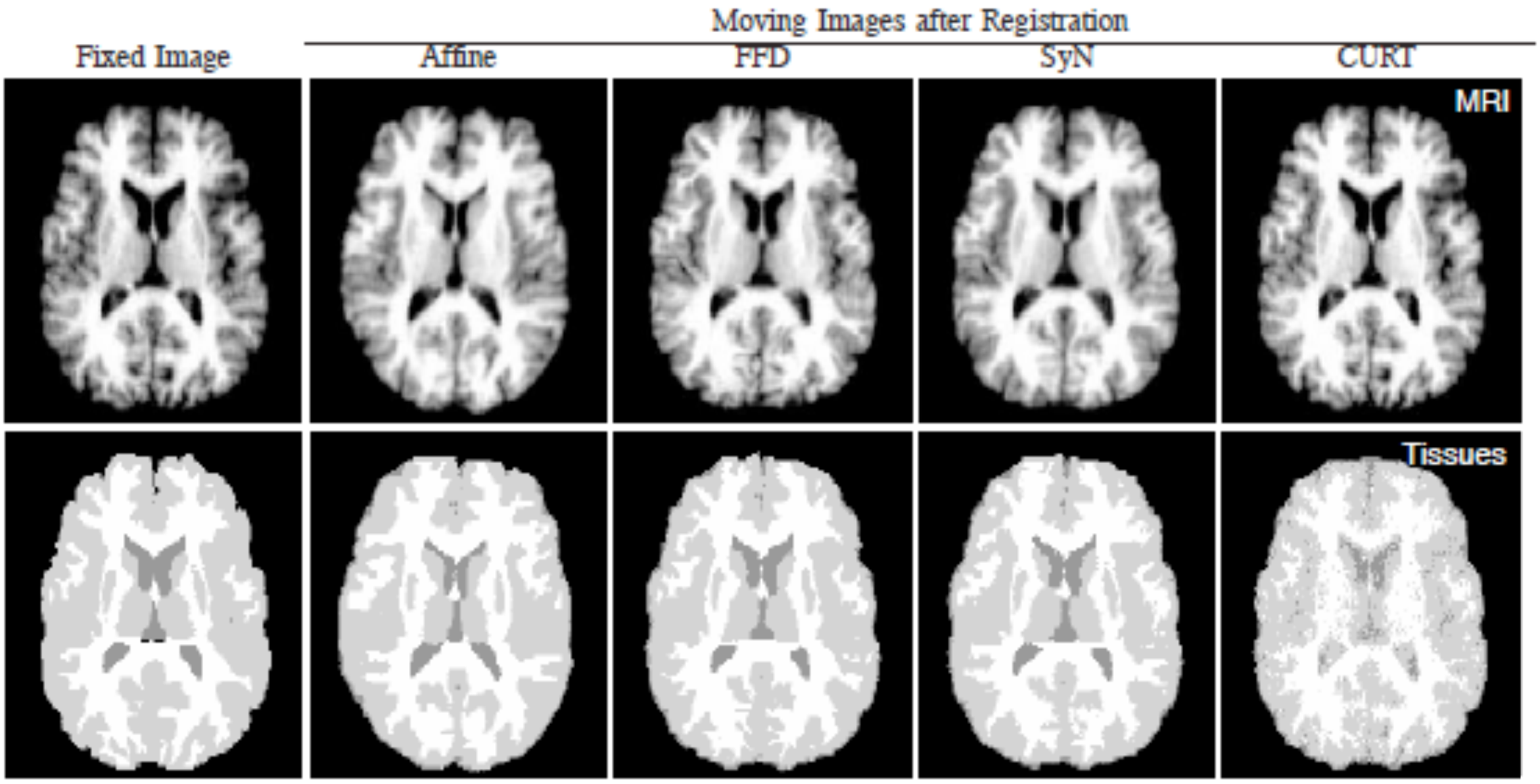
Validation: CURT

- Increased image similarity



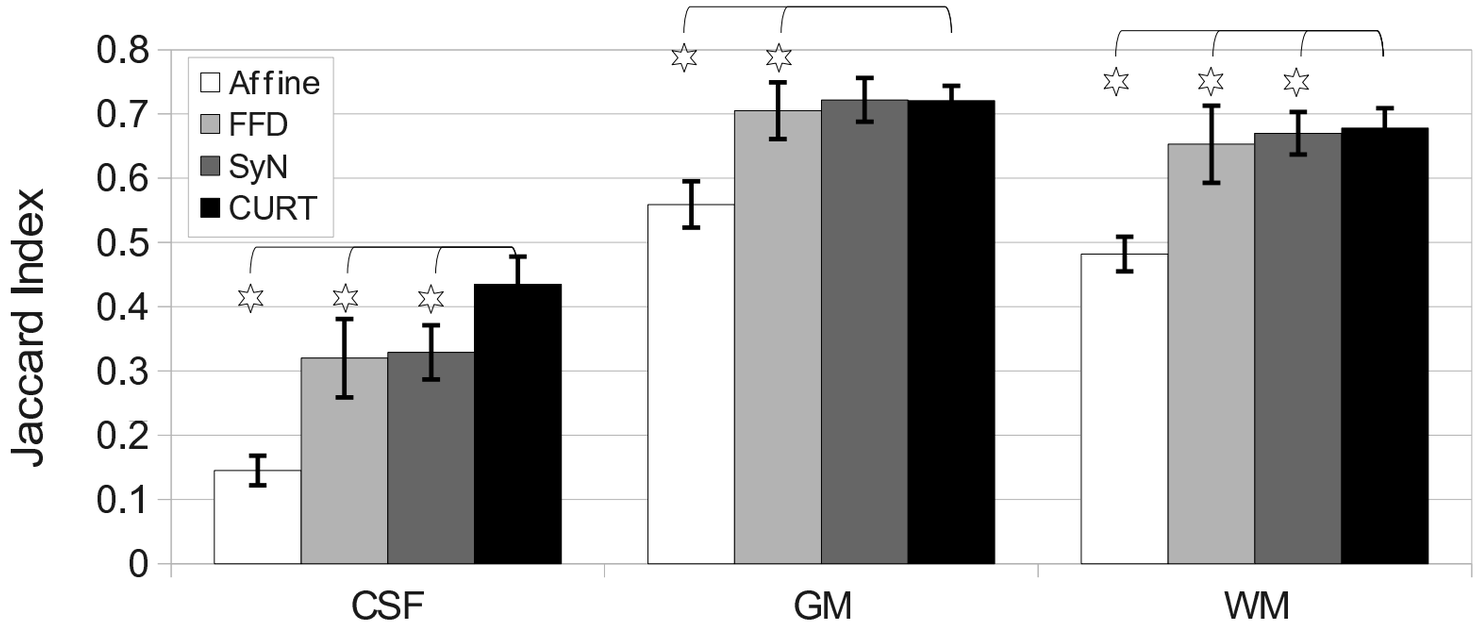


Validation: CURT



Validation: CURT

- Tissue segmentation overlap



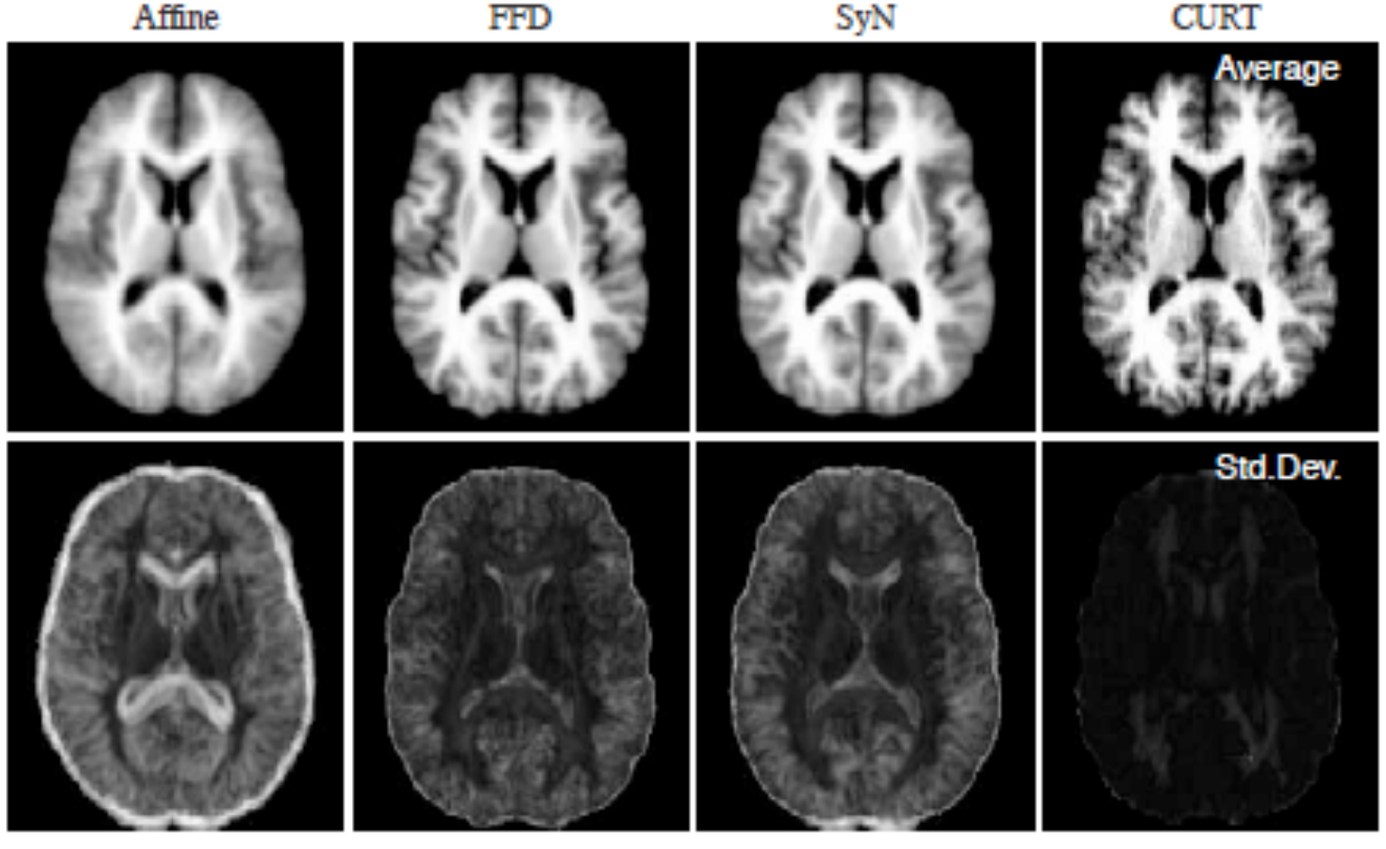
$$J_{AB} = \frac{|A \cap B|}{|A \cup B|}$$

$$D_{AB} = \frac{|A \cap B|}{|A| + |B|}$$

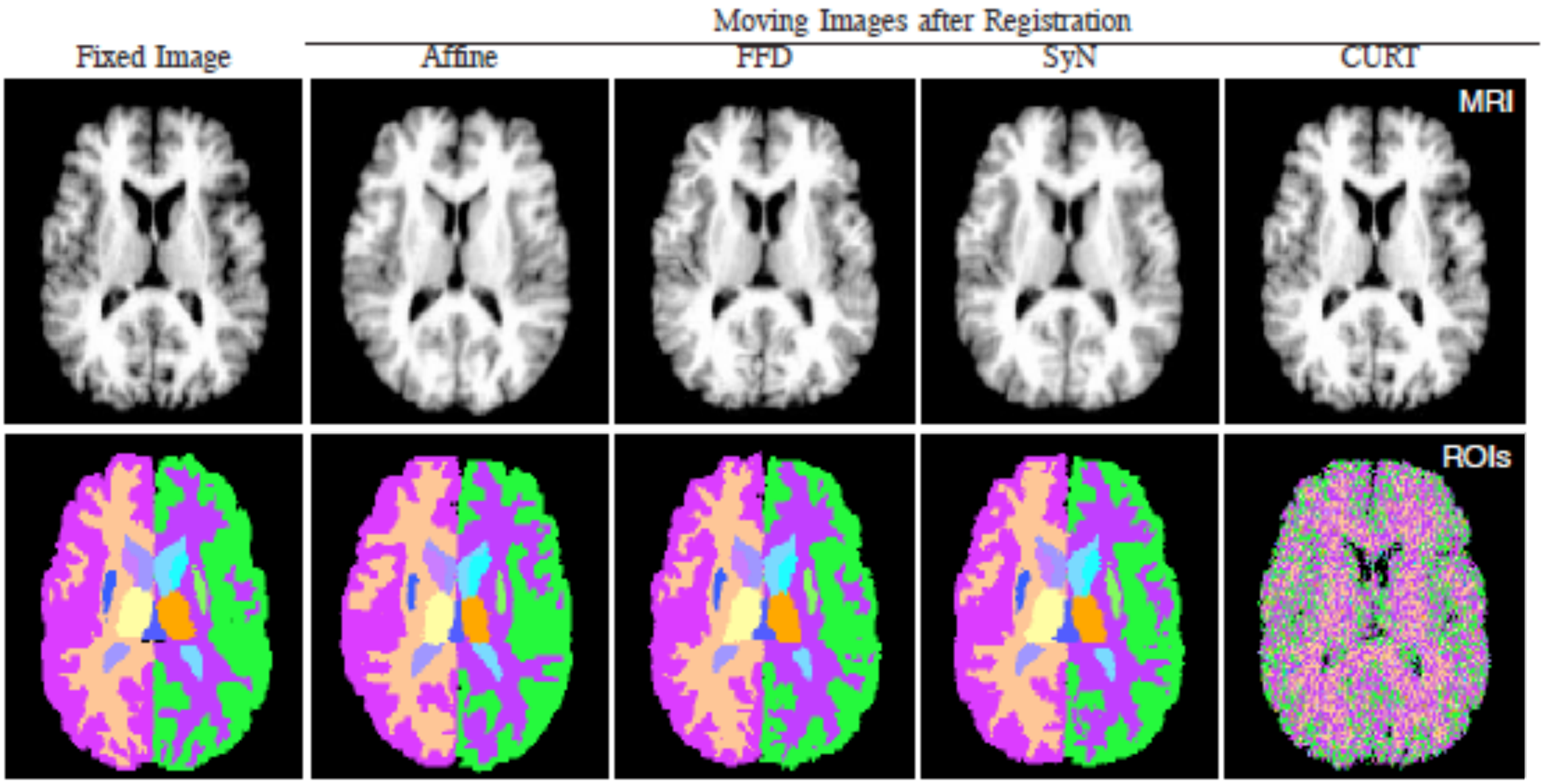
Validation: CURT

- Inverse consistency

	Registration			
	Affine	FFD	SyN	CURT
Inverse Consistency Error [mm]	25.8 ±16.3	26.2 ± 15.1	26.2 ± 16.2*	6.4 ± 9.0

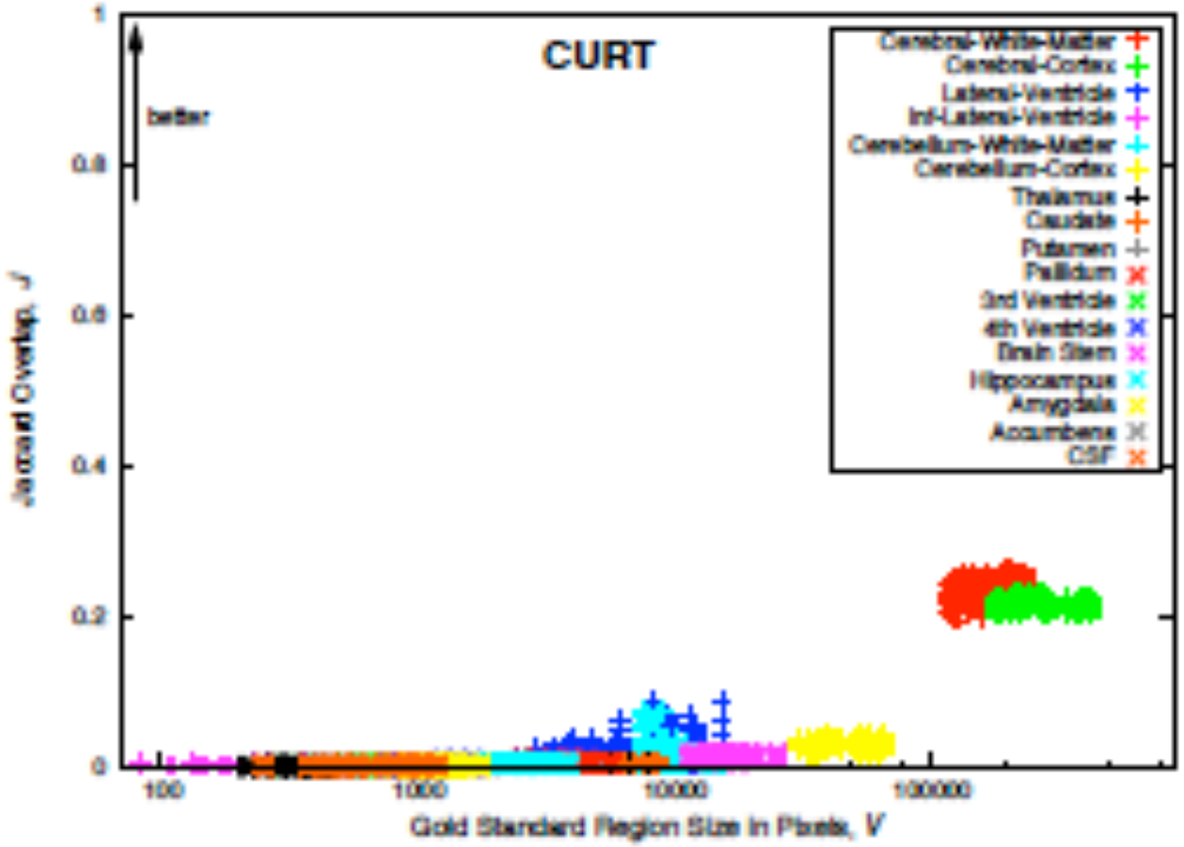


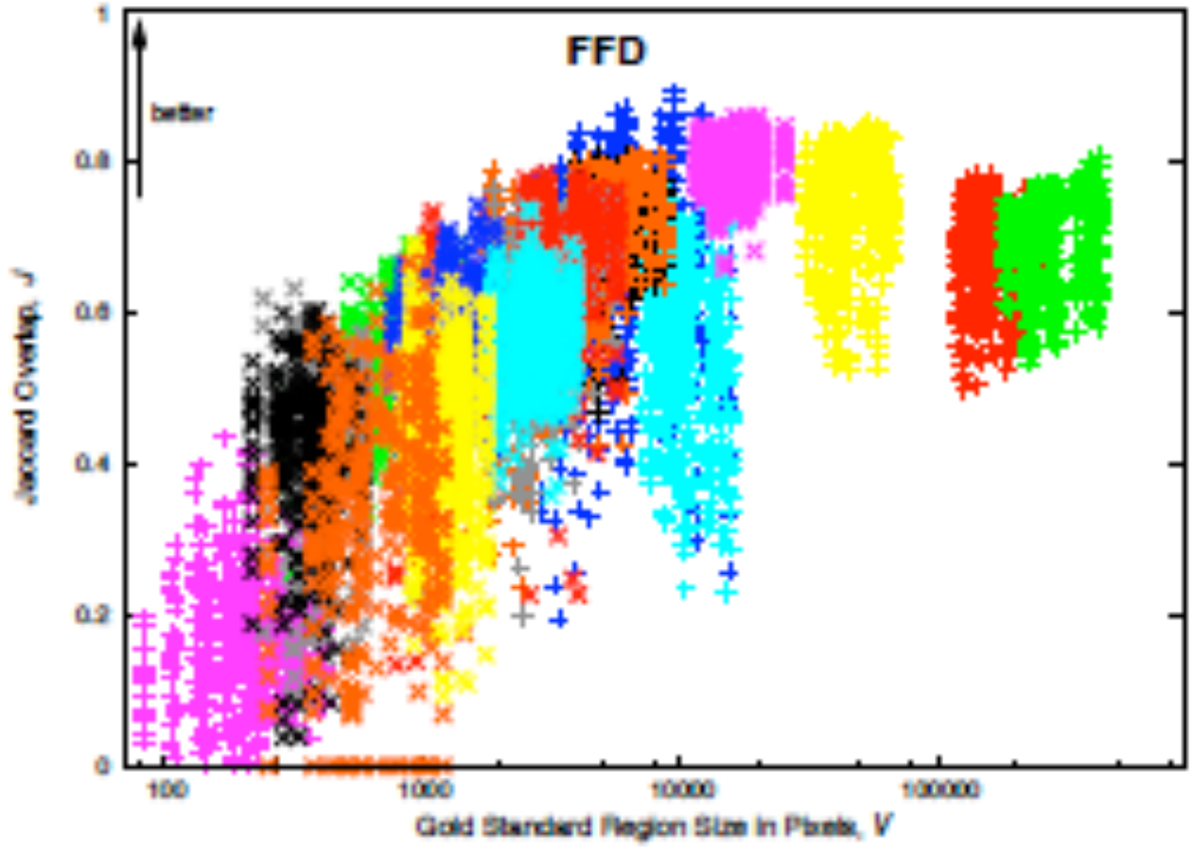
Validation: CURT



Validation: CURT

- But it does perform poorly if small enough regions are assessed!





Validation: CURT

- Validation commonly presented in the literature:
  - ~~An increase in image similarity?~~
  - ~~Improved overlap of image segmentations (Dice score)?~~
  - ~~Any volume change in the deformation field?~~
  - ~~Inverse consistency?~~
  - ~~Improved alignment of independent fiducial markers?~~
  - ~~Simulation/recovering of deformation field?~~

  - ***CURT*** = ***Completely Useless Registration Technique***

  - Need a mix of evaluation to compare registration result, only one does not tell a full story!