Simulating Neurodegeneration through Longitudinal Population Analysis of Structural and Diffusion Weighted MRI Data

Modat et al. MICCAI 2014

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Neurons, Gray Matter(GM), White Matter(WM) and Cerbral Spinal Fluid (CSF)

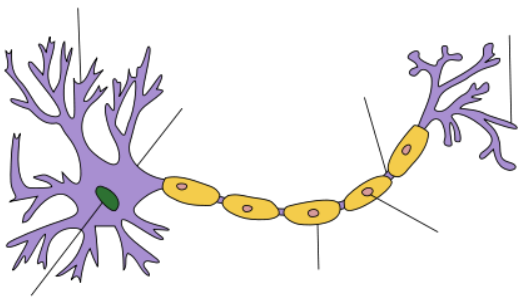

Figure:

Cortex.[http://en.wikipedia.org/wiki/File:Neuron_Hand-tuned.svg. Accessed on 08-01-2014]

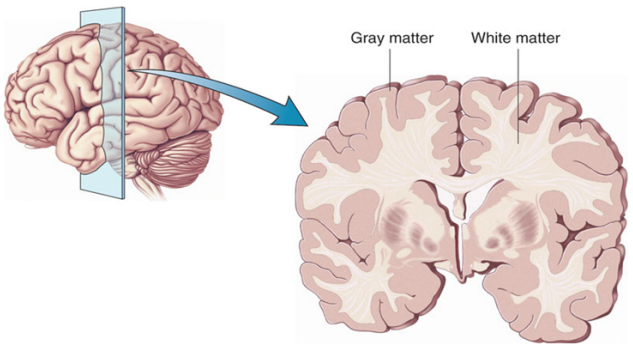

Figure:

GM/WM.[http://www.medinewsdigest.com/?p=3249. Accessed on 08-01-2014]

Neurodegeneration and Longitudinal images

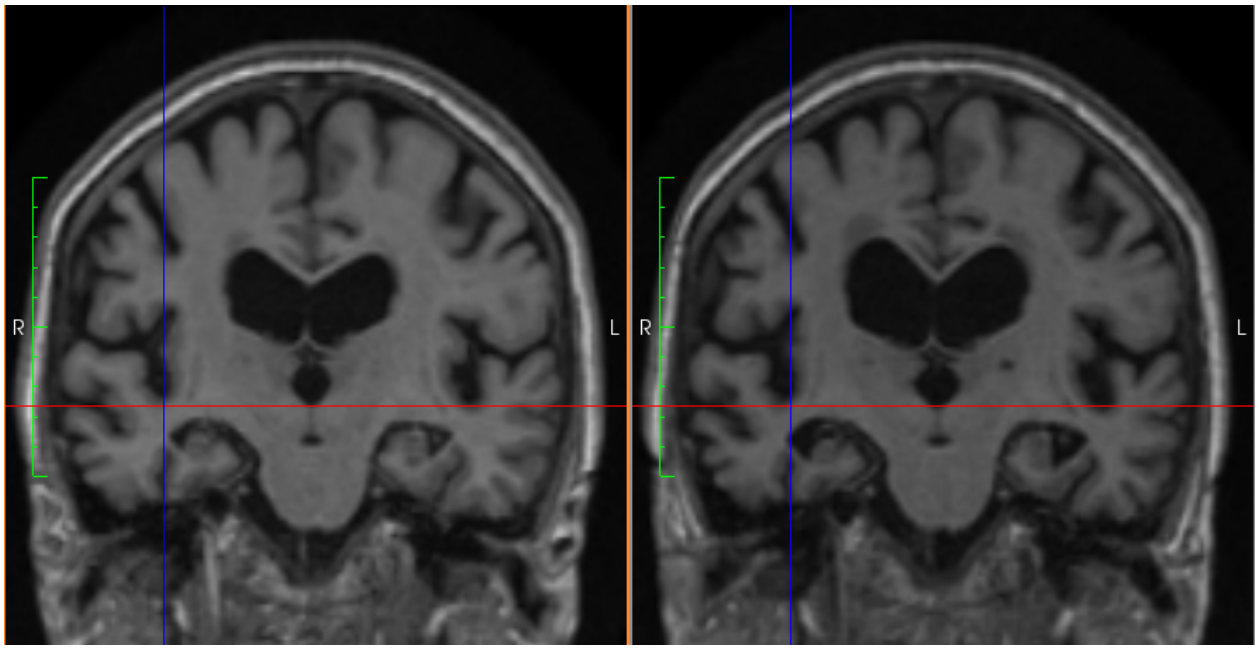

Figure: **Baseline** and **follow-up** images of an Alzheimer's Disease patient.

- **Neurodegenration:** Progressive loss of structure or function of neurons, including death of neurons [wikipedia]
- **Longitudinal images:** Time series images of a same subject.

Dementia and Alzheimer's Disease

- **Dementia:** Progressive decline of cognitive functions.
  - Loss of memory, mood changes, and problem with communication and reasoning.
- **AD:** Most common cause of Dementia, mostly affects older people.
  - Characterized by **atrophy**, Amyloid β (**A**β) plaques and Neurofibrillary tangles (**NFTs**).

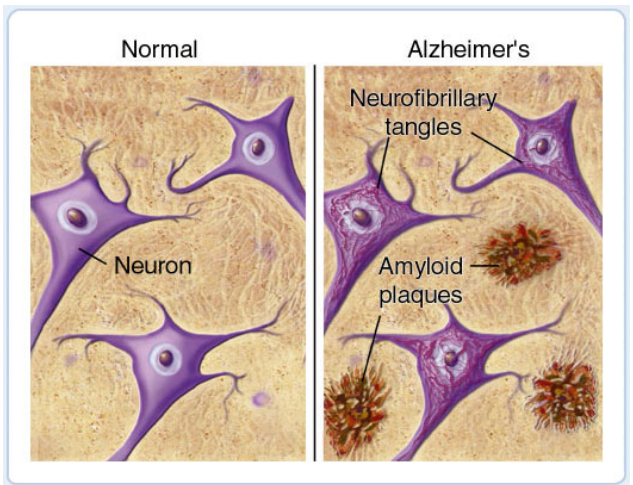

Figure: Aβ plaques and NFTs in AD [2000 BrightFocus Foundation]

Multimodal neuroimaging for AD

- **D**ifferent modalities required to get different types of information.

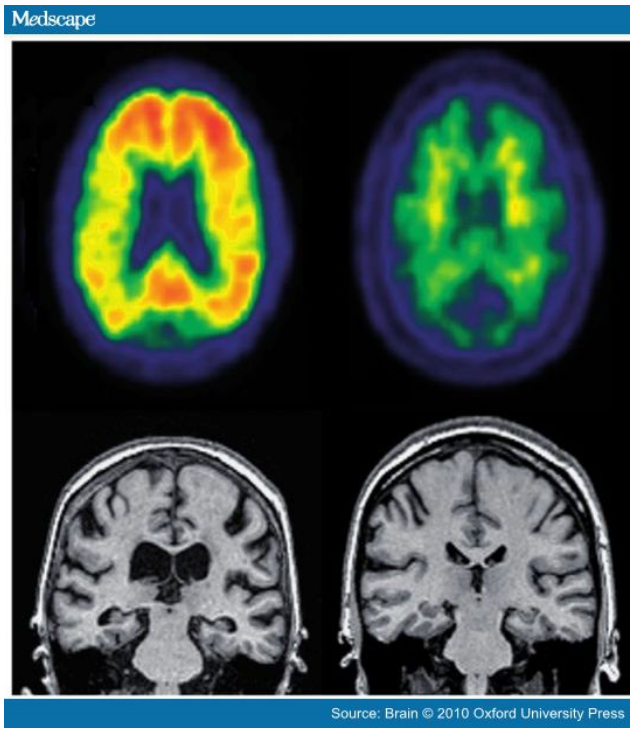

Figure: Amyloid imaging and structural MRI

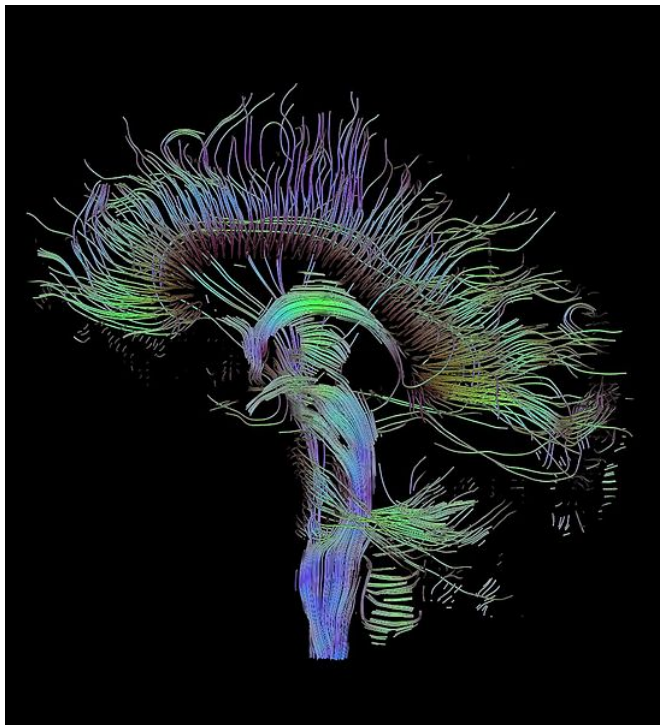

Figure: Tractography example [http://en.wikipedia.org/wiki/File:DTI-sagittal-fibers.jpg]

Atrophy Measurement

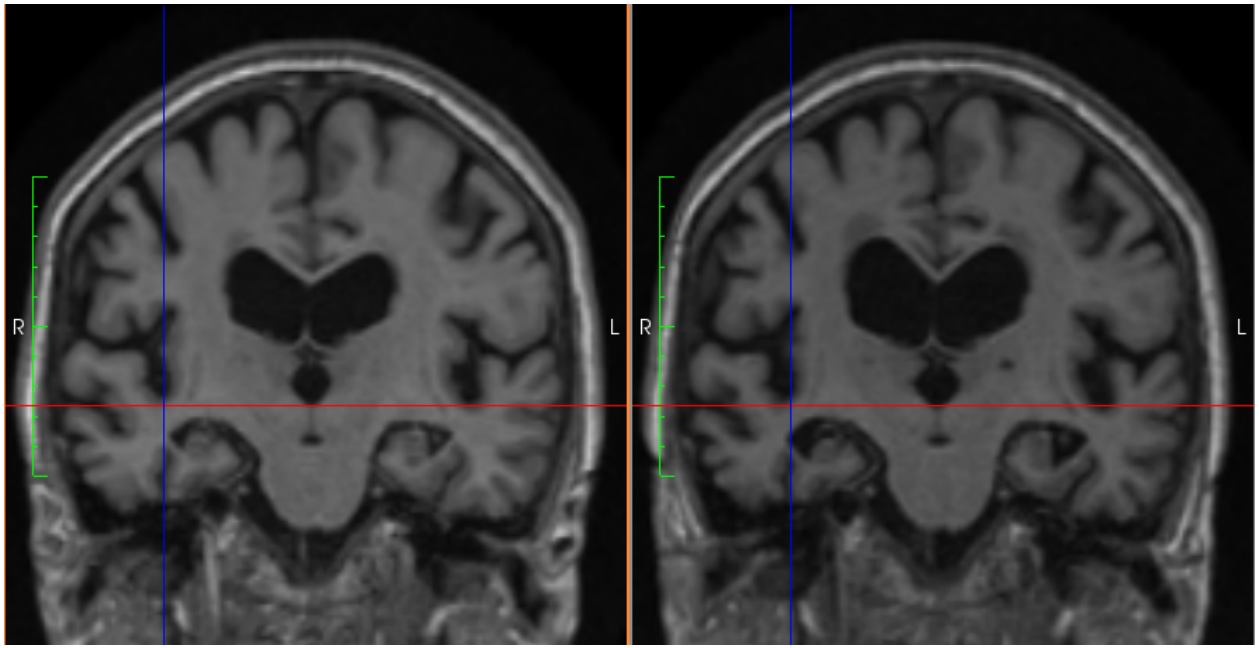

Figure: **Baseline** and **follow-up** images of an Alzheimer's Disease patient.

- Segmentation based methods.
- Registration based methods.

How to validate these methods ?

Registration

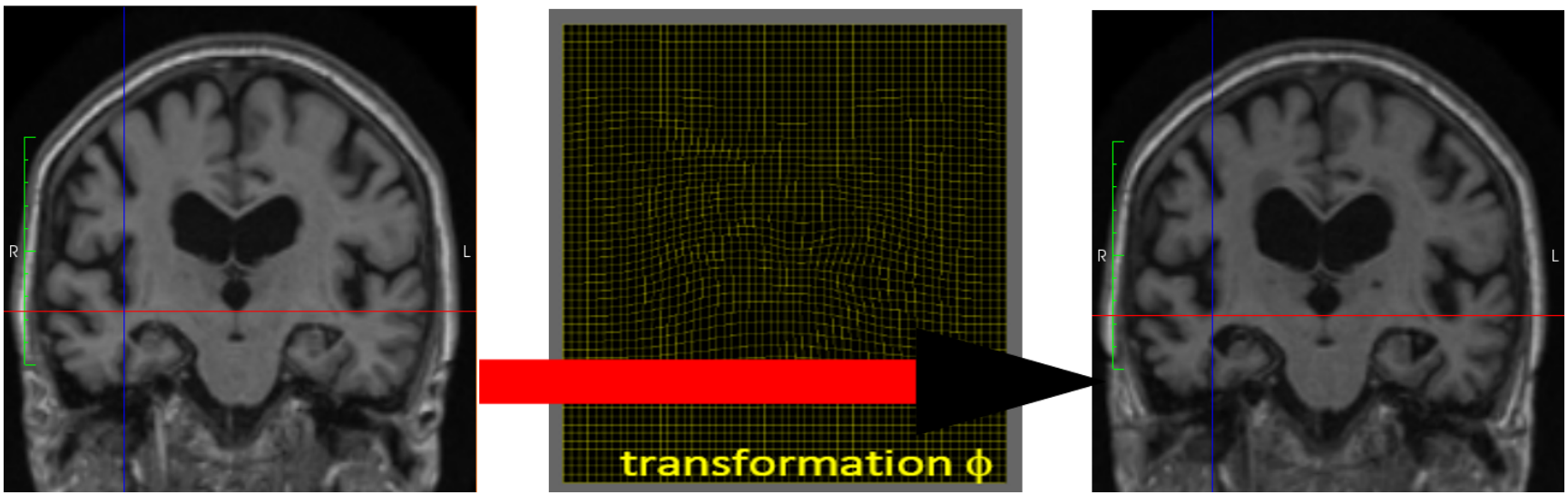

Figure: Nonlinear registeration of longitudinal images

Registration

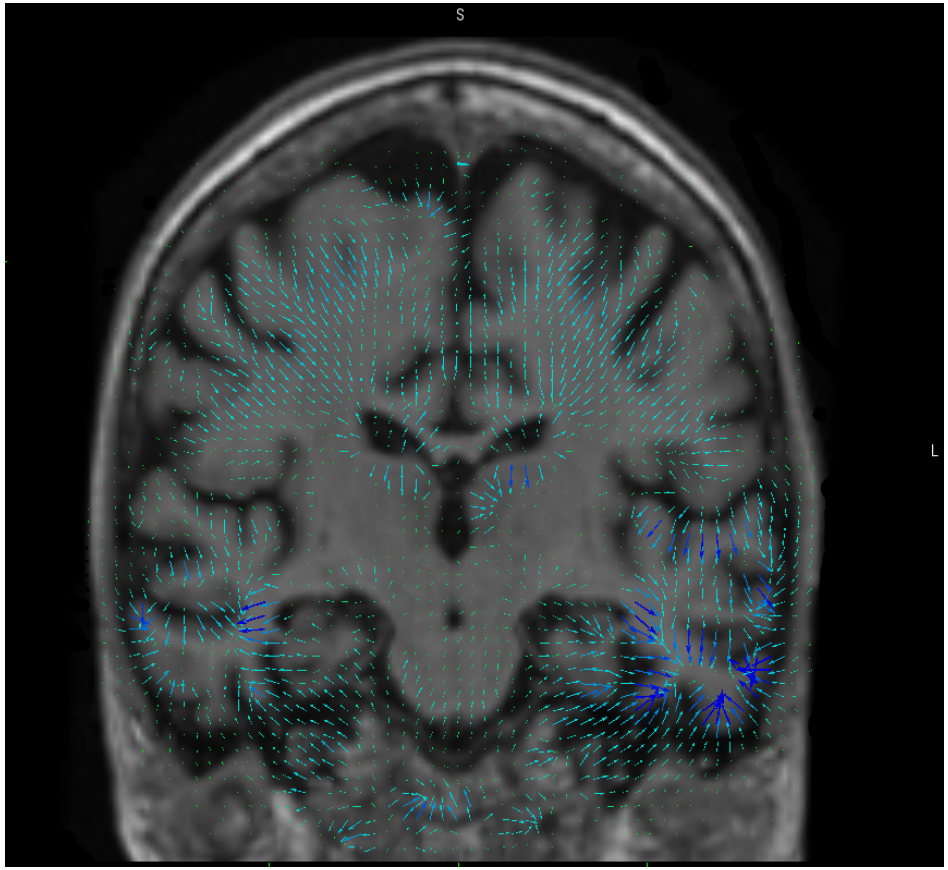

Figure: Example displacement fields of longitudinal evolution

Registration

$$\phi' = \arg\min_{\phi} \left[E_{\mathrm{D}}(I_{\mathrm{S}} \circ \phi, I_{\mathrm{T}}) + \lambda E_{\mathrm{R}}(\phi) \right]$$

$\phi : \mathbb{R}^d \rightarrow \mathbb{R}^d$
$I : \mathbb{R}^d \rightarrow \mathbb{R}$

Transformation ϕ:
- Choice of space determines inherent regularity and combination rules
- Parametrization required for digital representation (B-Spline FFDs, DCT, RBFs)

Difference Measure between:
- Target image I_T
- Warped source image $I_s \circ \phi$

Examples:
- Sum of squared differences (SSD)
- Sum of absolute differences (SAD)
- Correlation Coefficient (CC)
- Correlation Ratio (CR)
- Mutual Information (MI)

Regularization term:
- Models the behaviour of underlying elastic model (internal energy)

Figure: Registration overview [Sotiras et al BIASS2013]

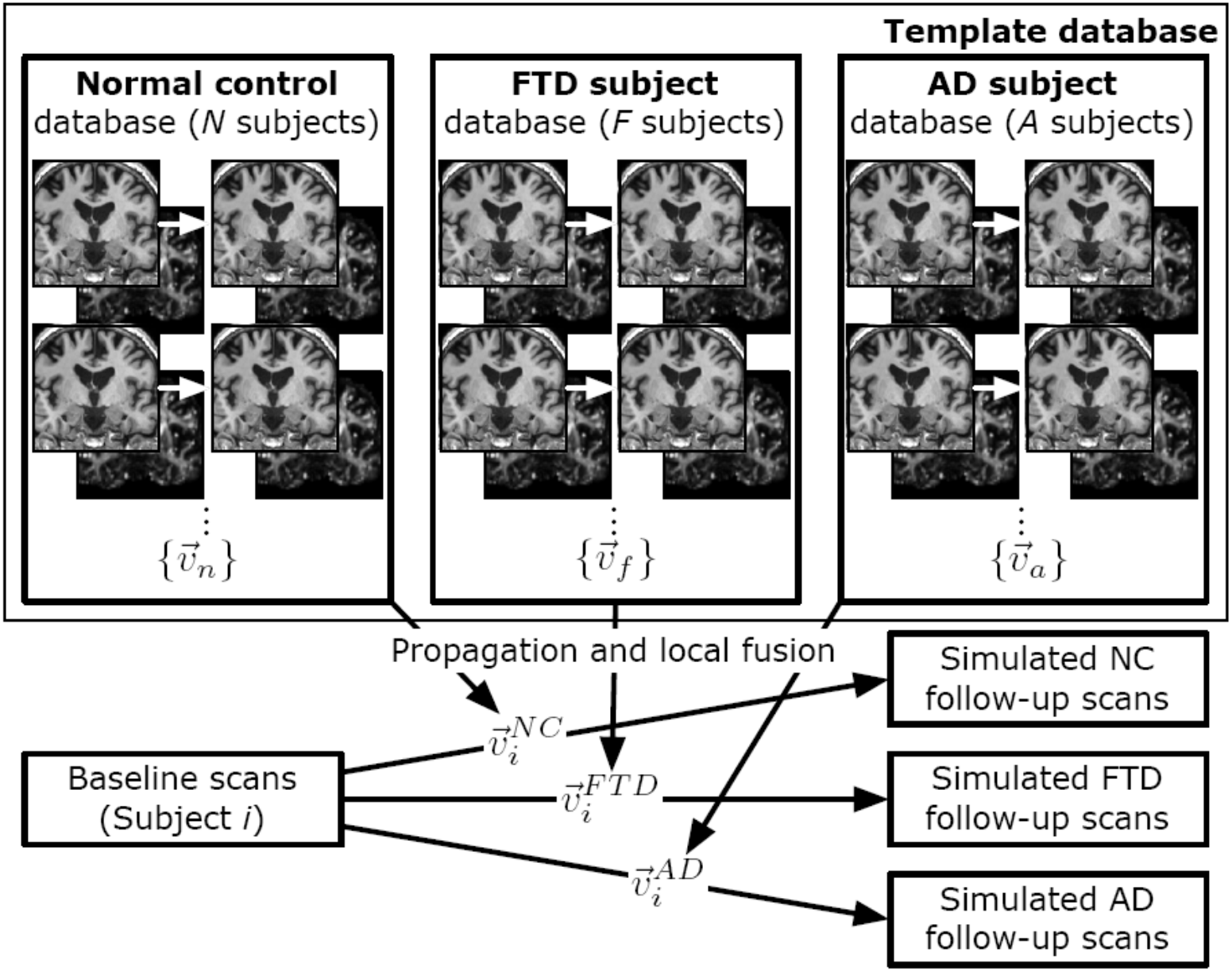

Figure: Framework of the overall pipeline

Weighting similarity measures from different modalities

Similarity measure M that drives the registration:

$$M(B, F; \mu) = \alpha \times M_s(B^s, F^s(\mathbf{u}; \mu)) + \alpha \times M_s(B^s(\mathbf{u}^{-1}; \mu), F^s) + \beta \times M_d(B^d, F^d(\mathbf{u}; \mu)) + \beta \times M_d(B^d(\mathbf{u}^{-1}; \mu), F^d) \quad (1)$$

where,

^{s}: Structural T1 image

^{d}: Diffusion weighted image

B: Baseline image

F: Followup image

M_s: locally normalised cross correlation summed over all voxels.

M_d: distance between the tensors, summed over all voxels.

α, β: Weights (empirically set to 0.5)

$\mathbf{u}$: Deformation field

μ: parameters, the cubic b-spline parameters.

Template database

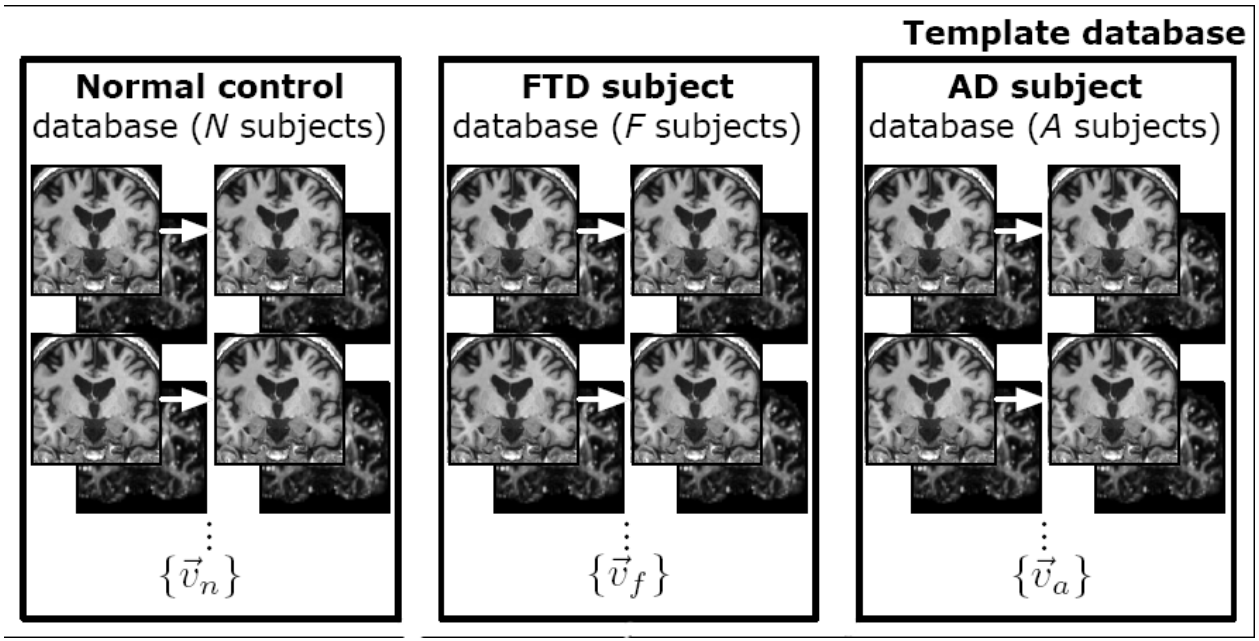

Figure: Template database

Registering new subject

- For a new subject i with its T1w and DTI image B_i,
- Register all baseline images from the template database to B_i.

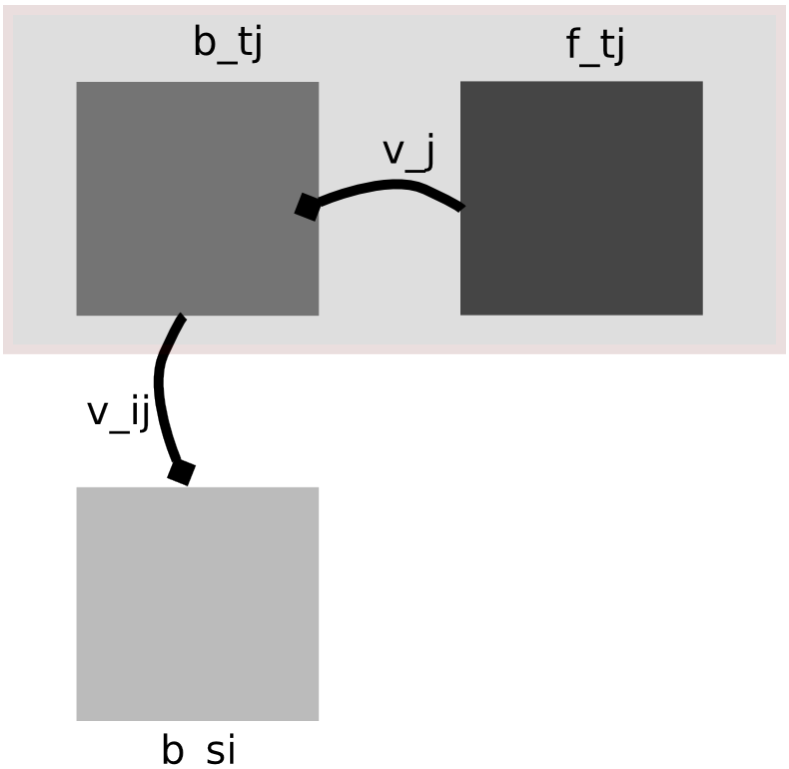

Figure: Schematic for registrations between template and the subject

Weighting the flows to create a new one

Weight flows based on the distance of the template's basline image to subject image distance.

$$\mathbf{v}_i^{grp} = \frac{\sum_{j \in grp} \left(\mathbf{u}_j^i \circ \mathbf{v}_j \right) \times e^{-D \frac{(B_i, B_j; \mathbf{u}_j^i)}{t}}}{\sum_{j \in grp} e^{-D \frac{(B_i, B_j; \mathbf{u}_j^i)}{t}}} \tag{2}$$

Simulated follow-up images F_i^{NC}, F_i^{FTD} and F_i^{AD} simulated from B_i as:

$$F_i^{grp} = exp(\mathbf{v}_i^{grp}) \circ B_i$$

Simulation Example

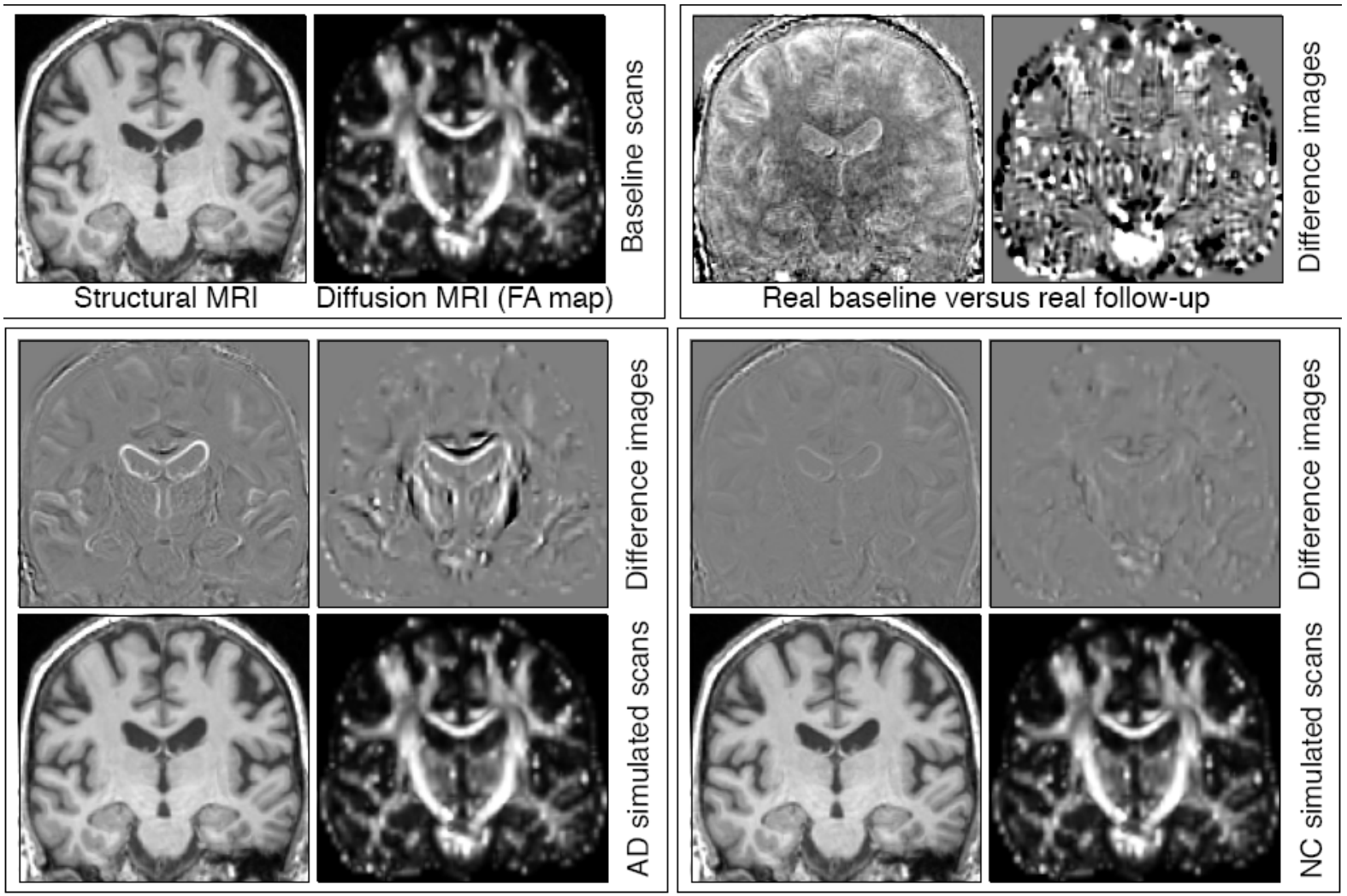

Figure: Subject and disease-specific longtudinal changes simulator result

Simulation Results

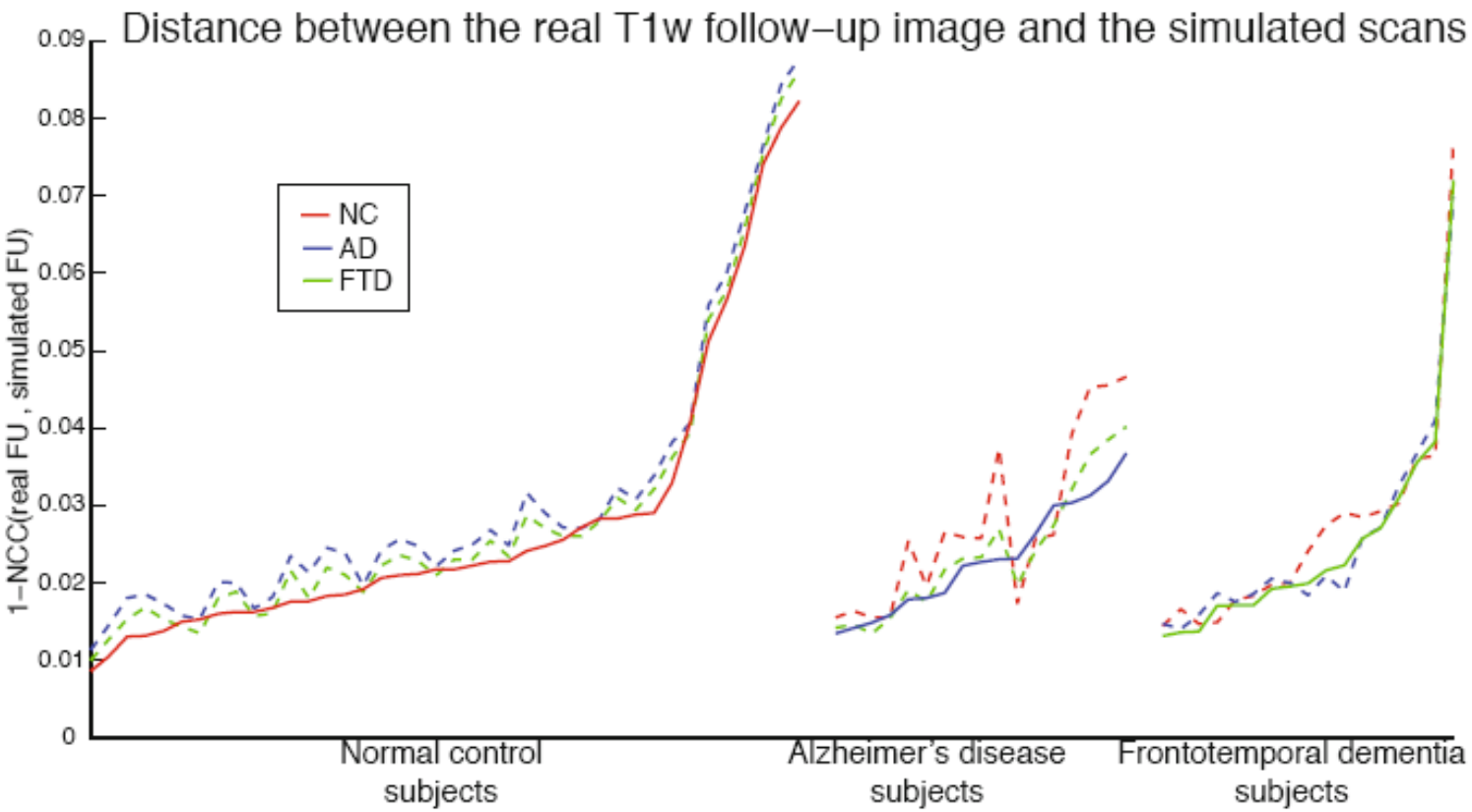

Figure: Distance sorted in ascending order

Simulation Results

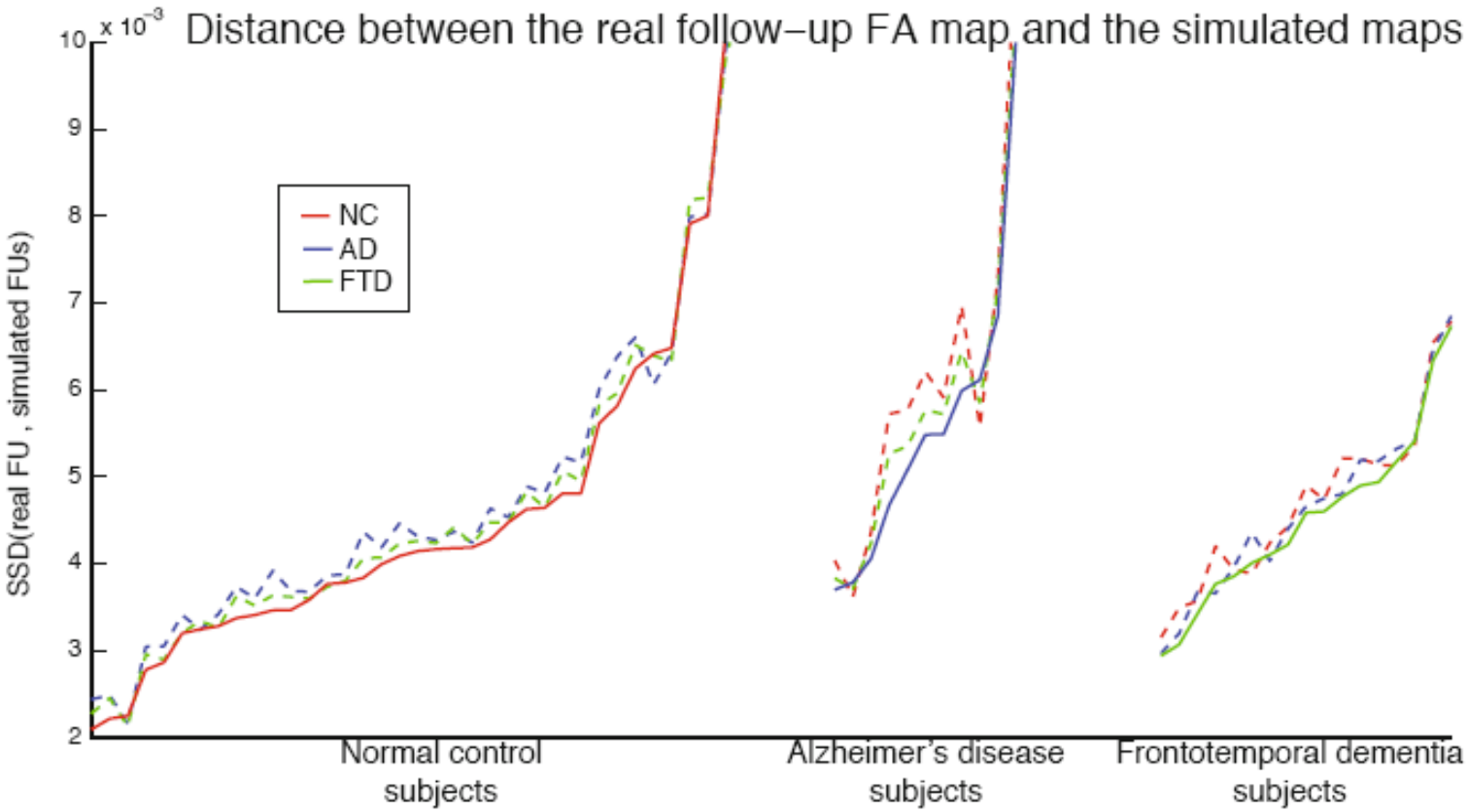

Figure: Distance sorted in ascending order

Discussion

- Using multi-modal data decreases variance of registration results. (Needs further experimental verification).
- Flow propagation method: Parallel transport and other techniques ?
- Can we extend to "learning of deformation fields" ?

Thankyou!