Studying Alzheimer's Disease related brain deformations using Generative Adversarial Networks

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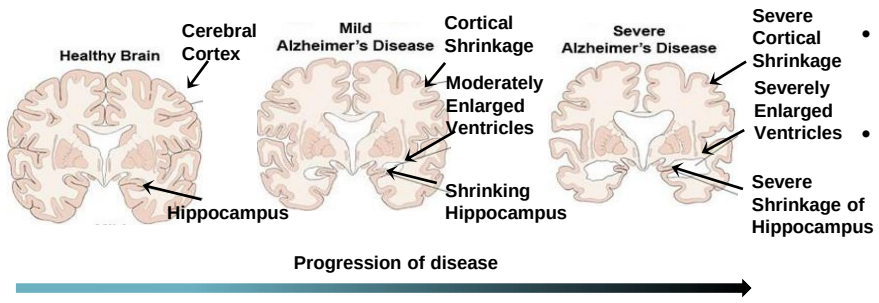
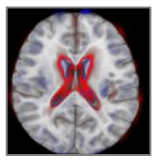
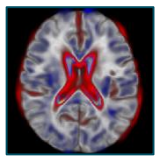
1. Motivation



- Alzheimer disease can be distinguished by enlargement in ventricles and atrophy of Hippocampus
- **Goal:** visualize the **subject-specific effects** of Alzheimer's disease(AD) with respect to Mild Cognitive Impairment(MCI)



Alzheimer disease (class c=1)



MCI (class c=0)

In currant method we find a **map generating function** *M* that when added to an image of class *c=1* will produce an image of class *c=0*

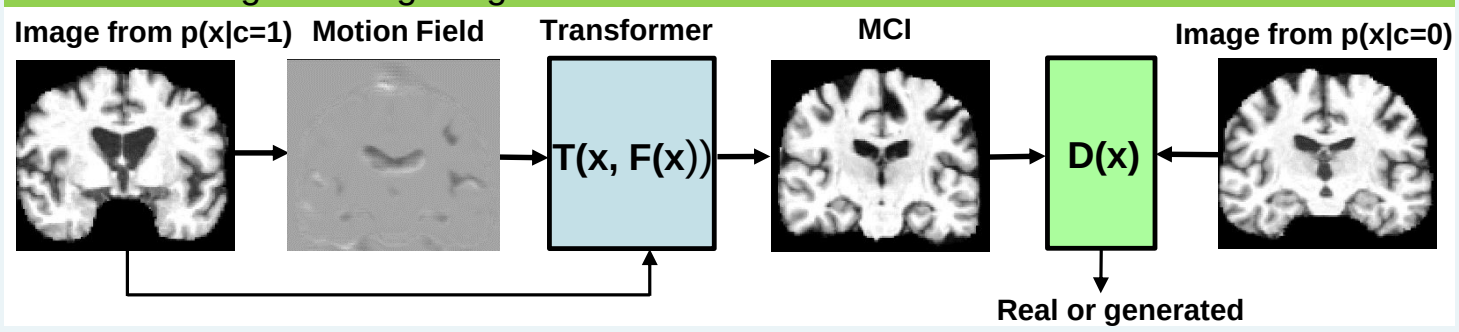
$$y = x + M(x)$$

Two problems:

- Model doesn't reflect physiological effect
- It provides just mask for one person

Contribution: We replaced additive model by deformation model which led to better results. Additionally, this allows calculating the Jacobian map. Secondly we developed a framework for estimating population-wide effect based on registration.

2. Method of generating images overview



3. Method description

We are trying to find a **generator function** F. Then we use spatial transform function T, taking F and image of class c = 1 (x) as arguments to produce an image of class c = 0 (y) :

$$y = T(F(x), x)$$

We use a **Wasserstein GAN framework** to make generated images indistinguishable from real images from class 0 using a critic network D

$$L_{gan} = E_{x\sim p(x|c=0)}[D(x)] - E_{x\sim p(x|c=1)}[D(T(x, F(x))]$$

An **L1-penalty on the mask** is added to limit the extent of the changes:

$$L_{reg} = ||T(F(x),x) - x||_1$$

To prevent the mask from noisiness we also use **total variation loss**

$$L_{totalvar} = ||\nabla F(x)||_2^2$$

Finally we solved the following optimization problem

$$M^* = \text{argmin max } L_{gan}(F, D) + \lambda^* L_{reg}(F) + \mu^* L_{totalvar}(F)$$

We found experimentally that best values for loss are:

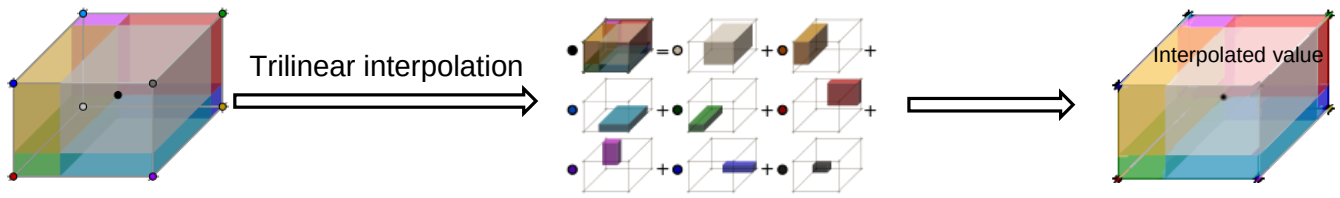
$$\lambda = 100;\ \mu = 0{,}1$$

4. How does the transformer work?

- To perform a spatial transformation of the input feature map, a sampler must take the input feature map x along
- with the motion field F
- For each voxel p, we compute a voxel location F(p) in x.
- We linearly interpolate the values at the **eight** neighboring voxels (Z(F(p)) are the voxel neighbors of F(p))

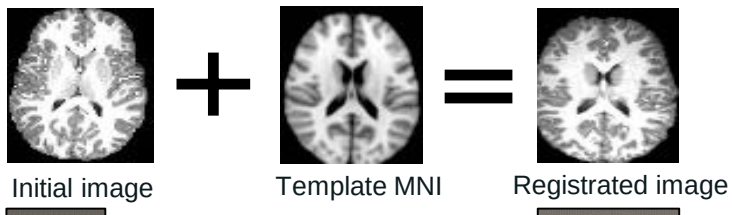
$$x(F(p)) = \sum_{q\in Z(F(p))} x(q) \prod (1-|F(p) - q|)$$

- Here we use bilinear sampling kernel. It gives a differentiable operation and allows to use standard gradient-based methods



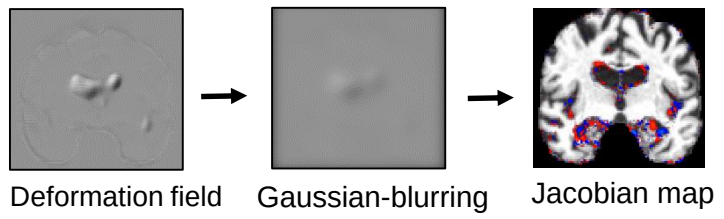
The product of the value at the desired point and the entire volume is equal to the sum of the products of the value at each corner and the partial volume diagonally opposite the corner.

5. Averaging and registration

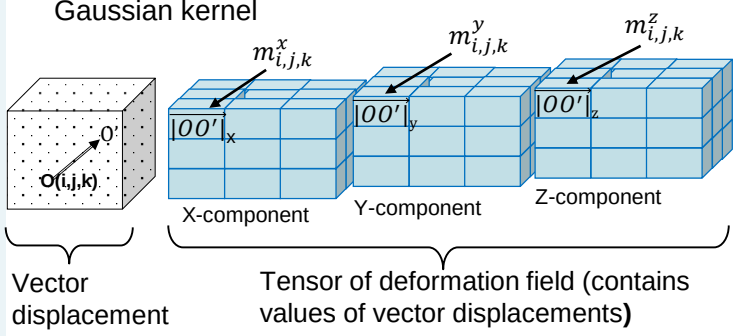


- We use existing method of non-linear registration Fnirt

6. Jacobian map



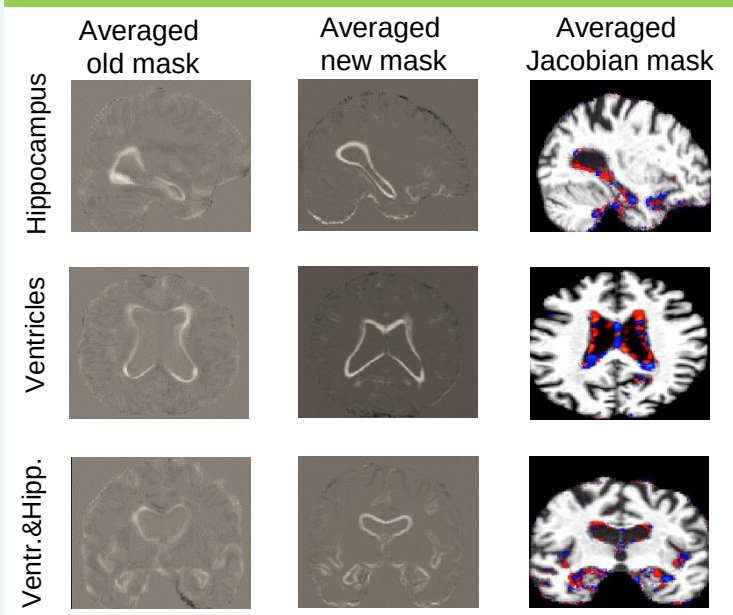
- Jacobian map is the determinant of the matrix of transformation
- We use motion field map to calculate local changes based on vectors of displacement
- Jacobian map estimates local tissue gain or loss
- Red regions mean tissue extending while blue tell about atrophy
- To make Jacobian map more homogeneous we preprocessed our motion field by convolving with a Gaussian kernel



Determinant of deformation's tensor:

$$J_{ijk} = \det \begin{pmatrix} m^x_{i+1,j,k} - m^x_{i,j,k} & m^x_{i,j+1,k} - m^x_{i,j,k} & m^x_{i,j,k+1} - m^x_{i,j,k} \\ m^y_{i+1,j,k} - m^y_{i,j,k} & m^y_{i,j+1,k} - m^y_{i,j,k} & m^y_{i,j,k+1} - m^y_{i,j,k} \\ m^z_{i+1,j,k} - m^z_{i,j,k} & m^z_{i,j+1,k} - m^z_{i,j,k} & m^z_{i,j,k+1} - m^z_{i,j,k} \end{pmatrix}$$

7. Results



- New mask is more outstanding (contours are more pronounced)
- Jacobian's map has more physiological meaning(we can judge about local tissue expanding or atrophy)

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