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Localization of Brain Microstructure Changes Associated with Alzheimer's Disease using Class Activation Maps

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Abstract

Recently, a general analytical formula to extract all of the 4th order Rotation Invariant Features (RIFs) from diffusion Magnetic Resonance Imaging (dMRI) data has been proposed [1]. These invariants have been shown to be linked to the underlying brain microstructure [1] and were recently used to identify Alzheimer Disease (AD) patients [2]. While these features indeed contain information that is useful to the identification of AD, the classification is based on the analysis of the whole brain volume and does not pinpoint local changes associated with AD. In this work, we propose to use explainable AI tools, namely Class Activation Maps (CAMs) [3], to localize brain microstructure changes associated with AD.

Problem Statement

Can microstructure changes caused by AD in the white matter be quantified using rotation invariant features of dMRI and localized using class activation maps?

dMRI signal and Rotation Invariant Features

The diffusion signal can be represented as a weighted sum of spherical harmonics:

$$f(\mathbf{u}) = \sum_{l=0}^{\infty} \sum_{m=-l}^l c_{lm} Y_l^m(\mathbf{u})$$

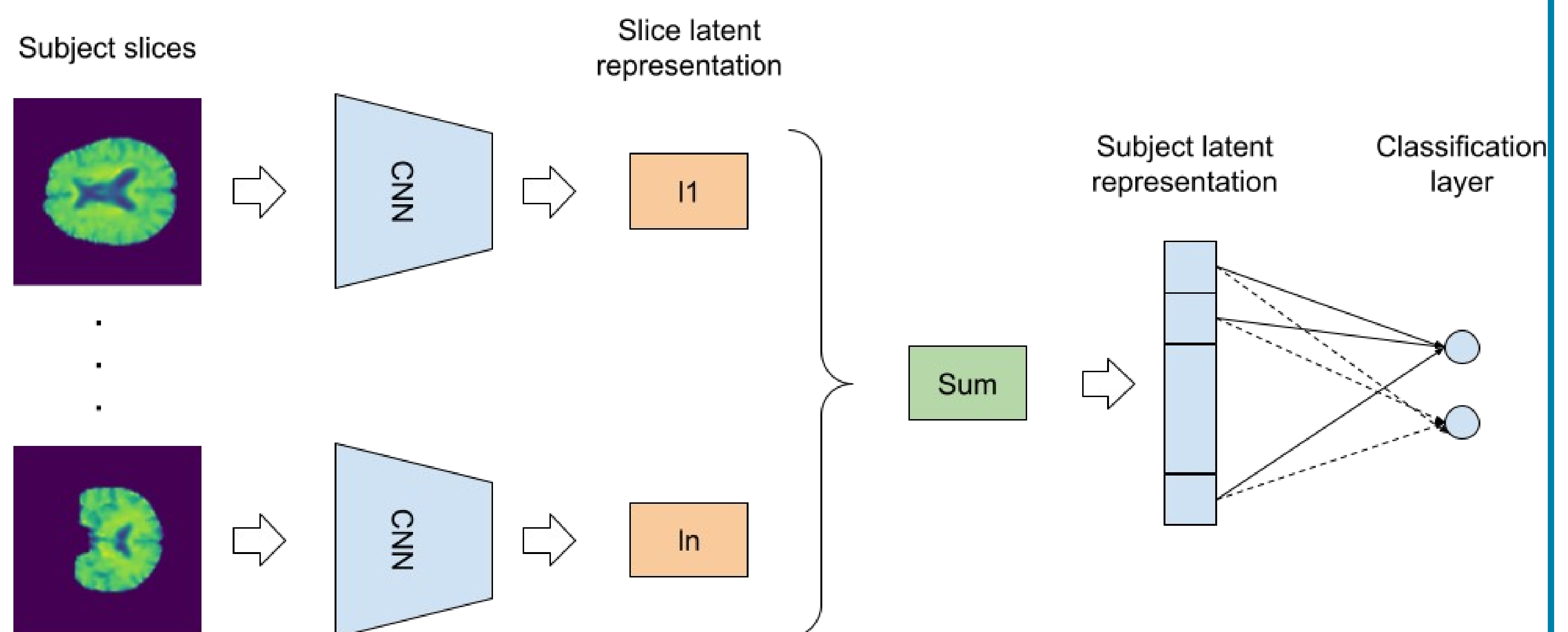
The Rotation Invariant Features (RIFs) [1] are given by

$$I_l[f] = \sum_{m_1=-l_1}^{l_1} \dots \sum_{m_d=-l_d}^{l_d} c_{l_1 m_1} \dots c_{l_d m_d} G(l_1, m_1 | \dots | l_d, m_d)$$

with G the Gaunt coefficients.

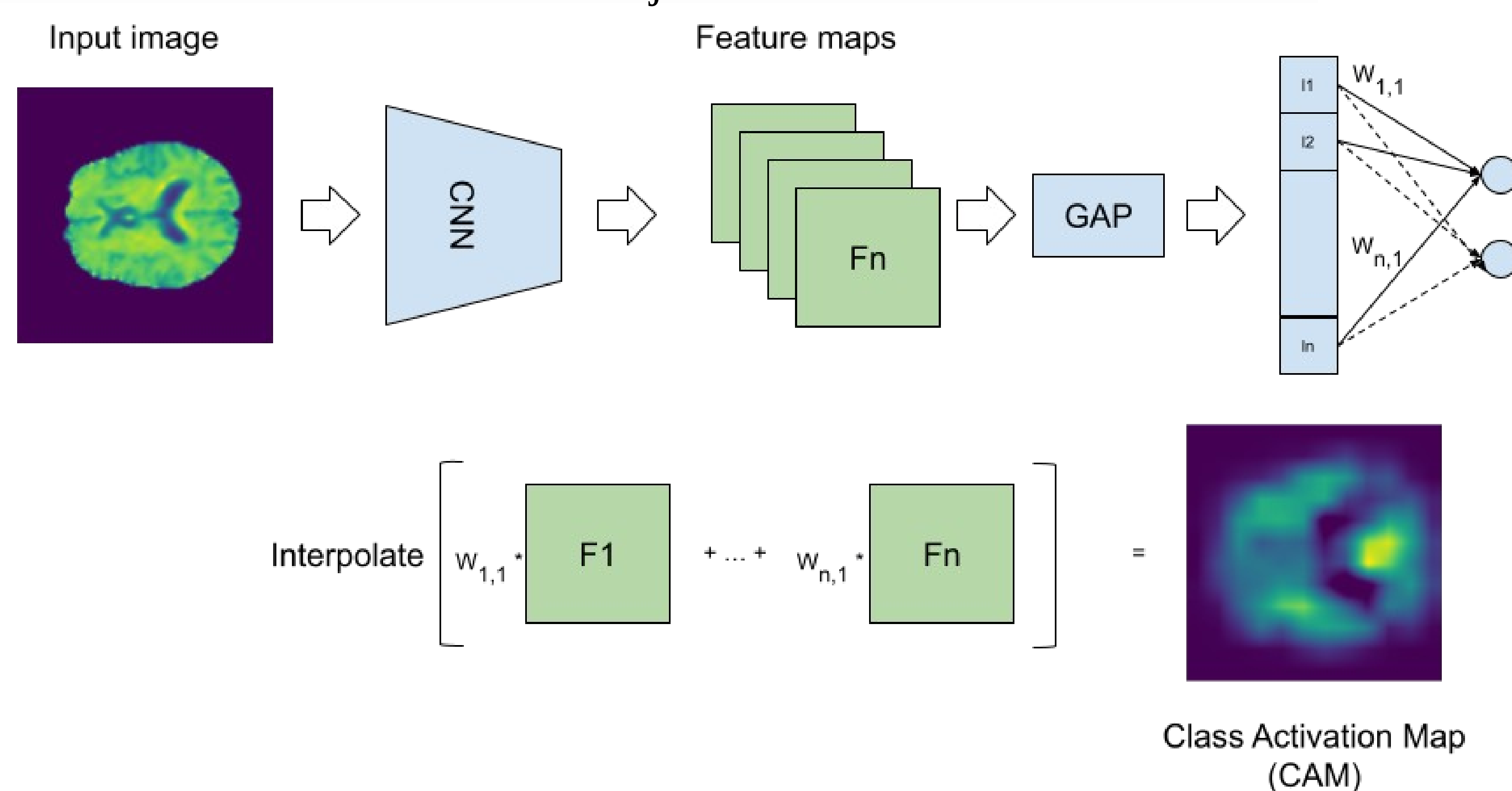
Subject CNN model

The proposed Subject CNN model that uses the encoding of each subject's slice to take the classification decision.



Class Activation Map

Class Activation Map can be extracted from our architecture and provides the location of salient voxels used for the classification of AD and CN subjects.



Data set and classification performance

Data used in the preparation of this article were obtained from the Alzheimer's Disease Neuroimaging Initiative (ADNI) database (adni.loni.usc.edu).

| | Train | Validation | Test | Not used |
|----|-------|------------|------|----------|
| AD | 30 | 6 | 10 | 0 |
| NC | 200 | 46 | 76 | 30 |

Combining the best RIFs as to improve performance:

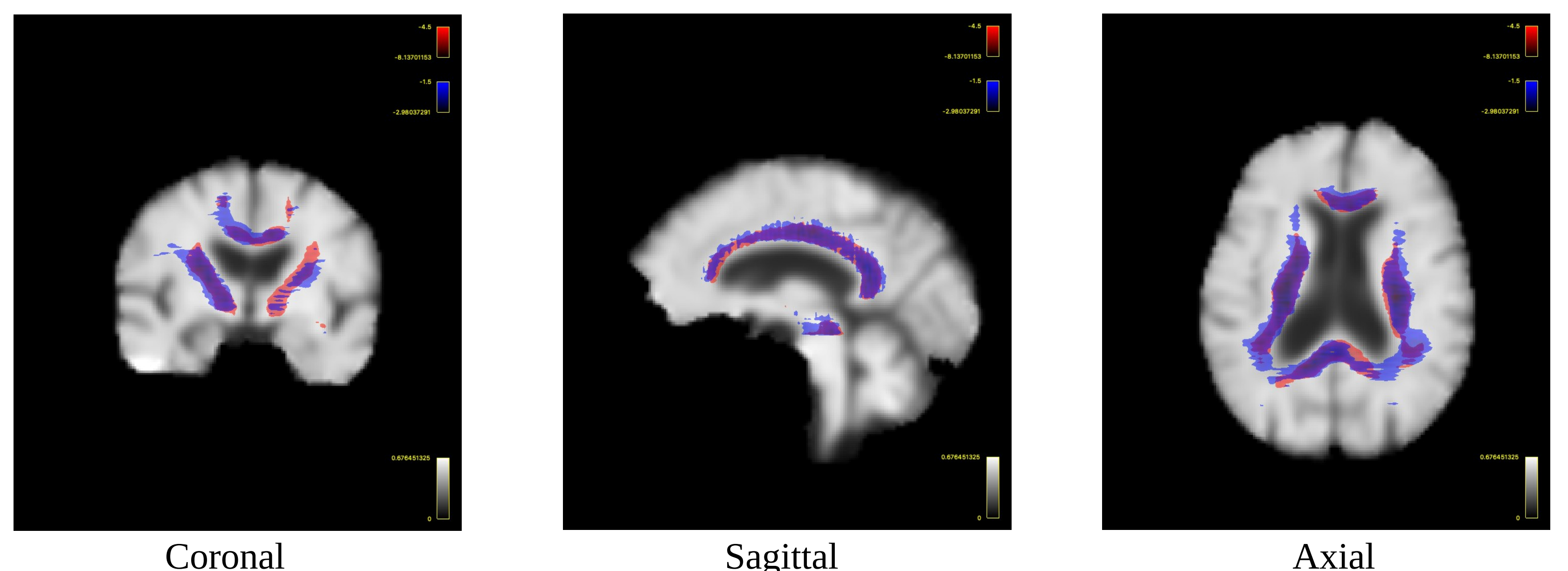
| RIF | B-score |
|--|---------|
| R_{22} | 76.71% |
| $R_{22} \oplus R_{22224}$ | 82.67% |
| $R_{22} \oplus R_{22224} \oplus R_{2224}$ | 75.26% |
| $R_{22} \oplus R_{22224} \oplus R_{2224} \oplus R_0$ | 73.62% |

CAM Results

Class Activation Maps extracted from our best performing model that uses $R_{22} \oplus R_{22224}$ and has a B-score of 82.67%.

The colors red and blue are used for CAMs for AD and NC classes, respectively.

For both AD and NC subjects, the model assigns a high importance to similar voxels of the **white matter in the vicinity of the ventricles**. This reflects that there are white matter changes captured by the RIFs in the highlighted region that are significant enough to **discriminate between the classes**.



Conclusion

Our results indicate that AD may cause microstructure changes in the white matter that can be quantified using rotation invariant features of dMRI and localized using class activation maps.

Acknowledgments

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