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Rotation invariant features for Alzheimer's disease identification using convolutional neural networks

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Abstract

Rotation Invariant Features (RIFs) [1] extracted from dMRI scans represent a generalisation of the usually used 2nd order invariants such as Fractional Anisotropy (FA) and Mean Diffusivity (MD). This work studies the usefulness all of the 12 algebraically independent RIFs extracted from Spherical Harmonics up to degree 4 in the context of Alzheimer Disease (AD) identification. To do so, we introduce a fair metric (*B-score*) that we use to evaluate the proposed deep Convolutional Neural Network (*Subject CNN*) which operates on subject slices to classify the whole subject while avoiding over-fitting. On the ADNI-SIEMENS¹ data set that contains 46 AD and 352 Normal Connectivity (NC) subjects respectively, we observe that the 12 algebraically independent 4th degree RIFs are not equivalently useful to the classification task. A particular combination of a low degree RIF (R_{22}) with a high degree one (R_{22224}) achieves the best performance of 82.67% B-score and 84.88% accuracy on this data set. Also, the generated 3D Class Activation Maps (CAMs) [2] show that to classify a subject as AD or NC the model focuses on the value of the RIFs in the white matter around the ventricles.

Problem statement : *How useful can the 4th order Rotation Invariant Features (RIFs) be in the context of Alzheimer's disease identification? And are all these RIFs useful to the task?*

dMRI signal and Rotation Invariant Features

Representing the diffusion signal as a weighted sum of spherical harmonics.

$$f(\theta, \phi) \approx \sum_{l=0 \mid l \% 2 = 0}^D \sum_{m=-l}^l c_l^m Y_l^m(\theta, \phi)$$

Formula for extracting Rotation Invariant Features (RIFs) [1]

$$R_{l_1, \dots, l_d} = \sum_{m_1=-l_1}^{l_1} \dots \sum_{m_d=-l_d}^{l_d} c_{l_1 m_1} \dots c_{l_d m_d} G(l_1, m_1 \mid \dots \mid l_d, m_d)$$

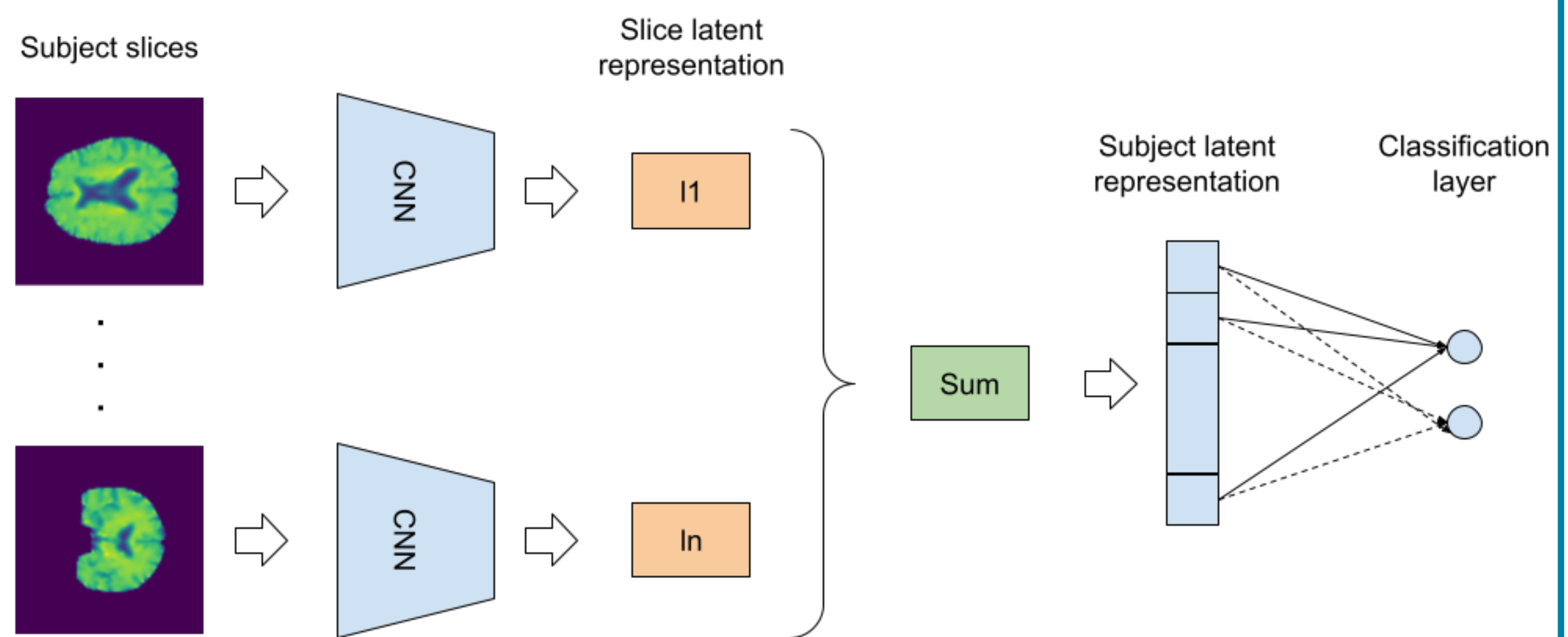
Data set

The data set split over the ADNI-SIEMENS¹ data set.

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

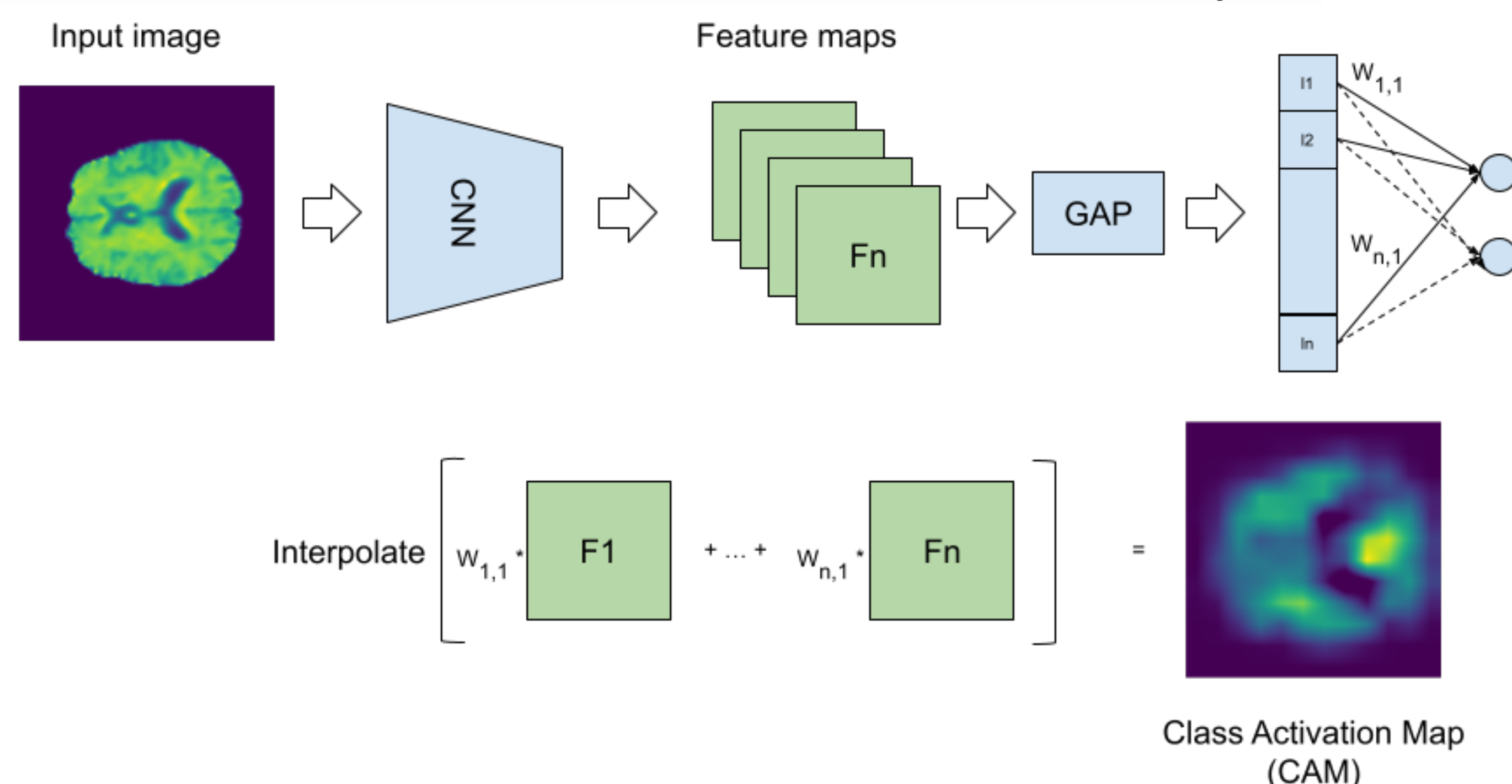
Subject CNN model

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.



Metric

A fair metric that gives equal weight to both classes regardless of the number of data points is crucial in the used imbalanced data set.

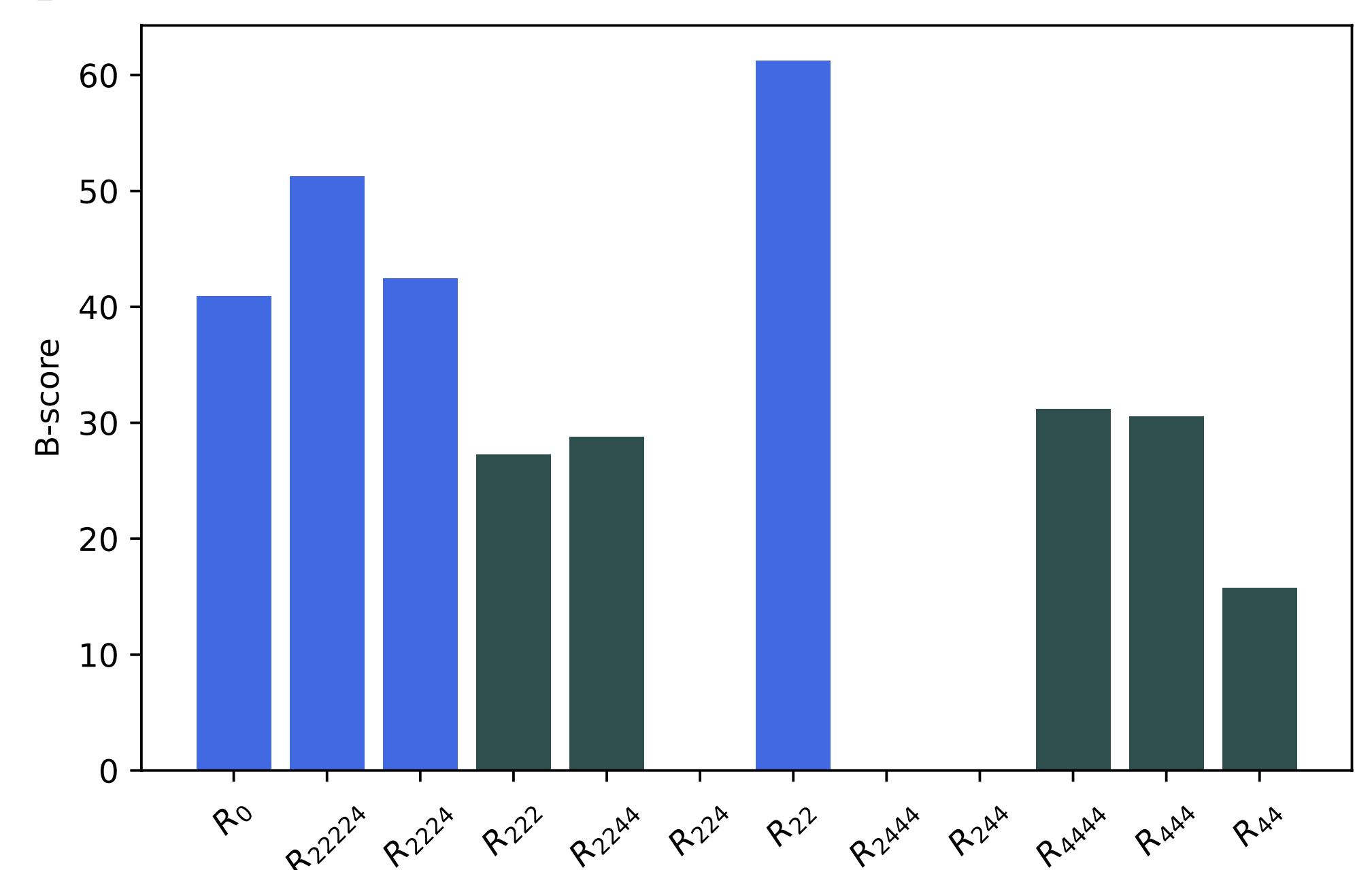
$$B\text{-score} = 2 \times \frac{TPR \times TNR}{TPR + TNR}$$

$$TPR = \frac{\#True\ Positives}{\#Positives}$$

$$TNR = \frac{\#True\ Negatives}{\#Negatives}$$

Single RIF performance

Identification of the most useful RIFs to the task of AD patient classification.



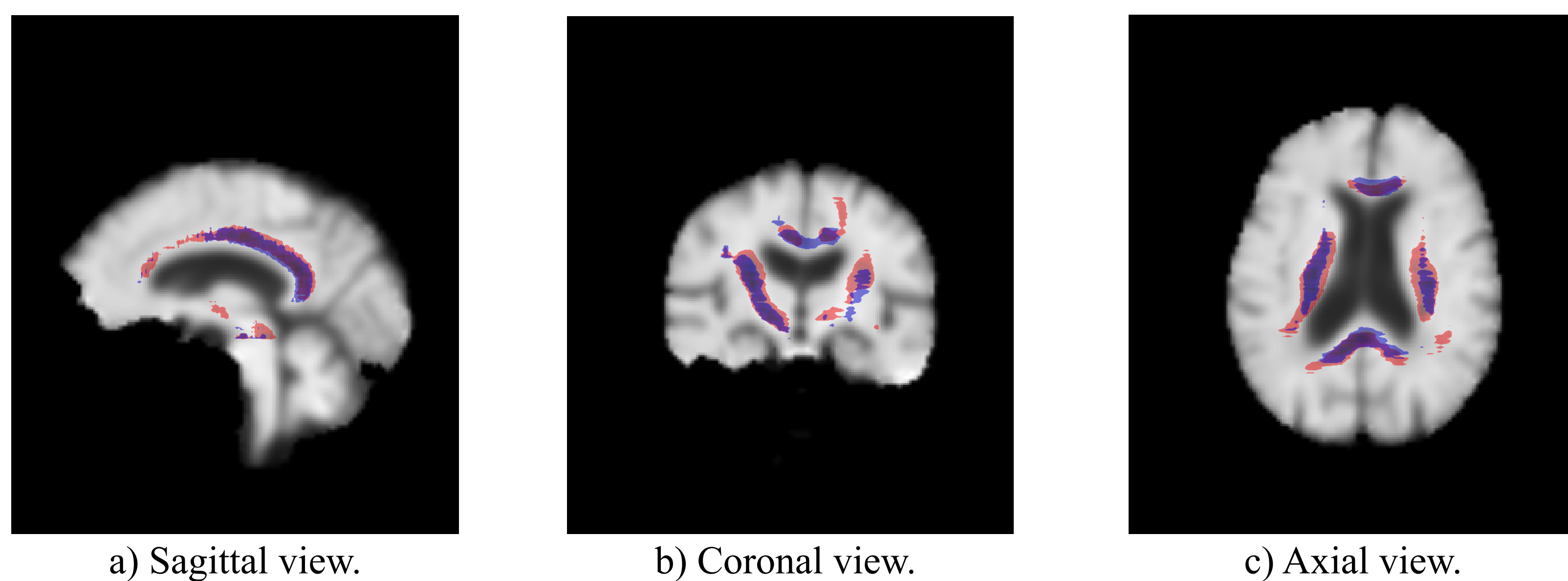
Multi-RIF performance

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%

Class Activation Maps on the used data set

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 colours red and bleu are used for CAMs for AD and NC classes respectively.



Conclusion

This work allows us to conclude that the 12 algebraically independent 4th degree RIFs contain information that is very useful to AD identification and we can achieve a high performance on the ADNI-SIEMENS data set. It can also be noted that not all the RIFs are equivalently informative to the task at hand and careful RIF selection is important.

References

- [1] Mauro Zucchelli, Samuel Deslauriers-Gauthier and Rachid Deriche. A computational framework for generating rotation invariant features and its application in diffusion MRI. Medical Image Analysis (2020).
[2] Zhou Bolei, Khosla Aditya, Lapedriza Agata, Oliva Aude, Torralba Antonio. Learning deep features for discriminative localization. CVPR (2016).

1. Alzheimer's Disease Neuroimaging Initiative website : <https://adni.loni.usc.edu/>

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