RETINAL IMAGE ANALYSIS
USING NEURO-SYMBOLIC AI TO DIAGNOSE NEURODEGENERATIVE DISEASES

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INTRODUCTION

Optical Coherence Tomography (OCT) and retinal fundus imaging show promise as non-invasive methods for early detection and monitoring of neurodegenerative diseases. These techniques provide detailed views of retinal structural and vascular changes linked to conditions like Alzheimer's, Parkinson's, and multiple sclerosis.

This study introduces a framework combining OCT and fundus imaging to analyze retinal layer and blood vessel variations, distinguishing between healthy individuals and those with Alzheimer's. A deep neural network segments and identifies retinal layer boundaries, detecting subtle morphological changes indicative of early neurodegeneration. Additionally, blood vessel characteristics such as diameter, tortuosity, and branching patterns are analysed for microvascular alterations associated with these diseases.

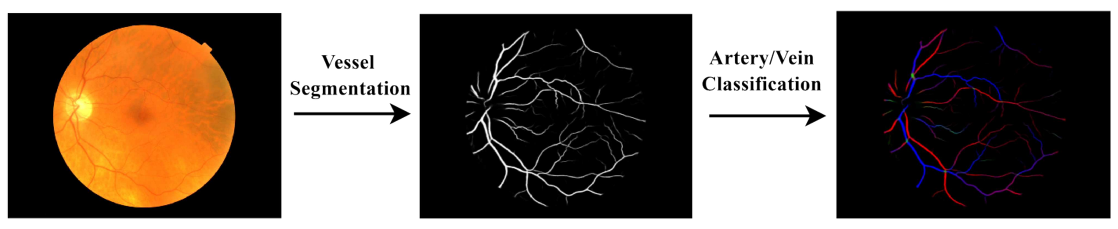

Figure 1: Blood vessel segmentation

Figure 2: Flattened OCT image from the UK Biobank dataset

To enhance clinical relevance, explainable AI techniques clarify the model's decision-making, highlighting features most influential to predictions. This integrated framework offers a powerful tool for identifying neurodegeneration biomarkers, enabling earlier diagnosis and improved disease monitoring. By combining advanced deep learning with symbolic AI, the approach enhances diagnostic accuracy, fosters trust in clinical use, and supports better patient outcomes. In a previous work [2] we used vascular features to learn explainable diagnostic rules from fundus images. In our new experiments we explore using OCT features as described in this poster.

METHOD

We have developed a framework combining deep learning and symbolic reasoning to enhance OCT analysis. First, a CNN model is employed to accurately identify and classify OCT layer boundaries, enabling detailed examination of retinal changes associated with various diseases, as illustrated in Figure 3. Subsequently, a symbolic approach using Inductive Logic Programming (ILP) is applied to generate explainable diagnostic rules based on extracted OCT features. Beyond layer thickness, it extracts features such as fractal dimension (FD) and tortuosity, providing insights into vascular complexity and curvature. These features are analysed across three retinal zones: Zone A (optic disc), Zone B (Central Retinal Equivalent, CRE, near the vasculature), and Zone C (peripheral retina) as demonstrated in Figure 4, allowing localised assessment of structural and vascular alterations. This approach enhances the detection of disease specific biomarkers.

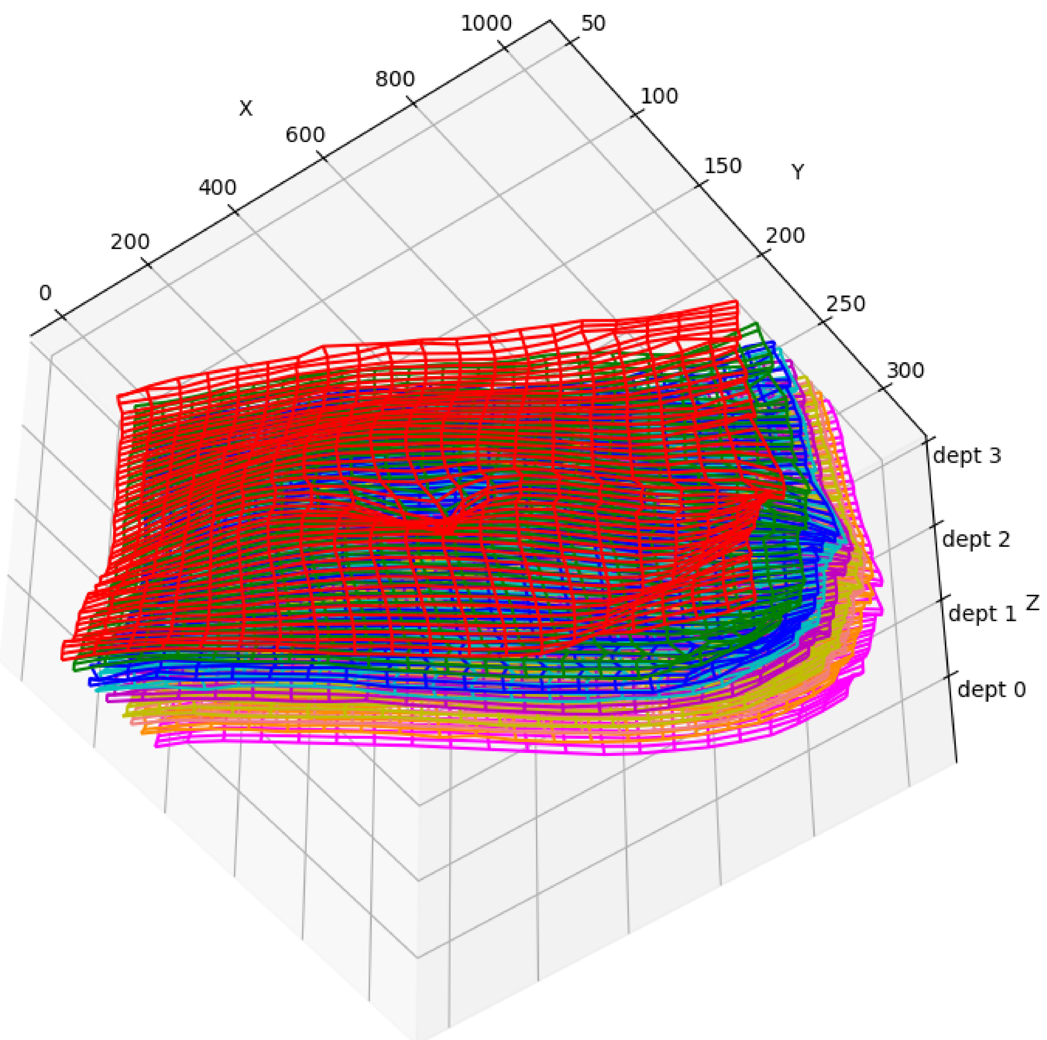

Figure 3: Visualisation of segmented OCT layers from a single patient.

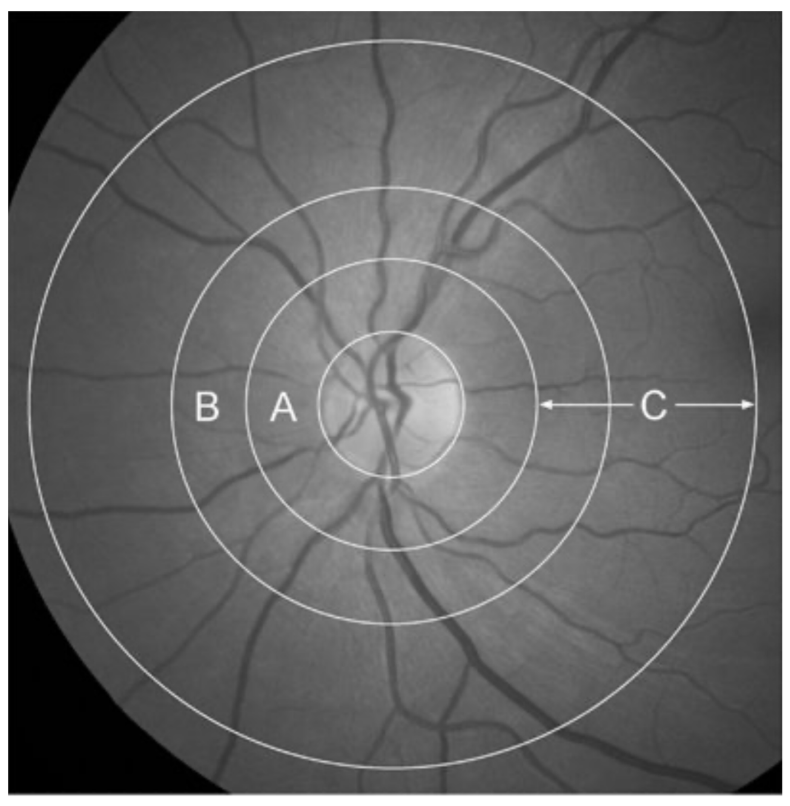

Figure 4: Retinal zones considered in this study. Three concentric zones were introduced for the computation of retinal fundus image features.

ILP is a symbolic AI approach that integrates logic and machine learning to extract interpretable rules from data. We developed **NumLog** [1], an ILP system specifically designed for discovering feature ranges. NumLog generates quantitative rules with well-defined confidence bounds to identify feature-range values from given examples. Below is an example of a rule generated by NumLog:

alzheimers(A):-
section_of_OCT(A,B),
layers_distance(B,C), C <35.0 .

In this rule, *A* represents the disease features, *B* denotes the extracted features from a specific section, and *C* indicate a specific layers distance range value.

RESULTS AND CONCLUSION

Our method combines 3D OCT layer boundary segmentation, distance measurement, and ILP-based learning from numerical data to differentiate Alzheimer's cases from healthy individuals. Experimental results show our Neuro-Symbolic approach using OCT features achieves approximately 80% accuracy, significantly outperforming 3D CNN models, which achieve around 60%. As future work, we will incorporates the OCT features as well as the vascular features we used in [2]. By identifying distinct OCT and vascular features, this framework could enhance the analysis of OCT/Fundus images, offering a powerful tool for early diagnosis and monitoring of neurodegenerative diseases.

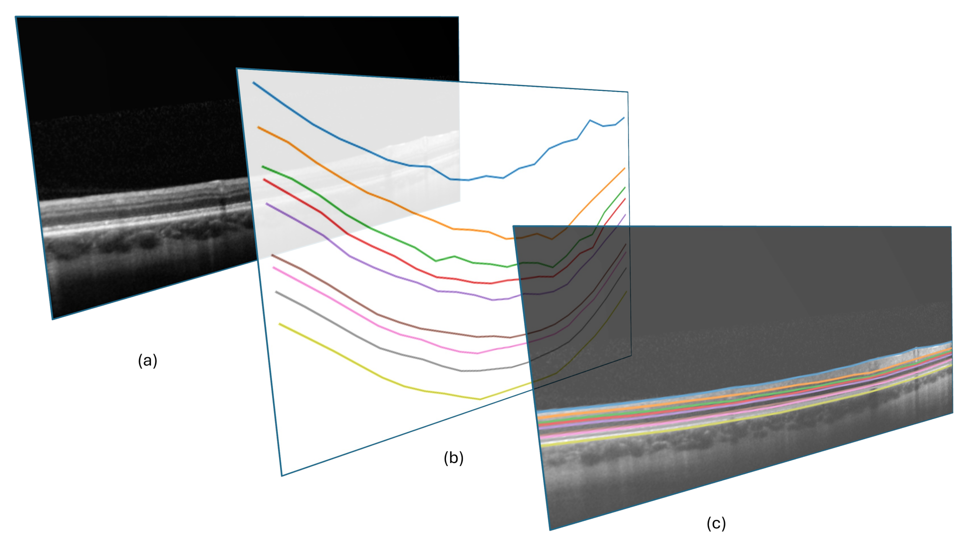

Figure 5: The input image (a), interpolated polylines (b), annotated image (c)

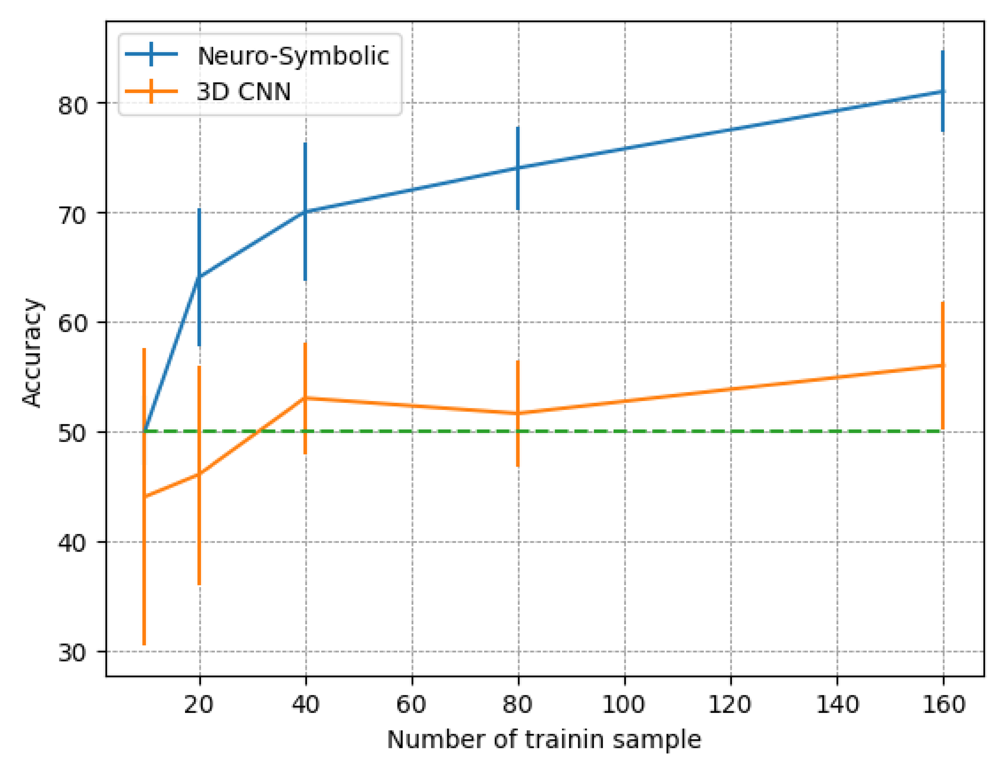

Figure 6: The accuracy of our Neuro-Symbolic approach compared with 3D CNN

ACKNOWLEDGMENT

We acknowledge the data obtained from UK Biobank application number 1969.

REFERENCE

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[2] D Varghese, R Bauer, A Tamaddoni-Nezhad, Few-shot learning of diagnostic rules for neurodegenerative diseases using Inductive Logic Programming, In Proc. of the Int Conf on ILP, pp. 109-123, Springer, 2023

Presented at the Royal Society Scientific Meeting: Digital Healthcare for the Management of Functional Neurological Disorder