Deep Learning methods for Lesion-Symptom Mapping

Cerebral Small Vessel Disease (SVD) is a common condition that can lead to stroke and dementia, especially in older adults. These conditions can significantly reduce the quality of life by bringing a range of cognitive and behavioural problems in the domains of memory, attention, language, and executive function. Predicting cognitive decline associated with SVD can be difficult, as it manifests as different types of lesions in Magnetic Resonance Imaging (MRI) scans.

Lesion-Symptom Mapping (LSM) is a neuroimaging technique used to identify the lesioned brain regions and determine the relationship between the locations of these regions and specific cognitive deficits. This information can help with developing treatments to improve a patient's cognitive and functional abilities and can also help doctors understand the brain mechanisms behind neurological and psychiatric disorders.

Current studies that have shown correlations between lesion locations and cognitive deficits use statistical and Machine Learning methods, but they have many limitations. Deep Learning (DL) methods have the potential of building complex models and extracting features from any kind of image data to make predictions, but very little research has been done using DL in the field of LSM. The drawback of DL-based systems is usually that they are very hard to interpret. However, new explanation techniques have emerged to show which features of the input contribute to the model's prediction. These techniques can generate maps that highlight the importance of each feature in an image.

This project aims to research how DL models and explanation maps can be used to improve upon the current methods used to research LSM, exploring the advantages and limitations of using CNNs to find lesion-symptom correlations. This study majorly consists of two parts. The first part aims to explore the existing methods and apply them to multi-output prediction models with a simple open-source dataset consisting of 2D images of faces and the corresponding labels for age, gender, and ethnicity. The overall objective of this part is to prove that all the explored techniques work for multiple-output models and to have an insight into the expected explanation maps. In the second part, single-output and multi-output 3D models were trained and evaluated with segmentations of lesions from brain MR images and a simulation of scores calculated for pre-defined regions of interest (ROIs). Several methods were implemented to validate that it is capable of identifying which locations of the lesions are responsible for each score. The study compares the performance of single-output and multi-output models and explores different methods to generate explanation maps to understand the information each can provide.

Figure 1 shows for every score and every model, a slice from the 3D volume of the calculated map that highlights the important features of the image, and the ROIs are shown in green. This Figure indicates a great overlap between the regions for all cases, which indicates that the model is not only capable of making good predictions of multiple scores but also able to identify which regions of the brain were key to getting those scores..

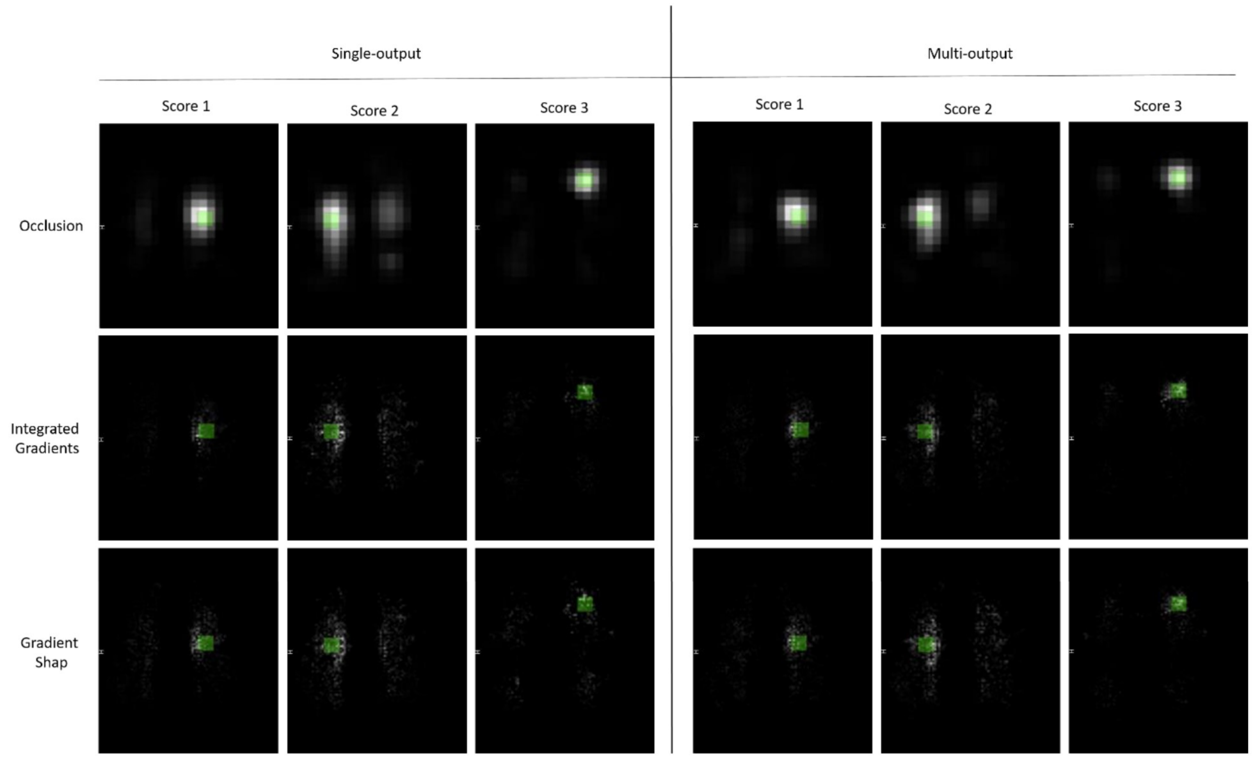

Figure 1: Explanation maps for the lesion brain MR images (white) overlapped with the regions of interest (green)

Overall, this project demonstrates that DL techniques can satisfactorily predict multiple score outputs from MR images and identify the ROIs that affect each score. This method, if used for real cognitive scores of VCI affected patients, has the potential of finding correlations between the location of the lesions in the brain and the different neurological outcomes that SVD can cause, which can help doctors get a better understanding of the underlying brain mechanisms that lead to neurological dysfunction. This is only a first step towards the use of Deep Learning for Lesion-Symptom Mapping, as many limitations still need to be addressed.