



Thesis Subject: Virtual instrumentation and deep learning for the detection of glial inflammations from diffusion MRI

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Location: CREATIS, [MYRIAD team](#) / INRIA Lyon, [AIstroSight](#) team

Associated Project: ANR Inflammage

Brain inflammation plays a central role in many neurological and psychiatric pathologies, including neurodegenerative diseases and certain neurodevelopmental disorders. This inflammation involves, in particular, the activation of glial cells, such as astrocytes and microglia. This activation corresponds to a change in the morphological state of the cells in response to a tissue disturbance: astrocytes and microglia can modify their size, branching, local density, and the organization of their processes. These rearrangements alter the microstructure of the brain tissue and can influence the local diffusion of water molecules.

In this context, diffusion MRI appears to be a promising modality for indirectly detecting signatures of glial inflammation (1). However, the link between glial activation, morphological changes, and the diffusion signal remains poorly characterized. This limitation is due to the complexity of brain tissue, the non-specificity of current dMRI biomarkers, and the lack of annotated data allowing for a direct association between an inflammatory state, a cellular morphology, and a measurable MRI signal.

This thesis is part of the [ANR Inflammage project](#), which aims to develop diffusion MRI markers capable of detecting brain inflammation non-invasively. A central challenge of the project is to understand how the cellular modifications associated with glial activation translate into the diffusion signal measured at the MRI voxel scale.

To address this challenge, the thesis build a virtual instrumentation allowing for a link between glial microstructure, biophysical simulation of water transport, and diffusion MRI signal.

The first objective will consist of developing a simulation chain of diffusion MRI signals from controlled brain microstructures. Cellular geometries may first be simplified (2), then progressively enriched from 3D reconstructions or segmentations of astrocytes, microglia, and axons (3-4). The diffusion of water molecules will be simulated by Monte-Carlo methods in these numerical environments (5-7), then coupled to different MRI acquisition sequences, such as PGSE or OGSE (8-9). This step will allow for the generation of annotated synthetic dictionaries linking morphological parameters, cellular composition, and dMRI signal.

The second objective will be to exploit these simulations to study the sensitivity of the diffusion MRI signal to glial alterations. It will involve identifying the most informative acquisition parameters—b-values, diffusion time, directions, sequences—to discriminate between different biological scenarios: control tissue, astrocytic activation, microglial activation, mixed

inflammation, or concurrent lesions such as demyelination and axonal loss. This step will contribute to the virtual optimization of MRI protocols before their experimental application.

The third objective will focus on the development of artificial intelligence models capable of exploiting the simulated data. Classical supervised approaches, followed by deep learning architectures, will be evaluated for two main tasks: detecting the presence of glial inflammation and identifying the predominant cell type involved, astrocytic or microglial.

An important methodological challenge of the thesis will concern the scaling of this virtual instrumentation. The generation of realistic cellular geometries, their discretization into exploitable 3D meshes, and then the Monte-Carlo simulation of water diffusion in these environments can lead to very long computation times and significant memory requirements. The thesis must therefore integrate dedicated numerical developments: GPU porting or optimization of critical steps, parallelization of simulations, submission of long jobs on grids or computing clusters, and implementation of save/resume mechanisms allowing for the restarting of an interrupted simulation without restarting the entire calculation. These aspects will be essential to produce a synthetic base sufficiently large and varied for supervised/deep learning.

Profile sought: Candidate with a Master's degree in image processing, applied mathematics, computer science, machine learning, or computational neurosciences. Skills in Python/Matlab, numerical modeling, MRI, or supervised learning will be appreciated.

How to apply : Send a CV, motivation letter and potential contacts for recommendations to carole.frindel@creatis.insa-lyon.fr and hugues.berry@inria.fr.

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