Characterizing and Localizing Instabilities Within Neuroimaging Pipelines

With a recent explosion in data collection across neuroscience we are entering an era of big-data. The UK BioBank [1], Human Connectome Project [2], Consortium of Reproducibility and Reliability (CoRR) [3], and others made available through CONP such as PreventAD, are among the many initiatives being launched to federate this data-tsunami. As a result of increased access to data alongside similar growth in the availability of diverse and customizable processing tools, the (lack of) reproducibility of claims has begun to fall under scrutiny. While on occasion this is the result of p-hacking, it is likely often due to much more innocent means such as software bugs [4], operating system selection [5], tool variability [6]–[8], or instability in the face of noise [8], [9].

Neuroimaging pipelines are often treated as black boxes in the context of large datasets. However, the nature of the operations being performed, such as fitting non-linear alignments or models, leaves the pipelines vulnerable to instability when presented with minor perturbations in either the data quality or processing implementations. Though the independent evaluation of pipeline components may be feasible in some cases [9], this ranges from impractical to impossible in the case of multi-step pipelines.

The objective of this project is to extend my prototypical analysis characterizing the numerical stability of neuroimaging pipelines [10] to both identify instabilities within tools and ultimately make this technology easily accessible for researchers. Over the course of this award I will 1) create an extensible set of computationally "fuzzy" environments for exploring the numerical stability of neuroimaging tools, and 2) develop a method to highlight localized and cumulative instabilities within a set of neuroimaging pipelines. Fuzzy environments will enable both tool developers and users to evaluate the stability of their experiments alongside their analyses transparently. I will use these fuzzy environments to identify unstable nodes within the Automated Fiber Quantification pipeline on the open-access NKI (Rockland Sample) diffusion MRI dataset [3], and present a framework for how this analysis can be exapted to other pipelines or domains.

This experiment will report on the consistency (numerical stability) of this pipeline alongside previously used measures of quality, such as biological feasibility or alignment with reported findings in the literature. The nature of this exploration will also lead to targeted development for pipeline components, in particular towards those with a large impact on stability. All software produced over the course of this project will be publicly available on Github immediately and on an ongoing basis. Each paper produced from this work will be released as a pre-print, submitted for publication in an open-access journal, and accompanied by a Jupyter Notebook providing a demonstration of the experiments and summarizing the salient results. The Jupyter Notebooks will be submitted for peer review to the NeuroLibre publication platform.

It would be a privilege to complete this work in the context of both the CONP scientific community and the produced platforms. While NeuroLibre will encourage me to communicate and disseminate my findings accessibly to the Canadian and Global neuroscience communities, working closely with the technical steering committee (upon which I sit) will enable me to put my research directly in the hands of scientists using the CONP Research Portal. The inclusion of my computationally "fuzzy" environments in the CONP portal has the potential to increase the stability or trustworthiness of findings produced by users of this platform relative to others.

Working on this project with Dr.s Evans and Glatard provides me with unique experience and resources both in terms of neuroimaging pipeline development and the evaluation thereof. I will be able to leverage my experience in diffusion MRI processing and connectome estimation to build upon the work performed in Dr. Evans' lab in which the effect of minor perturbations were evaluated on cortical surface estimation [9] and work of Dr. Glatard that explores cross-operating system variability [6]. Postdoctoral Fellow Dr. Yohan Chatelain will be joining Dr. Glatard's research group in March 2020, and has experience developing software which allows for the identification of sources of instability within C/C++/Fortran programs [11]. He will serve as an invaluable asset and resource for this project. Working in this environment I will be able to arm myself with skills that empower me to rigorously evaluate the quality of tools being used in neuroimaging. The skills and tools developed as a part of this fellowship will allow me to continue on a path that I plan to follow throughout my career focused on quantifying the trustworthiness of results and identifying how they may be improved.

The successful completion of my proposed project has the potential to simultaneously shed light on an important issue that has had an unquantified impact on results in neuroimaging, and enable mitigation of this issue through the targeted improvement of unstable derivatives. The recommendations provided will allow scientists to make principled decisions on tool selection for their studies, and inform further work quantifying the effect of instabilities across other modalities of neuroimaging or disciplines of computational science.

References

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