CENIIT final report for
"Bayesian methods for fMRI informed brain tumor treatment planning"

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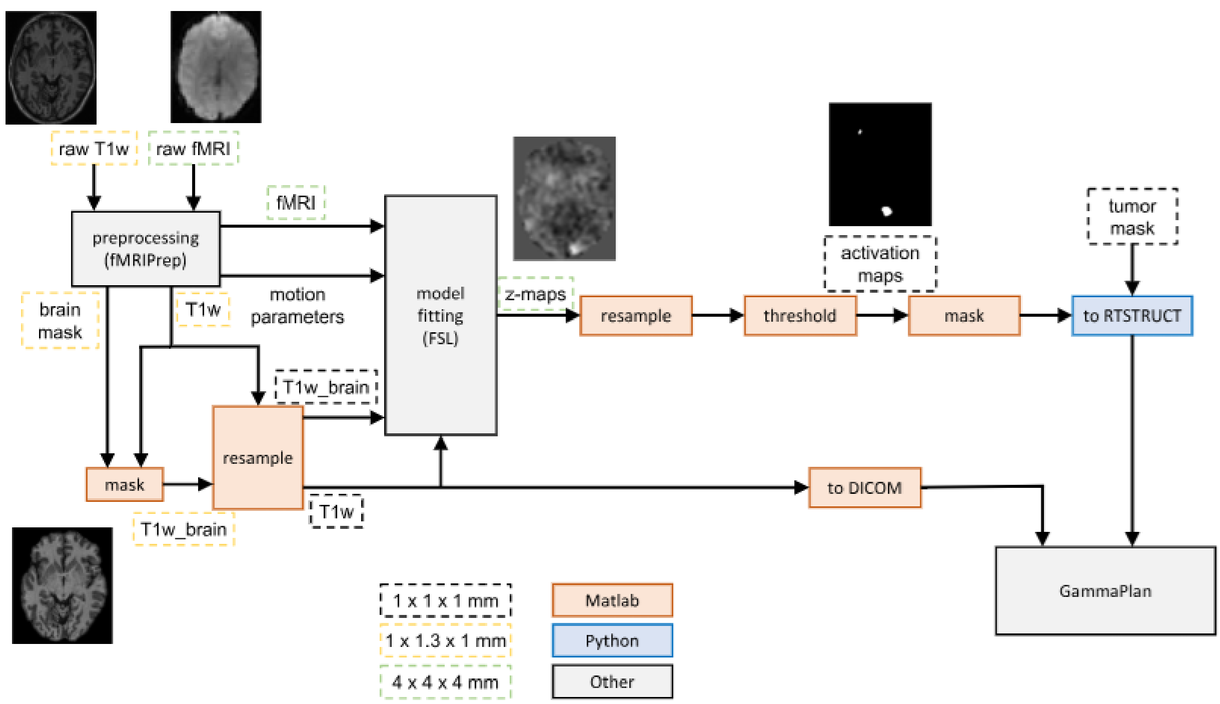
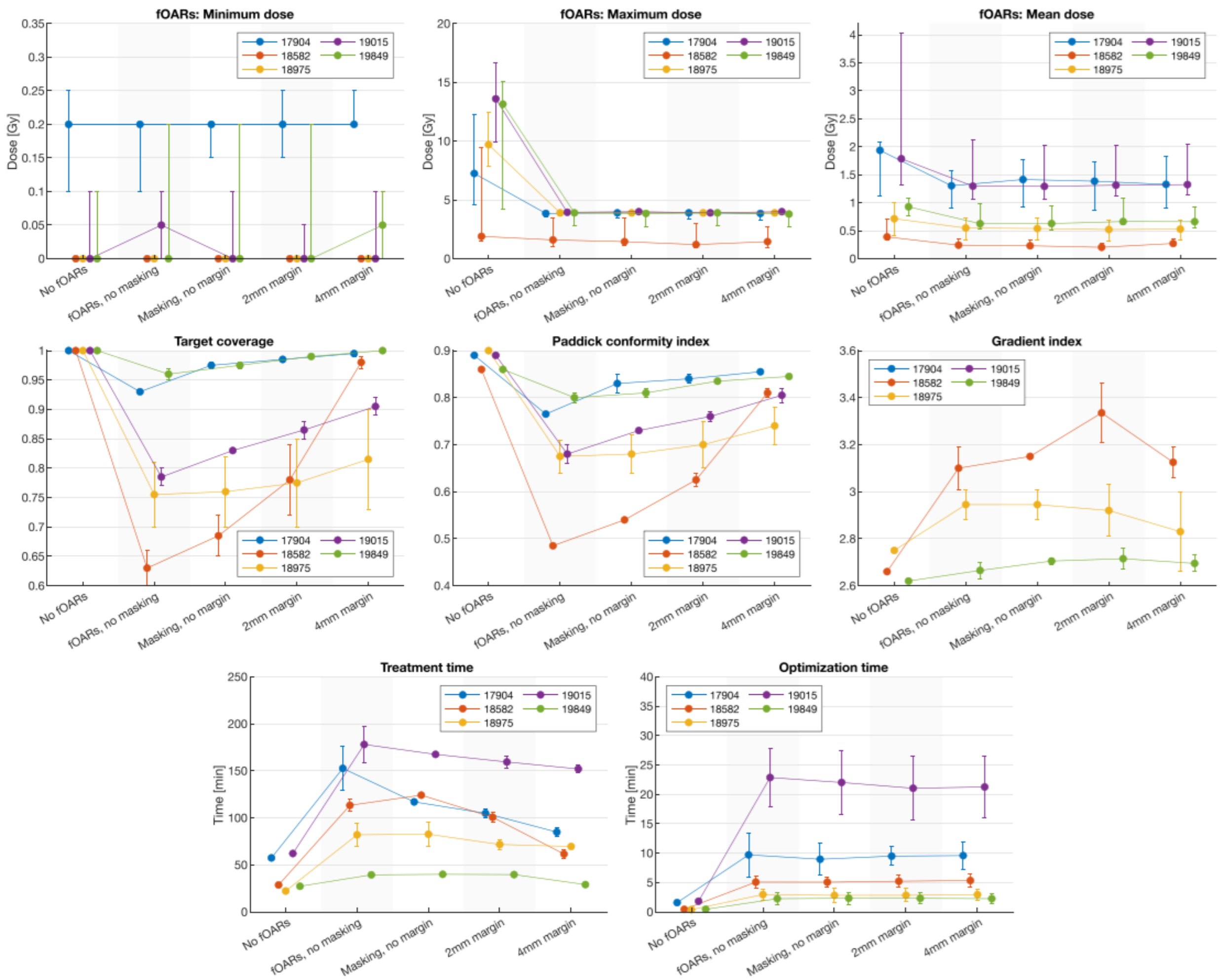
• A summary of the most important scientific results.

The most important scientific result is that we demonstrated how to use results from functional MRI data (brain activity maps) in the software GammaPlan, for radiosurgery treatment planning, and that this leads to reduced radiation levels in important brain areas. To import brain activity maps into GammaPlan was challenging, as can be seen in the flowchart below, due to the complicated DICOM format and due to many processing steps.



The plots below show that the radiation dose for the functional organs at risk (fOARS) is substantially reduced with our approach, for five patients, while the treatment time increases from 20-60 minutes to several hours. The time to generate a treatment plan increases from a few minutes to 5-20 minutes, as the optimizer in GammaPlan has to consider many constraints at the same time.



The project has also led to new (Bayesian) methods for analyzing functional MRI and diffusion MRI data, and for how to estimate the uncertainty of the results. Furthermore, as the project focused on brain tumors, we also developed some methods for deep learning-based tumor segmentation.

• A summary of the degrees and promotions the project has contributed to.

The project has been very important for David Abramian to obtain his PhD degree (2023), and for Anders Eklund to become senior associate professor (2021).

• A summary of the master's thesis works that have been performed within the project.

No master theses have been performed within the project. The major reason for this is that the project required a computer with the specific software GammaPlan from the company Elekta, and that computer was reserved for the PhD student working on the project. It was not until the end of the project that we were able to successfully import brain activity maps into GammaPlan.

• A summary of persons funded by the project.

The project has funded David Abramian during his PhD studies, and to a small extent Anders Eklund.

• A summary of which industrial connections the project has had and how scientific results have been transferred to the industrial partners. In those cases where scientific results have directly affected commercial products, this should be emphasized.

The project was carried out in collaboration with Elekta Instrument AB, which installed GammaPlan on one of our computers, and helped us to use the software and to interpret the results. At the end of the project, we had a final presentation at Elekta where we showed the final results, and Elekta was impressed that we managed to push their software to its limits (the optimizer in the software had not previously needed to consider so many constraints at the same time). As part of this presentation, and in several other meetings, we demonstrated that we found important errors in GammaPlan, and that these errors do not exist in an openly available software for DICOM data. However, Elekta did not seem interested in correcting the errors. Since our project was mainly about using their software in a novel way, and not about changing their software, it is not obvious how to transfer the results except for publishing the results.

• A summary of connections with other CENIIT projects and possible common results.

There have not been any connections with other CENIIT projects.

• A description of the extent the project has contributed to creating a new research group.

The CENIIT project has been very important for me as it was my first approved grant application, and since it made it possible for me to hire my first PhD student. The long duration of the project was also important, as it took longer than expected to get started. I have partly due to CENIIT had several funded projects where I have collaborated with other companies, mainly in the VINNOVA projects IMPACT and ASSIST. The CENIIT funding was important for the IMPACT project for the co-financing, as Elekta was also involved in IMPACT.

• A list of publications and patents

Journal papers, the paper marked in bold is the most important from this project

Sjölund, J., Eklund, A., Özarslan, E., Herberthson, M., Bånkestad, M., & Knutsson, H. (2018). Bayesian uncertainty quantification in linear models for diffusion MRI. *NeuroImage*, *175*, 272-285.

Eklund, A., Knutsson, H., & Nichols, T. E. (2019). Cluster failure revisited: Impact of first level design and physiological noise on cluster false positive rates. *Human brain mapping*, *40*(7), 2017-2032.

Gu, X., Eklund, A., Özarslan, E., & Knutsson, H. (2019). Using the wild bootstrap to quantify uncertainty in mean apparent propagator MRI. *Frontiers in Neuroinformatics*, *13*, 43.

Gu, X., & Eklund, A. (2019). Evaluation of six phase encoding based susceptibility distortion correction methods for diffusion MRI. *Frontiers in neuroinformatics*, *13*, 76.

Wilzén, J., Eklund, A., & Villani, M. (2020). Physiological Gaussian process priors for the hemodynamics in fMRI analysis. *Journal of Neuroscience Methods*, *342*, 108778.

Sidén, P., Lindgren, F., Bolin, D., Eklund, A., & Villani, M. (2021). Spatial 3D Matérn priors for fast whole-brain fMRI analysis. *Bayesian Analysis*, *16*(4), 1251-1278.

Abramian, D., Larsson, M., Eklund, A., Aganj, I., Westin, C. F., & Behjat, H. (2021). Diffusion-informed spatial smoothing of fMRI data in white matter using spectral graph filters. *Neuroimage*, *237*, 118095.

Abramian, D., Blystad, I., & Eklund, A. (2023). Evaluation of inverse treatment planning for gamma knife radiosurgery using fMRI brain activation maps as organs at risk. *Medical Physics, 50*(9), 5297-5311.

Tampu, I. E., Haj-Hosseini, N., Blystad, I., & Eklund, A. (2023). Deep learning-based detection and identification of brain tumor biomarkers in quantitative MR-images. *Machine Learning: Science and Technology*, *4*(3), 035038.

Wegmann, B., Lundquist, A., Eklund, A., & Villani, M. (2024). Bayesian modelling of effective and functional brain connectivity using hierarchical vector autoregressions. *Journal of the Royal Statistical Society Series C: Applied Statistics*, qlae014.

Conference papers

Cirillo, M. D., Abramian, D., & Eklund, A. (2021). Vox2Vox: 3D-GAN for brain tumour segmentation. In *Brainlesion: Glioma, Multiple Sclerosis, Stroke and Traumatic Brain Injuries: 6th International Workshop, BrainLes 2020, Held in Conjunction with MICCAI 2020, Lima, Peru, October 4, 2020, Revised Selected Papers, Part I 6* (pp. 274-284). Springer International Publishing.

Abramian, D., Sidén, P., Knutsson, H., Villani, M., & Eklund, A. (2020, April). Anatomically informed Bayesian spatial priors for fMRI analysis. In *2020 IEEE 17th International Symposium on Biomedical Imaging (ISBI)* (pp. 1026-1030). IEEE.

Abramian, D., & Eklund, A. (2019, April). Refacing: reconstructing anonymized facial features using GANs. In *2019 IEEE 16th international symposium on biomedical imaging (ISBI 2019)* (pp. 1104-1108). IEEE.