Ph.D Thesis Proposal

3D Transcranial Ultrasound Localization Microscopy (ULM) via Inverse Problem Solving

- **Location**: Equipe MINDS, Laboratoire IRIT, Toulouse, France
- **Funding** : A fully-funded 3-year PhD grant has been secured (approx. €2100 gross per month).
- **Starting date:** as soon as possible and no later than October 1, 2024.
- **Supervisors**: This Ph.D. will be supervised by:

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Keywords: ULM, transcranial imaging, super-resolution, 3D ultrasound imaging, inverse problem.

1 Description

Ultrasound Localization Microscopy (ULM) offers a solution to the conventional trade-off between spatial resolution and penetration depth by leveraging sparse microbubbles (MBs) contrast agents and ultrafast imaging [1]. The ULM process encompasses five stages: 1) data acquisition, 2) pre-processing (tissue filtering), 3) MB detection and localization, 4) MB tracking, and 5) ULM image rendering [1]. However, ULM is not without limitations:

- **Aberration Correction**: Pre-clinical studies often resort to craniotomies to mitigate aberrations, limiting the clinical applicability of ultrasound-based brain imaging [2].
- **2D Imaging Constraints**: The prevalent use of 2D imaging restricts access to vessels within the imaging plane, potentially biasing velocity estimates and hindering the development of reliable biomarkers based on hemodynamic changes [3]. The inherent limitations of 2D ULM underscore the need for volumetric ultrasound imaging techniques.
- **Localization and Acquisition Trade-off**: ULM introduces a trade-off between MB localization precision and data acquisition time [4]. High MB dilution enhances localization accuracy but extends acquisition time, whereas low dilution accelerates acquisition but compromises accuracy due to signal overlap.
- **Computational Efficiency**: Current ULM algorithms remain time-intensive.

Efforts to tackle these challenges include the adoption of deep learning (DL) methods, such as conventional convolutional neural networks (CNNs) for point target extraction from B-mode images [5], or comprehensive CNNs for spatiotemporal US data [6]. **This PhD thesis** aims to address these limitations by leveraging recent advancements in inverse problems in imaging, encompassing both model-based and data-driven approaches. The goal is to enhance the performance and efficiency of transcranial ULM, especially in scenarios involving high MB concentrations. In the model-based approach, we will explore direct models that account for imaging features and various inversion scenarios. Rather than relying on black-box end-to-end deep learning methods, our emphasis is on interpretable, model-driven or physics-based deep learning techniques, such as unfolding CNNs [7]. Additionally, we will investigate non-supervised or weakly supervised approaches, including diffusion models or similar frameworks, for unsupervised deep learning training [8], [9].

2 Required Skills

- Master's degree (or equivalent) in signal and image processing, or applied mathematics,
- Proficiency in machine learning/ deep learning techniques, with a focus on CNNs,
- Strong programming skills in either Matlab or Python,
- Proficiency in English,
- Interest in medical ultrasound imaging is beneficial but not mandatory.

3 Application

Prospective candidates should submit the following documents as a **SINGLE PDF** file:

- University transcripts.
- A one-page cover letter,
- Curriculum vitae, including publications if applicable,
- Two reference letters.

The position remains open until filled. Please send all documents to duong-hung.pham@irit.fr and denis.kouame@irit.fr.

4 References

[1] B. Heiles *et al.*, "Performance benchmarking of microbubble-localization algorithms for ultrasound localization microscopy," en, *Nat. Biomed. Eng*, vol. 6, no. 5, pp. 605–616, May 2022. DOI: 10.1038/s41551-021-00824-8.

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[3] P. Xing *et al.*, "Towards Transcranial 3D Ultrasound Localization Microscopy of the Nonhuman Primate Brain," 2024. DOI: 10.48550/ARXIV.2404.03547.

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[5] R. J. G. van Sloun *et al.*, "Super-Resolution Ultrasound Localization Microscopy Through Deep Learning," *IEEE Transactions on Medical Imaging*, vol. 40, no. 3, pp. 829–839, Mar. 2021. DOI: 10.1109/TMI.2020.3037790.

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[7] V. Pustovalov *et al.*, "Deep Unfolding RPCA for High Resolution Flow Estimation," in *2022 EEE Int. Ultrason. Symp. (IUS)*, ISSN: 1948-5727, Oct. 2022, pp. 1–4. DOI: 10.1109/IUS54386.2022.9957400.

[8] J. Ho *et al.*, "Denoising Diffusion Probabilistic Models," 2020. DOI: 10.48550/ARXIV.2006.11239.

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