3iA Côte d'Azur
Interdisciplinary Institute for Artificial Intelligence

Ph.D. research topic

- Title of the proposed topic: Interactive and Collaborative Learning for 3D Vessel Segmentation
- Research axis of the 3IA: Axis 2
- **Supervisor (name, affiliation, email):**
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- The laboratory and/or research group: EURECOM, Sophia Antipolis

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Apply by sending an email directly to the supervisor.
The application will include:

- Letter of recommendation of the supervisor indicated above
- Curriculum vitæ.
- Motivation Letter.
- Academic transcripts of a master's degree(s) or equivalent.
- At least, one letter of recommendation.
- Internship report, if possible.

- Description of the topic:

The segmentation of the 3D brain vessel tree is a crucial task for the diagnosis, management, treatment and intervention of a wide range of conditions with a vast population-level impact [1]. In clinical practice, most angiographic routines rely on manual segmentation. This is a challenging task due to the intricate morphology of the vascular tree: a highly bifurcated, convoluted and variable structure [2], which is complex to extract from 3D multi-modal scans [3]. Motivated by these factors, a vast amount of work has focused on the development of 3D vessel segmentation methods [3, 4] to assist clinicians in the extraction of the cerebrovascular tree, thus easing its analysis.

Studied for decades, classical semi-automatic and automatic 3D vessel segmentation methods rely on appearance and geometric models along with handcrafted image features, specifically tuned for the targeted application or image modality [3]. As a result, these methods are generally ad-hoc and difficult to tune, they do not generalize across imaging modalities, and the final segmentation often needs manual correction. Thanks to the progress seen by machine learning in medical image analysis tasks [5], learning-based techniques have been recently proposed to address the limitations of classical approaches [6-8]. In spite of the high reported accuracies, the use of learning-based methods to assist 3D vessel segmentation in clinical practice is hindered by the need of large training datasets with high quality

annotations. Firstly, large amounts of data are difficult and expensive to collect. Secondly, manual pixel-wise annotation of 3D vessel images is a demanding and time-consuming procedure that requires high expertise. The procedure lacks intra- and inter-operator repeatability and reproducibility [4], due to different tracing styles and the varying appearances of vessels across modalities. Finally, as with classic approaches, learning-based methods are modality specific, leaving the problem of generalization across modalities unsolved.

This PhD project aims to close the current gap that hampers the wide use of 3D vessel segmentation tools in clinical routine. To this end, it will build upon the demonstrated benefits of learning-based techniques [9], while tackling three fundamental problems of current 3D vessel segmentation methods relying on machine learning: **1)** the burden associated to manual labelling, **2)** the difficulty to collect large representative training samples, and **3)** the poor generalization and reproducibility of current vessel extraction approaches.

To achieve this ambition, the successful candidate will develop a novel interactive and collaborative learning-based framework for the 3D segmentation of the cerebrovascular tree. The realization of this goal will require the fulfillment of the following objectives:

1. *To define novel interactive learning-based algorithms that gradually learn from user-provided weak annotations; and*
2. *to develop and integrate domain adaptation and generalization techniques into the learning-based methods to account for the poor generalization across image modalities of current vessel segmentation methods.*

The clinical value of the project will be demonstrated by its use in the diagnosis process of multiple sclerosis (MS) through the detection of the central vein sign (CVS), an imaging biomarker in MS [10]. To this end, it will be developed in close collaboration with clinicians and researchers at CHU Nice (France), University College London (UK) and Siena University (Italy). The successful candidate will have regular meetings with the clinical collaborators and will perform at least one visit to the foreign collaborator's research groups during the PhD.

It is expected that the learning framework will be developed as an open source tool. Finally, thanks to an ongoing collaboration with ongoing 3IA initiatives and chairs, the framework will be deployed in a collaborative environment, using federated learning, to enable model training on data distributed across the different collaborating centers.

Keywords
Image segmentation, domain generalization, interactive machine learning, collaborative learning, vascular tree

References

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3. D. Lesage et al. A review of 3D vessel lumen segmentation techniques: Models, features and extraction schemes. Med. Image Anal. 13(6):819–845 (2009) [pre-print]
4. S. Moccia et al. Blood vessel segmentation algorithms—review of methods, datasets and evaluation metrics. Comput. Methods Programs. Biomed. 158:71–91 (2018) [pre-print]
5. G. Litjens et al. A survey on deep learning in medical image analysis et al. Med Image Anal 42:60–88 (2017)

[pre-print]
6. M. Livne et al. "A U-Net deep learning framework for high performance vessel segmentation in patients with cerebrovascular disease. Frontiers in Neuroscience 13:97 (2019) [open access]
7. G. Tetteh et al. DeepVesselNet: Vessel segmentation, centerline prediction, and bifurcation detection in 3-d angiographic volumes. Frontiers in Neuroscience 14 (2020) [open access]
8. L. Mou et al. CS2-Net: Curvilinear Structure Segmentation Network for Medical Images Med. Image Anal. 67: 101874 (2021) [pre-print]
9. V. Dang, F. Galati, et al. Vessel-CAPTCHA: an efficient learning framework for vessel annotation and segmentation. *Under review* [pre-print]
10. T. Sinnecker et al. Evaluation of the Central Vein Sign as a Diagnostic Imaging Biomarker in Multiple Sclerosis. JAMA Neurology 76:1446–1456 (2019) [open access]

Skills and profile

- MSc in physics, computer science, mathematics, engineering, or a comparable subject.
- Previous experience in computer vision and/or machine learning research through BSc or MSc projects.
- Good programming skills. Python preferably.
- English speaking and writing proficiency. French is appreciated.
- Strong communication skills.
- Previous knowledge of relevant computer vision, image processing or machine learning libraries (e.g. opencv, monai, itk, tensorflow, pytorch) is advantageous but not essential.