Physics-informed machine learning for the inference of mechanical properties of living tissues

M2 internship (5-6 months)

Location: IRPHE, 49 Rue F. Joliot Curie 13013 Marseille
Supervisors: Simon Gsell & Martin Lardy
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Salary: ~600 euros/month
PhD opportunity: Through application to the doctoral school or CENTURI PhD calls
Starting date: February 2025 (flexible)

Keywords

Machine learning, Physics-informed neural networks, Tissue morphogenesis, Fluid mechanics.

Context

During development, living tissues grow and undergo major deformations to form functional organs. These deformations are controlled by the complex and tunable mechanical properties of tissues, which thus play a fundamental role during morphogenesis [1]. However, little is known about these mechanical properties and how they affect tissue deformation, in particular because probing these properties in real tissues remains an interdisciplinary challenge. In this project, we collaborate with experimentalists developing microfluidic approaches, in which living embryonic tissues are aspired through microchannels and imaged using live microscopy [2] (Fig. 1(a)). **Our goal is to use these experimental images to infer tissue mechanical properties from the observed deformations**. To this end, we develop machine learning approaches [3] aiming to fit physical models to the experimental data. In parallel, we will use the physical models inferred from these perturbative experiments to recapitulate the spontaneous morphogenesis of in-vitro embryonic tissues [4].

[1] Lenne & Trivedi, 2022, Nature Communications. doi:10.1038/s41467-022-28151-9
[2] Tlili et al., 2022, Development. doi:10.1242/dev.200774
[3] Raissi et al., 2019, Journal of Computational Physics. doi:10.1016/j.jcp.2018.10.045
[4] Gsell, Tlili et al., 2023, bioRxiv. doi:10.1101/2023.09.22.559003

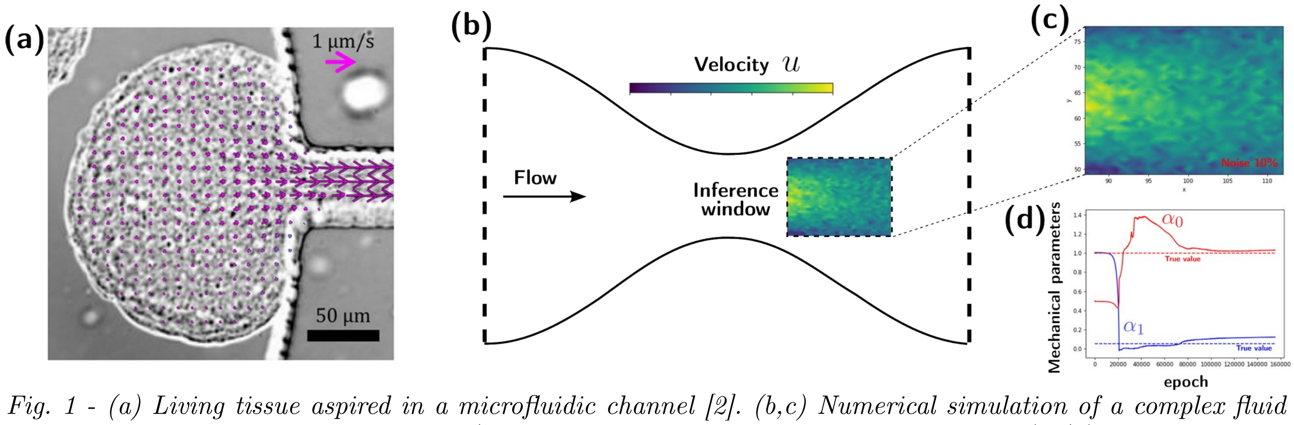

Fig. 1 - (a) Living tissue aspired in a microfluidic channel [2]. (b,c) Numerical simulation of a complex fluid flowing through a microfluidic channel (only the flow in the inference window is shown). (d) Inference of the fluid mechanical parameters from the noisy velocity field in (c).

Research objectives

The project started in 2023 with Martin Lardy's PhD thesis. We have already developed a first version of the algorithm able to infer mechanical parameters from noisy simulation data. The goal of the internship will be to get familiar with this algorithm and **to work on its convergence optimization** (loss balance, optimizer parameters, normalization, etc.). We also aim **to make progress in the fundamental understanding of the convergence dynamics**, in particular how the prescribed form of the physical models can affect the loss landscapes. The student will regularly interact with our experimental collaborators at the Marseille Developmental Biology Institute (IBDM) and benefit from a highly dynamic environment on machine learning for physics and engineering at IRPHE.

Candidate profile

The internship is open to students with a **background in applied mathematics, physics or mechanics**. Students without a strong background in machine learning are welcome to apply, as long as they have a strong motivation to be trained in the field. Biological background is not required either, but applicants should be motivated by the study of living systems.