Master 2: Physics of Complex Systems

INTERNSHIP PROPOSAL

Contact: Philippe Marcq
@: philippe.marcq@espci.fr Web: `https://blog.espci.fr/pmarcq/` Phone: 01 40 79 47 10
Internship location: Physique et Mécanique des Milieux Hétérogènes (PMMH), Jussieu, Paris
This internship can be followed by a thesis.

Learning tissue stress

Keywords: deep learning, theoretical biophysics, mechanobiology

Dynamical behaviors of multicellular assemblies play a crucial role during tissue development and in the maintenance of adult tissues. *In vitro* epithelial cell monolayers have been extensively studied to model *in vivo* tissue functions [1]. Mechanical forces in cell assemblies deform and propel the tissue, rearrange cells, orient cell polarity, and influence cell differentiation. A number of important biological questions, such as the determination of the molecular mechanisms that underlie the transmission of force within a tissue, necessitate a measurement of internal stresses.

We have recently demonstrated that Bayesian inversion allows to estimate the stress field of an epithelial cell monolayer given the traction force field that it exerts on a deformable substrate [2]. These two fields are related to each other through the force balance equation. This partial differential equation, once discretized on a finite grid, yields an underdetermined system of linear equations whose unknowns are the stress values. Bayesian inversion gives a probabilistic solution to the inversion problem: the stress estimate is the most likely value of the posterior distribution.

Deep learning has recently made major strides in numerous areas of physics [3]. In the context of hydrodynamics, deep neural networks allow to infer the pressure and velocity fields of a flow, given the concentration field of a passive scalar advected by the flow [4].

The goal of the internship is to build a deep neural network capable of inferring tissue stress from traction force data. One challenge of the project will be to successfully train and feed the network with *experimental* data [5], in addition to standard validation using numerical data.

The intern will determine whether or not deep learning can do better than Bayesian inversion at learning tissue stress.

References

[1] V. Hakim and P. Silberzan, *Collective cell migration: a physics perspective*, Rep. Prog. Phys. **80** 076601 (2017)
[2] V. Nier, S. Jain, C.T. Lim, S. Ishihara, B. Ladoux and P. Marcq, *Inference of internal stress in a cell monolayer*, Biophys. J. **110** 1625-1635 (2016)
[3] G. Carleo, I. Cirac, K. Cranmer, L. Daudet, M. Schuld, N. Tishby, L. Vogt-Maranto and L. Zdeborová, *Machine learning and the physical sciences*, Rev. Mod. Phys. **91** 045002 (2019)
[4] M. Raissi, A. Yazdani and G.E. Karniadakis, *Hidden fluid mechanics: Learning velocity and pressure fields from flow visualizations*, Science **367** 1026-1030 (2020)
[5] G. Peyret, R. Müller, J. d'Alessandro, S. Begnaud, P. Marcq, R.M. Mège, J.M. Yeomans, A. Doostmohammadi, B. Ladoux, *Sustained oscillations of epithelial cell sheets*, Biophys. J. **117** 464-478 (2019)

Expected skills: The project is primarily computational, at the interface between biophysics, mechanobiology, and machine learning. Prior experience with `Python` and `TensorFlow` is a plus.