Ph.D. proposal in machine learning / signal and image processing (2022-2025)

Physics-informed methods for learning low-rank models in polarization imaging. Application to cancer cell detection in bio-imaging.

Context Polarization information plays a major role in imaging. It allows to capture important characteristics of the observed medium, such as shape, roughness, orientation, physicochemical properties, etc. [1], [2]. These different features, often inaccessible to conventional intensity measurements, are crucial descriptors in many applications, including bioimaging characterization of cancerous tissues / cells [3]. Figure 1 below provides an illustration of the many insights offered by polarization information in bio-imaging.

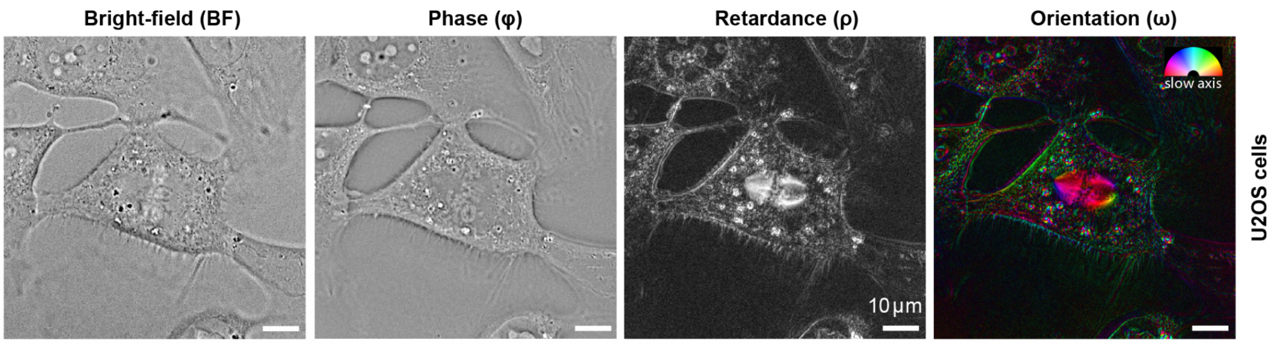

Figure 1: Polarization reveals architectural order in biological images of U2OS cells. Images of retardance and orientation are obtained by polarimetric measurement: they unravel biological elements invisible in standard bright-field or phase images, such as microtubule spindle in cells. Figure adapted from [4].

Goals Despite the numerous applications of polarization imaging, exploiting its full potential requires the development of new methodological tools that take into account the different physical constraints specific to the measurement and interpretation of polarization. This Ph.D. project aims at addressing these issues by focusing on the *development of physics-informed methods to learn low-rank models from datasets of polarized images.* The expected contributions will span theoretical (e.g. uniqueness conditions) and methodological (e.g. efficient algorithms) aspects. A complementary objective of this thesis will be to demonstrate, in collaboration with biology researchers at CRAN, the relevance of polarization to detect cancer cells in biological applications.

Research program The Ph.D. candidate will focus on developping new low rank-models for both passive and active polarization imaging. As a first step, he/she will focus on dimension reduction techniques for Stokes parameter datasets – a set of four energetic parameters widely used to describe polarization properties in passive imaging. Given the large amount of Stokes data which can be collected in a growing range of applications thanks to the rapid emergence of polarization cameras, dimension reduction techniques are essential to ensure that physically relevant features can be rigorously inferred from data. This is a key step before further processing (clustering, classification, regression, etc.) To this aim the Ph.D. candidate will take advantage of recent low-rank matrix factorization tools introduced in [5], which exploit geometric / algebraic representations of Stokes parameter data using quaternions. He/she will study identifiability properties and propose novel algorithms to efficiently solve the factorization problem.

As a second task, he/she will investigate the problem of low-rank modelling for matrix-valued polarization images. This modality, known as Mueller matrix imaging [6] permits the complete characterization of the polarization properties of a given medium, and is thus widely used in biomedical imaging [7]. As a promising new approach, such datasets will be represented as higher-order tensors for which the Ph.D. candidate will develop relevant low-rank tensor decomposition models and algorithms [8]. Just like above, a crucial aspect of this work will focus on preserving the physical relevance of the reduced model while enabling the addition of prior information and maintaining tractable algorithms.

The various theoretical and methodological contributions expected from this work will be validated around original applications in bio-imaging. This work, carried out in collaboration with the project "Molecular targets in a translational approach" of the BioSiS department of CRAN, will aim to demonstrate the potential of polarimetric information in bio-imaging. Two imaging modalities will be considered: high-resolution polarimetric camera imaging and polarimetric spectro-microscopy. The confrontation with experimental results will feed the development of methodological tools and inversely.

Candidate profile M2 or engineer diploma in one or more of the following fields: signal and image processing, machine learning, applied mathematics. The candidate should have good writing and oral communication skills.

Supervision and environment This PhD will be jointly supervised by Julien Flamant (CNRS research scientist) and Sebastian Miron (Associate Professor HdR at Université de Lorraine). The candidate will be located at (CRAN UMR 7039, `http://www.cran.univ-lorraine.fr/`) in Vandoeuvre-lès-Nancy, 54500 France, where he will join Simul research group (`https://cran-simul.github.io`).

References

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