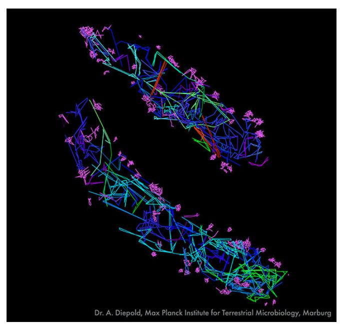
Learning regularized dynamics in complex systems

Supervisor: Dr. Marcello Carioni

Background

Understanding the dynamics of physical and abstract systems provides insights into the complexity of time-dependent phenomena. Classical mathematical fields such as dynamical system, partial differential equations, ergodic theory, statistical mechanics aim to address this problem by developing suitable frameworks able to capture different aspects of the evolution of the system under consideration. However, in real-life tasks, the dynamics needs to be reconstructed from few noisy observations of the system at different time instants in order to reduce the costs and speed up the reconstruction process. Dynamic inverse problems aim to achieve this goal by using a priori knowledge of the dynamic data to find a correlation between observations at different times.



Single-particle tracking and super-resolution. Dr. A. Diepold, Max Planck Institute for Terrestrial Microbiology, Marburg, Germany

Project goal

The goal of the master thesis is to explore how different choices of a priori regularization on the dynamics affect the reconstruction of the motion in physical and abstract systems [1]. The theoretical analysis of dynamic models will have a central role in the project and it will be complemented with the study of the optimization algorithms necessary for computing a satisfactory solution. Related numerical simulations will be then required to showcase the quality of the reconstruction for different tasks. In this perspective, machine learning methods will allow to learn the dynamic regularization from the data [4, 2], obtaining information about the motion, and ultimately leading to a better understanding of biological dynamical processes which underlying laws are unknown.
Applications to biological dynamic models such as single particle tracking for fluorescence microscopy [3] and congestion problems for crowd motion [5] could be considered.

References

[1] Kristian Bredies, Marcello Carioni, Silvio Fanzon, and Francisco Romero. A generalized conditional gradient method for dynamic inverse problems with optimal transport regularization. *Foundations of Computational Mathematics*, 23(3):833–898, 2023.

[2] Marcello Carioni, Subhadip Mukherjee, Hong Ye Tan, and Junqi Tang. Unsupervised approaches based on optimal transport and convex analysis for inverse problems in imaging. *arXiv preprint arXiv:2311.08972*, 2023.

[3] Mickaël Lelek, Melina T Gyparaki, Gerti Beliu, Florian Schueder, Juliette Griffié, Suliana Manley, Ralf Jungmann, Markus Sauer, Melike Lakadamyali, and Christophe Zimmer. Single-molecule localization microscopy. *Nature reviews methods primers*, 1(1):39, 2021.

[4] Subhadip Mukherjee, Marcello Carioni, Ozan Öktem, and Carola-Bibiane Schönlieb. End-to-end reconstruction meets data-driven regularization for inverse problems. *Advances in Neural Information Processing Systems*, 34:21413–21425, 2021.

[5] Filippo Santambrogio. Crowd motion and evolution pdes under density constraints. *ESAIM: Proceedings and Surveys*, 64:137–157, 2018.