

Inverse Problems and Data Integration for Microbial Biofilm Resistance to Pathogen Invasion

Laboratoire MaIAGE, INRAE Jouy-en-Josas

Contact: Lorenzo.sala@inrae.fr or beatrice.laroche@inrae.fr

Context

Understanding how natural microbial communities can protect ecosystems against pathogen invasion is increasingly important in the context of ecological transition towards sustainable, antibiotic free crop and breeding systems. Microorganisms form the invisible infrastructure that sustains soil health, food systems, and the well-being of animals and humans. Their capacity to stabilize environments, resist disturbances, and prevent the proliferation of pathogens is a key component of resilient and sustainable biological systems. Within the Biofilm1Health partnership (Lallemand – INRAE), a controlled experimental system has been developed to study how complex microbial communities growing as biofilms can naturally limit the colonisation of pathogenic strains. These biofilm communities represent a model for examining ecological processes such as cooperation, competition, and collective barriers against invaders - mechanisms that are central to ecosystem stability and to sustainable biotechnological applications.

The resulting dataset is multimodal, comprising structural descriptors of biofilms obtained from confocal microscopy and image analysis, compositional profiles derived from 16S sequencing, and functional outcomes that measure the success or failure of pathogen invasion. Mathematically, the project involves integrating heterogeneous data types, examining whether latent ecological patterns can be inferred from endpoint measurements, and determining which aspects of the community are most associated with pathogen resistance under uncertainty. These challenges are closely related to problems studied in the Dynenvie team (INRAE MaIAGE), which develops mathematical and computational frameworks for microbial systems using multivariate analysis, network modelling, generalized Lotka-Volterra formulations, and Physics-Informed Neural Networks (PINNs).

The internship will contribute to this broader research effort by exploring how to formulate and solve inverse problems in the context of biofilm-mediated pathogen exclusion.

Objectives

1. Understand the structure of the multimodal dataset and characterize the types of information each modality provides about the underlying microbial ecosystem.
2. Formulate the integration of these datasets as an inverse problem, identifying which aspects of the system can be inferred from the available observables and under which assumptions.
3. Explore and compare mathematical strategies - statistical, network-based, or mechanistic - to connect biofilm composition and structure with pathogen exclusion outcomes.
4. Identify robust microbial or ecological signatures associated with invasion resistance, while explicitly addressing uncertainty and identifiability.

5. Provide a reproducible analytical workflow and a conceptual framework that can support future modeling or mechanistic interpretation.

Collaboration

The internship will take place at INRAE MaIAGE (Jouy-en-Josas), within the Dynenvie team. Supervision will be provided by Beatrice Laroche and Lorenzo Sala, with interactions with colleagues from Micalis (B3D) and Lallemand.

Prerequisites

Candidates should be enrolled in a Master program (or equivalent) and demonstrate competencies in applied mathematics, data integration, and scientific computing, along with a strong interest in biology and ecology.