Internship position – Master 2 or Grande Ecole

Bacterial mixing in numerical models of colonies, populations and communities

Information

We are looking for someone with a background in physics or in mathematics, a priori experience in numerical simulations, preferentially with Python, and an interest for biological questions (although no biological expertise is required).

Dates	Starting date as early as possible in 2022. Duration is flexible.
Location	Toulouse Fluid Mechanics Institute (IMFT UMR 5502), 31400 Toulouse
Salary	Standard internship stipend between 500 and 600 euros/month
Application	Please send a CV along with recent grades & rankings to the following addresses Yohan Davit: yohan.davit@imft.fr Jean-Daniel Julien: jeandaniel.julien@imft.fr

Context

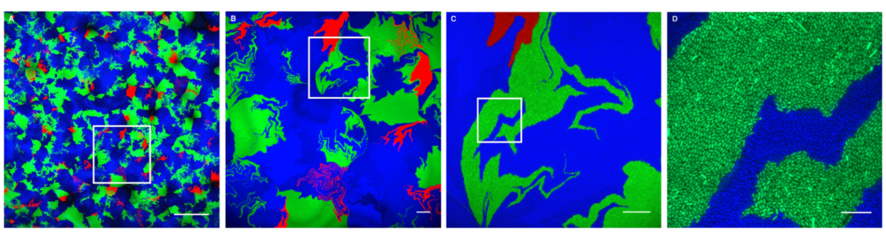

Figure 1: Experiments showing the fractal boundaries between populations of surface growing *E. coli*, labeled with three different fluorescent proteins. White boxes indicate successive magnifications. Scale bar from A to D: $1mm$, $100\mu m$, $100\mu m$, and $10\mu m$ respectively. Image taken from [2].

Bacteria are known to form highly complex and diverse spatial structures. Their organization results from different kind of interactions, like mechanical forces or chemical signals. One of the most striking mechanism can be seen at play in the fractal patterns created by rod-shaped bacteria, such as *Escherichia coli*. Experiments and numerical simulations showed that those patterns are due purely to the physical interactions of cells undergoing polar growth, and are therefore all the more marked that the bacteria are elongated [2] (see figure 1).

How bacteria mix within a community is not a detail: it affects how bacteria interact with each other, whether these interactions are positive or negative. For instance, killing via the type 6 secretion system (T6SS, a spear-like molecular machine) requires close proximity between the attacker and the target in order to be efficient [4]. Conversely, ecological interactions may also feedback upon structure and mixing patterns within communities. For example, cross-feeding favors mixing, while competition for nutrients lead to a sharp segregation between populations [1] (see figure 2).

Environmental factors can also modify colony organization and inter-species interactions. In recent experiments, random macroscopic obstacles had a different impact on colonies of cooperating or competing bacteria [1]. In an individual-based model, microscopic obstacles on a flat surface can either increase or hinder mixing, depending on their geometrical arrangement (see figure 3). Additionally, because bacteria with different shapes have different intrinsic mixing properties [2], their sensitivity to the obstacles is also radically different.

Objectives

Our goal is to investigate the impact of ecological interactions on mixing within bacterial populations, with and without physical obstacles.

The candidate will use an individual-based computational model of bacterial colony [3] with the following goals:

1. Reproducing experimental results on the fractal patterning of elongated bacteria.
2. Developing new metrics to quantify the mixing properties of the colonies.
3. Adding model (+, -) ecological interactions and quantifying impact on bacterial mixing.
4. Studying the impact of microscopic obstacles on mixing.

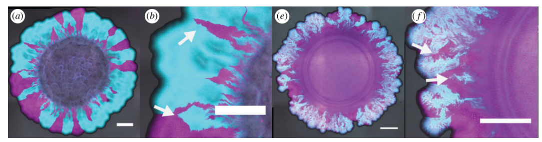

Figure 2: Growth of bacterial colonies, with competitive (a, b) or cooperative (e, f) interactions. Scale bars are equivalent to $1mm$. Image from [1]

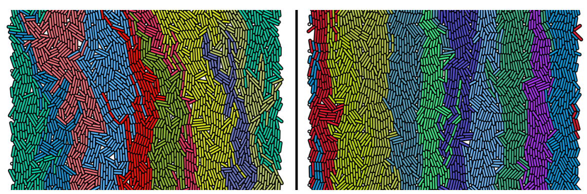

Figure 3: Simulations of bacterial colonies growing on a surface patterned with microscopic obstacles. Colors are initially assigned at random, and are inherited upon cell division, as the colony expands from bottom to top (left-right boundary conditions are periodic). Obstacles of diameter $d = 1\mu m$ are arranged over a triangular (left) or square array (right).

References

[1] D. Ciccarese, A. Zuidema, V. Merlo, and D. R. Johnson, *Interaction-dependent effects of surface structure on microbial spatial self-organization*, Phil. Trans. R. Soc. B, 375 (2020), p. 20190246.

[2] T. J. Rudge, F. Federici, P. J. Steiner, A. Kan, and J. Haseloff, *Cell Polarity-Driven Instability Generates Self-Organized, Fractal Patterning of Cell Layers*, ACS Synth. Biol., 2 (2013), pp. 705–714.

[3] T. J. Rudge, P. J. Steiner, A. Phillips, and J. Haseloff, *Computational Modeling of Synthetic Microbial Biofilms*, ACS Synth. Biol., 1 (2012), pp. 345–352.

[4] W. P. J. Smith, A. Vettiger, J. Winter, T. Ryser, L. E. Comstock, M. Basler, and K. R. Foster, *The evolution of the type VI secretion system as a disintegration weapon*, PLoS Biol, 18 (2020), p. e3000720.