Emergent Quenched Disorder Generated by Intraspecific Competition
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Summary

- Bacterial colonies growing on agar plates show different spatio-temporal patterns depending on environmental conditions.
- Competition for resources can generate pinning points, i.e., areas where the advance of the actively-replicating bacteria is hindered.
- This emergent spatial disorder may introduce a morphological phase transition for the colony.
- The physics of non-living fronts provide a single mesoscopic equation to characterize that morphological change.

Introduction

When a bacterial colony is grown in the laboratory, nutrient and substrate determine its emergent morphology.

Substrate influences bacterial mobility: the lower the concentration, the more freedom of movement for cells. On the other hand, the higher the nutrient concentration, the faster bacteria grow.

There are five reported qualitative patterns (click on figures to enlarge):

Methods and Results

Individual-based models allow for both qualitative and quantitative study of the fractal properties of the colony.

To this end, we used an existing model [5], very rich in biological detail. This model tracks individual cells’ growth and reproduction, as well as nutrient dynamics. In this model, cells cannot move actively, like in zone V. Thus, the model implements growth as a function of the availability of the diffusing nutrient ions; also, newborn cells are introduced after shoving existing ones to find their place in the colony.

The analysis of the in silico fronts confirmed their fractal behavior. We focused on the roughness of the interface colony-medium. Both the dynamics and finite-size scaling of the roughness follow scale-invariant behavior.

We used the exponents measured in the associated power laws to show that zone V really hides four different morphological behaviors [6] (click to enlarge):

However, substrate is not present in our model; only indirectly (cells cannot move actively).

Pinning points emerge from a feedback effect. At intermediate nutrient levels, differential-growth-rate areas develop. Thus, cells in the nutrient-depleted zones (valleys, in the figure) grow differentially more and more slowly than cells accessing the bulk concentration.

We have observed similar behavior in preliminary experiments (click to enlarge):

The interface may remain stuck in those places (divergent phase), eventually developing the zone IV patterns.

The flat behavior is the consequence of a high nutrient concentration. Kardar-Parisi-Zhang (KPZ) behavior is characteristic of interfaces allowing for frontal and lateral growth and certain fluctuations; in the colony, this corresponds to cell growth (pushing forward the interface) and random shoving (lateral growth and stochasticity). qKPZ represents the spatially-disordered version of KPZ, characterized by defects randomly placed in the propagating medium. These defects hinder the advance of the interface, like in the colony dynamics below (click to enlarge).

References


Acknowledgements

We would like to thank co-authors Nadell and Xavier as well as the support from DARPA (grant HR0011-05-1-0035/HR0011-08-1-055), the Princeton University Centennial Fellowship and an NSF graduate research fellowship.