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Assignment – No. 07

Simulation of Bacterial Colony Competition using Agent-Based Modeling (ABM)

Colab Link: https://colab.research.google.com/drive/1WAR5z5Q3IwIgahtWlpb0ejCr6iLp3zFc

Abstract

This project presents a computational simulation of the growth and competition of bacterial colonies on a Petri dish, based on the Agent-Based Modeling (ABM) approach. The classical segregation model by Schelling is adapted to represent two types of bacteria that interact and compete for resources. Population dynamics, nutrient consumption, and emergent spatial patterns are analyzed.

1. Introduction

The study of biological systems through computational simulation allows the modeling of complex dynamics in a realistic manner. In this project, bacterial competition is modeled using autonomous agents that interact in a dynamic environment governed by simple rules of survival, movement, and reproduction under limited resource conditions.

2. Theoretical Framework

Agent-Based Modeling (ABM)

An ABM approach models systems where individual entities (agents) operate based on local rules, producing global emergent behavior. It allows the study of systems from the bottom up—from local interactions to collective patterns.

Bacterial Colonies

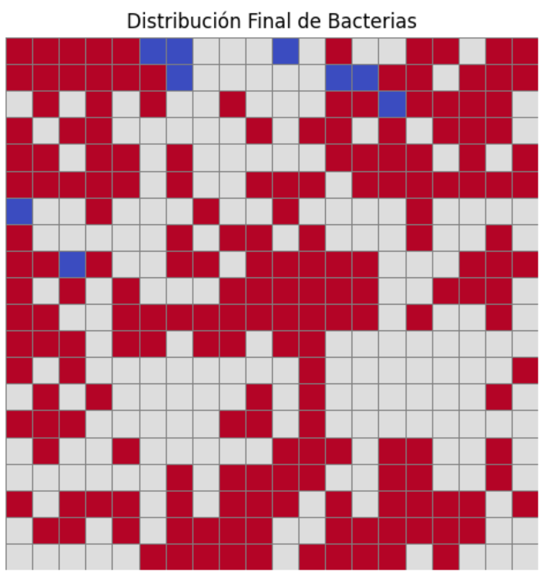
Bacteria on Petri dishes compete for space and nutrients. Their ability to reproduce and survive depends on local nutrient availability, resulting in emergent patterns such as rings, clusters, or dominant zones.

3. Model Design

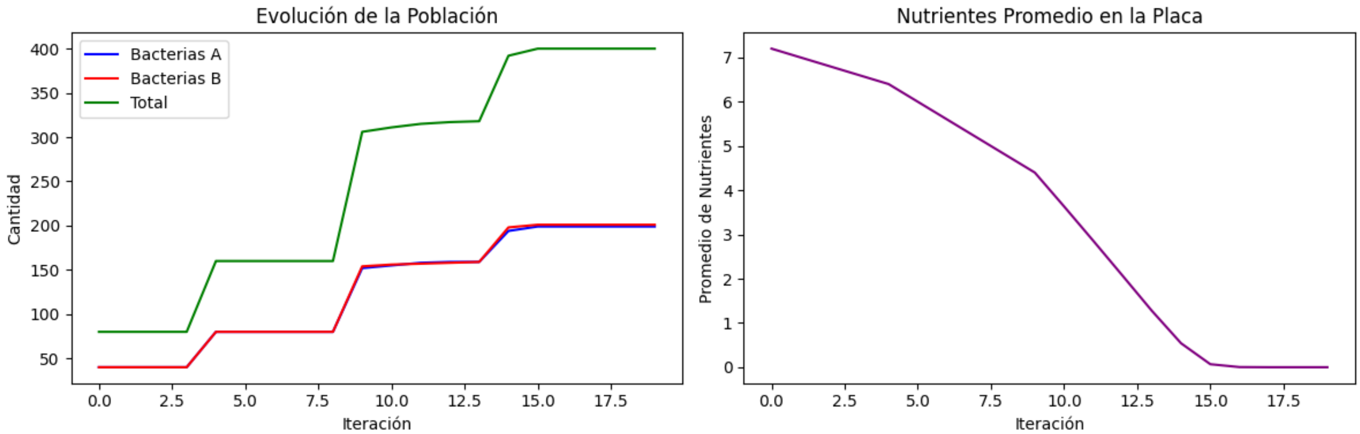
Agents: Type A (slow) and type B (aggressive) bacteria, each with attributes for energy, position, and type.
Environment: A 2D grid where each cell holds a quantity of nutrients.
Rules: Nutrient consumption, death by starvation, reproduction if energy exceeds a threshold, and migration toward nutrient-rich cells.

4. Results and Visualizations

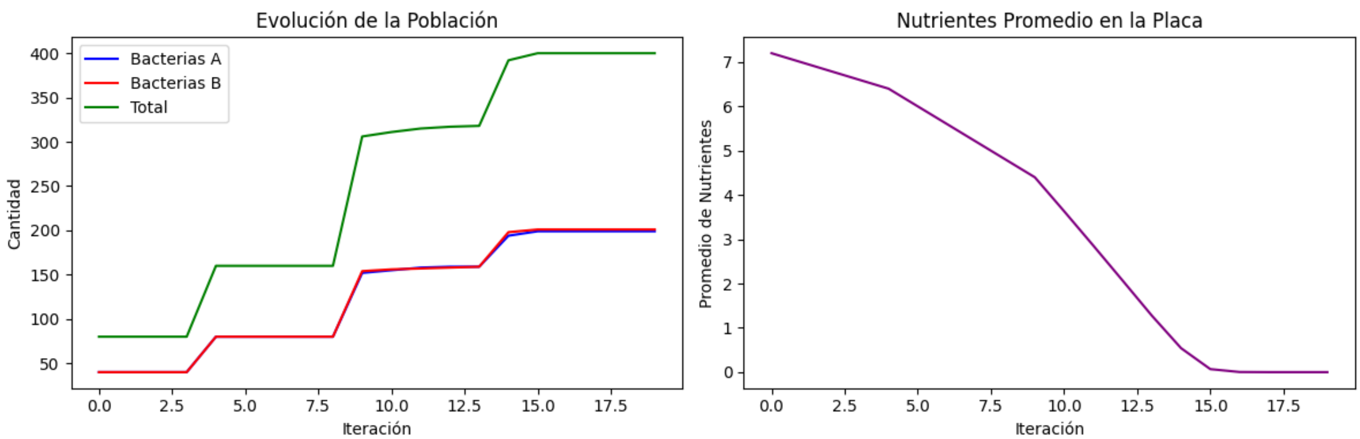
Final Bacteria Distribution



Remaining Nutrients



Temporal Evolution



5. Interpretation of Results

The simulation shows that both bacterial species can grow while nutrients are available. A sustained population increase is observed until a gradual depletion of resources occurs. Under the given parameters, growth was balanced between species, but small variations in consumption rates can lead to species dominance.

6. Conclusions

- The model accurately replicated competitive dynamics between bacterial species.
- Emergent behavior was observed (spatial self-organization and population cycles).
- The environment and resources strongly influence system evolution.

7. Development Environment and Libraries Used

This project was developed in **Google Colab**, using the **Python 3.x** programming language. The following libraries were used:

- **NumPy:** Used to create and manipulate the 2D nutrient matrix, enabling efficient vectorized operations.
- **Matplotlib:** For generating evolutionary and spatial graphs, and exporting them as images for reporting.
- **Seaborn:** To create detailed heatmaps of nutrient levels and bacteria distribution.
- **random:** Used to initialize agent positions and simulate stochastic behaviors in movement and reproduction.
- **Google Colab:** A cloud-based platform that allowed for notebook execution and sharing, with free access to computational resources.

These tools enabled the creation of an interactive, visual, reproducible, and efficient simulation, suitable for academic analysis in ecological modeling and computational statistics.

8. References

- Wilensky, U., & Rand, W. (2015). *An Introduction to Agent-Based Modeling.*
- Railsback, S. F., & Grimm, V. (2019). *Agent-Based and Individual-Based Modeling.*
- Schelling, T. C. (1971). *Dynamic Models of Segregation.*