Agent-based bacteria colony simulation - influence of various environmental factors

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Microbial growth

The actions of the agents are governed by generic rules such as survival, growth and division as is common for any individual in a resource-limited competitive environment.

Based upon several years of evolution, microbes have developed an advanced internal regulatory system (Kompala et al., 1984) that optimizes substrate uptake and maximizes growth.

The main objective of the cells is to survive and grow by utilizing the limited resources (biochemicals) and the skills (ability to make enzymes to metabolize substrates) available to them.

Examined bacteria: Escherichia coli

- E. coli is a model organism among bacteria. Its structure, genetics and metabolism are well understood and used in genetic research.
- It takes 20 min to create a new generation in real life
- Gram-negative - a thinner cell wall, but with additional cell membrane
- Relatively anaerobic rod - doesn’t need oxygen, but is not killed by it
- Food for those bacteria: glucose (likes the most), galactose (needs to adjust a bit to be able to eat it)

https://microbiology.ubc.ca/sites/default/files/roles/drupal_ungrad/JEMI/2/2-1.pdf

Microbial growth in binary substract environment

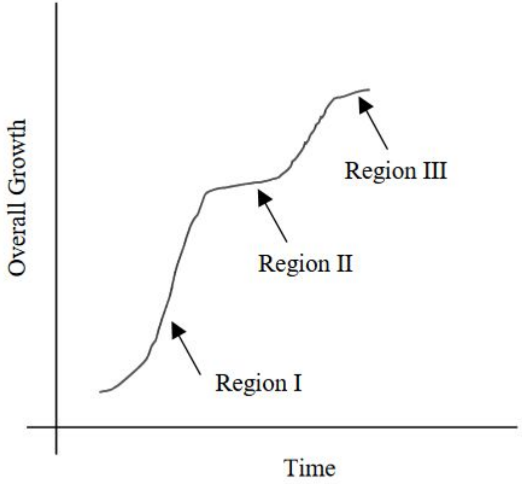

Fig. 1. Schematic of the microbial growth in a binary substrate environment.

Region I corresponds to the growth resulting from the uptake of faster growing substrate S1. When S1 is exhausted, the cells regulate their internal metabolic machinery to produce enzymes to consume the other available substrate, S2. The time taken in switching the regulatory process is known as the diauxie lag (Monod, 1942) and is represented by Region II. Region III shows the growth of cells on substrate S2. As is evident from Fig. 1, the slope of the growth curve in Region III is smaller than that of the slope in Region I. This is expected because substrate S1 is the faster-growth supporting one compared to that of S2.

1. S. Katare, V. Venkatasubramanian, “An agent-based learning framework for modeling microbial growth”, Engineering Applications of Artificial Intelligence, 2001

Model

In an environment consisting of substrates S1 and S2, where S1 is twice as effective as S2 in terms of the amount of biomass produced, the agent producing enzyme E1 accrues twice the amount of returns as that of an agent producing E2. The cell assimilates the sum of all the returns accrued by the agents and this defines the total growth of the cell.

A fixed percentage (STORAGE_PERCENTAGE) of the returns accumulated by an agent in every generation are stored for maintenance purposes. In order for the cells to maintain themselves, they have to expend MAINTENANCE_REQ amount of stored returns. So every agent is capable of producing biomass and hence gains returns and a percentage of the stored returns are expended towards maintenance.

An agent that is older than a specified age (ECLIPSE_TIME) can divide to produce two children, provided that it has accumulated sufficient returns (DIV_RET_LIMIT) required for division.

Other models - for eukaryotes

A cell consists of an agent of the class NUCLEUS and another agent of the class ENVIRONMENT that can be thought of as the protoplasm of the cell. All other cellular organelles are lumped and are represented as a single class of several agents—the CELLULAR-ORGANELLE agents.

The genetic machinery responsible for the expression/inhibition and activation/repression of the enzymes is represented by the time resource supplied by the nucleus of the cell. This could be understood, as the time required for the transcription of the genes to code for the various enzymes that are responsible for the assimilation of the corresponding substrates. Thus the ENVIRONMENT acts as a supplier of the substrates and the NUCLEUS as a consultant that provides the necessary skill sets.

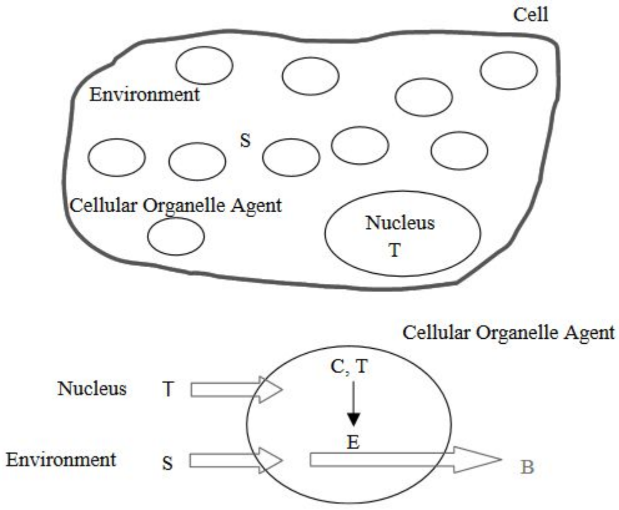

Fig. 2. Schematic of the agent-based model of a cell.

Other literature items

Models of root colonization by bacteria facilitate conceptual and practical understanding of fundamental processes that influence plant health, mineral nutrition, and stress tolerance. In this study, we explored the use of cellular automata and agent-based models to simulate the primary colonization of roots by bacteria as determined by selected parameters related to bacterial growth (nutrient uptake, fitness, reproduction and starvation) and environmental constraints (space, nutrient depletion, and pH).

2. Adrialy L. Muci, Milko A. Jorquera,et al,”A combination of cellular automata and agent-based models for simulating the root surface colonization by bacteria”, Ecological Modelling, 2012

The response of bacterial populations to antibiotic treatment is often a function of a diverse range of interacting factors. In order to develop strategies to minimize the spread of antibiotic resistance in pathogenic bacteria, a sound theoretical understanding of the systems of interactions taking place within a colony must be developed.

3. J. T. Murphy, R. Walshe and M. Devocelle,l,”MODELING THE POPULATION DYNAMICS OF ANTIBIOTIC-RESISTANT BACTERIA: AN AGENT-BASED APPROACH”, 2009

Our approach

Simulate the intelligent behavior of microbes in a binary substrate environment.

Model will consist of:

- bacteria cells
- 2 types of food for bacteria: glucose (more efficient) and galactose (less efficient)
- different temperatures
- influence of bacteriostatic / antibacterial agents on colony

https://www.nature.com/articles/ja20115
https://www.researchgate.net/publication/233761514_Influence_of_Temperature_on_Escherichia_coli_Growth_in_Different_Culture_Media