CITS4403 Project Report

A Model for Slime Mold Foraging Behavior

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1. Problem Statement

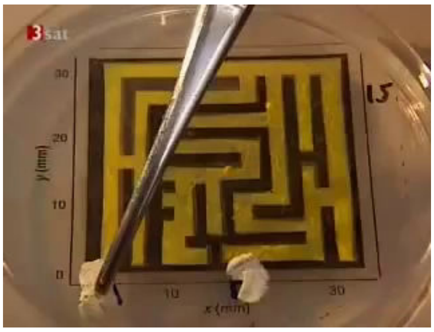
Case Background

The slime mold *Physarum polycephalum* is well-known in the field of graph theory. As a brainless single-cell organism, it has been found to be equipped with "judgemental and memory power" without any nervous system. At its smallest, *Physarum* can exist as microscopic cells, which actively swim about. These cells are attracted to each other, and when they swarm together, they can merge. The result is a single giant cell called a plasmodium, which can extend for meters [1]. The shortest path problem is a significant area in graph theory which focuses on finding the minimum weight path between two vertices. The slime mold was demonstrated to have genius in finding the shortest way to its food in a simplified laboratory environment. The path-finding experiment of slime mold [2] was originally conducted in 2006 by a Japanese research team led by Atsushi Tero from Hokkaido University's Graduate School of Science [3].

Research Motivation

We modelled this slime mold foraging behaviour in a maze as our project because of several ideal experiment features. First, its field is based on the fundamental graph theory concepts we learnt. Next, all the elements in this real-world experiment can be abstracted as points in a two-dimensional world that is similar to the segregation model and the sugarscape model we learnt in Agent-Based Modelling. Then, the brainlessness of slime mold makes it feasible to simplify and replicate in a computer-simulated environment. Finally, the original mold-maze model is extensible if we break the maze wall and put more oats around the single mold. This is another topic in graph theory called single-source shortest path. One well-known solution for this problem is Dijkstra's algorithm which we can apply for future work.

Suitability Evaluation for Agent-Based Modelling



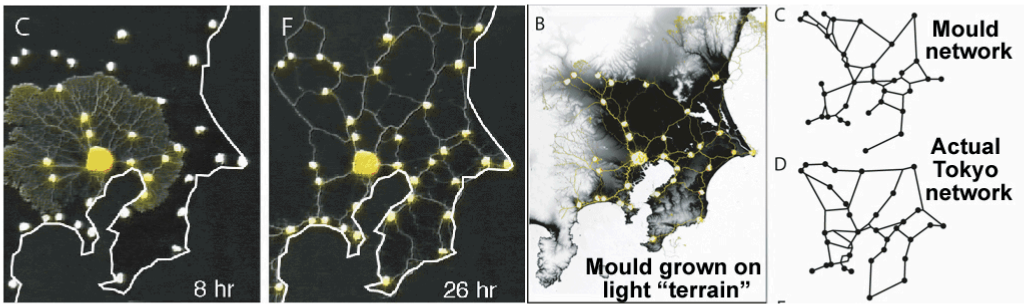
Our initial mold-maze model was based on Tero's shortest path problem experiment in 2006. The basic elements of agent-based modelling have a one-to-one correspondence with the components of this model. Evidently, the agent in our model is slime mold, who live in this 2-D vitural world. Next, the environment is the maze, which constrains the path of mold foraging. Then, both agent and environment have their unique attributes. The mold possesses energy or age constraints as its agent attributes, while the maze has god-given oats as its environment attribute. Finally, there is a mechanism for agent-to-environment interaction, as the slime mold instinctively searches for food to survive.

Complexity Factor Analysis

Although our model is a simplified mold-maze experiment, it does have the potential to simulate a more complex system. In a real-world scenario, there will be more factors that can influence the behaviour of slime mold:

- The real-world foraging logic of slime mold is much more intricate than our assumption. The slime mold primarily exhibits two different strategies: a BFS-like strategy for nearby foraging and a DFS-like strategy for accurately remote foraging which drived by attractions.
- Slime mold has its preference among various foods, and can also be influenced by repellents like salt, coffee, or light [1]. We can set the weight of different items in a maze to influence the track mold foraging in our future work.
- Slime mold is capable of learning. If the sole food source is placed on an island connected by a bridge filled with repellents, the mold will repulse, take risks, overcome, and ultimately habituate environmental interferences [1]. We can update the maze generation algorithm to better simulate this island model in our future work.
- Multiple slime molds have been confirmed for their cooperative behaviours. In the same bridge-crossing experiment, slime molds can tranfer what they learnt by merging with each other. Due to the memory ability at the cellular level, those molds are able to transmit information to another cell body, which makes informed molds across the bridge more quickly than naive individuals [7].

Model Application



An extended mold-network model was built upon another real-world research in 2010–the mold-inspired adaptive city network design[4]. This application was conceived by Atsushi Tero, too. The single slime mold in this experiment ultimately drew a network on a wall-less Petri dish that closely resembles the Tokyo-area railway system [5]. Later, followers who repeated this experiment in other countries also got nearly all interstate highways [1].

Our works align with the original intention of computational modelling, which is to simulate and study complex systems using computers.

2. Model Design Process

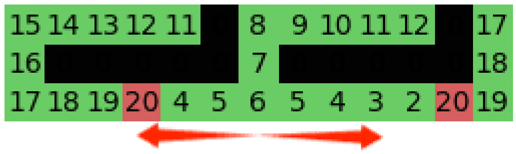
Model Design

We aim to replicate Tero's maze-mold experiment in a computer environment as our prototype model.

Assumptions

- The `maze` is loop-free and has no exit and, which prevent unexpected deadlock in `foraging()`.
- The `forage()` only uses a breadth-first search strategy, which can simplify its decision-making.

- The `forage_directions` in `foraging()` are constrained in 4 compass directions to prevent diagonal through-wall behaviour.
- All `path` in `maze` has the same weight.
- The `mold` has no `age` limitations.
- The `energy` flows non-reversibly.



Attributes

For agent: `energy`

For environment: `wall` and `oat`

Rules

- The `mold` attempts to `forage()` through the entire `maze`, as it is uninformed about `maze`'s full layout or `oat` amount.
- The `foraging()` range is constrained by `energy`, which can be supplied by `oats`.
- If `mold` cannot find any `oat`, it will `retract()` to its starting point presenting its death.

Initial configuration

1. Define the palette colors for the maze.
2. Set maze shape, mold energy constraint, and randomness seed.
3. Carve paths randomly through a solid maze using the depth-first search algorithm.
4. Place a single mold and multiple oats in the maze.

Complexity Reflection

- Ensure the randomness of maze generation and foraging direction.
- Consider multi-oat influence in the maze.
- Present a series of step-by-step visualisation.
- Omit energy flow between oats at the path fork.
- Omit mold's food preference and aversion.
- Omit mold's learning and adaptive behaviour.
- Omit the combination of mold's two different foraging strategies it actually has.
- Omit multi-mold cooperation and collective gene memory.

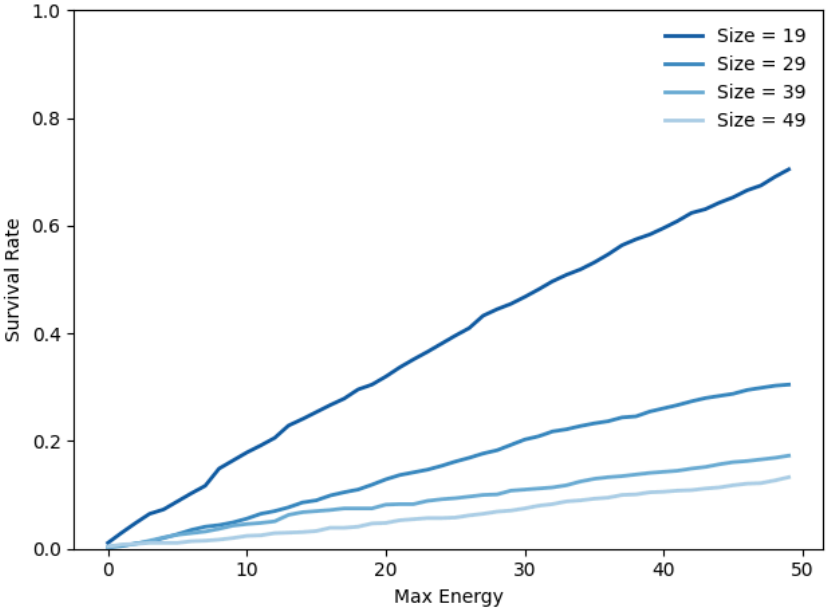
3. Simulation Results and Analysis

Quantitative Analysis

In this experiment, we define the `Survival Rate` as a quantitative indicator which represents the probability that the **single mold** successfully finds the **single oat** under given conditions. By changing the `Max Energy` of the slime mold and the `Size` of the maze, we observe how the `Survival Rate` of the slime mold changes under different `Max Energy` values when the square maze `size = [19, 29, 39, 49]`.

According to the information in the figure, as the `Max Energy` of the slime mold increases, its `Survival Rate` also increase. Cause the slime mold can move more steps with the higher energy, it increases the probability of finding oat. On the other hand, in the smaller maze, since the oat is relatively close to the starting point, it is easier for the slime mold to find the oat, so the `Survival Rate` is higher.

In addition, the `Survival Rate` of the slime mold decreases significantly as the maze `Size` increases. For example, when the `Max Energy == 50`, the `Survival Rate` is close to 0.8 when the maze `Size == 19`, while the `Survival Rate` is much lower when the maze `Size` is 49×49, showing the inhibitory effect of a larger maze on the `Survival Rate`.



Parameter Impact

Maze size

The larger the maze, the more difficult it is for slime molds to find oat, so the **Survival Rate** is significantly reduced. In a smaller maze (such as 19×19), slime molds can find oat faster, so the **Survival Rate** is higher. As the maze increases (such as 49×49), slime molds need to move a longer distance to find oat, and the failure rate increases.

Max Energy

Energy directly determines the number of steps that slime molds can take. Higher energy means that slime molds have a greater chance of exploring the maze and increase the probability of finding oat. When the `Max Energy` is low, slime molds can easily fail to find oat before consuming all the energy, resulting in a lower `Survival Rate`. As the `Max Energy` increases, the `Survival Rate` of slime molds shows an upward trend.

Real-World Reflection

The experimental results reflect the impact of energy consumption and exploration range on exploration success rate in real-life resource exploration problems. Similar to the situation in nature where slime molds and other organisms are looking for food, if the food is scarce or far away, the organisms will be more likely to die.

This is similar to the survival dilemma of animals in real life when environmental resources are limited [8]. Animals need to find enough resources within a limited energy (such as physical strength) range to survive. The experiment reveals the impact of maze (or environment) size on biological survival: the more complex the environment, the more difficult it is to find resources. Research on this phenomenon has also been applied to modern urban construction.

4. Conclusion

Summary

This experiment simulated the process of slime molds searching for food under different maze environments and maximum energy conditions, and mainly discussed the effects of maze size and maximum energy of slime molds on their survival rate.

The experimental results show that as the size of the maze increases, the probability of slime molds finding food, that is, the survival rate of slime molds, decreases significantly; while as the maximum energy of slime molds increases, their survival rate increases significantly. At the same time, if slime molds can find new food to replenish energy through the shortest path, their survival rate will also increase significantly.

These experimental results reveal the interaction between energy resources and environmental complexity in nature, and provide a reference for understanding the foraging strategies of natural organisms and human urban construction.

Limitations

A major limitation of this model is that the simulated environment is too simple. The maze is in the form of a regular grid, the food position is fixed, and the behavior rules of slime molds are relatively simple.

Real-world organisms are more complex in behavioral decision-making and environmental adaptation, such as memory paths, group cooperation, etc. In addition, organisms will face more complex interference factors during foraging, such as the weight of different foods, differences in energy recovery effects, etc. However, these factors have not yet been taken into account in this experiment.

In addition, the energy consumption model is relatively simple, consuming only a small amount of energy per step, while the energy consumption of organisms in reality varies according to different activities or modes of movement.

Future Work

To further improve the realism of simulation, future research can consider the following improvements:

- **Maze Complexity**: A more complex and dynamic environment can be introduced. For example, the shape of the maze can be more diverse, and even simulate the change of food location in a dynamic environment.
- **Improvements in behavioral models**: Slime molds can make more complex decisions based on past movement paths, such as introducing path memory or behavioral simulation of group coordinated foraging.
- **Refinement of energy consumption model**: In future work, different energy consumption mechanisms can be introduced according to the different distances or directions of slime mold movement to be closer to the real-world energy usage pattern.

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