Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Lecture with Computer Exercises:
Modelling and Simulating Social Systems with MATLAB

Project Report

Trail formation with Physarum polycephalum of the Swiss rail network

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Agreement for free-download

We hereby agree to make our source code for this project freely available for download from the web pages of the SOMS chair. Furthermore, we assure that all source code is written by ourselves and is not violating any copyright restrictions.

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1 Abstract

As most of the countries, Switzerland is growing. Cities are getting more inhabitants, growing together or arising new. With more people living in the cities and generally in Switzerland, more people will use the public transport system and the railroad network has to grow and develop. In this case, the main goal of this project is to simulate the Swiss railroad network depending on population growth to see where the systems should be improved.
The network is simulated like a biological model, based on Physarum polycephalum. This slime mold is a large single-celled amoeboid organism that forages for food sources. To maximize the searched area, it explores it's environment with a relatively continous foraging margin. It's forming different junctions and nodes to reduce the overall length of the connecting network [4]. And this principle is adapted to the main transport lines in Switzerland.

2 Individual contributions

3 Introduction and Motivations

Like a lot of other students we also use the public transport system almost everyday. Everyday thousands of commuters use the Swiss railroad network to reach their workspace or the university. And everyday the same railroad is used. But is it necessary, that the tracks are connecting the different cities exactly this way or are other connections possible?

We assume, that the railroad network is developed in a way that the connection between cities are most efficient. Certain biological organism connect their food sources in a similar way. In this project we try to let a biological organism simulate its own efficient connections between the cities. This leads us to the following questions:

1. Is the simulated railroad network a good approximation of the real network?
2. Are there inefficient junctions and are new junctions needed for the future?

To answer these questions, we compare the results from the simulation with the Swiss railroad network. For this comparison we used geodate from geodata.ethz.ch [2]. The data are prossesing with *Arcgis 10.1* to get the main matrix for the simulation. Therefor we distinguish between *Ghostland*, *Freeland* and *city*. Ghostland are the cells where the slime mold isn't allowed to be (foreign countries, lakes), Freeland are the cells where the slime mold can grow free and City represent food sources.

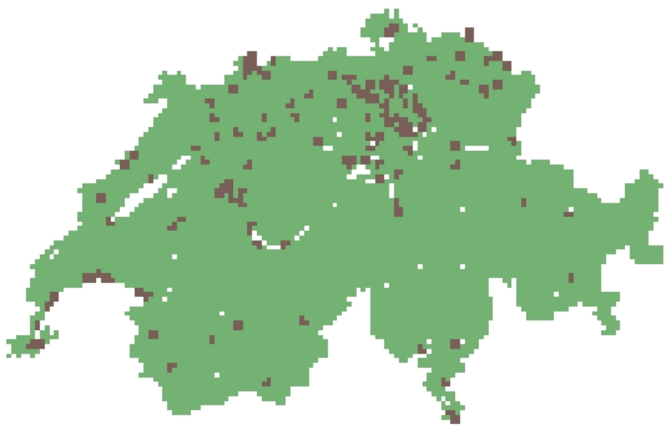

Figure 1: Rastardata from Arcgis with a gridsize of 2500m - white: Ghostland, green: Freeland, brown: City

The cities are choosen by the numbers of inhabitants in 2011 and if there is a railaway station. Additional are some cities with less than 10000 inhabitants but with an importance for the railroad network today. *Bilanz der ständigen Wohnbevölkerung (Total) nach Bezirken und Gemeinden*[1].

To answer the second question, ...

We expect that the most efficient network created by the simulation is a good approximation of the actual Swiss railroad network. We also expect that the network won't change even when the population is growing because a network changes the most at the beginning of developing. And the Swiss railroad network reaches the end of developement already.

4 Description of the Model

The model is inspired of the physarum polycephalum and the way it's searching for food. The organism have been subjected to successive rounds of evolutionary selection and have found an appropriate balance between efficiency, cost and resilience. The plasmodium contains a network of tubes, which enables chemical signals and nutrients to circulate through the organism. If some of the tubes have found food sources, this implies a positive feedback to the system. This tubes are getting thicker so the flux of nutrients increase. Other tubes which don't connect to a food sources are shrinking and tend to disapear because there is no flux available. Experiments showed two empirical rules. 1) Tubes with no connection to a source disappear and 2) if there are two tubes connecting the same source, the longer one disappears. This led to useful approaches to problem-solving like optimization of railroad systems or networks in general.

The mathematical model is based on *Physarum solver: A biologically inspired method of road-network navigation* [3]. Figure 2 shows the concept of the mathematical model. There are different nodes. The first two nodes corresponding to the food sources (N_1 and N_2) and other nodes (N_3, N_4 ... N_j). The junction between the node N_i and N_j is denoted as M_{ij}.

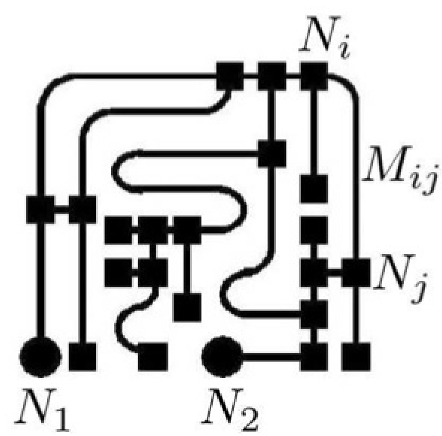

Figure 2: Concept of the mathematical model. Squares represent ordinary nodes, circles represent food sources, each line represent a junction.

The variable Q_{ij} stands for the flux through the junction M_{ij} from N_i to N_j. The flux Q_{ij} is given by an approximately Poiseuille flow where p_i is a pressure at the node N_i, L_{ij} is the length and D_{ij} is the conductivity of the junction M_{ij} :

$$Q_{ij} = \frac{D_{ij}}{L_{ij}} (p_i - p_j) \tag{1}$$

By considering Kirchhoff's law at each node, there is:

$$\sum_i Q_{ij} = 0 \quad \text{if} \, (j \neq 1, 2) \tag{2}$$

N_1 is assumed as a source node and N_2 as a sink and I_0 represent the flux from the source node and is in this model constant. It follows:

$$\sum_i Q_{i1} + I_0 = 0, \quad \sum_i Q_{i2} - I_0 = 0 \tag{3}$$

To describe the thickness of the junctions we assumed that the conductivity D_{ij} changes in time according to the flux Q_{ij}:

$$\frac{dD_{ij}}{dt} = f\,(\mid Q_{ij} \mid) - D_{ij} \tag{4}$$

where $f\,(\mid Q \mid)$ is a increasing function with $f(0) = 0$. Here $f\,(\mid Q \mid)$ is given by:

$$f\,(\mid Q \mid) = \frac{\mid Q \mid^{\gamma}}{1 + \mid Q \mid^{\gamma}} \tag{5}$$

The network Poisson equation for the pressure is derived from the equations (1), (2) and (3) as followed:

$$\sum_i \frac{D_{ij}}{L_{ij}} (p_i - p_j) = \begin{cases} -I_0 & \text{for } j = 1, \\ I_0 & \text{for } j = 2, \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

All p_i's can be determined by solving the equation system (6) wenn setting $p_2 = 0$ as a basic pressure level. With this also each Q_{ij} is obtained. They're definend bay the D_{ij}'s and L_{ij}'s at each time step. Conductivity is closely related to the thickness of the junctions and so when a conductivity of a junction is zero, it disappears.

5 Implementation

6 Simulation Results and Discussion

7 Summary and Outlook

A Matlab-Code

Matlab-Code

B Declaration of Originality

References

[1] http://www.bfs.admin.ch/bfs/portal/de/index/themen/01/02/blank/data/01.html.

[2] http://www.geodata.ethz.ch.

[3] Atsushi Tero, Ryo Kobayashi, and Toshiyuki Nakagaki. Physarum solver: A biologically inspired method of road-network navigation. *Physica A Statisticla Mechanics and its Applications*, 2006.

[4] Atsushi Tero, Seiji Takagi, Tetsu Saigusa, Kentaro Ito, Dan P. Bebber, Mark D. Fricker, Kenjo Yumiki, Ryo Kobayashi, and Toshiyuki Nakagaki. Rules for biologically inspired adaptive network design. *Science Magazine*, 2010.