MODELLING OF ALGAE POPULATION - VARIOUS APPROACHES

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SUMMARY

The alga Chlorella kessleri is an ecologically important species used to remove toxic metals from the environment. A simulator of this alga can be very useful for biologists because of high financial and time expenses of the laboratory experiments. This paper compares two approaches to modelling of the algae population. Both of them are based on the artificial life methods, which means the synthetical (bottom-up) design of the model. The first one is a 2-dimensional multi-agent model where the alga cell is the basic element and act as agent in the environment represented by a discrete lattice. The second one was created as a Lindenmayer-systems application. In this case, the discrete elements of the environment and the alga cells are represented by symbols in a 1-dimensional string. Both models implement the same algorithm for the vital functions of the cells and the processes in the environment. For each model a simulator was built and run under various initial conditions to compare the models. The algae population growth and corresponding toxic metal sorption dynamics were explored. The simulation results show several small differences between the models, which are caused e.g. by the dimesion reduction and could be reduced by adjusting model parameters.

Keywords: *ALife, biological modelling, Chlorella kessleri, L-system, multi-agent, simulation*

1. ALGAE SIMULATOR PROJECT

The aim of the project is to create a simulator of a green algae species to help the biologists to save financial and time expenses with some of their experiments. In this paper a new approach to the model is discussed. First the 2-dimensional multi-agent model was designed. Now we use L-systems to represent the alga and its environment, and compare the results to the agent model.

The simulated alga is *Chlorella kessleri*. This alga is one of the organisms that are able to adsorb and absorb various toxic elements (e.g. heavy metals) from the environment. Modelling of this biosorption process is particularly useful to predict its performance under different conditions [8].

2. TWO APPROACHES

Both our approaches are based on the ALife (artificial life) methods. The essence is in building the model synthetically – define the basic elements and their interactions, and then – during the simulation – observe the emergent behaviour of the whole [2]. This is also known as the "bottom-up" approach.

ALife is a general method that we can describe as generation of macroscopic behaviour from simple microscopic cooperating elements and this behaviour can be interpreted as a manifestation of life [1]. Its goal is to extend our knowledge about nature and improve our artificial models.

2.1 Multi-agent model

The first model consists of two main parts: the alga cell and the environment (widely described in [6] and [3]). The cell is considered as a reactive agent. Its actions are determined by few rules, which implement the key phenomena concerning the lifecycle and the sorption process of the cell. The environment is a 2-dimensional discrete lattice consisting of three 'substance' layers and one 'cell' layer. The substance layers store the concentrations of the toxic substance, minerals, and metabolite over the environment. The cell layer serves to store the positions of the cells. In addition, the behavior of the whole model depends on values of about 30 parameters.

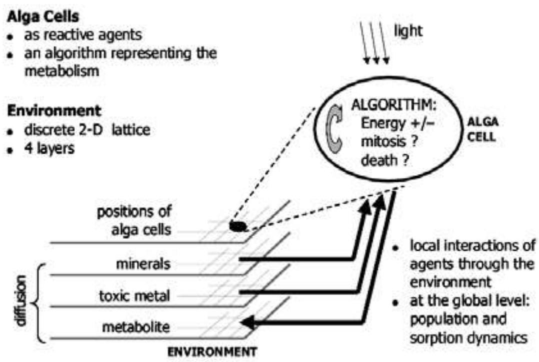


Fig. 1 Architecture of the multi-agent model

2.2 L-systems

The second model is based on L-systems. L-systems were introduced and firstly used by Aristid Lindenmayer in 1968 as a modification of formal grammars for the purposes of modelling of simple multicellular organisms development [4]. L-systems and their modifications became strong tool for generating fractals, self-similar structures, modelling of development of biological structures, etc. As mentioned above, L-systems are modification of formal grammars. The essential difference between Chomsky grammars and

L-systems lies in the method of applying of the productions. In Chomsky grammars, productions are applied sequentially, whereas in L-systems they are applied in parallel and simultaneously replace all letters in a given word. In addition, in L-systems, there is no distinction between terminal and non-terminal symbols and every symbol has just one production (except some special types of L-systems). Basic classes of L-systems are: context-free (0L-systems), stochastic, context-sensitive and parametric L-systems [5].

2.3 L-systems based approach

In this paper we present a new approach in the field of L-systems based biological systems modelling. We use parametric stochastic context-sensitive L-system as a tool for representation of the algae cells and their environment, as well as interactions between the cells and environment, and among cells themselves. Because of L-system the environment was reduced from the 2-dimensional discrete lattice to the 1-dimensional string.

Each element of the environment is represented by one parametric symbol in the string. First two parameters of that symbol contain information about environment. We decided to store the concentrations of the toxic substance and minerals. The concentration of the metabolite was excluded to make the model simpler, since it turned out not to be necessary at this level of experiments. The rest of parameters store information about alga (whether there is an alga cell in that element of the environment and what is the state of that alga). Key interactions between the algae and the environment, and among the algae themselves are represented by a set of L-system rules.

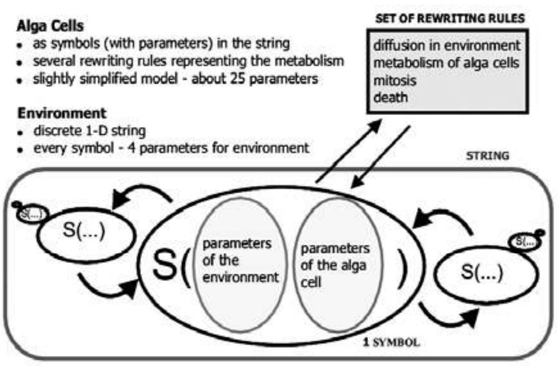


Fig. 2 Architecture of the L-system model

3. SIMULATIONS AND RESULTS

Several simulations with various initial conditions were run to find out the differences and the common features of the two models. The operation of the models was observed via the statistical data: the population growth, and the metal sorption dynamics of that population.

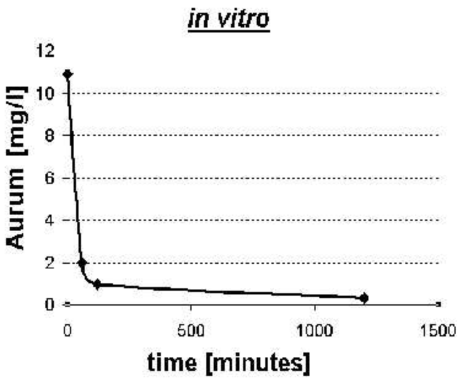


Fig. 3 A typical result of a real experiment (Sorption of gold by algae biomass)

3.1 Initial Conditions

The multi-agent model was realized using the ObjectiveC programming language and the SWARM libraries [7], which allowed us to create the environment of relatively large size. For computer memory reasons, we defined the lattice of 100 x 100 elements. However, for the L-system model implementation, we had a rather slow simulation tool. Therefore we decided to use smaller measures (a 512-element string) for the environment with the L-system model. The initial number of algae cells was stated as a percentage of the element count to make the simulations comparable. The initial amounts of the toxic metal and minerals were equivalent.

3.2 Simulation Results

In the figures 4 – 7, there are graphs with the results of several computer simulations using both multi-agent ('a' column) and L-systems ('b' column) approaches. The algae population growth in the environment without the toxic metal is represented in the figure 4. The subsequent figures display the population dynamics, as well as the corresponding metal sorption rate, in the case the environment is polluted by the toxic metal.

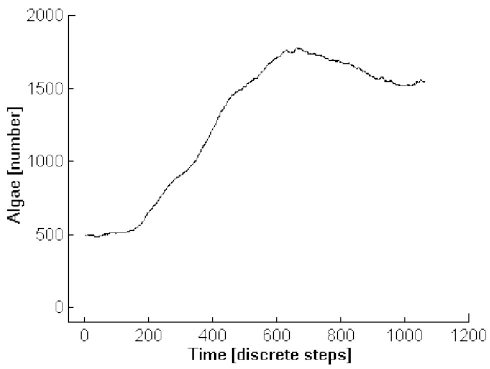
4. RESULT ANALYSIS

The growth and fall of the cell number using the multi-agent model is apparently steeper than with the L-system. The reason is that the population growth depends on the ambient light intensity. In both models the intensity is determined by the number of the neighbouring cells – the cells shadow each other. In the 2-dimensional multi-agent model the light is influenced by 8 neighbour positions, while in the 1-dimensional L-system string there are only 2 neighbour positions considered.

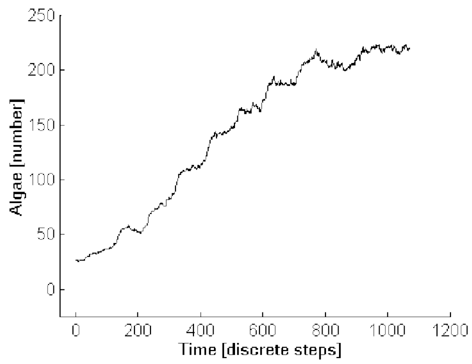
The metal concentration decrease is similarly steeper in the multi-agent simulations. It is possibly caused by faster population growth mentioned above, together with an additional dimension for moving in this model.

The graphs in the 'a' column are smoother than the 'b' graphs, because the amounts of cells in the L-system simulations are about 20 times smaller, so the perturbations are more apparent.

In the experiment with the medium amount of the algae mass (figure 6), we can observe that the cell number tends to get stable. In the case of multi-agent simulation it is about at 16 % of the environment size, and in the case of L-system it is about 45 %. The reason is the same as in the first paragraph – the light and the shadow.



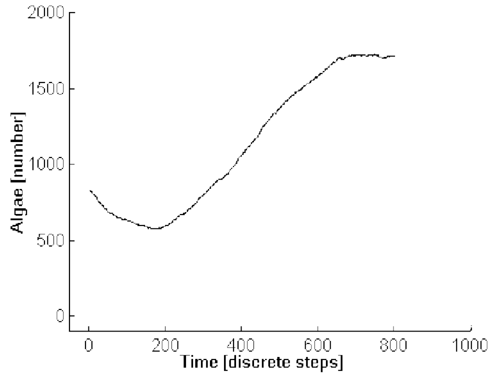
a

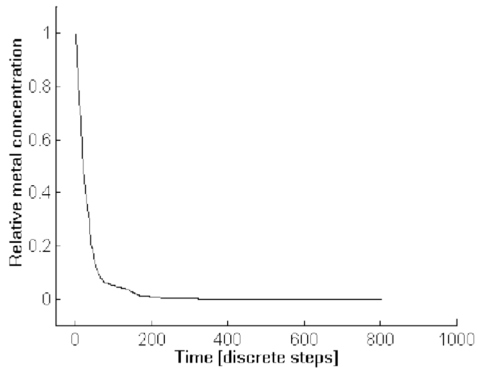


b

Fig. 4 The population growth in the environment without toxic metal
(The initial population size is 5%)

And finally, if we compare the real metal (e.g. gold) sorption dynamics (figure 3) to the artificial ones (figures 5 – 7), we can see that all the simulations roughly follow the real experiment. The deviations of the speed of the sorption process are caused just by the various initial population sizes.





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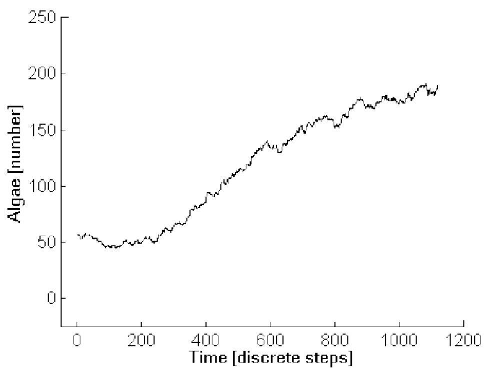
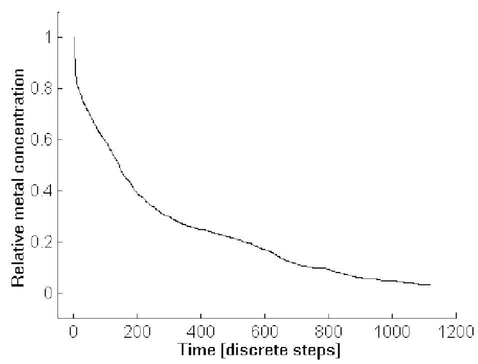
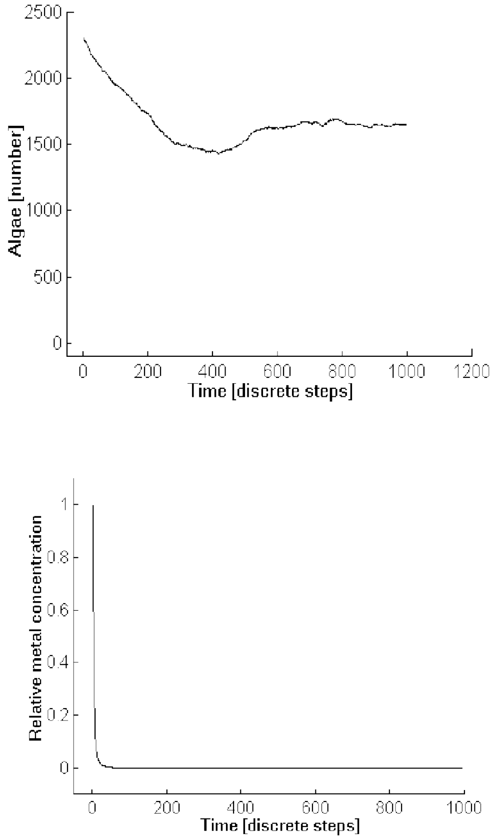




b

Fig. 5 Simulation with toxic metal and small initial number of algae cells (10% of the environment elements were occupied)



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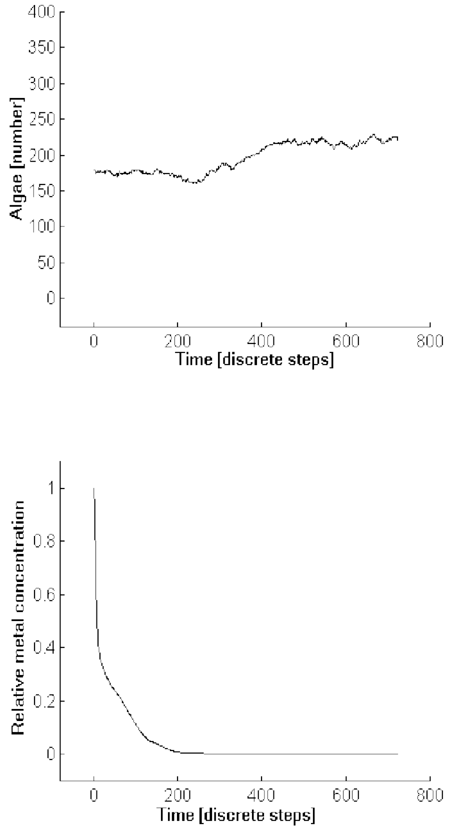
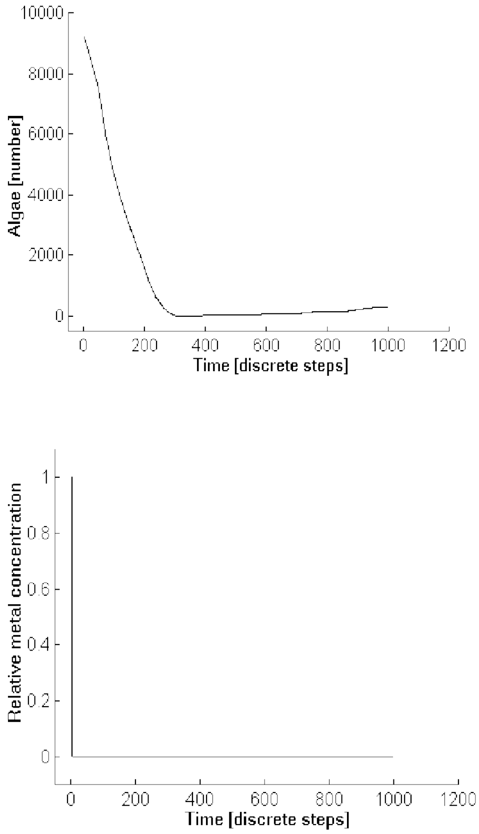
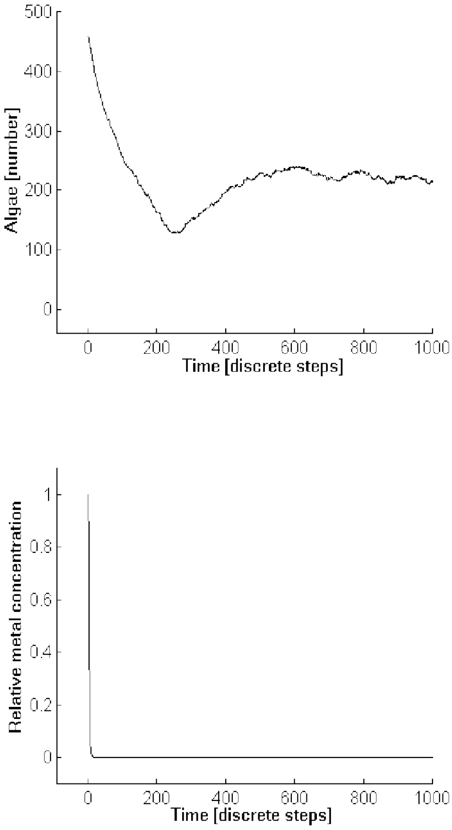


b

Fig. 6 Simulation with toxic metal and medium initial number of algae cells (25% for the **a**-simulation and 35% for the **b**-simulation)



a



b

Fig. 7 Simulation with toxic metal and large initial number of algae cells (90% of the environment elements were occupied)

5. CONCLUSION

The result analysis describes several differences between two models that were realized. We think, some of them (concretely the different steepness of the population growth and of the sorption dynamics, as well as the different stable value of the alga cells concentration) can be reduced, or even eliminated, by adjusting the L-systems model parameters. But at this level of experiments, the simulations follow the real sorption dynamics sufficiently well.

The results also encourage us to create and test a 3-dimensional model (possibly using the multi-agent approach).

6. ACKNOWLEDGEMENT

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BIOGRAPHY

Jozef Chvál was born on May 11th 1978. In 2001 he graduated (MSc.) at the Department of Cybernetics and Artificial Intelligence of the Faculty of Electrical Engineering and Informatics at Technical University in Košice. His thesis title was “Software for Generating of Lindenmayer Systems”. Since 2001 he has been PhD student at the same department. His scientific research focuses on artificial intelligence, artificial life and biological systems modeling.

Martin Palko was born on August 22nd 1977. In 2000 he graduated (MSc.) at the Department of Cybernetics and Artificial Intelligence of the Faculty of Electrical Engineering and Informatics at Technical University in Košice. Since 2000 he has been PhD. student at the same department. In spring 2001 he passed the dissertation exam and defended the thesis for dissertation exam named “Applications of the Artificial Life Simulators”. This time he is working on the final dissertation thesis on theme “Model Design of Biological System Using Evolutionary Algorithms”. Besides that he is intested in scheduling and multi-agent systems.