Virtual plants in high school informatics – L-systems

Janka Majherov

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Janka Majherová
Department of Informatics, Pedagogical Faculty, Catholic University Ružomberok

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Abstract:

A creation of models is becoming an important part of informatics education besides algorithmization and programming. An appropriate example concerning use of computer science while modelling real world are the L-systems. In the paper we describe a proposal of teaching of plant's growth modelling by the L-systems at a high school. Our goal is to help students to understand and try creation of plant's model on the computer.

1 Introduction

In today's theory of computer science education we can find recommendations concerning an introduction of modelling to education. The objective is to help students to learn with and about the models and modelling in science. Modelling is a reasoning skill, which refers to the development of the ability to construct and improve models. The process of scientific modelling is comparable to the process of computer programming.
A model, as a subject of modeling, can be found in computer science in many forms: relation models of data-bases, schemes of computer networks, designs of software development, models in computer graphics, models of computations and computers as well as automata of theoretic informatics etc. The examples of models used in the informatics and modelling approach can help students to understand the ways of the algorithmic creation of models.
At the high school, while teaching computer science, it is necessary to acknowledge a general term of a model and its expression in the computer science as well as the different types of modelling. In the computer science education, "the modelling" basically means a bounding of certain part of reality for the particular reason, processing of its important features while neglecting the additional ones as well as its description and structure determination by special techniques of the theoretical computer science. Natural phenomena can be represented by students through theoretical computing models a their visualisation.
Interesting types of model in the computer science are the L-systems, which were created in 1968 (Lindenmayer, 1968) by theoretical biologist A. Lindenmayer for the reason of plants' development observation. Based on created model, the L-systems allow us to describe and study phenomena that go along the growth and development of the plants. Students at the elementary school as well as the high school have already gained the basic knowledge concerning plants during subjects Natural History and Biology. Therefore they will be familiar with this topic.
During the education, we recommend to use a virtual learning environment for developing modelling skills, namely the applets on the Internet as well as a graphical computer based programming environment.

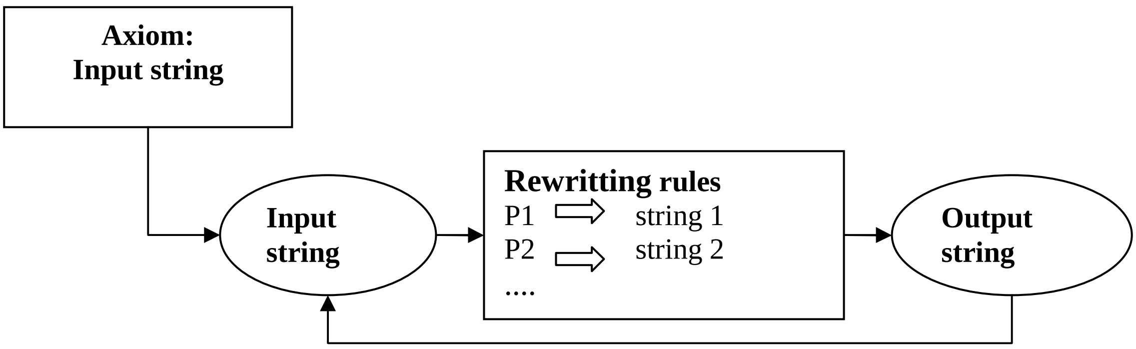
2 Why the L-systems?

Theory of the L-systems and their graphic representation provide for rich material for methodic processing of this topic for the use of high school education. The main idea is an algorithmic creation of model of the real object – a plant.

Initially the L-systems were focused on the purposes of modelling of development of simple poly-cellular organisms. Consequently the range of L-systems' application was extended to the higher plants and complicated branched structures. Following studies of the L-systems lead to the modelling of further more complicated types of plant organisms. Interesting details concerning the introduction and development of L-systems presented by the author of the model in (Kelemenová, Kelemen, 1984) can be use also to refresh the presentation of the topic.
The knowledge of model's features were recommended to use also in the course of theoretic informatics for high schools education (Kelemenová, Majherová, 2006). The overview of abilities of the L-systems' application during plants' modelling can be found in several available sources, most noticeably The Algorithmic Beauty of Plants (Prusinkiewicz, 2004).

Procedure of modelling by the L-systems has to follow certain basic principles of modelling, which consist of following three steps:

1. Firstly it is necessary to carry out a conception analysis of a problem, hence decide, which factors and parameters are relevant in the modelling process and it is required to include them into model and on the other hand, which ones can be neglected. While modelling plants we mind the morphology, structure of plant's body, e.g. type and number of limbs on a cane, their position on the cane and types of flowers. We neglect an impact of environment, e.g. wind, air temperature, sunshine, amount of rainfall of fertility of soil. On the higher level of model approaching reality we can mind also the properties of environment, e.g. level of irrigation or amount of manure.
2. In the second step we have to assembly a particular model from the chosen parameters. Choice of type of model (type of mathematic relation) depends on characteristics of modelling process, on abilities to get input data and abilities of results' verifications (confirmation or disapproval of relation justness). In the case of the L-systems it is generative model of theoretical computer science typical for formal language theory. We decide the type of the L-system we use: with or without the interaction, parametric or stochastic and appropriate shape of an axiom and rewritting rules.
3. After creating the model we have to verify its correctness. We verify whether the models have the required abilities, what can be done by visualization of the model in the program environment on the computer. We observe for example stages of plant's development and its shape.



Picture 1: Visual scheme of model's creation during an application of the L-systems

2.1 Models of the plants according to growth of their parts

During the construction of theoretic model of a plant we can look at the plant like at the “box of brick”, which consists of relatively small number of types of “building elements” (cane, letters, sprouts, flowers and fruits) and grows gradually. Mutual changes of the elements can be formally described in form of rewritting rules. Rewritting rules operate all of the modules of the plant: growth vertex, cane, letters or flowers.

L-systems represent the objects – plants as the strings of symbols. Every symbol represents object in certain state and has assigned a certain geometric significance, for example a transformation of generating of the object according to set of rules. We can represent also the side canes by the string of symbols, if we use parentheses to mark a point of branching. Even very simple set of rules is able to simulate the process of growth, morphology of complex plant structures.

During the creation of particular L-system we assume that we observe a growth of some initial structure (marked as axiom, initiator), whose development we observe in discrete time units: between each two subsequent moments of the observation, the structure changes in the way that all of its modules simultaneously replace modules prescribed by rewritting rules. Presented example of plant’s development could be described in following way:

axiom: vertex
rule 1: vertex → cane (vertex) vertex
rule 2: cane → cane

If we use symbol 0 for growth vertex, out of which a new branch grows, l for the cane, which doesn’t grow any more, symbols [ ] for branching rules can be written in following way:

axiom: 0
p1: 0 → 1[0]0
p2: 1→ 1

Note that symbol, which change is not described by any rule, is changing by “identical” rules, so we have [→ [,] →], for example.

Description of the first 3 steps of derivation looks in following way:

0→ 1[0]0 → 1[1[0]0]1[0]0 → 1[1[1[0]0] 1[0]0]1[1[0]0]1[0]0

With these examples, the students will intuitively learn the basic terms concerning formal grammars, e.g. symbol, string, rules, etc. Rules and strings of the symbols can be represented graphically.

3 Turtle graphics and the L-systems

For the purpose of strings’ depict we use a turtle interpretation of the L-systems known from the language LOGO. We familiarize students with the principles of turtle graphics that is known by them from the lectures of children’s programming language Comenius LOGO or Imagine. String of the symbols is in this case considered to be a series of orders for the turtle.

The turtle represents a graphic device. It is set by its status and table of actions. Status consists of two parts – position of the turtle and its orientation. The turtle reads string step by step and carries out the orders according to the table of actions. By the consequent execution of the orders it creates a picture represented by the string of the symbols. During a graphic representation of the L-systems we use following basic set of orders:

Symbol	Meaning
F	Movement of turtle forward
+	Turtle turns left for a given angle
-	Turtle turns right
(	Input of turtle's status into reservoir
)	Recovery of turtle's status from reservoir

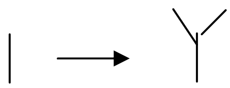
Tab. 1: Table of symbols and relevant denotations

The *F* symbol means for the turtle to draw a line from the initial point [0,0] to the end point [0, d], where d is a length of a step. Symbol parentheses *(* means to remember the coordinate of the end point and symbol *)* means to return the turtle to the memorized coordinates of the end point. Symbols + and – mark a turn of the turtle for a given angle.

Example 1. We want to design a L-system, which will generate a simple branched structure.

Axiom:

Rule:



Notation of an axiom and rules of L-system by the commands for the turtle:

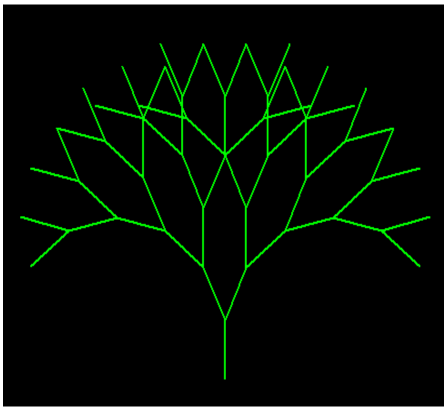
axiom: F
rule: F→ F[+F][-F]
With a use of the rule we obtain an order of strings:
0. step: F
1. step: F[+F][-F]
2. step: F[+F][-F][+F[+F][-F]][-F[+F][-F]]
etc.

After the visualization a plant created by this L-system after 6 steps looks like bush (picture 2). All of the visualizations of the L-systems in this paper are created in the program LSysMaker that is available at Alife portal (Chvál, 2003).

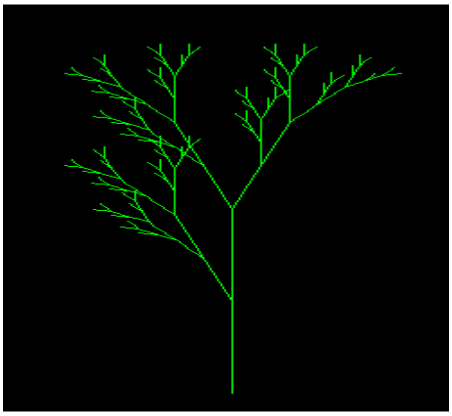
Example 2.
During the modelling of plant, where we distinguish whether it concerns growth vertex, from which a new branches of part of cane, which can be only extended, are able to grow, we can use symbols X and F and two rewriting rules distinguish between growth vertex and cane:

axiom: X
p1: X → F-[+X]+F[-X]+X
p2: F → FF

Representation of a plant after 5 steps of derivation is on the picture 3. A model of plant is more realistic than on the picture 2. The turning angle is 22.5°. This kind of branching characteristic e.g. for apple tree.



Picture 2. Visualization of the plant in LSysMaker



Picture 3. Plant with 2 rules

3.1 Time relations and environment influence

Methodology of plants' modelling by the L-systems is based on simulation of real plants' development, where our effort is to notice a fundament of growth process, which leads to a certain shape of the plant. This developing approach to the plants' modelling has following characteristic features:

- Emphasis is on space-time relations among the parts of the plant. On many plants we can observe different growth stages at once. For example some flowers can be in the stage of bud, while others are fully evolved and others are even changed into fruit.
- It has natural ability of growth's simulation. Since the entire development process is described by computing model, we can use it to generate the biologically correct pictures of plants in different stage and to creation of animations of plant's growth.

In order to make a model of plant more realistic, we include the element of coincidence to the rules, what is described by the stochastic L-system. The L-system includes probability of overwriting by the rule. Rules are written in the following manner: $A \rightarrow_p B$, where *p* is the probability that the symbol A will be overwritten by exactly this rule. A sum of the probabilities of the rules with the same left side has to equal one.

Example 3.

Axiom: F
r1: $F \rightarrow_{0.33}$ F[+F]F[-F]F
r2: $F \rightarrow_{0.33}$ F[+F]F
r3: $F \rightarrow_{0.34}$ F[-F]F

A plant generated by this system is represented on the picture 4.

We will familiarize the students also with the L-systems with the context. Concerning some of the plants, the change of growth vertex into the source of a flower is regulated by signal in form of plant hormones, which is sent from the lower part of the plant towards the vertex.
In the following example of the L-system we model this king of signal spreading from upper to lower part. A symbol F represents the cane, E represents cane with the signal. In the rule a notation $E<F \rightarrow E$ means that if in the string a symbol F is preceded by symbol E from the left, F overwrites into E, thus the signal will proceed.

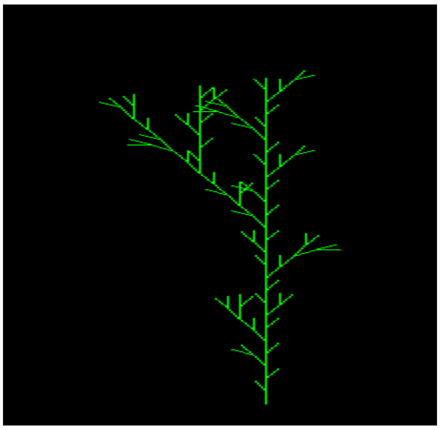
Example 4.

Axiom: E[+F]F[-F]F[+F]F[-F]F

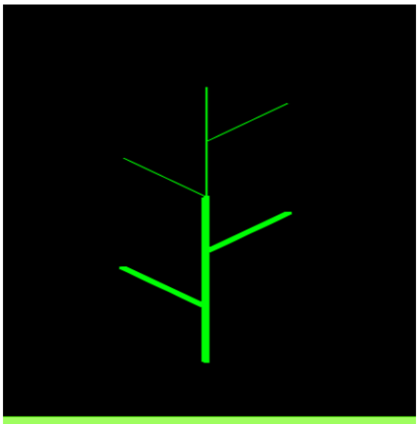
Angle 45°
Rule: $E<F \rightarrow E$

After 3 steps of derivation the string has following form: E[+E]E[-E]E[+F]F[-F]F. A plant is shown on picture 5.

At higher level of understanding we can try with the students the examples that cover also the influence of environment – sunshine, irrigation etc., represented by the parametric L-systems. In this way we can simulate a growth of plants with parameters, e.g. quantity of fertilizers and level of irrigation. Quality of the growth can be evaluated e.g. by addition of branches, letters or flowers for more kinds of plants and plants' levels.



Picture 4. A plant with a casualness



Picture 5. Signal spread in a plant

3.2 Virtual learning environments for modelling

The introductory lessons of modelling plants and the L-systems for the students' motivation can be dedicated to work with the Internet sources. Nowadays, the different applets, designed for a visualization and experimentation with the L-systems and created in language PHP or Java, are available online:

- http://home.clara.net/niknak/fractal/lowres.html
- http://zdeeck.borg.cz/wlse/l-system.php
- http://www.alife.pl/portal/lsyst/e/index.html
- http://www.vojtechmasa.com/applications/

Consequently we show the students the use of graphic interpretation of the L-systems, e.g. for the modelling of development of agricultural plants (corn – harvest prediction), in the schemas of building constructions, in the computer-supported landscape and garden architecture (ecological modelling) or computer-supported music composing.

We don't want to use only complete programs for modelling of plants by L-systems available on the Internet. Our goal is to help students to understand and try creation of plant's model on the computer. An appropriate tool for modelling are the children programming languages, e.g. Imagine or Baltie, where the programming is interactive and visual.
Baltie 4 C# is a friendly object-oriented programming tool for 3D, based on C#, DirectX and .NET. Also contains powerful 3D graphic library (SGPRTL). This tool is the ideal starting point for everyone who wants to learn an object-oriented programming (in C#) and to develop attractive 3D multimedia applications. This programming environment embodies some important programming concepts, such as conditional execution, subroutines, iteration, and variables, but it is at the same time an ideal tool for constructing models in natural sciences. Information about this program is available at www.sgpsys.cz/en.

Summary

Modelling with the help of computer at school during learning process is one of the use of CAL – Computer Aided Learning. CAL isn’t just a single computer program, but it’s one of the possible means of the educational strategy. Modelling on the lessons of informatics will thus become not only an instrument, but even the very subject of education, when, based on gained knowledge and with the help of computer and informatics’ tools, students create a model of certain part of real world, in our case world of plants.

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Author:

Janka Majherová, Ing.
Department of Informatics
Pedagogical Faculty
Catholic University Ružomberok
Nam. A. Hlinku 56
034 01 Ružomberok
Slovakia

Email: majherova@fedu.ku.sk