Integration of Fuzzy System into Genetic L-System Programming Based Plant Modeling Environment with Mathematica

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Abstract: Modeling of the plant growth can be visualized using the approach of Lindenmayer System (L-System). The L-System is generally used as the backbone to develop the realistic modeling for the plant’s growth. The Genetic L-System Programming (GLP) is evolutionary creation and development of parallel rewrite systems (L-Systems) which provide a commonly used formalism to describe developmental processes of natural organisms. To make the condition close to the real environment characteristic, it is required the axiom and syntax grammar for the L-System. In this paper, we propose the use of fuzzy system together with the Genetic L-System Programming method, to model the plant’s growth based on the current environment condition. At the beginning of plant growth, let the sprout of plant initially be denoted as axiom. This characteristic rules are illustrated in the reproduction of Genetic L-System Programming (simulated evolution and simulated structure formation) also occur in nature of plant growth conditions based on fuzzy system. The software used in this modeling is Mathematica. The growth parameters value is given based on the fuzzy system, the plant growth is visualized with the L-System method, controlled evolution of complex structures is exemplified by the development of tree structures generated by the movement of a 3D-turtle and the 3-Dimension graph is shown as the virtual plant growth. In this research, some samples of axiom have been given based on fuzzy system. This research also demonstrates that the Genetic L-System Programming is able to show the characteristic and structural visualization on the plant growth according to the environment.

Key word: L-System, modeling, fuzzy system, virtual plant growth, visualization.

INTRODUCTION

The modeling of plant growth is initialized by Aristid Lindenmayer, when he introduced the theory of Anabaena catenula cell growth using the method called rewriting string. Later on, this rewriting string is known as the Lindenmayer System (L-System) (Lindenmayer, et al., 1990).

Parallel rewrite systems or L-systems provide a useful formal model for the description of developmental processes in organisms. We will give some rudimentary definitions for context-free L-systems with stacking capability. As it is in general very difficult to create an L-system simulating some special growth process we will introduce a Genetic L-System Programming supporting L-system (Jacob, 1995) inference.

The development of L-System to explain the plant growth based on the environment condition can be seen on (Mech, et al., 1996). It is then improved by (Prusinkiewicz, et al., 2003). The basic concepts of axiom and rules are the basis of how the growth of L-System that works (Viruchpintu, 2005). It also has been identified that the environment also effects the plant growth (Karwowski, 2006). The L-System method can explain the way how the plant growth using grammar (Church, 2007).

At the beginning of plant growth, the sprout of plant initially denoted as axiom. Let axiom be the sprout of plant at the beginning of plant growth. This characteristic rules are illustrated in the further improvement of L-System that follows the plant growth naturally. It is followed by the growth of stalk, branch, leaf and bloom. The rule of plant growth is represented by the axiom. On the other hand, the value of axiom is generally generated using the probability (Atris, et al., 2010). To make the axiom value closer to the real environment condition, we propose the use of fuzzy system.

This research is aimed to generate plant growth with Genetic L-System Programming using axiom based on the fuzzy system. Design of plant growth used Mathematica programming (Heikki, 2009) on Windows Operating System. The output graphic on 3D reflected on plant growth as a virtual plant growth system.

Methods:

Research is carried out at Multimedia and Networking Laboratory, ITS Surabaya. Some references on plant growth are also used. Some data is collected on the plant growth based on the extra inorganic fertilizer (Nitrogen (N), Phosphor (P) and Potassium (K) and also organic fertilizer.

This research used Zinnia Elegante Jacq, organic fertilizer and inorganic fertilizer (Urea (N), Super Phosphate (P), Potassium Chloride (K), POC NASA and Harmonic with concentration 2 cc/l). Some tools are used, such as electric scale, leaf area meter, oven, termohigrometer and lux meter. Sample data are taken from...
the plant after 26 days from transplanting (HST). In this research, the amount of fertilizer given varies. The field
is in Karangploso, Malang, East Java. The data collection is taken between Januarys until May 2011.

Fig. 1: Shows the research methodology for Integration of fuzzy system into an L-System.

Fig. 1. Shows the research methodology, the observations are carried out in 2 things, the plant growth itself
and the environment. The plant growth observations are carried out by collecting data of the plant based on the
height, the stalk diameter, leaf (which includes height, width and area), the bloom diameter. On the other hand,
the environment observations include putting different combination of fertilizer, temperature, weather, humidity
and light intensity.

RESULTS AND DISCUSSION

The Design of Plant Growth Using L-System Method:

D0L-systems (D0 meaning: deterministic with no context) are the simplest type of L-systems. Formally a
D0L-system $L=(∑, a, P, T)$, capable of encoding geometrical structures, consists of the following ingredients: a)
an alphabet $∑=(δ_1, ..., δ_n)$, each symbol of which stands for a morphological unit, like a sprout, a stalk, a leaf and
a bloom b) a start string $α$, referred to as the axiom, which is an element of $∑$, the set of all finite words over the
alphabet $∑$, c) $P = (p_1, ..., p_n)$, a set of productions or rewrite rules, d) a geometrical interpretation $T$, a 3D
semantics for some of the symbols from $∑$, translating a string into a spatial structure, i.e. special symbols
represent commands to draw graphic objects like points, lines, polygons etc; this translation is commonly
known as turtle geometry interpretation.

Let us consider the following L-system: $G$

$Σ = \{a, b, c, d, e\}$

$ω = abc$

$P_1$ $a → bc$

$P_2$ $c → ae$

which generates the following sequence of strings:

Axiom : $abc$

Iteration 1 : $bcbae$

Iteration 2 : $baebbce$

Iteration 3 : $bbccebbaee$

In this case, some samples of Zinnia Elegane Jacq plant, Figure 2 shows an example L-system describing
growth sequences of sprouts, leaves and blooms of virtual plant, together with its graphical interpretation. The
D0L-system encodes turtle geometry macros for generating graphical representations of the leaves, blooms and
stalks.

Fig. 2: Visualizing growth stages of Zinnia Elegane Jacq plant modeled by the D0L-System.

The D0L-System encodes turtle geometry macros for generating graphical representations of the leaves,
blooms and stalks. An each symbol, f represent commands to move forward the turtle, b represent commands to
move backward the turtle and change the drawing tools orientation by rotation around its longitudinal, lateral,
and vertical axes is rl (roll left), rr (roll right), pu (pitch up), pd (pitch down), yl (yaw left) and yr (yaw right),
thus translating a one-dimensional string into a 3D geometrical object resembling a plant (some of these
commands do not occur in the example L-system).
The kLSystems package in MathEvolvica (Jacob, 1995) contains definitions for the application of parallel rewrite rules of L-Systems with left and right contexts with arbitrary length. Each rule of the form \(1 < p > r \rightarrow s\) as described above is represented by a Mathematica expression of the form `LRule[LEFT[1], PRED[p], RIGHT[r], SUCC[s]]`.

Accordingly, we define the production set as an LRULES expression `LRULES[ LRule[...], LRule[...], ...]` and an L-system is described as follows: `LSystem[ AXIOM, LRULES[__LRule]` With this representation we can easily derive the type of the expressions and sub expressions by only looking at sprout symbols. Application kLSystems package in MathEvolvica at plant growth of Zinnia Elegane Jacq (Lydia Kristi, 1998) can be expressed and visual zinged as virtual plant growth.

**Genetic L-system Programming:**

Genetic Programming (GP) has been introduced as a method to automatically develop populations of computer programs through simulated evolution (Koza, 1994). Considering L-systems as rule based development programs it is easy to define program evolution. Each program encoded as a symbolic expression has to be interpreted and is assigned a fitness value dependent on the optimization task to be solved. Principally, we want to be able to change any sub expression within the developmental programs which should not be considered as parameterized modules encoding some fixed L-system in a black box fashion (Niklas, 1986).

The following is a small collection of operators used for generating variations on expressions: (1). Mutation (2). Crossover. (3). Deletion. (4). Permutation. With a set of templates defined for each operator the effects of genetic operators can be constrained in a problem specific way. A more detailed description of a general scheme for the application of genetic operators on expressions can be found in (Jacob, 1995). Application Evolvica package (kLSystems, ExprGeneration, ExprModification, TurtleIntrepretation) in MathEvolvica at plant growth of Zinnia Elegane Jacq can be expressed templates serving as building blocks to generate L-system encodings.

The fitness for each individual is calculated for the strings generated after a fixed number of L-system iterations and their resulting graphical interpretation. The growth processes per se were included in the fitness evaluation. The demonstrate with a final example in this section how the dynamics of the structure formation can be included into the fitness function (The Code in Listing 1). The fitness is computed as the sum of the blooms for each L-system iteration.

**Listing 1:** The Code of fitness function for sum of the blooms.

```
If[Length[coordinates] > 1, 
{maxXCoord, maxYCoord} = 
Max[coordinates]; 
fitness = maxXCoord + maxYCoord; 
fitness]
```

The individual is selected according to its fitness. This plant is then run evolution experimentally at L-system for ten generations and ten iterations. The evolution result is shown in Figure 5. Based on this result, the best fitness occurs in 4th generation 3rd iteration and it also occurs in 7th generation 2nd, 4th iteration.

**The Integration of Genetic L-system programming and Fuzzy System:**

A fuzzy dynamic model has been proposed by (Takagi, 1985) to represent locally linear input/output relations for nonlinear systems. This relationship is generally the interactions among various elements of a growing structure and the environment. The fuzzy system output is used as values for the growth parameter, such as various elements of a growing structure which are sprout, stalk, leaf and bloom.

The experiment is conducted to the plant growth of Zinnia Elegane Jacq with various kinds of treatments. As an example, treatment 1 is without any fertilizers. Treatment 2 is with no organic and medium amount of inorganic, and so on. The amount of fertilizer that suits the plant growth will generate the growth parameter, as shown in Table 1.

**Table 1:** Growth Parameter from the treatment of various amount of fertilizer given to Zinnia Elegane Jacq.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stalk High (cm)</th>
<th>Leaves High (cm)</th>
<th>Leaves Width (cm)</th>
<th>Bloom Diameter (cm)</th>
<th>Plant High (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.3</td>
<td>9.9</td>
<td>5.7</td>
<td>18.7</td>
<td>51.2</td>
</tr>
<tr>
<td>2</td>
<td>9.4</td>
<td>10.4</td>
<td>6.5</td>
<td>19.7</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>10.1</td>
<td>6.8</td>
<td>21.1</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>9.3</td>
<td>10.3</td>
<td>5.8</td>
<td>23.3</td>
<td>51.8</td>
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<tr>
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<td>5.8</td>
<td>20.7</td>
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</tr>
<tr>
<td>6</td>
<td>10.9</td>
<td>10.4</td>
<td>6</td>
<td>19.2</td>
<td>58.2</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>10.4</td>
<td>6</td>
<td>23.2</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>10.5</td>
<td>6.1</td>
<td>25</td>
<td>55</td>
</tr>
</tbody>
</table>
In this observation, the measurement of plant growth is divided into two parts: a) 15 data is used as the parameters for the fuzzy system, as in table 1, b) 5 data is used as a comparator to the output of fuzzy system.

The modeling of fuzzy system with *Mathematica* software is using 2 parameter inputs which are combination of inorganic fertilizer and organic fertilizer and one parameter output which is the growth parameter (Stalk Height, Leaves Height, Leaves Width, Bloom Diameter, Length Branch, Number of Branch, Number of Bloom and Plant Height).

A crisp set is described by a characteristic function whose value is always either 0 or 1. A fuzzy set is defined by a membership function that takes values anywhere between 0 and 1. In a fuzzy system, we might represent the sets of low, medium, and height by the fuzzy membership functions (Purnomo, 2000). To present the fuzzy membership functions of organic fertilizer input (The Code in Listing 2), inorganic fertilizers input and stalk output, and defineSet function within *Mathematica* is used (Freeman, 1994).

<table>
<thead>
<tr>
<th></th>
<th>11.4</th>
<th>10.7</th>
<th>6.2</th>
<th>26.7</th>
<th>61.5</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
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<td>6.2</td>
<td>27.8</td>
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<td>27</td>
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</tr>
<tr>
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</tr>
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<td>12.7</td>
<td>11.4</td>
<td>6.6</td>
<td>31</td>
<td>61.5</td>
</tr>
</tbody>
</table>

**List. 2:** The Code of defineSet function for organic fertilizer.

**Fig. 3:** Rule of fuzzy system to identify the growth parameter.

Figure 3 shows the Rule of fuzzy system to identify the growth parameter based on the data measurement in research field. With these sets, fuzzy associations are defined. Fuzzy associations could be explained as the relation between various combinations of inorganic and organic fertilizers to generate growth parameter (sprout, stalk, leaf, bloom).

As an example, if the amounts of organic and inorganic fertilizers are *medium* (50%) and *medium* (50%), respectively, then the stalk (the growth parameter) is *medium*. It is then diagram as Figure 4.

**Fig. 4:** Two rules are combined to produce an output fuzzy set from an input \((\phi_1, x_1)\). The numerical output of the system is the centroid \(B_c\) of the output set.
To find the actual stalk value, the output fuzzy set is converted into a numerical value for $B_c$. This process is called defuzzification. The defuzzification process, as in equation (1), is a process to find the stalk value at the centroid output fuzzy set.

$$B_c = \frac{\int B f(B) dB}{\int B dB} \quad (1)$$

The output of the fuzzy system, is then compared to the actual data of plant growth in the field. From this figure 5, it can be seen that the difference between fuzzy system output and the actual plant growth is less than 7% on average.

![The simulation output is then compared to the actual data](image1)

**Fig. 5:** The comparison of simulation and actual output.

From the inference output of the fuzzy system, it can be derived the growth parameter from the mixture fertilizer that is already used. It is then implemented to the plant, in such a way that it is possible to get the crop as expected.

Once the stalk growth is obtained, then the leaf and bloom growth need to be found using the similar method of the fuzzy system. Those three values are then become the inputs that is applied to the best evaluated plant structure in the $7^{th}$ generation and the $2^{nd}$ iteration, which is then called as the $7.2^{th}$ generation. In order to visualize the plant, the virtual growth of Zinnia Elegance Jacq with the $5^{th}$ treatment (Both inorganic and organic fertilizer is high) is shown in figure 6.

![Growth processes of the best plant of generation 7,2.](image2)

**Fig. 6:** Growth processes of the best plant of generation 7,2.

**Conclusions:**

This research shows that the integration of fuzzy system into a Genetic L-system programming based Plant modeling Environment has been developed in software Mathematica and the method is ready to use for virtual plant growth applications. In this research it can be demonstrated that the difference between fuzzy system output and the actual plant growth is less than 7% on average. It is concluded from this research that the
agriculture of Zinnia Elegane Jacq plant could be develop further with the fuzzy system, which both controlled environment and controlled mixture of fertilizer are used as decision support system.

REFERENCES


