Adaptive L-system

Lin Lin Shing, and Lieu-Hen Chen
http://www.csie.ncnu.edu.tw
National Chi Nan University
Tel: 886-49-910960 ext. 4861   Fax: +886-3-8662781
E-mail: u7321014@ncnu.edu.tw

0. Abstract

In the research field of computer graphics, L-System is the most well-known method to simulate the growth of plants and construct the models of plants. Since it was proposed in 1972, L-system has evolved into several different versions for the capability and flexibility to simulate much more complicated 3D structures of plants. However, the more powerful the L-System evolves the more complicated and difficult its grammar grows. Furthermore, it is still very difficult to simulate the interactions between the plant organs and environment. These problems seriously restrict users to simulate the growth of plants with L-System.

In this paper, we propose a simulation system named SimEco to solve the above-mentioned problems by integrating the Particle System into the L-system. The basic concepts of SimEco are to describe the hierarchical botanic structure of plants by L-System, and to perform the physical effects which act on the plant organs by particle system. The complexity of L-System grammar is therefore reduced substantially. In the meanwhile, the 3D models of organs are deformed by the trajectory of particles which represent the growth path of organs, to provide the variety and flexibility of plants modeling. Through its original two-layered mechanism, SimEco also provides a solution to perform the botanical properties of phototropism and negative geotropism, and the physical effects of collision and gravity during simulating the growth of plants. Moreover, the feedback interface between the L-system layer and particle system layer enables further interactions between plants and environment to be proceeded. Experiment results show that our SimEco system successfully simulates the growth of plants and synthesizes interesting images.

1. Introduction

In the field of computer graphics, simulating and modeling the growth of plants are very interesting research topics. Most of the 3D plant models are constructed manually by using 3D CAD tools. Creating a lifelike plant model in this way is a very time-consuming and laborious task, not to mention the fact that the botanic correctness should be taken into account.

To model plants confirming to the botanic correctness, the L-system method is proposed in 1972 and has become one of the mainstream methods in the research field of computer graphics. L-System enables users to combine the botanic properties of plants into the format of the formal language. A string which is generated by iterating itself through the production rules of an L-System grammar represent the 3D hierarchical structure of plants. Because the botanic information such as the phyllotaxy, inflorescence, and the growth strategies are reflected in the composition of the L-system grammar, the string generated by this grammar therefore represents the properties of plants correctly. In recent years, the grammar structure of L-System has been modified and evolved continuously to represent much more complicated structures of plants and improve the botanic correctness. Among these previous research works, the most important and powerful one to simulate the varieties of plants is the parametric L-System. Parametric L-System improves the representation power of its grammar by passing enormous parameters to interchange information between different organs. Therefore, the grammar of parametric L-System grows more and more complicated. The more powerful the L-System evolves the more complicated and difficult its grammar grows, and consequently becomes too hard to be written and understood.

To solve the above-mentioned problems, we develop a simulation system named SimEco by integrating the Particle System into the L-system in this paper. The basic concepts of SimEco are to describe the hierarchical botanic structure of plants by L-System, and to perform the interactions among the plant organs and environment by particle system. The organs of plants, such as leaves and stems, are simultaneously represented by the alphabets in L-system and particles in particle system. Thus, our SimEco system basically consists of two layers, the L-system layer and the particle layer.

After the interactions between plants and environment are simulated at the particle stage, SimEco system deforms the 3D models of plants according to the calculated trajectory of particles. This approach provides a very flexible way to model and synthesize various images of plants.

In the following of this paper, a brief introduction to the L-system layer and particle system layer of SimEco system is given first. The configuration and implementation of the SimEco system are then explained. The experiment results and conclusion are given in the final section.

2. The L-system layer and the particle layer of SimEco system

2.1 L-system

SimEco system uses the non-deterministic and non-propagating L-System to describe the botanic structure of plants, such as the phyllotaxy and inflorescence of plants. The property of non-deterministic L-System uses multi-rulers to describe the multiple growing strategies of plants. Each production rule has its own probability which is selected by L-System. Therefore, two strings which are iterated from the same grammar may be completely different. The non-propagating L-System allows system to eliminate dead organs and reduce the redundancy of strings.

2.2 Particle System

In SimEco system, the particle system is used to calculate the physical effects which act on the organs of plants, such as the phototropism and collision avoidance of stems. In SimEco system, each organ of the Plant is treated as an independent particle generator. Each particle generator will shot particle(s) according to the types of the organs. By calculating its trajectory hierarchically, the 3D position, orientation and other physical properties of each organ can be determined. This approach removes most of the parameters used in the traditional parametric L-system. The complexity of L-System grammar is therefore reduced substantially. The feedback interface which updates the probability used by L-System also provides a mechanism to simulate the interactions between plants and environment. Each particle inherits its own information from its parent and updates this information along with the proceeding of lifecycle. This information consists of the relative position and orientation to the parent, the relative velocity and mass, and the duration of lifecycle.

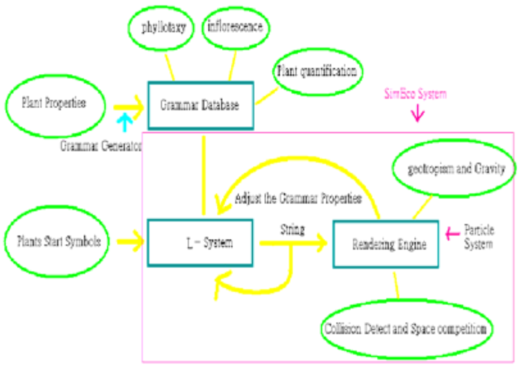
Since particles have been added into 3D scene by particle generators, every particle flies and changes its trajectory by interacting with environment. The trajectory of particle provides SimEco system very important information which is used to arrange and deform the models of plants. In fact, when system renders the plants according to the hierarchical structure of L-system, the trajectory of particle represents the growing path of the relative organ in 3D space. The calculated result trajectory therefore determines not only the position but also the orientation and the basic skeleton of the organ. Because every 3D models are deformed according this skeleton, two organs with the same base model may have completely different appearances. This approach enables users to synthesize very complicated plants with various appearances by only using a few cheap and simple 3D models of basic organs of plants.

2.3 Integration of L-System and Particle system

SimEco system combines non-deterministic and non-propagating L-system and particle system. When strings generated by L-System are fed to the rendering engine, each alphabet of strings will be treated as a particle generator. Each particle generator in Rendering Engine inherits the end position and end velocity of its parent particle. Generally speaking, each particle generator ejects only one particle. This particle then flies according to effects of environment, such as gravity or sunshine. In fact, the trajectory of particle is the skeleton of organs. SimEco system will set up models of organs in terms of the skeletons of organs.

3. System configuration and implementation

In this paper, a simulation system named SimEco System is proposed and developed. SimEco system provides a script language named SimEco Script for user to describe the botanic properties of plants and environment.

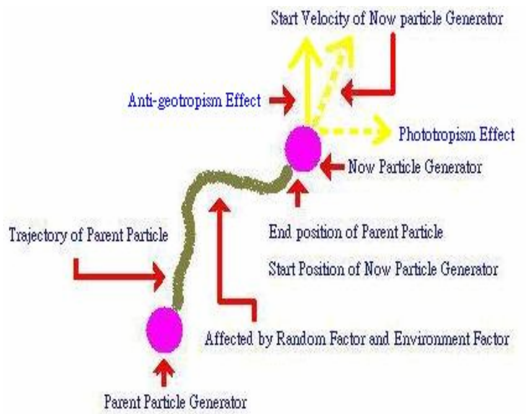


The above figure is the system dataflow of SimEco. First, SimEco system will interpret the plant grammar which is written by tools and users in order to obtain the properties of environment, the stages and the growing grammars of each plant defined in the garden. The system repeatedly iterated the plant grammars in terms of the growing grammars and the strings of plants generated by L-System possess the hieratical relationship among organs. L-System delivers strings step by step. When obtaining strings form L-System, Rendering Engine will calculate the actual 3D position of organs in terms of the interaction among influence of environment and particles.

SimEco Script has a hierarchical architecture as following.

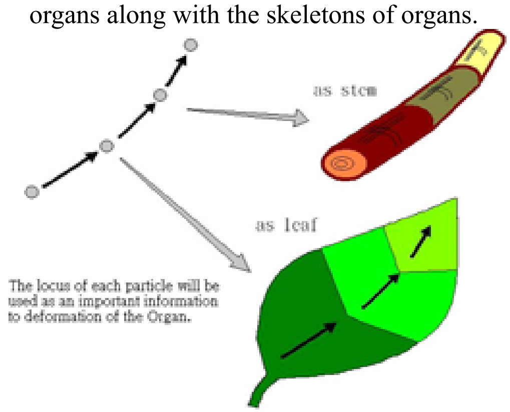
```
EcoSystem 1.0 "MySys" {
    ... (Environment properties)
    Plant "Brush" {
        ... (Plant properties)
        Apex {}
        Stem {
        ... (Stem properties)
        }
        Leaf {
        ... (Leaf properties)
        }
        Grow {
        ... (L-System Grammar)
        }
    }
    ... (Other Plant properties)
}
```

SimEco Script allows users to define the environment influence upon plants, for example of gravity. The effects of the environment affect each trajectory of particles shot by particle generator. Each particle is shot by its particle generator and initialized in terms of end position and end velocity of parent particles shot by parent particle generator.

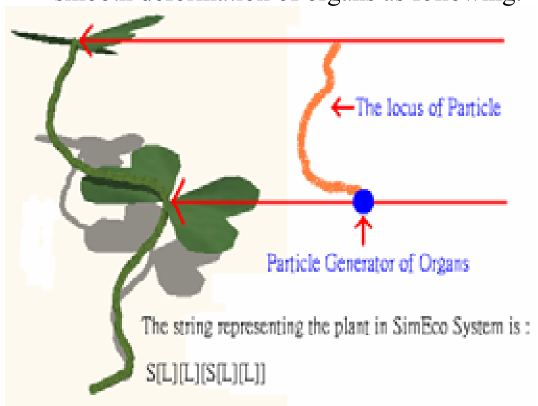


SimEco System builds up models of Organs according to the trajectory of particles. Deforming models of organs according to skeleton provides SimEco system for three advantages:

(1) SimEco System will not beforehand need complex models of organs supplied by users because of using smaller and simpler models to reconstruct organs along with the skeletons of organs.



(2) SimEco System will obtain the more varied and smooth deformation of organs as following.



(3) Because system treats the interaction between organs of plants and environment as an interaction between particles and environment, this approach reduces the complexity of the calculation for interaction. SimEco System considers the growing tactic of each particle independently.

Because each organ of plants is viewed as trajectory of particles independently, system uses divide-and-conquer algorithm to solve collision detection of plant by way of solving collision detection of particles. SimEco System provides a collision detection algorithm to solve collision of single particle in order to solving collision of plants.

Each particle tests its coming position to determine whether collision happens or not. When collision courses, the strategy of collision avoidance affects the result trajectory of particles.

$$\overrightarrow{NewVel} = (C_i - i)^{f(i)} * \vec{V} + i * \vec{R}$$

Where,

i : Now segment number of particles.

C_i : The collision segment number of particle.

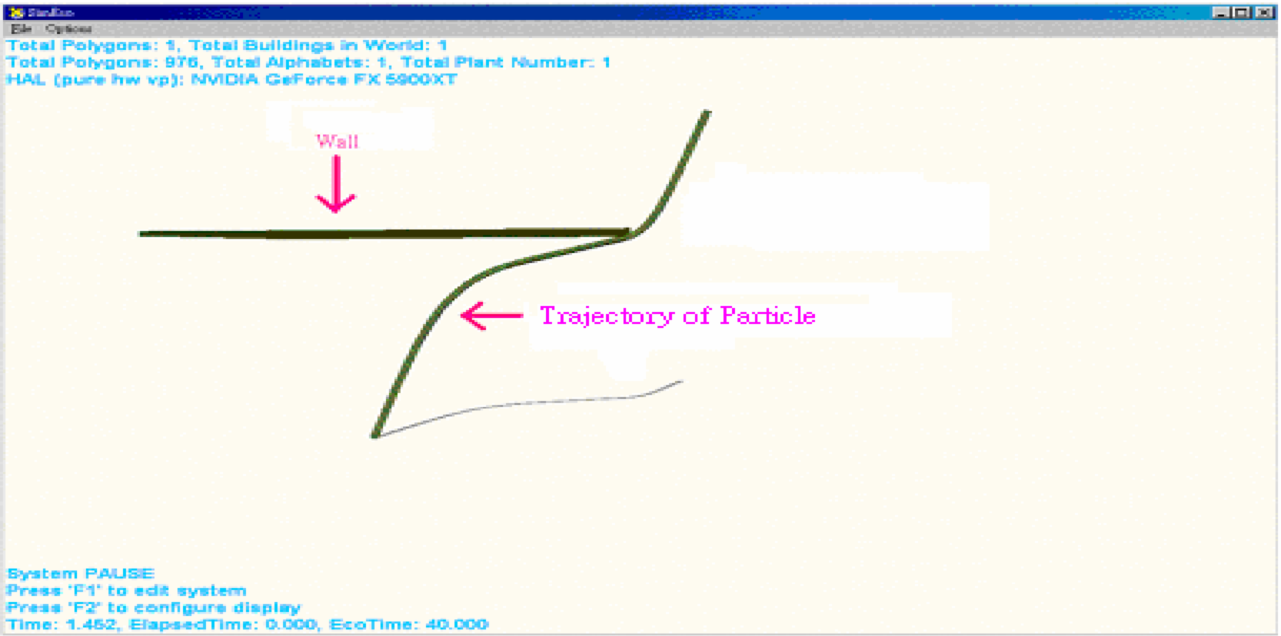
$\overrightarrow{NewVel}$: New velocity of particles after take in count the collision.

$f(i)$: The attraction of collision object.

$\vec{V}$: Original velocity of particles with interaction among effects of environment..

$\vec{R}$: directional vector of surface.

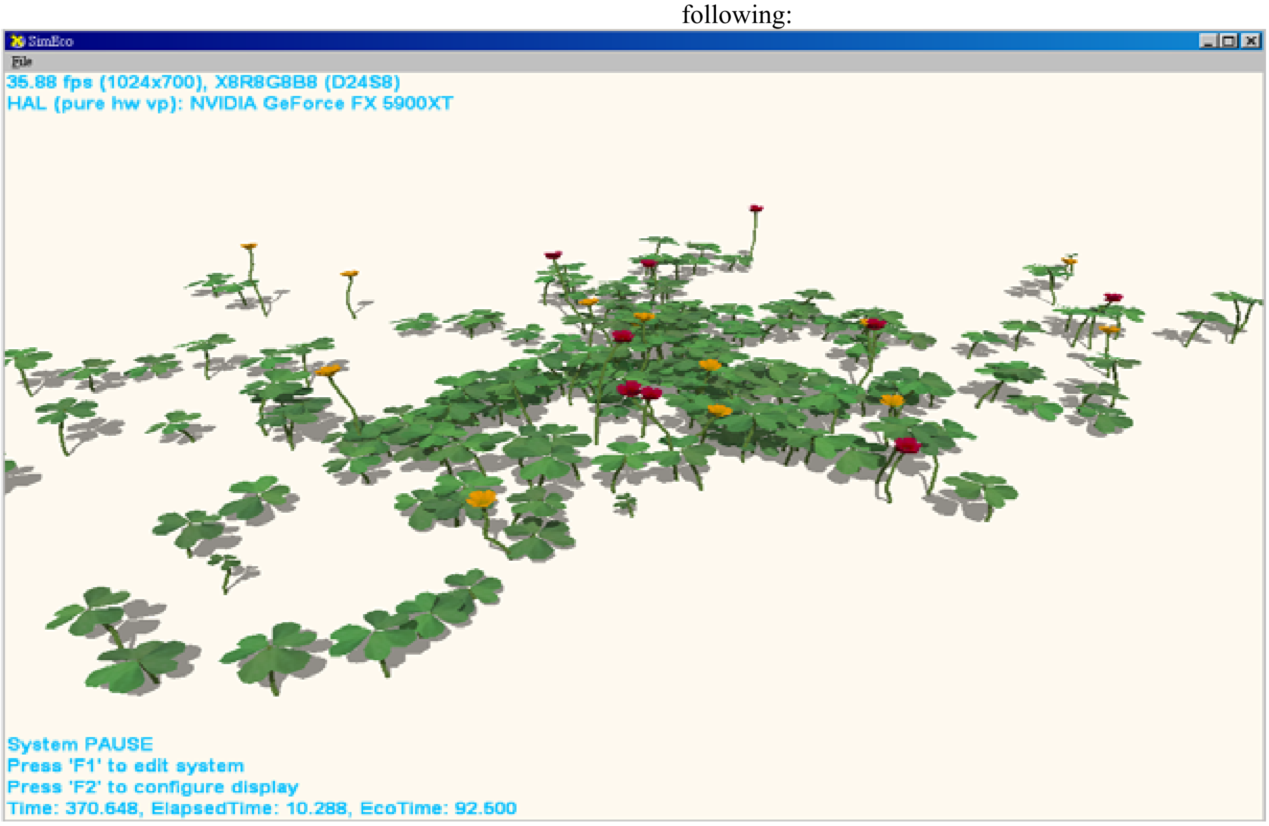
The experiment result of collision detection in SimEco System are shown and explained in the following figure.



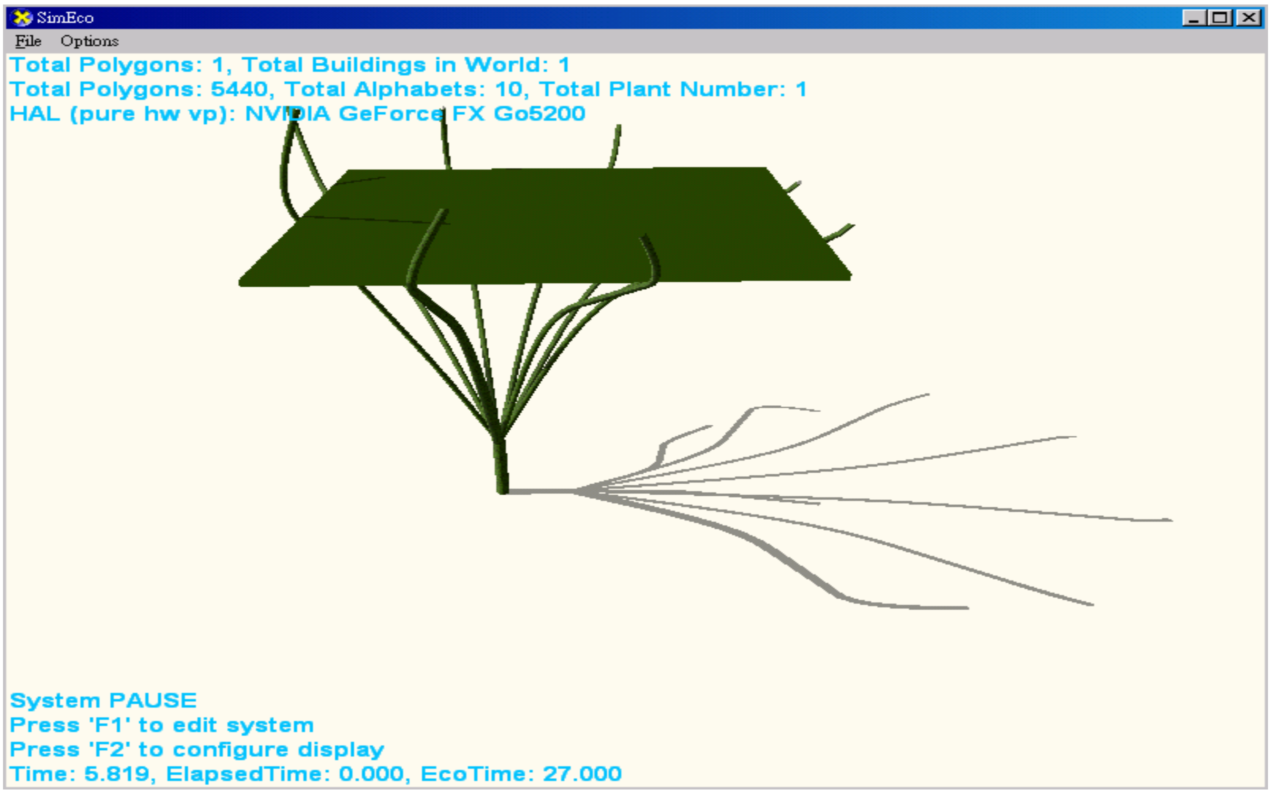
4. Result

By integrating the L-system with the particle system, SimEco reduces the complexity of L-System grammar substantially. The interactions between environment and particles are also simulated and affect the appearance of plants. SimEco provides an efficient and elegant solution to simulate and calculate these interactions, including of phototropism and collision avoidance, which are very difficult to be implemented by traditional L-systems.

The visual effect of random factor and anti-geotropism on creeping oxalis is shown as following:



The visual effect of collision avoidance and deformation on stems without leaves is shown as following:.



The equipments of SimEco System are described as following:

CPU: Inter® Pentium® 4 CPU 2.0GHz;

Ram: 1.00GB Ram;

Graphics Card: NVIDIA FX 5900 XT 128MB DDR

5. Reference

1 Adaptive L-System. U hao Chen, Lin Lin Shing, and Lieu-Hen Chen, Computer graphics Workshop 2003.

2 Przemyslaw Prusinkiewicz, Aristid Lindenmayer, James Hanan. Development models of herbaceous plants for computer imagery purposes. ACM SIGGRAPH Computer Graphics, Proceedings of the 15th annual conference on Computer graphics and interactive techniques June 1988 Volume 22 Issue 4, page(s): 141-150

3 Radomír Měch, Przemyslaw Prusinkiewicz. Visual models of plants interacting with their environment. Proceedings of the 23rd annual conference on Computer graphics and interactive techniques August 1996, page(s): 397 - 410

4 Lindenmayer, G. Rozenberg. Developmental systems and languages. Proceedings of the fourth annual ACM sumposium on Theory of computing May 1972, page(s): 214 - 221

5 The use of positional information in the modeling of plants. Proceedings of the 28th annual conference on Computer graphics and interactive techniques August 2001. Page(s): 289 – 300

6 William T. Reeves, Ricki Blau. Approximate and probabilistic algorithms for shading and rendering structured particle systems. ACM SIGGRAPH Computer Graphics, Proceedings of the 12th annual conference on Computer graphics and interactive techniques July 1985 Volume 19 Issue 3 Appendix, page(s): 313 – 322

7 Jason Weber, Joseph Penn. Creation and rendering of realistic trees. Proceedings of the 22nd annual conference on Computer graphics and interactive techniques September 1995, page(s): 119 – 128

8 Shlyakhter, I.; Rozenoer, M.; Dorsey, J.; Teller, S. Reconstructing 3D tree models from instrumented photographs. IEEE Computer Graphics and Applications , Volume: 21 Issue: 3 , May/Jun 2001, page(s): 53 -61

9 Przemyslaw Prusinkiewicz. Simulation modeling of plants and plant ecosystems. Communications of the ACM July 2000, Volume 43 Issue 7, page(s): 84 - 93

10 Kokai, G.; Toth, Z.; Vanyi, R. Evolving artificial trees described by parametric L-systems. Electrical and Computer Engineering, 1999 IEEE Canadian Conference on, Volume: 3 , 1999, page(s): 1722 -1727 vol.3

11 Stefanovski, S.; Loskovska, S.; Mihajlov, D. Representation and realistic rendering of objects defined by L-systems. Mediterranean Electrotechnical Conference, 1998. MELECON 98, 9th, Volume: 1, 1998, page(s): 86 -90 vol.1

12 Nagahashi, H.; Niwa, A.; Agui, T.; Competition and mutualism in a simulation of adaptive artificial organisms. Evolutionary Computation, 1995., IEEE International Conference on , Volume: 2 , 29 Nov-1 Dec 1995 , Page(s): 695 -700 vol.2

13 Thimbleby, H.W.; Witten, I.H.; Pullinger, D.J.; Concepts of cooperation in artificial life. Systems, Man and Cybernetics, IEEE Transactions on , Volume: 25 Issue: 7 , Jul 1995 , Page(s): 1166 -1171

14 Banzhaf, W.; Artificial selection in a system of self-replicating strings. Evolutionary Computation, 1994. IEEE World Congress on Computational Intelligence., Proceedings of the First IEEE Conference on , 27-29 Jun 1994, Page(s): 651 -655 vol.2

15 Shiyong Dai; Hu Cheng; A general procedure of self-propagation. Evolutionary Computation, 1995., IEEE International Conference on , Volume: 1 , 29 Nov-1 Dec 1996 , Page(s): 501

16 Fulkerson, B.; Parunak, V.; The living factory: applications of artificial life to manufacturing. Autonomous Decentralized Systems, 1995. Proceedings. ISADS 95., Second International Symposium on , 25-27 Apr 1995 , Page(s): 391 -397

17 Przemyslaw Prusinkiewicz, Mark Hammel, Radomír Měch; The Artificial Life of Plants. Artificial life for graphics, animation, and virtual reality, volume 7 of SIGGRAPH ’95 Course Notes, pages 1-1–1-38