

Chapter 2

Literature Review

This chapter surveys the publications related to several leaf modeling and growth simulation techniques. The chapter consists of three sections. The first section reviews about the researches that are related to the leaf model. The literatures related to branching structure are reviewed in the second section. The last section illustrates the researches concerning to the leaf growth simulation.

2.1 Review of Literatures Related to Leaf Model

Since the mathematical model called L-system was introduced by Aristid Lindenmayer for simulation of plant development in 1968 [1], plant modeling has received considerable attention. Several methods had been proposed to generate the plant model and its components. Past efforts on computer generation of plants generally have focused on branching patterns [1, 3, 4, 5, 6, 7], limbs and leaves were constructed from basic primitives [1, 4, 5, 6].

Peter E. Oppenheimer showed an exaggerated image of vein branching in a falling leaf [8]. The external boundary shape was the limit of growth of the internal vein fractal computer model.

Przemyslaw Prusinkiewicz, Aristic Lindenmayer and James Hanan [9] presented a method for modeling herbaceous plants using formalism of L-systems in 1988. The idea was to achieve realism by simulating mechanisms, which controlled the plant growth in nature. The developmental approach to the modeling of plant architecture was extended to the modeling of leaves and flowers constructed by closed and filled polygons.

In 1992, a method for modeling compound leaves in plants was proposed by Mark S. Hammel, Przemyslaw Prusinkiewicz, and Brian Wywill [10]. The paper focused on the specification and tracing of the margin. The layout of leaf lobes was captured by a branching skeleton, which generated using an L-system. The margin was defined as an implicit contour.

Przemyslaw Prusinkiewicz developed the modeling of biological structures and simulation of their development, and proposed new procedural techniques for realistic image synthesis [11]. The paper reviewed mathematical models of morphogenesis capable of producing realistic images of modeled patterns and forms. The venation pattern is generated by using Meinhardt's model of net-like structures on a hexagonal grid, and applied the principle of cellular automata to develop the geometric model in expanding space.

Keimei Kaino proposed a new modeling method called origami model [12]. By using this model, it was shown that complex digitate shapes such as *Acer*, *Cacalia yatabei* and *Humulus lupulus* would be well produced.

The model of an unfold leaf was proposed by H. Kobayashi, B. Kresling, and J.F.V. Vincent in 1998 [13]. Leaves of hornbeam (*Carpinus Betulus*) and beech (*Fagus Sylvaticus*) were modeled at the first approximation as plane surfaces, with straight parallel folds, using numerical methods.

Bernd Lintermann and Oliver Deussen presented a modeling method and graphical user interface for the creation of natural branching structures such as plants and their parts [14]. The model was represented graphically as a structure graph and can be edited interactively.

Chidchanok Lursinsap, Peraphon Sophatsathit, Suchada Siripant and Y. Shinagawa [15] concentrated their study on the problem of how to mathematically model the growth of leaf networks. Although a unified rewriting system that could generate any shape of leaf was proposed, the rewriting system was still far from the actual leaf shape. This is due to the curvature function of each branch interval and the branch length.

In 2000, the Origami modeling method of plant leaves [16] were proposed again by Keimei Kaino, Kuniaki Yajima and Norishige Chiba. They generated complicating venation of digitate leaves and gave realistic images of their budding process. Using the modeler, they could generate plant stems and various kinds of CG images of Japanese flower arrangement.

Somporn Chuai-aree, Suchada Siripant, and Chidchanok Lursinsap visualized their realistic model of plant based on bracketed L-system [17]. Leaves were represented using triangular polygons and made more realistic by a polygon mapping.

In 2001, Yodthong Rodkaew, Suchada Siripant, Chidchanok Lursinsap, and Prabhas Chongstitvatana proposed a combined method of L-system and Genetic Algorithm (GA) techniques for a rewriting expression describing leaf shapes [18].

Przemyslaw Prusinkiewicz, Lars Mündermann, Radoslaw Karwowski, and Brendan Lane [19] integrated into plant models three elements of plant representation identified as important by artists: posture, gradual variation of features, and the progression of the drawing process from overall silhouette to local details. Concerning leaf, an algorithm for modeling leaves and stems of a herb lily and a tulip that can control bending, twisting, and tapering of a generalized cylinder was proposed. They also used positional information to model a *Pellaea falcata* (sickle fern) leaf. But the detail of each leaf was not described in the paper yet.

A new algorithm for generate complex structure such as vein images of leaf was proposed by Yodthong Rodkaew, Suchada Siripant, Chidchanok Lursinsap, and Prabhas Chongstitvatana [20]. The algorithm created vein images from the trails of particles that scattered within a given leaf shape. The figures generated from this algorithm look very natural.

Stefan Maierhofer and Robert F. Tobler presented a user interface, which allows for semi-automatic extraction of parameters for leaf models directly from photograph [21]. A leaf component was defined by a set of control points, which specified the leaf outline, and an axial and lateral cross-section.

2.2 Review of Literatures Related to Branching Structure

Branching structures were used to explain complex structure such as plants and their components. Several branching model had been proposed by researcher. Jules Bloomenthal presented a method for representing tree skeleton and limb [22] consisting of spline segments as the outgoing limbs branched from branch points. A spline segment could be controlled by tended function.

In 1988, Peter E. Oppenheimer presented a fractal computer model of branching objects such as complex gnarled trees, leaves, and vein systems [8]. The geometry and topology of the model are controlled by numerical parameters, which are analogous to the organism's DNA.

Herein presented a new procedural method for generating images of trees. Xavier Gérard Viennot, Georges Eyrolles, Nicilas Janey, and Didier Arquès presented their approach differed from the previous methods [23]. They began by defining a certain “measure” of the form of a tree or a branching pattern. Their method had a powerful control of the final form, simple enough to produce quick designs of trees without losing in the variety and rendering of the images.

In 1993, Przemyslaw Prusinkiewicz proposed several methods for modeling and visualization of biological structure [11]. He used Meinhardt’s model of net-like structures on a hexagonal grid and principle of Gottlieb’s method to generate a leaf vein pattern. Branching structures generated by Ulam’s cellular automaton operating on a triangular grid. Cellular automata and Voxel automata were applied to model the tree trunk with roots.

Norishige Chiba and Shunichi Ohkawa proposed three-dimensional geometrical models that could change their shapes by changing parameter [24]. Shapes of branching model were controlled by effective of heliotropism and dormancy break.

Geoffrey B. West, James H. Brown, and Brian J. Enquist described branching structure in mammal and plant using scaling laws in biology [25]. They proposed a common mechanism that underlies these laws: Living things are sustained by the transport of materials through linear networks that branch to supply all parts of the organism. They developed a quantitative model that explains the transport system.

In 1998, biological structure such as blood vessels were implemented in virtual reality form using the method called “CCO (Constrained Constructive Optimization)” by R. Karch, W. Schreiner, F. Neumann, and M. Neumann [26,27]. The images of blood vessels, which were generated by CCO seem realistic one. However, this method could not generate the connected links between their sub-branches.

The effects of gravity and tropism are incorporated into a model of plant branch growth, yielding a model of the curving of a plant axis in a vertical plane. Catherine Jirasek and Przemyslaw Prusinkiewicz proposed the model of branch shape in plant [28]. The branch of plant was divided to the discrete segment. They could change the shape of branching structures using an empirical relationship between branch width and branching angles.

A unified rewriting system that could generate any shape of leaf was proposed by Chidchanok Lursinsap, Peraphon Sophatsathit, Suchada Siripant and Y. Shinagawa [15]. The modified model intensively to solve the problem of connected link between two components that found in leaf vein structure.

Yodthong Rodkaew, Suchada Siripant, Chidchanok Lursinsap, and Prabhas Chongstitvatana proposed rewriting rule for model the branching of leaf vein in 2001 [18], and presented a new algorithm for generating branching structure such as leaf vein images in the next year [20]. The latest algorithm could cover several leaf shapes and generate leaf veins images look very natural.

2.3 Review of Literatures Related to Leaf Growth Simulation

Some very impressive results have been obtained in the past few years in plants and trees image synthesis. Those algorithms are largely based on the irregularity and fuzziness of the objects, and use fractals, grafts or particle systems. Several researchers presented models, which integrate botanical knowledge of the architecture such as how they grow.

In 1988, Philippe de Reffye, Claude Edelin, Jean Françon, Mark Jaeger, and Claude Puech [29] proposed a model for the growth of plants and tree which incorporates the botanical knowledge of their architecture. Their approach was based on a mathematical simulation of botanical architectural models, which originated in Philippe de Reffye's thesis [30]. The plant was grown by de Reffye's mathematical macroscopic model of plant growth, the unit of discretized time was the time taken by the growth of a growth unit. Their animations were not smooth.

Przemyslaw Prusinkiewicz, Aristid Lindenmayer, and James Hanan [9] presented a method for generating realistic plant images and animating developmental processes. They used the formalism of L-system to present the developmental models of herbaceous plants, and showed the developmental sequence of a cordate leaf.

The model for animating simulated developmental processes in a manner resembling time-lapse photography was proposed [31]. The paper introduced a combined discrete/continuous model for plant development that integrated L-system-style productions and differential equations. Growth functions were proposed to control the development of plants.

Mark S. Hammel and Przemyslaw Prusinkiewicz presented a methodology for creating computers model that captured the development of plants using the formalism of L-systems and incorporating biological data [32].

In 1996, Mark Hammel and Przemyslaw Prusinkiewicz presented the visualization of developmental processes in nature [33]. Processes taking place in one or two dimensions could be visualized as objects in three-dimensional space, which was obtained by extruding the growing structures along a line or curve representing the progress. Development of compound leaf was shown in this paper.

David Steinberg, Stéphane Sikora, Claude Lattaud, Christian Fournier, and Bruno Andrieu purposed the simulation of the growth of plants in virtual world [34] in 1999. The work based on biological models where individuals were considered as situated entities. They presented an approach in which each plant was viewed as a society of organs (leaves, apex, buds, etc.) interacting with their environment.

In 2000, smoother plant growth simulation was proposed by Somporn Chuai-aree, Suchada Siripant, and Chidchanok Lursinsap [17]. They developed a prototype program called PlantVR for creating the continuous development of plant models by parametric functional symbols based on the bracket L-systems using soybean model as a case study. Their prototype for plant growth simulation could be used for generated the realistic model of any plant that has life cycle similar to soybean.