EUROGRAPHICS Workshop on Sketch-Based Interfaces and Modeling (2008)
C. Alvarado and M.- P. Cani (Editors)

# Sketch-based Parameterization of L-systems using Illustration-inspired Construction Lines

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**Abstract**

*We present a sketch-based interface for parameter control of rule-based models. It allows intuitive specification and creation of plant structures with L-systems. Construction lines inspired by concept sketches are employed as a way to define and manipulate global-to-local characteristics of L-system models. The overall structure, posture and proportions of the plant are initially sketched by the user as construction line arrangements. They are automatically encoded as a set of positional functions controlling internode lengths, branching angles, organ sizes, and stem shape. These positional functions are then used to parameterize pre-defined L-system templates representing phyllotactic patterns for positioning lateral organ surfaces such as leaves and petals. Results are presented for single monopodial plant structures, all generated from simple input construction line sketches.*

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling: Modeling packages;

## 1. Introduction

Global features, such as posture and silhouette, are essential characteristics in the depiction of a plant. They convey realism and distinctiveness to a model and can reflect the outcome of morphological development. Therefore, these features are important in a simulation-oriented context for plant modeling. However, in rule-based methods, such as L-systems [PL90], the global structure is given by the outcome of the interaction of local rules. This emergent aspect of the global properties makes them difficult to manipulate and control, since localized modifications cannot be specified easily, and changes in a single rule can affect the whole model.

Global-to-local specification was introduced into L-system-style models (actually, Chomsky grammars) in the form of user-controlled B-spline functions associated with parametric production rules [PMKL01]. These functions can be used to represent *positional information* and *morphogenetic gradients* in the plant model. In this manner, they allow regulating global features such as posture, insertion angles, and dimensions of the components of the model. Although they provide a powerful tool, manipulation of these functions introduces a degree of abstraction when creating shapes such as the curving stem or the silhouette of a plant. It would be more convenient to describe such features directly, without an intermediate construct. This convenience can be provided if construction lines from concept sketches (Figure 1) are used as an interface for the definition of these functions.

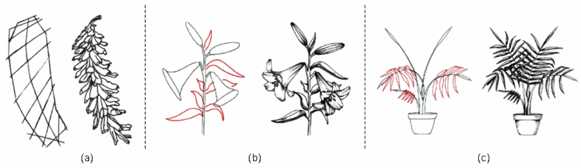


**Figure 1:** *Botanical illustrations at two drawing steps: concept sketches using construction lines and finished rendering. (a) pine cone [Wun91] © 1991 Eleanor B. Wunderlich. Used with permission; (b, c) lily, palm [Edi07] © 2008, Publications International, Ltd. All rights reserved.*

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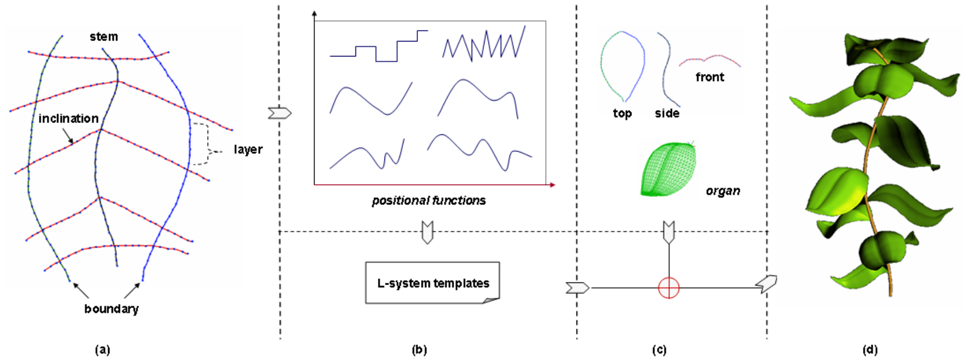


**Figure 2:** *The pipeline for our approach. (a) The user creates a construction-line-based sketch that is interpreted to (b) automatically derive a set of positional functions that parameterizes a predefined L-system template. (c) Plant organ surfaces are constructed from sketches and referred to by the L-system productions, resulting in the final model (d). Labels in (a) and (c) indicate the role of the construction lines.*

In this paper, we propose the use of botanical illustration-inspired construction lines to parameterize global features of L-system models. Illustrators use construction lines to determine the global features of the plant being depicted (Figure 1). These lines are sketched in the very beginning of the illustration process to quickly indicate posture, contours, proportions, topology, and constraints [Hod03, Wun91]. They work as guidelines for the artist when the drawing is further developed and details are progressively added.

Our technique is based on a specific example of construction lines for botanical illustration shown in Figure 1(a) [Wun91]. This illustration example was used by Prusinkiewicz *et al.* [PMKL01] to exemplify what was intended with the introduction of positional functions into L-systems, and by Anastacio *et al.* [ASSJ06] as the main reference for the definition of concept sketches. Similar construction line arrangements are also used in this paper. Our approach is illustrated in Figure 2. The process starts (a) with sketching the construction lines that define the overall structure of the plant (Section 3). An interpretation of the construction lines is then used (b) to automatically derive a set of positional B-spline functions (Section 4). These functions are used as parameters for productions in a predefined L-system template (Section 5). Finally, sketched organ surfaces (c) are incorporated in the model (Section 6), leading to its final 3D presentation (d).

Our approach thus incorporates sketch-based interfaces into the modeling process based on L-systems. Although productions are not specified via sketching, the global attributes of a monopodial model and its organ surfaces are obtained directly from what the user draws. This contributes towards a more intuitive way to create L-system models.

## 2. Previous work

The first sketch-based interfaces for plant modeling were focused on directly drawing branching structures [OI03, OOI05]. Okabe and Igarashi [OI03] present a system that creates 3D trees from freehand sketched lines using models based on the work of Weber and Penn [WP95]. Later on, they improved their approach by assuming that trees spread each branch in a way that maximizes the distance to the other branches [OOI05]. The key contribution of their method is the inference of a 3D geometry from the 2D sketches of the branching structure.

Ijiri *et al.* [IOOI05] introduced *floral* and *inflorescences diagrams* to organize sketched flower organs into flowers, and entire flowers into inflorescences, in a botanically correct way. By adding domain knowledge to the sketch composition, they were able to provide a more efficient method for sketching a plant model. Although restricted to the arrangements given by floral and inflorescence diagrams, the work of Ijiri et al. [IOOI05] represents a clear advance in sketching complex structures and positioning individually sketched elements.

In order to make the composition of a 3D plant model more general, while providing a seamless transition from the initial sketch to the detailed 3D model, Ijiri *et al.* [IOI06a] proposed to use a hierarchy of billboards. The billboards work as drawing planes for sketching individual organs. The organs can be saved into a library and reused later on. This work extends their previous technique and allows for a wider variety of plant models. However, in this case, the way the arrangement is composed is left to the user, without relying on botanical guidelines.

Anastacio *et al.* [ASSJ06] considered botanical illustration techniques to determine how the initial sketch should be defined and interpreted. The structured initial drawing is referred to as a *concept sketch*. The concept sketches are interpreted in the context of biologically-motivated rules for phyllotactic patterns, and combined with sketched organ surfaces to yield realistically looking monopodial plants. This technique provides a way of defining both the structure and the individual elements using SBIM.

An alternative way to derive the branching structure from sketched global elements is suggested by Zakaria and Shukri [ZS07]. Their technique, named *sketch-and-spray*, consists of directly sketching an initial structure for a tree (allowing copy-and-paste and individual deformation of branches), followed by "spraying" leaf surfaces (sketched in a separate environment) around a region of the crown. The branches in the initial structure then "grow" towards the sprayed leaves in order to complete the tree model.

The first attempt to use SBIM with L-systems was proposed by Ijiri *et al.* [IOI06b]. Their method allows the user to control the shape of the main axis of a recursively defined structure, and its depth of recursion, with gestural sketching. The stroke affects the module representing the main apex, changing its direction. It also controls the depth of recursion by prompting a new derivation step every time the sketched stroke reaches a length that is a multiple of the predefined apex size.

This paper proposes going further in the use of SBIM with L-systems. Instead of only controlling the recursion depth and the main axis shape, we propose using concept sketches [ASSJ06] as a way to control the appearance of an L-system model. The interpretation of the sketched construction lines provides a parameterization for a set of predefined L-system templates that implement different phyllotactic patterns. The parameterization makes use of the mechanism of positional functions introduced by Prusinkiewicz *et al.* [PMKL01]. This technique differs from Anastacio *et al.*'s [ASSJ06] by the use of the interpreted information and the construction of the plant model. It also provides a potentially easier way to create L-system models for plant structures.

## 3. Plant sketch processing

This section briefly revisits the aspects of the process of interpreting concept sketches that are utilized in this paper, which are based on the work by Anastacio *et al.* [ASSJ06]. Please refer to [ASSJ06] for more details.

**Stroke capturing** The stroke capturing mechanism used for the construction lines consists of four steps: resampling, reverse subdivision, conversion to a B-spline curve, and anchor point calculation. In the first step, the sparse input points received from the pointing device (mouse or tablet) are resampled to a density of one point per pixel. Then, in order to reduce the number of points and to smooth the stroke, Chaikin reverse subdivision [SB04] is iteratively applied. Three applications provide a smooth stroke that is very close to the original one. The points resulting from the reverse subdivisions are used as the control points of a quadratic B-spline.

**Structural components** The overall structure of the plant is defined by three groups of construction lines: stem, boundaries, and inclination lines (Figure 2 (a)). The stem line defines the main axis of the plant. The boundary lines are drawn on the left and right sides of the stem and determine the silhouette of the plant by establishing a bounding volume that contains the lateral organs. The inclination lines intersect both boundary lines and the stem and define the inclination (branching angle) of plant organs along the stem. The region between consecutive inclination lines is called a *layer*. Any number of plant organs can be placed within a layer.

**Node position** A *node* is the point in the stem, or main axis, where an organ originates. The chord length distance between two consecutive nodes (and, therefore, two consecutive organs) along the stem is called *internode length*. When defining a concept sketch, the user is able to specify the number of nodes/organs that should be placed per layer. These nodes are evenly distributed inside a layer, which implies that the internode length is the same for all nodes in the same layer.

**Branching intersections** The branching intersections define how big the organs should be so that they fit inside the bounding volume specified by the boundary lines. This information is obtained on a per-layer basis. For each layer, the angles between the inclination lines on the left and right sides of the stem and a reference vector defined with respect to the internode up directions are calculated. These two pairs of angles (one pair for the upper inclination lines and another for the bottom inclination lines) are linearly interpolated between the nodes inside the layer. Then, from each node, a ray is cast to each side of the stem with inclination given by its corresponding interpolated angle. The intersection of this ray with the respective boundary line determines how big the organ placed at this node should be, so that it fits inside the plant bounding volume. Therefore, the distance from the node position to this intersection point provides the organ size.

## 4. Function definition

The information extracted from the construction lines sketch needs now to be passed to an L-system. We define this kind of positional information by using B-spline functions [PMKL01]. These functions are referenced from inside L-system productions, returning a value that may be used as a parameter or applied in the calculation of a parameter for a rule. They are employed to represent *positional information* and *morphogenetic gradients*, such as relative branching points, organ distribution, element dimensions, deformations, etc. A function is given by a uniform cubic B-spline calculated from a set of control points. The control points for each function are obtained by re-sampling information obtained from the concept sketches (internode lengths, inclination angles, organ sizes, and stem shape) for each structural component.

### 4.1. Internode length and stem shape

All the values for internode length are given relative to the whole stem's arc length. The initial function point, which has independent or $x$-coordinate value equal to 0.0, has a dependent or $y$-coordinate value equal to the relative distance $d_1$ from the base $a$ of the stem to the first node $P_1$ (Figure 3(a)). From then on, the function points have values of the independent coordinate equal to the relative node position and, for the dependent coordinate, equal to the internode length (Figure 3(b)). This value depends on the layer $i$ that contains the node, and is equal to the arc length $L_i$ divided by the user-defined number of nodes in layer $i$. The exception is the point $P_n$ at the topmost inclination line. This point has the dependent value equal to the remaining distance to the end of the stem, given by $d_2$ (Figure 3(a)). In this manner, exceeding nodes are pushed outside the stem length. This leads to a constant internode value for each layer, resulting in a piece-wise constant function (Figure 3(b)). This uniform distribution inside a layer supports the representation of masses of organs from the illustration point of view.

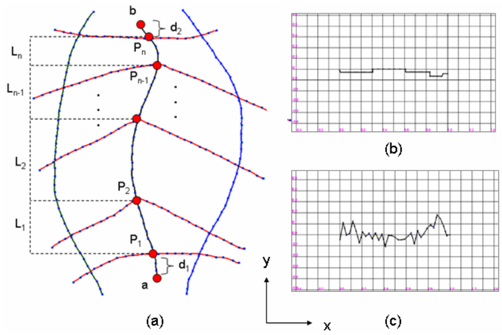


**Figure 3:** *(a) Scheme of construction lines for (b) the internode length function. (c) Stem shape function for the turtle turning angle (degrees) between consecutive tangent vectors along the stem construction line. In both functions, the x-axis corresponds to the relative position (arc-length parameterization) along the main stem construction line from points a to b.*

The stem shape is given by a function determining how much the L-system turtle should turn considering its current heading. As in the previous functions, the independent coordinate value is given by the relative position along the stem. The dependent value corresponds to the angle in degrees (as usually given in L-systems), by which the turtle turns between consecutive tangent vectors along the stem construction line. Figure 3 (c) shows one example of this function.

### 4.2. Inclination angles and organ sizes

For the inclination angles, we have two functions: one for the left side of the sketch and another for the right side. We need a linear interpolation between two consecutive inclination vectors $\vec{u}_i$, $\vec{u}_{i+1}$ (left side) and $\vec{v}_i$, $\vec{v}_{i+1}$ (right side). The resulting intermediate vectors are given by $\vec{W}_L$, $\vec{W}_R$ for the left and right sides, respectively (Figure 4(a)). The angle values, given in degrees, are set as the dependent value of the function. The independent value is again the relative position of a node along the main axis. For the points in the extremes of the function (independent values equal to 0.0 and 1.0), the dependent value of the respective closest point is assigned ($\alpha_1$ or $\beta_1$ and $\alpha_n$ or $\beta_n$, correspondently). This assures that the angle values in the bottom and upper parts of the stem, which do not have nodes, are constant and equal to the value for the closest node. This results in piece-wise linear functions, since we have linear interpolation between consecutive pairs of angle values. A sample of a pair of such functions can be seen in Figure 4(b, c).

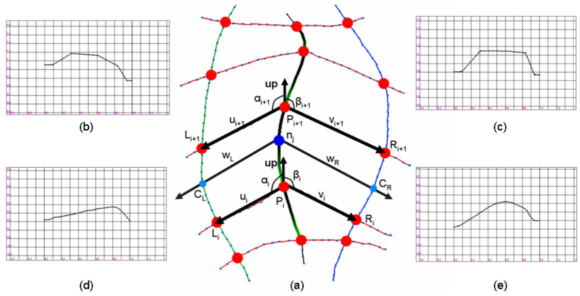


**Figure 4:** *(a) Scheme of construction lines defining inclination angles $(\alpha, \beta)$ and organ sizes $(u, v)$; (b, c) functions defining left and right inclination angles;(d, e) functions defining left and right organ sizes.*

There are also two functions for the organ sizes: one for the left side of the structure and another for the right side. Both are given by the size values calculated for every node. These values are given in relation to the whole stem arc-length. Similarly as it is done for the inclination angles, the points in the extremes of the function have dependent value equal to the value of the respective closest node. Examples of organ size functions for both sides can be seen in Figure 4 (d, e).

## 5. Phyllotactical settings

Pyllotaxis is the arrangement of plant organs around the stem. Common types of phyllotaxis include *distichous*, *decussate*, and *Fibonacci* patterns (Figure 5), which we incorporated into our models. These patterns were selected because they are found in a large number of plants and yield significantly different plant structures.

The choice of phyllotactic pattern determines productions in the L-systems template. The functions discussed in Section 4, provide the information on the stem shape, the placement of organs, and their inclination angle (Figure 2(b)). These functions are general for any kind of plant that fits in the used sketch guidelines. However, information is still missing on how much the L-system turtle should rotate about the stem between consecutive nodes, and how many organs should be placed at each node. This information is given by the user-chosen phyllotactical pattern.


**Figure 5:** *Patterns of phyllotaxis available in the system. (a) Distichous; (b) Decussate; (c) Fibonacci spiral.*

### 5.1. Distichous phyllotaxis

Distichous phyllotaxis is especially common in different kinds of fern leaves [PMKL01]. It is characterized by a pair of organs at each node growing in opposite directions (*i.e.*, 180° apart). There is no relative rotation between consecutive nodes. A diagram illustrating this pattern is given in Figure 5(a). An L-system specification of a monopodial plant with distichous phyllotaxis is given below:

$Axiom: \ A(0)$
$Productions:$
$1: \ A(x) \rightarrow S(x)\ B(x)\ A(x+\Delta x)$
$2: \ S(x) \rightarrow +(\kappa(x))\ F(\delta)$
$3: \ B(x) \rightarrow L(x)\ R(x)$
$4: \ L(x) \rightarrow [+(\varphi_L(x))\ Organ(h_L(x))]$
$5: \ R(x) \rightarrow [/(180)+(\varphi_R(x))\ Organ(h_R(x))]$

In this L-system, $x$ is the relative position along the stem arc-length; $\Delta x$ is the resolution with which the stem is drawn; $\delta$ is the internode length; $\kappa(x)$ is the value of the stem shape function at $x$ (Figure 3); $\varphi_L(x)$ is the value of the branching angle calculated from the inclination angle function for the left side at $x$; $\varphi_R(x)$ is the value of the branching angle calculated from the inclination angle function for the right side at $x$ (Figure 4(b,c)); $h_L(x)$ is the value of the length function for the left side at $x$; $h_R(x)$ is the value of the length function for the right side at $x$ (Figure 4(d, e)); $+$ is the symbol that rotates the L-system turtle to the left; /(180) is the symbol that rotates the turtle by 180° around the stem; and $Organ(y)$ represents the drawing of an organ of size $y$.

### 5.2. Decussate phyllotaxis

Decussate phyllotaxis is similar to distichous phyllotaxis in that a pair of opposite organs is placed at each node. However, in the decussate case, each pair is rotated by 90° with respect to the previous pair. Figure 5(b) illustrates this pattern. In terms of production rules, it requires keeping track of how the previous node is positioned. In the actual implementation, a node counter was added as a parameter in the sequence of productions and, whenever this counter indicates that the current node has an odd number, a rotation of 90° about the stem is applied before the organs are placed. Branching angle and organ length values are applied as in the distichous pattern for the non-rotated nodes. For the ones that are rotated, the arithmetic average between the left and right values is taken for both the branching angle and the organ length parameters. A corresponding L-system is given below.

$Axiom: \ A(0,0)$
$Productions:$
$1: \ A(x,i) \rightarrow S(x)\ B(x,i)\ A(x+\Delta x,\ i+1)$
$2: \ S(x) \rightarrow +(\kappa(x))\ F(\delta)$
$3: \ B(x,i): \ \{$
$\quad if\ (i\ \%\ 2 == 0)\ \theta = 0;$
$\quad else\ \theta = 90;$
$\quad \} \rightarrow /(\theta)\ L(x,i)\ R(x,i)\ /(-theta)$
$4: \ L(x,i): \ \{$
$\quad if\ (i\ \%\ 2 == 0)\ \{$
$\quad\quad angle = \varphi_L(x);\ \ length = h_L(x);$
$\quad \}\ else\ \{$
$\quad\quad angle = (\varphi_L(x)+\varphi_R(x))*0.5;$
$\quad\quad length = (h_L(x)+h_R(x))*0.5;$
$\quad \}$
$\quad \} \rightarrow [+(angle)\ Organ(length)]$
$5: \ R(x,i): \ \{$
$\quad if\ (i\ \%\ 2 == 0)\ \{$
$\quad\quad angle = \varphi_R(x);\ \ length = h_R(x);$
$\quad \}\ else\ \{$
$\quad\quad angle = (\varphi_L(x)+\varphi_R(x))*0.5;$
$\quad\quad length = (h_L(x)+h_R(x))*0.5;$
$\quad \}$
$\quad \} \rightarrow [/(180)+(angle)\ Organ(length)]$

In this L-system, $i$ is a counter of nodes, and thus of organ pairs attached to the stem. The remaining symbols have the same meaning as in the distichous case.

### 5.3. Fibonacci spiral phyllotaxis

Fibonacci spiral pattern is characterized by one organ supported at each node, and the rotation around the stem by a divergence angle of 137.5° between consecutive nodes. A scheme for this pattern is shown in Figure 5(c). As in the decussate case (Section 5.2), a counter keeps track of the number of the current node. This number is multiplied by the divergence angle and reduced to the $[0,360)$ interval. The resulting angle value is used as the parameter of a linear interpolation to calculate its branching angle and organ length from the function values for the left and right side. The equations are defined as follows:

$$\varphi(x,\theta) = (a)\,\varphi_L(x) + (b)\,\varphi_R(x)$$
$$h(x,\theta) = (a)\,h_L(x) + (b)\,h_R(x)$$

$$(a,b) = \begin{cases} \left(1-\frac{\theta}{180}, \frac{\theta}{180}\right) & , 0^\circ \leq \theta \leq 180^\circ \\ \left(\frac{\theta}{180}-1, 2-\frac{\theta}{180}\right) & , 180^\circ < \theta \leq 360^\circ \end{cases}$$

where $x$ is the position of the current node relative to the stem length, $\theta$ is the calculated phyllotactical angle for the current node, $\varphi(x,\theta)$ is the branching angle at the current node, and $h(x,\theta)$ is the organ size. The remaining symbols are as in Figure 4. The resulting L-system generating monopodial structures with the spiral phyllotaxis is given below.

$Axiom: \; A(0,0)$
$Productions:$
$1: \; A(x,i) \rightarrow S(x)\; B(x,i)\; A(x+\Delta x, \; i+1)$
$2: \; S(x) \rightarrow +(\kappa(x))\; F(\delta)$
$3: \; B(x,i): \{$
$\quad \theta = (i * 137.5) \;\%\; 360;$
$\quad angle = \varphi(x,\theta); \;\; length = h(x,\theta);$
$\} \rightarrow [+(angle)\; Organ(length)]$

Note that the method used here to calculate organ length is simpler than the method proposed by Anastacio *et al.* [ASSJ06]. That method calculates a smooth shape compound of two half-ellipses around the position of the organ in the stem. Theirs is a more precise approach than the linear interpolation used in this section which, in some cases, may generate cardioid curves. However, their calculations take into account several different variables that cannot be straightforwardly represented in a single-variable function. Furthermore, the simpler solution proposed here works well enough for cases that do not require higher levels of precision.

## 6. Modelling organs

In the final step, surfaces representing desired organs (leaves, petals, entire flowers, etc) are incorporated into the model. Any organ surface specification method can be used. In our system, the organs surface geometry is defined by the sketch-based 3-view stroke input method [ASSJ06] shown in Figure 2(c). This method provides a simple and quick way to create a varied range of plant organ surfaces to be used in the L-system models, employing a minimal number of strokes.

Four strokes are used embedded into three different viewpoints. The left and right boundaries are provided in a top view; the midrib or spine is given in a side view, and the cross-section is drawn in the front view (Figure 2(c):(1,2,3)). These strokes are combined in a composition of the *cross-sectional blending* surface with the *orthogonal deformation* operation [CSSJ05] to provide the final organ surface. For more details, please refer to Anastacio *et al.* [ASSJ06]. To have this surface displayed in an L-system model, the triangles that compose its mesh structure are written to a text file. The file is parsed by the L-system modeling program [Mec04], which recreates the mesh and incorporates its instances as defined by the organ placement algorithm.

## 7. Results

Application examples were generated on a 2.8GHz Pentium 4 with 1GB of RAM and a GeForce FX 5200 128MB video card. The results show that our approach produces plant models matching the construction lines arrangements of the input concept sketch. Based on our experiments and observations, most of the time spent creating a model is due to user edits of the sketched construction lines and L-system fine-tuning. The system instantaneously generates an L-system from the input sketch. A user can create simple models in just a couple of minutes.

In our implementation of the system, the sketch strokes are drawn in a dedicated program, which launches a cpfg [Mec04] visualization window displaying the resulting L-system model with the chosen phyllotactic pattern. If further editing of the L-system is desired, the resulting model can be exported to L-studio [PKMH99]. We observed that this complementary organization, while missing immediate feedback, provides a good workflow and is adequate enough for the production of appropriate results.

Figures 6 to 10 show results using our system. Each figure shows the original sketches, the derived functions (from left to right and top to bottom: internode length, stem shape, left inclination angle, right inclination angle, left organ size, and right organ size) and the final results.

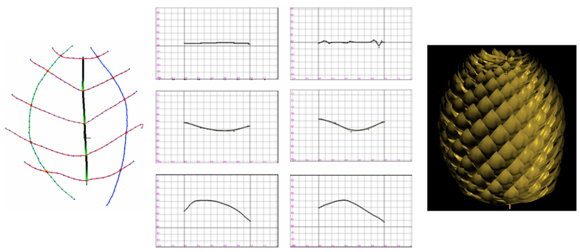

**Figure 6:** *Model of a pine cone with 55 nodes per layer.*

A simple sketch can be used to model a pine cone (Figure 6) with 55 organs (scales) per layer and the Fibonacci spiral phyllotaxis. Figure 7 illustrates the differences between the available phyllotactic patterns for a single concept sketch. All patterns have three nodes per layer. Even though the concept sketch is the same, the resulting plants look considerably different from each other.

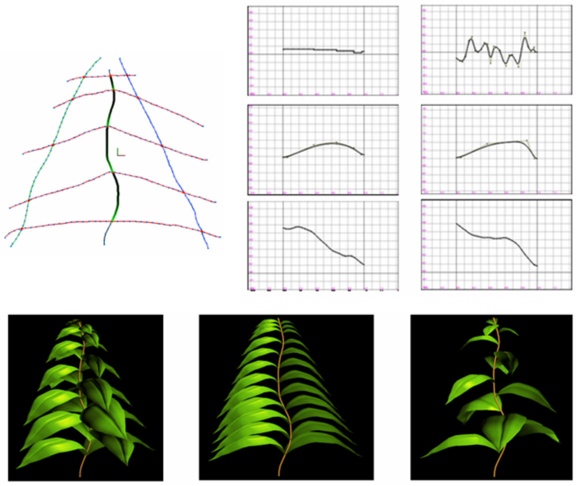

**Figure 7:** *Models with (left to right) decussate, distichous and Fibonacci spiral patterns.*

Our system also allows the user to edit the generated model by changing its L-system rules. This allows fine-tuning of specific aspects of the model as well as its utilization as a module in the composition of another plant structure. An example of this is given in Figure 8. It shows a model of a stem of a single-compound leaf along with the concept sketch and the derived functions used to model it. This model is then used as a module that is repeated along an axis following a distichous phyllotaxis pattern, resulting in a double-compound leaf.

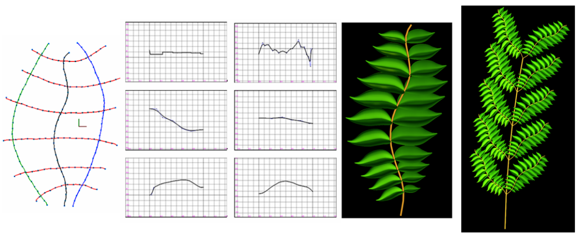

**Figure 8:** *Models of a single-compound leaf and a double-compound leaf.*

Our technique is based on a specific example of a construction lines arrangement (Figure 1(a)). Therefore, it cannot produce a very wide range of plant architectures. However, one way to achieve more variety of plants is by compositing L-systems of different models. The bromeliad created using image composition of concepts sketches shown in [ASSJ06] was recreated by combining the grammars of two parameterized L-systems (Figure 9). In Figure 10, a model of a foxglove inflorescence (*Digitalis purpurea*) is composed from the construction line sketches for the flower and leaf arrangements. The distribution of the organs was edited in the L-system rules. Coloring and texturing were applied to the organ surfaces to improve the model appearance.

## 8. Conclusion

This paper presents a sequence of experiments aiming at creating a synergy between sketch-based and procedural plant modeling techniques. We use the construction lines from concept sketches [ASSJ06] to define the overall plant structure based on traditional illustration techniques (Figure 1). We propose translating these sketched construction lines into functions [PMKL01] that are used to parameterize L-system production rules. This established an interface between sketches and L-systems, making more intuitive the construction of models that fit in our selected collection of templates.

Future improvements include investigating a more general definition of construction lines, covering the description of whole plants with different architectures. Furthermore, construction lines from concept sketches are limited to a single 2D plane and this limitation should be addressed to allow 3D stems. Concept sketches could be extended to describe sets of plants and ecosystems based on L-systems. We also plan to conduct formal evaluations and user studies to provide quality construction lines-based sketching tools for botanical illustrators.

## Acknowledgements

We would like to thank the anonymous reviewers for their careful and valuable comments and suggestions. This research was supported in part by Discovery Grants from the Natural Sciences and Engineering Research Council of Canada and by an iCORE Graduate Student Scholarship.

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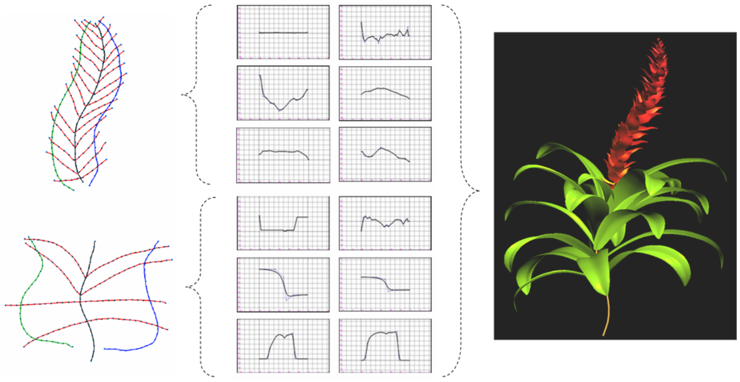

**Figure 9:** *Model of a bromeliad resulting from the combination of two L-systems parameterized using concept sketches.*

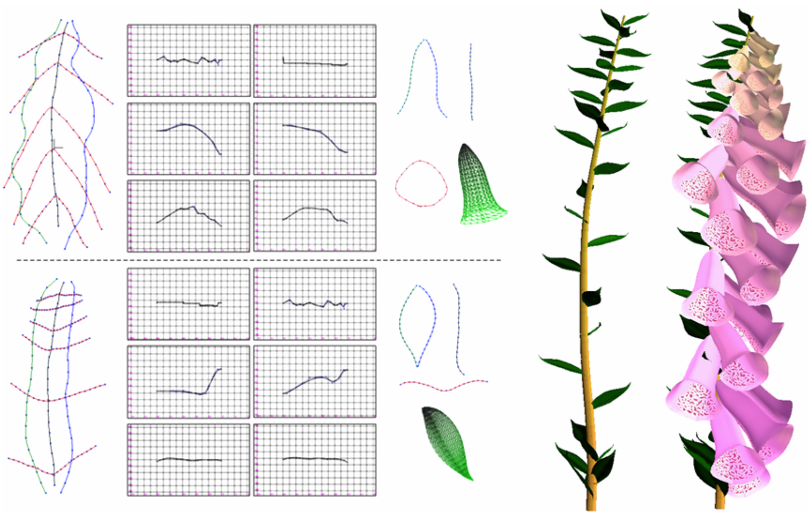

**Figure 10:** *Model of a Foxglove inflorescence (Digitalis purpurea).*


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