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Short Paper

Light-Guided Tree Modeling

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Abstract

Creation of realistic tree modeling is an important goal in computer graphics as well as in botanical research, such as horticulture and forestry. In this paper, we propose a method to model virtual trees with constraints of light resources and tree morphological properties. The light energy is calculated by sampling the environmental space. Diverse and realistic trees are modeled in different complex environments. By the allocation of received resources, modeling parameters are estimated, including branching directions and branching size. The proposed method shows a way to create tree models guided by light.

Keywords: *tree modeling, environmental constraints, light guided modeling*

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—I.6.8 [Simulation and Modeling]: Types of simulation—Visual

1. Introduction

Plant modeling is an important and popular topic in computer graphics, which has been successfully used in many applications. Over the last decades, an immense amount of efforts have been dedicated to the problem of realistic tree generation. Broadly speaking, these approaches include procedural modeling, reconstruction from real world data (e.g., photographs or scanned points), and interactive modeling. The reconstruction method can be used to generate trees with higher level of realism. However, trees modeled by this approach are usually static and can not react to the environment.

In contrast, procedural methods are capable of simulating the growth of trees of various species, meeting multiple constraints. One of the most relative procedural techniques is rule-based systems, especially L-systems [Hon71, PL90]. Runions et al. [RLP07] introduced a modeling method by simulating the competition for space among branches. Furthermore, Palubicki et al. [PHL*09] present a modeling method based on the concept of self-organization. In this approach, the tree modeling process is dominated by the competition of buds and branches for light and for space, and by the regulation by internal signaling mechanisms such as nutrient transportation. However, there are still some worthy issues for research: improvement of resource allocation model for growth simulation and exploitation of space competition and light influence.

In this paper, we propose new approach to model a virtual tree with constraints of light resources and tree species properties. Our method address those issues listed in above paragraph and also shows a new tree growth mechanism because of considering comprehensive roles from the external environmental factors.

2. Related work

Our topic belongs to procedural method, so we here discuss those landmarks and new progress works in recent years. Procedural methods like L-system,stochastic process and particle system all begin their development from the starting line. The basic mechanism of L-system, introduced by [Lin68] as a mathematical theory of developing plants, is

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Figure 1: *Modeling of two trees with competition for space.*

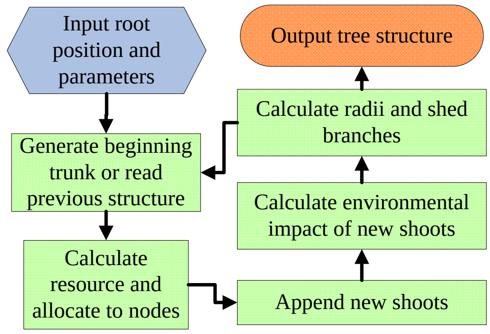

Figure 2: *Overview of algorithm.*

to apply iteration system to build a kind of procedure models according to a special and small set of symbolic rules. Tree growth was simulated by stochastic process since 1970' from de Reffye [PdR88]. Using parameters derived from observation, realistic structures faithful to botanic knowledge were simulated, where a bud can die, rest, or create a variable number of metamers. In addition, particle system method was used to simulate the tree growth in [NFD07].

Environment dependent methods were then introduced for tree modeling, since the above methods are not sufficient to describe the underlying mechanisms of plants reacting their environment. [MP96, PJM94] applied the L-systems to simulate the interaction between plants and environments. [SP12] developed a modeling method through applying systematically botanical analysis of trees. And based on space colonization method [RLP07, PHL*09], [LRBP12, XM12, WYZB14] proposed several advanced methods to reconstruct or simulate tree models realistically showing the trait of trees, convenient for modelers to control the shape of trees.

Comparing with those methods, our method consider both internal mechanism and effects of space and light on the branches' shooting, making the shape and complex branches more realistic.

3. Tree modeling method

We would like here at first to describe some modeling terminologies: a *node* is a point which constitutes a branch and probably supports stems or leaves; an *internode* means a part of stem between two nodes. And we divide tree occupied space into a grid of voxels. We set that the range of influence mode is from tree top to the ground, which means that a node influences all of beneath space. Note that, in our experiment the length of a voxel is half of an internode. Our method of simulating a tree is an iteration algorithm, as shown in Figure 2.

Input..Our input information include the initial location of root, the branching mode or phyllotaxis, and several tree morphological parameters introduced in next section.

Resource calculation and allocation. According to existing tree structure and environmental information, we acquire the light value of each node according to the light information of voxel where node locates and how long the node exists. We calculate the accumulation value of light received node by node from top to root, and save the total value of the whole tree at the root and then to allocate the received light resources from root to every node.

We combine 2 strategies proposed by [PHL*09]: Borchert-Honda (BH) mode and Priority mode and make full use of the advantage of each model by integrating both strategies into a new allocation model which is shown in Figure 3. BH model is to control the decurrent or excurrent inclination of shape which makes the more general shapes of trees while Priority mode is to control branches' trait such as the density and strength of lateral branch. Combination makes users control modeling general and detail trait at same time.

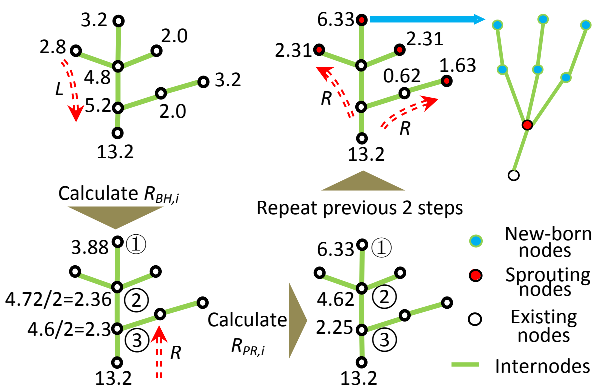

Figure 3: *An illustration for resource distribution for parameters:* $\lambda = 0.55, \omega_1 = 1.0, \omega_2 = 0.6, \omega_3 = 0.3$ *and an example of new-born nodes.*

In first phase(BH model), we calculate resource allocated to each node of a branch according to the value of received light by each node. For a node i which is a branching node, its light resource is allocated by formula (1):

$$R_{BH,i} = (L_{m,i} + L_{l,i}) \frac{(1-\lambda)L_{l,i}}{\lambda L_{m,i} + (1-\lambda)L_{l,i}}, i = 1,2,...,N_B \quad (1)$$

where $R_{F,i}$ is the resource value of node i, $R_{BH,i}$ is the received resource of node $i \in branchB$, $L_{m,i}$ and $L_{l,i}$ are respectively cumulative light value flowing into node i from main axis and from lateral axis; and $\lambda \in [0,1]$ is the weight for main axis ($\lambda > 0.5$) or lateral ($\lambda < 0.5$), or balance ($\lambda = 0.5$).

The second phase is Priority model for allocating resource which is to determine its priority in whole branch B according to $R_{BH,i}$, and then to calculate results with formula (2):

$$R_{PR,i} = R_{r,B} \frac{R_{BH,i}\omega_i}{\sum_{j=1}^{N_B} R_{BH,j}\omega_j}, i = 1,2,...N_B \quad (2)$$

where $R_{PR,i}$ is the eventual resource for the node i, $R_{r,B}$ is total resource flowing into B, and ω_i is the weight of node i according to its priority and complies with piecewise linear function.

If a node has already supported lateral branches, it does not sprout new branch. The number of new-born nodes is $n_i = \lfloor R_{PR,i} \rfloor$, the length of internodes $len_i = R_{PR,i}/n_i$. And new-born nodes are allocated to new shoots according to the phyllotaxis. We also introduce the growth equation to confine the growth of each new shoots in each cycle. By this way, if a node receives too much resources in a iteration, it won't grow too much in this cycle, which is not realistic and destroy the growth balance between sprouting branches.

Appendix of new shoots. When a node i has the chance to shoot based on its received resource, we define its ultimate direction $\vec{V}_u$ by three factors: the default direction $\vec{V}_d$, the optimal direction $\vec{V}_o$ and the tropism factor $\vec{V}_t$ with formula (3).

$$\vec{V}_u = \vec{V}_d + \mu\vec{V}_o + \gamma\vec{V}_t \quad (3)$$

The default direction $\vec{V}_d$ depends on the given phyllotaxis and branching angle and position of node. The branching angle is a constant [WYZB14] or a variable [WP95] specified by the user.

Using light information to define the optimal direction $\vec{V}_o$ is rational. we use Space Colonization Algorithm (SCA) [RLP07] to determine $\vec{V}_o$ with some modifications. Different from those generating global point clouds before simulation to represent light space, the random points are generated in a conical space around each sprouting node only after sprouting nodes and the number of nodes of appendix having been determined. Then we apply random nodes' position and their light information as weights to finally define $\vec{V}_o$. In this way, the memory and time cost can be reduced and new shoots are more sensitive to alteration of light.

Moreover, the tropism factor is another method to help users to control the branches' orientation, which is easy to understand its function.

Calculation of environmental impact.

The impact is calculated by equation: $l_n = l_o - b^{-q}$, where l_n is the updated value of voxel, l_o is the prior light value, and b^{-q} is the value of impact, q is the number of voxels vertically between the impacted voxel and the voxel that the node belongs. Parameter b is the impact degree of node on environment. The less the value is, the greater influence the node.

After updating space information, step *appendix of new shoots* is repeated until all sprouting nodes have shot.

Calculation of radii and shedding of branches. We calculate radii in a basipetal form of information flow. Each terminal node contributes an initial radius value. These values are accumulated along tree axes using the formula $r^d = \sum_{j=1}^{M} r_j^d$, where r is the radius of the internodes at the branch point, r_j is the radii of the children internodes of r, M is the total number of successor shoots including main axis and lateral branches, and d is a user-defined parameter related to tree species, usually between 2 to 3.5. Moreover, radii will not decrease by shedding of branches.

After each iteration, the branch shedding step is applied as [Tak94]. For each branch, the total amount of light it received is compared with the branch size measured in the number of internodes.

4. Experimental Results

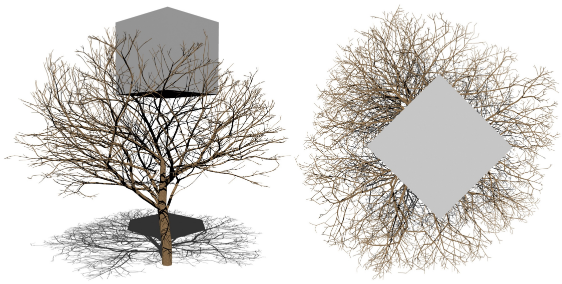

Figure 4: *Simulation of trees with solid obstacles.*

Modeling constrained by solid obstacles. We simulate a tree under a solid box (Figure 4). In the simulation, branches avert shooting into obstacle or shooting too much in shadow space and the whole tree adjusts its resource allocation according to the environment.

Growth modeling of two trees. Two trees showing the interacting effect on the environment and space competition between plants can be simulated with our algorithm expanded only by setting the tree number and their root positions. Initial light space should cover all the tree growth

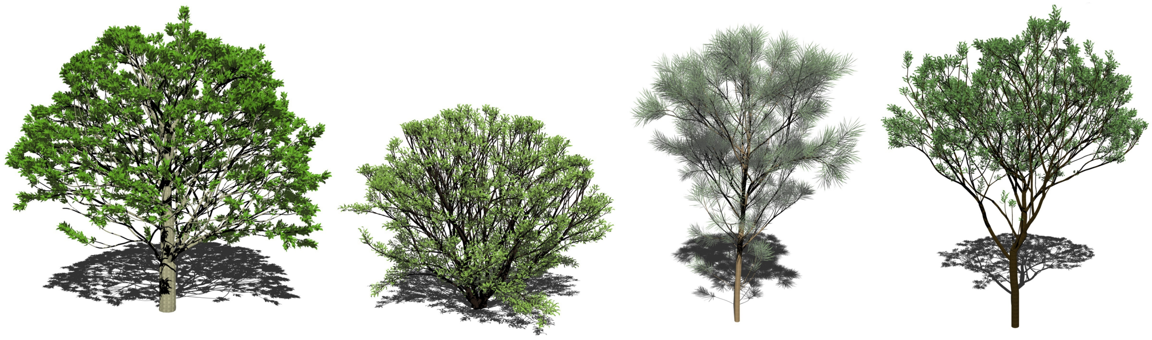

Figure 5: *Diverse tree models*

environment. After space and light resource competing, the output result is shown in Figure 1.

Diverse tree biomorphs and control parameters. By tuning several parameters with our method, we here list more experimental results as shown in Figure 5. In this figure, there are four tree models: an arbor, a evergreen shrubs, a pine and a dungarunga. Comparing with the tree models in [WYZB14], our trees have more complex skeleton structure with higher degree of randomness.

In order to generate these tree models, we specify some parameters listed in Table 1. In addition, the second model has 8 roots.

Table 1: *Parameters set for Figure 5.*

SN	λ	k	b	μ	γ	θ	r_s
1	0.52	0.5	2	1.5	0.5	45	0.35
2	0.46	0.5	2.1	1	0.5	45	0.25
3	0.54	0.35	2.2	1.5	0.2	30	0.25
4	0.52	0.35	2	1	0	38	0.35

5. Conclusion and Discussion

We present a tree modeling method which takes into account light resource, space occupation and resource allocation. The methodological contribution of our method is the tree growth simulation with resource allocation calculated according to light information based on environmental interaction. Compared with others' modeling method, our modeling method is able to control the general shape with decurrent or excurrent inclination and detailed trait of branches.

Our method still has limitations. First, the gravity influence to branching is not taken into account, which results in the shape of some branch not simulated well. Another is that the growth simulation partly exhibits growth progress which is lack of variation of growth rhythm. In the future, we also would like to consider improvement of model to realistically simulate the whole growth progress of plants based on internal mechanism and environmental influence.

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