GENERATING A MODEL OF PLANT USING NURBS

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An effort to find an algorithm for generating models of plants usable for computer graphics has continued since 1982. Because this problem has been unsolved until now we can see that it is very complex.

Existing methods work in two steps: during the first one a **topological description** is generated, while the second step generates a coresponding **geometrical model**.

The first phase creates a description of a neighbourhood of leaves, flowers, fruits and branches. Developed methods are mostly based on algorithms which work with probability assigned rules. The most known method, *L-systems*, is named by its author Aristid Lindenmayer [7] and was used for this reason, for the first time in [10] in 1984. Two new methods were introduced a *ramifield matrix* [11] and a *strands model* [5]. These methods are much more intelligible and give more possibilities to control the shape of a plant. They were developed in order to overcome biggest problem of L-systems – unabilty to estimate a final shape of plant.

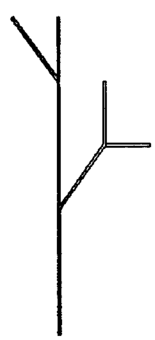

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Fig. 1: A string and its representation.

A product of the first step is a data structure which gives (after the application of the proper traversal algorithm) information about the structure of the plant. L-systems give a structure which is called **a bracketed string**. It uses characters to represent geometrical objects and two special characters: brackets to indicate a branch [10] (see Fig.1).

Both new methods [5] and [11] product a data structure coresponding to a binary tree.

The second step uses this information to generate geometrical representation.

This is in general a set of surfaces modelling the shape of the plant. This model must be suitable for rendering by the methods of computer graphics. This phase of generating the model is the hardest one, because the increasing level of credibility is reflected in the complexity of the model.

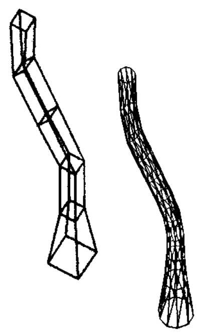

Fig. 2: A branch and its control polygon.

The lates research concerning this problem [1], [5], [6],[8] and [10] uses for describing the plants mostly Bézier surfaces. We use NURBS [3], [4], [9] which are generalisation of rational and nonrational Bézier surfaces (we pay for that with a higher complexity of all the algorithms: rendering, modelling and so on.) and which gives two basic advantages:

- an invariance to the perspective projection and
- a precise representation of conic sections and derived surfaces.

The second advantage consequently gives unified data representations of classical surfaces like a sphere, a box and free-form surfaces like "the utah teapot". Both advantages seem to be the reason for the intensive developement of NURBS theory and its application (*ACIS, PHIGS+, ALIAS, Iris Inventor*). This is the main reason why using of NURBS can be interesting for modelling the plants. The plant will be a set of free-form surfaces with the same data representation as all the objects in scene. If there is a quick rendering algorithm developed, the plant will be rendered quickly as well.

The key to the generation of a geometrical description of the plant is the joint between surfaces. For many technical reasons mostly surfaces of degree three in computer graphics are used. The C^2 continuity is a very strong condition so for a nice subjective perception G^2 is acceptable. The G^2 condition guarantees the same orientation of tangent vectors in both direction u and v.

The topological representation uses Weibull ordering scheme [5] where the weight of the branch is interpreted as its radius. Branches generating an algorithm goes through the topological representation and collects points which belong together and puts them in successive order into 3D space. These points determine a 3D polyline which is used as a sweep path for a polygon of seven-point definition of a circle or any (even changing) profile. The weights given by the ordering scheme determine the radius of the branch during the sweep (see Fig.2).

There are no complication with branch twisting when a sweeping path is a polyline. In case of a general interpolating curve branch twisting is solved by Frenet's frame [2].

The generated mesh is a control polygon of NURBS surface of a generalized cylinder [2] of a branch (see Fig.2).

The final orientation of a coordinate system in the control points of polyline during the sweep is calculated as an weighted average of orientation of ingoing and outgoing part of branch (see Fig.3).

An contributions of parts are calculated from their weights by expression (1).

$$\alpha_{new} = \alpha_{in} \frac{w_{in}}{w_{in} + w_{out}} + \alpha_{out} \frac{w_{out}}{w_{in} + w_{out}} \qquad (1)$$

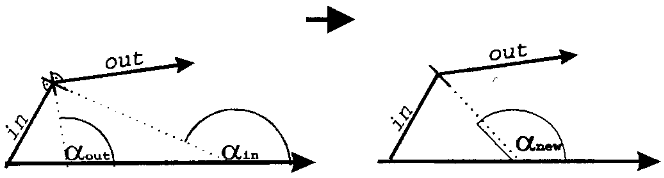

Fig. 3: Orientation of coordinate system.

A branching node is a point of generated polyline, which consists of one ingoing and at least two outgoing branches. To receive a smooth joining of two surfaces we need a tangent vector of

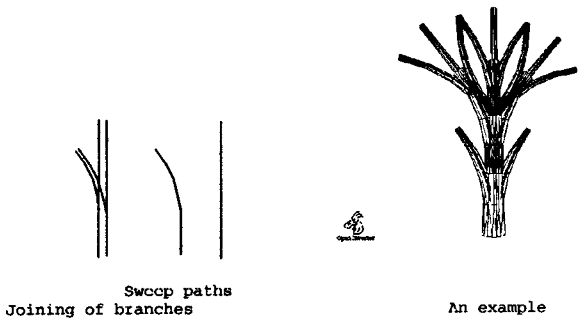

Fig. 4: The joining of surfaces.

sweep path in branching node to keep the same direction. For that we use two last points of the ingoing branch as the two first points of the outgoing branch (see Fig.4). A problem of intersection of NURBS surfaces is now unsolved at the level of the model and is solved by renderer.

A leaf is generated as three surfaces: a stem (an axe) and two patches (see Fig.5). Both

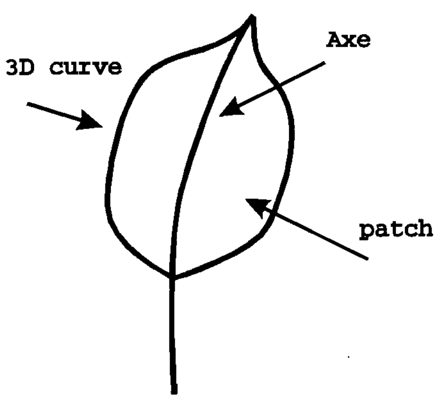

Fig. 5: Definition of leaf.

patches start from the stem and their orientation determines the local coordinate system. A joint into the tree structure is the same as for branching points except that the radius of the stem is constant. The patches are linear blending surfaces determined by their margin.

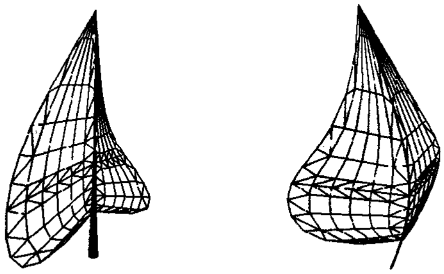

Fig. 6: A leaf in the wind.

The influence of global factors like wind, light and gravitation is also calculated. Each of them is represented as a vector where the size of the vector is an intensity. The amount of influence in each point of a branch is calculated from this vector, the distance of the point from the begining of the branch and the diameter of the branch. The same method is used for distorting the stem of the leaves. The distortion of the leaves surface is computed from the distance of stem. The global factors are applied **solely** for the control points of NURBS surfaces. So we can say that this extended definition is "invariant to the global factors".

References:

[1] BLOOMENTHAL, J.: *Modelling the mighty maple,* ACM SIGGRAPH85

[2] BROONSVOORT, W.F. - FOPKE, K.: *Ray Tracing Generalized Cylinders,* ACM Transaction on Graphics; October 1985

[3] FARIN, G.: *From Conics to NURBS,* IEEE Computer Graphics & Applications; September 1992

[4] HEWIT, W. T. - FENQIANG, L. - PRESTON, M.: *NURBS: A Tool or an Ornament for Graphics?,* EuroGraphics'92

[5] HOLTON, M.: *Strand, gravity and botanical tree imaginery,* Computer Graphics FORUM Vol.19, 1994

[6] KAWAGUCHI, Y.: *A morphological study of the form of nature,* ACM SIGGRAPH82

[7] LINDENMAYER, A.: *Mathematical model for cellural interaction in developement, Parts I and II,* Journal of theoretical biology 1968

[8] OPPENHEIMER, P.: *Real time design and animation of fractal plants and trees,* ACM SIGGRAPH86

[9] PIEGL, L.: *On NURBS,* IEEE Computer Graphics & Applications; January 1991

[10] SMITH, A. R.: *Plants, fractals and formal languages,* ACM SIGGRAPH84

[11] Viennot, X.G. - Eyrolles, G. *Combinatorial analysis of ramifield patterns and computer imagery of trees,* ACM SIGGRAPH CG, 23, 6, July 1989