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ABSTRACT

In the application in agriculture and forestry of modeling and simulation of three-dimensional plant growth, interactive visualization of virtual plant community using recently developed model processing and model simplification technology in computer graphics and virtual reality becomes a new focus.

The new methods in this paper are the simplifications of models with special shapes: Progressive Leaves Union and View-Dependent Branch Mesh Reorganization, where the originalities include: (1) topological structure modifying progressive simplification with error analysis for sparse parts of a plant, i.e., leaves, flowers and fruits; (2) multi-resolution remeshing for continuous parts, mainly branches; (3) simplification degree determined by viewpoint position, permitted errors, display resolution, and different positions of plants. Therefore, plant models with high proportional simplification are obtained keeping original visual effect within permission scope.

Plant modeling and the growth simulation methods in AMAP team are used and plant-positioning data are generated from software AMAP-Orchestra™ as data source. An interactive navigation in virtual orchard is accomplished, and a virtual apple orchard is presented as an example. All of this work is taken in the organization and environment of the high performance computation and visualization in ISA and SILVES projects of INRIA.

KEYWORDS: virtual orchard, multi-resolution, plant community visualization

INTRODUCTION

We live in an environment with various kinds of plants providing us with oxygen, and food and materials, and many industries are plant centred, including agronomy, forestry and environmental defence. One of the most important symbols of modern agriculture and forestry is virtual plant, a three-dimensional model of plant generated and growing in computer environment and simulating the architecture, growing process, interaction with their environments, and production of plants in real world [1], [2], [3], [4], [5], [6].

When integrating with production reality in agriculture and forestry, the research in plant growth modelling and simulation and plant community visualization will become a practicable technique. Two typical examples are the application of GreenLab plant growth modelling and simulation ideology and methodology in crop and vegetable production in CIRAD, INRIA, LIAMA and CAU [6], [7], [8], [9], [10], [11] and the establishment of project SILVES on the application of plant modelling and simulation to forest management on basis of geographic information system and in virtual reality environment in CIRAD, INRIA [2], [12], [13], [14].

In this paper, some recent research results in interactive plant community visualization of SILVES project are introduced using newly developed model processing and model simplification technology in computer graphics and virtual reality. It is our desire to show the application of SILVES, not only in forestry, but in agriculture also.

RELATED WORK

Plant modelling and simulation

Since its integration with biological, ecophysiological and physical laws, plant modelling and simulation provides three-dimensional plant models faithful to botanical structure and development based a great many fieldwork [1], [15], [16].

There are many successful modelling systems, such as AMAP, L-system, Xfrog, etc. AMAP is based on the theory of finite automata for plant life cycles [1], [12]. L-system, based on the thought of fractal patterns in living things' growth, uses syntactic methods to model plant growth [3], [17]. Xfrog is an easy tool to generate complex plant structures [18].

The original idea of plant growth simulation method developed by AMAP research team is based on botanical notions of plant architecture. In simulating metamorphosis, the notion of a reference axis is needed which shows all the stages of differentiation in a branch throughout its growth. If we consider the simultaneity of biological events, which characterize a plant's functioning, we can study the environmental (nutrition and precipitation needs) and spatial (crowding, light influence) interactions. The reference axis is structured like a finite automaton and the discrete events simulation (scheduler) is used for the parallel simulation of the growth [19], [20].

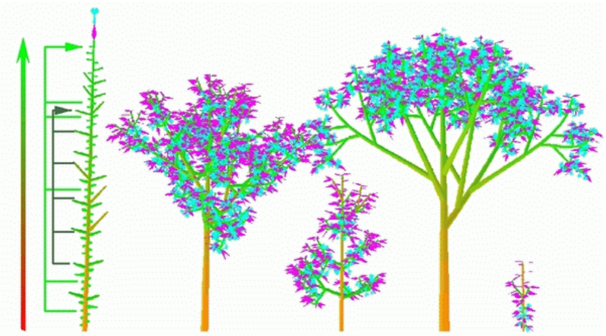


Fig. 1 Growth and metamorphosis of a theoritical plant.

Fig. 2 Simulation of two tropical trees with shyness effect

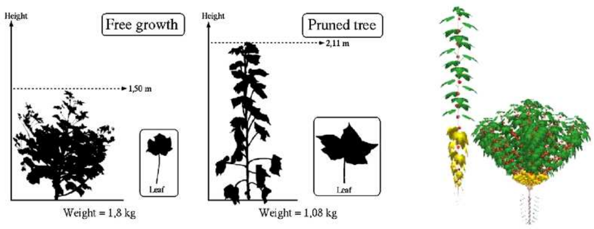


Fig. 3 Reaction of a cotton tree to pruning, and result of a simulation (right)

AMAP-Genesis^{TM} integrates the research in plant growth simulation in AMAP team with its special plant procedural growth engine and plant architecture. Commercial software AMAP-Orchestra^{TM} provides users with necessary tools of a large-scale landscape project, including AMAP-Genesis^{TM}. It can be used for processing terrain data, architectural objects and vegetation models. It is advanced software for scenery modelling, management and realistic visualization of a large-scale landscape.

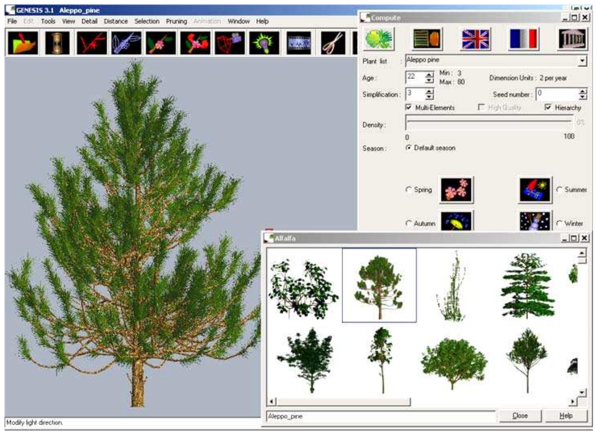


Fig. 4 *Genesis* module (AMAP™): tools for simulation of growth and plant visualization

Plant community visualization

Plant community contains a great amount of data in detailed foliage and branching information, independent, small in size, highly repetitive, convergent in distribution, and close to terrain. This leads to high rendering time and aliasing artifacts. Many methods have been developed to deal with these problems, mainly in five aspects, polygon decimation [21], image based rendering [22], volume [23] and texel [24], rendering, point based rendering [25], and silhouette estimation [26]. But they are not effective for rendering acceleration; therefore real-time visualization is still a challenging problem.

There are many achievements in mesh simplification [21], so that it becomes an efficient method obtained in realistic and interactive display. But its object is continuous mesh, in which the connectivity relation of polygons is kept in processing.

For foliage, the leaf polygons are discontinuously distributed in the space since leafstalks are always omitted. Foliage simplification is first considered in Foliage Simplification Algorithm (FSA) [27]: two leaves disappear to create a new one. Leaves obtained preserve an area similar to that of the collapsed leaves, and visual effect of foliage is kept to some degree after simplification with FSA.

Fig. 5 Realistic visualization of ecosystem[17]

Plant community visualization has attracted more and more people working in realistic image synthesis and virtual reality.

Orchard management

One important application of plant growth simulation and visualization is on fruit production estimation, quality and quantity, such as fresh matter accumulation for fruit during the stage of rapid development [28] and simulation model of carbon supply and demand for reproductive and vegetative growth of fruit trees [29]. Another application is on simulation of management activity in an orchard, such as pruning of fruit trees on the knowledge of many factors: structure, light penetration and distribution of wood ages [30].

In addition, interactive visualization of the integral orchard is a basic problem of fruit research and orchard management.

High performance computing and visualisation

High performance computing and visualization makes use of sophisticated graphics hardware, supercomputing hardware, advanced multimedia data services, and fast network services through intranets, the Internet, and the Grid. By combining high-performance graphics, computing, data management and networking technologies, it can play an indispensable role in solving complex problems that may be unapproachable only recently [31].

In this field, ISA introduced new software architecture making it possible to combine a multiprocessor and several graphic pipelines environment. This allows very important acceleration of overall geometrical calculations implemented in certain scientific applications, without penalising the acceleration of traditional parallelism.

High performance computing and visualization will be a basic working environment for interactive plant community visualization of magnanimous data [32], [13].

PROJECT SILVES

The resolution of the problems of forest stock management requires assembling complex processes, in space and time: integration of knowledge in software of simulation and geographical information systems (GIS), economic or ecological optimisation of silviculture.

A scientific project

Within the framework of a collaboration among INRIA-CIRAD-INRA-ENGREF institutes, one seeks to develop tools to help forest management by using GIS, the models of forest production of INRA, the models structure-function of CIRAD-AMAP and knowledge in calculation and visualization high performance of project ISA in LORIA. In particular, the possibility of being able, starting from the 2D GIS data, to model in 3 D a forest cover, allows to envisage many treatments: visualization, like tool for dialogue between the administrative organizations and the users of the forest, but also of aerodynamic calculations and transfer of energy [12], [13], [14].

Thus, within the framework of project ISA (applications for Increased Reality real time), scientific project SILVES should give rise to an integrated software platform making it possible to represent, simulate and visualize forestry spaces in their current state and during their evolution in order to better control the choices of silviculture and the decisions of management. The geometrical modelling of forest covers should also allow the coupling structure with other models interested by the structure of forest covers: simulation of fires of forest, calculations aerodynamic, estimate of the quality of wood according to the forestry constraints.

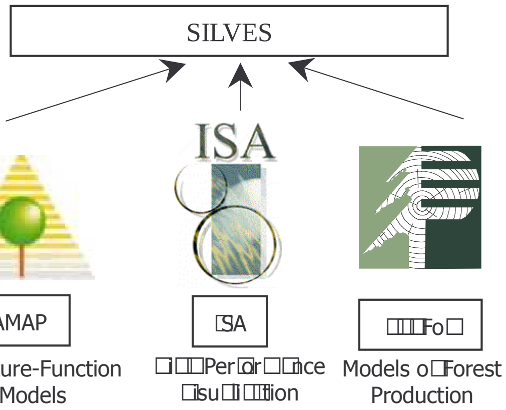


Fig. 6 Technical supports to SILVES

3D visualization of GIS data

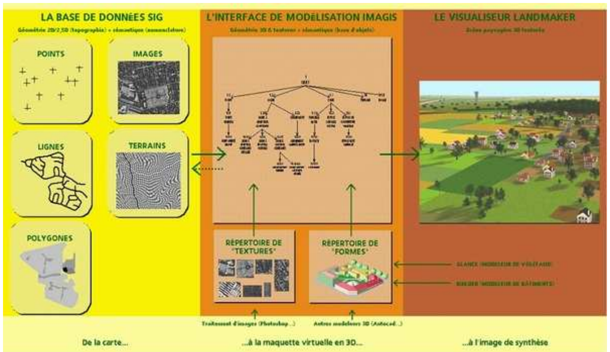


Fig. 7 IMAGIS structure: 3D representation of a GIS.

Use of the software IMAGIS (visualization of GIS) and software AMAP. In particular, it is necessary to develop the potentialities of IMAGIS (which was conceived originally for applications of landscape management) for a wider use in forest research topics. 2D images from GIS are the inputs of SILVES system. They are then processed for plant analysis (species, density, age, etc) and for the semi-automatic generation of 3D scenes with AMAP modelling and simulation techniques. 2D images from IMAGIS GIS, when combined with DEM (Digital Elevation Models) data, can also be used as background in bird-eye's views of 3D scenes.

Structure-function models and forest production models

The main idea of this part is to develop an interactive relationship between structure-function models and forest production models in order to pull together advantages of each system: in one hand, the tree architecture is well described but the stand structure is not managed, on the other hand, forest production is estimated at broad scales but the tree description is very simplified. Coupling both approaches would then offer realistic simulations on a large area, with a good description at the stand and the tree level (including tree architecture, wood quality etc.). The goal is to reconstruct completely the plant in 3D, throughout its life and with precision knowing the general rules of development of the species and knowing only some variables relative to a realization at a given time of the plant development. This problem of inversion of models and quasi-numeric is similar to the estimation of parameters or to the optimisation process.

Fig. 8 AMAP^{TM} structure-function models for forest

Visualization

Simulation of forest covers and visualization in immersed room. The characteristics of this topic are as follows:

(1) Development of a software platform allowing to simulate the development of a forest cover (by using existing competences of AMAP) and to visualize it in immersed room.

(2) Simulations in real time in order to allow an interaction between the user and the simulator (by using high performance virtual reality hardware and most recently developed techniques in computer graphics).

(3) Study of the multi-scale representation of a forest cover so to optimise the performances.

(4) Development of a unified interface allowing modifying the characteristics of the simulation (forestry choices for example) with AMAP and IMAGIS supported as back-end.

SILVES with agriculture

Although we do not want to show that orchard is the main object of SILVES, interactive visualization of virtual orchard for orchard management is an application of SILVE.

INTERACTIVE VISUALIZATION

The main techniques of interactive visualization in virtual orchard include three aspects: progressive foliage simplification, multi-resolution branch remeshing, and view-dependent visualization. New developments in plant community visualization in SILVES and their first application in virtual orchard are described below.

Foliage simplification

A new Foliage Simplification algorithm, Progressive Leaves Union (PLU), was presented to improve FSA to keep more visual effect while the number of quadrilateral leaves decrease greatly. Leaves union means choosing the best quadrilateral leaf to approximately represent the space two or more quadrilateral leaves have occupied, so that the shape and colour of the overall plant are approximately kept.

PLU is improved in this paper to include more shapes and more organs, so that triangle leaves, quadrilateral leaves and general polygon leaves can be processed simultaneously, and polygonal flower and polygonal fruits can be simplified also. See Fig.9 for the process of improved PLU, where the dashed lines in (a) represent the construction of the new leaf, and that in (b) represents the diameter of the new leaf.

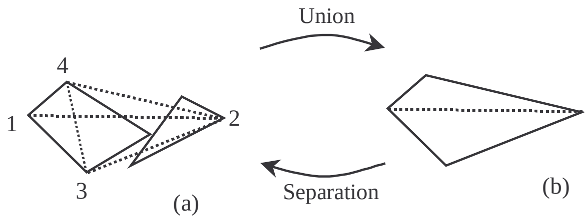


Fig. 9 Leaves union and separation

There are two main steps to accomplish improved PLU: Best pair choice and error estimation. Like PLU [14], the best pair in improved PLU comes from the pair with closest comprehensive similarity: normal similarity, positional similarity, area similarity, diameter similarity, union age similarity, and diameter similarity. Since precise error estimation of the leaves, flowers and fruits before and after union is difficult to calculate and the diameter of leaves before leaves union and the new leaf after union is the same, therefore this diameter is chosen as a measurement for error estimation.

We will show how the visual effect is kept by of foliage simplification related to the errors in the number of pixels---different permitted pixel errors in Fig.10 and Table.1.

0.5 4.5 13 30

Fig. 10 Progressive simplification of an apple tree with improved PLU

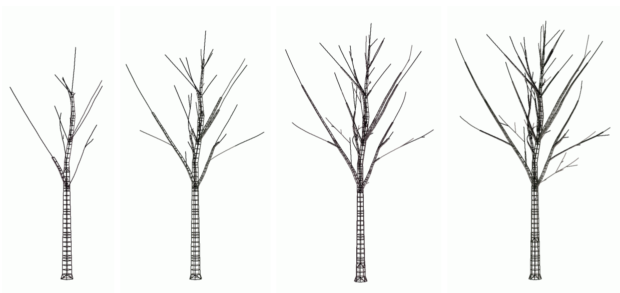
Table 1 Simplification for different resolution

Permitted pixel error	0.50	4.50	13.00	30.00
Leaf polygon number	1605	532	113	29
Percentage after simplification	%100.0	%33.1	%7.0	%1.8
Branch polygon number	4377	391	91	0
Branch line number	0	160	28	22

Fig.10 is an example of progressive simplification of a 11 years old Crab apple Makamik tree in spring season with improved PLU method with different permitted error value of 0.5, 4.5, 13, 30. The tree is 3.54 meters high and 8.91meters far away from the view. The detail degree of simplification of foliage with improved PLU and reorganization of branches with VDBMR (View-Dependent Branch Mesh Reorganization, explained below) in Fig.10 is in Table 1.

View-dependent branch mesh reorganization

Line model of tree branches represents the skeleton of tree. Tree branch polygons are reorganized through pixel error prediction in View-Dependent Branch Mesh Reorganization (VDBMR) algorithm, so that minimum number of polygons and line segments of branches are obtained which keeps the visual effect of original branch with much more polygons. When a branch is not too thin, polygon model is used to represent; when it is small, generally smaller than one pixel, stipple line segment model is used; when it is too small, generally smaller than one sixth of a pixel, it is decimated. Therefore the reorganization is a mixture of polygon model and line model.



7.5 4.5 3 2

Fig. 11 VDBMR of an apple tree

Fig.11 is an example of different models of an 11 years old Crab apple columnar Siberian tree with VDBMR method and with different permitted error value of 7, 4.5, 3, 2. The tree is 3.53 meters high. The detail degree of simplification of foliage with improved PLU and reorganization of branches with VDBMR in Fig.10 is in Table 2.

Table 2 Reorganization for different resolution

Permitted pixel error	7	4.5	3.0	2.0
Branch polygon number	219	533	934	1543
Branch line number	135	175	205	237

View-dependent visualization

The key technique of view-dependent visualization is choosing a right measurement of the degree for simplification. In SILVES, the number of pixels of a unit length inside the sphere of a tree is estimated by central projection, so the is also dependent on the size of the window, the size of the viewing angle, the distance of it to the viewer.

In SILVES, the solution for branch visualization is to think about a branch as a generalized cylinder, and the right error of a connected prisms to the generalized cylinder in pixel coordinate is calculated. This branch reorganization is carried out when rendering.

The solution for the visualization of different sparse parts, including leaves, flowers, and fruits, are treated separately with improved PLU, and the errors of corresponding polygons before and after union is recorded in preprocessing. All the polygon union process forms a binary tree SBT (Spars Binary Tree). In SBT, all the leaves are the spars polygons of the plant, and all the branches are newly generated leaves. The diameter of the child in SBT is no greater than that of his father. Therefore, this sparse parts simplification is carried out through traversing SBT and determining which sparse polygon is rendered.

With simplification　　Without simplification

Fig. 12　View-dependent simplification

Table 3　Simplification for different distnces

Tree NO	1	2	3	4	5	6
Distance (meter)	9.6	19	38	70	124	205
Leaf polygon	155	155	155	155	116	45
Flower polygon	2464	2464	1417	723	305	135
Branch polygon	1278	601	265	126	51	0
Branch lines	55	105	69	36	19	23

A Crab apple Makamik in spring season of 2.9 meters high is positioned in 6 different places from near to far to the viewer to compare the visual effect kept after simplification. It can be seen through Fig.12 that the simplification of trees with improved PLU and VDBMR are view-dependent and reduce the number of polygons greatly but keeps the visual effect well.

EXPERIMENTAL RESULTS

A virtual orchard of apples is established to realize interactive visualization. Two species of apple trees are used, Crab apple Makamik and Crab apple columnar Siberian tree, each is with 4 models in 4 different seasons. In each species, the first model is 9 years old in spring season, and the other three are 11 years old in summer, autumn, and winters respectively. All these models are generated by Genesis™ workshop of AMAP-Orchestra™.

Four seasons in orchard

Fig. 13　Spring in orchard

Fig. 14　Summer in orchard

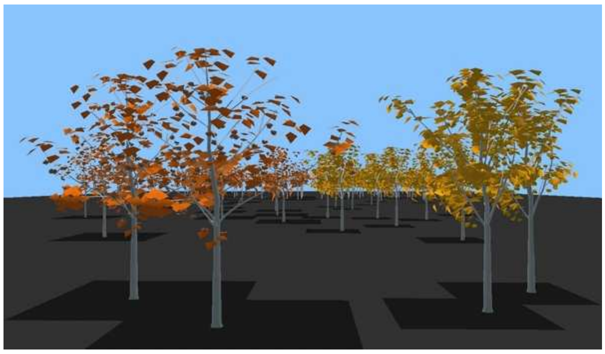


Fig. 15　Autumn in orchard

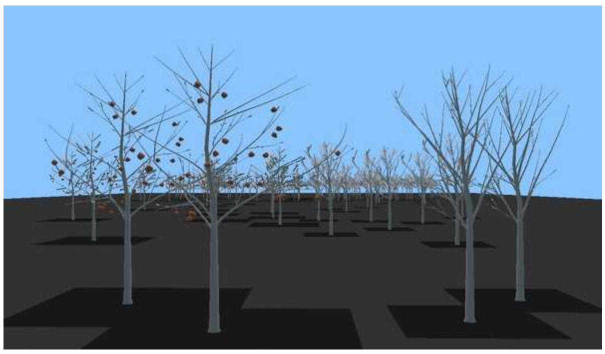


Fig. 16　Winter in orchard

Landmaker™ workshop of AMAP-Orchestra™ is used to distribute tree on the ground. There are 100 trees in this orchard, where the number of Crab apple Makamik trees is 45 and that of Crab apple columnar Siberian trees is 55.

Table 4 Data of interactive visualization in orchard

Seasons	Spring	Summer	Autumn	Winter
Sparse Polygon Number Original	284,746	178,970	160,600	14,256
Sparse Polygon Number used	32,622	21,739	19,229	4,579
Sparse Polygon Simplification Degree	11%	12%	12%	32%
Branch Polygon Number	3,894	5,613	5,691	50,804
Branch Line Number	2,486	3,703	3,784	13,421

Since the degree of the simplification with improved PLU for sparse part of trees is rather high, about 12% in average, and the number of branch polygons and branch lines is small, about 16500 polygons and 5848 lines in average, the visualization of the orchard is interactive.

Performance

This test of visualization is taken in Silicon Graphics Fuel™ Workstation with R14000A™ processor (1500 MHZ), 1024 MB memory, and VPro™ Graphics hardware V12 (128MB graphics memory).

RESULTS AND DISCUSSIONS

From the above description and experiment, it is evident that improved PLU and VDBMR method in this paper has four advantages for foliage simplification: (1) All sparse parts and branches of a tree are simplified simultaneously; (2) Closed silhouette of the original tree is kept; (3) The simplification process is view-dependent; (4) Aliasing is ameliorated.

This paper still has the following disadvantages for further work: (1) Topological structure maintenance: the process of leaf union should keep the topological structure of the tree. In each step, the union should be confined to all the leaves belonging to the same level of branch, including the union of a leaf cluster and that of a compound leaf. (2) Transparency: the union of overlapped leaves, flowers, or fruits, to a new big one will change the hiding effect, so that the simplified tree will be too dark, therefore a consideration of transparency changes is needed. Especially when sparse polygon area increases after union, its transparency needs decreasing. (3) Improved PLU errors: methods need be developed to estimate errors of the difference between before and after sparse polygon union in each step of simplification, so that error control would be more precise.

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