Information Sciences 220 (2013) 522–540

Contents lists available at SciVerse ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Environmental framework to visualize emergent artificial forest ecosystems

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ARTICLE INFO

Article history:
Received 28 May 2010
Received in revised form 17 January 2011
Accepted 18 July 2012
Available online 1 August 2012

Keywords:
Artificial life
Natural phenomena
Computational biomodeling
Ecosystem simulation
Computer animation
Forest ecosystem

ABSTRACT

We propose an environmental framework for simulation and visualization of woody plant forests. A complex application software system develops and animates a spontaneous afforestation process within this environment. The system considers several environmental properties and combines computer animation with artificial life. The main goal of the presented software system is to use it in computer animation for synthesis of natural environments and visual analysis of their natural look credibility. The afforestation process is modeled as an ecosystem simulation, where trees struggle for survival based on several growth factors. A detailed description of the procedures for simulating tree growth and the factors that might influence tree growth is provided. All the tree growth simulation procedures and factors are biologically inspired. They have been defined mathematically in the paper by designing a bottom-up agent model which emerges the artificial tree distribution by mediating to the simulation.

A flexible and adaptable procedural 3D model is used to visualize trees. Also, growth of individual trees is animated, from development of branch complexity to per-leaf precision, which allows a very realistic perception of the emerging ecosystem. The visualization of trees is sped up so that the models of trees have progressively lower-details proportional to the distance from a certain point of view. Locations and maturity of visualized trees are obtained from the ecosystem simulation results, and the afforestation process is animated over several centuries. The natural look of the artificial tree distribution is confirmed visually and statistically. Visually, it is confirmed from rendered sequences, and statistically, from graphs of tree species populations. Several patterns emerge permanently, such as the number of trees in the ecosystem simulation increasing exponentially and trees growing in communities.

1. Introduction

In this paper, we present an environmental framework for the simulation and visualization of woody plant forest ecosystems. To be able to visualize forests of woody plants, we must first be able to render individual trees using tree models. After we have visual models of trees, we can place them in an environment according to some distribution and other environmental factors. In this paper, these are obtained by computer simulation for artificial life of woody plants. In the following of this introduction, related work on modeling of trees, ecosystem modeling, artificial life, and landscape visualization is discussed briefly.

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http://dx.doi.org/10.1016/j.ins.2012.07.031

The tree modeling has a twenty year tradition in computer graphics, from game engines to cinematic scenery. At the beginning, the focus was on modeling the geometrical structures of individual trees. Manual modeling of tree structure and its leaves is a tedious task, because each branch and leaf position, rotation, size, and texture must be appointed. Therefore, procedural tree models are used instead and several following techniques for procedural models are available today. Let us briefly refer to some of the strongest representatives and their key distinguishing features. First, these procedural models differ in types of branching structure construction [36]. Also, they differ in the level of detail [2,4,39], the flexibility, and pretentiousness of modeling [19,52], space [32,47], and time complexity [32] in addition to the animation ability and representation of the built 3D model. The majority of these models try to determine some visible properties of the final 3D model, such as rotation of branches around their central axes. These properties are usually biologically inspired by *phyllotaxis*, i.e. the main influence on the tree's architecture [40].

Ecosystem simulation has been addressed in many fields, from biology to artificial intelligence [16,21]. Ecosystem simulation is also used by computer graphics to render a 3D ecosystem scene into an image [9,63]. To, generally, be able to simulate life, artificial life models exist, such as [38,22,27,17]. In simulating life of trees within a forest ecosystem, the spontaneous development [46,23] is one of the main processes of forest development which must be modeled. Following increases in computer power and computer graphics research, research interest from individual tree models rendering has grown to several trees rendering together in an image. Considering the limitations, the aim in modeling single trees is to obtain natural look when rendering. This aim in rendering several trees still persists, and can be represented by determining several environmental factors, such as locations of trees, their sizes, and interaction of trees with their environment. Manually defining these factors, even perhaps by using some help by general purpose 3D modelers (e.g. Maya, Lightwave), requires specialized knowledge and art, creativity, and labor time by the user. An automated tool can try to partly relieve the user in these requirements. Such tool tries to define tree locations and other considerable factors to get a naturally looking image. Type of trees to render at tree locations could be recognized from photographic imagery [41], or rather obtained by simulating an artificial ecological system and life within it.

The first to treat landscape visualization with forests and shrubs were Weber and Penn [52]. Their trees were represented by a procedural geometrical model and rendered with ray-tracing. As this model featured level of detail adaptation, they were able to visualize few thousand trees on a landscape. Trees on this landscape were manually placed and did not reflect any biological laws of spontaneous afforestation, this being one of considerable drawbacks of their approach.

Chiba et al. [6] represented trees using volumetric textures. An image was compiled by ray marching through voxels (3D image elements) and integrating their density and color. Trees were placed on landscapes using Poisson disk sampling [7], so that a new tree was successfully added only if its randomly selected location was not too close to the location of some other tree. The simulation was simple and fast, but their rendering process took several hours and the trees were of low detail. Using such an approach they created images with up to 20,000 trees on a landscape. Their simulation was more of a trial-and-error calculation and still, life was not simulated to obtain tree distribution.

Specialized for rendering ecosystems of woody plants, Deussen et al. [10] built the first ecosystem simulator used in computer graphics to follow some natural laws of spontaneous afforestation. Their highly detailed tree models were created using L-systems [35,56,51] and rendered using *ray casting* or *ray tracing*. Non-textured scene overview was possible with Gouraud shading by using OpenGL, but realistic image rendering took several hours and it was not intended for real-time animation. With so many ray-traced objects on scene, they came up with the conclusion that a compact procedural model for geometry generation and the *instancing* of created geometrical tree models must be used for objects to fit in the main memory. Another conclusion they drew is, that for rendered images not to look artificial, the perception of tree distribution in a scene should be authentic. Visually credible distribution of trees was achieved using two different approaches, one is from global to local, the other is from local to global. The first approach was semi-automatic requiring a standard paint program [10], the second was automatic calculation of the distribution, a pure simulation. This second approach, the simulation, included some natural laws of spontaneous afforestation, the interaction among the trees themselves and the environment. By passing a limited number of parameters to the model, many emerging trees have grown over the landscape according to the modeled natural laws of spontaneous afforestation.

Let us elaborate on laws of interaction Deussen et al. included in their second approach, which actually were bottom-up software agents [15,1,44] to thrive the simulation by mediating to the environment. The first such agent was a tendency for the same species of trees to grow in clusters, emerging the effects of *clustering* [3], *clumping* [25], and *under-dispersion* [20]. The second agent Lane and Prusinkiewicz considered in [25] was competition among individual trees in an area of *ecologic neighborhood* [8], where one tree can influence the growth of others. By intersection of two ecological neighborhood areas, the involved trees interact. One of the trees becomes dominated and when a tree is being dominated, its growth is slower or it may even die. Such competition principally results in a phenomena of tree distribution known as *self-thinning*, meaning that in the beginning of simulation, trees grow without interference, but as density increases, the dominated trees start dying off. Deussen et al. [10] defined the domination of a tree by comparing its competitive ability to the competitive ability of competing trees within its range. If a tree has inferior competitive ability than a neighbor, it becomes dominated. The competitive ability depends on the age of the tree, domination tolerance, water concentration at its location, and its preference for wet or dry areas. Considering the living conditions, this is a rather simplified growth model, since it only considers the moisture. Lane and Prusinkiewicz [25] introduced a clustering mechanism to this simulation, which enabled trees to grow in communities.

Motivation and objectives of our work are as follows. We want to combine models that are efficient for visualization and allow tuning of the simulation in real-time during animation. We want, that our simulation allows a great number of indi-