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Getting to the root of the problem in tree digital twin models

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Trees have immeasurable societal benefits. They provide wood, absorb carbon dioxide, and shelter animals and insects, but also provide shade and space for people to relax.

Although forests have been studied and observed for millennia, there are still many open questions to their growth and health. One of them is understanding the way trees consume resources. While tree digital twins (computer models) that simulate branch competition for resources exist, root modeling and interaction with nutrients is still lacking.

Researchers Bosheng Li and Bedrich Benes from Purdue University, together with their collaborators Wojtek Pałubicki from Adam Mickiewicz University Poland, Soeren Pirk from Adobe Research and the Christian-Albrechts-University in Kiel, Germany, and Jonathan Klein and Dominik Michels from KAUST, Saudi Arabia, have developed a novel interactive 3D model, called Rhizomorph, that simulates the complex interplay of the coordinated development of tree roots and their response to water and nutrients and the upper canopy and its response to light.

The rhizomorph model will be presented at the annual ACM conference Siggraph in Los Angeles in August 2023.

Taking soil, light, and water into account

The rhizomorph model simulates the coordinated development of shoots (upper tree canopy) and roots. It is an interactive computer model that integrates the layered soil model, where the water and nutrient flow is simulated by coupled differential equations that consider the 3D spatial and temporal domain.

The model simulates different structural compositions such as clay sand, loam, or humus. The nutrients and water flow through these materials and are absorbed by roots. The upper canopy of the tree reacts to light. The model integrates both inputs and uses a complex signaling mechanism that informs the roots and the shoots about the available energy that controls their development. The competition for resources results in the overall shape of both parts.

The authors show various examples of complex root systems: heart, lateral, sinker, taproot systems, roots reacting to varying nutrients, and soils.

"The paper successfully integrates modeling methods of trees and soil, substantially advancing the state of the art of tree modeling in an environmental context," says Przemysław Prusinkiewicz, professor emeritus of computer science, from the University of Calgary and an expert in the field.

This realistic computer model that simulates the 3D development of trees with their roots will likely advance applications in simulations of complex ecosystems where trees are exposed to varying environmental conditions. The interactive speed of simulation of complex 3D shapes makes the model suitable for digital forestry applications and generates "what-if" scenarios where unknown or varying environmental conditions arise, as shown in the image below.

"A scenario I like to use is imagining the effects on a 3D forest model exposed to a changing climate," said Benes. He added, "How will the tree and root shape be affected if there is not enough water? What happens when nutrients are not available, or the temperatures change?"

Existing models

Computer graphics has made significant strides in creating lifelike representations of trees and plants. In this pursuit, various techniques have been employed, with a particular focus on procedural modeling algorithms that incorporate biological principles.

These existing algorithms excel at generating intricate branching structures for individual trees, enhancing the realism of the models.

Unfortunately, many of these approaches have overlooked a crucial component: the root system of trees. Neglecting the representation of root systems not only compromises the visual authenticity of tree models but also disregards the vital role played by roots in the growth and development of trees.

Accurate representation

The inclusion of root systems in computer-generated tree models offers multiple benefits. It contributes to the overall visual fidelity of the models, ensuring a more accurate representation of real-life trees.

Furthermore, roots are integral to the survival and growth of trees, as they provide essential functions such as nutrient absorption, anchorage, and water uptake. By neglecting to model root systems, previous approaches have simplified this fundamental aspect of tree development.

Recognizing the significance of root systems, researchers in computer graphics are now exploring novel methodologies to incorporate root modeling into their algorithms. By integrating realistic root structures into their tree models, these advancements aim to achieve a more comprehensive and faithful representation of natural ecosystems in computer-generated graphics.

More information: Li, J. Klein, D. L. Michels, B. Benes, S. Pirk, W. Pałubicki, Rhizomorph: The Coordinated Function of Shoots and Roots, ACM Transactions on Graphics (Proceedings of SIGGRAPH), 2023,

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