RADIATA MANAGEMENT TECHNICAL NOTE (IFS)

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Xylem Transport Model

Summary

Accurate modelling of wood formation involves predicting the ascent of water in the xylem of trees. Xylem transport is a physical process which partially explains wood anatomy and structure. Studies are under way to understand xylem transport with regard to tree physiology and also to understand how the water status of the plant may affect wood quality. This is a component of the overall stem formation simulation system in the *Mechanobiology Of Wood Formation* framework. This is part of Intensive Forest Systems Objective 2 in the Radiata Management theme. This milestone is being delivered during year two of this six-year project.

This project models the relationship between the xylem pathway of trees and water transport by developing a Finite Element model. This model was based on the Cohesion-Tension theory explaining water flow in trees and builds on previous theoretical work undertaken in the scientific community.

A xylem transport model has been developed and is integrated in the *Mechanobiology Of Wood Formation* framework. This model is operational and will be expanded upon as more complex and realistic maps of xylem material properties become available.

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Introduction

Wood in trees provides both mechanical support and water conduction. In angiosperms, both functions eventually lead to two types of tissues – vessels and fibres – whereas conifer tracheids fill both roles [8]. According to the well-accepted Cohesion-Tension theory[4], long-distance transport of water in trees occurs as a result of water loss by evapotranspiration in the leaves, which puts the column of water in the xylem under tension and generates the flow [6]. Water transport in trees is only possible because of the capacity of tracheid cell walls to sustain important negative pressures[7]. Xylem transport is thus a physical process which partially explains wood anatomy and structure.

There exist various other reasons for studying xylem transport, namely because water is utilised to transport the photo assimilates, for phloem loading and unloading and also cambial growth[3]. Nutrients essential to tree growth and quality are also transported along the xylem pathway. The water status of the plant is also known to potentially affect wood quality (e.g., resin pocket defects, false ring occurrence). All those reasons make the development of a xylem transport model a key element of any tree growth model in general and the *mechanobiology* modelling framework in particular.

Methods

Theory

Diffusion is a process by which matter is transported from one part of a system to another as a result of random molecular motions[2]. The theory of diffusion is based on the hypothesis that the rate of transfer of the diffusing material through a unit area of a section is proportional to the concentration gradient normal to the section.

Strictly speaking, water transport in tree xylem occurs as a mass flow against a pressure gradient or, more precisely, a water potential gradient. However, we can use the diffusion analogy to model the transport of water, since equations for the distribution of water potential in a plant and diffusion of a substance in a medium are similar.

Finite Element Mesh

At any time of tree growth, the modelling framework can be stopped and queried for the current tree surface. Tree surface is available as a triangulated domain formatted as a Visualisation Toolkit (VTK) file or object www.vtk.org. A numerical routine has been developed to translate the surface into a volume corresponding to the space occupied by the tree xylem. The space inside tree surface is seeded with points and the domain is then triangulated into a solid mesh of tetrahedra using a 3D Delaunay mesher.

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Once the mesh is constructed, it is translated to ABAQUS (SIMULIA, Providence RI) input file format, which is the Finite Element software used to solve the equation of mass transport.

Analysis

The analysis requires material properties in relation to water transport. Hydraulic data for radiata pine are scarcely available in the literature. Kininmonth[5] and Booker[1] give permeability values in wood orthotropic directions. Values, once converted to hydraulic conductivity, fall into the expected range of variation for conifers[7]. Only longitudinal conductivity has been used during the model development. Little, if any, data has been found regarding the resistance of radiata pine wood to embolism and temporary loss of conductivity. Conductivity has been treated invariant to water potential.

Three test cases were carried out:

- Fixed soil and leaf water potentials, steady-state mass flow;
- Tree submitted to a daily variation of leaf water potentials, transient mass flow;
- Tree submitted to a daily variation of evaporative water fluxes, transient mass flow.

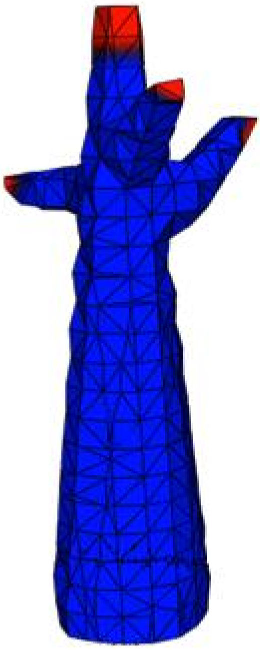

Figure 1: Evaporative fluxes corresponding to test case 3

Figure 1 shows the evaporative fluxes of test case 3.

Figure 2 (below) shows the distribution of water potential within a simplified tree structure for the first test case.

The distribution reflects the simplified xylem structure used to test the model. A cambium model predicting density profiles and spiral grain would be required to observe more complex water distributions. A heartwood model would also be a significant improvement. However, the xylem transport model is already well-adapted to accept more complex material description. An important aspect is that predicted water potentials can be transferred to any cambium model capable of using water information to predict growth rates and xylem structure.

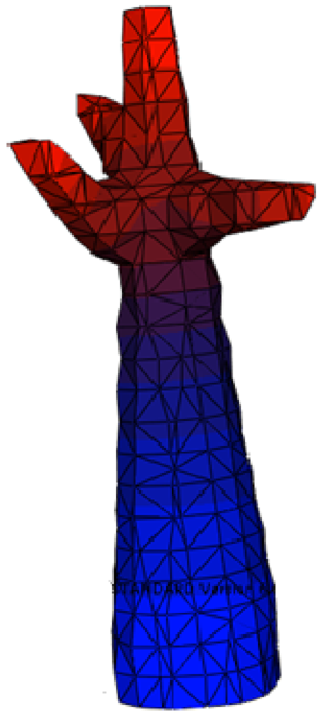

Figure 2: Distribution of water potential within a simplified tree structure corresponding to the first test case.

Conclusion

A xylem transport model has been developed and is integrated in the *mechanobiology of wood formation* framework. The model is operational and will be expanded upon as more complex and realistic maps of xylem material properties become available.

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