TREE GROWTH AND WOOD FORMATION – APPLICATIONS OF ANISOTROPIC SURFACE GROWTH

(Ensis Ltd)

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Ensis is a joint venture between Scion (New Zealand Forest Research Institute) and Australia's CSIRO Forestry and Forestry Products. They deal with problems relating to: genetics; wood and fibre quality; wood processing and products; pulp, paper and packaging; forest bio security and protection; sustainable production forestry and integrated environmental forestry. Approximately 300 staff are located at eight sites in Australia and New Zealand working in trans-Tasman teams.

The problem posed to MISG was to develop a model for growth of trees, with an emphasis on being able to provide a general framework for describing surface growth and to visualise the growth in three dimensions. The model had to be applied to a tree's surface, as well as cell wall thickening, and the formation of grain lines. Only growth of the girth of the tree's stem and branches (i.e. radial growth) needed to be modelled: the axial growth of the branch tips being considered outside the scope of the project. A numerically stable algorithm needed to be found, and implemented to solve the problems and produce the visualisation. Summarising, the main objectives were defined as: choose a suitable formulation for the surface velocity vector describing the tree's growth; determine grain directions; produce a stable numerical algorithm to evolve the anisotropic surface in time under any growth velocity; and then visualise the results.

An initial literature search was undertaken to ascertain the methods used by previous models of tree growth. Simple models were found describing the growth in height and girth of trees, as well as a model concerning the formation of grain patterns (which approximated the grain pattern as a fluid flow field), but no papers were found producing a three-dimensional visualisation of the growth of the tree stem and branches. It was also realised that the problem of cell-wall thickening could not be considered satisfactorily due to a lack of experimental results.

Literature and experimental samples provided by Ensis demonstrated that the velocity at which the stem and different branches grow is different and time dependent, so it was essential that the numerical algorithm was able to track the evolution of the trunk and branches separately – implying that there was more than one surface to track. The choice of the velocity became a critical problem, as there was little literature concerning its dependence on hormones, environmental factors, stress, curvatures, etc.

Some analytical work was undertaken to increase understanding of the effect of the velocity function, modelling the behaviour of a moving interface using partial differential equations for the position of the interface over time. Some theoretical results were obtained for simple curvature- and hormone-driven growth in two dimensions (although it was argued that curvature-driven growth is not likely to be a physically reasonable model for the growth velocity). These results reproduced some of the features observed in trees, notably the surface shapes seen at stem-branch junctions and when a tree is forced to grow around an external obstacle.

The grain was modelled as streamlines of an incompressible fluid flowing on the tree's surface. The stem grain around a dead branch or obstacle was modelled as flow around a circular obstacle, whilst the grain pattern for a live branch was modelled as flow out of a cylinder (or source). Although this model was not a realistic representation of the physiological processes leading to grain formation, the results produced were qualitatively realistic. The physiologically-based problem of grain orientation evolution in time (straight grain becoming spiral grain over a period of years, for instance) was not considered.

A fast marching method was implemented to track the surface evolution of a stem with multiple branches. This elegant method is based on the idea of representing the surface, at a given point in time, not explicitly using marker particles, but implicitly as the level set of some function. The method proved to be numerically efficient and stable, and was relatively straightforward to implement with simple velocity functions. Various scenarios of branch growth around objects and multiple branch growth were considered. Visualisation was then achieved using built-in tools in MATLAB, as shown in Fig. 1 where the fast marching method was implemented for a stem with five branches each with an independent growth rate.

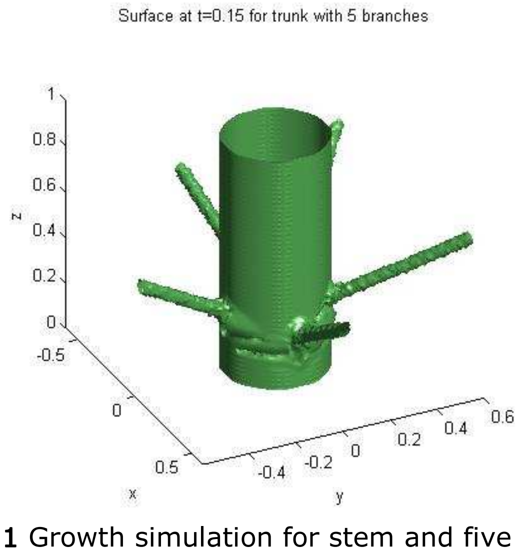

Figure 1 Growth simulation for stem and five branches, where the growth for the stem and each branch is independent.

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