

On the Implementation of the Functional-Structural Tree Model LIGNUM

Jari Perttunen¹⁾, Risto Sievänen¹⁾, Jouni Hartikainen¹⁾ and Eero Nikinmaa²⁾

The model LIGNUM

LIGNUM presents coniferous and deciduous trees with simple structural units called tree segment (TS), branching point (BP), and bud (B) that have close likeness to real tree parts. These units also capture the functioning of the tree. The main functioning unit is the cylindrical tree segment consisting of heartwood, sapwood and foliage.

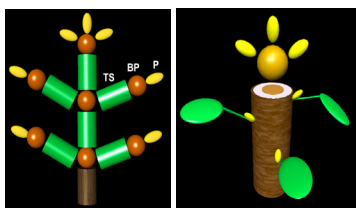


Fig. 1. The structural models for coniferous species (left) and hardwood species (right) in LIGNUM.

The data model of LIGNUM

The model LIGNUM is being developed with C++ language and STL library using generic programming. The structural units in LIGNUM are implemented as class templates. We have implemented one common framework of a tree and generic algorithms to operate in this framework. This allows efficient reuse of the program code and reduces the amount of work to implement new tree species.

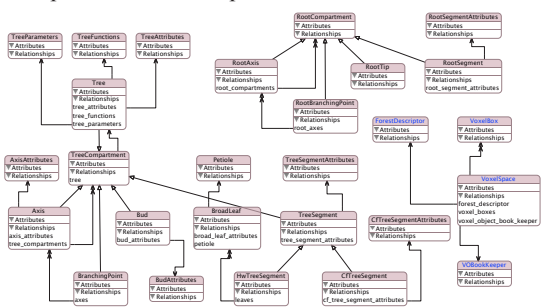


Fig. 2. The data model of the classes implementing LIGNUM.

Lindenmayer systems in LIGNUM

Lindenmayer systems (L-systems) are used to model architectural development of plants. The L-systems have been implemented using the language L (Fig. 3A, B).

```

Start //Begin
{
  produce F(0.30)SB(R)EB(1.1,0);
  B(g,1); //Bud produces tree segments (F) and buds (B)
  if (g==1) //Branches from the main axis
  produce F(1)SB(1)Pich(beta) B(g=1,1*P1)EB(1);
  SB(1)Roll(alpha,2,0)Pich(beta) B(g=1,1*P1)EB(1);
  SB(1)Roll(alpha,2,0)Pich(beta) B(g=1,1*P1)EB(1);
  B(g=1,1*P2); //Second order branches
  produce Bend(gamma) F(1)SB(1)Turn(beta) B(g=1,1*P3)EB(1);
  SB(1)Turn(beta) B(g=1,1*P3)EB(1);
  else if (g==2) //Third order branches
  produce F(1)SB(1)Turn(beta) B(g=1,1*P4)EB(1);
  SB(1)Turn(beta) B(g=1,1*P4)EB(1);
  B(g=1,1*P5); //Third order branches
  else //Branches g > 3 grow but do not fork off new branches
  produce F(1)SB(1)EB(1);
  Bend(g);
  {
    produce Pich(g);
  }
}
  
```

Fig. 3A. L-system for a crown architecture for Scots pine sapling.



Fig. 3B. Crown architecture produced by L-system in Fig 3A after eight development steps.

The LIGNUM Workbench

The LIGNUM Workbench (WBL) is a graphical user interface. The simulated trees can be saved in an XML file format that the WBL understands. The WBL has been implemented with the Qt library (see www.trolltech.com). It runs on Windows, Linux and Mac OS X. The WBL allows the visual examination of the simulated trees and to display all variables of tree segments and buds.

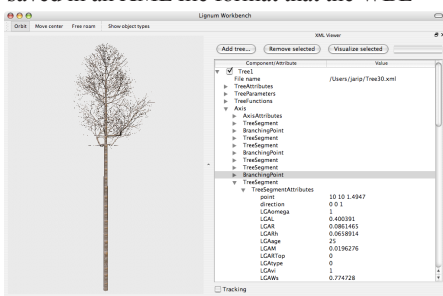


Fig. 4. The LIGNUM Workbench.

Applications of LIGNUM

1. When modeling tree growth with LIGNUM one has to deal with radiation regime, birth and senescence of structural units, allocation of the photosynthates and the architectural development of the tree. The first species implemented was Scots pine (Fig. 5A). An example of deciduous species is the study of understory sugar maple sapling survival (Fig. 5B).
2. LIGNUM has been used to simulate the effect of apical bud death in the growth response of cowberry (Fig. 6). An L-system controls the annual production and elongation of underground shoots, branching and both termination and activation of living buds. The data to parameterize the model was from field experiments.

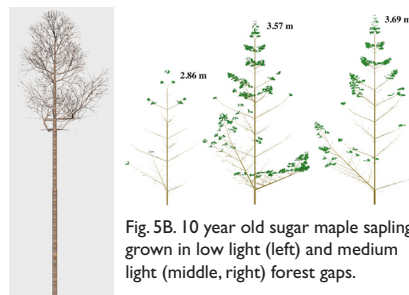


Fig. 5A. 30 year old forest grown Scots pine. Height = 9.3 m and diameter at 1.3 m = 18 cm.

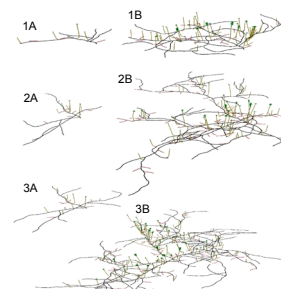


Fig. 5B. 10 year old sugar maple saplings grown in low light (left) and medium light (middle, right) forest gaps.

Fig. 6. Simulated branching patterns of cowberry from a single shoot after three (1A, 2A, 3A) and six (1B, 2B, 3B) growth cycles. The proportion of dead apical buds increasing the activation of lateral buds were 25%, 50% and 75% in 1, 2, 3 respectively.

3. Visualization of structural measurements of tree crowns is an effective way to quickly gain overall view of the results (Fig. 7A, Fig. 7B). It is then for example possible to analyze allometric relationships in the tree crown and calculate light regime to simulate further development of the tree with LIGNUM.



Fig 7A. Scots pine crown.

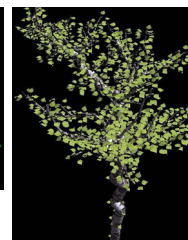


Fig 7B. Mountain birch.

4. LIGNUM has been the basis in the application for the research of wounds and decay of urban trees (Fig. 8A). The application implements the management of the photographic research material and generates the 3D models of tree trunks based on this material (Fig. 8B).

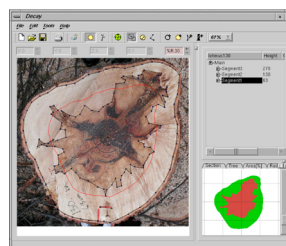


Fig. 8A. The user interface of the application to analyze wounds and decays of urban trees.

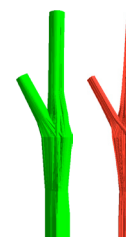


Fig. 8B. 3D model of a tree trunk (left) and the decay within it (right).

The LIGNUM home page: www.metla.fi/projects/lignum



¹⁾ Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FI-01301 Vantaa, Finland

²⁾ Department of Forest Ecology, University of Helsinki, P.O. Box 27, FI-00014 Helsinki, Finland