Rule-based integration of LIGNUM into GroIMP

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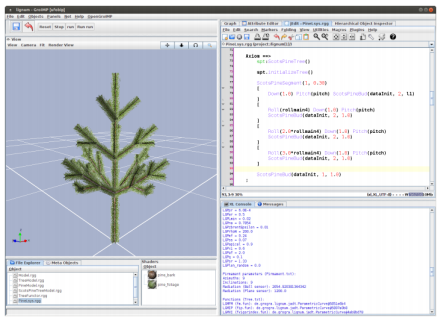
"Modelling of Ecosystems by Tools from Computer Science"



Outline

Motivation

LIGNUM FSTM

XL implementation

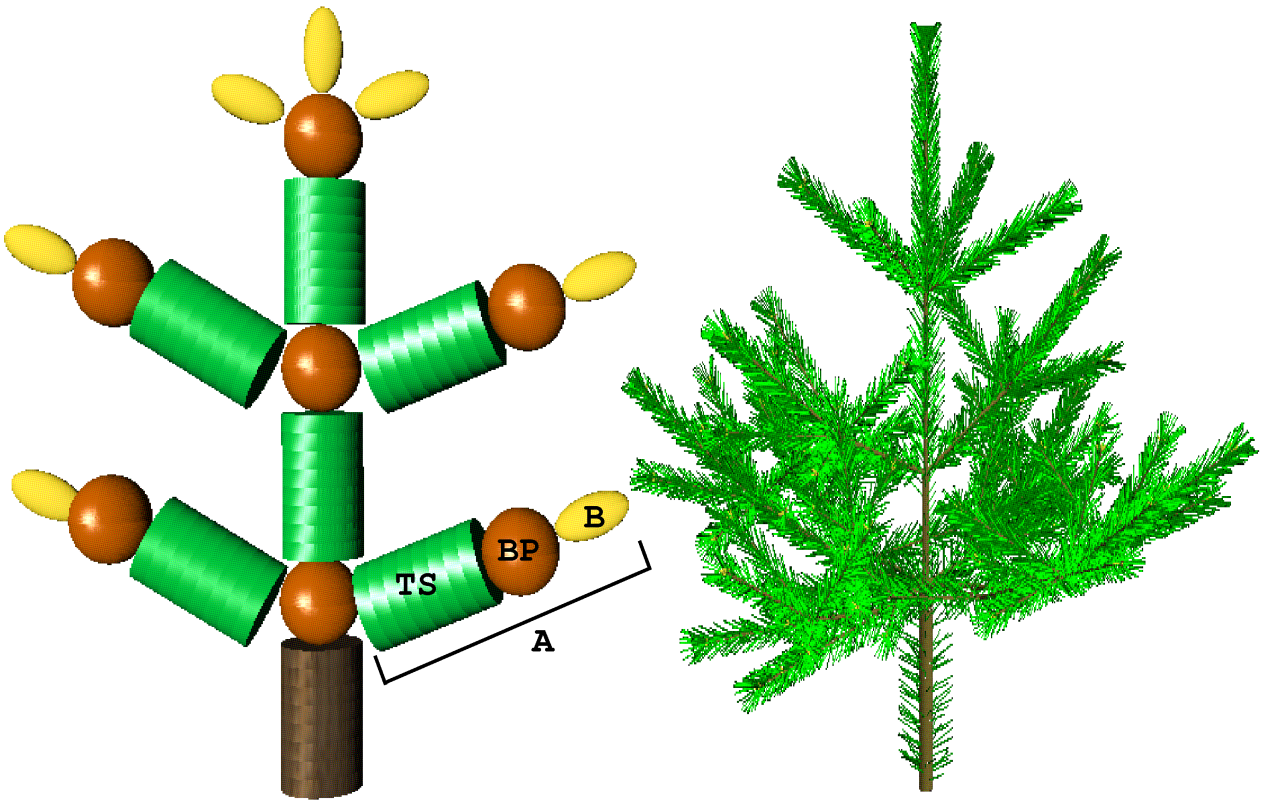
Motivation

- LIGNUM - Functional-Structural Tree Model (FSTM)
- Complex model applied to several tree species
- Test case for the component framework of GroIMP and for models comparison, on the example of Scots pine
- Analysis and (partial) reimplementation into XL

LIGNUM FSTM

- Developed at METLA, Finland
- Originates from a process-based model, being developed as FSTM since 1996 (Perttunen *et al.* 1996)
- Applied to both coniferous and deciduous trees, e.g.,
  - Scots pine (*Pinus sylvestris*)
  - Jack pine (*Pinus banksiana*)
  - Sugar maple (*Acer saccharum*)
  - Eastern cottonwood (*Populus deltoides*)
  - Silver birch (*Betula pendula*)
  - Mountain birch (*Betula pubescens* subsp. *tortuosa*)
- Applied to model both individual trees and stands

Basic structural units



(LIGNUM manual)

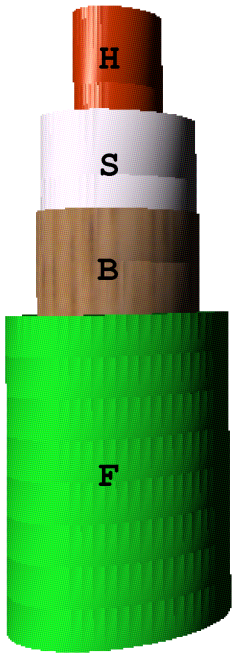
TS - tree segment

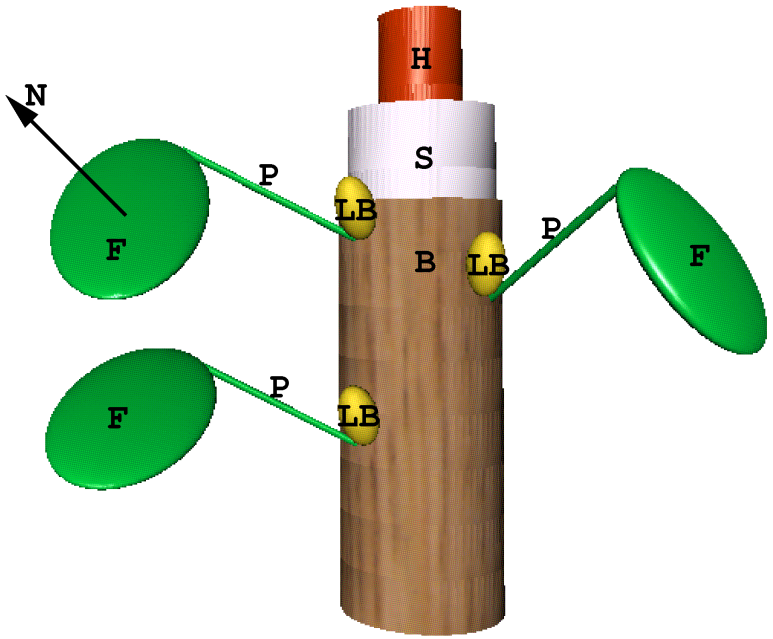
BP - branching point

B - bud

A - axis

Structure of tree segment





(LIGNUM manual)

coniferous deciduous

H - heartwood

S - sapwood

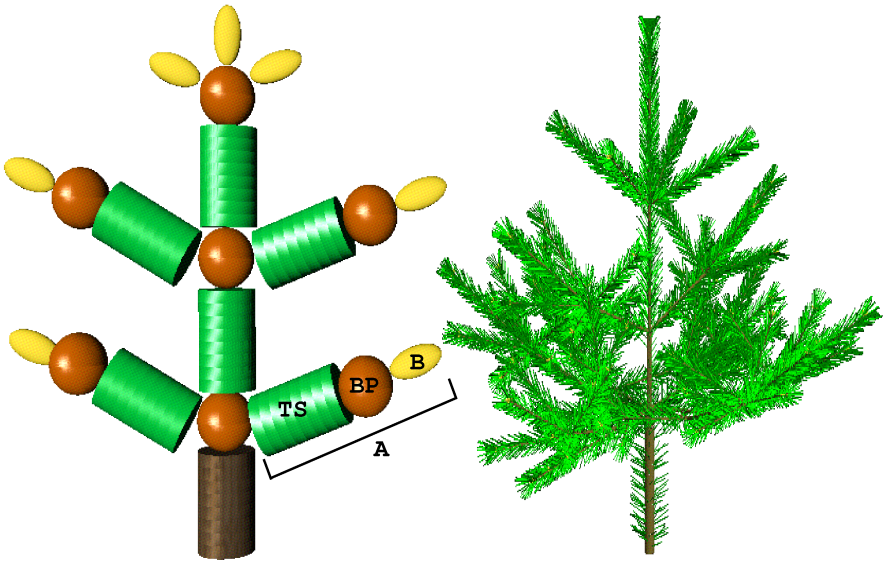
B - bark

LB - lateral bud

F - foliage

P - petiole

Tree topology



(LIGNUM manual)

- One (main) axis
- Axis - sequence of TSs, BPs & terminating B
- Each TS followed by 1 BP
- BP - list of axes

- Main axis (represented as a list):
- A = [TS, BP, TS, BP, TS, BP, B]
- A = [TS, [A, A], TS, [A, A], TS, [A, A], B]
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- ...

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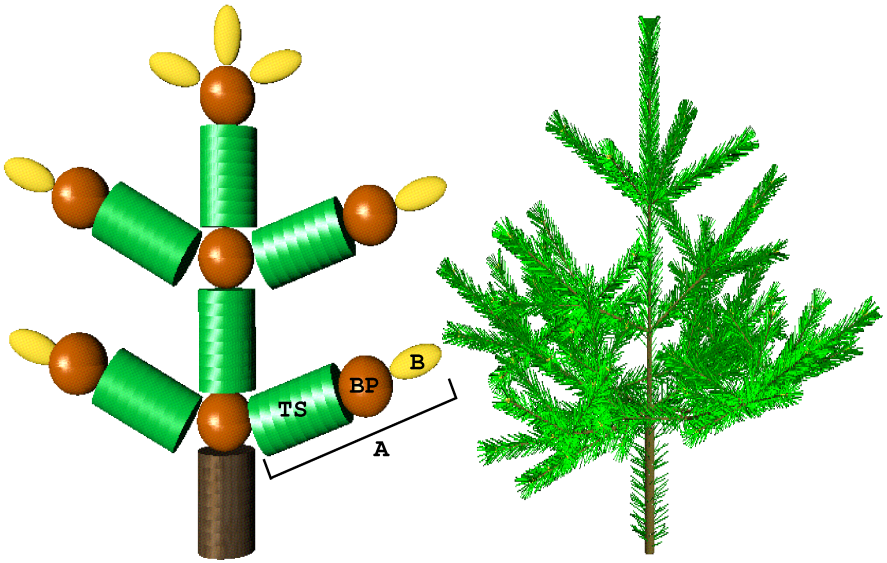

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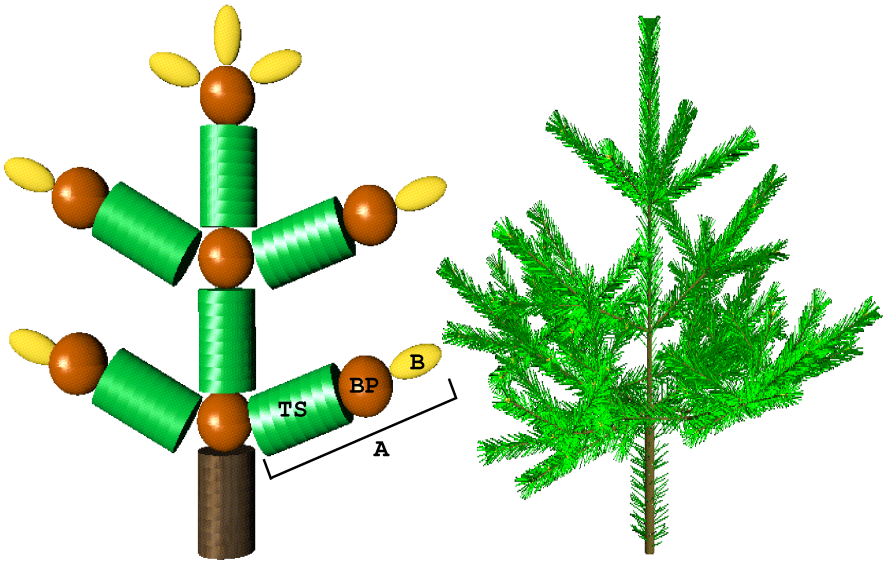

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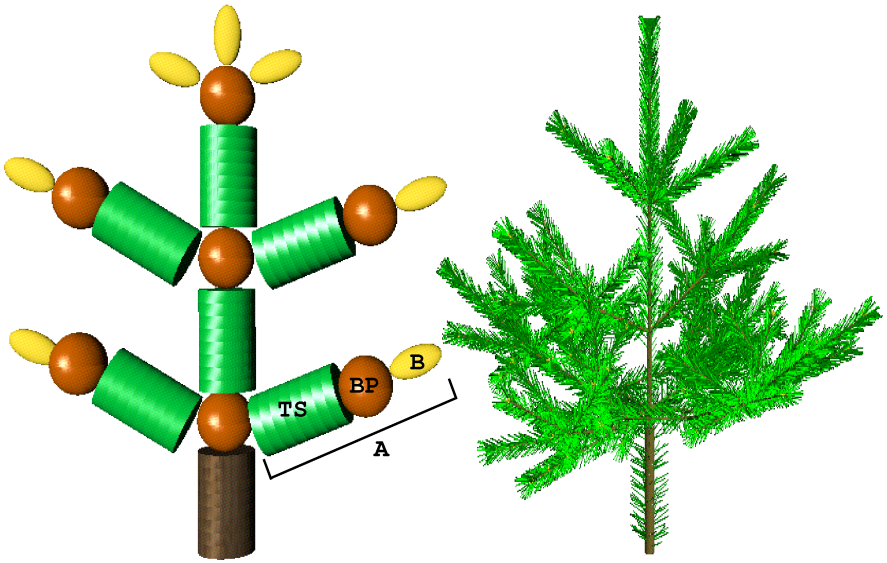

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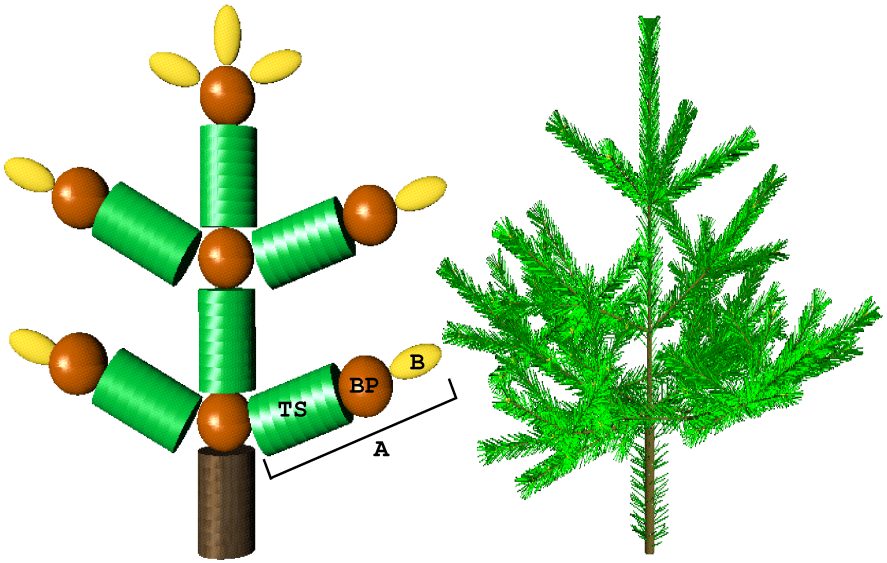

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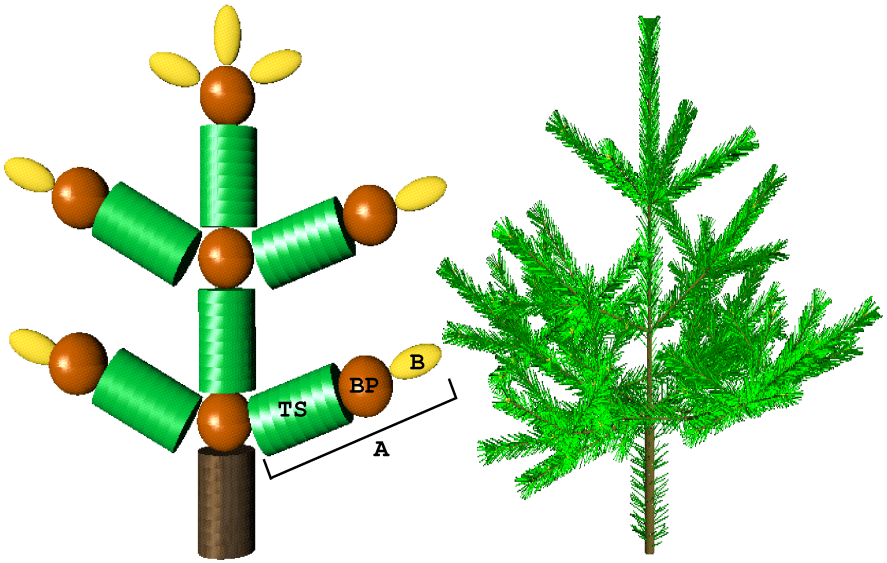

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- ...

Structure development

- Described by rules (species specific), written in the language L

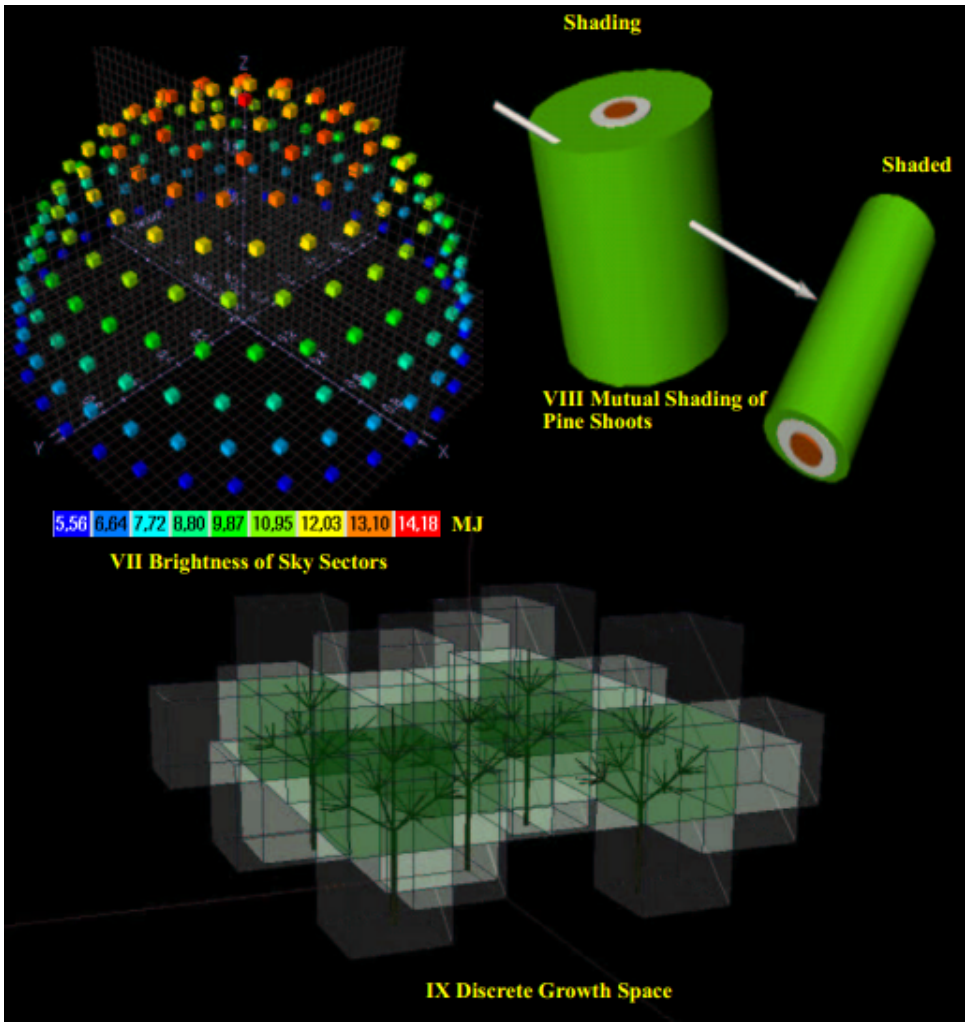
```
// initial structure
Start:
{
...
produce
   F(0.30)
   SB() Down(1.0) Pitch(pitch) B(data,2,0.9) EB()
   SB() Roll(rollmain4) Down(1.0) Pitch(pitch) B(data,2,1.0) EB()
   SB() Roll(2.0*rollmain4) Down(1.0) Pitch(pitch) B(data,2,1.0) EB()
   SB() Roll(3.0*rollmain4) Down(1.0) Pitch(pitch) B(data,2,1.0) EB()
   B(data,1,1.0);
}
```

Metabolic processes

- Two categories (w/o or w flow of information):
  - Photosynthesis
  - Respiration
  - Mortality
  - Length growth
  - Diameter growth
  - Up flow
  - Down flow
- Iterative allocation of new photosynthates into the organs

$$P - M = \Delta W_n + \Delta W_o + \Delta W_r \quad \text{and} \quad P - M > 0$$

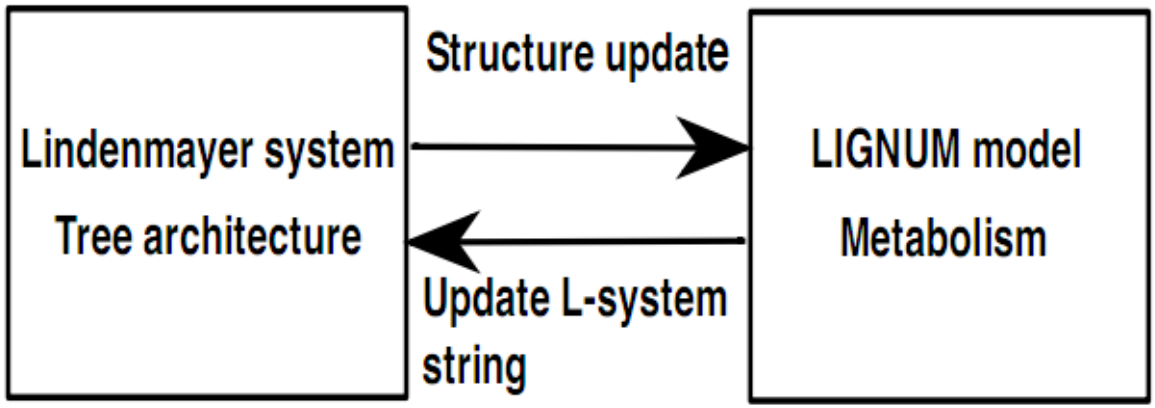
Light distribution



(Perttunen *et al.* 2002)

Implementation background

- Implemented in C++ (metab. processes), L (architecture)
- Two-way communication



4 generic algorithms

- For traversing the model tree, quering the status of the tree or passing information between tree compartments
- Sufficient to cover the computation of modelled metabolic processes
  - ForEach (e.g., calculate photosynthesis for each segment)
  - Accumulate (e.g., sum up photosynthates of all segments)
  - AccumulateDown (e.g., diameter growth)
  - PropagateUp (e.g., signal/data passing)

```
Tree<ScotsPineSegment, ScotsPineBud> scotspine;
ForEach(scotspine, Photosynthesis<ScotsPineSegment,
   ScotsPineBud>());
```

LIGNUM's structural components as XL modules

- Main structural units:
  TreeSegment, *Bud*
  (*BranchingPoint* and *Axis*, inevitable in LIGNUM, inherently expressed in XL)
- Modules for trees in general:
  Tree, *TreeCompartment*
- Modules specific for conifers, pine and Scots pine:
  CfTreeSegment, *PineSegment*, *PineBud*, *ScotsPineTree*, *ScotsPineSegment*, *ScotsPineBud*
- Modules to control branch orientation:
  Pitch, *Roll*, *Turn*, *Down*, *HDir*

Structure development (XL)

- Straightforward translation of L rules into XL rules

LIGNUM	GroIMP	Description
Start : { produce A(); }	*Axiom ==> A;*	Start symbol
A() : { produce B() A(); }	*A ==> B A;*	L-system rule
SB()	*[*	Branch start
EB()	*]*	Branch end

Structure development (XL)

```
Start:
{
...
produce
   F(0.30)
   SB() Down(1.0) Pitch(pitch) B(data,2,0.9) EB()
   SB() Roll(rollmain4) Down(1.0) Pitch(pitch) B(data,2,1.0) EB()
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   SB() Roll(3.0*rollmain4) Down(1.0) Pitch(pitch) B(data,2,1.0) EB()
   B(data,1,1.0);
}
```

```
Axiom ==>
   ...
   ScotsPineSegment(0.30)
   [ Down(1.0) Pitch(pitch) ScotsPineBud(data, 2, 0.9) ]
   [ Roll(rollmain4) Down(1.0) Pitch(pitch)
                              ScotsPineBud(data, 2, 1.0) ]
   [ Roll(2.0*rollmain4) Down(1.0) Pitch(pitch)
                              ScotsPineBud(data, 2, 1.0) ]
   [ Roll(3.0*rollmain4) Down(1.0) Pitch(pitch)
                              ScotsPineBud(data, 2, 1.0) ]
   ScotsPineBud(data, 1, 1.0)
;
```

Metabolic processes (XL)

LIGNUM	GroIMP	Example
ForEach	execution rule (*::>*)	*sps:ScotsPineSegment ::>* *sps.photosynthesis();*
Accumulate	aggregators (*sum*, *count*, *max*, ...), with queries ((* *))	*sum((* ScotsPineSegment *)* *.getP())* // sum up photosynthates

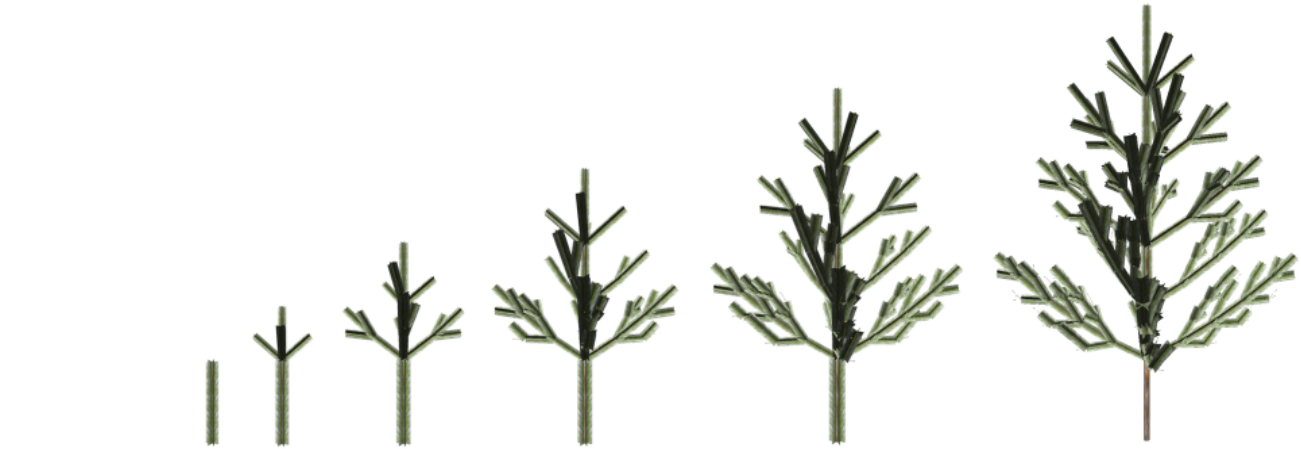
AccumulateDown
PropagateUp
	path patterns with directed relations (*-r->*, *<-r-*), with *r = minDescendants*, *descendants*, *ancestor*, shortcuts:
	-->, <-- = any edge,
	>, <= successor,
	+>, <+= branch
		sps:ScotsPineSegment ::>
		if (sps.getAge() == 0) {
		sps.setQin(
		(sps -ancestor->*
		*ScotsPineSegment *)*
		.getQin()
		);
		}
		// propagate up incoming radiant flux
		// to new segments

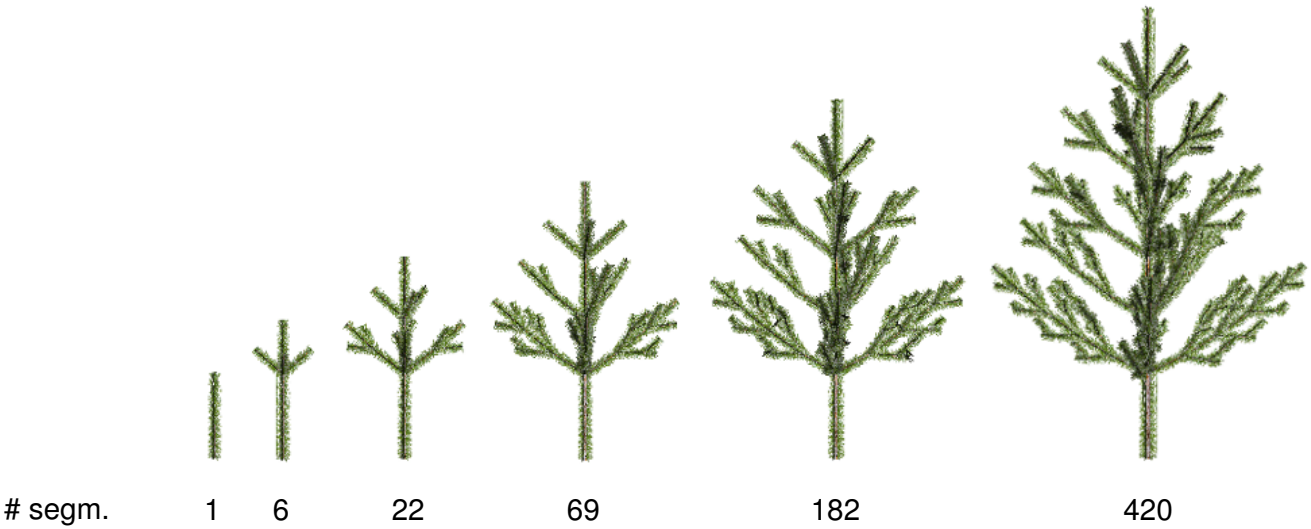
Light distribution

- Sky model and two (presented) light models used in LIGNUM were adapted into GroIMP
- Their code is hidden from the user
- Light models called using execution rules

```
sps:ScotsPineSegment ::> radiation.eval(sps);
```

Comparison





Summary

- Partial translation of both, the structural and the functional part of LIGNUM into the rule-based language XL
  - Architecture, radiation distribution, photosynthesis, respiration, senescence, allocation, elongation
- Focus on Scots pine
- Future work
  - Translation of missing parts - pruning
  - Model comparison
    - how will the final structure look like if different light models, photosynthesis, etc., are used
    - simulation of a same species with LIGNUM and GreenLab, comparison of outputs

Thank you for your attention!