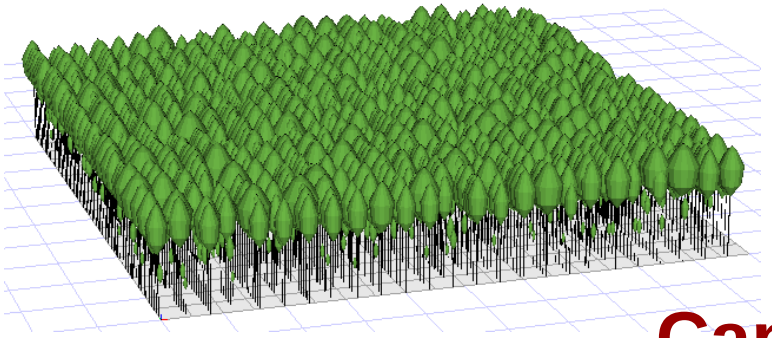


Capsis: 1994-2014

A Generic Software Platform for forestry modelling

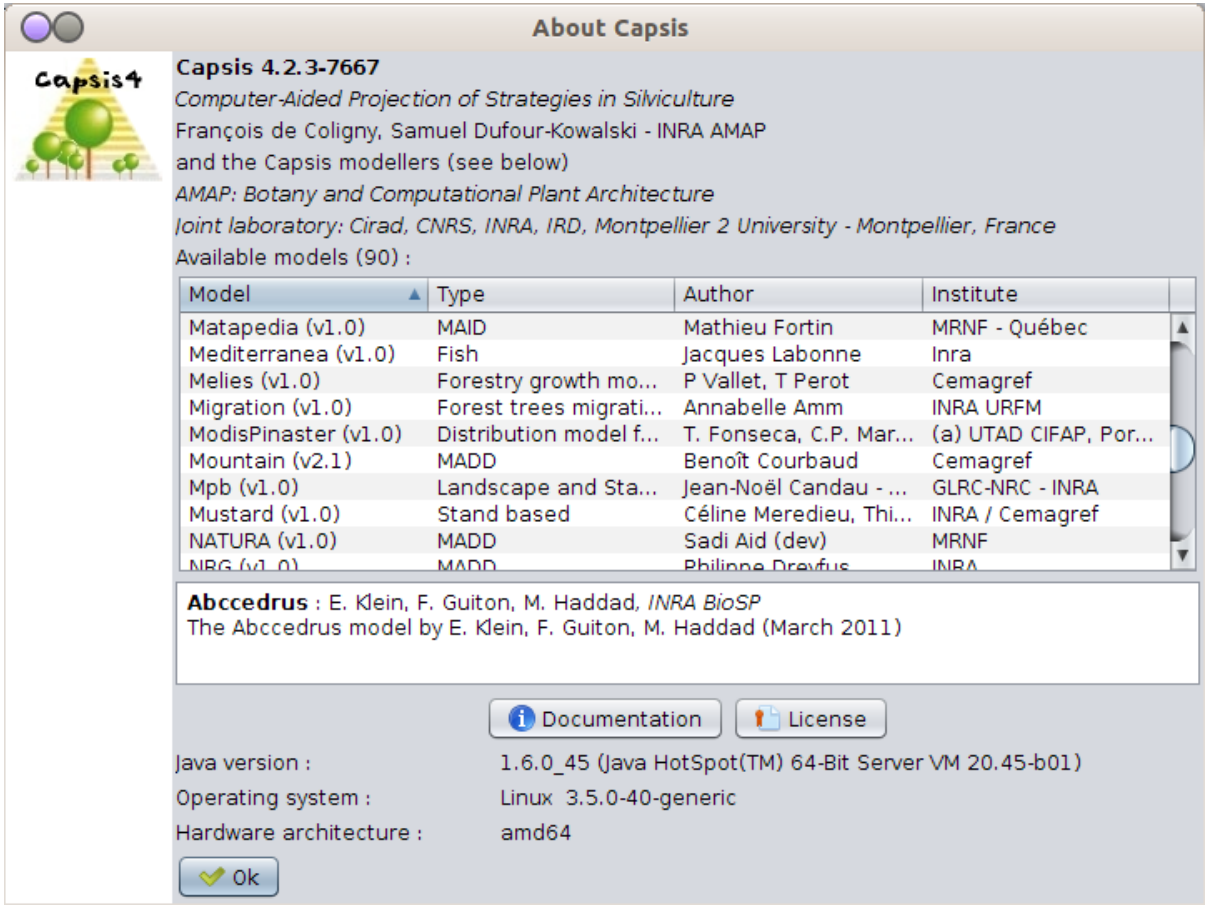
and AMAPstudio: a Software Platform for Plants Architecture Modelling

Francois de Coligny (INRA AMAP)
Sébastien Griffon (Cirad AMAP)

AMAP - Botany and Computational Plant Architecture
Montpellier, France

Capsis - Computer-Aided Projection of Strategies In Silviculture

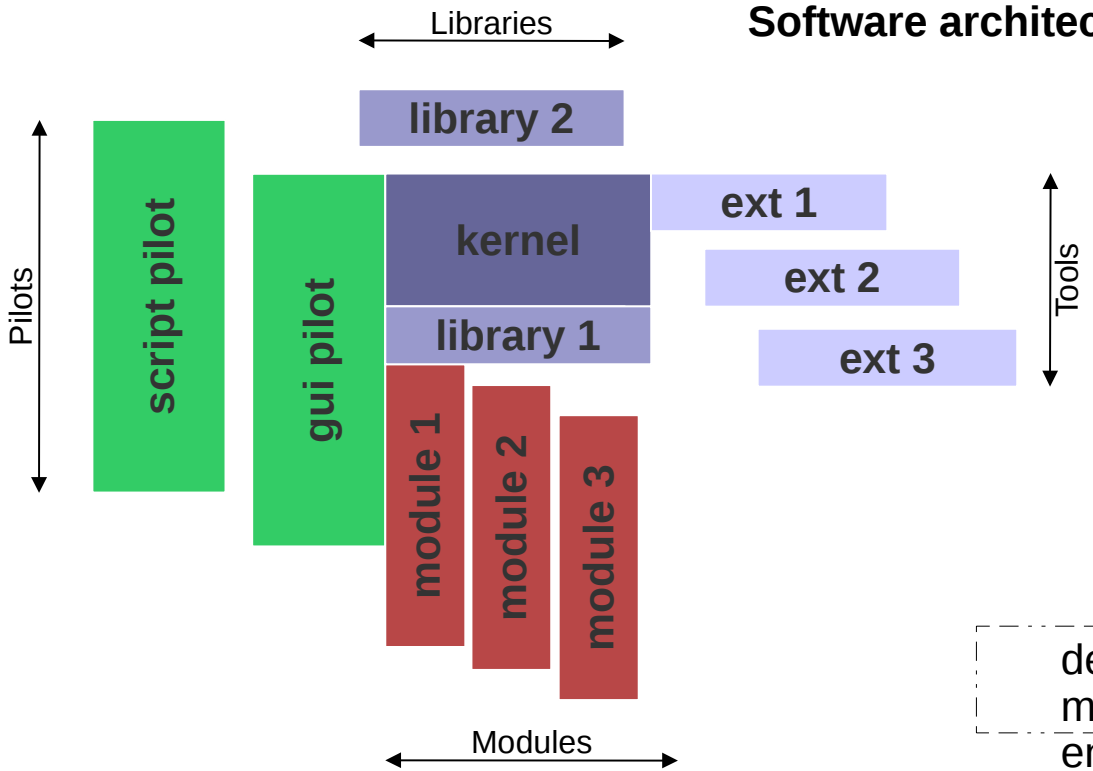
Objectives: Build a **software platform** to integrate **forest growth & yield / dynamics models** for **modellers, managers and teaching**



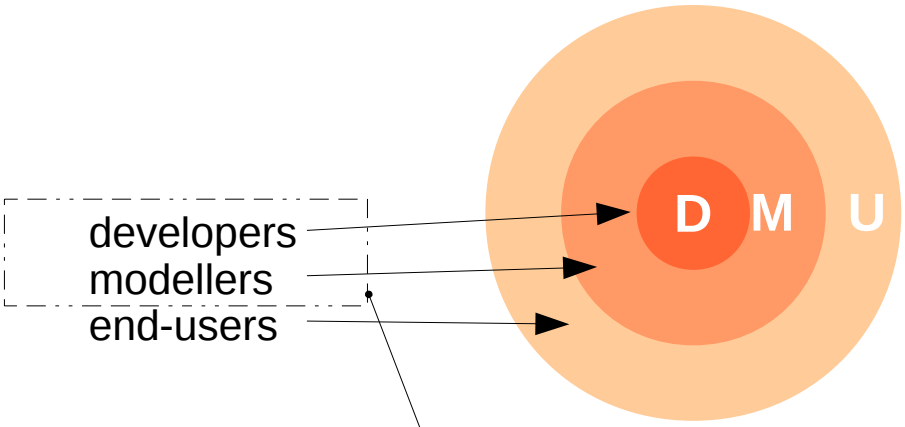
Started in 1994 by Philippe Dreyfus (INRA URFM, Avignon)

Capsis : main options

Software architecture



Actors and roles



The Capsis community:
developers + modellers
co-develop together

Clear participation rules

The common parts are free software (LGPL): everything except the **red parts** is reusable by anybody

The Capsis charter (extract):

- the modellers are in charge of the development of their models
- the growth models are not free: **red parts**
- all the source codes are freely accessible by all members in the Capsis community...

Capsis Methodology: help the modellers develop by themselves

1. First together...

short training course (1-2 days)
scientists become beginer developers

+ customized starting session (2-3 days)
start developping together
work on the scientist's machine

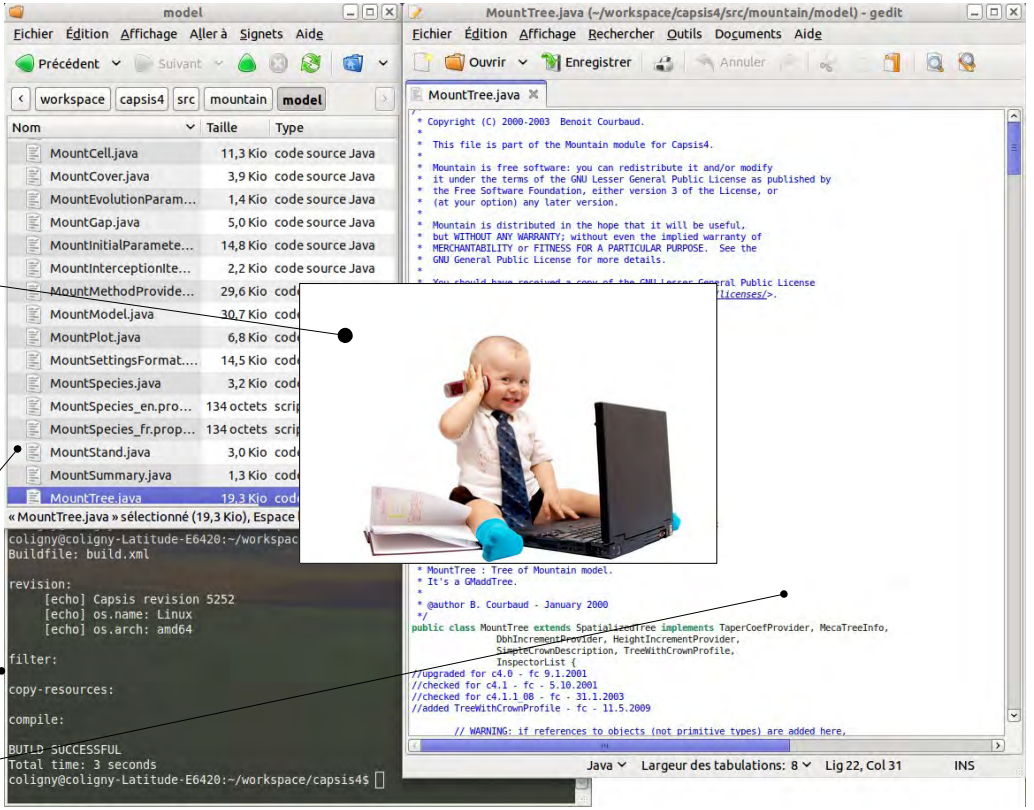
2. ...then in autonomy...

with a permanent and effective support
reactivity, availability

...with simple tools

an accessible language: Java
strict: accessible to scientists

a file manager
a terminal
a simple editor



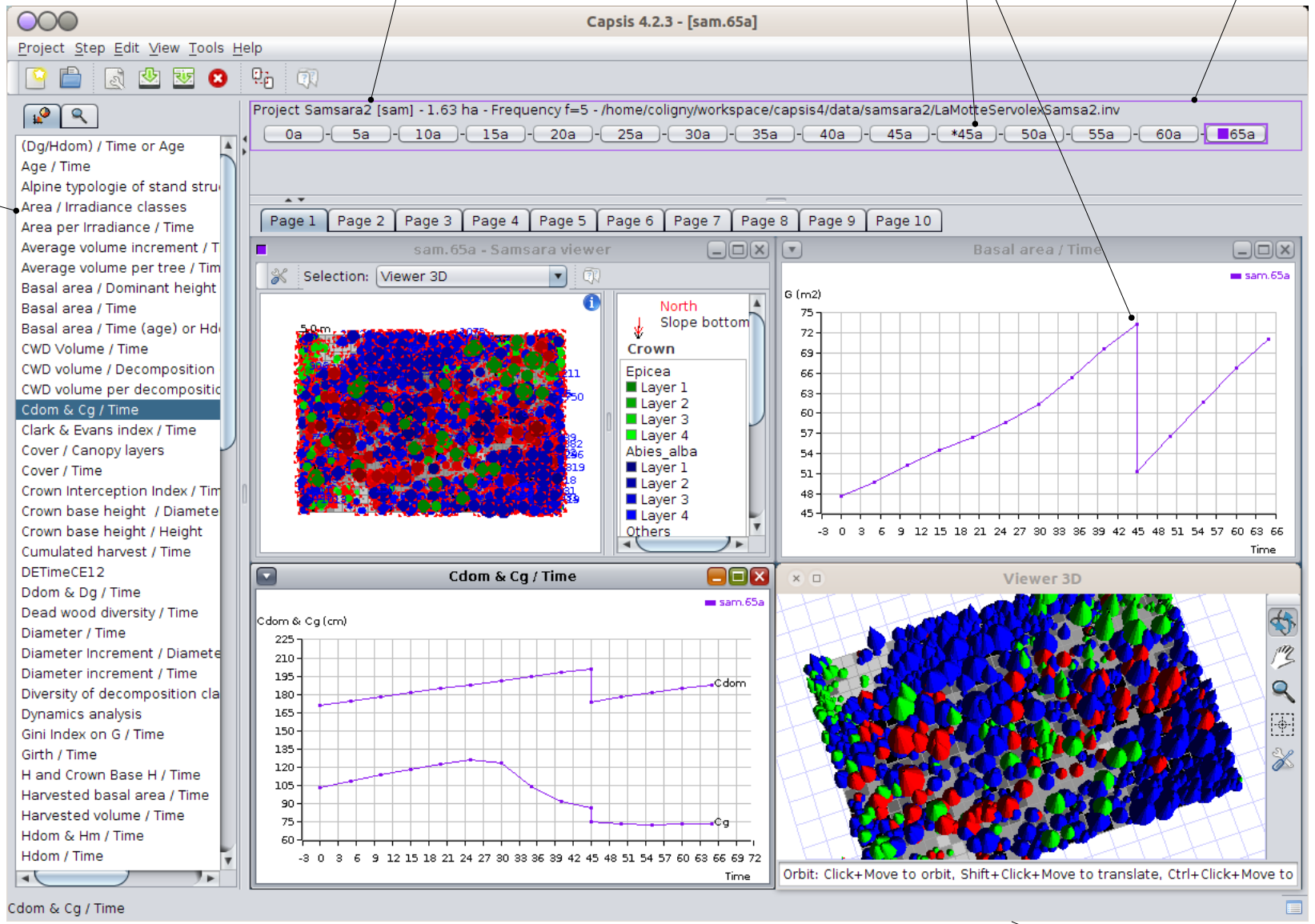
Capsis: how does it work ?

model : initialisation + time loop

intervention

project

integrated viewers and charts

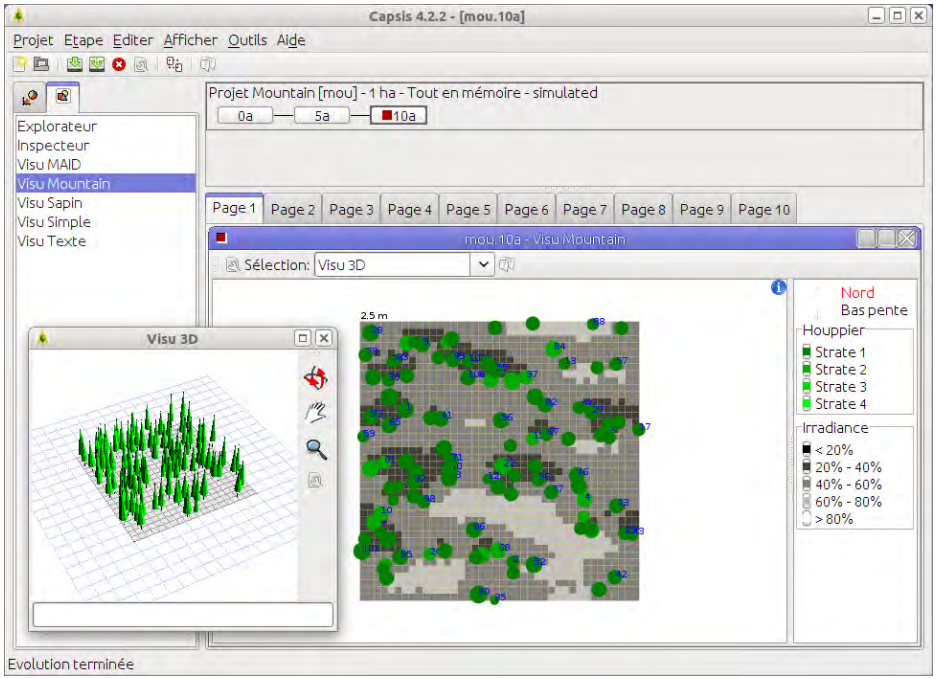


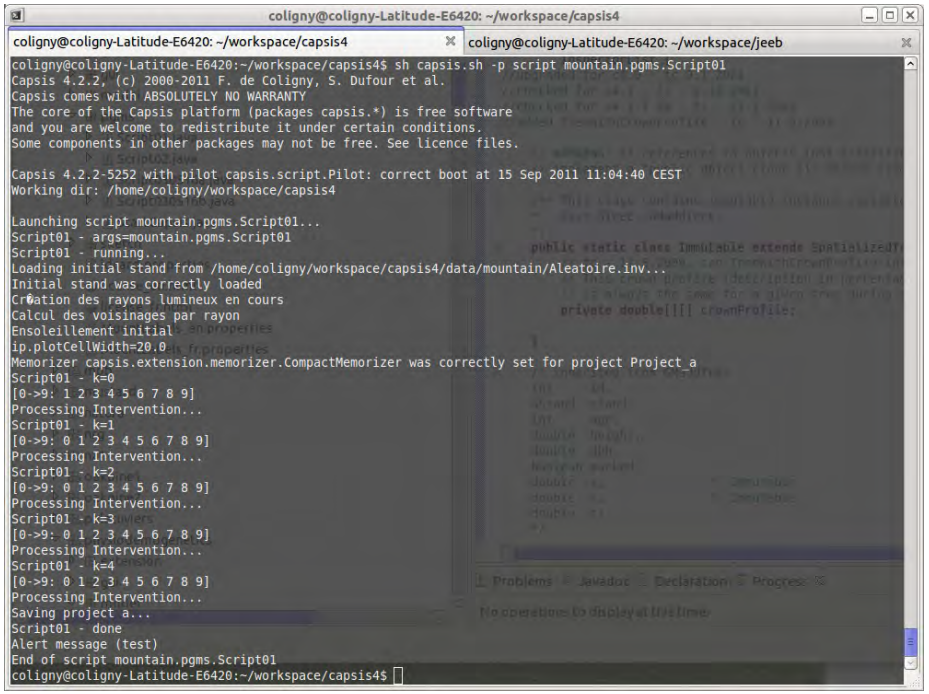
Capsis - Linux - Graphical user interface - English

export

Capsis: several ways of use

Interactive (french / english)

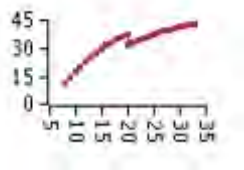




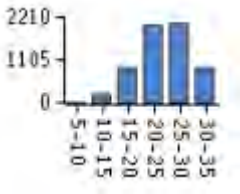
Not interactive: with scripts
- long simulations
- run on clusters
- sensitivity analyses...

Céline Meredieu, Thierry Labbé (INRA Biogeco, Bordeaux)

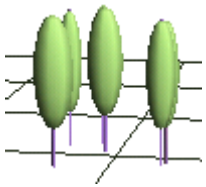
Models for maritime pine in the *Landes de Gascogne*



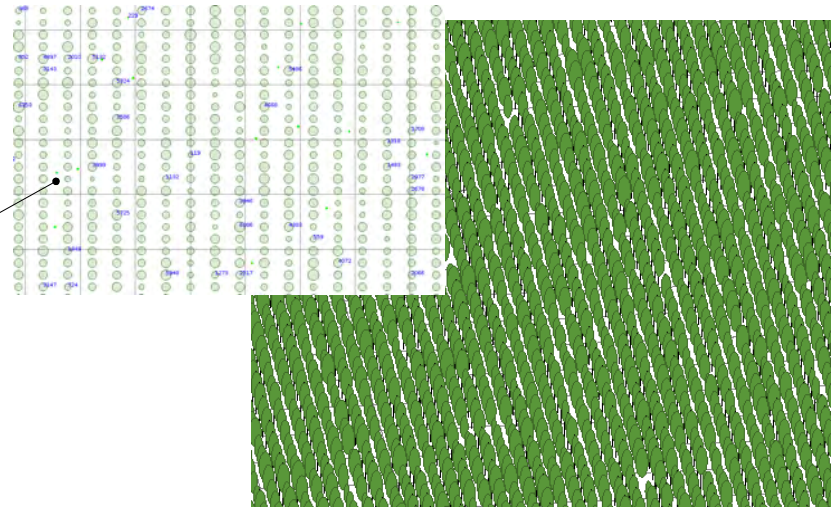
Lemoine model (stand level, plantation):
- age, number of trees, girth (dominant, mean), basal area, height (dominant, mean), volume (mean)



PP3 model (distribution model, plantation):
a list of trees
- age, diameter, height, volume of each tree, crown (height, diameter), other information (biomass, carbon, etc.) + number



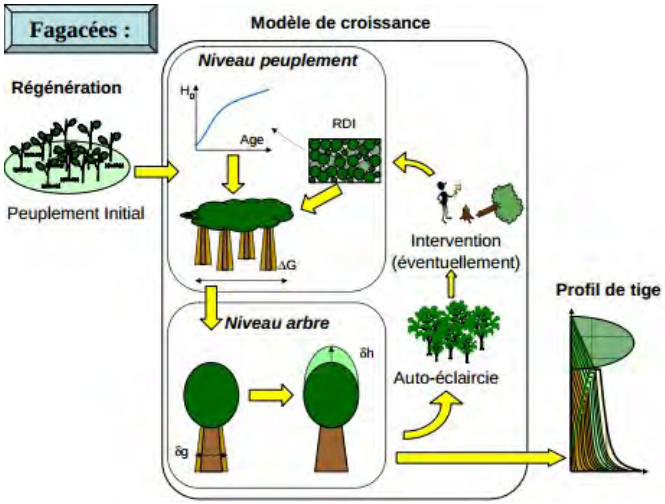
Pinus Pinaster (individual-based, spatialized)
a rewriting of PP3
integration of spatialized processes



Applications, further works:
- a permanent resource analysis system
  (with IFN - National Forest Inventory)
- dead wood modelling and biodiversity
- models transfer to the silviculture prescribers

Jean-Francois Dhôte (ONF), Patrick Vallet (Irstea), Mathieu Fortin (AgroParisTech Lerfob), Gilles Le Moguedec (INRA AMAP)

Fagacées: an invidual-based model for oak and beech



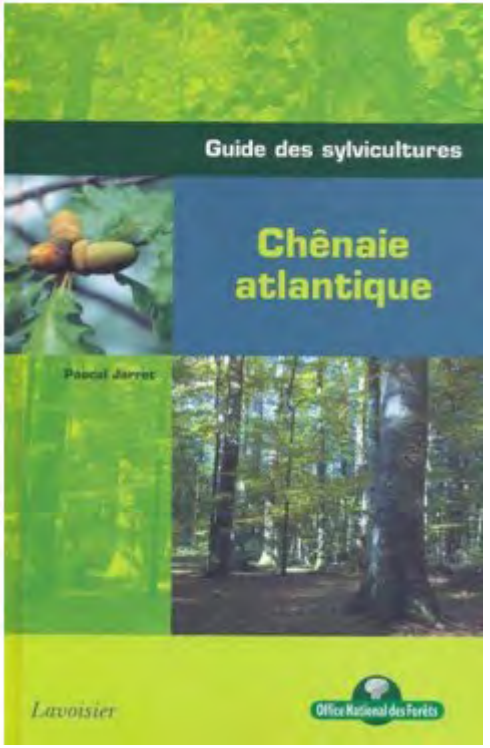
Fagacées relies on 5 fundamental relations at 2 levels

1. stand level
   - a growth model for dominant height (H0)
   - a self thinning model giving the relative density index (RDI)
   - a basal area (G) productivity model (Eichhorn)

2. tree level
   - a model for distributing the increases at the tree scale
   - a height / diameter model

Work under progress on the model to help revise the ONF *Chênaie Atlantique* silvicultural guide (Pascal Jarret, 2004)

Changing context, climatic change, productivity change...



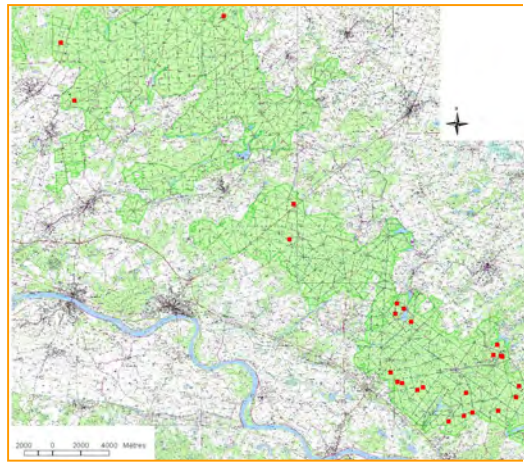
Le Moguédec G., Dhôte J.-F., 2012. Fagacées: a tree-centered growth and yield model for sessile oak (Quercus petraea L.) and common beech (Fagus sylvatica L.). **Annals of Forest Science** (2012) 69:257–269.

Marie-Ange Ngo Bieng (Cirad System, Montpellier), Thomas Perot (Irstea Ecosystèmes Forestiers, Nogent sur Vernisson)

Oakpine: oak and pine growing at the same time

Quantify the impact of the spatial structure type on the productivity of oak-pine forests
Method:

- simulate several types of realistic spatial structure (same list of trees)
- simulate growth for each structure type
- compare the obtained productivities



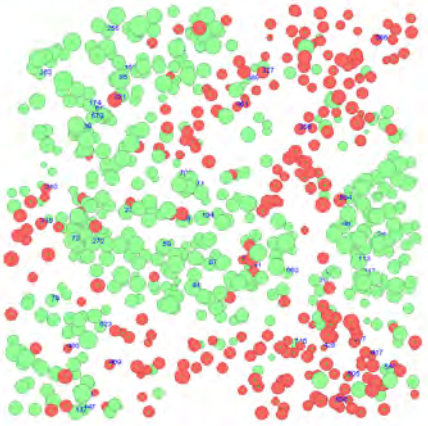
Spatial structure analysis on 34 plots:
typology: 4 types for the canopy / 3 types for the understorey

Spatial structures simulation: a combination of point processes

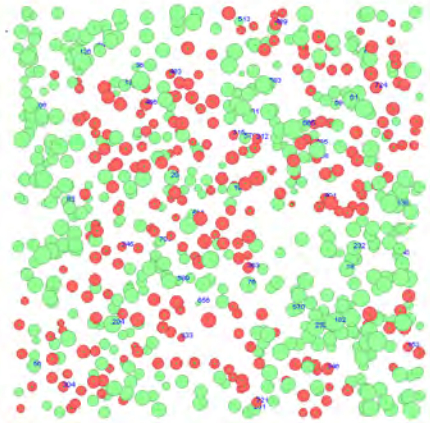
- specific structure: aggregation, random, regularity
- intertype structure: attraction, independence, repulsion

Simulation examples:

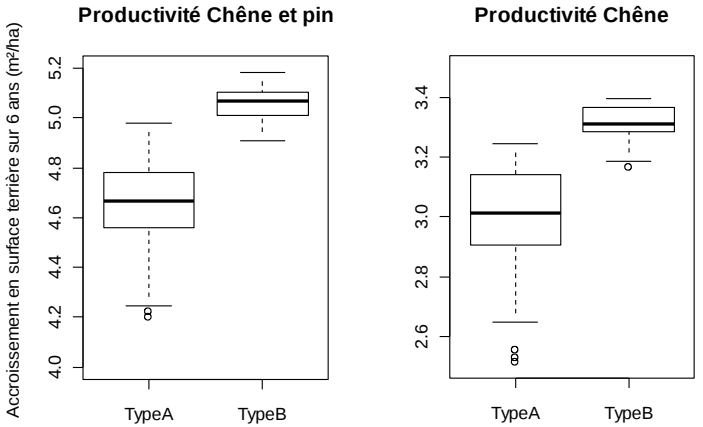
Canopée Type 1, modèle C7
Ss étage Type 2, modèle SE6



Canopée Type 3, modèle C4
Ss étage Type 2, modèle SE6



Script mode, repetitions, example of results:



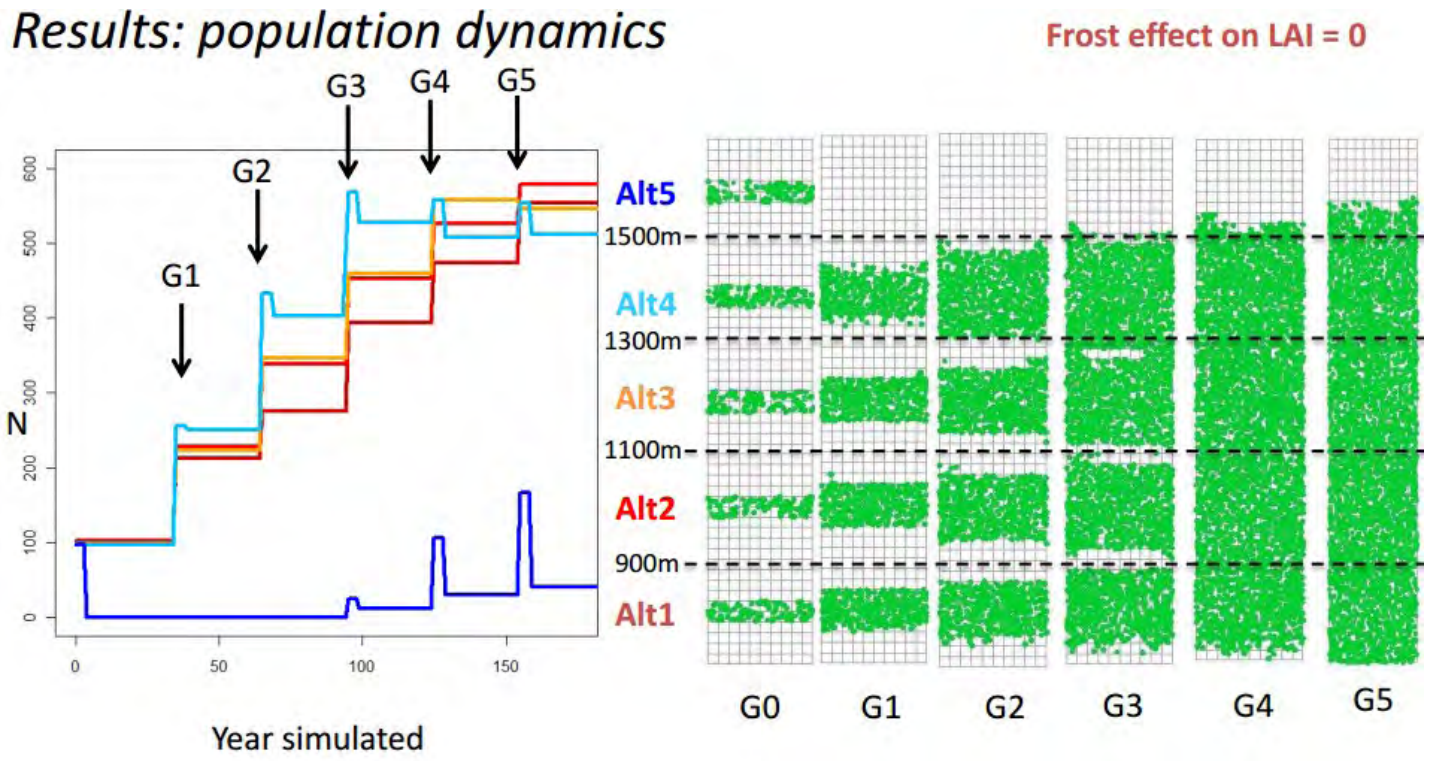
Ngo Bieng M.-A., Perot T., de Coligny F., Goreaud F., 2013. Spatial pattern of trees influences species productivity in a mature oak–pine mixed forest. **European Journal of Forest Research** (2013) 132:841-850

Sylvie Oddou-Muratorio, Hendrik Davi (INRA URFM, Avignon)

PhysioDemoGenetics

PhysioDemoGenetics aims at studying the genetic adaptation through natural selection driven by climatic variables in a continuous tree population
-> accounts for complex interactions among genes, functional traits and climate when environment or demography are unstable.

It relies on (1) explicit modelling of the genetic determinism of ecophysiology-related traits and (2) the coupling of ecophysiological processes at tree level (Castanea library in Capsis) with dynamical processes (dispersal, growth, mortality) and genetic processes (Genetics library in Capsis)



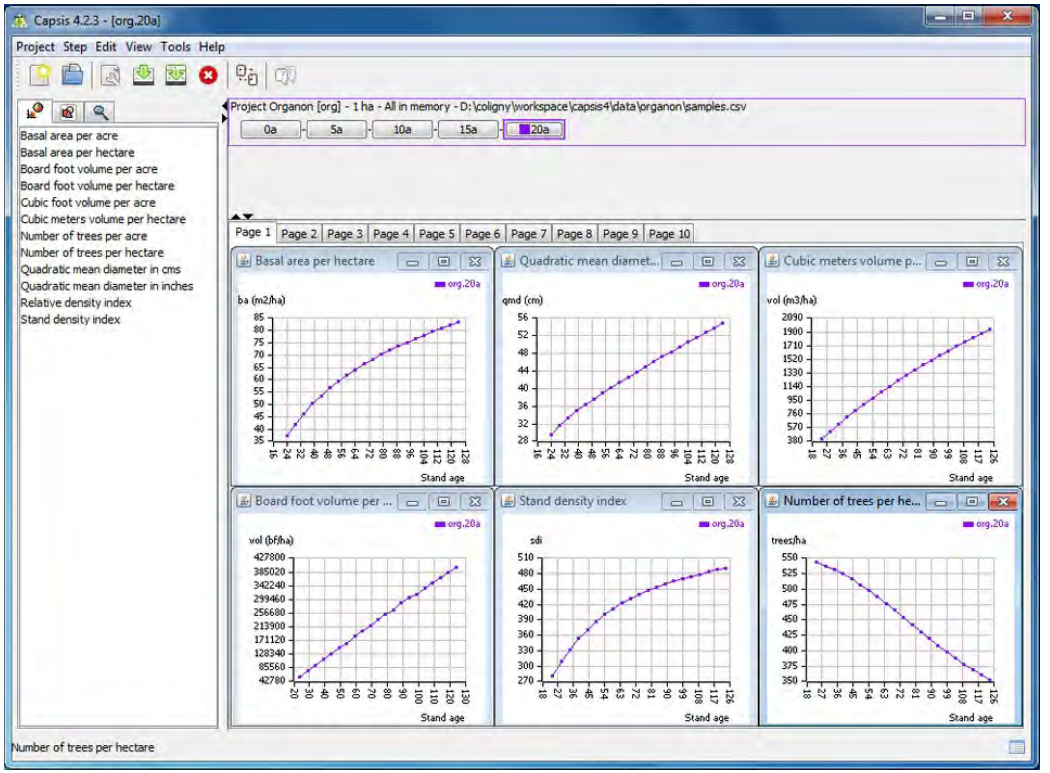
- Extinction of Alt5 at G0 and recolonisation at G3
- Treeline at 1620 m (versus observed =1700 m)

Nathaniel Osborne, Doug Maguire, David Hann (Oregon State University, USA)

Organon

- Organon is an empirical, spatial implicit, individual tree growth, yield and wood quality model from the Pacific Northwest
- The model will project forest development for several species mixtures, stand structures and silvicultural regimes
- A simplified version of Organon can be accessed through Capsis, works in metric system

Organon is managed by the Center for Intensive Planted-forest Silviculture at Oregon State University



Forecast: partnership with INRA-Lerfob (Francis Colin) and ONF R&D (Christine Deleuze)

- reparameterize Organon equations for french species
- develop wood quality equations for France

Mathieu Fortin, Luc Langevin (MRNF Québec / AgroParisTech Lerfob Nancy),
Jean-Francois Lavoie (Arcane Technologies)

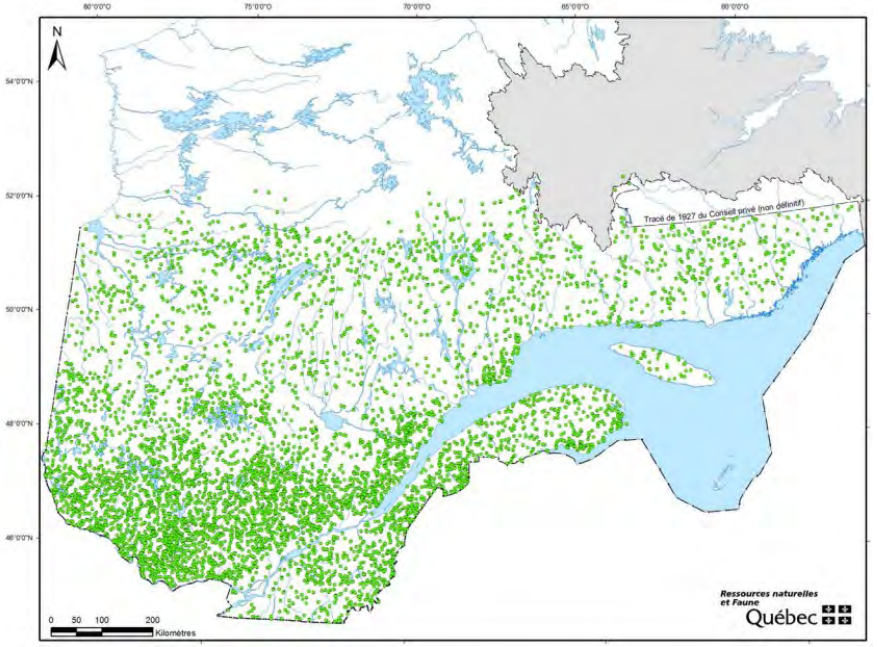
Artemis-2009

http://www.mffp.gouv.qc.ca/publications/forets/connaissances/recherche/Fortin-Mathieu/Memoire156.pdf

A distance-independent tree model for the main potential vegetations in the province of Québec

Objectives, at the provincial level:
- develop silvicultural strategies
- update sample plots
- calculate the allowable cut

Six sub-models to forecast
(i) the temporal change of mortality,
(ii) dbh of surviving stems,
(iii) the number of recruits, (iv) their diameters, (v) height and (vi) volume using dbh



The permanent plots of the MRNF-DIF in Québec: 12001 plots, from 1970

Other Capsis models by Québec MRNF since 2002:

- **Présage** (Daniel Mailly, Sylvain Turbis): a model of production and evaluation of scenarios to help management of forests in Québec

- **SaMARE** (Sadi Aid, Sylvain Turbis): a distance-independent tree model for sugar maple- dominated stands (sugar maple, yellow birch, American beech and other broadleaved species)

- **Natura** (Sadi Aid, Isabelle Auger): a whole-stand model for the province of Québec

- **Succès** (Mathieu Fortin, Luc Langevin): a succession model for the main forest types in Québec

- **Croireplant** (Guy Prégent, Jean Ménétrier, Geneviève Picher et Isabelle Auger): Volume table for white spruce, jack pine and hybrid poplar plantations, and yield tables/stand growth models for white spruce plantations in province of Québec

Philippe Dreyfus (INRA URFM / ONF R&D, Avignon)

Ventoux: modelling a forested massif

Realistic sylvicultural scenario and evolution over 100 years

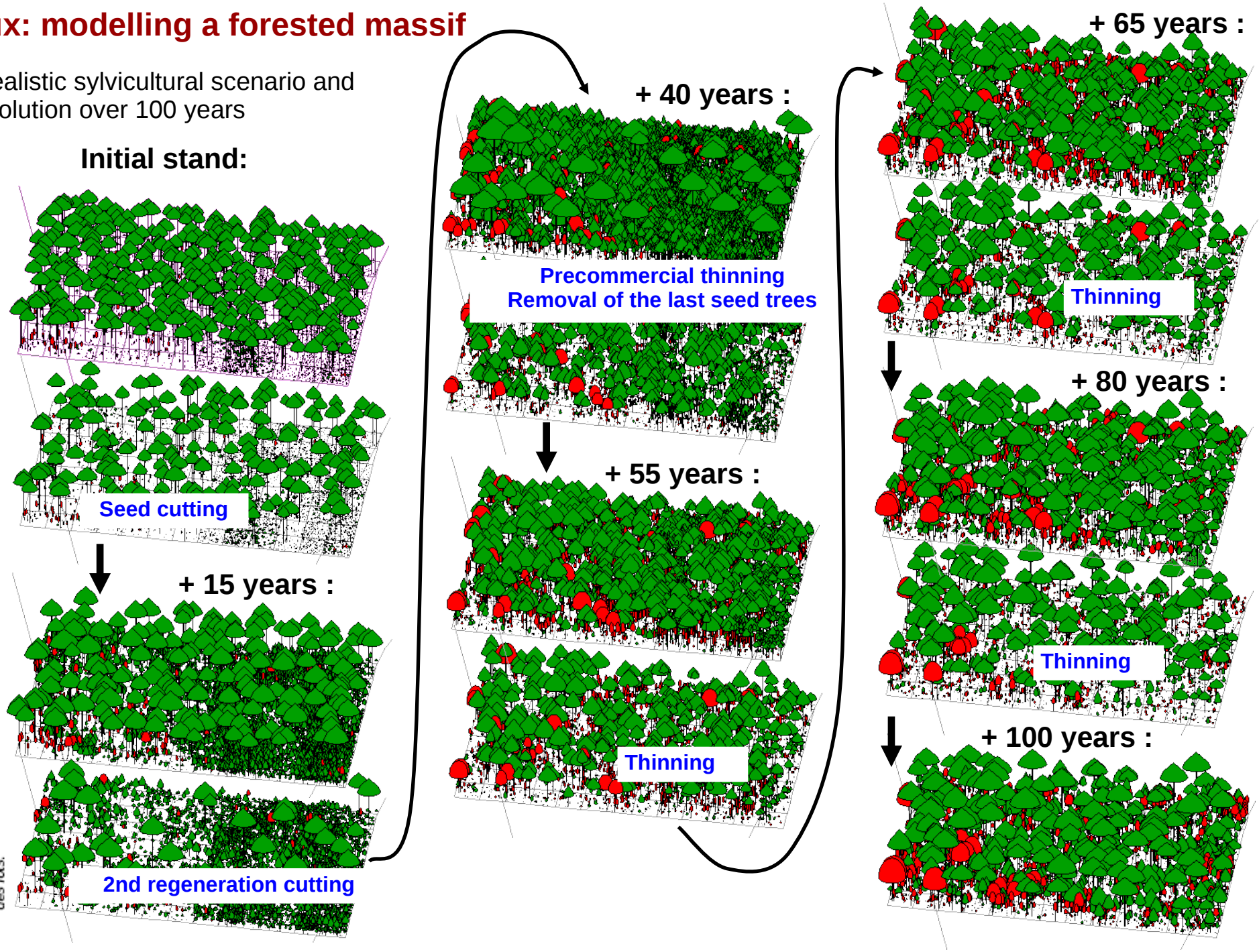
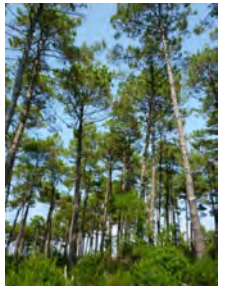


Figure 7 : Simulation d'un scénario sylvicole complet réaliste et évolution sur 100 ans d'une plantation de Pin noir (en vert) en cours de colonisation par le Hêtre (en rouge) : régénération par coupes progressives du couvert de Pin, qui bénéficie autant au Hêtre qu'aux semis de Pin ; dépressage unique, à l'occasion duquel la proportion des deux essences peut être en partie modifiée (mais le dynamisme du Hêtre et sa faculté à rejeter ne permettent pas de l'éliminer, même si on souhaite favoriser au maximum le Pin) ; éclaircies, en nombre limité compte tenu de la nécessité d'offrir un volume suffisant à chaque intervention pour favoriser la vente des lots.

Patrick Vallet, Véronique Cucchi (Irstea, Nogent sur Vernisson)

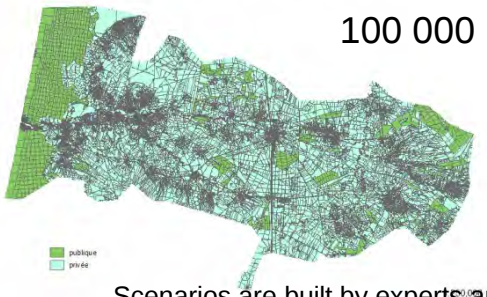
Simmem: modelling several forests



Simmem is a model simulating the management of several forests at the same time
Each forest grows with a specific Capsis model according to its species and forest structure
Connections to Fasy, Fagacées, FTChene, Gymnos, Lemoine, Melies, Laricio, Sylvestris...

integral — Future-oriented integrated management of European forest landscapes

Forêt publique - Forêt privée



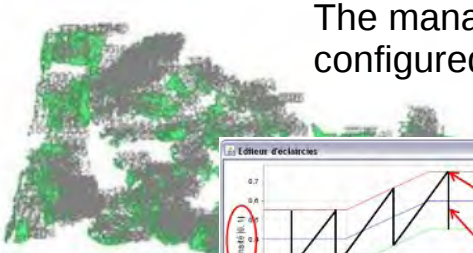
100 000 ha

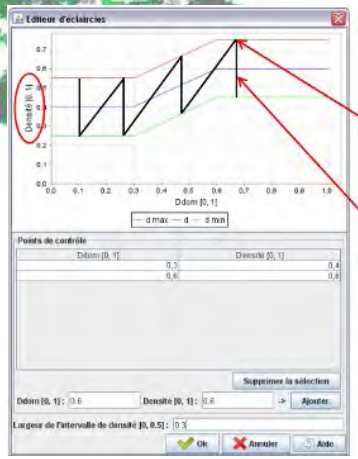
Scenarios are built by experts and stakeholders according to forest owner behaviour

scenario 1: Unfinished bioenergy
scenario 2: Biorefinery innovation & land-use tensions
scenario 3: The European biomass sink
scenario 4: The 'Green' innovative cluster
scenario 5: The territorial partnership
...

Capsis4
Simmem

The management rules are configured for the whole site

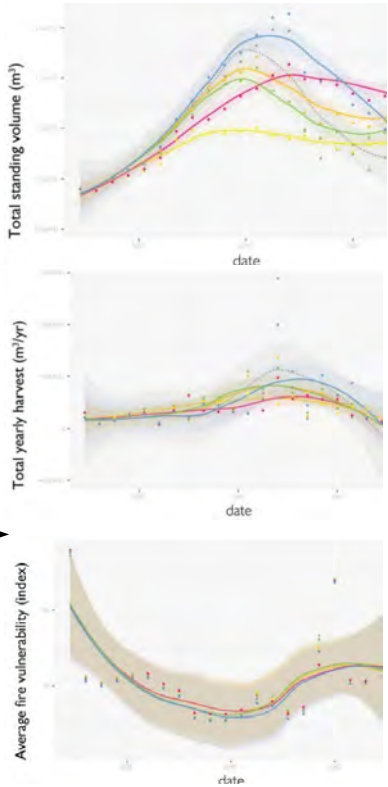




Inspiré de l'éclaircisseur « auto par le rdi » (F. Mothe, G. Le Moguedec)

déclenchement de l'éclaircie :
→ commune aux modules

méthode d'éclaircie :
→ spécifique à chaque module



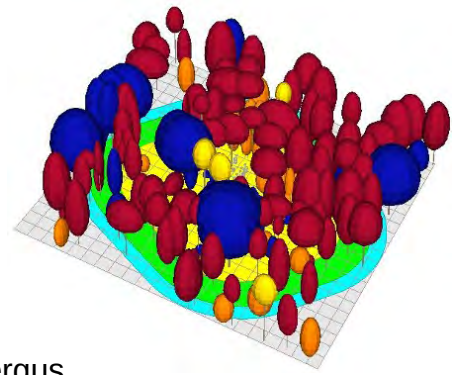
Several teams work together on Simmem...

- P. Vallet, T. Cordonnier (Irstea, Nogent sur Vernisson & Grenoble) **Forgeco project** (ANR)
  -> Foret d'Orleans, Massif du Vercors
- P. Lejeune, G. Ligot (ULG, Gembloux, Belgium)
  -> Ardennes belges
- C. Orazio (EFIATLANTIC, Bordeaux) **Integral project** (EU)
  -> Aquitaine

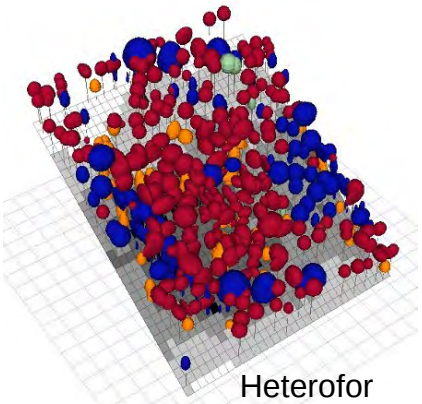
SamsaraLight: a reusable library for radiative balance

A library implementing the radiative balance of the Samsara model, to make it possible to reuse it in other models (Quergus, Heterofor, RReShar, Samsara and Samsara2, Mountain).

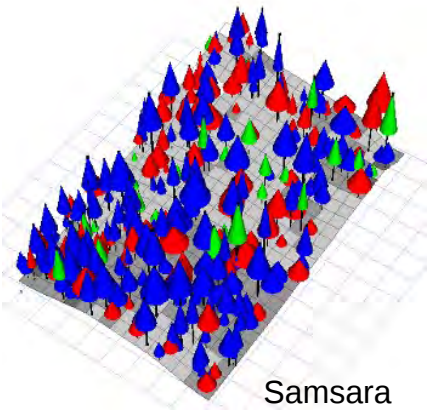
- adaptable to spatialized individual based models
- the crown is a kind of ellipsoid or a cone
- two modes: turbid medium volume or porous envelop
- irradiance (MJ) for each tree and each cell on the ground
- the irradiance can be considered for tree growth



Quergus
(G. Ligot, ULG, Belgium)



Heterofor
(M. Jonard, UCL, Belgium)

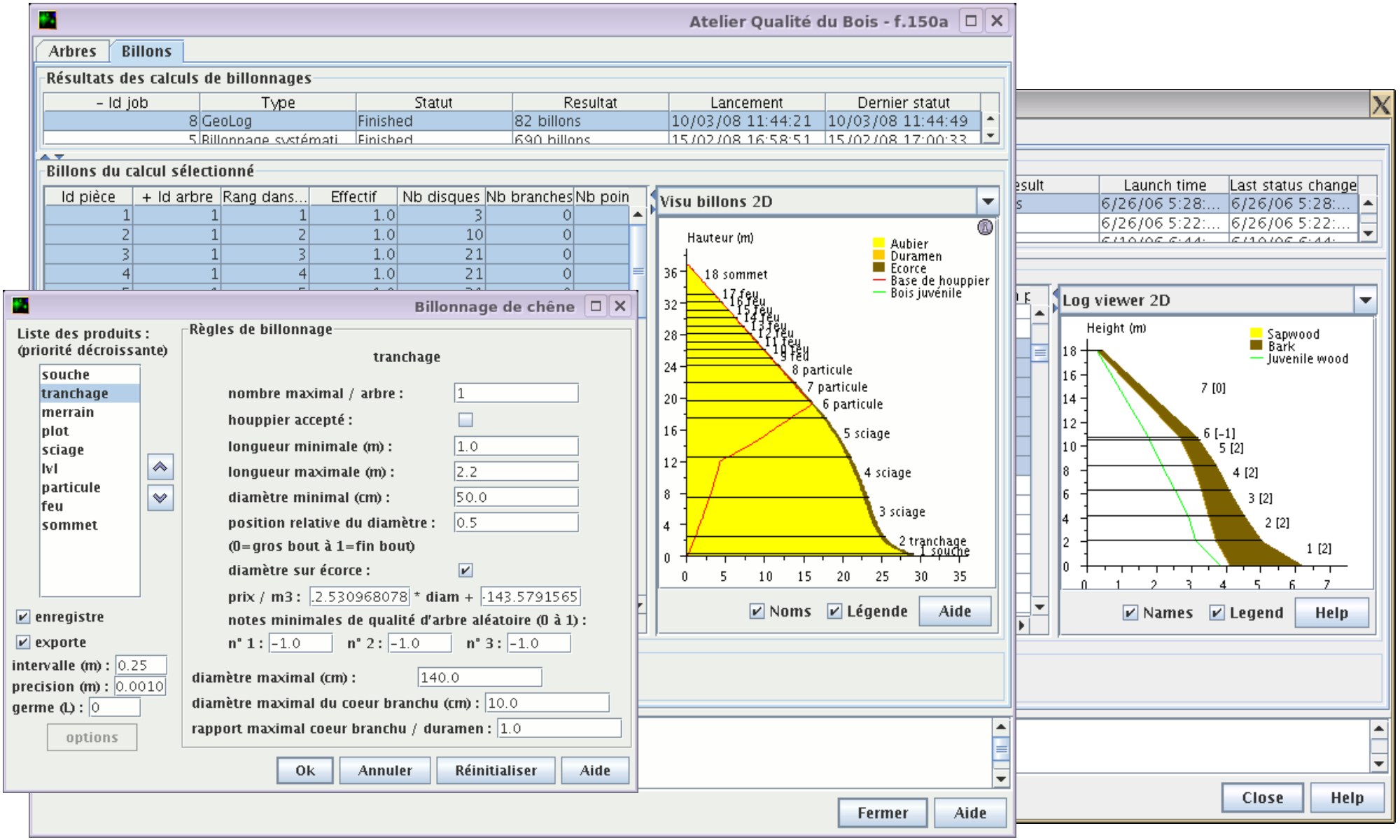


Samsara
(B. Courbaud, IRSTEA)

Dave Pont (Scion, New Zeland), Frédéric Mothe, Patrick Vallet (INRA Lerfob, Nancy), Céline Meredieu, Thierry Labbé (INRA Biogeco, Bordeaux)

Wood Quality Workshop

Coupled to a growth model (Radiata pine, Maritime pine, Oak), logging algorithms, sawing is possible



ForEnerChips

Forest Energy Chips : a library to simulate harvesting and transformation processes

- Assess the energy consumption of the forest wood chips chain of production
- Quantify the mineral extraction from the forest plot

First applied on the outputs of a Fagacées simulation
Aims at being compatible with other growth models in Capsis

```
FecExecutor executing...
FecExecutor ended, have run 4 processes
Executor: Scenario Fec1
All working processes:
  FellingProcess efficiency: 1.0 consumption: 0.629151830974916
  ShapingProcess efficiency: 1.0 consumption: 500.2581653181361
  ForwardingProcess efficiency: 0.7 consumption: 102.27564927611036
  ForwardingProcess efficiency: 1.0 consumption: 268.19090885901
All resources:
  Species name: beech softwood: false site: Plot status: Standing tree chainConsumption: 0.0 wetBiomass: 100.05163306362722
  Species name: beech softwood: false site: Plot status: Fallen tree chainConsumption: 0.629151830974916 wetBiomass: 100.05163306362722
  Species name: beech softwood: false site: Plot status: Log chainConsumption: 408.3079627084485 wetBiomass: 81.5357621754947
  Species name: beech softwood: false site: Plot status: Residual chainConsumption: 93.20850627163746 wetBiomass: 18.515870888132508
  Species name: beech softwood: false site: Roadside status: Residual chainConsumption: 195.48415554774783 wetBiomass: 12.961109621692753
  Species name: beech softwood: false site: Roadside status: Log chainConsumption: 676.4988715674585 wetBiomass: 81.5357621754947

FecScript01 wrote resource summary in /home/coligny/workspace/capsis4/tmp/fecscript01.resource
FecScript01 done
```

Capsis-ONF-2014

- a Capsis installer on an ONF server for internal distribution
- upgraded each year (december) by ONF
- with the Capsis developers and modellers
- a single Capsis with 18 modules:

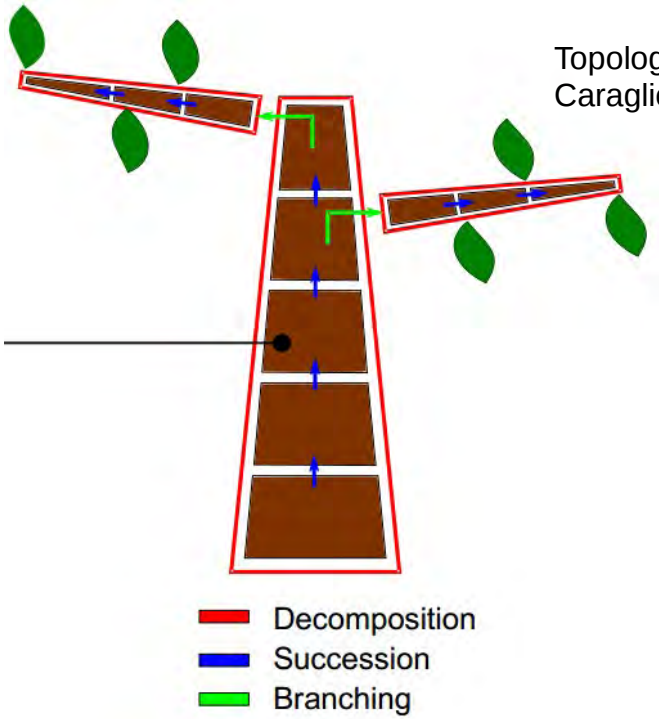
Abial (INRA)
Artemis (MRNF, Québec)
CA1 (INRA)
Fagacées (INRA)
Gymnos (Gembloux, Belgique)
Laricio (Irstea, INRA)
Lemoine (INRA)
Melies (Irstea)
NRG (INRA)
Oakpine1 et **2** (Irstea)
PiceaAbies (FCBA)
PNN2 (INRA)
Pp3 (INRA)
Pseudotsugamenziesii (FCBA)
Regix (FCBA)
Samsara (Irstea)
Sylvestris (Irstea)

Capsis helps write/update ONF silvicultural guides (about 17 since 2004)
e.g. *Massif Vosgien - Sapin, épicea et pin sylvestre*, Thierry Sardin (2012)

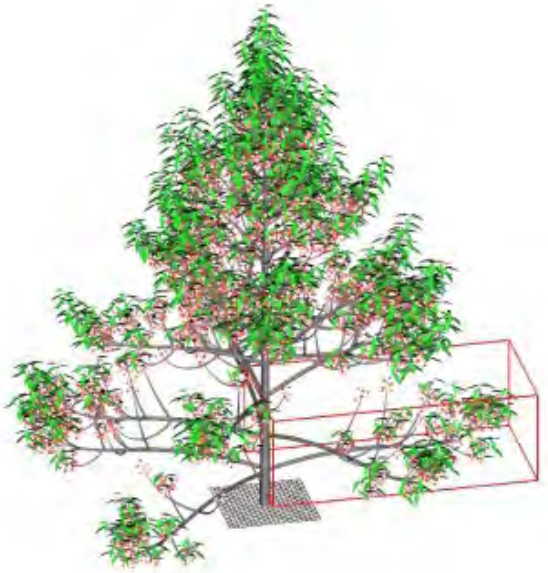
AMAPstudio: a software suite for plants architecture modelling

Objectives: Build a **software suite** to provide **editors** and **integrate simulators** for plants multi-scale architecture modelling, for the individual plant or the vegetal scene, for **modellers and teaching**

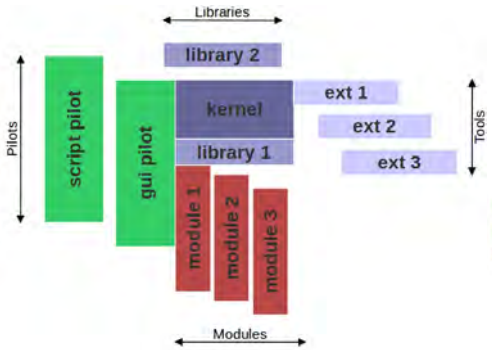
Node attributes
length
diameter
color
weight
...

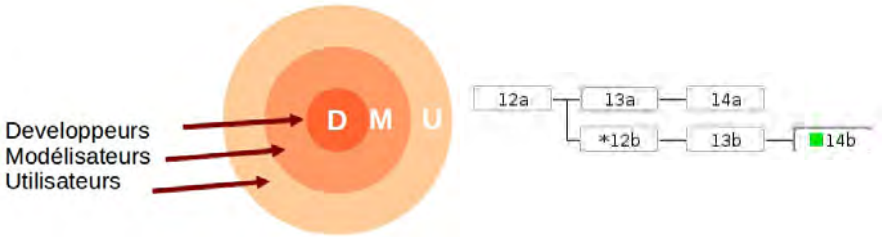


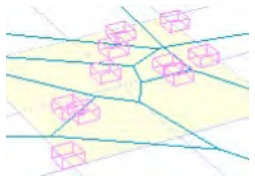
Topology based on the Multiscale Tree Graph formalism (C. Godin and Y. Caraglio, “A multiscale model of plant topological structures”, 1998)



Mutualisation







Sébastien Griffon (Cirad AMAP), Francois de Coligny (INRA AMAP)
and the AMAPstudio modellers

AMAPstudio: Xplo + Simeo

AMAPstudio

Xplo

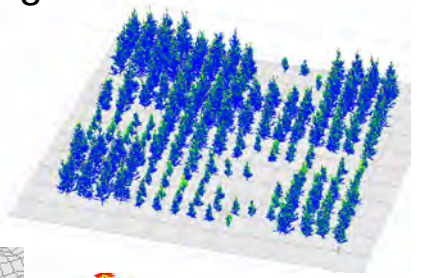
Multi-scale plant

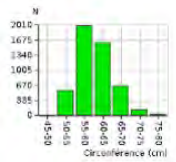
Forest dynamics models
Growth & yield models

Capsis

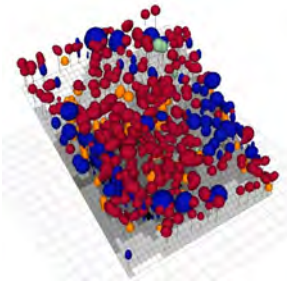
Simeo

High-detailed vegetal scene



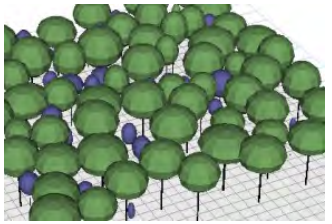


Capsis-
PP3

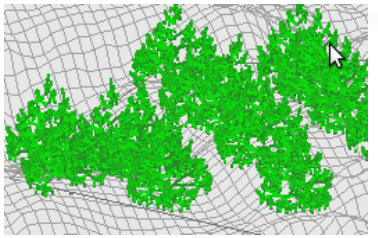


Capsis-
Heterofor

Capsis-
FireParadox
(800 000
trees)



Simeo-
Lollymangrove



Simeo-
Edito

Simeo-
Archimed

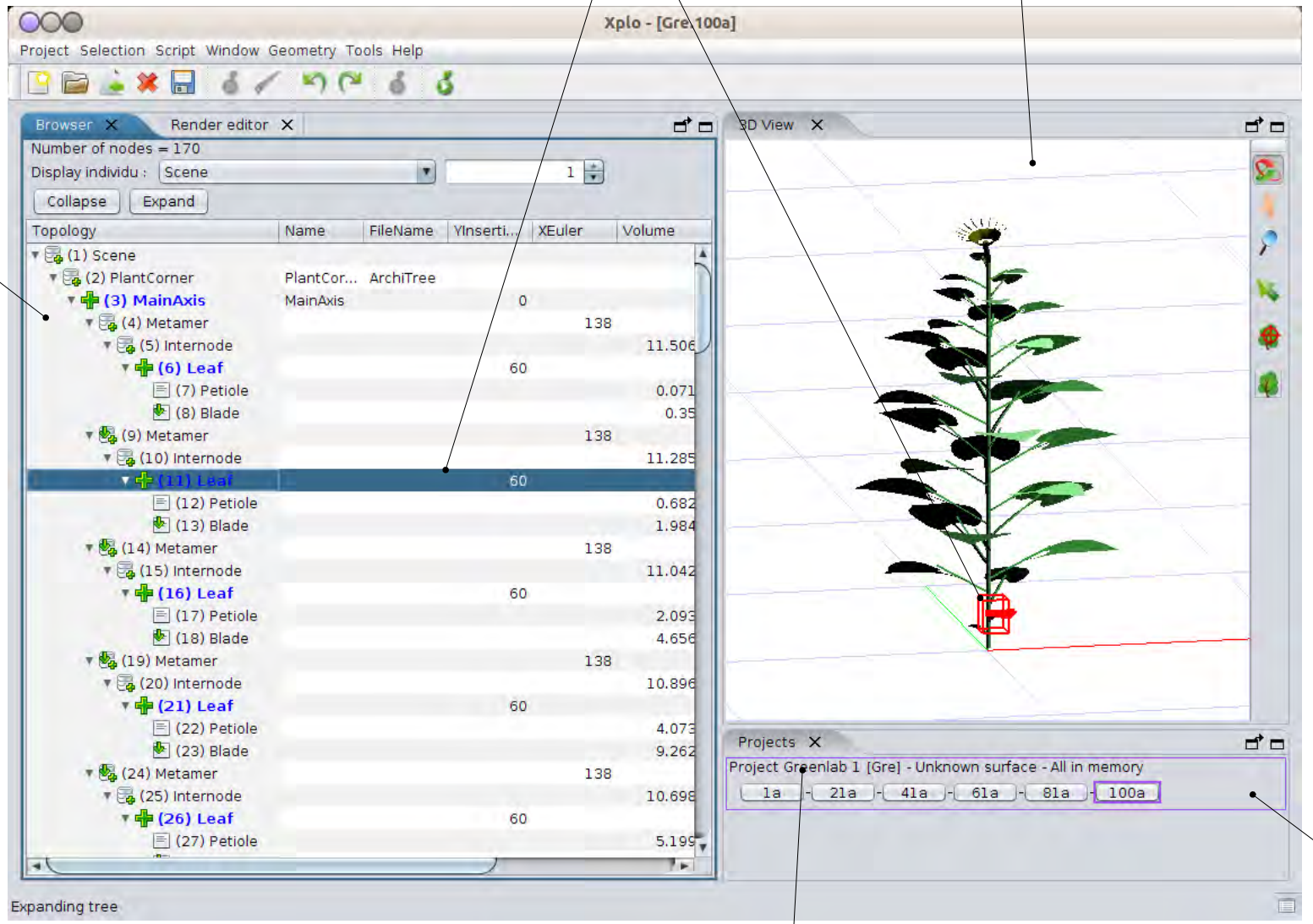
Xplo: how does it work ?

selection

export

3D View

Excel like editor

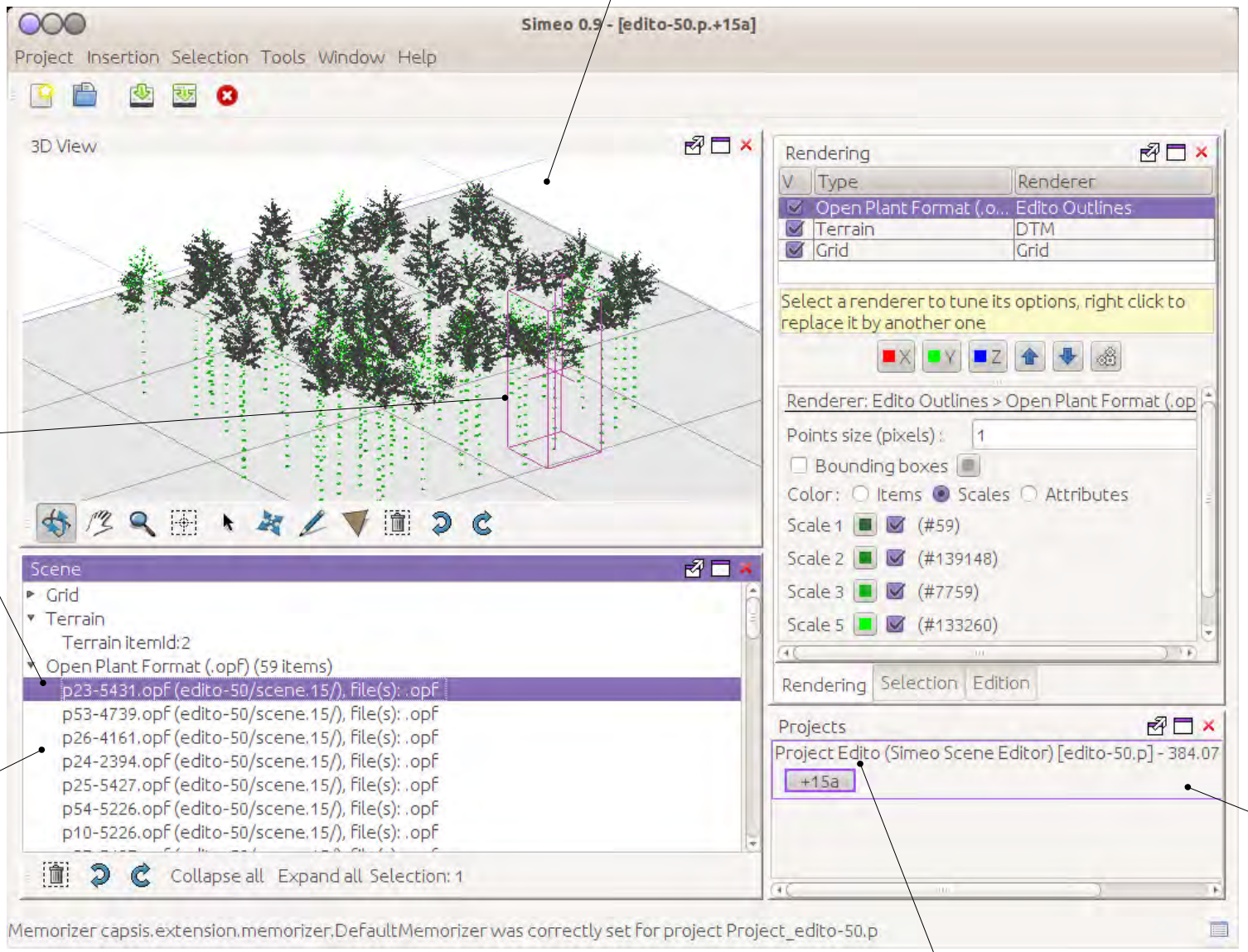


project

Xplo - Linux - Graphical user interface - English

model : initialisation + time loop (optional)

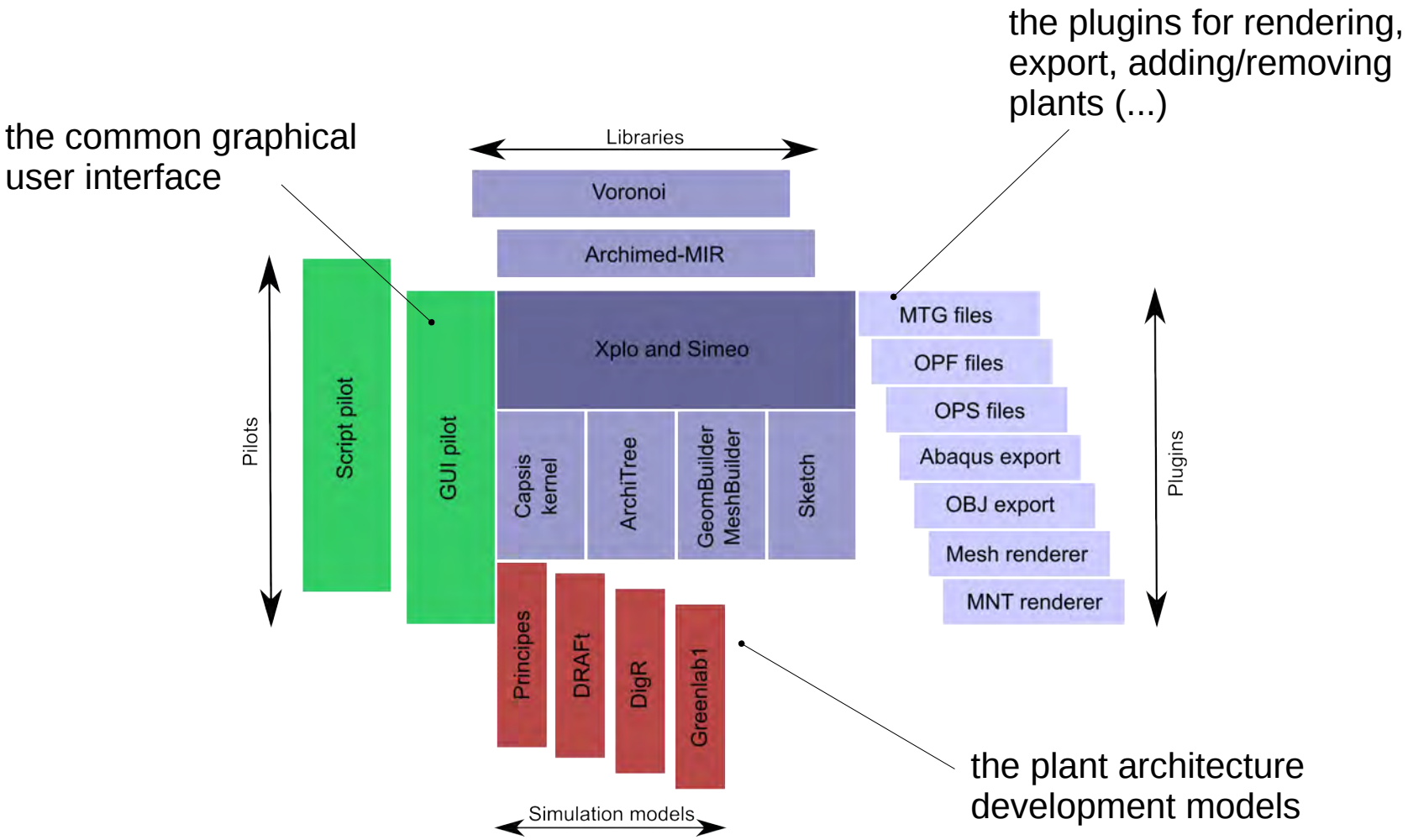
Simeo: how does it work ?



Simeo - Linux - Graphical user interface - English

model : initialisation + time loop (optional)

Xplo / Simeo: Software design

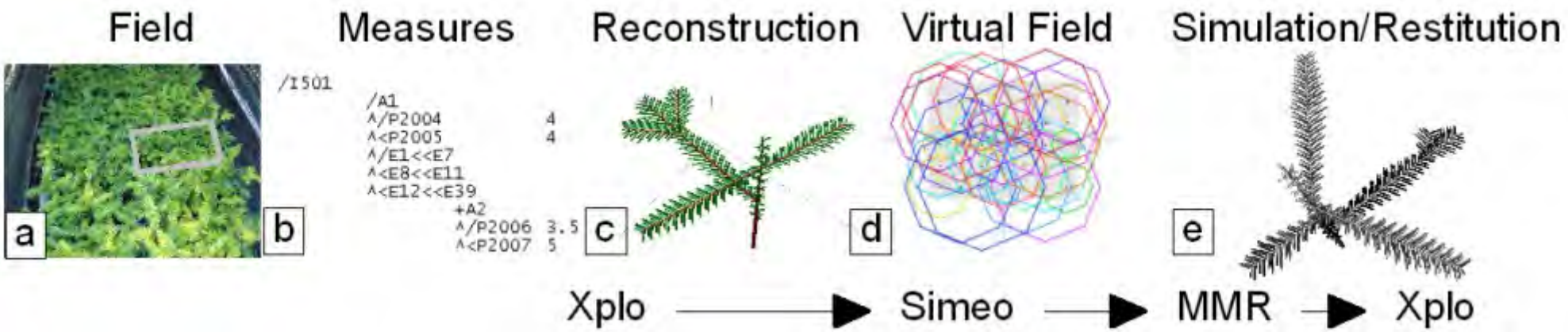


Sébastien Griffon (Cirad AMAP), Francois de Coligny (INRA AMAP)

Xplo and Simeo editors

- create plants / vegetal scenes interactively
- check and correct them, build geometry
- run biophysical simulations (e.g. biomechanics)
- load and save plant / vegetal scenes
- export to other formats

An example: Retrospective analysis of fir sapling growth vs. light interception (Taugourdeau et al. 2010)

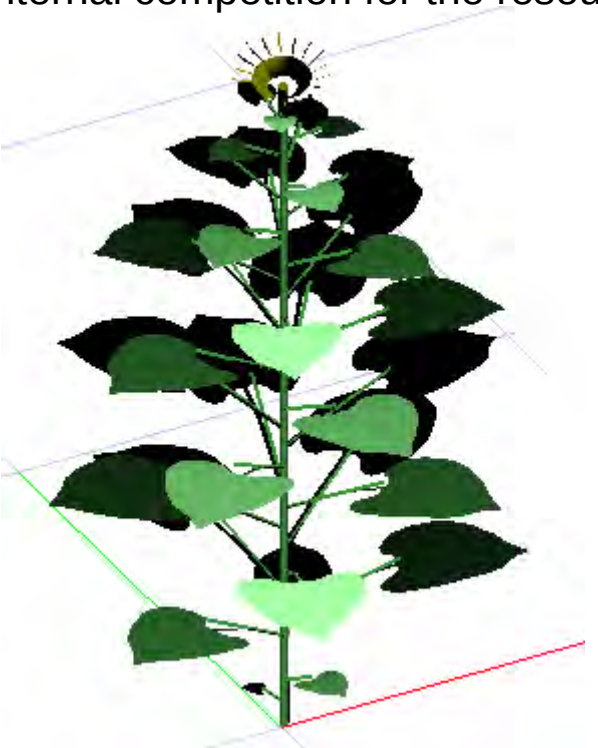


From plot to simulation, (a) view of a subplot in the dry (D) treatment, (b) plant architecture coded in accordance with AMAPMOD/MTG syntax (Godin & Caraglio, 1998), (c) topological and geometrical plant reconstruction with Xplo, (d) stand reconstruction with Simeo, (e) light interception calculated using MMR model and analyses by Xplo

Taugourdeau O., Dauzat J., Griffon S., de Coligny F., Sabatier S., Caraglio Y. & Barthélémy D., 2010. Retrospective analysis of fir sapling growth vs. light interception, Actes du 6ème colloque international sur la modélisation structure-fonction (Functional-Structural Plant Models, FSPM), 12-17/09/2010, Université de Californie à Davis (USA), pages (93-95)

Greenlab 1

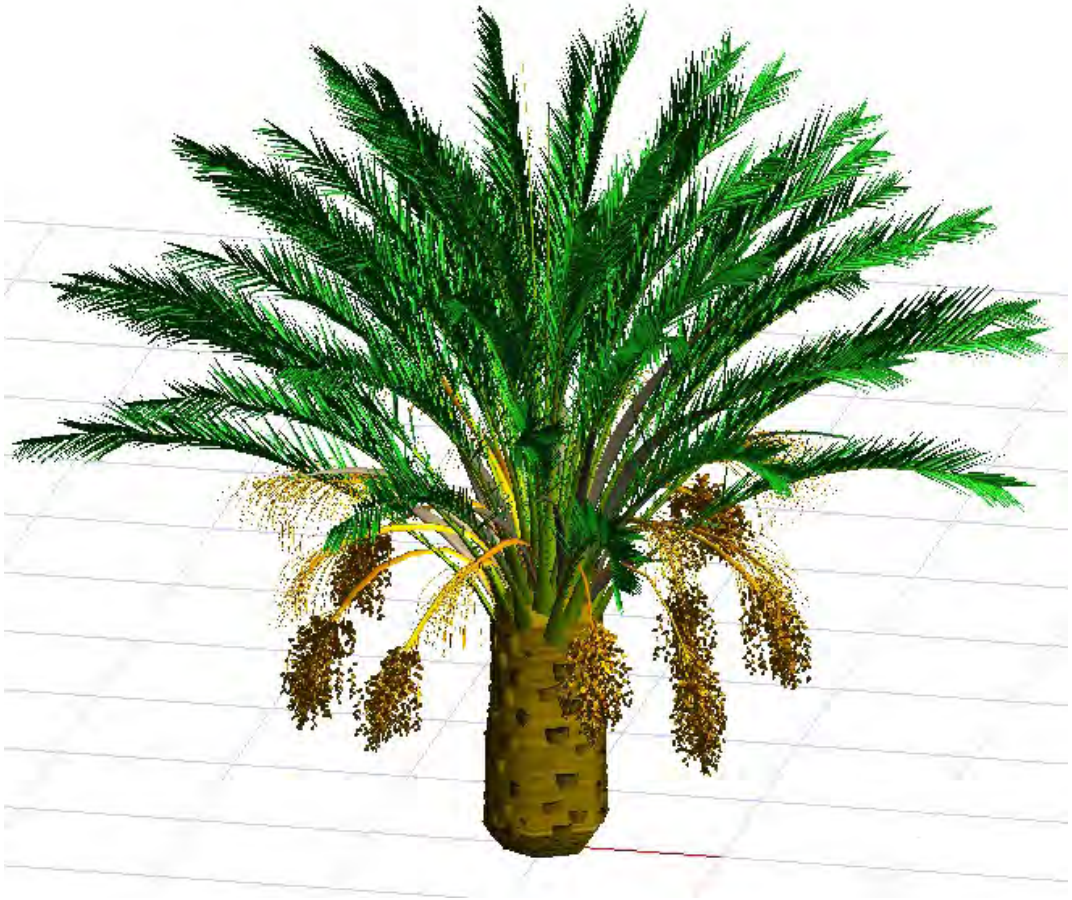
- *Greenlab* is a mathematical plant model simulating interactions between plant structure and functions
- biomass produced by organs (sources) is allocated to expanding organs (sinks) according to their relative demand
- plant parameters can be adjusted by fitting on real measurements
- Greenlab can compute the plant architecture for various species in interaction with their environment
- this model's underlying concepts can potentially predict the plant's phenotypic plasticity, for instance, pruning affects the internal competition for the resources and may lead to different leaf sizes



de Reffye P, Hu B-G. Relevant qualitative and quantitative choices for building an efficient dynamic plant growth model: GreenLab case. In: Hu B, Jaeger M, eds. Plant Growth Modeling and Applications (PMA03); Proceedings of the 2003 International Symposium on Plant Growth Modeling, Simulation, Visualization and Their Applications; Tsinghua University Press, Springer; 2003. p. 87-107

Principes

- models and simules the development and architecture of vegetative and reproductive parts of date palm (Phoenix dactylifera L.) from germination to any age
- a continuation of studies that have been carried out for almost 20 years on palm-tree architecture
- Principes brings a generic, multi-scale, structural model for palm-trees based on the organisation of the various organs
- each organ carries its own attributes (lengths, diameters, branching or deviation angles, inter organs distances, etc.)

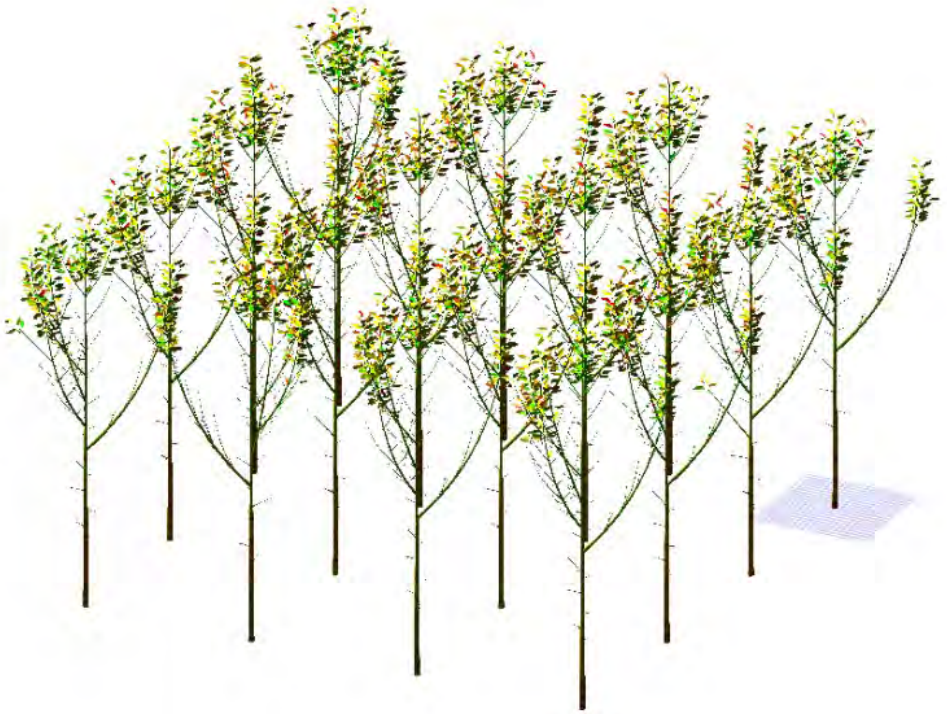


Tristan Charles-Dominique (Cirad AMAP), Francois Munoz (UM2 AMAP),
Yves Caraglio, Jean-Francois Barczi, Jean Dauzat (Cirad AMAP)

InSilEco - Architectural plasticity in ecological communities

- simulate the growth of several tree individuals in a forest stand
- the growth of an axis depends on the amount of light that it and its leaves receive
- the simulation process then combines architectural rules defined at species level (AmapSim), an illumination module used to assess light interception by leaves (MIR), and a coupling of axis growth and ramification capabilities with local light interception

The objective is to assess the effect of competition for light within and between species on the overall structure of the forest stand



Powered by AmapSim, Simeo and Archimed-MMR

Marion Jourdan (Cirad AMAP), Eloi Grau (CNES TETIS), Sylvie Durrieu (IRSTEA TETIS), Grégoire Vincent, Raphael Pélissier (IRD AMAP),
Cécile Antin, Jean Dauzat, Jean-Francois Barczi (Cirad AMAP)

CNES-StemLeaf project

- Build realistic 3D stand mockups to simulate a LiDAR retrodiffusion signal
- Case study: a plantation of Maritime pine in the Landes de Gascogne

a 19 years old plantation
of Maritime pine,
simulated with AmapSim,
viewed in AMAPstudio

AmapSim
tree growth according to management and steric pressure

AMAPstudio
mockups edition, parameters edition and extraction

Computree (ONF)
additive processing on mockups and LiDAR data, parameters extraction

DART (Cesbio Toulouse)
aerial LiDAR simulation on the mockups

Exporting to other formats / software

.ops / .opf / .mtg

```
# Simeo OpsFormatExport: Mon Oct 15 11:46:11 CEST 2012

# Part 1: one line per plant in the scene
#sceneId        plantId plantFileName    x       y       z       scal
1       1       opf/p1-mod_Rauh_14.opf  30.862822679993986      50.(
1       3       opf/p3-mod_Scarrone_7.opf       54.86255259261524
1       4       opf/p4-mod_Massart_10.opf       45.36609940359506

# Part 2 (optional), chaining: only if scenario or project, one line
#motherId       sceneId date
-1      1       0
```

AMAPstudio

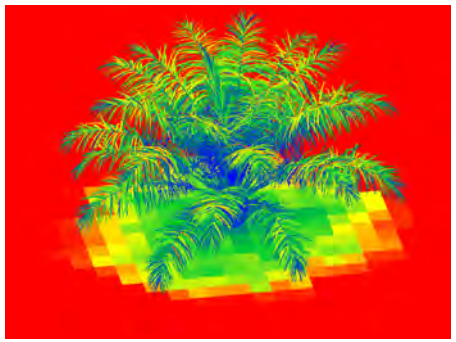
Xplo

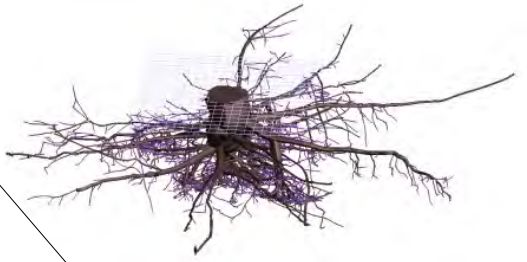
Simeo

.obj (Blender...)

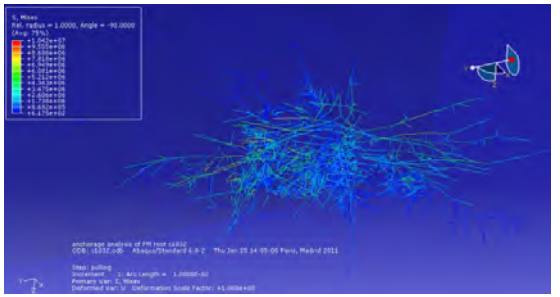
Olivier Sarrailh (AMAP)

Archimed MMR / ART / Lidar





Abacus



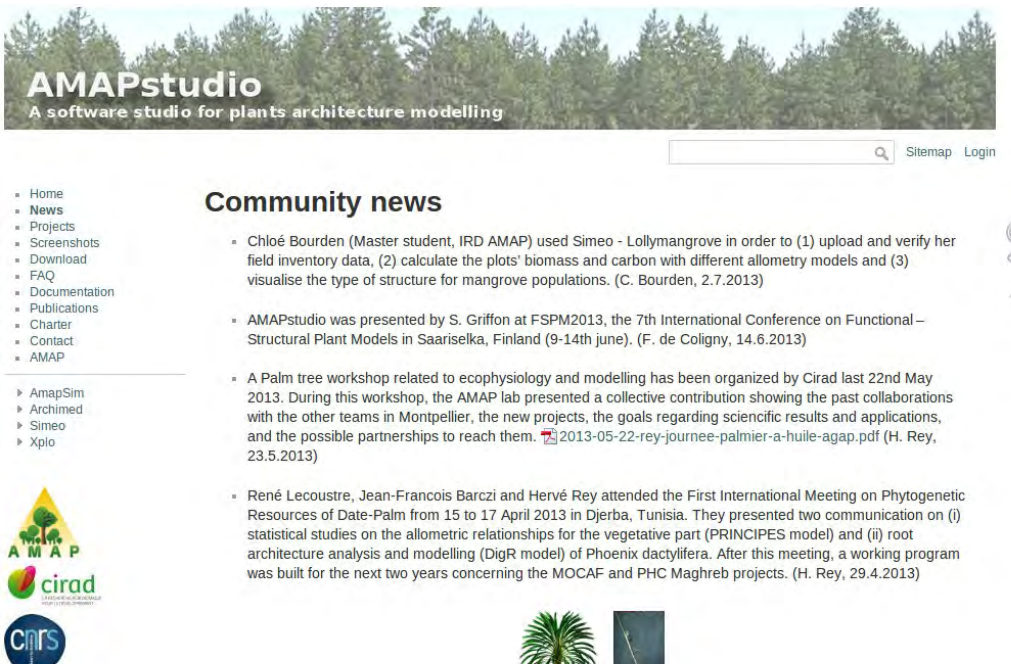
Perspectives

Capsis is in production: 60+ models integrated since 1999
- support new projects starting
- training courses, starting sessions
- permanent support
- annual meeting

AMAPstudio is younger
- improve our software
- support medium / big size projects like Capsis (ANR, European project...)
- find more partners outside the lab
- support simulation models for high detailed vegetation scenes

http://www.inra.fr/capsis

http://amapstudio.cirad.fr



Thank you for your attention

Dufour-Kowalski S., Courbaud B., Dreyfus P., Meredieu C., de Coligny F., 2012. Capsis: an open software framework and community for forest growth modelling. **Annals of Forest Science** (2012) 69:221-233

Griffon S., de Coligny F, 2014. AMAPstudio: an Editing and Simulation Software Suite for Plants Architecture Modelling. **Ecological Modelling** (2014) 290:3-10