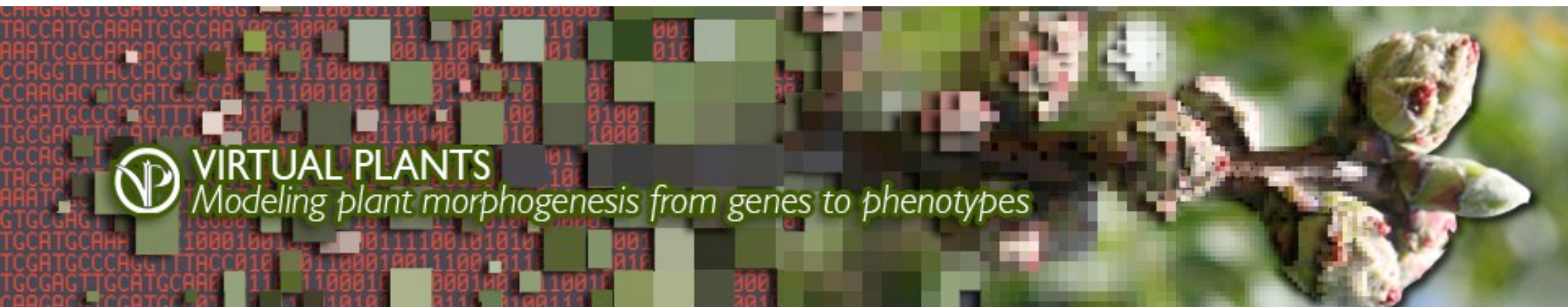


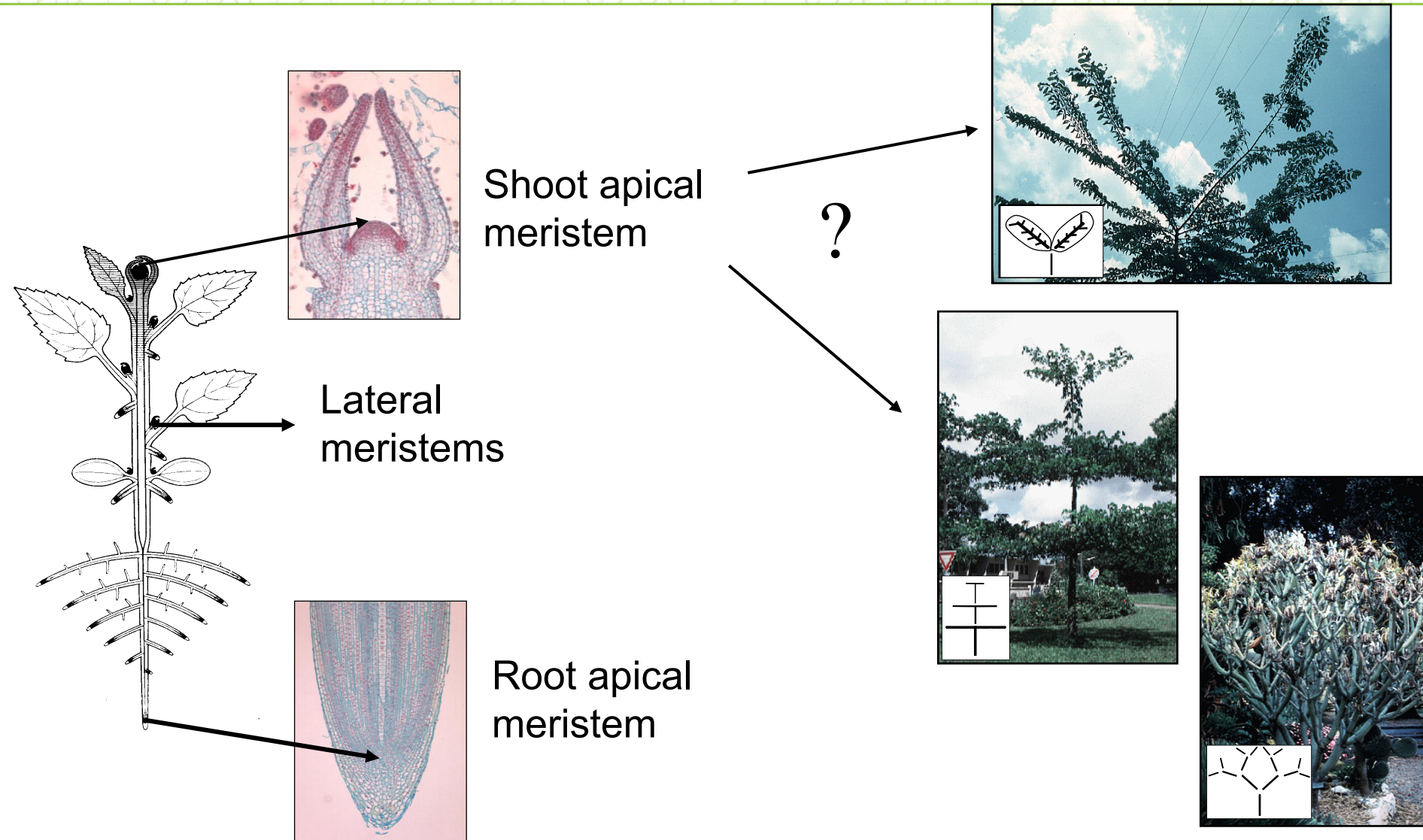
Modeling Plant Morphogenesis

F. Boudon

EPI Virtual Plants



Context : Studying plant morphogenesis

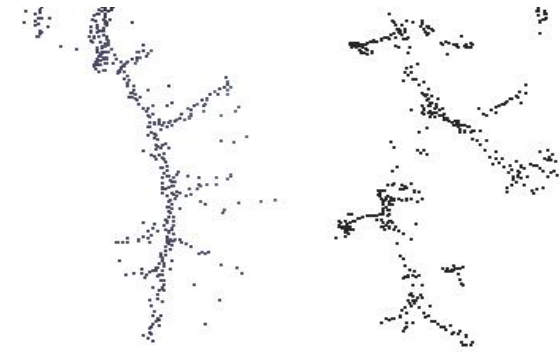


**In collaboration with biologists:
Develop a new generation of tools to study meristem development**



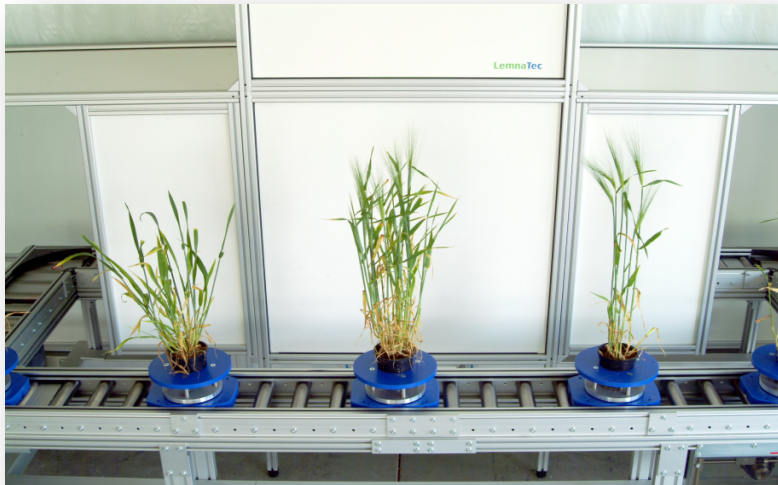
Acquisition of plant phenotype

- 👁️ Laser scanner devices produce 3D images of a plant



Unstructured noisy point set

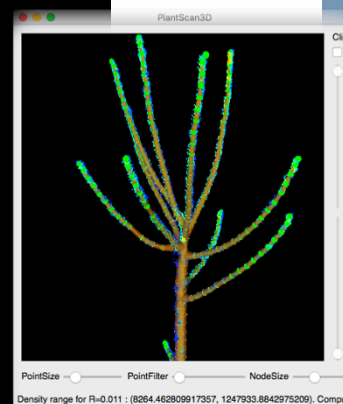
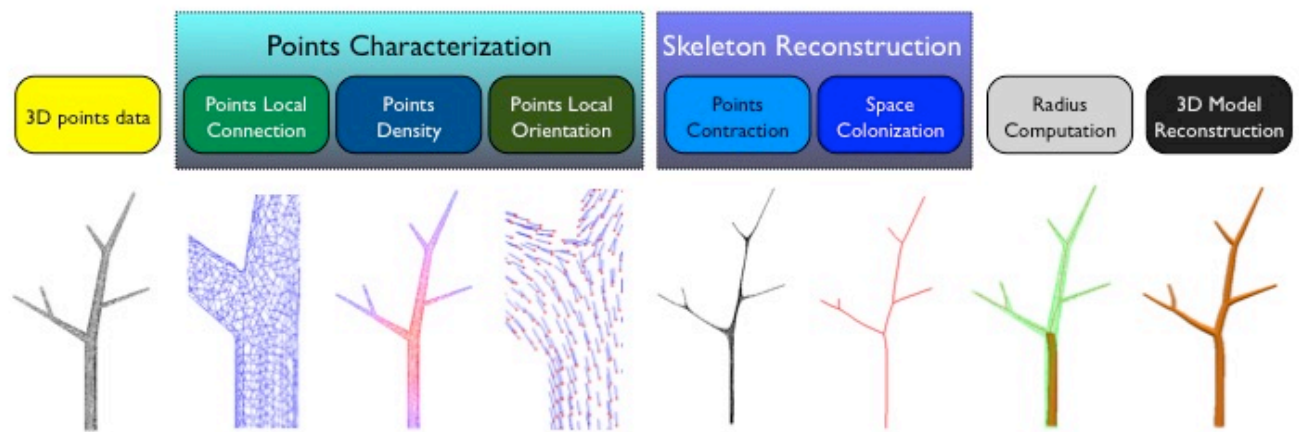
- 👁️ High throughput phenotyping platform



➡️ Complex and large set of data to process



Reconstruction of plant architecture scanner data

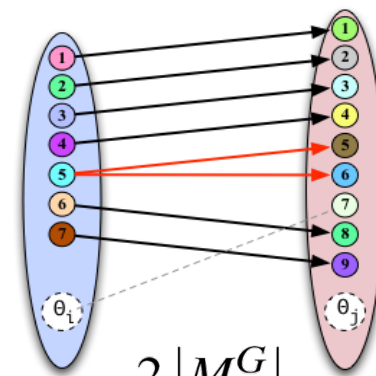
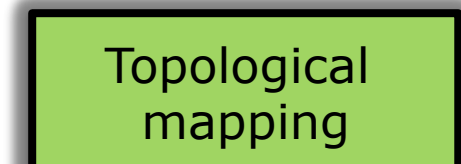
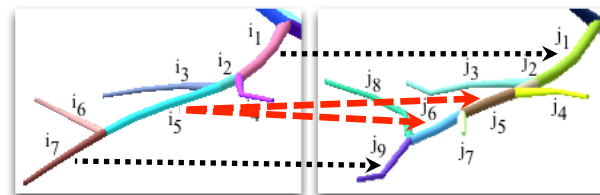
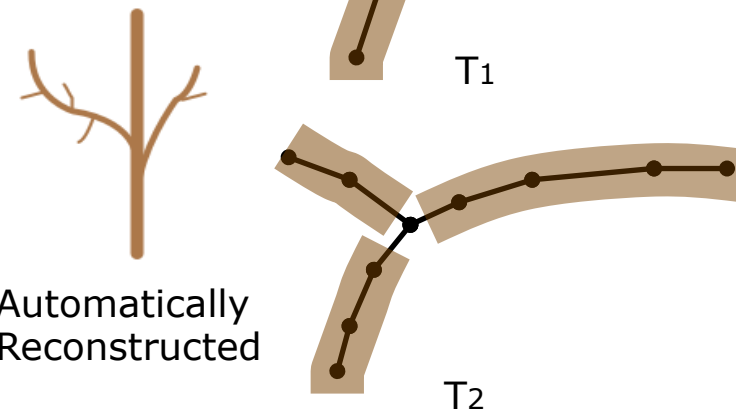


(Preuksakarn et al., FSPM, 2010)

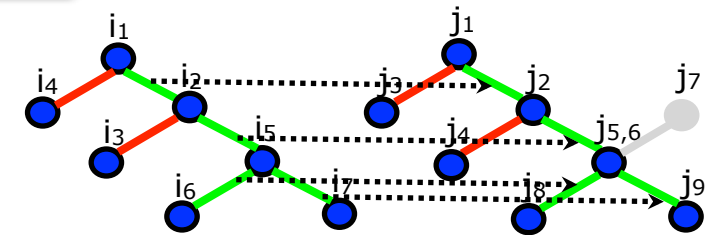
Validating reconstruction

(Boudon et al., Annals of Botany, 2014)

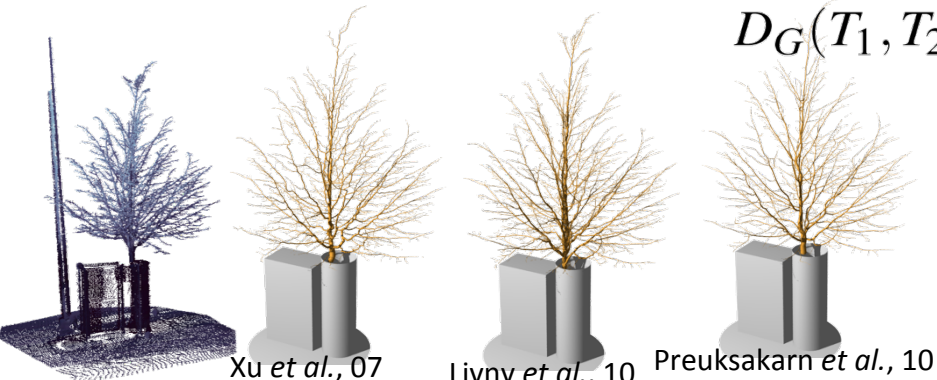
Finding geometrical and structural dissimilarities



$$D_G(T_1, T_2) = \frac{2 |M^G|}{|T_1| + |T_2|}$$

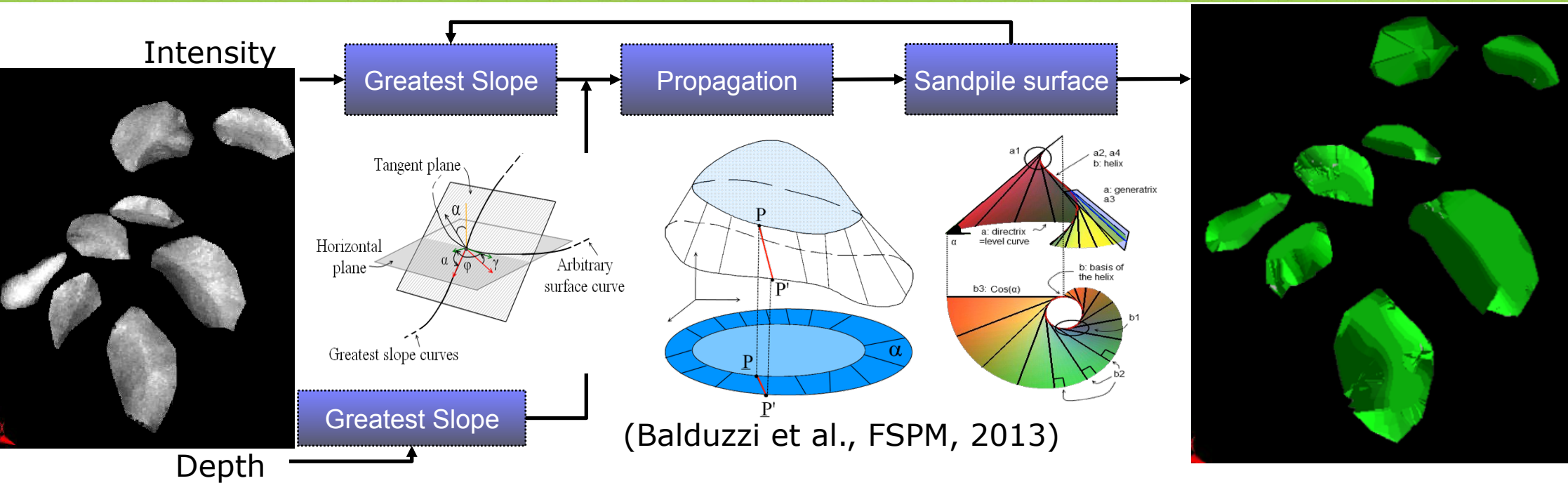


$$D_T(T_1, T_2) = \frac{2 |M^T|}{|E_1| + |E_2|}$$



Method	D_G	D_T
Xu et al. (2007)	0.81	0.87
Livny et al. (2010)	0.69	0.65
Preuksakarn et al. (2010)	0.90	0.72

Reconstruction of foliage and root structure

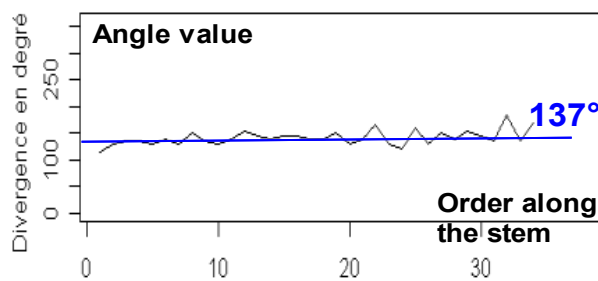
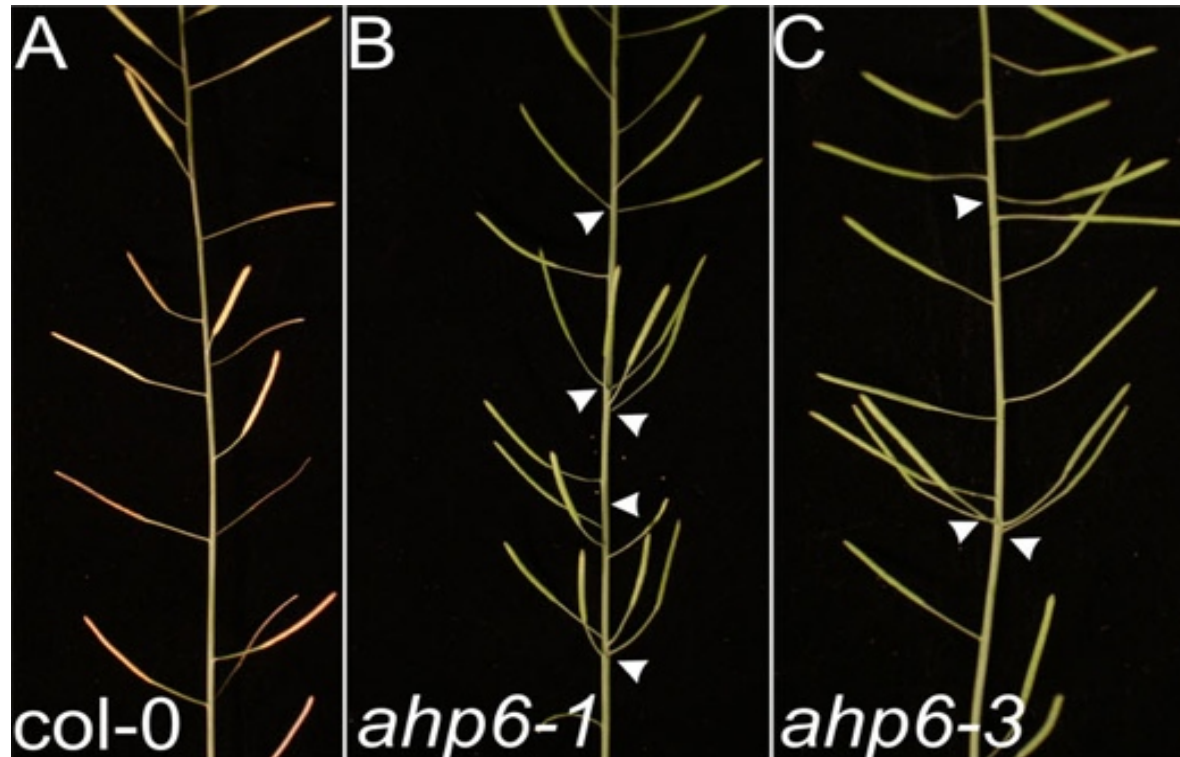


(Diener et al., FSPM, 2013)

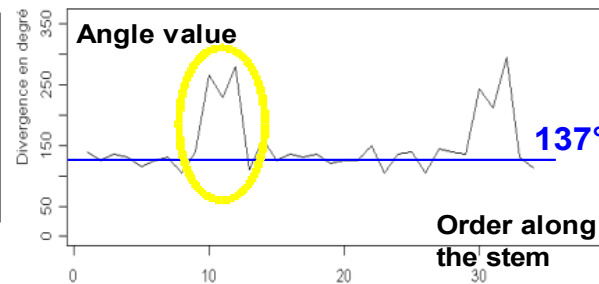


Analyse de la phyllotaxie

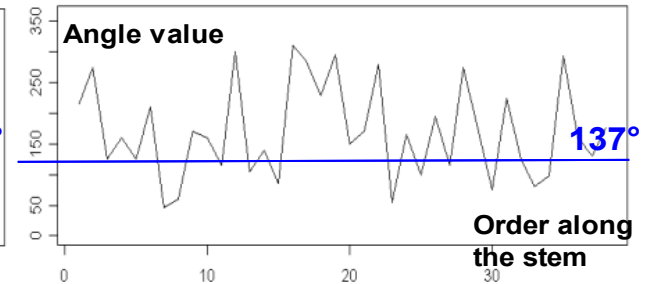
Coll: ENS-Lyon, Inra



Wild type

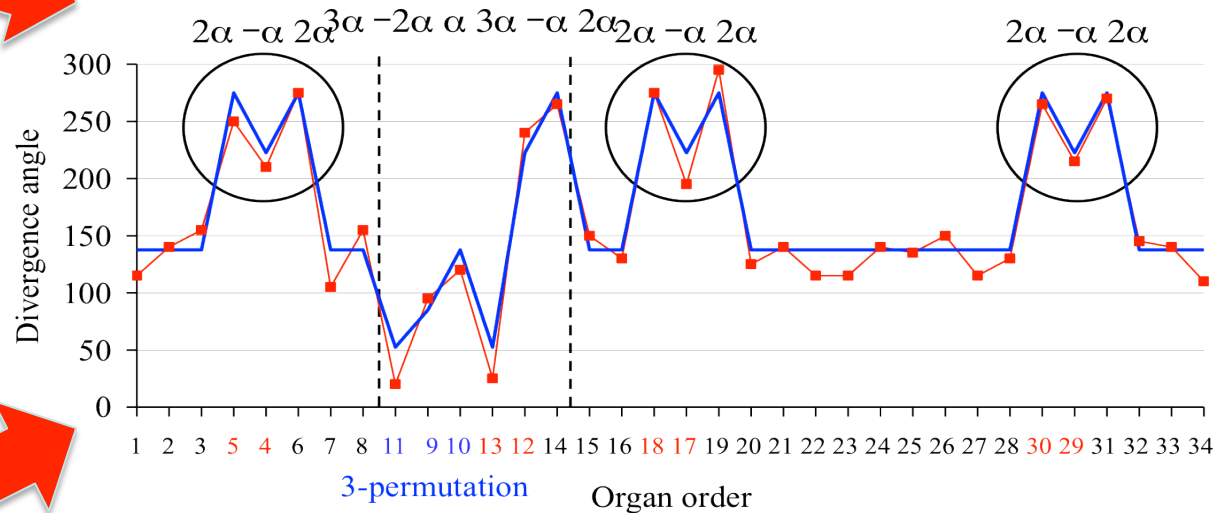
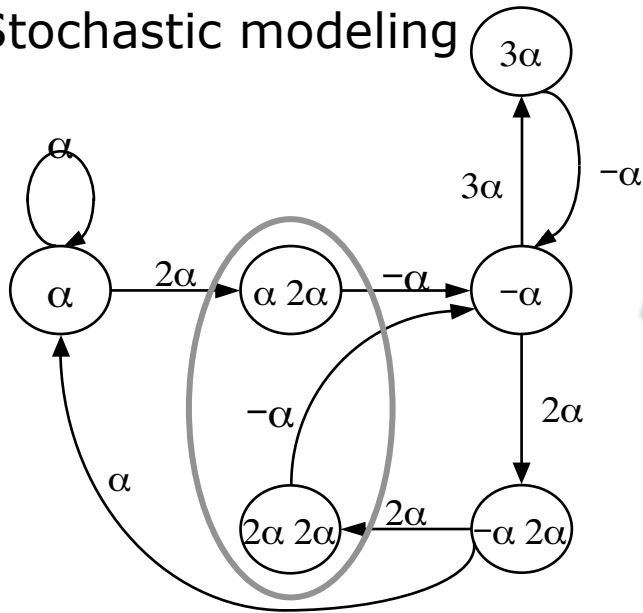


Mutants show heavily perturbed phyllotaxy

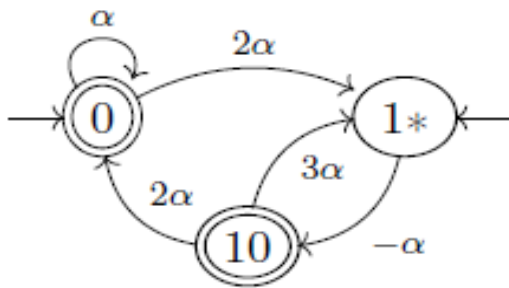


Analysis of phyllotaxy

Stochastic modeling



Combinatorial modeling

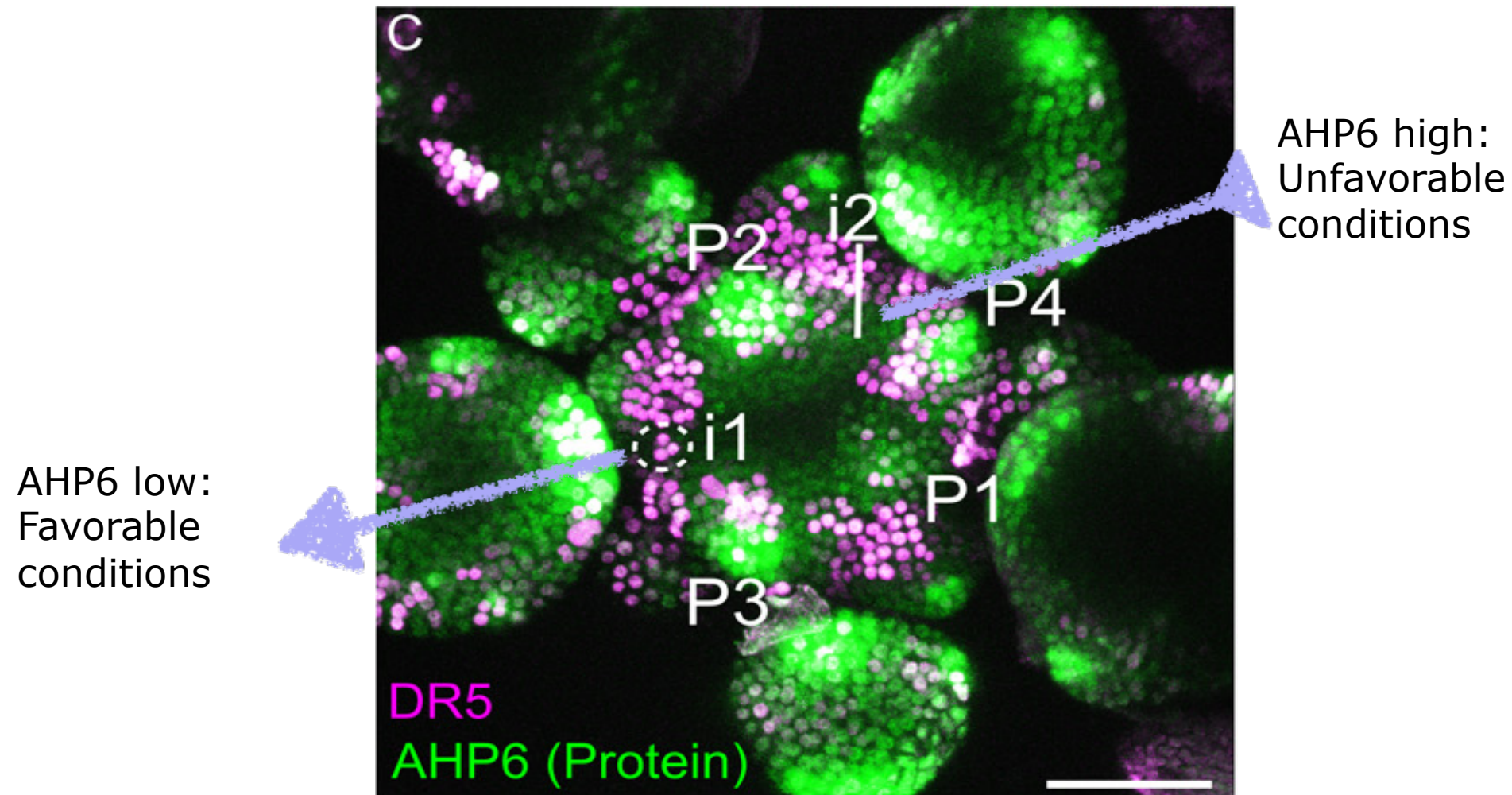


Organ permutations !

(Guédon *et al.*, J. Theoretical Biology, 2013)



Analysis of phyllotaxy



AHP6 acts as a second field, which
stabilize phyllotaxy

(Besnard et al., *Nature*, 2014)

Formalism to model plant growth and functioning

- A developing organism is a dynamical system with a dynamic structure (Giavitto and Michel, 2001)
- Lindenmayer-systems consist of an alphabet V , an axiom w and a set of productions P .
- Productions are applied to a string in parallel.

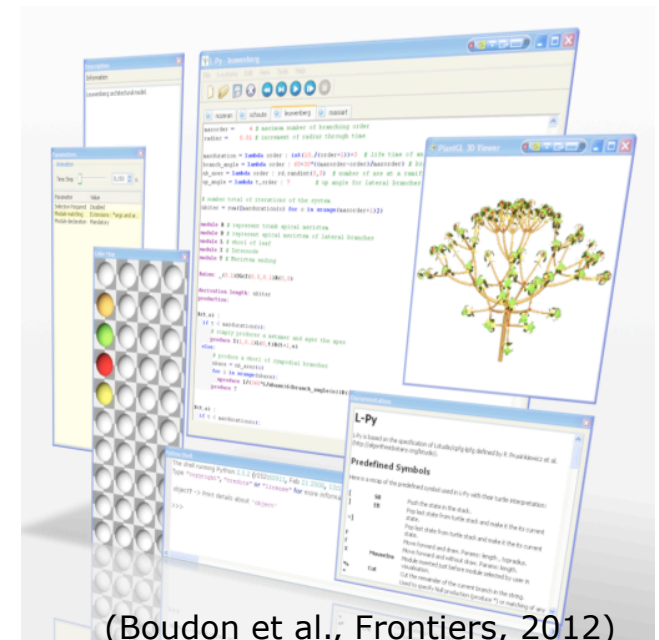
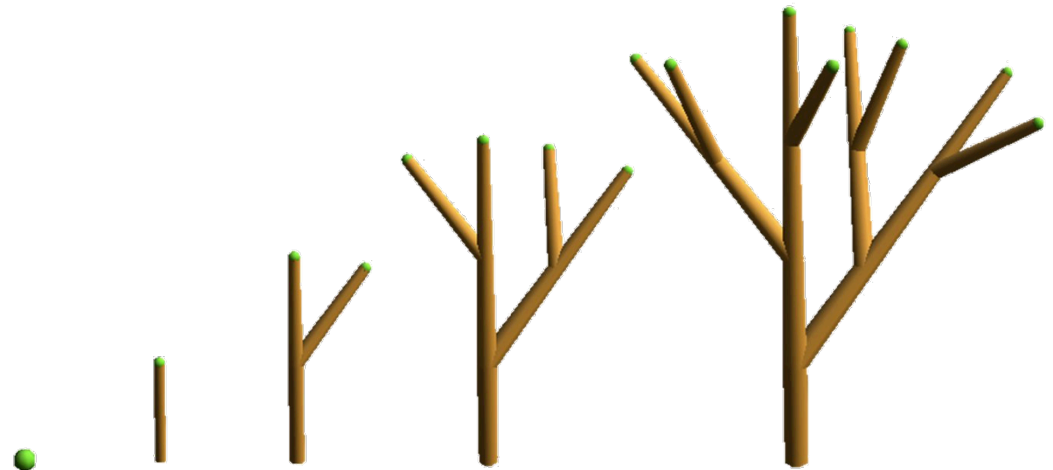
left context < *predecessor* > *right context* $\longrightarrow$ *successor*

- Example

$V = \{I, A, +, /\}$

$w = A$

$P: \begin{array}{lcl} A & \longrightarrow & I \ / \ [+A] \ A \\ I & \longrightarrow & II \end{array}$



(Boudon et al., Frontiers, 2012)



Mixing measurement and simulation

- Importing a digitized plant as an axiom and generating similar samples

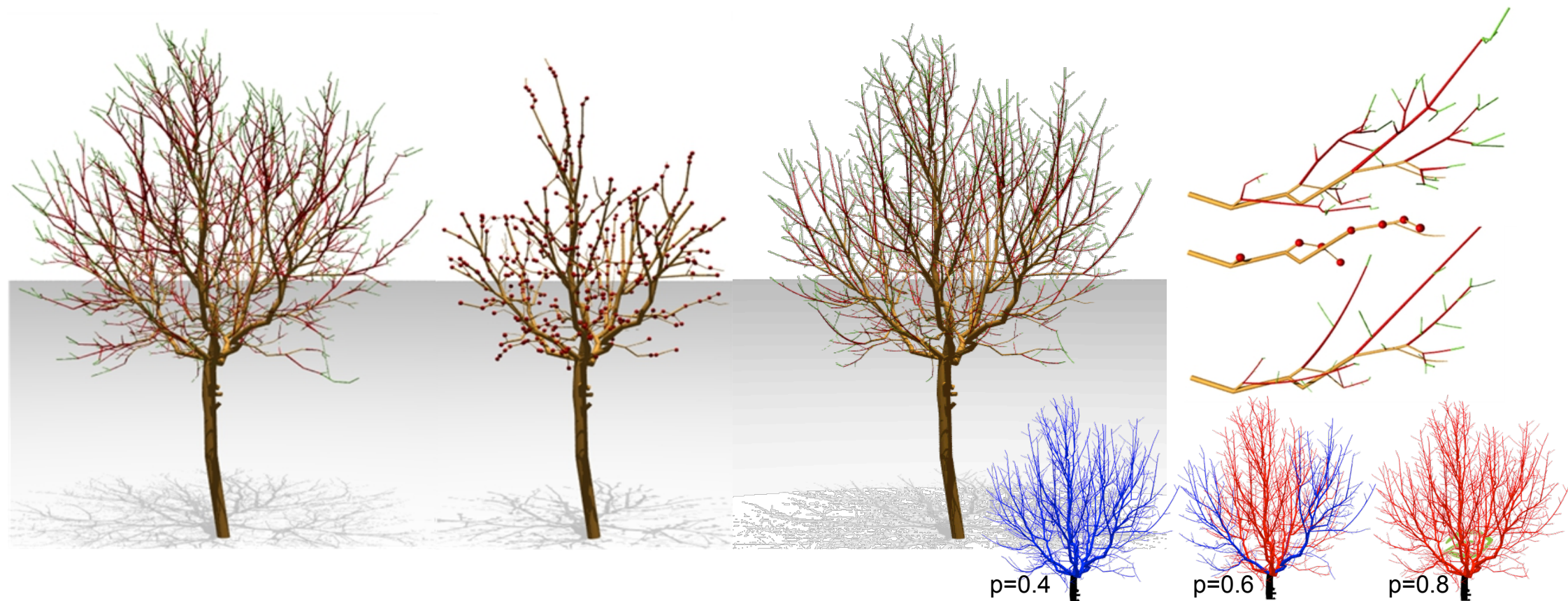
```
from openalea.mtg import *
```

Axiom:

```
intialmtg = MTG('walnut.mtg')  
pf = PlantFrame(intialmtg)  
lstring = mtg2lstring(intialmtg)  
sproduce(lstring)
```

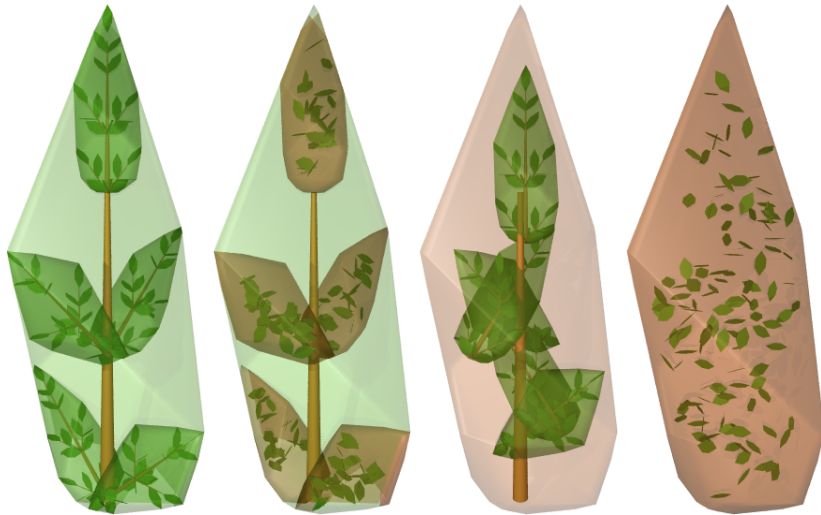
Bud :

```
nbelem = gauss(AVG_NBELEM, STDEV_NBELEM)  
for i in xrange(nbelem):  
    nproduce U  
    if random() < BRANCHINGPROB:  
        nproduce [ V ]
```

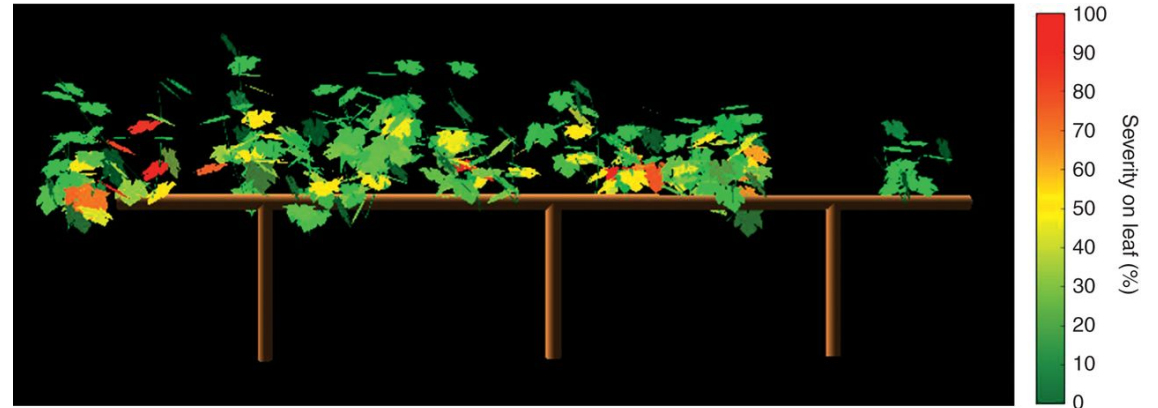


Ecophysiological processes

Light Interception

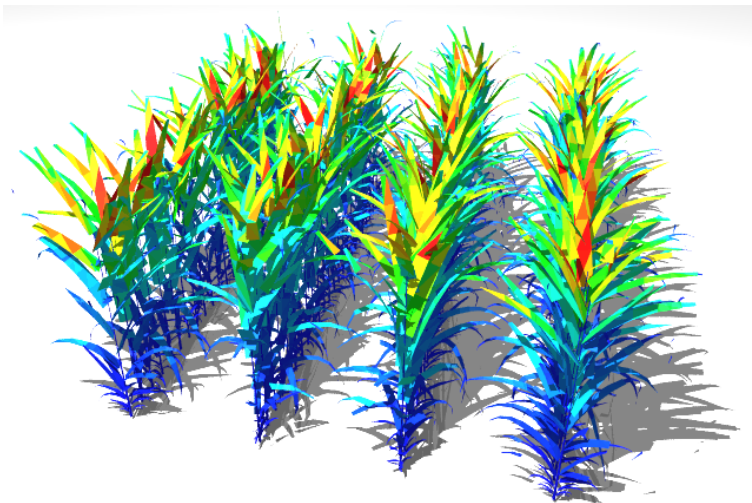


(Da Silva et al., FPB, 08)

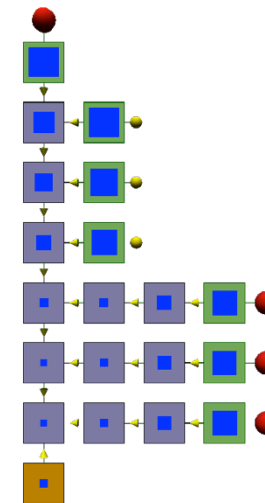


Disease propagation

(Garin et al., Annals of Botany, 08)



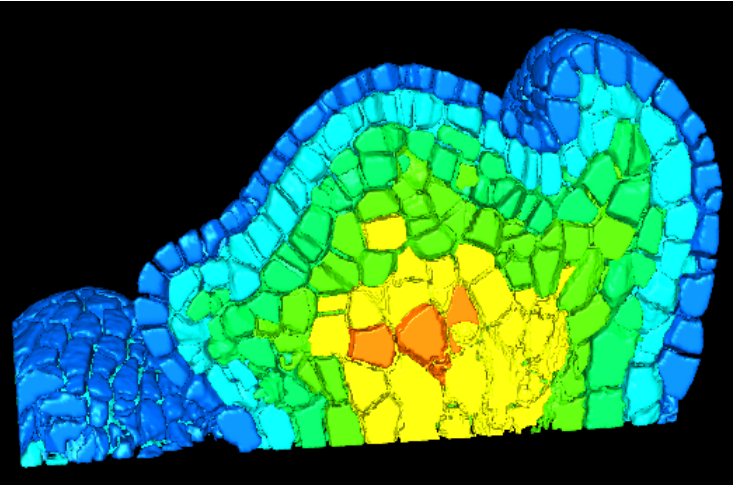
(Pradal et al., FPB, 08)



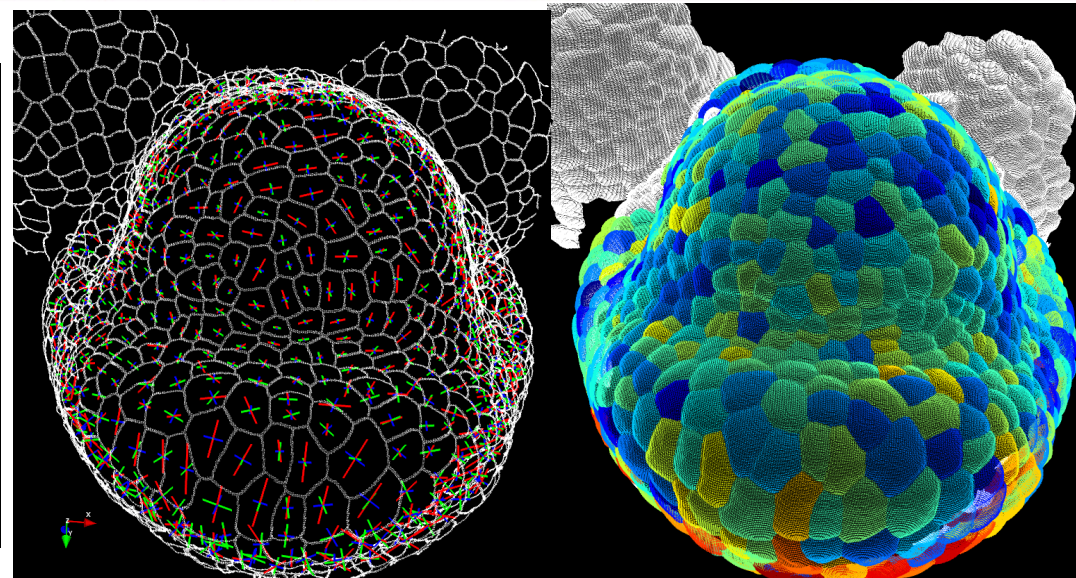
Auxin and Sugar Diffusion

(Collaboration Berthelot et al., en cours,
D'apres Prusinkiewicz et al., 2009)

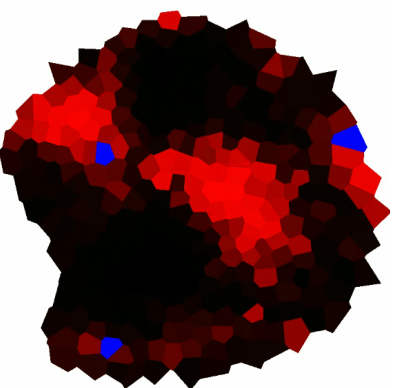
A similar approach at tissue scale



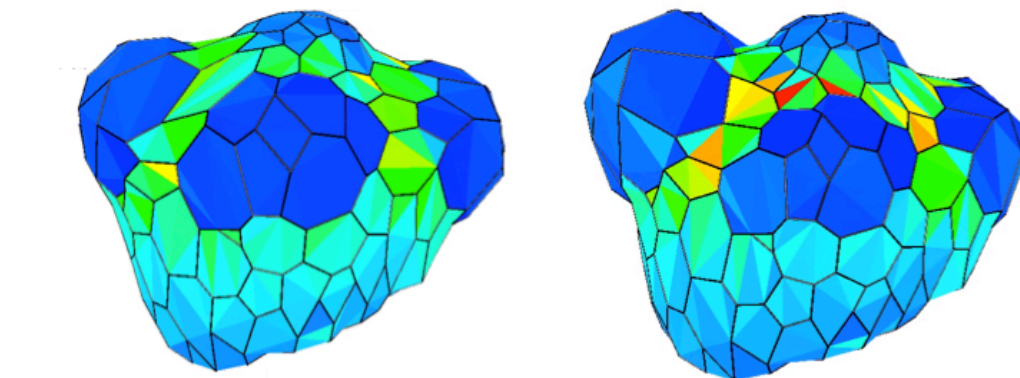
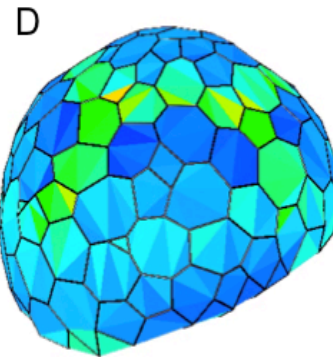
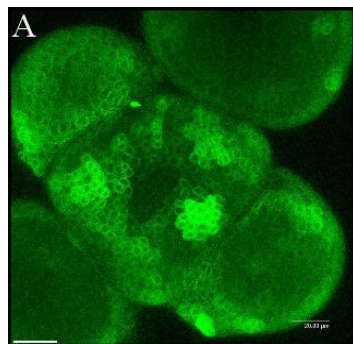
Acquisition
(Fernandez et al., Nature Methods, 10)



Analysis (Anisotropy)
(Legrand et al., in preparation)



Simulation of auxin regulation
(Stoma et al., PLoS Comp Biol, 08)



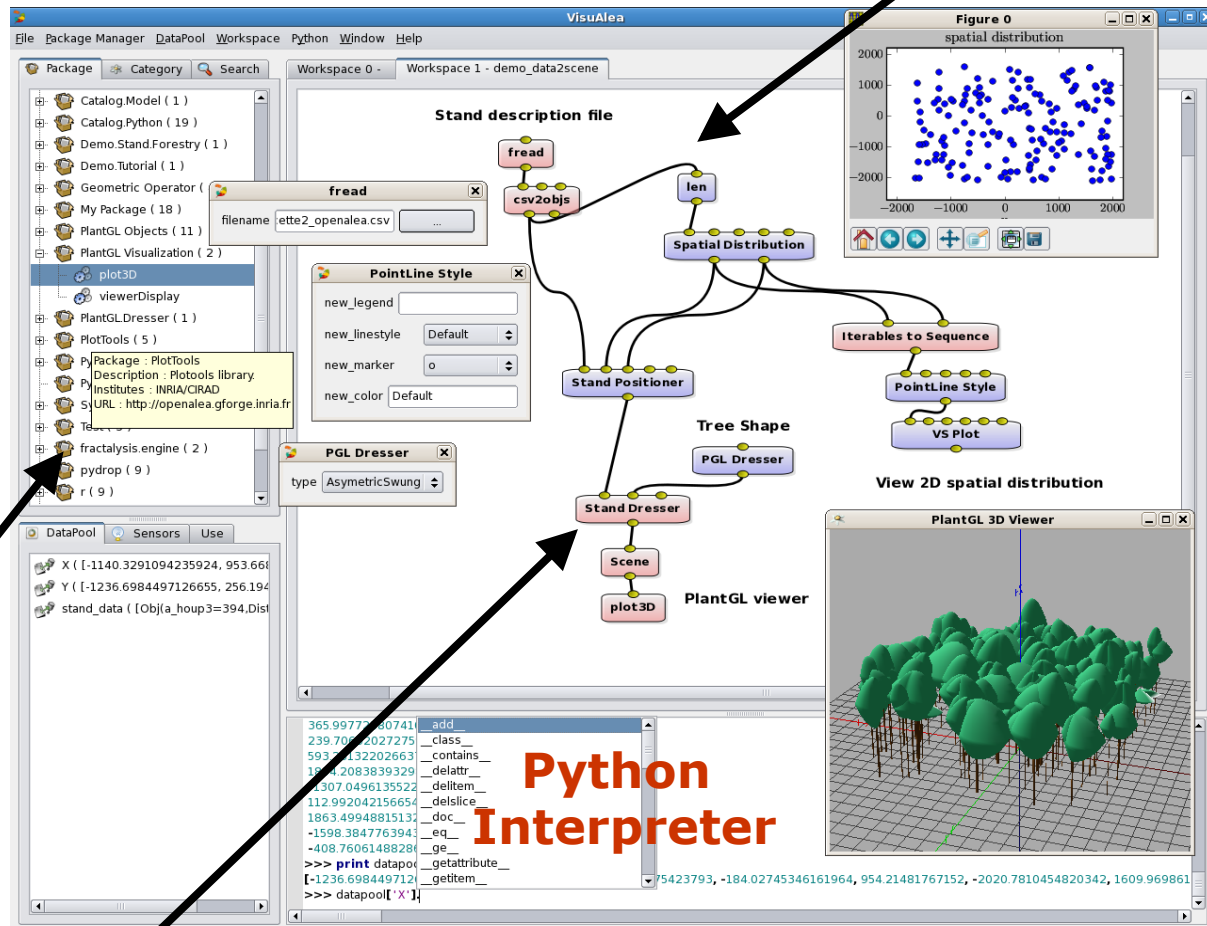
Mechanical simulation
(Boudon et al., PLoS Comp Biol, 15)

Software Plateform

- Platform for plant modeling
- Open software, open data
- Reusability, interoperability
- Modeling community (pluridisciplinary)

Package Manager

Dataflow



Python Interpreter

Component

- Supported by Inria, Inra, Cirad, Agropolis Foundation
- More than 530 000 downloads
- Strategic platform of Environment-Agronomy department at INRA



Open questions

- Acquisition from laser
 - Robust acquisition of foliage
 - Detection of botanical markers (scars, bulges)
 - Low cost phenotyping (kinect, etc)
 - Time series acquisition
- Analysis
 - Detecting self-similarity in the plant using combinatorial approach to identify development stage
 - Identification of complex pattern in branching structure using stochastic tools
- Simulation
 - Automatic inference of a growth model.
- Software
 - Toward reusable science: Publishing database and workflow on the web.

