GreenScilab: A Toolbox Simulating Plant Growth and Architecture in the Scilab Environment

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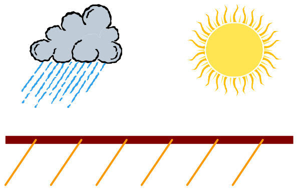
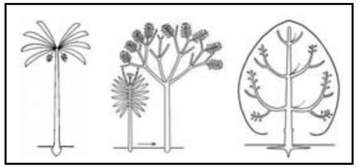
Plant Growth Modelling: a multidisciplinary subject

Bioclimatology
Soil Sciences

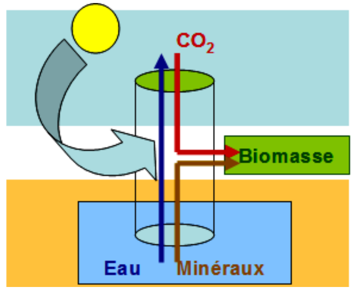


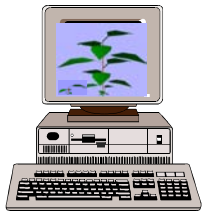
Botany

Plant
Architecture



Agronomy:
Ecophysiology





$$X^{n+1} = F(X^n, U^n, P_1, P_2)$$

Applied Mathematics

Stochastic Processes
Dynamical Systems
Optimization, Control

Plant Growth
Simulation

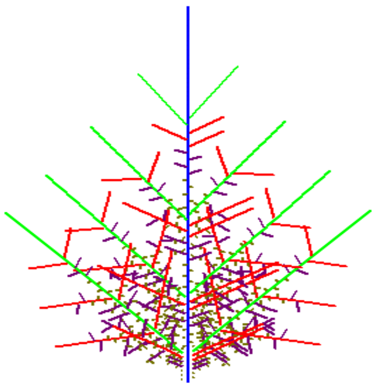
Computer sciences

Simulation visualization

A model combining two approaches

Morphological models

=> simulation of 3D development

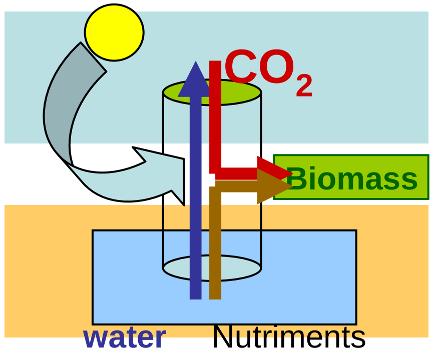


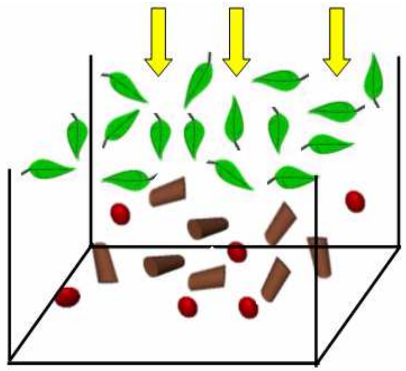
Organogenesis + empirical Geometry
= Plant Architecture.

Plant development coming from meristem trajectory (organogenesis)

Process-based models

=>yield prediction as a function of environmental conditions





Biomass acquisition (Photosynthesis, root nutriment uptake) + biomass partitioning (organ expansion)

Compartment level

Functional-structural models

A familly of Functional-Structural Models of plant growth initiated by P. de Reffye

Simulation

Organogenesis + Geometry

Botany

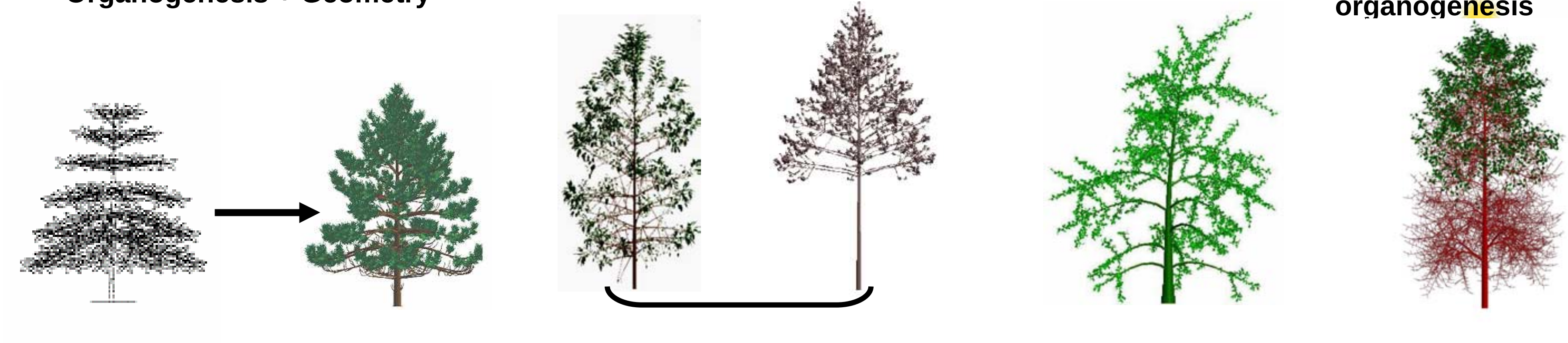
Functional growth

Mathematical Models

Dynamic model

Interaction

Photosynthesis x organogenesis



Sim HP
De Reffye
1980

Amap
Jaeger
1988

Amapsim I
Barczi
1993

Amaphydro
Blaise
1998

GL1 &2
Kang
2003

GL3
Cournède
2004

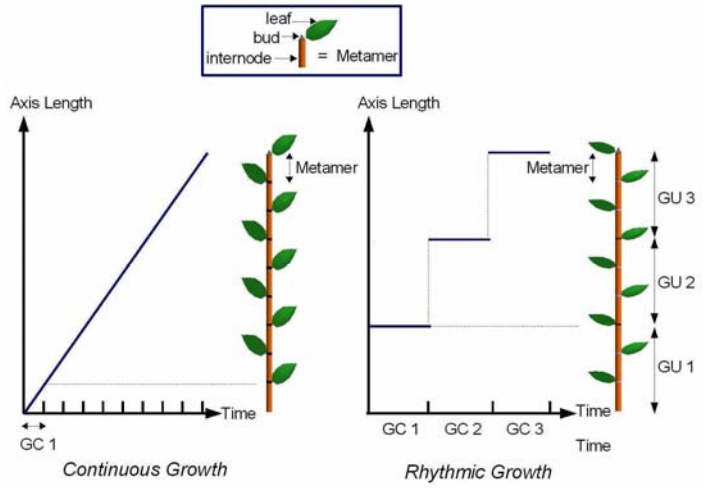
prototype — **AMAP** — **GREENLAB**

CIRAD INRA LIAMA INRIA CENTRALE PARIS

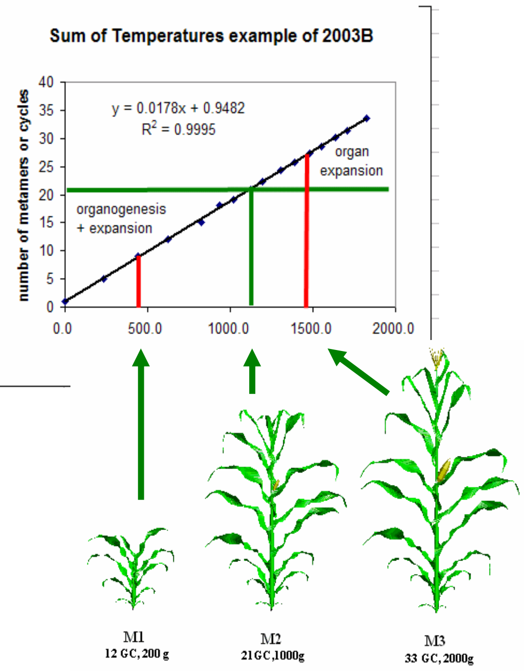
Africa — France — China — France

A « Growth Cycle » based on plant organogenesis

- Development of new architectural units:
  - continuous : agronomic plants or tropical trees
  - rhythmic : trees in temperate regions.
- Organogenesis Cycle = Growth Cycle, time discretization for the model
- Phytomer = botanical elementary unit, spatial discretization step
- For continuous growth, the number of phytomers depends linearly on the sum of daily temperatures.

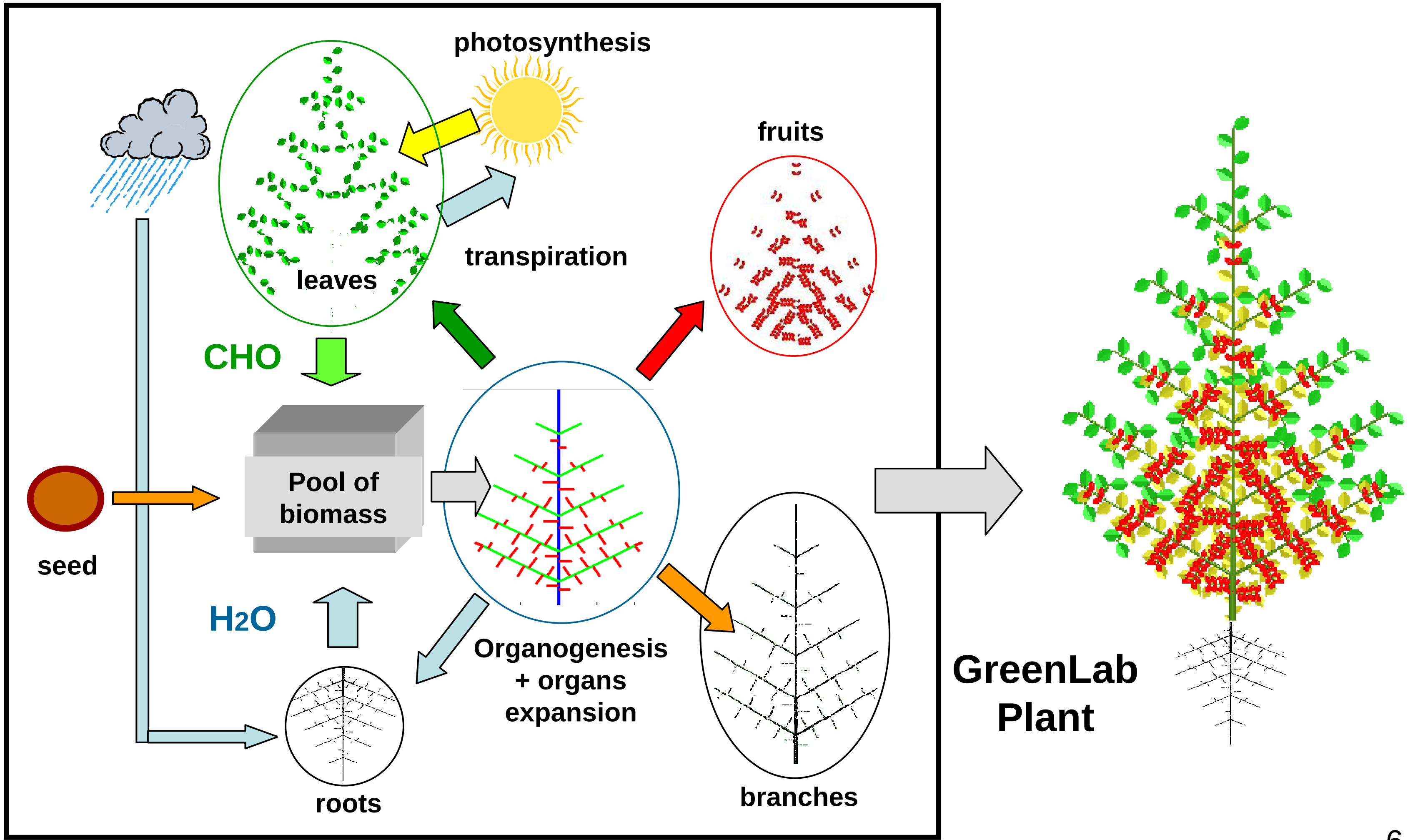


04/07/2003	0.0	1
13/07/2003	231.2	5
21/07/2003	438.6	9
28/07/2003	622.5	12
04/08/2003	823.8	15
08/08/2003	932.5	18
11/08/2003	1016.3	19
15/08/2003	1121.8	21
18/08/2003	1195.6	22
22/08/2003	1306.5	24
25/08/2003	1389.2	26
29/08/2003	1483.7	27
01/09/2003	1552.1	29
05/09/2003	1637.3	30
08/09/2003	1706.1	31
13/09/2003	1825	33



Guo and Ma (2006)

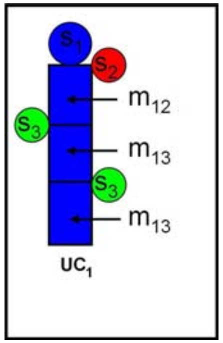
Flowchart for plant growth and plant development



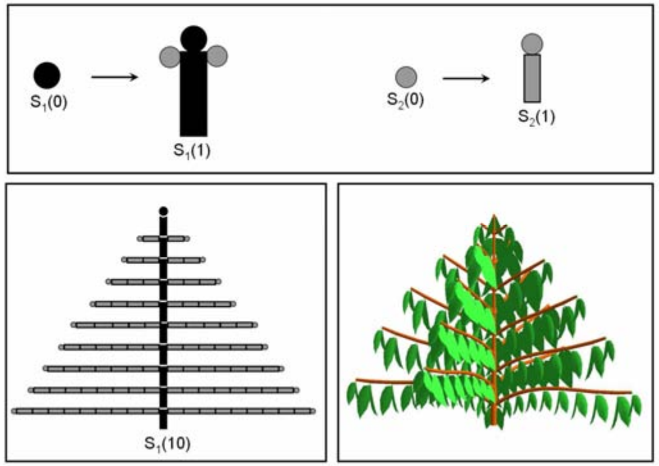
A formal grammar for plant development (L-system)

- Alphabet = {metamers, buds}

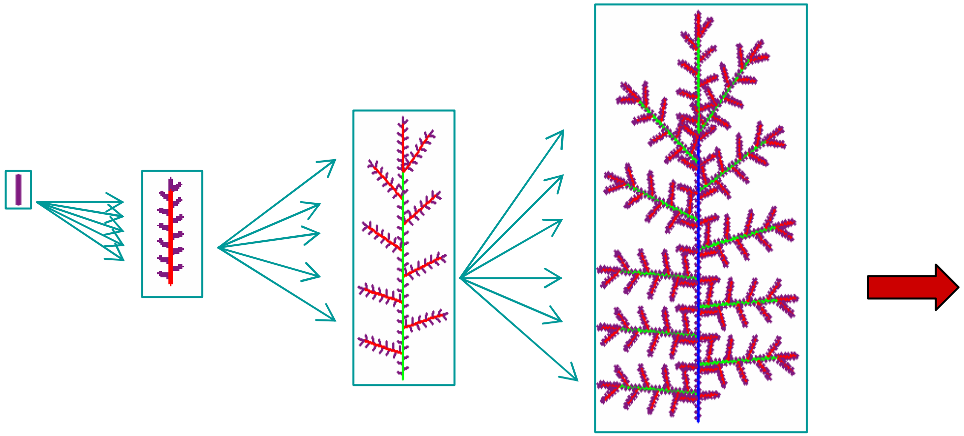
  (according to their physiological ages = morphogenetic characteristics)



- Production Rules : at each growth cycle, each bud in the structure gives a new architectural growth unit.



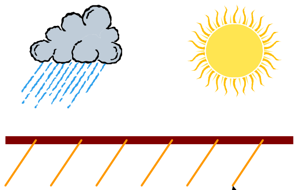
- Factorization of the growth grammar factorization of the plant into « substructures »



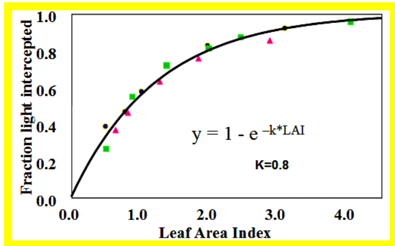
Computation time proportional to plant chronological age and not to the number of organs !

A generic equation to describe sources-sinks dynamics along plant growth

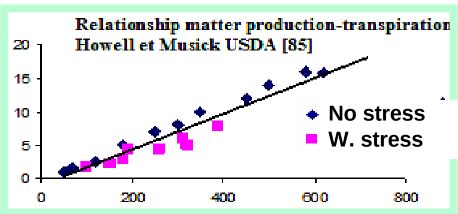
Environment



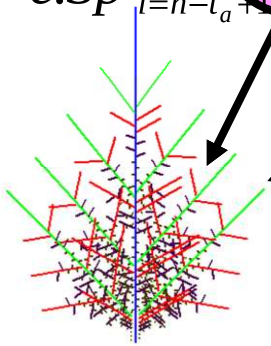
Light Interception



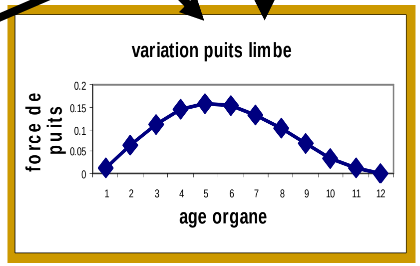
$$Q(n) = E(n)\mu Sp\left(1-\exp\left(-\frac{k}{e.Sp}\sum_{i=n-t_a+1}^{n} N_a(i)\sum_{j=i}^{n}\frac{p_a(j-i+1)Q(j-1)}{D(j)}\right)\right)$$



Energetic efficiency



Development



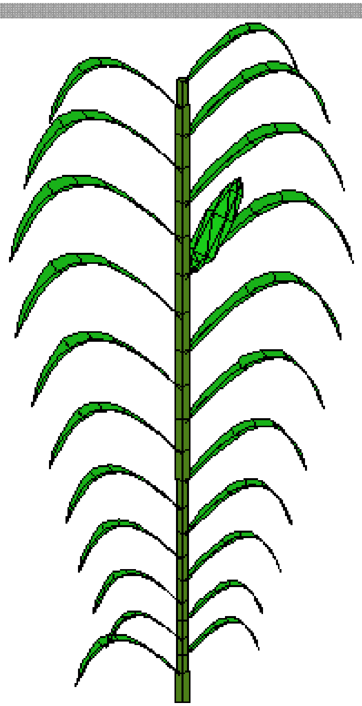
Sinks Function

GreenScilab

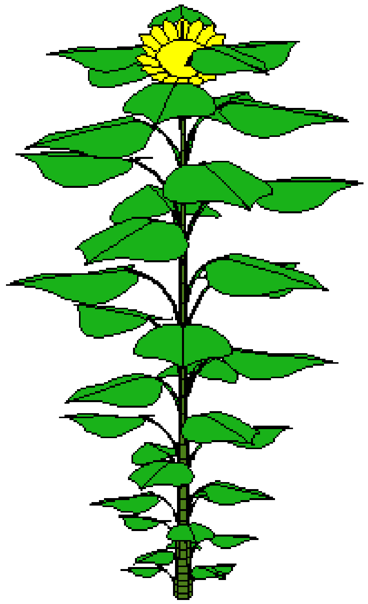
www.greenscilab.org

- A free tool implementing the GreenLab model in the Scilab environment, for teaching, research and applications.
- The mathematical formalism of the model allows an efficient use of Scilab's computational capacities
- User-friendly interface and visualization outputs

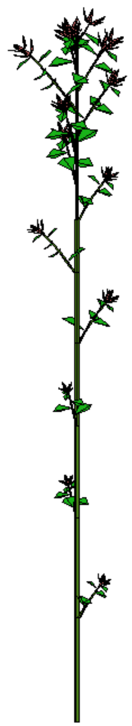
Features of GreenScilab: Simulation of Plant Growth in Different Environmental Conditions



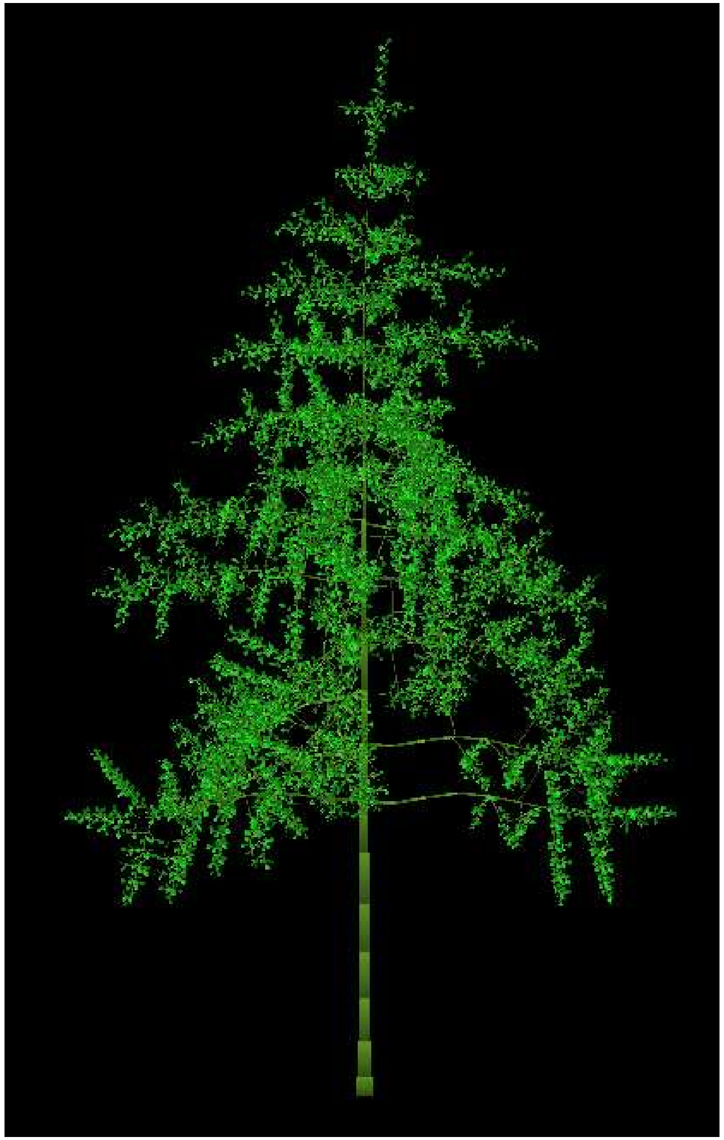
Maize



sunflower



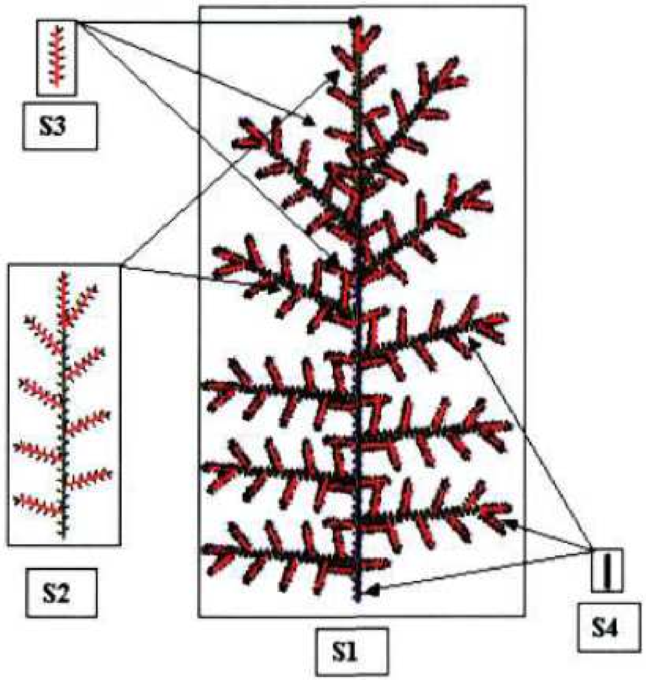
inflorescence



Gingko

Features of GreenScilab: Simulation Efficiency

- Substructure instantiations



- C codes are used in some parts of GreenScilab thanks to C interface supplied by Scilab in order to speed up some operations.

Estimation of model parameters from experimental data

- Plant = Dynamic System $X_{n+1} = F\left(X_n, P, U_n\right)$
  - State variables X_n = vector of biomass production
  - Input Variables U_n = environnement (light, temperature, soil water content)
  - Parameters P
  - Observations $Y = G\left(X_N, P\right)$

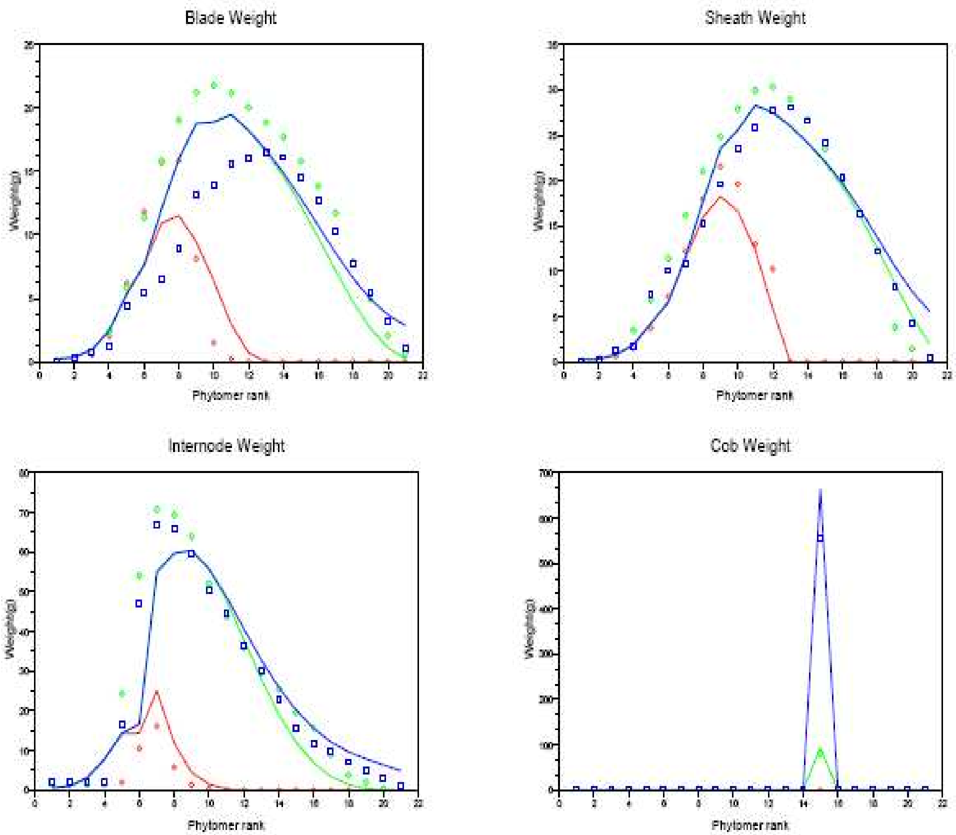
- Trace back organogenesis dynamics from static data collected on plant architecture (numbers of organs produced, modelling of bud functioning)
- Trace back source-sink dynamics (biomass production and allocation) from static data on organ masses.

- Estimate P: $P = \mathrm{ArgMin}\left\| Y^{\text{expérimental}} - Y^{\text{modèle}}\left(P\right)\right\|$

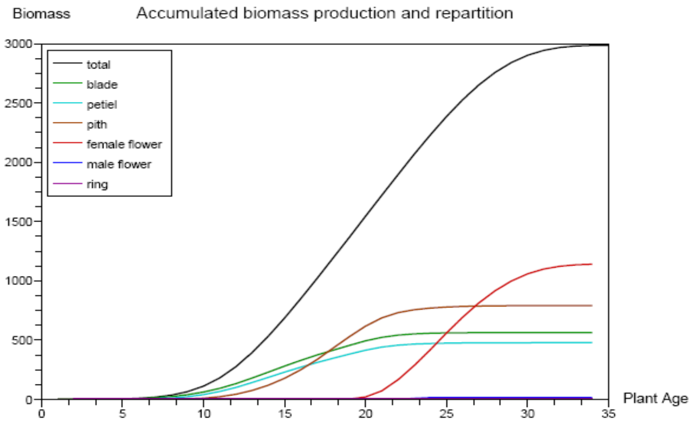
Generalized Least-Squares solved with Scilab function *lsqrsolve*

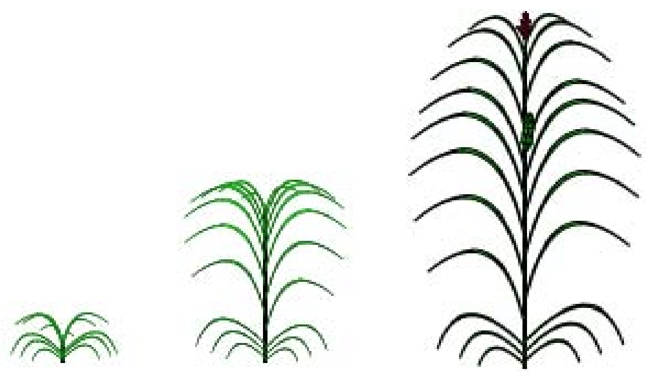
Estimation of model parameters from experimental data

Example: maize at different growth stages GC 12, 21, 30 (Guo, Ma 2006)



Fit





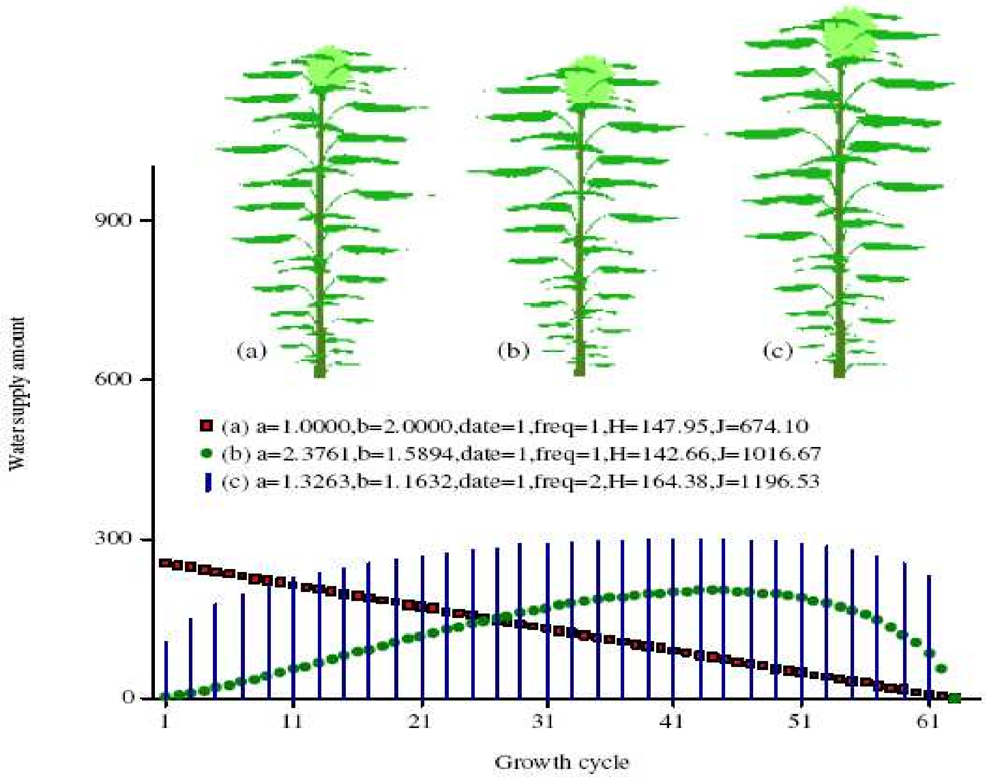
Simulation

Features of GreenScilab: Optimization and Control

- Genetic improvement: find the best set of parameters (implementation of heuristics in GSL: particle swarm optimization, simulated annealing, genetic algorithms)

- Optimal Control of Agricultural Practices

Ex: Water supply optimization for Sunflower (Wu,2004),



The Future …

- Take advantage of the new possibilities of Scilab for HPC to simulate plant populations at field or landscape levels

(Image: Jaeger, 2009)

Thank you!

www.greenscilab.org