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

Paul-Henry COURNEDE, Mengzhen KANG, Rui QI, Véronique LETORT, Philippe de REFFYE, Baogang HU
Plant Growth Modelling: a multidisciplinary subject

- Bioclimatology
- Soil Sciences
- Botany
- Plant Architecture
- Agronomy: Ecophysiology
- Applied Mathematics
- Stochastic Processes
- Dynamical Systems
- Optimization, Control
- Computer sciences
- Simulation visualization

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

Compartement level

Functional-structural models
A family 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

prototype

AMAP

GREENLAB

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.
Flowchart for plant growth and plant development

- Seed
- Photosynthesis
- Transpiration
- Pool of biomass
- Organogenesis + organs expansion
- Leaves
- Roots
- CHO
- H2O
- Fruits
- Branches
- GreenLab Plant
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

\[ Q(n) = E(n) \mu_S \rho \left( 1 - \exp \left( -\frac{k}{e.S} \sum_{i=n-t-1}^{n} N_a(i) \sum_{j=i}^{n} \frac{P_a(j-i+1)Q(j-1)}{D(j)} \right) \right) \]
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 \[ X_{n+1} = F(X_n, P, U_n) \]
  - State variables \( X_n \) = vector of biomass production
  - Input Variables \( U_n \) = environnement (light, temperature, soil water content)
  - Parameters \( P \)
  - Observations \( Y = G(X_N, P) \)

- 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 \( P : P = \text{ArgMin} \left\| Y_{\text{expérimental}} - Y_{\text{modèle}}(P) \right\| \)
  Generalized Least-Squares solved with Scilab function \texttt{lsqrsolve}
Estimation of model parameters from experimental data

Example: maize at different growth stages GC 12, 21, 30 (Guo, Ma 2006)
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),
Take advantage of the new possibilities of Scilab for HPC to simulate plant populations at field or landscape levels

(Image: Jaeger, 2009)
Thank you!

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