A generic plant cell division algorithm

Metadel K. Abera, Pieter Verboven, Thijs Defraeye, Solomon Workneh Fanta, Maarten L.A.T.M. Hertog, Jan Carmeliet and Bart M. Nicolai
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Most available models for plant cell division are limited to symmetric division with isotropic growth, and often the actual growth of the cell wall is either not considered or is only updated intermittently in a separate time scale from that of the cell expansion mechanics. Abera et al. develop a generic plant cell division algorithm based on biomechanics and ellipse fitting and compare the results with published data. The actual growth of the cell wall is simulated simultaneously with the cell expansion mechanics, and they find that the algorithm accounts for both symmetrically and asymmetrically dividing cells with isotropic and anisotropic growth. The algorithm is capable of producing different tissues with varying topological and geometrical properties.

Modelling the primary vascular structure of plants

Fabrizio Cartení, Francesco Giannino, Fritz Hans Schweingruber and Stefano Mazzoleni
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The process of vascular development in plants results in the formation of a specific array of bundles that run throughout the plant in a characteristic spatial arrangement. Cartení et al. present a spatially explicit reaction–diffusion model defining a set of logical and functional rules to simulate the differentiation of procambium, phloem and xylem, and their primary spatial patterns. The results show that the model is capable of reproducing most vascular patterns observed in plants, from primitive and simple structures to more complex and evolved ones. The simulations demonstrate, as a proof of concept, that a common genetic and molecular machinery can account for the intra- and interspecific variability of primary vascular arrangements.
Modelling biomechanics of bark patterning in grasstrees

Holly Dale, Adam Runions, David Hobill and Przemyslaw Prusinkiewicz

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Grasstrees (Xanthorrhoea) have an unusual, discrete, bark-like structure composed of old leaf bases connected by resin, making them particularly well suited for computational studies. Dale et al. create a dynamic model that captures the phyllotactic patterning of bases during primary growth and includes a biomechanical representation of the surface that permits the emergence of fractures through secondary growth of the trunk’s width. The model reproduces key features of grasstree bark patterns, and these have the same statistical character as those seen in real trees. Although the generality of the results are limited by the unusual structure of grasstree bark, the model supports the hypothesis that bark pattern formation is primarily a biomechanical phenomenon.

http://www.oxfordjournals.org/page/6054/5

Modelling seasonal carbohydrate dynamics in peach trees

David Da Silva, Liangchun Qin, Carolyn DeBuse and Theodore M. DeJong

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There is a lack of a clear conceptual and functional framework for simulating long-term carbohydrate storage and mobilization in tree models. Da Silva et al. grow peach (Prunus persica) trees under treatments designed to maximize differences in the source–sink behaviour during the growing season and use the results to parameterize a carbohydrate storage sub-model in the functional–structural L-PEACH model, including winter storage and spring remobilization. They find that by considering the storage sink and source as a function of the collective capacity of active xylem and phloem tissue, the model is able to successfully simulate the annual behaviour of the total non-structural carbohydrate mass fraction.

http://www.oxfordjournals.org/page/6054/6
Xylem and phloem transport in a 3-D model tree crown

Eero Nikinmaa, Risto Sievänen and Teemu Hölttä

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Tree models simulate productivity using general gas-exchange responses and structural relationships, but they rarely check whether leaf gas-exchange and resulting water and assimilate transport and driving pressure gradients remain within acceptable physical boundaries. Nikinmaa et al. use a mechanistic model of xylem and phloem transport together with a tested leaf assimilation and transpiration model in a realistic tree architecture to simulate leaf gas exchange and water and carbohydrate transport within an 8-year-old tree of Scots pine (Pinus sylvestris). Simulations show that daytime transpiration significantly hinders carbohydrate transport from shoots, but sink and storage dynamics may significantly influence the outcome. The ability to reproduce features that can be measured in real trees allows the model to assist in experimental analyses of whole-tree physiology.

http://www.oxfordjournals.org/page/6054/7

Modelling endogenous osmotic regulation in mangroves

Maurits Vandegehuchte, Adrien Guyot, Michiel Hubeau, Tom De Swaef, David A. Lockington and Kathy Steppe

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Although subjected to the same environmental conditions, the co-occurring mangrove species Avicennia marina and Rhizophora stylosa unexpectedly show totally different daily stem diameter variation patterns. Using in situ measurements, Vandegehuchte et al. apply a mechanistic model to assess the differences in osmotic storage water potential between these species, as such variations are mainly determined by the radial water transport between xylem and storage tissues. They find that a small shift in osmotic storage water potential underlays the differences in the variation, and conclude that in addition to environmental dynamics, endogenous changes must be taken into account in order to accurately predict stem diameter variation, and hence growth.

http://www.oxfordjournals.org/page/6054/8
Modelling photosynthetic limitations in cucumber canopies

Tsu-Wei Chen, Michael Henke, Pieter H.B. de Visser, Gerhard Buck-Sorlin, Dirk Wiechers, Katrin Kahlen and Hartmut Stützel

doi:10.1093/aob/mcu100

Maximizing photosynthesis at the canopy level is important for enhancing crop yield. Chen et al. construct a static virtual 3-D canopy structure of cucumber (Cucumis sativus) using digitized plant data and use it to quantify stomatal, mesophyll, biochemical and light limitations to photosynthesis at the leaf level, and then scale up these limitations to different canopy layers and the whole plant. The results indicate that maintaining biochemical capacity in the middle-lower canopy and increasing the leaf area of the upper canopy would improve photosynthesis in a high-wire cropping system. The model can thus provide insights into the influences of environmental conditions, physiological parameters and horticultural practices on canopy photosynthesis, and help inform future breeding strategies.


Modelling clumping in Scots pine crowns

Pauline Stenberg, Matti Möttus, Miina Rautiainen and Risto Sievänen

doi:10.1093/aob/mct310

Proper characterization of the clumped structure of forests is needed for calculation of absorbed radiation and photosynthetic production by a canopy. Stenberg et al. show that crown-level clumping in Scots pine (Pinus sylvestris) can be quantified by the crown silhouette to total needle area ratio (STAR_crown), and then study the dependency of this parameter on tree size using 3-D models of trees. They find that STAR_crown is nearly constant across a large variation in crown volume and needle area, and that similar values of are obtained by representing the crowns as ellipsoids filled with randomly distributed shoots, thus giving support to the stochastic modelling approach. The results suggest that crown-level clumping and the associated degree of within-crown shading are similar for small and large trees.

http://www.oxfordjournals.org/page/6054/10
Simulating tree uprooting with root breakage

Ming Yang, Pauline Défossez, Frédéric Danjon and Thierry Fourcaud

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Windstorms are a major natural hazard affecting forests, causing tree damage and timber losses. Yang et al. use the finite element method as a basis for developing a model for tree anchorage that includes the successive breakage of roots. The model describes the failure of individual roots, the root architecture and the soil mechanical strength, and is tested against experimental data for maritime pine (Pinus pinaster). They find that simulations give good estimations of anchorage strength and show realistic successive root breakages, which can be visually located within the root system at any stage of the simulations. The generic nature of the model permits its further application to other tree species and soil conditions.

http://www.oxfordjournals.org/page/6054/11

Cross-scale modelling of stomatal transpiration

Thijs Defraeye, Dominique Derome, Pieter Verboven, Jan Carmeliet and Bart Nicolai

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Transpiration takes place at the microscale level, namely via stomata that are distributed discretely over the leaf surface with a very low surface coverage. Defraeye et al. use an innovative 3-D cross-scale modelling approach to investigate convective mass transport from leaves, using computational fluid dynamics. The gap between stomatal and leaf scale is bridged by including all these scales in the same computational model, from $10^{-5}$ m to $10^{-1}$ m. They determine that the influence of stomatal size, aperture and surface density, and also flow-field parameters can be studied using the model. An important conclusion is that existing measures of conductances (e.g. from artificial leaves) can be significantly erroneous because they do not account for microscopic stomata, instead assuming a uniform distribution of evaporation, such as found in a fully-wet leaf.

http://www.oxfordjournals.org/page/6054/12
Modelling light partitioning in wheat–pea mixtures

Romain Barillot, Abraham J. Escobar-Gutiérrez, Christian Fournier, Pierre Huynh and Didier Combes

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Light partitioning in crop mixtures is closely linked to plant architecture. Barillot et al. use an existing functional–structural model for wheat (*Triticum aestivum*) and develop a new deterministic model for pea (*Pisum sativum*) in order to examine the effects on light partitioning of contrasting architectures of the two species. They find that the number of branches/tillers and the length of internodes significantly determines the partitioning of light within the mixtures. The effects differ according to the developmental stage of the mixture, with light capture mainly determined by architectural traits related to plant leaf area index during the early stages of development, and to plant height during the onset of interspecific competition.


A modelling approach for defining fruit tree ideotypes

David Da Silva, Liqi Han, Robert Faivre and Evelyne Costes

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The impact of a fruit tree’s architecture on its performance is still a matter of debate, especially in the context of selection of traits in breeding programs. Da Silva et al. use the MAppleT model to simulate topology and geometry in apple (*Malus × domestica*) over a number of years and conduct a sensitivity analysis to evaluate the relative impact of traits on light interception, a key parameter for optimizing production. The results demonstrate the potential contribution of modelling approaches for screening architectural traits for breeding and genetic selection in apple trees.

http://www.oxfordjournals.org/page/6054/14
Modelling the flexible timing of maize shoot development

Junqi Zhu, Bruno Andrieu, Jan Vos, Wopke van der Werf, Christian Fournier and Jochem B. Evers

doi:10.1093/aob/mcu051

Experimental evidence challenges the approximation, central in crop models, that developmental events follow a fixed thermal time schedule. Zhu et al. construct a model of maize (Zea mays) development based on three co-ordination rules between leaf emergence events and the dynamics of organ extension, and show that it can produce flexible timing of shoot development. Key aspects of whole-plant development such as the rate of leaf-tip and collar emergence, the dynamics of organ extension and the distribution of organ size along the stem can all be simulated successfully, without taking into account any regulation by assimilates. Whole-plant architecture is shaped through initial conditions that feed a cascade of coordination events.

http://www.oxfordjournals.org/page/6054/15

Simulated evolution of root water-foraging strategies

Michael Renton and Pieter Poot

doi:10.1093/aob/mcu018

Evolution should lead to plants finding efficient structural growth strategies for exploiting the limited resources available within their environment. Renton and Poot apply evolutionary algorithms to a functional–structural root growth model to investigate the case of perennial species growing in shallow soils. The simulated evolution results in populations with specialized root system morphologies with deeper rather than shallower lateral branching. These strategies enhance access to water resources in the underlying rock, and match the root structures observed in real shallow-soil endemics. They conclude that this approach can provide insights into both evolutionary processes and ecological costs and benefits of different plant growth strategies.

http://www.oxfordjournals.org/page/6054/16
Modelling effects of management on forest functioning

Joannès Guillemot, Nicolas Delpierre, Patrick Vallet, Christophe François, Nicolas K. Martin-StPaul, Kamel Soudani, Manuel Nicolas, Vincent Badeau and Eric Dufrêne

doi:10.1093/aob/mcu059

The structure of a forest stand, i.e. the distribution of tree size features, has strong effects on its functioning. Guillemot et al. assess the influence of management on forest functioning using a stand process-based model coupled to an empirical tree-to-tree competition module. The model is successfully evaluated on data inventories from 32 stands of *Fagus sylvatica* and *Quercus petraea* and then used to compare the effects of contrasting silvicultural guidelines on simulated carbon fluxes and growth. The simulations reveal contrasting increases in net primary productivity and growth in managed stands, and demonstrate that the model can help to identify areas where management efforts should be concentrated in order to mitigate predicted drought impacts on forest productivity.

http://www.oxfordjournals.org/page/6054/17

A modelling framework to simulate foliar fungal epidemics

Guillaume Garin, Christian Fournier, Bruno Andrieu, Vianney Houlès, Corinne Robert and Christophe Pradal

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Modelling of pathosystems can allow a better understanding of the major interactions inside these dynamical systems and may lead to innovative protection strategies. Garin et al. formalize different entities and interactions occurring in pathosystems in a conceptual model and then implement them within the open-source OpenAlea modelling platform, using its general strategy of modelling plant–environment interactions and extending it to handle plant interactions with pathogens. A library of elementary models involved in pathosystems is incorporated, and implementation of the framework using examples of septoria leaf blotch and grapevine powdery mildew illustrates its generic utility, and demonstrates that it can accommodate both previously developed models for individual aspects of pathosystems and new ones.

http://www.oxfordjournals.org/page/6054/18
Multiscale modelling with graph grammars

Yongzhi Ong, Katarína Streit, Michael Henke and Winfried Kurth

doi:10.1093/aob/mcu155

Methods exist for multiscale data representation and modification, but the advantages of using multiple scales in the dynamic aspects of functional–structural plant models (FSPMs) remain unclear. Ong et al. introduce a three-part graph data structure and grammar, together with a conceptual framework for multiscale modelling. The framework is used for identifying roles, and categorizing and describing scale-to-scale interactions, thus allowing alternative approaches to model development. Three example models are implemented using the proposed multiscale graph model and framework, and demonstrate that it is a viable method in FSPMs, and an alternative to correlation-based modelling.

http://www.oxfordjournals.org/page/6054/19

Automatic identification of radial cell files in wood

Guilhem Brunel, Philippe Borianne, Gérard Subsol, Marc Jaeger and Yves Caraglio

doi:10.1093/aob/mcu119

Analysis of anatomical sections of wood provides important information for understanding the secondary growth and development of plants. Brunel et al. develop a new method for the automatic detection and characterization of cell files in microscopic wood images, applicable to both gymnosperms and angiosperms. They find that image analysis using this method can be performed in less than 20 s, which compares with a time of approx. 40 min to produce the same results manually. Determination of reliability coefficients permits quick filtering of data for statistical analysis while also highlighting particular biological configurations present in the wood sections.

**Integrated method for quantifying root architecture of maize**

Jie Wu and Yan Guo

doi:10.1093/aob/mcu009

Methods for sampling and analysis of root system architecture of field-grown plants are generally inadequate. **Wu and Guo** develop an integrated methodology that includes a custom root-core sampling system, and a combination of a proprietary software and a novel program for collecting and visualizing the root architecture of mature maize (*Zea mays*). Field tests show that large root-cores can be sampled, and the topological and geometrical structure of root systems can be quantified and reconstructed successfully. The results indicate that second- and higher-order laterals contribute substantially to total root number and length, and that abundant higher-order laterals can arise from a single-bearing first-order lateral and concentrate in the proximal axile branching zone.

http://www.oxfordjournals.org/page/6054/21

**Assessing the accuracy of branching reconstructions**

Frédéric Boudon, Chakkrit Preuksakarn, Pascal Ferraro, Julien Diener, Philippe Nacry, Eero Nikinmaa and Christophe Godin

doi:10.1093/aob/mcu062

Laser scanners have made it possible to acquire 3-D images representing a sampling of an object’s surface, and these have been used to reconstruct branching patterns; however, questions remain about their accuracy. **Boudon et al.** present an evaluation framework in which laser-scanning data are first manipulated manually by experienced researchers in order to produce reference structures. Automatic reconstructions are then evaluated against these reference structures by comparison of their elements and organization. The evaluation framework successfully quantifies geometric and structural similarities between two structures, and it can be applied to the characterization and comparison of automatic reconstructions of plant structures from laser scanner data and 2-D images. As such, it can be used as a reference test for comparing and assessing reconstruction procedures.

http://www.oxfordjournals.org/page/6054/22
Modelling pathogen splash-dispersal in heterogeneous canopies

C. Gigot, C. de Vallavieille-Pope, L. Hubera and S. Saint-Jean
doi:10.1093/aob/mcu098

One option for reduced-input disease management is to grow mixtures of cultivars in order to slow the spread of epidemics. Gigot et al. use virtual 3-D plants of wheat, *Triticum aestivum*, to consider interactions between plant architecture and splash-dispersal of pathogens in heterogeneous canopies, and develop a biophysical model that assumes differing levels of host resistance and incorporates a mechanical description of trajectories of pathogen-bearing splash droplets. The results give good agreement with experimental data and suggest possibilities for optimizing the efficiencies of different mixtures of cultivars depending on their resistance levels, spatial patterns and their relative proportions within the canopy.

http://www.oxfordjournals.org/page/6054/23

Modelling responses to mepiquat chloride and population density

Shenghao Gu, Jochem B. Evers, Lizhen Zhang, Lili Mao, Siping Zhang, Xinhua Zhao, Shaodong Liu, Wopke van der Werf and Zhaohu Li
doi:10.1093/aob/mct309

The growth regulator mepiquat chloride (MC) is used to restrict vegetative growth and promote boll formation and yield in indeterminate cotton (*Gossypium hirsutum*). Gu et al. use the GroIMP platform to design a functional–structural model of 3-D cotton structural development to simulate pure and intercropped stands. Crop development is driven by thermal time, population density, MC application and topping of the main stem and branches. After validation with field data, they find that the model satisfactorily represents the effects of population at low densities and produces good results for the effects of MC. They conclude that the model has good future potential for optimizing the agronomic management of cotton crops.

http://www.oxfordjournals.org/page/6054/24

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