MINISYMPOSIUM

PLANT MODELS (A): PLANT DEVELOPMENT

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Minisymposium Keywords: plant morphogenesis, developmental patterns, regulatory mechanisms in plants, phenotyping data, mathematical modelling, SPH

Plants have many unique attributes that distinguish them from other forms of life on earth. Unlike many other organisms, they rely directly on deep soil resources and this makes them immobile. To compensate, they develop strategies to explore, sense and respond rapidly to the environment and establish relationships with neighbouring biological organisms. They have rigid cell walls and tissues to allow for the growth of large mechanically stable structures and for the long distance transport of substances. But they also establish local relationships with close soil organisms to capture water and nutrient and survive in the most diverse environments. The beauty and diversity of plant growth and forms has stimulated the development of new approaches to describe and model plant systems and their environment.

The objective of this symposium is to showcase recent theories and tools to describe the physics of plant growth and their interactions with the soil environment. The symposium will have two part. The first part will focus on the development of forms and structures (Plant Models A - Plant development). The second part will focus on biological models in soil (Plant Models B - Modelling life in soil).

Invited speakers of this minisymposium are: Leah R Band, University of Nottingham, UK; Arezki Boudaoud, École Normale Supérieure de Lyon, Lyon, France, George Bassel, University of Birmingham, UK; Yann Guédon, CIRAD, AGAP, Montpellier, France; and Matthias Mimault, The James Hutton Institute, Invergowrie Dundee, UK

Monday, July 23rd, 14:20 **Room: C8.2.06**

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MODELLING AUXIN DYNAMICS IN THE PLANT ROOT: CELL-BASED AND CONTINUUM APPROACHES

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Keywords: Plant hormone auxin, Plant modelling, Signalling processes in plants.

Many aspects of root architecture are controlled by the auxin dynamics in the root tip: auxin plays a crucial role in regulating the root growth and co-ordinating responses to environmental conditions. Determining how the organ-scale auxin distribution is regulated at the cellular scale is essential to understanding how these processes are controlled. To this end, we are developing mathematical and computational models to understand how cellular and subcellular components combine to control the organ-scale auxin dynamics. We will present two different modelling approaches that are providing complementary understanding of the system. We will first describe a computational vertex-based approach which enables us to simulate auxin transport within a tissue comprised of actual root cell geometries and carrier subcellular localizations. This model approach enables us to assess how key features of the tissue contribute to the auxin streams through the root tip, and enables us to test model predictions via quantitative comparisons with observed DII-VENUS fluorescent reporter distributions. We gain further understanding using an alternative modelling approach, using asymptotic analysis to derive continuum approximations of auxin models within idealised tissue geometries. These approximations reveal the underlying features of the system and precisely how cell-scale transport processes contribute to the overall tissue-scale fluxes. Our work illustrates the benefits of cell-based and asymptotic modelling approaches in understanding the multiscale nature of plant hormone dynamics.

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UNDERSTANDING THE ROBUSTNESS OF MORPHOGENESIS USING STOCHASTIC MECHANICAL MODELS OF ORGAN GROWTH

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Keywords: Morphogenesis of plants, Mechanical model for plant growth.

How do organs reach reproducible sizes and shapes despite substantial variability at the cellular level?

The current belief is that a morphogen gradient spanning the organ provides cells with positional information that controls organ size. Nevertheless, recent evidence suggests that the simple interpretation of a global morphogen gradient is insufficient for size control. Moreover, experiments on plants suggest that, counterintuitively, increasing the spatial homogeneous cell growth leads to (e.g. [1]). We investigate the mechanisms enhancing or buffering cell variability and the consequences on reproducibility of organogenesis.

We built a mechanical model for growth variability during the formation of 2D organs. This model consists of a set of coupled stochastic PDEs describing a viscous medium with spatially variable density and local nematic order, each of which are coupled to mechanical stress. We determined how variability changes across scales, to understand how heterogeneous cells yield robust organs. These results may be compared to available experimental data.

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THE INTERPLAY BETWEEN GLOBAL AND LOCAL RULES REGULATES MULTICELLULAR MORPHOGENESIS

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Keywords: Plant morphogenesis, Regulatory mechanisms in plants.

Multicellular organ development is driven by the combination of the division and expansion of cells, and the mechanical interactions between their neighbours. In plants, cells are immobilized through shared cell walls, and patterns emerge through the regulated placement of division planes. Rules following local cell geometry have been devised to predict where cells will divide, and it is proposed that the iterative repetition of these rules leads to the emergent cellular organization present within organs. While these local rules have been examined previously, it remains unknown whether global regulatory mechanisms also act to co-ordinate the organization of complex multicellular configurations. We explored this possibility by performing 4D imaging of each the tomato and Arabidopsis shoot apical meristems (SAM), and topologically analysing their intercellular connectivity using network science. This enabled the properties of cellular patterning and the outputs of the self-organizing process to be quantified. Using this approach, a previously undescribed global property of global cellular organization in the SAM was uncovered. Further analyses of these networks has provided compelling evidence for the presence of a global mobile signal that mediates the organization of cell across the shoot apex. These results indicate the presence of a higher-order regulatory mechanism which feeds down onto local rules within individual cells.

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IDENTIFYING DEVELOPMENTAL PATTERNS IN PLANT PHENOTYPING DATA

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Keywords: Developmental patterns, Phenotyping data.

The emergence of robotized plant phenotyping platforms and new generations of sensors makes available to biologists a huge amount of spatio-temporal plant data of high quality from the tissular to the whole plant scale. A strong effort has been put on sensor output treatment and high-throughput data management. Comparatively, the identification and characterization of complex plant developmental patterns using state-of-the-art methods at the crossroad between probabilistic models, statistical inference, machine learning and pattern recognition has been neglected. Hence, only a small proportion of the information contained in plant phenotyping data is really exploited. The objective of this presentation will be to show how to fill this gap transposing the approaches that made the success of computational molecular biology and quantitative ecology in the past decades. The identification of developmental patterns in plant phenotyping data will be illustrated on selected examples concerning both the root system and the above ground part of plants and both the tissular and the macroscopic scales.

Monday, July 23rd, 15:40 **Room: C8.2.06**

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MATHEMATICAL MODELLING AND ANALYSIS OF THE INTERPLAY BETWEEN AUXIN AND BRASSINOSTEROID IN PLANT TISSUES

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Joint work with Mariya Ptashnyk (Heriot-Watt University, Edinburgh)

Keywords: Auxin Flux, Plant Hormones, Plant Signalling Processe, Pattern Formation in Discrete Systems.

Plant hormone auxin has key roles in growth and development, many of which are defined by the heterogeneous distribution of auxin in tissues. It is thought that interactions between auxin signalling and auxin's efflux carrier protein PINFORMED (PIN), where PIN turnover within cells and PIN membrane localisation are governed by auxin and the auxin signalling pathway, are responsible for heterogeneous auxin patterning. It is observed that, in addition to auxin dynamics, a balance between auxin patterning and expression of brassinosteroid (BR), another key plant hormone, is required for optimal growth of plant tissues.

In this work, we derive a mathematical model that links the auxin signalling pathway with PIN-dependent auxin flux by establishing auxin signalling-mediated PIN turnover based upon experimental observations, as well as assuming that PIN membrane localisation is governed by the flux of auxin between neighbouring cells. A system of nonlinear ordinary differential equations is used to describe the dynamics of auxin, PIN, and the molecules involved in the auxin signalling pathway in a discrete representation of plant tissue. We show that our model can reproduce biologically observed patterns under certain conditions, and we also perform mathematical analysis to illustrate the conditions on the model parameters that are necessary to achieve various types of patterns in the distribution of auxin in tissue. When considering auxin flux through the apoplast we show that the dynamics of auxin's influx carrier protein AUXIN RESISTANT (AUX1) are essential for biologically realistic heterogeneous distributions of auxin. By including the crosstalk between the BR and auxin signalling pathways we analyse the impact of interactions between auxin and BR on auxin flux and distribution in a plant tissue.

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References

[1] L. Hong et al. (2016). *Variable cell growth yields reproducible organ development through spatiotemporal averaging.* Developmental Cell 38, 15–32.