Wednesday contributed talks 1

Galane J. Luo

University of Birmingham

"A fluid mechanical model of the plant cell wall reveals underlying mechanism for helical organ morphology"

Plant morphology emerges from cellular growth. The turgor-driven diffuse growth of a cell can be highly anisotropic: significant in the longitudinal direction and negligible in the radial direction. Such anisotropy is ensured by cellulose microfibrils (CMF) reinforcing the cell wall in the hoop direction. To maintain the cell's integrity during growth, new wall material including CMF must be continually deposited. In this talk, I will present a mathematical model which describes the cell as a cylindrical pressure vessel and the cell wall as a fibre-reinforced viscous sheet, explicitly including the mechano-sensitive angle of CMF deposition. The model incorporates interactions between turgor, external forces, CMF reorientation during wall extension, and matrix stiffening. I will explain the general formulation of the model from a fluid mechanics perspective, and summarise the technical steps required in order to obtain evolution equations for growth variables such as cell length and twist. I will discuss how the handedness of helical cell growth depends on external torque and intrinsic wall properties, and interpret numerical simulation results in light of recent experimental findings. Overall, the model provides a meaningful step towards a unified mechanical framework for understanding left- and right-handed growth as seen in many plants. Such a framework can help us harness the potential of plants in our effort to address society's sustainable development needs.

Euan Smithers

University of Birmingham

"How do plant leaf pavement cells form puzzle piece like shapes? Using a multi-model approach to simulate chemical and visco-elastic mechanical processes and experimental methods to discover their secrets."

Pavement cells in the plant leaf epidermis form interesting and intriguing interlocking puzzle like shapes with undulations of lobes and indents. However, no one has been able to fully explain how these shapes form. There are two possible pathways of pavement cell development, one involving a combination of plant Rho like GTPases signalling proteins and cytoskeleton components, specifically microtubules which could provide a feedback loop and the second being possible mechanical effects from the tissue. As a result, we have developed three models, one to model microtubule behaviour, the second to model the protein signalling dynamics and the third to model the mechanics of the cells, using a stochastic network, reaction diffusion equations solved via the finite element method and a visco-elastic vertex element model. I shall also outline some of the experimental procedures we have carried out to test how pavement cells develop. We can demonstrate that the signalling pathways provide a feedback loop to sustain pavement cell shape, but don’t initiate the shape, while the mechanical effects from the tissue can initiate pavement cell lobes.

Ulyana Zubairova

Russian Academy of Science

"Leaf epidermal pattern development in the cereals: lessons from LSM-image analysis and computer simulations"

The leaf epidermis of a monocotyledonous plant gives a unique model system for studying morphogenesis due to diverse cell types and constant growth direction. For such leaves, a unidirectional growth occurring for a long time enables us to observe a series of successive morphogenetic stages at one snapshot. In this work, we propose the concept of using a growing wheat leaf to study dynamical changes in morphogenesis, including stress-induced changes. Linear leaf of wheat, during its formation for a long time, maintains a phase of steady growth. Therefore, it is possible to observe a series of successive events of morphogenesis fixed in the cellular architecture of a mature leaf. High-resolution 3D LSM-images allow extracting quantitative characteristics describing the cellular structure of leaf epidermis. However, to obtain a large number of statistical data methods of high throughput, computer-based image segmentation should be used. We developed a workflow for the detection of structural properties of leaf epidermis from 3D images obtained from confocal LSM-images (Zubairova, U. S., Verman, P. Y., Oshchepkova, P. A., Elsukova, A. S., & Doroshkov, A. V. (2019). LSM-W 2: laser scanning microscopy worker for wheat leaf surface morphology. BMC systems biology, 13(1), 22.). The workflow includes the protocol of sample preparation, image processing ImageJ-plugin, and data extraction algorithms. The data on the cellular architecture further acts as a basis for the elaboration and verification of spatial models accounting for structural features of leaves. For the leaf epidermis of cereals, a brickwork-like pattern combined with unidirectional growth allows to reduce the dimension and use a quasi-one-dimensional representation of the cellular ensemble in the model. This idea was realized in the model (Zubairova, U., Nikolaev, S., Penenko, A., Podkolodnyy, N., Golushko, S., Afonnikov, D., & Kolchanov, N. (2016). Mechanical behavior of cells within a cell-based model of wheat leaf growth. Frontiers in plant science, 7, 1878.) growth of a linear leaf blade. The model allows for fitting of the visible cell length using the experimental cell length distribution along the longitudinal axis of leaf epidermis. In this work, we assume a unidirectional growing cell ensemble starting from a meristem-like layer of generative cells and then generating parallel cell rows from every cell of the initial layer. We considered the growth zone of the leaf includes division and elongation zones; also, the division zone consists of a region of asymmetric divisions forming specialized cells (trichomes and stomata). The model was verified on qualitative and quantitative data on stress-induced disturbances of morphogenesis in the epidermis of a wheat leaf. The study was carried out with a grant from the Russian Science Foundation (project No. 19-74-10037).

Tamsin Spelman

University of Cambridge

"Nucleus shape in plant root hair cells"

A plant root hair is a single long thin cell, which in Arabidopsis is ≈ 10 μm in diameter and reaches ≈ 1 mm in length, growing rapidly at speeds of ≈ 1 μm/min. The nucleus tracks the growing tip remaining ≈ 75 μm back from the growing front [1]. While the nucleus motion has been studied, less work has considered the nucleus shape during growth and how this impacts cell growth. Using a numerical model, we analyse the forces imposed on the nucleus by the cytoskeleton (the internal fibre network of the cell), for a range of nucleus shape, size and position enclosed within a cuboidal domain. We compare our results with experimental data from root hairs grown within microchannels. We segment the experimental images to reconstruct the 3D nuclei shapes, from which we can also estimate the spacial distribution of forces being imposed.

David Holloway

BCIT

"Polar auxin transport dynamics of primary and secondary vein patterning in dicot leaves"

The growth regulator auxin plays a central role in development across plants. Auxin spatial patterning is critical in the phyllotactic arrangement of leaves along a stem, the shapes of the leaves themselves, and venation within leaves. These patterns depend on polar auxin transport (PAT) at the cellular level, particularly the preferential allocation of PIN efflux proteins to certain areas of the plasma membrane. Two general mechanisms have been studied: an up-the-gradient (UTG) allocation dependent on neighbouring-cell auxin concentrations, and a with-the-flux (WTF) allocation dependent on the flow of auxin across walls. Auxin appears to flow both towards auxin maxima (associated with UTG) and away from auxin maxima (associated with WTF), depending on the developmental phenomena. Both types of flow are implicated in vein patterning in leaves. We have developed a UTG+WTF model to quantify these combined dynamics. The model simulates intracellular and membrane kinetics and intercellular transport, and is solved for a 2D leaf of several hundred cells. Building upon earlier models for primary vein (mid-vein) formation, we developed a model for the formation of the secondary vein pattern. These arise from the margin of the leaf, in a distal to proximal sequence, and connect with the mid-vein to form the main vascular network of the leaf. These networks can be characteristic of species, and associated with species-specific leaf morphologies. The model responds to decreasing PAT, as in experiments increasing the PAT inhibitor NPA, with: a switch from several distinct vein initiation sites to many less-distinct sites; a delay in vein canalization; inhibited connection of new veins to old; and finally loss of patterning in the margin, loss of vein extension, and

confinement of auxin to the margin. We have removed assumptions of long range attraction factors from earlier work. Simulations of vein patterning and leaf growth indicate that growth itself may help bridge the scale from the cell-cell resolution of the PIN-auxin dynamics to vein patterns on the whole-leaf scale.