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Modeling the Hydrodynamic and Mechanical Effects of Fluid-Storing Biological Flow Networks

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Abstract:

Biological flow networks, which are widespread in both animals and plants, play important roles in the physiological functions of these living systems through various effects on their hydrodynamic and mechanical properties. In plant biology, water-delivery vascular networks consisting mainly of xylem vessels are essential not only for keeping tissues hydrated and sustaining necessary fluid status (water potential or fluid content), but also for controlling certain hydraulically related motions involving large-scale shape changes such as petal expansion and deformations in flower blooming, with the help of water-storing cells in leaves or petals. Using a flow network model with local hydraulic conductance and fluid-storage capacitance, we theoretically study the water status dynamics of a model grass leaf under water stress to illustrate the significance of capacitor cells in the leaf's resilience against drought conditions. In order to study the shape morphing of a thin sheet controlled by its embedded flow network (as in a petal), we coupled the capacitive network model to a mechanical network (spring system describing the shape of the surface) to simulate its differential swelling and buckling processes, exploring the effects of venation architecture and hierarchies on the deformation pathways by using the minimal coupling model. These shape patterns reveal the underlying fluid distribution and mechanical changes, and may offer clues to the design and manufacture of thin materials whose shapes can be manipulated by adjusting internal hydraulics.

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About the speaker:

Yongtian Luo is a postdoctoral fellow at the Johns Hopkins University, working with Prof. Brian Camley in the field of theoretical and computational soft matter and biological physics. Previously, he was a postdoctoral researcher at the University of Pennsylvania in the group of Prof. Eleni Katifori, studying the effects of flow networks in plant biology and thin elastic structures, particularly leaf hydraulics and petal shape transformations, using theoretical models and computer simulations.

Yongtian earned his PhD in chemistry from the University of Washington where he studied the phase separation and deformation of lipid-bilayer membranes. Currently, he is working on the modeling of cell migration in extracellular matrix, especially the movement and interactions of fibroblasts on a nanofiber network, in the Camley group at JHU.

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