Math 288 - Seminar on Mathematics for Complex Biological Systems

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Bending, stretching, and breaking membranes: the biophysics of in- and out-of-equilibrium lipid bilayer processes

Abstract:

The cell membrane is the first interface that separates the inside of a cell from its surrounding medium. It serves not only as a protective mechanical barrier, but also as a platform for cells to exchange material with their environment. In this talk we will illustrate both of these essential membrane functions through two examples where the biophysics of lipid bilayers determine the response of the cell membrane. First, we will examine the out-of-equilibrium response of cell-sized lipid vesicles exposed to solute imbalance. Based on experimental observations that giant vesicles in hypotonic condition exhibit a non-intuitive pulsatile behavior characterized by swell-burst cycles, we will present a theoretical description of the system in the form of coupled stochastic differential equations. We will show how thermal fluctuations enable stochastic pore nucleation, leading to a dependence of the lytic strain on the load rates, and unravel scaling relationships between the pulsatile dynamics and the vesicles properties. We will then demonstrate how vesicles encapsulating polymer solutions - mimicking the crowded cytoplasm of a cell - undergo swell-burst cycles even in the absence of a concentration imbalance.

Then, we will investigate how membrane necks, a necessary step to produce trafficking membrane vesicles, are generated by curvature-inducing proteins. Based on an augmented Helfrich model for lipid bilayers to include membrane-protein interaction, we will show how the spontaneous curvature field induced by proteins can be computed based on the knowledge of the neck geometry. We will apply this methodology to catenoid-shaped necks, for which the shape equation reduces to a variable coefficient Helmholtz equation for spontaneous curvature, where the source term is proportional to the Gaussian curvature. We will finally present numerical results showing how boundary conditions and geometric asymmetries determine an energetic landscape constraining the geometry of catenoid-shaped membrane necks.

Hosts: Li-Tien Cheng, Bo Li, and Ruth Williams

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