Mathematical Methods and Models in Biosciences
June 18-23, 2023, Pomorie, Bulgaria
https://biomath.math.bas.bg/biomath/index.php/bmcs
Biomath Forum

Modelling cellular processes: from single cells to collective behaviour

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Living organisms are multi-scale systems organized at multiple levels. In nature, organisms can exist both as single cells, or, in multi-cellular forms. Diversification of forms and functions have led to the explosion of the variety of living beings among the prokaryotes, eukaryotes, plants and animals in our world. In higher multicellular organisms, single cells organize into tissues, which then form organs made with one or more types of tissues. For example, in humans, spatiotemporal organization of different organs performing different vital functions make up a whole body. The body functions properly only when all these constituent levels work coherently in an inter-dependent manner. Each cell, which is the lowest constituent of any living organism, has a well-structured interior with different organelles and large and small molecules doing different biochemical and biophysical reactions. Single and multi-cellular functional dynamics are regulated by these multi-step feedback/feed-forward regulated intra- and inter-cellular biochemical reactions.

Here, I will use a minimalist theoretical approach, with model cells having a simple set of regulated biochemical reactions, to elaborate the dynamics exhibited in a single cell, and in a group of cells having diffusive interactions among them. Using mathematical models of the pathways, first the role of types of feedbacks (negative and positive, single and coupled) on the single cell dynamics will be shown. Many different types of simple and complex dynamics like mono- and multi-stable states, oscillatory, and chaotic dynamics can be observed in these model single cells, which have correspondence in natural systems. Presence of fractal basins are also observed, which may underlie the occurrence of phenotypic variations observed in the same system in different environments. In multi-cell systems, their collective behaviour is studied for different tissue size, regular and random inter-cellular interaction strengths, etc. How complex dynamics in individual cells get suppressed (control) or enhanced (anti-control) in coupled cells are also discussed. These studies are summarized to give a view of dynamical changes that interacting systems can show at different organizational scales.