IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	Modeling and simulations of collective motion and pattern formation in tissues	
Project Number	**IMURA0960**	
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Research Clusters:

Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one**. For more information, see www.iitbmonash.org)*		**Highlight which of the Academy's Theme(s) this project will address?** *(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Advanced computational engineering, simulation and manufacture*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Infrastructure Engineering*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Water*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Nanotechnology*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Biotechnology and Stem Cell Research*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*	7	*Humanities and social sciences*
8	*HSS, Design, Management*	8	Design

The research problem

How does an initially uniform cluster of cells into the differentiated structures of a fully developed organism? This is fundamentally a problem in physics and mechanics. In order to form tissues and organs of specific shapes, cells must exert forces on one another, move around in a coordinated fashion and organize themselves spatially. However, not much is known about how all this activity is orchestrated in any single organism.

Computer simulations in our collaboration and elsewhere in the world have begun to show how complex spatial patterns can emerge when known features of cell motion and cell-cell interactions come together. For instance, we have shown that spatial patterning in cells can depend sensitively on whether chemical signals are exchanged between adjacent neighbours or between non-adjacent cells. Our simulations also show that under certain situations, cells can actively move about and change their neighbours without the spatial pattern of a chemical signal changing across the whole tissue.

Project aims

It is observed that, in many biological processes such as wound healing, cancer metastasis, branching morphogenesis and embryonic development, the processes of collective cell migration, cell mechanics, and cell-cell signalling are tightly coupled, that is, they closely influence each other. There must exist feedback mechanisms that regulate these interactions. We aim to extend our existing models and simulations to gain further insight into the regulation of pattern formation in tissues consisting of moving polygon-shaped cells that must always stay in contact with each other. A number of studies have shown that the dynamics of pattern formation in these systems can also be understood by using continuum models, computational fluid mechanics and other analytical tools such as instability analysis.

Figure: Simulation results showing stable long-term patterns of chemical signals (green and red) in a tissue monolayer consisting of static (top) or mobile (middle and bottom) hexagonal cells. Mobile cells can change their neighbours through a range of active processes. Such stable patterns of signalling chemicals can further lead to differentiation of cell types, formation of skin patterns, etc.

Expected outcomes

We expect to publish papers in high-impact journals elucidating the regulation of the mechanics of pattern-formation in tissues. The PhD project will provide training in several areas: advanced modelling of active, self-propelled, self-organizing materials; novel simulation tools and open-source packages for modelling and simulations of tissues and complex nonlinear materials; analytical techniques for quantifying complex morphologies; techniques for understanding and explaining pattern-formation. As such, the project can be a springboard for an exciting research career in microsale and macroscale modelling and simulations of complex materials with applications in biophysics, biomedical engineering, microfluidics or in conventional solid or fluid mechanics.

How will the project address the Goals of the above Themes?

The project aims to explain the origins of phenomena observed in biological processes using modelling and large scale computer simulations. It therefore addresses Themes1 & 6.

Capabilities and Degrees Required

Strong academic background in Chemical/Mechanical Engineering or Physics.

Strong interest in a long-term career in modelling and computation

Potential Collaborators

A collaboration between Profs. Raghu Chelakkot and Mandar Inamdar at IITB and Dr. Prabhakar Ranganathan at Monash is already in progress.