IITB-Monash Research Academy

An Indian-Australian research partnership

Indian Institute of Technology Bombay | MONASH University

Project Title:	**Modeling and simulation of collective surface colonization by swarms of motile bacteria**	
Project Number	**IMURA0298**	
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Research Academy Themes:

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. Advanced computational engineering, simulation and manufacture
2. Infrastructure Engineering
3. Clean Energy
4. Water
5. Nanotechnology
6. Biotechnology and Stem Cell Research

The Research Problem

In recent times, there's lot of interest in taking traditional fluid mechanics to biology *e.g.* for understanding the turbulent flow of blood in larger arteries, and how this influences arterial blockage in heart disease etc. However, at the cellular and sub-cellular level, this “engineering-for-biology” approach is now changing to one of “synthetic biology” as we know more about biological systems to be able to firstly modify them, and then build artificial biomimetic micro/nanoscale devices. Biology itself has undergone radical changes, moving from observing and classifying organisms to understanding them as complex (bio)chemical systems. But even that paradigm looks set to change, as we find that physics---especially solid and fluid mechanics---is far more important than previously recognized.

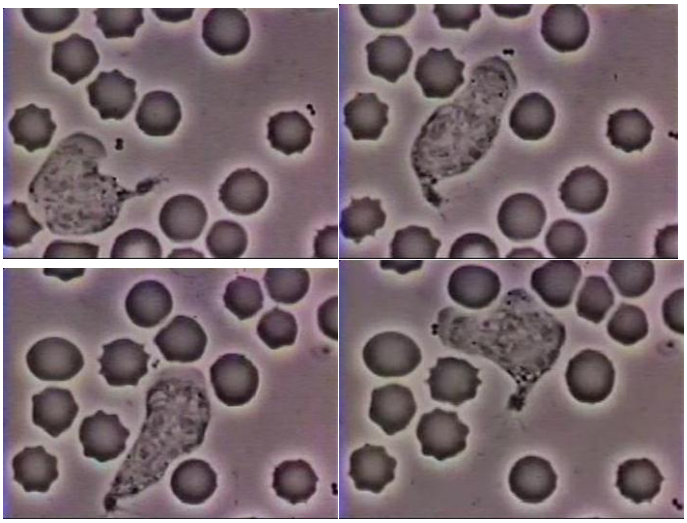

Fig. 1: The large blob in these pictures is a white blood cell, which is hunting down a tiny bacterium (the small black dots) in a field of stationary red blood cells. [Image source: www.biochemweb.org/neutrophil.shtml]

Consider the images in Fig. 1 (also see: http://www.biochemweb.org/neutrophil.shtml) which show a white-blood cell (wbc) chasing and consuming a bacterium. The motion of the wbc is remarkably fluid-like. In fact, that cell is a suspension of a swarm of particles that are propelled by tiny motors, and that constantly push and pull on the outer membrane of the cell. There has been a lot of interest in understanding such "active fluids" that are capable of self-propulsion, and self-organization. If we understand such suspensions well enough, we may one day be able to design artificial and soft microfluidic robots and reactors that can function autonomously, just like that wbc.

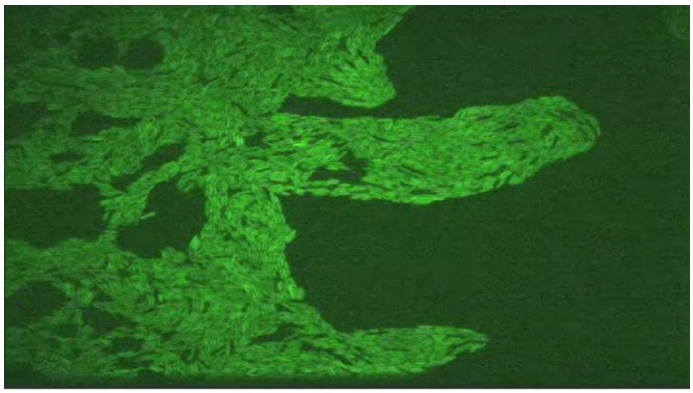

Fig. 2: An expanding surface colony of motile pathogenic bacteria: Finger-like rafts of cells co-operatively and rapidly spread over surfaces, such as tissue surfaces. The structures that thus form are reminiscent of patterns observed in flows of ordinary immiscible fluids in thin films. [Image courtesy Dr C. B. Whitchurch, i3 Institute, University of Technology Sydney]

It is experimentally difficult to work with single cells such as wbc's. But such self-organized behaviour is also found in suspensions of mobile bacterial cells, which are much easier to grow. We are working with microbiologists at the i3 Institute (previously the Instt. for Biotech. of Infectious Diseases) at the University of Technology Sydney to understand how these self-propelled suspensions are able to crawl across surfaces and begin to colonize them (Fig. 2). This has practical value as well: many such bacteria cause severe “nosocomial” infections (e.g. infections in hospitals from urinary catheters) that are almost impossible to get rid of, even with the

strongest antibiotics available today. So, understanding the mechanical behaviour of such suspensions may help one day develop strategies for controlling such infections (e.g. micropatterning urinary catheter surfaces). But beyond this practical application, bacterial suspensions serve as model active fluids, and if we are able to model and predict their self-driven "flows", we could use that understanding to begin modeling wbcs as well.

Project Aims

We aim to design simulations to model systems advancing surface swarms of bacteria, and validate them against experimental measurements. The project consists of the following broad steps:

- setting up simple models and using analytical tools to understand the shapes and structures that are observed in these systems in terms of interfacial instabilities in fluids;
- develop simulations of dense collections of self-propelled rods to model collective motion of bacterial monolayers;
- develop methods for analyzing experimental data obtained by tracking cell positions and orientations, so that we can compare with modeling and simulation results.

Expected Outcomes

These are challenging projects in the emerging and highly interdisciplinary field of computational bioengineering, and are aimed at advancing fundamental understanding as well as developing new computational techniques; very exciting, and a lot of fun! For you, it will be a solid PhD where you will learn several new techniques, with good of high-impact publications, and I think will be an ideal stepping-stone to either an academic or industrial career in advanced fluid computation, especially in micro/nano fluidics and bioengineering.

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

The models and simulations developed in this study address Goal 1. The subject of these simulations concerns biophysics and biotechnology of infectious diseases – this addresses Goal 6.

Capabilities and Degrees Required

- Undergraduate degree in physics, or chemical/mechanical/biochemical engineering
- Strong undergraduate performance in mathematics, computation, fluid mechanics/transport phenomena/ reaction engineering
- Project/ research experience in modeling/ simulations or other computation