Micro/nano-mechanics of Living Fluids

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.

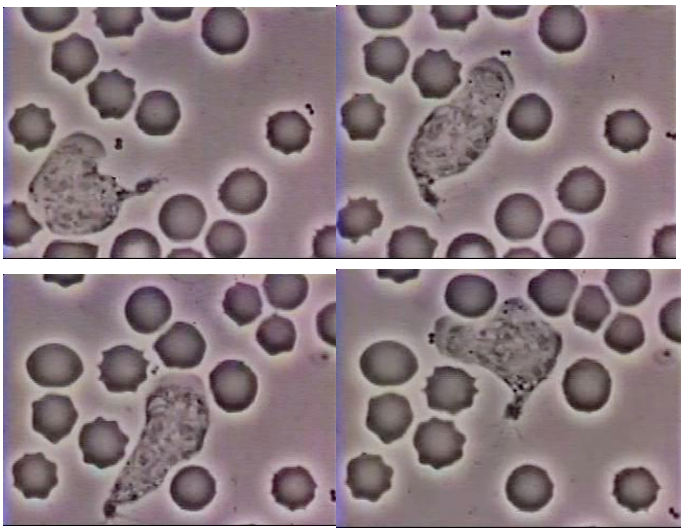

Fig. 1: The large blob in these pictures is a white blood cell, which is hunting down a tiny bacterium (the small black dots) in a field of stationary red blood cells. (Image source: www.biochemweb.org/neutrophil.shtml)

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.

Consider the images in Fig. 1 above (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 can design artificial and soft microfluidic robots and reactors that can function autonomously, just like that wbc. In our group, we are working towards moving that idea from the realm of sci-fi fantasy to practical reality.

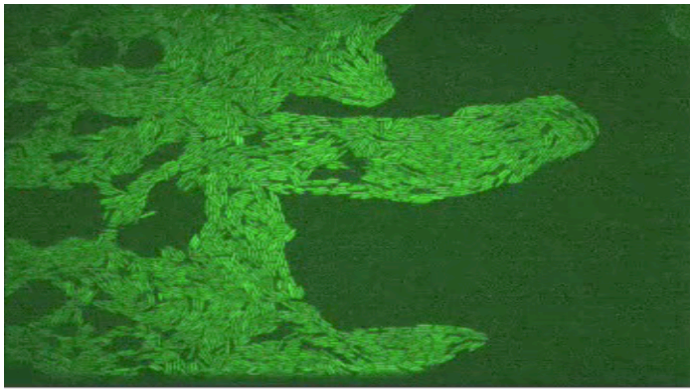

Fig. 2: An expanding surface colony of motile pathogenic bacteria: Finger-like rafts of cells co-operatively and rapidly spread over surfaces, such as tissue surfaces. The structures that thus form are reminiscent of patterns observed in flows of ordinary immiscible fluids in thin films. (Image courtesy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

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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. I am working with a microbiologist 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.

We want to use simulations to understand systems such as a single wbc (Project I) and advancing surface swarms of bacteria (Project II). The projects consist of the following broad steps:

1) 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;
2) in collaboration with Prof. Murray Rudman, setting up a more comprehensive 2D flow simulations of self-propelled complex (i.e. non-Newtonian) fluids confined in films or in vesicles, using a new particle-based technique (called Smoothed Dissipative Particle Dynamics or SDPD) that is comparable to Smoothed Particle Hydrodynamics (SPH);
3) using simulations of dense collections of self-propelled rods to compare with continuum simulations;
4) develop methods for analyzing experimental data obtained by tracking cell positions and orientations, so that we can compare with simulation results.

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.

If you are interested, please contact me (prabhakar.ranganathan@monash.edu) with your CV and academic transcripts. Scholarships for tuition fees and living expenses are available through the Monash Research Graduate School. Applications for students planning to commence in March 2012 close on 31 October, 2011.