Engineering Computational Biology Group
Department of Computer Science and Software Engineering

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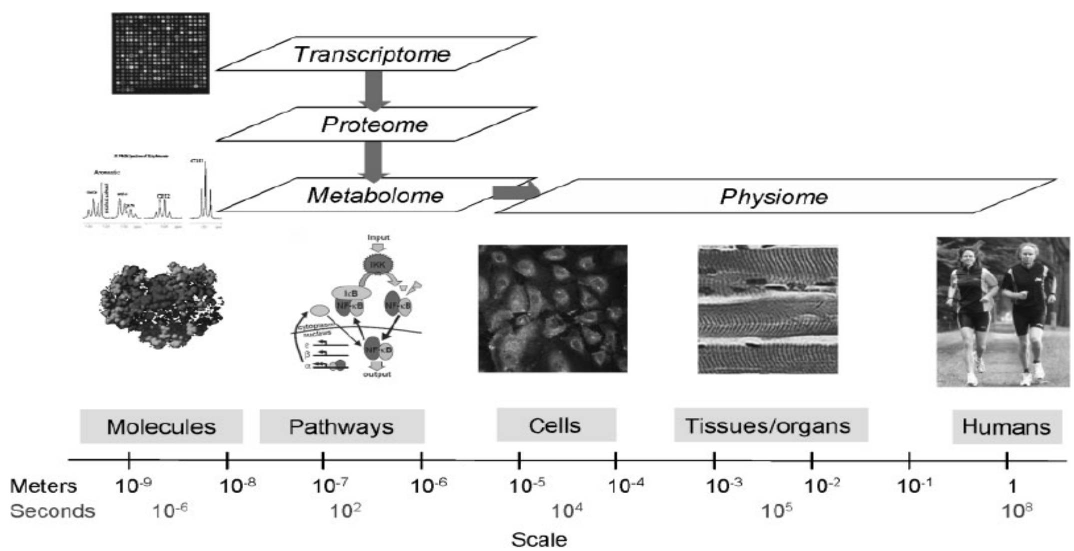
Introduction

The Engineering Computational Biology group uses a wide range of mathematical and computational methods to investigate biological systems. These methods are developed in close collaboration with biologists in various fields in order to identify essential system components, system functions, and interaction networks which aid understanding of systems behavior and formulation of new research hypotheses.

An important aspect of all biological systems is their multi-scale nature which essentially means that larger entities such as organisms, tissues etc are composed of smaller entities which interact with each other to form a functional whole. The smallest living entities are cells which depending on their environment exhibit different behaviours and functions. Depending on the problem of investigation spatial and temporal length scales may vary from 10^{-6}-10^{+8} sec to 10^{-9} – 1 m.



Based on the problem of investigation our research projects range from *systems biology* approaches applied to inter- and intra-cellular communication networks, to the more traditional *biomechanics* approaches applied to the regulation of tissues such as bone and cartilage including the chemo-mechanical environment of cells, to various *clinical applications*.

We invite you to spend some time to find out more about us and our research here. Our group consists of a variety of people with different educational background such as Civil Engineering, Physics, Applied Mathematics, and Chemical Engineering. Based on the many research projects, we are looking to expand our group. If you find our work interesting and you have a strong background in Engineering, Physics, Mathematics etc together with a strong desire to learn more about biology then we would urge you to contact us.

Systems Biology Projects – Intra- and Inter-cellular networks

Systems biology is a term used to describe a number of trends in bioscience research, and a movement which draws on those trends. Proponents describe systems biology as a biology-based inter-disciplinary study field that focuses on complex interactions in biological systems, claiming that it uses a new perspective (holism instead of reduction).

Cells may be thought of as wet ‘computers' and are used by biological organisms for processing environmental information and forming appropriate responses (among other things). Instead of wire, diodes and capacitors, cells use networks of chemical reactions to transmit and modify environmental signals to the cell nucleus and/or to neighbouring cells. These signalling networks are critical to many key processes and events in an organisms life - from the fundamental ‘big questions', such as: how is a adult organism formed from a fertilised egg (developmental biology)?; what is the cause (and cure) for cancer; how does the brain work?, to important physiological functions such as how is bone density regulated and what causes the heart to contract.

Developing a greater understanding of any of these processes would be enormously beneficial. Applications include regenerative medicine, drug target identification in a range of diseases (including cancer), metabolic engineering for drug manufacture and bioremediation, and the prevention of birth defects. A common characteristic of these signalling networks is their complexity. The techniques of engineering and mathematics can be used to understand these complex systems. Unfortunately most biologists do not have this knowledge base. Likewise most engineers do not have knowledge of biology. There is an enormous role for biologically-literate engineers in this area.

Current projects include:

- Bone Regulation-Cell Interactions to Disease
- Cancer metastases formation in bone tissue
- Prostate cancer development
- Wnt signaling and colorectal cancer
- EGF receptor mediated epithelial cell fate determination during development
- Calcium oscillations in smooth muscle

Biomechanics Projects – Tissue Biosynthesis

The traditional definition of biomechanics is the study of mechanical laws and their application to living organisms, especially the human body and its locomotor system. However, more generally biomechanics can be viewed as the application of traditional engineering concepts, such as continuum mechanics and mass transport (including advective-reactive-diffusion) to biological problems with the purpose to advance systems understanding. For example, cells may respond to chemical and mechanical signals in their environment. Quantitative models are needed to integrate the various chemical and physical processes operating in a tissue. Biosynthesis and matrix degradation both may alter the mechanical, transport and chemical properties of the tissue. Hence multiple feedback systems occur within tissues and will govern processes from tumour growth, organism development to drug uptake.

One branch of biomechanics concerned with estimating tissue properties such as stiffness, strength, permeability, and diffusivity involves application of multiscale modeling approaches based on continuum micromechanics. For example the ability of bone tissue to adapt in response to mechanical loading is controlled by osteocytes (i.e., cells embedded in the bone matrix) which sense changes in fluid shear stresses. Due to the fact that bone exhibits several levels of porosity one requires multiscale modeling techniques in order to estimate the fluid shear stresses in the microporosity (i.e., lacuna-canalicular porosity) due to macroscopic mechanical loading. Similar estimation of bone stiffness requires identification of lower scale properties which based on interactions of phases give rise to a macroscopic behavior.

We are involved in a number of projects which range from fundamental questions in physiology to potential improvements in clinical treatment strategies. Projects within this research theme are outlined below.

- Cartilage mechanics, nutrient transport & biosynthesis
- Control of oxygen delivery to renal tissue by arterial-to-venous oxygen shunting
- Bone mechanics & strain sensing
- Fluid mechanics and wound healing after glaucoma surgery
- Hydrocephalus hydrodynamics

Clinical Applications

Research in clinical application is concerned with development of devices and tools (including computational programs) to assist diagnostics, surgery and other clinical applications. While many of the clinical applications use tools from systems biology and/or biomechanics due to their applied nature we group them separately in this section in order to distinguish them from the more fundamental applications discussed previously.

A major advantage of using computational modeling tools rather than experimental methods alone is the possibility to theoretically investigate a range of clinical conditions and then to come up with the most successful treatment strategy.

Current projects we are involved in include:

- Fluid mechanics and wound healing after glaucoma surgery
- Design and optimization of 3D scaffolds for orthopaedic devices and applications
- Strategies for osteoporosis treatment
- Premature birth