Engineering Science & Biomedical Engineering

Part IV Projects 2013

(ENGSCI 700A & 700B)

These projects are open to both Biomedical Engineering and Engineering Science students 4

These projects are open to Biomedical Engineering students only 34

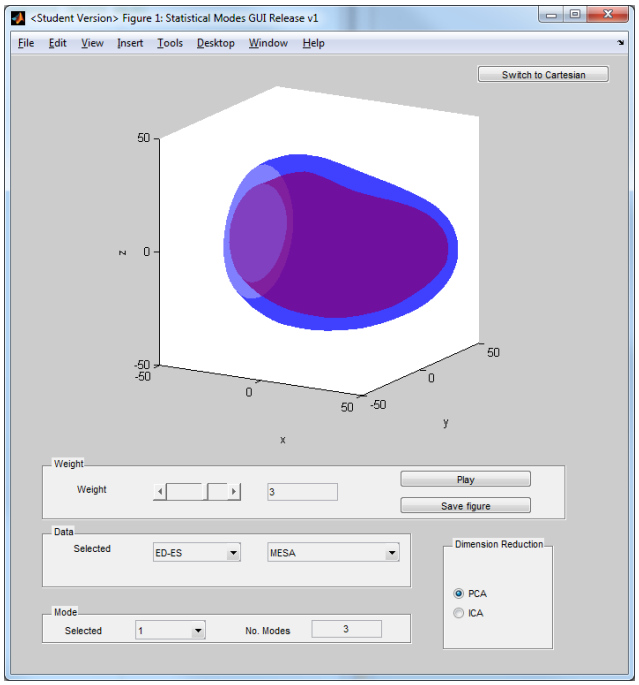
These projects are open to both Biomedical Engineering and Engineering Science students

1. Visualisation of Statistical Shape Models and Shape/Motion Models (Randall Britten)

A 3D model of human anatomy either models the anatomy of a specific individual, or aims to somehow represent an average anatomy. Statistical shape models capture the variation of within the population, and such statistical models have been created, for example human heart left ventricle, human femur. Visualising the statistical model using a 3D interactive tool is a powerful way of gaining an understanding of the population variation. WebGL is a recent standard way of embedding 3D interactive visualisations in web-pages. During this project, existing visualisation tools will be used to guide the development of a WebGL visualisation tool for statistical shape models. If time permits, the visualisation tool will be extended to support statistical models that include dynamic motion (e.g. during the heartbeat, or human gait).

Project Aims

- Create a WebGL version of the existing interactive 3D visualisation tool created for visualising the modes of variation of the statistical shape model from the cardiac atlas project (i.e. The tool that Pau created).
- Design a visualisation tool for statistical shape/motion model (for a specific model, such as cardiac motion).
- If there is time, extend the tool to enable more general visualisation of statistical shape/motion models (e.g. Support for other anatomical models such as human femur and gait).



1. Main Supervisor: Randall Britten (ABI, 90%)
2. Secondary Supervisors: Poul Nielsen (10%)

2. Computational Fluid Dynamics Modelling of CO2 in Patient Airways during Breathing Support (John Cater)

Optiflow is a successful new respiratory therapy designed and made by Fisher & Paykel Healthcare in Auckland that is exported to hospitals worldwide. Optiflow delivers heated and humidified air at 37°C and 100% relative humidity to patients at steady flows ranging from 5–60 l/min via a nasal cannula that sits on the upper lip. Optiflow allows patients to eat, drink and talk without interruption of the therapy and is more comfortable than traditional therapies that use a mask.

One of the proposed mechanisms of action behind improved patient oxygenation with Optiflow is deadspace washout. Unlike a fish, where the water enters through the mouth and exits the gills, and all of the fresh water is available for gaseous exchange, approximately 30% of the inspired tidal volume during normal breathing in a human is reused from the previous breath. Anatomical deadspace is the volume of gas in the airways that remains to be re-breathed at the end of expiration. The high flow rates and jetting from the Optiflow cannula are thought to flush the deadspace of end expiratory CO2 with fresh gas to increase airway oxygen concentration.

Project Aims

> The objective of this project is to use CFD to model the distribution of CO2 in the airways during natural and Optiflow assisted breathing, and produce quantitative results as well as concise animations to illustrate the deadspace washout effect.

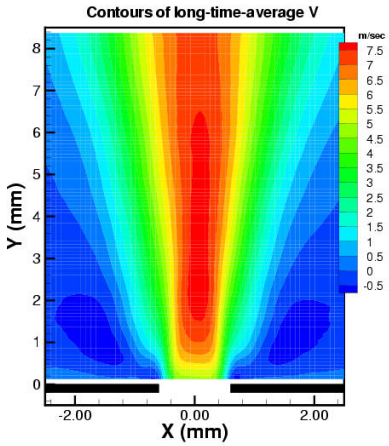
1. Main Supervisor: John Cater (50%)
2. Secondary Supervisors: Callum Spence (Fisher and Paykel) (50%)
3. Sponsoring Company: Fisher and Paykel Healthcare

3. Simulating Synthetic Jets (John Cater)

Synthetic jets are typically small devices that can inject momentum into a fluid at a surface, without adding fluid. They are attractive for applications in flow control and mixing, but the interaction of multiple devices is not well understood. In this project transient computational fluid dynamics (CFD) will be used to simulate clustering multiple slot jet actuators.

Project Aims

- Complete 2D Simulation of Synthetic Jet and validate using CFD
- Complete LES of High aspect ratio Synthetic jet
- Simulate the interaction of multiple jets side by side



1. Main Supervisor: John Cater (100%)

4. Techniques for Segmenting and Characterising ICC Network Imaging Data (Leo Cheng)

Interstitial cells of Cajal (ICC) are responsible for generating and coordinating electrical activity in the gastrointestinal (GI) tract, and these bioelectrical events in turn can determine contraction patterns in GI organs. Conditions such as diabetic gastroparesis and intestinal pseudo-obstruction have been associated with a degradation of the ICC networks. The network structure can be imaged using confocal microscopy, but currently most imaging data is analysed visually or by simply counting the number of cells visible within a certain area. Quantitative analysis of network structures is restricted by the lack of accurate and consistent imaging data segmentation techniques.

Project Aims

This project will develop methods for automatically extracting ICC network boundaries from human colon volumetric imaging data. The effectiveness of generic segmentation software (e.g., Seg3D, Voxx, Avizo) will be compared against software developed as part of this project. Once the ICC network boundaries have been extracted, quantitative parameters of the segmented imaging data (e.g., volume, density, distribution) can be calculated for potential inferences on the tissue physiology.

This project will suit a student with interests in exploring image processing methods, mathematical modelling and coding.

1. Main Supervisor: Leo Cheng (ABI) (50%)

2. Secondary Supervisors: Jerry Gao (ABI) (50%)

5. Blood flow in the placenta (Alys Clark)

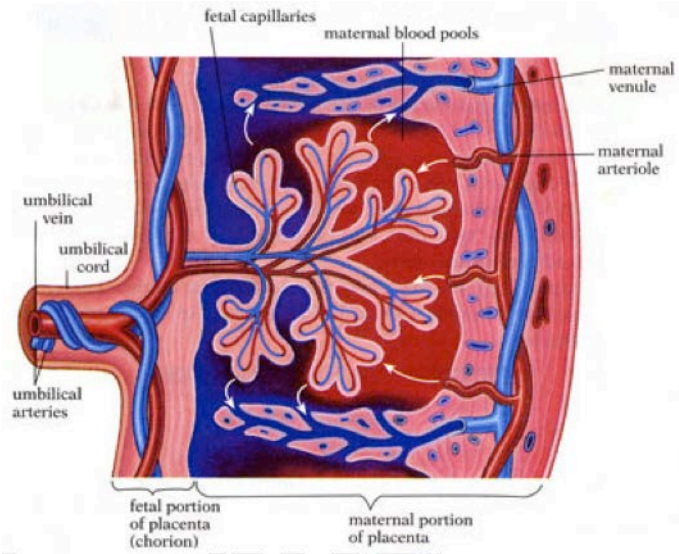
The placenta supplies the developing baby with its nutrient demands for the first 9 months of life and it is unique amongst organs, in that it develops only upon demand. It is also the organ that is the most variable amongst species, including the timing of placental development, its structure and cellular composition, and specific function. This restricts the amount of understanding of human placental development we can get from animal models. Computational modeling of placental function provides us with a way to understand placental development from the 'snapshots' we can obtain from limited human tissue samples.

Project Aims

This project aims to predict blood flow in the fetal capillaries at distinct stages in development. We will construct a branching tree-like structure to represent the blood vessels in the chorionic villous and simulate pulsatile blood flow within it using OpenCMISS.

This will involve:
• Constructing a branching tree-like geometry that represents the fetal capillaries.
• Simulating pulsatile blood flow within this geometry using OpenCMISS.
• Identifying appropriate parameterization for simulations.

This project will be particularly suited to those students with an interest in physiological systems, and will contain elements of both model development and computation.



1. Main Supervisor: Alys Clark (ABI) (70%)
2. Secondary Supervisors: Chris Bradley (ABI) (30%)

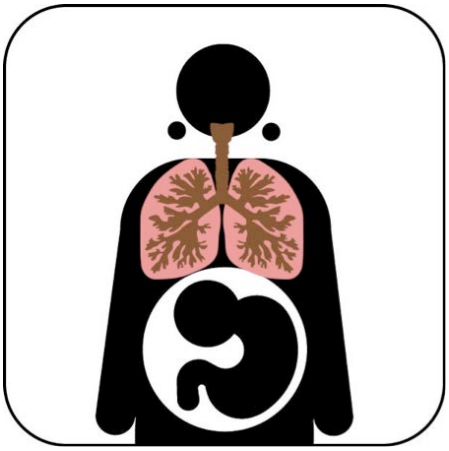
6. Can the placenta disrupt lung function? (Alys Clark)

The placenta is surrounded by a single cell layer that contains many nuclei. In a normal pregnancy aggregates are shed from this layer and enter the mother's blood stream before travelling to the lungs. The aggregates come in a variety of different shapes and sizes and contain a variable number of nuclei. It is thought that the aggregates might be slowly absorbed whilst residing in the pulmonary blood vessels, although some may pass through to the systemic circulation. On the order of hundreds of thousands are shed each day by the normal placenta, and this is increased in pre-eclampsia - a condition that results in maternal hypertension with no known cure other than delivering the child. The question motivating this project is then, can placental aggregates affect blood pressures in the lung to any significant extent, either in normal pregnancy or pre-eclampsia?

Project Aims

The aim of this project is to model the effect of placental aggregates within the framework of existing models of the pulmonary circulation. This will involve:
• Constructing a statistical description of the size, shape and possibly deformability of placental aggregates.
• Incorporating this description in a physiologically realistic manner into large and small-scale models of the pulmonary circulation.
• Assessing the driving pressures that may act to push aggregates through pulmonary blood vessels, and their effect on overall blood pressures.

This project will be particularly suited to those students with an interest in physiological systems, and will contain elements of both model development and computation.



1. Main Supervisor: Alys Clark (ABI) (50%)
2. Secondary Supervisors: Kerry Hedges (ABI) (50%)

7. Collective Dynamics of Swimming Micro-Organisms (Richard Clarke)

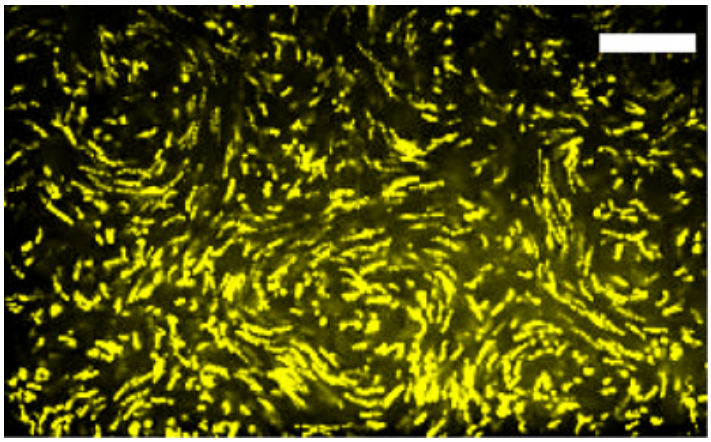
It is of common experience that large shoals of fish or flocks of birds can perform the most mesmerizing displays of collective behaviour. These spectacles, as impressive as they are, pale in

comparison with the intricate patterns generated by some of the smallest organisms, namely algae and bacteria. At such small scales, hydrodynamic effects dominate, and fluid-mediated interactions between cells can produce an array of complex patterns, ranging from cascading plumes to swirls and jets that are reminiscent of two-dimensional turbulence.

The over-arching goal of this project is to quantify these complex collective dynamics. It is a project which will be well-suited to students with an interest in continuum mechanics, mathematical modelling, and simulation

Project Aims:

- Model the interaction of point-like swimming micro-organisms using singularity theory
- Compare the predictions with more realistic simulations which take account of the finite geometry of the swimmers



Flow pattern generated by collective swimming of bacteria. *T. Ishikawa et al. (2011) PRL*

1. Main Supervisor: Richard Clarke (100%)

8. Fluid-Structure Interactions in Micro-Devices (Richard Clarke)

Many modern microdevices have microscopic components (see Figure below), which oscillate extremely rapidly (kHz-MHz) in a fluid environment. This motion generates significant fluid flows within the device, which are associated with large hydrodynamic forces that can deform any enclosing compliant surfaces. These deformations, in turn, modify the flow, hence the need for a full fluid-structure (elastohydrodynamic) description of the dynamics.

Project Aims:

- Compute the elastic P-, S- and Rayleigh waves generated in an elastic half-space due to the unsteady flows generated by a micro-device component, assuming thin-film flow
- Refine existing boundary-element code to generalise the analysis to more general situations

This project will be especially suited to students with an interest in mathematical analysis and continuum mechanics, and will involve a greater or lesser degree of either analysis or computational work, depending upon student preference.

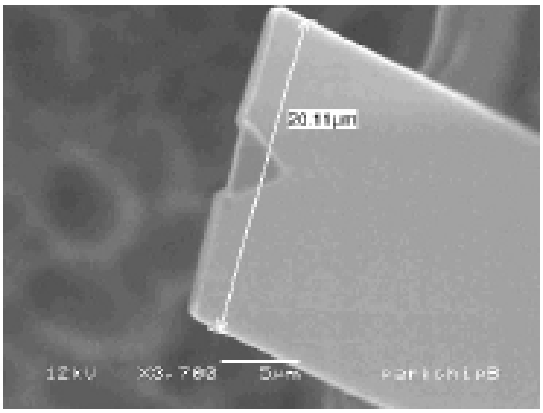


Figure: Microscopic cantilever, as used in an Atomic Force Microscope, which typically oscillates in the KHz range.

1. Main Supervisor: Richard Clarke (100%)

9. Modelling Flow Through Aquaculture Pens (Richard Clarke)

The New Zealand fishing industry is currently worth over $1.4bn/year, of which approximately $280 million derives from aquaculture. In late 2011 the Minister for Fisheries and Aquaculture, Mr Phil Heatley, announced plans for the further development of the New Zealand aquaculture industry, with the aim of delivering an additional $1 billion to the New Zealand economy by 2025. This growth can only be achieved in an environmentally responsible manner through improvement in our quantitative understanding of the marine environment in and around aquaculture sites.

The flow through and surrounding aquaculture structures is an important one from the perspective of nutrient and oxygen availability, and also for waste transport. Such flows are complex, presenting a wide range of features from the small scale (driven by the components of the structure itself, e.g. the cage mesh), to the intermediate scale of the aquatic organisms within the farm, up to the large scales of the farm itself. The complexity of the flow is further increased by the prevalence of biofouling in many aquaculture applications as well as the tidal motions (and large scale oceanographic effects) that are present in marine (both ocean and estuarine) environments.

This project will undertake CFD simulation to determine the flow through such pens, and determine transport of potential fouling materials within. There also may be the opportunity for some experimental design and measurements, using Particle Image Velocimetry (PIV).

This project will be well suited to students with a strong interest in continuum mechanics and modeling.

Project Aims:

i) Simulate the flow through an aquaculture pen
ii) Determine the potential for biofouling under a given set of conditions

1. Main Supervisor: Richard Clarke (34%)
2. Secondary Supervisors: Jim Denier (33%), John Cater (33%)

10. Core Annular Jets (Jim Denier)

This project will explore the structure and hydrodynamic stability of core annular jets. The two images show an example of a core annular jet, in this case the core fluid is air and the outer fluid is water. Initially the jet exits the annular nozzle in a laminar fashion and quickly develops a series of instabilities, in these pictures there are three possible instabilities. One due to the curvature of the jet as it falls to ground, the second due to the shear that exists between the water and air core and the other that arises due to the breakup of the jet itself. Although a largely mathematical and computational study of a complex fluid mechanical problem there is some potential to conduct some small scale experiments with an existing free jet experimental rig.

Project Aims

The aims of this project are twofold:

1. To derive and solve the equations governing a core-annular (round) jet
2. To explore the stability of such jets to small amplitude perturbations using methods from classical hydrodynamic stability theory.

1. Main Supervisor: Jim Denier (50%)
2. Secondary Supervisors: Richard Clarke (50%)

11. The Fluid Mechanics of the Umbilical Cord (Jim Denier)

The umbilical cord connects the developing foetus to its mother's placenta. The foetus depends on the cord for the supply of oxygen and nutrients from the placenta through the single umbilical vein and the return of blood from the foetus through two umbilical arteries. The entire cord, including its vasculature, exhibits a coiled structure. This project will develop a computational model of the flow in a model of the umbilical cord, exploiting existing computational fluid dynamics packages. The project will explore the effects of geometry and pulsatility on the flow through the cord.

Project Aims

The two main goals of this project are to

1. Develop a computational model, using an existing CFD package, of the flow in a coiled tube as a model for the flow within the umbilical cord

2. Use this model to explore the effects of geometry (ie coiling) and pulsatility on the flow.

The project will equip the student with experience in developing a CFD model of a highly complex flow

1. Main Supervisor: Jim Denier (50%)
2. Secondary Supervisors: Alys Clark (ABI, 50%)

12. Developing a platform for investigating the forward problem of electrophysiology (Peng Du)

Many organs in the human body produce bioelectrical activities that govern the contractions of the organs. These bioelectrical activities can be used as a promising indicator in the diagnosis of a number of acute and/or chronic diseases, e.g., electrocardiogram (ECG) or electrogastrogram (EGG). In this project, we seek to develop a 'torso tank' setup for detecting the 'signatures' of the bioelectrical activities from the body surface. The project will involve identifying, ordering, and constructing a torso phantom with an electrical functional generator from off-the-shelf components. Electrophysiological recordings will be conducted using the setup and complemented with a mathematical model to relate the generated electrical source to the measured body surface signals. Applicants should ideally have a good command of Labview and some knowledge in the operation of CMISS and MATLAB. Successful applicant will be working with the Auckland Gastrointestinal Research Group and supervised by Dr Peng Du and Dr Leo Cheng. The applicant will not be expected to perform experiments in live subjects but may have opportunities to observe clinical studies at Auckland City Hospital. This project is supported by a Faculty Research Development Fund, which includes budget for equipment purchase and a summer studentship.

Project Aims

Develop a torso tank setup
Develop an artificial signal source simulating cardiac and/or gastric bioelectrical activity
Develop a forward model of electrophysiology
Conduct recordings to validate the forward model

1. Main Supervisor: Peng Du (ABI, 50%)
2. Secondary Supervisors: Leo Cheng (ABI, 50%)

13. Modelling the Microstructure and Microcirculaiton in Fatty Livers (Harvey Ho)

The non-alcoholic fatty liver disease (NAFLD) affects 10 to 24 percent of the general population in various countries. A survey conducted in South Auckland suggests that NAFLD has been the major factor driving rising numbers of new cirrhosis cases in recent years. Although it is evident that the microstructure is destructed by severe lipid deposits in liver parenchyma, the exact consequence of NAFLD on liver microcirculation is still poorly understood. The aim of this project is to use

computer modelling methods to gain insights of the degradation picture of liver microstructures. We will collaborate with liver surgeons in the Auckland City Hospital to study histology slides of fatty rat livers, and use CMGUI to delineate sinusoidal (liver capillaries) structures, and MATLAB to perform functional modelling.

Project Aims

- Understand the microstructure and microcirculation of the liver through literature review
- Become familiar with the results of a previous Biomedical Engineering summer project on a similar topic
- Create the model and perform simulations
- Attend meetings with surgeons and histologists
- Write a summary article which could be extended as a research paper

1. Main Supervisor: Harvey Ho (ABI, 100%)

14. A Numerical Investigation of Cerebral Artery Remodelling under Hypertension (Harvey Ho)

Hypertension causes morphological alterations in cerebral arteries – a process known as remodelling. They become thicker and narrower restricting blood flow and oxygen delivery. Our aim is to study the basilar artery, which is the main blood vessel to the brainstem, a region essential for life. We will investigate the mechanisms underlying remodelling of the basilar artery in conditions of raised blood pressure. Since the interaction between the basilar wall and blood flow cannot be ignored, the ANSYS fluid-structure-interaction (FSI) framework will be employed to compute the effect of haemodynamics as well as elasticity of the wall. Our studies will reveal limitations of brain blood flow critical for understanding stroke, dementia and hypertension itself.

Project Aims

- Understand the cerebral hypertension and its impact on arterial wall through literature review
- Become familiar with the ANSYS fluid-structure-interaction (FSI) modelling environment
- Create the model and perform simulations
- Validate the model with literature or laboratory results
- Write a summary article which could be extended as a research paper

1. Main Supervisor: Harvey Ho (ABI, 100%)

15. Modelling Cancer Cell Growth and Blood Perfusion in Tumorous Tissues (Harvey Ho)

The ability of malignant colonies to grow and invade healthy tissue is restricted by its environmental factors such as the non-uniform oxygen distribution resulting from local microcirculation. Cancer cells will fail to populate in very poorly oxygenated regions, as simulated in a previous year IV project which used a 2D cellular automata method to simulate angiogenesis and cancer cell growth. The purpose of this project is to extend that project from 2D to 3D. By implementing the basic mechanisms/rules of cellular automata in a higher dimension, we aim to gain insights of cancer

growth and adaption. The student is expected to be proficient in using MATLAB and have excellent analytical skills. A background in biology is a bonus but not essential.

Project Aims

- Understand the blood rheology theory and the cellular automata method through literature review
- Become familiar with the work of the previous project (coding, limitations, potential, etc)
- Create the model and perform simulations
- Validate the model with literature or laboratory results
- Write a summary article which could be extended as a research paper

1. Main Supervisor: Harvey Ho (ABI, 70%)
2. Secondary Supervisors: Richard Clarke (30%)

16. Image Analysis of Stitched Fabrics for the use in Manufacturing Simulations (Piaras Kelly)

Fibre Reinforced Polymer Composites (FRPC) are used in a large number of applications, for example in the soon-to-be-introduced BMW i3 and i8 "green" automobiles (see picture). They are formed by combining a fibre reinforcement (Glass/Carbon/Kevlar fibres) with a polymeric resin matrix, inside a mould which forms the fabric to the final desired shape. In order to keep manufacturing costs down, and to avoid expensive trial and error prototyping, numerical simulation software is used to predict what will occur during manufacture, and this allows the manufacturer to use the optimum set of process parameters, e.g. resin injection pressure, mould closing speed, etc.

The benefit of such software is limited by the quality of the input information. Some of the most important input data relates to the geometry of the reinforcement structure. These include the permeability of the fabric (the ease with which a resin can be forced through its porous structure) and its compressibility when compacted in the mould. This permeability and compaction data is most often obtained from multiple experiments on layers of fabric.

This project's goal is part of an overall "holy grail" research goal, much sought after by BMW and other large-scale manufacturers – to develop tools which can capture fabric architecture using analysis of scanned images and to then use this data to correctly predict fabric permeability and compressibility, dispensing with the need for time-expensive experimental programs.

This project is concerned with stitched reinforcement fabrics, which consist of numerous large tows (themselves consisting of thousands of extremely fine fibres), held together with a thin stitching material. The project will focus on utilising image analysis techniques to extract the essential geometrical parameters, e.g. tow width, angle between tows, path taken by the stitching material, etc. This will be carried out using MATLAB programming. Initially, a unidirectional stitched fabric will be studied (similar to the one shown in the figure), with the aim of capturing the path that the stitching takes (by using both bottom and top images) as well as the path of the tows. The final image analysis program should be fully automated, robust and efficient. The extracted geometric data will then be used to successfully recreate the geometry and then used in software simulations.

The student working on this project will be supported by, and receive guidance from, Elinor Swery (of Mechanical Engineering) and Simon Bickerton of BMW (Germany).

Project Aims

Create scanned images of sticthed fabrics
Carry out Image Analysis to extract critical geometric parameters (in MATLAB)
Develop automated, robust and efficient computer tool
Use analysis to successfully regenerate sample fabrics

1. Main Supervisor: Piaras Kelly (100%)

17. Deformation Models for Textiles with Composite Materials applications (Piaras Kelly)

Textile materials are used in a wide-range of applications, including carpets, filters and clothing. One of the most important uses of textile materials is in Advanced Composite Materials, which are used in aircraft (see picture), spacecraft, land vehicles, wind turbines, sailing boats and an ever-increasing number of applications. Here, textiles are formed into complex shapes and the component is manufactured by binding the fibres together with a hardened polymeric resin (see picture). The material's light weight provides a huge advantage over more traditional materials.

Many of the recently developed composites manufacturing processes are poorly understand because of a lack of a true understanding of the nature of textile deformation. Knowledge of textile response is crucial in any prediction of what will happen during component manufacture, and therefore in any effort to optimize manufacture through reduction in cost and process time.

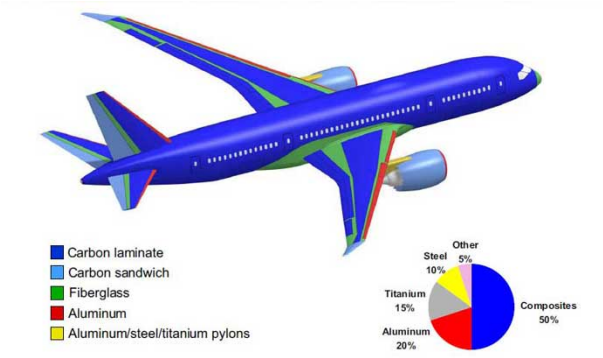
Textiles have an almost unique mechanical response to load, due to their characteristic structure of intertwining fibres, tows and yarns. This means that existing mathematical models for metals, plastics, etc. are not appropriate. On the other hand, their response is similar in some respects to "frictional materials" such as soils and sand, and to materials consisting of fibrous networks, for example paper, biological soft tissue, leather, bio-artificial tissue, etc.

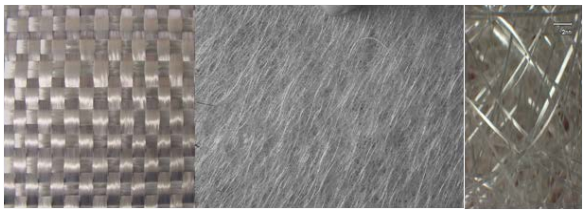
This project is concerned with developing a thermomechanical internal-variable model of textile material, with the internal variables describing the dissipative microstructural mechanisms of deformation. Textiles are regularly subjected to a regime of cyclic loading (repeated loading followed by unloading) during operation; such cycling is between low levels of load to fairly high, but almost always in a state of compression. The goal is to replicate some of the observed phenomena, for example cyclic softening (reduction in stress upon repeated cyclic loading), hysteresis and an increase in permanent deformation with cycling.

The overall goal of the project is to provide a model of textile deformation which can be used in practical full-scale simulations of composites manufacturing processes.

This project would suit somebody who enjoys mathematical modeling, mathematical physics, and programming.

Project Aims
Develop a rate-independent thermomechanical model with internal variables.
Develop the model so as to replicate the observed physical phenomena (cyclic softening, hysteresis and ever-increasing permanent deformation).





1. Main Supervisor: Piaras Kelly (100%)

18. Making your own wireless pressure system using a Low-power Bluetooth platform (Rob Kirton)

The Pelvic Floor research group are investigating why 1 in 5 woman develop Pelvic floor injuries that require corrective surgery to fix. We have a device that can gather information about abdominal pressure during a wide range of activities. In order to get abdominal pressure in a wide range of settings so we can better quantify pelvic floor loading during wider range of activities and everyday living, we need to re-develop the pressure system.
The ABI is developing a wireless Bluetooth platform to allow easier development of wireless sensor systems, which also have data storage capacity. This project is about utilising this platform, and developing a pressure sensing system from cost effective off the shelf items and using some clever engineering.
The end goals are a device that can be used in every day settings, during rehabilitation for post-surgical subjects, through to diagnosis in an Urodynamics Clinic.

Project Aims

Identify an appropriate low cost low power pressure sensor with suitable pressure range and stability that can be powered via battery supply.
Use clever hands on engineering to make cheap pressure balloons.
Interface the sensor to a Low energy Bluetooth.
Develop firmware to digitise and transmit data over low power Bluetooth protocol.
Develop PC based GUI to record transmitted data to disk and display in real time.
Perform bench-top testing of device to validate the design.

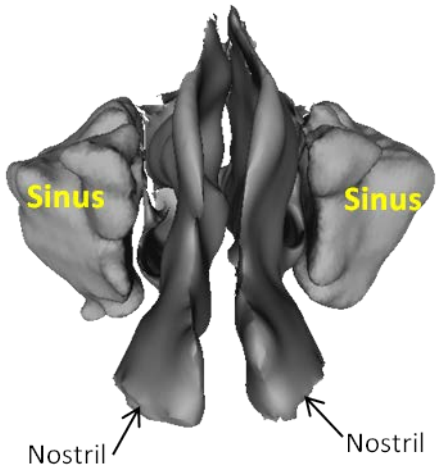
1. Main Supervisor: Rob Kirton (ABI, 50%)
2. Secondary Supervisors: David Budgett (ABI, 20%), Jenny Kruger (ABI, 15%), Poul Nielsen (30%)

19. CFD modelling of airflow in the nasal sinus (Haribalan Kumar)

The human nasal airway that transports air from the nose to lungs has a complicated geometry. The main nasal passages are connected to closed, air-filled pockets called sinuses (see figure) by narrow openings. In diseased patients and for those who have just undergone nasal surgery, drug delivery to the sinuses by nasal sprays is inefficient. An understanding of airflow and drug deposition patterns in healthy subjects will help guide the design of improved delivery strategies. This project aims to use computational fluid dynamics to simulate airflow in an anatomically accurate model of the human nasal airway and sinus.

The major tasks are:

1) Create a smooth finite element mesh of the nasal airways suitable for CFD simulations starting from an existing 3D geometry.
2) Determine airflow patterns within the sinus under physiological breathing conditions.
3) Analyse particle deposition within the sinus and its dependence on relevant parameters.



1. Main Supervisor: Haribalan Kumar (ABI, 50%)
2. Secondary Supervisors: Vinod Suresh (25%), Merryn Tawhai (ABI, 25%)

20. Micromachining Physiologically Representative Blood Vessels - A Platform to Study Pathways of Mechanotransduction (David Long)

Overarching Aim: To construct 3D tissue scaffolds into physiologically representative blood vessels, whose 3D geometry has been determined using non-invasive in vivo imaging techniques

Since human vascular endothelial cells were first cultured in the early 1970s, cell culture systems have been integral for studying and understanding the structure and function of cells. Although in vitro studies have been valuable, a key to continued utility is the design and fabrication of cell culture systems that more accurately reflect in vivo conditions. Traditional planar cell culture geometry often fails to capture the in vivo environment. A 3D cell culture system whose geometry and flow conditions better capture the in vivo physiology is needed.

Project Aims:

For this project, you will (1) use micromachining, image processing, and solid modeling to design and fabricate milli- and micro-fluidic devices of physiologically representative 3D blood vessels (collagen tissue scaffolds) and, (2) design, fabricate, and test a flow chamber that is compatible with microscopy and cell culture.

1. Main Supervisor: David Long (100%)

21. Micro-Particle Image Velocimetry Measurements of a Micro-Tube Flow (David Long)

The distribution in blood velocity within a microvessel must be accurately measured before the rheological quantities associated with that vessel can be determined. The greatest step forward, in the field of microcirculatory blood velocimetry in vivo, came in 1986 with the research of Tangelder and coworkers. They used fluorescently labeled endogenous flow tracers (e.g. platelets and RBCs) to provide the first quantitative estimates of velocity profiles in arterioles (17–32 microns in diameter) of the rabbit mesentery. More recently, exogenous flow tracers have been used to measure velocity profile in post-capillary venules.

For this project, you will (1) design and fabricate an in vitro flow chamber using custom-made small-diameter smooth glass tubes (30-80 microns) (2) design and fabricate a flow loop to steadily perfuse the glass tubes (3) preform micro-PIV experiments using a Newtonian fluid, and suspensions of neutrally buoyant suspensions of rigid spheres in a Newtonian fluid (with application to blood flow in the microcirculation).

Velocity distributions in steadily perfused glass tubes (30–80 microns in diameter) will be obtained using micro-PIV. Neutrally buoyant fluorescent polystyrene microspheres (diameter $0.47 \pm 0.01\mu m$) will be used as flow tracers. The fluorescent microspheres will be visualized using stroboscopic double-flash epi-illumination (DPS-2, Rapp Optoelectronics), and recordings will be made through a CCD camera (Sensicam QE Double Shutter).

Project Aims:

For this project, you will (1) design and fabricate an in vitro flow chamber using custom-made small-diameter smooth glass tubes (30-80 microns) (2) design and fabricate a flow loop to steadily perfuse the glass tubes (3) preform micro-PIV experiments using a Newtonian fluid, and suspensions of neutrally buoyant suspensions of rigid spheres in a Newtonian fluid (with application to blood flow in the microcirculation).

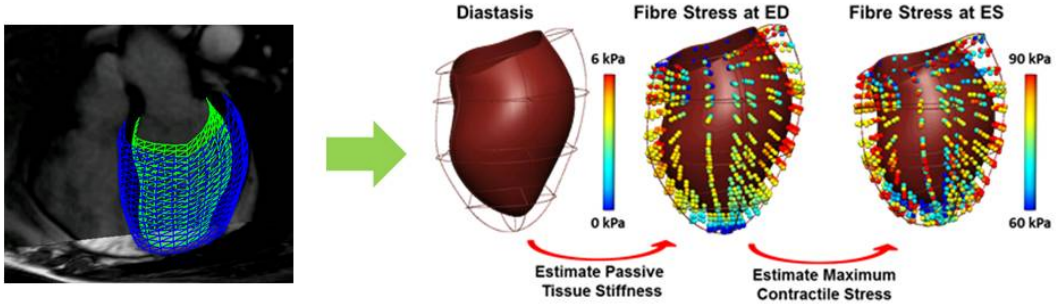
1. Main Supervisor: David Long (80%)
2. Secondary Supervisors: Yi-Chung Lim (ABI, 20%)

22. Characterising Mechanisms of Human Heart Failure (Martyn Nash)

More than half of the patients diagnosed with heart failure (HF) exhibit preserved contractile function (i.e. normal ejection fraction). This disease is commonly termed HF with preserved ejection fraction (HFPEF) and may be due to impaired relaxation and/or filling of the ventricles. Another major cause of HF is associated with the compromised ability of the heart to supply blood to the rest of the body, often referred to as HF with reduced ejection fraction (HFREF). The tissue-specific changes in mechanical properties during these two forms of HF are poorly understood. The primary objective of this project is to investigate the mechanisms of these different forms of HF on a patient-specific basis. This research will use a database of clinical cardiac imaging data from HF patients (supplied by our collaborators at St Francis Hospital, New York) to investigate the relative roles that changes in tissue-specific mechanical properties play in determining ventricular pump function. Outcomes from this project will assist with more specific patient stratification for the different types of HF, and potentially contribute to design of mechanism-targeted treatments. The student will gain skills in cardiac magnetic resonance image analysis, and characterisation of tissue-specific mechanical properties using nonlinear optimisation techniques in CMISS.

Project Aims:

1. Analyse clinical cardiac MR images to parameterise ventricular geometry and motion for a database of patient cases.
2. Develop an automated modelling framework to estimate tissue mechanical properties (both passive and contractile) by incorporating patient-specific haemodynamic measurements.
3. Perform statistical analysis to determine the changes in mechanical properties during different types of human HF.



1. Main Supervisor: Martyn Nash (30%)
2. Secondary Supervisors: Vicky Wang (ABI, 50%), Alistair Young (Physiology, 20%)

23. Statistical biomechanics of the breast (Martyn Nash)

The ABI's Biomechanics for Breast Cancer Imaging group is developing computer modelling tools to assist radiologists with interpretation of medical images of the breast to improve cancer detection. As part of this, a software platform is being developed and deployed at Auckland Hospital to automatically analyse magnetic resonance and x-ray images of patients' breasts using finite deformation elasticity biomechanics. In particular, we require reliable and efficient methods to predict deformation of the breast due to changes in gravity loading (e.g. from the prone to supine position) and/or compression loading (e.g. due to a mammographic x-ray machine).

This project will use physics-based finite element methods (FEM), and statistical partial least squares regression (PLSR) methods to predict deformations of the breast. Preliminary work by our group has shown some promising results. The primary aims of this project are to further develop the statistical PLSR biomechanics methods, and to validate the statistical biomechanics predictions using prone and supine MR images of the breast.
The ultimate goal of this research is to develop a software tool that is suitable for use by our clinical collaborators to rapidly and reliably predict breast deformations to merge information from the various medical images of the breast. The student would ideally be keen on programming and will develop skills with some or all of: CMISS (cm, cmgui, OpenCMISS), Matlab, Python, Perl, plus a number of image processing tools.

Project Aims:

1. Construct a PLSR statistical model (based on a database of existing FEM models) to represent prone-to-supine breast deformations.
2. Use the PLSR statistical model to predict the deformation of an unseen prone breast model to obtain the predicted supine breast shape.
3. Validate the PLSR approach by comparing predictions with FEM predictions of the supine breast.
4. Test statistical PLSR predictions against 3D MR images of the supine breast.

1. Main Supervisor: Martyn Nash (30%)
2. Secondary Supervisors: Duane Malcolm (ABI, 30%), Poul Nielsen (40%)

24. A finite element model of the renal nephron (David Nickerson)

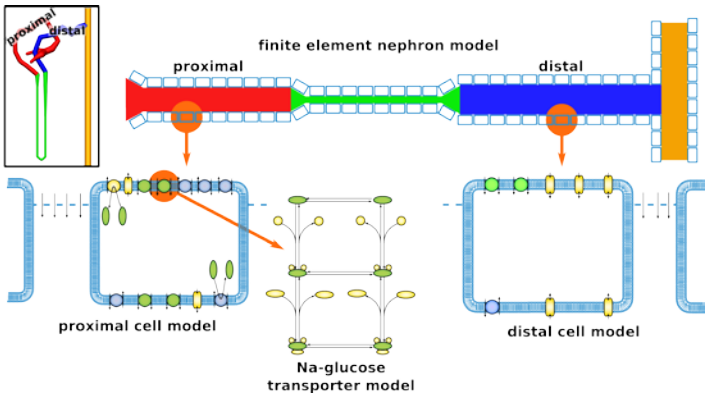
Disease resulting from hypertension (e.g., end-stage renal disease, diabetes and cardiovascular diseases) has a significant impact on the New Zealand population. The 2011/12 New Zealand health survey reported that one in six New Zealand adults are on medication for high blood pressure and one in 20 have been diagnosed with diabetes. The kidneys play a crucial role in regulating blood pressure and blood glucose, key determinants of hypertension and diabetes. We are developing integrative mathematical models and computational infrastructure that will provide a novel tool capable of investigating basic mechanisms underlying these diseases.

The renal nephron is the main functional unit of the kidney, with a normal human kidney having approximately one million nephrons. Taking a simplistic view, nephrons are one-dimensional tubes which take in excretions from the blood at the start, filter the good stuff back out to the blood along the length of the tube, and pass out urine at the end of the tube. The tube can be further divided into functional segments, with each segment consisting of epithelial cells with different compositions of transport proteins. The aim of this project is to develop a finite element model of the renal nephron, building up from a single functional segment.

Project Aims:

1) investigate available computational tools in which develop the finite element model;
2) model Poiseuille flow in a 1-dimensional nephron segment;

3) extend the model to include transport across the tube wall;
4) couple multiple functional segments together.



1. Main Supervisor: David Nickerson (ABI, 100%)

25. Buoyant breasts (Poul Nielsen)

The human body comes in many shapes and sizes. Differences in shape between individuals, and even changes in shape for a particular individual, are important information to gather when constructing personalized models. Breast shape is strongly influenced by gravity, making it difficult to determine an objective unloaded reference geometry for use on biomechanical modeling. One approach to address this problem is to counter the distorting effects of gravity by imaging the breast immersed in water. This project will design, construct, and calibrate a multicamera stereoscopic system to measure breast shape underwater. Preliminary design work for this project has been performed over summer. This project will suit someone interested in imaging and 3D geometric modeling.

Project Aims:

- Design a rigid frame, multicamera, and lighting system to allow images images of the human torso to be taken under water;
- Calibrate the cameras and stereoscopic system to quantify the 3D measurement accuracy of the device under water;
- Measure the geometry of a human torso, or torso-shaped object, under water.

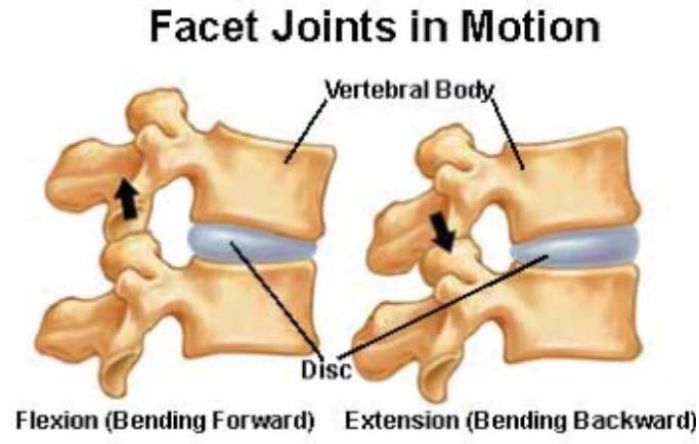
1. Main Supervisor: Poul Nielsen (50%)
2. Secondary Supervisors: Martyn Nash (50%)

26. Flexible Force (Poul Nielsen)

Nature provides us with elegant solutions to many problems. In the spine, for instance, each pair of vertebrae are separated by a soft fluid-filled bag that enables the bones to remain at a fixed spacing, but allows vertebrae to rotate and shear with respect to each other. We have taken this idea, and improved it, allowing us to design a novel flexible force transducer.
An ideal uniaxial force transducer records only the component of force acting along its measurement axis, being insensitive to all components of force orthogonal to this axis and all torques. Furthermore, it has infinite linear stiffness along its measurement axis, zero linear stiffness orthogonal to this axis and zero rotational stiffness about all axes. Current force transducer designs, usually based on strain gauge on metal, are typically stiff in all directions making them ill-suited for many applications. We have developed a new force transducer design that offers close to ideal behaviour. The design takes advantage of the unique combination of properties provided by a novel arrangement of reinforced elastomers and incompressible fluids or gels. There is now a need to test the performance of the transducer and, based on these measurements, improve the design. The project will suit someone interested in instrumentation, experimentation, and modeling.

Project Aims:

- Design and build a testing apparatus to characterize the mechanical properties, and measurement capabilities, of the current flexible force transducer design;
- Use finite element modeling to improve the design, and verify predicted behavior through further testing;
- Time permitting, several such devices will be combined to create a new 6-axis force/torque transducer.



1. Main Supervisor: Poul Nielsen (50%)
2. Secondary Supervisors: Andrew Taberner (50%)

27. Modelling the Orakei Korako Geothermal System (John O'Sullivan)

The Orakei Korako geothermal system is located near the heart of the Taupo Volcanic Zone (TVZ) and has a number of beautiful fault-stepped sinter terraces located along the banks of the Waikato River. Although the Orakei Korako system is protected from development because of its environmental and cultural significance it has been subjected to changes as a result of the creation of Lake Ohakuri. In 1961 the lake was created by damming the Waikato River and flooding valley. This had a direct impact on the geothermal system which could be measured by changes in the geothermal surface expressions.
By developing a numerical model of the Orakei-Korako geothermal system the nature of the changes experienced as a result of the flooding can be investigated. Once the model is calibrated it will also be able to provide valuable insight into the impact of potential future changes in the level of Lake Ohakuri.
Studying the Orakei-Korako also provides a good opportunity for testing new techniques for developing structurally controlled models of geothermal systems. These techniques include the use of inverse modelling to automatically calibrate models. Creating models of geothermal systems such as Orakei-Korako is analogous to creating models of "greenfield" geothermal power generation sites because the model must be created without detailed information from exploration and production wells. Developing such techniques is becoming increasingly important in the geothermal energy industry.

Project Aims

1. Understand geothermal systems
2. Characterise the Orakei-Korako geothermal system
3. Develop a structurally controlled model of the system using both forward and inverse modelling
4. Use the model to investigate the processes that took place during the flooding of the Lake Ohakuri and any future lake level changes

1. Main Supervisor: John O'Sullivan (50%)
2. Secondary Supervisors: Mike O'Sullivan (50%)

28. Optimising Resource Scheduling in Virtualised Environments (Michael O'Sullivan)

One of VMware's flagship products, vSphere, contains a Distributed Resources Scheduler (DRS) for determining the best use of virtualised resources. One drawback of DRS is that it doesn't consider resources that are being used outside the VMware environment.

In this project, we will develop an alternative resource optimisation method that also includes resources deployed outside the VMware environment and compare its performance to that of DRS.

Project Aims

1) Build test environment for testing DRS and alternative solution;
2) Develop alternative optimisation solution;
3) Test and compare DRS and alternative solution.

1. Main Supervisor: Michael O'Sullivan (50%)
2. Secondary Supervisors: Cameron Walker (50%)

29. Improving Water Resource Planning in the UK (Michael O'Sullivan)

Water Resources Planning (WRP) in the UK uses a government-specified framework for determining whether to employ either embellishment of water supply or restrictions on water demand. This framework includes both optimisation and simulation.

This project focuses on implementing the integrated optimisation/simulation framework from the UK WRP framework. This project is run in conjunction with ICS Consulting (London).

Project Aims

1) Implement the optimisation model;
2) Implement the simulation methods;
3) Integrate the optimisation and simulation;
4) Test on a real-world data set.

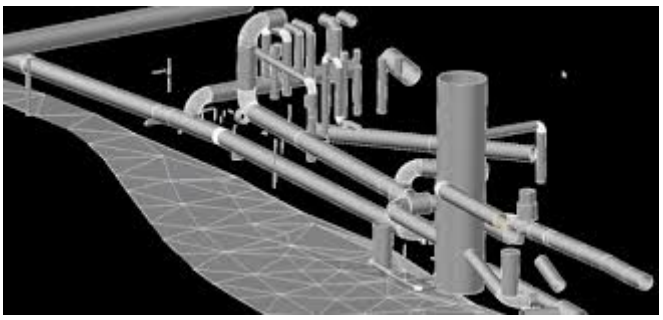
1. Main Supervisor: Michael O'Sullivan (50%)
2. Secondary Supervisors: Cameron Walker (50%)
3. Sponsoring Company: ICS Consulting (UK)

30. Optimising Geothermal Steam Field Design (Michael O'Sullivan)

Geothermal steam field design refers to the process of organising the pipes and equipment that deliver the high temperature fluid from the geothermal wells to the power generation plant. It is an integral part of producing electricity and is also a significant development cost. Current approaches use empirical rules and engineering knowledge to decide the network layout and many factors must be taken into account. These factors include steam field topography, cost of materials, cost of and access to land, pipe pressures, stresses and strains, fluid composition and well locations.
The significant increase in the amount of geothermal energy produced worldwide has led to a number of "greenfield" developments. Without the constraint of existing infrastructure there is a significant opportunity to use rigorous network optimisation techniques to design the layout of steam collection equipment. The development of an approach will require a combination of Operations Research and Continuum Mechanics methods.
This project will focus on the Menengai geothermal system in Kenya which is currently being developed by the Geothermal Development Company (GDC). The key factors affecting the steam field design will be identified and a network model will be developed. The model will be used to optimise the design of the development to reduce cost and provide the best quality steam.

Project Aims

1. Understand geothermal systems and steam field design
2. Identify and model an appropriate network problem
3. Solve the network problem and analyse the results
4. Use the network problem to forecast costs for different development options for the geothermal system



1. Main Supervisor: Michael O'Sullivan (34%)
2. Secondary Supervisors: John O'Sullivan (33%), Cameron Walker (33%)

31. What if the Navier Stokes equations are wrong? (Vinod Suresh)

A provocative idea that has been developed over the last ten years asserts that the classical Navier-Stokes-Fourier formulation of mass, momentum and energy transport in fluids depends upon a hidden assumption – that the mass and volume velocities of a fluid are identical – which is violated unless the fluid density is everywhere constant. By relaxing this assumption, a modified set of equations governing fluid flow and heat transfer have been derived. The aim of this project is to investigate the consequences of this modification and determine the magnitude of the resulting changes to the classical in a few model situations.

Project Aims

The goals of the project are:
1) To develop an understanding of the basis for and the derivation of the modified equations of motion
2) To determine solutions of the modified equations in illustrative situations, e.g. in a stationary fluid enclosed between heated walls maintained at different temperatures.
3) To determine the magnitude of the difference between the classical and modified solutions and thereby design experiments to test the validity of the modified equations.

1. Main Supervisor: Vinod Suresh (50%)
2. Secondary Supervisors: Richard Clarke (50%)

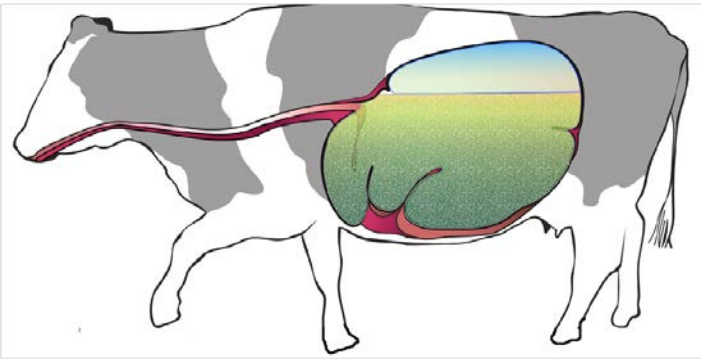
32. A CFD model of mixing in the rumen (Vinod Suresh)

If the cow is the engine of the New Zealand economy, the rumen is 150 litre fermentation engine powering the cow. Grass eaten by the cow is digested primarily in the rumen by microbial action. Rumen contractions aid in the breakdown of grass, influence microbial biochemistry by mixing the contents and are essential for the outflow of the digesta. Outflow rates from the rumen are correlated with the amount of methane, a potent greenhouse gas, produced by the cow and rumen mechanics are affected by a number of digestive disorders. We are interested in developing a computational model of rumen flow and mixing that will have applications in research related to feed conversion efficiency and mitigating greenhouse gas emissions. The aim of this project is to simulate flow in an

anatomically accurate model of the rumen using the computational fluid mechanics package ANSYS CFX.

Project Aims

The goals of the project are:
1) To adapt an existing finite element mesh to implement moving wall boundary conditions to simulate rumen contractions
2) To determine flow patterns and outflow rates in the contracting rumen under normal and diseased conditions
3) To determine the effect of non-Newtonian fluid properties on the solutions.



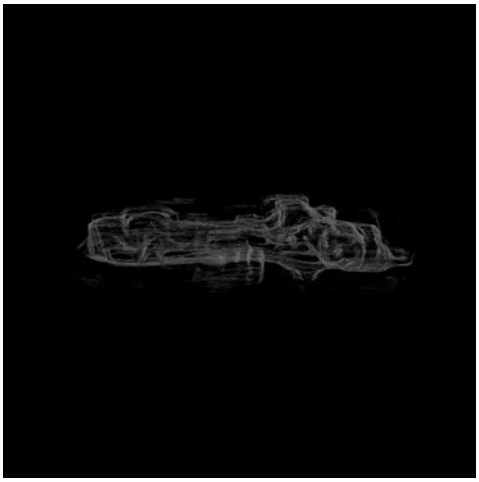
1. Main Supervisor: Vinod Suresh (50%)
2. Secondary Supervisors: John Cater (50%)

33. Volume measurement in optical coherence tomography (Andrew Taberner)

Optical coherence tomography (OCT) is an imaging technique that allows 3-dimensional images to be obtained from the interior of any material that scatters light, including biological tissue. Much like ultrasound, OCT works by measuring the time taken for emitted waves to return to a detector after being reflected or scattered, but the much smaller wavelength of visible light allows for very high image resolution. The much higher speed of light, however, requires the use of interferometry to make this measurement rather than simple timing. In the Bioinstrumentation group, we are interested in using OCT to measure the dimensions of cardiac muscle fibers (trabeculae) as they contract, and have built a prototype OCT system for this purpose.
This project focuses on the development and implementation of image processing algorithms to estimate the volume of cardiac trabeculae from OCT images obtained with our system. OCT images typically contain some noise and variations of image contrast that will require special attention to determine accurate volume estimates. This project will be well suited to a student interested in learning more about practical biomedical image analysis and signal processing.

Project Aims

1. Design a set of phantoms of known dimensions and volume and take images of them using our OCT system.
2. Develop software to estimate volume from OCT images, and use the phantom images to validate the algorithm.
3. Develop software/firmware to integrate real-time volume measurement with our OCT system, working closely with Ming Cheuk (the PhD student in charge of the apparatus).
4. Use the volume measurement algorithm to examine cardiac trabeculae, and make refinements to the algorithm and phantoms as needed.



1. Main Supervisor: Andrew Taberner (33%)
2. Secondary Supervisors: Poul Nielsen (33%), Bryan Ruddy (33%, ABI)

34. "Gearboxes" for high-volume needle-free jet injection (Andrew Taberner)

Although vaccines and drugs are commonly delivered to animals via injection, the needles usually required for this process can be problematic. Needle-stick injuries, blood-borne illnesses, and needle breakage all have high economic and human costs. To mitigate these problems, needle-free injection techniques have been developed. The most promising of these strategies is jet injection, where the drug solution is highly pressurized and then expelled through a small orifice to form a high-speed (~200 m/s) jet that can penetrate the skin. At the ABI, we have developed a uniquely controllable type of jet injector, powered by a linear Lorentz force actuator.

The goal of this project is to design and test mechanisms to allow a Lorentz-force-actuated jet injector to deliver the large drug volumes (up to 5 mL) required in animal husbandry. Ejecting these large volumes at the pressures required for skin penetration requires too much force for direct drive by a Lorentz force actuator. However, only a small amount of the total drug volume actually is needed in the form of a high-speed jet; the balance of the injection can be delivered at a much lower pressure. Thus, a mechanism, much similar in principle to an automatic gearbox, is needed to reduce the force needed for jet formation, allowing the actuator to optimally designed for that lower delivery pressure. This project would be ideal for a motivated student interested in learning about design of medical devices.

Project Aims

1. Design/construct or purchase an orifice that can be adapted to a commercially-available high-pressure syringe.
2. Build an instrumented bench-top injector apparatus that can be tested with different “gearbox” mechanisms.
3. Design and construct a force reduction mechanism, and integrate it with the benchtop apparatus.
4. Test the integrated injector apparatus, and consider possible future refinements.

1. Main Supervisor: Andrew Taberner (25%)
2. Secondary Supervisors: Poul Nielsen (25%), Bryan Ruddy (25%), Rhys Williams (25%)

35. A web-based image database for descriptions of ocular diseases (Jason Turuwhenua)

In an Optometry clinic, eye images provide a valuable source of diagnostic information. During training, it is important that optometry students see multiple examples of ocular disease, in order to recognize these diseases and their potential "real-life" variations. Carefully annotated image databases provide a potential avenue for increasing exposures to the multitude of potential eye conditions and their variations. In this software project, you will assist in developing further, our current database of eye images. Depending on skills, this project will involve: (1) developing a suitable front-end using appropriate web-based technologies (HTML, javascript), (2) setting up a small database of image examples (3) user based testing.

Project Aims

1 - Develop a front-end for the system
2 - Assist setting up example images
3 - Perform some user testing

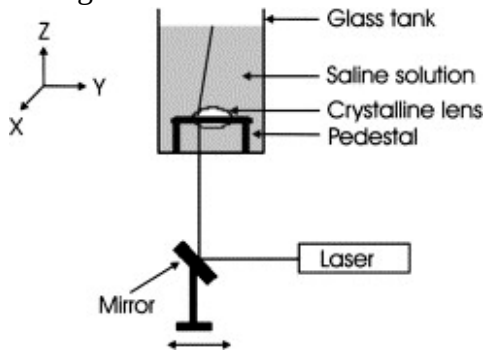
1. Main Supervisor: Jason Turuwhenua (ABI, 75%)
2. Secondary Supervisors: Jorge Perez-Velasco (25%)

36. A laser based device for measuring the refractive index of bovine lenses (Jason Turuwhenua)

Recent experiments using physiological perturbations have shown that it is possible to induce changes in the optical function of bovine lenses, prior to the onset of cataract. However, the detailed relationship between these physiological perturbations and their optical consequences is still an open question and therefore, further investigation is warranted.
In this project we will build a device to measure the refractive index of a bovine lens. This project will involve recording a bovine lens using multiple cameras, as laser beams are sent through the body of the lens. By recording these laser paths, we hope to reconstruct the refractive index profile of the lens. This project will revolve around construction of a device, using exisiting equipment and software. Some MATLAB coding may be required.

Project Aims

The major goals of this project are:
1 - To assemble existing equipment into a setup capable of measuring the lens
2 - To calibrate the system using our software setup
3 - To record laser paths using the setup
4 - To the run the resulting data through our reconstruction software



1. Main Supervisor: Jason Turuwhenua (ABI, 50%)
2. Secondary Supervisors: Ehsan Vaghefi (Optometry, 50%)

37. Mapping Neural Behaviour to EEG signatures (Charles Unsworth)

In biomedical science, the inverse problem attempts to relate how the signals detected at the surface of the scalp, on an electroencephalogram (EEG) record, map to the dynamic behavior of the neurons in the neocortex. This problem remains unsolved experimentally due to the difficulty of performing both internal and external measurements simultaneously in humans. Thus, our understanding of how very large populations of human neurons interact and translate to external EEG signals remains limited. The signal processing community has attempted to derive the behavior of the neurons from the EEG signal alone with limited success using techniques such as Independent Component Analysis (ICA). In this project, we are particularly interested in human epilepsy where the neurons undergo an abnormal synchrony and how their architecture and cellular dynamics translates to an epileptic EEG signal. There are 42 types of epilepsy each with very different EEG signatures. Thus,

the definition of what abnormal synchrony means for particular epilepsies is not well understood.

The project aims are are to create customised Artificial Neural Network models of virtual grids of interconnected neurons to produce a fictitious EEG signal at a virtual detector. Then by using multi-objective optimisation techniques together with the knowledge of what EEG signals are we will optimise the architecture, neuronal firing rates to attempt to approach the epilepsy signature of interest. This will be done for very simple systems first adding more complexity as the project evolves.

Project Aims

1) create customised Artificial Neural Network models of virtual grids of interconnected neurons
2) Determine propagated signals from network at a ficticious electrode on the scalp
3) Use optimisation techniques to adjust neuronal parameters to converge to a solution which is the EEG signal desired.

1. Main Supervisor: Charles Unsworth (50%)
2. Secondary Supervisors: Andrea Raith (50%)

38. Improving ordely transit simulation at Auckland City Hospital (Cameron Walker)

A Java simulation of the Orderly Transit Service at Auckland City Hospital currently exists, developed by a number of international interns and 4th year students over the last 2 years. The current model runs from historical data, which triggers transit requests and orderly dispatches. Work has also been done on improving the orderly dispatch process via optimisation, although this is currently a stand-alone model.

This project will focus on extending the existing simulation to include measures of variability, and embedded optimisation.

Project Aims

1) Extension of the simulation model to include stochastic travel times, and the implementation of summary reports across multiple replications.

2) Embedding of the existing optimisation model within the simulation to improve the orderly dispatch policy.

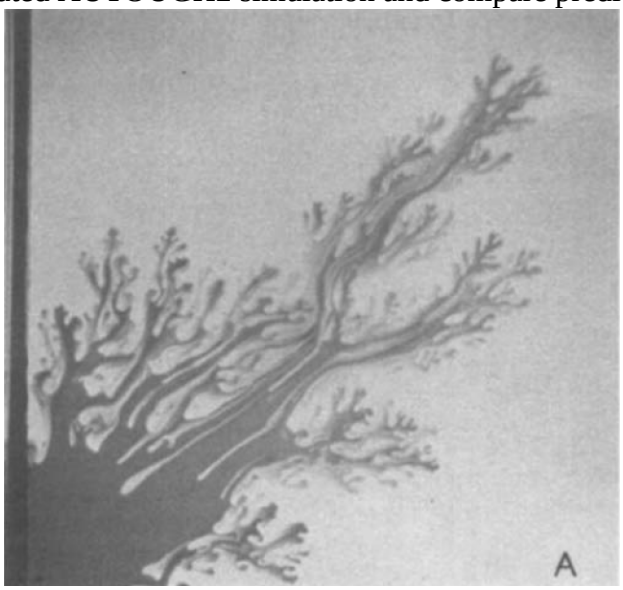
1. Main Supervisor: Cameron Walker (50%)
2. Secondary Supervisors: Michael O'Sullivan (50%)
3. Sponsoring Company: Auckland District Health Board

39. Modeling viscous fingering in the relation to reinjection in geothermal reservoir (Sadiq Zarrouk)

Viscous fingering is the formation of patterns in a morphologically unstable interface between two fluids in a porous medium or in a Hele-Shaw cell. It occurs when a less viscous fluid is injected displacing a more viscous one (in the inverse situation, with the more viscous displacing the other, the interface is stable and no patterns form). It can also occur driven by gravity (without injection) if the interface is horizontal separating two fluids of different densities, the heavier one being above the lighter In the rectangular configuration the system evolves until a single finger (the Saffman–Taylor finger) forms. In the radial configuration the pattern grows forming fingers by successive tip-splitting. The mathematical description of viscous fingering is the Darcy's law for the flow in the bulk of each fluid, and a boundary condition at the interface accounting for surface tension.
The project investigates different mathematical models for viscous fingering and the criteria for the onset of those fingers with a special interest in the potential occurrence in the reinjection in geothermal reservoirs. The AUTOUGH2 geothermal reservoir simulator will also be used for modelling viscous fingering in porous media.

The student will:

- Perform a critical analysis to predict conditions under which onset or instability occurs.
- Perform sophisticated AUTOUGH2 simulation and compare predictions with analysis



Homsy (1987) Ann. Rev. Fluid Mech.

1. First Supervisor: Sadiq Zarrouk (50%)
2. Second Supervisors: Richard Clarke (50%)

These projects are open to Biomedical Engineering students only

40. Skin Cancer Therapy (Mike Cooling)

Skin cancer is a serious health problem in New Zealand. Pharmacological skin cancer treatments are designed to reverse the effect of mutations in the cancer cells and make such cells behave normally again. But, some of the most promising drugs cause abnormal behaviour in non-cancerous cells. The attempted cure can often lead to new, different cancers in the surrounding normal tissue!

In the case of one commonly-used drug, the main cellular signalling pathway concerned, details of several common mutations and the mechanical basis for the drug itself are all believed to be known, some of these having come to light during 2012.

Engineering can make sense of the collected observations, and use them to suggest better drug targets in the following way. Using data from real human skin, and a realistic skin culture developed at the University of Auckland, we can apply high-school mathematics to produce small but powerful mathematical models of healthy and mutated cells, to 'test' the effects of cancer drugs in silico.

These models could then be used to suggest better, combined targets that would control the abnormal behaviour in mutant cells, and also avoid or control the unwanted known side-effects in normal skin cells. It may even be possible to suggest a 'cocktail' of drugs that would do this from currently available cancer drugs.

Project Aims
1) Summarise some key papers to understand the main signalling pathway, common mutations and mechanical basis for a currently-used cancer treatment drug.

2) Encode that information into three small models - one for the healthy cell and one for each of two common mutations.

3) Via simulation and a number of well-known analysis techniques (if needed), suggest at least one set of desirable changes that a drug would need to make to remove existing cancer growth and also reduce new cancer formation.

4) Depending on the student's progress, there is potential to work with cancer researchers at FMHS and propose a 'cocktail' of cancer drugs which will then be investigated experimentally.

1. Main Supervisor: Mike Cooling (ABI, 100%)

41. Keeping It Real (Mike Cooling)

Cardiovascular disease is the developed world's major killer. Many forms begin in the vasculature, where cells react to blood flow and hormonal stimulation. Mathematical models of many of the key intracellular processes exist, but to be useful they have to be realistic. Relevant experimental data is

published continuously, and models must adapt with new data. Many times, a modeller may not even realise that their model is rendered unrealistic without making a special effort.

To keep things real, we should evaluate old models in the light of new experimental data and, where such testing highlights a discrepancy between model and reality, iteratively constrain the model to both past and present data. This process should be automated as much as possible.

Many tools and algorithms for evaluating and constraining models exist. Protocols for defining virtual experiments on mathematical models are also emerging. This project will involve testing these methods against real models and experimental data in the context of cardiovascular disease. A simple workflow for evaluating and constraining models will be developed from the best-performing algorithms and protocols as a prototype testing-and-constraining process.

Project Aims

1) Produce a summary of a given set of simple mathematical models of cardiovascular disease.

2) Gather a set of experimental data relevant to the models, either from the literature or from in-house experimentation (this latter may be available).

3) Test constraining unparameterised versions of the models to the data using a variety of existing methods.

4) Choosing the best performing / most relevant methods, define a prototype test-and-constrain workflow for such models.

1. Main Supervisor: Mike Cooling (ABI, 80%)
2. Secondary Supervisors: David Nickerson (ABI, 20%)

42. Teaching a Computer to Build a Model (Mike Cooling)

Mathematical models can be constructed from smaller, component models - perhaps each individually representing one player or relationship in a model- that are used as building blocks to construct the larger whole. Imagine that we have a library of these blocks. Being able to specify which blocks to use and to have the computer construct models 'to spec' would reduce both the time needed to produce the model, and the human error rate in doing so.

We have recently produced a set of principles that make model components easy to connect to one another, and a collection of model components following those principles. Computers can use these components if they understand what the elements of the components mean, and how to connect those elements together. This can be achieved by tagging elements with agreed labels. Recently, such labels have been developed across many areas of bioengineering, and we have developed ways of tagging our component models with these labels. This project is about bringing these existing techniques together and demonstrating how they can be used to get the computer to assist (or even automate?) larger model construction from a set of tagged component models

Project Aims

1) Construct (by hand) an example model from existing component parts.

2) Devise a simple process for computer-assisting or automating the construction performed in 1), identifying which elements of the component parts should be tagged.

3) Devise a set of tags for use in 2).

4) Develop a prototype software program to conduct 2), and some example tagged components.

5) Validate 4) by using it to construct a few different models from the tagged components.

1. Main Supervisor: Mike Cooling (ABI, 80%)
2. Secondary Supervisors: David Nickerson (ABI, 20%)

43. Meaningful Modelling (Mike Cooling)

Getting a computer to 'understand' which parts of a mathematical model relate to which biomedical concepts is a hot topic in bioengineering. Such understanding allows software to connect different models together and search for logical contradictions and conclusions automatically. This increases our ability to understand and analyse complex biological situations and diseases, particularly those requiring very large models.

Recently, a tool has been developed that adds such understanding to models. As a prototype, it currently has a drawback: it converts the model from the original encoding to a simplified version. Much information that is not biological in nature but nevertheless important to model construction and reuse - particularly model structure information - is lost in the process.

We collaborate with the developer of the aforementioned tool, and have discussed a method that shows promise for removing the drawback. However, this has not been tested, and will likely require some refinement, especially as more complex examples are considered. We have an online repository of several hundred models from which to choose examples to test. This project is about testing and refining that method in order to retain both biological and structural model meaning.

Project Aims

1) Develop a familiarity with example model structures and the tool (documents and personal contacts exist for these).

2) Critically assess the suggested process by testing small models by hand. Suggest refinements if necessary and retest.

3) Develop a prototype software program, or potentially amend the tool itself, encoding the process so developed.

4) Validate 3) by testing with more, and larger models.

1. Main Supervisor: Mike Cooling (ABI, 100%)

44. Modelling the Development of Osteoarthritis in the Human Knee Joint (Piaras Kelly)

Osteoarthritis (OA) is a degenerative disease affecting joints of the body, in particular the weight bearing joints such as the hip and knee. Well over 50% of the population will have significant OA by the age of 65. It is second only to cardiovascular disease as the cause of chronic disability in adults. Billions of dollars are spent annually for its treatment and for lost days in work. OA is characterised by a thinning of articular cartilage (the cushioning padding on the bones within a joint), subchondral bone (specialised bone underneath the articular cartilage) stiffening, formation of osteophytes (excessive bone) and the presence of subchondral bone cysts (cavity within the bone near the joint).

Numerous factors can contribute to the development of OA, including genetics, abnormally-formed joints, traumatic injury to the joint, occupation and obesity. This project focuses on possible mechanical causes of OA. It has long been known that a stiffening of bone can lead to an increase in stress in cartilage, causing it to develop fissures and degrade. However, it is not clear how or why this increased stiffening of bone occurs.

The hypothesis at the heart of this project is that osteoarthritis is an expression of bone remodelling in the subchondral region. In some preliminary work testing this hypothesis, a threshold strain level within bone was assumed; strain levels above the threshold level lead to bone growth whereas levels below the threshold lead to bone loss. This was shown to lead to some stiffening of the subchondral bone and osteophyte formation under normal loading conditions, two of the characteristics of OA.

This project will build on this work: the protocol needs to be refined to include the genetic factor which regulates the strain threshold, and to include a range of maintenance strain and non-cyclical irregular loading. Further, research is required to investigate whether the process is self-limiting: if stiffening does occur, this in itself may lead to reduced strain, and thus the strain stimulus will die off.

This project will involve Finite Element modelling and stress analysis. It will also involve some coding (the writing of scripts to interact with input/output files of ABAQUS).

Project Aims

Incorporate physiological loading into models of the human knee joint.
Develop algorithms for increasing/decreasing bone density depending on the strain levels.
Investigate whether the subchondral bone stiffening leads to reduced strain, and therefore ieventually to reduced stiffening.

1. Main Supervisor: Piaras Kelly (90%)

2. Secondary Supervisors: Pranesh Kumar (Rotorua Hospital 10%)

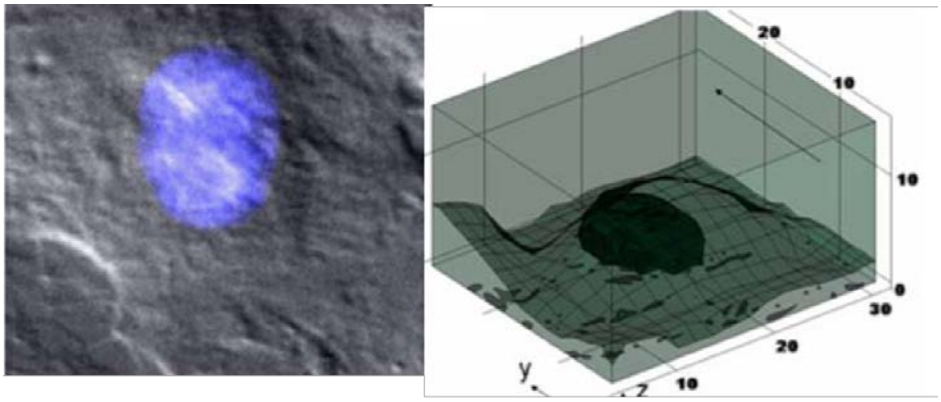
45. Imaging and Morphology of Endothelial Cells (David Long)

Endothelial cells convert blood flow-induced force into a biological response. Dysfunction of this process is linked to circulatory diseases such as atherosclerosis, so it may be possible to treat these diseases by intervening on the endothelium. However these potential treatments are hindered by an incomplete understanding of how force is transmitted into an endothelial cell.
Although force transmission can be estimated by computational modelling the validity of the estimates depends also on the experimental data used by the model. In particular the cell shape is a key determinant force transmission.

Project Aims

(1) This project aims involves using a combination of immuno-staining, fluorescent microscopy to image human umbilical vein endothelial cells (HUVEC).

(2) Process these images to build a computational model of the geometry of an endothelial cell which is suitable for mechanical analysis.



A) Micrograph of a bovine aortic endothelial cell with nucleus marked in blue.
B) Computational model of endothelial cell geometry. Model built from micrographs such as that shown in A.

1. Main Supervisor: David Long (40%)
2. Secondary Supervisors: Yi-Chung Lim (ABI, 30%), Sue McGlashan (Anatomy, 30%)

46. Sliding Skin (Poul Nielsen)

Our team have developed biomechanical models to predict deformation of the breast during mammographic compressions. However, the accuracy of these methods is hampered by the fact that the mechanical interactions between the skin and compression plates are unknown. To date, all models have assumed that the interaction is either frictionless or that the skin sticks rigidly to the plate. In reality, the interaction lies between these two extremes. This project will design and test a device that can make measurements of the forces and torques developed between human skin and an acrylic plate.

We are presently constructing a measurement system to allow us to quantify the forces and torques developed between skin and an acrylic plate. The system includes a 6-axis force/torque transducer and a camera that can accurately quantify the area of skin in contact with the plate. There is still significant work to be done on completing the design and construction of the device. This project will suit someone interested in instrumentation and experimentation. The experimental results will inform our biomechanical models to more reliably predict breast deformations during mammography.

Project Aims

- Test, and calibrate an existing 6-axis force-torque sensor;
- Design, assemble, and test a device for measuring skin friction by integrating the force-torque transducer with a video camera and acrylic plate;
- Quantify plate-skin interactions by conducting experiments to characterise pressure and shear conditions under which skin sticks or slides against a flat acrylic plate.

1. Main Supervisor: Poul Nielsen (50%)
2. Secondary Supervisors: Martyn Nash (25%), Jessica Jor (ABI, 25%)

47. Perfect prostheses (Poul Nielsen)

Bovine pericardium is the thin sack that encloses the hearts of cattle. Because it is tough and flexible, this tissue is often used to manufacture the leaflets in artificial heart valves. The mechanical properties of pericardium are primarily determined by the arrangement of strong collagen fibres that make up the tissue. Unfortunately, the orientation and density of collagen varies considerably between and within tissues. We have been trying to predict the mechanical behavior of pericardium using several approaches:

- measuring the mechanical response of samples in a biaxial stretching rig;
- using confocal microscopic imaging to measure the collagen fibre arrangement, and applying this to microstructurally-based constitutive relations;
- using a polarimeter to measure the meso-scale optical activity of tissue, and statistically relating these to the mechanical behavior.

The second approach destroys the sample, so is not useful for selecting appropriate portions for making valves. We want to use both the first and last approach, biaxial testing and polarimetry, to allow us to choose suitable portions for use as prosthetic valves. The primary aim of this project is thus to combine two existing instruments into a single versatile device for testing thin membranes.

Project Aims

• Design a platform to integrate a biaxial mechanical testing rig and a transmission polarimeter into a single device capable of characterising the optical activity of pericardium subjected to a rich set of deformations;
• Build and test the integrated device, demonstrating that the optical and mechanical properties of sufficiently large pericardial samples can be characterised;
• Use the device to identify regions of pericardium that have desirable mechanical and optical characteristics.

1. Main Supervisor: Poul Nielsen (34%)
2. Secondary Supervisors: Andrew Taberner (33%), Jessica Jor (ABI, 33%)

48. Kinetics of the CFTR chloride channel (Vinod Suresh)

The cystic fibrosis transmembrane conductance regulator (CFTR) is a chloride channel found in the epithelial cells of the lungs, skin, digestive tract and reproductive tract. Through its role in transporting chloride ions into and out of cells, it regulates the composition of body fluids such as mucus, sweat and digestive secretions. Mutations in CFTR lead to disorders such as cystic fibrosis in which epithelial fluid absorption and secretion are disrupted. Understanding the basic principles of CFTR operation is essential for the targeted design of drug or genetic therapies that aim to restore CFTR functionality in such diseases. The basic scheme of CFTR gating (i.e. opening and closing) is known: ATP binding to two intracellular domains (NBD1, 2; see figure) causes conformational changes that lead to opening of the channel. This ATP-mediated gating is primed by the addition of phosphate groups (phosphorylation) to a regulatory domain (not shown) connecting the two NBDs. The aim of this project is to develop a mathematical model of CFTR gating that can reproduce experimental measurements of chloride currents through the channel.

Project Aims

1) Develop a mass action kinetics model for ATP-mediated gating based upon a proposed scheme.

2) Extend an existing steady state model of CFTR phosphorylation to account for transient behaviour.
3) Couple the models in (1) and (2) and determine model parameters by fitting to experimental data.

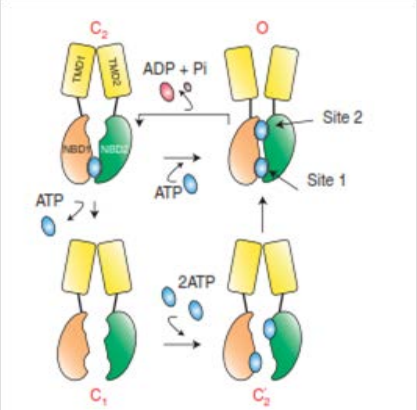


Figure 3. A simplified model for CFTR gating. The diagram illustrates dominant gating transitions ($C_2 \leftrightarrow O$) and a second gating cycle ($C_1 \rightarrow C_2' \rightarrow O \rightarrow C_2 \rightarrow C_1$) involving complete disengagement of the two NBDs. It should be noted that the transition from O to C_2 likely contains many transitional states

1. Main Supervisor: Vinod Suresh (50%)
2. Secondary Supervisors: Mike Cooling (ABI, 50%)

These projects are open to Engineering Science students only

49. Optimising Highly-Viscous Flows (Richard Clarke)

Flows on very small scales, for example those generated by microdevices or swimming micro-organisms, are referred to as Creeping Flows. It is known that an exact solution to the flow can be obtained by distributing a continuous collection of fundamental flow solutions, known as Stokeslets, over the surface of any fluid-immersed bodies – this is known as the Boundary Integral approach. Although accurate, this approach can be very computationally expensive. However, it has been suggested that it should be possible to obtain a reasonable approximation to the flow by using just a discrete number of these Stokeslets. However, their position and strength must be carefully chosen to best satisfy the required boundary conditions, whilst at the same time keeping the number of Stokeslets to a minimum.

Many of the past implements of this method have been ad hoc, either using trial-and-error or crude estimation techniques. This project will therefore apply Multiobjective Optimisation theory to more closely examine this approach, and determine its characteristics in terms of a well-defined optimisation problem.

Project Aims

i) Investigate and characterise the approach of approximating Creeping Flow using collections of Stokeslets from a Multiobjective Optimisation perspective
ii) Validate the algorithm against a number of test cases, where the optimal distribution of Stokeslets is already known
iii) Apply the method to more complex viscous flow problems

This project will be well suited to students with an interest in both Continuum Mechanics and Optimisation, and will involve both computation, and some analysis.

1. Main Supervisor: Richard Clarke (50%)
2. Secondary Supervisors: Andrea Raith (50%)

50. Generator Offer Optimization in the New Zealand Electricity Market (Tony Downward)

In the New Zealand wholesale electricity market, an optimization problem (Scheduling, Pricing and Dispatch, SPD) is solved every five minutes to determine the cheapest way that power can be supplied to consumers; this economic dispatch problem determines how much power each plant should produce, and the prices at all buses in the transmission grid. Firms submit offer stacks to this optimization problem detailing how much power they can supply at various prices.

In this project, we wish to determine the optimal way for a profit-maximizing generation firm to operate its plants, which may be located in multiple parts of the country. To do this we will build upon a model, written in python, developed over the summer. This model is a large deterministic

integer program that uses constraint branching techniques to find the optimal generation plan. However, due to inherent uncertainties in the electricity market (e.g. due to demand variability), we ought to be considering multiple scenarios, and be solving a stochastic optimization model which constructs offer stacks, rather than a single optimal generation quantity, for each plant.

Project Aims

This project will involve the following:

a) improving the solve time of the current model, particularly in the presence of line losses - this may involve developing heuristic techniques to find good incumbant solutions for the integer program;
b) incorporating uncertainty into the model thereby producing offer stacks;
c) incorporating the reserve market into the model;
d) applying this model to data from the NZEM to examine how the particular firms may behave.

1. Main Supervisor: Tony Downward (50%)
2. Secondary Supervisors: Golbon Zakeri (50%)

51. Transpower Project 3: Transmission Tower Painting Optimization (Tony Downward)

Transpower spends approximately $50 million per annum repainting steel transmission towers. While we know the condition and rate of deterioration (mostly rusting) of each tower and the ideal time to paint it, there is still a scheduling problem with a number of costs and constraints. If painting is delayed beyond the ideal time the cost will increase -- ultimately to the point where the tower must be replaced. Conversely, painting earlier than necessary will incur a financial penalty (or perhaps an opportunity cost).

Skilled staff are a very limited resource, and managed through a number of subcontractors. Teams often work in isolated country and require accommodation. For this and other reasons, painting adjacent towers consecutively often yields a more cost effective solution. However, this must be weighed against the requirement to minimize disruption to landowners (whose property may be crossed by multiple lines).

Transpower has already investigated some aspects of this problem using spreadsheets, but linear and integer programming techniques have not been applied.

Project Aims

This project will involve:

a) understanding all the constraints of the problem and determining, which to initially include in the model to keep it tractable;
b) formulating a mixed integer program (MIP) to attempt to schedule the painting of the towers in a deterministic setting;

c) investigating optimization techniques for this problem where uncertainty is a factor;
d) developing a tool to assist the maintenance managers in the optimization of the tower painting program.

1. Main Supervisor: Tony Downward (34%)
2. Secondary Supervisors: Golbon Zakeri (33%), Andy Philpott (33%)
3. Sponsoring Company: Transpower

52. 2D and 3D shape optimization, applied to dimond cutting (Tony Downward)

The Centenary Diamond, weighing 55g, was estimated to be worth $100 million when it was unveiled in 1991. This diamond was cut from a rough-stone weighing 120g; thus when cutting such a stone, it is imperative to orient the stone such that waste is minimized. We have developed an interactive tool which allows a user to visualise this problem. In this project, we wish develop an integer programming formulation to find the optimal orientation yielding the largest cut diamond. The efficiency of this model will then be compared to a local search heuristic.

Project Aims

This project will involve the following:

a) Extending 2D solution techniques to 3D
b) Developing a model for the problem of cutting multiple diamonds from a rough stone (in 2D and 3D)
c) Evaluate the efficiency of the global optimization model, compared to heuristic methods.

1. Main Supervisor: Tony Downward (100%)

53. Smart Column-wise Neighbourhood Search for scheduling helicopters in Antarctica (Andrew Mason)

Antarctica is the Earth's most southern continent, and is known for being cold, dry and very challenging to work in. However, its unique qualities make Antarctica an important focus for scientific research. Much of this research requires travelling by helicopter within the Antarctic region. These helicopters are a valuable but limited resource that need to be scheduled efficiently to best support the research activities while minimizing fuel use and the associated emissions. This project will extend a prototype optimization model and software tool developed to support the optimal scheduling of helicopter operations at the McMurdo Antarctic base. The current prototype works by enumerating all possible schedules for a helicopter, which makes it impractical for realistic sized problems because the number of possible schedules is too large.

Project Aims

This project will look at a new approach in which 'smart' algorithms are used to generate an initial set of schedules, which are then added to using column-wise neighbourhood search. This work is in collaboration with Dr Colin Harris, Director of the UK company Environmental Research & Assessment (ERA) (http://www.era.gs).

1. Main Supervisor: Andrew Mason (100%)
2. Sponsoring Company: http://www.era.gs

54. An optimisation model for efficient mail routing at NZ Post (Andrew Mason)

NZ Post have developed a mathematical optimisation model for helping determine how mail should be collected and sent to mail centres for efficient sorting. However, this existing model is currently only being solved using heuristics, and so optimal solutions cannot be guaranteed.

Project Aims

This project will develop a new optimisation-based approach to solve this problem in which complex non-linear features of the problem are linearised within new constraints. An implementation will be developed for delivery to NZ Post using the Excel add-in SolverStudio.

1. Main Supervisor: Andrew Mason (100%)
2. Sponsoring Company: NZ Post (TBC)

55. Optimal Well Placement (Andrew Mason)

The correct placement of an oil well can have a major effect on the production capacity of an oil field. Predicting this production capacity is a difficult problem that is typically solved using numerical simulation.

Project Aims

In this project, new algorithms will be developed that integrate tightly with an existing oil field simulator to efficiently explore alternative placements and depths for a well, and thus find an optimal (or very good) well configuration. This project will require expertise in optimisation (including heuristics, as taught in EngSci 760) and some knowledge of simulation and fluid modelling.

1. Main Supervisor: Andrew Mason (50%)
2. Secondary Supervisors: Rosalind Archer (50%)

56. Using SolverStudio to develop and deliver models for water conservation in Florida (Andrew Mason)

SolverStudio is a new Excel add-in that allows optimization models to be built using a range of modeling languages such as PuLP, AMPL, GAMS, and Gurobi's Python tools. SolverStudio is being considered by the St. Johns River Water Management District in Florida to develop models "to apply water conservation best-management practices to high water-using accounts." The District has a range of requirements including generating optimal solutions and exploring expenditure/benefit tradeoffs. These models have previously been developed in OpenSolver, which is able to solve some problems but is very slow.

Project Aims

This project will develop and test models using a number of different languages supported by SolverStudio, and report on the effectiveness of the different approaches. This work is in collaboration with Tom Blush and Max Castaneda of the St. Johns River Water Management District, Florida, USA, and Stuart Mitchell, developer of PuLP.

1. Main Supervisor: Andrew Mason (10tinent, and is known for being cold, dry and very challenging to work in. However, its unique qualities make Antarctica an important focus for scientific research. Much of this research requires travelling by helicopter within the Antarctic region. These helicopters are a valuable but limited resource that need to be scheduled efficiently to best support the research activities while minimizing fuel use and the associated emissions. This project will extend a prototype optimization model and software tool developed to support the optimal scheduling of helicopter operations at the McMurdo Antarctic base. The current prototype works by enumerating all possible schedules for a helicopter, which makes it impractical for realistic sized problems because the number of possible schedules is too large.

Project Aims

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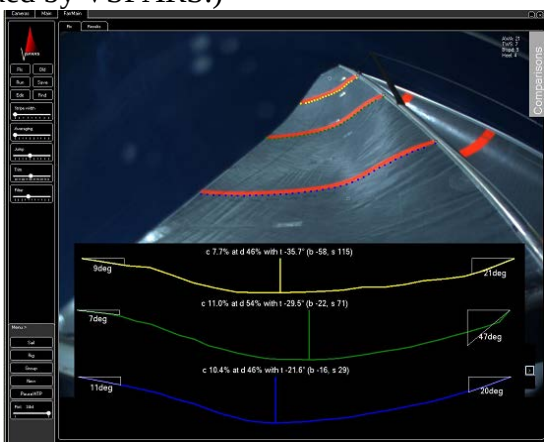
1. Main Supervisor: Andrew Mason (100%)
2. Sponsoring Company: http://www.era.gs

57. Real-time Sail Shape Fitting using Optimisation (Andrew Mason)

VSPARS (http://www.vspars.com) is a university spin-off company that has developed innovative technology for determining, in real time, the shape of a boat's sails and mast while the boat is sailing. Their system uses image processing techniques to deduce the shapes under load.

Project Aims

In this project, we will determine how best to formulate the sail and mast shape problem using an optimization approach, and then develop and test our new approach on data provided by VSpars. This project is in collaboration with David Le Pelley, VSpars and the University of Auckland Yacht Research Unit. (Image provided by VSPARS.)



1. Main Supervisor: Andrew Mason (45%)
2. Secondary Supervisors: Andy Philpott (45%), David LePelley (10%, YRU)

58. Design, construction and optimisation of a sand dredge for removing debris from beaches (Andrew Mason)

Many of the inner city beaches contain years of accumulated hard debris such as rocks and glass mixed in with their sand. This project aims to build, optimise, and test a dredging device to suck up a mixture of sand and water, pass this through a screening filter to remove the large objects, and then discharge the sand back to the beach. The device will use the approach found in gold mining dredges in which the flow is generated using a jet of water (produced from a separate powered water pump) that is injected into a larger diameter pipe, thereby ensuring no debris passes through the powered pump.

Project Aims

The project will include modelling and optimisation of the dredge design and building and testing of scaled and/or full-sized prototypes.

1. Main Supervisor: Andrew Mason (50%)
2. Secondary Supervisors: John Cater (50%)

59. Inverse modelling and Heuristics for calibrating geothermal models (Mike O'Sullivan)

For a computer model of a geothermal system nverse modelling using software such as PEST can be used to choose optimum values for model parameters such as permeabilities and porosities. However there is always considerable uncertainty in the geologiocal model which determines the assignment of rock-types within the geothermal model. For e3xample the boundary between an ignimbrite and a rhyolite may not be precisely known and within the ignimbrite there may be parts which are more fractured than the rest, and therefore should have a different permeability.The aim of this project is to experiment with various heuristic methods for rock-type assignment and/or subdivision within a geothermal model. After each PEST run the rock-types which are most important in determining the goodness of fit of the model results to the data will be identified and either the rock-type boundary adjusted and/o the rock-type subdivided. Then the whole process will be repeated.

Project Aims

The aim of the project is to develop a robust heuristic system for adjusting the rock-type assignment within a geothermal model that, coupled with the inverse modelling code PEST, can automatically produce a model that fits measured data very well. It is expected that the numerical experiments with various heuristic options will be carried manually but the ultimate aim is to automate the process using PYTHON scripts.

1. Main Supervisor: Mike O'Sullivan (50%)
2. Secondary Supervisors: John O'Sullivan (50%)

60. Parameter estimation including calculation of the Jacobian (Mike O'Sullivan)

Inverse modelling involves selection of model parameters so that model results optimally fit some data (measured by an objective function such as the sum of squares of errors between model results and data point). The most common methods for inverse modelling require the calculation of a Jacobian containing derivative of the objective function with respect to model parameters. Usually the Jacobian is calculated by making small changes to each model parameter in turn and re-running the forward model. Obviously this is a very time consuming process as many froward runs are required (number of model parameters plus one). The alternative is to set up a modified objective function to minimse that has the residuals from the forward problem multiplied by Lagrange multipliers, added on to the standard sum of squares of errors. Then equating to zero the derivative of the augmented objective function with respect to the Lagrange multipliers gives the standard forward problem to solve for the model unknowns. But equating to zero the derivative of the augmented objective function with respect to the unknowns give a new problem to solve for the Lagrange multipliers. Then the Jacobian required for inverse modelling can be calculated from the

results of these two solves (rather than the very many solves required in the standard procedure) The context for this work is the improvement of computer models of geothermal systems but in this project it will be tetsed first onsimpler well-test analysis of cold groundwater reservoirs. This mathematical model in this case is linear whereas for geothermal ressrvoirs the mathematical model is highly nonlinear.

Project Aims

The aim of this project is to implement the dierct calculation of Jacobians as part of inverse modelling. The method will be applied first to pressure test results for a cold ground water reservoir. If time permits the more complex geotehraml problem will also be addressed.

1. Main Supervisor: Mike O'Sullivan (34%)
2. Secondary Supervisors: John O'Sullivan (33%), Michael O'Suulivan (33%)

61. Geothermal tracer test analysis (Mike O'Sullivan)

A common method for trying to understand what is going on in a geothermal reservoir is to inject tracer in an injection well and then measure how much tracer returns in nearby production wells.Such tracer tests are useful for understanding if underground structures like major faults are acting a flow conduits in the reservoir. There are various simple mathematical models (mainly one-dimensional) used for analysing tracer tests but for any of them model parameters must be chosen to best fit the model to the data. This involves inverse modelling.

Project Aims

The aim of this project is to investigate the various simple mathematical models of tracer tests and to set up some inverse modelling methods to automate model fitting. Either existing inverse modelling code such as PEST will be used or else a simpler customised code will be developed.

1. Main Supervisor: Mike O'Sullivan (50%)
2. Secondary Supervisors: John O'Sullivan (25%), Michael O'Suulivan (25%)

62. Finding Optimal Vehicle Schedules (Michael O'Sullivan)

Crown Equipment has developed technology for guiding unmanned vehicles within a storage warehouse. However, the problem of determining where those vehicles should go is a difficult optimisation problem. ORUA is working alongside Crown Research Limited to develop methods to automatically generate and update schedules for vehicles to pick up orders.

One difficult subproblem in this process is determining the best schedule for a single vehicle given a set of possible orders with "desirability" values. When using a mixed-integer linear programming (MILP) approach, upper bounds on the optimal solution are found reasonably easily, but the lower bound takes a long time to converge to the upper bound. This project will investigate various techniques for speeding up the solution of the MILP approach to the vehicle scheduling subproblem.

Project Aims

Investigate, implement and test approaches to speed up solution time for the single vehicle scheduling problem.

1. Main Supervisor: Michael O'Sullivan (50%)
2. Secondary Supervisors: Cameron Walker (50%)
3. Sponsoring Company: Crown Equipment Pty Ltd

63. Finding efficient CDO portfolios (Michael O'Sullivan)

Collateralised Debt Obligations (CDOs) are a form of financial vehicle which allow investors to buy bonds that are secured against a pool of assets. The investors can purchase instruments at different risk tranches, based on the investors desired risk-return profile. CDOs are a reasonably developed sector within the financial world, with new issuance of approximately €900bn in Europe during 2009, whilst the US market is significantly larger. The average arbitrage CDO portfolio in Europe will be between €200mm and €800mm, with between 100-200 different positions.

The purpose of this project is to investigate multi-objective approaches to integrate with the existing model for determining the best possible combination of trades.

This project would involve working with professionals currently working in the financial sector in London, and may lead to working with a leading European asset manager (with over €140bn of assets in fixed income) who is also one of Europe's leading CDO managers.

Project Aims

1) Investigate multi-objective approaches for the CDO problem;
2) Develop multi-objective methods for the CDO problem;
3) Test the methods developed to build efficient CDO portfolios for real-world data.

1. Main Supervisor: Michael O'Sullivan (34%)
2. Secondary Supervisors: Cameron Walker (33%), Andrea Raith (33%)
3. Sponsoring Company: M&G Investments

64. Stagewise dependence models for reservoir inflows (Andy Philpott)

This project is concerned with the planning of the release of water from hydro reservoirs to make electricity. This is large-scale dynamic stochastic optimization problem that seeks to minimize the expected costs of thermal generation and electricity shortages by releasing water at the right times.

The Electric Power Optimization Centre (www.epoc.org.nz) has developed software called DOASA for solving this problem. Since future reservoir inflows are uncertain, DOASA assumes probability distributions on inflows. Currently these are assumed to be independent from week to week. Thus a large inflow into Tekapo this week does not increase the probability that it will be large next week.

In practice, the inflows are stagewise dependent. This presents some challenges for DOASA that this project will study. The simplest model assumes that the logarithm of weekly inflow follows an autoregressive process, e.g. AR1. This can be modelled in the optimization using extra state variables. The project will implement this in the DOASA code and test to see how much it improves the policies when simulated with historical inflow sequences.
A second more advanced aspect of this project will look at snowmelt in DOASA as an alternative source of reservoir inflow. This can be modelled as an extra reservoir with random releases. If time permits the student will implement this feature in the DOASA code and test to see how much it improves the policies when simulated with historical inflow sequences.

Project Aims

Implement AR1 inflow model for DOASA
Test the effect of correlation on policies
Implement a snowmelt sstate

1. Main Supervisor: Andy Philpott (100%)

65. Analytics models for pricing clothing for online sales (Andy Philpott)

Ezibuy is a New Zealand based online, catalogue and retail (NZ only) company servicing both the NZ and Australian markets. They focus on women's clothing but also sell men's clothing and homeware. Products are ordered online, and delivered from a distribution centre located in Palmerston North. Ezibuy are early and enthusiastic adopters of analytics: they have collected a large amount of historical data on customer choices in response to various marketing strategies. This project aims to improve Ezibuy's pricing strategies for selling clothing online. They procure different brands of clothing in advance and advertise it online. Clothing is procured in batches with several months lead time. We denote by c(i) the cost per unit of item i. High fashion items are sold at a premium price, but are discounted later in the season if they do not sell. Moreover different brands of the same item of clothing are substitutes, and so increased sales in one brand might decrease sales in another. Ezibuy's main interest in this project is in understanding the effect on profit of ordering too much or too little stock.

We will treat this problem as a monopolist selling n differentiated products in a multi-stage stochastic environment. The demand for item i will initially be modelled as
$d(i) = a(i) - B(i)Tp$ where a(i) is a constant, B(i) is a vector of n coefficients, and p is the vector of prices for items i=1,2,…,n. Typically the ith component of B(i) is positive and the other components are negative and smaller in magnitude than B(i). If the monopolist maximizes its profit then it seeks prices to maximize $\text{Sum i } d(i)(p(i)-c(i)) = \text{Sum i } (p(i)-c(i))(a(i) - B(i)Tp)$ which is a quadratic function. The first stage of the project will study this optimization problem for different numbers of brands.

The later stages of the project will look at the effect of random demand, fixed charges on ordering, and discount pricing of unsold items. The aim is to produce a model that will enable Ezibuy to make better procurement decisions.

Project Aims

Develop a differentiated products model for clothing prices
Use this to test the value of offering different ranges
Implement a stochastic pricing optimization model

1. Main Supervisor: Andy Philpott (100%)
2. Sponsoring Company: Ezibuy

66. Transpower Project 2: Modifying GEM to incorporate market behavior (Andy Philpott)

The need for new transmission lines is driven by electricity demand growth, or new generation being built. Transpower's long term plans for network development look up to 40 years into the future using the Electricity Authority's publicly available Generation Expansion Model (GEM).

GEM is a mixed integer programme with an objective to minimize the total cost of electricity investment and generation over the time horizon in question. It includes a cost stack of new generation projects (including a wide range of generation technologies) and, subject to certain constraints, it builds new generation required to meet demand, by choosing the next cheapest generation plant from the stack. Although this may be a reasonable approach were generators are independent companies who on-sell their electricity to retailers, that is not the case in New Zealand. New Zealand electricity generators are so called gentailers who own a retail wing. Such vertically integrated companies behave differently in regard to investment in new generation, primarily investing as required to keep their retail portfolios balanced.

This behaviour is not reflected in GEM and we do observe, in reality, that new generation is not built in the same order as the cost stack in GEM indicates.

This project will start by developing investment models for a gentailer. These model will be utilized to generate generation expansion scenarios that will be fed into GEM. We will investigate the diversity of the transmission expansion plans that ensue from the GEM outputs. We will also develop a rolling horizon model that will simulate a competitive market's approach to generation expansion and hence transmission planning and contrast this to the current regime.

Project Aims

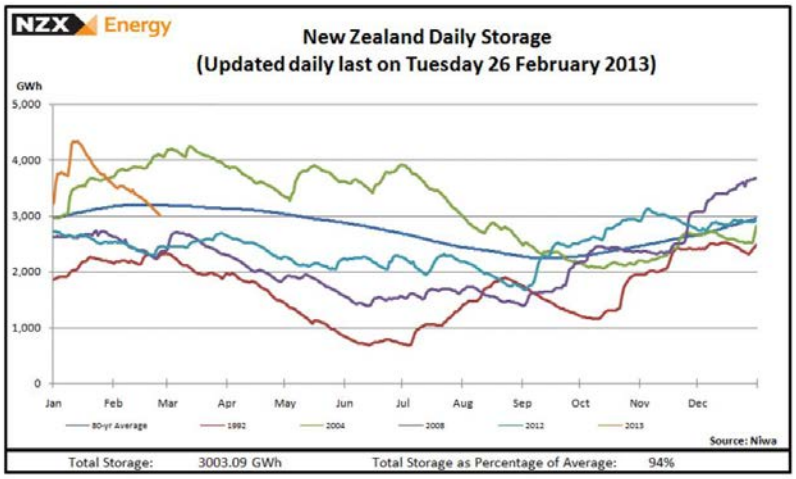
1) Developing plausible investment strategies for a gentailer through mathematical modelling.
2) Simulation of GEM outputs for a range of generation expansion scenarios.
3) Developing a rolling horizon competitive market model for generation expansion.

1. Main Supervisor: Andy Philpott (34%)
2. Secondary Supervisors: Golbon Zakeri (33%), Tony Downward (33%)

67. Reservoir inflows for capacity investment optimization (Andy Philpott)

This project is concerned with investment in electricity generation plant that operates in an environment dominated by hydro electricity. The question this project will tackle is “for a given level of future demand, how much non-hydro plant is needed in New Zealand to get through a dry winter?”

We will treat this problem as a Markov decision problem (see ENGSCI.760) with investments affecting the costs and capabilities of the non-hydro plant. The Markov decision problem can be formulated as linear program, which turns into a mixed integer program with integer variables representing the investment actions. This model can be solved using CPLEX or can be attacked using Benders decomposition.



Project Aims

This project will formulate a version of this software for New Zealand and investigate the optimal plant investments that will provide secure electricity through dry winters. The estimated expected cost of running the system using these investments can be tested using the Electric Power Optimization Centre’s DOASA software (see www.epoc.org.nz).

1. Main Supervisor: Andy Philpott (50%)
2. Secondary Supervisors: Golbon Zakeri (25%), Tony Downward (25%)

68. Analytics for farm drought management (Andy Philpott)

From time to time in New Zealand we have very dry periods of weather. This February has been one of the driest on record. The Hawke's Bay Regional Council has started preparing for a possible extended drought which could become the region's worst in over 50 years (Hawkes Bay Today, 27.02.2013). This poses problems for farmers (e.g. sheep farmers or vegetable growers) who must reduce stock or irrigate to support their production. If a drought persists, then yields of produce

decrease, and prices increase.

Source: NZHerald, Hawkes Bay today
This project is an exploration of the problem facing a farmer who has a limited stock of water that can be used for irrigation. This can be allocated to various products over time to maximize the expected profit earned over a growing period. This is done faced with the uncertainty in future weather conditions.
We will study this problem from an optimization perspective using dynamic programming. The stock of water could be a reservoir owned by the farmer or a contracted amount of water purchase. Each week, irrigation will be conducted accounting for the future prices of produce and the marginal value of water.


Project Aims

This project will require the student to start from scratch. I have no contacts in the industry, no data on water supply, and no clear idea of how farmers actually approach this issue. Discovering all of this, and developing models that they might find useful is part of the project.

1. Main Supervisor: Andy Philpott (100%)

69. Faster Shortest Path Computation for Traffic Assignment (Andrea Raith)

One of the major concerns of commuters in Auckland (and all over the world!) is road traffic and traffic congestion. Both the design of the road network and determining the best way to use it are complex questions that can be addressed based on so-called traffic assignment (TA) models, which are network equilibrium problems. These models can be used to assess the benefit of road upgrades or adding new roads to the network.

A TA problem models the route choice of users of a network with nonlinear travel time functions to capture congestion effects as more traffic flow on a road means slower travel time. The aim of TA is to identify how many network users end up choosing to travel along each individual arc in the network. This is done by assuming network users are selfish and choose to travel along their shortest path between origin and destination.

In solving such a TA equilibrium problem, an iterative approach is used. Initially all travel demand is assigned to the shortest paths computed for between each trip origin and destination based on zero-flow travel times. Then, travel times are updated based on the new flows. New shortest paths are identified and travel demand is re-assigned. This process continues until it eventually reaches the equilibrium solution.

The iterative scheme used by TA algorithms requires many shortest path calculations. Speeding up these shortest path calculations can lead to a significant speed up of TA algorithms, but the speed up technique used would differ for particular traffic assignment algorithms. One idea is to use A* search for TA algorithms that repeatedly compute shortest paths between single origin destination pairs. A* should lead to a significant improvement in runtime over using a standard label setting algorithm. Other speed-up techniques for shortest path algorithms will be identified and tested, exploiting the fact that while shortest paths change in every iteration of the algorithm, it may be possible to avoid fully re-computing shortest path trees. Avoiding re-computation of shortest path trees should benefit TA algorithms that require shortest paths between a single origin and all destinations.

Requirements: C/C++ Programming Skills.

Project Aims

- implement A* search within existing traffic assignment algorithm,
- identify and implement other promising speed up techniques,
- computationally investigate effects of using alternative shortest path methods within traffic assignment.

1. Main Supervisor: Andrea Raith (90%)
2. Secondary Supervisors: Olga Perederieieva (10%)

70. Road Network Design (Andrea Raith)

Road networks undergo continuing development as cities grow and transport needs change. Especially in New Zealand most of the spending in transport is going towards roading. The design of the road network is a complex task that can be addressed based on so-called traffic assignment (TA) models. These are network equilibrium models capable of capturing network congestion which is very important in cities with lots of commuters such as Auckland. These models can be used to assess the benefits due to road upgrades or due to the addition of new roads to the network.
In this project we develop and test models to help make a good choice of upgrades for an existing road network. Examples are the construction of new roads or the upgrade of existing roads to increase capacity. Decisions on upgrades are made under monetary constraints as funding agencies have limited budgets. It is therefore important to identify those upgrades that present best value for money. This value of upgrades consists largely of travel time savings for network users which can be measured using TA.

Components of this project are:
1) A TA problem is a nonlinear network equilibrium problem. In this project we will linearise this problem in order to be able to formulate a MIP that models possible network upgrades as integer decision variables but also captures the distribution of traffic flow in the network based on the linearised TA in its system-optimised formulation.
2) The initial model will be tested on simple road network instances.
3) A system-optimised formulation of TA models assumes that network users can be directed to travel to achieve an overall minimal travel time in the network. An alternative formulation of TA, also known as user equilibrium, assumes network users behave selfishly in choosing a route that is best for them which likely leads to worse overall travel times in the network. We will analyse the effects of the optimised network upgrades under both TA formulations.
4) Road network design requires long-term planning of upgrades made over time. The initial model can be refined to capture the temporal aspects of upgrades, to help prioritise them over a planning horizon.

Requirements: Programming Skills.

Project Aims

- formulate and test linearised system-optimal TA model,
- integrate and test a network design model with the TA model,
- analyse obtained solutions under system-optimised and user equilibrium TA,
- extend model to enable long-term network design.

1. Main Supervisor: Andrea Raith (50%)
2. Secondary Supervisors: Andy Philpott (50%)

71. Developing a Full Transport Model for Cyclists (Andrea Raith)

Non-motorised modes of transport such as public transport, walking and cycling become more important in view of increasing traffic congestion and oil prices. In this project, we focus on the improvement of cycling infrastructure in the Auckland region. Typically an agency such as Auckland Transport would have many different infrastructure development projects available, from

which a few are selected with highest benefit-to-cost ratio (BCR). The benefits within this BCR are derived based on travel time savings, safety improvements and most importantly new cyclists that change their mode of transport to cycling because of the newly constructed infrastructure. These new cyclists are also known as induced demand that appears after new infrastructure has been put into place. In this project the aim is to better understand and model induced cyclist demand. Better modelling of expected use of new infrastructure by cyclists means new cycle paths are developed where they are most needed.

It is not well understood how this induced demand for cycling could be modelled. In a conventional transport model the following aspects are modelled in sequence 1) how many trips from / to each origin / destination; 2) where exactly do those trip go to / come from and which mode of transport do they use 3) which routes are chosen by network users. A bi-objective shortest path route-choice model for cyclists in step 3) exists already. It is based on the assumption that cyclists aim to minimise their travel time as well as maximise the use of roads that are well suited to cycling. The aim of this project is to propose and test models to help determine how many trips travel from and to each zone, and how they are distributed. Models such as the gravity model exist for standard transport models and need to be modified to be compatible with the existing cycling route choice model. A crucial element of the gravity model is that it is based on cost of travel, which in the case of cycling consists of a travel time aspect but also a measure of the quality of route options. It will have to be determined how to alter the gravity model to incorporate these two objectives. Another improvement of the existing transport model is further improving the cyclist route choice model in Step 3) by better capturing factors affecting route choice such as road gradient and turning movements.

Requirements: Experience in C programming (existing code is available), Python

Project Aims

- Literature review on existing trip generation, mode share and distribution models for different transport modes
- Adaptation of most appropriate models to cycling
- Implementation of models within existing cyclist transport model
- Testing of obtained algorithms on the large real-world transport network of Auckland

1. Main Supervisor: Andrea Raith (100%)
2. Secondary Supervisors: Karl Jarvis (BECA)

3. Sponsoring Company: BECA

72. Estimating the Value of Freehold Properties (Cameron Walker)

In the UK, ownership of property can be split into freehold and leasehold. The freehold refers to the land itself and all immovable structures attached to the land, whilst a leasehold gives the tenant ownership of the property for a set period of time. At the end of the lease, the property reverts to the freehold owner. For the length of the lease, the leaseholder pays the freeholder a fee known as a ground rent.

As well as the ground rent, often the leaseholder has the right to purchase the freehold or extend the lease. This can either be transacted through commercial negotiation with the freeholder or through a statutory process. Lease extensions tend to occur when ownership of a leasehold is being transferred as banks don't generally offer mortgages on properties with a lease tenor of less than 70 years.

An important unknown in this asset class is the timing of leasehold extensions and the premia associated with this. The timing of leasehold extensions is strongly linked to the lease tenor, but property sale volumes will also have an impact. The premium calculation for an extension is dependent on a number of variables including property price, lease tenor and often inflation.
In this project we will investigate methods for calculating the premium on a lease and embed this calculation within an optimisation model for selecting a portfolio of leases

Project Aims

1) Develop a method (and associated software) for the premium calculation for a lease;
2) Develop an optimisation model (and associated implementation) for the selection of leases to build an optimal portfolio of leases.

1. Main Supervisor: Cameron Walker (50%)
2. Secondary Supervisors: Michael O'Sullivan (50%)

73. Insurance planning for 1-in-200 year events (Cameron Walker)

Insurance companies need to maintain capital to withstand the effect of rare events, e.g., a 1 in 200 year storm damaging a city. In order to get the amount of capital correct, the underlying time series of claim levels must correctly model these rare events. The effect of getting the underlying model wrong is that not enough capital is maintained and when the rare event occurs the company may fail.

However, most companies don't have sufficient data for multiple data sets of over 200 years. This project will investigate methods for predicting rare events from small data sets.

Project Aims

1) Perform extensive literature review;
2) Analyse data sets;

3) Develop methods for estimating 1-in-200 year events from small data sets;
4) Compare the effect of different methods for dealing with small data sets.

1. Main Supervisor: Cameron Walker (50%)
2. Secondary Supervisors: Michael O'Sullivan (50%)
3. Sponsoring Company: M&G Investments

74. Hedging Spot Price Uncertainty in the New Zealand Electricity Market (Golbon Zakeri)

In the New Zealand wholesale electricity market, an optimization problem (Scheduling, Pricing and Dispatch, SPD) is solved every five minutes to determine the cheapest way that power can be supplied to consumers; this economic dispatch problem determines how much power each plant should produce, and the prices at all buses in the transmission grid. This prices (also known as spot prices) can be very volatile and are influenced by many factors, such as demand levels, outages, hydrology conditions (e.g. if hydro storage is low, prices tend to be high). For this reason, it is important for market participants, both generators, retailers and large industrial consumers to be able to hedge against this uncertainty.

In this project, we will extend the capabilities of a model developed last year as a part 4 project. This model, used historic prices to construct distributions of future prices, and using a hidden markov model estimated the value of ASX futures contracts based on current observed spot prices. The key extension that needs to be included in this model is the impact of hydro storage and inflows on future electricity prices.

Project Aims

This project will involve the following:

a) developing simple rule-of-thumb techniques to take account of the effect of hydrology on electricity prices, to provide a benchmark for our more sophisticated model;
b) incorporating hydrology into the hidden Markov modelling framework to estimate electricity futures contract prices.
c) from the point of view of a risk-averse market participant construct a hedging strategic to reduce their exposure to the spot market, at least cost.

1. Main Supervisor: Golbon Zakeri (50%)
2. Secondary Supervisors: Tony Downward (50%)

75. Transpower Project 1: Binary Interruptible Load Optimization (Golbon Zakeri)

Electricity networks rely on reserves to maintain supply following a fault.
If there is a sudden deficit of generation over demand (e.g., from a generator disconnecting), the

power frequency will start to fall. Reserves are mechanisms to reduce demand or increase generation automatically following a drop in frequency.

The New Zealand electricity market relies upon a linear optimization dispatch engine, SPD, to schedule both generation and reserves on a least cost basis. A number of the demand-side reserve (interruptible load) providers are heavy industrial consumers that offer the {\em entire} load of a particular process, e.g. a steel smelter. However, SPD, is a linear programming engine (not a MIP solver) and therefore it is unable to impose ``all or nothing'' binary interruptible load constraints. As a result, SPD is solved as an LP, the interruptible load solutions are rounded and implemented. Thus, when one of these providers is partially curtailed through the LP, they would actually trip their entire load. This over provision can lead to an under frequency event becoming an over frequency event as too much interruptible load responds to the initial event.

This project will start by simulating the current process using a (full sized) replica of the SPD engine, called vSPD. This simulation will provide us with an estimate of the costs and other consequences of approximating the true MIP by an LP. We will then implement an enumeration scheme enumerating , solving the combinations of interruptible load. In the final phase, we will convert vSPD from its current linear form to a mixed integer program that will account for binary interruptible load. This is a useful benchmark on the implementability of a MIP based SPD that would cater for binary interruptible load.

Project Aims

1) Assessing the cost and consequences of scheduling binary interruptible load through current suboptimal practice.
2) Developing the integer programming formulation of vSPD to optimally allocate interruptible load curtailment.

1. Main Supervisor: Golbon Zakeri (34%)
2. Secondary Supervisors: Tony Downward (33%), Andy Philpott (33%)