PIMS/Fields/CRM

2017 Graduate Math Modelling in Industry Workshop

Winnipeg, MB

Project Descriptions

Project 1: Reconciling potential and effective air travel data

Mentor: Dr. Julien Arino

Description: Two main types of data sets are available regarding the global movement of individuals along the global air transportation network. The first type is anticipatory and describes the network configuration and its capacity, i.e. the number of seats available on regularly scheduled flights between pairs of airports. The second type of data set has the actual number of trips between pairs of airports, including intermediate stops. In a sense, the latter is a realization of the former. These types of data are extremely important in understanding the way individuals utilize the air transportation network, which has a variety of implications and in particular in terms of the potential for infectious pathogens to quickly disseminate globally.

The aim of this project is to compare the two types of data sets and try to reconcile the information they provide. Indeed, the granularity (temporal resolution) of the sets varies, with the anticipatory data given with a resolution of a minute and the posterior data aggregated over a month. Social network measures can be computed on the two networks, for instance, and it would be interesting to understand if and how they relate. Also, the networks can both be used to forecast the anticipated spread of an infectious pathogen, for example using Markov chains. How do the predictions using both network types differ?

Students working on this project should have:

- Some knowledge of network analysis
- Some knowledge of social network analysis
- A familiarity with Markov chains or other types of stochastic processes

Project 2: Modelling cell signalling pathways

Mentor: Dr. Marine Jacquier

Description: Cellular response to stimuli is the result of a series of molecular events following a signalling pathway. Most of these biochemical reactions are related to the phosphorylation of proteins and can ultimately impact many cellular processes including growth, proliferation and survival. Analysis of signalling pathways is an important tool to understand cellular mechanisms, in particular in cytopathologies. Concentrations of some proteins can be modified in some cells, due to diseases or drugs, resulting in a different behaviour of the signalling pathway.

The project will focus on modelling the network of interactions between molecules in relation with experimental data, including:

- Comparison of models based on different assumptions,
- Estimation of reaction rates of enzymes in the cell,
- Identification of the main components of the pathway,
- Evaluation of the effect of perturbations on the dynamics (for example the effect of drugs).

Students working on this project should have:

- Knowledge of ordinary differential equations
- A familiarity with stochastic modelling and/or numerical methods
- Some knowledge of mathematical biology, in particular biochemical modelling and enzyme kinetics, is an asset.

Project 3: Modelling a quantum spin network

Mentor: Dr. Sarah Plosker

Description: Quantum communication concerns the transmission of quantum states from one location to another. Physically, a quantum state is a description of some configuration of an atom of material, a photon of light, or some other basic physical object in quantum mechanics. Mathematically, a quantum state is represented as a vector in some linear space, typically an eigenvector of a matrix that mathematically models the physics of the atom, photon, or other quantum object.

One important aspect of quantum communication is the ability to transfer a quantum state between quantum processors or registers within a quantum computer. This transfer should occur quickly and accurately. Such a communication setup can be achieved through the use of spin network dynamics. Specifically, a quantum spin network can be modelled by way of a graph, and much work has been done recently by employing techniques from graph theory, combinatorics, number theory, linear algebra, physics, and quantum information theory.

This project will focus on a number of open problems in the area, including:

- Reconciling the numerical results obtained by physicists with analytic results from pure math (e.g. with respect to recent results on paths with potentials)
- Determining whether certain well-known graphs (e.g. trees) have perfect or pretty good state transfer
- Characterizing the pairs of vertices where perfect or pretty good state transfer occurs in recent constructions of graphs involving Hadamard matrices

Students working on this project should have:

- Knowledge in at least one of the following: linear algebra, graph theory, combinatorics, or mathematical physics/quantum mechanics
- A willingness to learn at least some material from any of the other listed subjects with which you are unfamiliar
- Familiarity with scientific programming languages and software (Matlab, Octave, SciPy, etc.) would be an asset

Project 4: Modelling the organization of the cytoskeleton

Mentor: Dr. Stephanie Portet

Description: The cytoskeleton is an intracellular network made of different types of structural proteins. The cytoskeleton is in charge of major functions in cells. Defaults in the structural organization of cytoskeletal networks are linked with human diseases; for instance, the presence of protein aggregates inside cells is observed in the case of neurodegenerative diseases. The organization of cytoskeletal proteins in cells results from the combination of processes of proteins assembly/disassembly, protein synthesis/degradation and the intracellular transport of these proteins. Various questions arise in investigating the organization of the cytoskeleton and the project will focus on a number of issues:

- How to represent the cytoskeleton in a mathematical model
- Problem of aggregation/fragmentation
- Problem of synthesis/degradation
- Modelling the intracellular transport

Students working on this project should have:

- An understanding of dynamical systems (ordinary/partial differential equations)
- Knowledge of numerical methods
- Some biological knowledge might be beneficial

Project 5: Financial risk forecasting

Mentor: Dr. A. Thavaneswaran & Dr. O. Paseka

Description: We are in a world saturated with data and information, and numerous quantitative methods for financial risk forecasting are proposed and used by many financial research institutions and organizations within recent years.

Quantitative financial risk forecasting is now a fundamental tool for investment decisions and capital allocation. The Global Financial Crisis (GFC) has emphasized the importance of accurate VaR (value at risk) forecasting for financial organizations, which requires accurate data driven volatility estimation.

The focus of this project is on the study of market risk forecasting from a quantitative point of view. The emphasis is on presenting data driven volatility models and forecasting techniques for the management of market risk and demonstrate their use by employing the two mathematical programming languages, R and Matlab. The project brings together three essential fields: finance, statistics and computer programming.

Students working on this project should have:

- A basic understanding of Statistics and Finance
- A Willingness to learn at least one of the programming languages R and Matlab