PIMS/Fields/CRM

2016 Graduate Math Modelling in Industry Workshop

Vancouver B.C.

Project descriptions

Project 1: Stochastic modelling for hydro-electric reservoir management

Mentor: Fabian Bastin - University of Montreal

Description: The operation of a hydroelectric generation facility that supplies electrical power must balance the demands for water flow into the generators with the availability of water in the large reservoir behind a damn. The electrical power demand can be predicted quite accurately, but the main uncertainty in the operation is the source of the water inflows, especially regarding the seasons. For instance, during Winter, there is practically no inflow of water to the reservoir, but the electrical demands are quite high. In the Spring, when the snow melts, large water inflows occur, while the electrical demand becomes smaller. Various questions arise in analysing this situation, and the project will focus on a number of issues, including:

- the modelling of inflows, based on historical data, and the creation of scenario trees;
- the optimization of reservoirs management. This may include using the progressive hedging algorithm, a popular but challenging technique in stochastic programming;
- the numerical simulation of the system.

A key goal is to develop a better way to model the uncertainty for this process. Some initial software models for the system are available, and the student will be looking to create better, more realistic simulation.

Desired background for students working in this project include:

- Stochastic processes and stochastic modeling
- Optimization
- Numerical methods

More resources: https://www.cirrelt.ca/DocumentsTravail/CIRRELT-2012-35.pdf

Project 2: Variable selection problem and statistical prediction for an industrial reactor

Mentor: Derek Bingham - Simon Fraser University

Description: A local company is designing and testing a prototype of a certain type of industrial device with the goal of creating a commercially viable, large-scale electrical power system. The system depends on a fundamental physical process that requires precise control and calibration to function correctly, and needs optimization to produce an economically viable production operation.

The physics and principles of operation for the device are very complex and involved, and the prototype is surrounded by a vast array of sensors that monitors the operation while collecting data on a wide variety of physical parameters (which could include temperature, density, pressure, rates of motion, vibrations, electromagnetic fields, etc), which are spatially and temporally sampled at high data rates.

The challenge in this project is to sort through this vast array of data and select variables that are statistically significant in predicting the operation of the key parts of the device. A keen understanding of the problem of uncovering statistical significance in a large data set will be necessary to make progress in the project.

Desired background for students working in this project include:

- Statistics and statistical tests of significance
- Machine learning and numerical methods for data analysis
- Some physics might be beneficial

More resources: to come.

Project 3: Growth of nanoparticles for industrial production

Mentor: Tim Myers - Centre de Recerca Matemàtica, Spain

Description: Nanoparticles are small units of matter with dimensions in the range of 1 to 100 nanometers. They have recently become the focus of intense research due to their unique characteristics. Nanoparticles exhibit many advantageous size-dependent magnetic, electrical, chemical and optical properties, which are not observed at the macroscale. As these properties are extremely sensitive to the particle size, the ability to produce monodisperse particles that lie within a controlled size distribution is critical. In the context of nanoparticles, monodispersity typically refers to size distributions where the standard deviation is less than five percent. Applications that require uniform particles include light emitting diodes, solar energy systems, multi-terabit magnetic storage and biological imaging.

Due to its ease of use and flexibility, precipitation of nanoparticles from solution is one of the most widely used production methods. In this process particles are first nucleated from a supersaturated solution. This is a very rapid part of the process, it is then followed by a slow growth stage. During the growth stage, the solution concentration decreases as the particles grow. The resulting two-phase system consists of varying sized particles, and is thus not in its lowest possible energy state, due to the presence of the smaller particles. Thermodynamic equilibrium is achieved by Ostwald ripening, whereby smaller particles dissolve due to their higher solubility and the material then released is used in the growth of larger particles. However, this simultaneous growth and dissolution of bigger and smaller particles, respectively, leads to the unwanted defocusing of the particle size distribution (PSD). That is, there is a greater spread in particle sizes. The PSD can be refocused by changing the reaction kinetics for example by the injection of additional material, adjusting the temperature or pH.

In this project we wish to develop a mathematical model for the growth of spherical nanocrystals from solution. Once the basic model is developed we will extend it to a number of particles and determine the factors controlling the size distribution, with the goal of producing particles of a similar size. We will then look for published experimental data and attempt to fit the model to such data.

Desired background for students working in this project include:
- Partial differential equations
- Numerical methods
- Some physics

More resources: to come

Project 4: This party is too big, folks! Setting room capacities for safety.

Mentor: Nilima Nigam - Simon Fraser University

Description: Most rooms for public gatherings will have signage about the maximum lawful capacity of people in the room. Similarly, elevators state a maximum number of people. In this project, the students' task is to develop a mathematical model to determine the maximum lawful capacity for the Chan Shun Concert Hall in the Chan Center for the Performing Arts at UBC. Similarly, the students will determine the maximum allowable number of people in the elevators leading to the Chan Center.

An initial focus is to consider what factors may be important. Layout? Access to exits? Speeds of humans? Seating arrangements? Remember that the Chan Shun Concert Hall has several options for configuration. Would one want to change the maximum lawful capacity in these cases? How will these proposed answers in the project compare to the technical specifications for the venue? Any mathematical model needs to be explicit about any simplifying assumptions and scaling arguments used.

As a more sophisticated variant, suppose the VSO schedules a performance of music aimed at children under 18 months, who are accompanied by at least one adult each. Assume the seats in the Chan Shun Concert Hall can be moved, and that each child will be in a stroller. Determine the maximum capacity of the venue in this case.

With very high probability, if the results of this project determine the lawful capacity is lower than what is stated on the Chan Center's website, the students can expect their results to be challenged! The final report needs to include a short statement to the public, defending your model.

Desired background for students working in this project include:
- Discrete mathematics
- Statistics and/or stochastics
- Numerical modeling

More resources: this project is based on an example in the 1999 Math Contest in Modelling, Math Contest in Modeling 1999 MCM problem,
http://www.comap.com/undergraduate/contests/matrix/PDF/1999mcmProblems.htm

Project 5: Modelling the performance of rechargeable Li-Ion batteries

Mentor: Brian Wetton - University of British Columbia

Description: Rechargeable batteries are now standard components in electronic devices and are becoming more widely used in electric vehicles. Lithium ion batteries are one of the most popular types for both of these applications. They have high energy density and a long shelf life, are cheap to construct, and are safe to store and operate (all in comparison to other battery types). In these batteries, energy is stored when Lithium ions enter a solid electrode of layered material. Basic information about Lithium ion batteries can be found, on Wikipedia and at http://batteryuniversity.com/

This project will explore the modelling of small scale Lithium ion batteries for electronic devices. Using experimental data on charging and discharging cycles, we will develop virtual battery simulation tools to predict performance in varying conditions and to develop optimal charging strategies. Models will begin with simple black box (system identification) and equivalent circuit models and can be extended to include more physics and chemistry. As time permits, we can consider using the simulation tools to investigate charging and operation of batteries with different characteristics arranged in parallel and series.

Students may measure battery performance themselves using simple electronic equipment, if time and resources permit. As a backup plan, the experimental data used to develop the models will be taken from the manufacturer's data and scientific literature.

Desired background for students working in this project include:

- Differential equations
- Numerical methods

More resources: http://batteryuniversity.com/

Project 6: Modelling and optimisation of traffic light signals

Mentor: Chris Budd - University of Bath, UK

Description: Traffic flow through a city is an important problem for transport planners; traffic jams can have serious economic implications both for the individuals stuck in the jams and the businesses that lose time and revenue as a result. Traffic light signalling is a crucial part of maintaining a good traffic flow and robust algorithms are needed to determine the signal timings. As flow rates increase during peak times, poorly chosen timings will cause the breakdown of the flow, and hence create a traffic jam. Well chosen timings will allow higher flow rates and hence delay the breakdown of the flow, potentially avoiding a traffic jam altogether.

Although many junctions are equipped with traffic sensors in the form of inductance loops buried in the road, a large number of traffic lights are still operated on a fixed timing system. (The fixed times may change throughout the day.) To determine the timings, historical traffic flow data is used. Robust methods are needed to determine appropriate timings given uncertainties in the flow rates.

A further level of sophistication comes when sensor input is available to the traffic light signaling software. The idea is that with accurate arrival data, signal timings can be chosen optimally. Moreover, GPS data from buses and other vehicles on the road may be used to give forecasts of future arrivals.

Desired background for students working in this project include:

- Differential equations
- Numerical methods
- Perhaps some stochastic methods