DEPARTMENT OF MATHEMATICS AND STATISTICS
Summer 2025 Research Projects (in no particular order)

Queen's UNIVERSITY

Last updated: 07 January 2025

Project Title: Markov genealogy processes

Supervisor: Felicia Magpantay and Troy Day

Project Description: During an epidemic the emergence of "variants of concern" is shaped by evolutionary pressures such as vaccination and competition. The pandemic has led to an explosion in genomic surveillance, highlighting the need for efficient and mathematically rigorous analysis of epidemiological time series coupled with genetic data. In this project we will look into the recently developed theory of Markov genealogy processes. We will also examine the implementation of this theory for statistical inference in the R package phylopomp and apply it to datasets.

Main reference: https://doi.org/10.1016/j.tpb.2021.11.003

Student's Role: The student will participate in our study of Markov genealogy processes and conduct a review of different approaches in phylodynamic analysis. The student will also learn about phylopomp and high-performance computing, and apply these to a disease modeling project using real data.

Prerequisites (req'd background/level of study): Solid background in probability, basic mathematical or statistical programming.

Project Title: Mathematics of Reinforcement Learning under Partial Information

Supervisor: Serdar Yuksel

Project Description: For many stochastic decision and control problems, an exact model of a system being studied is not available; and even when an approximate or exact model is available, the information at the decision maker with regard to the state being controlled is often limited and partial. Data-driven learning is an appropriate framework for such settings. The general goal of this project is to study the optimal design of decision/control policies in such stochastic systems with incomplete models and partial information via reinforcement or empirical learning methods. Depending on student interest, we will focus on one of the following, closely related, three main themes:

- (i) Optimal stochastic control with partial information: Non-linear filtering, approximations, and relations with reinforcement learning
- (ii) Multi-agent systems, stochastic teams, and games: Arriving at optimality/equilibrium under decentralized information
- (iii) Sample complexity in such learning algorithms

Student's Role: The expectation is that the student would study a wide variety of resources that will be provided, take part in regular research discussions through frequent meetings, and write a mathematically rigorous technical document at the end of the summer.

Prerequisites (req'd background/level of study): A strong foundation and interest in probability theory and analysis.

Project Title: : Investigating Secant Varieties

Supervisors: Mike Roth and Gregory G. Smith.

Project Description: A projective variety X is the common zero-locus of a family of homogeneous polynomial equations. The associated secant variety is the closure of the union of all secant lines to X; this new space is again described by polynomial equations. When X has dimension n, one expects that its secant variety will have dimension 2n+1, because the two points of contact on the secant line each move in an n-dimensional family (namely X) and the line adds one extra dimension. Embedded varieties where the dimension of a secant variety is strictly less than the expect dimension are called defective. Remarkably, the only algebraic variety where the defectivity of secants is understood for all embeddings is when X is itself a projective space. The goal of this project is to investigate the problem of defective secants when X is a toric variety. Toric varieties are particularly nice class of varieties with a strong connection to combinatorics and convex polytopes.

Student's Role: To learn some of the dictionary between the algebraic, geometric, and combinatorial ideas, as well as some basic background in geometry relevant to the problem. To use a computer to gather data on toric varieties (especially toric surfaces) with defective secants and to formulate conjectures.

Prerequisites (req'd background/level of study): The student should at least have taken Math 110, Math 120, and Math 210. Upper-year courses in algebra or geometry are a plus. The student should be willing to use a computer to do experiments, and be willing to learn how to use the software appropriate for these computations.

Be sure to check back as additional projects may be added.