THE UNIVERSITY *of* EDINBURGH

Student projects

Innovating Algorithmic Challenges in Finance and AI

Project ref: XFM164

Project supervisor: Dr Daniel Adams

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project is ideal for those eager to work at the intersection of blockchain technology, finance, and machine learning.

Algorithms shape the world around us—whether by finding the shortest path between nodes, optimizing neural network loss functions, or identifying the k-nearest neighbors to a vector. These mathematical challenges underpin modern computation, optimization, and artificial intelligence.

Our company, TIG (The Innovation Game), is developing a decentralized platform for designing and testing innovative algorithms. Our platform provides a collaborative ecosystem where Innovators create algorithms, and Benchmarkers validate them, driving progress in algorithmic research.

At TIG, algorithmic challenges must be asymmetric—meaning they are computationally expensive to solve but easy to verify. Problems with this structure play a crucial role in real-world applications.

As part of this MSc thesis, you will collaborate with our researchers to design and formalize a novel algorithmic challenge that aligns with the TIG framework. Your responsibilities will include:

 Clearly defining the challenge, including its objectives, constraints, and structure.

 Explaining its real-world or theoretical significance.

 Highlighting the problem's asymmetric nature.

 Establishing methods to control the challenge's difficulty.

This MSc thesis provides a high degree of freedom in selecting a challenge, though we are particularly interested in problems related to finance and machine learning. Potential directions include portfolio optimization, time-series anomaly detection, sparse feature selection, and fast approximation of NP-hard problems. Throughout the project, you will engage with state-of-the-art techniques and benchmark potential solutions. If successful, your challenge will be deployed on our platform as part of a decentralized system.

Computational component

40%

Prerequisites

The student should be comfortable with programming, machine learning, and probability theory. An interest in blockchain technology is a plus but definitely not essential.

Recommended reading

- The Innovation Game whitepaper
- https://www.youtube.com/watch?v=afZO45MvmA4&t=1141s

Noise sensitivity of Boolean functions and their application in Deep Learning

Project ref: FM237

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Noise sensitivity of Boolean functions has many application in statistical physics and has been pivotal to many important developments in percolation theory. In recent years Noise sensitivity has been applied in machine learning. The aim of this project is to understand these developments.

Computational component

Up to 10%

Prerequisites

Strong background in functional analysis and probability theory. Solid background in linear algebra.

Convex optimization in computer science

Project ref: FM260

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The aim of the project is to learn about application of ideas from convex analysis in problems originating in computer science.

Computational component

0%

Prerequisites

Strong background in probability theory, stochastic processes and functional analysis. Solid background in linear algebra and multivariate calculus.

Recommended reading

[1] Sebastien Bubeck, Ronen Eldan. "Multi-scale exploration of convex functions and bandit convex optimization"

Convex optimization in machine learning

Project ref: FM236

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The project aims to explore how concepts from convex analysis apply to machine learning problems. By studying these connections, we seek to enhance optimization techniques, improve model performance, and develop efficient algorithms. This research bridges mathematical theory and practical applications, contributing to advancements in modern machine learning methodologies.

Computational component

0%

Prerequisites

Strong background in functional analysis, stochastic processes and probability theory. Solid background in linear algebra and multivariate calculus.

Recommended reading

[1] Sebastien Bubeck, Ronen Eldan. "Multi-scale exploration of convex functions and bandit convex optimization"

stochastic block models - two communities recovery

Project ref: FM235

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The stochastic block model is a canonical model to study clustering in graphs and is often employed in data science. The aim of this project is to understand the model and in particular, to obtain exact recovery of two large sets in a connected graph.

Computational component

Up to 10%

Prerequisites

Strong background in probability theory. Solid background in linear algebra and combinatorics.

Recommended reading

[1] Emmanuel Abbe, Colin Sandon. "Recovering communities in the general stochastic block model without knowing the parameters"

stochastic block models - the MAP estimator

Project ref: FM234

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The stochastic block model is a canonical model to study clustering in graphs and is often employed in data science. The aim of this project is to understand the model and in particular, the MAP estimator that helps analyzing large data sets.

Computational component

Up to 10%

Prerequisites

Strong background in probability theory. Solid background in linear algebra and combinatorics.

Recommended reading

[1] Yuichi Kitamura, Louise Laage. "Estimating Stochastic Block Models in the Presence of Covariates"

Noise sensitivity of Boolean functions and their application in Percolation theory

Project ref: FM245

Project supervisor: Ofer Busani

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Noise sensitivity of Boolean functions has many application in statistical physics and has been pivotal to many important developments in percolation theory. The aim of this project is to understand the role of Noise sensitivity of Boolean functions in Percolation theory.

Computational component

0%

Prerequisites

Strong background in functional analysis and probability theory. Solid background in linear algebra.

An Actor-Critic reinforcement learning algorithm for the continuous-time optimal execution problem

Project ref: FM265

Project supervisor: Galen Cao

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project aims to construct an actor-critic reinforcement learning (RL) framework for the optimal execution problem in a continuous-time setting. The optimal execution problem is a widely discussed topic in algorithmic trading, concerned with designing trading strategies that minimise execution costs and maximise revenues when executing large numbers of shares. This problem was initially introduced and well-modelled by Almgren and Chriss. RL has recently become a powerful tool for solving stochastic optimisation problems. Unlike the traditional mathematical approach, which requires explicit modelling of the environment, RL is essentially data-driven and learns the optimal policy through interactions with the environment. Among the wide range of RL techniques, actor-critic algorithms are widely used, which learns the value function and updates the policy through a critic and an actor, respectively.

This project focuses on solving the exploratory (relaxed) control problem in the continuous-time Almgren-Chriss model and using the resulting analytical insights to develop an actor-critic algorithm that learns the optimal policy from interacting with the environment. This work can involve both theoretical analysis-establishing the convergence and error analysis of the algorithm-and numerical simulations to evaluate robustness of the algorithm under market uncertainty and model misspecification.

Computational component

up-to 50%

Prerequisites

- Confident in stochastic control theory
- Proficient in Python programming and numerical simulations
- Familiar with actor-critic reinforcement learning methods
- Interested in algorithmic trading and date-driven approaches in finance

Recommended reading

- Boyu Wang, Xuefeng Gao, and Lingfei Li. Reinforcement learning for continuous-time optimal execution:

actor-critic algorithm and error analysis. SSRN, 2023.
- Yanwei Jia and Xun Yu Zhou. Policy gradient and actor-critic learning in continuous time and space: Theory and algorithms. Journal of Machine Learning Research, 23(275):1–50, 2022.
- Alvaro Cartea, Sebastian Jaimungal, and Jose Penalva. Algorithmic and high-frequency trading. Cambridge University Press, 2015
- Robert Almgren and Neil Chriss. Optimal execution of portfolio transactions. Journal of Risk, 3:5–40, 2001.

Bridging Computational and Natural Language: An LLM Framework for Explaining DICE Climate Model Results

Project ref: XFM176

Project supervisor: Jiajia Cui

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The **DICE (Dynamic Integrated Climate-Economy) model** produces highly technical outputs (e.g., carbon price trajectories, temperature projections, economic trade-offs) that require expert knowledge to interpret. This creates barriers for policymakers, journalists, and the public in understanding climate policy implications.

This project proposes **fine-tuning a Large Language Model (LLM)** to:

 Automatically **translate DICE's numerical outputs** into clear, actionable summaries.

 Generate **tailored reports** for different audiences (e.g., technical vs. public-facing).

 Enhance **accessibility and usability** of climate-economic insights.

Research Objectives:

Develop a dataset pairing DICE outputs (e.g., CSV/JSON tables) with human-written explanations.

Fine-tune an LLM (e.g., Llama 3, Mistral, or GPT) to generate accurate, context-aware interpretations.

Evaluate output quality through expert review and readability metrics.

Deploy an interactive tool (e.g., web app or API) for real-time DICE report generation.

Computational component

60%

Prerequisites

Optimal Control, strong Python skills

Recommended reading

https://economics.yale.edu/sites/default/files/2024-03/barrage-nordhaus-2024-policies-projections-and-the-social-cost-of-carbon-results-from-the-dice-2023-model.pdf

https://www.datacamp.com/tutorial/fine-tuning-large-language-models

Estimating roughness index from signals

Project ref: XFM169

Project supervisor: Purba Das

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Processes with 'rough' behaviour are often observed in financial time series (a recent development is the rough volatility literature). Depending on the situation these processes may behave rougher/smoother/ similar to a typical path of semi-martingale. This project will mainly focus on different methods of measuring the "roughness" from a given signal.

The project will be structured in three parts:

→ Understanding theoretically the different notions of roughness, like Hurst exponent, Holder regularity, Besov regularity.

→ Exploring different methods of estimating roughness, this includes both model-based classical methods and model-free methods. Compare the estimators for simulated processes like fractional Brownian motion, fractional OU process, andrough Heston model.

→ In simple simulated setups for price paths, estimate the roughness of realized volatility.

Computational component

Between 30-50%, but can be adjusted depending on students preference.

Prerequisites

Basic knowledge of Brownian motion will be required.
Prior knowledge of fractional Brownian motions will be helpful for the project but not necessary.

Mean-field SDEs simulation under super linear growth coefficients

Project ref: FM269

Project supervisor: Goncalo dos Reis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

We study the simulation of mean-field or McKean-Vlasov Stochastic Differential Equations (MV-SDEs) with drifts of super-linear growth and random initial condition. These equations have attracted the attention of many researchers over the last 10 years due to their wide range of applicability, from finance, to biology to machine learning. We discuss numerical methods for MV-SDE when the coefficients are of super linear growth for which the usual Euler scheme can be shown to explode in finite time regardless of the size of teh time step.

We test numerically the theoretical convergence rates and illustrate a computational complexity advantages of the explicit over the implicit scheme. We provide numerical tests illustrating "particle corruption" effect where one single particle diverging can "corrupt" the whole particle system. Moreover, the more particles in the system the more likely this divergence is to occur.

Computational component

50%

Recommended reading

https://arxiv.org/abs/1808.05530

Levy Areas, Milstein scheme and multi level monte carlo

Project ref: FM272

Project supervisor: Goncalo dos Reis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Goal of this project: understanding what Levy areas are, why they are a big issue in the simulation of SDEs in higher dimensions and a surprising result coming out of Multi-Level Monte Carlo

See a presentation on the issue of simulating Levy Areas (and a solution to it):
https://www.youtube.com/watch?v=eAf7l57QXIw

In this project, we derive and implement Milstein scheme in multi-dimensions where the issue of Levey-Areas appears. We introduce a multilevel Monte Carlo (MLMC) estimator for multi-dimensional SDEs driven by Brownian motions and through the construction of a suitable antithetic multilevel correction estimator, we are able to avoid the simulation of Lévy areas and still achieve an efficient multilevel correction variance for smooth payoffs.

Computational component

high

Prerequisites

stochastics, SDE numerics, programming

Recommended reading

MAIN PAPER #1 (on Multi Level Monte Carlo) GILES , M. B. (2008). Multilevel Monte Carlo path simulation. Oper. Res. 56 607–617. MR2436856

MAIN PAPER #2: Giles 2014, Antithetic multilevel Monte Carlo estimation for multi-dimensional SDEs without Lévy area simulation

Books:

Glasserman. Monte Carlo Methods in Financial Engineering. Springer 2004
and
Platen and Kloeden, Numerical Solution of SDEs, 2004

Passive and Competitive Investment Strategies

Project ref: FM268

Project supervisor: Goncalo dos Reis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Making market investments has always a time-maturity dependency to it, the dependence on the horizon time (usually T). What happens when you change your mind mid-way and you want to change your investment strategy in way that introduces no arbitrage in the market? Most theories do not allow for this. In this project, we introduce the concept of "forward performance" in the context of hedge-fund managers.

In an Ito-diffusion market, we consider two fund managers who trade depending on each other's strategies. We analyze both the passive and the competitive cases, and under both asset specialization and diversification. To allow for dynamic model revision and flexible investment horizons, we introduce the concept of relative forward performance for the passive case and the notion of forward Nash equilibrium for the competitive one.

Computational component

up to 20%

Prerequisites

Stochastics,knowledge of optimal control would be helpful but is not necessary

Recommended reading

https://ssrn.com/abstract=2870040

Random Batch Methods (RBM) for interacting particle systems

Project ref: FM271

Project supervisor: Goncalo dos Reis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

We develop Random Batch Methods for interacting particle systems with large number of particles. These methods use small but random batches for particle interactions, thus the computational cost is reduced from O(N^2) per time step to O(N), for a system with N particles with binary interactions.

On one hand, these methods are efficient Asymptotic-Preserving schemes for the underlying particle systems, allowing N-independent time steps and also capture, in the $N to infty$ limit, the solution of the mean field limit which are nonlinear Fokker-Planck equations; on the other hand, the stochastic processes generated by the algorithms can also be regarded as new models for the underlying problems. For one of the methods, we give a particle number independent error estimate under some special interactions. Then, we apply these methods to some representative problems in mathematics, physics, social and data sciences, including the Dyson Brownian motion from random matrix theory, Thomson's problem, distribution of wealth, opinion dynamics and clustering. Numerical results show that the methods can capture both the transient solutions and the global equilibrium in these problems.

Computational component

50%

Recommended reading

https://doi.org/10.1016/j.jcp.2019.108877

McKean-Vlasov SDE and their simulation

Project ref: FM270

Project supervisor: Goncalo dos Reis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

McKean-Vlasov SDE equations have attracted the attention of many researchers over the last 10 years due to their wide range of applicability, from finance, to biology to machine learning. We study the basic constructions of McKean-Vlasov equatiosn and prove that the weak error between a stochastic differential equation and its approximation by the Euler discretization with time-step h of a system of N interacting particles is O(N −1+h). We provide numerical experiments confirming this behaviour and showing that it extends to more general mean-field interaction and study the efficiency of the antithetic sampling technique on the same examples.

Computational component

50%

Recommended reading

https://arxiv.org/abs/1809.06838

The Turnpike Property for Long-term Investments

Project ref: FM253

Project supervisor: Stefan Engelhardt

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The turnpike property is named after the observation that when you want to drive a long distance,the best solution often consists of quickly getting to the motorway, also called the turnpike,staying on it until you are close to the end and only then getting off in order to get to theactual destination.Investing is basically a control problem, where on long time-scales one can also observe thisphenomenon.In this project we will review theoretical results on the turnpike property for stochastic controlproblems with constant dynamics and do an implementation where we numerically very itfor long-term investments.This project can be extended by some theoretical results.

Computational component

up to 25%

Prerequisites

Stochastic Control and Dynamic Asset Allocation

Recommended reading

C.-f. Huang and T. Zariphopoulou, Turnpike behavior of long-term investments, Finance and Stochastics 3 (1999), 15–34.

J. Sun, H. Wang, and J. Yong, Turnpike properties for stochastic linear-quadratic optimal control problems, Chinese Annals of Mathematics, Series B 43 (2022), no. 6, 999–1022.

Numerical Approximation of conditional Expectations

Project ref: FM255

Project supervisor: Stefan Engelhardt

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Conditional expectations are at the heart of many stochastic problems. One where they cannotbe circumvented is the pricing of American-type options, where the Snell-envelope usually is anessential part.In this project we will have a look at different methods on how to approximate conditionalexpectations numerically and their appropriateness, for example by Monte-Carlo simulation,(linear) regression and neural networks. Those different methods can then be compared fordifferent application purposes.

Computational component

up to 40%

Prerequisites

Some familiarity with programming

Recommended reading

S. Becker, P. Cheridito, and A. Jentzen, Pricing and hedging american-style options with deep learning, Journal of Risk and Financial Management 13 (2020), no. 7, 158.
M. Mollenhauer and P. Koltai, Nonparametric approximation of conditional expectation operators, arXiv preprint arXiv:2012.12917 (2020).

The Differential Riccati Equation

Project ref: FM254

Project supervisor: Stefan Engelhardt

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

There are many applications of which the solution involves solving a differential Riccati equation.One known from the RNAP lecture is the zero-coupon bond price in an affine term structure.Another is solving stochastic linear quadratic control problems, where this differentialequation might be matrix valued.This project will consist of the derivation of those differential Riccati equations and theimplementation of numerical methods to solve them, which can then be applied to more specificproblems.

Computational component

up to 20%

Prerequisites

Stochastic Control and Dynamic Asset Allocation

Recommended reading

M. Kamali, N Kumaresan, and K. Ratnavelu, Solving differential equations with ant colony programming, Applied Mathematical Modelling 39 (2015), no. 10-11, 3150–3163.

J. Zhang, W. Zou, and C. Sui, Backward differentiation formula method and random forest method to solve continuous-time differential riccati equations, Asian Journal of Control (2024).

Using deep learning to solve BSDEs and PDEs

Project ref: FM252

Project supervisor: Stefan Engelhardt

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Finding solutions to backward stochastic differential equations (BSDE) and parabolic partialdifferential equations (PDE) in a high-dimensional setting, is a common and hard problem inmultiple disciplines. The difficulty often stems from the curse of dimensionality. In [HJ17]a deep learning approach was presented to circumvent this problem. The approach uses theequivalence of PDEs to BSDEs, which in turn can be viewed as control problems and then solvedby considering this as a least-squares learning problem.In this project we will understand and implement the method described in [HJ17] andtest its viability in multiple showcases. Optionally this method can also be extended to coupledforward backward stochastic differential equations (FBSDE) (see e.g. [HL20]) and differentconnections like to optimal control can be explored.

Computational component

up to 40%

Prerequisites

a basic understanding of neural networks and some skills in programming

Recommended reading

[HJ17] J. Han, A. Jentzen, et al., Deep learning-based numerical methods for high-dimensional parabolic partial differential equations and backward stochastic differential equations, Communications in mathematics and statistics 5 (2017), no. 4, 349–380.
[HL20] J. Han and J. Long, Convergence of the deep bsde method for coupled fbsdes, Probability, Uncertainty and Quantitative Risk 5 (2020), no. 1, 5.

National Empty Building Database

Project ref: XFM178

Project supervisor: Katherine Gunderson

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

National Empty Building Database - ingest, clean, and process geospatial datasets, in addition to other types of data, to create a Postgres environment that has every empty building in Scotland. Support various data capture and cleaning methodologies and create infrastructure elements needed to support the further growth and resilience of the database into the wider UK.

Data available

Some open source, some proprietary, some private. Up for review and discussion.

Computational component

80

Prerequisites

Data Science; AI and Machine Learning; Financial Mathematics

Numerical Methods for option pricing

Project ref: FM267

Project supervisor: Istvan Gyongy

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

PDEs for option prices are to be studied and solved numerically by finite difference methods. In particular, European type options to be investigated. The rate of convergence is to be studied theoretically and tested numerically.The students can choose between between sub-projects. They can study European options, basket options and American options and their partial differential equations more closely, and to implement finite difference schemes to calculate option prices numerically. Another possible sub-project is to present accelerated finite difference schemes for European options (basket options) and to test them numerically.

Computational component

up-to 40%

Prerequisites

Basic knowledge of option pricing, parabolic PDEs and the method of finite differences

Recommended reading

References:
[1] D. Lamberton and B. Lapeyre, Introduction to stochastic calculus applied to finance, 2nd edition. Chapman & Hall/CRC, Boca Raton 2008.

[2] International Journal of Computer Mathematics N. Hilber, O. Reichmann, C, Schwab and C. Winter, Computational Methods for Quantitative Finance, Springer 2013.

[3] Y. Achdou and O. Pironneau, Computational methods for option pricing, V 30, Frontier in Applied Mathematics, Society for Industrial and Applied Mathematics, Philadelphia , P.A. 2005.

[4] I. Gyongy, On Finite Difference Approximations in Option Pricing, Lecture at the conference on Stochastic Processes and their

Statistics in Finance, Naha, Okinawa (Japan), November 1, 2013.

[5] I. Gy□ongy and N. V. Krylov, Accelerated finite difference schemes for second order degenerate elliptic and parabolic problems in the whole space, Math. Comp. 80 (2011), 1431-1458.

[6] D. Siska, Error Estimates for Approximations of American Put Option Price, Computational Methods in Applied Mathematics Vol. 12 (2012), No. 1, pp. 108-120.

Stochastic Interest Rate Models and Their Impact on Derivative Pricing

Project ref: XFM172

Project supervisor: Dr Oana Lang

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project will explore the impact of stochastic interest rate models on the pricing and hedging of fixed-income derivatives. We will focus on non-constant interest rates, which better reflect the dynamics of real financial markets. Key models like CIR, Heston, or the Libor Market Model (LMM) will be examined. Using stochastic differential equations (SDEs), we will simulate interest rate paths and we will analyse their effects on derivative valuation under the risk-neutral measure. Techniques like Monte Carlo simulations and finite difference methods (FDM) will be employed to assess the pricing and hedging of these derivatives. The project will also investigate hedging strategies, evaluating bond portfolio sensitivities to rate volatility. This research will provide valuable insights into the role of stochastic interest rates in derivative markets and their implications for risk management and financial regulation.

Computational component

up to 40%

Prerequisites

Stochastic Calculus, Python

Rough Volatility and Fractional Brownian Motion in Finance

Project ref: XFM174

Project supervisor: Dr Oana Lang

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project will investigate the use of rough volatility models in financial markets, emphasizing their ability to capture the observed irregularities in asset price dynamics. By incorporating fractional Brownian motion (fBm), we will model long-range dependence in volatility, a key feature in real market data. Our study will focus on pricing and hedging financial derivatives under these models, exploring their impact on risk management strategies. Numerical simulations, including Monte Carlo methods, will be used to analyse the behaviour of rough volatility models, offering insights into their accuracy and efficiency for pricing options and other derivatives. This research aims to deepen the understanding of volatility dynamics and the advantages of rough volatility models in capturing real-market phenomena.

Computational component

up to 30%

Prerequisites

Stochastic Calculus, Python

Interest Rate Modelling with Fractional Brownian Motion: Pricing and Hedging Implications

Project ref: XFM173

Project supervisor: Dr Oana Lang

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project will explore the use of fractional Brownian motion (fBm) in modelling interest rates, addressing its potential to capture long memory and self-similarity observed in real financial markets. Unlike traditional models, which typically assume Markovian dynamics driven by standard Brownian motion, fBm allows for more realistic interest rate paths that exhibit dependencies over time. The project focuses on the application of fBm in bond pricing and the valuation of interest rate derivatives. It will examine the impact of fBm on risk management strategies, particularly in the context of non-constant interest rates. Through stochastic differential equations and numerical techniques such as Monte Carlo simulations, this research aims to analyse the advantages of fBm-based models over traditional approaches in terms of accuracy and realism in derivative pricing and hedging.

Computational component

up to 40%

Prerequisites

Stochastic Calculus, Python

Insider Trading Models with Stochastic Filtrations

Project ref: XFM171

Project supervisor: Dr Oana Lang

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Insider trading, where market participants possess privileged information, challenges market fairness and efficiency. This project explores stochastic models of insider trading using filtration enlargement techniques, which mathematically describe how additional private information affects asset price dynamics. We will analyse a financial market where an insider, with access to future asset values, optimally adjusts their trading strategy. By incorporating progressive enlargement of filtrations, we model the insider's ability to anticipate market movements and its impact on price formation. Using stochastic differential equations (SDEs) and Monte Carlo simulations, we compare insider-driven market dynamics with traditional models. Additionally, we will assess the implications for regulatory policies, evaluating how market efficiency changes under different levels of insider knowledge. This study will provide insights into the mathematical foundations of asymmetric information in finance and it will explore whether modern regulatory measures effectively mitigate the risks associated with informed trading.

Computational component

up to 30%

Prerequisites

Stochastic Calculus, Python

Deep Learning for Stochastic Differential Equations in Finance

Project ref: XFM170

Project supervisor: Dr Oana Lang

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Stochastic Differential Equations (SDEs) play a fundamental role in modelling financial markets, particularly in derivative pricing and risk management. Classical numerical methods, such as Monte Carlo simulations and finite difference schemes, often suffer from high computational costs, especially in high-dimensional settings. This project explores deep learning-based approaches, to efficiently approximate solutions for financial SDEs. We will investigate the application of deep learning techniques, including physics-informed neural networks, to solve SDEs governing various derivative pricing. Additionally, we will compare the performance of neural network solvers against traditional Monte Carlo methods in terms of accuracy, computational efficiency, and scalability. Our study aims to analyse the potential of deep learning for tackling complex financial models, taking into account simulation times, and pricing accuracy in high-dimensional markets. The findings will contribute to the growing intersection of machine learning and quantitative finance, paving the way for more efficient computational tools in financial modelling.

Computational component

up to 40%

Prerequisites

Stochastic Calculus, Python

The Signature Kernel in Causal Inference

Project ref: FM257

Project supervisor: Darrick Lee

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The path signature is a structured representation of paths which provides a rich set of features for studying time series data. The signature kernel [1] enables the use of kernel methods for time series data.In this project, we will learn some background on the signature kernel [2], with the goal of understanding a recent paper on applying the signature kernel to causal inference [3].

Computational component

up to 20%

Recommended reading

[1] Kiraly, Oberhauser, Kernels for Sequentially Ordered Data, Journal of Machine Learning Research (2019)
[2] Lee, Oberhauser, The Signature Kernel, arxiv (2023)
[3] Manten et al., Signature Kernel Conditional Independence Tests in Causal Discovery for Stochastic Processes, ICLR (2025)

Graph Adapted Wasserstein Distances

Project ref: FM258

Project supervisor: Darrick Lee

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Classical optimal transport theory provides Wasserstein distances for probability measures on metric spaces which take into account the metric information of the underlying space. Adapted Wasserstein distances [1] are defined for stochastic processes and take into account the linear temporal structure.In this project, the goal is to learn about adapted Wasserstein distances and explore a recent paper [2] on Wasserstein distances adapted to directed graphs, which has applications to developing metrics for causal models.

Computational component

0%

Recommended reading

[1] Backhoff-Veraguas et al., All Adapted Topologies are Equal, Probability Theory and Related Fields (2020)
[2] Cheridito, Eckstein, Optimal Transport and Wasserstein Distances for Causal Models, arxiv (2023)

Koopman Operators in Machine Learning

Project ref: FM256

Project supervisor: Darrick Lee

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Koopman operator theory studies nonlinear dynamical systems by representing their evolution through an infinite-dimensional linear operator acting on functions of the system's state. Instead of directly solving nonlinear equations, Koopman operators provide a linear embedding of nonlinear dynamics into a function space, enabling spectral analysis and operator-theoretic methods. By analyzing eigenfunctions and eigenvalues, Koopman theory captures system behavior, such as invariant sets and long-term dynamics.In this project, we will learn the basic theory of Koopman operators [1], and explore recent work on Koopman operators in machine learning [2], [3].

Computational component

up to 20%

Recommended reading

[1] Mauroy, Mezić, Susuki, The Koopman Operator in Systems and Control, Springer Lecture Notes (2020)
[2] Bevanda et al., Koopman Kernel Regression, NeurIPS (2023)
[3] Kostic et al., Learning Dynamical Systems via Koopman Operator Regression in RKHS, NeurIPS (2022)

Rough differential equations in finance

Project ref: FM241

Project supervisor: Jiawei Li

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project mainly focuses on the construction of path-wise stochastic integration using the controlled rough paths theory for stochastic volatility models arising from finance. The student will learn the rough paths theory, then applying the sewing lemma to constract a path-by-path solution to rough differential equations using the idea from [1].

[1] Gubinelli, M., 2004. Controlling rough paths. *Journal of Functional Analysis*, *216*(1), pp.86-140.

Computational component

0-10%

Backwards stochastic differential equations

Project ref: FM242

Project supervisor: Jiawei Li

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project, we study the basic theory of backwards stochastic differential equations (BSDEs). These backwards equations have been very popular due to their applications in finance. We will look into the theory of BSDEs, their connections with semilinear PDEs, and numerical method for solving BSDEs in this project.

Computational component

30%

Rough paths and finance

Project ref: FM240

Project supervisor: Jiawei Li

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project, we learn the applications of rough paths theory in finance. We will focus on understanding how to use rough paths signature to price exotic options based on the ideas in [1].

[1] Lyons, T., Nejad, S. and Perez Arribas, I., 2020. Non-parametric pricing and hedging of exotic derivatives. *Applied Mathematical Finance*, *27*(6), pp.457-494.

Computational component

30%

Backwards PDEs and option pricing

Project ref: FM243

Project supervisor: Jiawei Li

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project, we study backwards partial differential equations that can be used for pricing american options. We look into option pricing problems in rough volatility models which can be translated into solving one backward PDE (backward Black-Scholes) subject to some terminal condition. We will study the well-posedness of such SPDEs and then look into the numerical method for solving them.

Computational component

20%

Using simulation to price swaptions with short-rate models

Project ref: XFM158

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Hedge funds, banks and large corporations are the main users in the swaption market. Swaps are common derivatives that exchanges a stream of varying payments for a stream of fixed amount payments (or vice versa), swapping a floating interest rate for a fixed one. A swaption is an option to enter into a swap on a future date at a given rate. By introducing the LIBOR system, this project aims to derive the price formulae for swaptions under different short-rate models. There will also be scope for simulation of (approximate) solutions to the SDE's using Brownian motion, in particular, to see how well our derived formulae behave in different situations.

Computational component

Between 20% and up to 50%.

Prerequisites

Good understanding on material in Discrete-Time Finance and Risk-Neutral Asset Pricing is essential. Good programming (or other equivalent) skills is necessary.

Recommended reading

M. Baxter and A. Rennie, Financial Calculus: An Introduction to Derivative Pricing (1996) Cambridge University Press.
D.J. Higham, An Introduction to Financial Option Valuation: mathematics, stochastics and computation. Vol. 13. (2004) Cambridge University Press.
T. Bjork, Arbitrage theory in continuous time (2009) Oxford University Press.
N.H. Bingham, R. Kiesel, Risk-Neutral Valuation. Pricing and Hedging of Financial Derivatives (2004) Springer.
J.C. Hull, Options, Futures, and Other Derivatives (2012) Prentice Hall.

Understanding and setting prices for Exotic Options (Extendible type)

Project ref: XFM168

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

While vanilla options dominate in exchange trading, exotic options are popular derivatives in the over the counter market. Pricing these exotic options is not an easy task in general. In most cases explicit formulae for pricing these options are not known and so Monte Carlo methods are especially useful to estimate these option prices. These options have many interesting behaviors when we change various parameters. We will apply Monte Carlo pricing methods and compare with some exact pricing formula where available in Black-Scholes model. Further aims include a discussion on the advantage and limitations of the Monte Carlo methods and discovering various techniques to reduce computational speed and improve convergence rate of simulation results. In this project, we will investigate the fair price of a particular type of option called extendible type or related options.

Computational component

Between 20% and up to 50%

Prerequisites

Very good understanding on Discrete-Time Finance and Numerical Probability and Monte Carlo is essential.

Recommended reading

F. A. Longstaff, Pricing Options with Extendible Maturities: Analysis and Applications, The Journal of Finance , Jul., 1990, Vol. 45, No. 3 pp. 935-957 P. Zhang Exotic Options: A Guide to Second Generation Options (1997) World Scientific, Singapore.
M. Baxter and A. Rennie, Financial Calculus: An Introduction to Derivative Pricing (1996) Cambridge University Press.
D.J. Higham, An Introduction to Financial Option Valuation: mathematics, stochastics and computation. Vol. 13. (2004) Cambridge University Press.
S. M. Ross, Simulation (2012) Academic Press.
P. E. Kloeden and E. Platen, Numerical Solution of Stochastic Differential Equations (1992) Springer.

Understanding and setting prices for Exotic Options (Barrier type)

Project ref: XFM159

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

While vanilla options dominate in exchange trading, exotic options are popular derivatives in the over the counter market. Pricing these exotic options is not an easy task in general. In most cases explicit formulae for pricing these options are not known and so Monte Carlo methods are especially useful to estimate these option prices. These options have many interesting behaviors when we change various parameters. We will apply Monte Carlo pricing methods and compare with some exact pricing formula where available in Black-Scholes model. Further aims include a discussion on the advantage and limitations of the Monte Carlo methods and discovering various techniques to reduce computational speed and improve convergence rate of simulation results. In this project, we will investigate the fair price of a particular type of option called barrier type or related options.

Computational component

Between 20% and up to 50%

Prerequisites

Very good understanding on Discrete-Time Finance and Numerical Probability and Monte Carlo is essential.

Recommended reading

F. A. Longstaff, Pricing Options with Extendible Maturities: Analysis and Applications, The Journal of Finance , Jul., 1990, Vol. 45, No. 3 pp. 935-957 P. Zhang Exotic Options: A Guide to Second Generation Options (1997) World Scientific, Singapore.
M. Baxter and A. Rennie, Financial Calculus: An Introduction to Derivative Pricing (1996) Cambridge University Press.
D.J. Higham, An Introduction to Financial Option Valuation: mathematics, stochastics and computation. Vol. 13. (2004) Cambridge University Press.
S. M. Ross, Simulation (2012) Academic Press.
P. E. Kloeden and E. Platen, Numerical Solution of Stochastic Differential Equations (1992) Springer.

Regime switching models with applications on business cycles in an economic region

Project ref: XFM160

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Markov regime switching models was known to give good results on estimating various macroeconomic variables in dynamic systems with non-stationary behaviors. A range of models with different number of regimes are used theoretically but which model to select depends on the implementation. In empirical practices, the number of regimes is often decided by some a priori belief or some visual inspection of the data, which is kind of arbitrary and subjective.

In this project we will look at some complexity-penalized information criterion to construct our model selection strategy, with the scope of some applications on modelling business cycles and/or stock markets in a particular economic region.

Computational component

Between 20% and up to 50%.

Prerequisites

Good understanding on material in risk-neutral asset pricing and time series is essential. Some knowledge on Markov chain is preferred but not compulsory.

Recommended reading

J. D. Hamilton, Regime switching models. In: Durlauf, S.N., Blume, L.E. (eds) Macroeconometrics and Time Series Analysis. The New Palgrave Economics Collection. Palgrave Macmillan, London. (2010).
M. Cavicchioli, Determining the Number of Regimes in Markov-Switching VAR and VMA Models, Journal of Time Series Analysis, 35(2014) 173-186.
Agostino Capponi, José E. Figueroa-López and Jeffrey Nisen, Pricing and Semimartingale Representations of Vulnerable Contingent Claims in Regime-Switching Markets, Mathematical Finance, Vol. 24, Issue 2, pp. 250-288 (2014)
R. J. Elliott, and C. A. Wilson, The Term Structure of Interest Rates in a Hidden Markov Setting, in Hidden Markov Models in Finance, Springer (2007).

Optimal betting strategies for stocks

Project ref: XFM157

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

More than three centuries ago we already started to develop the concept of gambler's ruin, i.e., anyone who gamble (with non-positive expectation, e.g., buying lottery or stocks) will eventually bankrupt, irrelevant to any betting strategy. However, in reality we tend not to gamble so many times and tend to stop gambling if one achieves certain goal (e.g., to be a billionaire). There can also be short term gambling with positive expectation in the market occasionally. There are subtle differences between games, gambles and investments, in particular the level of focus on risk control.

The aim of this topic is to use various probability and statistics techniques including martingales, Optional Stopping Theorem and generating functions, to solve some cases of the general gambler's ruin problem. The problem can also be formulated in the sense of random walks. Some cases can be solved explicitly while in some cases only upper and lower bounds are known. There is also a scope of simulation for the cases without analytical solutions and considerations on practical applications on the gambler's ruin problem using various betting systems. These games in various settings exhibit stochastic behaviour and investment opportunities. The scope of the application of the project is very flexible, not limited to the stock market but can also involve other applications in daily life.

If you are interested in financial market applications please apply this one, otherwise apply the other project (Optimal betting strategies for games). If you are uncertain, then apply for the other one.

Computational component

Between 10% and up to 60%.

Prerequisites

Very good understanding on material in Discrete-Time Finance is essential. Basic knowledge on probability theory is essential. Good programming skills is desirable.

Recommended reading

E. O. Thorp, Optimal Gambling Systems for Favorable Games, Review of the International Statistical Institute, Vol. 37, No. 3 (1969), pp. 273-293
J. Billings, S. Del Barco, An Investigation into Laboucheres Betting System to Improve Odds of Favorable Outcomes to Generate a Positive Externality Empirically, Journal of Mathematics and Statistics 13(3), June 2017.
R. A. Epstein, The Theory of Gambling and Statistical Logic, 2nd ed., Elsevier, 2009.

W. Feller, An Introduction to Probability Theory and Its Applications, Vol. 1, 3rd ed., Wiley, 1968.
W. Feller, An Introduction to Probability Theory and Its Applications, Vol. 2, 3rd ed., Wiley, 1971.
G. R. Grimmett and D. R. Stirzaker, Probability and Random Processes, (3rd ed.). Oxford University Press, 2001.
G. P. Harmer, D. Abbott, A review of parrondo's paradox, Fluctuation and Noise Letters Vol. 2, No. 2 (2002), 71–107.
J. L. Kelly, A New Interpretation of Information Rate, Bell System Technical Journal. 35 (4): 917–926, 1956.
P. Del Moral, S. Penev, Stochastic Processes: From Applications to Theory Chapman & Hall/CRC Texts in Statistical Science, 2016.
D. Williams, Probability with Martingales, Cambridge Mathematical Textbooks, 1991.

Optimal betting strategies for games

Project ref: XFM167

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

More than three centuries ago we already started to develop the concept of gambler's ruin, i.e., anyone who gamble (with non-positive expectation, e.g., buying lottery or stocks) will eventually bankrupt, irrelevant to any betting strategy. However, in reality we tend not to gamble so many times and tend to stop gambling if one achieves certain goal (e.g., to be a billionaire). There can also be short term gambling with positive expectation in the market occasionally. There are subtle differences between games, gambles and investments, in particular the level of focus on risk control.

The aim of this topic is to use various probability and statistics techniques including martingales, Optional Stopping Theorem and generating functions, to solve some cases of the general gambler's ruin problem. The problem can also be formulated in the sense of random walks. Some cases can be solved explicitly while in some cases only upper and lower bounds are known. There is also a scope of simulation for the cases without analytical solutions and considerations on practical applications on the gambler's ruin problem using various betting systems. These games in various settings exhibit stochastic behaviour and investment opportunities. The scope of the application of the project is very flexible, not limited to the stock market but can also involve other applications in daily life.

If you are interested in non-financial market applications please apply this one, otherwise apply the other project (Optimal betting strategies for stocks). If you are uncertain then apply for this one.

Computational component

Between 10% and up to 60%.

Prerequisites

Very good understanding on material in Discrete-Time Finance is essential. Basic knowledge on probability theory is essential. Good programming skills is desirable.

Recommended reading

E. O. Thorp, Optimal Gambling Systems for Favorable Games, Review of the International Statistical Institute, Vol. 37, No. 3 (1969), pp. 273-293
J. Billings, S. Del Barco, An Investigation into Laboucheres Betting System to Improve Odds of Favorable Outcomes to Generate a Positive Externality Empirically, Journal of Mathematics and Statistics 13(3), June 2017.
R. A. Epstein, The Theory of Gambling and Statistical Logic, 2nd ed., Elsevier, 2009.

W. Feller, An Introduction to Probability Theory and Its Applications, Vol. 1, 3rd ed., Wiley, 1968.
W. Feller, An Introduction to Probability Theory and Its Applications, Vol. 2, 3rd ed., Wiley, 1971.
G. R. Grimmett and D. R. Stirzaker, Probability and Random Processes, (3rd ed.). Oxford University Press, 2001.
G. P. Harmer, D. Abbott, A review of parrondo's paradox, Fluctuation and Noise Letters Vol. 2, No. 2 (2002), 71–107.
J. L. Kelly, A New Interpretation of Information Rate, Bell System Technical Journal. 35 (4): 917–926, 1956.
P. Del Moral, S. Penev, Stochastic Processes: From Applications to Theory Chapman & Hall/CRC Texts in Statistical Science, 2016.
D. Williams, Probability with Martingales, Cambridge Mathematical Textbooks, 1991.

AI algorithms for forecasting the stock market

Project ref: XFM156

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Financial market modelling is a very popular subject in the literature. Aiming to accurately predict behaviour of future markets, a lot of models are developed analytically. Often, actual data was used to train the model to make the model more realistic. Finding enough of these data can sometimes be very difficult as there are various limitations and restriction for the selection of actual data that works well with the model. One way to get around with this problem is to generate some data that have certain properties that is similar to real data. Unfortunately, in the current literature, there are not many models or simulations that are capable to produce good quality market data with high realism. In this project, we will look at some approaches to produce stock market data that aim to support market designs and analysis problems, e.g. using generative adversarial network. There are two part in the process, the generator and the discriminator. The generator is used to generate some similar data to the real data, and the discriminator tries to distinguish the real data and generated data. The objective is to tune the generator in a way such that the discriminator is unable to differentiate the two types of data.

Computational component

Between 30% and up to 60%.

Prerequisites

Good understanding on material in risk-neutral asset pricing is essential. Very good R or Python (or other equivalent) skills is essential.

Recommended reading

Junyi Li, Xintong Wang, Yaoyang Lin, Arunesh Sinha, Michael P. Wellman: Generating Realistic Stock Market Order Streams. AAAI (2020) 727-734.
K. Zhang, G. Zhong, J. Dong, S. Wang, Y. Wang, Stock market prediction based on generative adversarial network, Procedia Comput. Sci. 147 (2019) 400-406.
Ian J. Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron C. Courville, Yoshua Bengio: Generative Adversarial Networks. CoRR (2014) abs/1406.2661

A PageRank-inspired indicator of systemic risk in financial systems

Project ref: XFM155

Project supervisor: Chak Hei (Hugo) Lo

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Systemic risk is dependent on the network of financial exposures across institutions and is defined as the risk of a significant piece of the financial system defaulting. Nevertheless, there isn't a generally acknowledged process for identifying a network's systemically crucial nodes. In a paper by Battiston et. al., they introduced a measure called DebtRank, a brand-new systemic effect metric modelled after feedback-centrality, inspired by the famous PageRank algorithm by Google. Our goal in this project is to understand this new measure, and to determine whether or not a collection of financial institutions will create a tightly linked network, with each node becoming systemically significant when closing to a system collapse. Furthermore, we want to see if small distributed shocks could have been enough to cause a systemic default. We will verify the paper results 10 years later to see if it still implies that the far more important topic of too-central-to-fail should be included in the conversation about too-big-to-fail organisations.

Computational component

Between 20% and up to 50%.

Prerequisites

Good understanding on material in Discrete-Time Finance and Risk-Neutral Asset Pricing is essential. Good programming (or other equivalent) skills is necessary.

Recommended reading

Battiston, S., Puliga, M., Kaushik, R. et al. DebtRank: Too Central to Fail? Financial Networks, the FED and Systemic Risk. Sci Rep 2, 541 (2012).
Sebastian Poledna & Stefan Thurner (2016) Elimination of systemic risk in financial networks by means of a systemic risk transaction tax, Quantitative Finance, 16:10, 1599-1613

Accelerating sampling with birth-death processes

Project ref: XFM182

Project supervisor: Mateusz Majka

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The project is concerned with Markov Chain Monte Carlo (MCMC) methods based on discretised Langeving Stochastic Differential Equations (SDEs) and their applications in producing approximate samples from probability measures, which is an important problem in many areas such as financial mathematics, Bayesian statistics and machine learning. The goal is to explore interacting particle systems based on such discretised SDEs and to accelerate their convergence to the target measure by modifying the system with an additional birth-death mechanism that is designed to remove "bad" particles and reproduce "good" particles. This idea has been recently explored in the machine learning/computational statistics literature (see the references) and the student working on this project will be expected to summarise the current state of knowledge about such methods and to illustrate their performance with appropriately designed numerical experiments.

Computational component

most likely between 20% and 40%; exact number depends on student's preferences (project can be either

more theoretical or mo

Prerequisites

Stochastic Processes, Numerical Probability and Monte Carlo

Recommended reading

[1] Y. Lu, J. Lu and J. Nolen, Accelerating Langevin Sampling with Birth-death, https://arxiv.org/pdf/1905.09863

[2] B. Pampel, S. Holbach, L. Hartung and O. Valsson, Sampling Rare Event Energy Landscapes via Birth-Death Augmented Dynamics, Phys. Rev. E 107, 024141

[3] G. Rotskoff, S. Jelassi, J. Bruna, and E. Vanden-Eijnden. Neuron birth-death dynamics accelerates gradient descent and converges asymptotically. In K. Chaudhuri and R. Salakhutdinov, editors, Proceedings of the 36th International Conference on Machine Learning, volume 97 of Proceedings of Machine Learning Research, pages 5508–5517. PMLR, 09–15 Jun 2019.

Lévy Processes and their applications in Markov Chain Monte Carlo methods

Project ref: XFM181

Project supervisor: Mateusz Majka

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Markov Chain Monte Carlo (MCMC) methods are used to produce approximate samples from probability measures, which is a problem of interest in many areas of finanacial mathematics, Bayesian statistics and machine learning. Many MCMC methods are based on discretised stochastic differential equations (SDEs) driven by Brownian motion. However, recently there has been some interest in the machine learning literature in using MCMC methods based on SDEs driven by Levy processes with jumps, especially alpha-stable processes. This has been motivated by the idea that jump processes provide a better exploration of the state space and hence such methods may converge faster than their classical counterparts. In this project the student will be expected to present an introduction to the theory of Levy processes and then compare the performance between classical and Levy-driven MCMC methods.

Computational component

most likely between 20% and 40%; exact number depends on student's preferences (project can be either

more theoretical or mo

Prerequisites

Stochastic Processes, Numerical Probability and Monte Carlo

Recommended reading

[1] Cont, R. and Tankov, P.: Financial Modelling with Jump Processes, CRC Press LLC, 2004.

[2] Şimşekli, U.: Fractional Langevin Monte Carlo: Exploring Lévy driven stochastic differential equations for Markov
chain Monte Carlo. In Precup, D. and Teh, Y.W. editors, Proceedings of the 34th International Conference on Machine Learning, vol. 70 of Proceedings of Machine Learning Research, pages 3200–3209, International Convention
Centre, Sydney, Australia, 06–11 Aug 2017. PMLR

[3] Ye, N. and Zhu, Z.: Stochastic fractional Hamiltonian Monte Carlo. In Lang, J. editor, Proceedings of the 27th International Joint Conference on Artificial Intelligence, pages 3019–3025, International Joint Conference on Artificial
Intelligence, Stockholm, Sweden, July 13–19, 2018.

Risk Management/Measurement

Project ref: XFM150

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

There have been a number of recent developments in the measurement of financial risk in both banks and multi national companies. These have been driven by regulatory changes and developments in risk measurement techniques and models. It is suggested that these developments will continue in the next decade. In this project students could consider the main risk management techniques (optimisation, VAR, modelling etc.) and some of the newer developments. They could then apply these techniques to actual financial data or through simulation.

Mathematical models are used for assessing and managing financial risk, with a particular focus on Value-at-Risk (VaR) and stress testing. As financial institutions increasingly rely on quantitative methods to assess market and credit risks, the ability to evaluate the potential for extreme losses and vulnerabilities to adverse events has become crucial. This project will apply advanced mathematical concepts and techniques to better understand and mitigate risks in financial markets.

Computational component

10-30%

Recommended reading

There are a large amount of academic/practical papers on risk management

Corporate Finance - M&As

Project ref: XFM153

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

There are a large amount of empirical projects that could be considered in the area of M&A in corporate finance. This will require understanding of the revelant theory/hypotheses, data collection and empirical testing which would include regression analysis and event studies.

Research questions on these areas include:

1. Panel data analysis of the determinants including firm specific and economic factors.

2. Does board structure, executive compensation, corporate governance influence ?

3. Does country/culture/industry influence?

4. The impact of financial crisis, Covid crisis

Many other possible ideas!

Computational component

10-30%

Recommended reading

Rajan, R. G. and L. Zingales, 1995, What do we know about capital structure? Some evidence from international data, Journal of Finance, Vol. 50, 1421-1460.
▪ Frank, M.Z. and V.K. Goyal, 2003, Testing the pecking order theory of capital structure, Journal of Financial Economics, Vol. 67, 217-248.
▪ Baker, M. and J. Wurgler, 2002, Market timing and capital structure, Journal of

Finance, Vol. 57, 1-32.
▪ Kayhan, A. and S. Titman, 2007, Firms' histories and their capital structure, Journal of Financial Economics, Vol. 83, 1-32
Brav, Alon, Graham, John R., Harvey, Campbell R. and Michaely, Roni, "Payout Policy in the 21st Century", Journal of Financial Economics, Vol. 77 (2005), 483-527.
Fama, Eugene F. and French, Kenneth R., "Disappearing Dividends: Changing Firm Characteristics or Lower Propensity to Pay?", Journal of Financial Economics, Vol. 60 (2001), 3-43.
Goergen, Marc, Renneboog, Luc and Correia da Silva, Luis, "When Do German Firms Change Their Dividends", Journal of Corporate Finance, Vol 11 (2005), 375-399.

Corporate Finance - Capital Structure

Project ref: XFM154

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

There are a large amount of empirical projects that could be considered in the area of corporate finance and capital structure. This will require understanding of the revelant theory/hypotheses, data collection and empirical testing which would include regression analysis and event studies.

Research questions on these areas include:

1. Panel data analysis of the determinants including firm specific and economic factors.

2. Does board structure, executive compensation, corporate governance influence ?

3. Does country/culture/industry influence?

4. The impact of financial crisis, Covid crisis

Many other possible ideas!

Computational component

10-30%

Recommended reading

Rajan, R. G. and L. Zingales, 1995, What do we know about capital structure? Some evidence from international data, Journal of Finance, Vol. 50, 1421-1460.
▪ Frank, M.Z. and V.K. Goyal, 2003, Testing the pecking order theory of capital structure, Journal of Financial Economics, Vol. 67, 217-248.
▪ Baker, M. and J. Wurgler, 2002, Market timing and capital structure, Journal of

Finance, Vol. 57, 1-32.
▪ Kayhan, A. and S. Titman, 2007, Firms' histories and their capital structure, Journal of Financial Economics, Vol. 83, 1-32
Brav, Alon, Graham, John R., Harvey, Campbell R. and Michaely, Roni, "Payout Policy in the 21st Century", Journal of Financial Economics, Vol. 77 (2005), 483-527.
Fama, Eugene F. and French, Kenneth R., "Disappearing Dividends: Changing Firm Characteristics or Lower Propensity to Pay?", Journal of Financial Economics, Vol. 60 (2001), 3-43.
Goergen, Marc, Renneboog, Luc and Correia da Silva, Luis, "When Do German Firms Change Their Dividends", Journal of Corporate Finance, Vol 11 (2005), 375-399.

Green Bonds/Climate Finance

Project ref: XFM152

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Green Bonds (GB) are used as the tools to contribute in the main domain of sustainable finance. Tang and Zhang (2020) use the event study method to see the signalling effect of GB issuance and also uses the difference-in-difference method to establish a causal relationship. Zerbib (2019) applies the matching method followed by a two step regression to estimate the two yield differential between GB and conventional bonds. Potential research questions are as follows: 1. Is there a higher demand in primary markets for green bonds, i.e., do green bonds attract higher oversubscription than their conventional counterparts? 2. Is there heterogeneity with respect to the bonds' subscription across issuers' characteristics, markets, countries, or other characteristics? 3. Do the dark green bonds attract larger number of investors (higher subscription and trading) than the light green bonds and other conventional counterparts in both markets?

Computational component

10-30%

Recommended reading

Baker, M., Bergstresser, D., Serafeim, G., & Wurgler, J. (2018). Financing the response to climate change: The pricing and ownership of US green bonds (No. w25194). National Bureau of Economic Research.
Flammer, C. (2021). "Corporate green bonds." Journal of Financial Economics.
Lou, X. and T. Shu (2017). "Price impact or trading volume: Why is the Amihud (2002) measure priced?" The Review of Financial Studies 30(12): 4481-4520.
Tang, D. Y. and Y. Zhang (2020). "Do shareholders benefit from green bonds?" Journal of Corporate Finance 61: 101427.
Zerbib, O. D. (2019). "The effect of pro-environmental preferences on bond prices: Evidence from green bonds." Journal of Banking & Finance 98: 39-60.

Fund Performance- ESG fund management

Project ref: XFM151

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

What is the value of active fund management in trusts/hedge funds. Are professional money managers able to beat the market after adjusting for risk? A crucial topic in finance research is how to measure the performance of funds, which involves testing market efficiency and has practical implications for investors. There has also been the developments in fund management in different countries and in investment styles including hedge funds. There are a number of research opportunities in these areas to develop a project, including: 1. different performance models 2. persistence in performance 3. different fund styles 4. Impact of ESG on fund management Students can develop the performance models and use data on different funds to test these models

Computational component

10-30%

Recommended reading

The academic papers of Fama and French will form the basis of this study.
Textbooks - one or more of the following
Bodie, Kane and Marcus, Investments, chapter 24 (theory) and sections 4.7 then 11.5 and 26.5 (empirical evidence, including hedge funds). Editions 10, 9 or 8 can be used.

Derivative Pricing - Swaps

Project ref: XFM149

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Of all the derivative market there has been remarkable growth in the swap market. There could be a number of different projects that the student could consider in this derivative market. Students can discuss with me their main areas of interest in the swap market. Potential projects would include: 1. Apply some of the theoretical pricing models to the swap market. This would include the theoretical development of the pricing model(s) and empirical in testing the data. The data can be from different types of swaps, international markets and/or time periods. 2. The students can consider a time series study and examine the implications of regulatory changes and/or financial shocks on the pricing and/or volatilty of the swaps. 3. The student could consider the development of new markets/derivative instruments based on swaps

Computational component

10-30%

Recommended reading

Valuing Derivatives: Funding Value Adjustments and Fair Value
Hull, John; White, Alan. Financial Analysts Journal; Charlottesville 70.3 (May/Jun 2014): 46-56
Libor Market Models versus Swap Market Models for Pricing Interest Rate Derivatives: An Empirical Analysis
Wang, Ming-Chieh; Szu-Lang Liao. The Journal of Futures Markets; Hoboken23.8 (Aug 2003): 751-772.

Corporate Financial Risk Management

Project ref: XFM161

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project will examine corporate hedging policies.

There are two main approaches:

1. To explain the decision to hedge.

2. To consider the impact of hedging on firm value.

Students will collect samples of hedging activity and empirically test one or both of these decisions using advanced techniques.

Computational component

10-30%

Prerequisites

None

Recommended reading

The determinants of foreign exchange hedging in Alternative Investment Market firms
January 2012 European Journal of Finance

Derivative Pricing - Options

Project ref: XFM148

Project supervisor: Professor Andrew Marshall

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The literature and practice has developed a number of option pricing models. In this project students will apply and compare some of the main models in option pricing. This project will be both theoretical and in the development of pricing model(s) and empirical in the testing of data - which could cover a range of alternative option contracts in different markets (including international markets). The student's project can consider a time series study, different types of options markets and/or examine the impact of new markets, new option products, changes in regulations and/or financial shocks to the models. There are many other areas that can be considered for a student interested in the option markets and these can be discussed as part of the project

Computational component

10-30%

Recommended reading

Valuing Derivatives: Funding Value Adjustments and Fair Value
Hull, John; White, Alan. Financial Analysts Journal; Charlottesville 70.3 (May/Jun 2014): 46-56
Jump-diffusion option pricing models: evidence from recent financial upheavals
Singh, Vipul Kumar. Studies in Economics and Finance; Bradford32.3 (2015): 357-378.

AI-driven pricing model

Project ref: XFM177

Project supervisor: Shivoh Chirayil Nandakumar

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The project focuses on developing an AI-driven pricing model for the RideScan solution, tailored to meet the diverse needs and perceived value of customers across different robotic applications. RideScan provides an independent auditing system to ensure the reliability and safety of autonomous robots, which holds varying levels of importance depending on the task and industry.

The core challenge lies in addressing the disparity in perceived value among different customer segments, such as robot manufacturers and integrators, performing tasks of varying complexity. For instance, a robot delivering coffee has a relatively low-risk impact compared to a robot delivering critical medicine in a hospital. Consequently, the pricing for RideScan must reflect this variation, ranging from £100 per month for low-risk applications to £600 per month for high-risk scenarios like healthcare.

The complexity deepens when considering additional factors such as robotic segment, capabilities, application types, and geographical variations in purchasing power. The AI-based pricing model aims to capture and balance these variables effectively, ensuring a fair, scalable, and profitable pricing strategy for RideScan.

Through this project, we aim to create a dynamic pricing framework that aligns the cost of RideScan with its value to the customer, fostering greater adoption across industries while maximizing customer satisfaction and business revenue. This innovative approach will serve as a benchmark for AI-enabled pricing in the robotics industry.

Access to data

Internal data obtained after the market research

Computational component

80

Prerequisites

Financial Mathematics; Data Science; Statistics; Operational Research (modelling and optimization); AI and Machine Learning;

Option pricing via path integrals

Project ref: XFM183

Project supervisor: Praxitelis Ntokos / Gonçalo dos Reis

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Path integrals were originally introduced in quantum mechanics to compute probability amplitudes as an average over all possible paths a quantum system can take. The goal of this project is to illustrate how this framework can be applied to pricing financial derivatives, where the "paths" are those taken by the underlying asset. The analysis will cover both path-independent (standard Black–Scholes) and path-dependent pay-off functions (such as Asian options and barrier options), and it will also extend to scenarios involving multiple underlying assets. The project may further develop pricing formulas for exotic derivatives (e.g., options with multiple barriers, lookback options) and compare these results with (approximate) analytic solutions available in the literature or with outcomes from numerical methods. Additionally, it could explore various numerical techniques—such as Monte Carlo, quasi Monte Carlo methods, and different discretisation schemes—for evaluating path integrals in the pricing of complex derivatives.

Computational component

Between 10% and 40%

Prerequisites

Very good understanding of calculus (PDEs, Fourier & Laplace transforms), Probability Theory and Stochastic Processes, Derivative Pricing Theory

Recommended reading

1)Linetsky, Vadim. "The Path Integral Approach to Financial Modeling and Options Pricing." Computational Economics 11 (1998): 129-163.
This paper provides an overview of the use of path integrals in options pricing.

2) Montagna, Guido, Oreste Nicrosini, and Nicola Moreni. "A path integral way to option pricing." Physica A: Statistical mechanics and its applications 310.3-4 (2002): 450-466.
A computational algorithm based on a path integral formulation of the pricing problem.

Quantum computing and risk analysis

Project ref: XFM185

Project supervisor: Praxitelis Ntokos / Gonçalo dos Reis

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The first objective of this project is to summarise the state-of-the-art research on potential quantum computing applications in finance. The student will compare classical methods with quantum and quantum-inspired approaches, highlighting the challenges and potential benefits of each. Additionally, the student will provide an overview of the relevant quantum algorithms and discuss practical considerations for their implementation.

The second part of the project focuses on applying quantum computing to evaluate key risk measures such as VaR and CVaR. In particular, the student will emphasise the use of amplitude estimation to compute these measures—a method that outperforms classical Monte Carlo techniques. The investigation should encompass algorithms that manage portfolios of varying complexity and extend to more sophisticated risk metrics, including Expectile Value-at-Risk (EVaR) and Range Value-at-Risk (RVaR).

Computational component

Between 10% and 40%

Prerequisites

Probability Theory and Stochastic Processes, Risk Measures, Linear Algebra and Numerical Methods, Exposure to Quantum Mechanics and ideally Quantum Computing

Recommended reading

1) Egger, Daniel J., Claudio Gambella, Jakub Marecek, Scott McFaddin, Martin Mevissen, Rudy Raymond, Andrea Simonetto, Stefan Woerner, and Elena Yndurain. "Quantum computing for finance: State-of-the-art and future prospects." IEEE Transactions on Quantum Engineering 1 (2020): 1-24.
This review paper offers a comprehensive survey of how quantum computing can address computational challenges in the financial sector.

2) Woerner, Stefan, and Daniel J. Egger. "Quantum risk analysis." npj Quantum Information 5, no. 1 (2019): 15.
This paper shows how to use quantum algorithms to evaluate risk measures.

3) Laudagé, Christian, and Ivica Turkalj. "Quantum Risk Analysis: Beyond (Conditional) Value-at-Risk." arXiv preprint arXiv:2211.04456 (2022)
This paper constructs quantum-based algorithm to evaluate EVaR and RVaR.

4) Brassard, Gilles, Peter Hoyer, Michele Mosca, and Alain Tapp. "Quantum amplitude amplification and estimation." arXiv preprint quant-ph/0005055 (2000).
This paper introduces amplitude estimation.

5)De Wolf, Ronald. "Quantum computing: Lecture notes." arXiv preprint arXiv:1907.09415 (2019).

Pricing Vanilla and Exotic options using the 3/2 Stochastic Volatility model

Project ref: FM250

Project supervisor: Sotirios Sabanis

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance

Project description

Using a new generation of explicit Euler-type numerical schemes for SDEs, one can show that the pricing of Exotic options under the assumption of the 3/2 Stochastic Volatility model can be performed in a more efficient way than before.(Multi-level) Monte Carlo simulations can be used to illustrate the implementation of this new methodology (and its agreement with the theoretical results).

Computational component

30

Prerequisites

Good knowledge of Stochastic Analysis and Numerics for SDEs is required.
Knowledge of some programming language (such as C++, Java, python, etc) or relevant mathematical package (MAPLE, Matlab, etc) is considered essential.

Recommended reading

- Sabanis, S. (2015). Euler approximations with varying coefficients: the case of superlinearly growing diffusion coefficients, Annals of Applied Probability, to appear.
- Kloeden P.E. and Platen, E. (1999). Numerical Solution of Stochastic Differential Equations. Applications of Mathematics, Springer, Berlin. MR1214374.
- Goard, J. and Mazur, M. (2013). Stochastic volatility models and the pricing of VIX options. Mathematical Finance 23 , no. 3, 439--458. MR3070371

Pricing Financial Solutions

Project ref: FM249

Project supervisor: Anton Shmatkov

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project you will learn how to structure, optimise and price financial transactions. You will familiarise yourself with pricing techniques which will encompass Rates, Inflation, Credit, Counterparty Credit, Funding angles.

Computational component

up to 20%

Recommended reading

Tuckman, B. (2022) Fixed Income Securities: Tools for Today's Markets, The Wiley Finance
Brigo, D., Mercurio, F. (2006) Interest Rate Models - Theory and Practice: With Smile, Inflation and Credit, Springer Finance
Duffie, D., Singleton, K. (2003) Credit Risk - Pricing, Measurement, and Management, Princeton University Press
O'Kane, D. (2011) Modelling Single-name and Multi-name Credit Derivatives, The Wiley Finance

Pricing Financial Instruments

Project ref: FM248

Project supervisor: Anton Shmatkov

Project type

academic

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project you will learn how to structure, optimise and price financial transactions. You will familiarise yourself with pricing techniques which will encompass Rates, Inflation, Credit, Counterparty Credit, Funding angles.

Computational component

up to 20%

Recommended reading

Tuckman, B. (2022) Fixed Income Securities: Tools for Today's Markets, The Wiley Finance
Brigo, D., Mercurio, F. (2006) Interest Rate Models - Theory and Practice: With Smile, Inflation and Credit, Springer Finance
Duffie, D., Singleton, K. (2003) Credit Risk - Pricing, Measurement, and Management, Princeton University Press
O'Kane, D. (2011) Modelling Single-name and Multi-name Credit Derivatives, The Wiley Finance

TabNet for Financial Data Analysis

Project ref: XFM180

Project supervisor: Wei Wei

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

TabNet is an end-to-end deep learning architecture specifically designed to work directly with raw tabular data. It leverages an attention mechanism to dynamically select and interpret features, making it particularly effective for structured datasets such as those found in finance. In this project, you will begin by learning how to build and implement a TabNet model for the analysis of financial data. You will then explore techniques for hyperparameter tuning and investigate the role of pretraining in enhancing model performance. Finally, you will conduct a comparative analysis between TabNet and other widely used machine learning models in financial data analysis. By the end of the project, you are expected to gain a solid understanding of TabNet and develop practical experience in applying deep learning techniques to real-world financial data.

Computational component

70%-80%

Prerequisites

Programming skill in python, basics of machine learning. PyTorch will be used in this project; however, prior experience with it is not required, as the supervisor will provide the necessary guidance and instruction during the project.

Recommended reading

Arik, Sercan Ö., and Tomas Pfister. "Tabnet: Attentive interpretable tabular learning." Proceedings of the AAAI conference on artificial intelligence. Vol. 35. No. 8. 2021.

Deep BSDEs for Credit Risk Models

Project ref: XFM179

Project supervisor: Wei Wei

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

The Deep Backward Stochastic Differential equation (BSDE) method,a deep learning–based numerical technique introduced by E, W., J. Han, and A. Jentzen (2017), has demonstrated outstanding performance in solving high-dimensional dynamic systems that are traditionally intractable using classical numerical methods. This project aims to develop and implement the Deep BSDE method within the context of high-dimensional credit risk models. The focus will be on evaluating the method's effectiveness in pricing credit risk under different closeout conventions, which are essential in the valuation of financial derivatives with counterparty risk. A key component of the project will involve a comparative analysis of computational efficiency across different modeling scenarios. The study will also provide insights into the practicality of the Deep BSDE method in financial applications. By the end of the project, the student is expected to acquire a comprehensive understanding of the Deep BSDE framework and apply deep learning techniques to quantitative finance problems.

Computational component

50%-60%

Prerequisites

stochastic calculus, basics of partial differential equations, programming skill in python. PyTorch will be used in this project; however, prior experience with it is not required, as the supervisor will provide the necessary guidance and instruction during the project.

Recommended reading

E, W., J. Han, and A. Jentzen (2017): "Deep learning-based numerical methods for high- dimensional parabolic partial differential equations and backward stochastic differential equa- tions," Communications in Mathematics and Statistics, 5, 349–380.

Rough differential equations for volatility

Project ref: XFM165

Project supervisor: Yue Wu

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

This project focuses on understanding a recent development for building a structured way to combine a standard Brownian motion W with a rough path X, which has low regularity. Specifically, we look at the case where X comes from a one-dimensional fractional Brownian motion, which may or may not be correlated with W. This method helps extend existing rough path models and allows us to describe financial markets using rough differential equations (RDEs), where both the price and volatility evolve together as part of the same equation. Even when W and X are independent, our approach remains useful because it can introduce correlations between price and volatility within the model's dynamics. A key part of the project is extending an existing technique, called the lead-lag approximation, to work with fractional Brownian motion. This helps us develop a numerical method that can be used for simulations. Finally, we will implement and test the model, using real market data to see how well it works in practice.

Computational component

up-to 30%

Prerequisites

This project is well suited for students interested in probability, stochastic processes, and numerical methods, especially in the context of financial modeling.

Recommended reading

https://arxiv.org/pdf/2412.21192
https://github.com/emilioferrucci/rough-vol-rough-paths

The expected signature model in time-series forecasting

Project ref: XFM163

Project supervisor: Yue Wu

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Machine learning tasks such as supervised learning use features of the input data to train models. For high-frequency time series data these features are commonly derived from classical statistics: range, mean, variance, and kurtosis, along with many others. The signature representation, a rising star in the machine learning area, can provide an efficient summary of a stream and its effects. Fundamental to this approach is the realisation that the evolving state of the system is best described or measured over short time intervals by considering the realised effect of the system on certain controlled systems. The aim of this project is to apply the expected signature features to feature selection from high-frequency time series data. relevant to finance/investment.

Computational component

up-to 50%

Prerequisites

Anyone with an interest in machine learning, some experience in time series and familiar with Python is welcome. No prior knowledge of path signatures is needed.

Recommended reading

I. Chevyrev and A. Kormilitzin. A primer on the signature method in machine learning. arXiv preprint arXiv:1603.03788, 2016.
D. Levin, T. Lyons, and H. Ni. Learning from the past, predicting the statistics for the future, learning an evolving system. arXiv preprint arXiv:1309.0260, 2013.
T. Lyons. Rough paths, signatures and the modelling of functions on streams. arXiv preprint arXiv:1405.4537, 2014.

Positivity-preserving numerical method for linear stochastic volatility models driven by α-stable process

Project ref: XFM166

Project supervisor: Yue Wu

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

Stochastic volatility models, which represent a new generation of option pricing models, gained significant attention following their introduction in 1987. A typical example of a stochastic volatility model is the GARCH diffusion model driven by Brownian motion. However, it is inadequate forBrownian motion to model realworld phenomena that exhibit large jumps with tail distributions following a power-law pattern, where jump-diffusion Levy processes provide a more suitable characterization. As stochastic volatility is often significantly impacted by sudden events, it is intuitive to use alpha-stable noise for modelling purpose. We will study appropriate numerical treatments for the stochastic volatility model driven by alpha-stable process as the solution is typically not available in closed form, where the challenging part is to preserve the positivity of the numerical solution.

In this project, the student will work on both the theoretical part and numerical part of stochastic volatility model driven by alpha-stable noise.

Computational component

up-to 30%

Prerequisites

stochastic analysis, numerical analysis, probability, and a little python

Recommended reading

https://arxiv.org/pdf/2502.00788 and the references therein

Deep learning volatility

Project ref: XFM162

Project supervisor: Yue Wu

Meets requirements of

Financial Modelling and Optimization
Computational Mathematical Finance
Financial Mathematics

Project description

In this project, we will study a neural network-based calibration method that performs the calibration task within a few milliseconds for the full implied volatility surface. The framework is consistently applied throughout a range of volatility models, including the rough volatility family and a range of derivative contracts. The aim of neural networks in this work is an offline approximation of complex pricing functions, which are difficult to represent or time-consuming to evaluate by other means. In a number of applications, we will demonstrate the prowess of this modeling approach regarding the accuracy, speed, robustness, and generality. Anyone with an interest in deep learning and some experience in Python programming is quite welcome.

Computational component

up-to 60%

Prerequisites

Python, basic knowledge of machine learning, option pricing

Recommended reading

Buehler, H., Gonon, L., Teichmann, J. and Wood, B., 2019. Deep hedging. Quantitative Finance, 19(8), pp.1271-1291.
Bayer, C., Horvath, B., Muguruza, A., Stemper, B. and Tomas, M., 2019. On deep calibration of (rough) stochastic volatility models. arXiv preprint arXiv:1908.08806.
Saporito, Y.F., Yang, X. and Zubelli, J.P., 2019. The calibration of stochastic local-volatility models: An inverse problem perspective. Computers & Mathematics with Applications, 77(12), pp.3054-3067.
Stone, H., 2020. Calibrating rough volatility models: a convolutional neural network approach. Quantitative Finance, 20(3), pp.379-392.