Quantitative Finance Summer School
Abstracts

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Optimal Transport and applications in Mathematical Finance

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This course is meant to give an overview of the main developments and applications of optimal transport in mathematical finance. We will explore how optimal transport theory can be used, in combination with tools from stochastic analysis, to address fundamental questions in finance, in particular related to uncertainty, sensitivity, and model misspecification. I will start by revisiting the fundamental ideas and results from the classical optimal transport theory. I will then present a generalization of it, named weak optimal transport, that allows to tackle a much wider class of problems, including the so-called martingale optimal transport. A dynamic version of the latter leads to the concept of Stretched Brownian motion, that allows to approximate the Dupire local volatility model. I will finally introduce the concept of adapted transport, suitable for comparing stochastic models while accounting for the evolution of information in time, especially for the purpose of dynamic stochastic optimization in a context of model uncertainty.

Carbon Emissions Regulation

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Introduction to carbon markets and their functioning, with a focus on compliance markets and the European case. Effects of policy on a heterogeneous system of emitting firms (Scope 1), with the determination of the optimal policy in a Stackelberg game between the regulator and firms under various types of constraints, both on total emissions and on temperature. Conclusions and further developments.

Generative AI for Finance: Dynamic universal approximation and modeling with neural and signature SDEs

Christa Cuchiero

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Generative AI has recently transformed a wide range of fields by enabling the modeling of complex, high-dimensional data and the synthesis of realistic new scenarios. In finance, it provides a modern framework for tasks such as market simulation and return generation. This course introduces the key principles of leading generative models, including autoencoders, GANs, diffusion models, and, in particular, neural and signature stochastic differential equations (SDEs), which constitute the main focus of the course.

After a general introduction of deep learning concepts, ranging from standard artificial neural networks to dynamical deep learning approaches like signature methods for time-series data, we will develop the mathematical foundations of neural and signature SDEs. In these models, the coefficients of the SDE are parameterized either by neural networks or by functions of the path signature, leveraging their classical universal approximation capabilities. While such results are typically formulated for static functions, our focus is on dynamic universal approximation at the level of stochastic processes. Specifically, we show that both standard SDEs and path-dependent SDEs can be approximated by suitably constructed neural and signature SDEs, respectively. For signature SDEs, this requires the development of a dedicated well-posedness theory. Building on this framework, we establish in particular that SDEs whose coefficients are entire functions of the signature act as dynamic universal approximators for path-dependent SDEs. Owing to their linear structure in the lifted signature state, this result further implies a universality property of affine processes within the class of Itô-processes.

On the applied side, we present recent advances including Bayesian calibration of neural SDEs in finance, a data-driven formulation of the Heath–Jarrow–Morton framework for interest rate modeling, and signature-based asset price models calibrated jointly to VIX and SPX options.

Mean Field Games and applications in Mathematical Finance

Mathieu Lauriere

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Mean field game (MFG) theory provides a powerful framework for analyzing strategic interactions among large populations of agents and has become increasingly important in the mathematical finance community. This mini-course will give an introduction to MFGs with a particular emphasis on financially motivated models and computational methods. We will discuss how many-player stochastic differential games lead, in the mean field limit, to coupled Hamilton–Jacobi–Bellman and Fokker–Planck equations, as well as to McKean–Vlasov forward-backward stochastic differential equations (MKV FBSDEs). Applications will include optimal execution with market impact, systemic risk and interbank lending models, and portfolio optimization with relative performance criteria. Alongside the theoretical framework, we will present numerical methods for solving mean field game models, including both classical PDE-based approaches and recent deep learning methods for high-dimensional problems.