STAR/NWO/FWO

23rd Winter School on Mathematical Finance

Special topics:

Reinforcement learning

Rough volatility

January 19–21, 2026
Conference Hotel Kontakt der Kontinenten, Soesterberg

Sponsored by STAR, NWO and FWO

Winter School on Mathematical Finance

In recent years, the mathematical theory associated with financial risk management and the pricing of contingent claims has been a highly active field of research. The area has established itself as one of the most vigorously growing branches of applied mathematics. Model-based analysis of contracts and portfolios has become a standard in the finance industry, and the number of academic institutions offering curricula in financial mathematics has increased rapidly. In this context, the winter school on Mathematical Finance that will take place on January 19–21, 2026 in Soesterberg aims at providing a meeting place for participants both from industry and from academia. The program provides ample opportunity for discussion.

The special topics of the 22nd winter school are *A control-theoretical perspective of continuous time reinforcement learning*, and *Rough volatility models*. These are the subjects of minicourses that will be taught by two distinguished speakers: Professors Xin Guo (University of California, Berkeley) and Christian Bayer (Technical University of Berlin). Additionally there will be three one-hour special invited lectures by Professors Eduardo Abi Jaber (École Polytechnique, Sorbonne University, Paris), Giorgia Callegaro (University of Padova), and Sigrid Källblad Nordin (Royal Institute of Technology, Stockholm).

Thirty-minute lectures on recent research work in the Netherlands will be presented by Josha Dekker (University of Amsterdam), Guanyu Jin (University of Amsterdam), Gijs Mast (TU Delft) and Marco Zullino (University of Amsterdam).

Auspices, sponsoring and grants

The Winter School takes place under the auspices of the mathematics cluster STAR and of PWN. The stochastics groups of the mathematics departments of the universities in the Netherlands cooperate in STAR. The winter school is supported financially by STAR and by the Research Foundation - Flanders (FWO). Administrative assistance is provided by the Korteweg–De Vries Institute for Mathematics of the University of Amsterdam. Financial support by NWO is under consideration at the time of writing.

The FWO research network *Modelling and Simulation with applications in Finance, Insurance and Economics* has made available a limited number of grants for young researchers (PhD students and postdocs) associated to the network to be used as a waiver for the registration fee for the winter school. For other young researchers a limited number of grants of € 250 each is available as a reduction on the registration fee for the winter school. Priority will be given to grant applications from PhD students whose supervisor is a member of the network, but others are invited to apply as well.

Applications for the grant can be sent by email to both Michel Vellekoop and Asma Khedher (make sure both are addressed, a.khedher@uva.nl and m.h.vellekoop@uva.nl). Applications are required to contain a brief motivation why the grant should be beneficial for the research of the applicant, a brief motivation why the applicant has a specific need for the grant, a (link to a) CV of the applicant and the name of her/his principal supervisor. Applications should be submitted before the deadline of November 20, 2025.

Organizers

The winter school is organized by:

Michel Vellekoop (Faculty Economics and Business, University of Amsterdam; tel. +31 20 5254210, e-mail m.h.vellekoop@uva.nl),

Asma Khedher (Korteweg–De Vries Institute for Mathematics, University of Amsterdam; tel. +31 20 5258221, e-mail a.khedher@uva.nl).

Program outline

The program starts with registration and coffee on Monday, January 19, from 10:30 to 11:30, and ends on Wednesday, January 21, at 16:00. The following events are planned:

Minicourses

Xin Guo
A control-theoretical perspective of continuous time reinforcement learning

Christian Bayer
Rough volatility models

Special invited lectures

Eduardo Abi Jaber
Path-signatures: memory and stationarity

Giorgia Callegaro
A stochastic Gordon-Loeb model for optimal cybersecurity investment under clustered attacks

Sigrid Källblad Nordin
Measure-valued martingales: theory and applications

Short contributions

Josha Dekker
Stochastic optimal control with randomly arriving control moments

Guanyu Jin
Constructing uncertainty sets for robust risk measures: a composition of ϕ-divergences approach to combat tail uncertainty

Marco Zullino
Dynamic star-shaped risk measures via BSDEs

Gijs Mast
A COS-tensor framework for credit exposure calculations

Schedule of lectures

	Monday January 22	Tuesday January 23	Wednesday January 24
09:00 - 10:00		Guo	Guo
10:30 - 11:30		Guo	Guo
11:30 - 12:30	Guo	Bayer	Bayer
14:00 - 15:00			Bayer
15:00 - 16:00	Bayer	Bayer	Callegaro
16:00 - 17:00	Abi Jaber	Källblad Nordin	
17:30 - 18:00	Dekker	Zullino	
18:00 - 18:30	Jin	Mast	

Venue

The winter school will take place in Conference Hotel Kontakt der Kontinenten, Amersfoortsestraat 20, 3769 AS Soesterberg, phone: +31 (0) 346 35 17 55. Located in the heart of the country, Kontakt der Kontinenten is one of the top accommodations in the Netherlands in terms of attractiveness of surroundings. Access by car or by public transportation is easy. By train, one can reach the city of Amersfoort, and then proceed from the station by bus (about 15 minutes, Bus 34 or Bus 56). See `https://9292.nl/en` for planning public transportation, use `Kontakt der Kontinenten` as the destination. Typically, from Schiphol (Amsterdam Airport) it takes 70–80 minutes for the complete journey. The bus stop is in front of the hotel (see directions on the webpage below). If you come by car, it is best to use a modern navigator. It is also possible to take a taxi from the taxi stand at railway station Amersfoort. For further details, please see `https://www.kontaktderkontinenten.nl/en` or Google maps (search for `Kontakt der Kontinenten`).

Website

`https://staff.fnwi.uva.nl/a.khedher/winterschool/winterschool.html`

Abstracts

Minicourse I

Xin Guo (University of California, Berkeley)

A control-theoretical perspective of continuous time reinforcement learning

Reinforcement Learning (RL) is a one of the fundamental machine learning paradigms, where an agent learns to make a sequence of decisions by interacting with an environment and possibly with other agents. Though primarily developed for discrete environments, RLs are intrinsically continuous.

This minicourse presents an overview of recent progress in continuous-time reinforcement learning (RL) from a control-theoretic perspective. Time permitting, the discussion will also cover how techniques from large language models can be integrated into the RL framework to enhance algorithmic performance and facilitate convergence analysis.

Minicourse II

Christian Bayer (Technical University of Berlin)

Rough volatility models

Rough volatility models are stochastic volatility models with a "rough" stochastic volatility process. In this context, rough means that the process behaves like fractional Brownian motion with Hurst index $0 < H < \frac{1}{2}$. Rough volatility models have become popular in the last few years, because they allow to take into account two consistent empirical observations:

1. Realized variance on short-scales is much rougher than the asset price time-series itself. When estimating Hölder/scaling coefficients, we typically see values significantly smaller than $\frac{1}{2}$.

2. The implied volatility surface exhibits a singularity for very short maturity. Specifically, the derivative w.r.t. the log-moneyness variable (a.k.a. "skew") shows a power-law explosion in terms of time-to-maturity going to 0.

As a consequence, rough volatility models are neither semi-martingales nor Markov processes, leading to considerable challenges in theoretical and numerical analysis.

In this mini-course, we will explore the path-regularity of realized variance time series of asset prices, and the empirical behavior of the implied volatility skew. This motivates the introduction of rough volatility models, specifically the rough Bergomi and rough Heston models. Using tools of the theory of large deviations, we show that rough volatility models exhibit power law behavior of the implied volatility skew. Finally, we study Markovian approximations of rough volatility models from a theoretical and a numerical point of view.

Special invited lectures

Eduardo Abi Jaber (École Polytechnique, Sorbonne University, Paris)

Path-signatures: memory and stationarity

We explore the interplay between path-signatures, memory, and stationarity, highlighting their implications for machine learning, representation of stochastic processes and applications in mathematical finance.

In a first part, we provide explicit series expansions to certain stochastic path-dependent integral equations in terms of the path signature of the time augmented driving Brownian motion. Our framework encompasses a large class of stochastic linear Volterra and delay equations and in particular the fractional Brownian motion with a Hurst index H in $(0, 1)$. Our expressions allow to disentangle an infinite dimensional Markovian structure. In addition they open the door to: (i) straightforward and simple approximation schemes that we illustrate numerically, (ii) representations of certain Fourier-Laplace transforms in terms of a non-standard infinite dimensional Riccati equation with important applications for pricing and hedging in quantitative finance.

In a second part, we introduce a time-invariant version of the signature: the fading-memory signature, and establish powerful algebraic, analytic and probabilistic properties with applications to learning stationary relationships in time series.
This is based on joint works with Paul Gassiat, Louis-Amand Gérard, Yuxing Huang, Dimitri Sotnikov.

Giorgia Callegaro (University of Padova)

A stochastic Gordon-Loeb model for optimal cybersecurity investment under clustered attacks

We develop a continuous-time stochastic model for optimal cybersecurity investment under the threat of cyberattacks. The arrival of attacks is modeled using a Hawkes process, capturing the empirically relevant feature of clustering in cyberattacks. Extending the Gordon-Loeb model, each attack may result in a breach, with breach probability depending on the system's vulnerability. We aim at determining the optimal cybersecurity investment to reduce vulnerability. The problem is cast as a two-dimensional Markovian stochastic optimal control problem and solved using dynamic programming methods. Numerical results illustrate how accounting for attack clustering leads to more responsive and effective investment policies, offering significant improvements over static and Poisson-based benchmark strategies. Our findings underscore the value of incorporating realistic threat dynamics into cybersecurity risk management.
This is a joint work with C. Fontana, C. Hillairet and B. Ongarato.

Sigrid Källblad Nordin (Royal Institute of Technology, Stockholm)

Measure-valued martingales: theory and applications

In this talk we will focus on a particular class of stochastic processes referred to as measure-valued martingales. They are probability-measure-valued processes featuring a certain martingale property. Such processes arise naturally for many problems such as stochastic control under partial information, enlargement of filtrations, and robust option pricing. Both

old and new results will be presented. In particular, we will discuss how the classical theory of stochastic control theory can be modified to encompass controlled processes of this type. Numerous examples and applications from both filtering theory and robust option pricing will then be discussed.
Based on joint work with A. Cox, M. Larsson, S. Svaluto and C. Wang.

Short contributions

Guanyu Jin (University of Amsterdam)

Constructing uncertainty sets for robust risk measures: a composition of ϕ-divergences approach to combat tail uncertainty

Risk measures, which typically evaluate the impact of large losses, are highly sensitive to model misspecification in the tails. In this talk, we discuss a robust optimization approach to combat tail uncertainty by proposing a unifying framework to construct uncertainty sets for a broad class of risk measures, given a specified nominal model.

Our framework is based on a parametrization of robust risk measures using two (or multiple) ϕ-divergence functions, which enables us to provide uncertainty sets that are tailored to both the sensitivity of each risk measure to tail losses and the tail behavior of the nominal distribution. In addition, our formulation allows for a tractable computation of robust risk measures, and elicitation of the ϕ-divergences that describe a decision maker's risk and ambiguity preferences. We illustrate and implement our results in several examples, including a newsvendor problem and a financial hedging problem.

Gijs Mast (Delft University of Technology)

A COS-tensor framework for credit exposure calculations

Monte Carlo (MC) simulation methods remain the predominant approach for computing credit exposures in the pricing and risk management practices of the financial industry, owing to their flexibility, implementation simplicity, and transparency. However, accurate computation of high-quantile exposure metrics for large portfolios remains time consuming due to the intrinsically slow convergence of MC simulation.

This paper introduces a novel "COS-tensor" framework that transcends MC simulation. It has the potential to serve as a computationally efficient alternative, particularly for large, liquid portfolios, while maintaining sufficient flexibility and transparency.

Our key insight is that the problem can be transformed and solved in the Fourier domain through two steps: First, rather than generating total exposure samples as in MC methods, we numerically compute the characteristic function of the total exposure and subsequently recover the cumulative distribution function via the one-dimensional COS method. Second, to circumvent the curse of dimensionality in characteristic function computations, we apply tensor decomposition to the Fourier-cosine coefficient tensor of the joint density function. This "COS-tensor" approach constitutes a general framework that generates distinct dimensionally reduced cosine expansions for different tensor decomposition techniques, effectively shifting the curse of dimensionality to the offline training phase for tensor decomposition.

The main part of this paper builds and studies the COS-CPD method, resulted from inserting low-rank Canonical Polyadic (CP) decomposition into the COS-tensor framework. A secondary innovation herewith is our Fourier-domain training algorithm for offline CP decomposition, which demonstrates over 100-fold improvements in speed and accuracy compared to physical-domain backpropagation with gradient descent.

Extensive testing on real-sized portfolios shows that achieving 0.1% error for portfolios of thousands of trades under seven risk factors requires only a fraction of the computation time of MC simulation. Results confirm our theoretical error analysis: exponential convergence with respect to Fourier-cosine terms and quadrature points at netting-set level, versus algebraic convergence at counterparty level. Notably, the computational performance remains largely unaffected as portfolio size increases, which is a stark contrast to MC methods.

The computational bottleneck lies in the offline training, where the dimensionality curse for risk factors persists. This limitation, combined with diverse extension avenues, indicates substantial potential for further research. For instance, as we will demonstrate in a companion paper, using Tensor Train decomposition can markedly alleviate high-dimensional training constraints. We further note that existing instrument-level acceleration methods remain compatible with our framework, and for portfolios with numerous risk factors, the COS-tensor methods can serve as effective variance reduction techniques for MC simulation.

Josha Dekker (University of Amsterdam)

Stochastic optimal control with randomly arriving control moments

Control problems with randomly arriving control moments occur naturally. Financial situations in which control moments may arrive randomly are e.g., asset-liquidity spirals or optimal hedging in illiquid markets. We develop methods and algorithms to analyze such problems in a continuous time finite horizon setting, under mild conditions on the arrival process of control moments.

Operating on the random timescale implied by the control moments, we obtain a discrete time, infinite-horizon problem. This problem may be solved accordingly or suitably truncated to a finite-horizon problem. We develop a stochastic primal-dual simulation-and-regression algorithm that does not require knowledge of the transition probabilities, as these may not be readily available for such problems. To this end, we present a corresponding dual representation result. We also discuss some insights regarding choices of regression functions and sampling methods and illustrate their effect on the duality gaps.

We then apply our methods to several examples, where we explore in particular the effect of randomly arriving control moments on the optimal control policies.
This is joint work with Roger J.A. Laeven, John G.M. Schoenmakers and Michel H. Vellekoop.

Marco Zullino (University of Amsterdam)

Dynamic star-shaped risk measures via BSDEs

In this talk, we present characterization results for dynamic return and star-shaped risk measures induced by backward stochastic differential equations (BSDEs). We begin by characterizing a broad family of static star-shaped functionals in a locally convex Fréchet lattice. Then, using the Pasch-Hausdorff envelope, we construct a suitable family of convex drivers of BSDEs, which induce a corresponding family of dynamic convex risk measures. The dynamic return and star-shaped risk measures arise as their essential minimum.

Moreover, we prove that if the set of star-shaped supersolutions of a BSDE is non-empty, then for each terminal condition there exists at least one convex BSDE with a non-empty set of supersolutions, yielding the minimal star-shaped supersolution. Finally, we illustrate our theoretical results with a few examples.

Registration

To register for the winter school, please use the electronic registration form that is available at the web page of the winter school (see https://staff.fnwi.uva.nl/a.khedher/winterschool/winterschool.html).

The registration fee includes accommodation (single room) for the nights of January 19-20 and January 20-21, all meals starting with lunch on Monday up to and including lunch on Wednesday, and tea and coffee during breaks. Payment can be made by transfer to IBAN account number: NL27 INGB 0007388994 of Winter School Amsterdam, Secretariaat Korteweg–De Vries Instituut, Amsterdam and (for international money transfers) BIC: INGBNL2A.

The fee schedule is as follows:

	early registration (before December 1)	late registration (after December 1)
industry professional	€1395	€1650
full-time academic	€650	€700

Inquiries concerning fees for partial attendance may be directed to a.michiara@uva.nl. Registration will be valid after full payment has been received. Refunds can be given only for cancellations received before January 1, 2026.

Please note that PhD students and postdocs who receive an FWO WOG grant should still register at the website, to ensure accommodation. You can mention "FWO WOG Grant" in the field "Remarks".

Accommodation at the venue is limited. Therefore, reservations will be treated on a first-come-first-served basis with priority for full arrangements. Participants who cannot be lodged at the venue will be accommodated in a hotel nearby. Transportation from the hotel to the venue and vice versa will be taken care of by the organization.

Further information

For further information regarding the scientific program, please contact one of the members of the organizing committee. For information concerning registration, please contact:

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