18th Oxford-Berlin Young Researcher's Meeting on Applied Stochastic Analysis

4 – 6 January 2024

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1. Welcome

It is our great pleasure to welcome you to the 18th Oxford-Berlin Young Researchers Meeting on Applied Stochastic Analysis held at Oxford. We hope you enjoy a productive meeting!

Scientific Board
Terry Lyons (University of Oxford)
Peter Friz (TU and WIAS Berlin)

Conference organisers
Lingyi Yang (University of Oxford)
Emilio Ferrucci (University of Oxford)
Thomas Wagenhofer (TU Berlin)
Luca Pelizzari (WIAS Berlin)

Location
All talks will be held in lecture theatre **L4** at the Mathematical Institute. The full address is The Mathematical Institute, Andrew Wiles Building, Radcliffe Observatory Quarter, Woodstock Rd, Oxford OX2 6GG. It is about a 20-minute walk from Oxford train station.

Workshop dinner
This will take place at St Anne's College on Friday 5th January.

Supporting Institutions

DataSıg

This meeting is generously supported by the DataSıg programme (EPSRC EP/S026347/1).

2. Schedule

Thursday, 4th January

9:50 AM–10:00 AM	**Welcome**		
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11:00 AM–11:30 AM	**Coffee Break**		
11:30 AM–12:00 PM	Lukas Gräfner (FU Berlin)	*Singular SDEs under supercritical distributional drift with critical divergence*	9
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03:30 PM–04:00 PM	Martin Albert Gbúr (University of Warwick)	*Tail Asymptotics of the Signature and its connection to the Quadratic Variation*	7
04:00 PM–04:30 PM	Sotiris Kotitsas (University of Warwick)	*The two-dimensional heat equation with a random potential that is correlated in time*	11
04:30 PM–05:00 PM	Sam Morley (University of Oxford)	*RoughPy: For when your paths are not smooth*	12
07:00 PM–09:00 PM	**Dinner at St Anne's**		

Saturday, 6th January

09:30 AM–10:00 AM	Rosa Preiß (MPI MiS Leipzig)	*An algebraic geometry of paths via the iterated-integals signature*	8
10:00 AM–10:30 AM	Oleg Butkovsky (WIAS Berlin)	*Weak and strong well-posedness and local times for SDEs driven by fractional Brownian motion with integrable drift*	11
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11:00 AM–11:30 AM	Paola Arrubarrena (Imperial College London)	*Anomaly Detection on Radio Astronomy using Signatures*	13
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3. Theory of Rough Paths

3.1 Flow techniques for non-geometric RDEs on manifolds

Hannes Kern, TU Berlin

Thursday 02:00PM–02:30PM

In 2015, Bailleul presented a mechanism to solve rough differential equations by constructing flows, using the log-ODE method. We extend his results to non-geometric rough paths, living in any connected, cocommutative, graded Hopf algebra. This requires a new concept, which we call a pseudo bialgebra map. We further connect our results to Curry et al (2020), who solved planarly branched RDEs on homogeneous spaces.

3.2 Branched Itô formula and natural Itô-Stratonovich isomorphism

Nikolas Tapia, WIAS Berlin

Thursday 02:30PM–03:00PM

Branched rough paths define integration theories that may fail to satisfy the integration by parts identity. The projection of the Connes-Kreimer Hopf algebra ($\mathscr{H}_{\mathrm{CK}}$) onto its primitive elements ($\mathscr{P}$) defined by Broadhurst-Kreimer and Foissy, allows us to view $\mathscr{H}_{\mathrm{CK}}$ as a commutative $\mathbf{B}_\infty$-algebra and thus to write an explicit change-of-variable formula for solutions to rough differential equations (RDEs), which restricts to the well-known Itô formula for semimartingales. When compared with Kelly's approach using bracket extensions, this formula has the advantage of only depending on internal structure. We proceed to define an isomorphism $\mathscr{H}_{\mathrm{CK}} \cong \mathrm{Sh}(\mathscr{P})$ (the shuffle algebra over primitives), which we compare with the previous constructions of Hairer-Kelly and Boedihardjo-Chevyrev: while all three allow one to write branched RDEs as RDEs driven by geometric rough paths taking values in a larger space, the key feature of our isomorphism is that it is natural when $\mathscr{H}_{\mathrm{CK}}$ and $\mathrm{Sh}(\mathscr{P})$ are viewed as covariant functors $\mathrm{Vec} \to \mathrm{Hopf}$. Our natural isomorphism extends Hoffman's exponential for the quasi shuffle algebra, and in particular the usual Itô-Stratonovich correction formula for semimartingales. Special emphasis is placed on the 1-dimensional case, in which certain rough path terms can be expressed as polynomials in the trace path indexed by $\mathscr{P}$, which for semimartingales restrict to the well-known Kailath-Segall polynomials. This talk is based on joint work with E. Ferrucci and C. Bellingeri.

3.3 Tail Asymptotics of the Signature and its connection to the Quadratic Variation

Martin Albert Gbúr, University of Warwick

Friday 03:30PM–04:00PM

We briefly summarize the work of Boedihardjo and Geng (2019) who found a connection between the signature of Brownian motion and the time elapsed, i.e. its quadratic variation. We prove this connection for a more general class of processes, namely for Itô signature of semimartingales, and establish a connection to the Hurst parameter in the case of fractional Brownian motion. We propose a conjecture for extension to multidimensional space, and discuss possible approaches for tackling this.

3.4 An algebraic geometry of paths via the iterated-integals signature

Rosa Preiß, MPI MiS Leipzig

Saturday 09:30AM–10:00AM

Contrary to previous approaches bringing together algebraic geometry and signatures of paths, we introduce a Zariski topology on the space of paths itself, and study path varieties consisting of all paths whose signature satisfies certain polynomial equations. Particular emphasis lies on the role of the non-associative halfshuffle, which makes it possible to describe varieties containing history. Specifically, we may understand the set of paths on a given classical algebraic variety in $\mathbb{R}^d$ starting from a fixed point as a path variety. This will allow us to define rough paths on algebraic varieties, an alternative to existing notions of rough paths on manifolds which should be nicely computable with computer algebra. While halfshuffle varieties are stable under stopping paths at an earlier time, we furthermore study varieties that are stable under concantenation of paths. Combining these two subclasses of path varieties makes it possible to work with path groupoids à la Kapranov in purely algebraic terms.

3.5 Summing Rough Paths

Martin Geller, University of Oxford

Saturday 12:00PM–12:30PM

We provide an account of how to sum rough paths which generalises the existing literature and is founded upon the notion of the coupling of rough paths.

4. Stochastic analysis

4.1 Singular SDEs under supercritical distributional drift with critical divergence

Lukas Gräfner, FU Berlin

Thursday
11:30AM–
12:00PM

On $\mathbb{T}^d$ and $\mathbb{R}^d$ we study

$$dX_t = b(t, X_t)dt + dB_t, \tag{4.1}$$

where $b : \mathbb{R}_+ \to \mathscr{S}'$ is distributional and B is a Brownian motion. We consider this equation in the scaling-supercritical regime using energy solutions and recent ideas for generators of singular SPDEs. In the periodic setting on the Besov scale, we show weak well-posedness of energy solutions with initial law $\mu \ll \text{Leb}$, $\frac{d\mu}{d\text{Leb}} \in L^{\tilde{p}}, \tilde{p} > 2$ when $b \in L^\infty_T B^{-\gamma}_{\hat{p},\infty} \cap L^q_T B^{-1}_{p,2}$ with $p, \hat{p}, q, \in [2,\infty], \gamma \in (0,1)$ such that $\hat{p} > \frac{2}{1-\gamma}, p\left(\frac{1}{2} - \frac{1}{q}\right) > \frac{\tilde{p}}{\tilde{p}-1}$ and furthermore $\Delta^{-1}\nabla(\nabla \cdot b) \in L^\infty_T L^d \cap \sqrt{L^2_T B^0_{d,1}}$. This allowes b to be super-critical with critical divergence part. For time-independent b we show weak well-posedness of energy solutions for locally diverging rough A, where A is the matrix field in the Helmholtz decomposition $b^i = \nabla \cdot A_i + \partial_i V + \hat{b}(0)^i$. This produces proper elements $b \in H^{-1,p}$ for any $p > 2$ in large enough dimensions. Our results in the periodic setting naturally generalize to $\mathbb{R}^d$.

4.2 Stochastic Convex Integration Solutions to the 3D Navier-Stokes Equations

Stefanie Berkemeier, Bielefeld University

Thursday
12:00PM–
12:30PM

For a prescribed deterministic kinetic energy we use convex integration to construct analytically weak and probabilistically strong solutions to the 3D in- compressible Navier-Stokes equations driven by a linear multiplicative stochastic forcing. These solutions are defined up to an arbitrarily large stopping time and have deterministic initial values, which are part of the construction. Moreover, by a suitable choice of different kinetic energies which coincide on an interval close to time 0, we obtain non-uniqueness.

4.3 Malliavin calculus for rough stochastic differential equations

Fabio Bugini, TU Berlin

Thursday
03:30PM–
04:00PM

Rough stochastic differential equations - as introduced by Friz, Hocquet, Lê (2021) - can be seen as a simultaneous stochastic generalization to both stochastic differential equations and rough differential equations. To make sense of them, one needs to develop a hybrid theory which takes into account both Itô calculus and rough path analysis. The purpose of this talk is to show how it is possible to apply Malliavin calculus to rough stochastic differential equations, aiming to prove that solutions admit a density with respect to the Lebesgue measure. This talk is based on my master's thesis and it is a joint work with Michele Coghi (University of Trento) and Torstein Nilssen (University of Agder).

4.4 Modelling the long-term dynamics of a multiscale diffusion driven by fractional Brownian Motion

Pablo Alonso Martin, University of Warwick

Thursday 04:00PM–04:30PM

Multiscale systems are widely used in the sciences. It is yet not always clear how observational data under the multiscale assumption should be used in order to fit the effective dynamics of the system. Results available in the literature suggest that it is often the case that data must go through an appropriate subsampling to make the estimation of the parameters accurate. However, the subject is unexplored for the case of fractional multiscale systems. We here study the problem of parameter estimation in this context, in particular we address the parameter estimation of a fractional second-order problem. We provide convergence results for the effective diffusion estimated using multiscaled data for the case $H \geq 1/2$. To do so, we derive asymptotic bounds for the spectral norm of the inverse covariance matrix of fractional Gaussian Noise.

4.5 Stochastic calculus through the lens of the Appell Integral Transform

Elena Boguslavskaya, Brunel University London

Friday 10:00AM–10:30AM

We introduce the Appell Integral transform, which shows a direct connection between deterministic calculus and the Malliavin Calculus. The Appell Integral transform can be viewed as a morphism between the Wick product and the pointwise product of deterministic functions. It also maps Malliavin derivative and Skorohod integral to correspondingly differentiation and integration of deterministic functions. Among other results, we show the Hermite transform can be interpreted as the inverse Appell Integral transform. We demonstrate how the Appell Integral transform can be used to define signatures and how a fractional order stochastic integral can be introduced. This talk is partly based on the work with Elina Shishkina.

4.6 Generalized-signature and the PDE representation of signature-based characteristic function

Jiajie Tao, University College London

Friday 10:30AM–11:00AM

We focus on the study of the law of time-homogeneous Ito diffusion processes, and adopt a PDE approach to derive the characteristic function of its signature defined at any fixed time horizon. A key ingredient of our approach is the introduction of the generalised-signature process which can be regarded as the signature process with arbitrary studying point. This lifting enables us to establish the Feynman-Kac-type theorem for the characteristic function of the generalised-signature process by following the martingale approach.

4.7 Semilinear BSPDEs and Applications to McKean-Vlasov Control with Killing

Philipp Jettkant, University of Oxford

Friday 02:30PM–03:00PM

We introduce a novel class of semilinear nonlocal backward stochastic partial differential equations (BSPDE) on half-spaces driven by an infinite-dimensional càdlàg martingale. The equations exhibit a degeneracy and have no explicit condition at the boundary of the half-space. To treat the existence and uniqueness of these BSPDEs we establish a sufficiently general version of Itô's formula for infinite-dimensional càdlàg semimartingales, which addresses the occurrence of boundary terms. In the second part of the article, we employ this class of BSPDEs to study the McKean–Vlasov control problem with killing in the presence of common noise proposed in (Hambly & Jettkant, 2023). The particles in this control model live on the real line and are killed at a positive intensity whenever they are located on the negative half-line, so the interaction occurs through the subprobability distribution of the living particles. We establish the existence of an optimal semiclosed-loop control that only depends on the particles' location but not their cumulative intensity. This problem cannot be addressed through the mimicking arguments in (Lacker, Shkolnikov & Zhang, 2020), because adopting the particles' location as a sole state variable leads to a time-inconsistent control problem. Instead we rely on a stochastic representation of the value function in terms of BSPDEs of the above type. This is joint work with Ben Hambly.

4.8 The two-dimensional heat equation with a random potential that is correlated in time

Sotiris Kotitsas, University of Warwick

Friday 04:00PM–04:30PM

We consider the PDE:

$$\partial_t u(t,x) = \frac{1}{2}\Delta u(t,x) + \beta u(t,x)V(t,x)$$

in the critical dimension $d = 2$ where V is a Gaussian random potential and β is the noise strength. We will focus in the case where the potential is not white in time and we will study the large scale fluctuations of the solution. This case was considered before in $d \geq 3$ and for β small enough. It was proved that the fluctuations converge to the Edwards-Wilkinson limit with a nontrivial effective diffusivity and an effective variance. We prove that this result can be extended to $d = 2$. In particular we show that after tuning β accordingly and renormalizing the large scale fluctuations of the solution, they converge in distribution to the Edwards-Wilkinson model with an explicit effective variance but with a trivial effective diffusivity. We able to prove this for all β below a critical value, after which the effective variance is infinite. Our main tools is the Feynman-Kac formula and a fine analysis of a specific Markov chain on the space of paths that was first introduced in $d \geq 3$ for the same problem.

4.9 Weak and strong well-posedness and local times for SDEs driven by fractional Brownian motion with integrable drift

Oleg Butkovsky, WIAS Berlin

Saturday 10:00AM–10:30AM

Consider a d-dimensional SDE

$$dX_t = b(t,X_t)\,dt + dW_t^H,$$

where W^H is a fractional Brownian motion, $H \in (0,1)$, and the drift $b \in L_q([0,1], L_p(\mathbb{R}^d))$. For $H = 1/2$, it is known that this equation has a weak solution if $1/q + d/p < 1$ (Krylov's condition) and a unique strong solution if $2/q + d/p < 1$ (Krylov-Rockner's condition), and these conditions are known to be optimal. However, for general $H \in (0,1)$, the techniques of Krylov and Krylov-Rockner do not apply. We will discuss our joint works with Samuel Gallay, Khoa Le, Toyomu Matsuda, and Leonid Mytnik, where, using the stochastic sewing lemma, we establish an extension of the Krylov and Krylov-Rockner conditions for general $H \in (0,1)$. We also study the existence of local times for the solution of this equation.

5. Signatures in data science

5.1 Log Neural Controlled Differential Equations

Benjamin Walker, University of Oxford

Thursday 10:00AM–10:30AM

A stream represents a time series, by returning its log-signature when queried over an interval. The Log-ODE method provides an efficient and accurate approximation to the solution of a controlled differential equation by treating the control as a stream. Log neural controlled differential equations (Log-NCDES) combine NCDEs with the Log-ODE method to achieve state-of-the-art performance on a range of multivariate time series classification benchmarks.

5.2 Path Development for Skeleton-Based Action Recognition

Lei Jiang, University College London

Thursday 10:30AM–11:00AM

Skeleton-based action recognition (SAR) is a common method for recognising human action. Recent SAR approaches mainly focus on the improvement of the graph convolution neural (GCN) network to enhance spatial connection while how can we effectively capture temporal relationship of the data remains a challenge. Only relying on the learning from the data, pure deep learning based techniques may not be sufficient to address the temporal challenge, as some complex temporal connections could be difficult to learn directly from the data. In this paper, we present a novel approach to SAR tasks by integrating path development principles drawn from rough path theory. This theoretical framework offers a universal way to extract features from a path, with each skeleton joint motion over time being regarded as one path within the 3D Cartesian space. Utilising the group structure and non-commutative property of the matrix multiplication, path development can effectively capture the temporal connection whilst well-maintain the order of the path along the time.

5.3 RoughPy: For when your paths are not smooth

Sam Morley, University of Oxford

Friday 4:30PM–5:00PM

There are several packages for computing signatures of stream-like data, but none of these packages actually provide a path object that you can interact with. RoughPy is different. In RoughPy, the main objects are streams, which can be quiried over intervals to obtain a signature - not an array containing the terms of the signature, but an actual free tensor object. Because of the persistence of the stream, we can make use of inteilligent caching and other techniques that can radically improve computation times. In this talk, I'll walk through a simple example of building and querying streams built out of the letters in a word.

5.4 Anomaly Detection on Radio Astronomy using Signatures

Paola Arrubarrena, Imperial College London

Saturday 11:00AM–11:30AM

An anomaly detection methodology is presented that identifies if a given observation is unusual by deviating from a corpus of non-contaminated observations. The signature transform is applied to the streamed data as a vectorization to obtain a faithful representation in a fixed-dimensional feature space. This talk is applied to radio astronomy data to identify very faint radio frequency interference (RFI) contaminating the rest of the data.

5.5 Adjoint Equations for Spiking Neural Networks

Christian Holberg, University of Copenhagen

Saturday 11:30AM–12:00PM

A memory efficient way to compute the derivative of a solution to a differential equations with respect to its initial condition is via the adjoint method in which the gradient is computed by solving another differential equation called the adjoint equation. While this method is known to work for a general class of continuous rough differential equations, it remains an open question what happens when the system experiences jumps triggered by internal events. We show that, under suitable conditions on the jump and event mechanisms, the derivative exists and we derive the adjoint equations. One major application is the computation of pathwise gradients for noisy spiking neural networks.

6. Mathematical finance

6.1 Primal and dual optimal stopping with signatures

Luca Pelizzari, WIAS Berlin

Friday 11:30AM–12:00PM

In this talk we introduce two signature-based methods to solve the optimal stopping problem – that is, to price American options – in non-Markovian frameworks. Both methods rely on a global approximation result for L^p-functionals on rough path-spaces, using linear functionals of robust, rough path signatures. In the primal formulation, we present a non-Markovian generalization of the famous Longstaff-Schwartz algorithm, using linear functionals of the signatures as regression basis. For the dual formulation, we parametrize the space of square-integrable martingales using linear functionals of the signature, and apply a sample average approximation. We prove convergence for both methods and present first numerical examples in non-Markovian and non-semimartingale regimes.

6.2 Weak error rate for marginals of discretised local stochastic volatility models

Thomas Wagenhofer, TU Berlin

Friday 12:00PM–12:30PM

Inspired by Math Finance we study so-called local volatility models. To achieve a good fitting of these models to real-world data one ends up with a singular McKean Vlasov SDE, where the coefficients depend on the conditional expectation given the solution of the SDE. Aside from special cases existence and uniqueness-theory for the resulting McKean Vlasov equation is (mostly) an open problem, nevertheless the one-dimensional distributions can be characterized easily. We study the Euler Scheme of the MKV SDE and derive a weak convergence rate of the marginals. Furthermore, we propose different methods for estimating the conditional expectation and derive the error from this estimation. Finally, we propose a particle system and show some simulations.

6.3 Mean Field Model for Optimal Investment under Relative Performance Concerns with Jump Signals

Gemma Lucia Sedrakjan, TU Berlin

Friday 02:00PM–02:30PM

This research project is built upon a fusion of the two works [Bank, Körber; 2022] and [Lacker, Zariphopoulou; 2019]. While the former is concerned with continuous-time stochastic control of an optimal investment problem in which the investor receives signals that warn him about impending price shocks, the latter investigates optimal investment under competition among investors, in both a finite population game and a mean field game. We intend to successfully unify the concepts of jump signals and competition through relative performance concerns into well-posed models of an n-investor and a mean field game, eventually leading to the search for Nash- and mean field equilibria in the respective cases of an n-investor game and a mean field game. We aim to prove the existence of such equilibria and to demonstrate that our results are consistent with those of [Bank, Körber; 2022] and [Lacker, Zariphopoulou; 2019].

7. Participants

Pablo Ramses Alonso Martin (University of Warwick)
Alif Aqsha (University of Oxford)
Paola Arrubarrena (Imperial College London)
Stefanie Berkemeier (Bielefeld University)
Thomas Blore (University of Oxford)
Horatio Boedihardjo (University of Warwick)
Elena Boguslavskaya (Brunel University London)
Simon Breneis (WIAS Berlin)
Fabio Bugini (TU Berlin)
Oleg Butkovsky (WIAS Berlin)
Bowen Fang (University of Warwick)
Emilio Ferrucci (University of Oxford)
Paterne Gahungu (Imperial College London)
Samuel Gallay (École Normale Supérieure de Rennes)
Martin Albert Gbúr (University of Warwick)
Martin Geller (University of Oxford)
Lukas Gräfner (FU Berlin)
Lin Hao He (University of Cambridge)
Stefanie Hesse (HU Berlin)
Christian Holberg (University of Copenhagen)
Philipp Jettkant (University of Oxford)
Shanshan Jia (Peking University)
Lei Jiang (UCL)
Hannes Kern (TU Berlin)
Kaan Kocaslan (TU Berlin)
Sotiris Kotitsas (University of Warwick)
Niels Cariou Kotlarek (UCL)
Maud Lemercier (University of Oxford)
Jian Liu (University of Birmingham)
Ziyang Liu (University of Warwick)
Terry Lyons (University of Oxford)
Peter Paulovics (University of Oxford)
Luca Pelizzari (WIAS Berlin)
Shyam Popat (University of Oxford)
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