
Introductory School
“Stochastic Analysis, Statistics, and Computation on Manifolds and
Singular Spaces”

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organized by
Karen Habermann, Yvo Pokern

Abstracts

Fabrice Baudoin (Aarhus University)

Moment Estimates and Intermittency for the Stochastic Heat Equation on the Sierpinski Gasket

Abstract: We study the parabolic Anderson model, or stochastic heat equation with multiplicative space-time white noise, on bounded fractal spaces, with particular emphasis on the Sierpiński gasket equipped with the Kigami Laplacian and Dirichlet boundary conditions. A central question is how the geometry of the underlying space influences the large-time behavior of the solution. Using heat kernel estimates, Wiener chaos expansions, and hypercontractivity, we derive upper bounds for the growth of moments of the solution and obtain matching lower bounds in the second moment. These estimates quantify the competition between the dissipativity of the Dirichlet heat semigroup and the excitability induced by the multiplicative noise. They also provide evidence for intermittency phenomena on fractals, where high peaks of the solution carry most of the mass at large times. The results reveal the role of the Hausdorff and walk dimensions in determining the Lyapunov-type exponents governing moment growth.

Marcelo Hartmann (University of Helsinki)

A class of tractable wrapped Gaussians for posterior approximations on statistical manifolds

Abstract: In Bayesian statistics, the Laplace approximation provides a computationally efficient approximation to posterior distributions. However, its Gaussian form restricts it to elliptical shapes, limiting its ability to capture important posterior features such as skewness, heavy tails, and narrow high-probability regions. Recent work has addressed this limitation by exploiting Riemannian geometry to push forward Gaussian distributions from the tangent space to a chosen manifold, referred to as wrapped Gaussians. While offering greater flexibility, they introduce substantial computational challenges. Sampling requires solving geodesic equations through the exponential map and density evaluation additionally depends on the logarithmic map and Jacobi fields, involving costly differential equation solvers alongside full matrices inverse operations, Christoffel symbols and curvature tensors. To overcome these limitations, we employ the theory of contrast functions to derive tractable

approximations of the logarithmic and exponential maps on statistical manifolds endowed with the Fisher–Rao metric and the prior distribution geometry. The resulting methodology bypass the need to compute these geometric quantities and numerical solvers thereby removing the principal computational bottlenecks of existing wrapped Gaussian approaches. Empirical results across a range of models demonstrate that the proposed approximation captures complex posterior geometries while remaining orders of magnitude faster than current geometric state-of-the-art approximation.

Yuga Iguchi (Lancaster University)

Parametric inference for hypoelliptic diffusions: Degenerate structure and approximate likelihoods

Abstract: I will discuss recent developments in likelihood-based parametric inference for diffusion processes observed at discrete times, with a particular focus on hypoelliptic diffusions with degenerate diffusion coefficients. Roughly speaking, the system can be divided into rough and smooth coordinates: only the rough coordinates are directly driven by Brownian motion. In general, the transition density, and hence the exact likelihood, is intractable, and so a standard practical approach is to construct a surrogate likelihood using a transition density approximation based on the Euler–Maruyama discretisation. For hypoelliptic diffusions, however, this approximation has a singular covariance matrix and therefore does not yield a well-defined likelihood.

In this talk, I will introduce two classes of hypoelliptic diffusions, which we call ‘Hypo-I’ and ‘Hypo-II’, according to whether the noise from the rough coordinates propagates to all smooth coordinates via the drift in a single step or requires two successive steps. I will then describe a recipe for constructing tractable approximate likelihoods tailored to each class and discuss how these constructions yield contrast estimators with desirable asymptotic properties, including consistency and asymptotic normality. I will conclude by formulating a conjectural extension beyond Hypo-II.

Naotaka Kajino (Kyoto University)

Analysis of Laplacians and diffusions on fractals

Abstract: The research field of analysis of Laplacians on fractals is aimed at establishing rigorous mathematical theory of description and analysis of fundamental physical phenomena like heat conduction and wave propagation. Since the usual notion of partial derivatives do not make sense on fractals, it is a highly non-trivial problem how one should define a canonical “Laplacian” on a given fractal (and what criteria one should apply in deciding whether it is “canonical”). Answering this question requires careful thoughts on the geometric features of individual fractals and has been successfully achieved only for limited classes of fractals.

This talk will mainly discuss the classical case of Euclidean self-similar fractals studied extensively since late 1980s, such as the Sierpiński gasket and the Sierpiński carpet. More specifically, it will explain the construction of Laplacians and diffusions on such fractals and present fundamental results such as sub-Gaussian heat kernel bounds, analogues of Gaussian bounds involving a space-time scaling exponent $\beta > 2$ called the walk dimension of the diffusion, and asymptotic behavior of the heat kernel and the eigenvalues.

Then the last part of the talk will briefly discuss the (im)possibility of realizing GAUSSIAN heat kernel bounds on fractals. Note that the walk dimension β in the heat kernel bounds could be considered as representing “how close the geometry of the fractal is to being smooth”. It has been observed by Kigami in [Math. Ann. 340 (2008), 781-804] that, in the case of the standard two-dimensional Sierpiński gasket, one can decrease β to two (so that Gaussian heat kernel bounds hold) by suitable changes of the metric and the measure while keeping the associated Dirichlet form (the quadratic energy functional) the same. The talk will present some details of this result, and if time permits,

further explain the subtlety underlying this phenomenon by mentioning a result, obtained by the speaker and Mathav Murugan (UBC) in [Invent. Math. 231 (2023), 263-405], that it is IMpossible to achieve Gaussian heat kernel bounds by similar constructions in the case of the N -dimensional Sierpiński gasket for $N > 2$.

Alexander Lewis (Chalmers University of Technology/University of Gothenburg)

TBC

Abstract: TBC

Radomyra Shevchenko (École Centrale Méditerranée and Université Côte d'Azur)

Geometric functionals of Gaussian fields

Abstract: In this talk, I will provide a brief overview of the asymptotic results for geometric functionals (such as the excursion area, the level curve length, or the associated Euler-Poincaré characteristic) of Gaussian fields on the plane for the growing observation window, focusing mainly on the so-called Berry random field that appears as a universal limit of random eigenfunctions of the Laplacian on Riemannian manifolds. I will also highlight some related statistical questions. Finally, I will present joint ongoing work with E. Di Bernardino and A.P. Todino, in which we study nonlinear perturbations of the Berry random field by another Gaussian field.

Anja Sturm (University of Göttingen)

Approximating Brownian motion on manifolds efficiently using retractions

Abstract: A version of Donsker's theorem shows that geodesic random walks on Riemannian manifolds converge to the respective Brownian motion. From a computational perspective, however, evaluating geodesics can be quite costly. We therefore introduce approximate geodesic random walks based on the concept of retractions. We show that these approximate walks converge to the correct Brownian motion in the Skorokhod topology as long as the geodesic equation is approximated up to second order. As a result we obtain an efficient algorithm for sampling Brownian motion and diffusion processes on compact Riemannian manifolds.

Frank van der Meulen (Vrije Universiteit Amsterdam)

Conditioning diffusions on a terminal bearing

Abstract: Stochastic differential equations provide a way to define probabilistic models on manifolds. In applications, often only temporal snapshots at specific times are obtained. Based on such data, one would like to reconstruct the process (filtering/smoothing) and estimate unknown parameters. Lack of a closed form expression for the likelihood makes this a difficult problem. Over the past 20 years, stochastic simulation methods have become increasingly popular to work around this. In this talk I will illustrate such methods for bearings only tracking. Towards the end of the talk I will highlight some open research questions in this field.

Kevine Toukam (Leipzig University)

Dynamical optimal transport with $\mathfrak{so}(d)$ -invariance: from theory to computation

Abstract: TBC
