General information

Welcome to Linz

We are very happy to welcome you to Linz on the occasion of the *Tenth IMACS Seminar on Monte Carlo Methods (MCM 2015)*. The MCM conference series has become one of the major events for researchers in the Monte Carlo and quasi-Monte Carlo community, both for theoretical and applied scientists. We are glad to host MCM for the second time in Austria since it was held in Salzburg in 2001.

We are also very pleased with the efforts of the program committee for their selection of plenary speakers and grateful to our colleagues who have created a high number of interesting special sessions. The speakers come from a variety of scientific backgrounds, countries, institutions, and stages of their career. We hope that you have the opportunity to meet colleagues, establish new contacts, and get new ideas from this meeting by talking with your fellow participants. If so, this conference will have been a success.

We understand that for some of you it has been a long journey to Austria, and we therefore hope you will be rewarded with a rich and interesting scientific program and a memorable experience of Linz. Linz is the third-largest city of Austria and the capital of the province of Upper Austria. The population of the city is 194,000, and that of the Greater Linz area is about 271,000. The city is located in the northern part of Austria on both sides of the River Danube and hosts four universities: The *Anton Bruckner Private University for Music, Drama, and Dance* (approx. 900 students), the *Catholic-Theological Private University Linz* (approx. 500 students), the *University of Arts and Industrial Design Linz* (approx. 1,000 students) and the *Johannes Kepler University (JKU)* (approx. 20,000 students) which hosts law, business, social sciences, medicine, engineering, and science faculties.

For Wednesday evening we have arranged a boat trip on the Danube where we will also have the conference dinner. We sincerely hope you will be able to join us on this cruise and enjoy the evening and the dinner on board of the MS "Linzerin".

We would like to thank the JKU Linz, the RICAM Linz, and all sponsors for making this event possible. Furthermore we are grateful to all members of the Steering Committee, the Program Committee, all speakers, chairs, and special session organizers for making MCM 2015 an outstanding scientific event. We also would like to thank Margot Berger, Cornelia Brandt-Springsits, Anita Großhaupt, Christian Irrgeher, Ralph Kritzinger, Frances Kuo, Helene Laimer, Gerhard Larcher, Florian Puchhammer, Michaela, Szölgyenyi, Melanie Traxler, Annette Weihs, and Sandra Winzer, who supported us in organizing this conference.

We wish you a pleasant, productive and interesting stay at JKU, Linz, and Austria!

Evelyn Buckwar (JKU) , Peter Kritzer (JKU) , Gunther Leobacher (JKU) (chair), Friedrich Pillichshammer (JKU) , and Arne Winterhof (RICAM)
MCM 2015 Conference Organizers

Johannes Kepler University (JKU), Linz, Austria

Conference website: `http://www.mcm2015.jku.at/`
Conference email: `mcm2015@jku.at`

Contents

History

The MCM Conference is a biennial meeting devoted to the study of Monte Carlo (MC) and related fields, such as (pseudo-)random number generation and quasi-Monte Carlo (QMC) methods, and their effective application in different areas. The conference regularly attracts an audience of roughly 100 participants. Its aim is to provide a forum where leading researchers and users can exchange information on the latest theoretical developments and important applications of these methods. In a nutshell, MC methods study complex systems by simulations fed by computer-generated pseudo-random numbers. QMC methods replace these random numbers by more evenly distributed (carefully selected) numbers to improve their effectiveness. A large variety of special techniques are developed and used to make these methods more effective in terms of speed and accuracy. The conference focuses primarily on the mathematical study of these techniques, their implementation and adaptation for concrete applications, and their empirical assessment.

The earlier MCM seminars took place at:

1. Brussels, Belgium, 1997
2. Varna, Bulgaria, 1999
3. Salzburg, Austria, 2001
4. Berlin, Germany, 2003
5. Tallahassee, USA, 2005
6. Reading, UK, 2007,
7. Brussels, Belgium, 2009,
8. Borovets, Bulgaria, 2011
9. Annecy-le-Vieux, France, 2013

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Special issue of Mathematics and Computers in Simulation

Selected papers covering the topic of a talk presented at MCM2015 will appear in a special issue of the IMACS journal *Mathematics and Computers in Simulation*.

Submission will be through the Elsevier electronic submission system, and the call for papers will be issued shortly after the conference. The deadline for submission will be December 31st, 2015.

Sponsors

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`http://www.finanz.jku.at/index.php?id=154`

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`https://www.dk-compmath.jku.at/`

Plenary lectures

Monday, July 6th, 09:00-10:00, Lecture Hall A, S3 Z17

Embeddings for high- and infinite-dimensional integration problems

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Coauthor(s): Michael Gnewuch, Mario Hefter, Aicke Hinrichs and Greg Wasilkowski

Plenary lecture

Embeddings between function spaces yield inequalities for many quantities of interest in information-based complexity and approximation theory. In particular, for numerical integration embeddings are often applied as follows: If F and G are two spaces of continuous functions on $[0,1]^d$ with a continuous embedding $i : F \hookrightarrow G$, then

$$e(Q_n, F) \leq \|i\| \cdot e(Q_n, G)$$

for the maximal errors of any (deterministic or randomized) quadrature formula Q_n on the unit balls in F and G, respectively. Upper bounds for integration on G therefore yield upper bounds for integration on F, and the reverse conclusion is valid for lower bounds.

In this talk we consider high-dimensional and, as the limiting case, infinite-dimensional integration, where it is crucial to understand the dependence of the norms $\|i\|$ of the embeddings on the dimension d. We survey some recent results for embeddings between weighted function spaces and sketch their application to integration. Specifically, we consider two of the most important types of spaces in high-dimensional integration: tensor product reproducing kernel Hilbert spaces and, beyond the Hilbert space setting, spaces of bounded mixed smoothness.

Monday, July 6th, 14:00-15:00, Lecture Hall A, S3 Z17

Boolean and p-ary bent functions, and normality

Wilfried Meidl
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Plenary lecture

Boolean and more general p-ary functions from an n-dimensional vector space V_n over $\mathbb{F}_p$ to $\mathbb{F}_p$ play a crucial role in pseudorandom number generation for instance for applications in cryptography (stream ciphers, block ciphers). Some quality measures for such functions are the balancedness, the algebraic degree, the correlation immunity and the nonlinearity. Boolean functions attaining the highest nonlinearity are called bent functions. Besides from applications in cryptography where bent functions can be used to generate cryptographically strong (Boolean) functions, bent functions are interesting because of rich connections to other mathematical objects like (relative) difference sets, designs, strongly regular graphs...

In the first part, an overview on Boolean bent functions and bent functions from V_n to $\mathbb{F}_p$, p odd, is given. The second part focuses on a property which is seemingly related to bent functions: A function f from V_n to $\mathbb{F}_p$, n even and p prime, is called normal (weakly normal) if there exists an $n/2$-dimensional affine subspace of V_n on which f is constant (affine). Whereas asymptotically almost all Boolean functions are not (weakly) normal, most classical constructions of Boolean bent functions yield (weakly) normal functions. It seems not even easy to find not (weakly) normal

Boolean bent functions, solely a few examples are known. The situation is somewhat different for p-ary bent functions. As recently shown, a so called weakly regular (but not regular) bent function cannot be (weakly) normal. Many questions about bent functions and normality are open, some open problems are summarized at the end of the talk.

Tuesday, July 7th, 09:00-10:00, Lecture Hall A, S3 Z17

Detailed population balance modelling of soot formation and oxidation

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Plenary lecture

The aim of the methods described is to solve the detailed population balance equations (PBEs) which describe the formation, growth and oxidation of soot particles. Particles are described as aggregates composed of primary particles which are in turn composed of individual polycyclic aromatic hydrocarbons (PAHs). The connectivity of the primary particles is stored and used to determine the sintering and the rounding of particles due to surface growth and condensation processes. A detailed PAH growth model describes the structure and growth of planar PAH molecules. The gas and particle phases are inherently coupled which may be achieved through an operator splitting technique. The simplest stochastic particle method for PBEs is the Direct Simulation Monte Carlo method; also called direct simulation algorithm (DSA). However the direct proportionality between physical particle concentration and computational particle number implies that the approach yields relatively little information about the rarest particles which are often of greater interest. In such cases stochastic weighted algorithms offer performance advantages over DSA. A variety of techniques are employed to accelerate the solution of the PBEs: a binary-tree is used to cache properties of the computational particles, the concept of majorant rates and fictitious jumps is utilised to exploit this binary-tree cache for free-molecular coagulation, and linear processes such as surface growth are deferred. Application of the detailed population balance model to a laminar flame is described briefly.

Tuesday, July 7th, 14:00-15:00, Lecture Hall A, S3 Z17

Approximation of linear operators between Hilbert spaces with standard information

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Plenary lecture

We study the approximation of a linear operator

$$S : H \to G$$

between Hilbert spaces H and G by algorithms of the form

$$A_n(f) = \sum_{i=1}^{n} L_i(f) g_i, \tag{2.1}$$

where the L_i are linear functionals. If H is a space of functions then a special case of (2.1) is

$$A_n(f) = \sum_{i=1}^{n} f(x_i) g_i. \tag{2.2}$$

We compare (2.1) and (2.2) and present new upper and lower bounds for the approximation with standard information (2.2).

The lecture is based on joint unpublished work with Henryk Woźniakowski and on earlier work, in particular by Hinrichs, Novak and Vybiral (JAT 2008); see our book with Henryk, Volume 3.

Wednesday, July 8th, 09:00-10:00, Lecture Hall A, S3 Z17

Numerical integration techniques for PDEs with random coefficients

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Plenary lecture

In this talk we discuss the the approximation of the expectation value of functionals of the solution of PDEs with random coefficients. We focus on the case where the random coefficients are uniformly distributed. Estimating such expectation values requires one to estimate infinite dimensional integrals. We discuss recent advances in integration techniques for such problems. The first method is based on higher order Quasi-Monte Carlo rules (so-called interlaced polynomial lattice rules) – these methods can achieve higher order of convergence. The second method is based on lattice rules – in this case the linear structure of the problem allows one to use a fast QMC matrix-vector multiplication based on circulant matrices and the fast Fourier transform.

Thursday, July 9th, 09:00-10:00, Lecture Hall A, S3 Z17

Adaptive importance sampling techniques

Tony Lelievre
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Plenary lecture

We will present some mathematical results on adaptive techniques to sample multimodal distributions which have been introduced in computational statistical physics. These techniques are used on a daily basis in the field of molecular dynamics in order to compute free energy differences. The analysis of convergence and efficiency of these techniques rely on various tools: functional inequalities for partial differential equations, martingale convergence theorems, general results for the convergence of stochastic approximation algorithms. . . .

[1] TL, M. Rousset et G. Stoltz, *Long-time convergence of an Adaptive Biasing Force method*, Nonlinearity, 21, 1155-1181 (2008).

[2] G. Fort, B. Jourdain, E. Kuhn, TL et G. Stoltz, *Efficiency of the Wang-Landau algorithm: a simple test case*, AMRX, 2, 275-311, (2014).

[3] G. Fort, B. Jourdain, E. Kuhn, TL et G. Stoltz, *Convergence of the Wang-Landau algorithm*, à paraître dans Mathematics of Computations.

Thursday, July 9th, 14:00-15:00, Lecture Hall A, S3 Z17

Computing stochastic partial differential equations: a variety of challenges

Annika Lang
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Plenary lecture

Computing numbers from solutions of stochastic partial differential equations is one of the current challenges in the numerical analysis of these evolution equations. The primary problems that have to be faced are rooted in areas like stochastic analysis, numerical analysis, mathematical statistics, and computer science. Once the mathematical questions of these approximation problems are sufficiently treated, it is time to create toolboxes that are able to compute numbers in a reasonable time with sufficient accuracy such that stochastic partial differential equations can be used by practitioners. The goal of the talk is to present the current challenges when simulating stochastic partial differential equations and some attempts to face these high-dimensional and computationally intense problems.

Friday, July 10th, 09:00-10:00, Lecture Hall A, S3 Z17

Multilevel uncertainty quantification

Robert Scheichl
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Plenary lecture

The term "Uncertainty Quantification (UQ)" is as old as the disciplines of probability and statistics, but as a field of study it is newly emerging. It combines probability and statistics with large-scale scientific computing and numerical analysis to provide a computational framework for quantifying input and response uncertainties which ultimately can be used for more meaningful predictions with quantified and reduced uncertainty.

The key challenge that UQ faces in applications, such as weather and climate prediction or subsurface flow, is the need for fast (tractable) computational tools for high-dimensional quadrature. Due to their tractability, Monte Carlo type methods are the most widely used techniques, but especially when combining input and output data in a Bayesian approach to inference they very quickly become too costly to be practically useful for large-scale scientific or engineering applications.

I will focus on multilevel Monte Carlo methods that exploit the natural model hierarchies in numerical methods for differential equations to overcome this difficulty. Most importantly they provide the genuine possibility to apply powerful, but typically expensive statistical tools, such as Metropolis-Hastings Monte Carlo Markov Chain (MCMC) or sequential Monte Carlo methods in actual large-scale applications. In particular, I will present a multilevel MCMC algorithm with a computational cost that scales optimally with respect to the required accuracy in our experiments with a model problem in subsurface flow, as well as a complete complexity analysis of the method. I will finish my talk by pointing to some possible future research directions and other potential applications for this promising new technology.

Friday, July 10th, 11:30-12:30, Lecture Hall A, S3 Z17

From interpolation to stochastic approximation and vice versa

Stefan Geiss
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Plenary lecture

Although interpolation theory of Banach spaces and approximation theory went hand in hand from the very beginning, during the last decade this interaction was actively re-investigated and extended in Stochastics regarding problems related to the Brownian motion, and more generally, to L'evy processes.

One starting point was the observation that a Binary option in the Black-Scholes model is more difficult to approximate (to hedge) by discrete time portfolios than a European Call. Although this was known to practitioners, the obtained quantitative rates were surprising. An explanation for these rates were finally given by interpolation theory on the Wiener space and could be extended to models with jumps by using interpolation on the L'evy-Ito space.

The talk gives some overview about this type of results in the context of stochastic integrals and Backward Stochastic Differential Equations (BSDEs). The latter equations can be seen as a combination of forward diffusions and stochastic integrals. The interaction of interpolation and approximation makes it possible to explain certain phenomena and to design better approximation schemes. The investigation of BSDEs yields to new Banach spaces of fractional smoothness allowing to treat path-dependent options, i.e. path-dependent terminal values for BSDEs, as well.

Contributed talks

Tuesday, July 7th, 10:30-11:00, Lecture Hall D, S2 059

Splitting integrators for finite spin-ensembles

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Coauthor(s): Evelyn Buckwar

Contributed talk

The stochastic Landau-Lifshitz-Gilbert (SLLG) equation describes the magnetisation of a ferromagnetic material, where the magnetisation direction is subject to thermal fluctuations.
Given a complete probability space $(\Omega, \mathcal{F}, \mathbb{P})$ with filtration $\mathcal{F}_t$, we consider an ensemble of N interacting magnetic spins

$$\begin{aligned} dm_i(t) =& - m_i(t) \times (\nabla_{m_i}\mathcal{E}(m(t)) - \alpha m_i(t) \times \nabla_{m_i}\mathcal{E}(m(t)))\, dt \\ &+ \nu m_i(t) \times \circ dW_i(t) \\ m_i(0) =& m_{i,0} \qquad\qquad \text{for} \qquad 1 \leq i \leq N \end{aligned} \tag{3.1}$$

with Hamiltonian $\mathcal{E} : \mathbb{R}^{3N} \to \mathbb{R}$, where $W(t)$ is an $\mathcal{F}_t$-adapted $\mathbb{R}^{3N}$-dimensional Wiener process and $\circ$ denotes the Stratonovich integral.
An important requirement for a successful numerical treatment is that a chosen numerical method respects the qualitative behaviour of the SLLG, e.g., for each spin, the solution trajectory evolves on the unit sphere $\mathcal{S}^2$.
In this talk we will discuss splitting approaches, where we decompose (3.1) into linear and non-linear deterministic subsystems, which can be solved either exactly or approximately via the Cayley-transform, and linear stochastic subsystems, which we approximate with methods based on the Magnus expansion. The composition of these flows yields a flexible integrator with favourable geometric properties under reasonable computational cost.

Friday, July 10th, 10:30-11:00, Lecture Hall D, S2 059

Efficient scalable Monte Carlo preconditioners and hybrid methods for solving systems of linear algebraic equations

Vassil Alexandrov
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Coauthor(s): Oscar Esquivel and Aneta Karaivanova

Contributed talk

The talk will present an extensive study on designing efficient highly parallel Monte Carlo Preconditioners and hybrid methods (stochastic/deterministic) for solving Systems of Linear Algebraic Equations. Thus we present a Monte Carlo preconditioners based on sparse Monte Carlo matrix inversion, which uses Markov Chain Monte Carlo (MCMC) methods to compute a rough approximate matrix inverse. This rough inverse is further used as a preconditioner while solving Systems of Linear Algebraic Equations. The proposed method is compared with the enhanced deterministic preconditioners computed by the optimized parallel Modified SParse Approximate Inverse (MSPAI) algorithm. Results of an extensive study of the efficiency of sparse parallel Monte Carlo preconditioners compared to the MSPAI preconditioners will be presented. Some results comparing sparse

approximate Monte Carlo with sparse approximate quasi-Monte Carlo preconditioners as well as these with MSPAI will also be presented.

Further results of studies and computational experiment how these can be optimized by an iterative filter process and a parallel refinement, to enhance the accuracy of the inverse and the preconditioner respectively will be presented. Computational experiments with hybrid methods using Monte Carlo and quasi-Monte Carlo preconditioners and deterministic methods such as BiCGSTAB , GMRES etc. to solve Systems of Linear Algebraic Equations as well as comparison with MSPAI/BiCGSTAB and MSPAI/GMRES showing the efficiency of our approach will be presented. The efficiency of the proposed approach will be demonstrated on classes of dense diagonally and non-diagonally dominant matrices as well as classes of general sparse matrices.

Wednesday, July 8th, 12:00-12:30, Lecture Hall B, S3 Z18

Multilevel Monte Carlo simulation of statistical solutions to the Navier-Stokes equations

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Coauthor(s): Christoph Schwab and Jonas Sukys

Contributed talk

We propose Monte Carlo, singlelevel and multilevel Monte Carlo methods for the numerical approximation of statistical solutions to the viscous, incompressible Navier-Stokes equations on a bounded, connected domain $D \subset \mathbb{R}^d$, $d = 1, 2, 3$ with no-slip or periodic boundary conditions on ∂D.

The Monte Carlo convergence rate of order $1/2$ is shown to hold independently of the Reynolds number with constant depending only on the mean kinetic energy of the initial velocity ensemble. We discuss the effect of space-time discretizations on the Monte Carlo convergence. We propose a multilevel Monte Carlo estimator, based on finite samples of numerical solutions with finite mean kinetic energy in a suitable function space and give sufficient conditions for mean-square convergence to a (generalized) moment of the statistical solution. We provide in particular error bounds for multilevel Monte Carlo approximations of statistical solutions to the viscous Burgers equation which are uniform with respect to the viscosity parameter.

Monday, July 6th, 10:30-11:00, Lecture Hall C, S2 053

Accelerated Monte Carlo schemes for bounded SDEs

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Coauthor(s): Juan A. Acebrón and Sara Mancini

Contributed talk

The numerical solution of stochastic differential equations in bounded domains have an $O(\sqrt{h})$ weak order of convergence with respect to the time step h due to the bias induced by the interaction between the diffusion and the boundary. This compares unfavourably with the case of free diffusions – which converge linearly in the weak sense – and leads to computational times of $O(\epsilon^4)$, where ϵ is the error upper bound of the numerical estimate. In the last years, a variety of improved schemes have been proposed which recover the linear weak order of convergence under some conditions. We will review them and experimentally compare their relative performance, and check that those conditions are usually rather conservative. Then, we will present a new algorithm, which exploits the fact that the asymptotic weak rate of convergence can be known in advance, to further speed up the simulations by replacing a 'cloud' of them, at different values of h, for the original single small-time-step simulation, and carrying out a proper regression analysis. Experiments suggest that speedups can be larger than 100.

Monday, July 6th, 12:00-12:30, Lecture Hall D, S2 059

Sequential importance sampling for high-dimensional integration

Zdravko Botev
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Coauthor(s): Pierre L'Ecuyer

Contributed talk

We consider the efficient Monte Carlo estimation of multivariate Gaussian integrals, multivariate student integrals, and the volume of bounded irregular polytopes. All three estimation problems have a common structure, which can be exploited by a sequential importance sampling method. This Monte Carlo method yields strongly efficient estimators for the tails of the Gaussian and student distribution. The theoretical and numerical results suggest that this approach may be the current best one for the evaluation of such integrals.

Friday, July 10th, 11:00-11:30, Lecture Hall C, S2 053

Trigonometric products

Johann Brauchart
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Contributed talk

We discuss trigonometric products that are intimately connected with exponential sums that play a central role in the estimation of the star discrepancy of sequences modulo 1. Our approach will be to interpret the negative logarithm of such a product as the logarithmic energy of points on the unit circle.

Thursday, July 9th, 10:30-11:00, Lecture Hall D, S2 059

Estimating the velocity of interacting random walkers in a disordered environment

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Coauthor(s): Aaron Smith, Rafal Kulik and Volker Schmidt

Contributed talk

Charge transport in disordered materials (such as organic semiconductors) is often modelled by considering charge carriers moving on the vertices of a weighted geometric graph. The dynamics of the charge carriers are described by a continuous time Markov chain, with the transition rates determined by the weights of the graph. Two charge carriers are not allowed to occupy the same vertex at any given time. Because of this restriction, the state space of the underlying process is enormous and Monte Carlo methods need to be used to estimate the average velocities of the particles. Realistic models of disordered materials have many traps (i.e. low energy regions with large rates leading into them and small rates leading out of them) in which charge carriers become stuck for long periods of time. This poses a significant problem for simulation, as almost all computational effort is spent on simulating charge carriers hopping around in trap regions. We propose a method for "coarsening" the state space in such a manner that we do not need to simulate the exact dynamics of the charge carriers in the trap regions whilst still extracting all the information we need in order to estimate velocity consistently. In particular, we show that it is possible to simulate exit probabilities and exit times from subsets of the state space without simulating the individual hops of the charge carriers within these subsets.

Thursday, July 9th, 12:00-12:30, Lecture Hall C, S2 053

Revisiting quasi-standard error

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Coauthor(s): Tony Warnock

Contributed talk

Warnock and Halton have proposed a method of treating multiple QMC estimates as replicates. Owen pointed out a limitation of that error estimate. In this talk, we explore the proposed QMC error estimate and reconsider how this quasi-standard error (QSE) can be trusted in applications.

Wednesday, July 8th, 11:00-11:30, Lecture Hall C, S2 053

New methods for approximating Brownian and Bessel hitting times

Madalina Deaconu
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Coauthor(s): Samuel Herrmann and Sylvain Maire

Contributed talk

We introduce a new method for the simulation of the exit time and position of the δ-dimensional Brownian motion and general Bessel processes from a domain. The originality of our method is that it avoids splitting time schemes as well as inversion of complicated series.

First, we introduce the walk on moving spheres algorithm for the Bessel processes with integer dimension. This method is new and mixes the method of images for the first hitting time, of a non-linear boundary for the Brownian motion, with the random walk on the spheres method, for the heat equation.

Secondly we approximate the hitting time of a non-integer Bessel process by using the additivity property of the distributions of squared Bessel processes. Each simulation step is split in two parts : one is using the integer dimension case and the other one considers hitting times for a Bessel process starting from zero.

By using the connexion between the δ-dimensional Bessel process and the δ-dimensional Brownian motion we construct a fast and accurate numerical scheme for approximating the exit time and position from a boundary for the δ-dimensional Brownian motion.

Wednesday, July 8th, 10:30-11:00, Lecture Hall D, S2 059

Multilevel Monte Carlo simulation of Bayesian Lasso

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Coauthor(s): Daoud Ounaissi and Nadji Rahmania

Contributed talk

We show that Lasso and Bayesian Lasso are very close when the sparsity is large and the noise is small. We propose to solve Bayesian Lasso using a multivalued stochastic differential equation. We obtain four discretization algorithms, and we present hilghly efficient multilevel Monte Carlo (MLMC) simulations. We also compare numerically Monte-Carlo (MC), (MLMC) and proximal Markov Chain Monte Carlo algorithms (PMALA).

Monday, July 6th, 10:30-11:00, Lecture Hall D, S2 059

A new unbiased stochastic algorithm for solving linear Fredholm equations

Ivan Dimov
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Contributed talk

In this talk we propose and analyse a new unbiased stochastic method for solving a class of integral equations, namely the second kind Fredholm integral equations. We study and compare three possible approaches to compute linear functionals of the integral under consideration: i) biased Monte Carlo method based on evaluation of truncated Liouville-Neumann series, ii) transformation of this problem into the problem of computing a finite number of integrals, and iii) unbiased stochastic approach. Five Monte Carlo algorithms for numerical integration have been applied for approach (ii). Error balancing of both stochastic and systematic errors has been discussed and applied during the numerical implementation of the biased algorithms. Extensive numerical experiments have been performed to support the theoretical studies regarding the convergence rate of Monte Carlo methods for numerical integration done in our previous studies. We compare the results obtained by some of the best biased stochastic approaches with the results obtained by the proposed unbiased approach. Conclusions about the applicability and efficiency of the algorithms have been drawn.

Thursday, July 9th, 11:00-11:30, Lecture Hall C, S2 053

A generalization of Sobol' sequences

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Coauthor(s): Christiane Lemieux

Contributed talk

In this talk, we will present a generalization of Sobol' sequences to arbitrary prime power bases and with monic irreducible polynomials. These sequences, which we call "Irreducible Sobol' sequences", retain two important properties of the classical Sobol' sequences in base 2 with primitive polynomials: their generating matrices are nonsingular upper triangular matrices and they have a column-by-column construction that requires only one linear recurrence relation for each coordinate. We prove that Irreducible Sobol' sequences are a sub-family of the wide family of generalized Niederreiter sequences and hence they satisfy all known discrepancy bounds for this family. Further, we have investigated their relations with Niederreiter sequences and found out that the two families only have a small intersection (which additionally requires to re-order the rows of the generating matrices of Niederreiter sequences in that intersection).

Thursday, July 9th, 11:00-11:30, Lecture Hall D, S2 059

Improved Monte Carlo algorithm for combinatorial optimization

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Coauthor(s): Krassimir Atanassov

Contributed talk

Combinatorial Optimization Problems (COP) require a huge amount of computational resources, like time and memory. They belong to the class of NP-hard problems. When the size of the problem grows, the computational time grows exponentially. The traditional numerical methods can not solve this kind of problems for reasonable time. Therefore for solving COPs are applied special kinds of Monte Carlo methods. One of them is Ant Colony (ACO). The ACO algorithm was inspired by real ants behavior. An important question is how the ants can find the shortest path between food sources and their nest. The ACO algorithm is a population based approach, which has been successfully applied to solve hard COP. One of its main ideas is the indirect communication among the individuals of a colony of agents with distributed numerical information called pheromone. We improve the ACO algorithm including "flying" ants. In traditional ACO algorithm the ants include new element in their partial solution applying probabilistic rule, regarding one step forward. In our improved ACO algorithm, the ants will calculate the transition probability, regarding more than one step forward, but they will include only one new element in the partial solution.

Wednesday, July 8th, 10:30-11:00, Lecture Hall B, S3 Z18

Improving the stochastic direct simulation method with applications to evolution partial differential equations

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Contributed talk

The stochastic direct simulation method is a numerical scheme for approximating the solutions of ordinary differential equations by path simulations of certain associated Markov jump processes. Its particular features make it suitable especially when applied to ODE systems originating from the spatial discretization of PDEs. In the talk we present further improvements to this basic method, which are made possible by the fact that in its context a full path of the jump process is computed. With this full set of data one can perform either Picard iterations, Runge-Kutta steps, or a combination, with the goal of increasing the order of convergence. The improved method is applied to standard test problems such as a reaction-diffusion equation modeling a combustion process in 1D and 2D as well as to the radiation-diffusion equations, a system of two partial differential equations in two space dimensions which is very demanding from the computational point of view. We also discuss optimization aspects related to the efficient implementation of sampling algorithms based on Huffman trees.

Wednesday, July 8th, 11:00-11:30, Lecture Hall D, S2 059

Optimization of mesh hierarchies in multilevel Monte Carlo samplers

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Contributed talk

We perform a general optimization of the parameters in the Multilevel Monte Carlo (MLMC) discretization hierarchy based on uniform discretization methods with general approximation orders and computational costs.

We optimize hierarchies with geometric and non-geometric sequences of mesh sizes and show that geometric hierarchies, when optimized, are nearly optimal and have the same asymptotic computational complexity as non-geometric optimal hierarchies. We discuss how enforcing constraints on parameters of MLMC hierarchies affects the optimality of these hierarchies. These constraints include an upper and a lower bound on the mesh size or enforcing that the number of samples and the number of discretization elements are integers. We also discuss the optimal tolerance splitting between the bias and the statistical error contributions and its asymptotic behavior. To provide numerical grounds for our theoretical results, we apply these optimized hierarchies together with the Continuation MLMC Algorithm. The first example considers a three-dimensional elliptic partial differential equation with random inputs. Its space discretization is based on continuous piecewise trilinear finite elements and the corresponding linear system is solved by either a direct or an iterative solver. The second example considers a one-dimensional Itô stochastic differential equation discretized by a Milstein scheme.

Thursday, July 9th, 16:30-17:00, Lecture Hall D, S2 059

A method to check soundness of statistical tests on randomness

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Contributed talk

There are many statistical tests on randomness for pseudorandom number generators (PRNGs), such as those implemented in NIST and TestU01. Such a test gives a p-value for a sample of length L sequence from the pseudorandom number sequence. A two-level test means to iterate the same test N times to obtain N p-values, and to test their distribution. It is often reported that some two-level statistical tests give false results, sometimes because of the accumulation of errors of the approximation formula for p-value, and sometimes because of wrong mathematical analysis. Detecting such a flaw in a statistical test is sometimes difficult: for example, NIST reports that some of the tests need modification (or even deletion) when a newer version is released.

We propose a method to detect such a flaw in advance, based on a three-level scheme proposed by Okutomi and Nakamura.

Thursday, July 9th, 16:00-16:30, Lecture Hall D, S2 059

Implementing 64-bit maximally equidistributed Mersenne Twisters

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Contributed talk

CPUs and operating systems are moving from 32 bits to 64 bits, and hence it is important to have good pseudorandom number generators designed to fully use the 64-bit words. However, the existing 64-bit huge-period generators based on linear recurrences modulo 2 are not completely optimized from the viewpoint of the equidistribution properties. In this talk, we develop 64-bit maximally equidistributed pseudorandom number generators which are optimal in this respect and have equivalent speed to 64-bit Mersenne Twisters. The key techniques are (i) state transitions with double feedbacks and (ii) linear output transformations with several memory references. We also compare our new generators with the SFMT (SIMD-oriented fast Mersenne Twister) generators in terms of some statistical tests.

Wednesday, July 8th, 11:30-12:00, Lecture Hall C, S2 053

Mixed precision multilevel Monte Carlo algorithms on hybrid computing systems

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Contributed talk

We present a method to speed up the classical Monte Carlo algorithm

$$\mathcal{A}^{\mathrm{MC}} = \frac{1}{n}\sum_{i=1}^{n} X_i, \quad \text{where } X_1, \ldots, X_n \text{ are independent copies of } X,$$

on a Hybrid Computing System, including an FPGA. On an FPGA every operation can be done with a freely configurable precision. The cost of an operation increases, if the precision increases. We exploit this. The idea is to use the Multilevel Monte Carlo algorithm, where the computations on one level are done with a customized precision.

Furthermore, we extend the idea to a quadrature problem given by a stochastic differential equation. In this case we have two parameters that control the quality of the approximation.

Supported by Center for Mathematical and Computational Modelling $(\mathrm{CM})^2$.

Tuesday, July 7th, 12:00-12:30, Lecture Hall D, S2 059

Modelling and simulation of the ballistic protection limit V50 by exact sampling of an integrated Brownian motion process with drift

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Coauthor(s): Ben Lauwens, Bruno Escribano and Johan Gallant

Contributed talk

A stochastic model is presented for the evaluation of the expectation and the variance of the ballistic protection limit V50. The V50 is defined as the velocity at which 50% of identical projectiles perforate a ballistic protection and the other 50% not. This limit is typically estimated by an experimental procedure that requires expensive targets and laboratory time. The deceleration of a projectile can be modelled by the following stochastic differential equation (SDE)

$$V(t) = V(0) - \int_0^t \mu(V(t))dt + \int_0^t \sigma(V(t))dW(t)$$

where μ is the average deceleration, σ its variance and W(t) is the standard Brownian Motion process. To match both the coefficients μ and σ to the experimental results an inverse problem has to be solved. First, an approximate numerical solution based on the Euler–Maruyama method including variance reduction techniques was obtained. But, only a very small time step allows an accurate evaluation and it introduces a large computing time. Therefore an efficient sampling

procedure of SDE paths with varying parameters is needed. The following novel algorithm is proposed in this paper:

1. Calculate the end point V(t)=0 by sampling the first passage time distribution; 2. The skeleton of intermediate points is based on scaled Chebyshev points of the second kind: 2.1. Using the properties of the Chebyshev polynomials new points are chosen which are situated between previous points; 2.2. For each new point a Brownian Motion process is sampled conditioned by the values of the left and right neighbouring points and physical limitations; 2.3. The distance travelled by the projectile is evaluated by the Clenshaw-Curtis quadrature; 3. Once the integration is converged, the thickness of the armor is compared with the distance travelled by the projectile allowing a match with the experimental data.

The novel algorithm is in orders of magnitude faster and makes the solution of the inverse problem feasible.

Wednesday, July 8th, 10:30-11:00, Lecture Hall C, S2 053

The first-passage time of the Brownian motion to a curved boundary: an algorithmic approach

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Contributed talk

Under some weak conditions, the first-passage time of the Brownian motion to a continuous curved boundary is an almost surely finite stopping time. Its probability density function (pdf) is explicitly known only in few particular cases. Several mathematical studies proposed to approximate the pdf in a quite general framework or even to simulate this hitting time using a discrete time approximation of the Brownian motion. The authors study a new algorithm which permits to simulate the first-passage time using an iterating procedure. The convergence rate presented in this work suggests that the method is very efficient.

Tuesday, July 7th, 11:30-12:00, Lecture Hall D, S2 059

A continuous-time particle filter for a nonlinear stochastic neural mass model

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Coauthor(s): Evelyn Buckwar

Contributed talk

Neural mass models provide a useful framework for modelling mesoscopic neural dynamics. We briefly discuss the Jansen and Rit Neural Mass Model (JR-NMM) which has been introduced as a model in the context of electroencephalography (EEG) rhythms and evoked potentials and has been used for several applications, e.g. for detecting epileptic diseases or generating visual evoked potentials. In this talk, we first propose a stochastic version of the JR-NMM incorporating random input and we briefly discuss existence and uniqueness of the solution of this system of equations. Then we apply the nonlinear filtering framework to the stochastic JR-NMM in order to solve the inverse problem, i.e. to compute certain parameters from EEG measurements. We determine an equation for the exact solution of the nonlinear filtering problem and solve it numerically by a continuous-time particle filter.

Thursday, July 9th, 15:30-16:00, Lecture Hall C, S2 053

Monte Carlo methods for charge density on a conducting surface

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Coauthor(s): James Given, Youngwon Kim and Sungbae Lee

Contributed talk

There are first-passage and last-passage algorithms, two diffusion Monte Carlo methods, which can obtain charge density on a conducting surface. In general, the first-passage algorithms have been used to obtain the capacitacne of the arbitrary-shaped conductors. In contrast, the last-passage algorithm was introduced to calculate the charge density at a general point on a conducting surface by using the diffusing paths that initiate at that point. Here, the conductor was held at unit voltage without any charge outside of the conductor. The two algorithms are inherently related. The last-passage algorithm is the time reversal of the first-passage algorithm. In this review, the two Monte Carlo methods are briefly reviewed and it is shown that Kai Lai Chung's last-passage algorithm is equivalent to the first-passage algorithm. In addition, based on the time reversality of the last-passage algorithms we extend the last-passage algorithm to calculate the charge density with a charge distribution and a dielectric interface also. Lastly, we mention the recent progress in which we can obtain the charge density on a conducting surface under the general non-constant Dirichlet boundary conditions.

Wednesday, July 8th, 12:00-12:30, Lecture Hall C, S2 053

Tractability of multivariate approximation defined over Hilbert spaces with exponential weights

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Contributed talk

We consider multivariate approximation defined over tensor product Hilbert spaces with exponentially decaying weights. In the worst case setting we study linear algorithms that use information evaluations from the class Λ^{all} which contains all continuous linear functionals. In this talk we show under which conditions we have (uniform) exponential convergence for the worst case error and moreover, we present necessary and sufficient conditions on the weights to achieve the standard and new notions of tractability.

Friday, July 10th, 11:00-11:30, Lecture Hall D, S2 059

A Monte Carlo approach to neural networks

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Coauthor(s): Jean Michel Sellier and Ivan Dimov

Contributed talk

Neural networks represent an important tool in many areas of applied mathematics. The classical approach to this theory is based on the concept of a network of deterministic artificial neurons. These neurons behave in a completely predictable manner which eventually prevents any further learning after the necessary initial optimization process. In this talk, we exploit the analogies between artificial neurons and quantum systems in order to achieve a continuous learning process. To validate the approach, we apply it to the problem of fitting known functions. We show the advantages provided by our novel technique.

Thursday, July 9th, 10:30-11:00, Lecture Hall C, S2 053

On symmetrized van der Corput sequences and generalized Hammersley point sets

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Contributed talk

We consider symmetrized van der Corput sequences in arbitrary bases as well as generalized two-dimensional Hammersley point sets scrambled with arbitrary permutations. Our aim is to give upper bounds on diverse norms of their local discrepancy, which include the L_p norms, and the Besov space norms.

Monday, July 6th, 16:00-16:30, Lecture Hall D, S2 059

A reduced fast component-by-component construction of lattice point sets with small weighted star discrepancy

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Contributed talk

The weighted star discrepancy of point sets appears in the weighted Koksma-Hlawka inequality and thus is a measure for the quality of point sets used in quasi-Monte Carlo algorithms. An important choice of point sets are lattice point sets whose generating vectors can be constructed one component at a time such that the resulting point sets achieve a small weighted star discrepancy.

We consider a reduced fast component-by-component algorithm which significantly reduces the construction cost for such generating vectors provided that the weights decrease fast enough.

The research was supported by the Austrian Science Fund (FWF): Project F5506-N26, which is a part of the Special Research Program “Quasi-Monte Carlo Methods: Theory and Applications”.

Friday, July 10th, 10:30-11:00, Lecture Hall C, S2 053

Discretization of stochastic heat equations with multiplicative noises on the unit sphere

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Contributed talk

In this work, we investigate the discretization of a class of stochastic heat equations on the unit sphere with multiplicative noise. A spectral method is used for spatial discretization while an implicit Euler scheme is used for time discretization. Some numerical experiments will be given. The project is inspired by a recent paper by A. Lang and Ch. Schwab (2014) and two classical papers by K. Ritter and T. Muller-Gronbach (2007).

Wednesday, July 8th, 11:30-12:00, Lecture Hall D, S2 059

Importance sampling for multilevel Monte Carlo

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Contributed talk

Many recent studies have proved the impressive efficiency of Multilevel Monte Carlo methods compared to crude Monte Carlo, which can still be improved by coupling them with importance sampling.

Ben Alaya, Hajji and Kebaier (2013) proposed to rely on stochastic approximation techniques to find the optimal importance sampling density. Jourdain and Lelong (2009) showed that *Sample Average approximation* methods provide a more robust and automatic way of computing the best importance sampling density. In this work, we study how to adapt the Sample Average Approximation technique to the multilevel Monte Carlo framework. This new estimator enables us to significantly reduce the variance. We prove that our estimator satisfies a strong law of large numbers and a central limit theorem with optimal limiting variance. We illustrate this theoretical study with numerical experiments coming from financial problems.

Thursday, July 9th, 15:30-16:00, Lecture Hall D, S2 059

A framework for testing, comparing and visualizing the performance of non-uniform random variate generators

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Coauthor(s): Angela Bitto and Wolfgang Hörmann

Contributed talk

There exist powerful libraries for testing uniform pseudo-random number generators, e.g., Marsaglia's Diehard test suite or L'Ecuyer's TestU01 library. Commonly used generators are extensively tested. For non-uniform random variate generators the situation seems to be quite different. Authors propose new algorithms, create proof-of-concept implementations, and report their experiences. Our personal impression is that code for the performance and validation tests often is especially written for the particular generator and hard to reuse. When running tests on a large range of parameter values for an experimental generator it is often hard to choose suitable sample sizes that result in practicable running times and to avoid to run the test at all on parameter values where the generator is prohibitively slow.

Another poor practice in literature is that performance figures like marginal generation times or rejection constants are often reported and compared to competitive algorithms by means of (small) tables. This is sufficient for the standard normal distributions but inadequate for distributions with one or more shape parameters like the GIG or the generalized hyperbolic distribution.

We therefore present a general framework for testing the correctness and performance of non-uniform random variate generators. It allows to run tests for many different parameter values and visualizes their results. To avoid problems with unexpected long running times a timeout can be set for each test. The test suite has been implemented in R as this allows interactive programming and provides many routines for further processing of the test results. Moreover generators that are coded in C/C++/Fortran can be easily included. We demonstrate the practical importance of our new framework by analyzing a couple of generators for the GIG distribution as well as generators for the beta distribution.

Thursday, July 9th, 16:00-16:30, Lecture Hall C, S2 053

Monte Carlo algorithms for electrical impedance tomography

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Contributed talk

In the first part, we introduce a Monte Carlo algorithm to deal with the simulation of diffusions in a media where the diffusion coefficient is constant or piecewise constant. The simulation before reaching the boundary of the domain or the interface between subdomains is ensured thanks to the Walk on Spheres method. The main difficulty in terms of simulations and for the computation of weak approximations appears when a boundary is reached. We introduce finite differences techniques to deal with this problem for the usual boundary conditions namely Neumann, Robin and transmission conditions. In the second part, we deal with electrical impedance tomography applied to the detection of breast cancer. The methods described in the first part are used to solve the direct problem occuring at each step of the inversion method. The inversion method relies on two stochastic algorithms, one based on the estimation of the distribution of the parameters of the tumor, the other on a versatile memetic algorithm. A very efficient variance-reduction method is also proposed.

Friday, July 10th, 11:00-11:30, Lecture Hall B, S3 Z18

Certain class of CARMA processes in financial models

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Contributed talk

Continuous-time autoregressive moving average (CARMA) processes of order (p; q) with a non-negative kernel and driven by a non decreasing semi-Levy process constitute a useful and general class of non-stationary processes with periodically stationary increments. Motivated by this we introduce periodically divisible distribution and its relation to semi-Levy random measure. For representation of the subordinator we use a semi-Levy Poisson process with a special intensity parameter. The moments and asymptotic behavior of the introduced model with some specified properties are presented. We show that this process is applied in stochastic volatility models as well.

Wednesday, July 8th, 12:00-12:30, Lecture Hall D, S2 059

A multilevel adaptive reaction-splitting simulation method for stochastic reaction networks

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Coauthor(s): Raul Tempone and Pedro Vilanova

Contributed talk

In this work, we present a novel multilevel Monte Carlo method for kinetic simulation of stochastic reaction networks characterized by fast and slow reaction channels. To produce efficient simulations, we automatically classify the reaction channels into the fast and slow classes. To this end, we first introduce the concept of the level of activity of a reaction channel, which depends on the current state of the system. Then, we propose a low cost heuristic that allows us to adaptively split the set of reaction channels into two subsets characterized by either a high or low level of activity. Based on a time splitting technique, the increments associated with high activity channels are simulated using the tau-leap method while those associated with low activity channels are simulated using an exact method. This path simulation technique, which we name mixed method, is amenable for coupled path generation and a corresponding multilevel Monte Carlo algorithm. To estimate expected values of observables of the system at a prescribed final time, our method bounds the global computational error to be below a prescribed tolerance, TOL, within a given confidence level. This goal is achieved with a computational complexity of order $\mathcal{O}\left(TOL^{-2}\right)$, the same as with a pathwise exact method, but with a smaller constant. We also present a novel control variate technique based on the stochastic time change representation by Kurtz, which may dramatically reduce the variance of the coarsest level at a negligible computational cost. Our numerical examples show substantial gains with respect to the standard Stochastic Simulation Algorithm (SSA).

Monday, July 6th, 16:30-17:00, Lecture Hall D, S2 059

A fast QMC computation by low-WAFOM point sets for cumulative distribution of multivariate normal distributions

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Coauthor(s): Makoto Matsumoto, Hiroki Kajiura and Ryuichi Ohori

Contributed talk

Let P be a finite point set in an s-dimensional cube generated by a base-2 digital net. Its Walsh Figure of Merit (WAFOM) is defined by Matsumoto et al. For a smooth function f, P with the lower WAFOM shows the better approximation in quasi-Monte Carlo integration of f by P. Using low-WAFOM point sets obtained by Ohori, we experiment QMC approximation of the cumulative distribution of multivariate normal distributions:

$$\int_{-\infty}^{b_1} \cdots \int_{-\infty}^{b_s} c \exp(-{}^t x A x)\, dx,$$

where c is the normalizing constant and A is a positive definite symmetric matrix.

The experiments show that our method is often much faster than Mathematica's Global Adaptive Method (the standard mehod in Mathematica) and Mathematica's QMC. Moreover, our method has far smaller errors. Our method is much faster than Miwa's algorithm implemented in R for $s \geq 9$ (with smaller errors). Our method is comparable with the randomized QMC known as "Genz-Bretz" implemented in R, where our method has smaller errors for $s \leq 10$.

Thursday, July 9th, 16:30-17:00, Lecture Hall C, S2 053

Efficient variance-based technique for sensitivity analysis of a large air pollution model

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Contributed talk

Computationally efficient sensitivity analysis of a large scale air pollution model is the basic problem we focus on in this talk. Sensitivity study plays an important role for reliability analysis of the results of complex nonlinear models as those used in the air pollution modelling. There is a number of uncertainties in the input data sets, as well as in some coefficients, which determine the speed of the main chemical reactions in the chemical part of the model. These uncertainties are subject to our quantitative sensitivity study. Monte Carlo and quasi-Monte Carlo algorithms are used in this study.

We present an efficient method for global sensitivity analysis of a particular air pollution model, the Danish Eulerian Model (DEM). A large number of numerical experiments with the model must be carried out in order to collect the necessary input data for the particular sensitivity study. Therefore we created an efficient high performance implementation (called SA-DEM), based on the parallel MPI version of the model (the package UNI-DEM). The code was initially developed by using the Bulgarian IBM Blue Gene/P (currently out of service). Later it was ported with some improvements and extended abilities on the IBM MareNostrum III at BSC - Barcelona, the most powerful supercomputer in Spain. Some numerical results, their analysis and the conclusions drawn, will be given in the talk.

Thursday, July 9th, 11:30-12:00, Lecture Hall C, S2 053

A Koksma-Hlawka inequality for general discrepancy systems

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Contributed talk

Motivated by recent ideas of Harman [Unif. Distrib. Theory 5 (2010), 65-78], we present a new concept of variation of multivariate functions on a compact Hausdorff space with respect to a collection $\mathcal{D}$ of subsets of the space. We obtain an abstract version of the Koksma-Hlawka theorem which holds for this notion of variation and discrepancy with respect to $\mathcal{D}$. As special cases we obtain well-known Koksma-Hlawka inequalities for classical notions of discrepancy, such as extreme or isotrope discrepancy. We show that the space of functions of bounded $\mathcal{D}$-variation is closed under natural algebraic operations and illustrate our results on concrete integration problems from integral geometry.

Monday, July 6th, 15:30-16:00, Lecture Hall D, S2 059

Utilizing fast decreasing weights for the construction of efficient lattice rules

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Contributed talk

We consider numerical integration based on lattice rules in weighted function spaces. Usually, conditions on the weights imply certain notions of tractability. For example, for product weights a common condition for strong polynomial tractability is that the infinite sequence of weights is summable. However, this condition does not distinguish between weights that decrease like j^{-2} or j^{-1000} for $j \to \infty$. In this talk we discuss ideas how one can utilize very fast decreasing weights in order to reduce the construction cost of the used lattice rules.

Wednesday, July 8th, 11:00-11:30, Lecture Hall B, S3 Z18

Monte Carlo solution system of parabolic equations

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Contributed talk

A number of computational problems can lead to the solution of a system of parabolic equations. Nowadays vector Monte Carlo algorithms are frequently used to solve system of integral equations proposed by G. Mikhailov. The following vector Monte Carlo algorithms are well known: an algorithm for solving the system of transfer equations with polarization taken into account, a vector algorithm for solving multigroup transfer equations, a Monte Carlo technique combined with the finite sum method and vector Monte Carlo method for solving metaharmonic equations [1, 2]. When we use this method the variance of the vector estimate depends on the form of transitional density. Appropriate choice of this density leads to reduction in complexity of the calculation, defined as the product of the variance and the computational time. The transitional density that corresponds to minimum complexity of algorithm is said to be optimal for the given problem. To determine this density is as difficult as to solve the problem itself, although in some cases it is possible to obtain a minimal criterion of uniform optimality of the method. In this presentation a new Monte Carlo algorithm will be proposed for the numerical solution of a system of parabolic equations. Our algorithm does not use matrix weights. That is why computational complexity of our new method is considerable reduced. Using the new algorithm we solved an initial boundary value problem for the system of parabolic equations. Finally the results of computational experiments are given.

[1] Mikhailov G. A., *Optimization of Weighted Monte Carlo Methods,* Springer Verlag, 1992, pp. 225

[2] Rasulov A, S., Klichman A., Eshkuvatov Z., Raimova G., *A new algorithm for system of integral equations,* Journal of Abstract and Applied Analysis, Volume 2014, http://dx.doi.org/10.1155/2014/236065, Hindawi Publishing Corporation

Monday, July 6th, 11:00-11:30, Lecture Hall C, S2 053

Estimation of option values under the Heston stochastic-local volatility model with CIR interest rates

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Coauthor(s): Andrei Cozma

Contributed talk

We consider full truncation Euler approximations to the Heston-CIR stochastic-local volatility model in the context of foreign exchange markets, which contains both a stochastic and a local volatility component for the exchange rate combined with the Cox-Ingersoll-Ross dynamics for the domestic and foreign interest rates. Under a full correlation structure and a realistic set of

assumptions on the so-called leverage function, we prove strong convergence of the exchange rate approximations and then deduce the convergence of Monte Carlo estimators for a number of vanilla and path-dependent options. In addition, we study a variance reduction method for this multi-factor model based on analytical formulae for the evaluation of some 'inner' conditional expectations appearing in the Monte Carlo estimators, while the other, 'outer' expectations are evaluated by standard sampling. We prove convergence and demonstrate the achievable variance reduction in numerical tests.

Monday, July 6th, 11:30-12:00, Lecture Hall C, S2 053

Multilevel Monte Carlo for a class of McKean-Vlasov equations

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Contributed talk

In many systems, stochastic variables depend on ensemble-averaged behavior as well as path-wise behavior. Examples include physical systems of interacting particles - e.g. plasmas and rarefied gases - and cooperative social behavior. Such phenomena are frequently modeled by McKean-Vlasov equations, which may be regarded as generalizations of SDEs to the case in which distinct paths are permitted to interact. We will discuss the extension of the multilevel Monte Carlo (MLMC) method - introduced in the SDE context by Giles - to a class of McKean-Vlasov equations. Convergence and complexity analysis will be discussed, and numerical examples from applications presented.

Thursday, July 9th, 11:30-12:00, Lecture Hall D, S2 059

Stochastic projection methods and applications to some inverse problems

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Contributed talk

We develop stochastic projection methods for solving linear and nonlinear inverse problems based on a randomized version of the Kaczmarz iteration process. In the linear case, this technique has been used by us to solve very large systems with sparse matrices. Inverse problems can be often formulated as linear or nonlinear systems of equations with additional linear constrains. We deal in this talk with this kind of inverse problems, and present simulation results for two inverse problems: (1) nanosize particle retrieving from diffusion battery measuremets, and (2) inverse diffraction problems. The stochastic algorithms are analyzed and compared against standard random walk methods. The study was supported by the Russian science fundation under grant 14-11-00083.

Thursday, July 9th, 17:00-17:30, Lecture Hall C, S2 053

Is nature a Monte Carlo algorithm?

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Contributed talk

In this talk we introduce a novel formulation of quantum mechanics based on signed particles, which comes from a physical interpretation of the Wigner Monte Carlo method in the light of recent experiments in the field of quantum tomography. In particular, we show that this new formulation not only can make the same predictions made by other more standard approaches, but has several important advantages such as intuitiveness, easy implementation and an incredible level of parallelization. We also show that general relativistic effects can be introduced to some extent in the theory thus opening the way towards the motion of quantum wave-packets along geodesics. We validate the new theory against well-known benchmark tests.

Friday, July 10th, 11:00-11:30, Lecture Hall B, S3 Z18

Computational aspects of the distribution of generalized discrepancies

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Contributed talk

In this talk, we consider the asymptotic statistical properties of a class of generalized discrepancies defined on the unit hypercube, originally introduced by Hickernell to assess the equidistribution of low-discrepancy sequences. We show that, when the number of points diverges, the asymptotic distribution of these discrepancies is an (infinite) weighted sum of chi-squared random variables. The rate of convergence of the finite-sample distribution to its asymptotic approximation is uncommon and particularly rapid. This raises the question whether for these discrepancies the most common methods of approximation of the finite-sample distribution, among which the bootstrap plays a prominent role, perform better or not than the asymptotic approximation. From a theoretical point of view, we show that the distance between the finite-sample distribution and the bootstrap approximation has the same rate of convergence to 0 of the distance between the finite-sample distribution and the asymptotic approximation. From an empirical point of view, we perform an extensive computational experiment, evaluating both approximations with respect to the finite-sample distribution. We conclude that also from an empirical standpoint the two approximations are comparable. This provides an illustration of one of the rare situations in which the bootstrap does not outperform the asymptotic approximation.

Thursday, July 9th, 17:00-17:30, Lecture Hall D, S2 059

Extensions of the Ziggurat algorithm for generating random variables

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Contributed talk

The Ziggurat algorithm for generating random values from monotone decreasing distributions and symmetric unimodal distributions was developed by George Marsaglia and others in the 1960s. During the last decades a lot of modifications which improved the efficiency of the algorithm have been introduced by different researchers and random number generators implementing the algorithm for normal and exponential random variables have been developed. Due to its simplicity, high statistical accuracy and speed, Ziggurat has been the default random number generation algorithm implemented in normal random number generators incorporated in MATLAB, JULIA, GNU mathematical functions libraries and other most widely used software environment for scientific and technical computing. We found that the Ziggurat algorithm can be extended to non-symmetric one dimensional, two-dimensional and three-dimensional unimodal distributions. Non-symmetric one dimensional, two-dimensional and three-dimensional versions of the Ziggurat algorithm have been developed, and random number generators implementing the new versions have been tested. The performance of the presented versions of the Ziggurat algorithm has proven to be as impressive as the performance of the original version in terms of efficiency. We are convinced that in the near future random number generators implementing the Ziggurat algorithm with necessary modifications will be used in many platforms as standard generators for sampling from some widely applied one dimensional distributions other than normal and exponential, two-dimensional and three-dimensional distributions.

Monday, July 6th, 12:00-12:30, Lecture Hall C, S2 053

Solving SDEs with discontinuous drift

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Contributed talk

When solving certain stochastic optimization problems, the optimal control policy often turns out to be of threshold type, meaning that the qualitative behaviour of the control is different depending on the position of the controlled process.
On studying the energy storage optimization problem introduced in the recent literature, SDEs appear that have a discontinuous drift and a degenerate diffusion parameter.
We prove an existence and uniqueness theorem for a general class of such SDEs. Then we apply this result to the setup from the energy storage optimization problem, however, we note that our theoretical result has applications in various fields of applied mathematics.
Additionally, we present a numerical method for approximating the solution to SDEs with discontinuous drift that convergences with strong order 1/2.

Monday, July 6th, 11:30-12:00, Lecture Hall D, S2 059

First passage times of bivariate correlated diffusion processes: analytical and numerical methods

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Coauthor(s): Laura Sacerdote and Cristina Zucca

Contributed talk

The first passage time problem of univariate stochastic processes through boundaries is relevant in different fields, e.g. economics, engineering, finance, neuroscience and physics, and it has been extensively studied in the literature.

On the contrary, results for the first passage time problem of bivariate processes are still scarce and fragmentary. In this talk we determine the joint density of the first passage times of the process to some constant boundaries. This quantity depends on the joint density of the first passage time of the first crossing component and of the position of the second crossing component before its crossing time. First we show that these densities are solutions of a system of Volterra-Fredholm first kind integral equations. Then we propose a numerical algorithm to solve it and we describe how to use the algorithm to approximate the joint density of the first passage times. The convergence of the method is proved for any bivariate process. Explicit expressions for these and other quantities of interest are derived in the case of a bivariate Wiener process. An illustration of the method through a set of examples is finally provided.

Thursday, July 9th, 17:30-18:00, Lecture Hall C, S2 053

Monte Carlo methods with control variate applied to groundwater flow problems

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Contributed talk

One of the main issues in hydrology is the study of the so called groundwater flow problem. In this framework, because of the lack of available measurements needed to accurately reconstruct some specific properties of the medium in which the flow takes place, such properties are often modeled as random fields leading to the solution of stochastic partial differential equations (SPDEs). Typically these random fields are characterized by a low spatial regularity; they can be expanded in series of uncorrelated random variables, however many of those have to be retained in the expansion to obtain a negligible truncation error. This prevents the use of deterministic approximation schemes such as polynomial chaos expansions. In this talk we focus on Monte Carlo schemes with variance reduction strategies based on approximations on hierarchies of spatial meshes (Multi Level Monte Carlo) and / or on control variates given by the solution of the SPDE model with smoothed versions of the input random fields. The latter approach combines the benefits of sampling (Monte Carlo-based) and deterministic (Stochastic Collocation / Galerkin) schemes. These methodologies will be then applied to the solution of the stochastic Darcy equations and to the problem of the delineation of the so called "time dependent capture zones" in aquifers, i.e. the zones starting from which a contaminant particle, driven by the Darcy velocity, reaches a prescribed location with a prescribed probability in a finite time T. Numerical results will be provided in order to show the effectiveness of the proposed strategies.

Tuesday, July 7th, 11:00-11:30, Lecture Hall D, S2 059

Characterisations of stiff stochastic differential equations

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Contributed talk

Although first observations of stiff problems date back to the 1950s, the problem of defining stiffness in a mathematically rigorous way turned out to be rather complex. Given its importance in practice, the concept and treatment of stiff problems have been discussed extensively in the literature and many approaches how stiffness can be defined were published. In many of these definitions, the notions and properties of the spectra, pseudospectra or logarithmic norms of the underlying (linearised) operators are employed.

For the numerical treatment of stochastic differential equations (SDEs), a characterisation of stiffness is also of great importance, especially if one considers problems where a necessary reduction of time step sizes for explicit methods leads to significantly higher computational cost. Examples of such problems are numerical simulations of stochastic partial differential equations and (multilevel) Monte Carlo methods for SDEs.

In this talk, we provide an overview of existing approaches to characterise stiffness for deterministic and stochastic problems. Furthermore, we extend a recently developed concept of stiffness for deterministic differential equations to the stochastic setting and link the proposed notion of stiffness in the mean-square sense with results from the stability theory of linear stochastic differential equations. We conclude the talk by presenting results from extensive systematic numerical experiments with linear SDEs.

Thursday, July 9th, 12:00-12:30, Lecture Hall D, S2 059

On extremal limits in uniform distribution theory

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Coauthor(s): Maria Rita Iacò and Robert F. Tichy

Contributed talk

Recently, extremes of

$$\lim_{N\to\infty} \frac{1}{N} \sum_{n=1}^{N} c(x_n, y_n),$$

with $\{x_n\}$, $\{y_n\}$ uniformly distributed sequences and real valued cost function c, have been studied in the field of uniform distribution theory.
In this talk I would like to link these extremal limits to the field of optimal transport. This *general* theory permits us to state simple alternative proofs of known results and to treat new questions. Furthermore, via a relationship with the linear assignment problem a numerical approximation method can be stated. Finally, some applications in mathematical finance are addressed.

Monday, July 6th, 11:00-11:30, Lecture Hall D, S2 059

Balancing of systematic and stochastic errors in Monte Carlo algorithms for integral equations

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Coauthor(s): Ivan Dimov and Rayna Georgieva

Contributed talk

In this talk we discuss error analysis of biased stochastic algorithms for a class of integral equations. There are unbiased and biased stochastic algorithms, but the latter algorithms are more interesting, because there are two errors in them- stochastic and systematic errors. The problem of balancing of both systematic and stochastic error is very important when Monte Carlo algorithms are used. A Monte Carlo method for integral equations based on balancing of systematic and stochastic errors is presented. An approach to the problem of controlling the error in non-deterministic methods is presented. The problem of obtaining an optimal ratio between the number of realizations N of the random variable and the mean value k of the number of steps in each random trajectory is discussed. Lower bounds for N and k are provided once a preliminary given error is given. Meaningful numerical examples and experiments are presented and discussed. Experimental and theoretical relative errors are presented. Monte Carlo algorithms with various initial and transition probabilities are compared. An almost optimal Monte Carlo algorithm is discussed and it is proven that it gives more reliable results.

Wednesday, July 8th, 11:30-12:00, Lecture Hall B, S3 Z18

An efficient forward-reverse expectation-maximization algorithm for statistical inference in stochastic reaction networks

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Contributed talk

In this work, we present an extension to the context of Stochastic Reaction Networks (SRNs) of the forward-reverse representation introduced in "Simulation of forward-reverse stochastic representations for conditional diffusions", a 2014 paper by Bayer and Schoenmakers. We apply this stochastic representation in the computation of efficient approximations of expected values of functionals of SNR bridges, i.e., SRNs conditioned to its values in the extremes of given time-intervals. We then employ this SNR bridge-generation technique to the statistical inference problem of approximating the reaction propensities based on discretely observed data. To this end, we introduce a two-phase iterative inference method in which, during phase I, we solve a set of deterministic optimization problems where the SRNs are replaced by their reaction-rate Ordinary Differential Equations (ODEs) approximation; then, during phase II, we apply the Monte Carlo version of the Expectation-Maximization (EM) algorithm starting from the phase I output. By selecting a set of over dispersed seeds as initial points for phase I, the output of parallel runs from our two-phase method is a cluster of approximate maximum likelihood estimates. Our results are illustrated by numerical examples.

Thursday, July 9th, 17:30-18:00, Lecture Hall D, S2 059

Efficient deterministic and non-deterministic pseudorandom number generation

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Coauthor(s): Jie Li and Jianliang Zheng

Contributed talk

A high performance and high quality pseudorandom number generator is presented in this paper. It takes less than one clock cycle to generate a pseudorandom byte on an Intel core i3 processor and passes all the 6 TestU01 batteries of tests. The generator can work in either deterministic mode or non-deterministic mode. When working in deterministic mode, it can be used for high speed data encryption and in other applications that require deterministic and reproducible pseudorandom sequences. When working in non-deterministic mode, the generator behaves much like a true random number generator, but with the advantages of low cost, high performance, and general availability. It is good for many applications that currently rely on true random number generators.

Special sessions

Application in finance

Organizers:

Emmanuel Gobet
Ecole Polytechnique Paris

Tuesday, July 7th, 10:30-11:00, Lecture Hall B, S3 Z18

On a weak multilevel Monte Carlo scheme for multidimensional Levy processes

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Special session: Application in finance

In this talk we develop a new weak approximation scheme for Levy-type processes (Levy-driven SDEs and time-changed Levy processes). The new scheme is based on continuous-time Markov chain approximation for the driving Levy process. Such an approximation makes the simulation of the Levy process feasible, especially in high dimensions. We also construct a multilevel version of the proposed scheme and analyse its complexity. Since the scheme is genuinely weak and there is no strong convergence, we propose a special coupling between chains via randomisation to bound the level variances.

Tuesday, July 7th, 11:00-11:30, Lecture Hall B, S3 Z18

Multilevel Richardson-Romberg stochastic approximation

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Special session: Application in finance

*Multilevel Richardson-Romberg (*ML2R*) extrapolation* is a recently introduced *weighted* Multilevel Monte Carlo (*MC*) method ([Lem-Pag, 2014)]). It improves the rate of regular Multilevel Monte Carlo ([Giles '08]) when the strong approximation rate of the random variable of interest by simulatable ones is slow. It is based on a higher order expansion of the *weak error* (or bias) of these approximating random variables. We show how a similar principle can be applied to recursive stochastic approximation, typically the Robbins-Monro zero search algorithm or stochastic gradient descents (and their Ruppert-Polyak's averaged versions) when the innovation of the algorithm cannot be simulated at a reasonable cost. We illustrate, among other possibilities, the efficiency of this *ML2R* stochastic approximation procedure on the computation of large loss probability, quantile approximation and Conditional Value-at-risk involving nested simulations with an application to the Solvency Capital Requirement of a company as defined by the Solvency II directive.

Tuesday, July 7th, 11:30-12:00, Lecture Hall B, S3 Z18

A hedged Monte Carlo approach to project evaluation

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Special session: Application in finance

Strategic decisions involving project evaluation have evolved tremendously in the last decades towards more quantitative methodologies. Such decisions require taking into account a large number of uncertain variables and volatile scenarios, much like financial market investments. Furthermore, they can be evaluated by comparing to portfolios of investments in financial assets such as in stocks, derivatives and commodity futures. This revolution led to the development of a new field of managerial science known as Real Options.

The use of Real Option techniques incorporates also the value of flexibility and gives a broader view of many business decisions that brings in techniques from quantitative finance and risk management. Such techniques are now part of the decision making process of many corporations and require a substantial amount of mathematical background. Yet, there has been substantial debate concerning the use of risk neutral pricing and hedging arguments to the context of project evaluation. We discuss some alternatives to risk neutral pricing that could be suitable to evaluation of projects in a realistic context with special attention to projects dependent on commodities and non-hedgeable uncertainties. More precisely, we make use of a variant of the hedged Monte-Carlo method of Potters, Bouchaud and Sestovic to tackle strategic decisions.

From the financial side, the methodology allows project evaluation from simulated scenarios that

were calibrated from historical observations and incorporating the managerial views. From a numerical viewpoint the challenges include the need to compute stopping time strategies and multidimensional approximations of pricing functions with a rather small number of simulations.

Tuesday, July 7th, 12:00-12:30, Lecture Hall B, S3 Z18

Rare event simulation using reversible shaking transformation

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Coauthor(s): Emmanuel Gobet

Special session: Application in finance

We introduce random transformations called reversible shaking transformations, which are used to design two schemes for estimating rare event probability. One is based on interacting particle systems (IPS) and the other on time-average on a single path (POP) using ergodic theorem. We discuss their convergence rates and provide numerical experiments including continuous stochastic processes and jump processes. Our examples cover rather important situations related to insurance, queuing system and random graph for instance. Both schemes have good performance, with a seemingly better one for POP.

Information-based complexity

Organizers:

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Erich Novak
Friedrich Schiller Universität Jena

Monday, July 6th, 10:30-11:00, Lecture Hall B, S3 Z18

Approximation of sums of ridge functions

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Special session: Information-based complexity

We address approximation of multivariate functions f, which can be written as a sum of ridge functions, i.e. $f(x) = \sum_{j=1}^{m} g_j(a_j \cdot x)$. Here, $g_j, j = 1, \dots, m$ are (unknown) univariate functions and $a_j, j = 1, \dots, m$ are (unknown) vectors in $\mathbb{R}^d$. Our recovery proceeds in several steps including dimensionality reduction from d to m, non-convex optimization and random sampling.

Monday, July 6th, 11:00-11:30, Lecture Hall B, S3 Z18

Open-type QMC rules for weighted Sobolev spaces

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Coauthor(s): Peter Hellekalek and Friedrich Pillichshammer

Special session: Information-based complexity

We discuss quasi-Monte Carlo (QMC) integration in weighted Sobolev spaces. In contrast to many previous results the algorithms considered here are of open type, i.e., they are extensible in the number of sample points without having to discard the samples already used. As the underlying integration nodes we consider randomized Halton sequences in prime bases, for which we study the root mean square worst-case error. The randomization method is a $\boldsymbol{p}$-adic shift which is based on $\boldsymbol{p}$-adic arithmetic.

Furthermore, we outline an approach in which candidates for good shifts can in fact be chosen from a finite set and can be found by a component-by-component algorithm.

Monday, July 6th, 11:30-12:00, Lecture Hall B, S3 Z18

Optimality of Taylor algorithm for solving systems of IVPs with presence of deterministic noise

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Special session: Information-based complexity

Initial value problems are widely studied in case of smooth (for instance Hölder) right-hand side function. Our aim is to generalize these results for problems when the information about the right-hand function consists of function or its derivatives values contaminated by some deterministic noise ε such that $|\varepsilon| \leq \delta$ for some $\delta \geq 0$. Lower bound on error in this case is on level $\max\left(\delta, n^{-(r+\rho)}\right)$ where n denotes the number of used function and derivatives values. By showing that Taylor algorithm's upper bound on error is on the same level, we conclude that the algorithm is optimal also in this case.

Monday, July 6th, 12:00-12:30, Lecture Hall B, S3 Z18

Complexity of oscillatory integrals on the real line

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Special session: Information-based complexity

We investigate univariate oscillatory integrals for the standard Sobolev space $H^s(\mathbb{R})$ and for the space $C^s(\mathbb{R})$ on the real line with an arbitrary integer $s \geq 1$. We obtain bounds for the worst case error of optimal algorithms that use n function values. In particular we study integrals with respect to the density of the normal distribution by using a partition of unity, and establish sharp bounds on the information complexity for the absolute or normalized error criterion.

Tuesday, July 7th, 15:30-16:00, Lecture Hall D, S2 059

New tractability results on Monte Carlo function approximation

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Special session: Information-based complexity

Many numerical problems include a dimensional parameter d which is the number of free variables of functions within a considered function class. Classical results on the order of convergence for both the deterministic and the randomized setting considered d as a fixed parameter, however often the gap between the implicit upper and lower constants grows exponentially in d. The aim of tractability analysis (see e.g. Novak, Woźniakowski: *Tractability of Multivariate Problems*, Vol. I-III, 2008-2012) is to examine the dependence of the information cost $n(\varepsilon, d)$ on a given error bound $\varepsilon > 0$ together with the dimension d. During the past few years for several problems it could be proved that the curse of dimensionality holds within the deterministic setting, that is for some fixed error bound $\varepsilon > 0$ the complexity $n(\varepsilon, d)$ grows exponentially in d. Whereas for integration problems randomization usually breaks the curse, because the error of standard Monte Carlo methods does not depend on the dimension of the domain, for function approximation problems the benefit of Monte Carlo Methods has been unknown for a long time. Here we present some new results on the d-dependence of Monte Carlo function approximation.

Tuesday, July 7th, 16:00-16:30, Lecture Hall D, S2 059

On mean outer radii of random polytopes

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Special session: Information-based complexity

In this work, we introduce a new sequence of quantities for random polytopes. Let $K_N = \mathrm{conv}\{X_1, \dots, X_N\}$ be a random polytope generated by independent random vectors uniformly distributed in an isotropic convex body K of $\mathbb{R}^n$. We prove that the so-called k-th mean outer radius $\widetilde{R}_k(K_N)$ has order $\max\{\sqrt{k}, \sqrt{\log N}\}L_K$ with high probability if $n^2 \leq N \leq e^{\sqrt{n}}$. We also show that this is the right order of the expected value of $\widetilde{R}_k(K_N)$ in the full range $n \leq N \leq e^{\sqrt{n}}$.

Tuesday, July 7th, 16:30-17:00, Lecture Hall D, S2 059

A universal cubature formula for functions with mixed derivatives

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Special session: Information-based complexity

We prove upper bounds on the order of convergence of Frolov's cubature formula for numerical integration in function spaces of dominating mixed smoothness on the unit cube. More precisely, we study worst-case integration errors for Besov and Triebel-Lizorkin spaces, and our results treat the whole range of admissible parameters. In particular, we study the effect of small smoothness.

Low-discrepancy point sets

Organizers:

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Harald Niederreiter
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Thursday, July 9th, 15:30-16:00, Lecture Hall B, S3 Z18

Walsh figure of merit with derivation sensitivity parameter for fast QMC integration in higher dimensions

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Coauthor(s): Ryuichi Ohori and Takehito Yoshiki

Special session: Low-discrepancy point sets

Walsh figure of merit of a digital net P (WAFOM(P)) is a positive real number that measures the performance of P for QMC integration. It is analogous to the $*$-discrepancy of P in that the QMC-integration error is bounded by the product of (1) a certain norm of the integrand and (2) WAFOM(P). A big difference is that WAFOM(P) decreases faster than the order of $|P|^{-1}$, and such order of convergence in QMC is observed through experiments for dimensions up to, say, 10.

One weakness of WAFOM(P) is that for dimension larger than, say, 15, it is hard to find a low-WAFOM point set of practical size.

We introduce a parameter c to WAFOM to define $\mathrm{WAFOM}_c(P)$. When c is chosen smaller, then it is easier to find a point set P with low $\mathrm{WAFOM}_c(P)$, at the cost of some more requirements on the growth of the norm of high order partial derivatives of the integrand. (If c is small, then QMC-integration by the selected point set is more sensitive to the derivatives. Hence named *derivation sensitivity parameter*).

We shall discuss on how to choose c according to the dimension and $|P|$. Experiments show good performance of point sets selected in this way.

Thursday, July 9th, 16:00-16:30, Lecture Hall B, S3 Z18

Quasi-random point sequences for compressed sensing

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Special session: Low-discrepancy point sets

This study compares some constructions of low-discrepancy points for image reconstruction from few data samples in compressed sensing. In contrast to Monte Carlo integration, samples are not averaged but their complementary information yields constrains of a large underdetermined linear system. An approximation of the missing information is recovered by solving an ill-posed inverse image reconstruction problem with iterative algorithms. Experiments are conducted on regular image and current research aims towards applying quasi-random constructions for efficient sampling in holographic interference imaging. Results demonstrate potential in using quasi-random sequences for progressive image formation, instead of constructions of sensing matrices using pseudo-random numbers for recovering sparse image approximations with the compressed sensing framework.

Thursday, July 9th, 16:30-17:00, Lecture Hall B, S3 Z18

Low-discrepancy sampling for non-uniform measures

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Special session: Low-discrepancy point sets

In order to apply the Quasi-Monte Carlo method for numerical integration we usually assume that the integration problem at hand is already reduced to a d-dimensional integral in the unit cube, and with respect to the uniform measure. Accordingly, the search for low-discrepancy point sets is usually conducted for the usual discrepancy, which is calculated with respect to the uniform measure. However, transforming an integration problem with respect to a general measure into an integration problem with respect to the uniform measure is a highly non-trivial procedure, which can cause serious computational problems, in particular if there are stochastic dependencies between the respective coordinates. Accordingly, it is of some interest to develop a theory of QMC integration which can be directly applied to integration problems with respect to general measures. We present some ingredients in such a general theory, including existence results for low-discrepancy point sets, tractability results, and a Koksma-Hlawka inequality.

Thursday, July 9th, 17:00-17:30, Lecture Hall B, S3 Z18

Sets of bounded discrepancy for multi-dimensional irrational rotation

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Special session: Low-discrepancy point sets

The equidistribution theorem for the irrational rotation of the circle may be stated by saying that the discrepancy $N(S,n) - nmes(S) = o(n)$, where S is any set whose boundary has measure zero, and $N(S,n)$ is the number of points falling into S among the first n points in the orbit.

For certain special sets S, the discrepancy obeys a much stricter bound; there are sets S for which the discrepancy remains bounded as n tends to infinity. Hecke and Kesten characterized the intervals with this property, called "bounded remainder intervals".

In this talk I will discuss the Hecke-Kesten phenomenon in the multi-dimensional setting.

Thursday, July 9th, 17:30-18:00, Lecture Hall B, S3 Z18

Empirical risk minimization in Sobolev spaces using digital nets

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Special session: Low-discrepancy point sets

Empirical risk minimization is a well known and much used statistical learning method. Commonly it relies on random points. Here we apply digital nets to obtain learning rates in tensor product Sobolev spaces.

Monte Carlo methods for PDEs

Organizers:

Nizar Touzi
Ecole Polytechnique Paris

Tuesday, July 7th, 15:30-16:00, Lecture Hall B, S3 Z18

Monte Carlo methods for diffusion in media with interfaces

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Special session: Monte Carlo methods for PDEs

There are many situations in which one encounters diffusive phenomena in media with discontinuous coefficients (due to sharp heterogeneities) and interfaces as permeable or semi-permeable barriers (limits of thin layers, ...). Numerous examples could be given in geophysics, brain imaging, population ecology, finance, ...

Although progresses have been done in the understanding of Monte Carlo simulations over the last decade, there are still many challenging problems concerning probabilistic representation of these PDE and their use for simulation.

In this talk, we will present some of these problems regarding permeable and semi-permeable barriers as some way to solve them by using stochastic analysis of diffusion processes of the properties of their local time.

Tuesday, July 7th, 16:00-16:30, Lecture Hall B, S3 Z18

On the convergence of monotone schemes for path-dependent PDE

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Special session: Monte Carlo methods for PDEs

We propose a reformulation of the convergence theorem of monotone numerical schemes introduced by Zhang and Zhuo (2014) for viscosity solutions of path-dependent PDEs (PPDE), which extends the seminal work of Barles and Souganidis (1991) on the viscosity solution of PDEs. We prove the convergence theorem under conditions similar to those of the classical theorem in the paper of Barles and Souganidis (1991). These conditions are satisfied, to the best of our knowledge, by all classical monotone numerical schemes in the context of stochastic control theory. In particular, the paper provides a unified approach to prove the convergence of numerical schemes for non-Markovian stochastic control problems, second order BSDEs, stochastic differential games etc.

Tuesday, July 7th, 16:30-17:00, Lecture Hall B, S3 Z18

Approximation of semilinear parabolic PDEs with GPUs via backward stochastic differential equations

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Special session: Monte Carlo methods for PDEs

It is known that Monte Carlo least-squares (MCLS) schemes based on BSDEs permit approximation of parabolic PDEs in a domain whose dimension is greater than what is possible for generic finite-difference and finite element schemes. Nevertheless, these schemes suffer from a memory bottleneck when the dimension of the domain is greater than 10. We design a re-simulation MCLS approach which reduces the dimensional constraint on the memory substantially. Moreover, we introduce a random initialization procedure which enables the approximation of the PDE at the initial time over a non-zero volume of the spacial domain, and not just from a fixed starting point. This initialization procedure is nonparametric in the sense that it does not depend on the PDE parameters. Furthermore, we are able to use this random initialization procedure improve the numerical stability of using piecewise polynomial type basis functions in regression. The most important aspect of this work is that the algorithm is fully implementable on graphics processing units (GPUs), which enables us to obtain substantial speedups compared to CPU implementations.

We present several numerical examples, including examples from finance, in order to illustrate the performance of the scheme and to corroborate theoretical results.

Multilevel Monte Carlo

Organizers:

Mike Giles
University of Oxford

Michael Gnewuch
Christian-Albrechts-Universität zu Kiel

Monday, July 6th, 15:30-16:00, Lecture Hall C, S2 053

MLMC for parabolic PDEs

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Special session: Multilevel Monte Carlo

The Feynman-Kac theorem enables solutions to high-dimensional parabolic PDEs to be expressed as expectations of functionals of Brownian diffusions. Existing methods using the Euler-Maruyama discretisation achieve $O(\varepsilon)$ RMS accuracy at a cost which is $O(\varepsilon^3)$. We present a new MLMC method with cost $O(\varepsilon^2 \log|\varepsilon|)^3)$. This relies heavily on theoretical results derived by E. Gobet and others, and is supported by numerical experiments.

Monday, July 6th, 16:00-16:30, Lecture Hall C, S2 053

Complexity of almost linear first order PDEs

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Special session: Multilevel Monte Carlo

We continue the study of the complexity of almost linear first order partial differential equations in the randomized setting. In preceding investigations the complexity was determined via reduction to parametric ODEs, however, under a restrictive condition on the coefficients. Here we present a new approach which allows to remove this condition. We present an algorithm which is based on iterative solution of parametric ODEs and uses a previously developed multilevel Monte Carlo algorithm for parametric indefinite integration.

Monday, July 6th, 16:30-17:00, Lecture Hall C, S2 053

Multilevel quasi-Monte Carlo methods for lognormal diffusion problems

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Coauthor(s): Robert Scheichl, Christoph Schwab, Ian Sloan and Elizabeth Ullmann

Special session: Multilevel Monte Carlo

We present a rigorous complexity analysis of a multilevel estimator based on randomly shifted Quasi-Monte Carlo (QMC) lattice rules for lognormal diffusion problems. These problems are motivated by uncertainty quantification problems in subsurface flow. They are of much higher practical relevance than similar model problems with uniform coefficients and affine parameter dependence. The analysis is also significantly more involved. We give a constructive proof on the dimension-independent convergence of QMC rules. More precisely, we provide suitable parameters for the construction of such rules that yield the required variance reduction for the multilevel scheme to nearly achieve an ε error with cost of $\mathcal{O}(\varepsilon^{-1})$ for sufficiently smooth data. This confirms that the computational gains due to the application of multilevel sampling methods and the gains due to the application of QMC methods are complementary. A series of numerical experiments shows that in practice the multilevel QMC method outperforms the multilevel MC method and both single-level variants consistently even for non-smooth problems.

Monday, July 6th, 17:00-17:30, Lecture Hall C, S2 053

Multilevel Richardson-Romberg estimators: from regular to Langevin Monte Carlo simulation

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Coauthor(s): Vincent Lemaire and Fabien Panloup

Special session: Multilevel Monte Carlo

We present a simple weighted multilevel estimator, called *Multilevel Richardson-Romberg extrapolation* (*ML2R*) which combines the Multilevel Monte Carlo (*MLMC*) paradigm introduced by M. Giles with a Richardson-Romberg extrapolation in order to take advantage of the existence of a higher orders expansion of the weak error, combined with the usual quadratic convergence rate assumption. When applied to (1-marginal Borel) functions of the Euler scheme of hypo-elliptic Brownian diffusions with smooth enough coefficients, its complexity grows as $O\big(\log(\frac{1}{\varepsilon})\varepsilon^{-2}\big)$ for a prescribed mean square error ε^2, i.e., $\log(\frac{1}{\varepsilon})$ times slower than with a regular *MLMC* estimator. This gain factor reaches $e^{O\left(\sqrt{\log(\frac{1}{\varepsilon})}\right)}$ when the quadratic convergence rate of the functional of the scheme is worse (like for digital or path-dependent barrier options in finance for example).

These *ML2R* estimators have also been successfully implemented and analyzed for nested Monte Carlo simulations in both smooth and singular settings, using a higher order extension of Gordy-Juneja's expansion result for quantiles.

Finally, we will show how to adapt this $ML2R$ approach to Langevin (ergodic) Monte Carlo simu-

lation in order to compute expectations of functionals of stationary ergodic diffusions satisfying a strong confluence assumption.

A detailed presentation of *ML2R* extrapolation is available on arXiv:1401.1177.

Monday, July 6th, 17:30-18:00, Lecture Hall C, S2 053

Multi-index Monte Carlo method

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Special session: Multilevel Monte Carlo

We propose and analyze a novel Multi-index Monte Carlo (MIMC) method for weak approximation of stochastic PDE models, that uses high-order mixed differences to achieve variance reduction, as opposed to first-order differences as in Multi Level Monte Carlo (MLMC).

We present complexity results which increase, with respect to MLMC, the set of parameters for which optimal convergence $1/\text{tol}^2$ is achieved, and propose a systematic construction of optimal sets of indices based on properly defined profits.

We present some numerical results that confirm the theoretical analysis.

Numerical methods for Levy driven SDEs

Organizers:

Steffen Dereich
WWU Münster

Christel Geiss
University of Jyväskylä

Wednesday, July 8th, 10:30-11:00, Lecture Hall A, S3 Z17

Some special functions and equations arising from a simple binomial order book model

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Special session: Numerical methods for Levy driven SDEs

We consider a simple binomial model for an electronic order book and its Brownian limit. Studying numerical quantitites such as the length of order avalanches is connected to Ito's theory of Brownian excursions and classical results about the zeta and theta functions. Studying the order volume process leads to some classical PDEs and a simple SPDE with rather explicit solution.

Wednesday, July 8th, 11:00-11:30, Lecture Hall A, S3 Z17

Simulation of BSDEs with jumps by Wiener chaos expansion

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Coauthor(s): Christel Geiss

Special session: Numerical methods for Levy driven SDEs

We present an algorithm to solve BSDEs with jumps based on Wiener Chaos Expansion and Picard's iterations. This paper extends the results given in Briand-Labart (2014) to the case of BSDEs with jumps. We get a forward scheme where the conditional expectations are easily computed thanks to chaos decomposition formulas. Concerning the error, we derive explicit bounds with respect to the number of chaos, the discretization time step and the number of Monte Carlo simulations. We also present numerical experiments. We obtain very encouraging results in terms of speed and accuracy.

Wednesday, July 8th, 11:30-12:00, Lecture Hall A, S3 Z17

Optimal simulation schemes for Lévy driven stochastic differential equations

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Coauthor(s): Kohatsu-Higa Arturo and Ortiz-Latorre Salvador

Special session: Numerical methods for Levy driven SDEs

We consider a general class of high order weak approximation schemes for stochastic differential equations driven by Lévy processes with infinite activity. These schemes combine a compound Poisson approximation for the jump part of the Lévy process with a high order scheme for the Brownian driven component, applied between the jump times. The overall approximation is analyzed using a stochastic splitting argument. The resulting error bound involves separate contributions of the compound Poisson approximation and of the discretization scheme for the Brownian part, and allows, on one hand, to balance the two contributions in order to minimize the computational time, and on the other hand, to study the optimal design of the approximating compound Poisson process. For driving processes whose Lévy measure explodes near zero in a regularly varying way, this procedure allows to construct discretization schemes with arbitrary order of convergence.

Wednesday, July 8th, 12:00-12:30, Lecture Hall A, S3 Z17

On tamed Euler and Milstein approximations of SDEs driven by Lévy noise

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Coauthor(s): Konstantinos Dareiotis and Chaman Kumar

Special session: Numerical methods for Levy driven SDEs

We extend the taming techniques developed in [1] to construct explicit Euler and Milstein schemes that numerically approximate Lévy driven stochastic differential equations with super-linearly growing drift coefficients.

[1] S. Sabanis, *A note on tamed Euler approximations*, Electronic Communications in Probability, 18 (2013), pp. 1-10.

Numerical methods for stochastic differential equations

Organizers:

Kristian Debrabant
University of Southern Denmark

Andreas Rößler
Universität zu Lübeck

Monday, July 6th, 15:30-16:00, Lecture Hall A, S3 Z17

Stability issues for SDEs

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Coauthor(s): Conall Kelly

Special session: Numerical methods for stochastic differential equations

In this talk we present recent results concerning the stability analysis for SDEs that are of interest in the practical application of numerical methods to SDEs. In particular we report on progress with the determination of almost sure stability conditions for certain test systems using the concept of Lyapunov exponents.

Monday, July 6th, 16:00-16:30, Lecture Hall A, S3 Z17

Stability properties of semi-implicit weak order 2.0 Taylor schemes for SDEs and SDDEs

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Special session: Numerical methods for stochastic differential equations

In this work, we consider the two-parameter family of semi-implicit weak second order Taylor schemes introduced by Milstein to investigate MS-stability properties of these schemes for systems of stochastic differential equations (SDEs). We obtain stability matrices and other conditions for the schemes to be MS-stable for normal and non-normal test systems. Also, we consider the two-parameter family of semi-implicit weak second order Taylor schemes based on the explicit form introduced by Küchler and Platen, for solving stochastic delay differential equations (SDDEs). We obtain the required conditions and parameters for those schemes to become GMS-stable for linear scalar SDDEs. Also, we consider some multi-dimensional test systems of SDDEs and obtain their mean square stability matrices of these numerical schemes. Finally, numerical examples are included to illustrate the stability properties of the schemes.

Monday, July 6th, 16:30-17:00, Lecture Hall A, S3 Z17

A micro-macro method to accelerate Monte Carlo simulation of stochastic differential equations

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Coauthor(s): Kristian Debrabant and Giovanni Samaey

Special session: Numerical methods for stochastic differential equations

We present a micro-macro acceleration technique for the Monte Carlo simulation of stochastic differential equations with a separation between the (fast) time-scale on which trajectories evolve and the (slow) time-scale on which we want to observe the (macroscopic) function of interest. The method combines short bursts of paths simulation with the extrapolation forward in time of a number of macroscopic variables (moments) which describe the microscopic distribution. After each extrapolation step, the new microscopic ensemble needs to be matched with the extrapolated macroscopic state based on a "best guess" strategy.

We discuss how the meaning of "best guess" can be made precise and address it via semi-infinite convex programming. Moreover, we provide a first analysis of the convergence of the method, solely with time-discretization, in terms of extrapolation time step and number of moments. As a motivating problem we consider the microscopic FENE dumbbells model. The effects of different choices of matchings and the resulting errors are illustrated with numerical experiments.

Monday, July 6th, 17:00-17:30, Lecture Hall A, S3 Z17

SPDE simulation: How does "P" increase the complexity?

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Special session: Numerical methods for stochastic differential equations

The change in computational complexity when extending stochastic (ordinary) differential equations to stochastic partial differential equations is big. One could think of letting the size of a system of stochastic differential equations tend to infinity. This leads to new challenges but also gives opportunities. As an example the simulation with multilevel Monte Carlo methods has more possible couplings available which enable us to reduce the work of computing a functional out of the solution of a stochastic partial differential equation to the complexity of solving the corresponding (deterministic) partial differential equation once. In this talk we will focus on how Monte Carlo methods change from SDE to SPDE simulations.

Monday, July 6th, 17:30-18:00, Lecture Hall A, S3 Z17

Monte-Carlo via Skorokhod embeddings

Harald Oberhauser
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Special session: Numerical methods for stochastic differential equations

We revisit the Skorokhod embedding problem. I will show that some very old and classic solutions of this problem can give rise to new, adaptive Monte-Carlo schemes and I will show some recent applications and numerical results.

(Pseudo-)random number generation

Organizers:

Alev Topuzoğlu
Sabanci University Istanbul

Arne Winterhof
RICAM Linz

Monday, July 6th, 10:30-11:00, Lecture Hall A, S3 Z17

Sequences and multisequences with high nonlinear complexities

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Coauthor(s): Wilfried Meidl and Chaoping Xing

Special session: (Pseudo-)random number generation

This talk pertains to the complexity-theoretic analysis of pseudorandom sequences over finite fields. The fundamental concept for this approach is that of the linear complexity, but it is generally acknowledged that this complexity measure is too weak for many purposes. At the other end of the hierarchy of computable complexity measures is the much stronger maximum-order complexity. We get a graded scale of complexity measures by considering the kth-order nonlinear complexity for any positive integer k, which for sufficiently large k is the same as the maximum-order complexity. Probabilistic results on the behavior of nonlinear complexities of random sequences over finite fields and explicit constructions of sequences yielding high nonlinear complexities are presented. Similar results are valid for multisequences over finite fields.

Monday, July 6th, 11:00-11:30, Lecture Hall A, S3 Z17

On the typical and minimal values of the cross-correlation measure

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Special session: (Pseudo-)random number generation

In order to study the pseudorandomness of generators of finite binary sequences Gyarmati, Mauduit and Sárközy introduced the notion of the cross-correlation measure.

Namely, let $\mathcal{S}$ be a finite set, then the *cross-correlation measure* $\Phi_k(G_N)$ *of order* k of a generator $G_N : \mathcal{S} \to \{-1,1\}^N$ of binary sequences $G_N(s) = (e_1(s), \ldots, e_N(s)) \in \{-1,1\}^N$ $(s \in \mathcal{S})$ is defined as

$$\Phi_k(G_N) = \max \left| \sum_{n=1}^{M} e_{n+d_1}(s_1) \ldots e_{n+d_k}(s_k) \right|,$$

where the maximum is taken over all integers $M, d_1, \ldots, d_k$ and $s_1, \ldots, s_k \in \mathcal{S}$ such that $0 \leq d_1 \leq d_2 \leq \cdots \leq d_k < M + d_k \leq N$ and and $d_i \neq d_j$ if $s_i = s_j$.

In this talk results are presented about the typical and minimal values of the cross-correlation measure $\Phi_k(G_N)$.

Monday, July 6th, 11:30-12:00, Lecture Hall A, S3 Z17

Digital explicit inversive pseudorandom numbers: improved results and derived constructions

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Special session: (Pseudo-)random number generation

We study the distribution of s-dimensional points of digital explicit inversive pseudorandom numbers with arbitrary lags. A previous bound on the discrepancy, given by Chen et al, is revised by means of hyperplanes arrangements, which leads to new results on the pseudorandomness of the binary threshold sequence derived from digital explicit inversive pseudorandom numbers. Hyperplane arrangements provide new bounds on the correlation measure of order k and the linear complexity profile. Finally, we are able to construct a d-dimensional array related to this generator and provide bounds for the multidimensional linear complexity.

Quasi-Monte Carlo methods and applications

Organizers:

Makoto Matsumoto
Hiroshima University

Dirk Nuyens
KU Leuven - Dept. Computer Science

Tuesday, July 7th, 10:30-11:00, Lecture Hall A, S3 Z17

Recent developments on Array-RQMC

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Coauthor(s): Christian Lécot and Bruno Tuffin

Special session: Quasi-Monte Carlo methods and applications

Array-RQMC is a method that simulates an array of n dependent realizations of a Markov chain in a way that each chain is generated from its exact probability law, and with the aim that the empirical distribution of the states at a given step of the chain provides a "low-discrepancy" approximation of the theoretical distribution of the state at that step. At each step, the n copies of the chain are sorted in a particular (multidimensional) order and then moved forward by one step using a randomized quasi-Monte Carlo (RQMC) point set of cardinality n. When the state has more than one dimension, the performance may depend strongly on the choice of sort strategy. We examine and compare different types of multivariate sorts, including one based on a Hilbert curve that was recently proposed. We are interested in the convergence rate of the discrepancy as a function of n, and also the convergence rate of the variance of the sample average of a (cost) function of the state at a given step, viewed as an estimator of the expected cost. We survey the currently known convergence rate results, show empirical results that suggest much better convergence rates than those that are proved, and state some open problems.

Tuesday, July 7th, 11:00-11:30, Lecture Hall A, S3 Z17

Implementation of the multivariate decomposition method using quasi-Monte Carlo cubature rules

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Coauthor(s): Frances Y. Kuo, Dirk Nuyens and Leszek Plaskota

Special session: Quasi-Monte Carlo methods and applications

This talk is on implementing the Multivariate Decomposition Method (MDM) for approximating integrals of functions with infinitely many variables $(x_1, x_2, \dots)$, as outlined in *The multivariate decomposition method for infinite-dimensional integration* by Kuo, Nuyens, Plaskota, Sloan and Wasilkowski. Loosely speaking, the MDM begins with a function f of infinitely many variables which admits a decomposition into the sum of countably many finite-dimensional functions. In this way the integral can be approximated by applying a separate quasi-Monte Carlo (QMC) cubature rule to each of the terms in the decomposition. Obviously it is impossible to approximate the integral of every term in the sum, so by studying the decay of the terms one can determine which are required so that the quadrature error is less than a desired bound. The set that identifies these necessary terms is referred to as the "active set".

After briefly outlining the MDM, the talk will focus on explicitly constructing the active set and how to recursively construct the QMC rules for approximating the integral of each term in the decomposition. Numerical results detailing these two aspects of the algorithm will be provided.

Tuesday, July 7th, 11:30-12:00, Lecture Hall A, S3 Z17

The b-adic tent transformation for digital nets

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Coauthor(s): Kosuke Suzuki and Takehito Yoshiki

Special session: Quasi-Monte Carlo methods and applications

In this talk, we first introduce the notion of the b-adic tent transformation (b-TT) for an arbitrary integer $b \geq 2$ by generalizing the original tent transformation (previously called baker's transform) $\phi(x) = 1 - |2x - 1|$. We then consider quasi-Monte Carlo integration rules based on digital nets over $\mathbb{Z}_b$ which are folded by using the b-TT, and study the worst-case error and the mean square worst-case error with respect to a randomly chosen digital shift in a reproducing kernel Hilbert space. The results are useful for a computer search algorithm to find good digital nets from the class of higher order polynomial lattice point sets, which achieve almost the optimal convergence in certain Sobolev spaces of smoothness of arbitrarily high order. The advantage of our approach is that the number of the candidates and also the construction cost required for a computer search algorithm can be reduced significantly as compared to ordinary higher order polynomial lattice point sets to which the b-TT is not applied.

Tuesday, July 7th, 12:00-12:30, Lecture Hall A, S3 Z17

Exponential convergence for integration over $\mathbb{R}^s$

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Special session: Quasi-Monte Carlo methods and applications

In this talk we study multivariate integration over $\mathbb{R}^s$ for weighted function space of infinitely many times differentiable functions for which the Fourier transform decays exponentially fast. The weights allows us to define the different influence of each variables. We prove that we can achieve the exponential convergence rate using a classical quasi-Monte Carlo method. More specific, we prove two convergence rates of $\mathcal{O}(e^{-N^{\frac{1}{D+B}}})$ and $\mathcal{O}(e^{-\frac{N^{\frac{1}{B}}}{\ln^{\frac{1}{D}} N}})$, where D and B are respectively defined by the exponential decay of the Fourier coefficients and of the integrand, for two different function spaces. We also show some numerical results that confirm our theorems.

Tuesday, July 7th, 15:30-16:00, Lecture Hall A, S3 Z17

Polynomial interpolation on Chebyshev lattices

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Special session: Quasi-Monte Carlo methods and applications

In a recent paper we showed how to construct Lagrange functions for s-dimensional trigonometric interpolation on $[0,1)^s$ when sampling a function on a lattice Λ periodic on $[0,1)$ grid. We also gave a precise description of the associated interpolation space.

In this talk we report on our experiences with multi-dimensional polynomial interpolation where the function is sampled on a Chebyshev lattice. That is if $T = \{\theta | \theta \in \Lambda\} \cap [0,1)^s$, then our sampling points are $T_C = \{\mathbf{x} = \cos\theta,\ \theta \in T\}$.

This is the multidimensional equivalence of transforming an equidistant 1D-grid to a grid of Chebyshev extremal points and replacing a Fourier approximation with a Chebyshev serie. In 1D a standard process which allows us t o use the FFT-algorithm for computing expansion coefficients to the Chebyshev serie. However, this process is not longer straightforward in multi dimension. Our lattice then have to satisfy certain symmetry restrictions for this to hold. We will establish the exact conditions needed and give some 2 and 3 dimensional examples of Chebyshev lattices.

Tuesday, July 7th, 16:00-16:30, Lecture Hall A, S3 Z17

Interlaced polynomial lattice rules achieving accelerating convergence for a class of smooth functions

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Coauthor(s): Josef Dick, Takashi Goda and Takehito Yoshiki

Special session: Quasi-Monte Carlo methods and applications

We study multivariate integration on the s-dimensional unit cube for a space of smooth functions equipped with the norm motivated by Yoshiki

$$\|f\| := \sup_{\alpha_1,\ldots,\alpha_s \in \mathbb{N}\cup\{0\}} \frac{\|f^{(\alpha_1,\ldots,\alpha_s)}\|_{L^1}}{\prod_{j=1}^{s} u_j^{\alpha_j}},$$

where $\{u_j\} \subset \mathbb{R}_{>0}$ is a positive decreasing sequence of weights. We approximate the integration value by algorithms which use function values of the integrand. It was proved by Suzuki that there exist quasi-Monte Carlo algorithms which achieve accelerating convergence of the worst-case integration error in the function space. Accelerating convergence means that the integration error converges to zero as $O(n^{-C(\log n)^p})$ for some $C, p > 0$, where n is the number of function values we use. It was also proved that the convergence behavior is independent of s if the weights $\{u_j\}$ decay sufficiently fast. These results, however, are not constructive. In this talk, we investigate constructive quasi-Monte Carlo rules which achieve accelerating convergence. We prove that such rules are given by interlaced polynomial lattice rules using component-by-component construction in at most $O(sn(\log n)^2)$ arithmetic operations.

Tuesday, July 7th, 16:30-17:00, Lecture Hall A, S3 Z17

A fast and good approximation of Walsh figure of merit (WAFOM) as the QMC error for an exponential function

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Special session: Quasi-Monte Carlo methods and applications

We study Quasi Monte Carlo(QMC) integration of smooth enough functions by a digital net P. Recently, Walsh figure of merit (WAFOM) of a digital net P is introduced by Matsumoto, Saito and Matoba. WAFOM bounds the error of the QMC integration value by a digital net P. It is a quickly computable criterion of digital nets P.

We show that an approximation of WAFOM turns out to be given as the QMC integration error of an exponential function, which involves no time-consuming bitwise operations which the original WAFOM requires. Thus we can find a low WAFOM point set more efficiently than before.

Stochastic partial differential equations

Organizers:

Anne de Bouard
CNRS/Ecole Polytechnique

Erika Hausenblas
Montanuniversität Leoben

Thursday, July 9th, 10:30-11:00, Lecture Hall B, S3 Z18

Splitting up method for the 2D stochastic Navier-Stokes equations

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Coauthor(s): Hakima Bessaih and Zdzislaw Brzezniak

Special session: Stochastic partial differential equations

We study the convergence of an iterative scheme for the 2-D stochastic Navier-Stokes equations. The stochastic system is split into two problems which are simpler for numerical computations. An estimate of the approximation error is given for periodic boundary conditions. In particular, we prove that the strong speed for the convergence in probability is almost 1/2. The assumptions on the diffusion coefficient depend on the fact that some multiple of the Laplace operator is present or not with the multiplicative stochastic term. Note that if one of the splitting steps only contains the stochastic integral, then the diffusion coefficient may not contain any gradient of the solution.

Thursday, July 9th, 11:00-11:30, Lecture Hall B, S3 Z18

On the weak approximation of stochastic partial differential equations

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Coauthor(s): Adam Andersson and Stig Larsson

Special session: Stochastic partial differential equations

In numerical analysis of stochastic partial differential equations (SPDEs) one usually differentiates between the notions of strong and weak convergence. While the first notion ensures a good pathwise approximation of the numerical discretization to the solution of the SPDE, a weakly convergent scheme only gives a good approximation of its law. Strong convergence implies weak convergence and, by a rule of thumb, the order of weak convergence is often up to twice the order of strong convergence. In this talk we propose a new approach to prove the weak order of convergence, which avoids the classical ansatz relying on the associated Kolmogorov backward equation. Instead we follow a more direct approach with a Gelfand triple based on a suitable subspace of the Sobolev-Malliavin space. The weak error analysis is then carried out by practically the same techniques as known from the strong error analysis but with a weaker norm. This ansatz is used to prove a weak convergence result for an Euler Galerkin finite element approximation of an SPDE with additive noise.

Thursday, July 9th, 11:30-12:00, Lecture Hall B, S3 Z18

Weak approximation of the stochastic wave equation with additive Levy noise

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Coauthor(s): Felix Lindner and Rene Schilling

Special session: Stochastic partial differential equations

We present an abstract framework to study weak convergence of numerical approximations of linear stochastic partial differential equations driven by additive Lévy noise. We first derive a representation formula for the error which we then apply to study a family of space-time discretizations of the stochastic wave equation. For twice continuously differentiable test functions with bounded second derivative, with an additional condition on the second derivative in certain cases, the weak rate of convergence is found to be twice the strong rate.

Friday, July 10th, 10:30-11:00, Lecture Hall A, S3 Z17

Multilevel Monte Carlo method for dispersive SPDEs

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Special session: Stochastic partial differential equations

We present a multilevel Monte Carlo method applied to some dispersive Stochastic Partial Differential Equations (SPDEs). We focus on the Stochastic Gross-Pitaevskii equation and on the nonlinear Schrödinger equation with white noise dispersion.

First, we are interested in the computational complexity of the Monte Carlo method, which uses a Crank-Nicolson scheme for both equations. We see that cubic nonlinearities lead to convergence results which are too weak to be able to prove the advantage, in terms of complexity, of this method compared with a classical Monte Carlo method. Nevertheless numerical simulations seems to show a much better complexity for the multilevel method. We give qualitative arguments about this observation.

Then, we shortly present numerical results we obtained by use of the multilevel Monte Carlo method. The nonlinear Schrödinger equation with white noise dispersion perturbs solitons of the determinist equation: they tend to spread in average. We numerically quantify this decrease and present the limits of the methods.

Friday, July 10th, 11:00-11:30, Lecture Hall A, S3 Z17

A high-order approximation scheme for sampling the invariant distribution for a class of parabolic SPDEs

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Coauthor(s): Gilles Vilmart

Special session: Stochastic partial differential equations

I will present a new time-discretization scheme for a class of parabolic SPDEs with space-time noise with improved order of convergence for the sampling of the invariant distribution. The order is increased by one when compared with the semi-implicit Euler scheme. The scheme is built using the idea of post-processed integrators.

Stochastic computation and complexity of high-dimensional problems

Organizers:

Stefan Heinrich
University of Kaiserslautern

Thomas Müller-Gronbach
University of Passau

Tuesday, July 7th, 10:30-11:00, Lecture Hall C, S2 053

A complexity theorem for multilevel stochastic approximation algorithms

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Coauthor(s): Thomas Müller-Gronbach

Special session: Stochastic computation and complexity of high-dimensional problems

We develop a complexity theorem for multilevel adaptations of stochastic approximation algorithms. In contrast to the classical multilevel Monte Carlo algorithm of Mike Giles we are now dealing with a parameterised family of expectations and the aim is to find zeroes. Our multilevel adaptations of the stochastic approximation algorithm are proved to converge of the same order as the classical variant does in the computation of a single expectation. The error analysis is carried out under mild assumptions that are similar to the classical ones.

Tuesday, July 7th, 11:00-11:30, Lecture Hall C, S2 053

Buffon's needle problem and the multilevel Monte Carlo algorithm

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Coauthor(s): Andrea Barth

Special session: Stochastic computation and complexity of high-dimensional problems

In many textbooks one of the first simple applications of the classical Monte Carlo method is Buffon's needle problem, where for a given length of the needle one is interested in the probability of the event 'needle hits one of the parallel lines'. If one interprets the length of the needle as a free parameter one can also apply a multilevel Monte Carlo (MLMC) algorithm in order to approximate the hitting probabilities for all admissible parameter values simultaneously. It turns out that for this problem the exact solution, the statistical bias, the computational effort and all variances can be computed explicitly. This allows us to given sharp lower and upper estimates of the complexity of the MLMC algorithm for this problem.

Tuesday, July 7th, 11:30-12:00, Lecture Hall C, S2 053

Weak convergence for semi-linear SPDEs

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Special session: Stochastic computation and complexity of high-dimensional problems

In recent work by Jentzen and Kurniawan weak convergence of both spatial and temporal discretizations for semi-linear SPDEs was proven. Their approach required the non-linear terms in the SPDE to be four times Fréchet differentiable as operators on a Hilbert space. In particular, their results can not be applied to non-linear terms arising from Nemytskii operators. In my talk I will explain how this problem can be overcome by working the more general Banach space setting.

Tuesday, July 7th, 12:00-12:30, Lecture Hall C, S2 053

Using Wiener Chaos to simulate backward SDEs with jumps

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Special session: Stochastic computation and complexity of high-dimensional problems

For a backward SDE driven by a Wiener process B and an independent compensated Poisson process $\tilde{N}$ we present an algorithm based on Wiener chaos expansion to simulate the solution. While for the chaos representation itself Monte Carlo simulations are used, the conditional expectations for the approximation scheme can be derived directly from the chaotic representation. Similar to [1], where the same approach for backward SDEs without jumps was considered we derive explicit error bounds with respect to the number of chaos, the discretization time step and the number of Monte Carlo simulations. The difference to the Brownian case is that we can not rely on the hypercontractivity property. Instead, we make use of an explicit expression for

$$\mathbb{E}(I_{n_1}(f_{n_1}) \cdots I_{n_l}(f_{n_l}))$$

in terms of tensor products of the chaos kernels f_{n_i}. Here $I_{n_i}(f_{n_i})$ denotes the multiple integral of order n_i with respect to $B + \tilde{N}$.

[1] P. Briand and C. Labart: Simulation of BSDEs by Wiener Chaos Expansion. *Annals of Appl. Prob.*, 24(3):1129-1171, 2014.

Tuesday, July 7th, 15:30-16:00, Lecture Hall C, S2 053

On the L_p-variation of BSDEs with path-dependent terminal conditions

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Special session: Stochastic computation and complexity of high-dimensional problems

We consider path dependent backward stochastic differential equations, where the generator might be quadratic and the terminal condition path-dependent. In the case that the terminal condition belongs to the Sobolev space $D_{1,2}$, we construct adapted deterministic time-nets, where the partition is based on the behaviour of the Malliavin derivative, that ensure an asymptotic optimal time-discretisation to minimise the L_p-variation of the exact solution. The background for this question is the design of optimal simulation schemes for these BSDEs.

Tuesday, July 7th, 16:00-16:30, Lecture Hall C, S2 053

Approximation in weighted cosine spaces

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Special session: Stochastic computation and complexity of high-dimensional problems

We analyze the worst case error (w.c.e) for approximation of d-variate non-periodic functions belonging to the weighted half-period cosine space. We use the so called "tent-transformation" on rank-1 lattice rules for the same. We briefly present some known results about cubature in these spaces and then present the results for approximation. We will start with the analysis of the approximation operator $App : H_d \to L_2([0,1]^d)$ where H_d is the half period cosine space. It can be shown that the w.c.e in these spaces can be related to the w.c.e in the Korobov space.

Tuesday, July 7th, 16:30-17:00, Lecture Hall C, S2 053

On the complexity of parametric integration problems

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Special session: Stochastic computation and complexity of high-dimensional problems

We study the complexity of parametric integration problems in the sense of information-based complexity theory. Our focus lies on parametric integration as well as parametric initial value problems. Both, the deterministic and the randomized setting is considered in order to investigate advantages of Monte Carlo algorithms. The optimal convergence order is reached by easy implementable multilevel Monte Carlo algorithms.

In this talk we recapitulate results of our previous work and continue this investigation. We present generalizations to Banach space valued input functions and improved rates up to logarithmic factors. Only in some limit cases small logarithmic gaps remain.

Thursday, July 9th, 17:30-18:00, Lecture Hall A, S3 Z17

Tamed Euler schemes for a class of stochastic partial differential equations

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Coauthor(s): Istvan Gyöngy and Sotirios Sabanis

Special session: Stochastic computation and complexity of high-dimensional problems

We prove stability and convergence of a full discretization for a class of stochastic evolution equations with super-linearly growing operators appearing in the drift term. This is done by using the recently developed tamed Euler method, which employs a fully explicit time stepping, coupled with a Galerkin scheme for the spatial discretization.

Thursday, July 9th, 11:00-11:30, Lecture Hall A, S3 Z17

Results for high- and infinite-dimensional integration via function space embeddings

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Special session: Stochastic computation and complexity of high-dimensional problems

In this talk we present upper and lower error bounds for high- and infinite-dimensional integration. We study spaces of integrands with weighted norms and consider deterministic and randomized algorithms and different cost models. Interesting examples of norms are norms induced by an anchored function space decomposition or the ANOVA decomposition.

In some settings (depending on the class of integrands we consider, the weighted norm, the class of algorithms we admit and the way we account for the computational cost) one can derive good or even optimal error bounds directly. If one changes the weighted norm, a correspondent direct error analysis can be much more involved and complicated. The focus of the talk is to discuss new results on function space embeddings of weighted spaces which allow for an easy transfer of error bounds.

Thursday, July 9th, 11:30-12:00, Lecture Hall A, S3 Z17

Minimal asymptotic errors for strong global approximation of SDEs with additive Poisson noise

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Special session: Stochastic computation and complexity of high-dimensional problems

We study strong global approximation of the following scalar stochastic differential equations (SDEs)

$$\begin{cases} dX(t) = a(t, X(t))dt + c(t)dN(t), & t \in [0, T], \\ X(0) = x_0 \in \mathbf{R}, \end{cases} \tag{4.1}$$

with $a : [0, T] \times \mathbf{R} \to \mathbf{R}$ and $c : [0, T] \to \mathbf{R}$ satisfy certain regularity conditions and $\{N(t)\}_{t\in[0,T]}$ is a homogeneous Poisson process with (unknown) intensity $\lambda > 0$.

We present exact convergence rate of the minimal errors that can be achieved by arbitrary algorithms based on a finite number of observations of the Poisson process. We consider two classes of methods, that use equidistant and nonequidistant sampling for the process N. We define optimal schemes, that are based on the classical Euler scheme, which asymptotically attain established minimal errors. It turns out that methods based on nonequidistant mesh are more efficient than those based on the equidistant sampling.

Thursday, July 9th, 12:00-12:30, Lecture Hall A, S3 Z17

Global optimization of smooth multivariate functions

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Special session: Stochastic computation and complexity of high-dimensional problems

We present an optimization algorithm for twice-continuously differentiable functions defined on the unit cube in d dimensions. The algorithm uses only adaptively chosen function evaluations. The convergence rate is bounded for the case that the objective function is random with a Gaussian distribution.

Thursday, July 9th, 15:30-16:00, Lecture Hall A, S3 Z17

On SDEs with arbitrary slow convergence rate for strong approximation at the final time

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Special session: Stochastic computation and complexity of high-dimensional problems

In the recent article [Hairer, M., Hutzenthaler, M., & Jentzen, A., Loss of regularity for Kolmogorov equations, Ann. Probab. (2015)] it has been shown that there exist stochastic differential equations (SDEs) with infinitely often differentiable and bounded coefficients such that the Euler scheme converges to the solution in the strong sense but with no polynomial rate. Hairer et al.'s result naturally leads to the question whether this slow convergence phenomenon can be overcome by using a more sophisticated approximation method than the simple Euler scheme. In this talk we answer this question to the negative. We prove that there exist SDEs with infinitely often differentiable and bounded coefficients such that no approximation method based on finitely many observations of the driving Brownian motion converges in absolute mean to the solution with a polynomial rate. Even worse, we prove that for every arbitrarily slow convergence speed there exist SDEs with infinitely often differentiable and bounded coefficients such that no approximation method based on finitely many observations of the driving Brownian motion can converge in absolute mean to the solution faster than the given speed of convergence.

Thursday, July 9th, 16:00-16:30, Lecture Hall A, S3 Z17

On tough quadrature problems for SDEs with bounded smooth coefficients

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Special session: Stochastic computation and complexity of high-dimensional problems

We study the problem of approximating the expected value $E(f(X(1)))$ of a function f of the solution $X(1)$ of a SDE at time 1 based on a finite number of evaluations of f and the coefficients of the SDE. We present classes of SDEs with bounded smooth coefficients such that this problem can not be solved with a polynomial error rate in the worst case sense.

Thursday, July 9th, 16:30-17:00, Lecture Hall A, S3 Z17

Variance reduced Monte Carlo path simulation method

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Special session: Stochastic computation and complexity of high-dimensional problems

In this work we present a novel modification of the Single level Monte Carlo path simulation approach, allowing for significant complexity reduction. The idea of the modification is to use the method of control variates to reduce variance up to certain power of the discretization step. We show that, under a proper choice of control variates, one can reduce the complexity order of the modified SMC algorithm. Theoretical results are illustrated by several numerical examples.

Thursday, July 9th, 17:00-17:30, Lecture Hall A, S3 Z17

Hedging certain path-dependent options using fractional smoothness

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Special session: Stochastic computation and complexity of high-dimensional problems

Hedging options perfectly requires trading continuously in time. This is of course not possible in practise - even supposing complete markets and no transaction costs - and using only finitely many trading times causes error as the stochastic integral describing the perfect hedging is approximated by a finite sum.

Connections between the behaviour of this hedging error and the smoothness of the pay-off function of the option have been studied mostly in the case of European options, where the final pay-off is of the form $F = f(X_T)$, with X the price process, $f : \mathbb{R} \to \mathbb{R}$ the pay-off function and $T > 0$ the terminal time. For functions f with some fractional smoothness, we have sharp results for the L_p-convergence rate ($p > 2$) when using Brownian motion or geometric Brownian motion as price process.

For path-dependent options, i.e. more general $F \in L_2$, many questions are still open, even when using Brownian motion W as the price process.

We compute the L_2 convergence rate for the special case $F = g(\int_0^T \eta(t)dW_t)$ from the properties of the functions $\eta \in L_2([0,T])$ and $g : \mathbb{R} \to \mathbb{R}$.

[1] S. Geiss and A. Toivola. *On fractional smoothness and L_p-approximation on the Gaussian space.* Ann. Probab, 43(2):605-638, 2015.

Stochastic models and algorithms for the nonlinear Smoluchowski equation

Organizers:

Karl Sabelfeld
Novosibirsk State University

Monday, July 6th, 15:30-16:00, Lecture Hall B, S3 Z18

Stochastic weighted particle methods for systems with coagulation, fragmentation and spatial inhomogeneity

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Coauthor(s): Kok Foong Lee, Wolfgang Wagner and Robert Patterson

Special session: Stochastic models and algorithms for the nonlinear Smoluchowski equation

This work entails the application of stochastic weighted particle methods to a multidimensional granulation model. An existing stochastic weighted algorithm is extended to include fragmentation and spatial inhomogeneity for the granulation model. One of the main features of this work is the development of fragmentation weight transfer functions which lead to stochastic particle algorithms for the numerical treatment of population balance equations. The weight transfer functions are constructed such that the number of computational particles stays constant during fragmentation jump events. The performances of the stochastic weighted algorithms are compared to the conventional direct simulation algorithm. It is found that especially in the presence of spatial inhomogeneity, one of the stochastic weighted algorithms offers significant performance advantage. The extent of this advantage depends on the particular system and on the quantities of interest.

Monday, July 6th, 16:00-16:30, Lecture Hall B, S3 Z18

Approximation errors for Smoluchowski Simulations

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Special session: Stochastic models and algorithms for the nonlinear Smoluchowski equation

The nonlinear structure of the Smoluchowski coagulation equation makes the use of stochastic particle methods attractive for numerical purposes. I will present some analysis of the errors resulting from simulations of coagulating particles being transported in fluid flow. There are two fundamental sources of error: the stochastic approximation of the deterministic evolution problem and the spatial discretisation. The additional aspect of a partial time discretisation will be overlooked. I will present initial theoretical and numerical analysis of the stochastic fluctuations and their decay and look at how this interacts with the spatial discretisation error at constant computational cost.

Monday, July 6th, 16:30-17:00, Lecture Hall B, S3 Z18

Stochastic simulation of electron–hole annihilation by tunneling and diffusion based on a system of Smoluchowski equations

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Special session: Stochastic models and algorithms for the nonlinear Smoluchowski equation

Based on a stochastic algorithm for simulation of annihilation of spatially separate electrons and holes in a disordered semiconductor, we present numerical results for the luminescence intensity in semiconductors. The model is based on a system of spatially inhomogeneous, nonlinear Smoluchowski equations with random initial distribution density. In the talk we focus on the model description, results of numerical experiments and some comparisons with measurements. In the conventional approach, the diffusion is treated macroscopically, ignoring density fluctuations. In the absence of nonlinear interactions such as chemical reactions, the macroscopic diffusion equations govern uniform concentration distributions. Thermal fluctuations, initial density inhomogeneities, and the randomness of reaction events lead to non-uniform concentration fields and changes the time dependence of the mean solution for asymptotically long times. Fluctuations are responsible for the spatial correlations, and in particular, they may lead to segregation, i. e., the formation of spatially separated clusters composed entirely of particles of either electrons or holes.

The main difficulties in the problem we solve, can be formulated as follows:
(1) The first and major difficulty arises from the inhomogeneity in space.
(2) The second difficulty of our problem is caused by the low and singular particle densities.
(3) Third, we are interested in the particle kinetics for very long times, say, up to about 10^{14} nanoseconds.
(4) Finally, we deal with stochastic initial conditions, and we have to take the average over a reach ensemble of initial distributions. In addition, other parameters of the governing equations may fluctuate randomly and have a large impact on the kinetics of the processes studied.

Monday, July 6th, 17:00-17:30, Lecture Hall B, S3 Z18

Stochastic weighted algorithms for population balance equations with multi-dimensional type space

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Special session: Stochastic models and algorithms for the nonlinear Smoluchowski equation

Stochastic particle methods provide powerful numerical tools in many applications, where the problems are high-dimensional so that the time evolution of functions of many variables has to be approximated. An important application area is chemical engineering, e.g., soot modelling, production of nanoparticles, granulate processing. Population balance equations are generalizations of Smoluchowski's coagulation equation, including fragmentation, growth, inception, and other processes. High dimensionality of the type space emerges from the necessity to model detailed particle properties such as chemical composition and aggregate structure.

During coagulation events colliding particles stick together, while during fragmentation events particles split into pieces. Direct simulation of these processes leads to a permanently changing number of numerical particles. This causes a particular challenge to the control of accuracy and fluctuations. In the talk recent results on stochastic weighted algorithms are presented. These methods keep the number of numerical particles constant during coagulation and fragmentation events. This leads to better approximation properties. Previous results are generalized to a multi-dimensional type space.

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