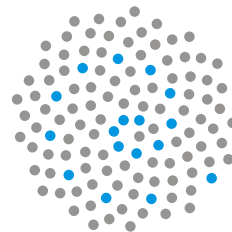
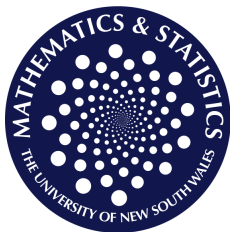

3rd Workshop on
High-Dimensional Approximation

Conference Program and Information

School of Mathematics and Statistics
University of New South Wales, Sydney, Australia
February 16–20, 2009

Dirk Nuyens Paul Leopardi



HDA09

	Monday	Tuesday	Wednesday	Thursday	Friday
09:00–09:30	Registration	Corless (p. 24)	Niu (p. 48)	Dick (p. 26)	Bailey (p. 20)
09:30–10:00	Hackbusch (p. 32)	Garcke (p. 28)	Ziveyi (p. 63)	Baldeaux (p. 21)	Borwein (p. 22)
10:00–10:30	Ullrich (p. 60)	Fasshauer (p. 27)	Kang (p. 40)	Gnewuch (p. 30)	Chernov (p. 23)
			Coffee/tea		
11:00–11:30	Leopardi (p. 46)	Pflüger (p. 51)	Pommier (p. 52)	Joe (p. 39)	Sørenvik (p. 58)
11:30–12:00	Le Gia (p. 45)	Lamichhane (p. 44)	Gerstner (p. 29)	Nuyens (p. 49)	Prizes + Closing
			Lunch		
14:00–14:30	Heinrich (p. 35)	Mhaskar (p. 47)	Sloan (p. 57)	Yserentant (p. 62)	
14:30–15:00	Schwab (p. 56)	Iske (p. 36)	Griebel (p. 31)	Schneider (p. 55)	
15:00–15:30	Surana (p. 59)	Sainudiin (p. 54)	Kucherenko (p. 42)	Heber (p. 33)	
			Coffee/tea		
16:00–16:30	Jakeman (p. 38)	Daum (p. 25)	Papageorgiou (p. 50)	Hegland (p. 34)	
16:30–17:00	Woźniakowski (p. 61)	Powell (p. 53)	Kuo (p. 43)	Jahnke (p. 37)	
	Reception+BBQ		Conference dinner		

Contents

Contents	1
1 Welcome	3
2 Sponsors	5
3 Committees and Organizers	7
4 Information	9
4.1 Conference Venue	9
4.2 Social events	10
4.3 Presentations	10
4.4 Acknowledgments	11
5 Schedule	13
6 Abstracts	19
A List of participants	65
Index	69

Welcome

We are pleased to host the 3rd Workshop on High-Dimensional Approximation at the School of Mathematics and Statistics of the University of New South Wales.

We hope you will enjoy the workshop and the talks and meet interesting colleagues. The program is certainly a full house with lots of well known names and very interesting topics. It looks like this HDA09 will be a continuation of the previous successful workshops, HDA05 and HDA07, at the Australian National University in Canberra.

There will be a special issue of Journal of Complexity devoted to papers from the workshop. The guest editors will be Ian Sloan, Markus Hegland and Stefan Heinrich.

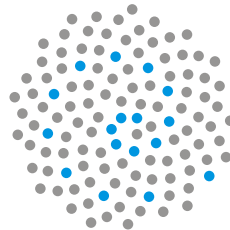
We hope you will also enjoy Sydney. On Monday evening we will have a reception and barbecue and on Wednesday evening there will be a conference dinner.

Please do not hesitate to ask us any questions you might have. We will do our best to help.

Dirk Nuyens and Paul Leopardi

Sponsors

- School of Mathematics & Statistics
UNSW: University of New South Wales
- CMA: Centre for Mathematics and its Applications
ANU: Australian National University
- MASCOS:
ARC: Australian Research Council
Centre of Excellence for Mathematics and Statistics of Complex Systems
- AMSI: Australian Mathematical Sciences Institute
- DFG SPP 1324:
DFG: Deutsche Forschungsgemeinschaft priority program on
Extraction of Quantifiable Information from Complex Systems



Committees and Organizers

The scientific committee for HDA09 is:

- Jochen Garcke (Matheon & TU Berlin, Germany)
- Michael Griebel (U Bonn, Germany)
- Wolfgang Hackbusch (Max Planck Institute Leipzig, Germany)
- Markus Hegland (ANU, Australia)
- George Karniadakis (Brown U & MIT, USA)
- Frances Kuo (UNSW, Australia)
- Ian Sloan (UNSW, Australia)
- Henryk Woźniakowski (Columbia U, USA & Warsaw U, Poland)
- Harry Yserentant (TU Berlin, Germany)

The organizers are:

- Dirk Nuyens (UNSW, Australia & KULeuven, Belgium)
- Paul Leopardi (ANU, Australia)

Information

4.1 Conference Venue

The workshop is hosted by the School of Mathematics and Statistics at the University of New South Wales, in the City of Randwick (more specifically Kensington), Sydney.

Note: there is a map at the backside of this booklet which will be used for reference throughout this text.

Registration, information desk, coffee breaks, and conference room

The presentations take place in the Webster A lecture theatre which is situated opposite the Red Centre where the School of Mathematics and Statistics is. (The School and the theatre are marked in red on the map.) The registration and information desk will be located at the entrance of the Webster A lecture theatre.

Coffee breaks will be held at the Naked Lady Lawn on the patio of UNSW International. One can walk underneath the School of Mathematics and Statistics to get from the lecture theatre to the Naked Lady Lawn. The Naked Lady Lawn is located just below the word “School” on the map, while the patio is just above the “oo”.

Lunch breaks

The participants are on their own for lunches. There are plenty of places to eat on campus, they are marked with a purple colour on the map. Typical lunch prices range from \$8 to \$10; a drink is about \$3.

Internet access

Wireless. Wireless Internet access is available for all participants through the UNIWIDE network. Upon registration you will receive a personal login and password with which you can connect to UNIWIDE.

Use the following information:

- **SSID/Network name:** uniwide_webauth
- **Security:** WPA personal (you probably do not need to set this yourself)
- **Cipher:** TKIP (you probably do not need to set this yourself)

- **WPA shared key: ***to be provided*****

You basically select the `uniwide_webauth` wireless network when available. Upon connecting to the wireless you will be asked for a “network key” or “security key” for which you use *****to be provided*****. When the connection is fully established you open up a web browser and the first request will be redirected to the UNIWIDE login page where you use your personal login you obtained at the registration desk.

Terminals. Those who do not have a laptop available (or do not want to use it) can also get internet access in the student PC laboratory M020 at the Mezzanine level (which is the level you enter) of the Red Centre. The laboratory is open from 8 am till 9 pm. A login and password will be provided at the registration desk.

4.2 Social events

Reception and barbecue

On Monday evening we will have a reception and barbecue at 6 pm. It will be held at JG’s which is on the university campus. Spouses are more than welcome.

Conference dinner

The conference dinner will be held on Wednesday evening, 7 pm, at a Thai restaurant called Real Thai located at the Spot in Randwick. This is walking distance from the university and is probably walking distance from your hotel. We will give more concrete directions on how to get there on Wednesday.

You can confirm and pay at the registration desk to participate in the conference dinner. Again, spouses are more than welcome.

4.3 Presentations

Lecture theatre

All talks of the workshop will be held in the Webster A lecture theatre (see map at the back of this booklet). This theatre is equipped with

- a desktop computer running Windows, with mouse and keyboard and two USB ports, and with internet connection;
- three projection screens, with the middle screen partially covering the two side screens;
- three blackboards and 1 whiteboard behind the screens;
- a fixed data projector (connected to the desktop) pointing to the middle screen;
- two overhead projectors on wheels (can be used on the side screens simultaneously with the data projector); and
- microphones, both corded and cordless.

Format of presentation

All talks are 25 minutes long, plus 5 minutes for questions and discussion. The session chair will give you a signal when you have 5 minutes remaining (i.e., 20 minutes into your talk). Please do not exceed your time.

We strongly encourage you to bring your talk in the form of a *PDF document*. You may bring it on a USB storage device or email it to the organizers. Please make sure that your talk is copied onto the desktop computer well before your talk.

The desktop in the lecture theater can display Powerpoint documents but we cannot guarantee that all fonts will be available. Note that postscript files *cannot* be displayed.

If you require access to other software packages or other audio-visual equipments, please communicate with the organizers well ahead of time to see if it can be arranged.

It is possible to connect your personal laptop to the data projector, but we prefer that you avoid this option due to the tight workshop schedule. If you must, please contact the organizers to test the connection well before your talk.

Making presentations available online

As in the previous two HDA workshops, we would like to collect your presentations in the form of a PDF document and make them available online – *available only to workshop participants*. If you are happy to participate, please email the organizers a version of your presentation without the display overlays.

Proceedings for the workshop

There will be a special issue of Journal of Complexity dedicated to HDA09. Every workshop participant is invited to submit a full paper based on her/his talk. Each submission should contain original research contributions not published elsewhere, and will be refereed to the usual high standard of Journal of Complexity.

Each paper should be submitted as a single PDF document by email to one of the three guest editors:

- Ian Sloan <i.sloan@unsw.edu.au>
- Markus Hegland <markus.hegland@anu.edu.au>
- Stefan Heinrich <heinrich@informatik.uni-kl.de>

The deadline for submitting a paper is *31 May 2009*.

4.4 Acknowledgments

This document was typeset with L^AT_EX macros adapted from those used to typeset the MCQMC 2008 and 2006 conference program. They were kindly provided by Pierre L'Écuyer and Alexander Keller.

We are grateful to Rob Womersley, Tony Dooley, Ian Sloan, Markus Hegland, Michael Griebel, Jochen Garcke, Frances Kuo, Catherine Greenhill, Jonathan Kress, Adelle Coster, Naratip Santitissadeekorn, Peter Kritzer, Jan Baldeaux, Josef Dick, Mayda Shahinian, Amber Tye, Bronwen

Smith, Neferity Narouz, Jan Lin, Duncan Smith, Robin Heron, Jayen Ashar, Amirah Abd Rahman, Michelle Dunbar, Joshua Capel and the full scientific committee for their help in organising HDA09.

Schedule

On the following pages you find the names and titles of the talks on each day. There is also a convenient timetable with only names on the inside of the cover.

Monday

Session chair morning: **Garcke**

- 09:00–09:30
Registration from 09:00
Official opening at 09:20
- 09:30–10:00
Hackbusch: *A new scheme for the tensor representation*, p. 32
- 10:00–10:30
Ullrich: *Tensor products of Sobolev-Besov spaces and approximation from the hyperbolic cross*, p. 60
- 11:00–11:30
Leopardi: *Quadrature using sparse grids on products of spheres*, p. 46
- 11:30–12:00
Le Gia: *Preconditioners for interpolation on the unit sphere using spherical basis functions*, p. 45

Session chair afternoon: **Griebel**

- 14:00–14:30
Heinrich: *Stochastic approximation of smooth functions*, p. 35
- 14:30–15:00
Schwab: *Sparse tensor FEM for elliptic SPDEs*, p. 56
- 15:00–15:30
Surana: *Scalable uncertainty quantification in complex dynamic networks*, p. 59
- 16:00–16:30
Jakeman: *Investigating the performance of high-order stochastic collocation methods*, p. 38
- 16:30–17:00
Woźniakowski: *On intractability of approximation of infinitely differentiable multivariate functions*, p. 61
- 18:00
Reception and barbecue at JG's

Tuesday

Session chair morning: **Leopardi**

- 09:00–09:30
Corless: *Pseudospectra of matrix polynomials expressed in alternative bases*, p. 24
- 09:30–10:00
Gärcke: *Machine learning with sums of separable functions*, p. 28
- 10:00–10:30
Fasshauer: *“Optimal” scaling and stable computation of meshfree kernel methods*, p. 27
- 11:00–11:30
Pflüger: *Approximation of non-smooth functions with spatially adaptive sparse grids in classification tasks*, p. 51
- 11:30–12:00
Lamichhane: *A new mixed finite element method for approximating thin plate spline*, p. 44

Session chair afternoon: **Hegland**

- 14:00–14:30
Mhaskar: *Function approximation on data defined manifolds*, p. 47
- 14:30–15:00
Iske: *Analysis of high-dimensional signal data by manifold learning and convolution transforms*, p. 36
- 15:00–15:30
Sainudiin: *Auto-validating trans-dimensional rejection sampler*, p. 54
- 16:00–16:30
Daum: *Nonlinear filters with particle flow induced by log-homotopy*, p. 25
- 16:30–17:00
Powell: *How many data are needed to estimate least values of convex quadratic functions in high dimensions*, p. 53

Wednesday

Session chair morning: **Sloan**

- 09:00–09:30
Niu: *Evaluating expectations of functionals of Brownian motions: A multilevel idea*, p. 48
- 09:30–10:00
Ziveyi: *Fourier transform approach to pricing multiple asset American Options*, p. 63
- 10:00–10:30
Kang: *The evaluation of American compound option prices under stochastic volatility using the sparse grid approach*, p. 40
- 11:00–11:30
Pommier: *High dimensional PDE's methods applied to option pricing*, p. 52
- 11:30–12:00
Gerstner: *Sparse binomial trees in computational finance*, p. 29

Session chair afternoon: **Heinrich**

- 14:00–14:30
Sloan: *The smoothing effect of the ANOVA decomposition*, p. 57
- 14:30–15:00
Griebel: *Dimension-wise integration of high-dimensional functions with applications to finance*, p. 31
- 15:00–15:30
Kucherenko: *The identification of model effective dimensions using global sensitivity analysis*, p. 42
- 16:00–16:30
Papageorgiou: *Tractability through increasing smoothness*, p. 50
- 16:30–17:00
Kuo: *Liberating the dimension*, p. 43
- 19:00
Conference dinner at Real Thai, The Spot, Randwick

Thursday

Session chair morning: **Woźniakowski**

- 09:00–09:30
Dick: *Geometrical properties of generalized nets and sequences*, p. 26
- 09:30–10:00
Baldeaux: *On the approximation of smooth functions using generalized digital nets*, p. 21
- 10:00–10:30
Gnewuch: *Algorithmic construction of low-discrepancy point sets via dependent randomized rounding*, p. 30
- 11:00–11:30
Joe: *Determining the rank of a lattice rule*, p. 39
- 11:30–12:00
Nuyens: *On higher order of convergence using lattice sequences*, p. 49

Session chair afternoon: **Hackbusch**

- 14:00–14:30
Yserentant: *Wave functions – high-dimensional objects of (theoretically) low complexity*, p. 62
- 14:30–15:00
Schneider: *Size consistent solution of the electronic Schrödinger equation by the coupled cluster method*, p. 55
- 15:00–15:30
Heber: *BOSSANOVA: A bond order dissection approach for efficient electronic structure calculations*, p. 33
- 16:00–16:30
Hegland: *On the approximation of some multi- and high-dimensional probability distributions arising in molecular biology*, p. 34
- 16:30–17:00
Jahnke: *An adaptive wavelet method for chemical master equations*, p. 37

Friday

Session chair morning: **Yserentant**

- 09:00–09:30
Bailey: *High-precision, high-dimension numerical integration (part I)*, p. 20
- 09:30–10:00
Borwein: *High-precision, high-dimension numerical integration (part II)*, p. 22
- 10:00–10:30
Chernov: *Quadrature for Galerkin approximation of integral equations*, p. 23
- 11:00–11:30
Sørøvik: *Multidimensional pseudo-spectral methods on lattice grids*, p. 58
- 11:30
Prizes and closing

Abstracts

The abstracts are listed in alphabetical order. To make it easier to navigate during the day, you will find a reference to the page number of the next talk. On the inside of the cover there is an overview timetable which also lists the page numbers of the abstracts. The index at the end can be used to look up the talks which are related to a specific researcher.

High-precision, high-dimension numerical integration (part I)

David H. Bailey (dhbailey@lbl.gov)

Lawrence Berkeley National Laboratory, USA

Joint work with:

Jonathan M. Borwein (University of Newcastle, Australia and Dalhousie University Canada)

Friday, 09:00–09:30

(Next talk on p. 22.)

Recently numerous scientific applications have arisen that require more than the standard 64-bit (15-digit) floating-point arithmetic available in hardware on modern computer systems. These applications range from supernova simulations to the theory of nonlinear dynamics. One particularly fruitful area is in the evaluation of definite integrals to high precision. These high-precision values can then be combined with constant recognition techniques of “experimental mathematics” to produce analytic evaluations. Dozens of new and intriguing results have been found in this manner, including results in Ising theory of mathematical physics, quantum field theory and even computational biology. In spite of these successes, progress is often hampered by the extremely long run times of evaluating high-dimensional integrals.

On the approximation of smooth functions using generalized digital nets

Jan Baldeaux (jan.baldeaux@student.unsw.edu.au)

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Josef Dick (University of New South Wales, Australia)

Peter Kritzer (University of New South Wales, Australia)

Thursday, 09:30–10:00

(Next talk on p. 30.)

In this talk, we study the approximation of functions using an algorithm which firstly approximates certain Walsh coefficients of the function and secondly approximates the function using a Walsh polynomial. A similar approach has previously been used for approximating periodic functions using lattice rules (and Fourier polynomials) and Walsh series using digital nets for functions in Walsh spaces. Here we use generalized digital nets (which have recently been shown to achieve higher order convergence rates for the integration errors of smooth functions) with which we approximate functions which have mixed partial derivatives of order $\alpha > 1$ in each variable which are square integrable.

The approximation error is studied in the worst-case setting in the \mathcal{L}_2 norm. We also discuss tractability of our proposed approximation algorithm and present numerical examples.

High-precision, high-dimension numerical integration (part II)

Jonathan M. Borwein (jon.borwein@gmail.com)

School of Mathematical and Physical Sciences, University of Newcastle, Australia; and
Faculty of Computer Science, Dalhousie University, Canada

Joint work with:

David H. Bailey (Lawrence Berkeley National Laboratory, USA)

Friday, 09:30–10:00

(Next talk on p. 23.)

Recently numerous scientific applications have arisen that require more than the standard 64-bit (15-digit) floating-point arithmetic available in hardware on modern computer systems. These applications range from supernova simulations to the theory of nonlinear dynamics. One particularly fruitful area is in the evaluation of definite integrals to high precision. These high-precision values can then be combined with constant recognition techniques of “experimental mathematics” to produce analytic evaluations. Dozens of new and intriguing results have been found in this manner, including results in Ising theory of mathematical physics, quantum field theory and even computational biology. In spite of these successes, progress is often hampered by the extremely long run times of evaluating high-dimensional integrals.

Quadrature for Galerkin approximation of integral equations

Alexey Chernov (alexey.chernov@hausdorff-center.uni-bonn.de)

Hausdorff Center for Mathematics & Institute for Numerical Simulation, University of Bonn, Germany

Joint work with:

Christoph Schwab (ETH Zürich, Switzerland)

Tobias von Petersdorff (University of Maryland, USA)

Friday, 10:00–10:30

(Next talk on p. 58.)

Galerkin methods for integral equations in \mathbb{R}^d require the evaluation of integrals

$$I = \int_{K^{(1)}} \int_{K^{(2)}} g(x, y) dy dx$$

where $K^{(1)}, K^{(2)}$ are d -dimensional simplices or cubes and g has a singularity at $x = y$. We assume that g is Gevrey smooth for $x \neq y$ and satisfies bounds for the derivatives which allow algebraic singularities at $x = y$. This holds for kernel functions commonly occurring in integral equations. We construct a quadrature rule Q_N using N function evaluations of g which achieves exponential convergence $|I - Q_N| \leq C \exp(-rN^\gamma)$ with $r, \gamma > 0$.

It turns out in practice that the efficient approximation of the singular integrals is a hard problem, because standard (e.g. Gaussian) quadrature methods deteriorate near the singularity, and the convergence of the resulting Galerkin method is very sensitive to quadrature errors.

Most methods in the literature rely on a very specific form of the kernel function $g(x, y)$. Our proposed method has the advantage that it only uses pointwise evaluations of $g(x, y)$ (no antiderivatives needed), works for integrands with noninteger singularity orders and logarithmic singularities, and uses the same algorithm in all dimensions d and all possible cases how $K^{(1)}$ and $K^{(2)}$ may touch.

- [1] Alexey Chernov, Tobias von Petersdorff and Christoph Schwab. Quadrature for Galerkin Approximation of Integral Equations. In preparation.
- [2] Christoph Schwab. Variable order composite quadrature of singular and nearly singular integrals. *Computing*, 53(2):173–194, 1994.

Pseudospectra of matrix polynomials expressed in alternative bases

Robert M. Corless (rcorless@uwo.ca)

Department of Applied Mathematics, University of Western Ontario, Canada

Joint work with:

Nargol Rezvani (University of Toronto, Canada)

Amirhossein Amiraslani (University of Calgary, Canada)

Tuesday, 09:00–09:30

(Next talk on p. 28.)

Spectra and pseudospectra of matrix polynomials are of interest in geometric intersection problems, vibration problems, and analysis of dynamical systems. In this talk we consider the effect of the choice of polynomial basis on the pseudospectrum and on the conditioning of the spectrum of regular matrix polynomials. In particular, we consider the direct use of the Lagrange basis on distinct interpolation nodes, and give a geometric characterization of “good” nodes. We also give some tools for computation of roots at infinity via a new, natural, reversal. The principal achievement of the paper is to connect pseudospectra to the well-established theory of Lebesgue functions and Lebesgue constants, by separating the influence of the scalar basis from the natural scale of the matrix polynomial, which allows many results from interpolation theory to be applied.

This talk is based on previous (one-dimensional) work by the authors, see [1]. There is some reason to hope that it would be valuable to extend this work to higher dimensions (other than by tensor products, which seem hopelessly expensive), because the conditioning results of [2] seem as extendable as those of [3].

- [1] Robert M. Corless, Nargol Rezvani, and Amir Amiraslani, Pseudospectra of matrix polynomials expressed in alternative bases. *Mathematics and Computer Science*, **1** 2 pp. 353–374 December 2007.
- [2] Robert M. Corless and Stephen M. Watt. Bernstein bases are optimal, but, sometimes, Lagrange bases are better. In *Proceedings of SYNASC, Timisoara*, pp. 141–153. September 2004.
- [3] T. Lyche and J. M. Peña. Optimally stable multivariate bases. *Advances in Computational Mathematics*, **20** pp. 149–159, January 2004.

Nonlinear filters with particle flow induced by log-homotopy

Fred Daum (frederick.e.daum@raytheon.com)

Integrated Defense Systems, Raytheon, USA

Joint work with:

Jim Huang (Raytheon, USA)

Tuesday, 16:00–16:30

(Next talk on p. 53.)

We derive and test a new nonlinear filter that uses particle flow to implement Bayes' rule with an ODE rather than a pointwise multiplication of two functions. We compare the computational complexity of our new algorithm with a carefully designed particle filter for an interesting class of smooth fully coupled (i.e., not sparse) nonlinear filter problems of increasing dimension ($d = 1$ to 20) for optimal estimation accuracy. The computational complexity of the new log-homotopy filter is many orders of magnitude less than the classic particle filter (for optimal estimation accuracy) for d greater than 2. The dimension of the state vector of the Markov process to be estimated is denoted by d . The flow of particles induced by the log-homotopy allows us to migrate the particles smoothly using an ODE, thereby avoiding one of the fundamental problems with particle filters, namely 'degeneracy' or 'particle collapse' as a result of Bayes' rule. This problem is especially severe for applications with accurate measurements and/or high dimensional state vectors. The initial condition of the ODE for our log-homotopy is the log of the unnormalized conditional density prior to the k th measurement, and the final solution of the ODE is the log of the unnormalized conditional density after the k th measurement. It turns out that a homotopy of the density itself does not work at all, owing to singularity of the initial condition, whereas a homotopy of the log of the density removes this singularity and works well. We derive the particle flow induced by the log-homotopy using the chain rule, the generalized inverse and Liouville's criterion for particle flow in physics. We use adaptive Metropolis-Hastings with optimal scaling to resample particles after computing Bayes' rule with log-homotopy.

We show new performance results for our log-homotopy particle filter, including: (1) problems with linear, quadratic & cubic nonlinearities in the measurement equations; (2) various signal-to-noise ratios (SNR = 0 dB, 10 dB & 20 dB); (3) various dimensions of measurement vector ($m = 3$ & $m = d$); (4) various dynamics (stable & unstable, parameterized by the eigenvalues of the state transition matrix); (5) movies of particle flow, including highly non-Gaussian probability densities which are not unimodal; (6) comparison with EKF estimation accuracy; (7) estimation accuracy vs. number of particles. In particular, our log-homotopy filter is an order of magnitude more accurate than the EKF for problems with quadratic measurement nonlinearities.

Geometrical properties of generalized nets and sequences

Josef Dick (josef.dick@unsw.edu.au)

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Jan Baldeaux (University of New South Wales, Australia)

Thursday, 09:00–09:30

(Next talk on p. 21.)

Generalized digital nets and sequences have been introduced for the numerical integration of smooth functions using quasi-Monte Carlo rules. In this talk we present geometrical properties of such nets and sequences. The definition of our nets and sequences does not depend on linear algebra over finite fields, it only requires that the point set or sequence satisfies certain distribution properties. Generalized digital nets and sequences appear as special cases. We prove some propagation rules and give bounds on the quality parameter t .

“Optimal” scaling and stable computation of meshfree kernel methods

Greg Fasshauer (fasshauer@iit.edu)

Department of Applied Mathematics, Illinois Institute of Technology, USA

Tuesday, 10:00–10:30

(Next talk on p. 51.)

Meshfree reproducing kernel methods are frequently used in the recovery of an unknown function given by a set of values sampled at a (scattered) set of points in \mathbb{R}^s . Even if we decide on a particular reproducing kernel Hilbert space as our approximation space we usually need to determine one or more *shape parameters* of the kernel — the variance of a Gaussian kernel may serve as a typical example. We will report on recent studies performed in our group at IIT on determining such shape parameters in an “optimal” way.

Closely connected to the determination of “optimal” shape parameters is the need for stable computation of the kernel approximation since the best results are often obtained when the corresponding system of linear equations is ill-conditioned. One of the best-known approaches to deal with such problems involves the singular value decomposition which was shown to be computationally feasible by Gene Golub, William Kahan and Christian Reinsch in the late 1960s and early 1970s. Another technique — perhaps much less known — is due to James Riley [1]. We will explain Riley’s algorithm (which we just recently became aware of) and compare it to SVD-based implementations.

- [1] J. D. Riley. Solving systems of linear equations with a positive definite, symmetric, but possibly ill-conditioned matrix. *Mathematical Tables and Other Aids to Computation* 9/51 (1955), 96–101.

Machine learning with sums of separable functions

Jochen Garcke (garcke@math.tu-berlin.de)

Matheon, Germany; and

Institut für Mathematik, Technische Universität Berlin, Germany

Joint work with:

Gregory Beylkin (University of Colorado at Boulder, USA)

Martin J. Mohlenkamp (Ohio University, USA)

Tuesday, 09:30–10:00

(Next talk on p. 27.)

We present an algorithm for learning (or estimating) a function of many variables from scattered data. The function is approximated by a sum of separable functions, following the paradigm of separated representations. The central fitting algorithm is linear in both the number of data points and the number of variables, and thus is suitable for large data sets in high dimensions. This is valid for the least squares error as well as loss functions more suited for classification like the negative log likelihood or the huberised hinge loss.

We give numerical evidence for the utility of these representations for classification and regression.

- [1] G. Beylkin, J. Garcke, and M. J. Mohlenkamp. Multivariate regression and machine learning with sums of separable functions. *SIAM Journal on Scientific Computing*, 2008, accepted.
- [2] J. Garcke and M. J. Mohlenkamp. Classification with sums of separable functions. 2008, in preparation

Sparse binomial trees in computational finance

Thomas Gerstner (gerstner@ins.uni-bonn.de)

Institute for Numerical Simulation, University of Bonn, Germany

Wednesday, 11:30–12:00

(Next talk on p. 57.)

Tree or lattice methods are widely used by practitioners for the pricing of Bermudan, American and many other complex derivative securities as they are among the most intuitive, simple and flexible numerical approaches.

In this talk we focus on the pricing of options which depend on several underlying assets such as basket, rainbow, product or performance-dependent options. For multi-asset options which are only based on a small number of underlying assets, d-dimensional extensions of the binomial method have been proposed, e.g., by [1] and [2]. The main drawback of these methods is that their computational cost increases exponentially with the number of assets which prevents their application for problems with more than three or four assets. Furthermore, they often cannot guarantee that the probabilities of all up- and down-steps in the tree are positive.

Here, we propose a new multidimensional extension of the binomial method based on the sparse grid approach. This method uses special tensor-products of one-dimensional trees which by construction only have positive probabilities. A sparse binomial tree is then constructed using a certain combination of these tensor-product trees. This way, the exponential cost in the number of assets is avoided.

Numerical experiments demonstrate the usefulness of this method for the pricing of American-style multi-asset options with ten or more underlying assets. In particular, the performance of the method with respect to the smoothness of the payoff is investigated.

- [1] P. Boyle, J. Evnine and S. Gibbs. Numerical evaluation of multivariate contingent claims. *The review of the financial studies*, 2(2):241-250, 1989.
- [2] B. Kamrad and P. Ritchken. Multinomial approximating models for options with k state variables. *Management science*, 3:1640-1652, 1991.

Algorithmic construction of low-discrepancy point sets via dependent randomized rounding

Michael Gnewuch (mig@informatik.uni-kiel.de)

Department of Computer Science, Christian-Albrechts-Universität Kiel, Germany

Joint work with:

Benjamin Doerr (Max-Planck-Institut für Informatik, Germany)

Peter Kritzer (University of New South Wales, Australia)

Friedrich Pillichshammer (University of Linz, Austria)

Magnus Wahlström (Max-Planck-Institut für Informatik, Germany)

Thursday, 10:00–10:30

(Next talk on p. 39.)

The star discrepancy is intimately related to high-dimensional numerical integration of certain function classes as expressed by the well-known Koksma-Hlawka inequality. A sharp version of this inequality states that the worst-case error of approximating the integral of functions from the unit ball of a distinguished Sobolev space by an equal-weight cubature is exactly the star discrepancy of the set of sample points.

The classical bounds on the smallest possible star discrepancy show a good asymptotic behavior, but the number of sample points one needs to reach the asymptotic range is exponential in the dimension d . For high dimensional numerical integration such a large number of sample points is infeasible. For this reason one is interested in pre-asymptotic bounds that exhibit a better behavior in the dimension d and in sets of sample points that satisfy these bounds.

In this talk we want to present two algorithms that generate low-discrepancy sample sets of small size. The first algorithm uses first a deterministic step based on the derandomization of dependent randomized rounding and uses randomness afterwards to vary the actual local placement of the generated sample points. The second algorithm is again based on the derandomization of dependent randomized rounding, but this time the derandomization is carried out successively for each component of the resulting sample points.

We present numerical results and discuss relations to other methods. So e.g., the proof method we used to establish that the points generated by our second algorithm satisfy a certain discrepancy bound showed in addition to be useful to prove good probabilistic bounds for point sets that result from padding quasi-Monte Carlo (QMC) by Monte Carlo (MC). Since our algorithm can be used to extend given point sets in the dimension, it may be used to produce interesting variants of padding QMC by MC.

The talk is based on joint work with Benjamin Doerr, Peter Kritzer, Friedrich Pillichshammer, and Magnus Wahlström.

Dimension-wise integration of high-dimensional functions with applications to finance

Michael Griebel (griebel@ins.uni-bonn.de)

Institute for Numerical Simulation, University of Bonn, Germany

Joint work with:

Markus Holtz (University of Bonn, Germany)

Wednesday, 14:30–15:00

(Next talk on p. 42.)

We present a new general class of methods for the computation of high-dimensional integrals. The quadrature schemes result by truncation and discretization of the anchored-ANOVA decomposition. They are designed to exploit low effective dimensions and include sparse grid methods as a special case. To derive bounds for the resulting modelling and discretization errors, we introduce effective dimensions for the anchored-ANOVA decomposition. We show that the new methods can be applied in a locally-adaptive and dimension-adaptive way and demonstrate their efficiency by numerical experiments with high-dimensional integrals from finance.

A new scheme for the tensor representation

Wolfgang Hackbusch (wh@mis.mpg.de)

Max-Planck-Institute for Mathematics in the Sciences, Germany

Monday, 09:30–10:00

(Next talk on p. 60.)

A representation scheme for tensors is described which is more flexible than the usual ones. It is more powerful in the sense that r -term representations, subspace representations (Tucker) as well as sparse grid representations can be mimicked by this scheme. One advantage is stability. Furthermore, the important truncation procedure can be performed by standard algebraic tools.

BOSSANOVA: A bond order dissection approach for efficient electronic structure calculations

Frederik Heber (heber@ins.uni-bonn.de)

Institute for Numerical Simulation, University of Bonn, Germany

Joint work with:

Michael Griebel (University of Bonn, Germany)

Jan Hamaekers (University of Bonn, Germany)

Thursday, 15:00–15:30

(Next talk on p. 34.)

Many problems in nature sciences are of high-dimensional complexity and thus plagued by the curse of dimension. Dimension-wise decomposition approaches have long been known. One of them is the ANalysis Of VAriance (Hoeffding). One of the possible fields of employment are electronic structure calculations, where in the Born-Oppenheimer approximation a high-dimensional electronic Schrödinger equation remains to be solved. Early attempts have been called additivity models, more recent advances are the so-called High-Dimensional Model Representation, see references in [1], or general fragmentation schemes such as [2]. Usually, molecular systems are solved by the density functional or Hartree-Fock theory approximately. We propose a dimension-wise decomposition scheme that would act as a preconditioner in a Krylov subspace sense, regarding a molecular system as an ANOVA decomposition (see [3]) of fragments, of one-body, two-body, three-body fragments and so on in a superposition sense. We discuss this new method which results not only in linear scaling complexity but also in eventually an exact solution of the Schrödinger equation and demonstrate its qualities for a wide range of molecules.

- [1] M. Y. Hayes, B. Li, and H. Rabitz. Estimation of molecular properties by high-dimensional model representation. *Journal of Physical Chemistry*, 110:264–272, 2006.
- [2] M. A. Collins and V. A. Deev. Accuracy and efficiency of electronic energies from systematic molecular fragmentation. *Journal of Chemical Physics*, 125:104104–1 – 104104–15, 2006.
- [3] M. Griebel. Sparse grids and related approximation schemes for higher dimensional problems. *Foundations of Computational Mathematics (FoCM05), Santander*, pages 106–161, 2006.
- [4] M. Griebel, J. Hamaekers, and F. Heber. BOSSANOVA: A bond order dissection approach for efficient electronic structure calculations. *Multiscale Modeling and Simulation*, submitted, December 2009.

On the approximation of some multi- and high-dimensional probability distributions arising in molecular biology

Markus Hegland (markus.hegland@anu.edu.au)

Mathematical Sciences Institute, Australian National University, Australia

Thursday, 16:00–16:30

(Next talk on p. 37.)

In my talk I will discuss some of the computational challenges related to high dimensionality and statistical dependence. Tensor product based ideas like sparse grids, optimal combination techniques and their connections with graphical models and ANOVA decompositions will be covered.

Stochastic approximation of smooth functions

Stefan Heinrich (heinrich@informatik.uni-kl.de)

Department of Computer Science, University of Kaiserslautern, Germany

Monday, 14:00–14:30

(Next talk on p. 56.)

We study the approximation of functions from a Sobolev space $W_p^r(Q)$ in the norm of another Sobolev space $W_q^s(Q)$ (and, in particular, in the norm of $L_q(Q)$) by randomized linear algorithms of the form

$$A_\omega(f) = \sum_{i=1}^n f(x_{i,\omega}) \psi_{i,\omega} \quad (\omega \in \Omega), \quad (1)$$

with n a natural number, $(\Omega, \Sigma, \mathbb{P})$ a probability space, $x_{i,\omega} \in Q$ and $\psi_{i,\omega} \in W_q^s(Q)$. Here $Q \subset \mathbb{R}^d$ is a bounded Lipschitz domain, $1 \leq p, q \leq \infty$, r is a non-negative integer, and s is an arbitrary integer. The parameters are assumed to be such that the embedding $J : W_p^r(Q) \rightarrow W_q^s(Q)$ exists. The error is defined as

$$e(J, (A_\omega)_{\omega \in \Omega}, \mathcal{B}_{W_p^r(Q)}, W_q^s(Q)) = \sup_{f \in \mathcal{B}_{W_p^r(Q)}} \mathbb{E}_{\mathbb{P}} \|f - A_\omega(f)\|_{W_q^s(Q)},$$

where $\mathcal{B}_{W_p^r(Q)}$ denotes the unit ball of $W_p^r(Q)$. For fixed n the minimal error among all approximations of the form (1) is

$$e_n^{\text{ran}}(J, \mathcal{B}_{W_p^r(Q)}, W_q^s(Q)) = \inf_{(A_\omega)_{\omega \in \Omega}} e(J, (A_\omega)_{\omega \in \Omega}, \mathcal{B}_{W_p^r(Q)}, W_q^s(Q)).$$

In this talk we survey known results about the minimal error of randomized and also of deterministic approximation. Then we present new results establishing the order of the optimal error, as a function of n , for all p, q, r, s as above, this way solving two problems posed in a recent monograph by Novak and Woźniakowski [1].

It turns out that there is a number of situations where randomized approximation yields better rates than deterministic one. Of particular interest is the case $s < 0$ in view of applications to the complexity of elliptic equations in weak form.

- [1] Erich Novak and Henryk Woźniakowski. Tractability of Multivariate Problems, Volume 1, Linear Information. European Mathematical Society, Zürich, 2008.

Analysis of high-dimensional signal data by manifold learning and convolution transforms

Armin Iske (iske@math.uni-hamburg.de)

Department of Mathematics, University of Hamburg, Germany

Joint work with:

Mijail Guillemard (University of Hamburg, Germany)

Tuesday, 14:30–15:00

(Next talk on p. 54.)

Recent advances in nonlinear dimensionality reduction and manifold learning have provided novel methods in the analysis of high-dimensional signals. In this problem, a very large data set $U \subset \mathbf{R}^n$ of scattered points is given, where the data points are assumed to lie on a compact submanifold \mathcal{M} of \mathbf{R}^n , i.e. $U \subset \mathcal{M} \subset \mathbf{R}^n$. Moreover, the dimension $k = \dim(\mathcal{M})$ of \mathcal{M} is assumed to be much smaller than the dimension of the ambient space \mathbf{R}^n , $k \ll n$. Now, the primary goal in the data analysis through dimensionality reduction is to construct a low-dimensional representation of U . To this end, we combine suitable techniques from manifold learning with signal transformations to construct a projection map $P : \mathbf{R}^n \rightarrow \mathbf{R}^k$ which then outputs the desired low-dimensional representation $P(U) \subset \mathbf{R}^k$. But the projection map P is required to preserve intrinsic geometrical and topological properties of the manifold \mathcal{M} in order to obtain a sufficiently accurate (low-dimensional) approximation to U . Therefore, the construction of P needs particular care. In our construction of P , customized convolution filters and suitable wavelet transformations are utilized to analyze the geometric distortion of the manifold \mathcal{M} . The good performance of the resulting nonlinear dimensionality reduction method is illustrated by numerical examples concerning low-dimensional parameterizations of scale modulated signals and solutions to the wave equation at varying initial conditions.

An adaptive wavelet method for chemical master equations

Tobias Jahnke (jahnke@math.uni-karlsruhe.de)

Department of Mathematics, Universität Karlsruhe, Germany

Thursday, 16:30–17:00

Biochemical reaction systems are traditionally modelled by ordinary differential equations representing the concentrations of the species. The reaction-rate approach, however, is insufficient if some of the species are present in a very low number of copies and small-scale stochastic fluctuations can have large-scale effects. This is the case, e.g., in gene regulatory networks where gene expression is regulated by a few activators or repressors, in viral kinetics where the fate of very few infectious individuals decides whether the infection spreads over large parts of the population, or in predator-prey systems where the presence of a few predators keeps the entire ecosystem in equilibrium. In all these examples, small changes in the population numbers of the critical species due to inherent stochastic noise can cause large-scale effects. For such applications, the appropriate description is provided by the chemical master equation. Its solution is a time-dependent probability distribution $p(t, x_1, \dots, x_d)$ which indicates the probability that at time t exactly x_i particles of the i -th species exist. Unfortunately, solving the chemical master equation is often a formidable task, because many applications involve multiple scales in space and time, low regularity and multi-modal, metastable solutions. The main challenge, however, is the tremendous number of degrees of freedom, which originates from the fact that the solution $p(t, x)$ has to be approximated in each state x of a large and multi-dimensional state space.

In this talk, we present an adaptive method for chemical master equations which allows to reduce the large number of degrees of freedom considerably. The method is based on a spatial representation of the probability distribution in a sparse Haar wavelet basis, time discretization by Rothe's method, and a strategy which in each time-step selects the basis vectors required to approximate the solution. The accuracy of the method is discussed, and its efficiency is illustrated by a numerical example

Investigating the performance of high-order stochastic collocation methods

John Jakeman (jakeman@maths.anu.edu.au)

Department of Mathematics, Australian National University, Australia

Joint work with:

Stephen Roberts (Australian National University, Australia)

Monday, 16:00–16:30

(Next talk on p. 61.)

Differential equations are used to model a wide range of systems and processes that are subject to a wide range of uncertainty in initial and boundary conditions, model coefficients, forcing terms and geometry. The effects of such uncertainty should be traced through the system thoroughly enough to allow one to evaluate their effects on prediction of model outputs. The large amount of computational time needed to solve the underlying deterministic equations limits the effectiveness of traditional Monte-Carlo techniques. Stochastic collocation (SC) has recently emerged as more efficient alternative. SC utilise sparse grid interpolation, to obtain a functional approximation of the solution, and sparse grid quadrature to easily evaluate important statistics such as mean and variance. SC has the ability to deal with steep non-linear dependence of the solution on random model data and achieves a much faster rate of convergence than traditional Monte Carlo methods when the solutions possess sufficient smoothness in random space. However, when the regularity of the solution decreases, the rate of SC deteriorates. Multi-Element Probabilistic Collocation and dimension-adaptive SC attempt to address this limitation. Here compare the performance of these two methods with traditional global SC on a number of benchmark problems.

Determining the rank of a lattice rule

Stephen Joe (stephenj@math.waikato.ac.nz)

Department of Mathematics, University of Waikato, New Zealand

Joint work with:

James Lyness (Argonne National Laboratory, USA and University of New South Wales, Australia)

Thursday, 11:00–11:30

(Next talk on p. 49.)

In some computer searches for good s -dimensional lattice rules, one makes use of the $s \times s$ generator matrix B of the dual lattice. In such searches, one might be interested in the rank of the current lattice rule being considered. (The rank of a lattice rule may be considered to be the minimum number of sums required to write it down.)

Here we present recent results showing how this lattice rank may be determined from this integer matrix B without necessarily having to reduce B to Smith normal form. These results make use of standard matrix ranks of modulo p versions of B , where p is a prime number.

This presentation is based on work that appeared in [1].

- [1] J. N. Lyness and S. Joe. Determination of the rank of an integration lattice, *BIT Numerical Mathematics* **48**, pp. 79–93, 2008.

The evaluation of American compound option prices under stochastic volatility using the sparse grid approach

Boda Kang (boda.kang@uts.edu.au)

School of Finance and Economics, University of Technology Sydney, Australia

Joint work with:

Carl Chiarella (University of Technology Sydney, Australia)

Wednesday, 10:00–10:30

(Next talk on p. 52.)

We consider the problem of evaluating numerically American compound option prices when the dynamics of the underlying are driven by stochastic volatility, in particular following the square root process of Heston (1993) in [4]. A compound option (called the mother option) gives the holder the right, but not obligation to buy (long) or sell (short) the underlying option (called the daughter option). Geske (1979) in [2] developed the first closed-form solution for the price of a vanilla European call on a European call.

The incorporation of stochastic volatility into the price of compound options was first attempted by Han (2003) in his thesis [3]. Fouque and Han (2004) in [1] introduce a fast, efficient and robust approximation to compute the prices of compound options such as call-on-call options within the context of multi-scale stochastic volatility models. However, they only consider the case of European option on European option. Also their method relies on certain expansions so the range of validity of their approach is not entirely clear.

In this paper, we set up the partial differential equation (PDE) approach to pricing European and American-type compound options. We assume that both the mother and the daughter options may be American-type. The compound option prices are modelled as a solution of a two-pass free boundary PDE problem.

It seems computationally demanding to solve those two nested PDEs, however, we have applied a modified sparse grid combination approach which was developed by Reisinger in his PhD thesis [6] to solve high dimensional PDEs in a fast and accurate manner. Since the underlying share price has different scale characteristics compared with the levels of the volatility, it is difficult to implement the techniques in Reisinger's thesis directly. Instead, we have found that by modifying their approach slightly, namely by adding some fixed number of points to the volatility direction in each of the subspaces results in a relative "balance" in both direction and this modification produces accurate and efficient results.

We implemented our modified sparse grid combination technique to solve the free boundary PDE followed by the price of the daughter option so that we obtain the desired prices and free boundaries by further interpolation and extrapolation. In this way we obtain the initial and boundary conditions for the mother option. Next, we apply this technique again to solve the free boundary PDE followed by the prices of the mother option to obtain the prices of the compound option. In fact, we solve those PDEs in each of the subspaces on a parallel cluster, which makes the process very efficient.

We implement Monte Carlo Simulation together with the Method of Lines to evaluate the prices of American compound option as well. Comparing the two approaches, we find that the modified sparse grid combination technique works well in producing both efficient and accurate prices for the compound option under stochastic volatility dynamics.

- [1] Jean-Pierre Fouque and Chuan-Hsiang Han. Evaluation of compound options using perturbation approximation. *Journal of Computational Finance*, **9(1)**, Fall 2005.

- [2] Robert Geske. The valuation of compound options. *Journal of Financial Economics*, **7**, 63-81, 1979.
- [3] Chuan-Hsiang Han. Singular Perturbation on Non-Smooth Boundary Problems in Finance. Dissertation, North Carolina State University 2003.
- [4] Steven L. Heston. A closed-form solution for options with stochastic volatility with applications to bond and currency options. *Review of Financial Studies*, **6(2)**, 327-343, 1993.
- [5] Alfredo Ibáñez and Fernando Zapatero. Monte Carlo Valuation of American Options through Computation of the Optimal Exercise Frontier. *Journal of Financial and Quantitative Analysis*, **39(2)**, (2004), 253-275.
- [6] Christoph Reisinger. Numerische Methoden für hochdimensionale parabolische Gleichungen am Beispiel von Optionspreisaufgaben. Universität Heidelberg, 2004.
- [7] Christoph Reisinger and Gabriel Wittum. Efficient Hierarchical Approximation of High-Dimensional Option Pricing Problems. *SIAM Journal on Scientific Computing*, **29(1)**, 440-458, 2007.

The identification of model effective dimensions using global sensitivity analysis

Sergei Kucherenko (s.kucherenko@ic.ac.uk)

Centre for Process Systems Engineering, Imperial College London, United Kingdom

Joint work with:

Balazs Feil (Imperial College London, United Kingdom)

Nilay Shah (Imperial College London, United Kingdom)

Danil Asotsky (Russian Academy of Sciences, Russia)

Wednesday, 15:00–15:30

(Next talk on p. 50.)

Modern mathematical models can exhibit very high complexities and include hundreds or even thousands of variables. Quite often such models have effective dimensions in the truncation d_T and/or superposition d_S senses much lower than their nominal dimensions. We suggested classification of models based on their effective dimensions [1]: 1) type A models with not equally important variables: $d_T < n$; 2) type B models with equally or almost equally important variables and with dominant low order interaction terms in ANOVA decomposition: $d_S < n$ and $d_T = n$; 3) type C functions with equally or almost equally important variables and with dominant high order interaction terms in ANOVA decomposition: $d_S = d_T = n$. We show that global sensitivity analysis allows the estimation of the effective dimensions at reasonable computational costs. Namely, d_T can be found by calculation of the Sobol' sensitivity indices for subsets of variables [2]. d_S can be estimated by using the random sampling high dimensional model representation (RS-HDMR). We further developed and improved the RS-HDMR method by applying quasi random sampling based on Sobol' sequences.

Evaluation of the Sobol' sensitivity indices and coefficients of the QRS-HDMR method necessitates the computation of multidimensional integrals. We apply recently developed a high-dimensional Sobol' sequence generator with advanced uniformity properties. In the second part of our talk we consider a relationship between Properties A and A' for Sobol' sequences. We show that for dimensions higher than 3 it is possible to construct the Sobol' sequence satisfying Property A' but not Property A.

- [1] S. Kucherenko, M. Rodriguez-Fernandez, C. Pantelides and N. Shah. Monte Carlo evaluation of derivative based global sensitivity measures. Accepted for publication in *Reliability Engineering & Systems Safety*, 2008.
- [2] I.M. Sobol, S. Tarantola, D. Gatelli, S. Kucherenko and W. Mauntz. Estimating the approximation error when fixing unessential factors in Global Sensitivity Analysis. *Reliability Engineering & System Safety*, 92(7):957–960, 2007.

Liberating the dimension

Frances Y. Kuo (f.kuo@unsw.edu.au)

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Ian H. Sloan (University of New South Wales, Australia)

Henryk Woźniakowski (Columbia University, USA and University of Warsaw, Poland)

Grzegorz W. Wasilkowski (University of Kentucky, USA)

Wednesday, 16:30–17:00

Many recent papers considered the problem of multivariate integration, and studied the “tractability” of the problem as the dimensionality d increases. The typical question is: can we find an algorithm for which the error is bounded polynomially in d , or even independently of d ? And the general answer is: yes, if we have a suitably “weighted” function space.

Here we take one step further: we consider the integration problem with *infinitely* many variables – thus liberating the dimension – and we seek algorithms with small error and low “cost”. In particular, we assume that the cost for evaluating a function depends on the number of “active” variables. The cost plays a crucial role in the infinite dimensional setting and forced us to be creative when designing the algorithms.

A new mixed finite element method for approximating thin plate spline

Bishnu Lamichhane (bishnu.lamichhane@maths.anu.edu.au)

Mathematical Sciences Institute, Australian National University, Australia

Joint work with:

Markus Hegland (Australian National University, Australia)

Linda Stals (Australian National University, Australia)

Stephen Roberts (Australian National University, Australia)

Tuesday, 11:30–12:00

(Next talk on p. 47.)

We consider a mixed finite element method for the discretization of thin plate splines. The mixed formulation is obtained by introducing the gradient of the corresponding function as an additional unknown. An efficient numerical scheme is obtained using a biorthogonal system to discretize the gradient of the corresponding function. The curse of dimensionality can be overcome by using sparse grids and combination techniques.

Preconditioners for interpolation on the unit sphere using spherical basis functions

Quoc Thong Le Gia (qlegia@unsw.edu.au)

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Ian H. Sloan (University of New South Wales, Australia)

Thanh Tran (University of New South Wales, Australia)

Monday, 11:30–12:00

(Next talk on p. 35.)

The interpolation problem on the unit sphere using scattered data has many applications in geodesy and earth science in which the sphere is taken as a model for the earth. When spherical basis functions are used to construct the interpolant, the underlying linear systems are ill-conditioned. In this talk, we present an additive Schwarz preconditioner to accelerate the solution process. An estimate for the condition number of the preconditioned system will be discussed. Numerical experiments using MAGSAT satellite data will be presented.

Quadrature using sparse grids on products of spheres

Paul Leopardi (paul.leopardi@maths.anu.edu.au)

Mathematical Sciences Institute, Australian National University, Australia

Monday, 11:00–11:30

(Next talk on p. 45.)

This talk will examine the use of sparse grids for quadrature on products of unit spheres in \mathbb{R}^3 and compare it with the component-by-component method of Hesse, Kuo and Sloan [1].

- [1] Kerstin Hesse, Frances Y. Kuo and Ian H. Sloan, A component-by-component approach to efficient numerical integration over products of spheres. *Journal of Complexity*, 23(1):25–51, 2007.

Function approximation on data defined manifolds

Hrushikesh N. Mhaskar (hnhaska@calstatela.edu)

Department of Mathematics, California State University, USA

Tuesday, 14:00–14:30

(Next talk on p. 36.)

Many applications require approximation of functions based on data that may be assumed to lie on a small dimensional manifold embedded in high dimensional ambient Euclidean space, but the manifold is not otherwise known. We will discuss some recent work in this direction.

Part of this work is joint with M. Maggioni and F. Filbir.

- [1] M. Maggioni and H. N. Mhaskar Diffusion polynomial frames on metric measure spaces
Applied and Computational Harmonic Analysis, Volume 24, Issue 3, May 2008, Pages 329-353

Evaluating expectations of functionals of Brownian motions: A multilevel idea

Ben Niu (nben@iit.edu)

Department of Applied Mathematics, Illinois Institute of Technology, USA

Joint work with:

Fred J. Hickernell (Illinois Institute of Technology, USA)

Wednesday, 09:00–09:30

(Next talk on p. 63.)

Pricing a path-dependent financial derivative, such as an Asian option, requires the computation of $\mathbb{E}[g(B(\cdot))]$, the expectation of a payoff functional, g , of a Brownian motion, $(B(t))_{t=0}^T$. One natural finite dimensional approximation of the Brownian motion is, $B^{(d)}$, a Karhunen-Loève expansion of the Brownian motion truncated at d terms.

A multilevel idea involves Monte Carlo simulation with different truncated dimensions $d_l, l = 1, 2, \dots, L$. At each level l , the number of sample paths is n_l . The expectation may be decomposed as follows:

$$\mathbb{E}[g(B(\cdot))] = \mathbb{E}[g(B^{(d_1)}(\cdot))] + \sum_{l=1}^{L-1} \mathbb{E}[g(B^{(d_{l+1})}(\cdot)) - g(B^{(d_l)}(\cdot))] + \mathbb{E}[g(B(\cdot))] - \mathbb{E}[g(B^{(d_L)}(\cdot))]. \quad (1)$$

The estimator for each piece above is a Quasi-Monte Carlo estimator. At each level l , the cost of evaluating $g(B^{(d_{l+1})}(\cdot)) - g(B^{(d_l)}(\cdot))$ for a single sample path is assumed to be proportional to d_{l+1} . The cost of approximating the expected payoff by an average over n_l paths is proportional to $N_l = n_l d_{l+1}$, and the total computational cost is $\mathcal{O}(N)$, where $N = \sum_{l=1}^{L-1} n_l d_{l+1}$. This idea was used by [1].

This talk investigates the worst case error as a function of both n_l and d_l for payoff functionals that arise from weighted reproducing kernel Hilbert spaces with moderate smoothness, similar to [2]. The definition of the Hilbert space allows us to write the square worst-case error in evaluating $\mathbb{E}[g(B(\cdot))]$ as the sum of square worst-case error of the terms on the right hand side of (1). They correspond to difference of square discrepancies. The optimal choice of n_l and d_l for a fixed computation budget N depends on how quickly the importance of the higher numbered variables decays.

- [1] Creutzig, J., Dereich, S., Müller-Gronbach, T. and Ritter, K. Infinite-dimensional quadrature and approximation of distributions, preprint, 2007.
- [2] Hickernell, F. J. and Wang, X. The error bounds and tractability of quasi-Monte Carlo algorithms in infinite dimension, *Math. Comp.*, **71**, 1641-1661, 2002.

On higher order of convergence using lattice sequences

Dirk Nuyens (dirk.nuyens@cs.kuleuven.be)

Department of Computer Science, K.U.Leuven, Belgium; and

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Fred J. Hickernell (Illinois Institute of Technology, USA)

Peter Kritzer (University of New South Wales, Australia)

Frances Y. Kuo (University of New South Wales, Australia)

Thursday, 11:30–12:00

(Next talk on p. 62.)

We study the worst case integration error of combinations of quadrature rules in a reproducing kernel Hilbert space. We show that the error, with respect to the total number N of function evaluations used, cannot decrease faster than $O(N^{-1})$ in the case where several quasi-Monte Carlo rules are combined to a compound quasi-Monte Carlo rule. However, if the errors of the quadrature rules constituting the compound rule have an order of convergence $O(N^{-\alpha})$ for $\alpha > 1$ then, by introducing weights, this order of convergence can be shown to be recovered for the compound rule. We apply our results to the case of lattice sequences.

Tractability through increasing smoothness

Anargyros Papageorgiou (ap@cs.columbia.edu)

Department of Computer Science, Columbia University, USA

Joint work with:

Henryk Woźniakowski (Columbia University, USA and University of Warsaw, Poland)

Wednesday, 16:00–16:30

(Next talk on p. 43.)

We prove that some multivariate linear tensor product problems are tractable in the worst case setting if they are defined as tensor products of univariate problems with logarithmically increasing smoothness. This is demonstrated for the approximation problem defined over Korobov spaces of periodic functions and the approximation problem of certain diagonal operators. For these two problems we show necessary and sufficient conditions on the smoothness parameters of the univariate problems to obtain strong polynomial tractability. We prove that polynomial tractability is equivalent to strong polynomial tractability, and that weak tractability always holds for these problems. The choice of Korobov spaces is crucial since the approximation problem defined over Sobolev spaces of non-periodic functions with a special choice of the norm is *not* polynomially tractable for *all* smoothness parameters no matter how fast they go to infinity. Furthermore, depending on the choice of the norm we can even lose weak tractability.

- [1] Frances Y. Kuo, Grzegorz W. Wasilkowski and Henryk Woźniakowski. On the power of standard information for multivariate approximation in the worst case setting. *Journal of Approximation Theory* (to appear), 2009.
- [2] Erich Novak and Henryk Woźniakowski. Tractability of Multivariate Problems, Volume 1, Linear Information. European Mathematical Society, Zürich, 2008.
- [3] Joseph F. Traub, Grzegorz W. Wasilkowski and Henryk Woźniakowski. Information-Based Complexity. Academic Press, New York, 1988.
- [4] Arthur G. Werschulz and Henryk Woźniakowski. Tractability of multivariate approximation for a weighted unanchored Sobolev space. *Constructive Approximation* (to appear), 2009.

Approximation of non-smooth functions with spatially adaptive sparse grids in classification tasks

Dirk Pflüger (pflueged@in.tum.de)

Department of Informatics, Technische Universität München, Germany

Joint work with:

Hans-Joachim Bungartz (Technische Universität München, Germany)

Stefan Zimmer (Technische Universität München, Germany)

Tuesday, 11:00–11:30

(Next talk on p. 44.)

The classification problem arising in Data Mining – learning an unknown function by a set of scattered training data – requires the representation of functions on a typically high dimensional feature space. Recent developments show that spatially adaptive methods – implementing a successive grid refinement – allow tackling currently up to 160 dimensions. To understand the underlying mechanisms, suitable basis functions, adequate refinement criterias and error measures have to be developed and examined.

We show techniques which enable us to reach from about 40 to more than 160 dimensions, with a main focus on considerations on the choice of basis functions and the regularization operator. Results on typical real-world datasets as well as artificial ones are demonstrated. To gain further insight, we started the examination of the approximation of non-smooth indicator functions. First results will be shown.

This work is based on previous work by the authors, see [1] and [2].

- [1] Hans-Joachim Bungartz, Dirk Pflüger, and Stefan Zimmer. Adaptive sparse grid techniques for data mining. In H.G. Bock, E. Kostina, X.P. Hoang, and R. Rannacher, editors, *Modelling, Simulation and Optimization of Complex Processes, Proc. Int. Conf. HPSC, Hanoi, Vietnam*, pages 121–130. Springer, March 2006.
- [2] Dirk Pflüger, Ioan Lucian Muntean, and Hans-Joachim Bungartz. Adaptive sparse grid classification using grid environments. In Yong Shi, Dick van Albada, Jack Dongarra, and Peter Sloot, editors, *ICCS 2007*, volume 4487 of *LNCS*, pages 708–715. Springer, May 2007.

High dimensional PDE's methods applied to option pricing

David Pommier (david.pommier@inria.fr)

MATHFI, INRIA Rocquencourt, France; and

Laboratoire Jacques-Louis Lions, Université Paris 6, France

Joint work with:

Yves Achdou (Laboratoire Jacques-Louis Lions, Université Paris 6, France)

Wednesday, 11:00–11:30

(Next talk on p. 29.)

Recent developments have shown that it may be possible to use deterministic numerical methods for elliptic or parabolic problems in dimension d , for $4 \leq d \leq 20$: these methods are based either on sparse grids [1] or on sparse tensor product approximation spaces [2, 3].

In this talk, we discuss such methods for option pricing in finance. We will focus on the difference between the two above mentioned approximation techniques and consider two practical problems for which only one these techniques works properly.

In the first part of the talk, we consider a European vanilla contract with a multivariate generalization of the one dimensional Ornstein-Uhlenbeck-based stochastic volatility model. This type of model is used in practice to capture information on new products like options on variance. A relevant generalization is to assume that the underlying asset is driven by a jump process, leading to partial integro-differential equation (PIDE). The jump size depend of the volatility, so the classical Merton jump operator is replaced by

$$\int_{\mathbb{R}} P(x + \sigma z, \sigma) - P(x, \sigma) \nu(dz).$$

Due to the curse of dimensionality, classical deterministic methods are not competitive to Monte Carlo methods. We discuss sparse grids finite difference methods for solving the PIDE arising in this model with $d = 4$. In particular, the numerical approximation of the integral term involves a wavelet collocation method. We discuss the consistency of the method and we present numerical experiments, both for the PDE and the PIDE problems.

In the second part of the talk, we consider a Basket option on several assets (five in our example) in the Black & Scholes model. We discuss Galerkin methods in a sparse tensor product space constructed with wavelets. We insist on the boundary conditions and the projection of the initial condition. We also give some remarks on the practical implementation problems.

- [1] M. Griebel. Adaptive sparse grid multilevel methods for elliptic PDEs based on finite differences. *Computing*, 61(2):151–179, 1998.
- [2] M. Griebel and P. Oswald. Tensor-product-type subspace splittings and multilevel iterative methods for anisotropic problems. *Advances of Computational Mathematics*, 4:171–206, 1995.
- [3] T. von Petersdoff and C. Schwab. Numerical solutions of parabolic equations in high dimensions. *Mathematical Modelling and Numerical Analysis*, 38(1):93–128, 2004.
- [4] C. Zenger. Sparse grids. In W. Hackbusch, editor, *Parallel Algorithms for Partial Differential Equations*, volume 31 of *Notes on Numerical Fluid Mechanics*, Braunschweig/Wiesbaden, 1991. Vieweg.

How many data are needed to estimate least values of convex quadratic functions in high dimensions

Mike J. D. Powell (mjdpcam.ac.uk)

DAMTP, University of Cambridge, United Kingdom

Tuesday, 16:30–17:00

Let the least value of a convex quadratic function of n variables be required, the function being specified by a subroutine that calculates its value for any vector of variables. It is elementary to solve the problem using $(n+1)(n+2)/2$ values, because then there are enough data to define the function completely. Numerical experiments with the NEWUOA software of the author, however, suggest that the position of the minimum in the space of the variables can be estimated to high accuracy using only of magnitude n function values when n is large. Some results of computations that give this conclusion will be presented. The possibility of establishing the discovery theoretically will also be considered.

Auto-validating trans-dimensional rejection sampler

Raazesh Sainudiin (r.sainudiin@math.canterbury.ac.nz)

Department of Mathematics and Statistics, University of Canterbury, New Zealand

Joint work with:

Thomas York (Cornell University, USA)

Tuesday, 15:00–15:30

(Next talk on p. 25.)

In Bayesian statistical inference and computationally intensive frequentist inference, one is interested in obtaining independent samples from a high dimensional, and possibly multi-modal target density. The challenge is to obtain samples from this target without any knowledge of the normalizing constant. Several approaches to this problem rely on Monte Carlo methods. One of the simplest such methods is the rejection sampler due to von Neumann. Here we introduce an auto-validating version of a trans-dimensional extension of the rejection sampler via interval analysis. We show that our rejection sampler does provide us with independent samples from a large class of target densities in a guaranteed manner. These samples along with their importance weights can be used in rigorous estimates of challenging integrals. We illustrate the efficiency of the sampler by theory and by examples in up to 10 dimensions. Our sampler is immune to the ‘pathologies’ of some infamous densities including the witch’s hat and can rigorously draw samples from piece-wise Euclidean spaces of small phylogenetic trees with different dimensions.

This work is based on previous work by the authors, see [1].

- [1] Raazesh Sainudiin and Thomas York. An Auto-validating Rejection Sampler. Cornell University, BSCB Department Technical Report BU-1661-M, 2005. <http://www.math.canterbury.ac.nz/~r.sainudiin/preprints/AutoValidSampler.pdf>

Size consistent solution of the electronic Schrödinger equation by the coupled cluster method

Reinhold Schneider (schneidr@math.tu-berlin.de)

Mathematical Institute, Technische Universität Berlin, Germany

Thursday, 14:30–15:00

(Next talk on p. 33.)

The electronic Schrödinger equation describes the stationary nonrelativistic behaviour of an quantum mechanical N electron system in the electric field generated by the nuclei. The (Projected) Coupled Cluster Method has been developed for the numerical computation of the ground state energy and wave function. It provides a powerful tool for high accuracy electronic structure calculations. The present talk aims is about a rigorous analytical treatment and convergence analysis of this method. If the discrete Hartree Fock solution is sufficiently good, the quasi-optimal convergence of the projected coupled cluster solution to the full CI solution is shown. Under reasonable assumptions also the convergence to the exact wave function can be shown in the Sobolev H^1 norm. The error of the ground state energy computation is estimated by an Aubin Nitsche type approach. Although the Projected Coupled Cluster method is non-variational it shares advantages with the Galerkin or CI method. In addition it provides size consistency, which is considered as a fundamental property in many particle quantum mechanics.

Sparse tensor FEM for elliptic SPDEs

Christoph Schwab (schwab@math.ethz.ch)

Seminar for Applied Mathematics, ETH Zürich, Switzerland

Joint work with:

Albert Cohen (Paris VI, France)

Ron DeVore (Texas A& M, USA)

Roman Andreev (ETH Zürich, Switzerland)

Marcel Bieri (ETH Zürich, Switzerland)

Monday, 14:30–15:00

(Next talk on p. 59.)

We consider the Finite Element Solution of second order elliptic problems in a physical domain $D \subset \mathbb{R}^d$ with spatially inhomogeneous random coefficients.

We present convergence rates and complexity estimates for sparse Galerkin semidiscretization in the probability domain of the random solution. It is parametric in the first M Karhúnen-Loève (KL) variables of the input data [1].

Two cases are distinguished:

(i) Exponential decay of the input's KL expansion based on [2]

and

(ii) algebraic decay of the input's KL expansion.

In (i), a “polynomial chaos” type Galerkin discretization is shown to yield spectral convergence rates *in terms of* N_Ω , *the number of deterministic elliptic problems to be solved*. In (ii), first approximation rates in terms of N_Ω are available.

Finally, in

(iii) ongoing work [3, 4, 5] on the total complexity vs. accuracy of (adaptive) tensor Galerkin discretizations in both, stochastic as well as in the deterministic domain D will be addressed.

Sufficient conditions on the joint pdf's of the random field input to ensure better complexity than with (Quasi) Monte Carlo in the probability domain and with Galerkin discretization in D will be identified and implementational issues will be addressed in each case.

- [1] Ch. Schwab and R.A. Todor, Karhúnen-Loève Approximation of Random Fields by Generalized Fast Multipole Methods. *Journal of Computational Physics* **217** (2006), 100-122.
- [2] R.A. Todor and Ch. Schwab, Convergence Rates of Sparse Chaos Approximations of Elliptic Problems with stochastic coefficients. *IMA Journ. Numer. Anal.* (2007).
- [3] M. Bieri and Ch. Schwab, Sparse high order FEM for elliptic sPDEs (in press in *Comp. Meth. Appl. Mech. Engg.* 2009).
- [4] R. Andreev, M. Bieri and Ch. Schwab, Sparse Tensor Galerkin FEM for elliptic sPDEs (in review 2008).
- [5] A. Cohen, R. DeVore and Ch. Schwab (in preparation 2009).

The smoothing effect of the ANOVA decomposition

Ian H. Sloan (i.sloan@unsw.edu.au)

School of Mathematics and Statistics, University of New South Wales, Australia

Joint work with:

Michael Griebel (University of Bonn, Germany)

Frances Y. Kuo (University of New South Wales, Australia)

Wednesday, 14:00–14:30

(Next talk on p. 31.)

In this talk we establish a smoothing property of the ANOVA decomposition, first remarked upon by Owen and Liu, namely that the early terms of the ANOVA decomposition of a continuous function f defined on $[0, 1]^d$ can be smooth even when f itself is not smooth. This may explain why quasi-Monte Carlo and sparse grid methods often exhibit a better-than-Monte Carlo rate of convergence for functions f with a gradient discontinuity, as in option pricing problems. The application to the pricing of Asian options is considered in detail.

Multidimensional pseudo-spectral methods on lattice grids

Tor Sørenvik (tor.sorevik@math.uib.no)

Department of Mathematics, University of Bergen, Norway

Joint work with:

Hans Munthe-Kaas (University of Bergen, Norway)

Friday, 11:00–11:30

When multidimensional functions are approximated by a truncated Fourier series, the number of terms typically increase exponentially with the dimension s . In this paper we argue for a way of reducing this number by omitting insignificant terms. We then show how lattice rules can be used for approximating the associated Fourier coefficients, allowing a similar reduction in grid-points as in expansion terms. We also show that using a lattice grids permits efficient computation of the Fourier coefficient by the FFT-algorithm. Finally we put all this together in a pseudo-spectral method and demonstrate its efficiency on the Poisson equation.

Scalable uncertainty quantification in complex dynamic networks

Amit Surana (suranaa@utrc.utc.com)
United Technologies Research Center, USA

Joint work with:

Andrzej Banaszuk (United Technologies Research Center, USA)

Monday, 15:00–15:30
(Next talk on p. 38.)

The issue of management of uncertainty for robust system operation is of interest in a large family of complex networked systems. Such systems typically involve a large number of heterogeneous, connected components, whose dynamics is affected by possibly an equally large number of parameters. Uncertainty quantification (UQ) methods like probabilistic collocation suffer from the curse of dimensionality and become practically infeasible when applied to networks as a whole. However, many networks of interest (e.g. power systems, biological networks) are often composed of weakly interacting subsystems. We propose an iterative UQ approach that exploits these weak connections to overcome the dimensionality curse and radically accelerate uncertainty propagation in large systems. This approach relies on integrating network decomposition techniques and waveform relaxation scheme with UQ methods like probabilistic collocation and polynomial chaos.

Network decomposition can be realized by spectral graph theoretic techniques to identify weakly interacting subsystems. Waveform relaxation, a parallelizable iterative method, on the other hand, exploits this decomposition and evolves each subsystem forward in time independently but coupled with the other subsystems through their solutions from the previous iteration. At each waveform relaxation iteration we propose to apply probabilistic collocation at subsystem level and then use polynomial chaos to propagate the uncertainty among the subsystems. Since UQ methods are applied to relatively simpler subsystems which typically involve a few parameters, this renders a scalable iterative approach to UQ in networks. We illustrate this iterative scheme on a power system network and numerically analyze its convergence properties.

This work was in part supported by DARPA DSO (Dr. Cindy Daniell PM) under AFOSR contract FA9550-07-C-0024 (Dr. Fariba Fahroo PM).

Tensor products of Sobolev-Besov spaces and approximation from the hyperbolic cross

Tino Ullrich (tino.ullrich@hcm.uni-bonn.de)

Hausdorff Center for Mathematics, University of Bonn, Germany

Joint work with:

Winfried Sickel (University of Jena, Germany)

Monday, 10:00–10:30

(Next talk on p. 46.)

Besov as well as Sobolev spaces of dominating mixed smoothness on \mathbb{R}^d are shown to be tensor products of d spaces defined on \mathbb{R} . Using such a representation we can transfer wavelet isomorphisms from the one-dimensional to the d -dimensional situation. Based on that we point out consequences for hyperbolic cross and best m -term approximation, in particular with respect to tensor product splines.

This work is based on a previous work by the authors, see [1].

- [1] Winfried Sickel und Tino Ullrich. Smolyak's algorithm, sampling on sparse grids and function spaces of dominating mixed smoothness. *East Journal on Approximations* 13(4):387–425, 2007.

On intractability of approximation of infinitely differentiable multivariate functions

Henryk Woźniakowski (henryk@cs.columbia.edu)

Department of Computer Science, Columbia University, USA; and
Department of Applied Mathematics, University of Warsaw, Poland

Joint work with:

Erich Novak (Friedrich-Schiller-Universität Jena, Germany)

Monday, 16:30–17:00

We prove that the L_∞ approximation of C^∞ functions defined on $[0, 1]^d$ is intractable and suffers from the curse of dimensionality. This is done by showing that the minimal number of linear functionals needed to obtain for an algorithm with worst case error at most $\varepsilon \in (0, 1)$ is exponential in d . This holds despite the fact that the rate of convergence is infinite.

Wave functions – high-dimensional objects of (theoretically) low complexity

Harry Yserentant (yserentant@math.tu-berlin.de)

Institut für Mathematik, Technische Universität Berlin, Germany

Thursday, 14:00–14:30

(Next talk on p. 55.)

This talk considers the electronic Schrödinger equation of quantum theory that describes the motion of N electrons under Coulomb interaction forces in a field of clamped nuclei. Solutions of this equation depend on $3N$ variables, three spatial dimensions for each electron. Approximating the solutions is thus inordinately challenging, and it is conventionally believed that a reduction to simplified models, such as those of the Hartree-Fock method or density functional theory, is the only tenable approach. We indicate why this conventional wisdom need not be ironclad: the regularity of the solutions, which increases with the number of electrons, the decay behavior of their mixed derivatives, and the antisymmetry enforced by the Pauli principle contribute properties that allow these functions to be approximated with an order of complexity which comes arbitrarily close to that for a system of only two electrons.

Fourier transform approach to pricing multiple asset American Options

Jonathan Ziveyi (jonathan.ziveyi@student.uts.edu.au)

School of Finance and Economics, University of Technology Sydney, Australia

Joint work with:

Carl Chiarella (University of Technology Sydney, Australia)

Wednesday, 09:30–10:00

(Next talk on p. 40.)

This paper extends the Integral Transform Approach of [1] and [2] to the pricing of American Options written on two underlying assets. We derive the bivariate density function of the two underlying assets using Fourier Transform Techniques and solve the resulting integral equation using numerical integration techniques.

- [1] Henry McKean Jr. Appendix: A Free Boundary Problem for the Heating Function Arising from a Problem in Mathematical Economics. *Industrial Management Review* - 1965, pages 32–39, 1965.
- [2] Carl Chiarella and Andrew Ziogas. A survey of the Integral Representation of American Option Prices. *Quantitative Finance Research Centre*, paper number 118, 2004.

List of participants

David Bailey

Computational Research Department
Lawrence Berkeley National Laboratory
USA
dhbailey@lbl.gov

Jon Borwein

School of Mathematical and Physical Sciences
University of Newcastle
Australia
jon.borwein@gmail.com

Alexey Chernov

Institute for Numerical Simulation
University of Bonn, Hausdorff Center for Mathematics
Germany
alexey.chernov@hausdorff-center.uni-bonn.de

Rob Corless

Department of Applied Mathematics
University of Western Ontario
Canada
rcorless@uwo.ca

Josef Dick

School of Mathematics and Statistics
University of New South Wales
Australia
josef.dick@unsw.edu.au

Greg Fasshauer

Department of Applied Mathematics
Illinois Institute of Technology
USA
fasshauer@iit.edu

Jan Baldeaux

School of Mathematics and Statistics
University of New South Wales
Australia
jan.baldeaux@student.unsw.edu.au

Leung Lung Chan

School of Finance and Economics
University of Technology Sydney
Australia
leunglung.chan@uts.edu.au

Carl Chiarella

School of Finance and Economics
University of Technology Sydney
Australia
carl.chiarella@uts.edu.au

Fred Daum

Advanced Concepts
Raytheon
USA
frederick_e_daum@raytheon.com

Yuan Fang

Mathematical Sciences Institute
The Australian National University
Australia
fyqiuizi@gmail.com

Jochen Garcke

Institut für Mathematik
TU Berlin
Germany
garcke@math.tu-berlin.de

Thomas Gerstner

Institute for Numerical Simulation
University of Bonn
Germany
gerstner@ins.uni-bonn.de

Michael Griebel

Institute for Numerical Simulation
University of Bonn
Germany
griebel@ins.uni-bonn.de

Wolfgang Hackbusch

Department of Scientific Computing
Max-Planck-Institute for Mathematics in the Sciences
Germany
wh@mis.mpg.de

Markus Hegland

Mathematical Sciences Institute
Australian National University
Australia
markus.hegland@anu.edu.au

Kerstin Hesse

Department of Mathematics
University of Sussex
United Kingdom
k.hesse@sussex.ac.uk

Tobias Jahnke

Institute for Applied and Numerical Mathematics
Universitaet Karlsruhe (TH)
Germany
jahnke@math.uka.de

Stephen Joe

Department of Mathematics
University of Waikato
New Zealand
stephenj@math.waikato.ac.nz

Chin Foon Khoo

Mathematical Sciences Institute
Australian National University
Australia
boda.kang@uts.edu.au

Sergei Kucherenko

Centre for Process Systems Engineering
Imperial College London
United Kingdom
s.kucherenko@ic.ac.uk

Michael Gnewuch

Department of Computer Science
Christian-Albrechts-Universitaet Kiel
Germany
mig@informatik.uni-kiel.de

Zhi Jun Guo

School of Finance and Economics
University of Technology Sydney
Australia
zhijun.guo@uts.edu.au

Frederik Heber

Institute for Numerical Simulation
University Bonn
Germany
heber@ins.uni-bonn.de

Stefan Heinrich

Department of Computer Science
University of Kaiserslautern
Germany
heinrich@informatik.uni-kl.de

Armin Iske

Department of Mathematics
University of Hamburg
Germany
iske@math.uni-hamburg.de

John Jakeman

Department of Mathematics
Australian National University
Australia
jakeman@maths.anu.edu.au

Boda Kang

School of Finance and Economics
University of Technology Sydney
Australia
boda.kang@uts.edu.au

Frances Kuo

School of Mathematics and Statistics
University of New South Wales
Australia
f.kuo@unsw.edu.au

Bishnu Lamichhane

Centre for Mathematics and its Applications
Australian National University
Australia
blamichha@yahoo.com

Paul Leopardi

Centre for Mathematics and its Applications
Australian National University
Australia
paul.leopardi@maths.anu.edu.au

James Lyness

Mathematics and Computer Science Division
Argonne National Laboratory
USA
lyness@mcs.anl.gov

Ben Niu

Department of Applied Mathematics
Illinois Institute of Technology
USA
nben@iit.edu

Dirk Pflüger

Department of Informatics
Technische Universität München
Germany
pflueged@in.tum.de

Friedrich Pillichshammer

Department of Financial Mathematics
University of Linz
Austria
friedrich.pillichshammer@jku.at

Michael Powell

Centre for Mathematical Sciences
University of Cambridge
United Kingdom
mjdp@cam.ac.uk

Andrew Royal

Quantitative Applications Division
Macquarie Group
Australia
andrewjohnroyal@gmail.com

Donna Mary Salopek

School of Mathematics and Statistics
University of New South Wales
Australia
donnas@maths.unsw.edu.au

Quoc Thong Le Gia

Department of Mathematics and Statistics
University of New South Wales
Australia
qlegia@unsw.edu.au

Hernan Eugenio Leövey

Department of Mathematics
Humboldt Universität Berlin
Germany
leovey@mathematik.hu-berlin.de

Hrushikesh Mhaskar

Department of Mathematics
California State University, Los Angeles
USA
hmhaska@gmail.com

Dirk Nuyens

School of Mathematics and Statistics
University of New South Wales
Australia
dirk.nuyens@cs.kuleuven.be

Duong Pham

School of Mathematics and Statistics
University of New South Wales
Australia
pflueged@in.tum.de

David Pommier

MATHFI
INRIA
France
david.pommier@inria.fr

Stephen Roberts

Centre for Mathematics and its Applications
Australian National University
Australia
stephen.roberts@anu.edu.au

Raazesh Sainudiin

Department of Mathematics and Statistics
University of Canterbury
New Zealand
r.sainudiin@math.canterbury.ac.nz

Reinhold Schneider

Department of Mathematics
TU Berlin
Germany
schneidr@math.tu-berlin.de

Christoph Schwab

Department of Mathematics
ETH Zurich
Switzerland
schwab@math.ethz.ch

Ernst Stephan

Department of Mathematics
Leibniz University Hannover
Germany
stephan@ifam.uni-hannover.de

Amit Surana

System Dynamics and Optimization
United Technologies Research Center
USA
suranaa@utrc.utc.com

Thanh Tran

School of Mathematics and Statistics
University of New South Wales
Australia
thanh.tran@unsw.edu.au

Li-Lian Wang

School of Physical and Mathematical Sciences
Nanyang Technological University
Singapore
lilian@ntu.edu.sg

Rob Womersley

School of Mathematics and Statistics
University of New South Wales
Australia
r.womersley@unsw.edu.au

Harry Yserentant

Institut fuer Mathematik
Technische Universitaet Berlin
Germany
yserentant@math.tu-berlin.de

Jonathan Ziveyi

School of Finance and Economics
University of Technology Sydney
Australia
jonathan.ziveyi@student.uts.edu.au

Ian Sloan

School of Mathematics and Statistics
University of New South Wales
Australia
i.sloan@unsw.edu.au

Vikram Sunkara

Mathematical Sciences Institute
Australian National University
Australia
kickcem@gmail.com

Tor Sørenvik

Department of Mathematics
University of Bergen
Norway
tor.sorevik@math.uib.no

Tino Ullrich

Hausdorff Center for Mathematics
University Bonn
Germany
tino.ullrich@hcm.uni-bonn.de

Ben Waterhouse

School of Mathematics and Statistics
University of New South Wales
Australia
benjw@maths.unsw.edu.au

Henryk Woźniakowski

Department of Computer Science
Columbia University
USA
henryk@cs.columbia.edu

Atiya Zaidi

School of Mathematics and Statistics
University of New South Wales
Australia
atiya@maths.unsw.edu.au

Index

- Achdou, Yves, 52
Amiraslani, Amirhossein, 24
Andreev, Roman, 56
Asotsky, Danil, 42
- Bailey, David H., 20, 22
Baldeaux, Jan, 21, 26
Banaszuk, Andrzej, 59
Beylkin, Gregory, 28
Bieri, Marcel, 56
Borwein, Jonathan M., 20, 22
Bungartz, Hans-Joachim, 51
- Chernov, Alexey, 23
Chiarella, Carl, 40, 63
Cohen, Albert, 56
Corless, Robert M., 24
- Daum, Fred, 25
DeVore, Ron, 56
Dick, Josef, 21, 26
Doerr, Benjamin, 30
- Fasshauer, Greg, 27
Feil, Balazs, 42
- Garcke, Jochen, 28
Gerstner, Thomas, 29
Gnewuch, Michael, 30
Griebel, Michael, 31, 33, 57
Guillemard, Mijail, 36
- Hackbusch, Wolfgang, 32
Hamaekers, Jan, 33
Heber, Frederik, 33
Hegland, Markus, 34, 44
Heinrich, Stefan, 35
Hickernell, Fred J., 48, 49
Holtz, Markus, 31
Huang, Jim, 25
- Iske, Armin, 36
- Jahnke, Tobias, 37
Jakeman, John, 38
Joe, Stephen, 39
- Kang, Boda, 40
Kritzer, Peter, 21, 30, 49
Kucherenko, Sergei, 42
Kuo, Frances Y., 43, 49, 57
- Lamichhane, Bishnu, 44
Le Gia, Quoc Thong, 45
Leopardi, Paul, 46
Lyness, James, 39
- Mhaskar, Hrushikesh N., 47
Mohlenkamp, Martin, 28
Munthe-Kaas, Hans, 58
- Niu, Ben, 48
Novak, Erich, 61
Nuyens, Dirk, 49
- Papageorgiou, Anargyros, 50
Pflüger, Dirk, 51
Pillichshammer, Friedrich, 30
Pommier, David, 52
Powell, Michael J. D., 53
- Rezvani, Nargol, 24
Roberts, Stephen, 38, 44
- Sørevik, Tor, 58
Sainudiin, Raazesh, 54
Schneider, Reinhold, 55
Schwab, Christoph, 23, 56
Shah, Nilay, 42
Sickel, Winfried, 60
Sloan, Ian H., 43, 45, 57

Stals, Linda, 44
Surana, Amit, 59

Tran, Thanh, 45

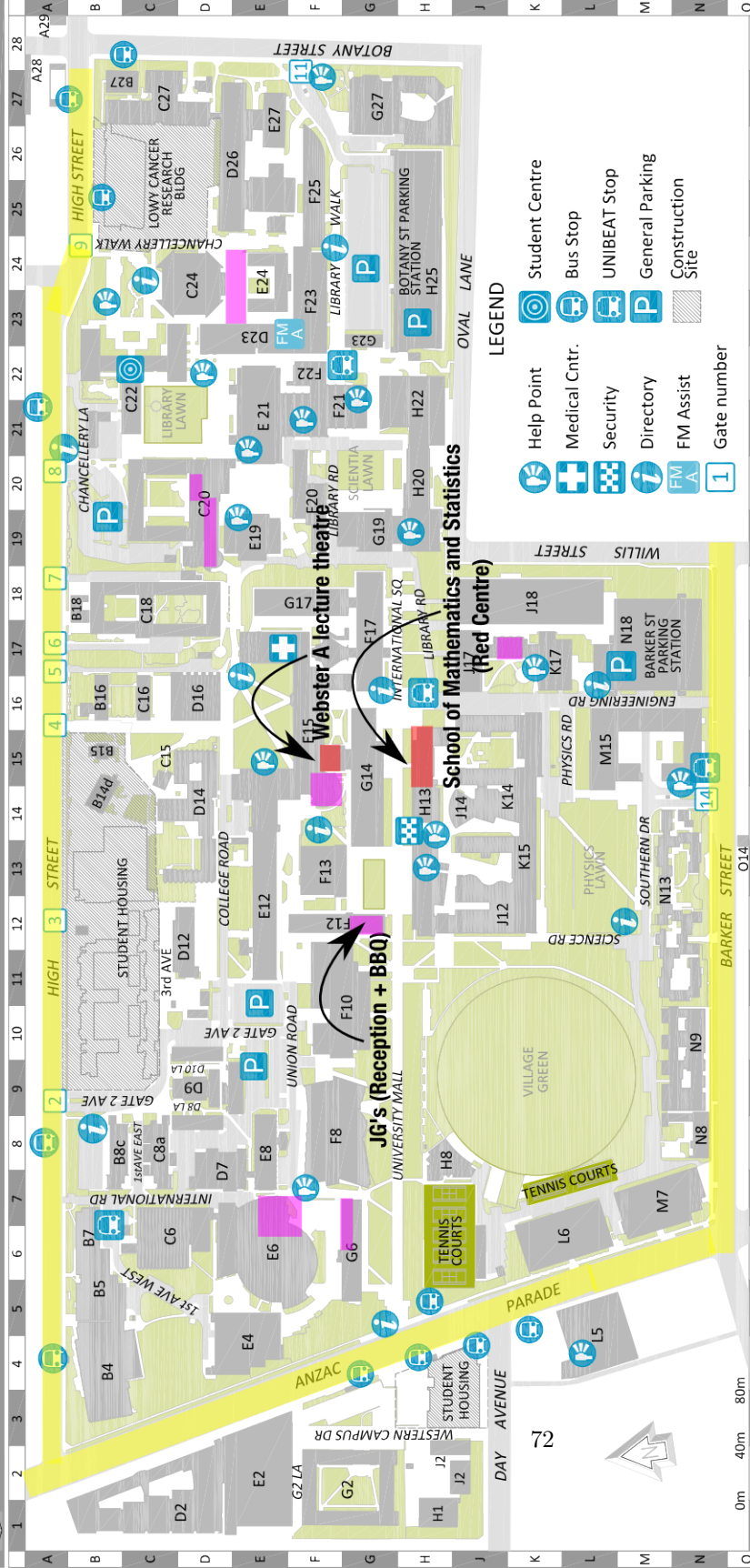
Ullrich, Tino, 60

von Petersdorff, Tobias, 23

Wahlström, Magnus, 30
Wasilkowski, Grzegorz W., 43
Woźniakowski, Henryk, 43, 50, 61

York, Thomas, 54
Yserentant, Harry, 62

Zimmer, Stefan, 51
Ziveyi, Jonathan, 63



BUILDINGS				THEATRES				SERVICES			
A29	Golf House 38 Botany Street	F20	John Goodsell Library Stage 2	B14d	Fig Tree Theatre	A29	Nura Gill Student Centre	E15	Counselling Service	H8	Sports Association
B8cC8a	Food Science	F21	Library Stage 2	C24	Clancy Auditorium	B4	47 Botany Street	F8	Freemasons Library	H13	Security Centre
B27	Medical Administration	F25	Mathematics	D9	IO Myers Studio	B5	Physiotherapy Clinic	F20	Engineering and Design Centre	L5	International Student Centre
C27	Movien Brown	G6	Blockhouse	E2	Parade Theatres	B5	UNSW Fitness and Aquatic Centre	F20	Accomm. Housing Office	L5	Foundation Studies
C27	Wallace Wurth	G14	Robert Webster	E15	Macaulay Theatre	B15	Squash Courts	F20	Student Recruitment Office	L5	FM Assist ID Cards
D7	NIDA	G17	The John Niland Scientia	E19	Central Lecture Block CLB	C17	Admissions and Enrolment	F21	Biomedical Library	M15	Institute of Languages
D12	Petroleum Engineering	G19	Electrical Engineering	F8	Blacks Theatre	C17	Housing Office	F21	IT Service Desk	M15	Coop program
D26	Biological Sciences	G26	AGSM Cricknell Pavilion	F8	Blacks Theatre	C22	Student Association	F21	New South Global IPL	M15	Graduate Research School
E6	Roundhouse	H13	Red Centre	F8	Law Theatre	C22	Human Resources	F22	Post Office	M15	Optometry Vision Services
E8	Materials Science	H20	Civil Engineering	F10	Chemical Sciences Theatre	C22	Student Centre	F23	Environment Management	M15	Research Services
E12	Quadrangle	H22	Valentine Annex	F13	Science Theatre	C22	Marketing Development	F23	Facilities Management		
E15	Australian School of Business	J2	University Regiment	G14	Webster Theatre	C22	UNSW Student Centre	F23	Parking permits etc		
E24	Library	J7	Newton	G15	Webster Theatre	E4	Chaplains Centre	F23	Planning and Development		
E24a	The Arcade	J18	Willis Annex	G19	Ritchie Theatre	E4	CONTACT	F23	Venues and Events Services		
F8	Law	K15	Old Main Building	H13	Red Centre Theatre	E15	Medical Centre	G2	CentreUNSW RMRC		
F10	Chemical Sciences	L5	Computer Science	H20	Civil Engineering G1	E15	Careers Employment Office	G6	ArctUNSW		
F12	Dalton	M15	Rupert Myers	J14	Keith Burrows Theatre	E15	UNSW Bookshop	G23	Injury Risk Management Research		