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Welcome to Montreal for MCQMC 2008

I am pleased to welcome you in Montreal for the *Eighth International Conference on Monte Carlo and Quasi-Monte Carlo Methods in Scientific Computing.* I hope you will spend a memorable week here, enjoying both the scientific program and the city.

The quality of the scientific program and of the presentations depends very much on you, the participants, and very little on us, the organizers. Based on my examination of the abstracts, and in many cases my reading of the related articles from the speakers, I am extremely pleased and excited about the overall quality and variety of the proposed talks. It is a great privilege to organize what has become the world's primary event on both Monte Carlo and Quasi-Monte Carlo methods. Harald Niederreiter created this event and co-organized the first seven editions; he deserves our warmest thanks for his far-reaching vision and dedication. These previous editions were held in Las Vegas, USA (1994), Salzburg, Austria (1996), Claremont, California, USA (1998), Hong Kong (2000), Singapore (2002), Juan-Les-Pins, France (2004), and Ulm, Germany (2006). My gratitude extends to the organizers of these remarkable events.

Our scientific program features ten invited plenary talks top contributors in our field. Each day, we start with one plenary talk in the morning, and we have another one just after lunch. These plenary talks are 55 minutes long. Then there are 125 regular talks of 30 minutes each (including questions), regrouped in 19 special sessions (in which the speakers were mostly invited by the session organizers) and 19 sessions of contributed talks. The regular talks are organized in three parallel tracks. We regret that the parallelism will force all of us to miss at least two thirds of these talks, but setting them in less than three tracks was just impossible. There are excellent selections in each time slot. We also have three parallel tutorials of three hours each, on Sunday afternoon. They are highly recommended. If you forgot to register to one of these tutorials, it is still possible to do so until July 6 (but preferably before). In the schedule, the plenary talks appear in gold, the special sessions in green, the contributed sessions in blue, the tutorials in magenta, and the social events in orange. As I am writing this (mid-June) there are 180 people already registered to the conference.

Following the tradition, Springer-Verlag will publish the conference Proceedings in a book entitled *Monte Carlo and Quasi-Monte Carlo Methods 2008*. Instructions on how and when to submit your manuscripts are provided in this document, with further details given on the MCQMC Conference web page after the conference: http://www.crm.math.ca/mcqmc08.

All registered participants are invited to a wine and cheese reception on Monday, after the presentations, at HEC Montréal, and to the conference banquet, Wednesday evening, in Chambly. We encourage you to visit Montreal by yourself in your free evenings, and also before or after the conference if you can. You may want to arrive a few days earlier to catch the world's famous Montreal Jazz Festival, held in the days that immediately precede the conference, from June 26 to July 6.

If you have any problems or special requests during the conference, please do not hesitate to ask us. We will do our best to help.

Sponsoring Societies

We are very grateful to our sponsors, whose financial contributions cover the expenses of the ten invited plenary speakers and the three tutorials speakers, and part of the other conference expenses. Without their help, the registration fee would have been much higher. These sponsors are the Centre de Recherches Mathématiques (CRM), the Groupe d'Études et de Recherche en Analyse de Décisions (GERAD), MITACS, and the National Science Fundation (NSF) from the USA.



www.crm.umontreal.ca



www.gerad.ca



www.mitacs.ca



www.nsf.gov

Committees and Organizers

The MCQMC Conference series has a *Steering Committee* whose main task is to define guidelines on the conference topics and format, select the organizers, and provide advice when needed. The committee members are:

- Stefan Heinrich, University of Kaiserslautern (Chair)
- Fred J. Hickernell, Illinois Institute of Technology
- Alexander Keller, Mental Images GmbH, Berlin
- Frances Y. Kuo, University of New South Wales, Sydney
- Pierre L'Ecuyer, University of Montreal
- Wolfgang Ch. Schmid, University of Salzburg
- Art B. Owen, Stanford University

The role of the conference *Program Committee* is to make sure that both the conference presentations and the proceedings are of the highest possible quality. This includes suggesting plenary speakers, organizing special sessions, reviewing abstracts of contributed talks, and reviewing (or handling the revision) of papers submitted to the proceedings. The members of the Program Committee for MCQMC 2008 are:

- Pierre L'Ecuyer, University of Montreal (Chair and conference organizer)
- Ronald Cools, Katholieke Universiteit Leuven
- Henri Faure, CNRS Marseille
- Luc Devroye, *McGill University*
- Paul Glasserman, Columbia University
- Peter W. Glynn, Stanford University
- Stefan Heinrich, University of Kaiserslautern
- Fred J. Hickernell, Illinois Institute of Technology
- Aneta Karaivanova, Bulgarian Academy of Science
- Alexander Keller, Mental Images GmbH, Berlin
- Adam Kolkiewicz, University of Waterloo
- Frances Y. Kuo, University of New South Wales, Sydney

- Christian Lécot, Université de Savoie Chambéry
- Jun Liu, Harvard University
- Peter Mathé, Weierstrass Institute Berlin
- Makoto Matsumoto, Hiroshima University
- Thomas Müller-Gronbach, Otto von Guericke Universität, Magdeburg
- Harald Niederreiter, National University of Singapore
- Gilles Pagès, Université Pierre et Marie Curie (Paris 6)
- Art B. Owen, Stanford University
- Klaus Ritter, TU Darmstadt
- Karl Sabelfeld, Weierstrass Institute Berlin
- Wolfgang Ch. Schmid, University of Salzburg
- Ian H. Sloan, University of New South Wales
- Jerome Spanier, Claremont, California
- Bruno Tuffin, IRISA-INRIA, Rennes
- Henryk Woźniakowski, Columbia University

The following persons are taking care of the local organization. They are the ones who end up doing most of the work and they deserve our warmest thanks.

- Francine Benoît, GERAD (proceedings)
- Carole Dufour, GERAD (registration, logistics and social events)
- Marilyne Lavoie, GERAD (program, abstract submission and facilities)
- Louis Pelletier, CRM (travel and housing for plenary speakers)
- Suzette Paradis, CRM (conference web page)

Information

4.1 Conference Venue

The conference is held at HEC Montréal, 3000 chemin de la Côte-Sainte-Catherine, Montreal (see the map on the back cover or on the conference web page). The HEC building is at short walking distance from the *Université de Montréal* metro station; you can use the entrance near the Eastern corner of the building, which is the closest to the metro station.

Detailed information on Montreal's public transportation system can be found at http://www.stm.info. Maps of the entire network are available for free in the metro stations, where you can also buy a weekly pass, called CAM hebdo, giving unlimited access to the STM network (metro and bus) from Monday to Sunday.

If you come by car, parking at HEC is available from Monday to Friday, 6:00 to 22:30, at 3 dollars per half hour and 12 dollars for the day. The parking is closed on Saturday and Sunday (you can find a parking on the street on Sunday). Bicycles can park for free!

4.1.1 Registration, information desk, coffee breaks, and conference rooms

The registration and information desk will be located in front of the *Amphithéâtre IBM*, on the main floor (rez-de-jardin) of the HEC building (see the Maps section).

A message board will be located near the registration/information desk. It will provide updates to the program and all other last-minute announcements and information. Messages to participants can be left on the message board.

The coffee breaks will be in the SGF room, next to the Amphithéâtre IBM.

All the plenary sessions will be held in the Amphithéâtre IBM.

The parallel sessions and the tutorials will be in rooms Banque CIBC, Banque Scotia, Banque de développement du Canada, and TAL Gestion globale d'actifs inc., located on the first floor, in the green and blue sections (see the Maps section).

4.1.2 Lunch breaks

The participants are on their own for lunches.

The easiest and least expensive solution is to use the HEC Cafeteria, located on the main floor, not far from the registration desk. It will be open from 8:00 to 15:00, from Monday to Friday. It is closed on Sunday.

For more fancy food and a nicer setting (including a nice view), the restaurant *Le Cercle*, located on the 7th floor of HEC Montréal (accessible by the elevator on the south side of the building) offers breakfast from 7:30 and lunch until 14:00, from Monday to Friday. Prices are quite reasonable for the quality. However, room is very limited and reservations are required. They can be made only by phone (514-340-7170) or by going in person to the restaurant during opening hours. Group reservations can be taken for a maximum of 20 people only.

Outside the building, there are many restaurants on Côte-des-Neiges street, as well as on Gatineau (south of Lacombe) and on Lacombe (between Gatineau and Côte-des-Neiges). However, you would have to walk between one and two kilometers each way, and it may be difficult to make it within the 90 minutes time frame, unless you walk fast and get served quickly.

Some suggestions in the Côte-des-Neiges area:

Le Béarn (French restaurant), 5613 Côte-des-Neiges, 514-733-4102 Bistro Olivieri (French), 5219 Côte-des-Neiges, enter through book store, 514-739-3639 Il Galateo (Italian), 5315 Gatineau, 514-737-1606 Le Camélia (Vietnamese), 5024 Côte-des-Neiges, 514-738-8083 Atami (Japanese), 5449 Côte-des-Neiges Lao Beijing (Chinese, very low price), 5619A Côte-des-Neiges Restaurant Oriental Ngan Dinh (Vietnamese BoLaLop, low price), 5540 Côte-des-Neiges Tabascobar (burgers, sandwiches, salads, low price), 5414 Gatineau Frite Alors (burgers and fries, low price), 3527 Lacombe La Maisonnée (sports, large TV screens, burgers, sandwiches, low price), 5385 Gatineau

See also:

http://www.mapageweb.umontreal.ca/furstenf/restaurants.htm

4.1.3 Internet access

Wireless Internet access will be available only in the Salon L'Oréal and Salon National, on the main floor. Detailed information (in french only) on how to connect your laptop to the wireless network can be found at:

http://www.hec.ca/gti2/capsules/reseau_et_internet/reseau/page33731.html

The procedure is quite standard.

- Username: Invite590
- Password: MCQMC08

The same username and password will also give you Internet access by cable (with your laptop computer) from almost anywhere in the HEC building. For this, however, you must bring your own Ethernet cable. (The organizers will not provide cables.)

For the participants who do not carry their own laptops, a computer room with Internet access will be open from 9:00 to 17:00 in the Cogeco room.

Adapter plugs for the American electric outlets can be purchased in electronic shops. They may want to sell you an expensive kit that contains several types of adapters. If you need only an *European to American* adapter, you can buy one for almost nothing at *Dollarthèque*, 5168 Côte-des-Neiges (close to Queen-Mary).

4.1.4 Links for tourist information

Montreal official tourist site: http://www.tourisme-montreal.org/

Quebec's Government officiel tourist site: http://www.bonjourquebec.com/

4.1.5 Eating in Montreal

Montreal has a rich variety of restaurants of all kinds, with food from practically any country of the world. If you are looking for fine gourmet dining experiences, have a look at Luc Devroye's map to the best places: http://cg.scs.carleton.ca/~luc/ and look for "Luc's places" near the bottom. Most high-end restaurants give their menu on their web page. Top recommendations (not cheap) include: La Chronique, Le Club Chasse et Pêche, Ferreira Café, Au Pied de Cochon, Toqué.

4.1.6 Climate

The temperature in Montreal is highly variable (perhaps we should introduce QMC in there!). Temperatures above 30° C and high humidity are not uncommon in July. On an average July day, the maximum and minimum temperatures are 26° C and 15° C.

4.2 Social events

4.2.1 Wine and Cheese Reception

A wine and cheese reception will take place on Monday July 7, at 18:30, at Salon L'Oréal, located on the main floor, at the South end of the building. You will have a chance to try Canadian wine, several varieties of local cheeses, and other goodies.

4.2.2 Conference Banquet

The conference banquet will be held on Wednesday evening at the Restaurant Fourquet Fourchette, in Chambly (approximately 30 km south of Montreal). A shuttle bus will take participants and guests from HEC to the restaurant. It will leave at 15:15 and return to HEC at around 23:00.

The banquet and the bus transportation are included in the conference registration fee. Other guests may attend the banquet by purchasing a ticket in advance (at registration time, or at the information desk if there are still tickets available) for 100 Canadian dollars. The number of tickets is limited and they will be sold on a first-come-first-served basis.

The menu will give you the rare chance of tasting Caribou meat from the Canadian North. If you prefer a vegetarian meal, you must send an email to Carole Dufour, or tell the registration desk, *at least two days* before the banquet.

Before the banquet, you might want to visit Fort Chambly, a witness to the early French presence in North America. It was built about 300 years ago (that's very old by Canadian standards) to protect New France from British attacks from the South. It is located less than 500 meters from the restaurant.

http://www.pc.gc.ca/lhn-nhs/qc/fortchambly/index_e.asp

4.3 Presentations

4.3.1 Instructions for speakers

Plenary talks are 50 minutes plus 5 minutes for questions and discussion. All other talks are 25 minutes, plus 5 minutes for questions and discussion.

Please make sure that you do not exceed your time. Focus on the essential of your message. Given the short time allowed to each speaker, it is generally not possible to give the full details of your work. You should concentrate on providing a clear explanation of your main results and their significance.

The MCQMC audience comes from a wide variety of backgrounds: there are mathematicians, computer scientists, statisticians, physicists, financial engineers, and so on. The majority of attendees are unlikely to be familiar with the subject of your talk. So you should reserve some time to explain your topic from a broad perspective.

The conference covers both theory and practice. If your talk is theory-oriented, it is important to discuss how your findings can eventually help the practitioners. If you are focusing on a specific application, do not forget to point out issues on which you think theoreticians might help, and problems for which general state-of-the-art techniques (such as carefully-designed Quasi-Monte Carlo methods, for example) could eventually improve efficiency. Fruitful exchanges between theoreticians and practitioners are a key objective of this conference.

A nice set of guidelines for giving a good presentation, prepared some years ago by James Henriksen for the WSC Conference, is available here:

http://www.wintersim.org/AuthorKit/GuidelinesforMakingaGoodPresentation.pdf

4.3.2 Instructions for Session Chairs

It is the session chairs' responsibility that the speakers adhere tightly to the schedule. Some participants might want to jockey between parallel sessions to listen to their favorite speakers, or attend specific talks for any reason. To make sure that this can be done easily, the session chairs should enforce strict adherence to the schedule. We will provide cards to be shown to the speaker for indicating 5, 3, and 1 remaining minutes of speaking time. Session chairs should also contact their session speakers ahead of time to verify their presence and inform the organizers of any potential no-shows.

4.3.3 Equipment

Each lecture room will be equipped with a computer and a projector for displaying computer output and an overhead projector.

If you have any special requests for other type of audio-visual equipment, please let us know in advance by sending an email to: Marilyne.Lavoie@gerad.ca.

4.4 Proceedings

The proceedings of MCQMC 2008 will be published by Springer-Verlag, in a book entitled *Monte Carlo and Quasi-Monte Carlo Methods 2008*. Every conference speaker is invited to submit a paper based on her/his talk. Each submission will be referred and there will be a limit on the size of the volume. As

a guideline, manuscripts based on a presentation in a special or contributed session should not exceed 15 pages in the required format, and preferably less. These manuscripts should contain original research contributions not published elsewhere. The manuscripts based on invited plenary talks may be longer and can also be more survey-oriented.

The manuscripts must be prepared in IAT_EX with Springer's svmult style file, which is available for download (with instructions) from their web site. Links and further details will be given on the conference web page.

Manuscripts must be submitted as a single .pdf file, on the conference web site. The deadline is **November 21, 2008**. Upon acceptance, the IAT_EX source file of your document will be required. It may include other .pdf documents (for pictures and graphics, for example). Note that the book will be typeset as a single large IAT_EX document that will contain all the manuscripts. For this reason, you must refrain from redefining IAT_EX commands globally in your manuscript, because this will affect other manuscripts as well. In case you must redefine IAT_EX commands for your document, make sure that you reset the original definition at the end of your document.

4.5 Acknowledgments

This document was typeset with LATEX macros adapted those used to typeset the MCQMC 2006 conference program. They were kindly provided by Alexander Keller.

Maps

HEC Montréal 3000, chemin de la Côte-Sainte-Catherine Montréal (Québec) H3T 2A7

MAIN FLOOR (PLAN DU REZ-DE-JARDIN)

Faculté de l'aménagement de l'Université de Montréal



Collège Jean-de-Brébeuf

HEC Montréal 3000, chemin de la Côte-Sainte-Catherine Montréal (Québec) H3T 2A7





Collège Jean-de-Brébeuf

Le chiffre inscrit en dessous du nom de la salle indique le nombre de places disponibles.

Mai 2008

Carte du campus

- 520, chemin de la Côte-Sainte-Catherine 1
- 2 1420, boulevard Mont-Royal
- 3 Pavillon Marie-Victorin
- 4 Pavillon de la Faculté de musique
- 5 Centre d'éducation physique et des sports (CEPSUM)
- 6 2101, boulevard Édouard-Montpetit
- 7 Pavillon J.-A.-DeSève (Centre étudiant)

- 8 Résidence C
- 9 Résidence A et annexe
- 10 Pavillon Thérèse-Casgrain
- 11 École Polytechnique
- Pavillons Pierre-Lassonde 12
- et Claudette McKay-Lassonde
- 13 Pavillon J.-Armand-Bombardier
- 14 Pavillon Roger-Gaudry

- 15 Pavillon Claire-McNicoll
- 16 Pavillon de la Direction des immeubles
- 17 Centre des technologies de fabrication en aérospatiale
- 18 Centrale thermique
- 19 Pavillon René-J.-A.-Lévesque
- 20 Pavillon André-Aisenstadt
- 21 Pavillon Jean-Coutu

- 22 Pavillon Marcelle-Coutu
- 23 Pavillon Paul-G.-Desmarais
- 24 Garage Louis-Colin
- 25 Pavillon Samuel-Bronfman
- 26 Pavillon Maximilien-Caron
- 27 Pavillon Lionel-Groulx
- 28 3200, rue Jean-Brillant
- 29 HEC Montréal 5255, av. Decelles



- 31
- 32 33

30

3333, chemin Queen-Mary 3744, rue Jean-Brillant 3050-3060, boulevard Édouard-Montpetit 3032-3034, boulevard Édouard-Montpetit 34 2910, boulevard Édouard-Montpetit 35 HEC Montréal – Pavillon principal 36 Pavillon de la Faculté de l'aménagement

- 37 Pavillon Liliane de Stewart
- 38 Pavillon Marguerite-d'Youville

Stationnement pour visiteurs

Université m de Montréal

Schedule

Sunday afternoon, July 6

13^{00}	Registration opens		
$14^{00} - 17^{00}$	Advanced Tutorial	Advanced Tutorial	Advanced Tutorial
	TAL Gestion globale d'actifs inc. room	Banque Scotia room	Banque CIBC room
	Jeremy Staum	Alexander Keller	Art B. Owen
	MC and QMC in Finance	MC and QMC in Computer Graphics	MC and QMC in Statistics
	Chair: <i>R. Cools</i>	Chair: B. Tuffin	Chair: J.S. Rosenthal
$*15^{30} - 15^{45}$	Coffee break		

Monday morning, July 7

7^{45}	Registration opens		
$8^{30} - 9^{00}$	Opening session (Amphithéâtre IBM)		
	Pierre L'Ecuyer		
	Invited Plenary Talk (Amphithéâtre IBM)		
$9^{00} - 9^{55}$	Josef Dick		
	On Higher Order Convergence of the Integrati	on Error Using Quasi-Monte Carlo Rules	
	Chair: H. Niederreiter		
Coffee break			
	Special Session	Technical Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Honoring Ian Sloan on His 70th Birthday:	Variance Reduction Methods in Finance	Monte Carlo for Differential Equations and
	New Results and Promising Directions in		Linear Systems
	QMC Methods, Part I		
	Chair: F. Kuo	Chair: G. Pagès	Chair: B. Tuffin
$10^{30} - 11^{00}$	H. Niederreiter	P. Étoré, B. Jourdain	A.V. Burmistrov
	On the Exact <i>t</i> -Value of Some Standard Low-	Adaptive Methods in Stratified Sampling and Ap-	Monte Carlo Method for Solving the Elliptic
	discrepancy Sequences	plications to Option Pricing	BVPs
$11^{00} - 11^{30}$	H. Woźniakowski	J. Lelona, B. Lapevre	V. Lukinov
	Tractability for Multivariate Integration: My 15-	An Adaptive Framework for Monte-Carlo Meth-	The Analytical Extension of the Resolvent for the
	Year Partnership with Ian Sloan	ods	Helmholtz Equation by Technique of Parametric
			Differentiation
$11^{30} - 12^{00}$	F.J. Hickernell	Y. Lai. Y. Wana	S. Ermakov, K. Timofeev
	Approximating Functions of Many Variables	Variance Reduction Methods for Exotic Option	MCQMC Method of Solving of Evolutionary
		Pricing under Variance Gamma and Gaussian	Equations
		Models	
$12^{00} - 12^{30}$	R Cools D Nuvers	A Cormin V Kashtanov	
14 14	Extensions of Fibonacci Lattice Bules	The Weighted Variance Minimization in a Jump-	
		Diffusion Stochastic Volatility Model	

Lunch break

Monday afternoon, July 7

	Invited Plenary Talk (Amphithéâtre IBM)		
$14^{00} - 14^{55}$	Paul Glasserman		
	Sensitivity Estimates for Lévy-Driven Models	in Finance	
	Chair: P.W. Glynn		
	Special Session	Technical Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Honoring Ian Sloan on His 70th Birthday:	Markov Chain Monte Carlo	Applications in Physics and VLSI Testing
	New Results and Promising Directions in		
	QMC Methods, Part II		
	Chair: F. Kuo	Chair: M. Bédard	Chair: C. Lécot
$15^{00} - 15^{30}$	S. Joe	G. Giroux	Y. Laosiritaworn
	Sobol' Sequences with Improved Two-	Study of an MCMC Algorithm Related to Dirich-	Monte Carlo Simulations in Advancing Magnetic
	Dimensional Projections	let Laws	Recording Applications
$15^{30} - 16^{00}$	J. Dick	K.C. Ma, G. Iyengar	M. Fushimi
	The Other Kind of Lattice Rule	A Tick-by-Tick Model for Price and Volume that	Numerical Analysis of Phase Shifts and Correla-
		Incorporates Behavioral Biase	tions of $90/150$ Cellular Automata Sequences
Coffee break			

Monday afternoon, July 7

	Special Session	Technical Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Efficient Monte Carlo Methods in Engineering	Lattice Constructions	QMC, Effective Dimension, and Applications
	and Science		in Finance
	Chair: J.H. Blanchet	Chair: I.H. Sloan	Chair: K.S. Tan
$16^{30} - 17^{00}$	P.W. Glynn	F. Pillichshammer, H. Niederreiter	S. Varet, S. Lefebvre, G. Durand, A. Roblin,
	New Insights on the Steady-State Simulation	The Construction of Good Extensible Integration	S. Cohen
	Problem	Lattices	Effective Dimension and Discrepancy
$17^{00} - 17^{30}$	S. Kou	V. Sinescu, S. Joe	P. Sabino
	Multi-Resolution Monte Carlo Inference of	Lattice Rules for Integration Over Euclidean	Pricing and Hedging Asian Basket Options with
	Stochastic Models from Partially Observed Data	Space	Quasi-Monte Carlo Simulations
$17^{30} - 18^{00}$	J. Blanchet, P. Dupuis	S. Dammertz, H. Dammertz, A. Keller	R. Makarov
	Efficient Simulation for Random Walks Avoiding	Efficient Search for Low-Dimensional Rank-1 Lat-	Hybrid Monte Carlo and Quasi-Monte Carlo
	Hard Obstacles	tices to approximate Spectra	Methods for Path-Dependent Option Pricing

 $18^{00} - 21^{00}$ | Wine and cheese reception

Tuesday morning, July 8

	Invited Plenary Talk (Amphithéâtre IBM)		
$9^{00} - 9^{55}$	Jeffrey S. Rosenthal Markov Chain Monte Carlo Algorithms: Theory and Practice Chair: A.B. Owen		
Coffee break			
	Special Session	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Advances in QMC for Finance Chair: <i>B. Waterhouse</i>	Efficiency of MCMC Methods, Part I Chair: <i>P. Mathé</i>	Stochastic Differential Equations Chair: A. Karaivanova
$10^{30} - 11^{00}$	D. Nuyens	M. Bédard	C. Labart, E. Gobet
	Adaptive Strategies for "High Dimensional"	On the Optimal Scaling Problem for Hierarchical	An Adaptive Monte Carlo Algorithm to Solve
	Problems	Target Distributions	Backward Stochastic Differential Equations
$11^{00} - 11^{30}$	J. Imai, K.S. Tan	P. Neal	S. Geiss, C. Geiss
	An Enhanced Quasi-Monte Carlo Method for	Curse of Dimensionality: Random walk Metropo-	On Approximations of Stochastic Backwards
	Simulating Generalized Hyperbolic Lévy Process	lis for Discontinuous Target Densities	Equations
$11^{30} - 12^{00}$	J. Baldeaux	D. White, M. Pitt, A. Stuart	T.A. Averina
	QMC for Derivative Pricing in Jump-Diffusion	Optimal Scaling of MCMC for Conditioned Dif-	Simulation of Systems with Random Structure,
	Models	fusions	Given by Stochastic Differential Equations
$12^{00} - 12^{30}$	B. Waterhouse, J. Keiner	A. Beskos, A. Stuart	N. Suciu, C. Vamos
	Fast Implementation of PCA for QMC for Finan-	Optimal Tuning of MCMC Algorithms in Infinite	Ergodic Estimations of Upscaled coefficients for
	cial Problems of Unequal Time-Steps	Dimensions	Diffusion in Random Velocity Fields

Lunch break

Tuesday afternoon, July 8

	Invited Plenary Talk (Amphithéâtre IBM)		
$14^{00} - 14^{55}$	Andrew Stuart		
	MCMC Methods for Sampling Function Space)		
	Chair: P. Mathé		
	Special Session	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Monte Carlo Methods in Finance, Part I	Efficiency of MCMC Methods, Part II	MC and QMC for Partial Differential Equa-
			tions in Coagulation Models
	Chair: P. Glasserman	Chair: J.S. Rosenthal	Chair: C. Lécot
$15^{00} - 15^{30}$	R. Cont	Y. Guan	A. Tarhini, C. Lécot
	Sequential Monte Carlo Methods for Inverse	Hot Small World or: How I learned to Stop Wor-	A Quasi-Monte Carlo Scheme for the Simulation
	Problems in Option Pricing	rying and Start to Use Hot Empirical Distribu-	of the Coagulation-Fragmentation Equation
		tions to Ease Sampling	
$15^{30} - 16^{00}$	W. Morokoff	P. Mathé, E. Novak	M.A. Korotchenko
	Application of Importance Sampling and Quasi-	Efficiency of Metropolis-Hastings-Algorithms	Value Modifications of Statistical Modeling for
	Monte Carlo to Multi-Step Credit Portfolio Sim-		Solving the Smoluchowski Equation
	ulations		
$16^{00} - 16^{30}$	R.M. Reesor, T. Whitehead, M. Davison	D. Rudolf	M. Marchenko
	Correcting the Bias in Monte Carlo Estimators of	Explicit Error Bounds for Markov Chain Monte	Study of Parallel Monte Carlo Algorithm to Solve
	American-Style Option Values	Carlo Methods	Nonlinear Equation of Coagulation
Coffee break			

Tuesday afternoon, July 8

	Special Session	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Monte Carlo Methods in Finance, Part II	Adaptive Monte Carlo for Transport Prob- lems	Low-Discrepancy Digital Constructions
	Chair: P. Glasserman	Chair: J. Spanier	Chair: H. Faure
$17^{00} - 17^{30}$	M. Giles	J. Spanier, M. Ambrose, R. Kong	R. Hofer
	"Vibrato" Monte Carlo Evaluation of Greeks	Novel Adaptive Monte Carlo Algorithms for General Transport	On the Distribution of Digital Sequences
$17^{30} - 18^{00}$	N. Chen	C. Hayakawa, R. Kona, J. Spanier	L. Grünschloß. A. Keller
	Exact Simulation of Stochastic Differential Equa-	A Computational Primitive for Monte Carlo Sim-	(t, m, s)-Nets with Large Minimum Distance us-
	tions	ulations	ing Permutations
$18^{00} - 18^{30}$	KK. Kim, P. Glasserman	K. Bhan, R. Kong, J. Spanier	V. Ostromoukhov
	Approximate Simulation of the Heston Stochastic	Application of New Adaptive Monte Carlo Algo-	Recent Progress in Improvement of Extreme
	Volatility Model	rithms to Heterogeneous Transport Problems	Discrepancy and Star Discrepancy of One-
			Dimensional Sequences

Wednesday morning, July 9

	Invited Plenary Talk (Amphithéâtre IBM)		
$9^{00} - 9^{55}$	Klaus Ritter On the Complexity of Infinite-Dimensional Quadrature Problems Chair: H. Wozniakowski		
Coffee break			
	Special Session Banque de développement du Canada room	Special Session Banque Scotia room	Technical Session Banque CIBC room
	Advances in Simulation Methodology Chair: R. Szechtman	Discrepancy and Digital Point Sets Chair: F. Pillichshammer	Function Approximation and Optimization Chair: K. Ritter
$10^{30} - 11^{00}$	K. Leder, P. Dupuis, H. Wang Large Deviations and Importance Sampling for a Tandem Network with Slow-Down	<i>H. Faure</i> On Generalized Two-Dimensional Hammersley Point Sets	S. Heinrich A Multigrid Monte Carlo Algorithm for the Poisson Equation
$11^{00} - 11^{30}$	B.L. Nelson, B.E. Ankenman, J. Staum Simulation on Demand	B. Doerr, M. Gnewuch, P. Kritzer, F. Pil- lichshammer Component-by-Component Construction of Low- Discrepancy Point Sets of Small Size	T. Müller-Gronbach, K. Ritter, T. Wagner Optimal Pointwise Approximation of Infinite- Dimensional Ornstein-Uhlenbeck Processes
$11^{30} - 12^{00}$	C. Alexopoulos, C. Antonini, D. Goldsman, M. Meterelliyoz, J.R. Wilson Folded Variance Estimators for Stationary Markov Chains	M. Gnewuch, C. Winzen Calculation of the Star Discrepancy and Related Problems	S. Maire, E. Tanré Stochastic Spectral Formulations for Elliptic Problems
$12^{00} - 12^{30}$	R. Szechtman, P.W. Glynn Monte Carlo Estimation of the Distribution Func- tion of Conditional Expectations: Continuous Conditioning Spaces	G. Larcher, R. Hofer, F. Pillichshammer Distribution of the Sums of Digits of Integers in Different Bases and the Discrepancy of General- ized Digital (\mathbf{T}, s) -Sequences	E. Zhou, M.C. Fu, S.I. Marcus Solving Continuous-State POMDPs via Projec- tion Particle Filtering

Lunch break

Wednesday afternoon, July 9

$14^{00} - 14^{55}$	Invited Plenary Talk (Amphithéâtre IBM) Daan Frenkel Biased Sampling Techniques to Study Soft Materials and Biological Systems Chair: J. Spanier
15 ¹⁵	Bus leaves for Chambly
$ \begin{array}{l} 16^{00} \\ 17^{00} \\ 18^{00} - 22^{00} \end{array} $	Arrival in Chambly, free time to walk around and visit Fort Chambly Apero Conference banquet

Thursday morning, July 10

	Invited Plenary Talk (Amphithéâtre IBM)		
$9^{00} - 9^{55}$	Wolfgang Ch. Schmid		
	On (t, m, s) -Nets and (t, s) -Sequences		
	Chair: S. Heinrich		
Coffee break			
	Special Session	Technical Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Approximation and Integration in High Di-	Modeling and Simulation in Finance	Importance Sampling, Splitting, and Rare-
	mensions, Part I		Event Simulation
	Chair: F.J. Hickernell	Chair: P. Glasserman	Chair: B. Tuffin
$10^{30} - 11^{00}$	I.H. Sloan	T. Tichý	R. Kawai
	QMC for Flow Through a Porous Medium	The Portfolio Risk Modeling with Lévy Processes	Optimal Importance Sampling Parameter Search
			for Lévy Processes Via Stochastic Approximation
$11^{00} - 11^{30}$	J. Shen, H. Yu, W. E	M. Sbai, B. Jourdain	W. Niemiro, P. Pokarowski
	A Sparse Grid Method for Boltzmann Equation	Exact Simulation Methods. Application to the	Optimal Sequential Monte Carlo Algorithms with
		Pricing of Continuous Asian Options.	Fixed Relative Precision
$11^{30} - 12^{00}$	W.L. Kath	HW. Teng, YD. Lyuu	I.N. Medvedev, G.A. Mikhailov
	Methods for Simulating Rare Events in Nonlinear	Efficient and Unbiased Greeks of Rainbow Op-	"Value" Modelling with Branching in the Monte
	Lightwave Systems	tions with Importance Sampling	Carlo Method
$12^{00} - 12^{30}$	P. Kritzer, X. Zeng, F.J. Hickernell	A. Kaganov, A. Lakhany, P. Chow, A.	G. Rubino, H. Cancela, P. L'Ecuyer, M. Lee,
	On the Approximation of Functions Using Poly-	Kreinin	B. Tuffin
	nomial Lattices	FPGA Acceleration of Monte-Carlo Based Credit	Combining Path-Based Methods, RQMC and
		Derivatives Pricing	Zero-Variance Approximations in Static Model
			Analysis

Lunch break

Thursday afternoon, July 10

	Invited Plenary Talk (Amphithéâtre IBM)		
$14^{00} - 14^{55}$	Arnaud Doucet		
	Particle Markov Chain Monte Carlo		
	Chair: C. Lemieux		
	Special Session	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Approximation and Integration in High Di-	Random Number Generation and Evaluation,	Markov Chains and Particle Methods I
	mensions, Part II	Part I	
	Chair: F.J. Hickernell	Chair: M. Matsumoto	Chair: A.B. Owen
$15^{00} - 15^{30}$	X. Zeng	A. Klapper	J. Propp
	Chebyshev Spectral Methods on Lattices for	Algebraic Methods of Sequence Generation	The Rotor-Router Mechanism for Quasirandom
	High-Dimensional Functions		Walk and Aggregation
$15^{30} - 16^{00}$	B. Niu	M. Saito, M. Matsumoto	F. Daum, J. Huang
	Monte Carlo Simulation of Stochastic Integrals	A Uniform Real Random Number Generator	Particle Flow for Nonlinear Filters with Log-
	when the Cost of Function Evaluation is Dimen-	Obeying the IEEE 754 Format Using an Affine	Homotopy
	sion Dependent	Transition	
$16^{00} - 16^{30}$	F.Y. Kuo	T. Nishimura	R. Douc, G. Fort, E. Moulines, P. Priouret
	On Decompositions of Multivariate Functions	Exact Methods for Evaluating Linear Pseudoran-	Forgetting of the Initial Distribution for the Filter
		dom Number Generators	in General Hidden Markov Models
Coffee break			

Thursday afternoon, July 10

	Special Session	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Stochastic Approximation and Adaptive	Random Number Generation and Evaluation,	Markov Chains and Particle Methods II
	Monte Carlo Methods in Finance	Part II	
	Chair: G. Pagès	Chair: M. Matsumoto	Chair: A.B. Owen
$17^{00} - 17^{30}$	N. Frikha	S. Mertens	R.G. Esteves, C. Lemieux, M. McCool
	Efficient Computation of Both VaR and CVaR	YARN Generators in Large Scale Distributed	An Implementation of the Quasi-Monte Carlo
	Using Stochastic Approximations	Monte Carlo: Theory	Baum-Welch Algorithm Using the Stream Pro-
			cessing Model
$17^{30} - 18^{00}$	V. Lemaire, G. Pagès	H. Bauke	E. Spiller, A. Budhiraja, K. Ide, C. Jones
	Unconstrained Adaptive Variance Reduction and	YARN Generators in Large Scale Distributed	Modified Sequential Monte Carlo Methods for La-
	Application to Monte Carlo Option Pricing	Monte Carlo: Practice	grangian Data Assimilation
00			
1800 - 1830	F. Panloup, G. Pagès	H. Haramoto, M. Matsumoto	C. Besse, B. Chaib-draa
	Functional Approximation of the Distribution of	Automatization of Statistical Tests on Random-	Rollout and Particle Filters for Decentralized
	a Stationary Diffusion with Jumps with Applica-	ness to Obtain Clearer Conclusion	Control of Multiple Agents
	tion to Stochastic Volatility Models		

 19^{30}

Dinner and Business meeting for the steering committee

Friday morning, July 11

	Invited Plenary Talk (Amphithéâtre IBM)		
$9^{00} - 9^{55}$	Christiane Lemieux		
	New Perspectives on $(0, s)$ -sequences		
	Chair: R. Cools		
Coffee break			
Conce break	Special Session	Technical Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room
	Sorting and Quasi-Monte Carlo	Random Number Generation and Evaluation	Applications in Statistics
		III	r r
	Chair: A. Keller	Chair: J. Leydold	Chair: F. Bastin
$10^{30} - 11^{00}$	J. Propp	Z. Chen, D. Gomez, A. Winterhof	F. Özbudak, A.D. Sezer
	Derandomized Parallel Simulation of Markov	Distribution of Explicit Digital Inversive Pseudo-	Infinite Families of Mixed Level Orthogonal Ar-
	Chains Via <i>P</i> -Machines	random Numbers and Applications to Some Bi-	rays
		nary Sequences	
$11^{00} - 11^{30}$	A. Keller	S. Harase	M. Zalewska, A. Grzanka, W. Niemiro, B.
	On the Relation of Quasi-Monte Carlo, Sorting,	Maximally Equidistributed Pseudorandom Num-	Samoliński
	and the Rotor-Router Model	ber Generators Via Linear Output Transforma-	Identification of Outlying Subsets of Data: A New
		tions	Algorithm Based on Resampling
$11^{30} - 12^{00}$	P. L'Ecuyer, C. Lécot, A. L'Archevêque-	LY. Deng, JJ. Horng Shiau, GH. Tsai	OA. Damian
	Gaudet	Parallel Random Number Generators Based on	Stochastic Volatility in the Context of the Struc-
	Randomized Quasi-Monte Carlo Simulation of	Large Order Multiple Recursive Generators	tural Credit Risk Model of Merton (1974)
	Multidimensional Markov Chains		
$12^{00} - 12^{30}$	R. El Haddad, C. Lécot, G. Venkiteswaran	P. Leopardi	B. Addepalli, D. Edwards, C. Sikorski, E.R.
	Quasi-Monte Carlo Simulation of Diffusion in a	Testing the Tests: Using Pseudorandom Number	Pardyjak
	Nonhomogeneous Medium	Generators to Improve Empirical Tests	Performance Evaluation of QMC Point-Sets in
			the Solution of an Atmospheric Source Inversion
			Problem

Lunch break

Friday afternoon, July 11

	Invited Plenary Talk (Amphithéâtre IBM)			
$14^{00} - 14^{55}$	Jun Liu			
	Monte Carlo Methods for Studying Protein Structures			
	Chair: JM. Dufour			
	Special Session	Technical Session	Technical Session	
	Banque de développement du Canada room	Banque Scotia room	Banque CIBC room	
	Simulation-Based Statistical Inference in	Random Number Generation and Evaluation	Radiation Transfer and Transport in Semi-	
	Econometrics	IV	conductors	
	Chair: JM. Dufour	Chair: A. Klapper	Chair: A. Karaivanova	
$15^{00} - 15^{30}$	P. Valery, JM. Dufour	LY. Deng, H.HS. Lu, TB. Chen	B. Kargin	
	Exact Tests for Testing Short- and Long-Memory	A Class of Generators Suitable for Both Security	Weight Statistical Modeling of Optical Radiation	
	Features on Stochastic Volatility Models	and Simulation Applications	Transfer in Randomly-Inhomogeneous Scattering	
			Media	
$15^{30} - 16^{00}$	A. Taamouti, JM. Dufour	D. Gomez, E. El-Mahassni	N.V. Tracheva	
	Confidence Intervals for Causality Measures and	On the Multidimensional Distribution of Num-	Monte Carlo Algorithm for Estimating the	
	Tests of Non-Causality	bers Generated by Iterations of Dickson Polyno-	Asymptotic Parameters of Polarized Radiation	
		mials		
$16^{00} - 16^{30}$	T. Jouini		E. Atanassov, T. Gurov, A. Karaivanova	
	Bootstrapping Stationary Invertible VARMA		Quasi-Random Approach in the Grid Application	
	Models in Echelon Form: A Simulation Evidence		SALUTE	
Coffee break				
Conee break				

Friday afternoon, July 11

	Special Session	Technical Session
	Banque de développement du Canada room	Banque Scotia room
	Monte Carlo Methods for Discrete Choice Es-	Nonuniform Variate Generation and Distribu-
	timation Problems	tion Approximation
	Chair: F. Bastin	Chair: LY. Deng
$17^{00} - 17^{30}$	C. Cirillo, F. Bastin, P.L. Toint	A. Genz
	Flexible Forms of Discrete Choice Models: A	Computation of Dirichlet Distribution Probabili-
	Non-Parametric Mixed Logit Model for Central	ties
	Bank Intervention	
$17^{30} - 18^{00}$	D. Bolduc, N. Boucher, R. Alvarez-Daziano	W. Hörmann, G. Derflinger, J. Leydold
	Hybrid Choice Modeling of New Technologies for	Numeric Inversion
	Car Use in Canada: A Simulated Maximum Like-	
	lihood Approach	
$18^{00} - 18^{30}$	F. Bastin, V. Malmedy, M. Mouffe, P.L.	J. Leydold, W. Hörmann
	Toint, D. Tomanos	Random Variate Generation and Testing in Inter-
	Adaptive Retrospective Trust-Region Methods in	active Environments
	Stochastic Programming and Discrete Choice Es-	
	timation	

 18^{30}

End of the conference

Abstracts

7.1 Plenary Talks

On Higher Order Convergence of the Integration Error Using Quasi-Monte Carlo Rules

Josef Dick

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A quasi-Monte Carlo rule approximates the integral of a function over the unit cube $[0, 1]^s$ using the average of function values at quadrature points $\mathbf{x}_0, \ldots, \mathbf{x}_{N-1}$, i.e.,

$$\int_{[0,1]^s} f(\mathbf{x}) \mathrm{d}\mathbf{x} \approx \frac{1}{N} \sum_{n=0}^{N-1} f(\mathbf{x}_n).$$

It has been shown that there are quadrature points based on digital nets and sequences such that the integration error achieves a convergence of order $N^{-\alpha}(\log N)^{\alpha s}$, where $\alpha \geq 1$ can be arbitrarily large for sufficiently smooth integrands.

This result uses the behaviour of the Walsh coefficients of smooth functions. For example, if f has continuous partial mixed derivatives up to order $\delta \geq 1$, then the question is: what can we say about the decay of its Walsh coefficients? The answer to this question will yield a criterion on the generating matrices of digital nets and sequences via the integration error.

Finally, we show how we can explicitly construct generating matrices of digital nets which satisfy this criterion, hence yielding explicit constructions of quadrature points such that the integration error converges with order $N^{-\alpha}(\log N)^{\alpha s}$.

The talk will be mainly based on the results in [1, 2].

- [1] J. Dick, "Explicit Constructions of Quasi-Monte Carlo Rules for the Numerical Integration of High-Dimensional Periodic Functions", SIAM Journal on Numerical Analysis, 45(5):2141–2176, 2007.
- J. Dick, "Walsh Spaces Containing Smooth Functions and Quasi-Monte Carlo Rules of Arbitrary High Order", SIAM Journal on Numerical Analysis, 46(3):1519–1553, 2008.
Particle Markov Chain Monte Carlo

Arnaud Doucet

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Markov chain Monte Carlo (MCMC) and Sequential Monte Carlo (SMC) methods have emerged as the two main tools to sample from high-dimensional probability distributions. Although asymptotic convergence of MCMC algorithms is ensured under weak assumptions, the performance of these latters is unreliable when the proposal distributions used to explore the space are poorly chosen and/or if highly correlated variables are updated independently. We show here how it is possible to build efficient high-dimensional proposal distributions using SMC methods. This allows us to design effective MCMC algorithms in complex scenarios where standard strategies fail. We demonstrate these algorithms on a non-linear non-Gaussian state-space model, a

stochastic kinetic model and Dirichlet process mixtures.

Biased Sampling Techniques to Study Soft Materials Biological Systems

Daan Frenkel

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The study of complex molecules and complex free energy landscape requires extensions of the conventional Markov Chain Monte Carlo approach. In my talk I will discuss how biased sampling can help in the study of crystal nucleation and how the sampling of rejected trial moves can help in the study of chaperone-assisted protein folding.

Sensitivity Estimates for Lévy-Driven Models in Finance

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Lévy processes with jumps and, more generally, stochastic differential equations driven by Lévy processes have been proposed as models for financial data to address shortcomings of diffusion models. These models have been used, in particular, to match market prices of options and other derivative securities. Some options can be valued through closed-form expressions or numerical transform inversion, but others require Monte Carlo simulation. Hedging options requires the calculation of price sensitivities, so we investigate the estimation of sensitivities by Monte Carlo in Lévy-driven models. We consider applications of the likelihood ratio method (LRM) and pathwise differentiation. As a benchmark, we analyze the error in LRM estimates when the relevant

probability densities are known only through their Laplace transforms and the score function is evaluated through numerical transform inversion. We then analyze approximations, including estimates based on compound Poisson approximations and saddlepoint approximations.

This is joint work with Zongjian Liu.

New Perspectives on (0, s)-Sequences

Christiane Lemieux

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Low-discrepancy sequences that fall in the category of (0, s)-sequences have always been of interest to both practitioners and theorists, mainly because they reach the optimal value of 0 for their *t*-parameter, but also because their definition is simple. However, it has been noted by several researchers—especially those interested in financial simulations—that the Sobol' sequence was often performing better than the original (0, s)-sequences in prime bases proposed by Faure in 1982, although the former construction does not have an optimal value of 0 for its *t*-parameter.

The purpose of this talk is to discuss some new ideas that can be used to find improved constructions for (0, s)-sequences in prime bases. To do so, we study them within the framework of generalized Niederreiter sequences, which was introduced by Tezuka in 1993. This allows us to make connections with the Sobol' sequence, which is also included as a special case of this family. We take a closer look at the structure of the corresponding generating matrices, as this helps us to better understand the differences and analogies between the constructions that we are interested in. This study is then used to guide our search for improved (0, s)-sequences that have better properties than the originally proposed construction. Numerical results are presented to illustrate the performance of the proposed constructions, and compare them with the Sobol' sequence.

Monte Carlo Methods for Studying Protein Structures

Jun S. Liu

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I will describe some of our recent efforts in the development of Monte Carlo strategies (both MCMC and SMC) for simulating and optimizing molecular structures. I will illustrate these ideas using examples from Hydrophobic-Hydrophilic (HP) protein model (both 2-D and 3-D) optimization, protein side-chain entropy (SCE) estimation, and near-native structure (NNS) simulations. By applying the new SMC and MCMC schemes, we were able to achieve the best results for all the 2-D and 3-D HP structural optimization examples we can find in the literature. In particular, the new approach achieved better results for these HP models than a modified PERM algorithm and the equi-energy Sampler (Kou et al. 2006). For the SCE and NNS problems, we can

characterize accurately many important ensemble properties of NNS and compute efficiently the SCE of a given structural backbone for any given energy function. We also found that widely used pairwise potential functions behaved surprisingly badly for stabilizing near native protein structures, and adding a term representing the SCE of the protein can help greatly in discriminating true native structures from decoys.

This is joint work with Jinfeng Zhang and Sam Kou.

On the Complexity of Infinite-Dimensional Quadrature Problems

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Numerical integration (or quadrature) on finite-dimensional domains like $[0, 1]^d$ or \mathbb{R}^d is a classical topic, and also its complexity is well studied in different settings. In this talk we focus on quadrature problems on infinite-dimensional domains X, and here we are mainly interested in integration w.r.t. Gaussian measures or w.r.t distributions of diffusion processes on X = C[0, 1], say. In the latter case Monte Carlo algorithms based on weak Itô Taylor schemes are frequently used in computational practice.

We first discuss reasonable cost models for infinite-dimensional quadrature, which are based on different sampling regimes for the integrands $f: X \to R$, namely fixed

subspace sampling, variable subspace sampling, and full space sampling. Then we present complexity results for the quadrature problem on the class of Lipschitz functionals f, both for deterministic as well as for randomized (i.e. Monte Carlo) algorithms. It turns out that the complexity of the quadrature problem is closely related to quantization numbers and Kolmogorov widths for the underlying measure. For variable-subspace-sampling suitable multi-level Monte Carlo methods turn out to be almost optimal.

Joint work with Jakob Creutzig (Darmstadt), Steffen Dereich (Berlin), and Thomas Müller-Gronbach (Magdeburg).

Markov Chain Monte Carlo Algorithms: Theory and Practice

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Markov chain Monte Carlo (MCMC) algorithms are often used to sample from complicated probability distributions. Various theoretical issues arise, including time to convergence, accuracy of estimates, efficiency, optimality, etc. It is also to have the computer automatically "adapt" the algorithm while it runs, in an attempt to improve efficiency, though this presents additional challenges. In this talk, we will review various theoretical and implementation issues surrounding MCMC, and also attempt to make some connections to QMC.

On (t, m, s)-Nets and (t, s)-Sequences

Wolfgang Ch. Schmid¹

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Efficient quasi-Monte Carlo methods require well distributed point sets in the (often high-dimensional) unit-cube. Currently, the most effective constructions of point sets and sequences with low discrepancy are based on the concepts of (t, m, s)-nets and (t, s)-sequences. It is well known that there are close connections between nets, codes, orthogonal arrays, and ordered orthogonal arrays in various depths. In fact, the class of ordered orthogonal arrays include the former ones as special cases. Many bounds and efficient constructions depend on these connections, but also on other objects like algebraic curves or function fields. Keeping an overview is not an easy task at all.

MINT (http://mint.sbg.ac.at/), a web based database system, is not only the most complete reference for nets and sequences but also for the other classes mentioned above, including the important case of linear codes. By means of MinT we present a comprehensive survey of nets and sequences, and of the variety of relations mentioned above.

This is joint work with Rudolf Schürer.

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MCMC For Sampling Function Space

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Applied mathematics is concerned with developing models with predictive capability, and with probing those models to obtain qualitative and quantitative insight into the phenomena being modelled. Statistics is data-driven and is aimed at the development of methodologies to optimize the information derived from data. The increasing complexity of phenomena that scientists and engineers wish to model, together with our increased ability to gather, store and interrogate data, mean that the subjects of applied mathematics and statistics are increasingly required to work in conjunction in order to significantly progress understanding.

This talk is concerned with a research program at the interface between these two disciplines, aimed at problems in differential equations where profusion of data and the sophisticated model combine to produce the mathematical problem of obtaining information from a probability measure on function space. In this context there is an array of problems with a common mathematical structure, namely that the probability measure in question is a change of measure from a product measure. We illustrate the wideranging applicability of this structure, to problems in the atmospheric sciences, chemistry, econometrics and signal processing.

For problems whose solution is determined by a probability measure on function space, information about the solution can be obtained by sampling from this probability measure. One way to do this is through the use of MCMC methods. We show how the common mathematical structure of the aforementioned problems can be exploited in the design of effective MCMC methods and we analyze the computational complexity of these methods.

7.2 Tutorial Talks

Monte Carlo and Quasi-Monte Carlo Methods in Computer Graphics

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Photorealistic images synthesis consists of computing functionals of the solution of a Fredholm integral equation of the second kind. The tutorial provides an understanding of the mathematical problem and the tools needed to implement high performance high quality image rendering software as used in industry for product design and movies.

Structured in three parts, we first introduce the global illumination problem and high performance ray tracing, followed by a part on algorithmic aspects of randomized and deterministic quasi-Monte Carlo methods. The third part combines the previous

ones by presenting rendering algorithms for light transport simulation. The tutorial is self contained, gives a lot of references for further study and research, and points out open problems.

The presented techniques like high performance ray tracing, the high speed generation of (t, s)sequences, parallel adaptive quasi-Monte Carlo integration, the simultaneous simulation of Markov chains
using sorting, or treating weak singularities in a robust way have many applications outside the domain
computer graphics, too.

Monte Carlo Methods in Statistics

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This talk will examine the ways that Monte Carlo methods are used in statistical inference. The goal is to convey something of the goals of statistical inference, as well as to expose opportunities for quasi-Monte Carlo methods to be substituted for Monte Carlo.

A core problem in statistical inference is to judge the sampling uncertainty in an estimated quantity. Sometimes we want to tell whether the quantity may be purely an artifact of noise. Monte Carlo methods are coming to dominate the process, at least for complicated problems.

The methods to be studied will include bootstrap resampling, cross-validatory sampling, permutation tests and related methods like rotation tests, as well as Markov chain Monte Carlo.

Monte Carlo and Quasi-Monte Carlo Methods in Finance

Jeremy Staum

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In computational finance, MC/QMC simulation is one of the principal numerical tools. How much is a financial security worth? What risks are involved in holding a financial portfolio, how large are they, and what can be done to mitigate them? What portfolio best suits one's financial goals? What do security prices imply about stochastic models of financial markets? Simulations of financial markets are used in answering all of these questions: given a stochastic model of the markets, MC/QMC methods provide an approximation to a functional of a relevant distribution, such as the expectation or a quantile of the distribution of wealth at a future date. We give an overview of computational problems in derivative security pricing, risk management,

portfolio optimization, and model calibration, and explain the ways in which simulation is applied to them.

One theme is computational efficiency of simulation procedures, emphasizing aspects of efficiency improvement specific to finance. For example, it is often possible to find very good control variates in financial simulations and to make Quasi-Monte Carlo work well even on very high-dimensional problems. Also, the simulations of financial markets used in computational finance typically take the form of exact or approximate solution of stochastic differential equations (SDEs) over a finite time horizon. We discuss the implications of an analysis of the error due to discretizing SDEs for simulation efficiency.

Another theme is ways in which simulation methodology has been cleverly extended to do more than approximate the distribution of a financial random variable. We present good simulation methods for sensitivity analysis: what is the rate of change of an expectation as underlying financial variables or model parameters change? We explain how simulation can be used in studying American-style options, which involve an optimal stopping problem. We consider the interplay between simulation and optimization when the goal is to find an optimal trading strategy or a best-fitting model. We also discuss the application of response surface modeling in financial simulations.

7.3 Talks

Performance Evaluation of QMC Point-Sets in the Solution of an Atmospheric Source Inversion Problem

Bhagirath Addepalli¹, Dave Edwards², Christopher Sikorski² & Eric R. Pardyjak¹

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As part of the Department of Homeland Security's BioWatch program, environmental sensors have been placed in various cities to allow early detection of chemical/biological/radiological (CBR) release events. The atmospheric source inversion problem involves locating the source of a CBR agent using data recorded at the sensors. The simplest model that describes the transport of atmospheric contaminants is the Gaussian plume dispersion model, which has been chosen as the forward model. For this 5D inverse problem, the parameter space consists of the spatial co-ordinates (x, y and z locations) and strength of the source and the ambient wind direction at the source. Popular approaches appearing in the literature to solve such problems comprise of using genetic algorithms, random search methods with simulated annealing, Bayesian inference methods with MC sampling and the principle of maximum entropy. Our solution methodology combines quasi-random sampling and gradient optimization with regularization. We have considered several low-discrepancy point sets (e.g., Halton, Hammersely, Sobol', Niederreiter-Xing, ShiftNet and Special Niederreiter points) and several different stabilizing functionals for the gradient methods. Since quasi-random point sets are deterministic, we also investigated different techniques for randomizing the points. The goal of this experiment is to find which point set yields the best results for the application, in terms of the accuracy of the predicted model parameters and the total execution time of the program. For this 5D source inversion problem, we found that running the forward model over approximately 50,000 quasi-random points consistently produced good results without the further need for inversion. The performance of the point sets was evaluated against both synthetic and field data (The Copenhagen Tracer Experiments - Erik and Lyck, 1998). We have also developed a new method for weighting sensors with 'zero' hits, which helps eliminate non-uniqueness encountered in the solution of inverse problems. In the future, we plan to investigate and document the correlation between the star discrepancy of a point set and the effectiveness of those points in solving the atmospheric source inversion problem. Also, the performance of the proposed approach will be evaluated against the other approaches suggested in the literature.

Folded Variance Estimators for Stationary Markov Chains

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A central problem in Markov Chain Monte Carlo is accurate and precise estimation of the asymptotic variance parameter—that is, the sum of autocovariances at all lags. We formulate a new class of estimators for the variance parameter by repeatedly applying a "folding" operation to the standardized time series obtained from the Markov chain. By forming appropriate linear combinations of the variance estimators based on different levels of folding, we obtain substantial improvements in estimator accuracy and efficiency. A comprehensive experimental performance evaluation demonstrates the improvements that can be achieved in practice.

Quasi-Random Approach in the Grid Application SALUTE

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SALUTE (Stochastic ALgorithms for Ultra-fast Transport in sEmiconductors) is a grid application developed for solving various computationally intensive problems which describe ultrafast carrier transport in semiconductors. SALUTE studies memory and quantum effects during the relaxation process due to electron-phonon interaction in one-band semiconductors or quantum wires. Formally, SALUTE integrates a set of novel Monte Carlo, quasi-Monte Carlo and hybrid algorithms for solving various computationally intensive problems which describe the femtosecond relaxation process of optically excited carriers in one-band semiconductors or quantum wires.

There are two main reasons for running this application on the computational grid: (i) quantum problems are very computationally intensive; (ii) the inherently parallel nature of MC applications makes efficient use of Grid resources. Effectively exploring the power of distributed MC application requires that the underlying random number streams in each subtask are independent in a statistical sense. The efficient application of quasi-Monte Carlo algorithms entails additional difficulties due to the possibility of job failures and the inhomogeneous nature of the Grid resource. In this paper we study the quasi-random approach in SALUTE and the performance of the corresponding algorithms on the grid, using the scrambled Halton and Sobol' sequences. A large number of tests have been performed on the EGEE and SEEGRID grid infrastructures using specially developed grid implementation scheme. Novel results for energy and density distribution, obtained in the inhomogeneous case with applied electric field will be discussed.

Simulation of Systems with Random Structure, Given by Stochastic Differential Equations

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Modern problems of automatic control are described by the mathematical models given by different equations on random time intervals, i.e. there are used models of stochastic systems with a sudden random changed structure (or systems with random structure) [1].

The system with random structure is described by the mixed process $[\mathbf{y}(t), s(t)]$. The process s(t) is a discrete random scalar process with integer values 1..., S. Here S is the number of determinate structures. The process $\mathbf{y}(t)$ for each of the *l*-th structures, l = s(t), is given by the stochastic differential equations. A one-dimensional distribution density for each of the *l*-th structures of the system $p^{(l)}(\mathbf{y}, t)$ satisfies the generalized Focker-Planck-Kolmogorov equation [1].

We consider systems with conditional Markov process s(t), when the dependence on the vector $\mathbf{y}(t)$ is statistically given. These are the systems with distributed transitions. The analytical solution for such systems can be found only in exceptional cases. A statistical simulation algorithm for the probabilistic analysis of systems with distributed transitions was proposed in [2]. This algorithm is based on numerical methods of SDE systems [3].

In this paper the problem of the optimal choice of parameters of the statistical algorithm is solved for the calculation of an estimation $p^{(l)}(\mathbf{y}, t)$. The comparison of the proposed method and the spectral method is given for some problems of automatic control.

The results show that the estimations of the method of statistical simulation are asymptotically unbiased, which provides the control of the spectral method.

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QMC for Derivative Pricing in Jump-Diffusion Models

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For the past decade, Quasi-Monte Carlo (QMC) methods have been applied successfully to the pricing of financial derivatives in the Black-Scholes setting. However, the shortcomings of the Black-Scholes model are well-known and a lot of research has been devoted to address these. From the point of view of QMC methods, these extensions have been neglected and in particular jump-diffusion models have enjoyed very little attention in the literature. In this talk, we apply QMC methods to a particular jump-diffusion model, namely the Kou model.

In the context of the Kou model, we investigate firstly if QMC methods outperform Monte Carlo (MC) methods, which was generally observed in the Black-Scholes setting. We choose a naive incrementby-increment construction for the jump-diffusion process corresponding to the standard construction in the case of Brownian motion.

Secondly, we investigate the effect of changing the order in which variates are simulated. It is wellknown that in the Black-Scholes model, this can result in significant improvements in the performance of QMC methods. For this purpose, we introduce a reordering scheme for the Kou model which generalises the Brownian Bridge construction for Brownian motion. Using this reordering scheme, we investigate if improvements in the performance of QMC methods can be achieved.

Adaptive Retrospective Trust-Region Methods in Stochastic Programming and Discrete Choice Estimation

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Bastin, Malmedy, Mouffe, Toint, and Tomanos [2] recently proposed a variant of the classical trustregion, called retrospective trust-region, to solve unconstrained nonlinear problems. In trust-region methods, one considers a model m_k of the objective function which is assumed to be adequate in a "trust region", which is a neighborhood of the current iterate x_k . This neighborhood is often represented by a ball in some norm, whose radius Δ_k is then updated from iteration k to iteration k + 1 by considering how well m_k predicts the objective function value at iterate x_{k+1} . In retrospect, this might seem unnatural since the new radius Δ_{k+1} will determine the region in which a possibly updated model m_{k+1} is expected to predict the value of the objective function around x_{k+1} . Bastin et al. constructed a variant of the algorithm that determines Δ_{k+1} according to how well m_{k+1} predicts the value of the objective function at x_k , thereby synchronizing the radius update with the change in models, and show that the retrospective approach is overall more efficient, and just as reliable.

The model prediction can also be used in adaptive techniques that allow altering the accuracy of the objective computation. When the objective evaluation is expensive, it is indeed useful to compute only a cheaper estimation of this objective when possible. Bastin, Cirillo, and Toint [1] devised such an approach in the context of stochastic programming based on sample average approximations. The approximations are obtained by sampling from the underlying random variables. The larger is the number of draws, the most accurate is the approximation, but also the most expensive it is. They applied the technique to mixed logit models estimation and show that the adaptive algorithm outperforms the traditional approach. In this paper, we capitalize on these two algorithmic modifications, in an attempt to combine their benefits and improve the numerical efficiency associated to the optimization of some stochastic programs, especially log-likelihood maximization for advanced discrete choice models estimation.

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YARN Generators in Large Scale Distributed Monte Carlo: Practice

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YARN generators are a new class of pseudorandom number generators that excel as high quality pseudorandom number sources in sequential as well as in parallel large scale Monte Carlo applications. Its theoretical properties are well understood and its excellent statistical properties have been confirmed by many empirical tests.

In this talk we focus on practical aspects of YARN generators: its empirical quality and how to boost YARN generators to maximal performance by table look-up and other special implementation techniques. Furthermore, we introduce "Tina's Random Number Generator Library". It provides a state of the art open source C++ implementation of the new generator class in order to facilitate its proliferation.

On the Optimal Scaling Problem for Hierarchical Target Distributions

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Random walk Metropolis algorithms with Gaussian proposal distributions are an important class of MCMC algorithms. In order to implement these algorithms, it is necessary to tune the variance of the Gaussian distribution so that the Markov chain converges rapidly to its stationary distribution. Results about the optimal scaling of the proposal distribution and the optimal acceptance rate of the algorithm for the special case of multidimensional target distributions with independent components are available in the literature. I propose to extend these results to multidimensional target distributions with correlated components. To do so, a natural avenue to explore is that of hirarchical targets; these models are widely used in practice and have a simple density function. We also compare the Metropolis-within-Gibbs with the random walk Metropolis algorithm for sampling from hierarchical models.

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Optimal Tuning of MCMC Algorithms in Infinite Dimensions

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We investigate local MCMC algorithms in infinite dimensions [1, 2, 3]. We are motivated by inverse problems in data assimilation, geophysics, and signal filtering/smoothing. For such complex problems, one can naturally select a linear (Gaussian) law to construct an a-priori distribution for the unknown (infinite-dimensional) parameters. We present Random-Walk Metropolis and Langevin algorithms to simulate from the a-posteriori distributions encompassing the data. We show that *implicit* methods for the derivation of the MCMC proposals are highly relevant in the context of the Gaussian reference measure. From another perspective, we find the optimal scaling for such local MCMC algorithms in high dimensions for general selections of reference measure. Our theory extends already established results for the iid case in the more realistic scenario of non-product target distributions.

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Rollout and Particle Filters for Decentralized Control of Multiple Agents

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A major research challenge is presented by scalability of algorithms for solving decentralized and partially observable Markov decision processes (DEC-POMDPs [1]) because of their double exponential worst-case complexity in time and their exponential use of space for finite horizon problems.

First algorithms like optimal dynamic programming [3] have only been able to solve very small instances on very small horizons. One exception is the Memory-Bounded Dynamic Programming algorithm (MBDP [4]) – an approximation technique that has proved efficient in handling same sized problems but on large horizons. This algorithm thus reduces computational expenses by combining forward search heuristics and memory limited dynamic programming.

In this talk, we present an algorithm on the same instances of finite horizon DEC-POMDPs but in an online way. This algorithm is first based on a parallel version of the Rollout algorithm [2] through the use of several heuristics (of which MBDP) at a time. Then, particle filters are also used to estimate the value of these heuristics and select the best control in an efficient manner.

As results, as no comparative algorithm exists for the moment, a comparison to the best heuristic used is thus given to emphasize the gain produced by this kind of algorithm on state-of-the-art problems.

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Application of New Adaptive Monte Carlo Algorithms to Heterogeneous Transport Problems

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In earlier work [1, 2, 3] we have developed an adaptive, geometrically convergent Monte Carlo algorithm and we have tested its performance on simple radiative transport (RT) model problems. This algorithm is able to estimate the global solution of RT problems with near-machine precision by expanding the solution as a series of basis functions and then estimating the desired number of coefficients through adaptive learning of several kinds. While very important for theoretical reasons, these first generation algorithms encounter computational difficulties that diminish the role they might play in solving complex, multi-dimensional problems arising in many applications. For these reasons, novel second and third generation algorithms have been developed that overcome most, if not all, of the computational shortcomings of the first generation algorithms.

In this study we apply the second and third generation algorithms to model problems designed to capture the principal computational challenges of various real applications areas; in particular, problems with heterogeneity (i.e., varying material properties). We define the computational efficiency of the various algorithms tested and compare the efficiencies of the first, second and third generation adaptive algorithms with conventional Monte Carlo simulations. These studies reveal the potential of the new algorithms for making possible the rapid, accurate and automated solution of many heterogeneous RT problems that are now out of reach of conventional Monte Carlo.

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Efficient Simulation for Random Walks Avoiding Hard Obstacles

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In this talk we will describe an asymptotically optimal (in a precise sense) importance sampling estimator for the probability that, for a long time, a random walk avoids obstacles randomly placed in the space. Classical large deviations results by Donsker and Varadhan provide logarithmic asymptotics for such probabilities. However, the large deviations techniques typically applied to this problem are indirect in the sense that one avoids a direct construction of "the most likely path" based on an appropriate change-of-measure – a construction that often provides the key elements for the optimal design of importance sampling algorithms. It turns out that the optimal trajectory followed by the random walk to avoid the obstacles involves keeping track of the range visited by the random walk and therefore the state-space increases, which makes the design of an efficient algorithm challenging. The talk is about describing how can we construct algorithmically an importance sampling estimator that keeps track of the history of the process in a way that mimics the optimal path close enough to achieve asymptotically optimal variance properties.

Hybrid Choice Modeling of New Technologies for Car Use in Canada: A Simulated Maximum Likelihood Approach

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In the last decade, a new trend in discrete choice modeling has emerged in which psychological factors are explicitly incorporated in order to enhance the behavioural representation of the choice process. In this context, Hybrid Choice Models expand on standard choice models by including attitudes and perceptions as latent variables.

The complete model is composed of a group of structural equations describing the latent variables in terms of observable exogenous variables, and a group of measurement relationships linking latent variables to observable indicators. With a standard Multinomial Logit model to describe the choice, the contribution of a given observation to the likelihood function is an integral of dimension equal to the number of latent variables in the model system. Although the estimation of Hybrid Choice Models requires the evaluation of complex multi-dimensional integrals, simulated maximum likelihood is implemented in order to solve the integrated multi-equation model. In practice, we replace the multidimensional integrals with a smooth simulator with good properties, thus leading to a maximum simulated likelihood (MSL) solution.

In this paper we apply the Hybrid Choice Modeling framework to data from a survey conducted by the EMRG (Simon Fraser University, 2002-2003) of virtual personal vehicle choices made by Canadian consumers when faced with technological innovations. The survey also includes a complete list of indicators, allowing us to apply a Hybrid Choice Model formulation. In our application, the choice model is assumed to be of the Logit Mixture type, which increases the computational complexity in the evaluation of the likelihood function. Our framework also makes it possible to tackle the problem of measurement error in variables in a very natural way.

We conclude that Hybrid Choice is genuinely capable of adapting to practical situations by including latent variables among the set of explanatory variables. Incorporating perceptions and attitudes in this way leads to more realistic models and gives a better description of the profile of consumers and their adoption of new private transportation technologies.

Monte Carlo Method for Solving the Elliptic BVPs

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We consider 3-dimensional exterior Dirichlet problem

$$\begin{cases} Lu(r) \equiv \Delta u(r) + c(u, r)u(r) + (v(r), \nabla u(r)) + g(r) = 0, \ r \in D_1, \\ u(s) = \varphi(s), \ s \in \Gamma = \partial D_1. \end{cases}$$

$$(7.1)$$

Here $D_1 = R^3 \setminus D$, and D is a bounded domain in R^3 . We suggest to use non-central Green function $\mathcal{G}_{r_0}^{\kappa}(r,r')$ for the operator $\Delta_{\kappa} \equiv \Delta - \kappa^2$ to solve the exterior BVP (7.1). We can use the following expression:

$$\mathcal{G}_{r_0}^{\kappa}(r,r') = \frac{1}{4\pi} \left[\frac{\sinh\left\{\kappa(R-|r-r'|)\right\}}{\sinh\left\{\kappa R\right\}|r-r'|} \right] - \sum_{n=0}^{\infty} \varrho_n(r') P_n(\cos\theta) \frac{\tilde{\nu}_n(\kappa|r-r_0|)}{\tilde{\nu}_n(\kappa R)},$$

here $r_0 \in D$ is the center of some ball of radius R: $B(r_0, R) \supset D$; $r, r' \in D_1$; $P_n(\cdot)$ are Legendre polynomials; θ is the angle between $(r - r_0)$ and $(r' - r_0)$; $\tilde{\nu}_n(x) = \sqrt{\frac{\pi}{2x}} K_{n+\frac{1}{2}}(x)$ are modified spherical Bessel functions; and

$$\varrho_n(r') = \frac{2n+1}{2} \int_{-1}^{1} \frac{1}{4\pi} \left[\frac{\sinh\left\{\kappa(R - \sqrt{R^2 + |r' - r_0|^2 - 2R|r' - r_0|\xi})\right\}}{\sinh\left\{\kappa R\right\}\sqrt{R^2 + |r' - r_0|^2 - 2R|r' - r_0|\xi}} \right] P_n(\xi) \mathrm{d}\xi.$$

Then we obtain a system of local integral equations which is equivalent to the initial problem (7.1) and solve it by the random walk algorithm. For $c(u, r) = u^n(r)$ we introduce a branching algorithm.

For solving the analogous interior BVP with $c(u, r) \equiv -\kappa^2$ and c(u, r) = c(r) we used the central Green function (in this case $r, r' = r_0 \in D$ [1, 2]).

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Exact Simulation of Stochastic Differential Equations

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In the article we investigate a Monte Carlo method to exactly generate the distributions for stochastic differential equations (SDEs). Discretization methods can be used for simulating but they also introduce bias into the simulation. A large number of time steps are needed to reduce the discretization bias to an acceptance level. This article suggests an acceptance-rejection approach to obtain sample paths of SDEs. Starting from the sample path generation of a Brownian motion, which is relatively convenient, we are able to achieve the target SDE distribution by rejecting a random subset of the generated candidates. The accepting-or-rejecting criterion is related with the simulation of a time-inhomogeneous Poisson process, which is also easy to be generated by the technique of stochastic thinning. In this article we adopt the idea of localization to relax the prohibitive assumption imposed by Beskos and Roberts (2005) to apply the method. Financial applications such as path-dependent option pricing are also considered.

Distribution of Explicit Digital Inversive Pseudorandom Numbers and Applications to Some Binary Sequences

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Inversive methods are attractive alternatives to the linear method for generating pseudorandom numbers. In this talk we analyze the distribution of *digital explicit inversive pseudorandom numbers* introduced in [2].

Let $q = p^r$ be a prime power and \mathbb{F}_q the finite field of q elements. We order the elements of $\mathbb{F}_q = \{\xi_0, \xi_1, \cdots, \xi_{q-1}\}$ using a fixed ordered basis $\{\gamma_1, \cdots, \gamma_r\}$ of \mathbb{F}_q over \mathbb{F}_p :

$$\xi_n = n_1 \gamma_1 + n_2 \gamma_2 + \dots + n_r \gamma_r$$
 if $n = n_1 + n_2 p + \dots + n_r p^{r-1}, \ 0 \le n_i < p, \ i = 1, \dots, r.$

Then the digital explicit inversive pseudorandom number generator of period q is defined by

$$\rho_n = \overline{\alpha \xi_n + \beta}, \ n = 0, 1, \cdots,$$

where $\overline{\gamma} = \begin{cases} \gamma^{-1}, & \text{if } \gamma \in \mathbb{F}_q^*, \\ 0, & \text{if } \gamma = 0. \end{cases}$ From $\rho_n = c_{n,1}\gamma_1 + c_{n,2}\gamma_2 + \dots + c_{n,r}\gamma_r, \ 0 \le c_{n,i} < p$, we derive *digital*

explicit inversive numbers of period q in the interval [0, 1) by $y_n = \sum_{j=1}^r c_{n,j} p^{-j}$.

For $s \ge 1$ the distribution of points $(y_n, y_{n\oplus 1}, \ldots, y_{n\oplus (s-1)})$, where $n \oplus k = d$ if $\xi_n + \xi_k = \xi_d, 0 \le n, k, d < q$, was studied in [2]. Here we study the distribution of the points $(y_{n+d_1}, \ldots, y_{n+d_s})$ for any integers $0 \le d_1 < \ldots < d_s < q$ and the integer addition +. We prove a discrepancy bound which is based on estimates for exponential sums.

As an application we use some results of [3] and [1] to derive bounds on the *correlation measure* and *linear complexity* of the binary sequences (r_n) defined by

$$r_n = \begin{cases} 0, & \text{if } 0 \le y_n < \frac{1}{2}, \\ 1, & \text{if } \frac{1}{2} \le y_n < 1. \end{cases}$$

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Flexible Forms of Discrete Choice Models: A Non-Parametric Mixed Logit Model for Central Bank Intervention

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Discrete choice models have been successfully applied in various fields (transportation, energy, housing, marketing, finance,...). Over the past ten years tremendous progress has been made, leading to a new generation of flexible choice models called mixed logit (MML). This flexibility comes at the expenses of computational complexity; MML models are not in closed mathematical form for their choice probabilities and require the resolution of multidimensional integrals. This is usually done via Monte Carlo simulations, which provide a numerical approximation to integrals. Some research has turned to the cheaper quasi-Monte Carlo approaches in order to reduce computing time. Adaptive Monte Carlo algorithms that make profit of error and bias estimators have also be proposed.

Usually, in random coefficients MML, parametric distributions are a priori specified and the parameters for these distributions are estimated. This way to proceed has lead to many practical problems. Firstly, it is difficult to assess which is the more appropriate analytical distribution; secondly, unbounded distributions often produce a range of values with difficult behavioral interpretation; and thirdly, little is known about the tails and their effects on the mean of the estimates.

In this paper we propose non-parametric methods for mixed logit models. The random variables of the objective functions are assumed to be continuous, independent, and we are interested in the inverse cumulating distribution functions, in order to benefit from the traditional way to generate pseudorandom numbers. These functions are modeled by means of cubic B-splines with strictly increasing base coefficients, a sufficient condition to construct monotonic (increasing) functions. The resulting estimation problem is formulated as the maximization of a sample average approximation of the (nonlinear nonconvex constrained) log-likelihood function. This problem can be efficiently solved using adapted optimization techniques. We will in particular explain how to solve it with a trust-region algorithm using suitable projections on the feasible set. We will illustrate our technique by considering a model of intervention policies of central banks. A mixed logit model will be applied to detect variability in the parameter determining the size of the intervention. Non-parametric distributions will be applied and the results compared to parametric distribution (normal and lognormal) usually used by econometricians.

Sequential Monte Carlo Methods for Inverse Problems in Option Pricing

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The inverse problem of recovering parameters of an option pricing model (or risk-neutral process) from a set of observed option prices, known in finance as the model calibration problem, gives rise to many examples of nonlinear, ill-posed inverse problems, which have often been tackled by applying deterministic optimization methods to a (regularized) least squares formulation of the problem. These methods yield a single set of model parameters calibrated to market data and ignore the non-uniqueness of the solution, which reflects parameter uncertainty.

We formulate a notion of solution to these inverse problems which takes into account non-uniqueness and noise in observations and propose a "sequential" Monte Carlo algorithm which generates a random sample from the set of solutions, starting from a prior distribution on model parameters. Using "propagation of chaos" results recently obtained by DelMoral, Doucet and Peters, we exhibit conditions under which such the algorithm asymptotically generates an IID sample of solutions for the inverse problem. Furthermore, we show how such a sample can be used to construct a coherent risk measure (in the sense of Artzner et al) which allows to compute the impact of parameter uncertainty in the valuation of exotic options and explore the impact of additional data on parameter uncertainty. The algorithm is applied to a stochastic volatility model with jumps, the Bates-Scott model.

Extensions of Fibonacci Lattice Rules

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Fibonacci lattice rules are equal weight integration rules for approximating 2-dimensional integrals over a square. They have the form

$$\int_{[0,1]^2} f(\mathbf{x}) \, \mathrm{d}\mathbf{x} \approx \frac{1}{F_k} \sum_{j=0}^{F_k-1} f\left(\frac{j}{F_k}, \frac{jF_{k-1}}{F_k}\right),$$

where F_k is the k-th Fibonacci number, defined by $F_0 = 0$, $F_1 = 1$ and $F_k = F_{k-1} + F_{k-2}$ for k > 1. There are many quality criteria for integration rules in general, and this is also the case for lattice rules. We will focus on the *trigonometric degree*, as was done previously in joint work of the speaker with Ian Sloan [2]. The trigonometric degree of Fibonacci lattices is known explicitly and can be written in terms of Fibonacci numbers [1].

There is an interest in embedded pairs (or longer sequences) of integration rules. For 1-dimensional quadrature, Kronrod and Patterson extensions of Gauss quadrature rules are well known. The idea behind this is that in practice one needs more than one approximation to obtain an estimate for the integral as well as for the error of the approximation. If one uses embedded integration rules, one can re-use function evaluations, and save computations. There are some analogous results for algebraic degree of precision in more than one dimension. For the trigonometric degree case almost nothing is known.

We investigate pairs of embedded lattice rules, where the higher degree rule is an extension of a Fibonacci lattice rule. Again we will see that the degree of the extended rule can be written in terms of Fibonacci numbers. We will also see that such extensions are not always economical. In other words, one must carefully select the rule one wants to extend.

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Stochastic Volatility in the Context of the Structural Credit Risk Model of Merton (1974)

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Pioneered by Black & Scholes (1973) and Merton (1974), the structural approach to measuring credit risk views corporate liabilities as contingent claims on the company assets. Regarding the model estimation, the researcher is faced with the problem of using the observable stock price data for deriving the unobservable process of company assets. The traditional approach in estimating the model parameters was introduced by Ronn and Verma (1986) and consists in solving a system of equations which link the observed equity prices and historical volatility with the unobserved asset values and the company asset's stochastic process parameters. A second venue in the estimation of the model is based on the maximum likelihood method (MLE). The paper of Duan (1994) is the first to use MLE for the estimation of the Merton (1974) credit risk model using stock price data.

The first objective of this working paper is to compare the properties of MLE and the Markov Chain Monte Carlo (MCMC) mean Bayesian estimators in the framework of the Merton (1974) constant volatility credit risk model. We find that the small sample properties of the MLE and MCMC estimators are similar in terms of simulated mean square errors (MSE) and conclude that the MLE should be used due to lower computation times. The empirical findings for 20 Dow Jones Industrial Average (DJIA) non-financial firms confirm our conclusions.

Second, the paper explores the implications of a richer specification for the underlying volatility. We study the square root stochastic volatility specification as in Heston (1993). Similar to in Duan(1994) we use the Jacobian transformation to derive the joint likelihood function for the Euler discretization of the log asset price and variance processes. Under this specification the MLE approach becomes cumbersome as it needs heavy simulations for the estimation of the conditional likelihood of the observable data. The alternative explored is the MCMC algorithm. We provide and MCMC algorithm for the zero-debt case and implement the algorithm for three DJIA low-debt companies. The results for the three companies point out the existence of a leverage effect between the returns and the variance process while the variance processes are characterized by a slow volatility mean reversion and a long term mean similar to the one derived in the constant volatility model. For the fully fledged model (nonzero debt with stochastic volatility) we present the numerical challenges encountered in constructing the corresponding MCMC chain.

Last, we illustrate in a simulated pricing exercise the implications of the stochastic volatility versus the constant volatility specification on the level of credit spreads under the Merton (1974) hypothesis on debt. We also document numerically the possible impact of the assumption that debt holders can recuperate only a constant proportion of the company value in case of default.

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² This report is a version of the Masters Thesis to be submitted in fulfillment of the degree Maîtrise ès sciences en gestion (M. Sc.) at HEC Montréal, 3000, chemin de la Côte-Sainte-Catherine.

Efficient Search for Low-Dimensional Rank-1 Lattices to approximate Spectra

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Recently, the algorithmic benefits of rank-1 lattices selected by mutual maximized minimum distance have been investigated in the context of image pixel layout, anti-aliasing, and simulation. With an application focus in computer graphics, only low-dimensional lattices are necessary due to the lowdimensional structure of the integrands. However, already the two-dimensional search is computationally very expensive.

So far, for two dimensions there exists only an efficient search algorithm for maximized minimum distance rank-1 lattices in Korobov form, which prevents to find the best lattice with respect to maximized minimum distance in some cases, though. Thus it it not possible to determine general maximized minimum distance rank-1 lattice for a large number of points on-the-fly. We examine an approach in which the search space for the generator vectors is restricted by a rasterization algorithm. Using the fact that the hexagonal lattice achieves the largest minimum distance in two dimensions, this algorithm yields nearly optimal results with respect to the search criterion and mostly outperforms the results obtained in Korobov form. Moreover, this approach also helps to accelerate the search for maximized minimum distance rank-1 lattice sequences.

Whereas lattices found by this approach expose an isotropic spectrum, this is not always desirable in applications. We therefore present a simple approach to determine the generator vector of a rank-1 lattice, such that a specific spectrum is approximated.

Particle Flow for Nonlinear Filters with Log-Homotopy

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We derive and test a new nonlinear filter that uses particle flow to implement Bayes' rule with an ODE rather than a point wise 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 1 or 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 "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 kth measurement, and the final solution of the ODE is the log of the unnormalized conditional density after the kth 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 loghomotopy 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. Our new log-homotopy algorithm is something like a deterministic version of Metropolis-Hastings. In contrast to the large performance improvement due to log-homotopy, it turns out that quasi-Monte Carlo sampling is only slightly better than Monte Carlo sampling; in particular, QMC saves only a factor of two or three in computational complexity compared with MC.

A Class of Generators Suitable for Both Security and Simulation Applications

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Designing a pseudo-random number generator (PRNG) which is appropriate for *both* simulation and security applications is a challenging task. Classical generators like Linear Congruential Generator (LCG) or Multiple Recursive Generator (MRG) are suitable for simulation applications but not secure applications. They are considered insecure because it is easy to predict the whole sequence from just a few of the realization values. Therefore, they are not suitable for cryptographic applications. Some pseudo-random bit generators (PRBGs) such as the Blum-Blum-Shub PRBG or the RSA PRBG are considered secure but they tend to be very slow. In addition, there is no assurance of desirable property like a uniform distribution can be made for such PRBGs. Hence, they are not suitable for simulation applications. We consider a class of generators that can fit in both types of applications. The key future for the new class of generators is to break the linearity structure of some classical linear generator by coupling with its "future" of a "random step" determined by another companion generator. We provide evidence in evaluating the security, efficiency, and empirical performance for the new generator.

Parallel Random Number Generators Based on Large Order Multiple Recursive Generators

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Classical random number generators like Linear Congruential Generator (LCG) and Multiple Recursive Generator (MRG) are popular for large scale simulation studies. To speed up the simulation process, we need a "good" systematic method to construct and parallelize the backbone random number generators so that they can run simultaneously on several computers or processors. The resulting parallel random number generator (PRNG) should have good theoretical properties and great empirical performances, both within and among different generators. LCGs and MRGs have served as backbone generators for some PRNGs constructed in the literature. In this paper, we consider the parallelization problem particularly for a general class of efficient and portable MRGs with large order that have mostly non-zero terms in the recurrence equation. With many non-zero terms, this type of MRGs has an advantage over the MRGs with few nonzero terms that they can recover more quickly from a bad initialization. We present the efficient implementation of the proposed PRNG and discuss some comparisons with other general construction methods.
The Other Kind of Lattice Rule

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Ian Sloan has done a vast amount of research on lattice rules. This talk deals with 'the other kind of lattice rule' (also called polynomial lattice rules). We compare lattice rules with polynomial lattice rules and survey what results for lattice rules also have an analogon for polynomial lattice rules and vice versa.

Component-by-Component Construction of Low-Discrepancy Point Sets of Small Size

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We investigate the problem of constructing small point sets with low star discrepancy in the sdimensional unit cube. The size of the point set shall always be polynomial in the dimension s. Our particular focus is on extending the dimension of a given low-discrepancy point set.

This results in a deterministic algorithm that constructs N-point sets with small discrepancy in a component-by-component fashion. The algorithm also provides the exact star discrepancy of the output set. Its run-time considerably improves on the run-times of the currently known deterministic algorithms that generate low-discrepancy point sets of comparable quality.

We also study infinite sequences of points with infinitely many components such that all initial subsegments projected down to all finite dimensions have low discrepancy. To this end, we introduce the inverse of the star discrepancy of such a sequence, and derive upper bounds for it as well as for the star discrepancy of the projections of finite subsequences with explicitly given constants. In particular, we establish the existence of sequences whose inverse of the star discrepancy depends linearly on the dimension.

Forgetting of the Initial Distribution for the Filter in General Hidden Markov Models

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The forgetting of the initial distribution for the filter in discrete time Hidden Markov Models (HMM) is a crucial ingredient either for ensuring the long time stability of a particle system or for obtaining the ergodic properties of the maximum likelihood estimator. In this work, the forgetting of the initial distribution is addressed: a new set of conditions is proposed, to establish the forgetting property of the filter, at a polynomial and geometric rate. Both a pathwise-type convergence of the total variation distance of the filter started from two different initial distributions, and a convergence in expectation are considered. The results are illustrated using different HMM of interest: the dynamic tobit model, the non-linear state space model and the stochastic volatility model.

Quasi-Monte Carlo Simulation of Diffusion in a Nonhomogeneous Medium

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Monte Carlo (MC) simulation is a valuable tool for investigating processes involving the diffusion of substances. In the case of constant diffusion coefficient, the substance is modelled by an assemblage of discrete particles. Time is discretized and in a short time interval Δt , each particle is moved with an increment chosen from a Gaussian distribution with variance $2D\Delta t$, where D is the diffusion coefficient. Advantages of MC method include the simplicity of the algorithm and the ability to deal with complicated geometries. A disadvantage of the MC method is that many runs are often needed to obtain reliable mean values.

In some cases, one may have a diffusion coefficient that varies with position. The naive extension of the constant diffusion coefficient case is to use a spatially variable variance $2D(x)\Delta t$: it is well known that this leads to biased results and a correction to the Gaussian step length must be done.

One possibility to reduce the discrepancy of the MC method is to replace pseudo-random numbers with quasi-random numbers; in addition, sorting the ensemble of particles after each time step can improve convergence.

In this presentation we propose a quasi-Monte Carlo simulation of diffusion processes in a spatially nonhomogeneous medium. The number of simulated particles can vary with time. The quasi-random numbers used are (t, m, s)-nets: to make a proper use of the better uniformity of nets, the ensemble of particles is split into subsets after each time step.

The efficiency of the scheme is assessed through the simulation of diffusion of calcium ions which are released from a point source, in a nonhomogeneous medium, with variable diffusion coefficient. Sergej Ermakov, Konstantin Timofeev

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One of important methods of solving evolutionary equations is based on approximate substitution of equation by a large systems of ordinary differential equations.

Let's consider an equation

$$\frac{dU}{dt} = F(t, X, U)$$

where $U = (u_1, \ldots, u_n)$ is a vector-function, $u_j = u_j(t, X)$, $X = (x_1, \ldots, x_n) \in D \subset \mathbb{R}^n$ and F is a fixed operator.

Domain D can be approximated by a net domain with M nodes. So the number of obtained ODE will be equal to Mn.

The system of ODE can be solved with the use of numerical methods (Euler, Runge-Kutta etc). Even in the simplest case of numerical method one must perform iterations

$$\widehat{U}^{m+1} = \widehat{U}^m + \Delta t \widehat{F}(t_m, \widehat{X}, \widehat{U}^m),$$

where hat marks denote the Mn dimension of corresponding vector. The number of arithmetical operations which are to be performed on each iteration can be very big.

The authors suggest a method of randomization. With the use of this method \hat{F} is substituted by its unbiased (or slightly biased) estimate. For modeling of this estimate one can use not all but "essential" components of vector \hat{U}^m . The method is illustrated by an example of solving initial-boundary value problem for Navier-Stokes equation.

The possibility of using QMC methods is discussed.

An Implementation of the Quasi-Monte Carlo Baum-Welch Algorithm Using the Stream Processing Model

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The Expectation Maximization (EM) algorithm, first proposed in 1977, is widely used in many application areas to estimate the parameters of a statistical model from a series of observations. In the case of Hidden Markov Models (HMMs), a well-known EM algorithm is the one proposed by Baum and Welch, which estimates the transition and emission probability densities that maximize the likelihood of the observed sequence. The Baum-Welch algorithm involves the computation of integrals that, depending on the problem, may be high-dimensional and inconvenient or impossible to treat analytically. To overcome this difficulty, Monte Carlo or quasi Monte Carlo (QMC) estimation methods have been proposed. However, for the sequential processing of observations to infer complicated models, greater performance is necessary. In this paper, we present an implementation of the Baum-Welch algorithm that allows the on-line inferencing of HMMs with continuous state-space and continuous emission densities. This implementation combines the use of QMC-based particle filters with the massive parallelism included in modern multi-core architectures, as exposed by the stream programming model. We compare the performance of our implementation to that of a non-parallelized version in the context of the problem of handwriting recognition.

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Adaptive Methods in Stratified Sampling and Applications to Option Pricing

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In [ÉJ07] we first propose a stratified sampling algorithm in which the strata are fixed, and the random drawings made in the strata to compute the expectation of interest are also used to adaptively modify the proportion of further drawings in each stratum. These proportions converge to the optimal allocation in terms of variance reduction. And our stratified estimator is asymptotically normal with asymptotic variance equal to the minimal one. Numerical experiments confirm the efficiency of our algorithm, especially on the example of the pricing of an asian option previously studied by Glasserman et al. in [GHS99].

We secondly study an algorithm in which we adaptively modify not only the proportion of further drawings in each stratum but also the strata themselves.

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On Generalized Two-Dimensional Hammersley Point Sets

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Hammersley and Halton introduced in 1960 their closely related multi-dimensional Hammersley point sets and Halton infinite sequences for the purpose of solving multivariable problems and evaluating multi-dimensional integrals. The basic ingredients of these constructions are van der Corput sequences in arbitrary bases b and the special case of base 2, at the origin of the theory, goes back to Roth in 1954. Since then, many studies have been devoted to generalizations of these sets and sequences, especially to the Hammersley point sets in two dimensions that we are presently interested with: by Halton and Zaremba in base 2 (1969), White (1975), DeClerck (1986), Faure (1986) in arbitrary bases and, more recently, by Pillichshammer (2002), Larcher and Pillichshammer (2003), Kritzer (2006), Kritzer and Pillichshammer (2007) in base 2 and by Faure (mcqmc06, 2008) in bases b.

In this communication, we shall survey present progress on generalized Hammersley point sets in two dimensions and in arbitrary bases b, regarding both the star discrepancy and the L_p discrepancy (joint work with F. Pillichshammer). These results generalize to bases b all previous results in base 2 cited above and give further improvements on those in bases b. Moreover, in the light of our approach, we revisit the study of White and obtain further knowledge on the perturbation, due to Halton and Warnock, utilized by White to obtain the exact order of L_2 discrepancy for the so-called Zaremba sequences in bases b.

Efficient Computation of Both VaR and CVaR Using Stochastic Approximations

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This paper deals with the problem of computation of two widely used risk measures using stochastic approximations (with decreasing steps): Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) (also known as Expected Shortfall and which has better properties). In many regular cases, the distance of the algorithm to its target (multiplied by $\sqrt{\gamma_n}$, γ_n being the step of the procedure) satisfies a (Gaussian) Central Limit Theorem. To improve the algorithm an adaptative importance sampling procedure can be added whose aim is to reduce the variance of both VaR and CVaR procedures. This kind of algorithm has been first introduced by Arouna. In its original form, it contains some so called "Projection a la Chen" to prevent the procedure to explode. Recently, it was deeply revisited by Lemaire and Pagès to remove this constraint, modifying the original algorithm.

We show that the rate of the resulting (VaR-CVaR) procedures is ruled by a Central Limit Theorem with minimal variance.

Numerical Analysis of Phase Shifts and Correlations of 90/150 Cellular Automata Sequences

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Since the number of gates integrated into a VLSI chip is enormous, it is impossible to test a chip for malfunction by exhaustively checking all the states that the chip can assume. So a VLSI chip is usually checked by some mechanism of random sampling. A linear feedback shift register (LFSR) or a cellular automaton (CA) is used to generate random test patterns to be fed into a chip. It is natural to include a testing mechanism into a chip in order to shorten the time required for test procedures. This method of testing is called BIST (built-in self-test).

In this talk, we restrict our attention to characteristics of maximum-length 90/150 (hybrid of rules 90 and 150) CA's with null boundary conditions applied to BIST. The successive configurations of a CA are taken as a random vector sequence to be used for a random sampling. It is known that the output sequence of any particular cell of such a CA is the same as the output sequence of the corresponding LFSR except the phase shift. Thus it is important to choose a CA whose phase differences between output sequences of any pair of cells are larger than the number of test patterns to be used for BIST. Most of CA's appearing in literature do not satisfy this requirement. We have found such CA's with various number of cells that satisfy this requirement by extensive numerical computations. It is also important to compute actual correlations between any pair of output sequences of such a CA. We report the computational results.

On Approximations of Stochastic Backwards Equations

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Backwards stochastic differential equations (BSDEs) are systems of stochastic differential equations that consist of a forward diffusion and and a backwards component. They appear in different contexts like in optimal control as dual problem or in Stochastic Finance to consider option pricing models under transaction costs. In the latter application the terminal condition can be interpreted as a pay-off function of an option. The numerical simulation of the backwards component of BSDEs is rather complex and is highly influenced by the precision of the approximation of the forward component. The talk concerns two aspects: firstly, we discuss recent results about the connection between the complexity (or precision) of the backwards component of an BSDE and the fractional smoothness of the terminal condition in the Malliavin sense. Here we weaken conditions on the driving function, that describes the essential part of the system by coupling the forward and the backwards component. Secondly, we discuss a particular inequality that describes the additional error in the backwards algorithm that originates from the approximation of the forward component. This inequality turns to be out to be of importance in Monte Carlo algorithms as well.

Computation of Dirichlet Distribution Probabilities

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The problem of the numerical computation of probabilities for the cumulative multivariate Dirichlet distribution is considered. Several Monte Carlo and quasi-Monte Carlo simulation methods are constructed, based on the distribution function in standard form, the distribution transformed to a product of beta distributions and the distribution transformed to a multivariate inverted gamma distribution. These methods are compared with a direct numerical method which uses iterated recursive integration to provide approximations for the Dirichlet probabilities. Test results are discussed for problems with as many as twenty variables.

"Vibrato" Monte Carlo Evaluation of Greeks

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In computational finance, the pathwise sensitivity approach is a very effective technique for the Monte Carlo estimation of first order derivatives known as Greeks. The adjoint implementation introduced by Giles & Glasserman [3] makes it particularly efficient when a large number of sensitivities needs to be computed. However, it relies on the financial payoff function being differentiable, or at least Lipschitz.

In this paper I will present a new idea which avoids this restriction by generalising a technique of conditional expectation, one timestep before the end of the path simulation. This approach is presented in Glasserman's book [4] in a setting in which it is possible to evaluate the conditional expectation analytically. The generalisation to multi-variate cases uses Monte Carlo estimation, and the corresponding sensitivities are obtained by combining pathwise sensitivity with the alternative Likelihood Ratio Method for the final conditional expectation.

The presentation will also explain the generalisation to include payoffs which depend on the value of the underlying asset at multiple intermediate times, and the use of the same technique to improve the efficiency of multilevel Monte Carlo analysis [1, 2] for discontinuous payoffs.

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Study of an MCMC Algorithm Related to Dirichlet Laws

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Using Dirichlet forms we obtain the exact value of the global spectral gap for the Metropolis algorithm, using a Markov chain, introduced in Matsui et al. (2003); for now, only when the target distribution is a symmetric Dirichlet law. Our proof is based on the method of Carlen et al. (2003). We hope that the techniques developed in Bédard (2007) will help to obtain analogues results in the non symmetric case. We believe that these techniques may help put some light on models of Financial Engineering, where the target distribution is not explicitly known; see Ferland-Giroux (2008) and Duffie-Giroux-Manso (2008).

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New Insights on the Steady-State Simulation Problem

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In the setting of performance engineering applications of simulation, the most widely used performance measures relate to the steady-state of the system being simulated. However, computing a steady-state expectation is often challenging, both because of the presence of the initial transient due to initialization via a distribution which is generally atypical of equilibrium behavior, and because of the difficulties inherent in building confidence intervals in the presence of auto-correlated data. In this talk, we will discuss several new sampling-based algorithms for mitigating the presence of the initial transient that have a provable theoretical basis, and will also discuss some theoretical limitations of existing algorithms for constructing steady-state confidence intervals that are likely to have an impact on their practical performance. In contrast to much of the existing theoretical literature on the initial transient problem, our methods rely on using statistical information accumulated from the simulation itself to correct for the presence of the initial transient, rather than using theoretical bounds on rates of convergence or carefully crafted perfect simulation algorithms. This talk is based on joint work with Hernan Awad, Jose Blanchet, and Eunji Lim.

On the Multidimensional Distribution of Numbers Generated by Iterations of Dickson Polynomials

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We study the multidimensional distribution of sequences of iterations of Dickson polynomials over prime finite fields. Despite mainly concentrating on sequences of length N = T, where T is the sequence period, the case N < T is also considered. These results follow the path of [1, 2, 3, 5] and complement the earlier work in [4], where the bounds of the exponential sums only apply to the 1-dimensional case over the entire period. Although these results do not have any immediate applications, it may be of interest in other cases which require polynomial generators of pseudorandom numbers.

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The Weighted Variance Minimization in a Jump-Diffusion Stochastic Volatility Model

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Monte Carlo method provides a general approach for the options prices valuation. It is especially useful in the cases of complicated models, path-depended options or multidimensional underlyings. A specific feature of such valuation is that we usually calculate several prices depending on some parameter (a strike price, a barrier, an expiration date etc.) on the same paths. So, the problem of how to minimize the weighted sum of the estimators' variances arises naturally.

We considered this problem in our paper [1] in the case of the diffusion model. Here we extend the previous results to the case of a jump-diffusion stochastic volatility model. We point out optimal estimators for two variance reduction methods: importance sampling and control variates. We apply these estimators to some particular options and demonstrate their efficiency with numerical examples. It may be noted that in some cases the optimal estimator is described by the solution of a non-linear PDE.

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Calculation of the Star Discrepancy and Related Problems

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In many applications it is of interest to measure the quality of certain sets by calculating their star discrepancy, e.g., to test whether successive pseudo random numbers are statistically independent or whether certain sample sets are suitable for multivariate numerical integration of certain classes of integrands.

But all known algorithms for calculating the star discrepancy or approximating it up to a user-specified error that have been presented so far, exhibit a running time exponential in the dimension d.

Since no efficient algorithm for the exact calculation or tight approximation of the star discrepancy is known, some authors tried to deal with this large scale integer programming problem by using optimization heuristics.

E. Thiémard [Math. Meth. Oper. Res. 54 (2001) 21–45] gave an integer linear programming formulation for the problem and used techniques such as cutting plane generation and branch and bound to tackle it. With the resulting algorithm he was able to perform non-trivial star discrepancy comparisons between low-discrepancy sequences. The key observation to approach a highly non-linear expression as the star discrepancy via linear programming is that one can divide it into at most 2n sub-problems of the type "optimal volume subintervals with k points": Given n points in the d-dimensional unit cube, find a subinterval of minimum or maximum volume that contains k of the n points. However, Thiémard suspected these sub-problems to be NP-hard, but admitted that he was not able to prove it.

In this talk we establish the NP-hardness of these optimal volume subinterval problems. Moreover, we use these results to show that indeed the problem of calculating the star discrepancy is also NP-hard. Furthermore, we want to discuss the practical impact of these results and relate them to the problem of derandomized constructions of low-discrepancy sets of small size.

(t, m, s)-Nets with Large Minimum Distance using Permutations

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Low-discrepancy point sets used for multivariate quasi-Monte Carlo integration are often generated using (t, m, s)-net constructions. Such nets have excellent stratification properties and they are usually constructed using generator matrices.

For small values of s and an optimal quality parameter of t = 0, these matrices have previously been optimized to generate point sets with large minimum distance. Point sets with a large minimum distance are especially useful in the domain of computer graphics, e.g. for anti-aliasing.

In this talk we present a new construction to generate (0, m, 2)-nets in base 2 that yields point sets with a minimum distance that is even larger. These point sets cannot be constructed using the classical way of generator matrices, instead we employ permutations based on the Latin Hypercube property of (0, m, s)-nets.

Furthermore we discuss the use of index permutations for existing (0, 2)-sequences in order to generate (0, m, 3)-nets with a larger minimum distance.

Hot Small World or: How I learned to Stop Worrying and Start to Use Hot Empirical Distributions to Ease Sampling

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When sampling a multi-modal distribution, a MCMC that uses local proposals is slowly mixing. However, a small world sampler, which amounts a portion of "long range" proposals in addition to the local proposals, is fast mixing. The claims have been proved by using Cheeger's inequality and isoparametric inequality on log-concave distributions (Guan and Krone, Ann. App. Prob. 2007). In real applications, faster convergence may be achieved if one generates "long range" proposals from an empirical distribution that approximates a heated version of the original distribution. We compare results with Equi-energy sampler (Kou, Zhou and Wong, Ann. Stat. 2006) on some toy problems.

Automatization of Statistical Tests on Randomness to Obtain Clearer Conclusion

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Here we propose automatizing the following folklore procedure for statistical tests on the pseudorandom number generators: "when we observe a suspicious *p*-value, then we raise the sample size, until we can conclude whether it is by chance or by deviation of the generator". An implementation, embedded in TestU01, and the result of experiments are reported.

Usually, statistical test-suites such as Diehard (Marsaglia), NIST, and the more comprehensive TestU01 (L'Ecuyer and Simard), obtain a large number of p-values from large number of different tests. When one observes a few suspicious p-values, it is not clear whether the generator is defective or not. This is more confusing for non-specialists.

TestU01 solves this problem by summarizing only the *p*-values less than 10^{-10} (or greater than $1 - 10^{-10}$) as "clear rejections," and those less than 10^{-4} (or greater than $1 - 10^{-4}$) as "suspicious".

Here, we propose the following: if an observed *p*-value of chi-square statistics is less than 0.1, then the generator is tested by the same test with the doubled sample size. If again the *p*-value is < 0.1, then the sample size is doubled. We iterate this until the *p*-value is, say, $< 10^{-10}$, or the number of iterations exceeds, say, five. This method has a merit in the speed and the clarity of the result: while TestU01 accepts the *p*-values between 10^{-4} and $1 - 10^{-4}$, this method tries to test all *p*-values with p < 0.1, by doubling the sample size. Thus, the proposed method uses more information from the tests, and consequently is more sensitive.

Maximally Equidistributed Pseudorandom Number Generators Via Linear Output Transformations

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We discuss construction of maximally equidistributed \mathbf{F}_2 -linear feedback shift register generators by using linear output transformations. To attain maximal equidistribution (ME), L'Ecuyer and Panneton proposed a concept of output transformation matrices mapping from a state vector to a word-size vector. Matsumoto-Kurita tempering is a good example but some generalization is possible.

Here, we study a strategy to construct a linear output transformation to attain ME. Roughly speaking, mixing bits in state vectors improves equidistribution. However, the key to attain ME is to use a suitable backtracking algorithm. As a result, the following maximally equidistributed generators have been obtained:

- 1. For Mersenne Twister MT19937, by replacing the tempering method, we found a maximally equidistributed Mersenne Twister, MEMT19937. Furthermore, we also mention that this transformation fits modern CPU architecture such as SIMD instructions discussed by Saito and Matsumoto.
- 2. For WELL generators, we found fewer operations than the original tempering that attain ME. The obtained generators are faster than WELL generators on some platforms.

Table 7.1 gives a summary of a benchmark test on a Pentium 4, 32-bit, 2.8GHz computer and VC++6.0 with 02 optimization, where Δ denotes the sums of the dimension gaps of the generators.

Generators	time(s)	Δ	Generators	time(s)	Δ
MT19937	49.7	6750	WELL44497a	99.6	7
MEMT19937	63.2	0	+ new oper.	102.6	0
WELL19937c	86.2	0	WELL44497b	110.8	0

Table 7.1: Time to generate $10^9 \times 5$ integers and Δ .

A Computational Primitive for Monte Carlo Simulations

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We have identified and begun to exploit systematically a computational "primitive" that is of value in solving radiative transport equations (RTEs) by Monte Carlo simulation. This primitive consists of matching a forward RTE solution with an adjoint RTE solution in opposite unit directions. A map of this primitive throughout phase space is being used to inform the design of optical probes as well as to increase the computational efficiency of adaptive Monte Carlo algorithms.

In the design of optical probes to interrogate living tissue noninvasively, the primitive is used to generate a map of the spatial distribution of the light propagating from source to detector [1]. This map provides valuable information regarding the relationship between the placement and configuration of a specific laser probe and the amount of light that interrogates each tissue region. Such interrogation density maps reveal intrinsic transport properties of the three body system consisting of a source, any targeted subregion of the tissue and a detector, and therefore provide quantitative measures of the contributions of different tissue regions to the optical signal.

The primitive has also been manipulated to extend the geometric learning of newly developed adaptive Monte Carlo algorithms [2]. The adaptive algorithm makes sequential use of correlated sampling to lower the variance systematically. Modifications to this algorithm based on information from the primitive map enables improved geometric convergence rates compared to those attained using conventional Monte Carlo.

We provide the needed definitions and derivations upon which these applications of the primitive maps are based. Numerical results will illustrate the utility of these maps in solving problems that present formidable challenges for conventional Monte Carlo executions.

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A Multigrid Monte Carlo Algorithm for the Poisson Equation

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There are well-known Monte Carlo algorithms for solving the *d*-dimensional Poisson equation such as walk on balls and spheres or (closely related) Green's function Monte Carlo. These algorithms aim at the approximation of a scalar quantity: the solution in a point or the value of a functional of the solution. In this talk we are concerned with approximating the solution on a given d_1 -dimensional subset, where d_1 is any integer with $0 \le d_1 \le d$. In particular, the above mentioned solution in a point occurs for $d_1 = 0$, while for $d_1 = d$ we seek to approximate the solution on subsets of full dimension.

In previous work [1, 2, 3, 4] we introduced and studied multilevel Monte Carlo methods for parametric integrals, integral equations and approximation of weakly singular integral operators. Based on these techniques we present a multigrid Monte Carlo method which outperforms the standard approaches of applying Monte Carlo estimators separately for each point of a fixed grid and then using interpolation.

In the talk we present a convergence and cost analysis, discuss optimality of the algorithm on certain classes of functions, and compare it with other, direct approaches. For $d_1 = d$ the new algorithm provides a quadratic speedup over previous methods. We also discuss further ways of variance reduction as well as possible extensions.

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Approximating Functions of Many Variables

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Function approximation is the problem of constructing a surrogate, \hat{f} , to approximate a *d*-variate function of interest, $f : \Xi \subseteq \mathbb{R}^d \to \mathbb{R}$, for which one can obtain function data, $(y_i = f(\boldsymbol{x}_i))_{i=1}^n$, gathered over the design, $P = \{\boldsymbol{x}_i\}_{i=1}^n \subseteq \Xi$. Linear algorithms take the form $\hat{f} = A_n(\boldsymbol{y}) = \sum_{i=1}^n y_i \psi_i$, where the ψ_i are called *cardinal functions*. Polynomial interpolation, linear regression, and splines are all of this form for different choices of the cardinal functions.

The error of the algorithm A is the largest possible L_p -norm of the difference between the true function and the surrogate when looking at the unit ball of a Banach space of functions, \mathcal{F} , i.e., $\operatorname{err}(A_n) = \sup_{\|f\|_{\mathcal{F}} \leq 1} \left\| f - \hat{f} \right\|_p$. Unfortunately, many algorithms and error analyses suffer a curse of dimensionality, $\operatorname{err}(A_n) = \mathcal{O}(n^{-\alpha/d})$, i.e., the convergence rate decays significantly with increasing numbers of variables. There have been several recent attempts to overcome the curse of dimensionality via low discrepancy designs [1, 2, 3, 4].

This talk presents recent results on function approximation using low discrepancy designs by the author and his collaborators: Josef Dick, Peter Kritzer, Kwong-Ip Liu, and Xiaoyan Zeng. The case of spline approximations with $p = \infty$, $\Xi = \mathbb{R}^d$ and lattice designs is emphasized. The actual number of design points is infinite, and so *n* represents the number of design points per unit volume of the domain. The group structure of the design allows one to apply Fourier transforms to obtain an expression for $\operatorname{err}(A_n)$ that is amenable to analysis. Lattice designs were developed by Ian Sloan and his collaborators, and this talk is a tribute to Ian's important contributions to the quasi-Monte Carlo community.

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On the Distribution of Digital Sequences

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Well known constructions of s-dimensional low discrepancy sequences are the concept of Halton sequences in bases q_1, \ldots, q_s on the one hand and the concept of digital (\mathbf{T}, s) -sequences over Z_q with q a prime on the other. Both can be interpreted as an s-dimensional generalization of the one-dimensional van der Corput-sequence. In our talk we consider the distribution of digital sequences produced by a hybrid construction principle that contains both digital (\mathbf{T}, s) -sequences and Halton sequences as special cases:

Let q_1, q_2, \dots, q_v be different primes and let v, w_1, \dots, w_v be positive integers. For $l \in \{1, \dots, v\}$ and $j \in \{1, \dots, w_l\}$ we have given $N \times N$ -matrices $C^{(l,j)}$ over Z_{q_l} . We define the s-dimensional sequence $(\boldsymbol{x}_n)_{n \geq 0}$ in $[0, 1)^s$, where $s := w_1 + \dots + w_v$, with

$$\boldsymbol{x}_n := \left(x_n^{(1,1)}, \dots, x_n^{(1,w_1)}, x_n^{(2,1)}, \dots, x_n^{(2,w_2)}, \dots, x_n^{(v,1)}, \dots, x_n^{(v,w_v)} \right).$$

The component $x_n^{(l,j)}$, for $j \in \{1, \ldots, w_l\}$, $l \in \{1, \ldots, v\}$, is generated as follows. Let $n = n_0^{(l)} + n_1^{(l)} q_l + n_2^{(l)} q_l^2 + \cdots$ be the q_l -ary representation of n for $l \in \{1, \ldots, v\}$. Then we set (by using matrix multiplication in Z_{q_l})

$$C^{(l,j)} \cdot \left(n_0^{(l)}, n_1^{(l)}, \ldots\right)^{\top} =: \left(y_1^{(l,j)}, y_2^{(l,j)}, \ldots\right)$$

and

$$x_n^{(l,j)} := \frac{y_1^{(l,j)}}{q_l} + \frac{y_2^{(l,j)}}{q_l^2} + \cdots$$

In the case of $w_l = 1$ for all $l \in \{1, \ldots, v\}$ and $C^{(l,1)}$ is the unit matrix we get the van der Corput-Halton sequence, which is well-known as a low discrepancy sequence. If we set v = 1 the definition above is consistent with the definition of digital (t, s)-sequences over Z_{q_1} as introduced by Niederreiter (see [4] and [5]) or more generally digital (\mathbf{T}, s) -sequences in the sense of Larcher and Niederreiter (see [3]), which for special chosen matrices are also sequences of low discrepancy.

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Numeric Inversion

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The inversion method for generating non-uniform random variates has some advantages compared to other generation methods, since it monotonically transforms uniform random numbers into nonuniform random variates. Hence it often is the method of choice for MC and even more for QMC applications. However, for most distributions the inverse CDF does not allow for a closed form representation. Thus numerical methods have to be used. This is considered as a major draw back of the inversion method by some users of MC or QMC. Numeric inversion is often implemented using (very) crude approximation algorithms or (very) slow iterative methods.

In [1] we demonstrated that fast numerical inversion with small errors is possible using Hermiteinterpolation of the inverse CDF. The resulting algorithm requires the CDF of the desired distribution and moderately sized tables to reach acceptable small errors.

However, the CDF often has to be computed by numerical integration routines. In many experiments we have observed that direct use of these routines in a preprocessing step leads to a very slow set-up. A more efficient approach combines Gauss-Lobato integration for calculating the CDF and Newton interpolation which is very close to Chebyshev interpolation to approximate the inverse CDF by polynomials. Thus we are able to compile an algorithm that uses the same subintervals for both tasks and thus reduces the total time of the set-up considerably. Using adaptive interval splitting very small error bounds close to machine precision can be reached using moderately sized tables that allow for a fast generation procedure.

In the talk we address the general problems of numeric inversion algorithms. We discuss possible notions of error and introduce the u-error which we consider to be the most sensible error measure for numeric inversion. Then we present the details of our new algorithm. In the final part of the talk we report the performance of the new algorithm regarding approximation quality and speed. We compare these results with the performance of other numeric inversion algorithms and with the speed of well known algorithms for standard distributions. The results indicate that our new algorithm is superior to all known numerical inversion algorithms. Its speed compares well with fast algorithms for special distributions.

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An Enhanced Quasi-Monte Carlo Method for Simulating Generalized Hyperbolic Lévy Process

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In this paper, we propose an enhanced quasi-Monte Carlo (QMC) method for pricing derivative securities when the underlying asset price follows an exponential generalized hyperbolic Lévy process. The enhanced QMC is based on a generalization of Imai and Tan (2006)'s linear transformation (LT) method. The original LT method applies to a Gaussian process and enhances QMC via dimension reduction. Numerical examples are provided to compare the numerical efficiency of the proposed algorithm to other existing methods. The relation between the effective dimension and the numerical efficiency of each method is also discussed.

Sobol' Sequences with Improved Two-Dimensional Projections

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Sobol' sequences are a popular technique for approximating integrals over the *d*-dimensional unit cube. An implementation allowing the approximation of integrals in up to 40 dimensions may be found in Algorithm 659 of the Collected Algorithms of the ACM. This implementation was extended by Joe and Kuo in 2003 to allow integrals in up to 1111 dimensions.

This extended implementation did not guarantee that all the two-dimensional projections were 'good'. Since there are certain applications in which the integrands are of low effective dimension, it would be useful to have Sobol' sequences with improved two-dimensional projections.

This talk gives an outline of our ideas for finding new direction numbers for Sobol' sequences which attempt to achieve this. This is based on treating Sobol' sequences as a special case of (t, s)-sequences in base b.

This is joint work with Frances Kuo of the University of New South Wales.

Bootstrapping Stationary Invertible VARMA Models in Echelon Form: A Simulation Evidence

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In this paper we propose bootstrapping Hannan and Rissanen (1982) estimators in stationary invertible VARMA models, with known order (p,q). Although we consider bootstrapping such models under the echelon form parameterization, the results we derive herein remain valid to other alternative identification issues. In particular, we shall exploit the theoretical developments stated in Dufour and Jouini (2005) and Dufour and Jouini (2008) to establish the asymptotic validity of bootstrapping such models for parametric and nonparametric bootstrap methods to approximating the joint distribution of the echelon form VARMA parameter estimates. The finite sample accuracy of our proposed method is evaluated through a Monte Carlo (MC) simulation, specifically, by further studying the echelon form VARMA parameter confidence interval empirical coverage rates.

Keywords: Echelon form; VARMA models; parametric bootstrap; nonparametric bootstrap; MC simulation; confidence interval; empirical coverage rates.

FPGA Acceleration of Monte-Carlo Based Credit Derivatives Pricing

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Recent years have seen increased demand for computationally intensive financial calculations. The demand is generally attributed to the growing need for faster calculation speed which is required to make real time decisions, the complexity of the financial instruments, the size of the problem and the sheer volume of the instruments in a client's portfolio. This demand has necessitated the use of novel computational tools that perform well beyond the level of the traditional desktop PC. The complexity of the instruments generally necessitates the use of Monte Carlo methods for pricing under large number of scenarios. This method, though computationally intensive, is very flexible and is extremely amenable to parallel computing. The inherent parallelism available in Monte Carlo pricing can easily be exploited on Field Programmable Gate Arrays (FPGAs), thereby providing significant speedups.

Our objective in this talk is to explore the possibility of using FPGAs to speed up Monte Carlo pricing of credit derivatives such as Collateralized Debt Obligations(CDOs). We believe this is especially useful because default is a rare event and accurate pricing of such a contract requires a very large number of scenarios. We will demonstrate the potential speedup that can be achieved in pricing a CDO, using a single factor Gaussian Copula approach, by offloading the numerically intensive Monte Carlo simulation of default events on multiple modules running in parallel on an FPGA.

Weight Statistical Modeling of Optical Radiation Transfer in Randomly-Inhomogeneous Scattering Media

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Problems of statistical modeling of optical radiation transfer in stochastic scattering and absorbing media are discussed. The optical parameters of these media are considered to be random functions of space and/or time. The standard approach to solving such problems with the Monte-Carlo method, based upon the so-called "double randomization" principle, includes the construction of numerical realizations of random fields of optical parameters of scattering media and consequent modeling of random photon trajectories for these realizations. If the analogue (physical) photon trajectories are modeled, then such an approach completely accomplishes the direct modeling of optical radiation transfer in scattering media. There exist three algorithm groups for numerical construction of random fields of optical parameters: so-called "flow" algorithms, allowing to construct piecewise-constant realizations of 3D random fields; spectral models, providing continuous realizations of 3D fields and Poisson models, designed for obtaining realizations of discontinuous 3D random fields. Numerical construction of random field realizations for all the three groups requires great calculational expenditure. Moreover, modeling trajectories for realizations of random media obtained in this way is in many cases a complex and labor-consuming task. These properties of all the above-mentioned algorithms have a significant influence on the effectiveness of direct modeling, which in many practical problems may be very low. In the paper weight algorithms, based upon the so-called "dependent trials" method allowing to optimize modeling are presented. In this approach random photon trajectories are modeled for a determined medium chosen in an appropriate way, and random variations of optical parameters of the medium are taken into account with the help of calculating special weight multipliers. In many cases of practically important problems of the stochastic media optics such algorithms allow simple numerical integrations of corresponding numerical estimates, which are required for calculating average characteristics of radiation fields. The developed algorithms are designed mainly for construction of numerical models for the electromagnetic radiation fields in the randomly-inhomogeneous cloudy Earth atmosphere.

Methods for Simulating Rare Events in Nonlinear Lightwave Systems

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Lightwave communication systems are used to transmit information at extremely high data rates. Transmission is not perfect, of course: various physical impairments deform the propagating signal during transmission, leading to errors. Because probabilities associated with these errors are typically designed to be small, e.g. one part in 10^{12} or more, overall system performance is determined by extremely rare events. In the case of impairments due to amplified spontaneous emission noise, it is possible to deal with the problem of rare events through the use of importance sampling and other variance reduction techniques. A direct approach is difficult, however, because of the high-dimensional sample space — a typical simulation can involve hundreds of thousands of independent random variables.

The overall dimensionality can be reduced, however, by using the structure of the governing equations to focus on only the most significant directions of sample space. The simplest version of the governing equations, the nonlinear Schrödinger (NLS) equation [1]

$$i\frac{\partial u}{\partial z}+\frac{1}{2}\,\frac{\partial^2 u}{\partial t^2}+|u|^2u=0\,,$$

possesses soliton solutions, $u_s(z,t) = A \operatorname{sech}[A(t-T-\Omega z)] \exp[i(\Omega t + (A^2 - \Omega^2)z/2 + \Phi)]$. Since any value of the parameters A, Ω , T and Φ is allowed, noise that perturbs the solution in these directions can build up to large variations after many amplifiers. Thus, these directions provide the lower-dimensional basis with which to perform importance sampling [2, 3]. In the case of non-soliton pulses, it is possible to employ the singular value decomposition (SVD) to determine the most important modes [4].

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Optimal Importance Sampling Parameter Search for Lévy Processes Via Stochastic Approximation

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The author proposes stochastic approximation methods of finding the optimal measure change by the exponential-tilting for Lévy processes in Monte Carlo importance sampling variance reduction. In accordance with the structure of the underlying Lévy measure, either a constrained or unconstrained algorithm of the stochastic approximation has to be chosen. For both cases, the almost sure convergence to a unique stationary point is proved. Numerical examples are presented to illustrate the effectiveness of our method.

On the Relation of Quasi-Monte Carlo, Sorting, and the Rotor-Router Model

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The straightforward application of quasi-Monte Carlo methods to the simulation of Markov chains often results in a performance that is hardly superior to the Monte Carlo method in practical applications. However, the full superiority of correlated over independent sampling can be exposed when simultaneously simulating multiple Markov chains and after each transition sorting them by some order on their state space.

For the example of Einstein's diffusion problem we investigate how quasi-random walks with state space sorting are related to the rotor-router model by James Propp. We then complete recent work by contributing a deterministic high-dimensional algorithm for the simultaneous simulation of Markov chains with sorting.

Approximate Simulation of the Heston Stochastic Volatility Model

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The Heston model has been one of the most popular stochastic models in financial engineering. Complex derivatives that are path-dependent usually invoke the use of Monte Carlo method and this makes an efficient simulation method of the Heston model attractive. There are well known methods such as Euler scheme, Milstein scheme and the exact simulation method of Broadie and Kaya which recovers the usual Monte Carlo convergence rate. And recently, Andersen proposed a new discretization scheme called QE method and showed that his method outperforms other discretization methods.

In this talk, we propose new approximate simulation methods based on the Broadie–Kaya method and on the Bessel bridge decomposition. In the Broadie–Kaya method, the most time consuming part is the simulation of the path integral of the variance process V conditional on the end points, i.e. $\left(\int_0^t V_s ds | V_0, V_t\right)$. It turns out that this can be represented as the sum of three independent random variables:

$$\left(\int_0^t V_s ds \middle| V_0 = v_0, \, V_t = v_t\right) \stackrel{d}{=} X_1 + X_2 + X_3$$

where $X_1 = \left(\int_0^t V_s^1 ds | V_0^1 = v_0 + v_t, V_t^1 = 0\right)$ with $dV_s^1 = -\kappa V_s^1 ds + \sigma \sqrt{V_s^1} dW_s^1$ and X_2, X_3 are defined in a similar fashion with different parameters.

While X_2 and X_3 are easy to simulate and straightforward, the simulation of X_1 is not easy to do it faster. To speed up the simulation, we propose two approximate approaches:

• Gamma approximation based on the series representation: for some sequences λ_n , γ_n

$$X_1 \stackrel{d}{=} \sum_{n=1}^{\infty} \frac{1}{\gamma_n} \sum_{j=1}^{Poiss((v_0+v_t)\lambda_n)} Exp_j(1)$$

• Beta approximation based on the infinite divisibility of X_1

We test these ideas and compare the results with other methods.
Algebraic Methods of Sequence Generation

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Linear Feedback Shift Registers (LFSRs, equivalent to linearly recurrences), are used for sequence generation in many of applications: Monte Carlo, stream ciphers (for cryptanalysis and design of keystream generators), CDMA, radar ranging, and error correcting codes. Their importance comes from their speed, their engineering simplicity, and their associated algebraic structures that make their analysis tractable. These structures are based on the algebra of power series over finite fields. This makes it possible to identify those LFSRs that have the statistical properties needed for these applications. Nonetheless, it is desirable to have new sources of fast pseudorandom sequence generators.

In 1994 a new type of sequence generator was discovered independently by Couture and L'Écuyer (under the name multiply with carry generator), and by Goresky and Klapper (under the name feedback with carry shift registers, or FCSRs) [1, 2]. The former authors were working in the area of random number generation for QMC, the latter in the area of stream ciphers. These registers are nearly as fast as LFSRs. They have an algebraic theory that parallels that of LFSRs, in this case based on the integers and N-adic numbers. Many of the properties of FCSR sequences have been studied, and this theory for a large part parallels the theory of LFSRs.

LFSRs and FCSRs have a common generalization, algebraic feedback shift registers (AFSRs) [3] whose basic properties I will describe. Each AFSR is based on an algebraic ring R and $\pi \in R$ (LFSRs: R = F[x]and $\pi = x$, F a finite field; FCSRs: R is the integers). A sequence $\mathbf{a} = a_0, a_1, a_2, \cdots$ is associated with the π -adic number $\sum_{i=0}^{\infty} a_i \pi^i$. There is a rich algebraic theory of π -adic numbers that allows us to analyze AFSRs in much the same way that power series can be used to analyze LFSR sequences. Associated with each class of AFSRs is a security measure, the π -adic complexity. I will describe some of our recent results on the asymptotic and average behavior and stability of π -adic complexity.

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Value Modifications of Statistical Modeling for Solving the Smoluchowski Equation

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We study the evolution of multiparticle ensembles which is governed by pure coagulation Smoluchowski equation and analyze the efficiency of various modifications of weighted value modeling for estimating the total monomer and dimer concentration in ensemble. A considerable gain in computational costs is achieved via the approximate value modeling of the "free path" of the ensemble combined with the value modeling of the index of a pair of interacting particles.

The technique presented is a development of the methods proposed in [1, 2].

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Multi-Resolution Monte Carlo Inference of Stochastic Models from Partially Observed Data

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Stochastic models, diffusion models in particular, are widely used in science, engineering and economics. Inferring the parameter values from data is often complicated by the fact that the underlying stochastic processes are only partially observed. Examples include inference of discretely observed diffusion processes, stochastic volatility models, and double stochastic Poisson (Cox) processes. Likelihoodbased inference faces the difficulty that the likelihood is usually not available even numerically. The conventional approach discretizes the stochastic model to approximate the likelihood. In order to have desirable accuracy, one has to use highly fine discretization. However, fine discretization usually imposes unbearable computation burden. In this talk we will introduce the framework of Bayesian Monte Carlo multi-resolution inference to address this difficulty. By working on different resolution (discretization) levels simultaneously and by letting the resolutions talk to each other, we not only substantially improve the computational efficiency, but also significantly increase the estimation accuracy. This work is joint with Ben Olding.

On the Approximation of Functions Using Polynomial Lattices

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Digital nets and, in particular, polynomial lattice points are widely known as useful tools in quasi-Monte Carlo integration. On the other hand, it has been shown recently that such point sets can also be effectively used for the approximation of elements of suitable function spaces. In our talk, we present new results on the approximation of functions from high dimensional weighted reproducing kernel Hilbert spaces based on Walsh functions, using digital nets or polynomial lattice points.

On Decompositions of Multivariate Functions

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We present general formulas that allow us to decompose a function of d variables into a sum of 2^d terms, with each term depending on a group of variables indexed by a particular subset of $\{1, 2, \ldots, d\}$. The decompositions are optimal with respect to dimensionality, and the terms are orthogonal in a Hilbert space setting. The general formulas come in both recursive and explicit forms. Special cases include the ANOVA decomposition and anchored decomposition – the former requires multivariate integrals of the function, while the latter is based only on function samples. If the function is of finite order q, then the anchored decomposition can be computed using $\mathcal{O}(d^q)$ samples.

This is joint work with Ian H. Sloan, Grzegorz W. Wasilkowski, and Henryk Woźniakowski.

An Adaptive Monte Carlo Algorithm to Solve Backward Stochastic Differential Equations

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We present and analyze a numerical algorithm to solve backward stochastic differential equations (BSDEs hereafter) of the following type, where $X \in \mathbb{R}^d$, $Y \in \mathbb{R}$ and $Z \in \mathbb{R}^q$

$$\begin{cases} -dY_t = f(t, X_t, Y_t, Z_t)dt - Z_t dW_t, \ Y_T = \Phi(X_T), \\ X_t = x + \int_0^t b(s, X_s)ds + \int_0^t \sigma(s, X_s)dW_s. \end{cases}$$
(7.2)

Several algorithms to solve BSDEs can be found in the literature, they are mainly based on the dynamic programming equation. Our algorithm approximates the solution (Y, Z) of (7.2), by combining Picard's iterations — we approximate (Y, Z) by the solutions of a sequence of linear BSDEs converging geometrically fast to (Y, Z) — and an adaptive control variate method. The convergence of our algorithm is geometric. Moreover, it provides a regular solution w.r.t. time and space.

We recall that solving the BSDE (7.2) is equivalent to solving a semilinear PDE, whose solution is denoted u. More precisely, we can write $(Y_t, Z_t) = (u(t, X_t), \partial_x u(t, X_t)\sigma(t, X_t))$, for all $t \in [0, T]$. Our algorithm provides an approximated solution of u. We deduce from the previous equality an approximation of the solution of BSDE (7.2). At iteration k, one has $(Y_t^k, Z_t^k) = (u_k(t, X_t^N), \partial_x u_k(t, X_t^N)\sigma(t, X_t^N))$, for all $t \in [0, T]$, where X^N is the approximation of X through an Euler scheme and u_k denotes the approximation of u at step k. We build u_k in the following manner: we begin with $u_0 = 0$ and at step k, we combine Picard's iteration and the adaptive control variate to build u_k :

$$u_{k}(t,x) = u_{k-1}(t,x) + \frac{1}{M} \sum_{m=1}^{M} [\Phi(X_{T}^{m,N}) - u_{k-1}(T,X_{T}^{m,N}) + \int_{t}^{T} f(s,X_{s}^{m,N},u_{k-1}(s,X_{s}^{m,N}),(\partial_{x}u_{k-1}\sigma)(s,X_{s}^{m,N})) + (\partial_{t} + \mathcal{L}^{N})u_{k-1}(s,X_{s}^{m,N})ds].$$

We prove the geometric convergence of our algorithm. For two constants η and ϵ tending 0 when the parameters tend to infinity we get $||Y - Y^k||^2 + ||Z - Z^k||^2 \le S_k + O(\frac{1}{N})$, where $S_k \le \eta S_{k-1} + \epsilon$.

BSDEs appear in numerous financial problems (like the pricing and hedging of European and Amercian options). In a complete market, we are able to construct a portfolio which attains as final wealth the amount $\Phi(X_T)$, where the process X represents the asset. The dynamics of the value of the replicating portfolio Y is given by a BSDE with linear generator f, and Z corresponds to the hedging portfolio.

Variance Reduction Methods for Exotic Option Pricing under Variance Gamma and Gaussian Models

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In this talk, we will discuss the Monte Carlo and quasi-Monte Carlo methods combined with some variance reduction techniques for exotic option pricing where the log returns of the underlying asset follow both the variance gamma distribution and the normal distribution. An arithmetic Asian option, an Up-and-Out Asian option and a reset option are considered in this paper. Our test results show that variance reduction methods can usually reduce variances significantly if they are chosen carefully. The results also show that the (randomized) quasi-Monte Carlo method is more efficient than the Monte Carlo method if both are combined with the same variance reduction method.

Monte Carlo Simulations in Advancing Magnetic Recording Applications

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The ferromagnetic thin films have been a subject of intensive interests in view of both technological applications [1] and fundamental interests, where physics in reduced structure is different from those in bulk. However, the description of how the magnetic behavior in films structure are affected by the external field is not quite well set up due to complexity of the reduced dimension. For example, multilayered systems are known to change from two to three dimensional class with increasing numbers of layers [2]. Magnetic films, however, should belong to a two dimensional universality class owing to dimensional ratio. Therefore, this discrepancy highlights the importance of the dimensional pinning to the problem. Nevertheless, direct observations are difficult to obtain; consequently, many numerical techniques have been used to understand the ferromagnetic behavior e.g. the mean-field method or the 'first principles' electronic structure calculation. However, these two methods have not yet properly taken the thermal fluctuation into account. Therefore, that the results obtained from these methods are applicable and correct for a wide range of temperatures is still of some curiosities. On the other hand, the Monte Carlo simulation (based on a stochastic method) has proved to be a useful model in cooperating with thermal disturbance. For example, the Monte Carlo simulations in two-dimension Ising model agree very well with the exact solutions. Therefore, the Monte Carlo is expected to be a promising technique when considering the effect of thermal fluctuation on magnetic properties in various structures.

In this talk, the Monte Carlo techniques used in statistical physics especially in magnetic thin-films modeling are introduced [3]. A few algorithms which follow the stochastic detailed balance and ergodicity in thermal equilibrium are given and briefly described. Then, the applications of this Monte Carlo in some ferromagnetic thin-films systems are presented. Based on its results, these have provided another fruitful step in understanding the ferromagnetic phenomena and suggest Monte Carlo's role in advancing the magnetic recording applications. Finally, as an addition to ferromagnetic studies, an extension of this Monte Carlo technique to other ferroic topics such as ferroelectric applications is also suggested and discussed.

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Distribution of the Sums of Digits of Integers in Different Bases and the Discrepancy of Generalized Digital (T, s)-Sequences

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Two of the most important concepts for the generation of high-dimensional low-discrepancy pointsequences in a unit-cube are the concept of van der Corput - Halton and the concept of digital (\mathbf{T}, s) sequences introduced in full detail by Niederreiter.

In a series of papers the authors have introduced a hybrid of these two concepts by studying (\mathbf{T}, s) sequences with bases not necessarily the same in all coordinates, thereby generalizing both concepts.

For the construction of digital (\mathbf{T}, s) -sequences and of our generalized digital (\mathbf{T}, s) -sequences we make use of $s \ N \times N$ - matrices C(i), $i = 1, \ldots, s$ over a residue ring Z_b .

When analyzing the distribution properties and discrepancies of generalized digital (\mathbf{T}, s) -sequences it turns out, that the analysis is straightforward if all the matrices C(i) have finite rows, i.e., if every row has only finitely many entries different from zero.

If, however, there are infinite rows, then the analysis becomes much more involved and leads to problems concerning the simultaneous distribution of the weighted sum of digits of integers with respect to different bases, which are well known as notorious difficult problems.

We give a survey on recent results on this topic.

Randomized Quasi-Monte Carlo Simulation of Multidimensional Markov Chains

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We study a randomized quasi-Monte Carlo method for the simulation of discrete time Markov chains with either discrete or continuous multidimensional state space. The method simulates n copies of the chain in parallel, using highly uniform point sets randomized independently at each step. In addition, at each step, the copies are sorted according to some multidimensional order. Under some conditions, we prove the convergence of the method as $n \to \infty$ and we also obtain bounds on the convergence rate of the variance as a function of n. For the one-dimensional case, we prove that the variance converges as $O(n^{-2+\epsilon})$. We compare the efficiency of various ordering strategies. We provide numerical illustrations where the variance reduction with respect to standard Monte Carlo is substantial.

Large Deviations and Importance Sampling for a Tandem Network with Slow-Down

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We consider a variant of the two node tandem Jackson network where the upstream server reduces its service rate when the downstream queue exceeds some prespecified threshold. The rare event of interest is the overflow of the downstream queue. Based on a game/subsolution approach, we rigorously identify the exponential decay rate of the rare event probabilities and construct asymptotically optimal importance sampling schemes.

An Adaptive Framework for Monte-Carlo Methods

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Monte Carlo methods are widely used in financial engineering and the challenge is now to find efficient and automatic ways to reduce the variance. Here, we present a generic framework for constructing an adaptive variance reduction (see Arouna [1]) based on truncated stochastic algorithms and aimed at giving a generic and automatic procedure. Suppose you want to compute $\mathbb{E}(f(X))$ where X is a real-valued r.v. and suppose you can construct a family of r.v. $(U(X,\theta), \theta \in \mathbb{R}^d)$ such that $\mathbb{E}(U(X,\theta)) = \mathbb{E}(f(X))$. Then, if $\mathbb{E}(f(X))$ is to be computed using Monte Carlo simulations, it is quite natural to try to find the value θ^* of the parameter θ that minimises $\mathbb{Var}(U(X,\theta))$. The idea is to compute an estimator of θ^* using a truncated stochastic algorithm and to plug the estimator in the Monte Carlo algorithm in an adaptive way.

In view of the new convergence results for truncated stochastic algorithms (see [2]), we have managed to improve the work of Arouna by localising all the assumptions needed for the convergence of the stochastic algorithm, namely we need that the function $\mathbb{E}(|U(X,\theta)|^2)$ is locally bounded, which is a weak and easy to check assumption. Not only have we managed to localise the assumptions, but they are expressed independently of the algorithm paths which was not the case before. These new results obviously improves the range of application of the technique. Finally, We will present some applications of this method to option pricing. In this context, we will explain how to construct such a family $(U(X,\theta), \theta \in \mathbb{R}^d)$ in a Gaussian framework, i.e. when X is a Gaussian vector.

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Unconstrained Adaptive Variance Reduction and Application to Monte Carlo Option Pricing

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We propose an *unconstrained* stochastic approximation method of finding the optimal measure change (in an *a priori* parametric family) for Monte Carlo simulations. We consider different parametric families based on the Girsanov theorem and the Essher transform (or exponential-tilting). In a multidimensionnal Gaussian framework, Arouna uses a projected Robbins-Monro procedure to select the parameter minimizing the variance (see [1]). In our approach, the parameter (scalar or process) is selected by a classical Robbins-Monro procedure without projection or truncation. To obtain this unconstrained algorithm we intensively use the regularity of the density of the law without assuming smoothness of the payoff. We prove the convergence for a large class of multidimensionnal distributions and diffusion processes.

We illustrate the effectiveness of our algorithm via pricing of exotic options in different markets: Black-Scholes, Heston and a Lévy market.

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Testing the Tests: Using Pseudorandom Number Generators to Improve Empirical Tests

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A number of pseudorandom number generators are now good enough that they can be used to find errors in the implementation of empirical tests. This talk describes how simple techniques were used to find and fix errors and inaccuracies in the implementation of the Run test [4] and the OPSO, OQSO and DNA serial tests [7, 8, 5] of the TestU01 test package [6]. Some of the inaccuracies in the serial tests are related to the difference between the statistics of words in strings [2, 3, 9, 10, 11] and the equivalent statistics of words in cycles [1].

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Random Variate Generation and Testing in Interactive Environments

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Interactive environments for scientific and statistical computing like R or ROOT provide a rich tool-set for testing and visualizing samples of pseudo-random point sets. They are popular as they also allow for fast prototyping of stochastic models and analysis of their corresponding output distributions. Therefore, random variate generation is an important issue in those environments. Following requests from interested users we have compiled an interface to our UNU.RAN library of non-uniform random number generators [1] for R and ROOT. Thus the so called automatic algorithms implemented in UNU.RAN are now directly available for users of those environments. This allows convenient random variate generation from nonstandard distributions without coding new algorithms. Only the density or the distribution function must be provided. Using the facilities of the interactive environment it is also very easy to run test procedures for random variate generation algorithms.

Although stringent mathematical proofs must of course be the fundament of every generation method we found empirical tests very convenient to detect both problems with floating point arithmetic and even design errors. For example, it requires a single line of R code to visualize that a sample of beta distributed variates with shape parameter 0.001 does not always behave as expected. We even found a design error in a frequently used Gaussian random variate generator. Automatic random variate generators that accept quite arbitrary target distributions are even more sensible against limitations of floating point arithmetic. UNU.RAN was tested with many standard distributions and lots of randomly chosen parameter values. But it lies in the nature of such a library that unexpected problems may arise for new (untested) distributions. Fortunately, the interactive environment facilitates the testing of automatic algorithms with the distributions and parameter settings actually required for a simulation problem.

In this talk we show how the automatic UNU.RAN generation procedures for (non-standard) distributions can be used and tested in R. We demonstrate the above problems and discuss its reasons. Finally, we conclude with a suggestion for a standard testing procedure that should be applied to random variate generation algorithms before they are used for simulations.

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The Analytical Extension of the Resolvent for the Helmholtz Equation by Technique of Parametric Differentiation

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Let us consider the Dirichlet problem for the Helmholtz equation in a domain $D \subset \mathbb{R}^3$ with boundary Γ :

$$(\Delta + c)u = -g, \quad u|_{\Gamma} = \varphi \tag{7.3}$$

Let us assume that conditions provided the existence and uniqueness of the solution to problem (7.3) are supposed fulfilled. In particular, $c < c^*$, where $-c^*$ is the first eigenvalue of the Laplace operator defined on the domain *D*. It is well known (see [1]), that under above stated conditions there is random walks by spheres method, which is applicable to problem (7.3). Under $c < c^*$ the solution to the problem (7.3) is represented by convergent Neumann series. There are two aims of this talk. First, if parameter *c* is too close to c^* then the rate of convergence of the corresponding Neumann series and Monte Carlo method is unsatisfying. Second, if we have the following inequality $c > c^*$ then the Neumann series diverge and we can't use the corresponding estimates of Monte Carlo method for solving problem (7.3).

We can use the analytical extension of the resolvent by the shift of the parameter c [3]. We have the following equations

$$\begin{cases} (\Delta + (c - c_0))^{i+1} (u_i - u_{i-1}) = (-1)^{i-1} c_0^i g, \\ (\Delta + (c - c_0))^i (u_i - u_{i-1})|_{\Gamma} = (-1)^i c_0^i \varphi, \\ (\Delta + (c - c_0))^k (u_i - u_{i-1})|_{\Gamma} = 0, \quad k = 0, \dots, i-1. \end{cases}$$

$$(7.4)$$

Using the parametric differentiation of the based on walks by spheres estimator of the solution to problem (7.3) with a special functions g, φ we constructed the corresponding estimator for the solution $u_i - u_{i-1}$ to problem (7.4)[2]. In this way, we constructed corresponding random walks on spheres estimates and extension of probabilistic representation to the solution of problem (7.3).

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A Tick-by-Tick Model for Price and Volume that Incorporates Behavioral Biase

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We propose a model for simultaneously predicting stock price and volume on a tick-by-tick basis. We model the investors' trading characteristics by a random utility model [1] that incorporates several important behavioral biases such as the status quo bias [2], the disposition effect [3], and loss-aversion [4]. Our model is a version of the logistic regression model with incomplete information [5]. Consequently, we cannot use the Maximum Likelihood method to estimate the parameters of the model and have to resort to Markov Chain Monte Carlo (MCMC) to fit the model to a time series of price and volume, (p_t, v_t) , data available in The Trade and Quote (TAQ) database. Moreover, the restriction that the volume predicted by the MCMC model *exactly* equal the observed volume v_t introduces serial correlation in the stock price. Thus, the standard MCMC methods for calibrating parameters do not work. We develop new modifications of the Metropolis-within-Gibbs method to estimate the parameters in our model. Our primary goal in developing this model is to be able to predict the price-impact function of individual stocks that can subsequently be used in asset allocation models.

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Stochastic Spectral Formulations for Elliptic Problems

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The Feynman-Kac formula enables to achieve stochastic representations of the pointwise solution of partial differential equations like diffusion or transport equations. The solution of Dirichlet boundary value problems in a domain $D \subset \Re^d$ with a sufficiently smooth boundary ∂D

$$-Au = f$$

with boundary conditions

u = g

on ∂D is given $\forall x \in D$ by

$$u(x) = E_x \left[g(X_{\tau_D}) + \int_0^{\tau_D} f(X_s) ds \right],$$

where X_t is a stochastic process solution of the stochastic differential equation relative to the operator A and where τ_D is the exit time of this process from the domain D. We have introduced in [1, 2] sequential Monte Carlo algorithms to compute global solutions of such equations with a great accuracy by combining this Feynman-Kac formula and deterministic spectral approximations. In a recent work [3], we have introduced new tools to optimize these algorithms in the case of the Poisson equation on a square domain. These tools are one random point schemes for the evaluations of source terms and quantization methods. Finally, we have given a new interpretation of the algorithm as a direct spectral formulation similar to deterministic collocation methods but with almost perfect properties in terms of conditioning. We intend to describe and to study these new formulations in more general situations, that is for a general operator A in a complex domain D. In particular, we will show that in the case when interpolation is used in the deterministic approximations, the condition number is always small. Numerical examples will be given on various situations.

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Hybrid Monte Carlo and Quasi-Monte Carlo Methods for Path-Dependent Option Pricing

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Using bridge sampling to reduce the effective dimension of a multivariate problem was first proposed by Moskowitz and Caffisch in 1996 for pricing path-dependent option under the geometric Brownian motion. This approach followed by application of quasi-Monte Carlo methods becomes a classical example of variance reduction and is widely used in computational finance. For instance, it is successfully applied to pricing options under the variance gamma and normal inverse Gaussian models. In reality, the increase of the complexity of a model leads to a significant increase of the computational cost of the bridge sampling method. For example, quasi-Monte Carlo methods or other variance reduction methods often involve computations of the inverse of a distribution function. For many interesting models that arise in mathematical finance, the inverse of a distribution function can be computed only by numerical solution of a corresponding differential equation. Therefore, a more correct statement of problem is the minimization of the computational cost of a Monte Carlo algorithm (which is directly proportional to a product of the variance of an estimator and the average computing time per one sample) rather than the minimization of the variance only.

Our approach consists in combining bridge sampling with adaptive Monte Carlo techniques and randomized quasi-Monte Carlo methods. Starting with a path-integral representation of a discrete-time path-dependent option, we rearrange the variables and partition the state space of integral variables into two subspaces so that the variance of a standard Monte Carlo estimator of the path integral depends mostly on variables of one of the subspaces of smaller dimension that can be called the effective subspace. The variables of the effective subspace explain most of the variability of a sample path and are used to construct a path "skeleton". A bridge Monte Carlo sampling method is then applied to fill out gaps between the nodes of the path "skeleton". After that, we apply a combination of variance reduction techniques only in the effective subspace. The main motivation to concentrate our efforts on the effective subspace is that variance reduction methods are usually more time-consuming than a plain Monte Carlo simulation method. In result, we can achieve almost the same efficiency in variance reduction, as if the variance reduction methods would be applied to the entire state space, but for the less cost. We illustrate the large efficiency improvements on numerical examples for Asian, lookback, and barrier options under exponential Lévy models, such as the variance gamma and NIG models, and state-dependent volatility diffusion models.

Study of Parallel Monte Carlo Algorithm to Solve Nonlinear Equation of Coagulation

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Consider a Cauchy problem for a system of nonlinear equations governing the process of spatially inhomogeneous coagulation (the system will be referred to as coagulation equation):

$$\frac{\partial c_1}{\partial t} + \operatorname{div}(vc_1) = -c_1 \sum_{j=1}^{\infty} K(1,j)c_j,
\frac{\partial c_i}{\partial t} + \operatorname{div}(vc_i) = \frac{1}{2} \sum_{j=1}^{i-1} K(i-j,j)c_{i-j}c_j - c_i \sum_{j=1}^{\infty} K(i,j)c_j, \quad i \ge 2,
c_i(0,x) = c_i^0(x).$$
(7.5)

Here $c_i = c_i(t, x)$, i = 1, 2, ... is the concentration of *i*-mers at time *t* and position $x \in \mathbb{R}^3$, v = v(x) is the spatially inhomogeneous velocity field, K(i, j) is the coagulation kernel, $c_i^0(x)$ is the concentration of *i*-mers at t = 0. We consider the equation inside the time-space domain $(0, T] \times \Omega$, $\Omega \subset \mathbb{R}^3$. We evaluate the following functionals of the equation solution:

$$\varphi_i(t) = \int_G c_i(t, x) dx, \ \psi_r(t) = \int_G \sum_{i=1}^\infty i^r c_i(t, x) dx, \ G \subseteq \Omega$$
(7.6)

We introduce a parallel Monte Carlo algorithm based on the simulation of test particles ensembles to solve the coagulation equation (7.5). The Monte Carlo algorithm is based on so called "majorant frequency" principle. Thus the computational time is in direct proportion to the initial number of test particles.

We studied a behavior of a variance $D\zeta$ of stochastic estimators ζ to functionals (7.6). In particular, we proved the variance finiteness and studied its dependence on the algorithm parameters.

We also studied a behavior of the algorithm's computational cost $C(\zeta) = t_1 \varepsilon_{det}^{-2} D\zeta$ and the relative efficiency of simulation $\Phi = t_1|_{M=1}/t_1|_{M>1}$. Here M is a number of processors, t_1 is a computer time to simulate one sample of ζ , ε_{det} is a deterministic error of the estimator. We developed a technique to change the algorithm's parameters when $M \to \infty$ to enable maximum relative efficiency. We proved that if one follows this technique then an asymptotic behavior of Φ may be close to M^d , where d > 0.

Efficiency of Metropolis-Hastings-Algorithms

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When designing Metropolis-Hastings-algorithms for specific (high-dimensional) integration problems the issue of efficiency must be taken into account, and we understand this with respect to some classes of problem instances. Within this framework lower bounds for errors of MCMC integration can be established. Furthermore we discuss how to design and tune the underlying proposal Markov chain. We highlight how an efficient choice of it depends on the underlying class of integration problems.

This talk is based on joint work with E. Novak, Jena, which appeared as [1].

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"Value" Modelling with Branching in the Monte Carlo Method

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In practice statistical simulation is most often used to solve problems of physics and technology which are based on probabilistic models associated with some terminating Markov chains. Direct simulation of such chain trajectories can be interpreted as an algorithm for estimating linear functionals of a solution of an integral equation of the second kind with the corresponding substochastic kernel which coincides with the density of the initial Markov chain. In order to obtain an estimator with a better accuracy we can use weight modifications of simulation. In this case linear functionals are estimated with the use of an "auxiliary" weight which is multiplied after each elementary transition by the ratio of the corresponding (maybe generalized) densities of the original distribution to the simulated one. It is well-known that the most useful tool for decreasing the variance of estimator are "value" and partial "value" modelling. These types of weight modifications are related to the construction of simulated distribution for some auxiliary random variable by multiplying the initial density by the "value" function which is usually corresponds to the solution of adjoint integral equation of the second kind [1],[2].

In this talk new weighted Monte Carlo algorithms for statistical simulation with the use of branching are defined and studied. The idea is to branch simulated trajectory only if the next "auxiliary" weight is greater than 1. In this case the "auxiliary" weight on each branch is less than or equal to 1 and the variance of modified estimator is finite. The efficiency analysis of "value" simulation with the use of branching is presented.

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YARN Generators in Large Scale Distributed Monte Carlo: Theory

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Pseudorandom number generators based on linear feedback shift register sequences in finite fields are perfectly suited for large scale, parallel Monte Carlo applications: They are theoretically well understood, have long periods, and can be parallelized very efficiently by leapfrog and block splitting methods. Their linearity, however, comprises a well known weakness: When used to sample coordinates in a space with dimension larger than the depth of the feedback shift register, sampling points lie on regular hyperplanes.

In this talk we introduce a new class of pseudorandom number generators, the YARN generator. YARN generators are based on linear feedback shift register sequences and inherit all their favorable features. The hyperplane structure is destroyed by a nonlinear transformation. We review the theoretical bases of linear feedback shift register sequences and YARN generators with a focus on their application in parallel Monte Carlo simulations.

Application of Importance Sampling and Quasi-Monte Carlo to Multi-Step Credit Portfolio Simulations

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The loss distributions of financial portfolios subject to credit risk (default and credit quality deterioration) feature heavy tails due to the generally rare but plausible scenario of multiple correlated defaults. For example, the loss at 99.9% confidence may easily be 20 times greater than the expected loss. Such calculations are of critical importance to banks in determining the level of capital to hold against their loan portfolios.

Loss distributions are often generated with Monte Carlo simulation when it is important to capture detailed properties of individual credit exposures in a non-homogenous portfolio. Variance reduction methods have been studied for this problem by several authors for the case of determining the loss distribution at a specified time horizon.

This talk presents two extensions of an importance sampling method developed by the author for the credit portfolio problem based on increasing the covariance of exposures to generate samples with greater loss. First, a Quasi-Monte Carlo sequence is incorporated in the simulation and the impact on reducing simulation error is studied. Second, the method is extended to the case when it is necessary to track the time evolution of the loss distribution at multiple time horizons, as may be required in the analysis of portfolio credit derivatives such as CDOs and CPDOs.

Optimal Pointwise Approximation of Infinite-Dimensional Ornstein-Uhlenbeck Processes

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We consider an infinite-dimensional Ornstein-Uhlenbeck process on the spatial domain $]0,1[^d$ driven by an additive nuclear or space-time white noise, and we study approximation of this process at a fixed point in time. We determine the order of the minimal errors as well as asymptotically optimal algorithms, both of which depend on the spatial dimension d and on the decay of the eigenvalues of the driving Wiener process W in the case of nuclear noise. In particular, the optimal order is achieved by employing driftimplicit Euler schemes with non-uniform time discretizations, while uniform time discretizations turn out to be suboptimal in general. By means of non-asymptotic error bounds and by simulation experiments we show that the asymptotic results are predictive for the actual errors already for small size discretizations.

Curse of Dimensionality: Random walk Metropolis for Discontinuous Target Densities

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Markov chain Monte Carlo (MCMC) methods are now employed in all branches of statistics to obtain a sample $X = (X_0, X_1, ...)$ from a *d*-dimensional (target) distribution Z. In particular, a Markov chain is constructed with Z as its stationary distribution. Obviously there is a multitude of possible Markov chains, but a straightforward *default* choice is the random walk Metropolis (RWM) algorithm. That is, at each step of the Markov chain a value Y_{t+1} is proposed from a probability distribution centered about the current value X_t . Often the proposal distribution is taken to be multivariate Gaussian with variance matrix $\sigma^2 I_d$. The proposed value is then either accepted $(X_{t+1} = Y_{t+1})$ or rejected $(X_{t+1} = X_t)$. A key question of interest is, what is a good choice of σ ?

This question has been studied extensively in the case where Z has a continuous pdf. In particular, a simple and practical rule for choosing σ has been obtained. In this talk we discuss the extension of the results to the case where Z has a discontinuous pdf. The situation is far more complex than for continuous pdfs and depends upon the discontinuity in the pdf. However, progress can be made in analyzing X and simple practical rules exist for choosing σ . In particular, we consider the cases where Z is non-zero on the d-dimensional hyper-sphere or the d-dimensional hyper-cube. The former behaves in a similar manner to continuous pdfs whilst the latter exhibits rather different behaviour. In particular, it can be shown that full dimensional RWM performs worse than lower dimensional updating schemes.

Simulation on Demand

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Decision support is an important use of Monte Carlo simulation. Often, decision makers want to explore and discuss alternatives by asking questions about specific alternatives, getting answers, and using those answers to choose further alternatives to investigate. Simulation can seldom provide answers quickly enough to enable this kind of decision-making process. In this environment, computer time is plentiful, but decision-maker time is scarce. We propose an approach of "simulation on demand," which will provide the speed and ease of use of a simple spreadsheet model with nearly the fidelity of a detailed simulation. While there may not be time to simulate alternatives as they are proposed by decision makers, there may be ample time before decision makers are involved to map response surfaces of simulated performance measures as functions of the alternatives. In other words, there is time to build metamodels of the simulation model. Simulation on demand harnesses networked computing capacity that is often idle to build metamodels from a simulation experiment designed to capture information about a wide range of alternatives. The metamodels then provide rapid answers about any of the alternatives in which decision makers are interested.

We develop a response surface methodology based on interpolation among estimates of the response given certain alternatives. These alternatives serve as design points for the response surface, which is produced by simulations performed at each design point separately. Our framework can quantify the uncertainty about the response at any point on the response surface: spatial correlation modeling provides a way of assessing uncertainty due to interpolation, and we show how to combine this with uncertainty due to Monte Carlo sampling. This quantification of uncertainty is useful in itself and especially in guiding adaptive experimental designs for the simulation. It allows us to answer the question "given what we have learned about the response surface from the simulations so far, which alternatives should be simulated next, and how many Monte Carlo samples should be performed for each alternative?"

On the Exact t-Value of Some Standard Low-discrepancy Sequences

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This talk considers several well-known families of (t, s)-sequences. First the exact t-value of Niederreiter sequences is determined. Then the exact t-value of generalized Niederreiter sequences – which include Sobol' sequences – is analyzed and it is shown that, for a range of dimensions of practical interest, Niederreiter-Xing sequences are demonstrably better than Sobol' sequences in terms of the exact t-value. Previously, such a conclusion was not possible since only upper bounds on the exact t-value of these sequences and a general lower bound for all (t, s)-sequences were available.

The talk is based on joint work with Josef Dick.

Optimal Sequential Monte Carlo Algorithms with Fixed Relative Precision

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We consider a series of Monte Carlo experiments designed to estimate an unknown quantity θ . Let us assume that we can generate a sequence X_1, X_2, \ldots of nonnegative bounded random variables with common expectation θ such that $X_n - \theta$ are martingale differences. The special case of i.i.d. observations is most important, but generalization to martingale differences is useful for adaptive importance sampling. The problem is to approximate θ within given relative precision ε at a given level of confidence $1 - \alpha$, i.e. to find an estimator $\hat{\theta}$ such that $P(|\hat{\theta} - \theta| > \varepsilon \theta) \leq \alpha$ for all θ . This problem, referred to as (ε, α) approximation, has a solution only if the sample size is random and depends on the outcomes of previous experiments. We consider the stopping rule $N_r = \min\{n : S_n \geq r\}$, where $S_n = \sum_{i=1}^n X_i$ and two sequential estimators: S_{N_r}/N_r and r/N_r . We prove the exponential inequality $P(|r/N_r - \theta| > \varepsilon \theta) \leq e^{-rk(\varepsilon)} + e^{-rk(-\varepsilon)}$, where $k(\varepsilon) = \ln(1 + \varepsilon) - \varepsilon/(1 + \varepsilon)$. This inequality is used to set an appropriate value of $r = r(\varepsilon, \alpha)$. We also derive a lower bound on the worst case complexity of the (ε, α) approximation problem. We examine the efficiency of our algorithm, understood as the ratio of the the lower bound to the required sample size. We show that this efficiency approaches 1 if $\varepsilon \to 0$ and $\alpha \to 0$. Thus the estimators considered here are nearly optimal (in the worst case sense), if high precision and high confidence level are required.

The first exact (i.e. nonasymptotic) solution of the (ε, α) approximation problem appeared only in 1995 and was given by P. Dagum, R. Karp, M. Luby and S. Ross (*FOCS'95* and [1]). Their work is restricted to the case of i.i.d. observations. The authors show that the efficiency of their algorithm is bounded by some absolute constant. This deep and elegant optimality result has only limited practical value because the constant is actually quite big.

We also consider an L^2 analogue of the problem of fixed relative precision approximation: to find $\hat{\theta}$ such that $E(\hat{\theta} - \theta)^2 \leq \varepsilon^2 \theta^2$. To our knowledge, there are no earlier nonasymptotic results concerning fixed precision estimation in this sense. We use our exponential inequality to obtain an upper bound for the relative L^2 error and thus to choose $r = r(\varepsilon)$.

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Exact Methods for Evaluating Linear Pseudorandom Number Generators

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We evaluate qualities of linear pseudorandom generators over \mathbb{F}_2 in the weight distribution test with the weight discrepancy test proposed in [1]. With the weight discrepancy test, we can estimate sample sizes for which linear pseudorandom number generators fail in the weight distribution test.

In [2], a variant of GFSR generators whose characteristic polynomial is of the form $x^n + x^{m+1} + x^m + x + 1$ is proposed. We analyze this generator with the weight discrepancy test. Qualities of the generators in the weight distribution test are almost the same as those of conventional GFSR generators based on pentanomials.

We consider its generalization based on a polynomial of the form $x^n + \sum_{i=0}^{k-1} x^{m+i} + \sum_{i=0}^{k-1} x^i$. Using a trick, the latter generator runs as fast as the previous, almost independently of $k \ge 2$. However, the weight discrepancy test on this generator shows that the qualities of the generators in the weight distribution test do not improve even if we increase k.

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Monte Carlo Simulation of Stochastic Integrals when the Cost of Function Evaluation is Dimension Dependent

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We are interested in the use of Monte Carlo simulation to compute the expectation of a real-valued function, f, of a Brownian motion, B(t), i.e., $\mathbb{E}(f(B(\cdot))$. This problem arises from the pricing of financial derivatives that are path dependent. The Karhunen-Loéve expansion of the Brownian motion is used to simulate it. The Reproducing Kernel Hilbert Space methodology is used to derive the worst case error bound for the Monte Carlo algorithm, which is the sample average of evaluating f at n sample paths. The integration error is a discrepancy. We introduce weighted reproducing kernel of product form with weight γ_j . The decay order of the weight γ_j is assumed to be r. In numerical computation, we must truncate the Karhunen-Loéve expansion at a finite dimension d, and the computational cost of one function evaluation is assumed to be d. Therefore, the total cost of a simulation involving n replication sample paths is N = nd. Because the cost of one function evaluation is d, we expect that in general the convergence rate is somewhat worse than what would be expected if the cost of a single function evaluation were one. An optimal relationship between n and d is derived by minimizing the discrepancy, and this relationship depends on r.

We analyze the root mean square discrepancy of a random point set \mathcal{P} , when the points are independent identically distributed, and give a closed form for $\mathbb{E}[\mathcal{D}^2(\mathcal{P})]$. We conclude that given a budget of computation cost N = nd, the optimal relationship between n and d is $d = \mathcal{O}(n^{1/r})$, which induces that $\mathbb{E}[\mathcal{D}^2(\mathcal{P})] = \mathcal{O}(N^{-1+1/(1+r)})$.

This is joint work with Professor Fred J. Hickernell.

Adaptive Strategies for "High Dimensional" Problems

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Derivative pricing problems can often be nicely formulated as high dimensional integrals and as such quasi-Monte Carlo rules can be applied to calculate their fair price. For some of these high dimensional integrals it is known that the effective dimension of the problem is actually quite low, say two instead of hundreds. This fact alone is already an important stimulant to use a quasi-Monte Carlo method over a standard Monte Carlo one.

Additionally, for some low to moderate dimensional integrals it pays off to apply adaptive methods, however if the dimension is too high one quickly runs into problems. Two well known adaptive methods, MISER and VEGAS, have already been adapted to be used with quasi-Monte Carlo integration, see [1]. The problems we consider in this talk however do not fall into the category of being moderate dimensional.

A natural idea now is to combine the concepts of low effective dimension and classical adaptive algorithms for solving high dimensional problems. Depending on the effective low dimensionality the adaptive strategy could range from classical quadrature or cubature to adaptive QMC. In this talk we will explore the possibilities of these combinations.

This talk explores further ideas on adaptive QMC strategies from joint work with Ben Waterhouse [2].

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Recent Progress in Improvement of Extreme Discrepancy and Star Discrepancy of One-Dimensional Sequences

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In this communication, we report on recent progress in improvement of extreme discrepancy and star discrepancy of one-dimensional sequences. Namely, we present new permutations of "Babylonian" sequences in base 60, which improve the best known results obtained by Henri Faure in 1981 and 1992 [1, 2]. Our best result for extreme discrepancy in base 60 is $10635/(7198 * \log(60)) \approx 0.3609$ (Faure's best result in base 36 is $23/(35 * \log(6)) \approx 0.3668$); our best result for star discrepancy in base 60 is $111/(122 * \log(60)) \approx 0.2222$ (Faure's best result in base 12 is $1919/(3454 * \log(12)) \approx 0.2236$). Some extensions to higher dimensions are equally discussed.

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Infinite Families of Mixed Level Orthogonal Arrays

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There is a well known duality between linear error-correcting codes and orthogonal arrays. Recently, linear error-block codes were constructed using ideas from algebraic geometry [1, 2]. Using duality, linear error-block codes and other construction methods we obtain infinite families of mixed level orthogonal arrays. Some of these arrays are optimal in the sense that they reach certain coding theoretical bounds. We also study the asymptotic of the parameters (strength, dimension and number of factors) of mixed level orthogonal arrays.

As the number of factors and strength increase, the constructed arrays will have many number of runs. Such arrays have applications in computer experiments.

In real life applications mixed level orthogonal arrays arise naturally. Typically, each factor has any integer number of levels. One of the limitations of the constructed mixed level orthogonal arrays obtained from linear error-block codes is that the levels can only take values in \mathbb{F}_q or \mathbb{F}_q^k . To address this issue we also provide simple algorithms which convert the constructed linear orthogonal arrays to experimental designs with more general number of levels. The resulting arrays will in general not be orthogonal or linear. Therefore, for feasible array sizes, we use some of the standard performance measures in the experimental design literature to evaluate the effectiveness of these designs.

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Functional Approximation of the Distribution of a Stationary Diffusion with Jumps with Application to Stochastic Volatility Models

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In order to approximate the invariant distribution of a Brownian diffusion, Lamberton and Pagès built in [1, 2], a sequence of weighted empirical measures based on an Euler scheme with decreasing step and studied its convergence properties. Then, this algorithm was extended by Lemaire [3] and Panloup [5, 6] to Brownian diffusions with non Lipschitz drift term and Lévy driven SDE's, respectively. In this talk, we present a recent work with Gilles Pagès (see [4]) where we propose and study an algorithm that leads to the approximation of the whole distribution of a stationary diffusion with jumps. As a numerical application, we will see that this algorithm provides an efficient way of option pricing in stochastic volatility models when the volatility process is assumed to be stationary.

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The Construction of Good Extensible Integration Lattices

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Extensible integration lattices have the attractive property that the number of points N in the node set may be increased while retaining the existing points. It has been shown by Hickernell and Niederreiter [1] that there exist generating vectors for integration lattices which yield small integration errors for $N = p, p^2, p^3, \ldots$ Similar results have been shown by Niederreiter [2] for extensible polynomial lattices.

In this talk we provide an algorithm for the construction of good extensible generating vectors. The algorithm works for classical as well as polynomial lattices.

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The Rotor-Router Mechanism for Quasirandom Walk and Aggregation

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The rotor-router mechanism for quasirandom simulation of Markov chains, when applicable, is a parallelizable and provably convergent scheme that gives accurate estimates of such quantities as the stationary measure of a set of states in a Markov chain, the expected time for a Markov chain to enter a set of states, or the probability that a Markov chain will enter one set of states before entering another. In many cases, the error of the estimate is O(1/n) where n is the number of trials (which is the best one can hope for when n is specified in advance); in other cases, the error is $O((\log n)/n)$.

For instance, consider ordinary random walk on the two-dimensional integer lattice. The probability that a random walker starting from (0,0) will eventually reach (1,1) without first re-visiting (0,0) (the "escape probability") is rigorously known to be $\pi/8$. Under the classic MCMC approach (with independent random trials), the number of escapes in n trials would be $n(\pi/8)$ plus or minus a random quantity on the order of \sqrt{n} . Under MCQMC simulation using rotor-routers, the \sqrt{n} becomes $\log n$, and both numerical evidence and rough heuristics suggest that the true bound might be O(1), so that quasirandom estimates of the escape probability would have error O(1/n).

Work of Joshua Cooper and Joel Spencer shows that for multi-particle random-walk on grids of any finite dimension d, quasi-random simulation with rotor-routers (via "*P*-machines") allows one to estimate relevant quantities with error O(1/n).

One finds similar benefits for simulation of random aggregation. One can use rotor-routers to derandomize the Internal Diffusion Limited Aggregation (IDLA) model of Persi Diaconis and William Fulton, and the resulting deterministic process hews very closely to the average case behavior of the random process. The picture jamespropp.org/million.gif shows what quasirandom IDLA looks like after one million steps; the striking degree of circularity (recently shown to hold asymptotically by Lionel Levine and Yuval Peres) is a dramatic counterpart to the asymptotic circularity result of Greg Lawler et al. for (random) IDLA.

Although this work (conducted jointly with Ander Holroyd and Lionel Levine) is superficially quite different from earlier schemes for quasirandomizing Markov chains, there are surprising connections: the van der Corput sequence can be derived from rotor-router walk on an infinite binary tree; many rotorrouter algorithms are covertly calculating integrals on probability spaces; and combinatorial analogues of the Koksma-Hlawka inequality play a crucial role in several proofs.

Derandomized Parallel Simulation of Markov Chains Via P-Machines

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For Markov chains in which the number of allowed transitions from any given state is small, a simple yet powerful way to derandomize is to have the transitions from each state be governed by a simple mechanism called a "rotor-router". One might consider rotor-routing a sort of time-based sorting scheme, in contrast to the space-based sorting schemes discussed by other speakers in this session. The rotor-router method of simulating a Markov chain is parallelizable and provably convergent, and in many cases gives estimation methods whose error falls like O(1/n) or $O((\ln n)/n)$, where n is the number of particles being simulated.

I will begin with the problem of estimating the value of a harmonic function at a transient state of an absorbing Markov chain, given the values of the function at the absorbing states. (Many probabilistic problems, such as the problem of computing the probability that a Markov chain will enter one set of states before entering another, can be recast in this framework.) Here, a close examination of the relevant notion of discrepancy allows one to write the error of a simulation-derived estimate as a sum of contributions made by the individual states of the Markov chain, and the effort to make each of these separate contributions as small as possible leads one inevitably to re-invent rotor-routing as the optimal method of discrete simulation.

I will then discuss a result of Josh Cooper and Joel Spencer that shows that for discrete random walk, even in high-dimensional grids, quasi-random simulation with rotor-routers (via "P-machines") allows one to estimate probabilities with error O(1/n).

If time permits, I will also discuss the relationship between rotor-routing, chip-firing, and the (continuous) mass-flow method (also known as divisible chip-firing or the method of relaxation).

Correcting the Bias in Monte Carlo Estimators of American-Style Option Values

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We present a method for reducing the bias present in Monte Carlo estimators of the price of Americanstyle contingent claims. This method works by subtracting an asymptotic expression for the bias, which we derive using large-sample theory, from the estimators at each step in order to produce bias-corrected estimators. The derived expression is independent of dimensionality, holds for very general asset-price processes and payoff structures, and is easily evaluated. We apply this method to a well-studied multivariate pricing problem.

Combining Path-Based Methods, RQMC and Zero-Variance Approximations in Static Model Analysis

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We consider the problem of evaluating the probability of a rare event in the case of a static model, that is, a model where time does not play an explicit role. More specifically, we address the problem of network reliability estimation using Monte Carlo, where the network is modeled by a graph with nodes and/or edges subject to independent failures. When the reliability of the components (the probability that they are operational) is close to one, the path redundancy in the graph makes that the probability of the existence of at least a path between two selected nodes (for instance) is extremely high, and thus, that the unreliability of the whole network (the probability that the two nodes are not connected) is very small.

In this work we design efficient Monte Carlo methods for the estimation of the unreliability of such a network, by combining three approaches. First, as in other works, we use easy-to-get knowledge about the network, namely its path structure, to follow a conditional approach allowing to bound the target (this is based on ideas presented in [1]). In this talk we show, in particular, how to derive methods having bounded work-normalized relative variance in the homogeneous-lines case. Second, we explore the Randomized Quasi-Monte Carlo (RQMC) technique in this context, in order to accelerate the estimations. Third, we show that the so-called zero-variance importance sampling approximation, well established in the field of Markovian models, for instance, can be extended to this static model, and we explore the properties of the obtained procedure. The idea here is to introduce artificially a (discrete) time variable given by an order on the set of network components. A first component is chosen at time 1, then a second one at time 2, and so on.

Numerical results illustrate and compare the effectiveness of the different considered techniques, as well as their combination.

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Explicit Error Bounds for Markov Chain Monte Carlo Methods

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Markov chain Monte Carlo methods for approximating the expectation play a crucial role in numerous applications. The problem is to compute the integral of f with respect to a measure π . A straight generating of the desired distribution is in general not possible. Thus it is reasonable to use Markov chain sampling with a burn-in. Certain asymptotic error bounds are known, which can be proved via isoperimetric inequalities, the Cheeger inequality and estimates of eigenvalues. Here in contrast, an explicit error bound with burn-in time n_0 for

$$S_{n+n_0}(f) := \frac{1}{n} \sum_{i=1}^{n} f(X_{i+n_0})$$
(7.7)

will be shown. This is an extension of an outcome of [1]. Our results apply to lazy Markov chains which have a positive conductance and where the initial distribution ν has a bounded density with respect to π . All findings are in a general framework, such that after an adaption it is possible to apply the theory in different settings. So a solution of a problem stated in [2] concerning tractability or the curse of dimension is provided.

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Pricing and Hedging Asian Basket Options with Quasi-Monte Carlo Simulations

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We aim to extend the studies presented in a series of manuscripts by Dahl and Benth [2] and Imai and Tan [3] where the problem of pricing Asian basket options in a multidimensional Black-Scholes model with constant volatilities is considered. The authors describe how to identify the effective dimension of the problem (see Caffisch et al. [1]), that plays an essential role for (R)QMC simulations, using the principal component analysis (PCA) and the linear transformation (LT), respectively. Our numerical experiment consists in the RQMC estimation of the prices and the sensitivities of high-dimensional Asian basket options in a model with time-dependent volatilities. This setting is computationally more complex because we cannot rely on the properties of the Kronecker product. To this aim, we present a fast Cholesky decomposition algorithm tailored for block matrices that tremendously reduces the computational cost. Moreover, we present a new path-generation technique based on the Kronecker product approximation (see Pitsianis and Van Loan [4]) of the correlation matrix of the multidimensional brownian path that returns a suboptimal ANOVA decomposition with a substantial advantage from the computational point of view. The KPA, Cholesky, PCA and LT approaches are tested both in terms of accuracy and computational time. We demonstrate that the LT construction becomes more competitive than the PCA even from the computational point of view, provided we use the fast Cholesky algorithm we present and the ad hoc QR decomposition we showed in [5]. Finally, the KPA construction proves to be as accurate as the PCA requiring a lot lower computational time.

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We proposed a fast pseudorandom number generator SFMT (SIMD-orientd Fast Mersenne Twister) in MCQMC 2006.

Here we propose a pseudorandom number generator specialized to generate double precision floating point numbers in IEEE 754 format. The idea is simple: to generate pseudorandom 64-bit patterns with the most significant 12-bit specified, so that they represent real numbers in the range [1,2) obeying the IEEE 754 format in memory, using an \mathbb{F}_2 affine transition. Here, affine means $x \mapsto Ax + c$ where x is a state vector, A is an \mathbb{F}_2 matrix, and c is a constant vector. This constant is necessary to fix the most significant bits. By a slight modification of the classical linear case, one can obtain the (lower bound of) period and the dimension of equi-distribution of the generator.

Using SIMD instruction set, we designed dSFMT (double precision floating point SFMT), which generates two floating point numbers at one recursion. The generation speed is almost the same, or faster, than Mersenne Twister's single precision floating point number generation.

Table 7.2 shows the consumed time (second) for generating 10^8 double precision floating point numbers using SIMD instruction set. The time includes the conversion from [1, 2) to [0, 1) in the case of dSFMTs. (MT single generates single precision floating point numbers.)

	MT single	MT	SFMT	dSFMT(old)	dSFMT
Power PC G4 1.33GHz	2.723s	5.501s	2.994s	1.401s	1.212s
Athlon 64 2.4GHz	0.786s	1.588s	0.763s	0.818s	$0.680 \mathrm{s}$
Core2 Duo 1.83GHz	0.966s	2.327s	1.317s	0.457s	0.380s

Table 7.2: generation time of 10^8 double floating point numbers using SIMD

Exact Simulation Methods. Application to the Pricing of Continuous Asian Options.

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We consider two closely related exact simulation methods. The first one, due to Beskos, Papaspiliopoulos and Roberts (*Bernoulli* 12, December 2006) consists of an algorithm which allows to simulate exactly sample-paths of the solution of a 1-dimensional stochastic differential equation : by a suitable change of variables, one may suppose that the diffusion coefficient is equal to one. Then, according to Girsanov theorem, one may deal with the drift coefficient by introducing an exponential martingale weight. Because of the one-dimensional setting, the stochastic integral in this exponential weight is equal to a standard integral with respect to the time variable up to the addition of a function of the terminal value of the path. Under suitable assumptions, conditionally on a Brownian path, an event with probability equal to the normalized exponential weight can be simulated using a Poisson point process. This allows to accept or reject this Brownian path as a path solution to the SDE with diffusion coefficient equal to one.

However, in many applications, such as in finance, one is interested in computing expectations rather than exact simulation of the paths. In this perspective, computation of the exponential importance sampling weight is enough. The entire series expansion of the exponential function enables us to replace this exponential weight by a computable weight with the same conditional expectation given the Brownian path. This leads to the exact computation of expectations algorithm that we introduce in the present paper. Some of the assumptions necessary to implement the algorithm of Beskos *et al* can then be weakened at the price of a reinforced integrability condition.

We take advantage of these methods to propose an exact simulation based technique for the pricing of arithmetic average Asian options within the Black&Scholes framework. Unlike existing Monte Carlo methods, we are no longer prone to the discretization bias resulting from the approximation of continuous time processes through discrete sampling. We also give some numerical results and consider variance reduction techniques.

A Sparse Grid Method for Boltzmann Equation

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The Boltzmann equation is among the most fundamental equations in mathematical physics. However, its numerical approximation is very challenging due to its high dimensionality. Traditional grid-based methods such as finite difference and finite elements are not suitable for high dimensional problems. Monte Carlo Methods are powerful tools for dealing with high dimensional problems but they suffer from low accuracy and noisy outputs. In this talk, we present a numerical method based on sparse grids for the Boltzmann equation. In particular, we develop an efficient sparse grid method for unbounded domains and apply it to the six-dimensional Boltzman-BGK equation.

Lattice Rules for Integration Over Euclidean Space

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Lattice rules for the numerical approximation of integrals over the unit cube have been constructed under several assumptions and by using several criteria of goodness. Less work however has been done on integration over Euclidean space. For integrals over unbounded regions, it is quite common to apply some transformation of the integration domain to the unit cube in order to make use of lattice rules.

One of the criteria of goodness we propose to approximate integrals over Euclidean space is based on a worst-case error in reproducing kernel Hilbert spaces with the kernel based on the Fourier transform of functions. Under a product weighted setting, we show that we can construct shifted lattice rules that produce a theoretical convergence order of $O(n^{-1/2})$ with the involved constant independent of the dimension. Although such a convergence is the same as the one resulting from Monte Carlo methods, numerical experiments seem to suggest that in practice the actual convergence rate is better.

Another criterion of goodness is based on the weighted star discrepancy. In such a case, we obtain an improved theoretical convergence of $O(n^{-1+\delta})$ for any $\delta > 0$ and with the involved constant independent of the dimension. This approach also presents the advantage of allowing more generality on the weights.

In both situations, we construct shifted lattice rules by using the well-known component-by-component technique.

QMC for Flow Through a Porous Medium

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The problem of flow through a porous medium, with the permeability treated as a Gaussian random field, can be thought of as a high-dimensional problem: the dimensionality is the number of terms in a truncated Karhunen-Loève expansion. In this paper, describing joint work with F. Kuo, I. Graham and R. Scheichl, we expore the use of QMC to study the dispersion of the fluid as it seeps through the medium, and compare the results with MC. The preliminary results are encouraging.

Novel Adaptive Monte Carlo Algorithms for General Transport

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In the past decade, there has been a concerted effort to develop adaptively modified Monte Carlo algorithms that converge geometrically to solutions of the radiative transport equation. Our group has concentrated on algorithms that extend methods first proposed for matrix equations by Halton in 1962 to integral equations. This was accomplished by expanding the solution in suitable basis functions and estimating a finite number of expansion coefficients by random variables that are based either on correlated sampling or importance sampling, adaptively improved in stages. Geometric convergence has been rigorously demonstrated for these "first generation" algorithms but their practical utility is limited by computational complexities imposed by the expansion technique itself. Recently, we have developed new adaptive algorithms that overcome most of the computational restrictions of the earlier algorithms and we have also demonstrated the geometric convergence of these "second generation" algorithms. In this presentation we will outline the main ideas involved and indicate how the new algorithms can be used to draw inferences about the transport process itself and to optimize the algorithm design. Simple examples will illustrate these ideas and demonstrate the gains in computational efficiency that the new methods can achieve.

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Modified Sequential Monte Carlo Methods for Lagrangian Data Assimilation

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Issues surrounding the assimilation of data into models have recently gained prominence in almost all areas of geophysics. The quantity and quality of data have increased dramatically with ever-improving observational technologies. At the same time, the ability to run extensive simulations on ever-faster computers has enhanced the use of models. Data assimilation is the problem of estimating the optimal prediction that combines model output, with its attendant uncertainty, and observations, which will also contain errors.

In this talk we will describe data assimilation techniques applied to a point-vortex fluid model. Owing to small dimensionality and yet complex nonlinear (Lagrangian) dynamics, vortex models are a natural paradigm for the investigation of systems with Lagrangian observations. The ultimate goal of this investigation is to estimate hidden states of a nonlinear, stochastic dynamical system by combining model predictions and noisy partial observations of the system. Sequential Monte Carlo (SMC) techniques allow one to approximate posterior distributions of hidden states at an observation instant without making assumptions of linearity on the dynamic model or of Gaussianity on the prior or posterior distributions of the state variables. Particle filters are a way to implement SMC using a large number of random samples, or particles, to obtain discrete approximations of these distributions. We will describe several modifications to particle filters that improve their performance, and we will compare these methods to a standard (Kalman based) assimilation method.

Ergodic Estimations of Upscaled coefficients for Diffusion in Random Velocity Fields

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Ergodic simulations, which estimate ensemble statistics of the effective diffusion coefficients by space averages with respect to locations of the initial concentration pulse computed for a single sample of a random velocity field with finite correlation range [1], indicate the ergodicity of a suitably defined Lagrangian velocity field. The latter is constructed by sampling the random velocity field on a single trajectory of the diffusion process. Hence, some ergodic estimations can be further simplified by fixing not only the velocity sample but also the trajectory of the diffusion process. This is the case of upscaled diffusion coefficients, defined as hydrodynamic long time limit of ensemble coefficients (i.e. ensemble averages of effective coefficients corrected for the randomness of the center of mass of the solute body). We show that the upscaled diffusion coefficients can be computed by summing up correlations of increments of the positions process, or equivalently of Lagrangian velocity, over a finite-time path on the trajectory. The correlations are estimated by space averages with respect to moving origins of the path on the same trajectory. The first term in this path correlations expansion corresponds to Markovian behavior and is the only one contribution for processes with independent increments. The next terms describe memory effects on ensemble diffusion coefficients until they level off to the value of the upscaled coefficients. The accuracy of the estimation increases with the length of the simulated diffusion trajectory. Since the convergence with respect to the path length is rather fast and no repeated Monte Carlo simulations are required, this method speeds up the computation of upscaled coefficients over methods based on hydrodynamic limit and ensemble averages [2] by four orders of magnitude. Besides its computational efficiency, the path correlation expansion of the upscaled coefficients can be utilized to evaluate ergodic properties of random fields generators and is especially well suited for investigations on diffusion in fractal velocity fields.

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Monte Carlo Estimation of the Distribution Function of Conditional Expectations: Continuous Conditioning Spaces

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We study the problem of estimating the distribution function of conditional expectations, where the conditioning component takes values in a continuous outcome space. Our estimation procedure consists of two steps: sampling the conditioning element (external sampling), followed by sampling the conditioned variable (inner sampling). The measure of efficiency is rate of convergence, as measured against simulation budget. We determine asymptotic mean squared error expressions, which can be exploited to compare the performance of several variations of the estimation algorithm: constant inner-sampling, variable inner-sampling, and biased inner sampling. We also present central limit theorems and large deviations results for some of our estimators.

Confidence Intervals for Causality Measures and Tests of Non-Causality

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The concept of causality introduced by Wiener (1956) and Granger (1969) is defined in terms of predictability one period ahead. This concept can be generalized by considering causality at a given horizon h, and causality up to any given horizon h [Dufour and Renault (1998, *Econometrica*)]. This generalization is motivated by the fact that, in the presence of an auxiliary variable vector Z, it is possible that a variable Y does not cause variable X at horizon 1, but causes it at horizon h > 1. In this case, there is an indirect causality transmitted by the auxiliary variable vector Z. An important related consists in measuring causality at different horizons [Dufour and Taamouti (2006)]. In this paper, the statistical reliability of nonparametric bootstrap confidence intervals for causality measures at different horizons is studied. Simulation-based tests for non-causality at different horizons are also derived from these confidence intervals and compared with alternative causality tests.

A Quasi-Monte Carlo Scheme for the Simulation of the Coagulation-Fragmentation Equation

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The coagulation-fragmentation equation is a non linear integro-differential equation, describing the evolution of the number density of particles c(x,t) of mass x at time t, under the influence of physical processes, such as coagulation and fragmentation.

Many deterministic and stochastic approaches have been proposed to simulate Smoluchowski's coagulation equation [1, 2] or the coagulation-fragmentation equation [3]. In [4], a quasi-Monte Carlo scheme to simulate the discrete coagulation equation is proposed. This algorithm is extended to the continuous coagulation/condensation equation in [5].

In this communication, we propose a QMC algorithm for the coagulation-fragmentation equation. The steps of this algorithm can be summarized as follows : a fixed number N of numerical particles is used to approximate the initial size distribution. Time is discretized and quasi-random numbers are used to move the particles according to the equation dynamics. To insure the convergence of the scheme, particles are relabeled by their mass at each time step.

The algorithm is validated in the case where analytical solutions are available and compared with a standard Monte Carlo method. Numerical results show that the QMC algorithm is more efficient than the standard MC scheme and can be considered as a reference method.

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Efficient and Unbiased Greeks of Rainbow Options with Importance Sampling

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The price of a derivative security equals the discounted expected payoff of the security under a suitable measure, whereas Greeks are price sensitivities with respect to parameters of interest. Monte Carlo simulation has proved invaluable to computing the prices and Greeks of derivative securities. Although finite difference with resimulation is the standard method for estimating the Greeks, it is in general biased and suffers from erratic behavior when the payoff function is discontinuous. This paper builds a new mathematical formulation so that formulas of Greeks for a broad class of derivative securities can be derived systematically. It then presents an importance sampling method to estimate the Greeks. For numerical illustrations, our method gives unbiased Greeks of two popular multi-asset options (also called rainbow options). These are the first in the literature.

The Portfolio Risk Modeling with Lévy Processes

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An inherent part of financial modeling is the portfolio modeling procedure. It is important mainly for risk management of financial institutions. Portfolios of financial institutions are sensitive to several market risk factors. As highly important, we can regard exchange rates of foreign currencies. In this paper, we try to model the probability distribution of real returns of a portfolio sensitive to several foreign exchange rates with selected processes of Lévy family. This allows us to model also the skewness and kurtosis of the underlying distribution. We concentrate our attention first of all on modeling of the dependency among particular sources of randomness which requires to deal with a copula function. Although we find slight inconsistences between the empirical distribution and the modeled one, the application of multivariate Lévy models represents a substantial improvement comparing with the Gaussian case.

Monte Carlo Algorithm for Estimating the Asymptotic Parameters of Polarized Radiation

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There exists a number of problems in radiation transfer theory where researchers are interested in asymptotic behavior of radiation beams for large time periods in light-scattering media. It is known that for nonpolarized radiation under some rather general conditions such time asymptotics is exponential. A parameter of this exponential asymptotics is the principal eigenvalue of the homogeneous stationary transfer equation with standard boundary conditions (see [1]). Our work deals with solution of problems related to extending this assertion to the case of polarized radiation, on the basis of large-scale Monte Carlo simulation.

Earlier, it was obtained for homogeneous infinite media that asymptotic parameter in the case of polarized radiation coincides with one in the case of nonpolarized radiation [2]. Also, using precision calculations by the Monte Carlo technique it was shown that for bounded media in the case of molecular and aerosol scattering, values of the asymptotic parameter for modelling without polarization and with one are not equal, moreover the depolarization of the particle flux is slightly delayed with respect to passing to the asymptotics [2].

In this work we consider problem of estimation of time asymptotic parameters of polarized radiation flow emitted from a semi-infinite layer of scattering and absorbing media with a light source on its boundary. Based on a method of parametric differentiation of special representation of the solution of the nonstationary vectorial transfer equation we obtain estimates of desired asymptotic parameters of intensity of radiation flow and illuminance of the boundary of a semi-infinite layer, i.e., backscattering noise for the corresponding version of optical sounding. It is shown, that asymptotic parameters while modelling with polarization and without are in close agreement for this problem. However variances of estimates of parameters in a vector case are greater, than in scalar one.

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Exact Tests for Testing Short- and Long-Memory Features on Stochastic Volatility Models

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In this paper we are concerned with testing hypotheses on parameters of stochastic volatility (SV) models with short and long memory. Following Breidt, Crato and de Lima (1998), a long memory stochastic volatility model (LMSV) is constructed by incorporating an ARFIMA process in the standard stochastic volatility scheme. Exploiting the fact that short-range and long-range SV models are parametric models involving only a finite number of unknown parameters, our basic outlook is to develop finite-sample simulation-based procedures as opposed to procedures based on establishing asymptotic distributions. For that purpose, we rely on extensions of the basic idea of Monte Carlo (MC) tests originally proposed by Dwass (1957) and Barnard (1963). When the distribution of a test statistic does not depend on (unknown) nuisance parameters, the technique of MC tests yields an exact test provided one can generate a few i.i.d. (or exchangeable) replications of the test statistic under the null hypothesis; for example, 19 replications are sufficient to get a test with level 0.05; see Dufour-Khalaf (2001). This technique can be extended to test statistics which depend on nuisance parameters by considering maximized Monte Carlo (MMC) tests; see Dufour (2006). MMC tests yield exact tests whenever the distribution of the test statistic can be simulated as a function of the nuisance parameters: no additional assumption on its distribution is needed. More specifically, we propose specification tests for testing short versus long memory in the form of a likelihood-ratio-type statistic. The likelihood-ratio-type statistic is built from a GMM objective function and will also serve as a basis for hypotheses tests. In a simulation study, we will investigate the finite sample behavior of the test procedure before considering its application on real financial data (S&P 500 index).

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Effective Dimension and Discrepancy

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We consider a numerical code which takes in entry a large number of parameters. These parameters describe an aircraft in its environment and calculates the corresponding infrared signature, which is considered as a real valued response. Moreover, several sources of variability lead to a dispersion of the output values. In order to size the optronics systems, we need to evaluate the dispersion of the response, near the threshold of detection, due to the uncertainty of the inputs. It means we need to evaluate the detection probability of the aircraft. Our study thus consists in estimating the integral of an unknown function h defined on a high dimensional space. The standard Monte Carlo (MC) method is frequently used. Sometimes the evaluation of h with a good precision is time consuming and it is not possible to find a sufficiently large sample of values of h. In this case the alternative is the Quasi-Monte Carlo method (QMC), thanks to a better rate of convergence, which depends on the dimension. More precisely, when the dimension is too large, the Monte Carlo method is theoretically better. To reduce the dimension before applying the Quasi-Monte Carlo method, we use the factorial designs method. We study the impact of the variation of the inputs on the output, through a Fisher's test. This sensitivity analysis yields an order of importance of the variables for h under a normality assumption concerning the response h. But this assumption is not always fulfilled in our framework. Besides, it is known that some low-discrepancy sequences used in Quasi-Monte Carlo method present irregularity of distribution on some low order projections [1]. Such irregularities for important variables could lead to bad rates of convergence.

In this talk, first I will present an analysis of factorial designs that yields an order of importance of the variables for h without the normality assumption in using continuous ANOVA's. I will also deduce a way to compute the effective dimension. Next I will present a criterion that enables us to choose the best sequence adapted to the function of interest. Then I will construct a low discrepancy sequence that takes into account the information contained in the factorial design to compute efficiently the integral of h. Finally, I will illustrate these results with numerical simulations.

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Pricing American Options in High Dimensions: A Primal-Dual QMC Simulation with Dimension Reduction

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The pricing of American options is one of the most challenging problems in computational finance, especially when the options are written on multiple underlying assets and/or have path dependent feature. Progress has been made in using Monte Carlo (MC) simulation to give both the lower bound (say, by least-squares Monte Carlo method — LSM) and the upper bound by a duality approach. In this paper, we investigate the adaptations of quasi-Monte Carlo (QMC) simulation based on digital nets and good lattice points to compute the lower bound by LSM and the upper bound by duality approach of American option prices. We design strategies of using dimension reduction techniques, such as the Brownian bridge and principal component analysis and their combinations. We perform numerical experiments on American-Bermudan-Asian options and Bermudan max-call options and demonstrate that the use of QMC simulation and dimension reduction can significantly increase the efficiency in computing the lower and upper bounds. The duality gap, i.e., the difference in upper and lower bounds, obtained by QMC is much smaller than that in MC.

Fast Implementation of PCA for QMC for Financial Problems of Unequal Time-Steps

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In recent years quasi-Monte Carlo (QMC) methods have been shown to have significant advantages over Monte Carlo (MC) methods in the fast evaluation of integration problems from mathematical finance. The performance of QMC methods can be further improved by formulating the integral so that more variance is placed in the opening dimensions of the problem where the QMC points are "of better quality". Two of the common ways of doing this for Gaussian-based problems are via the Brownian Bridge technique and the Principal Components Analysis (PCA) technique. The advantage of the Brownian Bridge technique is that a *d*-dimensional path can be constructed in $\mathcal{O}(d)$ operations, whereas the matrixvector multiplication of the PCA technique requires $\mathcal{O}(d^2)$ operations. Recently it was shown that if the time-steps are of equal size, then the PCA method could be implemented with an FFT in $\mathcal{O}(d \log d)$ operations. In this talk we will show how this can be extended to cases where the time-steps are not of equal size. Each matrix-vector multiplication can be approximately calculated in $\mathcal{O}(d \log d)$ with a one-off calculation of the eigenvalue and eigenvectors taking $\mathcal{O}(d^2)$ operations.

Optimal Scaling of MCMC for Conditioned Diffusions

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I intend to outline a set of configurable methods for sampling conditioned diffusions. Conditions diffusions arise in many applications. Therefore it is important to understand how to optimise the efficiency of sampling methods. In particular, I am interested in the case where the drift dominates the noise.

To understand this issue, the methods are applied to the problem of sampling conditioned OU processes. The conditioned OU process is constructed with a single parameter, k, which governs the size of the drift. This effectively controls the difficulty of the sampling problem. This parameter is used to assess the algorithm efficiency of each of the proposed methods. I will outline how the optimal configuration of each algorithm is found as a function of k. Complementary theory and numerical results will be presented to substantiate the claims made. If time permits, results from other more complicated sampling problems will be presented.

Tractability for Multivariate Integration: My 15-Year Partnership with Ian Sloan

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In 1994 I visited Ian Sloan for the first time in Sydney and we started to work on tractability of multivariate integration. The main point was, and still is, to prove that error bounds of some QMC algorithms using n function values for integrals with d variables do not depend exponentially on d and go to zero polynomially with n^{-1} . We realized that to achieve this goal we must have *weighted* spaces for which the influence of successive variables or, more generally, groups of variables is moderated by weights. In 1998 we published the first paper where weighted spaces were introduced and necessary and sufficient conditions on *product weights* were given for polynomial error bounds of some QMC algorithms.

Today, the subject of tractability of multivariate integration as well as of other multivariate problems is thoroughly studied by many people. Different weights has been proposed to study including *finiteorder* weights proposed in our joint paper with Joseph Dick and Xiaogun Wang. The first tractability results were non-constructive. Then Ian and Stephen Joe initiated the study of CBC (component-bycomponent) algorithms to get constructive tractability results. The major breakthrough was the work of Frances Kuo to achieve constructively the best exponents of convergence by using lattice rules, and the work of Ronald Cools and Dirk Nuyens to design fast CBC algorithms. We also studied with Frances tractability of multivariate approximation in both the worst case and average case settings using lattice rules.

In my talk, I explain the recent progress on tractability of multivariate integration and approximation for a specific weighted Sobolev space of smooth functions which has a very intriguing reproducing kernel. I present necessary and sufficient conditions on the smoothness parameter and weights to obtain various types of tractability. In particular, it will be shown that smoothness and tractability are not related, and that smoothness may sometimes hurt tractability. The last part of my talk will be based on a joint paper with A. G. Werschulz.

Identification of Outlying Subsets of Data: A New Algorithm Based on Resampling

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The problem of identifying or detecting outlying subsets is important in various applications of data analysis, in particular in medicine and biology. So far it has received much less attention than identifying single outliers [1]. We propose a new method, based on existing techniques of discriminant analysis. Our algorithm can be considered as a special case of a highly multivariate test of homogeneity in which we essentially make use of Monte Carlo methods. The main idea is to quantify atypicality of a questionable subset of data by computing a specially constructed measure of separability. This measure is based on resampling estimators of correct classification by a discriminant function (which is in principle arbitrary but in our applications usually quadratic). The critical values and p-values of the resulting test are computed by Monte Carlo methods, using resampling from the main bulk of data.

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Chebyshev Spectral Methods on Lattices for High-Dimensional Functions

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It is well-known that the number of nodes required to obtain a given accuracy using product algorithms increases exponentially with increasing dimension. Lattice methods are widely used in multiple integration to avoid the curse of the dimensionality. Recently some algorithms for approximation of periodic functions using lattice points have been developed by Li & Hickernell (2003), Kuo, Sloan & Wozniakowski (2005) and Zeng, Leung & Hickernell (2005).

In this paper, we present a numerical method for the approximation of non-periodic functions. The designs, $\{\mathbf{x}_i\}$, considered here, in contrast to the classic ones, are half of the node sets of integration lattices with a cosine transformation. It is supposed that f can be expressed by an absolutely convergent multidimensional Chebyshev series expansion. We approximate its Chebyshev coefficients at some selected nonnegative wavenumbers by a lattice rule and set the other Chebyshev coefficients to be zero. The approximation of f is then taken to be the Chebyshev expansion based on these approximate Chebyshev coefficients. The error of the approximation is discussed in a weighted L^2 norm. The convergence rate is related to the rate of the true Chebyshev coefficients' decay. We also provide the numerical simulation result of the 8 dimensional borehole function with experimental convergence rate as $O(N^{-1})$.

This is a joint work with Fred J. Hickernell, Jingtang Ma and Dong Li.

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Solving Continuous-State POMDPs via Projection Particle Filtering

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Research on numerical solution methods for partially observable Markov decision processes (POMDPs) has primarily focused on discrete-state models, and these algorithms do not generally extend to continuous-state POMDPs, due to the infinite dimensionality of the belief space. In this paper, we develop a computationally viable and theoretically sound method for solving continuous-state POMDPs by effectively reducing the dimensionality of the belief space via density projections. The density projection technique is incorporated into particle filtering to provide a filtering scheme for online decision making. We provide an error bound between the value function induced by the policy obtained by our method and the true value function of the POMDP, and also an error bound between the projection particle filtering and the optimal filtering. Finally, we illustrate the effectiveness of our method through an inventory control problem.

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