Accelerating Industrial Innovation with Quantum Computing and Data Science

8 March 2023

National University of Singapore, Singapore

As the era of big data continues to evolve, the need for efficient and effective quantitative techniques is becoming increasingly important for industrial innovation. The advent of quantum computing and data science promises to revolutionize the way we understand and make decision with complex data and environment. This workshop will explore the latest advancements in the intersection of data science and quantum computing, and how these technologies can be harnessed to accelerate industrial innovation. The workshop will cover a broad range of topics, including quantum machine learning, quantum optimization, and industrial optimization, as well as their applications in industrial settings. Experts in both data science and quantum computing will present their latest research and provide practical insights on the potential benefits and challenges of incorporating these cutting-edge technologies to drive industrial innovation.

Organized by:

Department of Mathematics, National University of Singapore

Centre for Quantum Technologies, National University of Singapore

Institute of Operations Research and Analytics, National University of Singapore

Asian Institute of Digital Finance, National University of Singapore

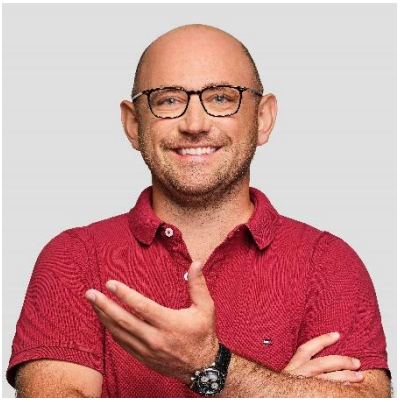
Workshop program

Date: March 8, 2023 (Wednesday)

Venue: Room I4-01-03, Innovation 4.0 (I4) Building, 3 Research Link, NUS, 117602

9:30-9:50	Registration
9:50-10:00	Opening
10:00-10:40	Stefan Woerner, IBM Zürich, Switzerland Title: The Power & Complexity of Quantum Machine Learning Models
10:40-11:20	Thorsten Koch, Technische Universität Berlin & Zuse Institute Berlin, Germany Title: Solving QUBOs on Digital Computers and Quantum Annealers
11:20-11:50	Tea Break
11:50-12:20	Ralf Borndörfer, Freie Universität Berlin & Zuse Institute Berlin, Germany Title: Flight Trajectory Planning
12:20-13:00	Dabin Wang, J.P. Morgan, Germany Title: Blockchain Security and Post-QC Applications
13:00-14:30	Lunch
14:30-15:00	Patrick Rebentrost, National University of Singapore, Singapore Title: Quantum finance: pricing of classical and quantum assets
15:00-15:30	Ariel Neufeld, Nanyang Technological University, Singapore Title: Quantum Monte Carlo algorithm for solving Black-Scholes PDEs for high-dimensional option pricing in finance and its proof of overcoming the curse of dimensionality
15:30-16:00	Tea Break
16:30-17:00	João Doriguello, National University of Singapore, Singapore Title: Quantum algorithm for stochastic optimal stopping problems with applications in finance
17:00-17:30	Debbie Lim, National University of Singapore, Singapore Title: A Quantum Online Portfolio Optimization Algorithm
17:30	Closing Remarks

Title: The Power & Complexity of Quantum Machine Learning Models



Speaker: Dr. Stefan Woerner (IBM Zürich, Switzerland)

Abstract: Applying quantum computing in the field of machine learning is a very active and promising area of research. First quantum machine learning models have been proven to achieve an exponential speed-up over classical approaches on constructed learning problems. For practical applications, the scaling and power of such models needs to be analyzed further as well as demonstrated empirically. In this presentation we discuss quantum support vector machines and quantum neural networks, compare their practical scaling, analyze how they may outperform classical approaches, and discuss practical implementations and obstacles that need to be resolved on the way.

Bio: Dr. Stefan Woerner is a Principal Research Scientist and Manager of the Quantum Computational Science group at IBM Quantum, IBM Research Europe – Zurich. He received a Master of Science in Applied Mathematics from ETH Zurich in 2010, and a Doctor of Sciences in Operations Management from ETH Zurich in 2013. The focus of his research is the development and analysis of quantum algorithms for optimization, simulation, and machine learning as well as their practical applications, particularly in finance.

Title: Solving QUBOs on Digital Computers and Quantum Annealers

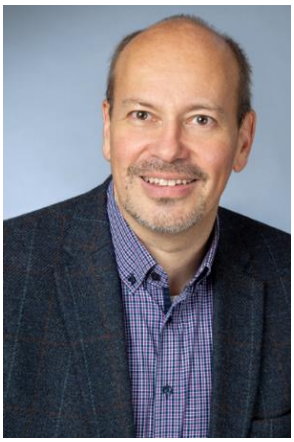
Speaker: Prof. Dr. Thorsten Koch (Technische Universität Berlin & Zuse Institute Berlin, Germany)

Abstract: It is regularly claimed that quantum computers will bring breakthrough progress in solving challenging combinatorial optimization problems relevant in practice. In particular, Quadratic Unconstraint Binary Optimization (QUBO) problems are said to be the model of choice for use in (adiabatic) quantum systems. Now that first commercial quantum-based systems are advertised to solve such problems. We present results from comparing the performance of these system with state-of-the-art software on classical digital computers on NP-hard optimization problems.

Bio: Prof. Dr. Thorsten Koch is Professor for Software and Algorithms for Discrete Optimization at TU-Berlin and head of the Applied Algorithmic Intelligence Methods and

the Digital Data and Information for Society, Science, and Culture departments at the Zuse Institute Berlin (ZIB). He has worked in several areas, especially the planning of infrastructure networks, chip verification, mathematics education and integer optimization. From 2008-2014 he was the coordinator of the FORNE project, an industry collaboration project regarding gas transportation involving five universities and two research institutes. The project received the 2016 EURO Excellence in Practice Award of the European OR Society.
From 2013-2019 he was head of the GasLab and the SynLab within the Research Campus MODAL (Mathematical Optimization and Data Analysis Laboratory). The project Optimized Execution of Dispatching conducted together with Germanys largest Gas Transmission System Operator became finalist of the 2020 INFORMS Innovative Applications in Analytics Award.
Currently, the work is focused on developing high-performance parallel methods for solving large-scale structured optimization problems. Such problems arise, for example, in data-driven, real-world analysis and planning of sustainable network infrastructures. This includes high-performance solvers for Steiner Tree Problems in Graphs (STPG) and Quadratic Unconstraint Binary Optimization (QUBO).

Title: Flight Trajectory Planning



Speaker: Prof. Dr. Ralf Borndörfer (Freie Universität Berlin & Zuse Institute Berlin, Germany)

Abstract: The Flight Planning Problem deals with the computation of a best possible aircraft route subject to weather conditions, traffic flow restrictions, and overflight fees, the objective is usually to minimize a combination of costs and travel time. The problem can be approached from a discrete and from a continuous point of view. From a discrete point of view, the problem can be modelled as a time-dependent shortest path problem in a world wide 3D airway network and solved using A* techniques. These are tailored to the specific application using special preprocessing technique, lower bounds derived from super-optimal winds and idealized vertical profiles, and multi-label algorithms to deal with several objectives and constraints. From a continuous point of view, which is currently gaining importance under the upcoming free flight paradigm, the problem is a generalization of the classical Zermelo navigation problem. In this case, it is possible to solve the global optimization problem to proven optimality (up to any desired accuracy) using a discrete-continuous adaptive discretization approach. The talk discusses these developments and their application in one of the leading flight planning systems.

Bio: Prof. Dr. Ralf Borndörfer is a Professor for Discrete Mathematics at Freie Universität Berlin and head of the Network Optimization department at Zuse-Institute Berlin; he also serves as Scientist in Charge of the Application Area Networks of the Berlin Mathematics

Excellence Cluster Math+, as president of the heureka Foundation for Environment and Mobility, and as one of the heads of the Traffic and Transport working group of the German Operations Research Society. His work is on combinatorial optimization and integer programming with applications to traffic and transport.
He was head of several projects with Deutsche Bahn AG, in which RotOR, an ICE highspeed train rotation optimizer based on hypergraphical methods, was developed. This optimizer is integrated in DB's FEO planning system, which was presented in the finals of the 2020 INFORMS Edelman award.
He is one of the founders of LBW Optimization, a supplier of commercial high performance vehicle and duty optimization systems.
His current research is on geometric optimization methods for periodic timetabling, discrete and continuous optimization methods for flight planning, electric vehicle scheduling, predictive railway maintenance, air cargo scheduling, and toll enforcement.

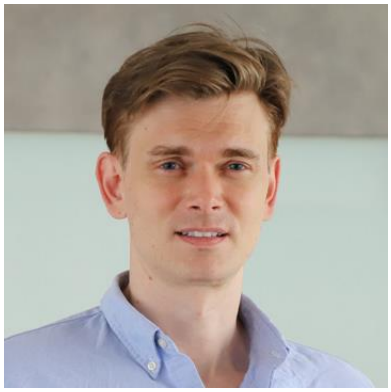
Title: Blockchain Security and Post-QC Applications

Speaker: Dr. Dabin Wang (J.P. Morgan, Germany)

Abstract: TBD

Bio: Extensive experience in portfolio analysis across multiple asset classes (held Series 7) and specialization in FX, Commodities, Emerging Markets, capital modeling
Adjunct Professor at Columbia University
Experience in Big Data, system built-out and machine learning
Economist with strong communication, quantitative skills and keen to innovate
Electronic Trading, Analytics and Model Risk

Title: Quantum finance: pricing of classical and quantum assets



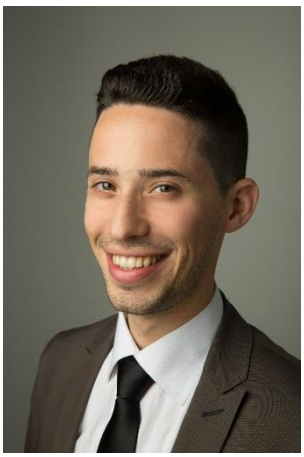
Speaker: Dr. Patrick Rebentrost (National University of Singapore, Singapore)

Abstract: Quantum computers have the potential to provide advantages for solving problems in finance. First, we briefly review the pricing of financial derivatives using quantum subroutines for Monte Carlo estimation. Second, we investigate new market scenarios and asset classes that

could arise from the emergence of quantum technologies for computation and communication. We define the notion of quantum assets and develop an extended definition of arbitrage. We provide a quantum version of the first fundamental theorem of asset pricing, with application to new types of financial derivatives.

Bio: Patrick Rebentrost's research interests are in quantum computing, quantum algorithms, quantum machine learning, learning theory, and mathematical finance. He currently leads a project on "Computer science approaches to quantum computing for finance" supported by Singapore's Quantum Engineering Programme. This project looks at how quantum computers can address computational challenges such as options pricing, portfolio optimisation and trading. He joined CQT in 2018 as a Senior Research Fellow, becoming a PI in 2022. His previous affiliations include Massachusetts Institute of Technology and Xanadu Quantum Technologies.

Title: Quantum Monte Carlo algorithm for solving Black-Scholes PDEs for high-dimensional option pricing in finance and its proof of overcoming the curse of dimensionality

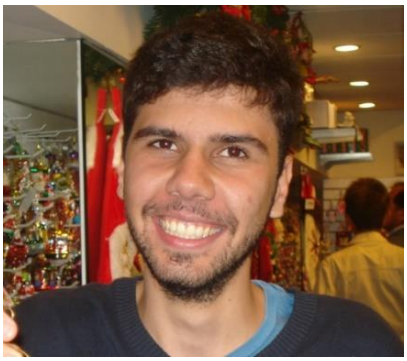


Speaker: Prof. Ariel Neufeld (Nanyang Technological University, Singapore)

Abstract: In this talk we provide a quantum Monte Carlo algorithm to solve high-dimensional Black-Scholes PDEs with correlation for high-dimensional option pricing. The payoff function of the option is of general form and is only required to be continuous and piece-wise affine (CPWA), which covers most of the relevant payoff functions used in finance. We provide a rigorous error analysis and complexity analysis of our algorithm. In particular, we prove that the computational complexity of our algorithm is bounded polynomially in the space dimension d of the PDE and the reciprocal of the prescribed accuracy ε and so demonstrate that our quantum Monte Carlo algorithm does not suffer from the curse of dimensionality.

Bio: Ariel Neufeld is a Nanyang Assistant Professor in mathematics at the Nanyang Technological University in Singapore. He received his PhD in mathematics in May 2015 at ETH Zurich, where he spent half of his PhD at the Columbia University in the City of New York. Prior to joining NTU he was a postdoctoral researcher at ETH Zurich. His research focuses on machine learning algorithms and their applications in finance and insurance, model uncertainty in financial markets, financial and insurance mathematics, stochastic analysis and stochastic optimal control, as well as stochastic optimization and applied probability theory.

Title: Quantum algorithm for stochastic optimal stopping problems with applications in finance



Speaker: Dr. João Doriguello (National University of Singapore, Singapore)

Abstract: The famous least squares Monte Carlo (LSM) algorithm combines linear least square regression with Monte Carlo simulation to approximately solve problems in stochastic optimal stopping theory. In this work, we propose a quantum LSM based on quantum access to a stochastic process, on quantum circuits for computing the optimal stopping times, and on quantum techniques for Monte Carlo. For this algorithm, we elucidate the intricate interplay of function approximation and quantum algorithms for Monte Carlo. Our algorithm achieves a nearly quadratic speedup in the runtime compared to the LSM algorithm under some mild assumptions. Specifically, our quantum algorithm can be applied to American option pricing and we analyze a case study for the common situation of Brownian motion and geometric Brownian motion processes.

Bio: João Doriguello finished his PhD at the University of Bristol under the supervision of Ashley Montanaro and is currently based at the National University of Singapore working with Miklos Santha and Patrick Rebentrost. He is mainly interested in communication complexity, Boolean analysis, quantum algorithms and quantum finance

Title: A Quantum Online Portfolio Optimization Algorithm

Speaker: Debbie Lim (National University of Singapore, Singapore)

Abstract: Portfolio optimization plays a central role in finance to obtain optimal portfolio allocations that aim to achieve certain investment goals. Over the years, many works have investigated different variants of portfolio optimization. Portfolio optimization also provides a rich area to study the application of quantum computers to obtain advantages over classical computers. In this work, we give a sampling version of an existing classical online portfolio optimization algorithm by Helmbold et al., for which we in turn develop a quantum version. The quantum advantage is achieved by using techniques such as quantum state preparation, inner product estimation and multi-sampling. Our quantum algorithm provides a quadratic speedup in the time complexity, in terms of n, where n is the number of assets in the portfolio. The transaction cost of both of our classical and quantum algorithms is independent of n which is especially useful for practical applications with a large number of assets.

Bio: Debbie Lim is a PhD student at the Centre for Quantum Technologies, supervised by Patrick Rebentrost. She obtained BSc in Mathematical Sciences from Nanyang Technological University in 2018. Her current research interest are quantum algorithms, online learning algorithms and optimization algorithms.