# Singapore Mathematics Symposium 2026 Lectures

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# The Connections Between Discrete Geometric Mechanics, Information Geometry, Accelerated Optimization and Machine Learning

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Geometric mechanics describes Lagrangian and Hamiltonian mechanics geometrically, and information geometry formulates statistical estimation, inference, and machine learning in terms of geometry. A divergence function is an asymmetric distance between two probability densities that induces differential geometric structures and yields efficient machine learning algorithms that minimize the duality gap. The connection between information geometry and geometric mechanics will yield a unified treatment of machine learning and structure-preserving discretizations.

In particular, the divergence function of information geometry can be viewed as a discrete Lagrangian, which is a generating function of a symplectic map, that arise in discrete variational mechanics. This identification allows the methods of backward error analysis to be applied, and the symplectic map generated by a divergence function can be associated with the exact time-$h$ flow map of a Hamiltonian system on the space of probability distributions. We will also discuss how time-adaptive Hamiltonian variational integrators can be used to discretize the Bregman Hamiltonian, whose flow generalizes the differential equation that describes the dynamics of the Nesterov accelerated gradient descent method.

## ABOUT THE SPEAKER

Melvin Leok is professor of mathematics and director of the Computational Science, Mathematics and Engineering program at the University of California, San Diego. His research interests are in computational geometric mechanics, computational geometric control theory, discrete differential geometry, and structure-preserving numerical schemes, and particularly how these subjects relate to systems with symmetry. He received his Ph.D. in 2004 from the California Institute of Technology in Control and Dynamical Systems under the direction of Jerrold Marsden.

He was a PIMS Marsden Memorial Lecturer, Simons Fellow in Mathematics, three-time NAS Kavli Frontiers of Science Fellow, and has received the DoD Newton Award for Transformative Ideas, NSF Faculty Early Career Development (CAREER) Award, SciCADE New Talent Prize, SIAM Student Paper Prize, Leslie Fox Prize (second prize) in Numerical Analysis, A*STAR International Fellowship, and Loke Cheng-Kim Foundation Scholarship. He has given plenary talks at Foundations of Computational Mathematics, NUMDIFF, and the IFAC Workshop on Lagrangian and Hamiltonian Methods for Nonlinear Control, and is the coauthor of a research monograph entitled, “Global Formulations of Lagrangian and Hamiltonian Dynamics on Manifolds.”

## Can Quantum Computing Speed Up Monte Carlo? A Case Study in Option Pricing

Ariel Neufeld

*Nanyang Technological University*

In this talk, I will begin with a gentle introduction to the basic principles of quantum computing and discuss how quantum algorithms may offer computational advantages over classical methods, with particular emphasis on quantum versus classical Monte Carlo methods.

I will then present a quantum Monte Carlo algorithm for pricing options in the multi-dimensional Black–Scholes model with correlated assets. A central objective of our work is to go beyond idealized, oracle-based complexity estimates by providing a rigorous end-to-end analysis of the numerical procedure, including both its approximation error and computational cost.

We prove that the complexity of the algorithm grows at most polynomially in the dimension $d$ and the reciprocal of the prescribed accuracy $\varepsilon$. Furthermore, for bounded payoff functions, we establish a provable computational speed-up over classical Monte Carlo methods.

The talk will emphasize the main ideas and mathematical challenges rather than technical details, and no prior knowledge of quantum computing or mathematical finance will be assumed. This talk is based on joint work with Jianjun Chen and Yongming Li.

### ABOUT THE SPEAKER

Ariel Neufeld is an Associate Professor in the Division of Mathematical Sciences at Nanyang Technological University, which he joined as a Nanyang Assistant Professor in 2019. His research focuses on numerical methods for high-dimensional nonlinear PDEs, the mathematical foundations of artificial intelligence, financial and insurance mathematics under model uncertainty, stochastic analysis and stochastic optimal control, and stochastic optimization.

He received his PhD from ETH Zurich in 2015 under the supervision of Marcel Nutz and Martin Schweizer, and was a postdoctoral researcher in financial and insurance mathematics at ETH Zurich until 2018. In 2021 he received the Early Career Prize of the SIAM Activity Group on Financial Mathematics and Engineering, the first time the prize went to a researcher based at an Asian university, and in 2024 his joint work on robust Q-learning was selected as an Editors' Choice paper of *Automatica*. He received the Willi Studer Award for the best ETH Zurich master's degree in mathematics of his year, and the Nanyang Education Award in 2023. He is an Associate Editor of *Finance and Stochastics*.

# Structure and Hardness in Quantum Optimization

Antonios Varvitsiotis

*Singapore University of Technology and Design*

Algorithms running on current quantum hardware often follow a hybrid approach: a classical computer tunes the parameters of a quantum circuit, while the quantum device is used to run the circuit and estimate the quantities needed to guide the optimization. This leads to a distinctive class of optimization problems that inherit strong algebraic and geometric structure from the underlying circuit.

In this talk, I will explore how this structure shapes the complexity of training. We will see that, in general, finding good solutions can be computationally difficult, even when one only seeks local solutions. At the same time, additional structure can sometimes be exploited to obtain efficient algorithms or useful classical descriptions. The broader goal is to understand which features make training intrinsically hard, which make it tractable, and where the boundary between these two regimes lies.

## ABOUT THE SPEAKER

Antonios Varvitsiotis is an Assistant Professor in the Engineering Systems and Design pillar at the Singapore University of Technology and Design, a Fellow of the Centre for Quantum Technologies, and an affiliated researcher at the Archimedes Research Unit in Greece. His research is on fundamental aspects of continuous and discrete optimisation, motivated by applications in data science, machine learning, engineering and quantum information, and ranges over semidefinite and sum-of-squares methods, quantum correlations and nonlocal games, and the dynamics of learning in games.

He received his PhD in mathematical optimization in 2013 from Centrum Wiskunde & Informatica in Amsterdam and Tilburg University, under the supervision of Monique Laurent, and holds MSc and BSc degrees from the National University of Athens. Before joining SUTD he was a Research Fellow in the Computer Science group at the Centre for Quantum Technologies and in the Department of Electrical and Computer Engineering at the National University of Singapore. His work has appeared in *Mathematical Programming*, the *SIAM Journal on Optimization*, the *Journal of Combinatorial Theory* and *Physical Review Letters*.

## Effective Ratner for Products of $\mathrm{SL}_2$

Lei Yang
*National University of Singapore*

In this talk, I will talk about recent developments on effective versions of Ratner's equidistribution theorem. After a brief introduction and survey, I will explain a recent result joint with Elon Lindenstrauss and Amir Mohammadi on effective Ratner for unipotent subgroups in products of $\mathrm{SL}_2$.

Main novelties of the proof include: (1) a Bourgain type projection theorem that allows us to analyze local obstructions of a bootstrapping step; (2) a new dynamical framework that allows us to combine the local obstructions and get a global obstruction coming from an intermediate subgroup.

### ABOUT THE SPEAKER

Lei Yang is an Associate Professor in the Department of Mathematics at the National University of Singapore, which he joined in 2024. His research concerns dynamical systems of group actions on homogeneous spaces and their applications to number theory, with recent emphasis on Diophantine approximation on manifolds and on effective equidistribution of unipotent orbits.

He received his PhD from The Ohio State University in 2014 under the supervision of Nimish Shah, and held postdoctoral positions at Yale University, MSRI Berkeley and the Hebrew University of Jerusalem before becoming an Associate Professor at Sichuan University, where he stayed from 2017 to 2023. In 2023–24 he was Shiing-Shen Chern Member of the School of Mathematics at the Institute for Advanced Study in Princeton.

His work has appeared in the *Annals of Mathematics*, *Acta Mathematica*, *Inventiones Mathematicae*, the *Duke Mathematical Journal* and *Geometric and Functional Analysis*; his effective version of Ratner's equidistribution theorem for $\mathrm{SL}(3,\mathbb{R})$ appeared in the *Annals of Mathematics* in 2025.

## Stability and Growth for the Incompressible Euler Equations

Yao Yao

*National University of Singapore*

The incompressible Euler equations describe how the velocity field of an incompressible, inviscid fluid evolves over time. Even in the regimes where the global well-posedness of solutions is known, there are many open questions regarding the long-time dynamics and infinite-in-time growth of solutions. In this talk, I will discuss some recent results on the nonlinear stability of traveling wave solutions and infinite-in-time growth results.

### ABOUT THE SPEAKER

Yao Yao is an Associate Professor in the Department of Mathematics at the National University of Singapore and Vice Dean of the NUS Graduate School. Her research is on the mathematical analysis of nonlinear partial differential equations arising in fluid mechanics and mathematical biology, in particular finite-time singularity formation in fluid equations, aggregation-diffusion equations modelling chemotaxis, and transport equations.

She received her PhD from the University of California, Los Angeles, in 2012 under the supervision of Inwon Kim, and held positions at the University of Wisconsin–Madison and the Georgia Institute of Technology before joining NUS in 2021. She was awarded a Sloan Research Fellowship in 2020 and an NSF CAREER grant in 2019, and was named in the inaugural cohort of Asian Young Scientist Fellows in 2023; she received the NUS Annual Teaching Excellence Award in 2024.

Her work has appeared in the *Annals of Mathematics*, *Inventiones Mathematicae*, the *Duke Mathematical Journal* and *Communications on Pure and Applied Mathematics*, and she serves as an Associate Editor of the *SIAM Journal on Mathematical Analysis*, the *Proceedings of the London Mathematical Society* and *Nonlinearity*.