QuantAlgo Workshop 2019 Program

Wednesday Sep 18 (CWI room L016)

13:00 Arrival and standing lunch

13:55 Opening

14:00 **Shantanav Chakraborty** (Brussels): How fast do quantum walks mix?

14:40 **Stacey Jeffery** (CWI): Quadratic speedup for finding marked vertices by quantum walks

15:20 Coffee/tea break

15:40 **Yassine Hamoudi** (IRIF Paris): Quantum and classical algorithms for approximate submodular function minimization

16:20 **Simon Martiel** (Atos): Practical implementation of a quantum backtracking algorithm

Thursday Sep 19 (CWI room L016)

10:00 **Richard Jozsa** (Cambridge): Magic states for matchgate computations

10:40 **Alex Bredariol Grilo** (CWI): Hamiltonian complexity meets derandomization

11:20 **Kaspars Balodis** (Riga): Quantum query lower bounds for Dyck languages and finding paths on 2D grid

12:00 Lunch. Business meeting for the site-coordinators (room L017)

14:00 **Invited: Vedran Dunjko** (Leiden): A divide-and-conquer hybrid method for smaller quantum computers

14:40 **Changpeng Shao** (Bristol): Quantum speedup of training radial basis function networks

15:20 Coffee/tea break

15:40 **Alessandro Luongo** (IRIF Paris): Quantum algorithms for clustering and generalised mixture models

16:00 **Dániel Szilágyi** (IRIF Paris): Quantum algorithms for Second Order Conic Programming and Support Vector Machines

16:20 Rump session (short talks, open problems, announcements, etc.). See program overleaf.

18:30 Conference dinner at Poesiat & Kater, Polderweg 648 (15-minute walk from CWI)

Rump session

16:20 **Leonardo Novo** (Brussels): Quantum advantage from energy measurements of many-body quantum systems

16:30 **Changpeng Shao** (Bristol): Computing eigenvalues of matrices in quantum computer

16:40 **Debbie Leung** (Waterloo): Quantum data compression

16:50 **Maksims Dimitrijevs** (Latvia): Quantum Drive and Quantum programming workshops

17:00 **Miklos Santha** (Paris): Announcement of ISQA conference

Friday Sep 20 (CWI room L016)

10:00 **Sergii Strelchuk** (Cambridge): Efficient benchmarking and simulation of quantum processes in Weyl basis

10:40 **Matthias Christandl** (Copenhagen): Noise-robust exploration of quantum matter on near-term quantum devices

11:20 **Makrand Sinha** (CWI): Exponential separation between quantum communication and logarithm of approximate rank

12:00 Lunch

14:00 **Christoph Hirche** (Copenhagen): The quantum information bottleneck: Properties and applications

14:40 **Mathieu Brandeho** (Brussels/Riga): Quantum information and communication

15:20 **João Doriguello** (Bristol): The Hidden Matching problem for arbitrary functions

16:00 Closing

Shantanav Chakraborty (Brussels): How fast do quantum walks mix?
Abstract: The fundamental problem of sampling from the limiting distribution of quantum walks on graphs, known as mixing, finds widespread applications in several areas of quantum information and computation. Of particular interest in most of these applications, is the minimum time beyond which the instantaneous probability distribution of the quantum walk remains close to this limiting distribution, known as the quantum mixing time. However, this quantity is only known for a handful of specific graphs. In this article, we prove an upper bound on the quantum mixing time for almost all graphs, i.e. the fraction of graphs for which our bound holds, goes to one in the asymptotic limit. To this end, using several results in random matrix theory, we find the quantum mixing time of Erdos-Renyi random graphs: graphs of n nodes where each edge exists with probability p independently. For example for dense random graphs, where p is a constant, we show that the quantum mixing time is $O(n^{3/2+o(1)})$. Besides opening avenues for the analytical study of quantum dynamics on complex networks, our work could find applications beyond quantum information processing. In particular, our general results on the spectral properties of random matrices could lead to novel insights into the equilibration times of isolated quantum systems defined by random Hamiltonians, a foundational problem in quantum statistical mechanics.
Joint work with Kyle Luh and Jérémie Roland.

Stacey Jeffery (CWI): Quadratic speedup for finding marked vertices by quantum walks
Abstract: A quantum walk algorithm can detect the presence of a marked vertex on a graph quadratically faster than the corresponding random walk algorithm (Szegedy, FOCS 2004). However, quantum algorithms that actually find a marked element quadratically faster than a classical random walk were only known for the special case when the marked set consists of just a single vertex, or in the case of some specific graphs. We present a new quantum algorithm for finding a marked vertex in any graph, with any set of marked vertices, that is (up to a log factor) quadratically faster than the corresponding classical random walk.
Joint work with Andris Ambainis, András Gilyén, Martins Kokainis.

Yassine Hamoudi (IRIF Paris): Quantum and Classical algorithms for approximate submodular function minimization
Abstract: We present a classical and a quantum algorithm for minimizing submodular functions with additive error ϵ. Our classical result runs in time $O(n^{3/2}/\epsilon^2 \cdot \mathrm{EO})$, where EO denotes the cost to evaluate the function on any set. It improves on the previously fastest algorithm [CLSW17] that runs in time $O(n^{5/3}/\epsilon^2 \cdot \mathrm{EO})$. Our quantum algorithm is, up to our knowledge, the first attempt to use quantum computing for submodular optimization. The algorithm runs in time $O(n^{5/4}/\epsilon^{5/2} \cdot \log(1/\epsilon) \cdot \mathrm{EO})$. The main ingredient of the quantum result is a new method for sampling with high probability T independent elements from any discrete probability distribution of support size n in time $O(\sqrt{Tn})$. Previous quantum algorithms for this problem were of complexity $O(T\sqrt{n})$.
Joint work with Patrick Rebentrost, Ansis Rosmanis and Miklos Santha.

Simon Martiel (Atos): Practical implementation of a quantum backtracking algorithm
Abstract: In previous work, Montanaro presented a method to obtain quantum speedups for backtracking algorithms, a general meta-algorithm to solve constraint satisfaction problems (CSPs). In this work, we derive a space efficient implementation of this method. We make explicit our implementation for graph coloring and SAT problems, and present emulation results. Finally, we discuss the impact of the usage of static and dynamic variable ordering heuristics in the quantum setting.

Richard Jozsa (Cambridge): Magic states for matchgate computations
Abstract: Magic states were introduced in the context of Clifford circuits as a resource that elevates classically simulatable computations to quantum universal capability, while maintaining the same gate set. Here we consider magic states in the context of matchgate (MG) circuits, where the notion becomes more subtle, as MGs are subject to locality constraints. Our main result is to show that every pure fermionic state which is non-Gaussian, i.e., which cannot be generated by MGs from a computational basis state, is a magic state for MG computations. This result has significance for prospective quantum computing implementation in view of the fact that MG circuit evolutions coincide with the quantum physical evolution of non-interacting fermions.
Joint with M. Hebenstreit, B. Kraus, S. Strelchuk, M. Yoganathan.

Alex Bredariol Grilo (CWI): Hamiltonian complexity meets derandomization
Abstract: The derandomization of MA, the probabilistic version of NP, is a long standing open question. In this work, we connect this problem to a variant of another major problem: the quantum PCP conjecture. Our connection goes through the surprising quantum characterization of MA by Bravyi and Terhal. They proved the MA-completeness of the problem of deciding whether the groundenergy of a uniform stoquastic local Hamiltonian is zero or inverse polynomial. We show that the gapped version of this problem, i.e., deciding if a given uniform stoquastic local Hamiltonian is frustration-free or has energy at least some constant ε, is in NP. Thus, if there exists a gap-amplification procedure for uniform stoquastic Local Hamiltonians (in analogy to the gap amplification procedure for constraint satisfaction problems in the original PCP theorem), then MA = NP (and vice versa). Furthermore, if this gap amplification procedure exhibits some additional (natural) properties, then P = RP. We feel this work opens up a rich set of new directions to explore, which might lead to progress on both quantum PCP and derandomization.
Joint work with Dorit Aharonov.

Kaspars Balodis (Riga): Quantum query lower bounds for Dyck languages and finding paths on 2D grid
Abstract: We examine the problem of finding a path from one corner of a 2D grid to the opposite corner. For a directed $n \times n$ grid we prove an $\Omega(n^{1.5-o(1)})$ quantum query complexity lower bound. For an undirected $n \times n$ grid we prove an $\Omega(n^{2-o(1)})$ lower bound. The results are obtained via a reduction from the Dyck language with a constraint that the maximum depth of the brackets must be at most k. For that problem we show an $\Omega(n^{1-o(1)})$ lower bound when $k = \Omega(\log n)$.
Joint work with Andris Ambainis, Jānis Iraids, Krišjānis Prūsis.

Vedran Dunjko (Leiden): A divide-and-conquer hybrid method for smaller quantum computers
Abstract: Theory shows that arbitrary-sized quantum computers may offer computational advantages for many problems. However, quantum computers on a reasonable horizon will be restricted in many ways, including size. Motivated by this, we investigate whether a smaller quantum computer (limited to M qubits) can genuinely speed up interesting algorithms, even when the problem size (n) is much larger than the computer itself ($n \gg M$). We show that this is possible for a class of algorithms which employ a divide-and-conquer strategy, provided that certain conditions on the space complexity of the quantum algorithm are met. We will illustrate the approach on a specific hybrid quantum-classical algorithm to solve 3SAT, and on an algorithm for finding Hamilton cycles in qubic graphs, both of which achieve significant speeds up over their fully classical counterpart, for any ratio m/n. Finally, we briefly discuss the consequences the hybrid method, and related

ideas, may have for achieving practically relevant speed-ups with near-term devices.
Joint work with Yimin Ge and Ignacio Cirac.

Changpeng Shao (Bristol): Quantum speedup of training radial basis function networks
Abstract: Radial basis function (RBF) network is a simple but useful neural network model that contains wide applications in machine learning. The training of an RBF network reduces to solve a linear system, which is time consuming classically. Based on the HHL algorithm, we propose two quantum algorithms to train RBF networks. To apply the HHL algorithm, we choose using the Hamiltonian simulation algorithm proposed in [P. Rebentrost, A. Steffens, I. Marvian and S. Lloyd, Phys. Rev. A 97, 012327, 2018]. However, to use this result, an oracle to query the entries of the matrix of the network should be constructed. We apply the amplitude estimation technique to build this oracle. The final results indicate that if the centers of the RBF network are the training samples, then the quantum computer achieves exponential speedup in the number and the dimension of training samples over the classical computer; if the centers are determined by the K-means algorithm, then the quantum computer achieves quadratic speedup in the number of samples and exponential speedup in the dimension of samples.
Reference: Changpeng Shao, QIC, 19(7& 8), 0609–0625, 2019.

Alessandro Luongo (IRIF Paris): Quantum algorithms for clustering and generalised mixture models
Abstract: We present quantum algorithms for unsupervised learning. In particular, we will describe q-means, a quantum algorithm for clustering and Quantum Expectation Maximization, a quantum algorithm for generalized mixture models.

Dániel Szilágyi (IRIF Paris): Quantum algorithms for Second Order Conic Programming and Support Vector Machines
Abstract: We present a quantum algorithm for second order cone programs (SOCPs) based on a quantum variant of the interior point method. We present applications to the support vector machine (SVM) problem in machine learning that reduces to SOCPs. We provide experimental evidence that the quantum algorithm achieves an asymptotic speedup over classical SVM algorithms with a running time $\widetilde{O}(n^{2.557})$ for random SVM instances. The best known classical algorithms for such instances have complexity $\Omega(n^3)$.
Joint work with Iordanis Kerenidis and Anupam Prakash.

Sergii Strelchuk (Cambridge): Efficient benchmarking and simulation of quantum processes in Weyl basis
Abstract: Correctly identifying and analysing errors that arise in the process of quantum evolution when two or more sources of noise simultaneously affect the computation is a hard problem. Current approaches make heavy use of the properties of Clifford unitaries and are designed to learn a single noise source. We present a method to efficiently identify and learn a mixture of error models which occur during the computation. We achieve this with the help of Weyl-Heisenberg unitaries. I will describe this approach and illustrate some of its applications.

Matthias Christandl (Copenhagen): Noise-robust exploration of quantum matter on near-term quantum devices
Abstract: We describe a resource efficient approach to studying many-body quantum states on

noisy, intermediate-scale quantum devices. We employ a sequential generation model that allows to bound the range of correlations in the resulting many-body quantum states. From this, we characterize situations where the estimation of local observables does not require the preparation of the entire state. Instead smaller patches of the state can be generated from which the observables can be estimated. This reduces the required circuit size and number of qubits for the computation of physical properties of quantum matter. Moreover, we show that the effect of noise decreases along the computation. Our results apply to a broad class of widely studied tensor network states and can be directly applied to near-term implementations of variational quantum algorithms.

Makrand Sinha (CWI): Exponential Separation between quantum communication and logarithm of approximate rank
Abstract: Chattopadhyay, Mande and Sherif (ECCC 2018) recently exhibited a total Boolean function, the sink function, that has polynomial approximate rank and polynomial randomized communication complexity. This gives an exponential separation between randomized communication complexity and logarithm of the approximate rank, refuting the log-approximate-rank conjecture. We show that even the quantum communication complexity of the sink function is polynomial, thus also refuting the quantum log-approximate-rank conjecture. Our lower bound is based on the fooling distribution method introduced by Rao and Sinha (ECCC 2015) for the classical case and extended by Anshu, Touchette, Yao and Yu (STOC 2017) for the quantum case. We also give a new proof of the classical lower bound using the fooling distribution method.
Joint work with Ronald de Wolf.

Christoph Hirche (Copenhagen): The Quantum information bottleneck: Properties and applications
Abstract: In classical information theory, the information bottleneck method (IBM) can be regarded as a method of lossy data compression which focuses on preserving meaningful (or relevant) information. As such it has of late gained a lot of attention, primarily for its applications in machine learning and neural networks. A quantum analogue of the IBM has recently been defined, and an attempt at providing an operational interpretation of the so-called quantum IB function as an optimal rate of an information-theoretic task, has recently been made by Salek et al. The interpretation given by these authors is however incomplete, as its proof is based on the conjecture that the quantum IB function is convex. Our first contribution is the proof of this conjecture. Secondly, the expression for the rate function involves certain entropic quantities which occur explicitly in the very definition of the underlying information-theoretic task, thus making the latter somewhat contrived. We overcome this drawback by pointing out an alternative operational interpretation of it as the optimal rate of a bona fide information-theoretic task, namely that of quantum source coding with quantum side information at the decoder, which has recently been solved by Hsieh and Watanabe. We show that the quantum IB function characterizes the rate region of this task, Finally, we discuss some further properties, applications and the related privacy funnel function.

Mathieu Brandeho (Brussels/Riga): Quantum information and communication
Abstract: We introduce a new lower bound method for the information complexity of distributions, and by extension also for amortized communication complexity. Information complexity is based on a two-party communication model with shared randomness, where the cost of a protocol is given in terms of the mutual information between the parties' inputs and the communication transcript (here, we assume a product input distribution). In contrast, this new method is based on a similar

model without communication, but allowing the two parties to apply post-selection on the shared randomness. Then we show that the mutual information between the inputs and the post-selected shared randomness provides a lower bound on the information complexity. We apply this method to two well-known distributions in quantum physics: CHSH and EPR-Bohm distributions.
For the CHSH distribution $\mathbf{p}_\mu$, we know by Roland and Szegedy that the information complexity is upper bounded by $1 - H(\mu)$. Our new method provides a lower bound $1 - H(\mu) - O(H(\mu)^2)$. For the EPR-Bohm distribution, we also know by Roland and Szegedy that the one-way information complexity is upper bounded in dimension 2 by $(\ln \pi - 1)/\ln 2$. Using our new method we obtain a matching lower bound.

João Doriguello (Bristol): The Hidden Matching problem for arbitrary functions
Abstract: In this work we revisit the Hidden Matching communication problem, which was the first communication problem in the one-way model to demonstrate an exponential classical-quantum communication separation. In the Hidden Matching problem, Alice is given a bit-string, Bob is given a partition of the input bits into pairs, and Bob is asked to output the parity of an arbitrary pair of bits. Here we generalise the Hidden Matching problem by replacing the parity function with an arbitrary function f. Efficient communication protocols are presented depending on the sign-degree of f. If the sign-degree is less than or equal to 1, we show an efficient classical protocol. If the sign-degree is less than or equal to 2, we show an efficient quantum protocol. We then completely characterise the classical hardness of all symmetric functions f of sign-degree 2, except for one family of special cases. We also present partial results on a classical lower bound in terms of the pure high degree of f.