TUE 6: Quantum Computing and Communication: Contributed Session I (Algorithms & Theory)

Time: Tuesday 14:15–16:00 Location: ZHG007

TUE 6.1 Tue 14:15 ZHG007

Measurement-driven quantum advantages in shallow circuits — •Chenfeng Cao[1] and Jens Eisert[1,2] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

Quantum advantage schemes probe the boundary between classically simulatable quantum systems and those that computationally go beyond this realm. Here, we introduce a constant-depth measurement-driven approach for efficiently sampling from a broad class of dense instantaneous quantum polynomial-time circuits and associated Hamiltonian phase states, previously requiring polynomial-depth unitary circuits. Leveraging measurement-adaptive fan-out staircases, our "dynamical circuits" circumvent light-cone constraints, enabling global entanglement with flexible auxiliary qubit usage on bounded-degree lattices. Generated Hamiltonian phase states exhibit statistical metrics indistinguishable from those of fully random architectures. Additionally, we demonstrate measurement-driven globally entangled feature maps capable of distinguishing phases of an extended SSH model from random eigenstates using a quantum reservoir-computing benchmark. Technologically, our results harness the power of mid-circuit measurements for realizing quantum advantages on hardware with a favorable topology. Conceptually, we highlight their power in achieving rigorous computational speedups.

TUE 6.2 Tue 14:30 ZHG007

A quantum protocol for applying arbitrary phase transformations — Siavash Davani[1,2] and •Falk Eilenberger[3,1,2] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Max Planck School of Photonics, 07745 Jena, Germany — [3]Fraunhofer-Institute for Applied Optics and Precision Engineering, 07745 Jena, Germany

The standard approach to developing algorithms for quantum computers involves constructing a sequence of unitary gates to manipulate a quantum register. We show an alternative approach that directly uses quantum information stored in memory as instructions and performs a transformation on a register based on the state of the instruction state. This enables programming quantum computers by encoding different instructions as quantum information in the memory. The approach unifies the role of memory in quantum computers as containing both data and software similar to the von Neumann architecture in classical computers. Using this technique, we introduce a protocol capable of arbitrary phase transformations on wavefunctions, allowing for the simulation of large classes of Hamiltonians on quantum computers. The protocol functions by temporarily entangling the instruction and data registers, and it consumes the instruction state during the process.

TUE 6.3 Tue 14:45 ZHG007

Quantum Approximate Optimization via Weak Measurements — •Tobias Stollenwerk[1] and Stuart Hadfield[2] — [1]Forschungszentrum Jülich — [2]NASA Quantum Artificial Intelligence Laboratory

Algorithms based on non-unitary evolution have attracted much interest for ground state preparation on quantum computers. One recently proposed method makes use of ancilla qubits and controlled unitary operators to implement weak measurements related to imaginary-time evolution. In this work we specialize and extend this approach to the setting of combinatorial optimization. We first generalize the algorithm from exact to approximate optimization. We then show how to modify the paradigm to the setting of constrained optimization for a number of important classes of hard problem constraints. For this we adapt the algorithm to penalty-based approaches and elucidate the resource overhead. As an alternative approach we show how one may design and employ operators that preserve the subspace of feasible problem solutions in order to to avoid the overhead of penalty terms. In particular, we show that mixing operators from the quantum alternating operator ansatz may be directly imported, both for the necessary eigenstate scrambling operator and for initial state preparation, and discuss quantum resource tradeoffs. Finally, we consider the effects of hardware noise and propose further algorithmic variants towards ameliorating its effects.

TUE 6.4 Tue 15:00 ZHG007

State Specific Measurement Protocols for the Variational Quantum Eigensolver — •Davide Bincoletto — University of Augsburg, Augsburg, Germany

A central roadblock in the realization of variational quantum eigensolvers on quantum hardware is the high overhead associated with measurement repetitions, which hampers the computation of complex problems, such as the simulation of mid- and large-sized molecules. In this work, we propose a novel measurement protocol which relies on computing an approximation of the Hamiltonian expectation value. The method involves measuring cheap grouped operators directly and estimating the residual elements through iterative measurements of new grouped operators in different bases, with the process being truncated at a certain stage. The measured elements comprehend the operators defined by the Hard-Core Bosonic approximation, which encode electron-pair annihilation and creation operators. These can be easily decomposed into three self-commuting groups which can be measured simultaneously. Applied to molecular systems, the method achieves a reduction of 30% to 80% in the number of measurement and gates depth in the measuring circuits compared to state-of-the-art methods. This provides a scalable and cheap measurement protocol, advancing the application of variational approaches for simulating physical systems.

TUE 6.5 Tue 15:15 ZHG007

A complexity theory for non-local quantum computation — •Simon Höfer[1], Andreas Bluhm[1], Alex May[2,3], Mikka Stasiuk[2], Philip Verduyn Lunel[4], and Henry Yuen[5] — [1]Univ. Grenoble Alpes, CNRS, Grenoble INP, LIG — [2]Perimeter Institute for Theoretical Physics — [3]Institute for Quantum Computing, Waterloo, Ontario — [4]Sorbonne Université, Paris — [5]Columbia University

Non-local quantum computation (NLQC) replaces a local interaction between two systems with a single round of communication and shared entanglement.

Despite many partial results, it is known that a characterization of entanglement cost in at least certain NLQC tasks would imply significant breakthroughs in complexity theory, so we take an indirect approach to understanding resource requirements in NLQC, by studying the relative hardness of different NLQC tasks by identifying resource efficient reductions between them.

Most significantly, we prove that f-measure and f-route, the two best studied NLQC tasks, are in fact equivalent under reductions, with only constant overhead in the entanglement cost, regardless of the function f.

This result simplifies many existing proofs in the literature and extends several new properties to f-measure, such as sub-exponential upper bounds on entanglement cost.

Beyond this, we study a number of other examples of NLQC tasks and their relationships.

TUE 6.6 Tue 15:30 ZHG007

Application of quantum computing in Life Sciences - a Case Study — •Klaus Mayer, Artemiy Burov, Clément Javerzac-Galy, and Oliver Mülken — School of Life Sciences, FHNW Fachhochschule Nordwestschweiz, Hofackerstr. 30, 4132 Muttenz, Switzerland

We study the practical application of currently available intermediate-scale Quantum Computers in the Life Sciences context [1]. Among the various conceivable applications where quantum utility or even advantage may be achieved, Hamiltonian simulation is among the most relevant.

As a concrete example, we explore the applicability of modern quantum computing algorithms (such as Qubitization and Quantum Signal Processing) to the simulation of nuclear magnetic resonance (NMR) spectra, which are highly relevant, for instance, in the field of protein characterization for drug discovery or in the material sciences. To this end, a Heisenberg Hamiltonian for liquid-state NMR is mapped to a higher-dimensional unitary which can be implemented in a Quantum Computer. We investigate resource scaling of the implementation and compare our results to product formula implementations [2].

[1] K. Mayer, A. Burov, C. Javerzac-Galy, O. Mülken (2025), *to be*

submitted
[2] A. Burov, O. Nagl, C. Javerzac-Galy (2024), *arXiv:2404.17548*

TUE 6.7 Tue 15:45 ZHG007

Beyond Classical Approximation Guarantees in the NISQ Era — •Chinonso Onah[1,2] and Kristel Michielsen[2,3] — [1]Volkswagen Group, Germany — [2]Department of Physics, RWTH Aachen, Germany — [3]Forschungszentrum Jülich, Germany

We present the first constant-low-depth, ancilla-free constrained QAOA variant that (1) provably concentrates inverse-polynomial probability on the target bit-strings, (2) exponentially outperforms generic QAOA at any depth by massively boosting the probability of legal solutions, (3) amplifies any generic QAOA parameter set by a super-exponential factor, and (4) serves as the quantum core of an Exact Hybrid Quantum*Classical solver that is a fully-polynomial randomized approximation scheme whose success probability*and additive-gap performance under Hungarian repair*cannot be matched by any polynomial-time classical sampler unless NP is contained in BPP. On the QOPTLib TSP benchmark (all instances up to one hundred qubits that fit on today*s superconducting hardware), our solver recovers or improves upon every previously published tour*achieving up to a 12.3 percent shorter route on the hardest instance. This dramatic gain on the most challenging benchmarks underlines the practical promise of our approach on near-term devices.