THU 6: Quantum Computing and Communication: Contributed Session II (Concepts)

Time: Thursday 14:15–15:45 Location: ZHG007

THU 6.1 Thu 14:15 ZHG007

Quantum resource in quantum optimization — •Gopal Chandra Santra[1,2,3], Daniel J. Egger[4], and Philipp Hauke[1,2] — [1]Pitaevskii BEC Center, INO-CNR and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy — [2]INFN-TIFPA, Trento Institute for Fundamental Physics and Applications, Via Sommarive 14, I-38123 Trento, Italy — [3]Kirchhoff- Institut fur Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [4]IBM Quantum, IBM Research Europe - Zurich, Säumerstrasse 4, CH-8803 Rüschlikon, Switzerland

Variational quantum algorithms are promising for solving combinatorial optimization problems on near-term, pre-fault-tolerant quantum hardware. However, to what extent these algorithms harness quantum correlations and whether current quantum devices can provide them remains unclear. This work investigates this open question by examining the roles of entanglement and nonstabilizerness within the Quantum Approximate Optimization Algorithm (QAOA). To begin, we leverage a strong connection between QAOA and quantum metrology, using quantum squeezing to analyze entanglement through numerical simulations and experiments on IBM quantum hardware. While increasing bipartite entanglement with system size is known to be insufficient for fully unlocking quantum computational advantages, we address this limitation by focusing on genuine multipartite entanglement. Finally, we examine the role of nonstabilizerness in QAOA and investigate how it relates to output fidelity. Our results provide deeper insights into how quantum resources influence quantum optimization.

THU 6.2 Thu 14:30 ZHG007

Regular parameterizations of the special unitary group and convergence of variational algorithms — •Marco Wiedmann[1], Daniel Burgarth[1], and Christian Arenz[2] — [1]Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstraße 7 91058 Erlangen, Germany — [2]Arizona State University, 650 E Tyler Mall, Tempe, AZ 85281, USA

Variational algorithms have gained a lot of attention in the recent years as a potential application of quantum computers. In broad terms, a parameterized unitary is implemented on a quantum computer, which is then used to measure some objective function that should be minimized by a classical optimization routine.

Gradient based optimizers can however get stuck at singular points of the parameterization, which resembles a gimbal lock like effect. We show that some popular parameterizations do indeed admit these singular points and propose alternatives which are globally regular. Finally, we use these parameterizations to prove that if the Variational Quantum Eigensolver does not run off to infinity, it almost always converges to a true ground state of the problem Hamiltonian.

THU 6.3 Thu 14:45 ZHG007

Accuracy of Quantum Simulation under Random Errors and Noise — •Jayant Rao, Jens Eisert, and Tommaso Guaita — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

Quantum simulation emerges as a highly promising application of quantum computing. At present, a critical question revolves around the robustness of digital and analog approaches to simulating quantum systems in the presence of errors and noise.

We consider the task of simulating local observables in a d dimensional lattice. Each local Hamiltonian carries an error bounded by a small parameter δ in spectral norm to the correct Hamiltonian. We compute the deviation from the ideal evolution in a worst case, where we find that the error scales with $O(\delta t^{d+1})$ in both the analog and digital method. We consider as a more realistic model randomly distributed Hamiltonian error terms, where we can show that the Trotter circuits error concentrates at $O(\delta)$ with high probability. We also show similar concentration effects which emerge considering random input states.

It is widely believed that analog quantum simulators are more resilient to noise because they allow for more error interference to happen. Our considerations show that strong error cancellation is present in Trotter based simulation as well. This leads us to motivate rethinking some beliefs about which strategies for quantum simulation are indeed more resilient to errors and noise.

THU 6.4 Thu 15:00 ZHG007

Local Complementation Orbit Scaling and Universal Resources for MBQC — •Frederik Hahn — Electrical Engineering and Computer Science Department, Technische Universität Berlin, 10587 Berlin, Germany

In Measurement-Based Quantum Computing (MBQC), quantum computation is performed through adaptive measurements on entangled resource states, with graph states serving as the canonical example. The computational power and efficiency of MBQC is fundamentally connected to the properties of these underlying graph states. Here, we focus on how classes of quantum graph states transform under local Clifford operations and how these transformations scale in the number of qubits. It is well known that local Clifford transformations can be represented by local complementations of the underlying graphs. All graphs that can be reached via local complementation from a given starting graph form that graph's local complementation orbit. We can now investigate how the size of these local complementation orbits scales with the number of qubits n of the underlying graph states. For simple classes, such as GHZ states, this scaling is known to be linear in n and an upper bound is given by 3^n. However, for general graph states, counting the orbit sizes is a problem that is known to be $\#P$-complete. Can we still calculate the orbit scaling for classes of graph states that are known to be universal quantum computing resources?

THU 6.5 Thu 15:15 ZHG007

Expressivity Limits of Quantum Reservoir Computing — •Nils-Erik Schütte[1,2], Niclas Götting[2], Hauke Müntinga[1], Meike List[1,3], Daniel Brunner[4], and Christopher Gies[2] — [1]German Aerospace Center, Institute for Satellite Geodesy and Inertial Sensing, Bremen, Germany — [2]Institut für Physik, Fakultät V, Carl von Ossietzky Universität Oldenburg — [3]University of Bremen — [4]Institut FEMTO-ST, Université Franche-Comté CNRS UMR, Besançon, France

Quantum machine learning (QML) merges quantum computing and artificial intelligence, two transformative technologies for data processing. While gate-based quantum computing employs precise unitary operations on qubits via parameterized quantum circuits (PQCs), quantum reservoir computing (QRC) leverages physical systems as quantum neural networks, relying on Hamiltonian dynamics rather than controlled gate operations, with learning performed at the output layer. Despite their differing foundations, these approaches share connections and can be formally mapped onto each other.

We formulate the QRC approach in the language of gate-based circuits and apply recently developed methods for PQCs to QRC. Contrary to expectations, we find that the effective computational dimensionality of quantum reservoirs does not scale with the reservoir dimension but is mainly determined by the input encoding [1]. For commonly used single-qubit rotations, we show that exponential scaling, one of the main promises of QRC over classical RC, cannot be reached.

[1] Schütte et al., arXiv: 2501.15528

THU 6.6 Thu 15:30 ZHG007

Connection between memory performance and optical absorption in quantum reservoir computing — •Niclas Götting, Steffen Wilksen, Alexander Steinhoff, and Christopher Gies — Institute for Physics, Faculty V, Carl von Ossietzky University Oldenburg, 26129 Oldenburg, Germany

Quantum reservoir computing (QRC) leverages dynamical quantum systems to perform machine learning tasks. Due to the complex quantum dynamics, it exhibits the capability to store information over a period of time determined by the system properties. This short-term memory capacity (STMC) has become an abundant benchmark for QRC architectures, but relies on the processing of large amounts of data, thus posing a challenge for real-world application.

In our work, we lay new grounds for the memory analysis in QRC by connecting the fields of information theory (i.e. the STMC) and optics. We demonstrate how the STMC of a QRC setup based on open quantum systems can be assessed solely via optical absorption measurements. By establishing a link between absorption and STMC via the dissipation strength of the open quantum reservoir, we unravel the particular “sweet-spot” behavior the STMC has shown in several studies with respect to the dissipation [1-3]. This physical view on information-theoretical properties in QML opens up a new avenue for problem-specific hardware design.

[1] N. Götting et al., Physical Review A 108, 052427 (2023)
[2] F. Monzani et al., arXiv:2409.07886 (2024)
[3] Y. Kurokawa et al., arXiv:2408.09577 (2024)