QI 10: Quantum Machine Learning II

Time: Tuesday 11:00–12:45 Location: HS VIII

QI 10.1 Tue 11:00 HS VIII

Quantum Machine Learning for Natural Language Processing — •Charles Varmantchaonala M.[1], Jean Louis E. K. Fendji[2,3], and Christopher Gies[1] — [1]Institut für Physik, Fakultät V, Carl von Ossietzky Universität Oldenburg, 26129 Oldenburg — [2]Department of Computer Engineering, University Institute of Technology, University of Ngaoundere, P.O. Box 454 Ngaoundere, Cameroon — [3]Stellenbosch Institute for Advanced Study (STIAS), Wallenberg Research Centre at Stellenbosch University, Stellenbosch, South Africa

Quantum Machine Learning (QML) offers exciting possibilities for improving many fields by leveraging the unique properties of quantum mechanics to solve problems more efficiently. Natural Language Processing (NLP) is a key area of artificial intelligence that focuses on helping machines understand and work with human language. The intersection of NLP and QML – Quantum Natural Language Processing (QNLP) – is a new and intriguing research field [1], as it could lead to major improvements in how machines understand human languages, process meaning, and handle complex linguistic tasks. Exploring how QML and NLP can work together is important, as it may provide better solutions and more accurate models for language understanding. This talk will explore the current progress in both QML and QNLP, and explore the aspect of classical-to-quantum sentence or sequence encoding.

[1] Varmantchaonala, C. M., Fendji, J. L. E., Schöning, J., & Atemkeng, M. (2024). Quantum Natural Language Processing: A Comprehensive Survey. IEEE Access.

QI 10.2 Tue 11:15 HS VIII

Pulse Engineering via Projection of Response Functions — •Nicolas Heimann[1,2,3], Lukas Broers[1,2], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

We present an iterative optimal control method of quantum systems, aimed at an implementation of a desired operation with optimal fidelity. The update step of the method is based on the linear response of the fidelity to the control operators, and its projection onto the mode functions of the corresponding operator. Our method extends methods such as gradient ascent pulse engineering and variational quantum algorithms, by determining the fidelity gradient in a hyperparameter-free manner, and using it for a multi-parameter update, capitalizing on the multi-mode overlap of the perturbation and the mode functions. This directly reduces the number of dynamical trajectories that need to be evaluated in order to update a set of parameters. We demonstrate this approach, and compare it to the standard GRAPE algorithm, for the example of a quantum gate on two qubits, demonstrating a clear improvement in convergence and optimal fidelity of the generated protocol.

QI 10.3 Tue 11:30 HS VIII

sQUlearn - A Python Library for Quantum Machine Learning — David Kreplin, •Moritz Willmann, Jan Schnabel, Frederic Rapp, Manuel Hagelüken, and Marco Roth — Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany

sQUlearn introduces a user-friendly, NISQ-ready Python library for quantum machine learning (QML), designed for seamless integration with classical machine learning tools like scikit-learn. The library's dual-layer architecture serves both QML researchers and practitioners, enabling efficient prototyping, experimentation, and pipelining. sQUlearn provides a comprehensive toolset that includes both quantum kernel methods and quantum neural networks, along with features like customizable data encoding strategies, automated execution handling, and specialized kernel regularization techniques. By focusing on NISQ-compatibility and end-to-end automation, sQUlearn aims to bridge the gap between current quantum computing capabilities and practical machine learning applications. The library provides substantial flexibility, enabling quick transitions between the underlying quantum frameworks Qiskit and PennyLane, as well as between simulation and running on actual hardware.

QI 10.4 Tue 11:45 HS VIII

How bandwidth-tuned quantum kernels become classically tractable — •Roberto Flórez Ablan, Marco Roth, and Jan Schnabel — Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany

Quantum Kernels have been a popular approach in Quantum Machine Learning (QML). However, they have generally not been shown to outperform classical ML methods. A key reason for this is that QKs suffer from the exponential concentration problem. As the number of qubits increases, the overlap between states vanishes, preventing generalization. One strategy to mitigate this problem is to rescale the data points entering the quantum model. This technique, known as bandwidth tuning, has been shown to enable generalization in QKs. However, it has been numerically demonstrated that this method results in QKs that fail to provide a quantum advantage over classical methods in terms of generalization. Here, we propose an explanation for this phenomenon. We show that due to the size of the optimal rescaling factors, QKs become similar to classical kernels. Furthermore, we numerically demonstrate and propose an analytical toy model that captures how key quantities of the kernel in classification experiments are modified as a function of bandwidth. Our results align with recent trends in QML, which suggest that successful QML models become classically simulatable.

QI 10.5 Tue 12:00 HS VIII

Quantum Kernel Methods under Scrutiny — •Jan Schnabel, Roberto Flórez Ablan, and Marco Roth — Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany

Quantum kernel methods (QKMs) have emerged as a promising approach in quantum machine learning, offering both practical applications and theoretical insights. Two primary strategies for computing the Gram matrix in QKMs are fidelity quantum kernels (FQKs) and projected quantum kernels (PQKs). Benchmarking these methods is crucial to gain robust insights and to understand their practical utility.

In this talk, we present a comprehensive large-scale study examining QKMs based on FQKs and PQKs across a manifold of design choices, covering both classification and regression tasks. Our work spans five dataset families and 64 datasets, resulting in over 20,000 models trained and optimized using a state-of-the-art hyperparameter search. We delve into the importance of hyperparameters on model performance scores and provide a thorough analysis addressing the design freedom of PQKs and explore the underlying principles responsible for learning. Rather than pinpointing the best-performing models for specific tasks, our goal is to uncover the mechanisms that drive effective QKMs and reveal universal patterns. These insights contribute to better understand certain properties of QKMs and what distinguishes good from bad models.

QI 10.6 Tue 12:15 HS VIII

Quantum Support Vector Machines Kernel Generation with Classical Post-Processing — •Anant Agnihotri, Thomas Wellens, and Michael Krebsbach — Fraunhofer IAF, Tullastrasse 72

We investigate the optimization of kernel generation for quantum support vector algorithms for data classification. Classical post-processing techniques are employed to improve the efficiency of classification. First, high-dimensional data is preprocessed using Principal Component Analysis (PCA) to reduce dimensionality while retaining significant features. A training kernel is then generated using the ZZ feature map. In the post-processing step, the overlap with all states (not only the all-zero state, as it is the case for the standard quantum kernel) is utilized, where the kernel entry is computed as a weighted sum of these overlaps. This allows us to determine the kernel entries with reduced number of shots. The method is run on MNIST dataset to distinguish between handwritten digits *0* and *1*. We compare the kernel score, i.e., the fraction of unseen datapoints correctly identified by the standard quantum kernel, on the one hand, and the kernel with our post-processing method, on the other hand. Our findings indicate that the post-processed version outperforms the standard version especially for higher numbers of qubits.

QI 10.7 Tue 12:30 HS VIII

An SPSA-based Adaptive Shot Optimizer for variational algorithms — •Matteo Antonio Inajetovic and Anna Pappa — Technische Universität Berlin, Berlin, Germany

Adaptive shot optimizers dynamically adjust shot budget based on gradient variance, ensuring efficient shot allocation and significantly reducing the number of shots required for variational quantum algorithms. This is especially critical for concrete applications on noisy intermediate-scale quantum (NISQ) devices, where limited hardware access and high measurement costs pose substantial challenges. This work introduces adaptiveSPSA, a novel optimization method combining Simultaneous Perturbation Stochastic Approximation (SPSA) with adaptive shot strategies. Unlike other shot-frugal optimizers that rely on parameter-shift rules, adaptiveSPSA, leveraging the inherent efficiency of SPSA, computes gradient estimates using only two circuit executions per optimization step. Therefore, the proposed work is more robust to problem scaling, as the parameter-shift rule requires a number of gradient evaluations that scales linearly with the number of parameters, whereas SPSA maintains a constant number of evaluations regardless of parameter count. Numerical experiments on the Quantum Approximate Optimization Algorithm benchmark demonstrate that adaptiveSPSA outperforms Rosalin, one of the state-of-the-art methods, achieving superior performance still using a small amount of shots. These results underscore its potential to enhance the scalability and efficiency of variational quantum algorithms in practical applications with nowadays devices.