Introduction to quantum computing for PhD students

Mini lecture series from 11-13 January 2021, 10 -11:30 a.m. and 1 - 2:30 p.m.
Additional daily consultation hour at 4 - 5 p.m. from 11-13 January 2021
Venue: Online via Zoom
Registration: https://indico.desy.de/event/28086/

Lecture I-III: Introduction to quantum computing (11-12 Jan 2021)

Stefan Kühn, Computation-Based Science and Technology Research Center
The Cyprus Institute

The three lectures provide a short summary of the very basics of quantum computing and quantum information. After a brief introduction to the circuit model of quantum computation, we will discuss some quantum algorithms and applications. If time permits, we will have a look at IBM's openly available quantum devices and implement some simple quantum programs on those.

Lecture IV: Dimensional Expressivity Analysis (12 Jan 2021)

Tobias Hartung
The Cyprus Institute & University of Bath

In this lecture, we will be looking at quantum circuits comprising parametric gates and analyse their expressivity in terms of the space of states that can be generated by a given circuit.

A standard tool in quantum computing are Variational Quantum Simulations (VQS) which form a class of hybrid quantum-classical algorithms for solving optimization problems. For example, the objective may be to find the ground state of a Hamiltonian by minimizing the energy. As such, VQS use parametric quantum circuit designs to generate a family of quantum states (e.g., states obeying physical symmetries) and efficiently evaluate a cost function for the given set of variational parameters (e.g., energy of the current quantum state) on a quantum device. The optimization is then performed using a classical feedback loop based on the measurement outcomes of the quantum device.

In the case of energy minimization, the optimal parameter set therefore encodes the ground state corresponding to the given Hamiltonian provided that the parametric quantum circuit is able to encode the ground state. Hence, the design of parametric quantum circuits is subject to two competing drivers. On one hand, the set of states, that can be generated by the parametric quantum circuit, has to be large enough to contain the ground state. Otherwise, we may at best find the ground state of the Hamiltonian restricted to the states generated by the chosen quantum circuit. On the other hand, the circuit should contain as few parametric quantum gates as possible to minimize noise from the quantum device. In other words, when designing a parametric quantum circuit we want to ensure that there are no redundant parameters.

Thus, we will consider the parametric quantum circuit as a map from parameter space to the state space of the quantum device. Using this point of view, the set of generated states forms a manifold. If the quantum circuit is free from redundant parameters, then the number of parameters is precisely the dimension of the manifold of states. This leads us to the notion of dimensional expressivity analysis. We will discuss means of analyzing a given parametric design in order to remove redundant parameters as well as any unwanted symmetries (e.g., a gate whose only effect is a change in global phase). In order to know how many independent parameters are necessary to ensure that the entire space of physical states is generated by the parametric quantum circuit, we will furthermore discuss the manifold of physical states. Looking into the manifold of physical states can also provide us with guidance towards custom circuit design for physical applications.

Lecture V: Introduction to Error Mitigation (13 Jan 2021)

Lena Funcke
Perimeter Institute for Theoretical Physics

Quantum computers have the potential to outperform classical computers in a variety of tasks ranging from combinatorial optimization to machine learning to intrinsically evading the sign problem. However, current intermediate-scale quantum devices still suffer from a considerable level of noise. This lecture will introduce different sources of noise and their mitigation techniques, with a particular focus on the final qubit measurement. While measurement error mitigation techniques are usually only applicable to a small number of qubits, the lecture presents a novel method that can be applied to any operator, any number of qubits, and any realistic bit-flip probability. The experimental realization of the method is demonstrated on IBM quantum hardware, reducing the final measurement error by up to one order of magnitude.

Lecture VI: A Lightning Introduction to Machine Learning for Quantum Physicists (13 Jan 2021)

Pan Kessel
TU Berlin und BIFOLD

In the lecture, I will first give a high-level overview of why Machine Learning techniques are useful for Quantum Computing. I will then give an accessible introduction to some basic concepts of Machine Learning for which no previous knowledge of the subject is required. Particular emphasis will be put on Neural Networks and Supervised Learning. If time permits, I will explain their applications in the context of Quantum Computation in more detail.

Zoom meeting details will be forwarded to all registrants in due course.
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