Quantum Machine Learning: Strategies Based on Quantum Annealing and Gated Quantum Computing

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Abstract:

Quantum Computers (QCs) are machines based on quantum bits (qubits) that take full advantage of the laws of quantum mechanics (QM). They hold the promise to outperform current classical computing capabilities. There is an expectation that machine learning (ML) will be among the most influential killer apps for the first generation of commercially-available QCs, and specifically for the hardware that will dominate the QC landscape during the so called Noisy Intermediate-Scale Quantum (NISQ) era. It is predicted that ML will be impacted in the near-term by both Adiabatic Quantum Annealers (AQAs) and gated QCs. Commercial AQAs with more than 100 qubits have been available for more than a decade while no gated QC with more than 100 qubits is currently commercially available. As a result, there is already a rich history of applying AQAs to ML problems. On the other hand, gated QC hardware is attracting great interest today since it is the foundation upon which a future general-purpose (rather than an application-specific) QC will be based. The recent progress in gated QC hardware, algorithms, and early proof-of-concept applications point to these devices also making substantial inroads into ML, and they currently enjoy the lion's share of the scientific publications related to quantum ML (QML).

In this talk, we will review the most basic QM concepts behind qubits, the use of the so-called bra-ket notation to describe the state vector of a system of qubits, and the density matrix formalism. Those are often the things that intimidate and confuse researchers who are new to QM and discourage them from trying to understand published QC algorithms. We will build intuition about the elusive concept of quantum interference, its connection to quantum probability amplitudes, and how interference (usually in a hidden way) may influence probabilistic outcomes compared to those in classical probabilistic models. Finally, we will try to address typical misunderstandings about quantum parallelism.

We will proceed by introducing AQAs and their connection with un-directed probabilistic graphical models (Markov Random Fields), which are an important part of the modern ML toolkit. Two main tasks – combinatorial optimization and sampling from complex probability distributions – will be discussed. We will also discuss the reasons for why the introduction of the AQA hardware reignited interest in generative models based on Restricted Boltzmann Machine (RBMs). We will then move to the gated QC concept, the circuit model of computation, and the field of the quantum feedforward neural networks. We will introduce a family of variational quantum algorithms and explain why they are expected to become the most promising solution given the practical limitations of near-term QCs, specifically the NISQ hardware.

Biography:

Yaroslav Koshka is a Professor in Electrical and Computer Engineering at Mississippi State University, the Director of the Emerging Materials Research Laboratory and the Chair of the Quantum Information Science and Quantum Computing Working Group. His current main research area is quantum computations and their application to machine learning. Other research interests include micro- and nano-electronic materials and device computer-aided design, characterization, defect engineering, synthesis of wide-bandgap semiconductor materials and nanostructures, physics of semiconductor devices, and nanoelectronics. He received a Ph.D. in Electrical Engineering from the University of South Florida in 1998.