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The HEP.QPR Project: Quantum Pattern Recognition for Charged Particle Tracking

Universal Quantum Computing may still be a few years away, but we have entered the Noisy Intermediate-Scale Quantum era which ranges from D-Wave commercial Quantum Annealers to a wide selection of gate-based quantum processor prototypes. These provide us with the opportunity to evaluate the potential of quantum computing for HEP applications.
We will present early results from the DOE HEP.QPR project (https://hep-qpr.lbl.gov) on the impact of Quantum Computing on charged particle tracking. Due to the increase in data rates and event complexities, tracking has become one of the most pressing HEP computational problems.
In HEP.QPR, we are studying the potential of the Quantum Associative Memory (QuAM) and Quantum Annealing (QA) algorithms. QuAM provides in principle an exponential increase in storage capacity compared to the classical associative memory algorithm used, e.g., for LHC data triggering. We will present a prototype implementation of the QuAM protocols and analyze the topological limitations for running QuAM on the IBM Q chips - a family of superconducting gate-based quantum processors. We will review several difficulties integrating the end-to-end quantum pattern recognition into a real-time production workflow and discuss possible techniques for mitigation.
We will also present some promising results we achieved expressing the LHC track finding problem as a Quadratic Unconstrained Binary Optimization (QUBO) that can be solved using a D-Wave Quantum Annealer. We generated QUBOs that encode the pattern recognition problem at the LHC on the TrackML dataset, and we solved them using D-Wave qbsolv hybrid optimizer. Those early experiments achieved a performance exceeding 99% for purity, efficiency, and for the TrackML score at low track densities. We plan to extend the performance of such algorithms at higher track densities by improving seeding algorithms, geographical partitioning, and our QUBO models. We will also evaluate if the hybrid classical/quantum annealing approach used by qbsolv provides performance improvements compared to purely classical QUBO solvers.

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