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Inspiring Quantum Data Analysts

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ABSTRACT

The quantum revolution has swept into data analytics with quantum computers promising better algorithms for machine learning, optimization, and other techniques. In this commentary to Prof. Yazhen Wang's (2021) article on making data science quantum, I note that it may be some time before quantum computers mature enough for data analytics to come online. Nevertheless, there are quantum explorations appropriate for even today's data analysts. Here I outline two possibilities, looking at quantum-inspired algorithms and information technologies and formulating benchmarks for quantum technologies.

Keywords: quantum-inspired algorithms, quantum machine learning, quantum benchmarks, quantum metrics

Media Summary

The fusing of quantum computers and data analytics promises a revolution in machine learning and other optimization and related computational capabilities. However, there are no quantum computers currently capable of outperforming their conventional counterparts for these applications. Here I suggest two areas of exploration for today's data analysts interested in quantum: quantum-inspired analytics, viewing information technologies from the vantage point of quantum in order to make gains in conventional systems, and benchmarking quantum technologies.

1. Introduction

In a concluding proposal to develop quantum data analytics, professor Yazhen Wang (2021) identifies major areas in which quantum computers can revolutionize data science. These areas include machine learning, games, and data augmentation. Wang also notes that data analytics is vital in exploring the question of thermal-based classical annealing versus tunneling-based quantum annealing. Given these already identified areas, Wang called for continued identification and analysis of areas of overlap as quantum computers mature.

The major drawback of these ideas forwarded by Wang is the lack of a fully mature quantum computer. To this point, there have only been three demonstrations of so-called quantum supremacy (Arute et al., 2019; Wu et al., 2021; Zhong et al., 2020), where a quantum computer is shown to clearly outperform the fastest of today's supercomputers. The problems solved in those demonstrations are tailor-designed for the quantum computer and without practical application. We still await a demonstration of a quantum advantage for a useful application. Not surprisingly, there are contradictory opinions as to when a quantum computer of sufficient maturity will come online. The recent in-depth evaluation by Sevilla and Reidel (2020) predicted with 50% confidence that there will not be a quantum computer capable of breaking the 2048-bit version of the public

key Rivest-Shamir-Adelman (RSA) cryptosystem until 2050. If so, to what end are studies of quantum data science if there is no quantum computer?

One may counter that there is a vast difference between RSA, which is broken with Shor's algorithm, and machine learning or optimization. The argument would go as follows. Factoring and similar problems have one solution. There is no utility in coming close to the correct answer. One either gets the answer or not. Optimization, however, may have an optimal solution but also many suboptimal solutions. Though today's quantum computers, defined by Preskill (2018) as noisy, intermediate-scale quantum (NISQ) computers, may not be able to identify the optimal solution due to noise and errors, those errors will merely push the computation to a suboptimal, but still useful, solution and do so more quickly than conventional computers. In response to this argument, it could be pointed out that in a typical quantum computing architecture there is no a priori reason that errors should act in a way to lead to a suboptimal solution rather than completely disrupting the computation.

Thus, we are left with the question: Is there a short-term gain in exploring quantum data analysis?

Here I would like to suggest two positive answers to this question. First, quantum data analytics may provide a new perspective to classic problems. That perspective opens the door for solutions that exploit quantum phenomena but has also inspired new ideas that emulate, rather than exploit, such phenomena. Second, data analytics can be used to formulate metrics and benchmarks for emerging quantum computers and other quantum technologies. For reason of cross-platform comparison and the identification of trends to make predictions, metrics and benchmarks have an important role to play even today, when quantum computers cannot, with rare exception, outperform conventional devices.

2. Quantum Inspired

Six years ago, Kerendis and Prakash (2016) released a paper on “Quantum Recommendation Systems,” demonstrating an exponential speedup for quantum computers over their classical counterparts for a machine learning application. Less than three years later, Tang (2019) presented a conventional algorithm, only polynomially slower than the quantum algorithm. Tang's algorithm was quantum inspired, meaning that the conventional computer attempts to emulate certain aspects of quantum mechanics to gain a computational advantage. To date, there have been quite a few quantum-inspired algorithms tackling problems of optimization (Cai et al., 2021), machine learning (Ding et al., 2021), and linear algebra (Chakhmakhchyan et al., 2017) (the references provide only a few examples). In addition, the Fujitsu Digital Annealer (Aramon et al., 2019) is a classical analog of quantum annealers such as those produced by D-Wave.

Quantum inspiration is not limited to computing. Utilizing quantum information theory, Tsang et al. (2016) demonstrates the ability to improve imaging systems, specifically the ability to resolve two objects that are in close proximity to each other. It had been generally assumed that two objects were unresolvable if they violated the Rayleigh criterion, meaning that the two objects were close enough that their Airy discs (proportional to the

wavelength of the light divided by the size of the sensing aperture) overlapped. However, Tsang et al. demonstrated that this criterion is irrelevant if only one approached the problem from a quantum information standpoint. No part of the novel sensing system proposed by Tsang et. al, requires quantum mechanics. All that changed was that they had taken a quantum perspective.

Today's data analysts looking to expand into the area of quantum may want to build on any of the above-mentioned work or explore new areas looking to be quantum inspired. One area that may hold promise is quantum-inspired games, such as discussed in Khan et al. (2018). Wang (2021) in his article already used a quantum game to show the utility of quantum information. Is there a path for quantum-inspired games that achieve similar results when sampling over a large ensemble or via some other method? Another area is quantum networks and communication systems, as discussed by Pirandola et al. (2017). These fields have borrowed heavily from their classical counterparts. Are there techniques that can go the other way?

In summary, though there is no quantum computer yet capable of implementing quantum data analytics, there is a large space for the quantum data analyst to continue to explore.

3. Quantum Metrics and Benchmarks

As quantum technologies mature, there is a need to understand what applications are enabled as new versions of the technologies are developed. In addition, the field is looking for ways to identify trends and make predictions as to future capabilities. To that end, proper metrics and benchmarks are needed. Here I define a metric as a number gauging some aspect of a quantum technology while a benchmark is a method used to determine a metric.

An example of a metric for quantum computers is number of quantum bits (or qubits). The advantage of number of qubits as a metric is that it is easy to determine how many qubits are in the computer (the benchmarking process is straightforward) and since it is generally known how many qubits are necessary to accomplish certain tasks, such as determined in Roetteler et al. (2017) for breaking RSA encryption, the number of qubits gives an idea as to the potential power of the quantum computer. The weakness of employing number of qubits as a metric is that it does not account for inaccuracies in the operation of the qubits. No qubit today is perfect. Some measure of imperfection would be useful in gauging the actual capability of a quantum computer.

In response to this issue, Cross et al. (2019) defined an alternate metric known as quantum volume (QV). The QV accounts for both the number of qubits and their ability to implement gates accurately. Effectively it represents the largest square circuit (number of qubits by number of time steps where gates are implemented) that can be implemented by the quantum computer. One drawback of the QV is the difficulty in determining its value. This is because it is necessary to test the accuracy of gates between every possible pair of qubits. However, current qubit architecture, where qubits are arranged in a square or other type of lattice, does not allow for easy implementation of two-qubit gates between any pair.

Other metrics and benchmarks have been devised to determine the accuracy or power of quantum computers. However, the goal of this commentary is not to review current metrics and benchmarks but to inspire data analysts to formulate new ones. What data is needed, what benchmarks are useful, how can the power of a quantum computer, or a quantum network, or any of the emerging quantum technologies be communicated in a straightforward fashion? These are the questions I would like to place in front of today's enterprising data analysts.

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Disclosure Statement

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