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Financial use cases for quantum computing

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Executive Summary

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Computing capacity requirements have been growing rapidly in the financial sector in recent years. Going forward, quantum computing is expected to play a role in meeting the sector's growing computing needs. Financial institutions may be able to gain a competitive advantage by applying quantum computing to core financial services. Given the structural differences between quantum computers and classical computers, it will be important for financial institutions to develop in-house expertise in quantum computing.

Computational needs continue to grow

As essentially an information processing industry, the financial sector has long required massive computing capacity. Financial institutions, many of which were historically among the earliest adopters of computers, are perennially in need of more, faster computing power.

In recent years, the ongoing growth in financial institutions' computing needs has been accelerated by changes in their operating environment. One such change is advanced risk management requirements imposed by regulatory capital rules, most notably Basel III. Such rules require financial institutions to accurately quantify the risk of the assets they own, a computationally intensive process. Moreover, risk management requirements are expected to become even more stringent. Such a trend would drive growth in computing costs. Another change in the environment is the advent of big data and adoption of machine learning and other AI technologies that enable big-data analytics. When AI is used in marketing for tasks such as credit scoring and real-time recommendations based on analysis of customers' behavioral patterns, it requires massive computation to identify correlations among multidimensional data.

The challenge with today's computers ("classical computers") is that computational workload increases exponentially as a function of the amount of data processed. With classical computers, exponential growth in computational requirements tends to lead to exponential cost increases. Quantum computers, however, have the potential to vastly reduce computation relative to classical computers.

NOTE

1) Daniel J. Egger et al. "Quantum Computing for Finance: State-of-the-Art and Future Prospects" https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9222275

A paper[1)] published by the Institute of Electrical and Electronics Engineers identified three financial use cases for quantum computing: simulation, optimization and machine learning. Following is an overview of these use cases based on the IEEE paper.

Simulation

Simulations typically entail defining separate probability functions for multiple parameters, formulating multiple scenarios and repeatedly computing outcomes under each of the scenarios. With classical computers, computational workload grows exponentially as more parameters and/or scenarios are added. Quantum computers, by contrast, can substantially reduce computational workload by using qubits (quantum bits) to represent the parameters' respective features.

Simulation use cases for quantum computing include derivative pricing, VaR (value at risk) estimation and computation of risk-weighted asset estimates that factor in market volatility.

Optimization

Optimization usually identifies the best decision or action among multiple alternatives or the most efficient combination of alternatives. With classical computers, optimization problems typically must be solved by brute force (i.e., by testing all combinations of alternatives). In such cases, computational workload increases exponentially as the number of alternatives increases. Consequently, optimization problems with too many alternatives cannot be solved on a practical timescale using classical computers.

Quantum computers can solve optimization problems without getting bogged down in massive computations by assigning each of the alternatives to a qubit and finding the combination with the most stable inter-qubit energy state. Optimization use cases for quantum computing include optimal portfolio construction/rebalancing and optimal trade matching among multiple sell and buy orders[2)]. In a somewhat different vein, quantum computing could be applied to M&A matching also.

2) In general, constructing an optimal portfolio comprising an arbitrary number of assets selected from a set of N assets requires 2^N computational iterations (assuming the portfolio is equal-weighted and the assets are uniformly priced). Under these assumptions, 10 assets can be combined into 1,024 (2^{10}) different portfolios, a manageable number. If the number of assets increases to 100, however, the number of possible combinations is 2^{100}, roughly equivalent to 10^{30} or one quadrillion squared. The computations required to generate 2^{100} combinations cannot be completed on a practical timescale. However, the computational workload can be reduced somewhat by using the Markowitz model, which enables portfolio optimization to be converted from a combinatorial problem into a linear system (matrix algebra) problem. Specifically, the Markowitz model identifies the combination of assets that minimizes portfolio variance under a risk tolerance constraint, based on the assets' respective ex ante rates of return and inter-asset return correlations (covariances). While the Markowitz model substantially reduces computational workload relative to a pure combinatorial problem, it still requires multi-dimensional algebraic computations that become increasingly intractable as the number of assets increases.
With quantum computing, computational workload can theoretically be reduced to log(N) iterations by using the Harrow-Hassidim-Lloyd (HHL) algorithm, which enables linear systems of equations to be solved expeditiously. In the above example, the HHL algorithm can theoretically solve portfolio optimization problems in one iteration when $N = 10$ and only two iterations even when $N = 100$.

Machine learning

Machine learning can find otherwise undetectable data structures or patterns by discovering correlations among multidimensional data. It can be used to make predictions based on historical time-series data, classify data into similarity-based categories and detect designated patterns (e.g., anomalies, indicia of misconduct).

Specific machine-learning use cases for quantum computing include market forecasting, credit risk assessment, refinement of customer segmentation and detection of money laundering or other improprieties.

Currently, however, there is no clear theoretical proof that quantum computers are more computationally efficient than classical computers in the machine learning realm.

Preparing for commercial quantum computing

Classical computers alone will not be sufficient to continue meeting financial institutions' growing computational needs. With classical computers, exponentially growing computational workloads are prone to lead to exponential cost increases. Even when classical computers are capable of performing a certain computation, they are of no value if they take a month to complete it. Risk management always entails time constraints. Without quantum computers, the likelihood of encountering problems that cannot be solved on a practical timescale is high.

Additionally, quantum technology has broad applicability to cybersecurity also, though such use cases are beyond the scope of this paper. Quantum key distribution (QKD) in particular, which enables ultra-secure information transmission, is rapidly progressing toward commercialization. It is now being feasibility-tested even in Japan[3].

3) The Nikkei reported on December 21, 2020 that Nomura Holdings and Toshiba are testing QKD for adoption in the financial sector.

Because quantum computers differ so much from classical computers in terms of their principles and structure, their utilization requires completely different skills and knowledge. Developing human resources that understand quantum computing principles and can apply quantum computing's problem-solving capabilities to real-world problems will become increasingly important.

Under IBM's roadmap, quantum computers are slated to make twofold performance gains year after year. IBM is projecting commercialization of general-purpose quantum computers by around 2030. The likes of Google and IBM are developing noisy intermediate-scale quantum (NISQ) computers with tens to hundreds of qubits that may reach the commercialization stage within a few years. Quantum computing is on track to soon be more than just a dream technology.

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