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Quantum computing: applications to banking

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Overview

Many financial institutions are currently investigating the possibilities of benefiting (and securing themselves) from the quantum leap, i.e. the advent of quantum computation on a large scale. Portfolio optimization, Monte Carlo simulations and pricing derivatives are only a few of the many applications for which a quantum computer will outperform even the fastest supercomputers. This article presents an overview of the applications of quantum computing to banking.

Quantum mechanics, superposition and entanglement

Quantum mechanics is the theory that describes the dynamics of microscopic particles [1] [2]. Such particles behave differently from what we are used to seeing in the classical macroscopic world in which we live. In certain conditions these microscopic particles (e.g. electrons or photons) behave like waves. This means that quantum particles are not described by single points or hard objects, as it happens in classical mechanics, but they are described by probability distributions. Quantum mechanics is the theory that defines the evolution of the probability distribution of microscopic particles.

This probabilistic nature of quantum particles leads to two non-classical phenomena which are the basis of quantum computation: superposition and entanglement.

Superposition is the simultaneous existence of a particle in multiple states. A quantum particle can be simultaneously “dead” or “alive”, “0” or “1”, “on” or “off”.

Entanglement is the state of perfect correlation between two particles, for which a measurement on one of the two leads instantaneously to the change of the state of the other particle.

In the following we describe the idea behind quantum computing and the applications of quantum computing to the financial industry.

Quantum computing: a new paradigm?

Calculations on a classical computer are based on the binary system, where the information is carried by bits of either value 0 **or** 1.

A quantum computer [3] [4] is a computer which processes information using quantum particles. The smallest unit of information is the quantum bit, or qubit. The qubit is the state of a quantum particle, which due to the quantum superposition property of particles can simultaneously assume values 0 **and** 1. More specifically a qubit can assume a value of any linear combination of 0 and 1.

This feature, together with the entanglement between qubits, makes a quantum computer more efficient at certain types of data-intensive applications and calculations which would be harder to perform on a classical computer. As an example, k qubits can potentially represent 2^k bits of information. Further functions on quantum qubits (quantum operators or gates) can be used to: find patterns and correlations that point toward a solution (Grover algorithm [5]), exchange a key in a “super-secure” way (BB84 protocol [6]), or even exponentially speed up classical operations (Quantum Fourier Transform [7]), etc.

On the other hand, there are calculations which are easy to perform on a classical computer that are currently more expensive on a quantum computer (e.g. scientific computing, term-to-term product, etc.). This suggests that the applications of quantum computers in the near future will be based on hybrid architectures, in which the advantages of quantum calculations are embedded in a classical framework.

Quantum banking

The financial industry is constantly searching for new technologies that can leverage higher performances in the hope of achieving higher profits. For instance, the progress in the fields of data science and artificial intelligence is an example of how financial services have been, and still are, benefiting of new technologies such as exploring new business models and markets which they would not have been able to even imagine in the past.

Quantum computing is presently being investigated by several big players in the financial industry [8] [9] [10] to be ready for the quantum leap, i.e. the moment in which the quantum computers will be available on large scale for practical applications.

Most of investigation is focused on data-intensive applications (big data), optimization problems, simulations and modelling. [11] [12]

Besides the experimental research on the construction of a stable quantum computer, from a theoretical point of view the research is based on determining quantum algorithms (i.e. algorithms on a quantum computer architecture) which present an advantage in terms of input capabilities or speed with respect to a classical computer.
Several optimization algorithms have been developed for quantum computers, i.e. quantum optimization algorithms. Portfolio optimization is an NP-hard (non-deterministic polynomial time-hard) problem, that is it is very difficult for classical computers to efficiently determine the best portfolio composition. In particular, quantum annealing is a promising quantum optimization algorithm. This algorithm finds the global minimum of a function by using quantum fluctuation to investigate the space of possible solutions. Google published a result in 2016 that seems showing how quantum annealing outperforms the classical simulated annealing by a factor of a factor of 10^8 [13].

From a banking perspective, the models used to determine the price of a financial instrument or portfolio only include some of the drivers needed to describe the full dynamics. The optimization of a portfolio becomes in fact more and more complex and time consuming when the number of instruments, drivers and targets grows. Tasks like multi-objective optimization are expected to speed-up the performance of the algorithms when implemented on a quantum computer.

Besides optimization, another methodology extensively used in finance is simulation (Monte Carlo). For instance, a stochastic approach can be used to simulate the effect of uncertainties around the drivers of the price of a financial derivative or obtain the credit exposure of a risky portfolio. On a classical computer, the precision of the simulation depends on the number of simulations. On the other hand, several quantum algorithms have been constructed to perform simulations on a quantum computer. The most promising algorithms are extensions of the amplitude estimation and amplification methods used in the Grover's search algorithm [14]. It has been shown that these types of algorithms provide a quadratic speed-up compared to their classical counterparty [15]. Applications to finance in this regard have been proposed [16] [17].

Another field that is currently at the center of investigation of the financial industry is data science, and more specifically machine learning. In particular, neural network models have been proven successful in analyzing credit risks, predicting market changes, fraud detection, trading, etc.

Training a machine learning model corresponds roughly to finding the solution to a large system of equations, which is also equivalent to diagonalizing a large matrix. In 2009 Harrow, Hassidim and Lloyd introduced a quantum algorithm (the HHL algorithm) [18] to solve linear systems of equations on a quantum computer. This algorithm shows an exponential improvement relative to the best classical algorithm, and furthermore it has since been extended to create many more quantum machine learning algorithms. Few famous examples are quantum principal component analysis (QPCA) [19], quantum support vector machines [20] and quantum machine learning [21] [22].

Besides these applications, researchers are currently looking at possible applications of quantum computing to banking from many other points of view. We close this section with an honorable mention of these applications: security. Cryptography is in fact another key application to the banking industry. Currently most of the encryption systems rely on the difficulty of finding the prime factors of very large numbers. For classical computers this calculation is generally slow, which ensures the security of this system. However, on a quantum computer, the Shor's algorithm [23] provides an exponential speed-up compared to classical algorithms. When a sufficiently powerful quantum computer is built, our data might not be safe if no alternative for our security system has been found.

Waiting for the quantum leap

Google, IBM, Microsoft, Honeywell, D-Wave, and many other companies are currently investing a lot of resources in the run to "quantum supremacy". Insights from this run suggest three things mainly: 1. quantum computing works, 2. it can be faster than classical computers and 3. it seems to open many doors to new applications.

However, there are still many challenges to be faced before quantum computing breaks through a large scale usage. In particular, state preparation (input) and decoherence are two of the main challenges which slow down the progress and the possible testing of many algorithms. In fact, there is no efficient way yet to prepare the qubit states in a given configuration, e.g. to represent a time series. Several ideas have been proposed, among which the qRAM [24] is a promising way which would allow the implementation of many of the existing quantum machine learning algorithms. Decoherence is instead a consequence of the quantum particles which constitute the quantum computer interacting with the environment (including the computer itself and the measurement devices), leading to noise and loss of information from the quantum computer into the environment. For this reason, a lot of research is focused on the so-called error correction algorithms, to avoid loss and restoring quantum information.

A lot of attention is also invested on the possible applications of quantum computing. Finance, banking and data science will be boosted once the quantum supremacy is reached. This is therefore the best time to understand the challenges and to catch the opportunities that quantum computing is unveiling.

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