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Quantum Optimization

External Public

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Introduction

Optimization problems and their significance

Quantum computers are expected to outperform classical computers in solving certain types of problems, including several types of optimization problems. The advantage of quantum computers over classical computers lies in their ability to exploit quantum mechanical phenomena such as superposition and entanglement to perform computations on a large number of states simultaneously. In short, quantum computers are expected to handle more combinations of variables at any given moment, than a classical computer.

Optimization problems play a crucial role in modern business decision-making, providing a rigorous and quantitative approach to solving complex problems. In short, optimization involves finding the best solution to a problem that maximizes, or minimizes, a given objective when subjected to constraints. Every day, we solve optimization problems, whether it is planning meals, deciding the best route to work, or choosing our activities for the day. The significance of optimization problems in business lies in their ability to help organizations make better decisions. By using mathematical models and algorithms, optimization problems can provide insights into complex problems and help businesses allocate their resources more efficiently. For example, optimization can be used to minimize costs, increase revenue, improve production efficiency, and reduce waste.

Optimization problems are applicable in all business sectors, such as finance, operations, marketing, and supply chain management. Optimization allows businesses to explore different scenarios and evaluate the impact of different decisions on its performance, identifying potential risks and opportunities, and make informed decisions that can drive growth and profitability. An example optimization problem in the healthcare sector includes optimizing patient scheduling. Healthcare providers need to schedule patients efficiently to maximize the use of resources such as doctors, nurses, and equipment. However, scheduling is challenging due to the variability of patient needs, availability of resources, and the need to balance urgent and routine appointments. To address this challenge, optimization techniques can be used to develop efficient scheduling algorithms that minimize patient wait times, maximize resource utilization, and balance patient needs and provider availability. This involves using data on patient needs and provider availability to develop mathematical models. These models optimize scheduling decisions based on multiple criteria such as patient priority, treatment duration, and resource availability.

Current challenges

Complexity is the most significant challenge in optimization. As optimization problems become more complex, finding the optimal solution becomes increasingly difficult. Increased complexity means the optimization algorithms require a larger amount of computational resources and time to find the best solution, making them impractical, and sometimes impossible, for certain applications.

Another challenge is the reliance on accurate and up-to-date data to make decisions. In many cases, data may be limited, incomplete, or unreliable, which can affect the accuracy and effectiveness of optimization solutions. Optimization problems also assume that all inputs and parameters are known and fixed. The challenge is that many factors are uncertain and/or evolve, making it difficult to develop robust and adaptive optimization solutions.

Because of the limitation of computational resources, many optimization solutions require trade-offs among different objectives. For example, reducing costs may lead to lower quality or longer delivery times. Finding the best balance among these trade-offs can be difficult and may require subjective judgment.

Why can't we have it all?

DELL and EY quantum teams explored just that with the power of quantum annealing to solve for the optimization challenges of complexity, data, uncertainty, and trade-offs.

Use Cases and Solutions

Dell and EY explored portfolio optimization using a Dell quantum platform with options for quantum annealers. Quantum annealing offers the potential to accelerate decision-making processes, drive innovation, and unlock new insights that may have been previously unattainable. Quantum annealing is a computational approach that leverages quantum mechanics to solve optimization problems efficiently. Quantum annealing works by utilizing quantum effects such as superposition and tunneling to explore a vast search space of viable solutions simultaneously. This simultaneous functionality enables practitioners to quickly identify the best configuration of resources, processes, or strategies that maximizes desired outcomes like cost reduction, revenue generation, or resource allocation. By harnessing the computational power of quantum annealing, businesses can address challenges like portfolio optimization.

Portfolio optimization is the process of creating an investment portfolio that selects a combination of assets with a set of objectives, such as maximizing the returns while minimizing the risk of the portfolio. Dell and EY set to optimize the portfolio's return while maintaining a high level of sensitivity to Sustainability factors and minimizing risk. Together, the teams performed the following steps to solve the portfolio optimization problem:

- **Define objective**: The first step of designing an optimization algorithm is to clearly articulate the objective(s). In the case of the Dell/EY portfolio optimization, the objective was to maximize the best sustainability score, while yielding the greatest return of the portfolio, along with the desired value-at-risk.
- **Define constraints**: depending on users' preference, various constraints can be defined to generate portfolio allocation strategies unique to the users. Constraints can include portfolio size, sector preference, risk management, and other real-world demands.
- **Construct data source**: Having a clean data source constructed is the next crucial step to solving portfolio optimization. Dell/EY grouped the assets into practical industry segments, so if a portfolio manager wished to optimize based on "technology stocks," that would be feasible.
- **Formulation**: With the objectives, constraints and data defined, the team then needs to next determine the best formula/algorithm and then write the quantum code for the selected algorithm. Based on the Dell/EY knowledge of the financial use case as well as knowledge of the quantum annealer's strengths (and limitations), Dell/EY selected the best formulation for solving the portfolio optimization equation, which is Quadratic Unconstrained Binary Optimization (QUBO). In the following sections, QUBO is described in more detail.
- **Selecting assets**: The final step is selecting the assets, which can be done automatically using an optimization solver or using defined rules that characterize the constraints for selecting the assets. This team in this instance uses the annealer to automatically select the assets.

The formula defined from the steps above had near 6,500 binary variables with 498 stocks from the S&P 500 index. The formula was solved in less than 1 minute with an annealer, which demonstrates the feasibility of the approach and the applicability of the formula. The outcome of solving the portfolio optimization leveraging QUBO formula was successful, in that the team reached an optimized output that met the targeted objective, while satisfying the defined constraints.

More critically, we learned from the process that real-world problems can be formulated and solved with QUBO. The process of implementing the QUBO formula and constraints is easier compared to some classical optimization method. Furthermore, enterprises can utilize QUBO as a transitional technology, to generate value in the immediate future, while waiting for gate-based quantum processing units to mature.

What QUBO (Quadratic Unconstrained Binary Optimization) can do for you

EY utilized a QUBO algorithm within Dell's Quantum Annealer technology to execute portfolio optimization. A QUBO problem is an optimization problem that seeks to find the optimal binary values for a set of variables that minimize a quadratic objective function. QUBO problems can be expressed as matrices or sparse arrays and can be solved using classical and quantum annealing. The wide range of applications for a QUBO problem is infinite and nowadays used to solve real world problems across different industries. One example of the fundamental problem that can be solved using QUBO is Traveling Salesperson Problem (TSP). TSP serves as the foundation for solving various routing problems in logistics. These variations increase the complexity of finding solutions to these problems. Additionally, the large size of real-world problems necessitates the exploration of new techniques to effectively solve QUBO problems.

With quantum annealing and simulation technologies, the solutions to many optimization use cases can be sufficiently estimated today. Practitioners can immediately realize return-on-investment, by digitally transforming existing optimization challenges. When QPUs become more powerful in the future, the existing QUBO implements can be migrated to the QPUs seamlessly, for potentially even better solution quality or higher performance.

What other problems can be solved with QUBO

QUBO can be used to model a wide range of use cases, including finance and investment problems, such as risk management and portfolio management explored by DELL and EY Quantum teams. Other use cases that can be solved effectively and efficiently using quantum annealers include, but not limited to:

- Scheduling problems, such as staff and equipment scheduling.
- Logistics and transportation problems, such as vehicle routing, facility location, and warehouse optimization.
- Energy optimization problems, such as power plant dispatch, demand response, and energy storage optimization.
- Machine learning problems, such as clustering and classification.
- Graph problems, such as graph coloring, maximum independent set, and minimum vertex cover.

Scaling relative to classical solver

Depending on the scale of the problem being solved with QUBO, there are various software stacks and hardware accelerators that can be used. The scaling of a quantum annealer relative to a classical solver depends on the specific problem being solved and the size of the problem. In general, quantum annealers can solve certain types of optimization problems (i.e., spin glass) faster than classical solvers for certain problem sizes. There are several benchmarks [1] that demonstrate the benefit of utilizing quantum tunneling from quantum annealers helps to speed up the solution of irregular landscapes of functions that we want to optimize.

For small problem sizes, classical solvers can often find the optimal solution more efficiently than quantum annealers. However, as the problem size increases, quantum annealers may be able to find the optimal solution more efficiently than classical solvers.

It is worth noting that not all optimization problems are well-suited for quantum annealing, and in some cases, classical solvers may still be the best option. Additionally, the performance of quantum annealers is heavily dependent on the specific hardware and software used, as well as the algorithms and techniques employed to solve the optimization problem.

Actions to Take

Getting started

Getting started in the exploration of quantum optimization problems is as simple as a phone call to our team. Exploring quantum optimization problems requires a thorough understanding of both the problem domain, and the capabilities and limitations of quantum hardware and software. The consultant should collaborate closely with the client to ensure that the quantum approach is well-suited to the problem and that the solution is reliable and scalable. We follow and recommend a four (4) step process for quantum practitioners who are supporting business process owners:

1. Define the problem with as much clarity as possible. This includes identifying the objective function, constraints, and other relevant parameters. It is important to ensure the problem is well-formulated and can be translated into a QUBO problem that can be solved using quantum optimization.

2. Evaluate the quantum advantage and assess whether quantum optimization is a) feasible and b) likely to provide an advantage over classical optimization methods for the given problem.

3. Develop a formulation for the problem which involves mapping the problem variables and constraints to binary variables and a quadratic objective function that can be solved using quantum optimization.

4. Choose a quantum optimization algorithm based on factors such as the problem size and complexity, available hardware and software, and desired level of accuracy.

How Dell & EY are working together for customers

While there is significant interest from enterprises to begin their quantum journey and to further optimize their core businesses, many have found it difficult to get started and navigate. There are many challenges that enterprises face, such as the high cost of computational infrastructure, a lack of in-house expertise, and difficulties of identifying and implementing the right business-critical use cases.

Dell and EY are committed to help our customers to solve these challenges.

Dell provides best-in-class computational infrastructure that can sufficiently solve some of the most complex and challenging problems. Dell has recently released its first hybrid quantum computing solution, which lowers the barrier of entrance for quantum computing. The solution comes equipped with a significant amount of computational power that able to solve problems with simulated annealing. Furthermore, Dell has a wide range of software, as well as classical and quantum hardware partners who can provide additional capabilities, to further ease the challenges that enterprises face. Dell is dedicated to continuing to lead the way for customers through the complex ecosystem of quantum annealing and computing.

The EY Global Quantum team of 200+ quantum experts provide Quantum guidance, education and a holistic quantum ecosystem that expedites a client’s quantum journey. The EY Quantum ecosystem is designed to lower the barrier of entry and allow democratized access to quantum computing. EY Quantum works closely with clients to identify and implement practical, business-critical use cases that rapidly demonstrate a return-on-investment. By leveraging the Dell and EY alliance, clients are able to quickly gain an understanding of the value that quantum annealing, and computing can have on businesses.

Further Reading

Dell Quantum Computing Solution: https://www.dell.com/en-us/dt/solutions/quantum-computing/index.htm

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Reference

[1] Heng, Sovanmonynuth, Dongmin Kim, Taekyung Kim, and Youngsun Han. "How to Solve Combinatorial Optimization Problems Using Real Quantum Machines: A Recent Survey." *IEEE Access* 10 (2022): 120106–21. https://doi.org/10.1109/ACCESS.2022.3218908.

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