Master Thesis overview

Optimization of a cloud services access problem using a quantum annealing based computer.

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Keywords: cloud, optimization, quantum annealing, D'Wave

1 Introduction

The general idea of cloud services is based on the public availability. This causes the problem of queuing access to such resources, as there is a limited number of them. The best solution of the problem would minimize the cost (whatever the cost is defined as, it can be time, money, processors usage etc.), so this is an optimization problem. Since D-Wave quantum computer has been released as a cloud service, it has become possible to try to solve problems on it. The way it works (quantum annealing) makes the computer a good choice for sampling and optimization problems. The purpose of this work is to translate the cloud resources access problem to the D'Wave quantum computer and run it on the real machine via the cloud service available.

2 Problem statement

The main obstacle in this work is the following fact: quantum annealing computers currently existing cannot solve every correctly formulated QUBO/Ising problem. If this was true, every NP-hard problem could be solved on them, as solving QUBO/Ising problem is an NP-hard problem (as proven in (*1*). Every problem (or at least type of problem) must be separately overthought and translated into the language of the specific machine. The research objectives are to check if it is possible to accelerate solving optimization problems related to cloud systems on the quantum annealing based computer.

3 Methodology

Solving a problem on a computer solving QUBO/Ising problems, the only example of which currently is D-Wave Two, requires:

- (optionally) formulating the problem as the constraint satisfaction problem, this form is closer to QUBO/Ising as conversion from CSP to QUBO comes down to penalizing the solutions with unsatisfied constraints with correct factors
- formulating the problem in the form of QUBO/Ising problem
- (optionally) Divide a problem into smaller pieces so that they fit the architecture of the machine
- minor embedding the problem to match the architecture of the computer

The first and the third steps are optional, however for larger problems they can be unavoidable. The methodology of the research follows these steps to solve a cloud services access problem on the quantum annealing based computer provided by D-Wave.

4 Related work

Ising model and QUBO are not a novelty in the physics and computer science (for example described in (*2*) in 1970). However, in recent years it is becoming more popular due to the possibility of implementing these problems (that are both NP-hard - polynomially reductible to each other) on the real computer provided by D-Wave. Many commonly known problems have already been solved on the D-Wave machine, e.g. job shop problem in (*3*) or traffic flow optimization problem in (*4*) Some works focus on the specific parts of solving problems on quantum annealing computers. The work (*5*) shows the practical approach to finding graph minors which is almost unavoidable for solving large problems on the real quantum annealing computer. The authors of the work (*6*) present the methods of embedding problem to two D-Wave architecture: currently used Chimera and architecture of not yet released Pegasus chip (to be released in mid 2020). There are also attempts for benchmarking the quantum annealing based computers, presented in the work (*7*). An cloud optimization problem that can be applied for the D-Wave machine is described in (*8*).

5 Solution

The new solution contains:

- formulation of the chosen cloud optimization problem as constraint satisfaction problem
- translating this CSP to Quadratic Unconstrained Binary Optimization problem
- minor embedding the problem for the D-Wave Chimera architecture
- collecting the results and veryfying them (as described in the **evaluation** chapter

There are no universal mappers of QUBO problems into quantum annealing computer. Every such problem mapping is a novelty, so is the solution proposed in this work.

6 Evaluation

The solution evaluation is problematic (as mentioned in (*7*)). Quantum annealing computer can solve problems exponentially faster than the classical computer, what follows: for large problems finding a classical solution to verify the correctness of the quantum one. Also the computer is analog, so the results can be wrong in spite of correct QUBO formulation and correct minor embedding. The evaluation process will follow the steps:

- finding a few instances of a chosen problem, describing them in very details
- running it on D-Wave computer and on a classical computer using a well described algorithm (e.g. tabu search algorithm (*9*))

Based on this evaluation, conclusions will be taken for the further work.

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