Benchmarking Metaheuristic-Integrated QAOA against Quantum Annealing

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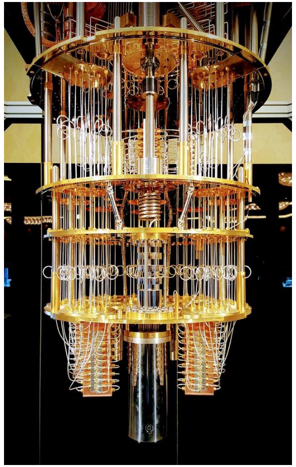
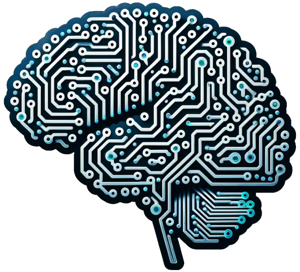
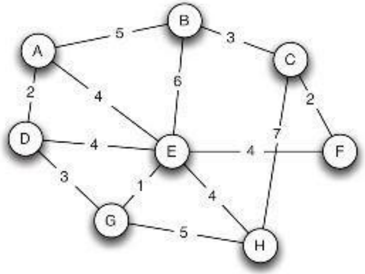
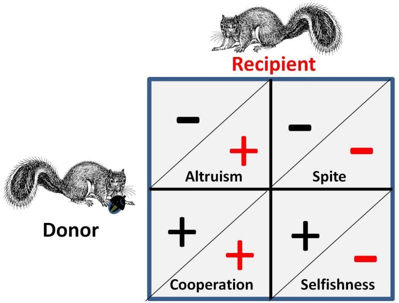
Quantum Computing in Combinatorial Optimization

- Quantum Computing can be used to solve intractable problems
- NISQ-computers are limited by the number of available fault-tolerant quantum bits (qubits)
- One promising area is Combinatorial Optimization



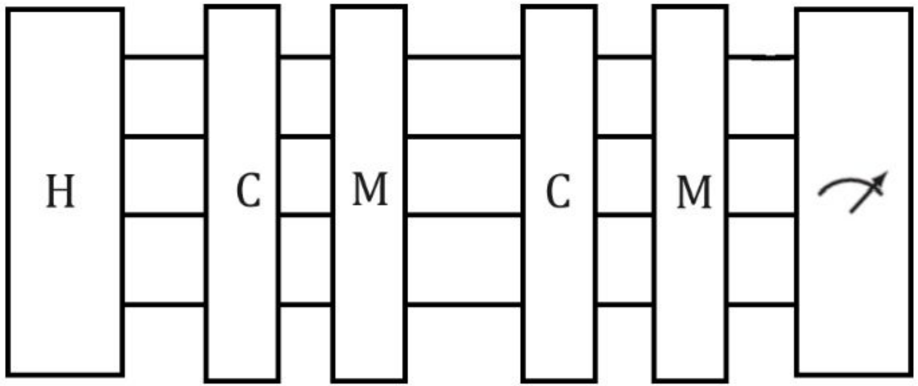






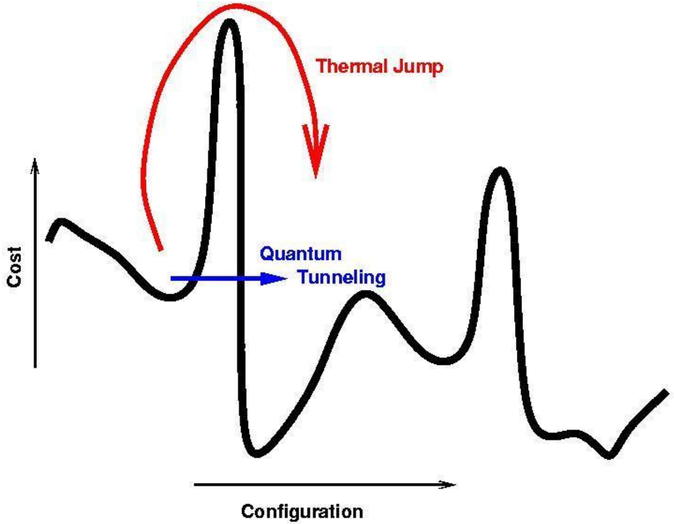
NISQ Algorithms for Combinatorial Optimization

Quantum Approximate Optimization Algorithm (QAOA):



1. initialize random parameters and superimpose
2. apply cost and mixer hamiltonians
3. optimize the parameters towards optimal solution

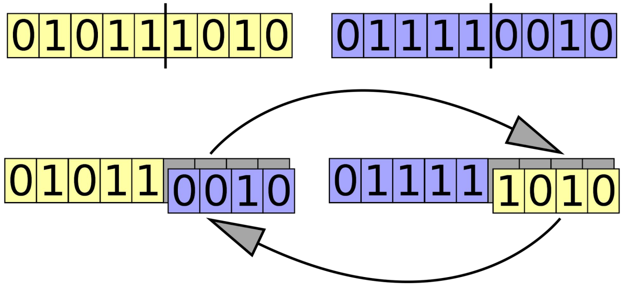
Quantum Annealing



1. encode the problem as hamiltonian for the quantum system
2. gradually evolve the system and the lowest energy state is the solution

Past Research and Our Work

- past work has compared QAOA against Quantum Annealing
- previous research also studies the effects of different optimizers on QAOA
- No work benchmarks the metaheuristic-optimized QAOA against Quantum Annealing
- We integrate the following metaheuristics optimizers
    - Genetic Algorithm
    - Differential Evolution
    - Particle Swarm Optimization
    - Ant Colony Swarm Optimization



Target Problem and Approach

- Require a Quadratic Unconstrained Binary Optimization (QUBO) Model

$$\min_{\mathbf{x}\in\{0,1\}^n} [\mathbf{x}^T\mathbf{Q}\mathbf{x} + c]$$

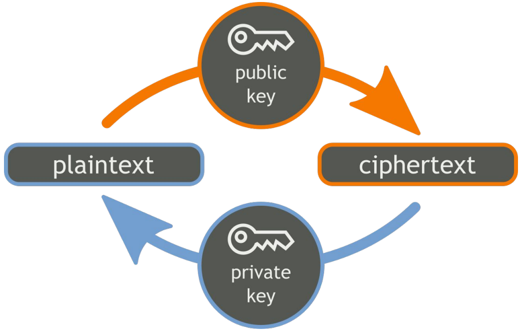
- Focused approach on the Number Partitioning Problem (NPP)

Given arbitrary array **S** partition into arrays **S \ A** and **A** such that the difference between their sums in minimized

S = [1, 5, 11, 5]

A = [1, 5, 5]

S \ A = [11]

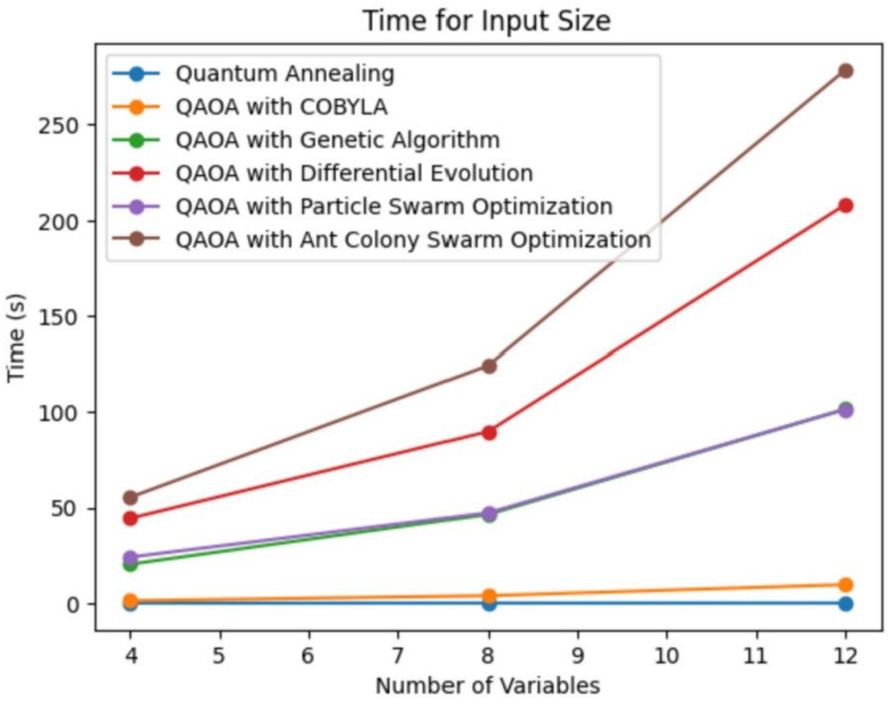


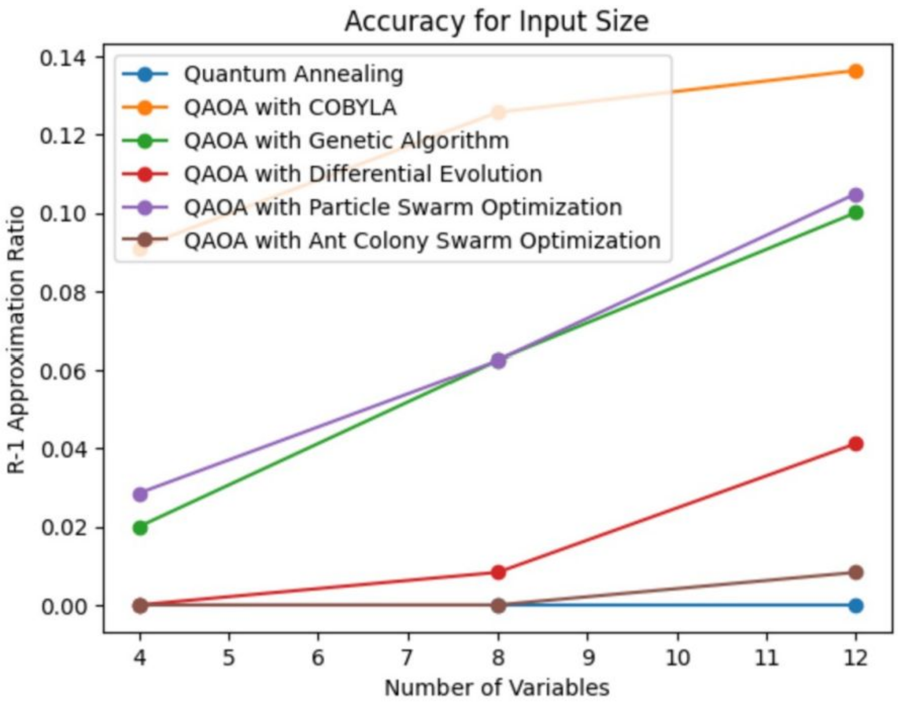
Testing

- Both algorithms were tested on randomly sampled NPP instances
- Input sizes were 4, 8 and 12 variables
- QAOA circuits were tested on IBM QASM Simulator
    - Referenced against QAOA using COBYLA
- Quantum Annealing was run on DWAVE Systems
- Measured Execution Time and Accuracy
- Quantum Annealing: QPU Access Time
- QAOA: Circuit Execution and Optimization

- Used **R - 1** to model accuracy

Results


Time for Input Size
Quantum Annealing
QAOA with COBYLA
QAOA with Genetic Algorithm
QAOA with Differential Evolution
QAOA with Particle Swarm Optimization
QAOA with Ant Colony Swarm Optimization
Time (s)
0
50
100
150
200
250
4
5
6
7
8
9
10
11
12
Number of Variables


Accuracy for Input Size
Quantum Annealing
QAOA with COBYLA
QAOA with Genetic Algorithm
QAOA with Differential Evolution
QAOA with Particle Swarm Optimization
QAOA with Ant Colony Swarm Optimization
R-1 Approximation Ratio
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
4
5
6
7
8
9
10
11
12
Number of Variables

Conclusions

- metaheuristic optimizers have the potential to drastically improve accuracy of QAOA circuits at the expense of time
- Current quantum annealing is still superior to standard and modified QAOA approaches

Future Work

- testing metaheuristic-optimized QAOA on noisy hardware
- evaluating adaptive optimizers for QAOA optimization