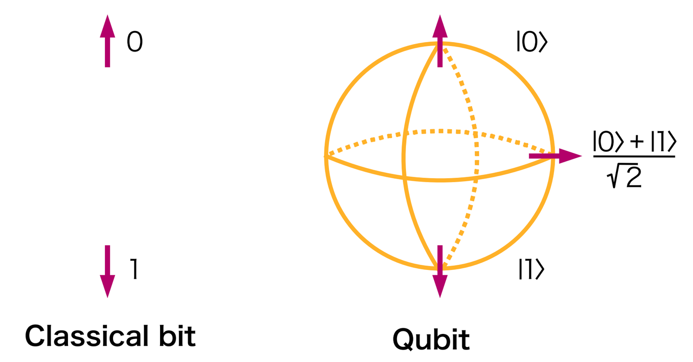
Quantum Computing

CENTRAL MICHIGAN UNIVERSITY

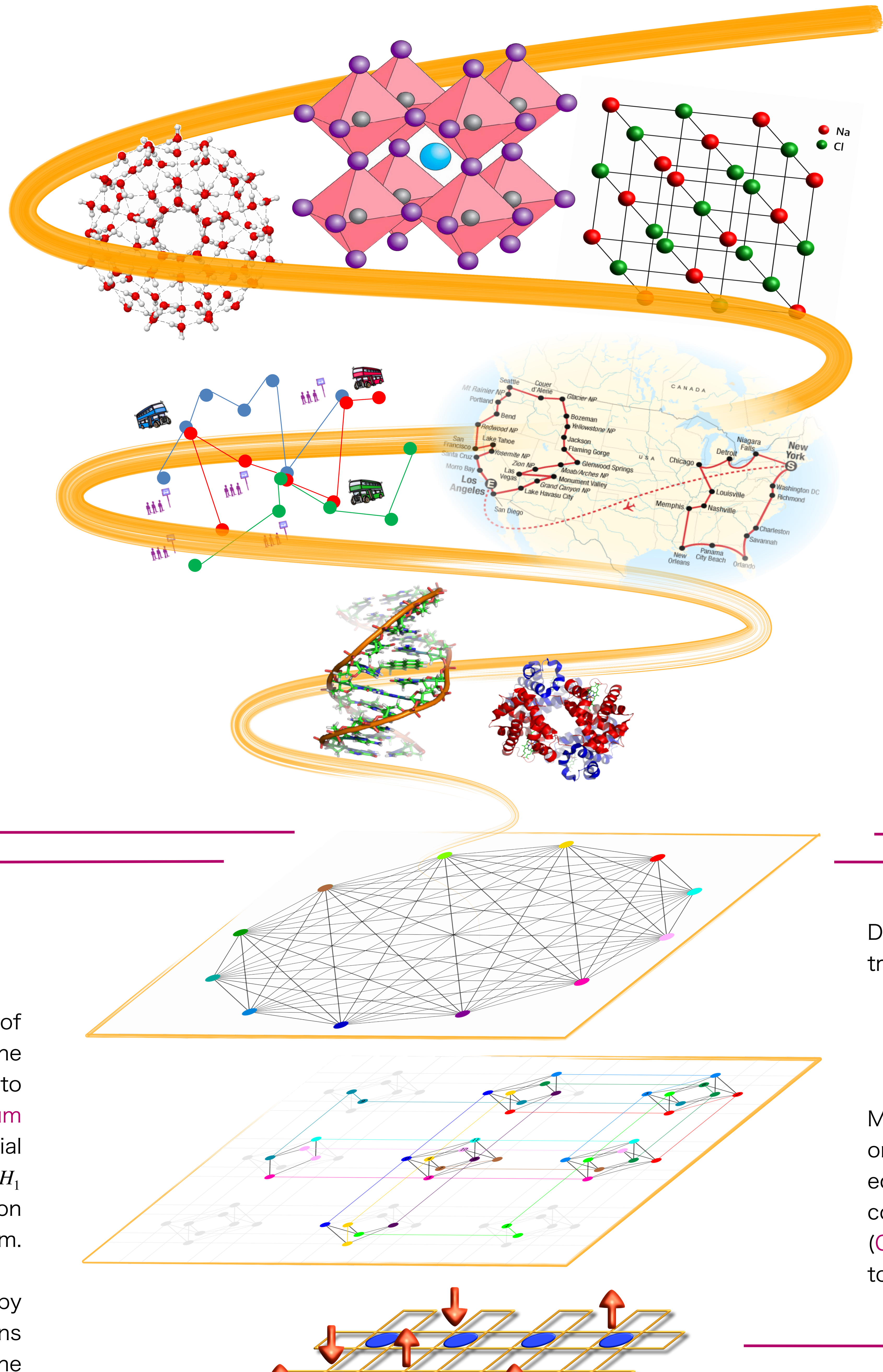
Virginia Carnevali, Ilaria Siloi, Terry Ethan Stearns and Marco Fornari

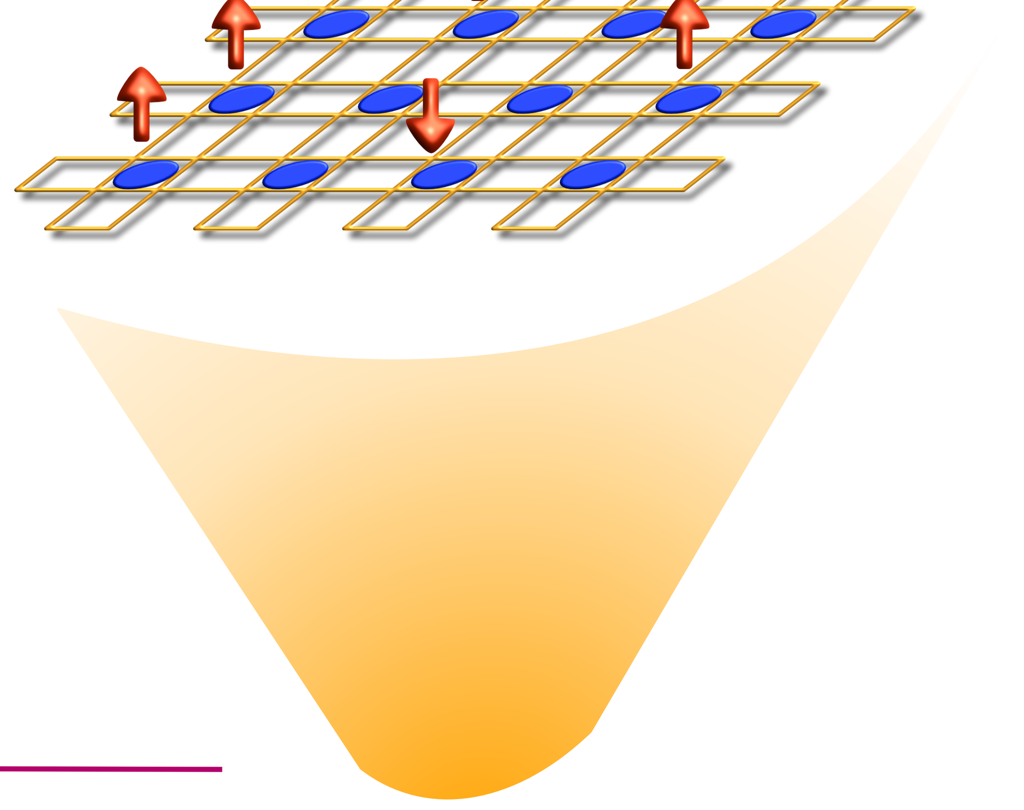
Bit vs Qubit

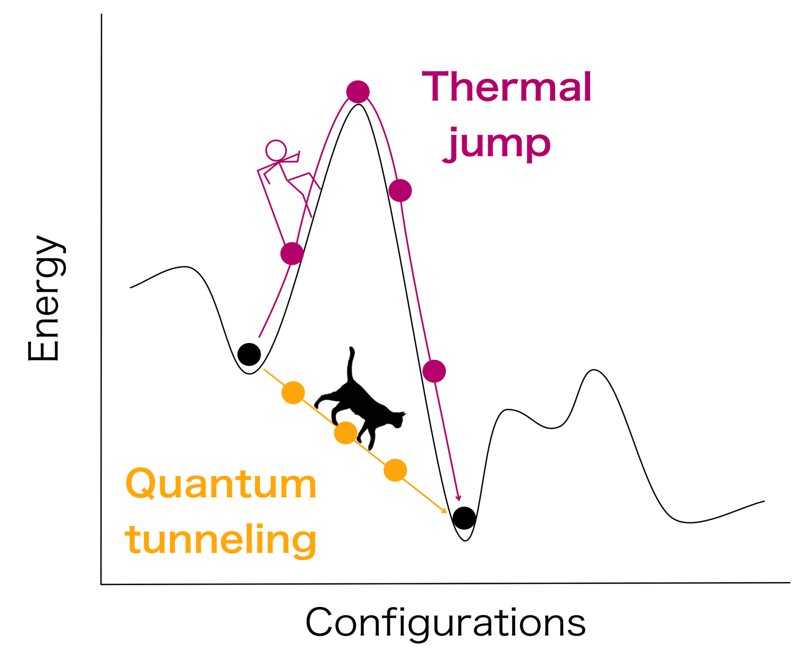
Where a classical bit can either be a 0 and 1, a quantum bit (qubit) is instead any possible combination or "superposition" of 0 and 1. Not only can each qubit be in such superposition state, but the system as a whole can be in a superposition of every combination of different states of all the qubits. This is why a quantum computer could be so immensely powerful.



If we have N qubits then there are 2^N possible states in the superposition. A quantum computer with 30 qubits would have a superposition of 1,073,741,824 states, and a quantum computer with 300 qubits would have roughly the same number of states in superposition as the total number of atoms in the known universe.







Quantum annealers have a wide community of users whose goal is mainly to apply adiabatic quantum optimization (AQO) to a diverse set of computational problems in fields ranging from materials and biological properties, to machine learning, fault detection and optimization. AQO mimics classical simulated thermal annealing but uses quantum superposition and tunneling instead of thermal fluctuations in order to reach a global minimum.

D-Wave (DW)

DW is a quantum annealer composed of an array of superconductive qubits. The algorithm that this computers uses to solve problems is called adiabatic quantum optimization. AQO proceeds from an initial Hamiltonian H_0 to a final Hamiltonian H_1 whose ground state encodes the solution of the computational problem.

The evolution is controlled by $t\in[0,T]$ through two monotonic functions $A(s)$ and $B(s)$, with $s=\frac{t}{T}$ and T is the annealing time ($5\mu s<T<2000\mu s$ for DW2X).

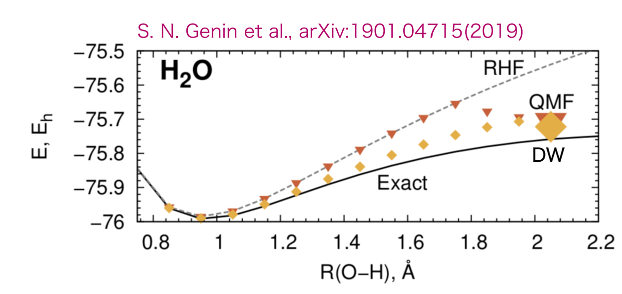
https://www.dwavesys.com

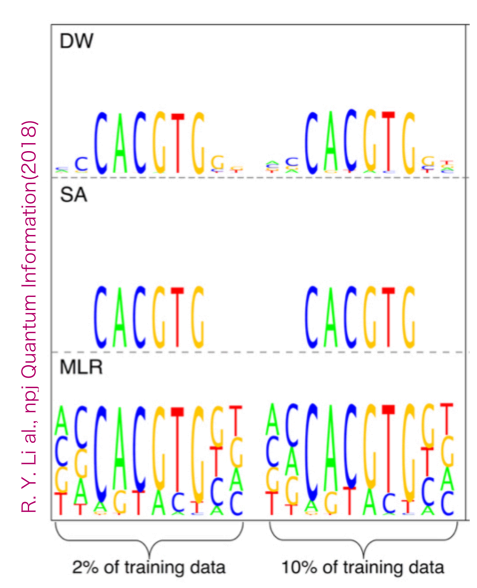
DW can solve only minimization problems translated into Ising Hamiltonian.

$$H(s_1,s_2,\ldots,s_N)=\sum_i h_i s_i+\sum_{ij} J_{ij}s_i s_j \quad s_i\in[-1,1]$$

Morover, DW's qubits are not fully linked. The original Ising problem has to be recasted into equivalent problems defined on a graph compatible with annealer's architecture (Chimera graph). Special tools are available to map the problem on the Chimera graph.

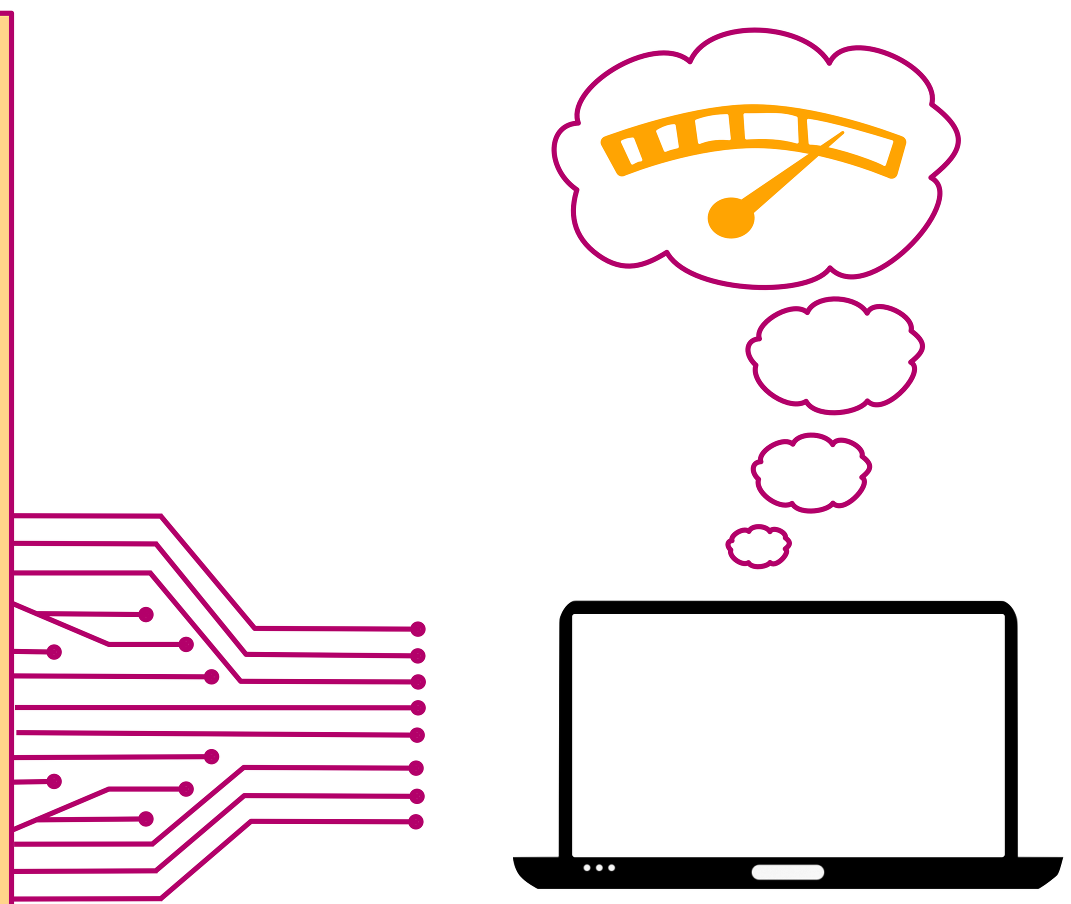
Solution





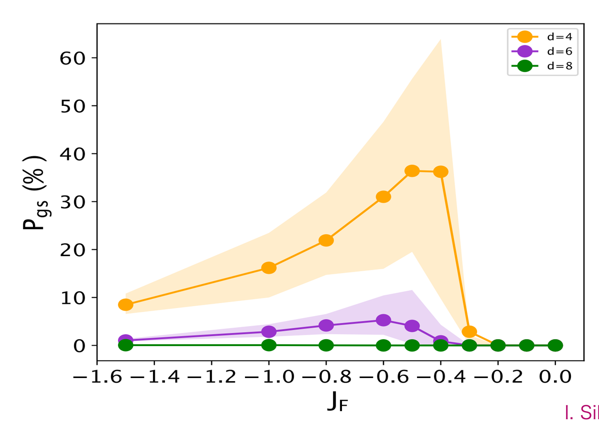
The ground state spin configuration has to be decoded in oder to obtain the solution of the original problem. Then, to address the quality of the results obtain by DW, a comparison with other theoretical methods (such as simulating annealing, tabu alghoritms etc.) and/or experimental results is necessary.

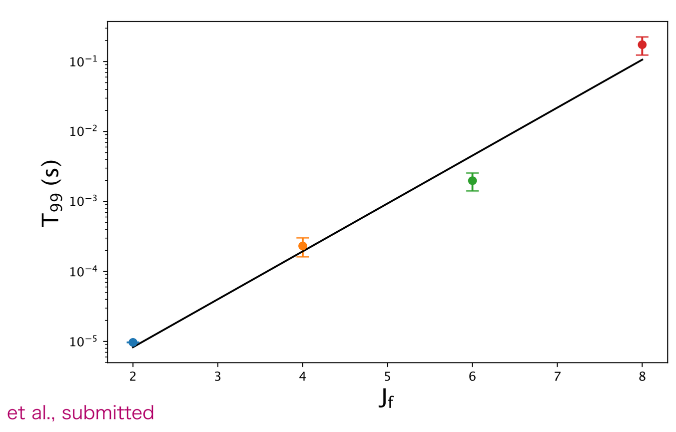
```
bqm= dimod.BinaryQuadraticModel.from_qubo(Q,offset=0.0)

solver=DWaveSampler(endpoint='https://usci.qcc.isi.edu/
sapi', token='XXXXX', solver='DW2X')

__, taget_edgelist, target_adjacency = solver.structure

.....

{0:0, 1:0, 2:0, 3:0, 4:0, 5:0, 6:0, 7:0, 8:0, 9:1, 10:0,
11:0, 12:0, 13:0, 14:0, 15:1, 16:0, 17:0, 18:0, 19:0,
20:1, 21:1, 22:0, 23:0, 24:0, 25:1, 26:0, 27:1, 28:0,
29:0, 30:0, 31:0, 32:1, 33:1, 34:0, 35:0} -4.902676
Occurrences 1 chain break fraction 0.0
{0:1, 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:0, 10:1,
11:1, 12:1, 13:1, 14:1, 15:0, 16:1, 17:1, 18:1, 19:1,
20:0, 21:0, 22:1, 23:1, 24:1, 25:0, 26:1, 27:0, 28:1,
29:1, 30:1, 31:1, 32:0, 33:0, 34:1, 35:1} -4.856447
Occurrences 1 chain break fraction 0.0
```



Performance

The size of the optimization problem and the parameter setting of DW affect the probability of finding the correct solution within a certain time. Therefore, a statistical analysis on the parameters both when using minimization or quantum learning algorithms.





I. Siloi et al., submitted