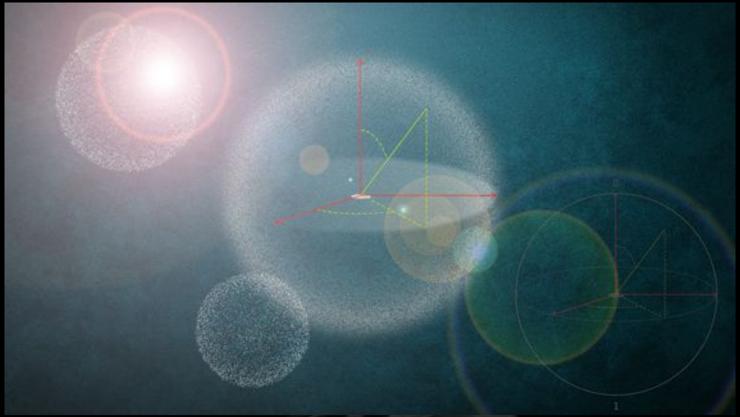
Calibration/Alignment with Hopfield Networks



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Motivation

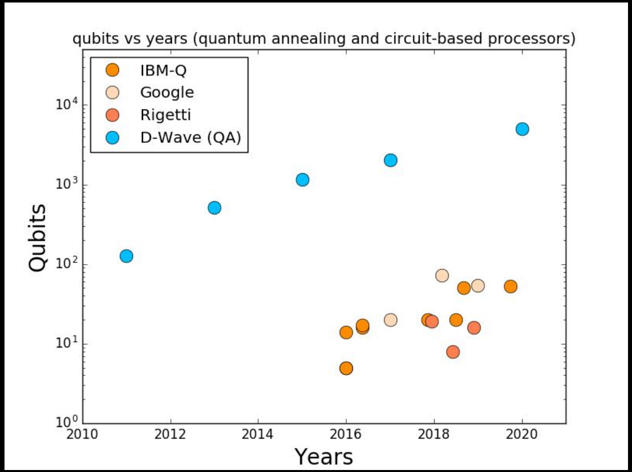
- In the A.I. for Nuclear Physics Workshop held at JLab, Tim Hallman emphasized how a new discipline combining artificial intelligence and quantum computing was at its onset.

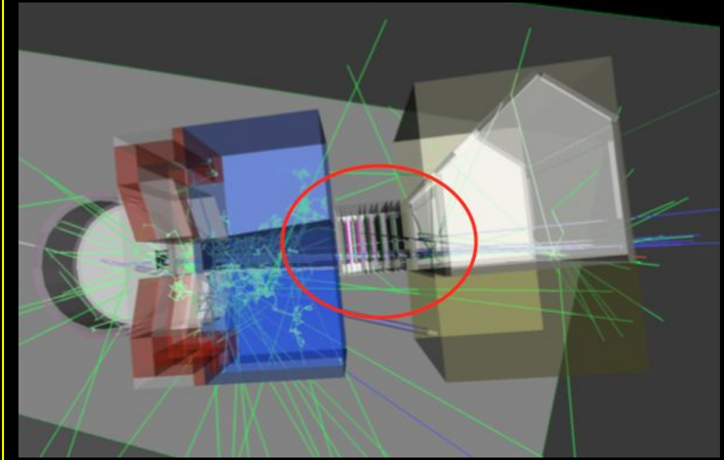
- This project (“TraQCking and fast detector alignment” at ORNL) is an example of such applications.

- Team: CF*, E. Cisbani, A. Del Dotto, W. Phelps, A. Quiroga."

- Starting point: Hopfield network already developed in CF, E. Cisbani, and A. Del Dotto. For the GEM SBS tracker *J. Phys. Conf. Ser.* Vol. 608. No. 1. IOP Publishing, 2015 and deployment on QPU.

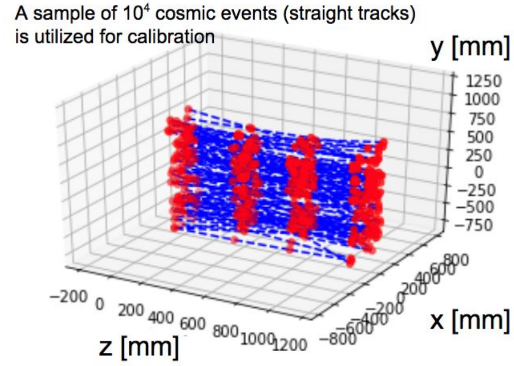
- Focus: alignment of GEM planes. Outlined novel approach for near real time alignment/calibration.

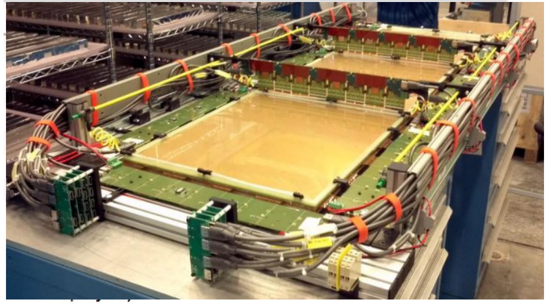


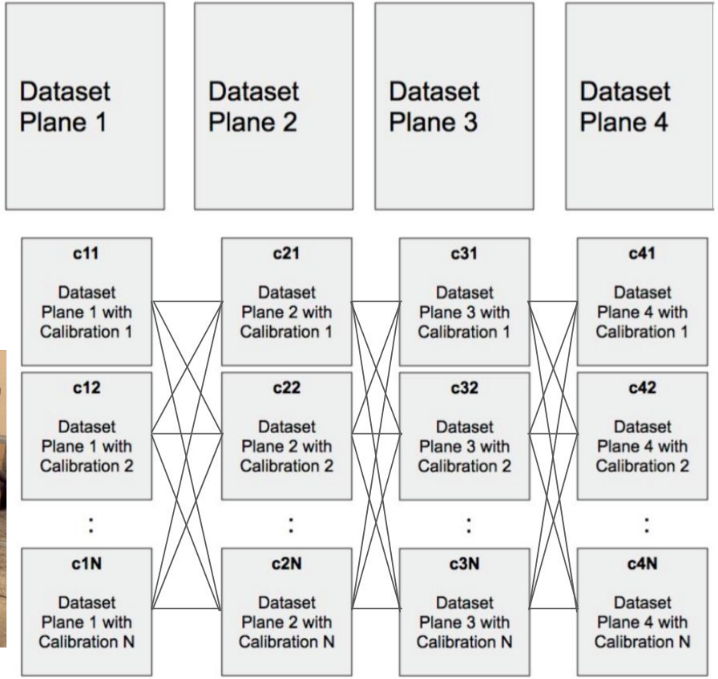


Idea

- We calibrate a batch of 10^4 (or larger) cosmic events taken together.
- We consider the calibration sets as quantum states.
- Each plane has 6 parameters to align (spatial and angular).



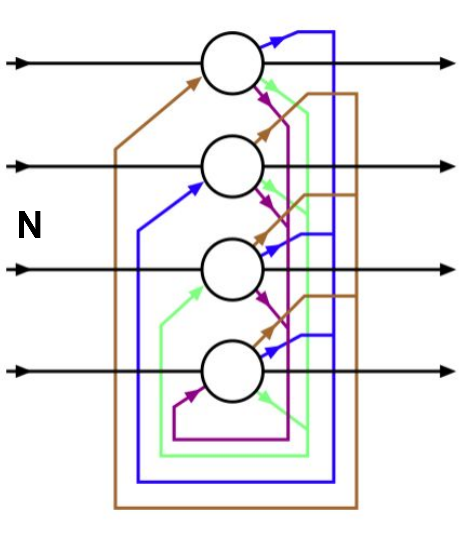


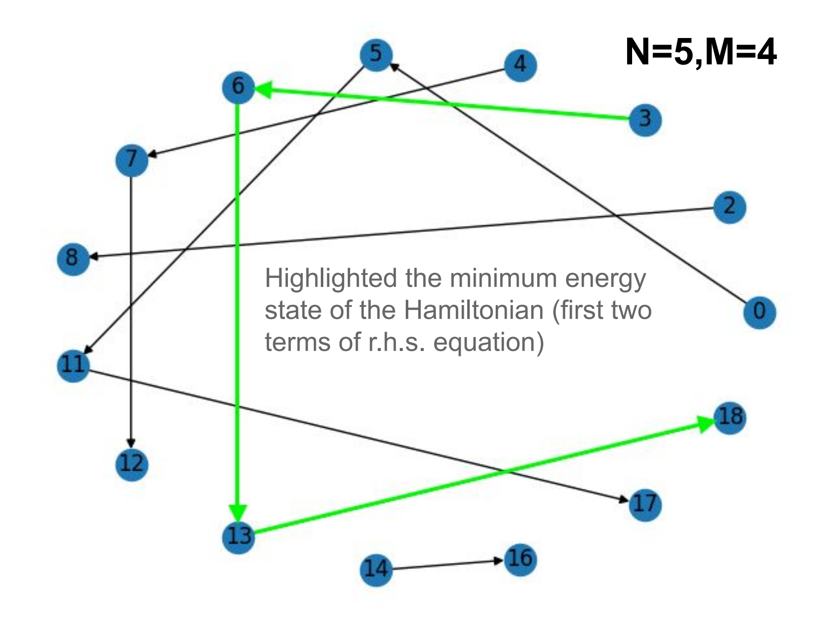


- With the current limits on available qubits we can process (study as a “whole”) ~10^3 different sets of calibration constants in $\gtrsim$ ms (depending on how many samples)
- Ideally more qubits = more configurations explored at once.

Preliminary results

- Calibrations are units in the Hopfield network.
- The graph shows different possible solutions (a combination of calibration states, one per plane).

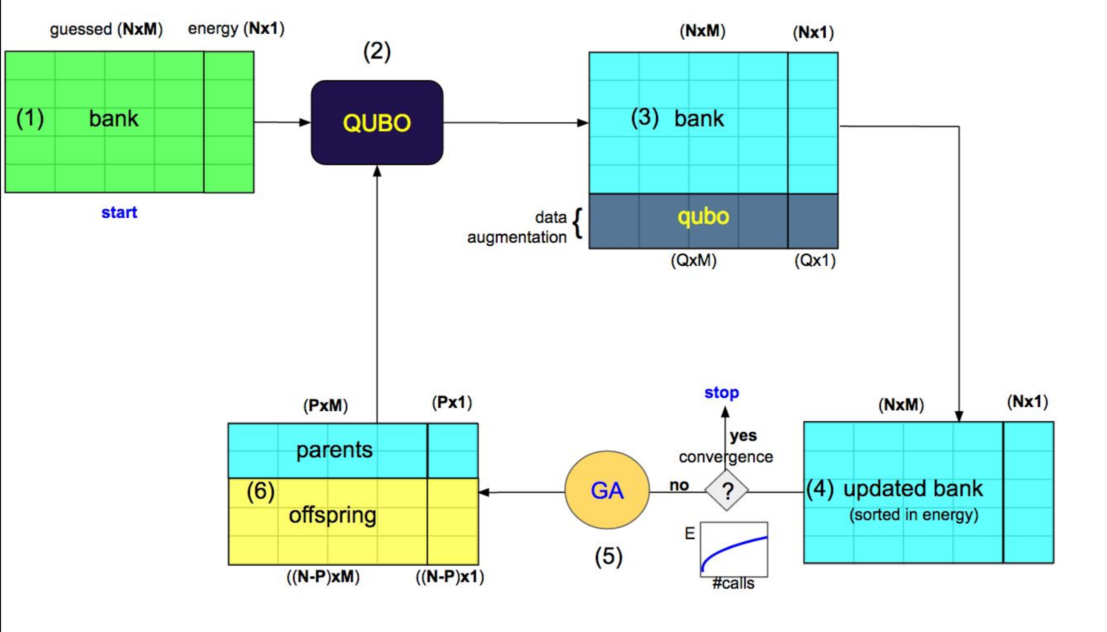




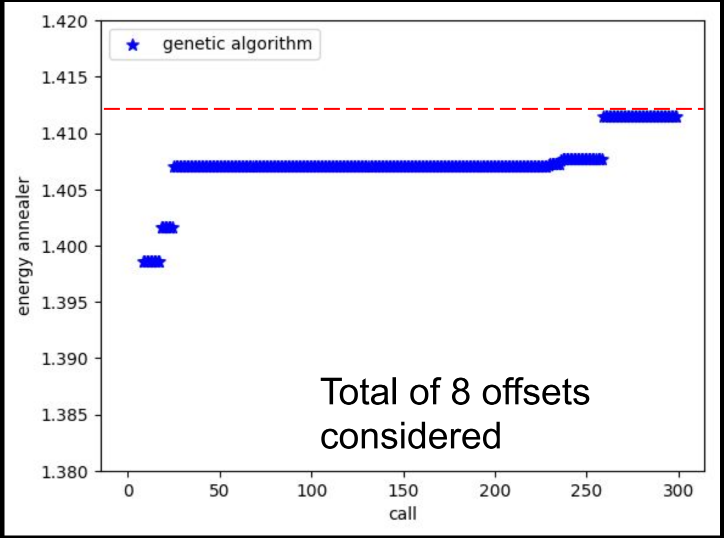
$$E = -\sum_{i,j,k} \frac{S_{i,j}S_{j,k}}{\sqrt{2\cdot d^2 + \Delta\Theta^2_{x\ i,j,k} + \Delta\Theta^2_{y\ i,j,k}}} + \alpha \cdot \underbrace{\sum_{i,j,k}(S_{i,j}S_{i,k} + S_{i,j}S_{k,j})}_{bifurcations} + \beta \cdot \underbrace{\sum_{i,j}(S_{i,j} - N)^2}_{constraint}$$

Bonus: you can find the solutions in mean field theory approximation, *J. Phys. Conf. Ser.* Vol. 608. No. 1

Optimization



GA: genetic algorithm



Each call has a total effective time on D-Wave system of ≳O(10) ms

Perspectives

- This is an explorative project for fast calibration using real data. At the core of the procedure there is quantum annealing, which is supported by A.I. due to the limited number of qubits available at present.

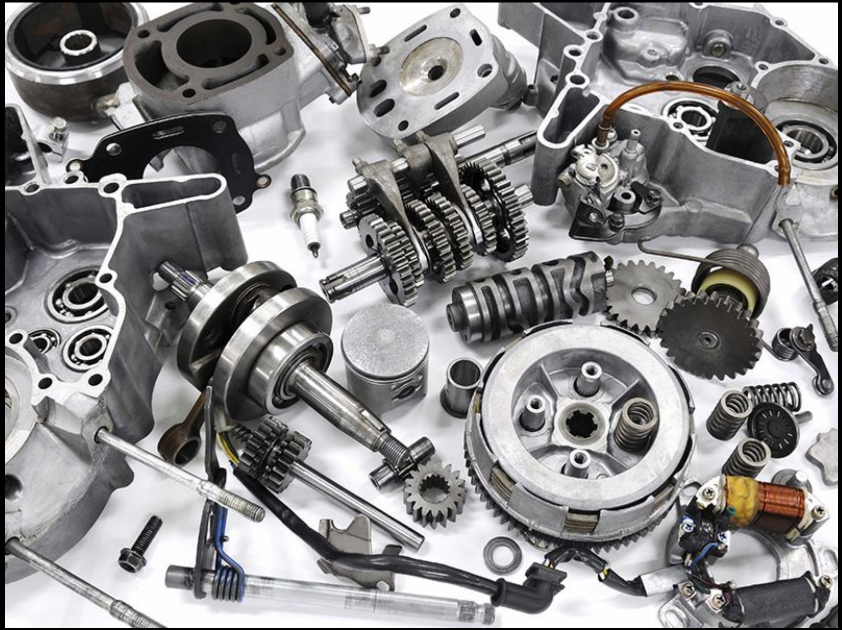
- This results in “quantum-empowered” calibration algorithm.

- This approach considers calibrations as states, and lays the foundation for future pure quantum calibration.

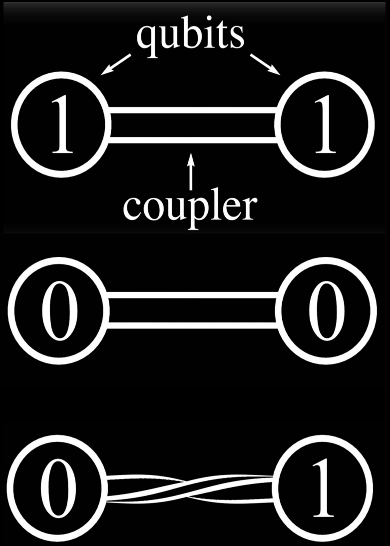
- Interesting preliminary results. Working for a closure test with realistic conditions (several parameters per plane), then deployment on real data.

- Comparison with established calibration procedure for GEM tracker.

SPARES



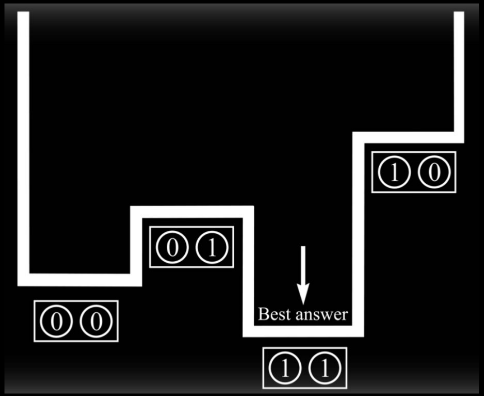
Couplers



Couplers: The real power of this processor is when linking the qubits together, hence couplers allow the qubits influence each other. A coupler can make the two qubits end up in the same state.

Alternatively, the coupler can make the neighbouring qubits want to be in the opposite states, so either 0 1 or 1 0.

Couplers use quantum entanglement (the 2-qubits entangled can be considered as a single object).

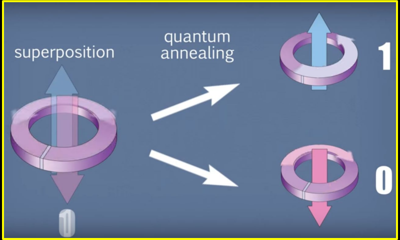


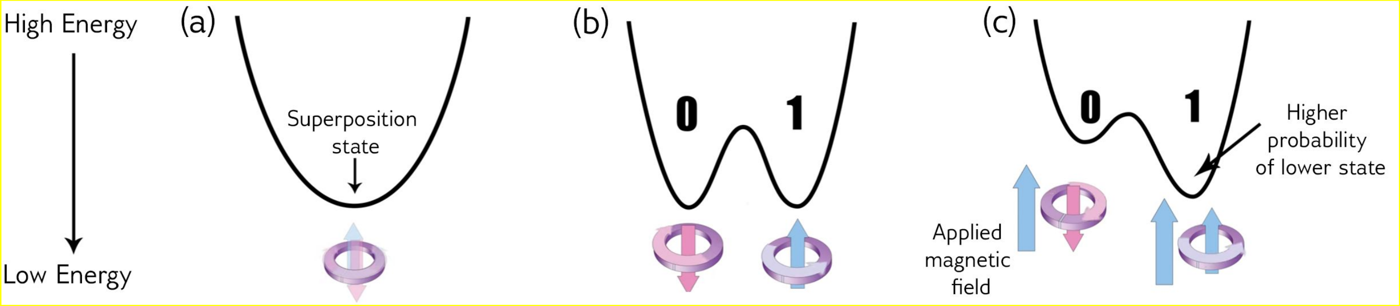
Couplers make the two qubits energetically favorable (either if the same or opposite).

Quantum Annealing

Main applications:
- Optimization
- Probabilistic Sampling (-> ML)

Quantum Annealing finds the minimum state of a problem

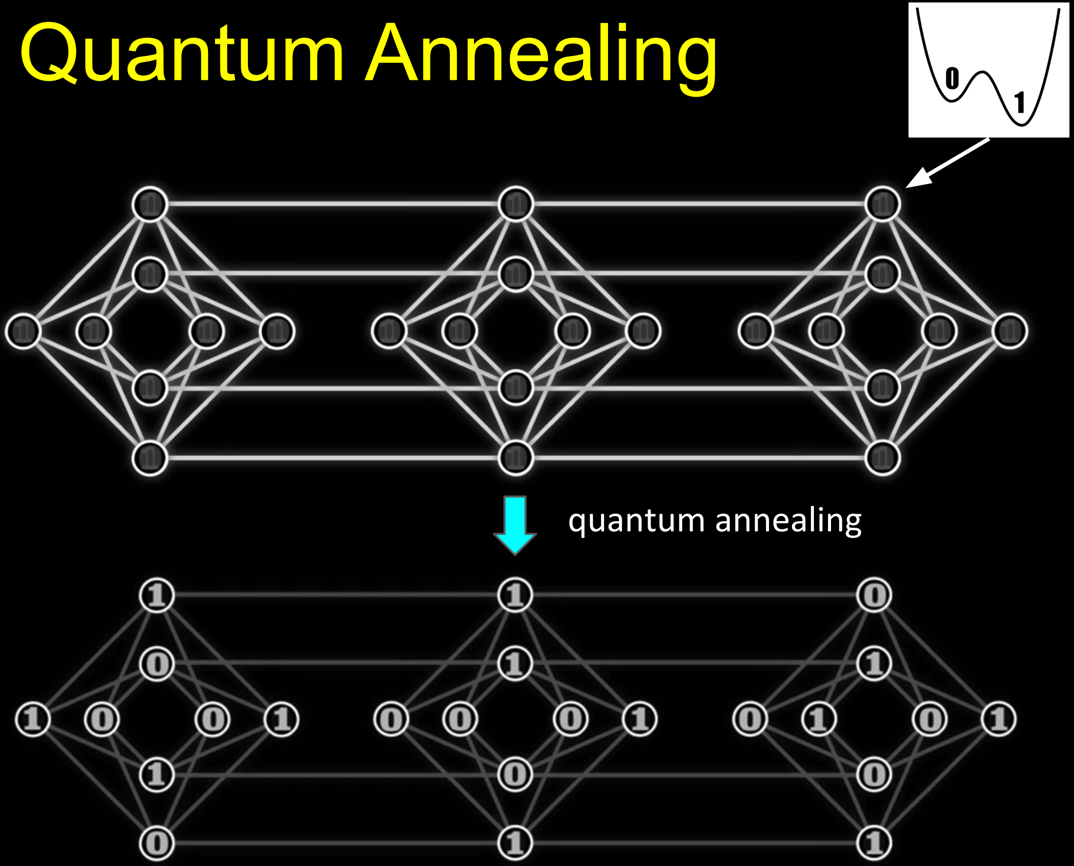




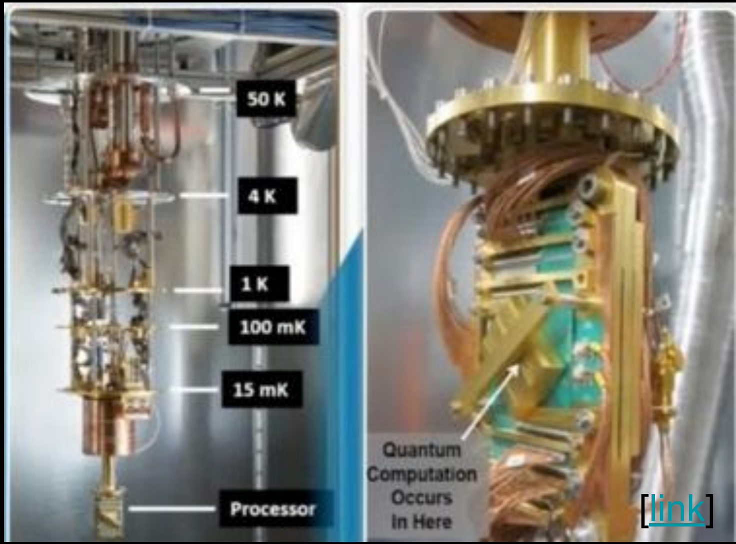
(a) Start with one valley, lowest point corresponds to superposition of states.
(b) A barrier is raised and energy diagram is a double well potential. Probability of ending in one of the two states is equal.
(c) Apply external magnetic field to "control" probability of falling into 0 or 1, i.e. tilt the double well potential with an external magnetic field is called a bias to favor a configuration with lower well.

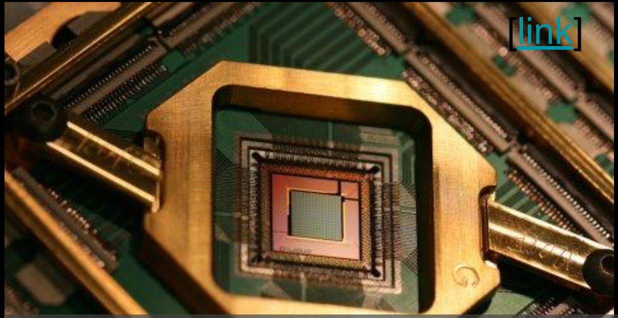
Qubits are coupled so that they can influence with each other. We try to harness the natural evolution of quantum states although without any control over that evolution.

Quantum Annealing



All this happens in D-Wave chips in ~20 μs





5th generation 5000-qubit system will be made available on mid-2020