D-Wave Adiabatic Quantum Computer

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Erica Grant

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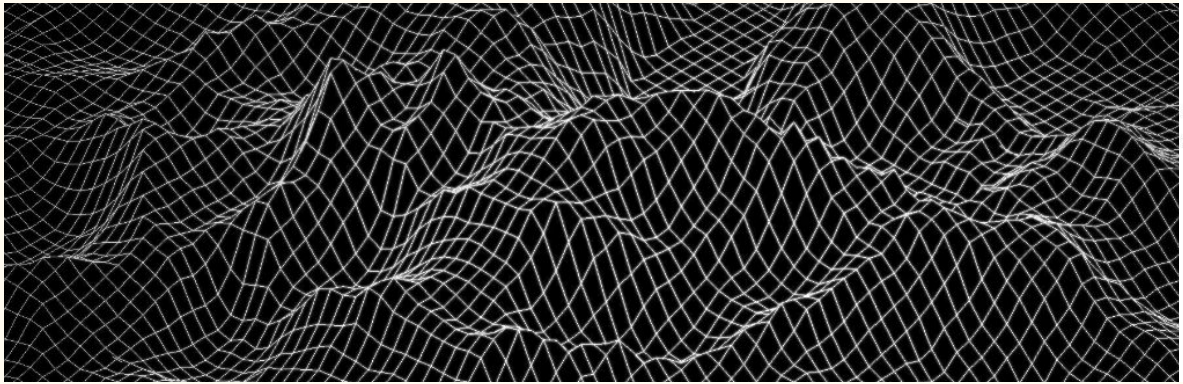
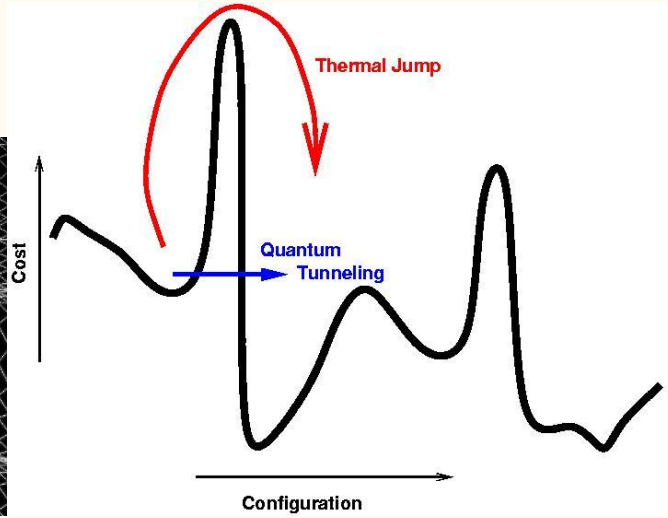
Introduction to D-Wave, Inc.

- Based out of Canada, the first company to develop and release a commercially available quantum computer.
- Lockheed Martin, Google, NASA, and USRA collaboration
- D-Wave 2x processor has 1,000 qubits.
- An **Adiabatic** quantum computer: implements a simplified version of Adiabatic quantum computation in order to solve discrete optimization problems.
- A literal black box.

Ising Model Quantum Annealing

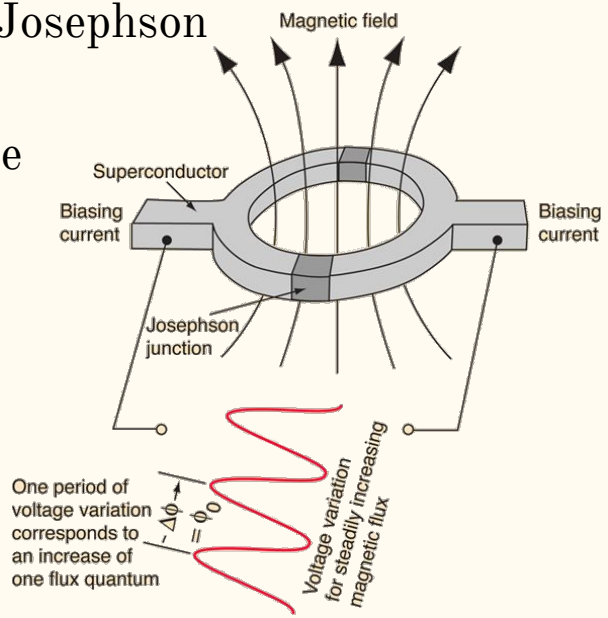
- A less precise version of AQC in which the qubits are strongly coupled to the environment and the initial Hamiltonian is simplified.
- Solves problems by searching for the global minimum.
- Demonstrated to outperform thermal (simulated) annealing by utilizing quantum tunneling phenomena.





D-Wave Hardware

- Each qubit is a superconducting niobium loop with a Josephson Junction.
- Each qubit generates a magnetic field according to the right-hand-rule.
- The magnetic fields are the couplings between qubits. (Analogous to quantum entanglement.)
- Hamiltonians can then be embedded to the qubit system by applying qubit weights and coupling strengths.
- Quantized magnetic field detectors then detect the magnetic field direction after the anneal has completed.



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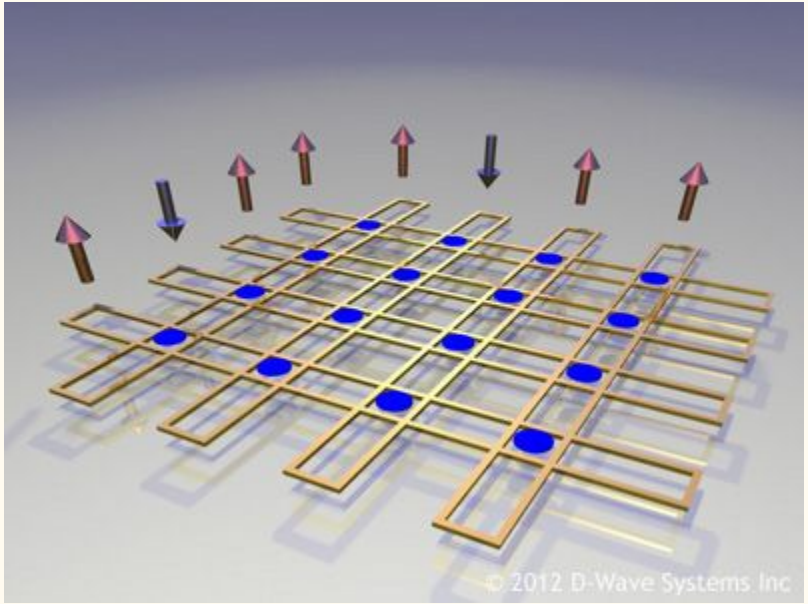

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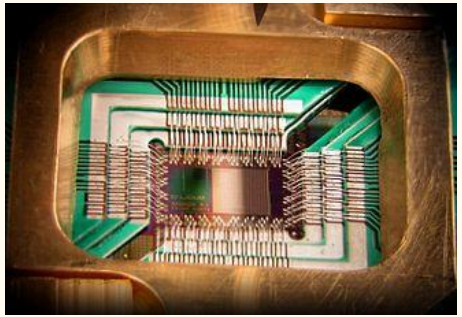
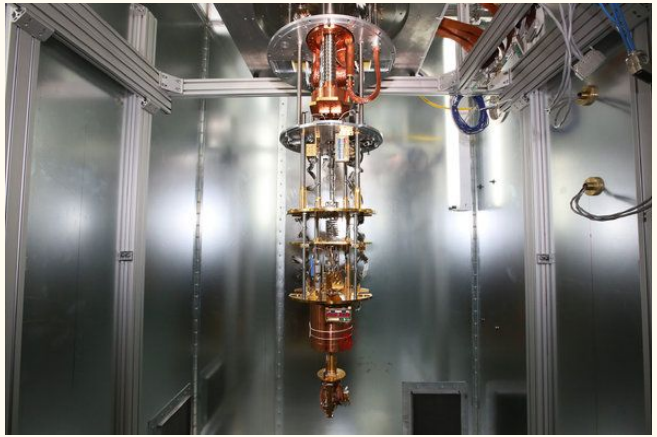
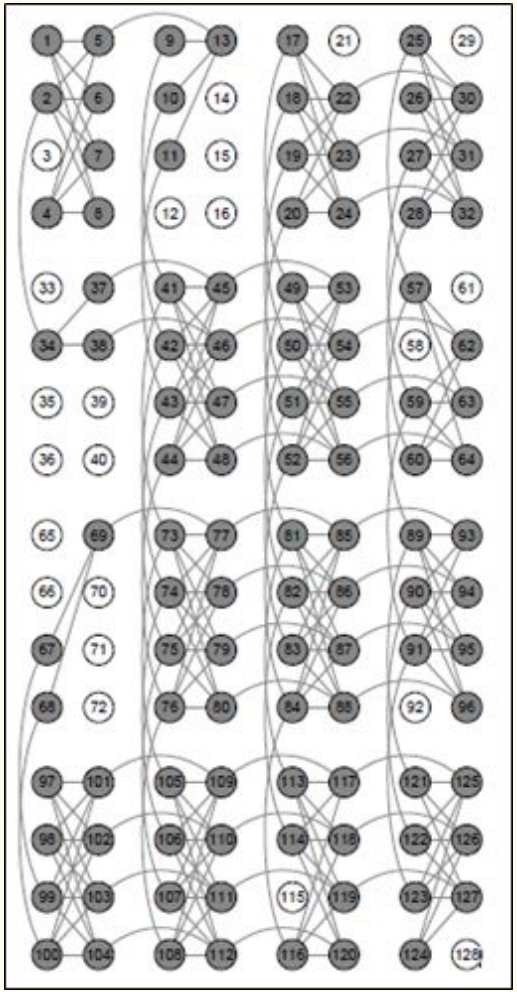
- The number of runs needed: $R=\ln(1-p)/\ln(1-s)$ where p is the desired probability and s is the success probability.
- This qubit system is kept in a high vacuum at 0.015K, shielded to 50,000x less than the Earth's magnetic field.
- Magnetic interference, heat, etc. can cause excitations and yield incorrect energy values.



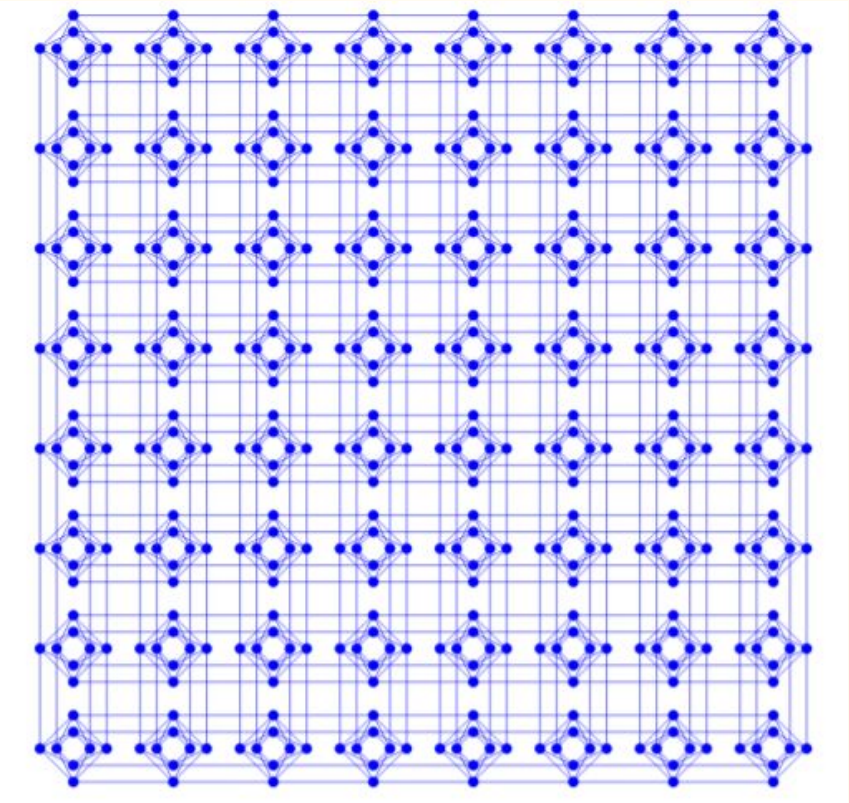


QUBO

- Quadratic Unconstrained Binary Optimization Problem.
- NP hard problem that D-Wave is specialized to solve.
- Pattern matching technique.
- Can be visualized with chimera graphs.



Chimera Graph

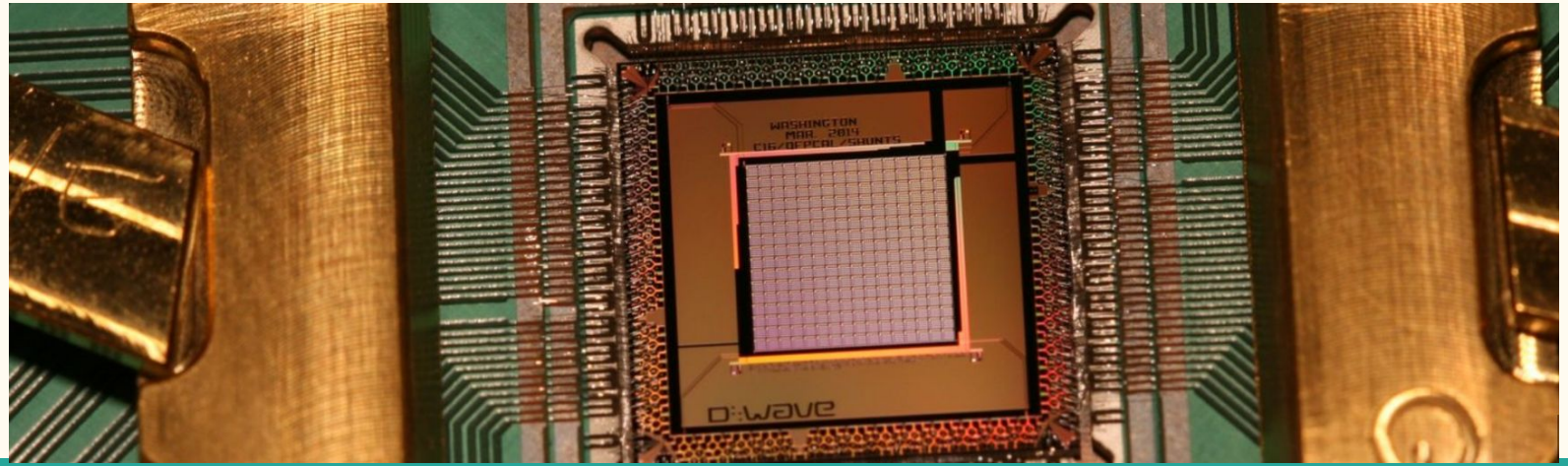


Criticism

- Circulating debate regarding how “quantum” the D-Wave truly is.
- Controversy when analyzing whether or not the hardware is capable of solving discrete optimization problems faster than simulated annealing.
- 2007: Umesh Vazirani stated that D-Wave misunderstood the principles of Adiabatic Quantum Computation.
- 2011: Scientific community agreed the hardware has quantum mechanical properties but shows no speed up after release of *Nature* paper.
- 2014: A lot of ups and downs. Tunneling spectroscopy was used to demonstrated that the qubits are coupled quantum mechanically. Quantum speedup was more thoroughly defined and it was found that D-Wave showed no quantum speedup.

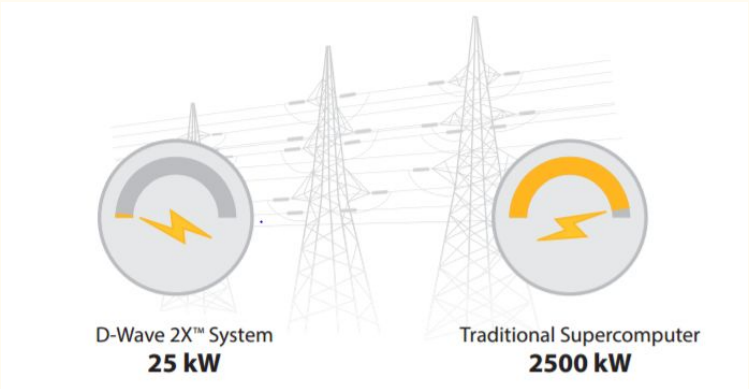
D-Wave problems

- No error correction methods.
- Embedding QUBO's to the hardware is a discrete optimization problem.
- The system is not at zero temperature.
- Whether or not D-Wave is capable of speedup is still widely debated.
- Many missing qubits because of magnetic interference.



Hardware Potential

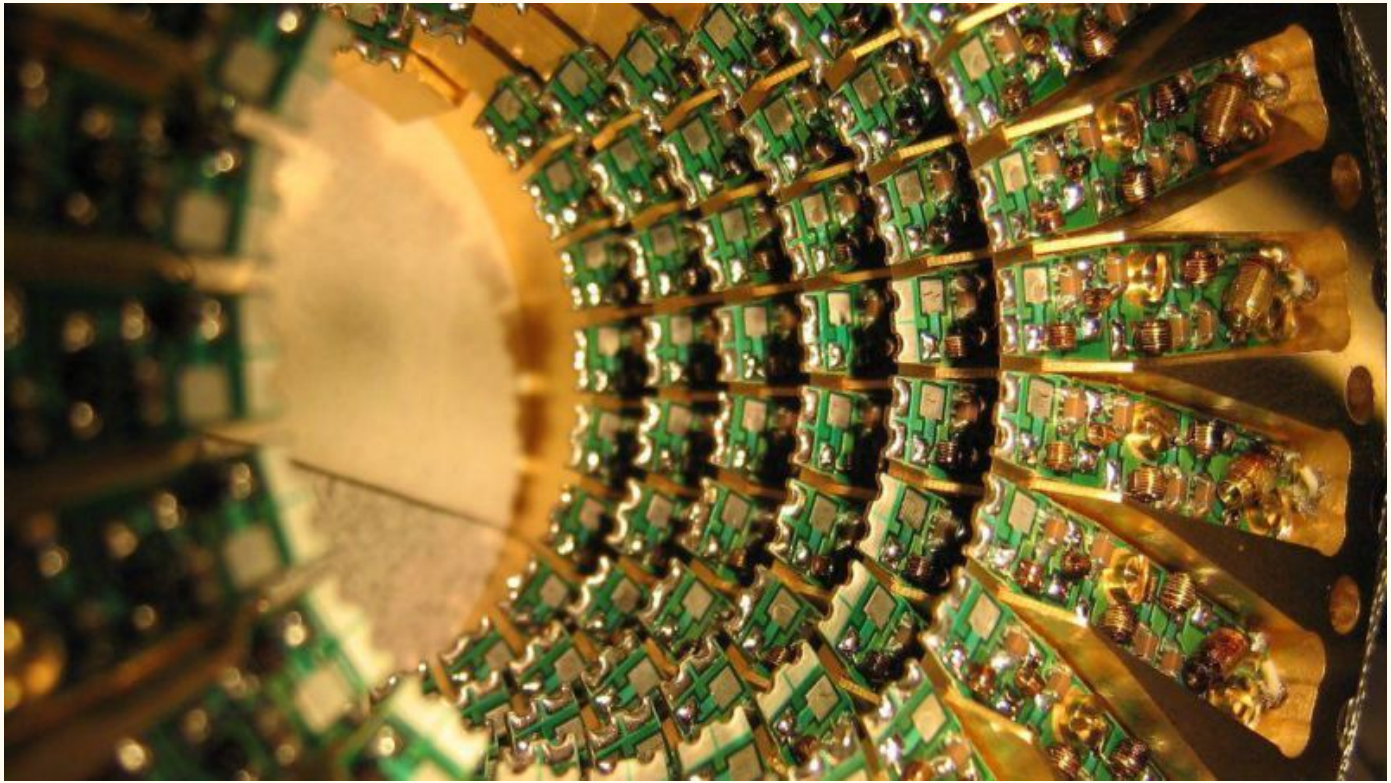
- The D-Wave hardware requires about 1/10 the energy needed to supply a computer of similar capability.
- There may be undiscovered problem classes in which there is significant speedup with the current hardware.
- Improvements to the hardware may yield significant quantum speedup on the order of 3,600 times faster than classical simulations. (Optimistic end)



Future Development

- Search for problem classifications that show speedup
- Develop better embedding algorithms
- Develop software which allows more comprehensive user interface
- Create specialized initial Hamiltonians
- Reduce magnetic interference
- Develop error correction methods
- Increase number of qubits

Questions?



References

[1] Arnab Das Quantum Annealing and Other Optimization Methods workshop, 2005, https://commons.wikimedia.org/w/index.php?curid=16097396

[2]http://www.dwavesys.com/sites/default/files/D-Wave%202X%20Tech%20Collateral_0915F.pdf

[3]https://arxiv.org/pdf/1406.2741.pdf

[4]https://www.technologyreview.com/s/514686/d-waves-quantum-computer-goes-to-the-races-wins/

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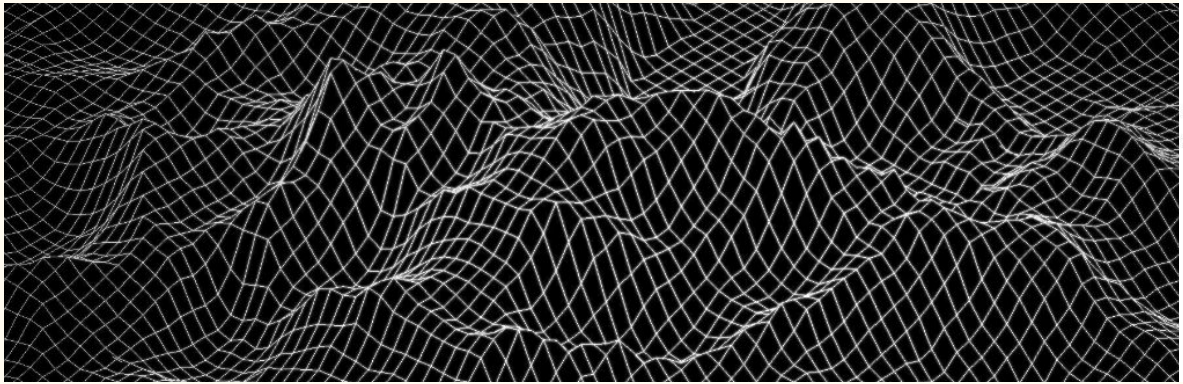

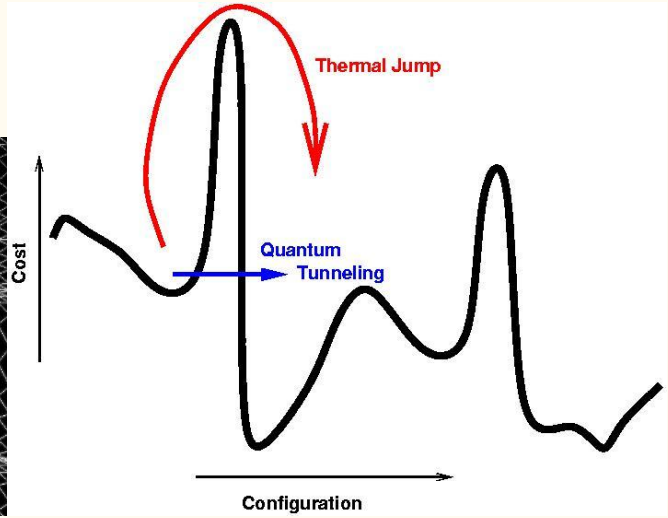

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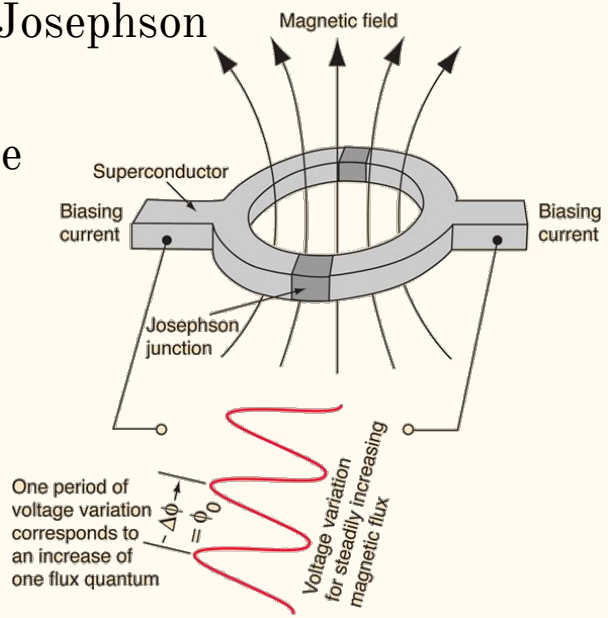

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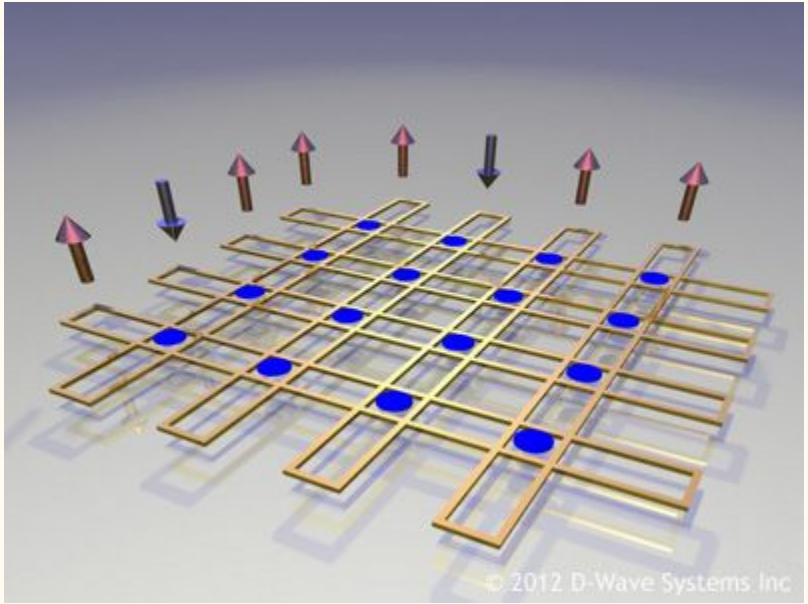

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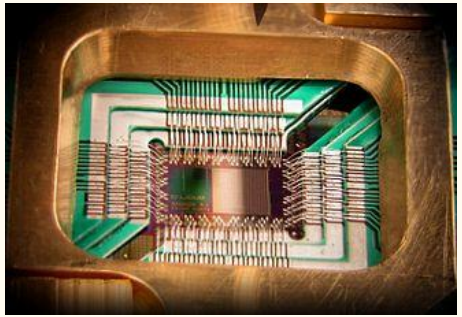

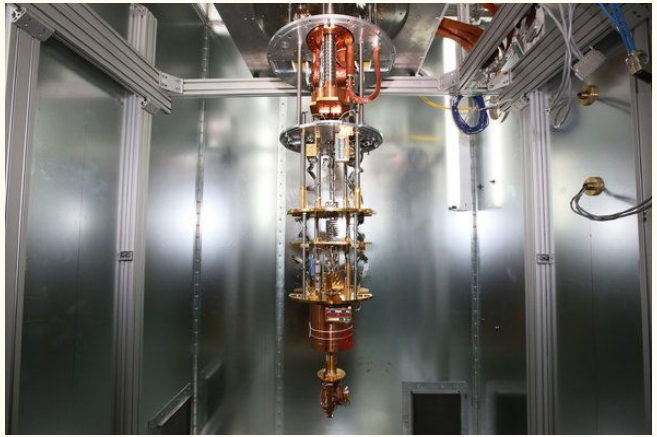

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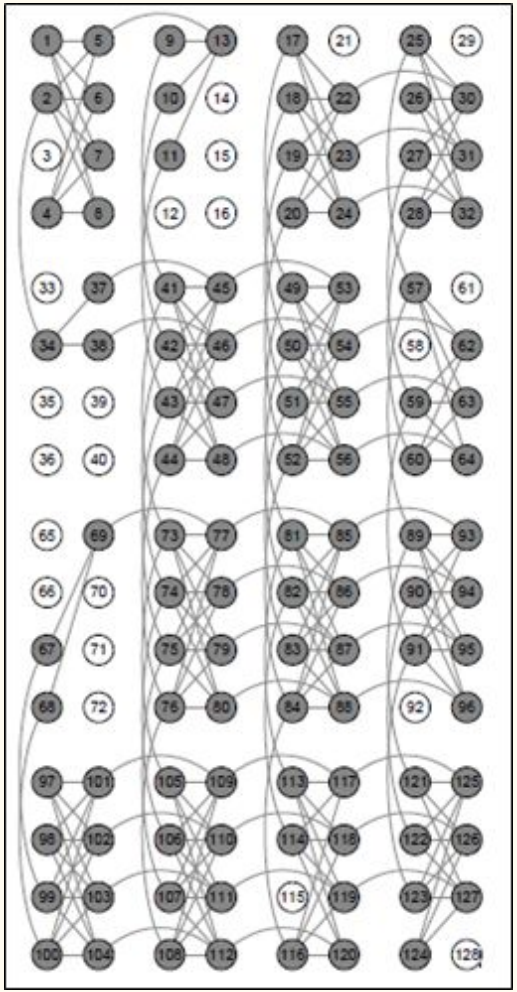

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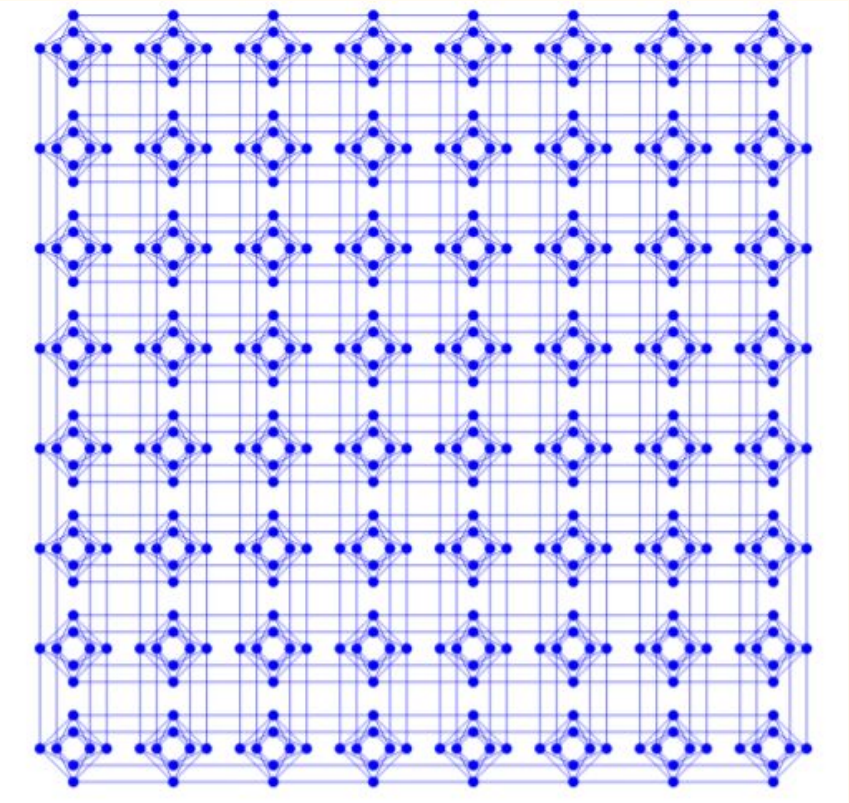

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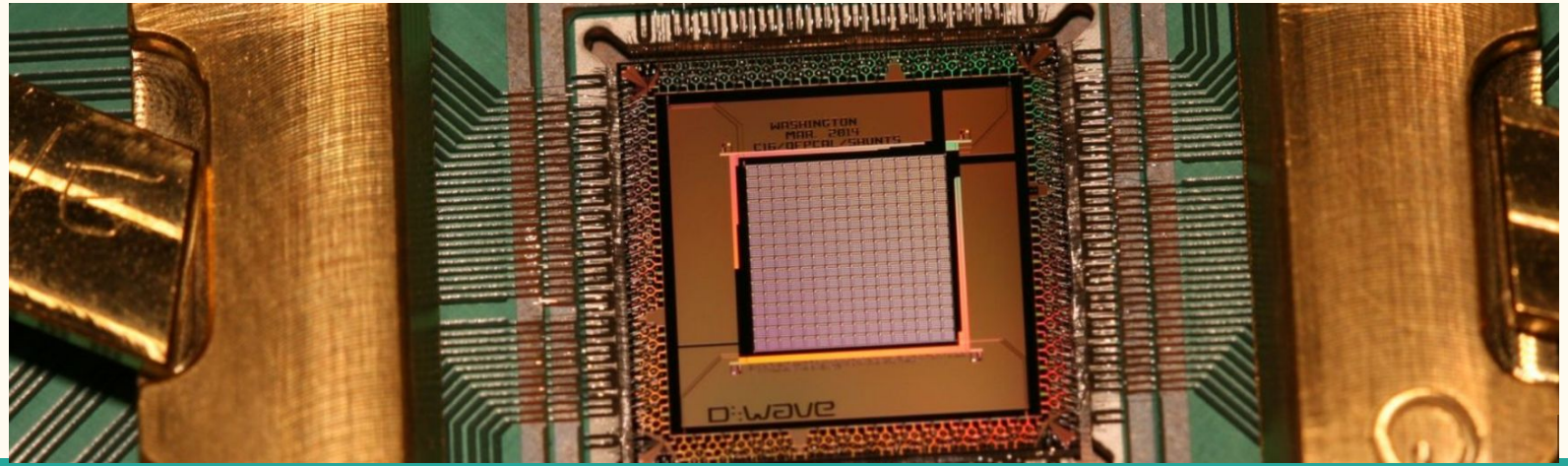

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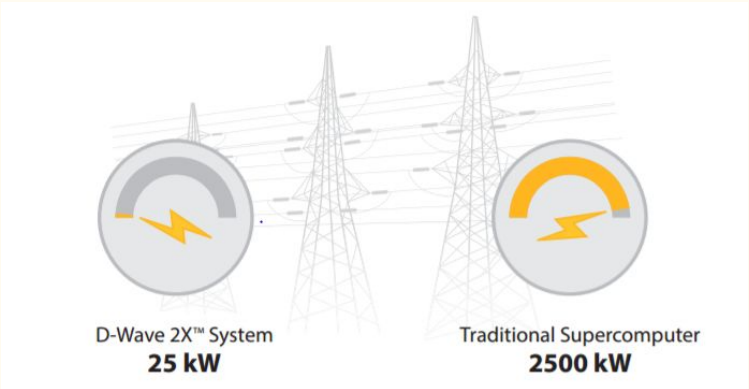

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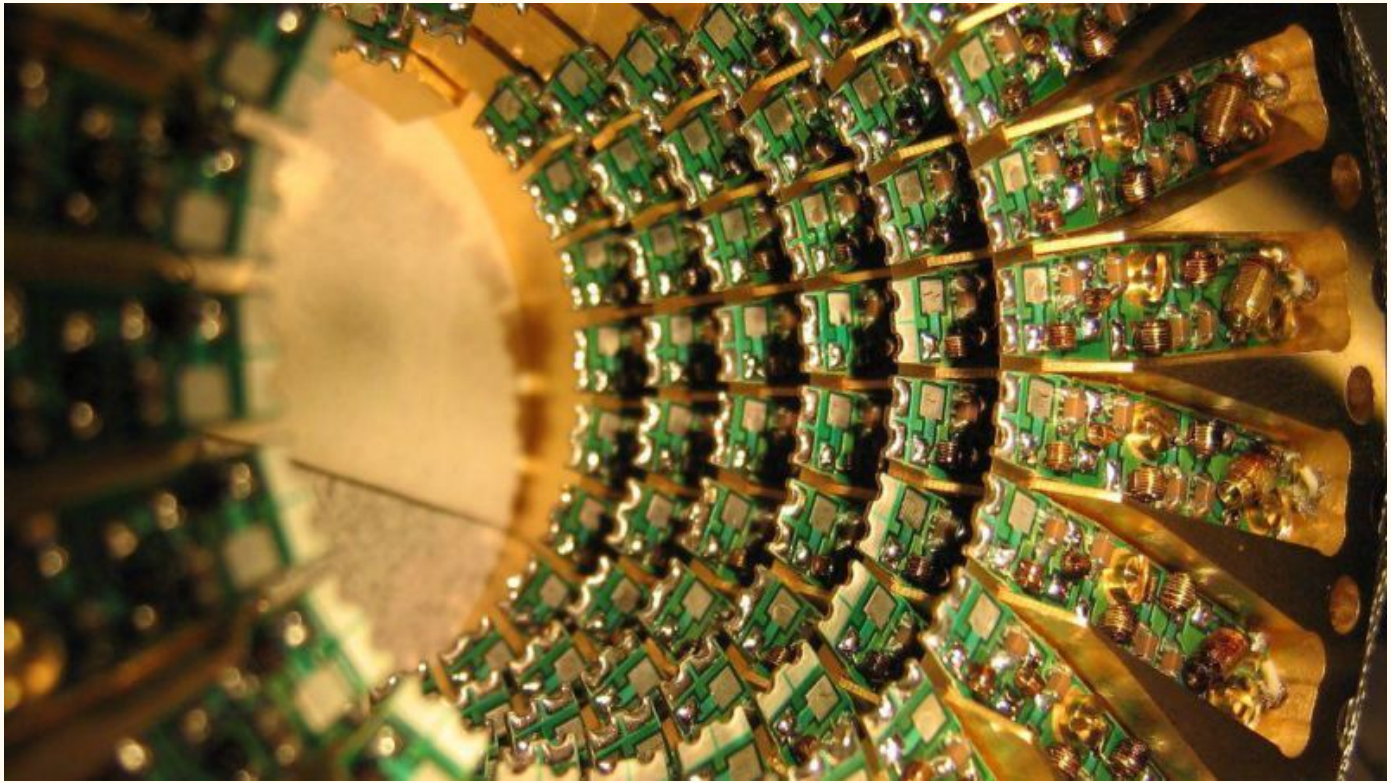

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