Adiabatic Quantum Computation

at D-Wave Systems Inc.

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Computer Science
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MA 591 Special Topics in Quantum Computation

Outline

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Adiabatic Theorem

Max Born and Vladimir Fock (1928)

A physical system remains in its instantaneous eigenstate if a given perturbation is acting on it slowly enough and if there is a gap between the eigenvalue and the rest of the Hamiltonian's spectrum.

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Application

- Quantum systems evolve according to the Schrödinger equation.

$$i\frac{d}{dt}|\psi(t)\rangle = \mathcal{H}(t)|\psi(t)\rangle$$

- Start with $|\psi(0)\rangle$ as the ground state of $\mathcal{H}(0)$.
- If there is a non-zero gap between $|\psi(0)\rangle$, and the next lowest energy level as long as $\mathcal{H}(t)$ varies slowly enough (i.e. little energy is added to the system) $|\psi(t)\rangle$ will remain close to the instantaneous ground state of $\mathcal{H}(t)$.

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The Magic

- Encode the solution in the ground state of a problem Hamiltonian $\mathcal{H}_P$.
  - Specifying $\mathcal{H}_P$ is easy but finding its ground state is difficult.
- Choose an initial Hamiltonian $\mathcal{H}_B$ whose ground state is easy to find.
- Construct the system:

$$\mathcal{H}(t) = (1 - t/T)\mathcal{H}_B + (t/T)\mathcal{H}_P$$

Where T is a parameter to control the rate at which $\mathcal{H}(t)$ varies. Normalized to $\tilde{\mathcal{H}}(s), 0 \leq s \leq 1$:

$$\tilde{\mathcal{H}}(s) = (1 - s)\mathcal{H}_B + s\mathcal{H}_P$$

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History

- Founded in 1999 by:
  - Haig Farris
  - Geordie Rose (CTO)
  - Bob Wiens (former CFO)
  - Alexandre Zagoskin (Chief Scientist)
- Started as an off-shoot of the University of British Columbia funding academic research in quantum computing.
- Currently located in Burnaby, British Columbia.

Goals

- Find low cost solutions to Quadratic Unconstrained Binary Optimization (QUBO) problems.
  - arXiv:quant-ph/0001106v1 3-SAT
  - NPC controversy
- Equivalent to finding low energy states of classical Ising Hamiltonian:

$$\mathcal{H} = \sum_i h_i \sigma_{zi} + \sum_{ij} J_{ij} \sigma_{zi} \sigma_{zj}$$

- Find a reasonable way to do it

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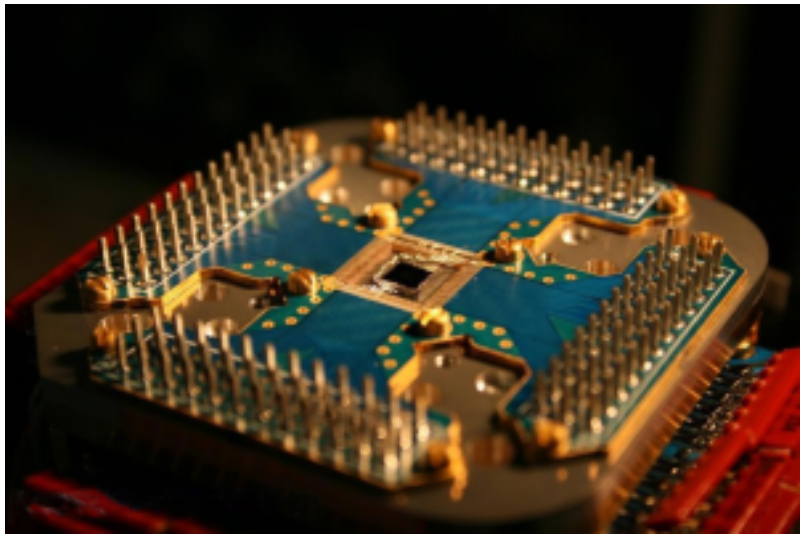
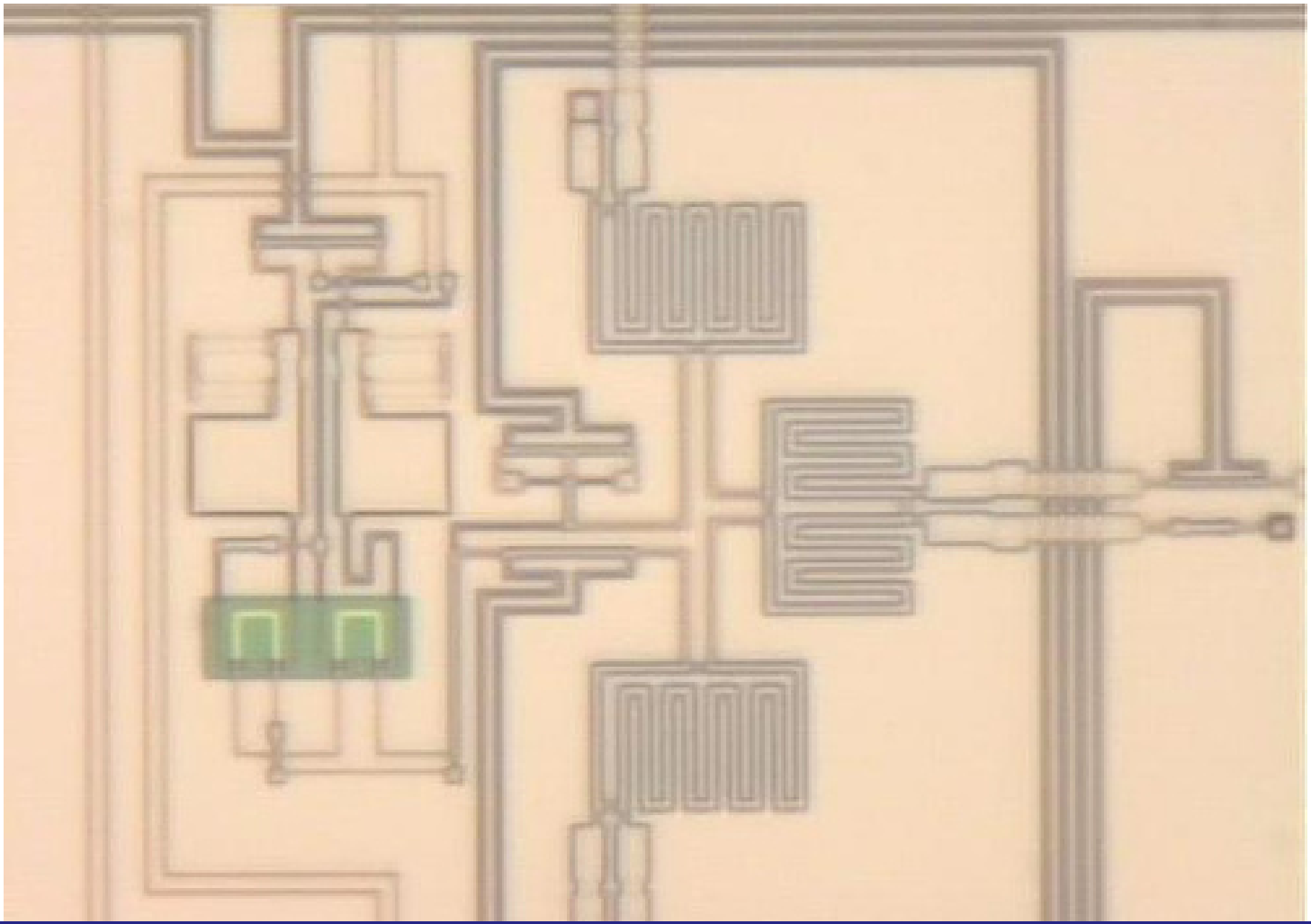
Infrastructure

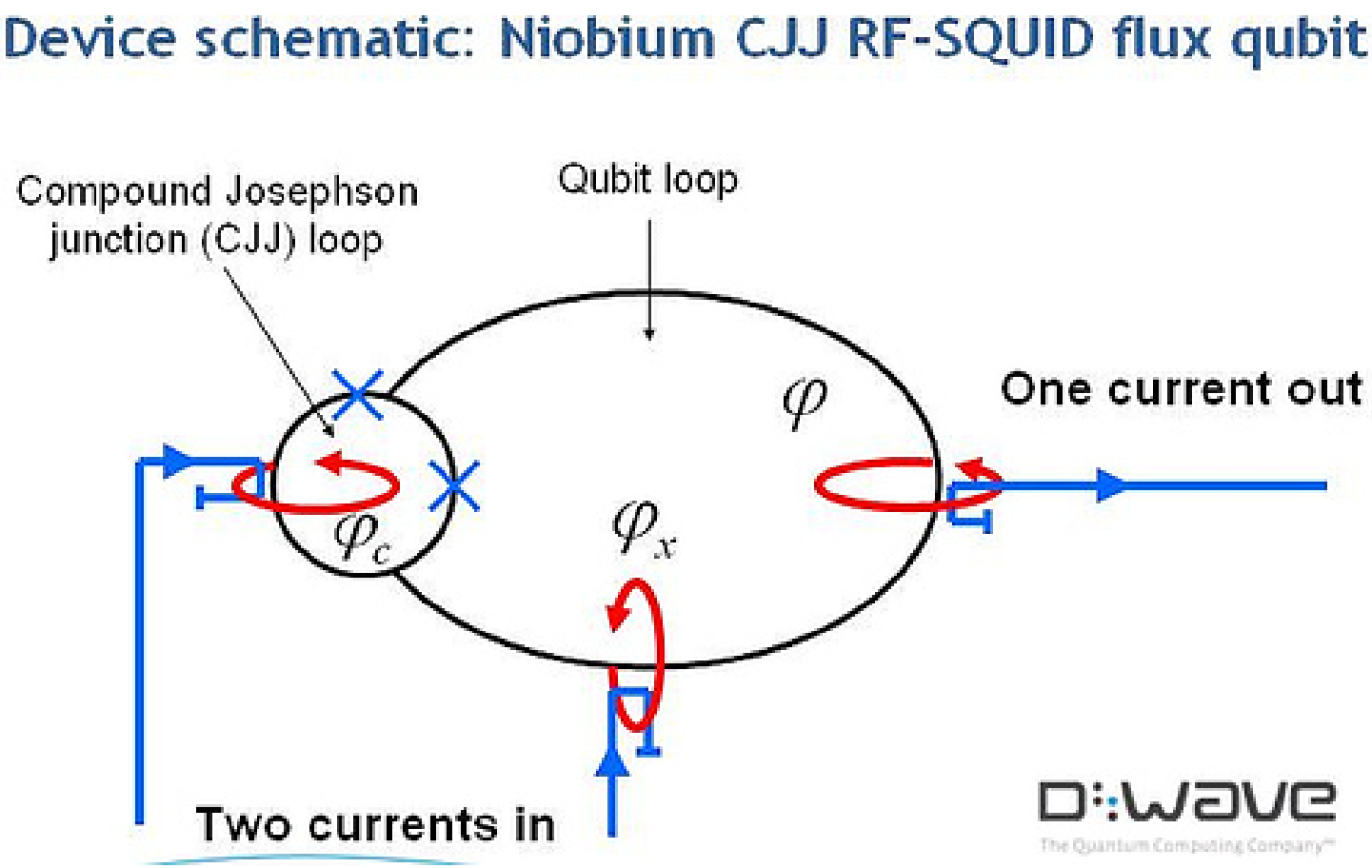


- Superconducting metals operating at ultra low temperatures
- Manufactured with existing fabrication techniques

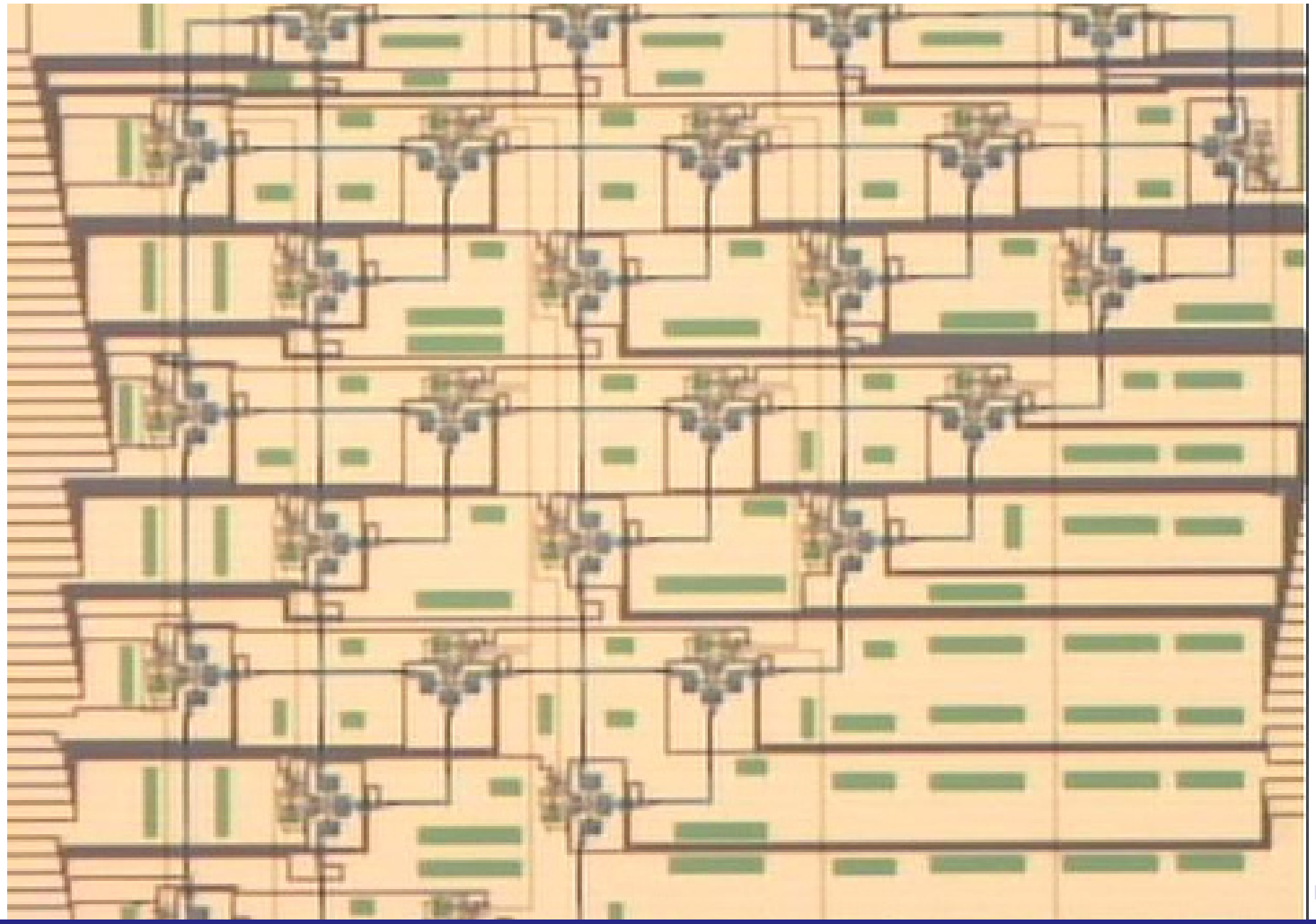
The Qubit



Schematic


Device schematic: Niobium CJJ RF-SQUID flux qubit
Compound Josephson junction (CJJ) loop
Qubit loop
One current out
Two currents in
φ
φ_c
φ_x
D-Wave
The Quantum Computing Company

System



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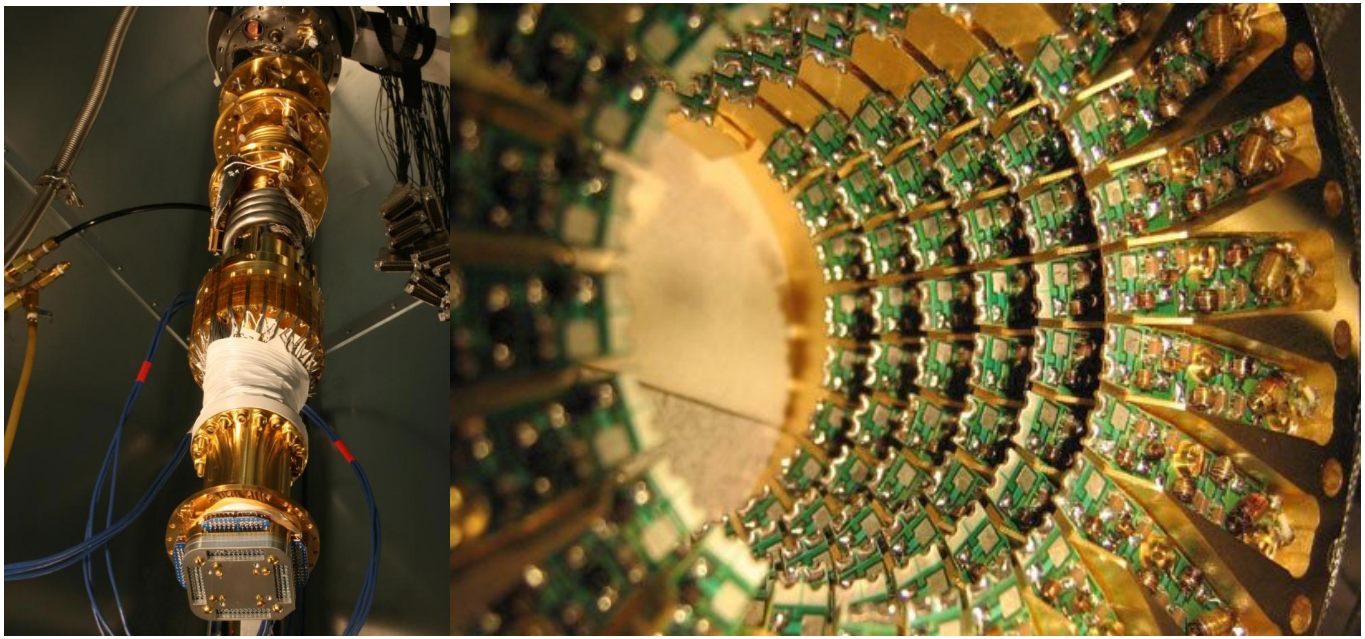
Orion



- 16 qubit System
  - www.apps.dwavesys.com
  - Orion web services API

Google's Interest

- Image matching
  - Google Goggles
  - Face Recognition
- Machine learning
  - Recognizing cars

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DiVincenzo

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2. The ability to initialize state
3. Long relevant decoherence times
4. Universal set of quantum gates
5. The ability to measure specific quibits

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P == NP?

- QUBO $\supset$ P
- Goldstone, Gutmann, and Sipser adiabatic algorithmic solution for 3-SAT
- Aharonov, van Dam, et al adiabatic quantum computation is equivalent to standard computation (NMR)
- Problems with simulated annealing
  - QUBO solutions are only NP-Hard

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Summary

- Adiabatic quantum computating is feasible with current manufacturing techniques and because of long decoherence times.
- The Chimera C4 chip has been demonstrated successfully.
- The actual quantum nature of the system is controversial.

- Outlook
  - D-Wave has yet to produce a fully entangled system due to bus connectivity issues.
  - The backend of Orion is still a simulation but should be up and running soon.

More Resources I


D. Aharonov, W. vanDam, J. Kempe, Z. Landau, S. Lloyd, O. Regev
Adiabatic Quantum Computation is Equivalent to Standard Quantum Computation.
arXiv:quant-ph/0405098v2,2005.


D. DiVincenzo.
The Physical Implementation of Quantum Computation.
arXiv:quant-ph/0002077v3,2000.


E. Farhi, J. Goldstone, S. Gutmann, M. Sipser
Quantum Computation by Adiabatic Evolution.
arXiv:quant-ph/0001106v1,2000.

More Resources II


R. Harris et al.
Experimental Demonstration of a Robust and Scalable Flux Qubit
arXiv:0909.4321v1 [cond-mat.supr-con],2009.


H. Neven
Machine Learning with Quantum Algorithms
http://googleresearch.blogspot.com/2009/12/machine-learning-with-quantum.html,2009.


G. Rose
rose.blog
http://dwave.wordpress.com/

More Resources III


H. Neven, G. Rose
Google Tech Talks: Quantum Computing
http://www.youtube.com/watch?v=I56UugZ8DIfeature = channel, 2007.


D-Wave Systems Inc.
http://www.dwavesys.com/