QC WARE

Q2B

2017

The Journey from Digital to Quantum Computing, an Introduction

Bo Ewald

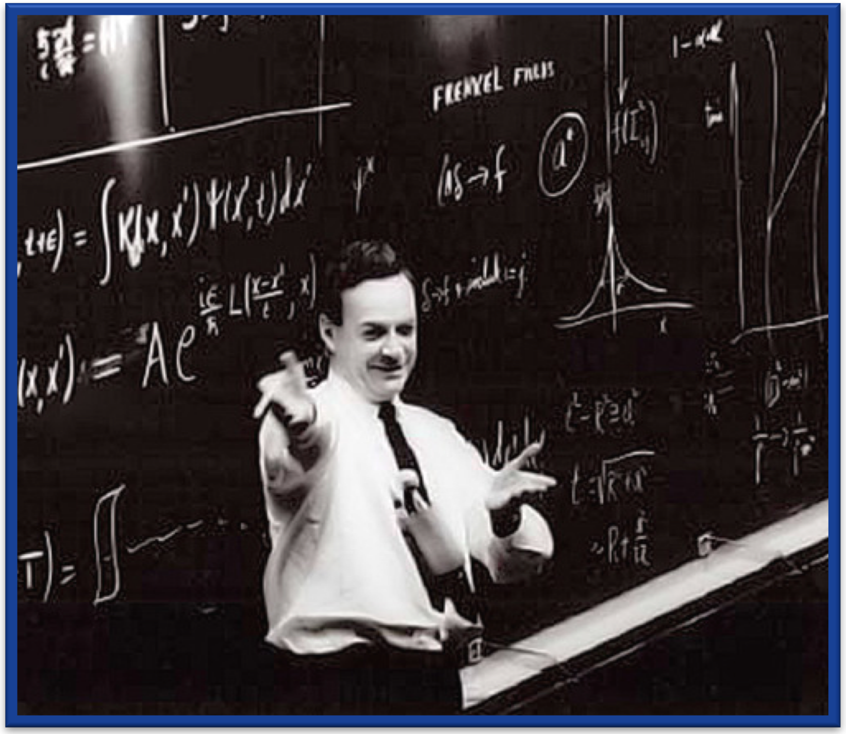
December 5, 2017

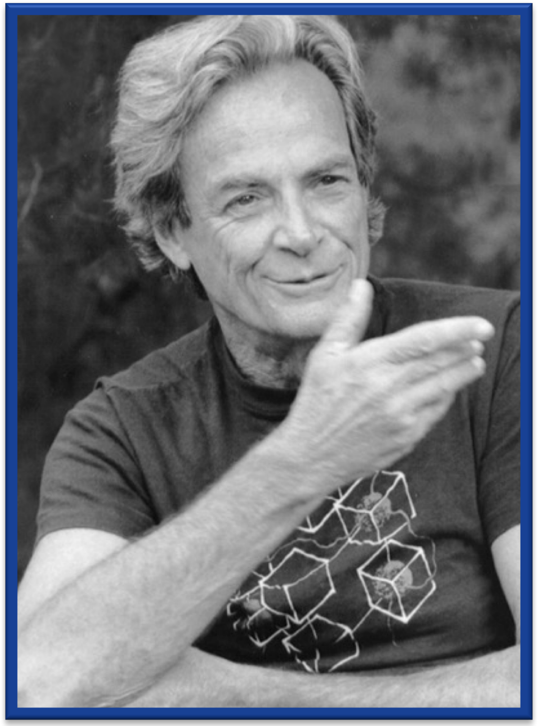
The Quantum Computing Company™

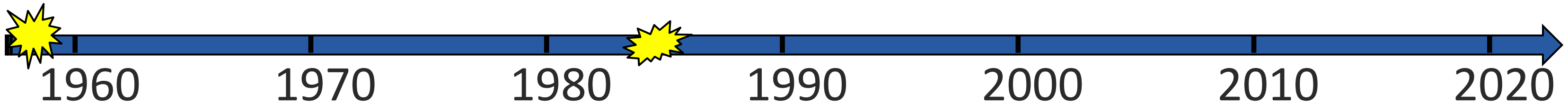
TOPICS

- Introduction to Quantum Computing
- D-Wave Quantum Systems
- Why Should You Care?
- Questions

Richard Feynman







April 1983 – Richard Feynman's talk

LOS ALAMOS NATIONAL LABORATORY
40th ANNIVERSARY CONFERENCE
NEW DIRECTIONS IN PHYSICS AND CHEMISTRY
April 13–15, 1983

Wednesday, April 13

6:00–8:00 P.M.—Informal Reception at Fuller Lodge

Thursday, April 14

Main Auditorium, Administration Building

8:45 A.M. Welcome—Donald M. Kerr, Director
Los Alamos National Laboratory

Session I—Robert Serber, Chairman

9:00 A.M. Richard Feynman
"Tiny Computers Obeying Quantum-Mechanical Laws"

10:00 A.M. I. I. Rabi
"How Well We Meant"

11:00–11:15 A.M.—Intermission

Session II—Donald W. Kerst, Chairman

11:15 A.M. Owen Chamberlain
"Tuning Up the Time Projection Chamber"

12:15–1:15 P.M.—Lunch

1:15 P.M. Felix Bloch
"Past, Present and Future of Nuclear Magnetic Resonance"

2:15–2.30 P.M.—Intermission

Session III—Edwin McMillan, Chairman

2:30 P.M. Robert R. Wilson
"Early Los Alamos Accelerators and New Accelerators"

3:30 P.M. Norman Ramsey
"Experiments on Time-Reversal Symmetry and Parity"

4:30 P.M. Ernest Titterton
"Physics with Heavy Ion Accelerators"

Title: Los Alamos Experience
Author: Phyllis K Fisher
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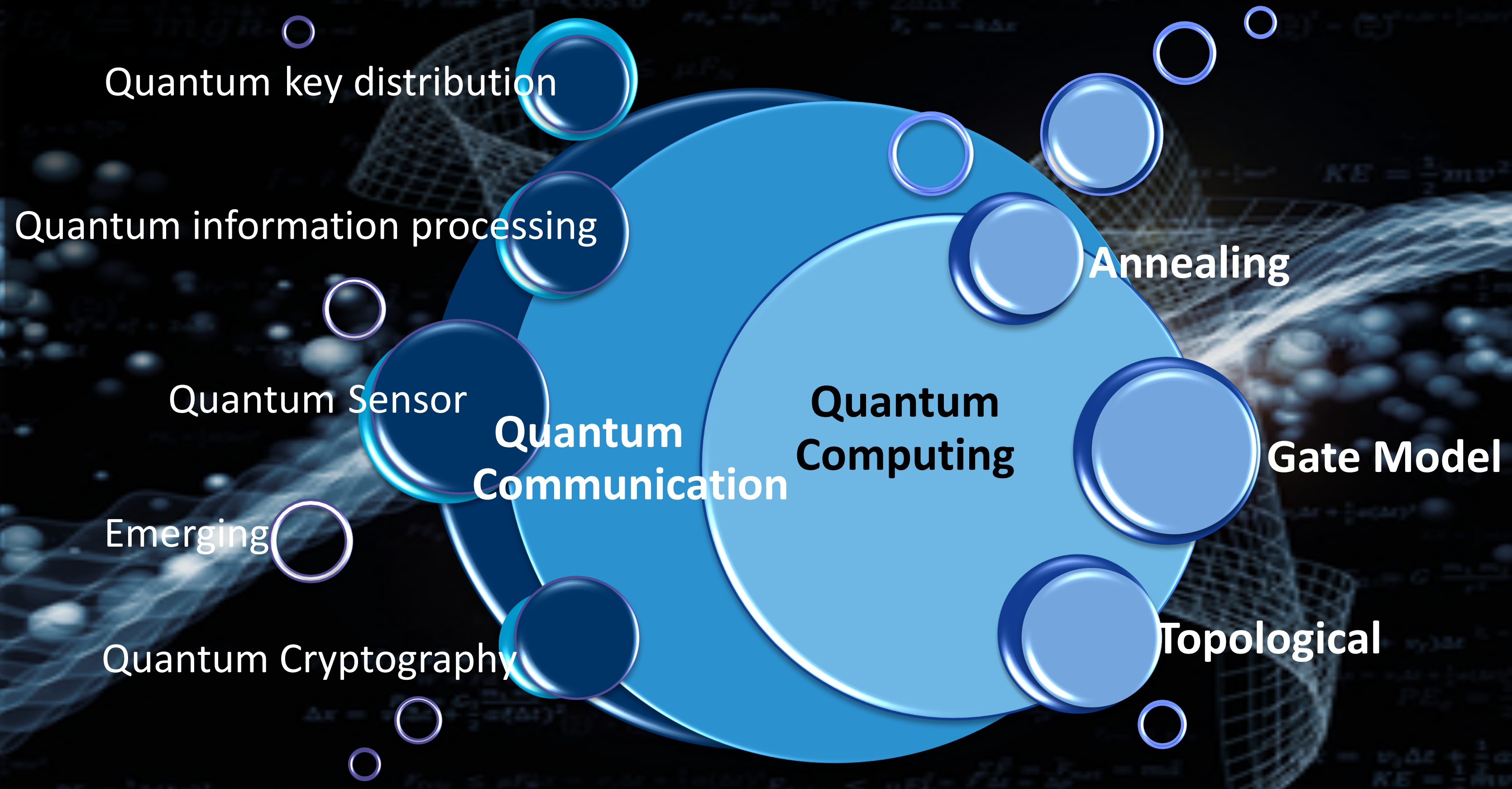
Quantum Information Science



Qubits Being Investigated

Quest for qubits

Gabriel Popkin*

Science 02 Dec 2016:
Vol. 354, Issue 6316, pp. 1090-1093
DOI: 10.1126/science.354.6316.1090

A bit of the action

In the race to build a quantum computer, companies are pursuing many types of quantum bits, or qubits, each with its own strengths and weaknesses.

Superconducting loops
A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into super-position states.

Trapped ions
Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in superposition states.

Silicon quantum dots
These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.

Topological qubits
Quasiparticles can be seen in the behavior of electrons channeled through semi-conductor structures. Their braided paths can encode quantum information.

Diamond vacancies
A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light.

	Superconducting loops	Trapped ions	Silicon quantum dots	Topological qubits	Diamond vacancies
Longevity (seconds)	0.00005	>1000	0.03	N/A	10
Logic success rate	99.4%	99.9%	~99%	N/A	99.2%
Number entangled	9	14	2	N/A	6
Company support	Google, IBM, Quantum Circuits	ionQ	Intel	Microsoft, Bell Labs	Quantum Diamond Technologies
Pros	Fast working. Build on existing semiconductor industry.	Very stable. Highest achieved gate fidelities.	Stable. Build on existing semiconductor industry.	Greatly reduce errors.	Can operate at room temperature.
Cons	Collapse easily and must be kept cold.	Slow operation. Many lasers are needed.	Only a few entangled. Must be kept cold.	Existence not yet confirmed.	Difficult to entangle.

Note: Longevity is the record coherence time for a single qubit superposition state, logic success rate is the highest reported gate fidelity for logic operations on two qubits, and number entangled is the maximum number of qubits entangled and capable of performing two-qubit operations.

CREDITS: (GRAPHIC) C. BICKEL/*SCIENCE*; (DATA) GABRIEL POPKIN

TOPICS

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Original Simulated Annealing Paper

THE JOURNAL OF CHEMICAL PHYSICS VOLUME 21, NUMBER 6 JUNE, 1953

Equation of State Calculations by Fast Computing Machines

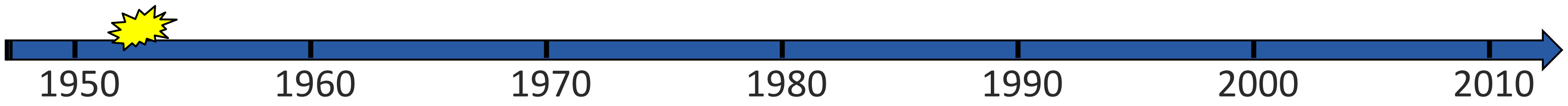
NICHOLAS METROPOLIS, ARIANNA W. ROSENBLUTH, MARSHALL N. ROSENBLUTH, AND AUGUSTA H. TELLER,
Los Alamos Scientific Laboratory, Los Alamos, New Mexico

AND

EDWARD TELLER,* *Department of Physics, University of Chicago, Chicago, Illinois*

(Received March 6, 1953)

A general method, suitable for fast computing machines, for investigating such properties as equations of state for substances consisting of interacting individual molecules is described. The method consists of a modified Monte Carlo integration over configuration space. Results for the two-dimensional rigid-sphere system have been obtained on the Los Alamos MANIAC and are presented here. These results are compared to the free volume equation of state and to a four-term virial coefficient expansion.



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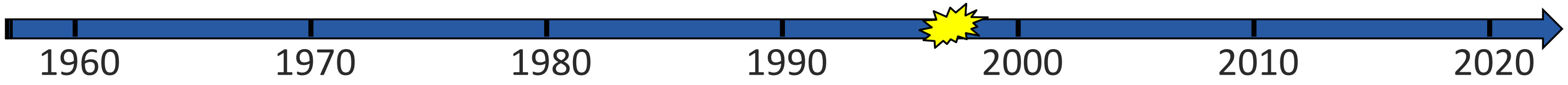
Quantum Annealing Outlined by Tokyo Tech

PHYSICAL REVIEW E VOLUME 58, NUMBER 5 NOVEMBER 1998

Quantum annealing in the transverse Ising model

Tadashi Kadowaki and Hidetoshi Nishimori
Department of Physics, Tokyo Institute of Technology, Oh-okayama, Meguro-ku, Tokyo 152-8551, Japan
(Received 30 April 1998)

We introduce quantum fluctuations into the simulated annealing process of optimization problems, aiming at faster convergence to the optimal state. Quantum fluctuations cause transitions between states and thus play the same role as thermal fluctuations in the conventional approach. The idea is tested by the transverse Ising model, in which the transverse field is a function of time similar to the temperature in the conventional method. The goal is to find the ground state of the diagonal part of the Hamiltonian with high accuracy as quickly as possible. We have solved the time-dependent Schrödinger equation numerically for small size systems with various exchange interactions. Comparison with the results of the corresponding classical (thermal) method reveals that the quantum annealing leads to the ground state with much larger probability in almost all cases if we use the same annealing schedule.
[S1063-651X~98!02910-9]



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MIT Group Proposes Adiabatic QC

arXiv:quant-ph/0001106v1 28 Jan 2000

Quantum Computation by Adiabatic Evolution

Edward Farhi, Jeffrey Goldstone*
Center for Theoretical Physics
Massachusetts Institute of Technology
Cambridge, MA 02139

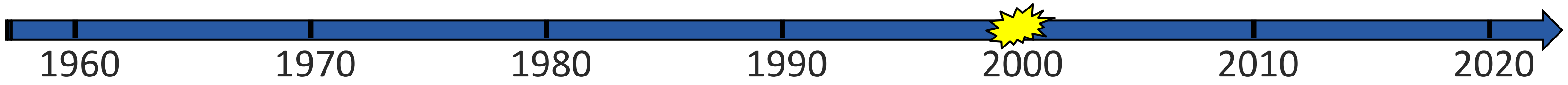
Sam Gutmann†
Department of Mathematics
Northeastern University
Boston, MA 02115

Michael Sipser‡
Department of Mathematics
Massachusetts Institute of Technology
Cambridge, MA 02139

MIT CTP # 2936 quant-ph/0001106

Abstract

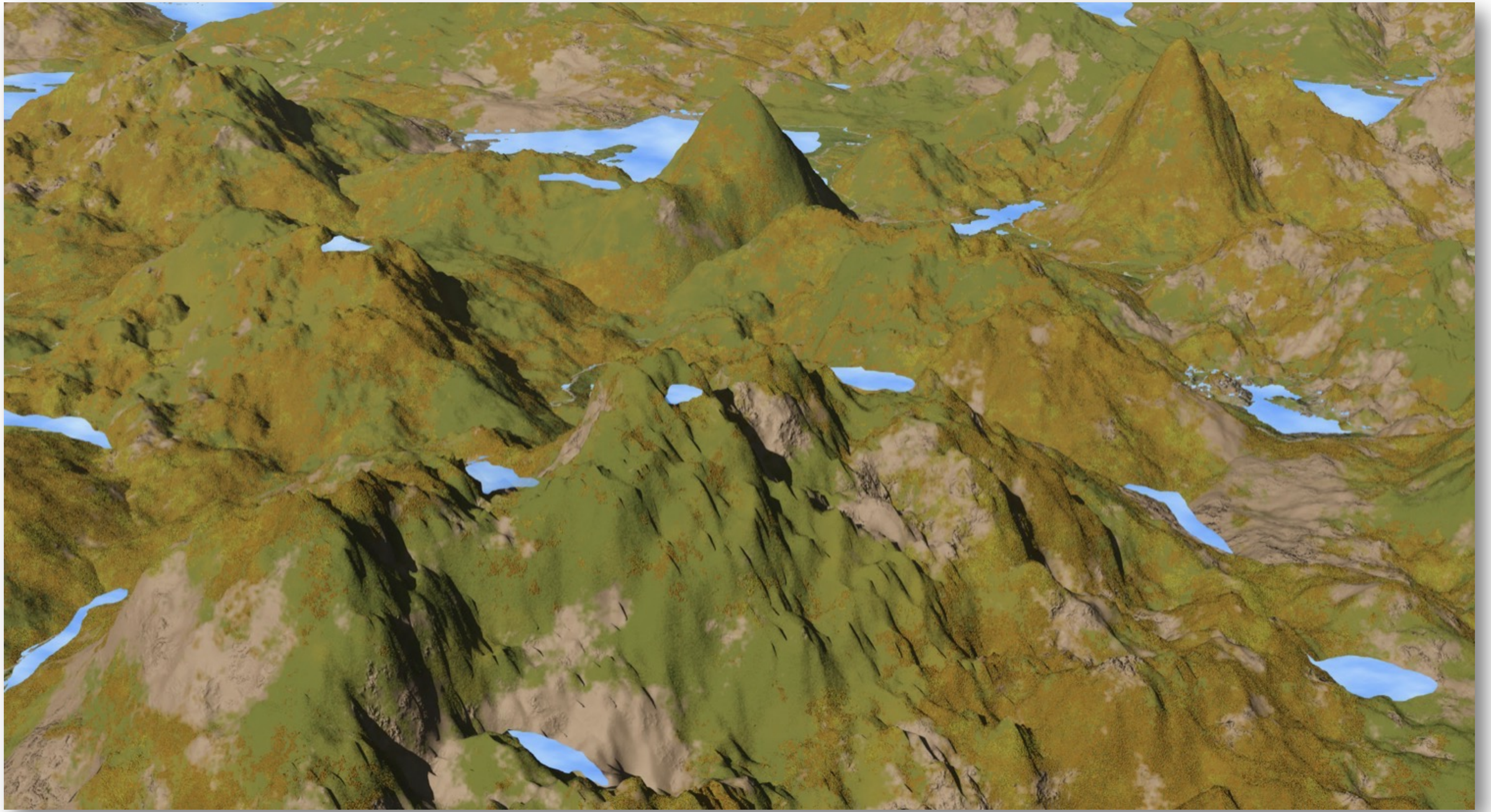
We give a quantum algorithm for solving instances of the satisfiability problem, based on adiabatic evolution. The evolution of the quantum state is governed by a time-dependent Hamiltonian that interpolates between an initial Hamiltonian, whose ground state is easy to construct, and a final Hamiltonian, whose ground state encodes the satisfying assignment. To ensure that the system evolves to the desired final ground state, the evolution time must be big enough. The time required depends on the minimum energy difference between the two lowest states of the interpolating Hamiltonian. We are unable to estimate this gap in general. We give some special symmetric cases of the satisfiability problem where the symmetry allows us to estimate the gap and we show that, in these cases, our algorithm runs in polynomial time.



Company Background

- Founded in 1999
- World's first quantum computing company
- Public customers:
  - Lockheed Martin/USC
  - Google/NASA Ames/USRA
  - Los Alamos National Laboratory
  - Temporal Defense Systems
  - Oak Ridge National Laboratory
- Other customer projects done via cloud access
- ~150 U.S. patents

How it Works



But, It Is Fundamentally Different Than Anything You've Ever Done Before!

	Intel 64	D-Wave
Performance (GFLOPS)	~20 (12 cores)	0
Precision (bits)	64	4-5
MIPS	~12,000 (12 cores)	0.01
Instructions	245+ (A-M) 251+ (N-Z)	1
Operating Temp.	67.9° C	-273° C
Power Cons.	100 w +/-	~0
Devices	4B+ transistors	2000 qubits
Maturity	1945-2016	~1950's

D-Wave Container –Faraday Cage - No RF Interference

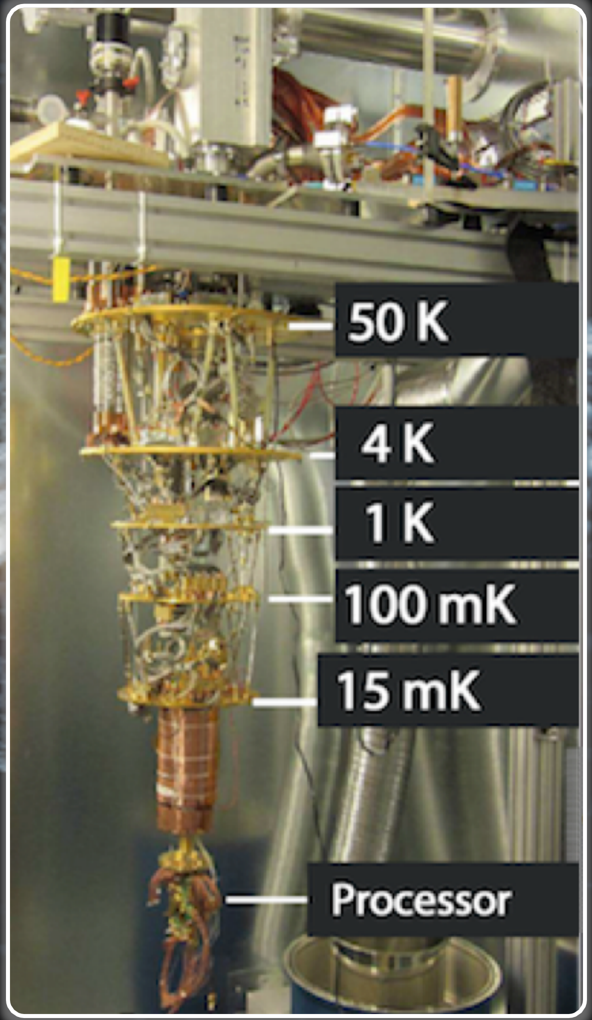
System Shielding

- 16 Layers between the quantum chip and the outside world

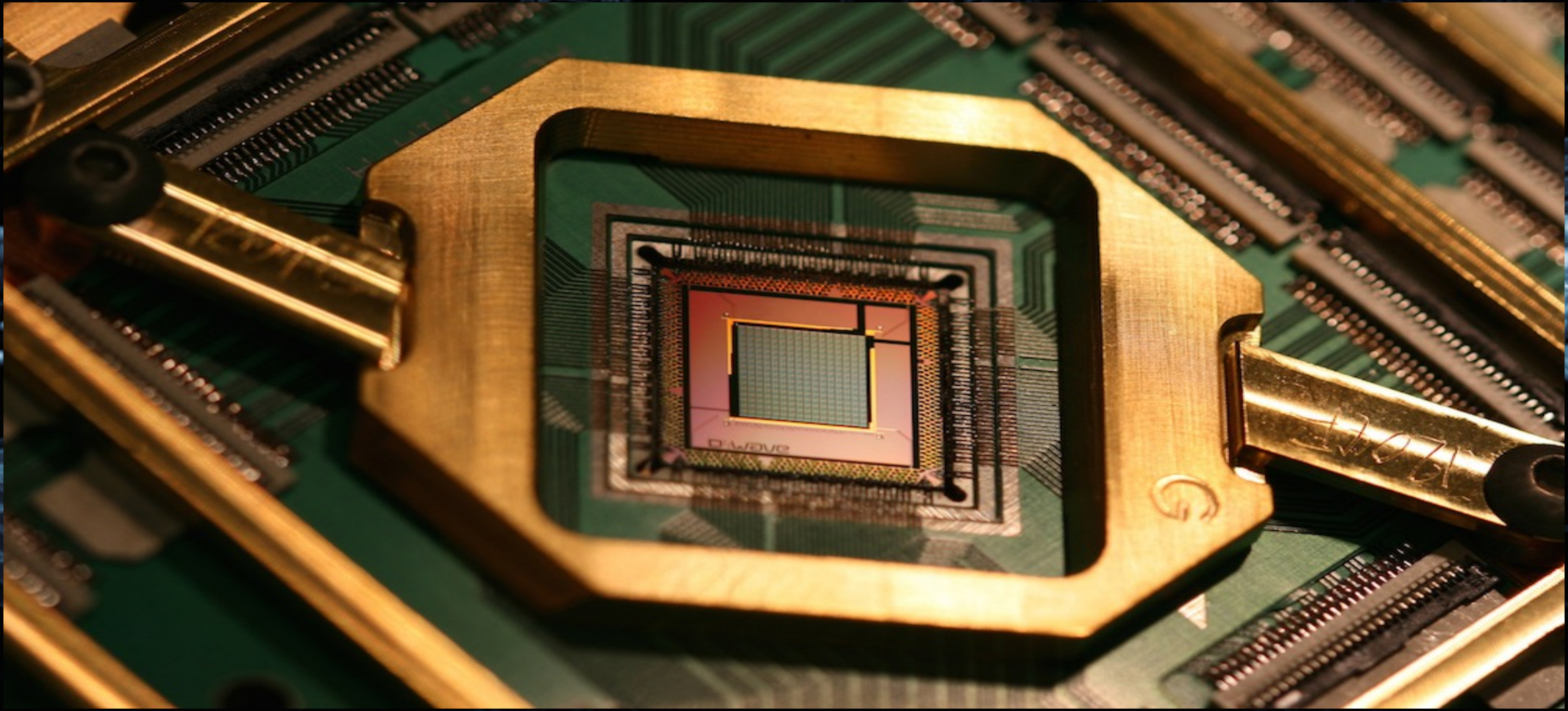
- Shielding preserves the quantum calculation

Processor Environment

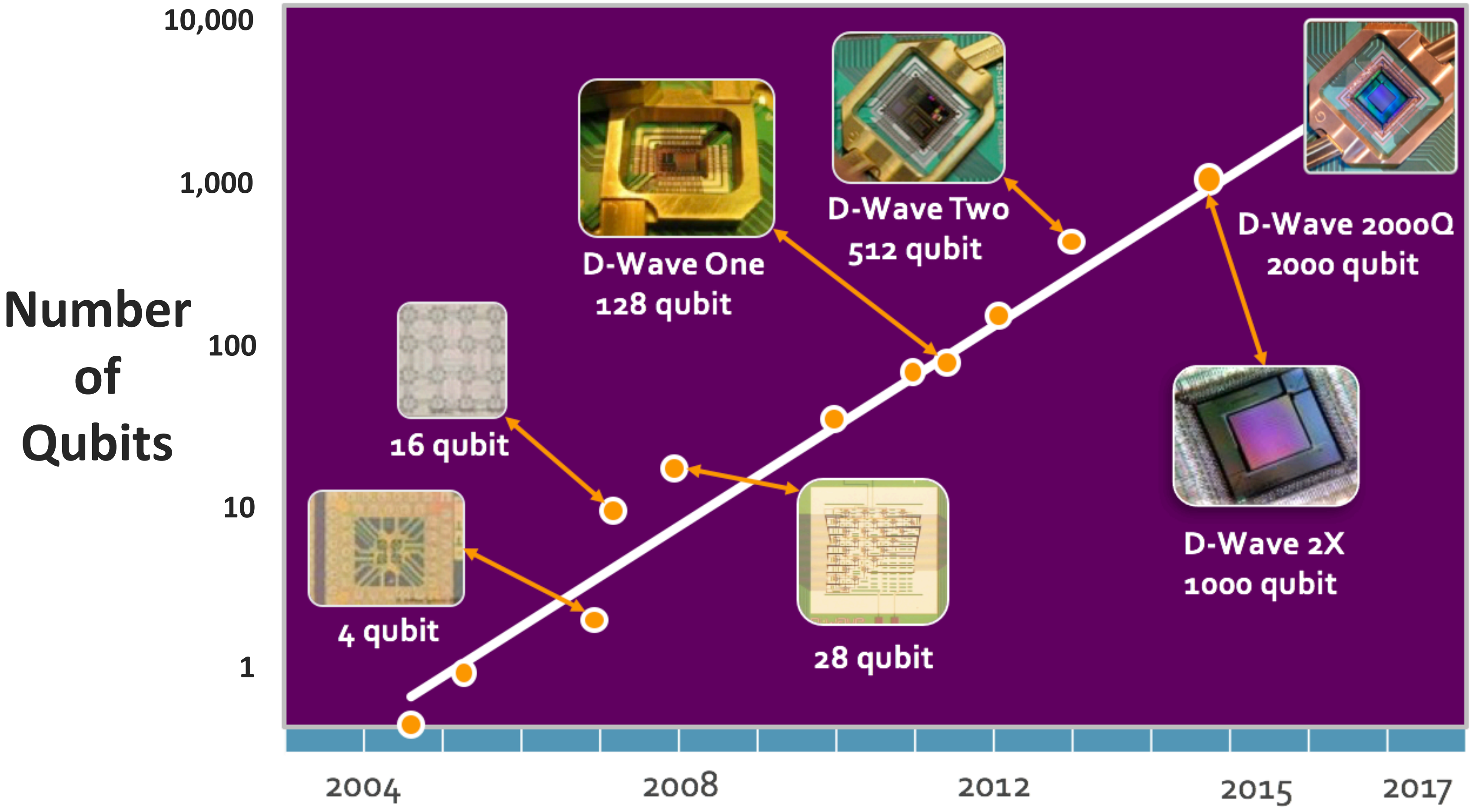
- Cooled to 0.015 Kelvin, 175x colder than interstellar space
- Shielded to 50,000✕ less than Earth's magnetic field
- In a high vacuum: pressure is 10 billion times lower than atmospheric pressure
- On low vibration floor
- <25 kW total power consumption – for the next few generations



D-Wave 2000 Quantum Processor



D-Wave Product Generations



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Mission

To help solve the most challenging problems in the multiverse:

- Optimization
- Machine Learning
- Monte Carlo/Sampling
- Material Science

Customer Application Areas

- **Lockheed/USC ISI**
  - Software Verification and Validation
  - Optimization – Aeronautics
  - Performance Characterization & Physics
- **Google/NASA Ames/USRA**
  - Machine Learning
  - Optimization
  - Performance Characterization & Physics
  - Research
- **Los Alamos National Laboratory**
  - Optimization
  - Machine Learning, Sampling
  - Software Stack
  - Simulating Quantum Systems
  - Other (good) Ideas
- **Temporal Defense Systems**
  - Cybersecurity
- **Oak Ridge National Laboratory**
  - Similar to Los Alamos
  - Material Science & Chemistry

Use Case	2016	2017	Total	%
Combinatorial Optimization	5	5	10	45%
Machine Learning, Sampling	2	2	4	18%
Understanding Device Physics	2	1	3	14%
Software Stack/Embeddings	1	1	2	9%
Simulating Quantum Systems		2	2	9%
Other (good) Ideas	1		1	5%
Total	11	11	22	100%

The LANL Rapid Response Project results for 2016 and 2017 are available as PDF's at: http://www.lanl.gov/projects/national-security-education-center/information-science-technology/dwave/index.php

D-Wave “Rapid Response” Projects (Stephan Eidenbenz, ISTI)

Round 1 (June 2016)

1. **Accelerating Deep Learning with Quantum Annealing**
2. **Constrained Shortest Path Estimation**
3. **D-Wave Quantum Computer as an Efficient Classical Sampler**
4. **Efficient Combinatorial Optimization using Quantum Computing**
5. **Functional Topological Particle Padding**
6. **gms2q—Translation of B-QCQP to D-Wave**
7. **Graph Partitioning using the D-Wave for Electronic Structure Problems**
8. **Ising Simulations on the D-Wave QPU**
9. **Inferring Sparse Representations for Object Classification using the Quantum D-Wave 2X machine**
10. **Quantum Uncertainty Quantification for Physical Models using ToQ.jl**
11. **Phylogenetics calculations**

Round 2 (December 2016)

1. Preprocessing Methods for Scalable Quantum Annealing
2. QA Approaches to Graph Partitioning for Electronic Structure Problems
3. Combinatorial Blind Source Separation Using “Ising”
4. Rigorous Comparison of “Ising” to Established B-QP Solution Methods

Round 3 (January 2017)

1. The Cost of Embedding
2. Beyond Pairwise Ising Models in D-Wave: Searching for Hidden Multi-Body Interactions
3. Leveraging “Ising” for Random Number Generation
4. Quantum Interaction of Few Particle Systems Mediated by Photons
5. Simulations of Non-local-Spin Interaction in Atomic Magnetometers on “Ising”
6. Connecting “Ising” to Bayesian Inference Image Analysis
7. Characterizing Structural Uncertainty in Models of Complex Systems
8. Using “Ising” to Explore the Formation of Global Terrorist Networks

A sampling of “Ising-active” LANL scientists (from D-Wave user group meeting)

- **Quantum Computing Environment**
  - Edif2qmasm – Scott Pakin
  - BQPJSON & Friends – Carleton Coffrin
  - Panel: Dan O’Malley

- **Quantum annealing approaches to graph portioning on the D-Wave system – Sue Mniszewski**
- **Unsupervised machine learning and facial recognition – Dan O’Malley**
- **Opening the D-Wave quantum box: hidden multi-body interactions and the echo of the chip architecture – Andrey Lokhov**

- **Programming models for the D-Wave system – George Stelle**
- **D-Wave benchmarking made easy: open source tools… - Carleton Coffrin et al.**
- **Tuning Hamiltonians by genetic algorithms – Marcus Daniels**

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