National Aeronautics and Space Administration

NASA facts

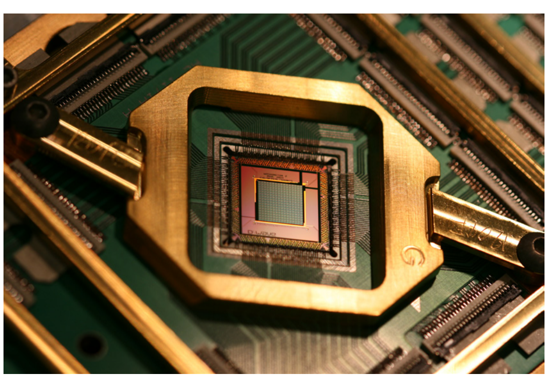
Quantum Computer Project

Accelerating Advanced Computing for NASA Missions

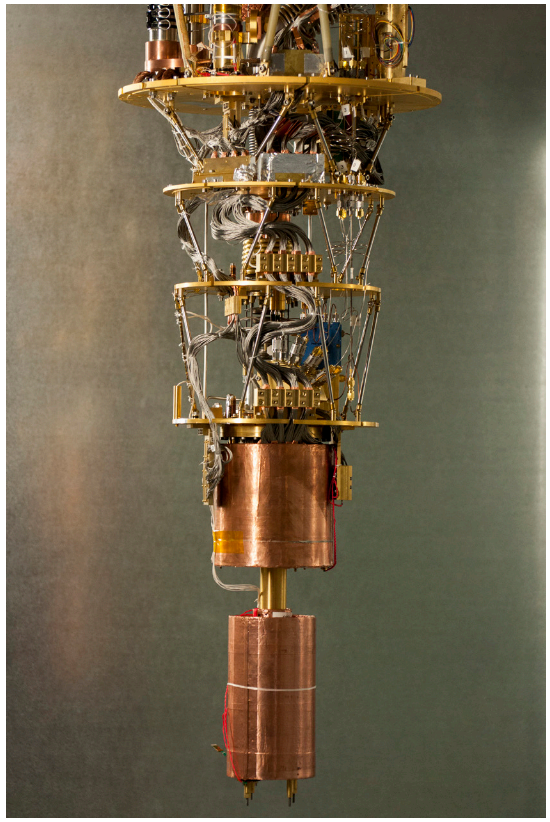
NASA's quantum computing project is a long-term research activity to assess the potential of quantum computers to perform calculations that are difficult or impossible using conventional supercomputers in a realistic timeframe. The project is an innovative collaboration among teams at NASA, Google, and the Universities Space Research Association (USRA). NASA's goal is to demonstrate that quantum computers and quantum algorithms could someday dramatically improve the agency's ability to solve challenging computational problems for missions in aeronautics, Earth and space sciences, and space exploration.

The NASA team has been conducting extensive studies using a D-Wave 2X™ quantum system operated at the NASA Advanced Supercomputing (NAS) facility's Quantum Artificial Intelligence Laboratory (QuAIL) at NASA's Ames Research Center in Silicon Valley. The hardware performs quantum annealing—an optimization process that takes advantage of quantum effects such as superposition and tunneling. This 1,097-qubit system—currently the largest quantum annealer in the world—was upgraded in summer of 2015, more than doubling the number of superconducting flux qubits in the original 509-qubit D-Wave Two™ system installed in summer 2013.

Current efforts focus on quantum approaches to optimization problems for applications such as air traffic control; mission planning and scheduling; machine autonomy, fault diagnosis, and robust system design. Examples of quantum algorithms that can benefit NASA missions include:

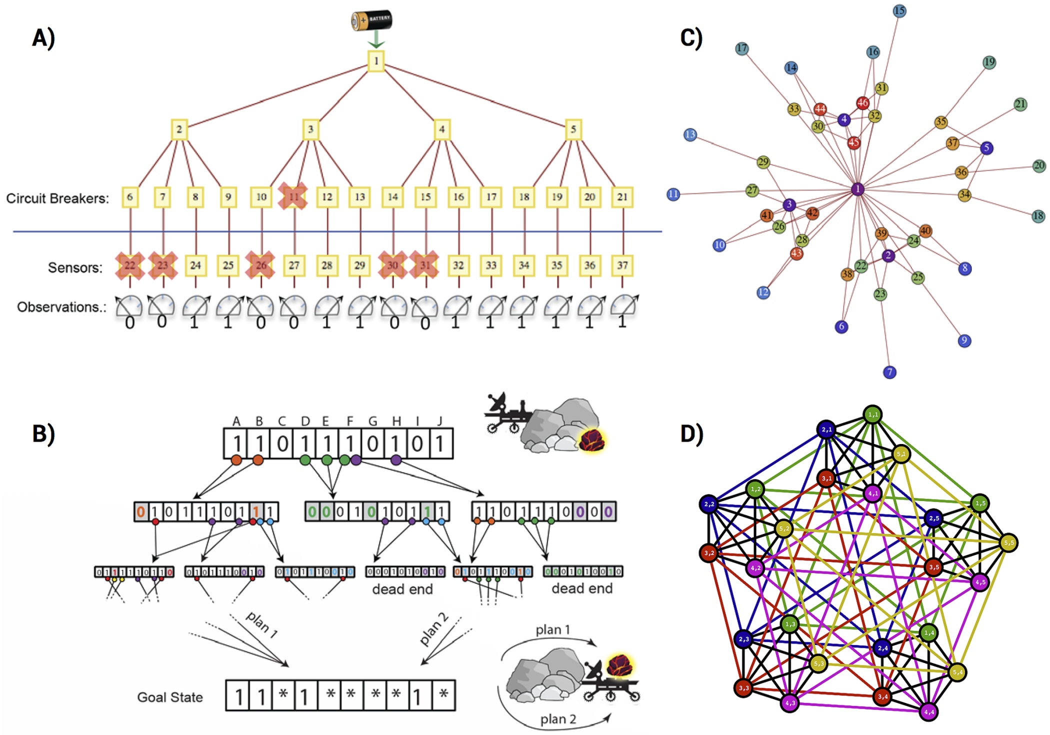


The D-Wave superconducting 1,097-qubit Washington processor chip.



Dilution refrigerator containing the D-Wave processor.

- Advanced diagnosis and fault management in engineering systems; for example, the detection of multiple faults in complex electrical power networks onboard the International Space Station (ISS).
- Automated mission planning to determine the best use of limited resources—including time and electrical power—for ongoing and future space missions such as the Mars Science Laboratory's Curiosity rover and the ISS.
- Scheduling algorithms to automatically determine the optimal time for making Low Earth Orbit satellite observations; and to optimize aircraft flight routes and landing patterns, taking into account weather conditions and air traffic management priorities.



Images representing programming elements of problems run on the D-Wave quantum annealer at NASA's Ames Research Center. **A)** Scheme of an experimental realization for the diagnosis of multiple faults: an electrical power system network with one power source and 21 circuit breakers. **B)** Operational planning problems: the binary representation of the initial state can be modified by available actions that have preconditions and effects up to reaching a final state. **C)** and **D)** Examples of quadratic binary unconstrained optimization graphs necessary for programming the D-Wave device for problems **A** and **B**, respectively.

The QuAIL team is exploring several applications to understand which areas may benefit most from quantum annealing technologies, and developing appropriate strategies, algorithms, and advanced programming techniques. Key outcomes from the preliminary research studies include:

- Performance benchmarks for near-term quantum annealers for optimization problems in planning, scheduling, fault diagnostics, graph analysis, transportation and communication networks, and machine learning.
- Best practices for programming a quantum annealer and compiling problems.
- Novel hardware characterization and calibration techniques that increase performance by an order of magnitude or more by addressing imprecise specifications in computational problems.
- Case studies to validate that use of quantum annealing effects results in improved solution accuracy, as compared to classical annealing—in a real-world quantum annealer subject to machine noise.

Techniques developed by the QuAIL team as part of NASA's research efforts will assist quantum annealing programmers as they go beyond proof-of-concept work toward real-world application problems.

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In addition to these studies, the broader academic community, through USRA, is using the D-Wave 2X system to conduct research on algorithms and programming techniques for quantum annealing, with the objective to advance the state-of-the-art in quantum computing and its application to artificial intelligence.

NASA researchers are sharing their design insights and hardware characterization results with teams around the world who are building quantum hardware and developing quantum algorithms. Such collaboration among the science community may bring about leaps in quantum computing technologies to vastly improve performance on a wide range of tasks, leading to new discoveries and technologies, and significantly changing the way we solve challenging real-world problems.

For more information about NASA's quantum computing project, visit: http://www.nas.nasa.gov/quantum

For information on USRA's Research Opportunities, visit: http://www.usra.edu/quantum/

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