Highly Scalable Quantum Computing with Neutral Atoms

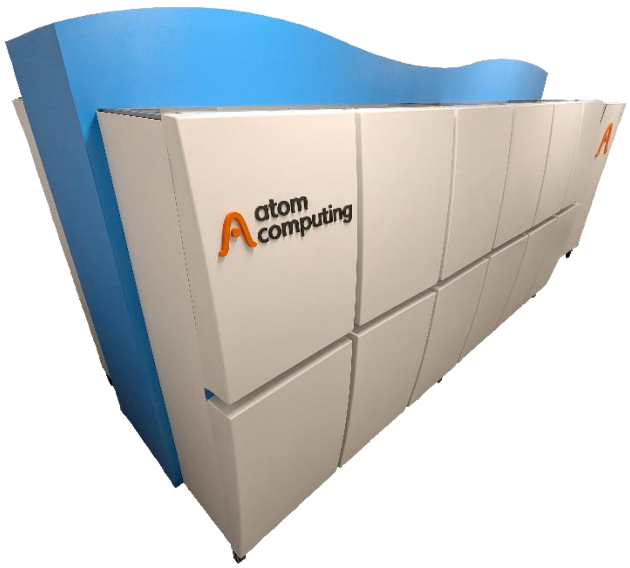
Atom Computing
918 Parker St. Suite A-13, Berkeley CA 94710

A Pioneer in Scalable Quantum Computing

Quantum computing is a disruptive technology that will impact the future of our society. It will fundamentally change the way problems will be solved in the future, and Atom Computing's unique vision and technology will make this future possible faster than expected.

Experts from all over the globe, both in academia and in industry, are exploring applications that will revolutionize the way we solve difficult computational challenges.

Progress is accelerating with companies pursuing a variety of approaches to building quantum computers. Each technology leverages a specific physical platform, including neutral atoms, ions, photons, and superconductors.



While many of these technologies have shown potential in small-scale demonstrations, a technological gap exists between basic demonstrations and full-scale systems which enable economically valuable applications.

To provide true economic value, quantum computing platforms need to be able to perform in the so-called Fault-Tolerant Quantum Computing (FTQC) regime, where gate-based algorithms can be executed with negligible errors.

In the race to reach FTQC, Atom Computing has recently become a leading contender because of its straightforward ability to scale to the performance levels required for operating at the FTQC level, and by demonstrating a 64-logical-qubit architecture, entanglement of 24 logical qubits, and running an algorithm with 28 logical qubits.

Atom Computing is a true pioneer in developing the scalable neutral atom technology for fault-tolerant gate-based quantum computers that lead the race to economically valuable quantum computing.

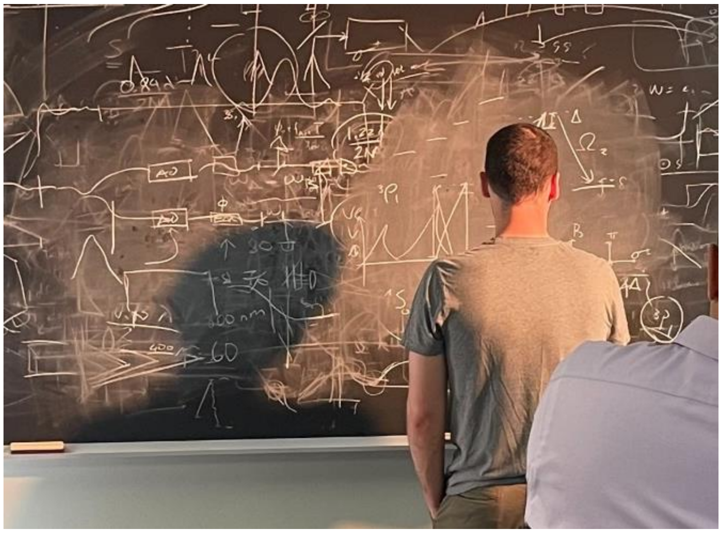
The Necessity of Fault Tolerant Quantum Computing

The fundamental building block of a quantum computer is the quantum-bit, also known as a qubit. There are many ways a qubit can be defined, and all depend on the physical nature of the qubit whether it is a superconducting circuit, a photon, an ion, or a neutral atom.

Physical qubits are not perfect; they can pick up environmental noise, have unwanted interactions with each other, and can be difficult to manipulate within the platform itself. The nature and magnitude of the challenges vary per platform, and these can significantly affect the speed at which technological improvements can be achieved.

There is a solution to overcoming the limitations in performance of physical qubits: using advanced algorithms and techniques, multiple physical qubits can be grouped to form a single so-called "logical qubit" which then acts like a single qubit with very low error.

The advantage of logical qubits is that they can be scaled to have arbitrary low error rates by leveraging numerous physical qubits and clever encoding schemes. This paves the road to running algorithms that are extremely resistant to the imperfect operations of individual physical qubits.



The first promising economically valuable applications with logical qubits are estimated to require approximately 100 logical qubits. Each of these logical qubits is expected to require 10 to 1,000 physical qubits according to error-correction researchers. Thus, to cross the threshold to valuable applications, many thousands of qubits are required.

Atom Computing's unique choice of qubit and highly scalable neutral atom technology is poised to meet this challenge with a roadmap that enables multiple logical qubits in the current generation, which has recently been demonstrated [1], and an order of magnitude more with each consecutive generation.

The Atom Computing Advantage

Founded in 2018 by Dr. Ben Bloom and Dr. Jonathan King, Atom Computing's mission is to build fault-tolerant universal gate-based quantum computers using neutral atoms.

The company achieves this by leveraging state-of-the-art lasers, optical solutions, control system electronics, and its own hardware-controlling software stack.

The company's success is based on a clear vision to deliver state-of-the-art hardware, leveraging the team's extensive knowledge and experience in working with lasers, developing optical solutions, control system electronics, and its own software stack.

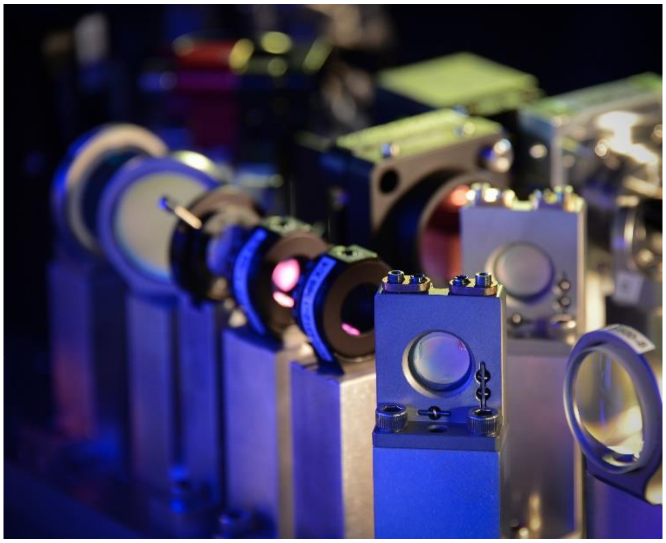
Everything is fine-tuned to orchestrate precise timing and sequencing of lasers, imagers, magnets, and electro-optical components that form the quantum computing platform.

Atom Computing's world-leading team of scientists and engineers, with over 600 publications and extensive technical expertise in both quantum hardware and academic research, are accelerating the development of robust systems.

In a short amount of time the team has demonstrated multiple critical technological capabilities that are essential to build a fault-tolerant quantum computer.

Scalability

Atom Computing's 100-qubit prototype system is now superseded by their second-generation system hosting over 1,200 qubits [2]. These industry-leading qubit numbers are enabled by Atom Computing's unique optical technology, which has paved a straightforward road for future generation of platforms that will increase the number of qubits by 10x with each generation.



Long Coherence

By encoding the qubit in the nuclear spin of an atom, quantum information stays preserved for tens of seconds [3], which significantly reduces errors caused by loss of information, and provides substantial overhead for calculating and performing error correcting operations that are essential for constructing logical qubits.

Mid-circuit Measurement

Essential to error correction is the ability to perform measurements of specific qubits in the platform without disturbing other qubits while the quantum computer is operating. Atom Computing's technology enables this capability, known as mid-circuit measurement, with immediate qubit reset and reuse [4] which is nearly unmatched within the industry.

High Fidelity

Atom Computing has demonstrated excellent high-fidelity single- and two-qubit operations with nuclear-spin qubits [5] that enable logical qubits efficiently and in a scalable way, and were essential to the world's first demonstration of entangling 24 logical qubits, and running an algorithm with 28 logical qubits [1].

Real-time Error Correction

Using the platform's mid-circuit measurement capability, the quantum computer's software stack can determine which errors have occurred on the qubits, and through logical branching determines which future operations need to be executed on the qubits to correct for the identified errors [4].

Logical qubits

By bringing together all technical tools to perform error detection and correction, Atom Computing has demonstrated how logical qubits can be created on their platform, showing an architecture of 64 logical qubits, entangling 24 logical qubits, and by running an algorithm with 28 logical qubits [1].

Sustainability

As Atom Computing's systems scale to larger numbers of qubits, their physical footprint and energy consumption will remain relatively constant, unlike many other modalities which will require large amounts of space and power. Atom Computing systems can be operated in office buildings without putting extraneous strain on the existing infrastructure.

Addressing Real-World Applications

Atom Computing's gate-based platforms provide the resources for researchers to develop real-world applications that can be continuously developed as the system capabilities improve with each generation.

Working with government organizations, universities, companies, and individuals, Atom Computing is making quantum technology more available and accessible.

In addition to straightforward access to Atom Computing's platforms for researchers, the company's direct collaboration with domain experts is accelerating their rate of innovation, allowing them to set up funded projects that are focused on making a positive impact on society as soon as possible.

Atom Computing has been actively working with domain experts from the healthcare [6] and energy [7] sectors to help them develop solutions that can scale in complexity along with the company's technology roadmap.

Real-world applications for these partners include accelerating drug discovery, improving rural healthcare, bolstering the robustness of the energy grid, and developing more resilient government responses to various disasters.

These partnerships provide domain experts with the tools to build up quantum computing expertise within their own organization, and to be in a leading position to leverage ever-improving quantum hardware as it becomes more readily available.

Revolutionary advances do not happen in isolation – computers are tools for scientific discovery, engineering advancement, and creating novel solutions. By focusing on building scalable quantum computers, Atom Computing's goal is to provide the world's best quantum tool for their partners and customers.

atom computing

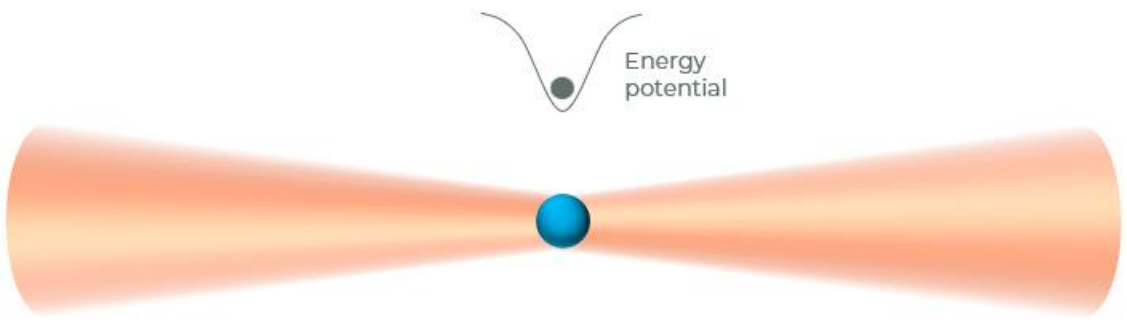
Neutral Atom Quantum Computing Technology

Atom Computing utilizes tools and techniques developed by the scientific community over the past 40 years to prepare and manipulate neutral atoms for quantum computing. Building on research which has explored fundamental physical interactions between atoms, and subsystem development which has matured into robust commercial components, Atom's multiple engineering teams are integrating a variety of technologies to build cutting-edge quantum systems.

Here are three key technologies that Atom Computing uses to establish their unique position in the quantum computing industry.

Key Technology #1: Optical Tweezer Arrays

An optical tweezer is created when a laser beam is focused through a microscope objective lens. As the laser beam gets focused it forms into a "tweezer" capable of holding miniscule objects.

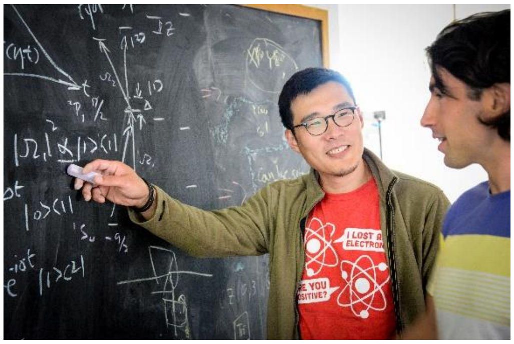


This is possible because light can attract or repulse a particle depending on the color (wavelength) of the light. By choosing the right wavelength, a particle will be drawn or attracted to the region with the highest intensity of light, which is where the beam is focused.

To create an array of optical tweezers, the laser beam is manipulated before it is focused through a microscope objective lens to create a custom-made array of optical tweezers that can be tailored to specific needs for topology, dimensions, and orientation.

In addition to optical tweezer arrays, Atom Computing has shown how an optical technology called "optical cavities" is used in their second-generation systems to create light fields that can scale to facilitate many orders of magnitude more qubits than what is currently available [2].

Key Technology #2: Nuclear-Spin Qubits from Alkaline Earth Atoms

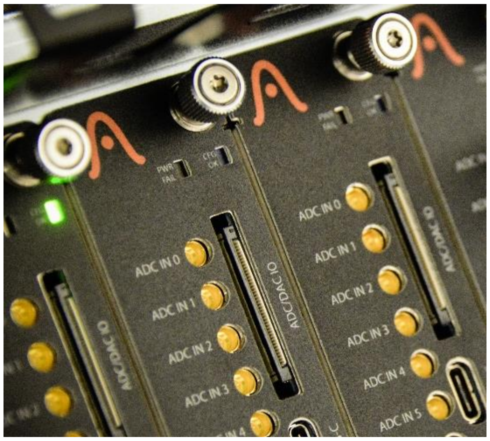


Atom Computing uses the spin of the atom's nucleus as the physical qubit, where the direction of the spin (clockwise or counterclockwise) defines the two states of the qubit. This choice is unique in the quantum computing industry.

A nuclear-spin qubit has two important advantages. First, the nucleus of the atom is insensitive to external noise, allowing for very long coherence times that allow for optimal performance of hybrid quantum-classical algorithms and error correction schemes. Second, the nucleus cannot dissipate to other quantum states, meaning that there is no spontaneous decay in the qubit. If the noise sources are sufficiently controlled, the qubit will live with infinite memory.

The choice of atom is crucial. Atom Computing's use of Alkaline Earth atoms such as strontium and ytterbium opens up a large toolbox of optical techniques to control and manipulate the qubits. These tools are less applicable to other types of atoms that are used for quantum computing applications and have enabled the development of state-of-the-art solutions that accelerate the company's path to building fault-tolerant quantum computers.

Key Technology #3: Fully-Integrated Control Systems



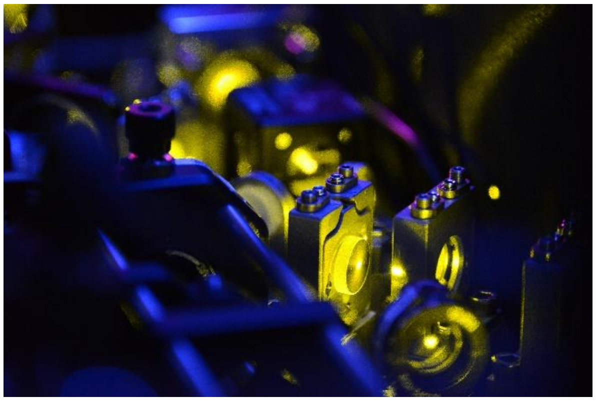
Orchestration of all operations within a quantum computing platform requires state-of-the-art control software and electronics to meet a broad spectrum of performance requirements, including the ability to perform error correction and logical qubits.

To guarantee optimal pulse compilation and execution, Atom Computing has been developing proprietary control systems that form the signaling nexus of each platform.

This strategic choice enables the interdisciplinary engineering teams to rapidly develop, debug, and improve the control systems, resulting in an exceptional speed of innovation that is essential in the marathon to building highly scalable quantum computers.

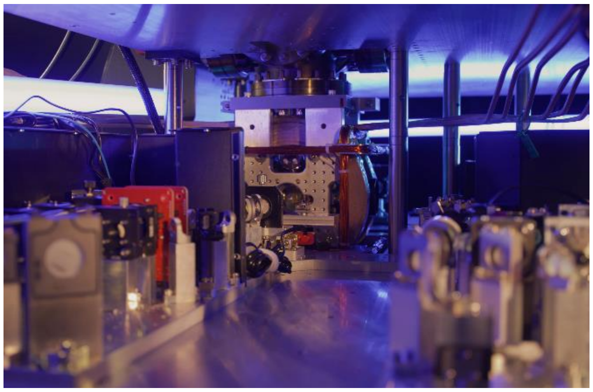
What Happens Inside an Atom Computing Platform

The platform consists of a multi-vacuum chamber design, in which the first chamber provides a source of very slowly moving atoms, and the second chamber facilitates the actual quantum computation.



The process of preparing the system for operating as a quantum computer starts with a solid sample of our alkaline earth metal which is heated in a small oven, creating a hot and fast-moving stream of atoms directed into the first vacuum chamber. A combination of lasers and magnetic fields rapidly cool and slow down the atoms, bringing them to an almost complete stop.

A pair of laser beams then form an "optical elevator" that transports the cold atoms from the first chamber to the second chamber and parks the atoms inside an auxiliary optical tweezer array called the "reservoir". This reservoir can be reloaded at any time, providing a continuous and on-demand supply of atoms.



The atoms in the reservoir are then shuttled using separate optical tweezers to the main optical tweezer array which is called the "computing array". For Atom Computing's second-generation platforms the computing array can be as large as 1,225 sites and can be almost perfectly filled [2].

Inside the computing array the atoms now act as qubits and a quantum circuit can be executed on them. Site-specific single-qubit gates can be executed in parallel in rows across the array, increasing the overall computational efficiency of the system [3]. Two-qubit gates can be performed between pairs of qubits. Laser pulses excite atoms to a highly energized state called a "Rydberg state" in which the atoms' electrons orbit the nucleus at a much greater distance than usual to "reach out" and interact with nearby atoms, creating entanglement between the qubits.

After a quantum circuit has been fully executed, the results of the computation are read out optically, using a camera to detect optical fluorescence from qubits in a pattern of 1s and 0s. The qubits are immediately reinitialized and are ready to run another quantum circuit, without the need to reload the entire computing array.

References

[1] Reichardt, B.W., et al., "Logical Computation Demonstrated with a Neutral Atom Quantum Processor," arXiv, 2024. [Online]. Available: https://arxiv.org/abs/2411.11822.

[2] Norcia, M.A. et al., "Iterative Assembly of Yb-171 Atom Arrays with Cavity-Enhanced Optical Lattices," PRX Quantum, 2024. [Online]. Available: https://link.aps.org/doi/10.1103/PRXQuantum.5.030316.

[3] Barnes, K. et al., "Assembly and coherent control of a register of nuclear spin qubits," Nature Communications, 2022. [Online]. Available: https://www.nature.com/articles/s41467-022-29977-z.

[4] Norcia, M.A. et al., "Midcircuit Qubit Measurement and Rearrangement in a Yb-171 Atomic Array," Physical Review X, 2023. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevX.13.041034.

[5] Muniz, J.A., et al., "High-fidelity Universal Gates in the Yb-171 Ground State Nuclear Spin Qubit," arXiv, 2024. [Online]. Available: https://arxiv.org/abs/2411.11708.

[6] University of Colorado - Anschutz Medical Campus, "Partnership Forms to Explore Quantum Computing for Healthcare," 2024. [Online]. Available: https://news.cuanschutz.edu/news-stories/partnership-forms-to-explore-quantum-computing-for-healthcare.

[7] NREL, "Quantum Computers Can Now Interface With Power Grid Equipment," 2023. [Online]. Available: https://www.nrel.gov/news/program/2023/quantum-computers-can-now-interface-with-power-grid-equipment.html.

atom computing

Learn More:

https://atom-computing.com/

info@atom-computing.com