atom computing

Highly Scalable Quantum Computing with Atomic Arrays

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

Introduction

Interest in quantum computing is steadily growing with simultaneous advancements in quantum computing platforms and innovations in industries like healthcare and finance as experts explore the power of quantum computing to optimize efficiency and simulate complex systems. Diverse technical approaches to quantum processors utilize physical systems such as ions, photons, and superconductors as qubits. While many of these approaches have shown potential for building quality qubits, atomic array technology has recently emerged as a leading contender to quickly scale to large qubit counts and to achieve the high fidelities required for valuable computation. Atom Computing is pioneering atomic array technology for gate-based quantum computers by creating qubits using the nuclear spins of neutral atoms to achieve an expanded range of benefits.

What Are the Benefits of Atomic Arrays?

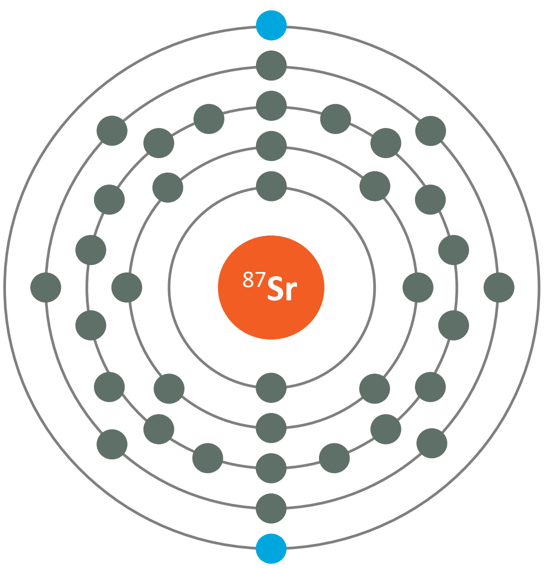
The case for using atomic arrays of neutral atoms for quantum computing was published more than 20 years ago[1], but only recently have atomic array systems been assembled and demonstrated to have notable advantages over other approaches[2,3]. The benefits include:

Scalability: Because neutral atoms lack electric charge and are not subject to electrostatic forces, they can be tightly packed into a computational array of qubits, reducing the size of the quantum processor core. Lasers hold the atomic qubits in position in this tight array and manipulate them to perform quantum computations wirelessly with pulses of light. At only microns apart, this arrangement of individually trapped atoms allows for massive scalability, as it is possible to expand the qubit array size without substantially changing the overall footprint of the system.

Fidelity: Atoms exist in nature as intrinsically identical particles and have been extensively characterized since John Dalton pioneered atomic theory in 1808. Well established control techniques allow us to manipulate the atomic states of the qubits in a repeatable manner across the entire array. Sources of error, such as environmental conditions and laser noise, can be measured and minimized through diligent engineering efforts. With neutral atoms, there are no fundamental physics obstacles to achieving sufficiently high fidelity to enable fault tolerance at scale.

Reduced Complexity: All of the control functions of neutral atom qubits are mediated by light. The active control systems that direct and modulate the light are based on high speed electronic signaling technology that has been developed at scale for various industrial applications and refined over many years. Because each qubit is controlled wirelessly by light through free space, rather than individual electrical cables attached to each qubit, the size and complexity of the system is greatly simplified.

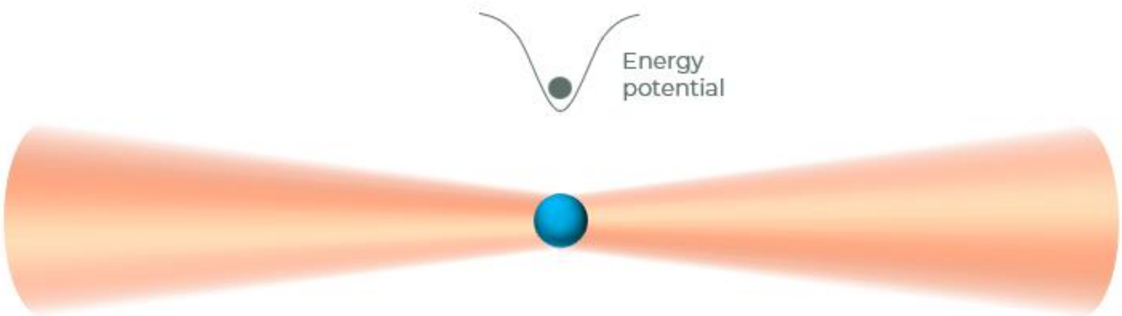
Long Coherence: Atom Computing uses alkaline-earth metals as qubits because of their favorable noise-immunity characteristics. These qubits are encoded in the nuclear spin of atoms rather than the electron spin. The complete (or "closed") outer electron shell of these atoms provides protection against environmental perturbations such as the light used to trap atoms and stray magnetic fields. With this protection and inherent insensitivity to certain noise sources, our qubits can achieve very long coherence times that allow for optimal performance of hybrid quantum-classical algorithms and error correction schemes.



How Are Atomic Array Systems Realized?

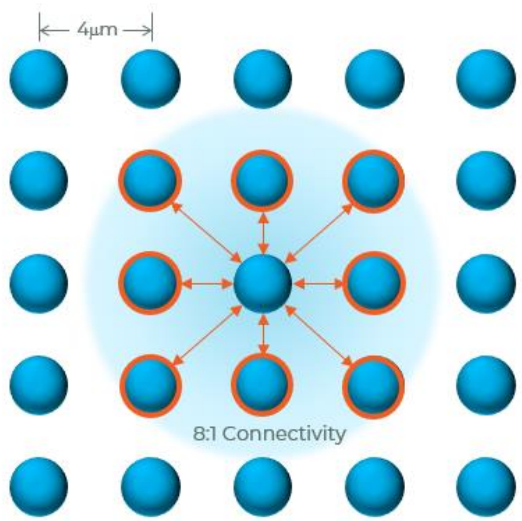
Atom Computing utilizes tools and techniques developed by the scientific community over the past 40 years[4] to prepare and manipulate neutral atoms and adds targeted improvements to make systems more robust and commercially viable.

The process starts with preparing the atoms to form qubits. An alkaline earth metal source material, such as Strontium, is first heated, releasing a fast stream of atoms into a vacuum chamber. Using strong magnetic fields and lasers, rather than cryogenic environmental cooling, the atoms are progressively slowed to almost a complete stop. Stopping the vibration and movement of an atom can be described as creating the “cold” atoms. They sit in a small vacuum chamber which insulates them from the room temperature environment outside the chamber. The cold atoms, at temperatures of about 4μK, form a cloud in a reservoir. The atoms from the cloud are then moved into a science chamber, where they are loaded into optical tweezers arranged in an evenly spaced two-dimensional array.



We use optical tweezers for containing and manipulating neutral atom qubits. Optical tweezers are a scientific technique whereby a highly focused laser beam holds and moves objects like atoms and nanoparticles. The tweezers induce a light-dependent force on the atom, which then traps the atom in the central focus of the tweezer beam. A single laser can generate the entire array of optical tweezers and the array can be easily reconfigured and scaled. This technology has been in use for decades in the fields of medicine, genetics, and chemistry. In fact, Arthur Ashkin, “the father of optical tweezers,” was awarded the Nobel Prize in Physics in 2018.[5]

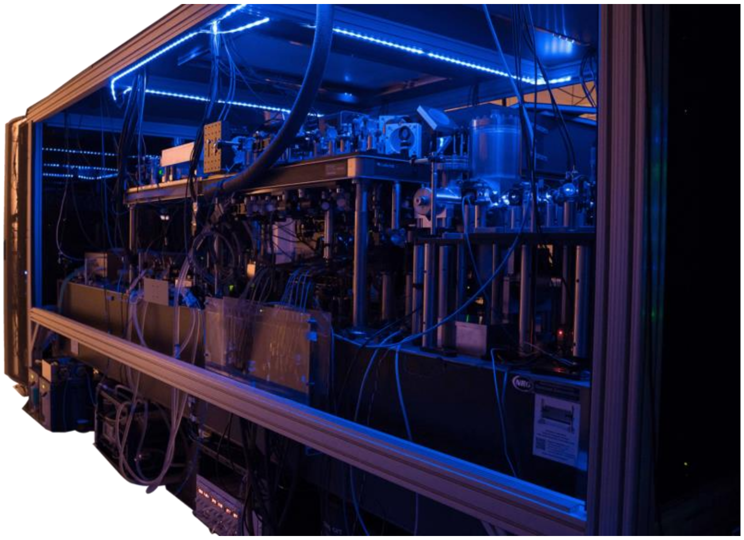
After the array has been filled in an organized grid, quantum computations can start. Atoms are transformed into qubits using laser pulses which adjust the nuclear spin of the atoms. One- and two-qubit gates can be performed on the qubits in various sequences and combinations to execute quantum circuits.



With Atom Computing's system, site-specific single-qubit gates can be executed in parallel in rows across the array, which increases the overall efficiency of the system. Two-qubit gates can be performed between qubits and their nearest neighbors. Laser pulses excite atoms to a highly energized state called a "Rydberg state" in which their electrons orbit the nucleus at a much greater distance than usual to "reach out" and interact with nearby atoms. Subsequent pulses entangle pairs of qubits, thus realizing one of the fundamental building blocks of quantum computing that allows for improvements over classical algorithms. Multiple two-qubit gates can be performed in parallel on different portions of the array. After a quantum circuit has been fully executed, the results of the computation are read out optically, using a camera to detect fluorescence from qubits in a pattern of 1s and 0s. Once read out, qubits can be reinitialized to run further computations, obviating the need to reload the atomic array.

How Will Atomic Arrays Address Real-World Applications?

Atom Computing's first-generation platform, named Phoenix, harnesses the power of 100 qubits constructed from coordinated neutral atoms to perform quantum algorithms. Phoenix employs state-of-the-art control system electronics, which are fine-tuned to orchestrate precise timing and sequencing of lasers, imagers, magnets, and electro-optic components. While Phoenix is a prototype, it has proven to be an important building block to validate our technology and architectural building blocks so that we can build commercial systems at a larger scale. Additionally, Phoenix allows the company and its partners to utilize its unique capabilities to explore optimized quantum algorithm development.



With machines like Phoenix, developers can use the power of atomic arrays to address real-world problems using a universal quantum gate set. Quantum computers are showing promise for complex optimization problems, chemical and molecular simulation, and acceleration of machine learning. With large numbers of qubits, long coherence, and improved fidelities, atomic arrays are a key component in building successful quantum algorithms. In healthcare, quantum algorithms may accelerate drug trials and help test drug safety and efficacy without the cost or need for human subjects. Financial professionals are exploring quantum cryptography and quantum algorithms to make transactions secure and prevent future fraud. Meteorologists are exploring the potential for quantum computing to help enhance data analysis, pattern recognition, and non-linear modeling capabilities for weather forecasting. These examples only scratch the surface of the vast potential of quantum computing, illustrating the versatility of this technology.

What Makes Atom Computing Unique?

Atom Computing stands out as the company that built a 100-qubit system faster than any of its predecessors. We are growing rapidly and establishing ourselves as a market leader. With our unique approach to highly scalable quantum computing, we are offering new tools for quantum algorithm developers to explore more optimized approaches for tackling challenging computations and applications.

Our team of scientists and engineers has over 600 publications and draws on our extensive technical expertise to deliver advanced quantum hardware. We focus on a multidisciplinary approach, using tools from a variety of fields and from decades of landmark research in the scientific community, to deliver unique advantages to our partners and customers. Computing advances do not happen in isolation – computers are tools for scientific discovery, engineering advancement, and creating novel solutions. At Atom Computing, we are solely focused on building scalable quantum computers and are committed to enabling our partners to reach their next big breakthroughs.

Seeking to drive quantum computing toward utility, Atom Computing emphasizes collaboration. With a diverse pool of global partners and multiple Atom Computing locations across the U.S., we have created an integrated network to improve quantum computing technology and deploy it in the service of positive change. Working with universities, companies, and individuals, Atom Computing has found a way to help make quantum technology more available and accessible. We are ready to engineer the quantum future together with our partners.

Please contact us to learn more about how to collaborate with Atom Computing and explore the unique advantages of atomic array technology.

References:

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