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Quantum Baseball: Pitch and Catch for Neutral Atom Quantum Computing

Stanford University Simon Lab researchers have developed a new qubit transport protocol for neutral-atom quantum computing that decouples rearrangement overhead from array size and transit distance for faster, more scalable architecture.

Current neutral-atom processors rearrange qubits by dragging a laser trap (optical tweezer array) continuously from site to site, requiring a beam-pattern update at every incremental step. Control overhead therefore grows with both move distance and the number of atoms relocated in parallel, capping rearrangement speed and limiting processors to roughly 1,000 qubits.

The Simon Lab approach launches atoms into brief free flight using short laser pulses and catches them at the target site, with movement speeds limited only by available laser power. A single pre-computed beam configuration drives a complete transfer regardless of travel distance. That same configuration simultaneously addresses many atom pairs moving along independent paths. This approach requires no additional laser photons and induces no additional decoherence compared to a conventional tweezer move over the same distance and time. The result is a faster, more scalable rearrangement architecture with a path to processors well beyond the ?1,000-qubit ceiling of today's systems.

Stage of Development- Proof of Concept
Analytical framework and theoretical modeling complete.

Applications

- **Quantum computing**:

    - Neutral-atom quantum processor hardware for large-scale, fault-tolerant quantum computing
    - Optical control systems for qubit array routing and quantum circuit compilation
    - Quantum computing research platforms requiring high-throughput qubit rearrangement
    - Quantum processors enabling logic gates between atoms during transit

Advantages

- **~1,000x Faster qubit rearrangement** (10? vs. 10^2 moves/sec at 1 kHz) for faster quantum circuit execution
- **Lower framerates** - fixed overhead of just 5 optical frames per move **supports processor scaling well beyond 1,000 qubits**
- **More robust** - eliminates recooling between sequential moves, **reducing error accumulation and preserving qubit coherence** at no quality cost
- Single beam configuration simultaneously drives transport for hundreds to thousands of atoms, making **speed gains scale** with array size

Innovators

- Jon Simon
- David Schuster
- Monika Aidelsburger

Licensing Contact

David Mallin

Licensing Manager, Physical Sciences

Email