QUERA

INTRO TO QUANTUM COMPUTING WITH NEUTRAL ATOMS

QHACK

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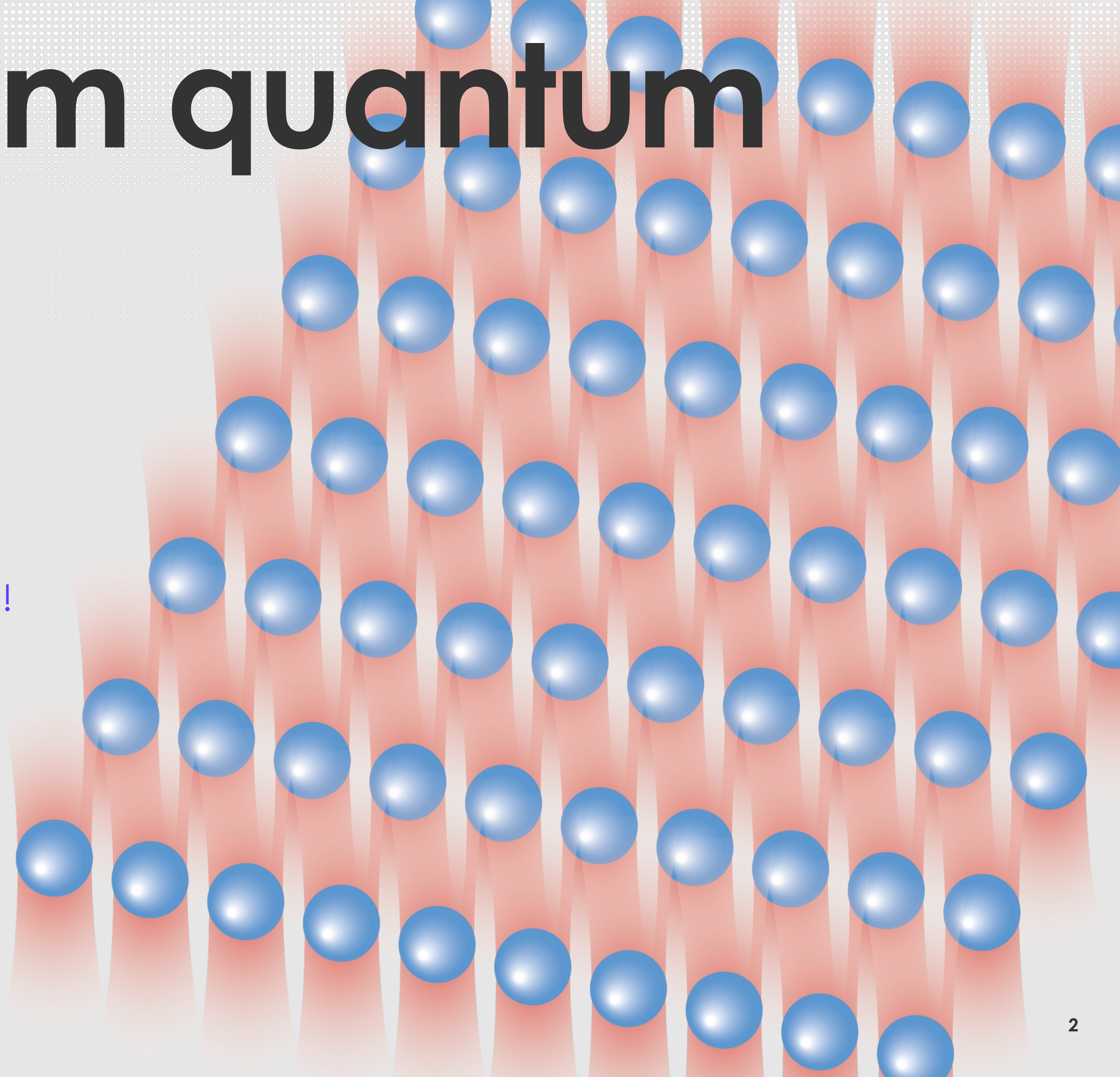
|QuEra⟩

Neutral-atom quantum processor



- Densely packed qubits (atoms)
- Efficient qubit control
- Flexible problem encoding
- New ways to think quantum computing!

What is quantum computing?
=> new rules!

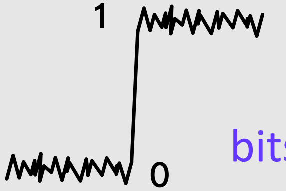
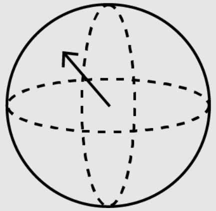
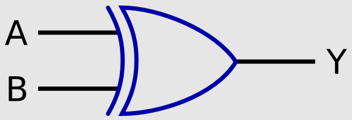
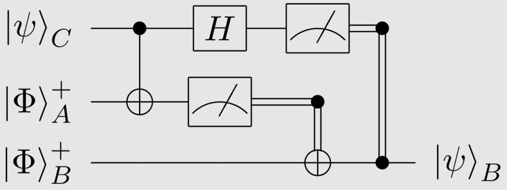
Information input

↓

Information processing

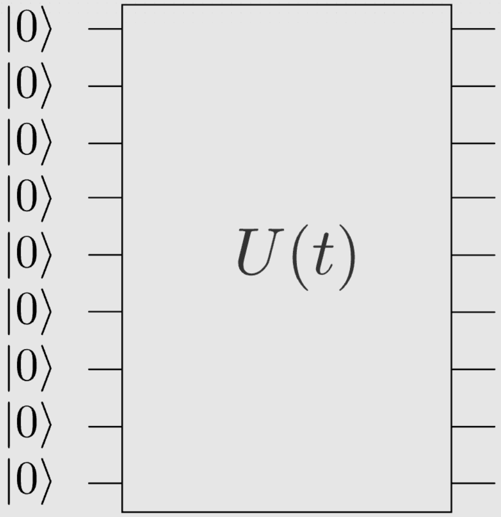
↓

Results & output

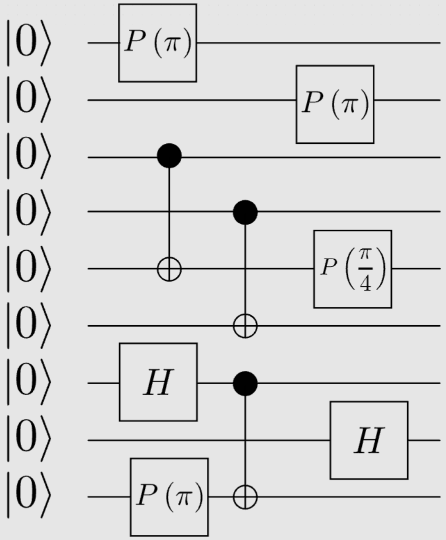
Classical	Quantum
 bits	 qubits
 Logic gates	 Quantum gates
Deterministic	Probabilistic & deterministic

Analog Processing

Analog operation



Digital operation



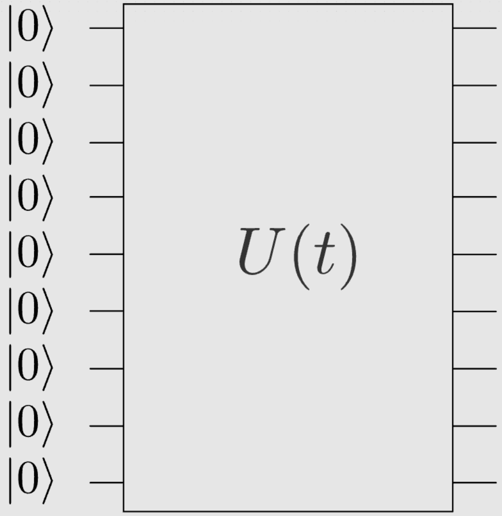
Designed for the early stage of maturity of the quantum computing resources of today…

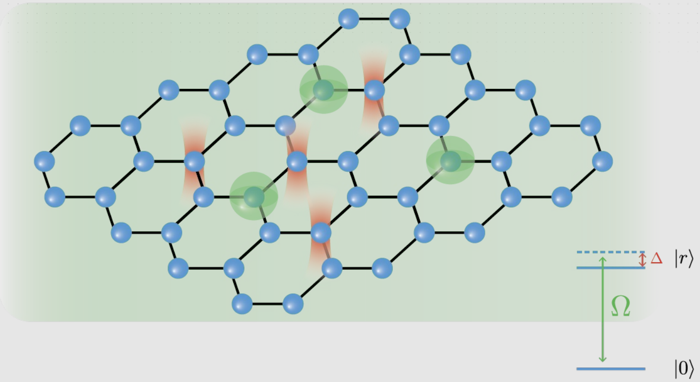
- ✓ Robustness to errors
- ✓ Easy control
- ✓ Single-step large entanglement
- ✗ Universal applicability

More on analog processors:
Nature **volume 607**, p. 667–676 (2022)

Field Programmable Qubit Arrays (FPQAs)

Analog operation





Control qubit positions! Control qubit connectivity!

=> Many possibilities!

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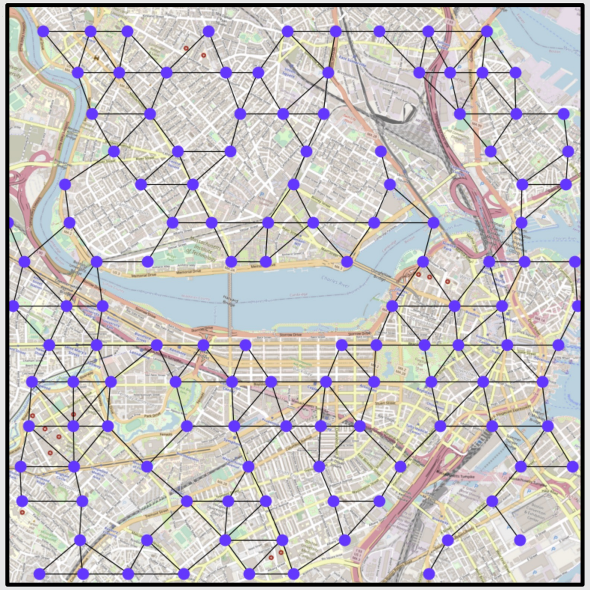
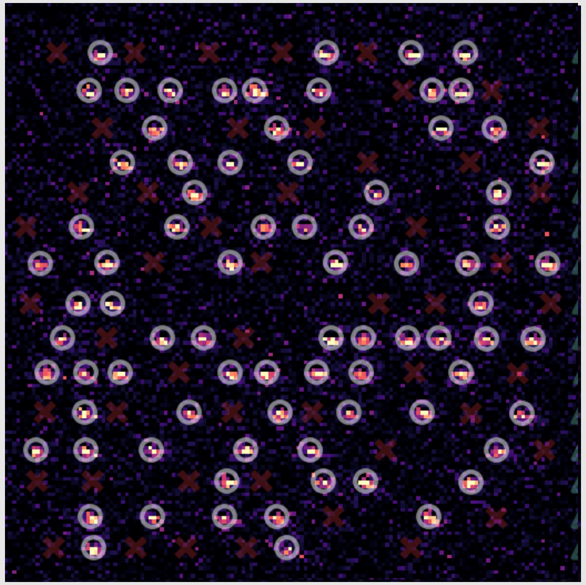
FPQA = Efficient Problem Encoding

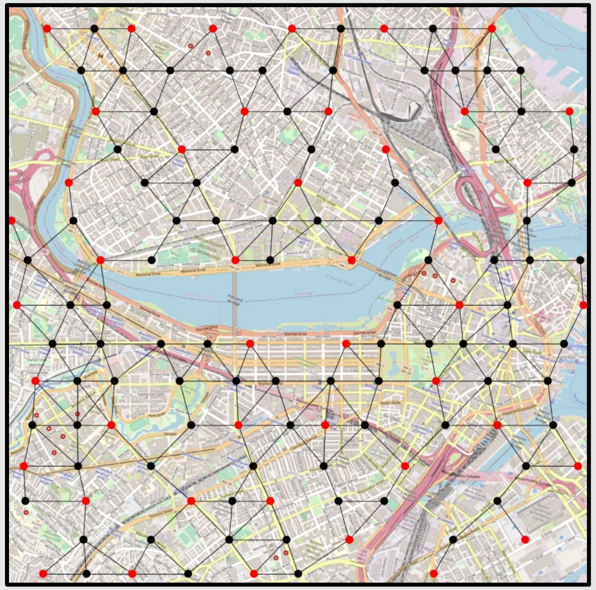
Problem: choosing optimal locations in Boston



Possible locations as atom coordinates

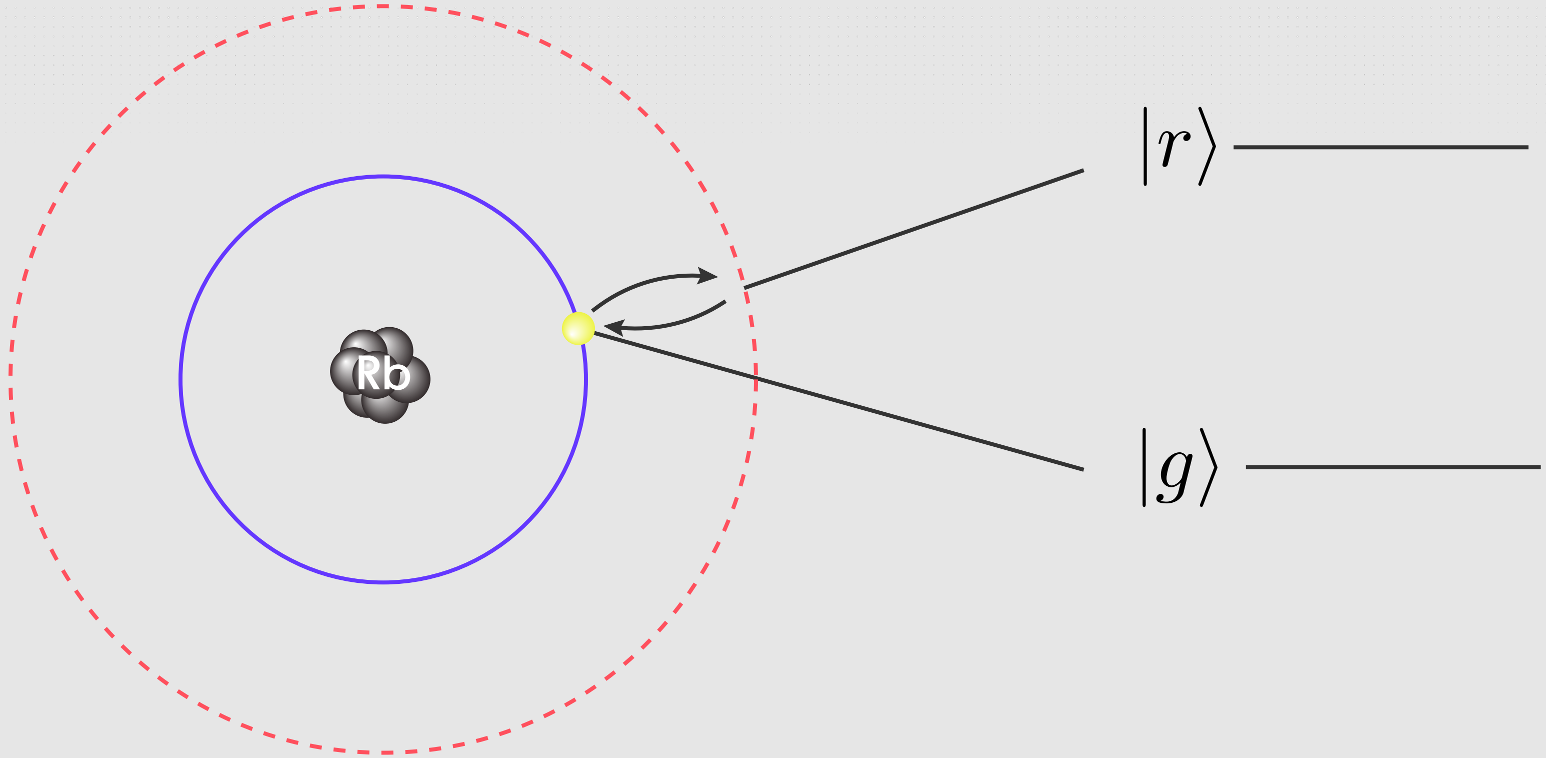


Solution



The analog computation provides the optimal solution

Qubits = puffed atoms



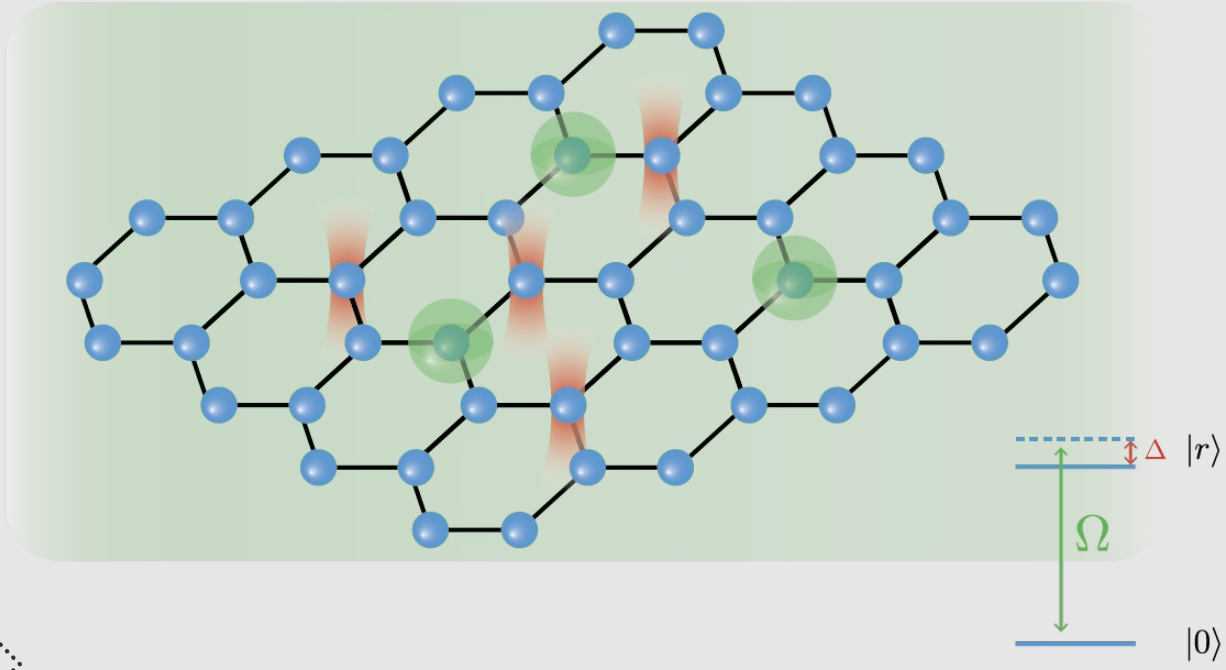
Algorithm = time evolution

Unitary control = Hamiltonian control

$$U(t) = \mathcal{T} e^{-i\int_0^t d\tau \boxed{H(\tau)}}$$

Analog quantum dynamics control

$$H = \sum_i \frac{\Omega(t)}{2}\left(e^{i\phi(t)}|g_i\rangle\langle r_i| + e^{-i\phi(t)}|r_i\rangle\langle g_i|\right) - \sum_i \Delta(t) n_i + \sum_{i<j} V_{ij} n_i n_j$$



$$n_i = 1 * |r_i\rangle\langle r_i| + 0 * |\mathrm{g}_i\rangle\langle \mathrm{g}_i|$$

$$V_{ij} \sim d_{ij}^{-6}$$

Rydberg blockade: phenomenology

$|rr\rangle$

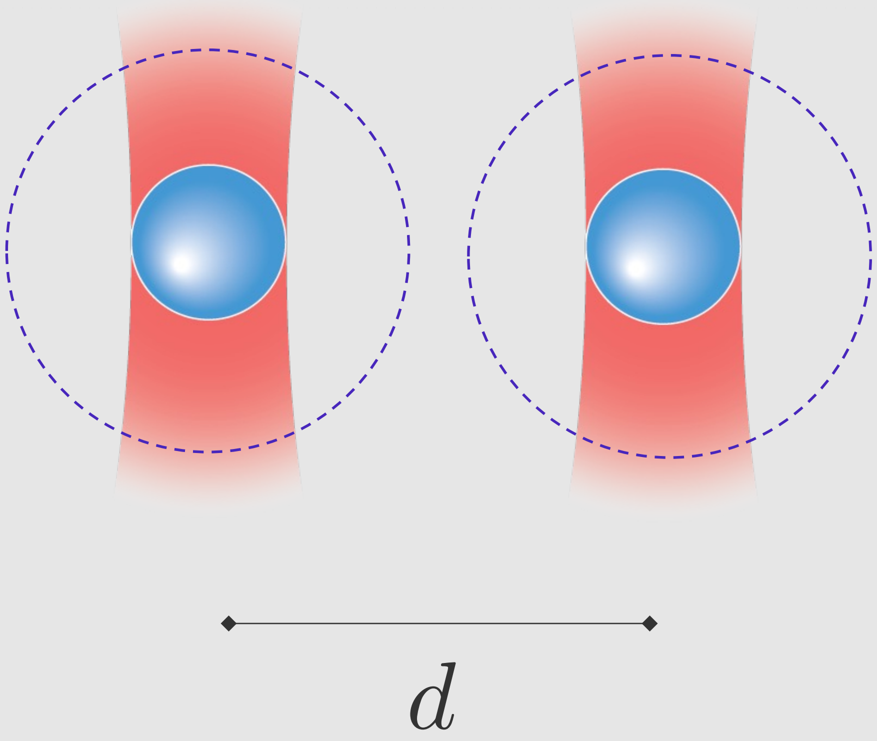
$V + \Delta$

$|gr\rangle \quad |rg\rangle$

Δ

$|gg\rangle$

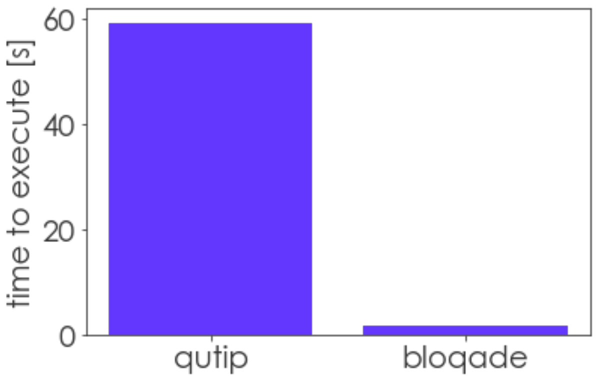
$$V \sim d^{-6}$$

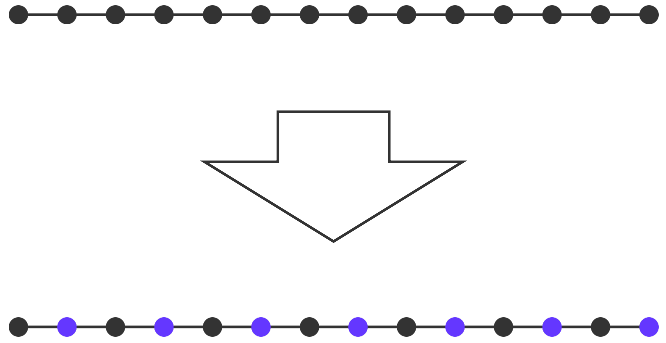


Z2 state preparation (adiabatic)

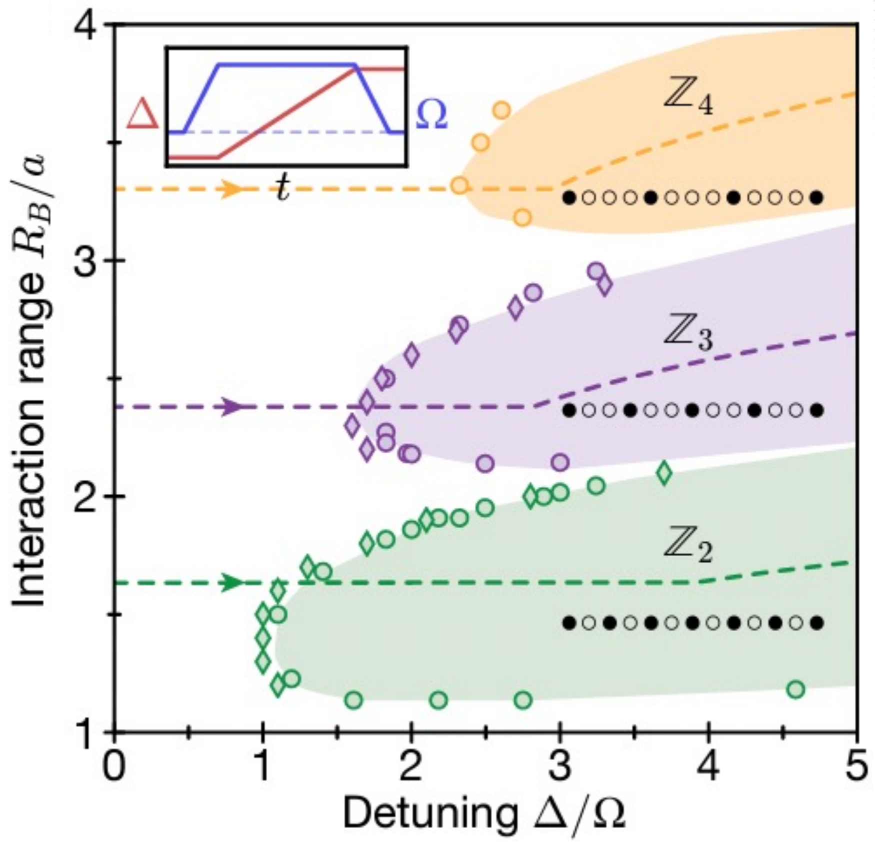
$$H = \Omega(t)\sum_i (|g_i\rangle\langle r_i| + H.c.) - \Delta(t)\sum_i n_i + \sum_{i<j} V_{ij} n_i n_j$$

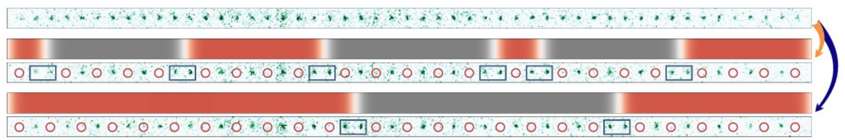
$$R_b = (C_6/\Omega)^{1/6}$$





Nature 568, 207 (2019)





More benchmarks @ https://github.com/yardstiq/bloqade_benchmarks

Programming neutral atoms in 5 simple steps

1. Define atom positions => Rydberg radius
2. Define time traces of Hamiltonian parameters
3. Initialize Hamiltonian
4. Evolve!
5. Measure!

More complex state preparation schemes

Problem

- Adiabatic state preparation is limited by minimal energy gap to first excited state

- This gap generally gets smaller the more qubits we have

Solutions

- Hardware (brute-force): develop local controls that enable the preparation of specific states

- Algorithmic: develop optimized protocols that mitigate effects of non-adiabaticity

Suggestions: counterdiabatic protocols

- https://www.pnas.org/doi/full/10.1073/pnas.1619826114
- https://arxiv.org/abs/1904.03209

How do I get started?

https://queracomputing.github.io/Bloqade.jl/dev/

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