SESSION IV:
MIS OPTIMIZATION

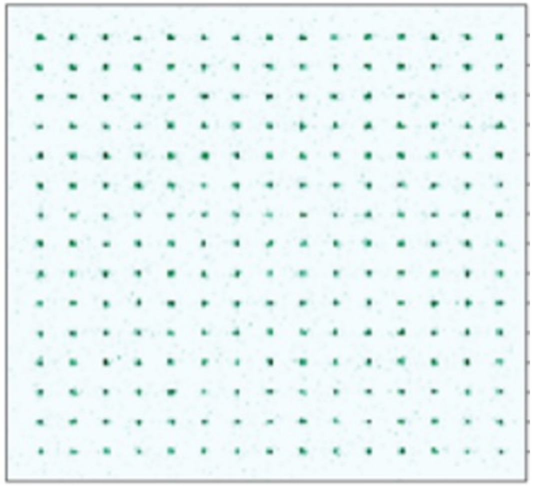
|QuEra⟩

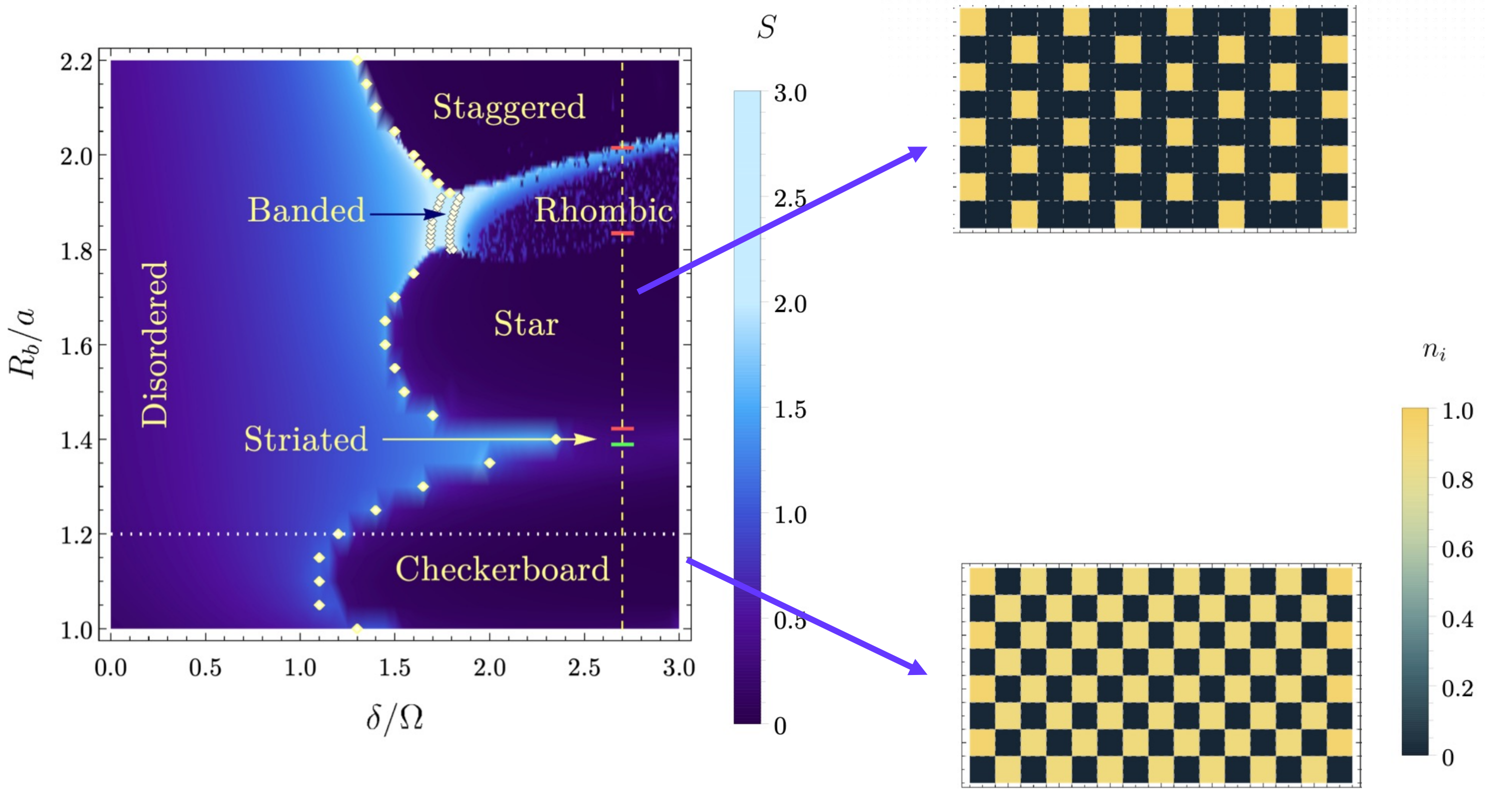
Learning objectives

By the end of the workshop, you will be able to:

- **Encode** unit-disk graph maximum independent set problems in Rydberg atoms
- **Determine** the Rydberg blockade radius for adiabatic algorithms for optimization
- **Write down** a Bloqade code pipeline to solve maximum independent set problems on unit-disk graphs

Starting point: patterns



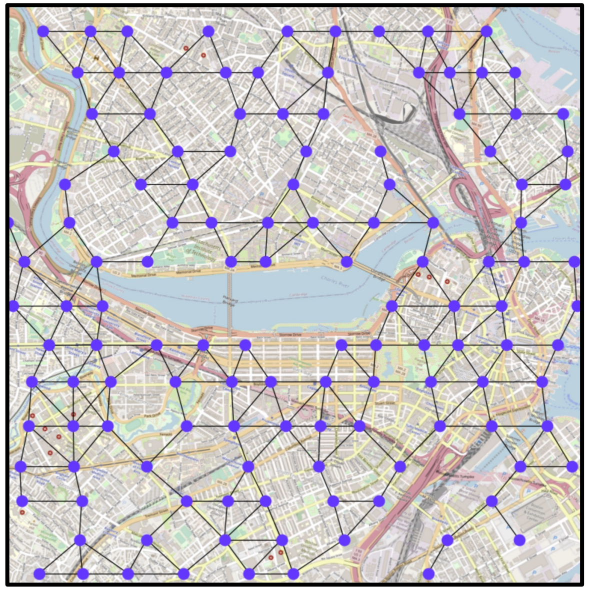


$$R_b = (C_6/\Omega)^{1/6}$$

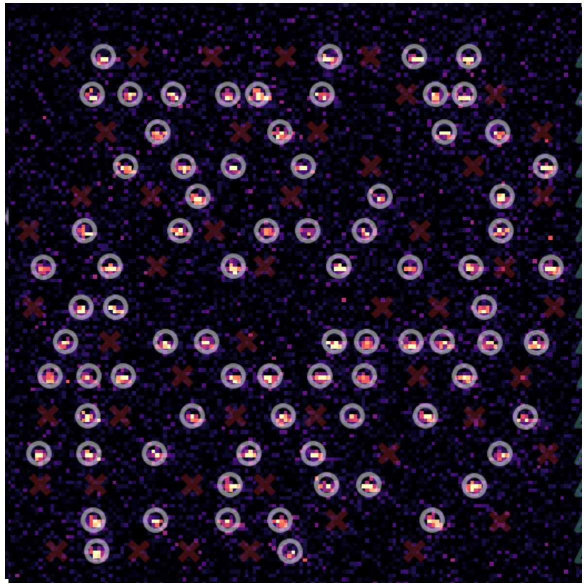
R. Samajdar et al., Phys. Rev. Lett. 124, 103601 (2020)

Hardware-efficient Optimization

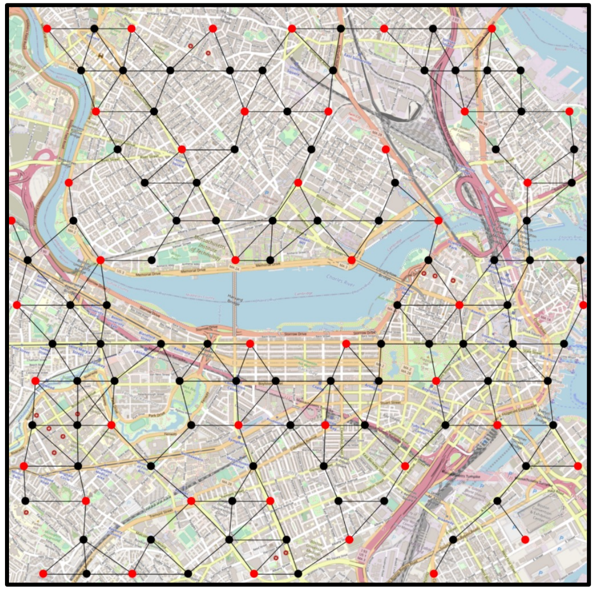
Choose possible locations



Create an atomic twin



Excite atoms to find answer!



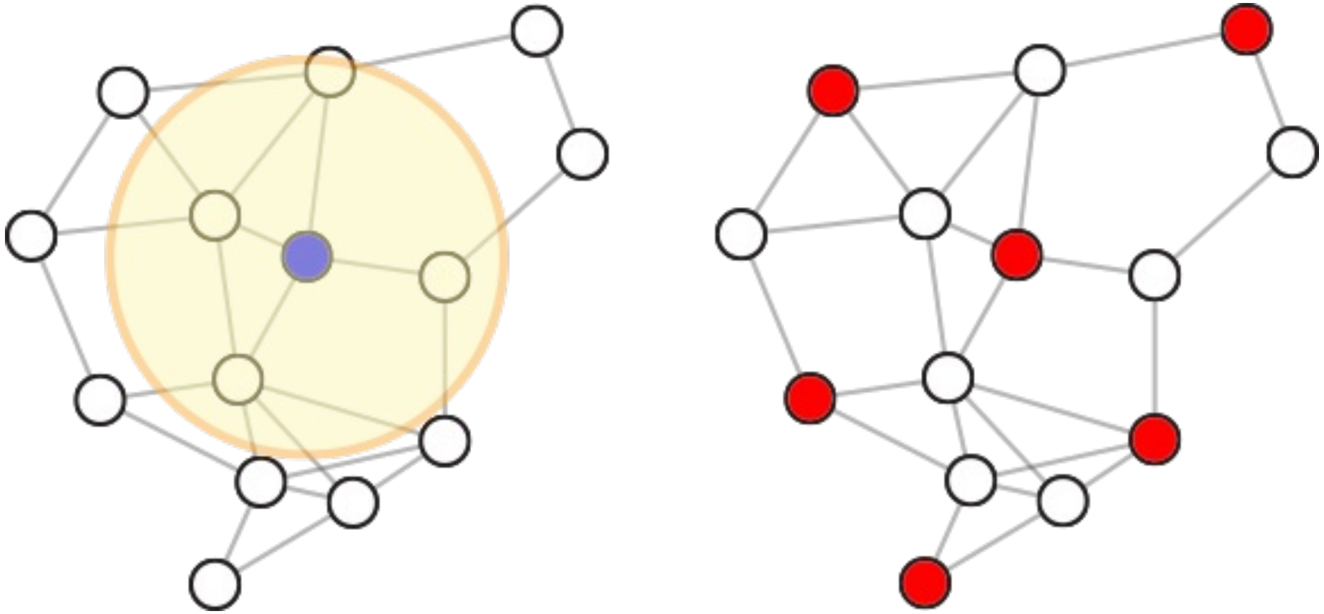
How to optimally cover Boston with coffee shops?

Optimization

Vertex= atom
Edge = blockade
Cost function = Hamiltonian

Maximum
Independent
Set

(NP-Complete)



Adapted from Ebadi et. al
Science, 376, 6598 (2022)

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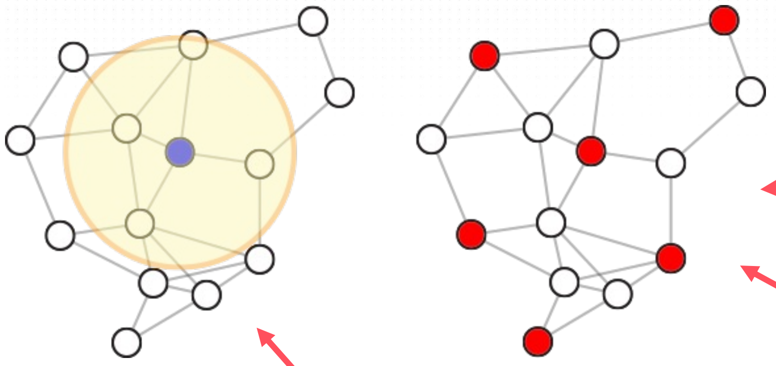
Adiabatic algorithms



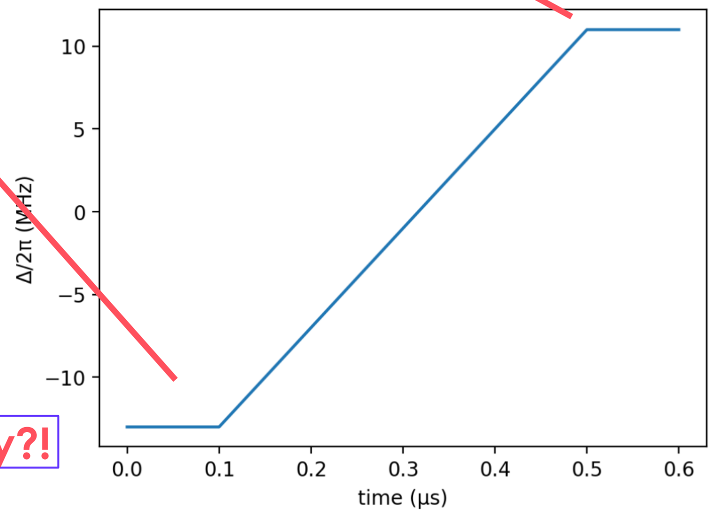
$$H = \Omega(t)\sum_i \left(|g_i\rangle\langle r_i| + H.c.\right) - \Delta(t)\sum_i n_i + \boxed{\sum_{i<j} V_{ij} n_i n_j}$$

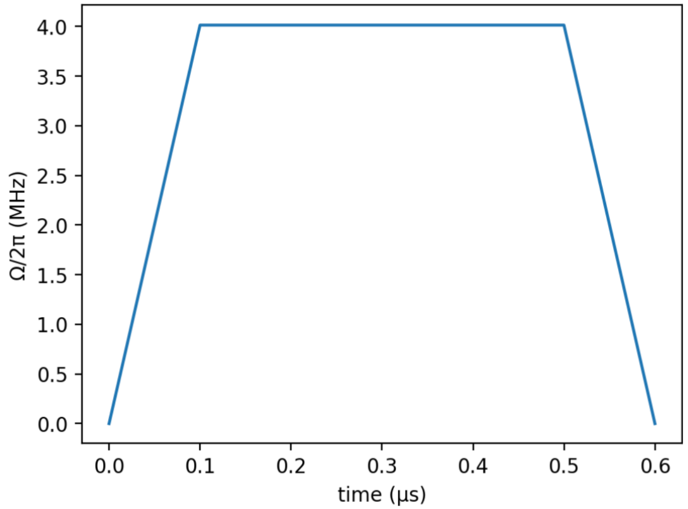
Precludes global mutual excitation

Pushes atoms to
Excited state

Quantum scrambling! (superposition)

Pushes atoms to
ground state

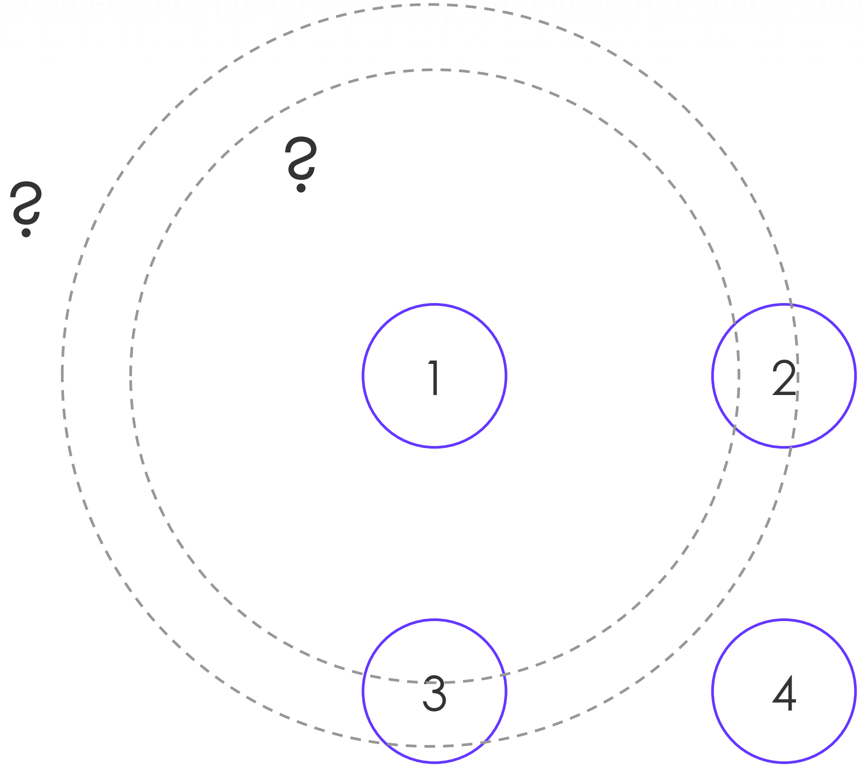




How do we define connectivity?!

Blockade radius choice

Choose a blockade radius so that only first neighbors are connected in the unit-disk sense



Blockade radius choice

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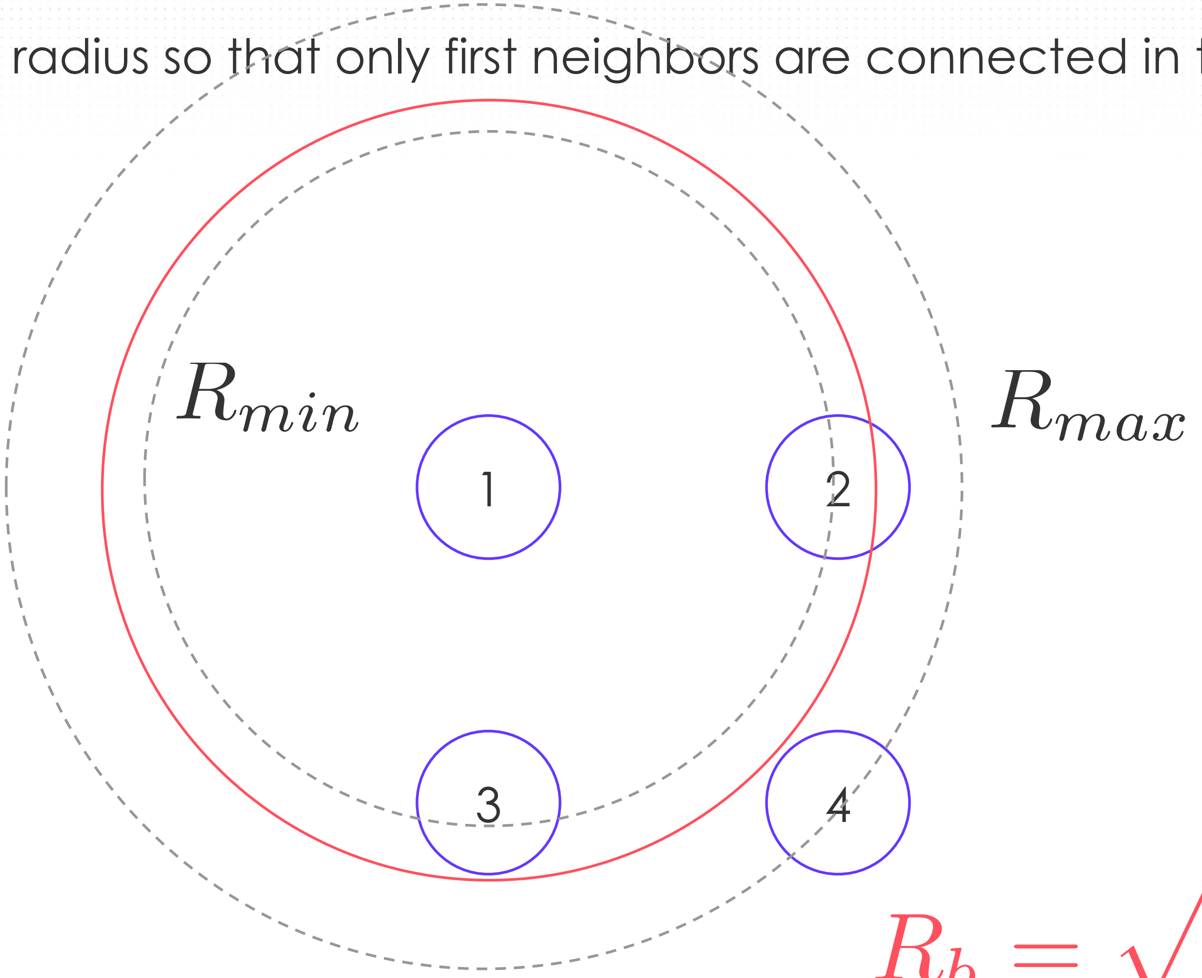


$$R_b = \sqrt{R_{max} R_{min}}$$

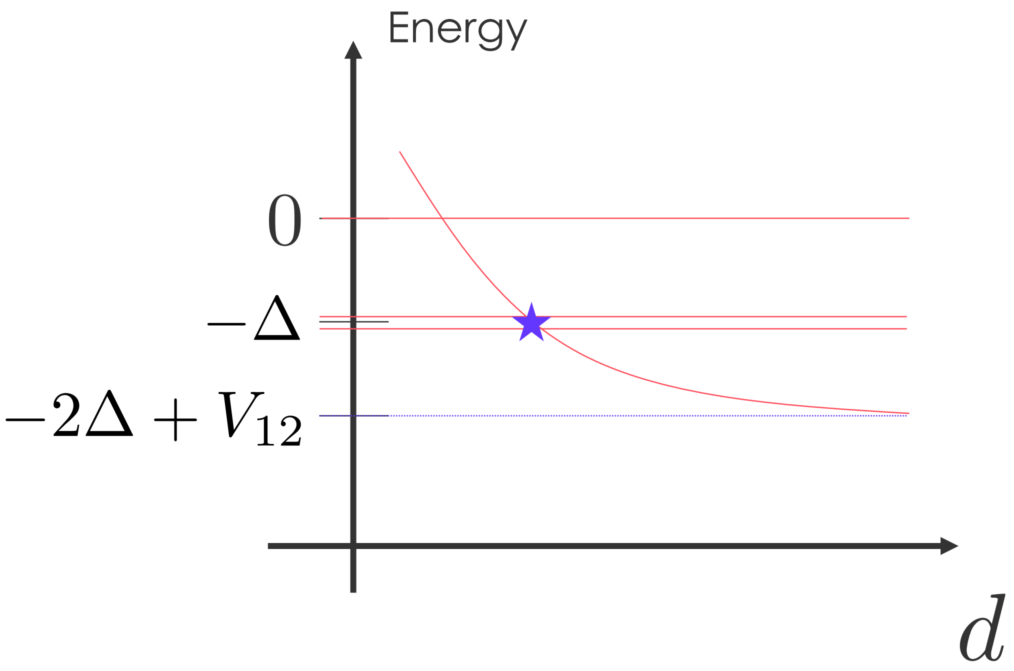
Rydberg blockade paradigm

$$V_{12} = \frac{C_6}{d^6}$$

$$H = -\Delta\left(n_1 + n_2\right) + V_{12} n_1 n_2$$

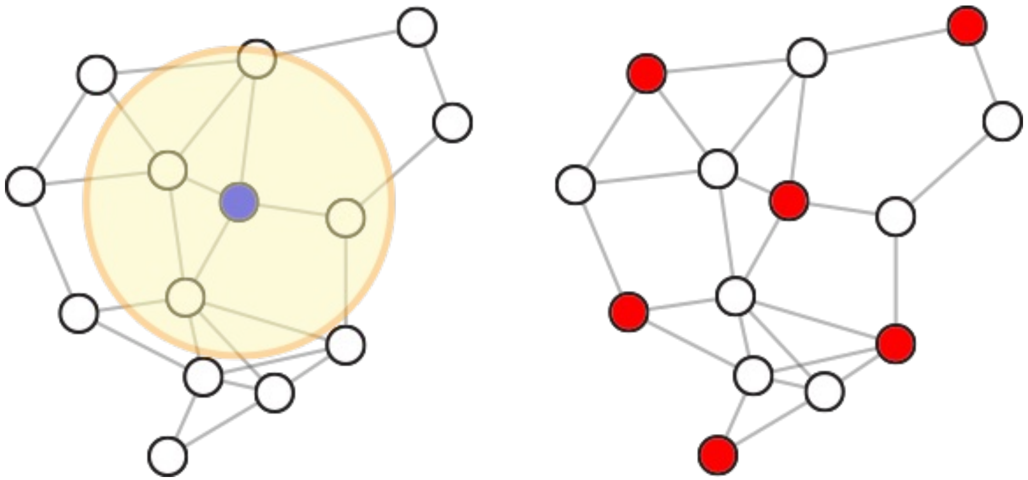
$$= \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & -\Delta & 0 & 0 \\ 0 & 0 & -\Delta & 0 \\ 0 & 0 & 0 & -2\Delta + V_{12} \end{pmatrix}$$

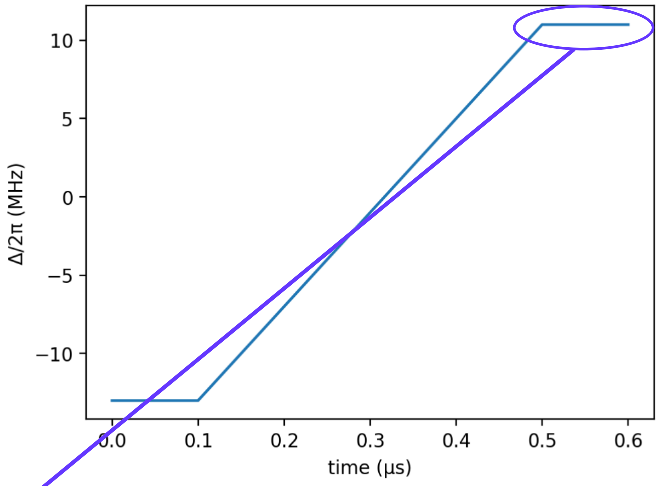
$$R_b = (C_6/\Delta)^{1/6}$$

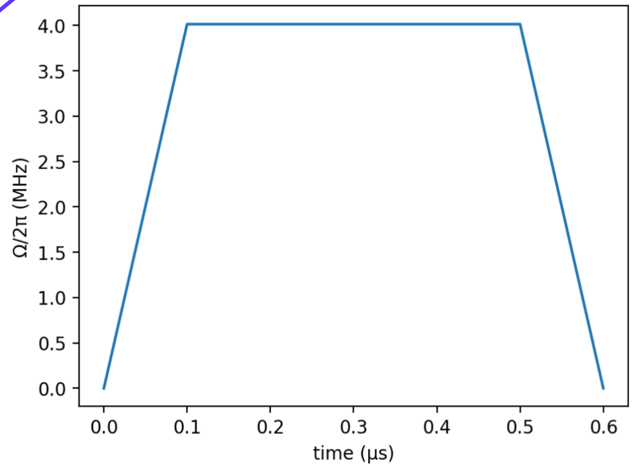


Adiabatic algorithms

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

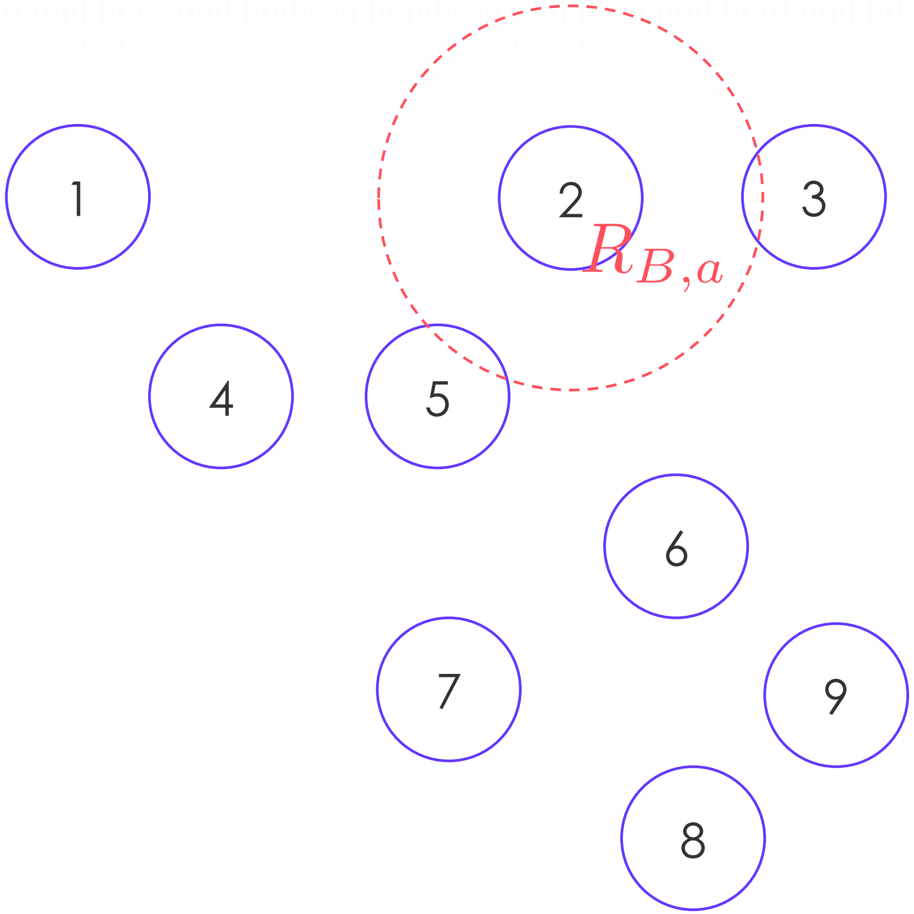




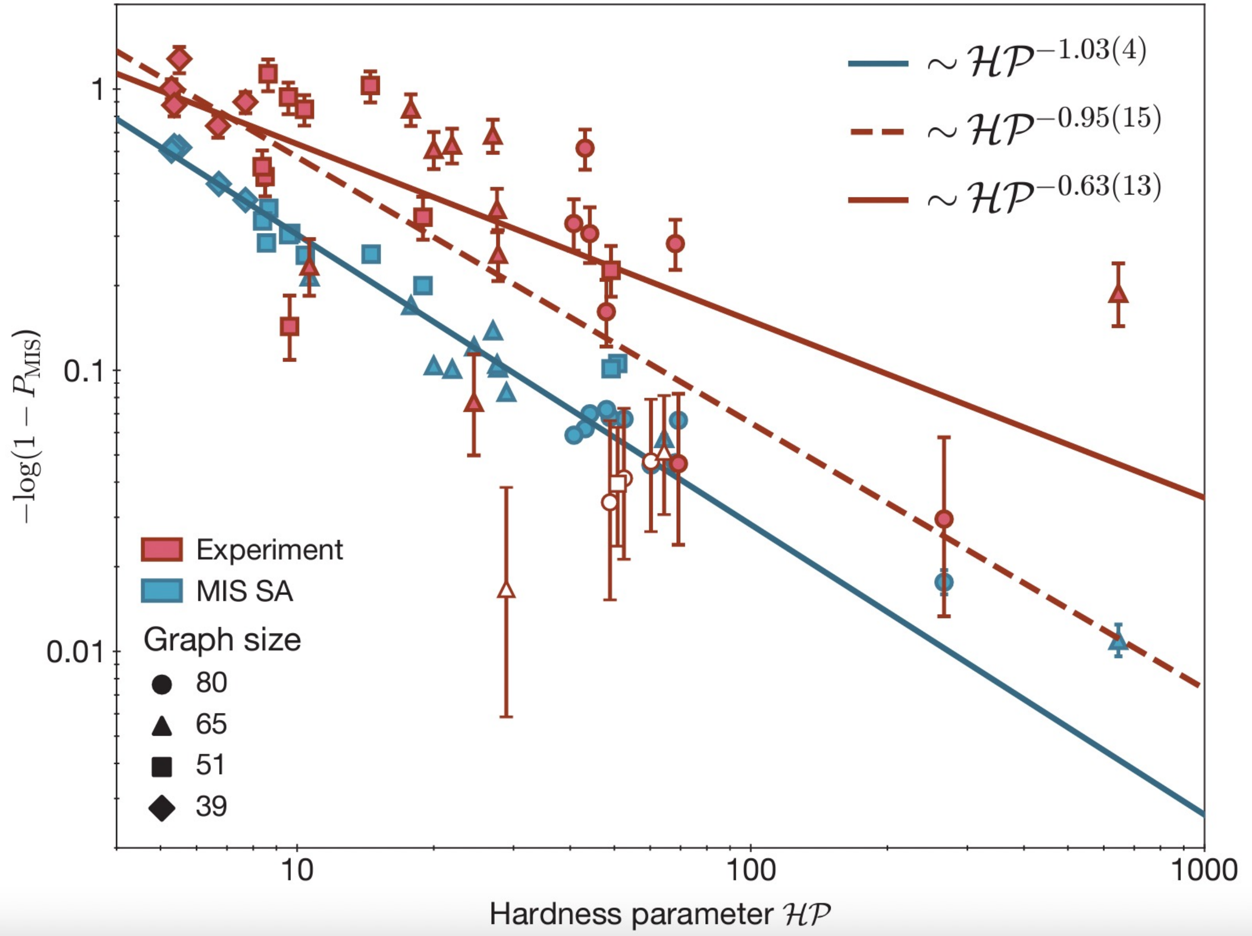


$$R_b = (C_6/\Delta)^{1/6}$$

Activity: build UDG, find MIS

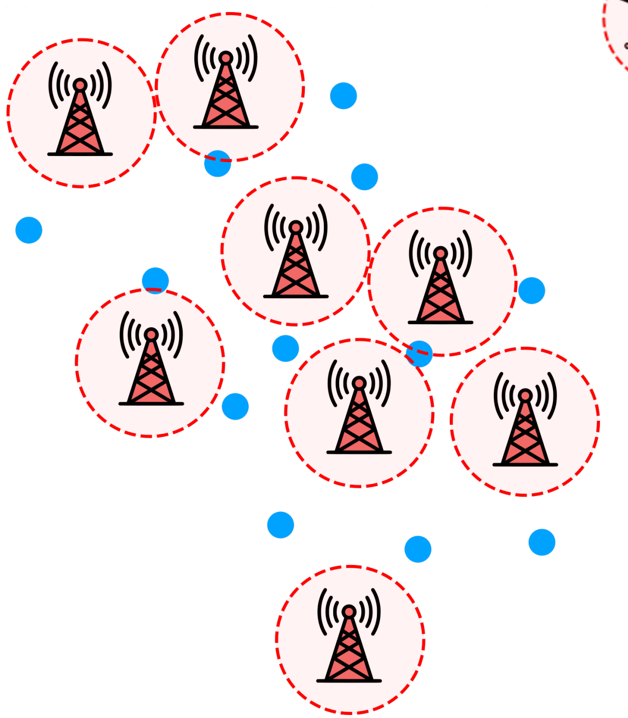


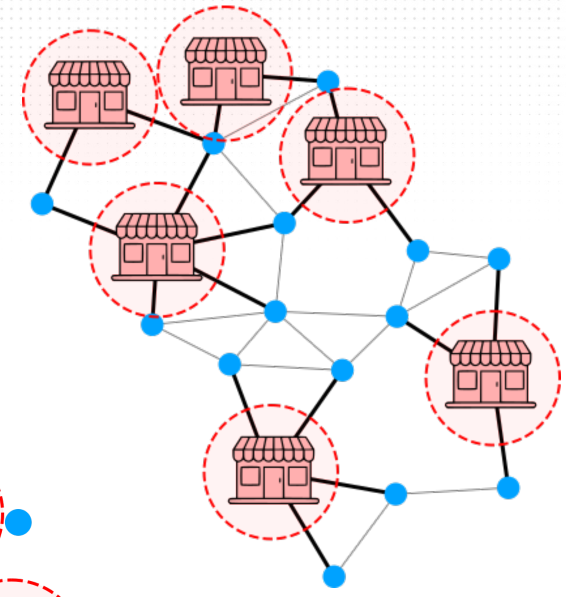
Quantum effects on hard MIS instances

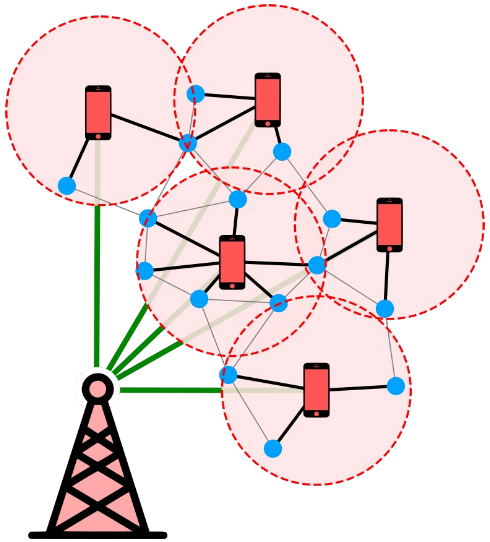


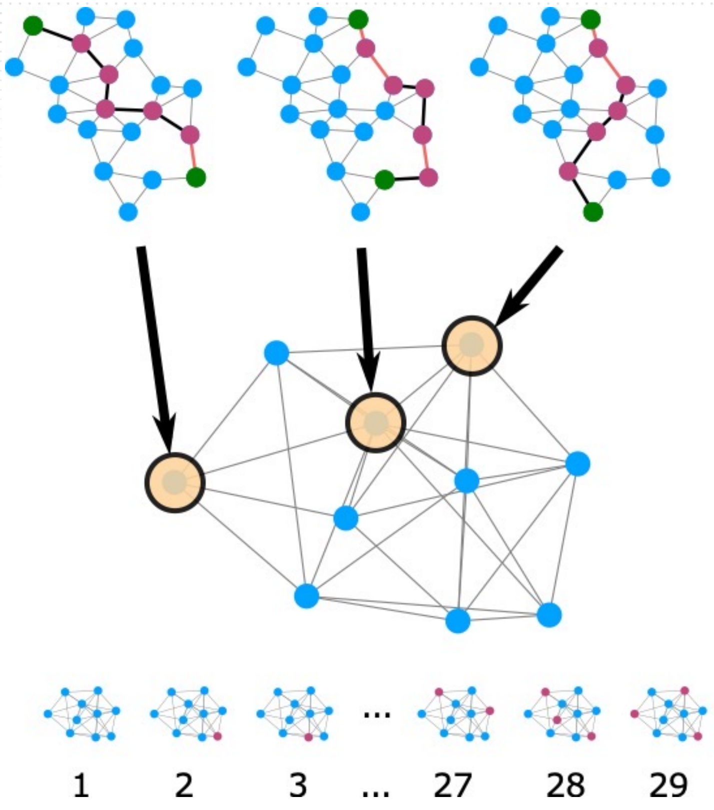
Adapted from Ebadi et. al
Science, 376, 6598 (2022)

MIS applications are ubiquitous





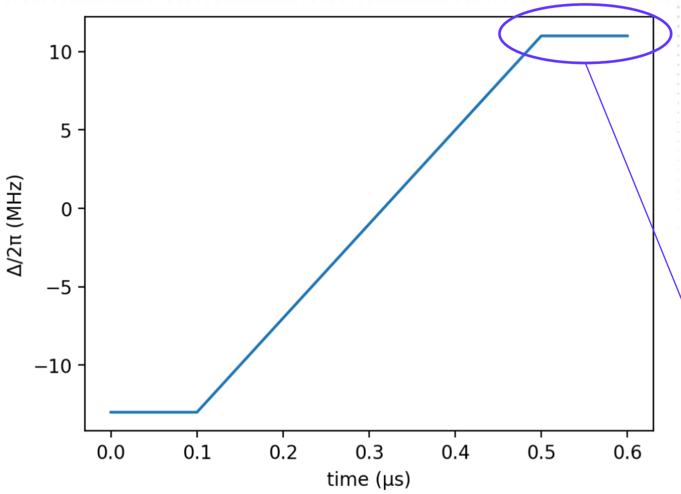


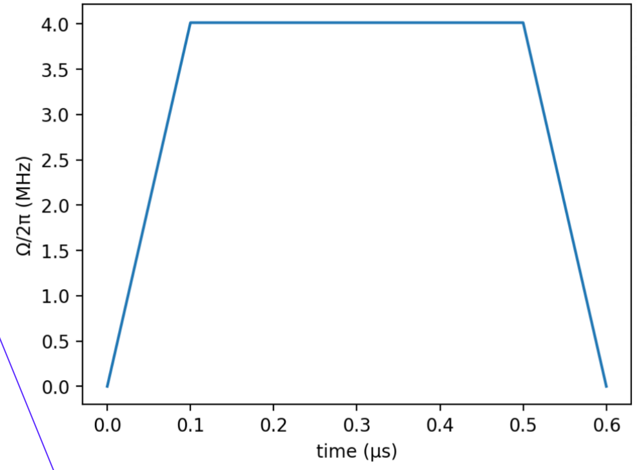


Wurtz et al., "Industry applications of neutral-aom quantum computing solving independent set problems"
https://arxiv.org/abs/2205.08500

Summary

Quantum adiabatic algorithm





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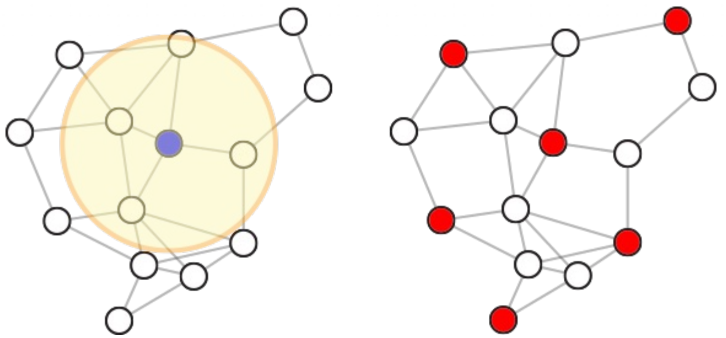
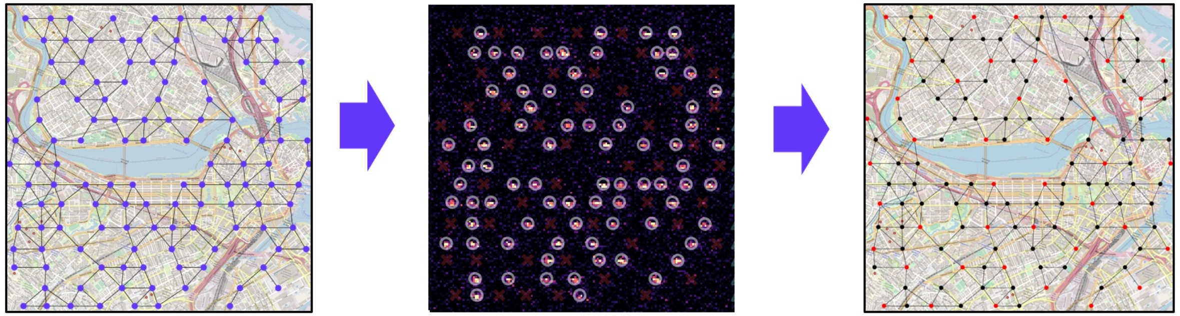
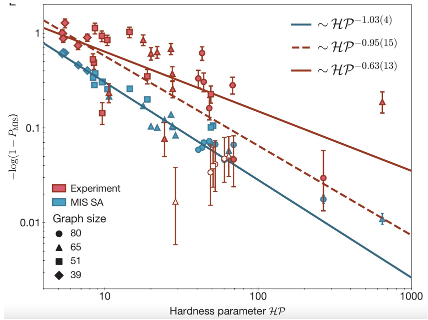
Maximum Independent Sets



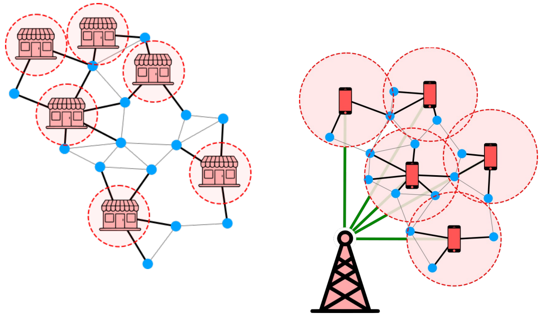
Hardware-efficient encoding



Quantum Matters



Many applications



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Now you are able to:

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MIS Mindset

Graph	Atom register
Node	Atom
Independent set	Excited atoms
Edge	Rydberg blockade
Cost function	Hamiltonian
Optimization problem	Energy minimization