Session IV: MIS Optimization

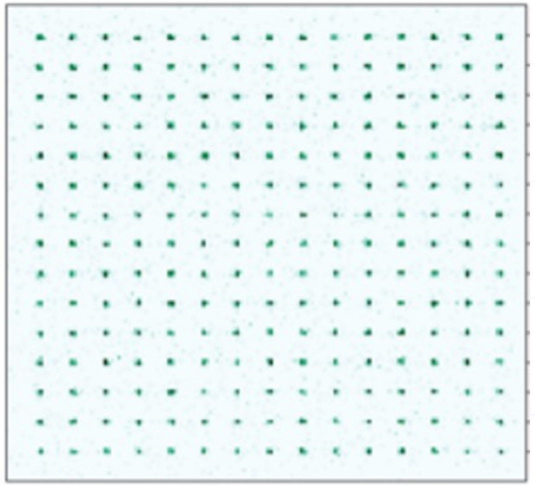
Learning objectives

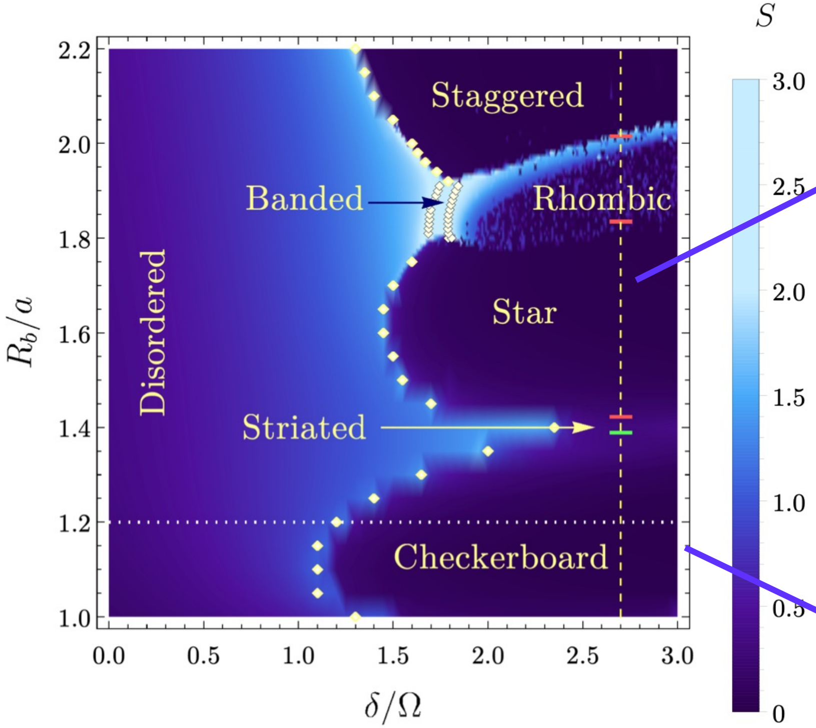
By the end of this class, you will be able to:

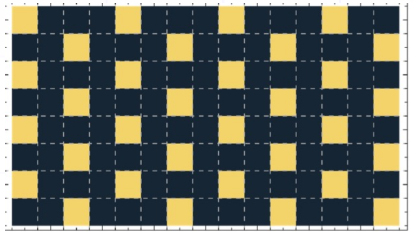
- **Encode** unit-disk graph maximum independent set problems in Rydberg atoms
- **Determine** the Rydberg blockade radius for adiabatic algorithms for optimization
- **Write** down a Bloqade code pipeline to solve maximum independent set problems on unit-disk graphs

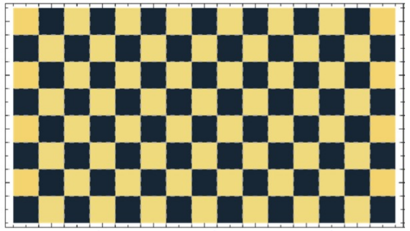
Starting point: patterns

Activity:
think-pair-share. Seen as 0s and 1s what kind of logical relation atoms impose on each other and how Rb affects it?





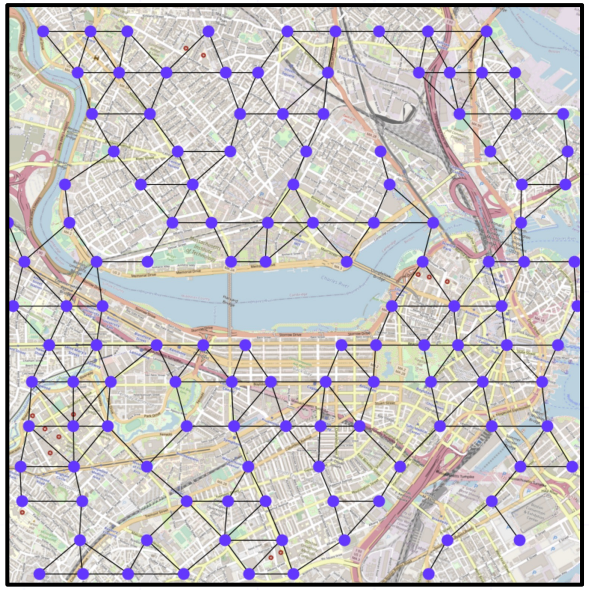




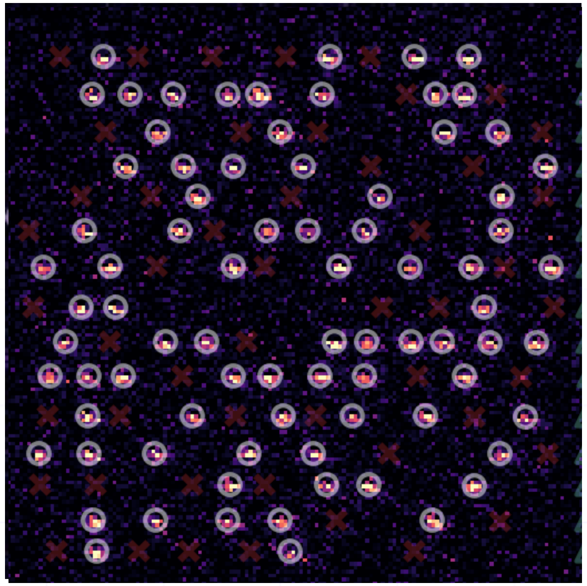
$$R_b = (C_6/\Omega)^{1/6}$$

Hardware-efficient optimization

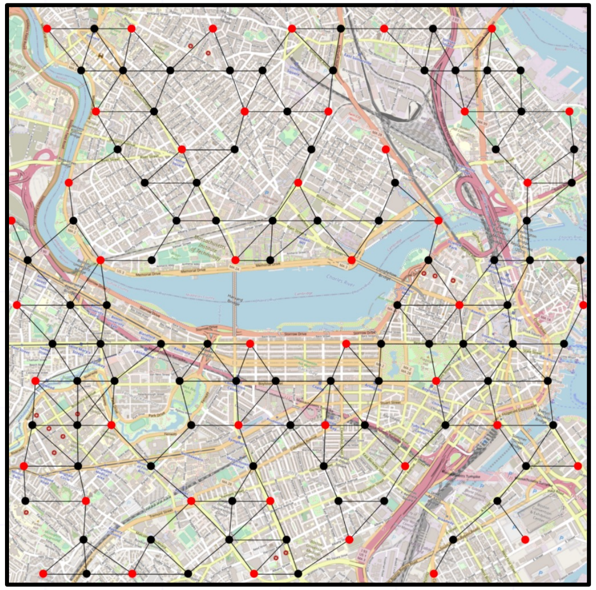
Adapt pattern to problem



Create an atomic twin



Excite atoms to find answer!

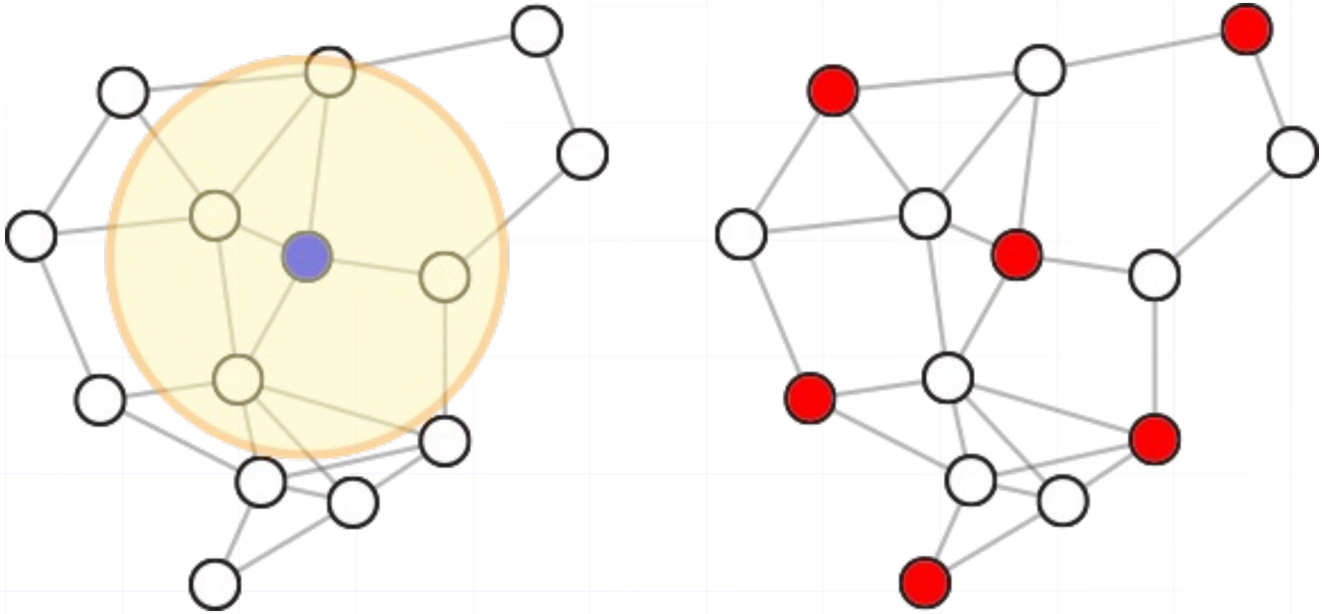


How to optimally cover Boston with coffee shops?

Optimization

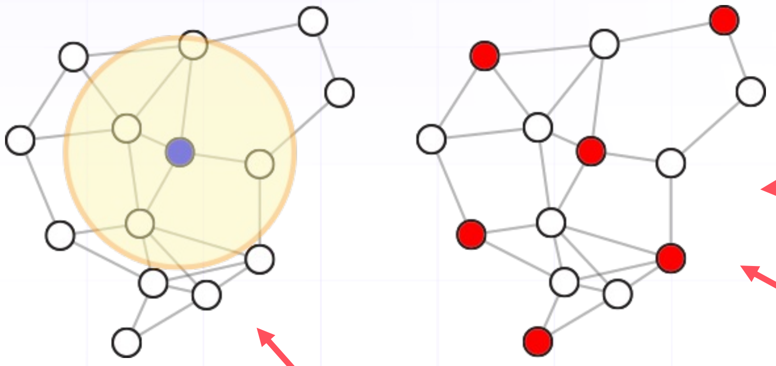
Vertex= atom
Edge = blockade
Cost function = Hamiltonian

Maximum
Independent
Set



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

Adiabatic algorithms 1.

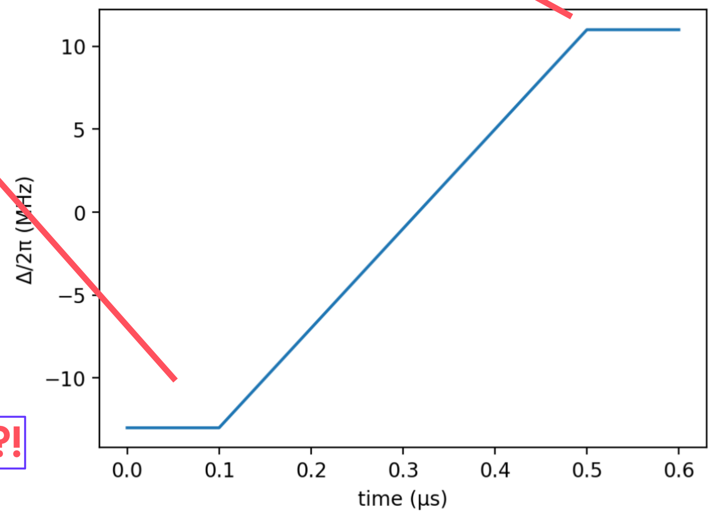


$$H = \Omega(t)\sum_i (|g_i\rangle\langle r_i| + H.c.) - \Delta(t)\sum_i n_i + \boxed{\sum_{i<j} V_{ij} n_i n_j}$$

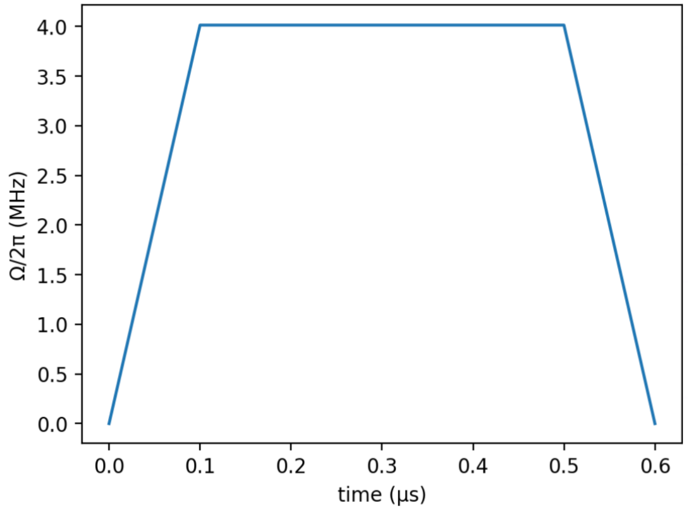
Precludes global mutual excitation

Pushes atoms to
Excited state

Pushes atoms to
ground state



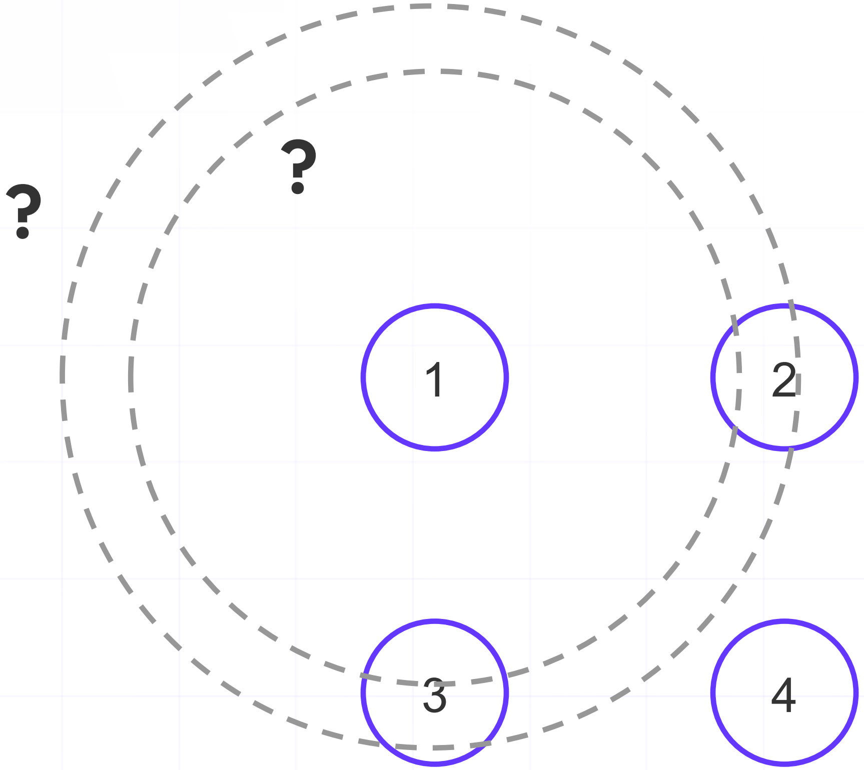
Quantum scrambling! (superposition)



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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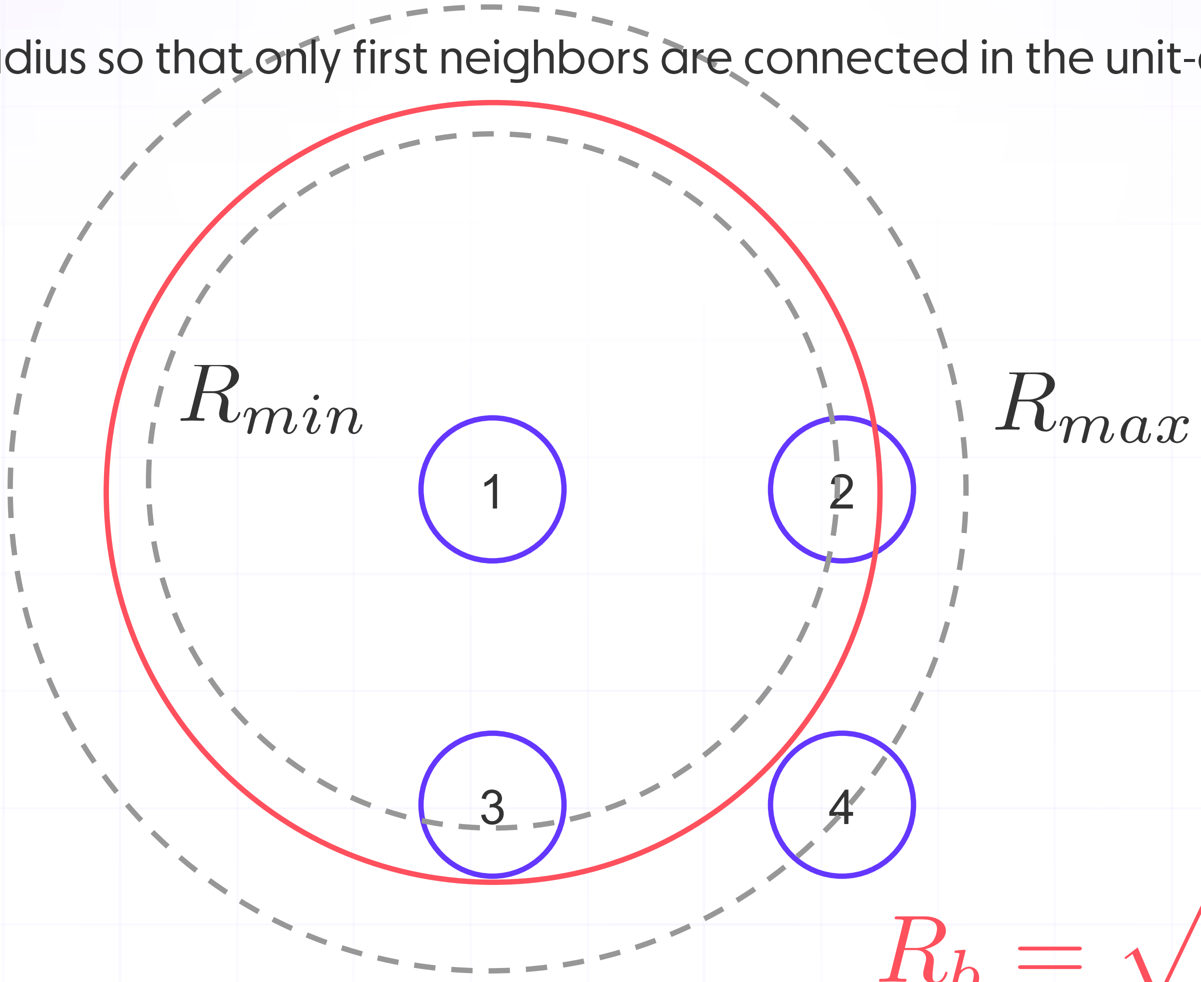


$$R_b = \sqrt{R_{max} R_{min}}$$

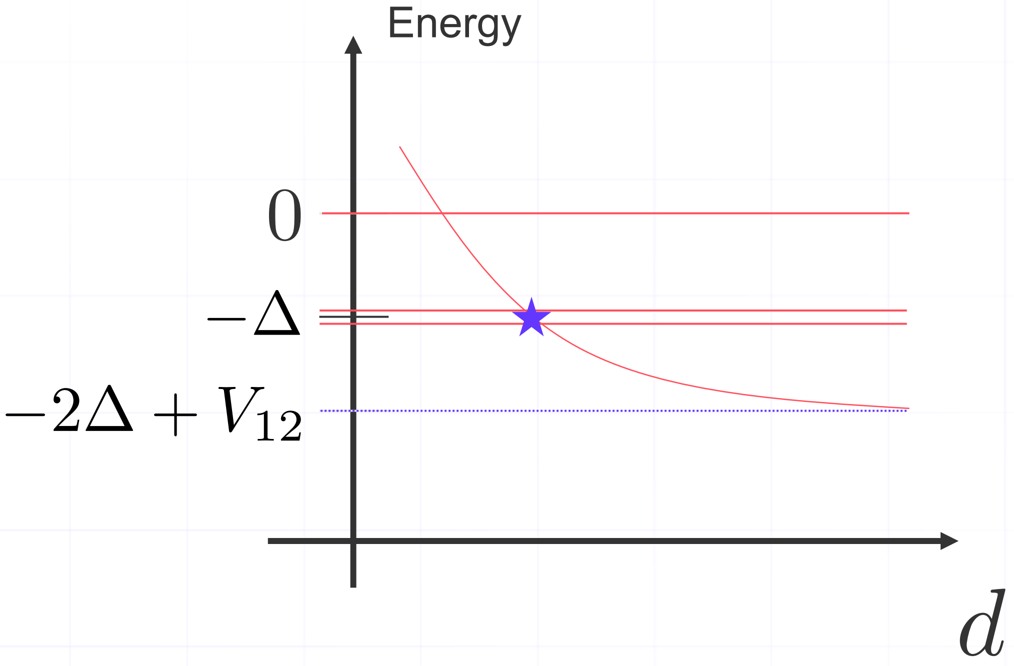
Rydberg blockade paradigm

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

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

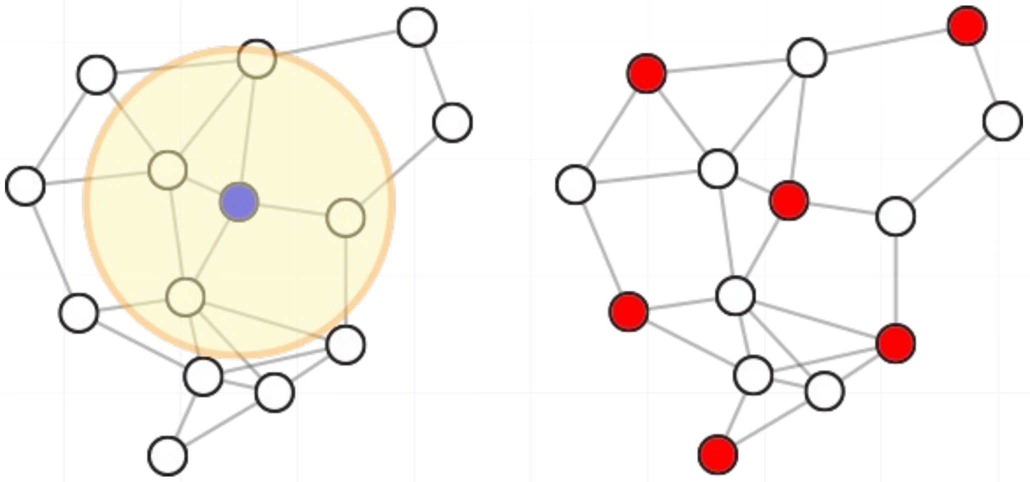
$$= \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & -\Delta & 0 & 0 \\ 0 & 0 & -\Delta & 0 \\ 0 & 0 & 0 & -2\Delta + V_{12} \end{pmatrix}$$

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



Adiabatic algorithms 2.

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



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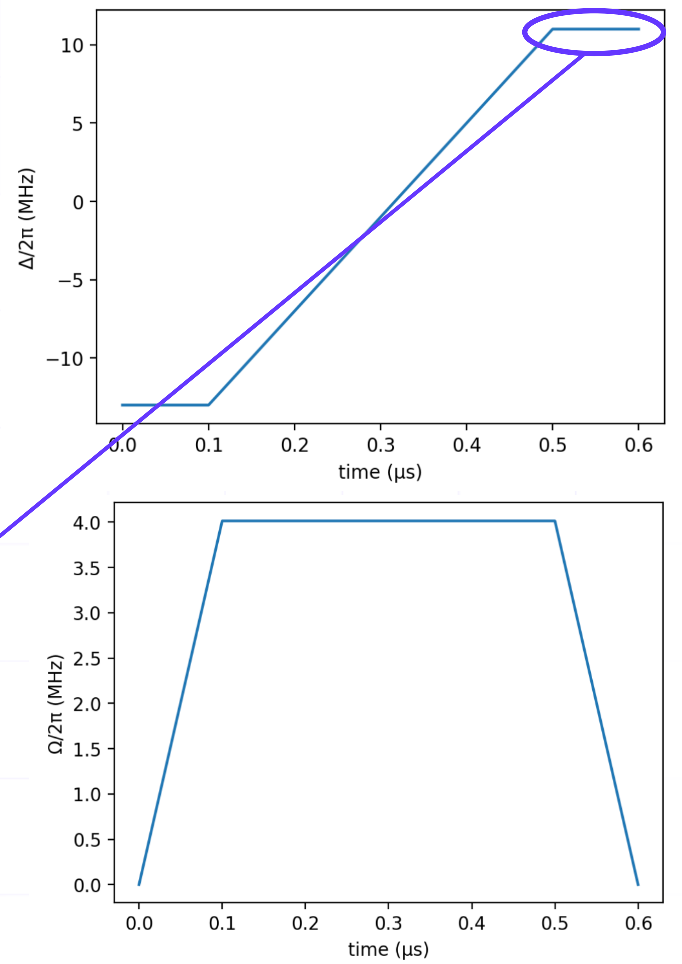
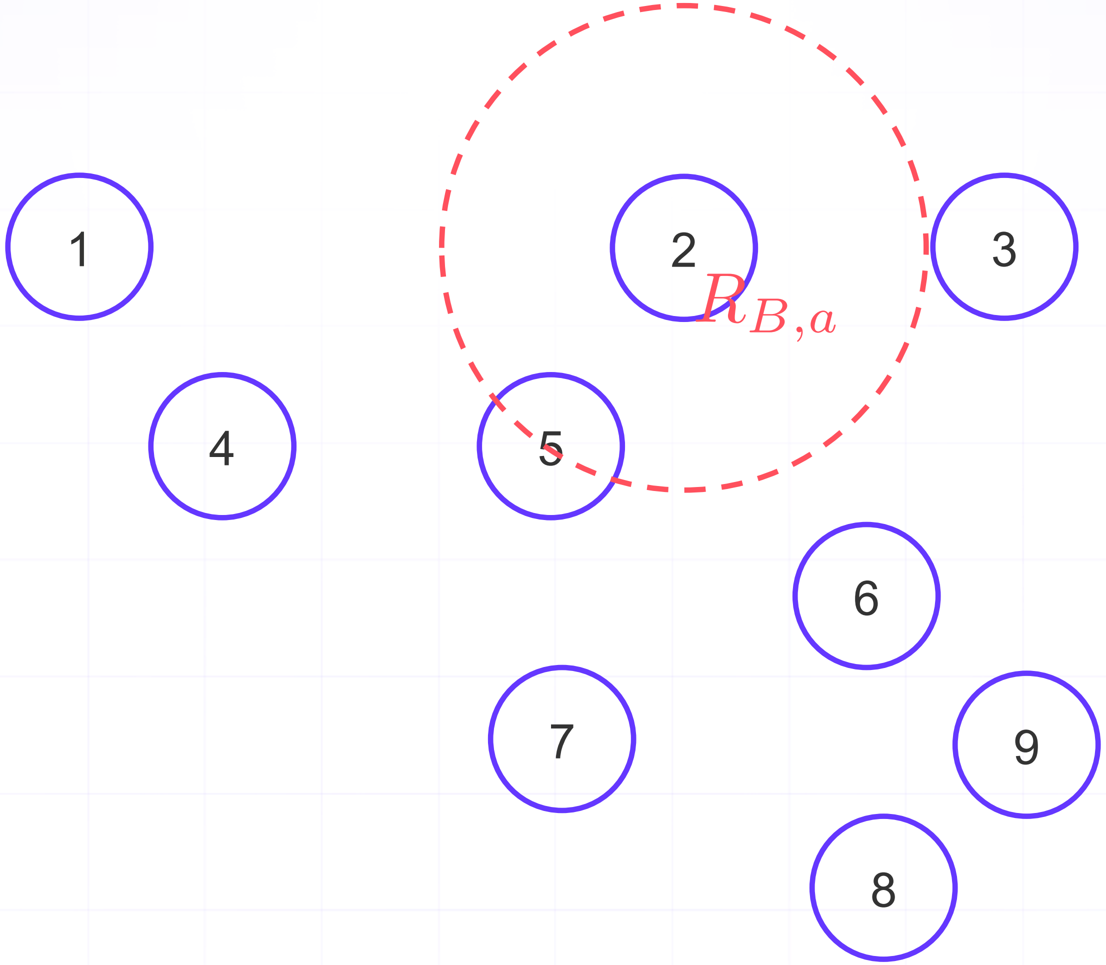
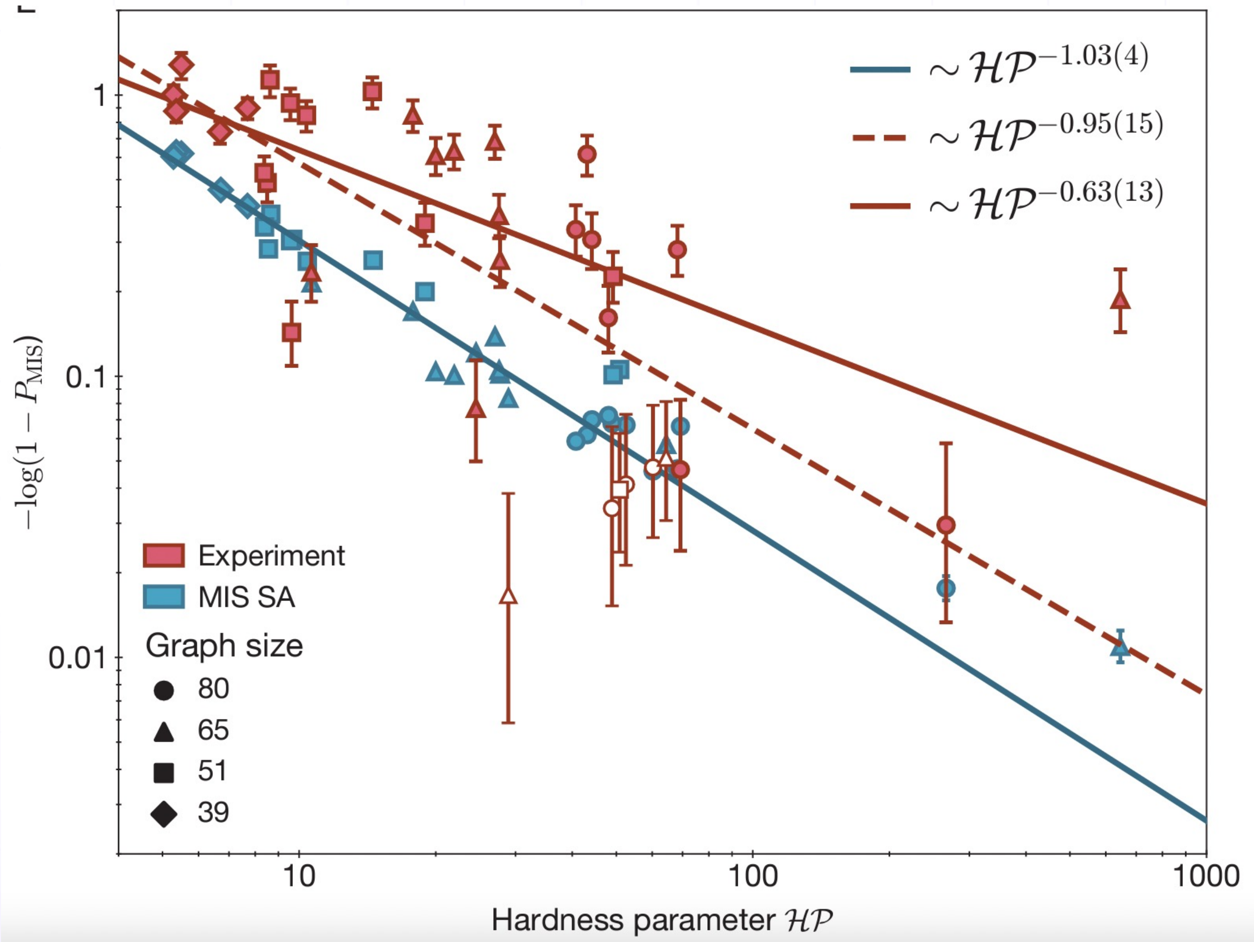


Activity: build UDG, find MIS



Quantum effects on hard MIS instances



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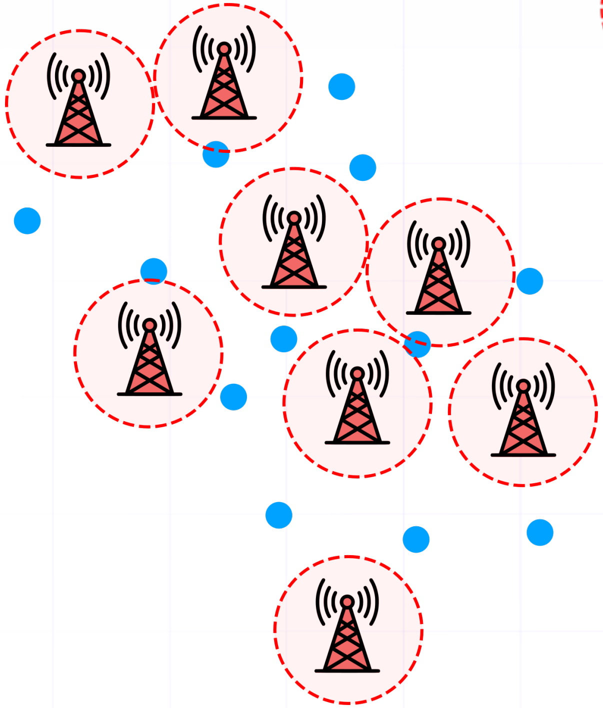
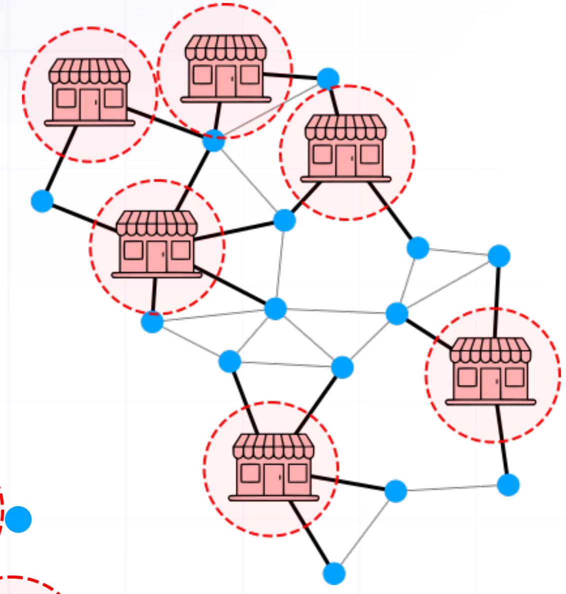
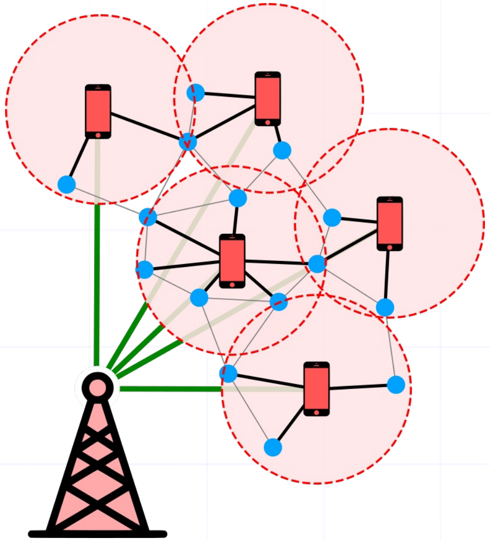
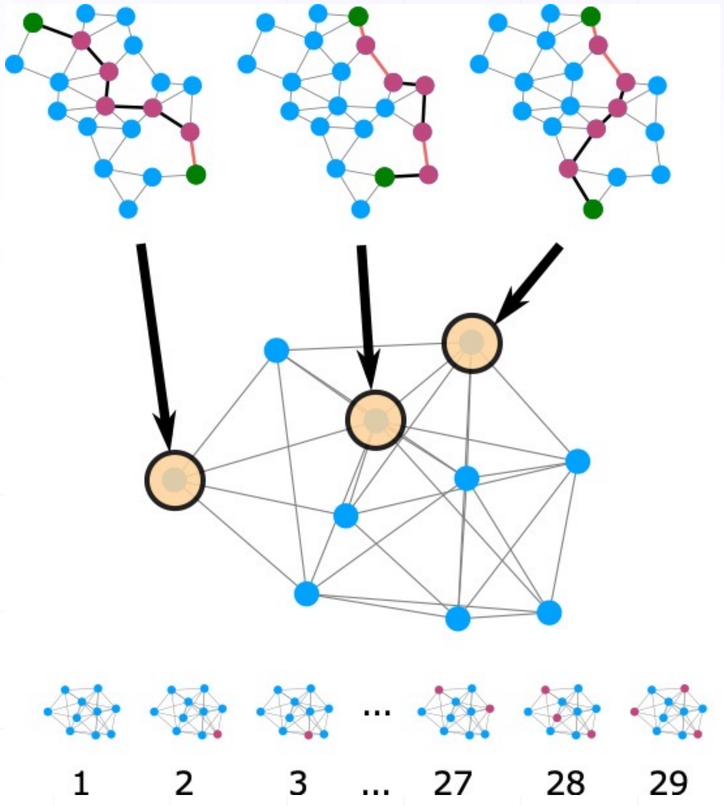
Further developments
arXiv:2306.13131
arXiv:2306.13123
arXiv:2307.09442

MIS applications are ubiquitous





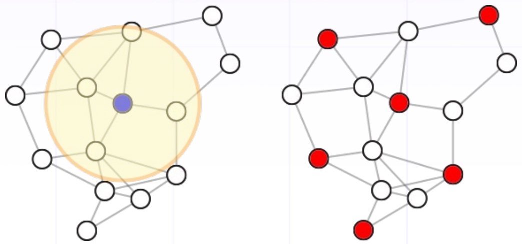




Wurtz et al., “Industry applications of neutral-aom quantum computing solving independent set problems” https://arxiv.org/abs/2205.08500

Summary

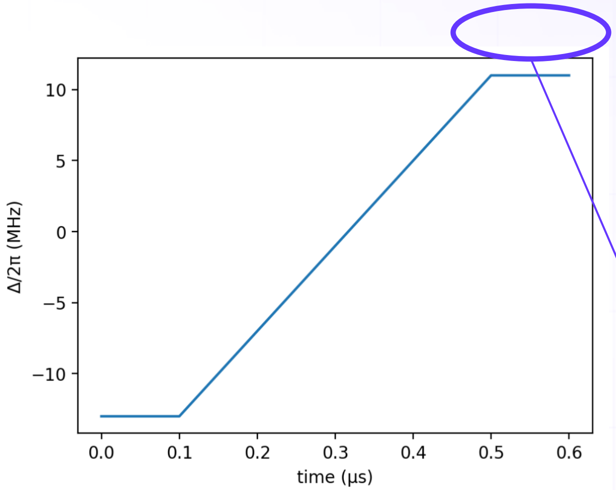
MIS

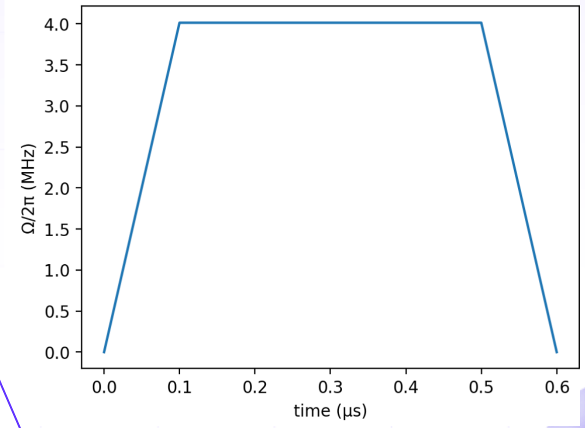


Graph	Atom register
Node	Atom
Independent set	Excited atoms
Edge	Rydberg blockade
Cost function	Hamiltonian
Optimization problem	Energy minimization

Atomic MIS Mindset

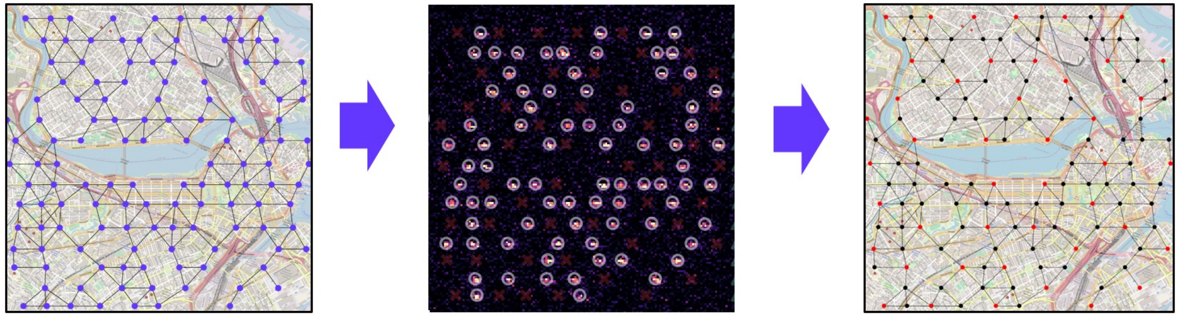
Quantum adiabatic algorithm



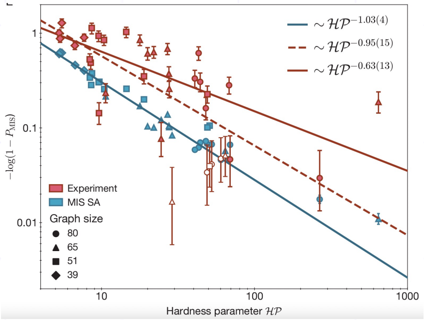


$$R_b = (C_6/\Delta)^{1/6}$$

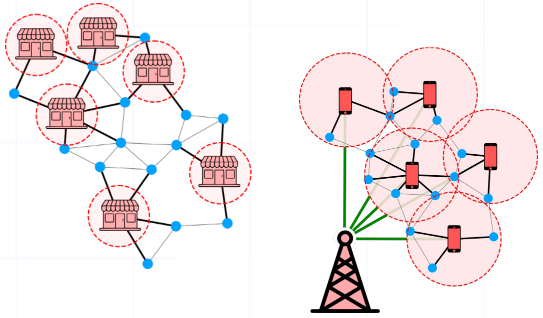
Hardware-efficient encoding



Quantum Matters



Many applications



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