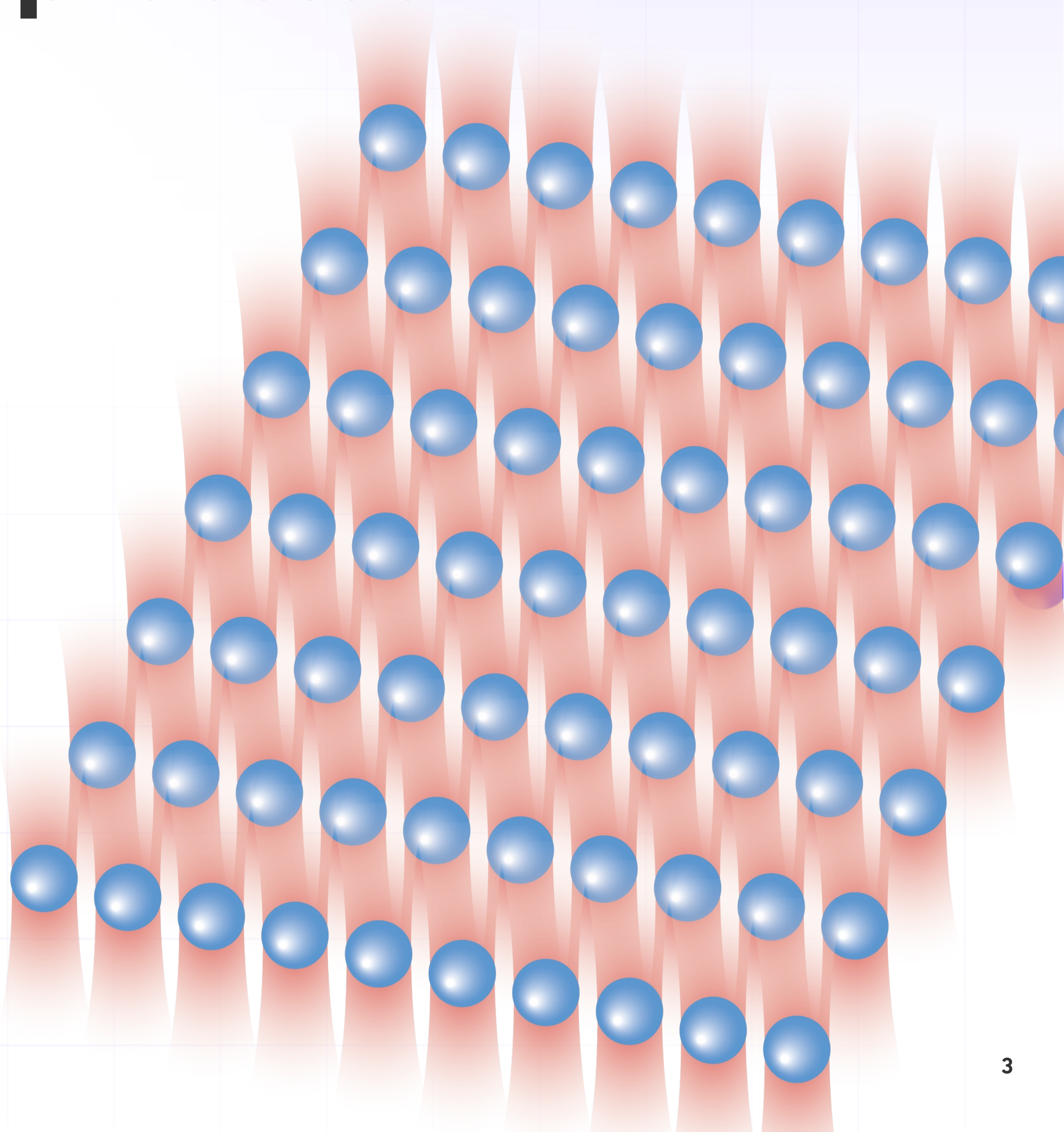
Session I: Basics

Neutral-atom quantum processor

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

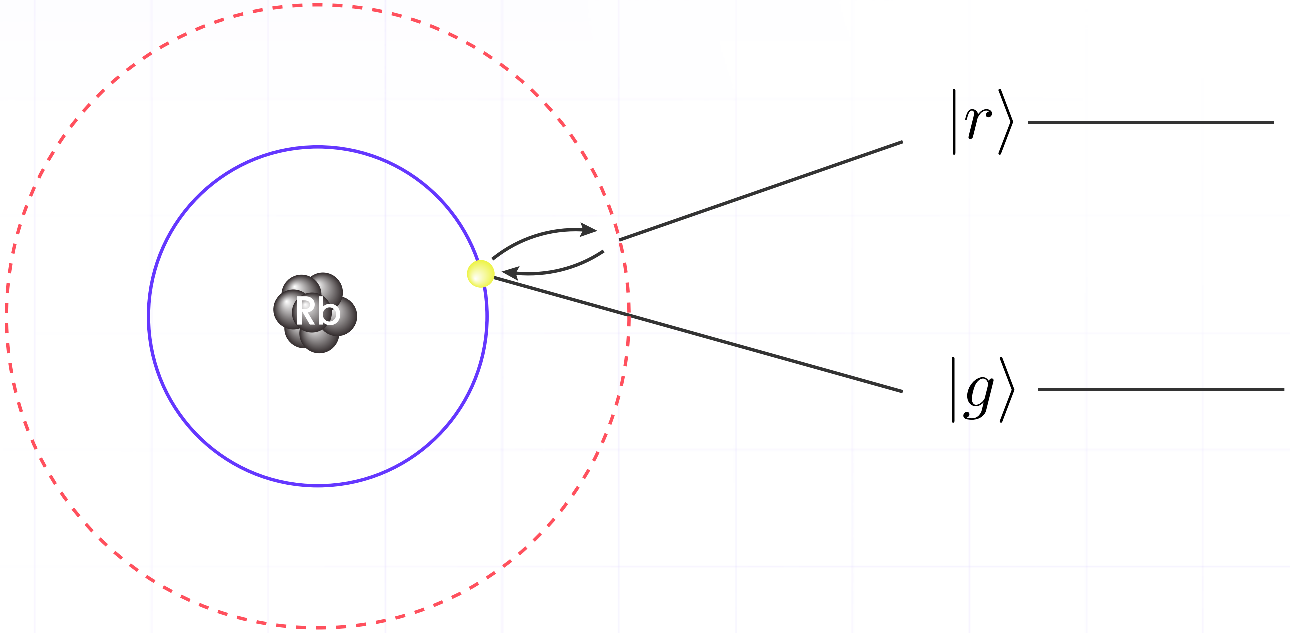


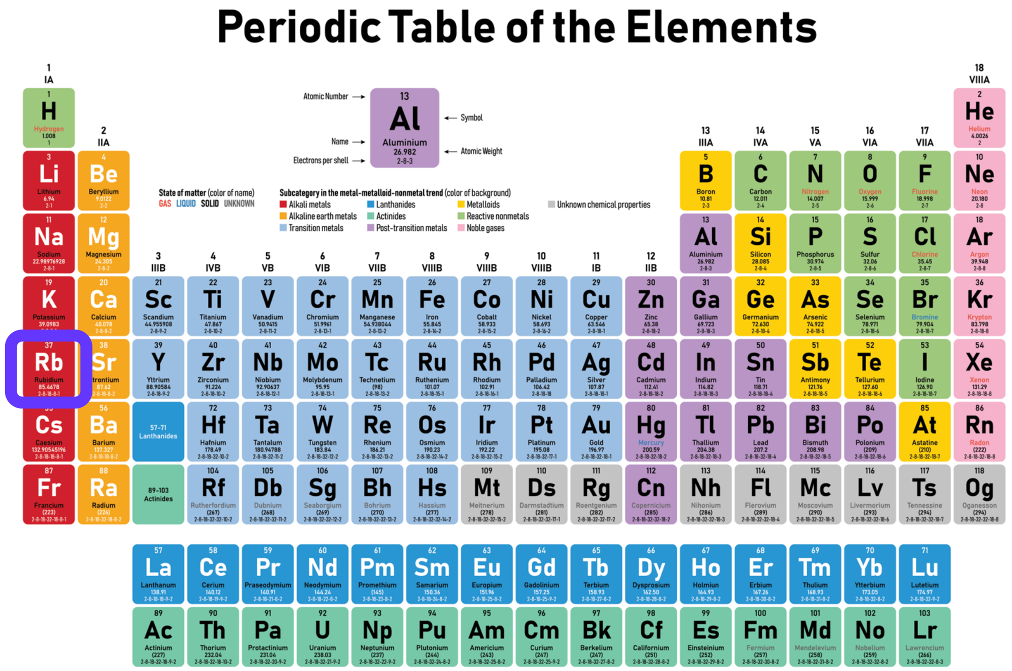
Learning objectives

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

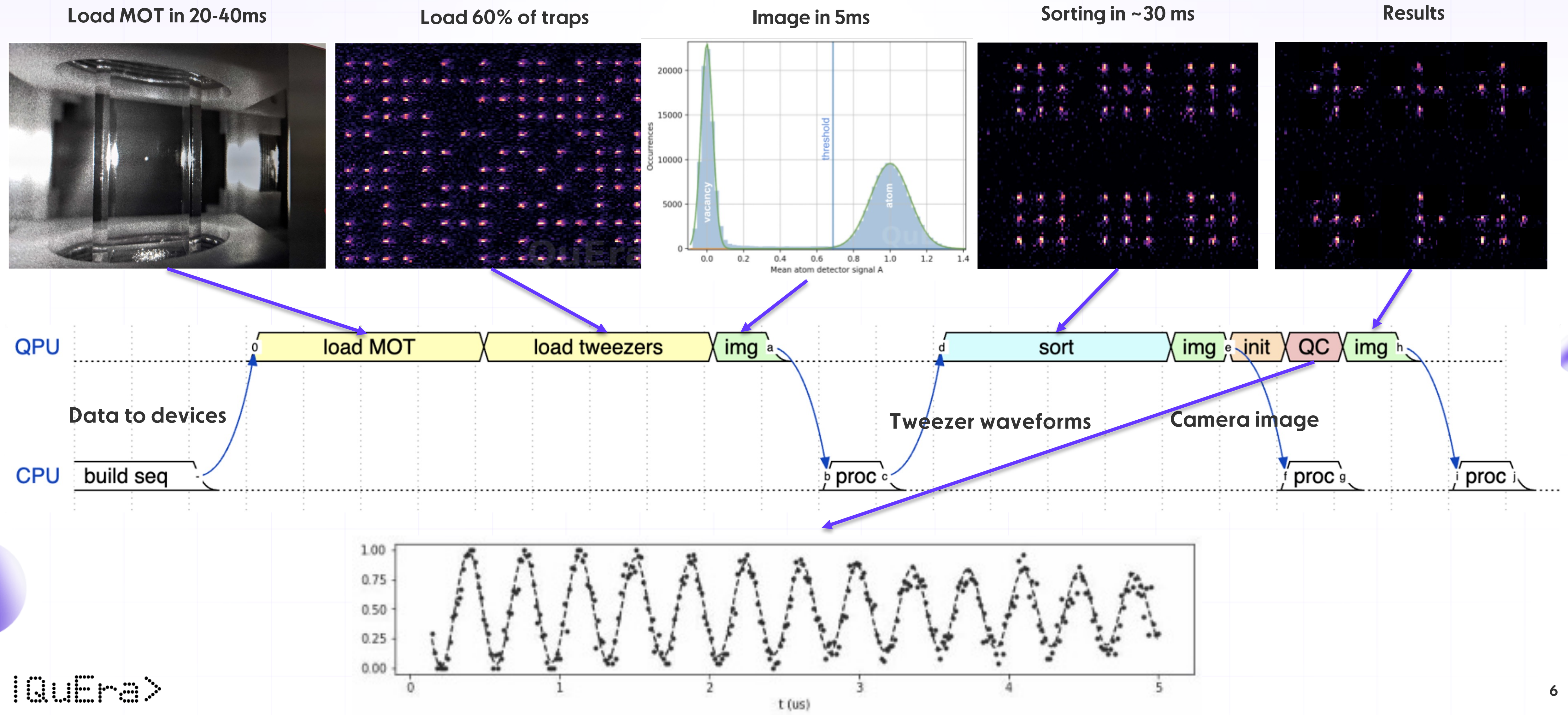
- **Explain** how **neutral atoms** can be used as a **platform** for quantum computing
- **Distinguish analog** and **digital** (gate-based) quantum computing
- **Define field-programmable qubit arrays** and **exemplify** some of their advantages
- **Describe** Aquila's **programming** range
  - its Hamiltonian and controllable parameters, limitations of service

Qubits by puffing atoms



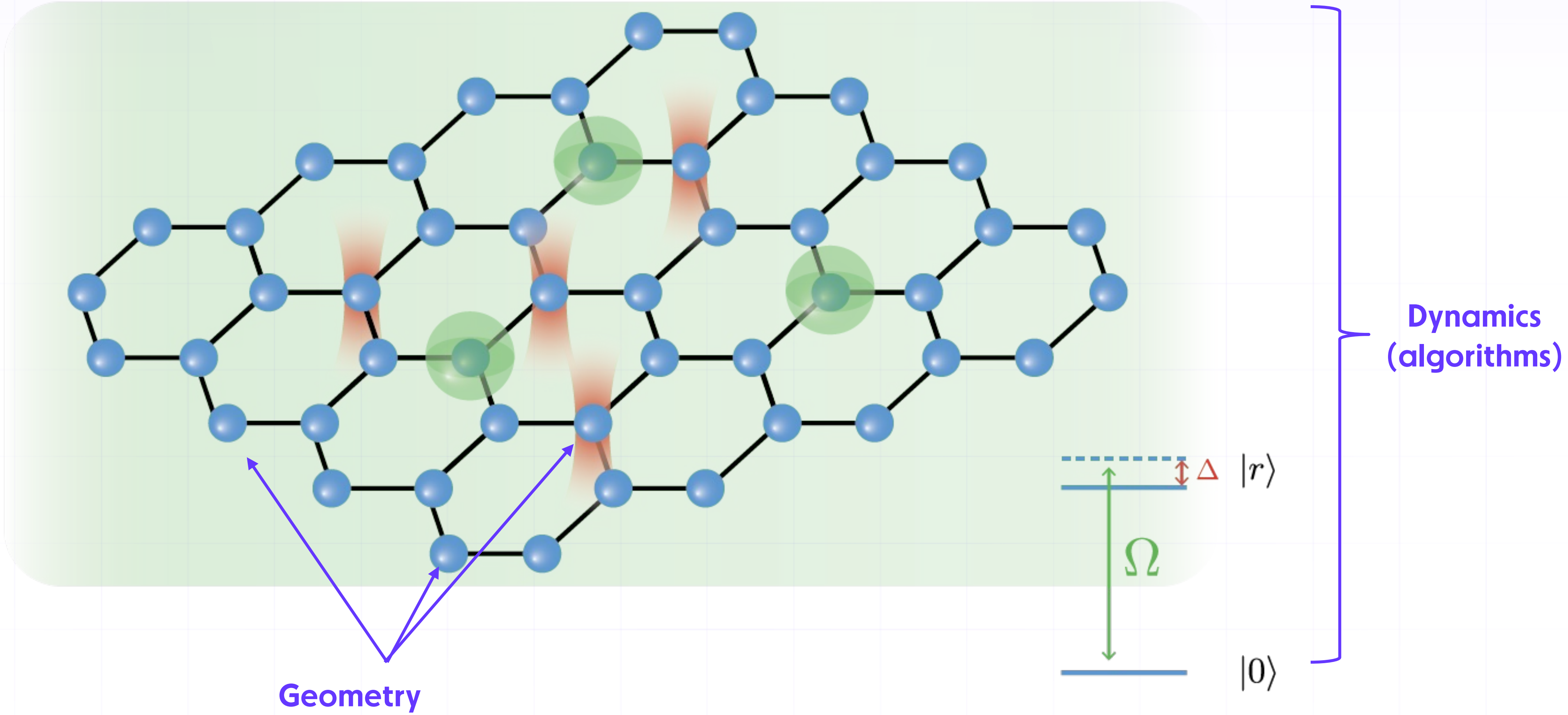


The routine

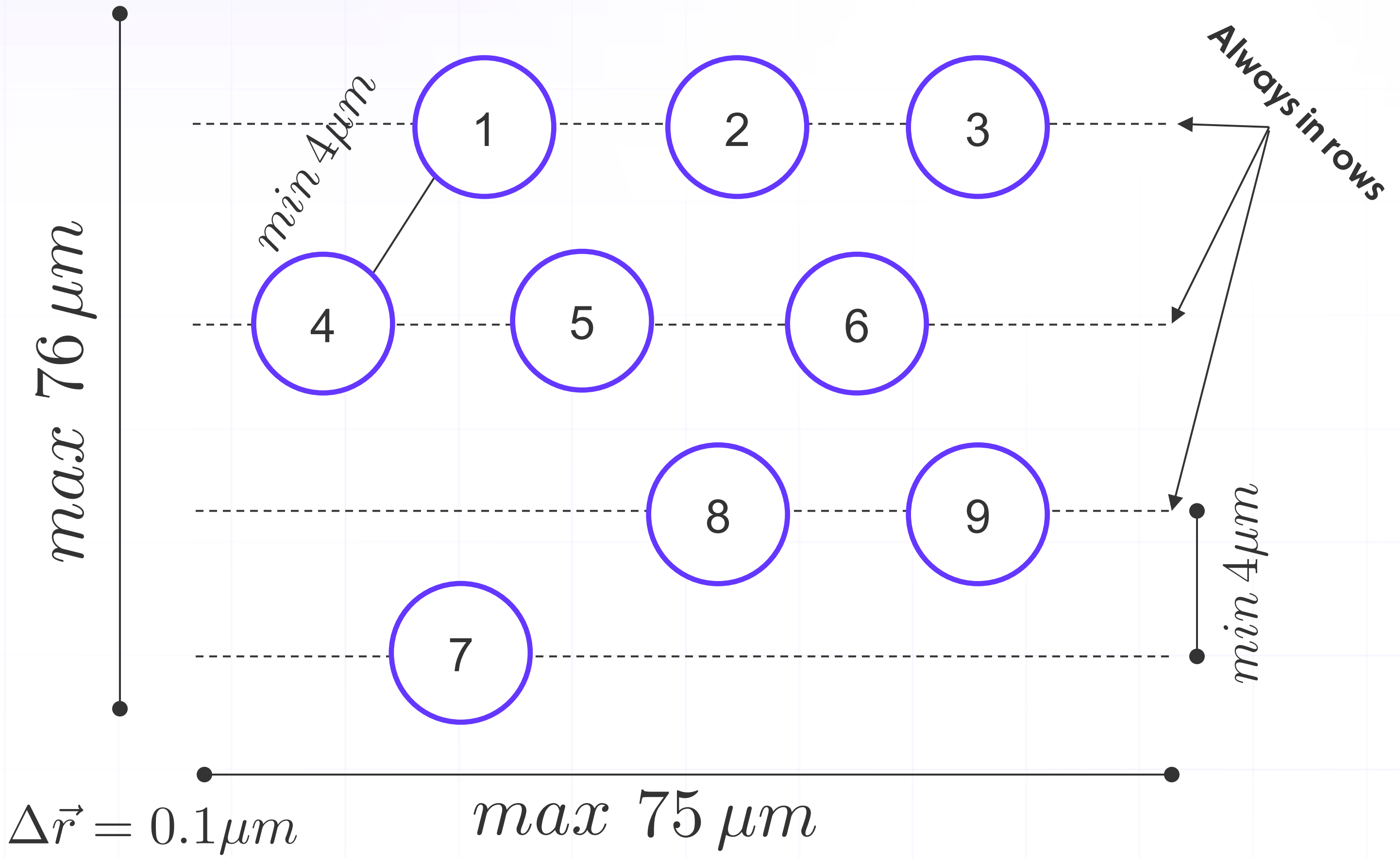


Load MOT in 20-40ms
Load 60% of traps
Image in 5ms
Sorting in ~30 ms
Results
Occurrences
vacancy
threshold
atom
Mean atom detector signal A
QPU
load MOT
load tweezers
img
sort
init
QC
CPU
build seq
proc
Data to devices
Tweezer waveforms
Camera image
t (us)

A neutral-atom quantum processor



Hardware constraints: Geometry



Activity 1:
Think-pair-share. What do you think is the origin of each of these constraints?

Activity 2:
defining qubit positions on Bloqade

More details @
https://queracomputing.github.io/Bloqade.jl/dev/capabilities/

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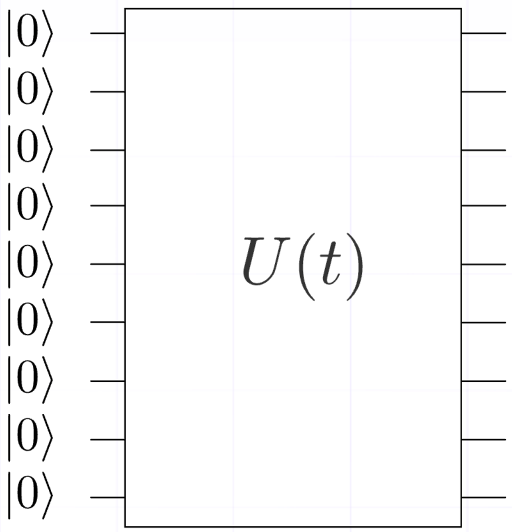
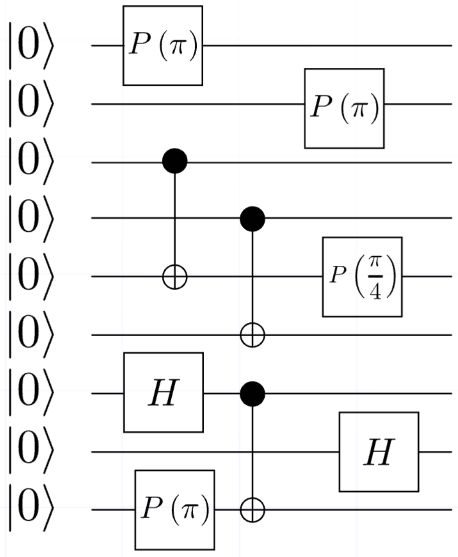
Information processing: Analog computing

Analog operation



Digital operation



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

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

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

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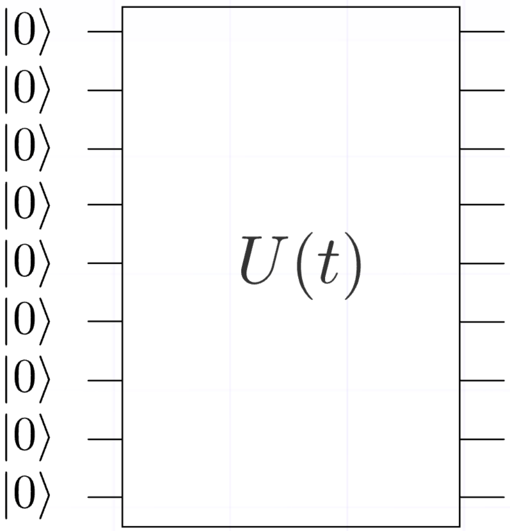
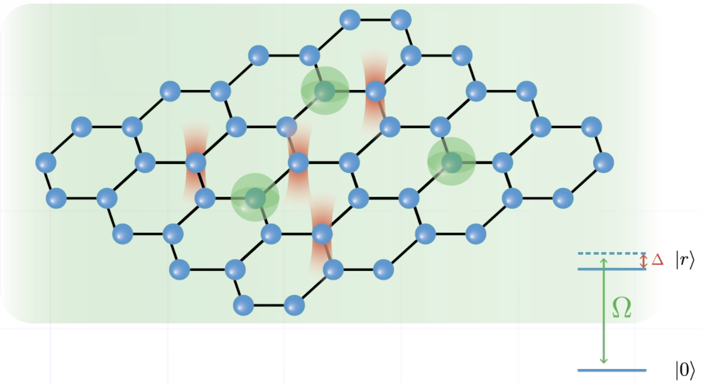
Field Programmable Qubit Arrays (FPQAs)

Analog operation





Control qubit positions! Control qubit connectivity!

$\Rightarrow$ **Many possibilities!**

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- ✓ Single-step large entanglement
- ✗ ~~Universal applicability~~

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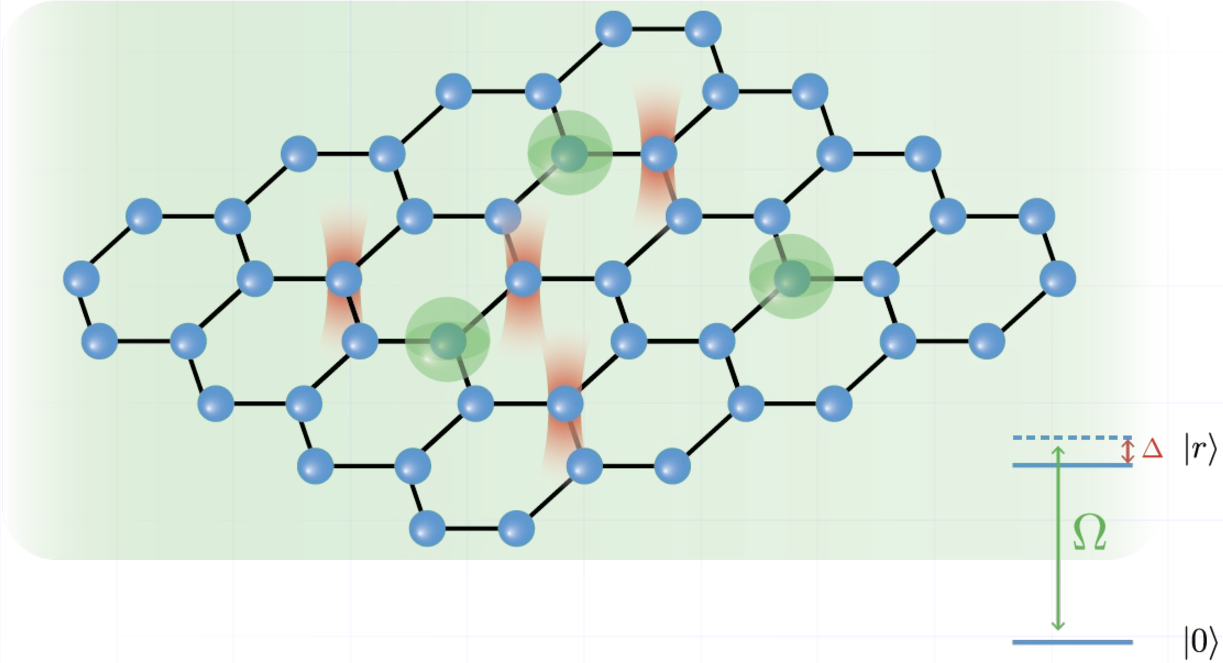
Algorithm = time evolution

$$i\frac{\partial}{\partial t}|\psi\rangle = \boxed{H}|\psi\rangle$$

Analog quantum dynamics control

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



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

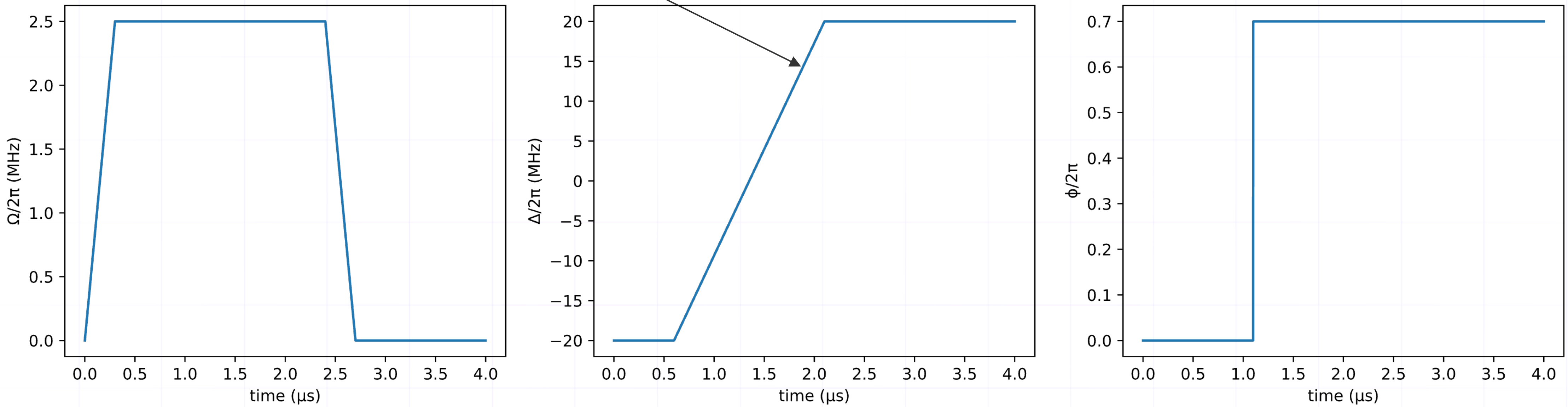
$$V_{ij} \sim d_{ij}^{-6}$$

Hardware constraints: dynamics

Activity: Encoding waveforms on Bloqade

Piecewise-linear

max max

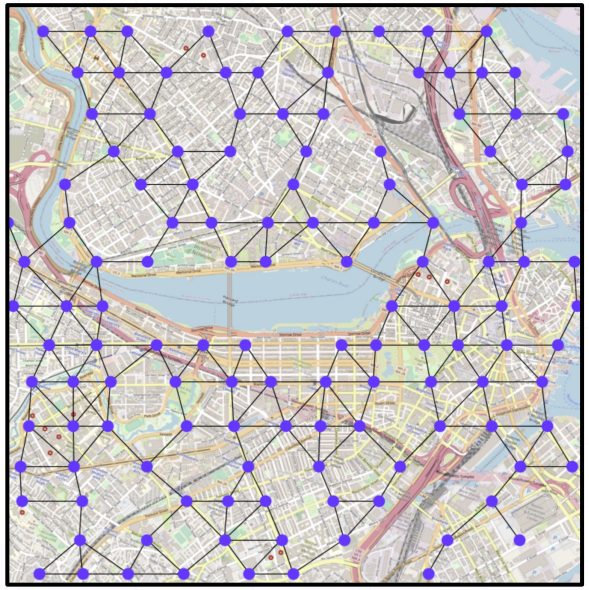


$$t_{max} = 4\mu s$$

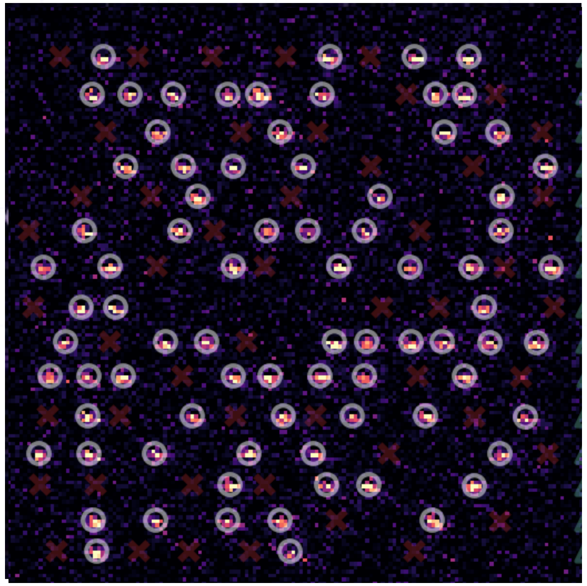
Piecewise-constant

FPQA = Efficient Problem Encoding

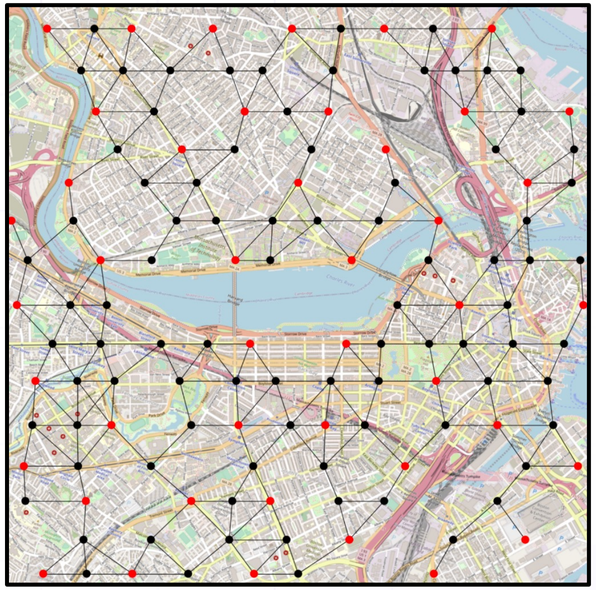
Choose possible locations



Create an atomic twin

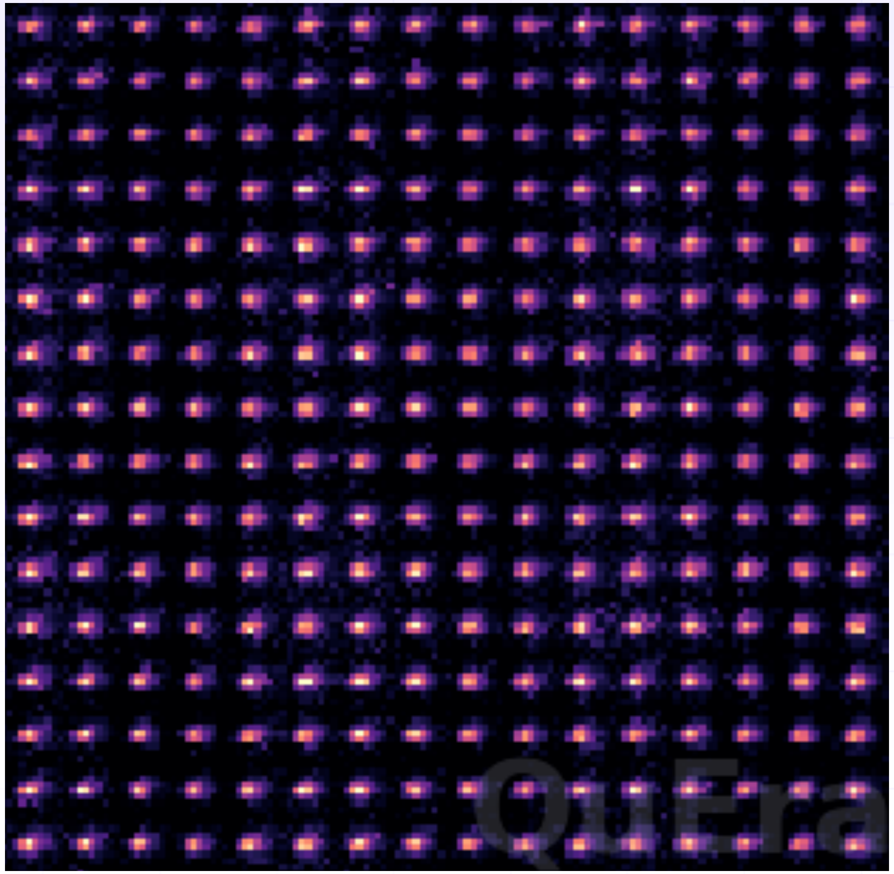


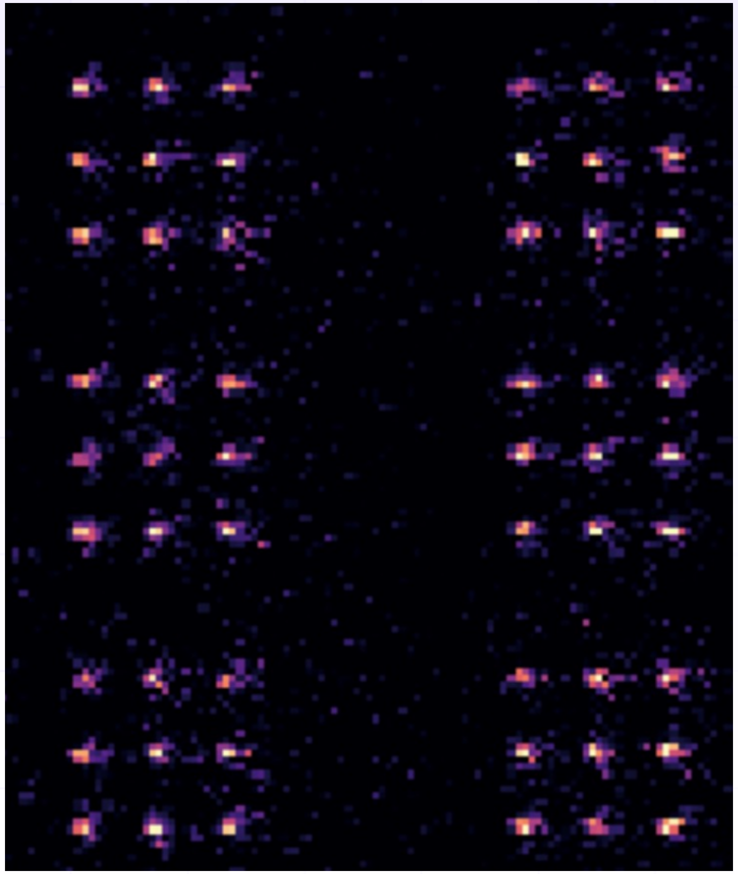
Excite atoms to find answer!



How to optimally cover Boston with coffee shops?

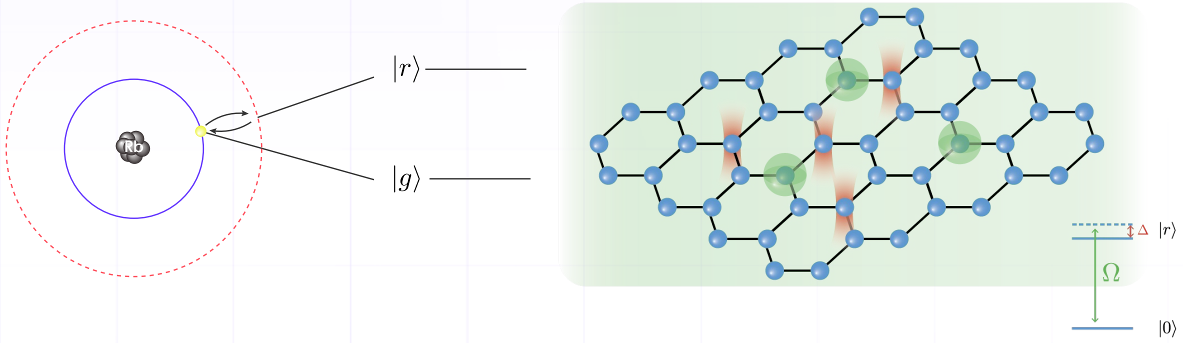
FPQA = Parallelization



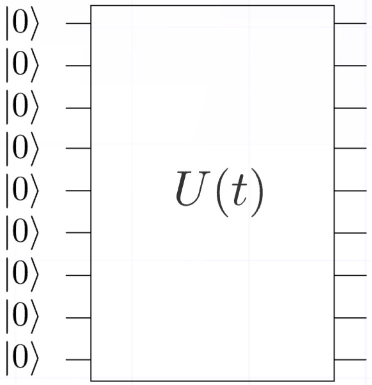


Summary

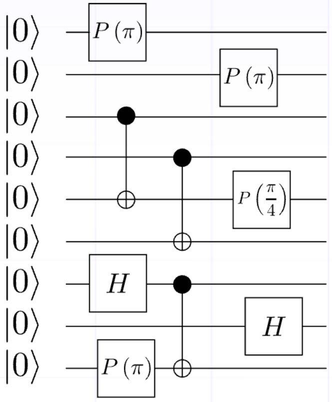
Architecture



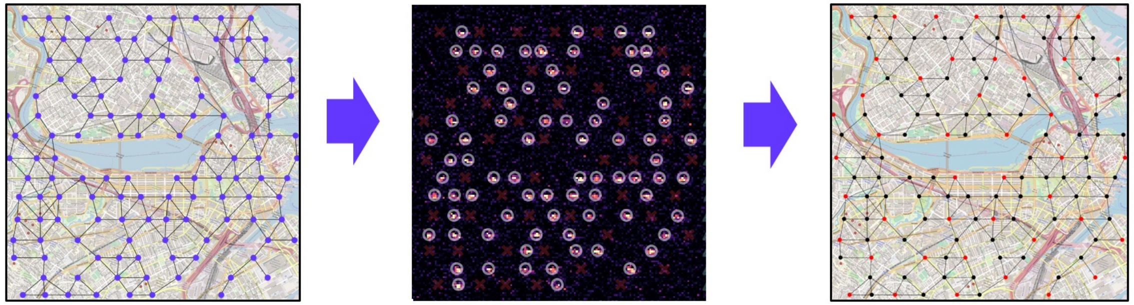
Analog operation



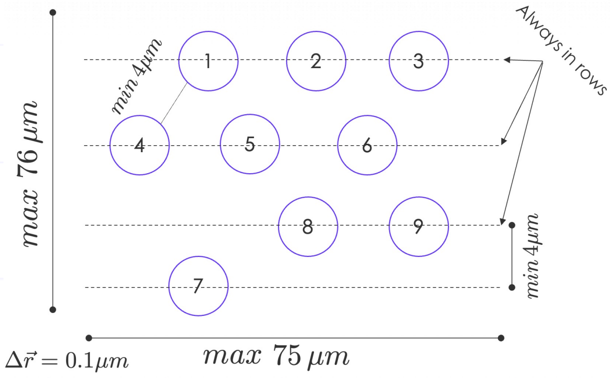
Digital operation

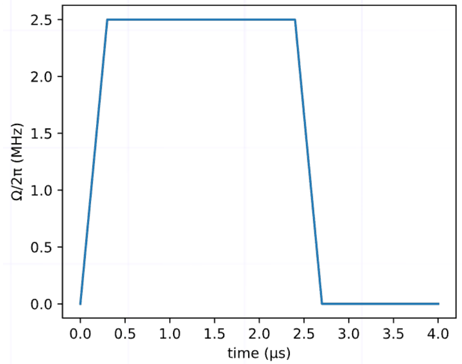


FPQA paradigm



Hardware constraints





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