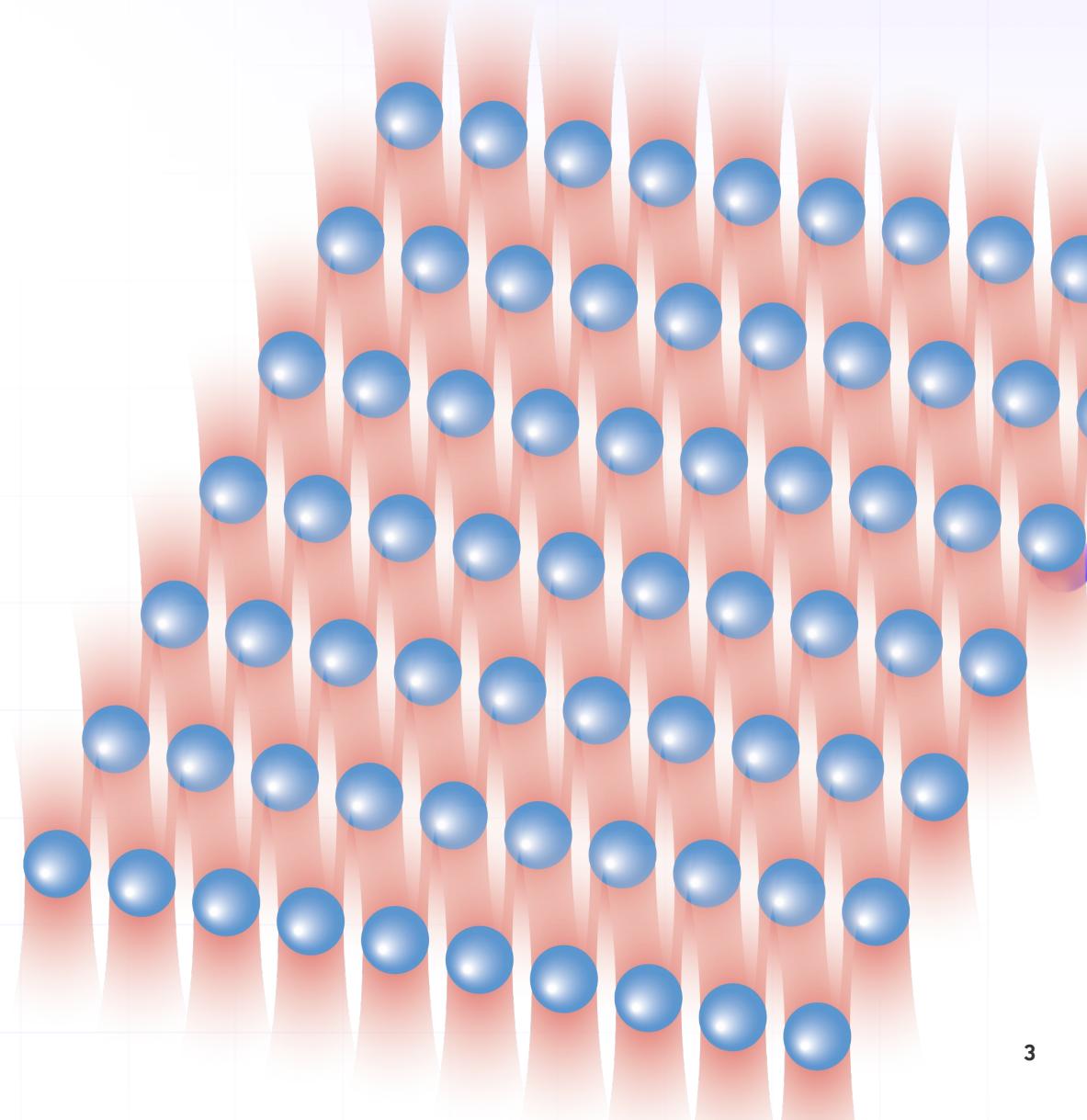


IQuEra>

# Session I: Basics

# Neutral-atom quantum processor

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

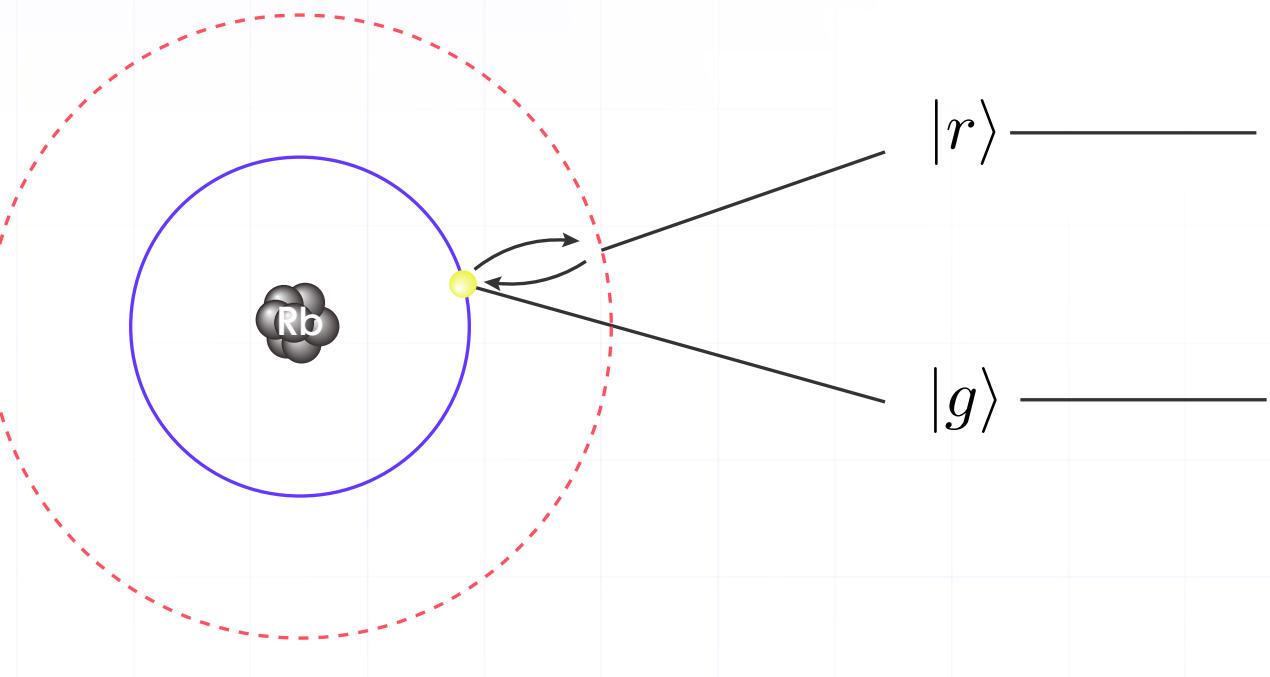


# Learning objectives

**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



Periodic Table of the Elements

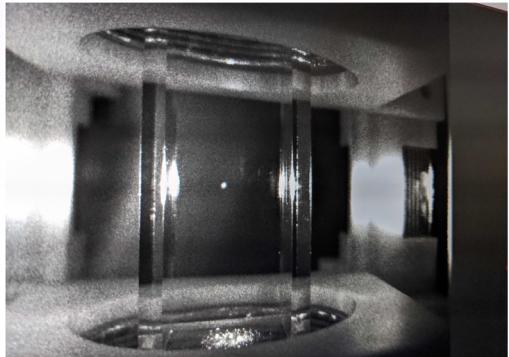
**Periodic Table of the Elements**

The table includes the following annotations:

- Callout for Alumina ( $\text{Al}_2\text{O}_3$ ):** Shows the element number (13), symbol (Al), name, atomic weight (26.982), and electrons per shell (2-8-3).
- State of matter (color of name):** GAS (green), LIQUID (blue), SOLID (orange), UNKNOWN (yellow).
- Subcategory in the metal-metalloid-nonmetal trend (color of background):**
  - Alkali metals (red)
  - Alkaline earth metals (light blue)
  - Lanthanides (light orange)
  - Actinides (light green)
  - Transition metals (yellow)
  - Metalloids (grey)
  - Post-transition metals (light grey)
  - Nonmetals (pink)
  - Noble gases (purple)
- Electrons per shell:** Indicated for each element.
- Unknown chemical properties:** Indicated by a grey question mark icon.

# The routine

Load MOT in 20-40ms



Load 60% of traps

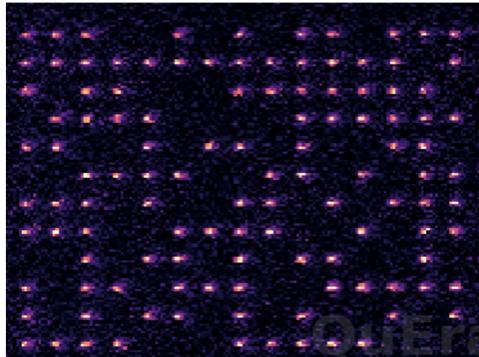
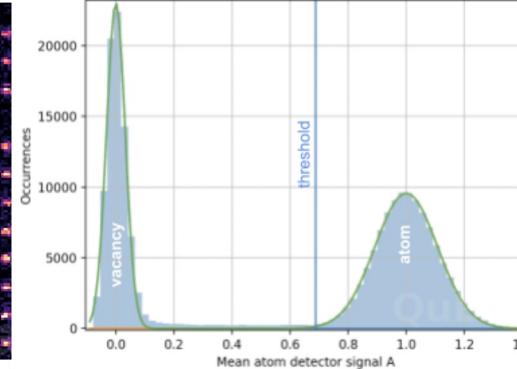
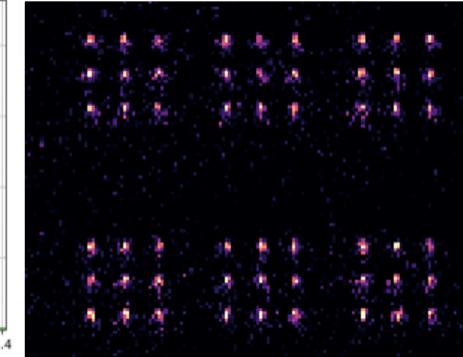


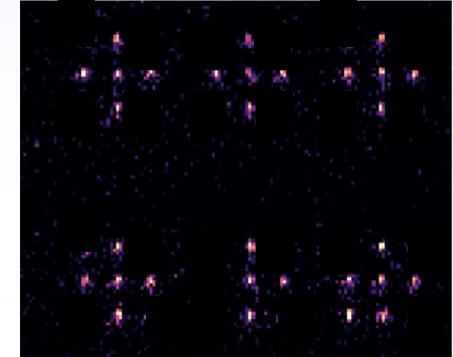
Image in 5ms



Sorting in ~30 ms



Results



QPU

load MOT

load tweezers

img a

sort

img e

init

QC

img h

Data to devices

CPU

build seq

Tweezer waveforms

Camera image

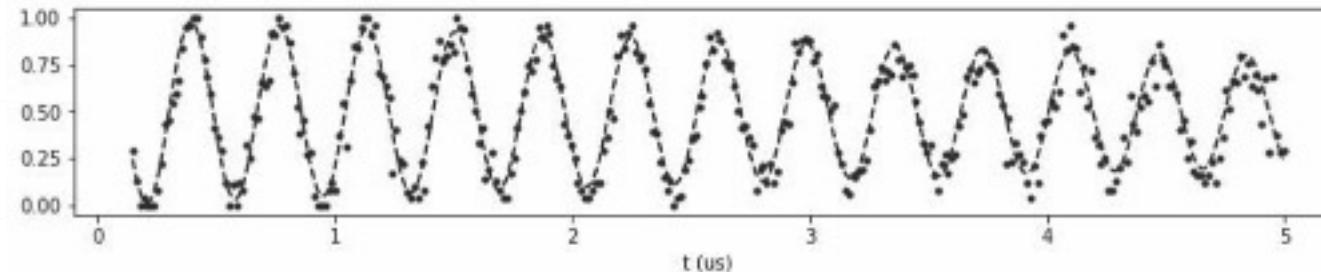
proc b

proc c

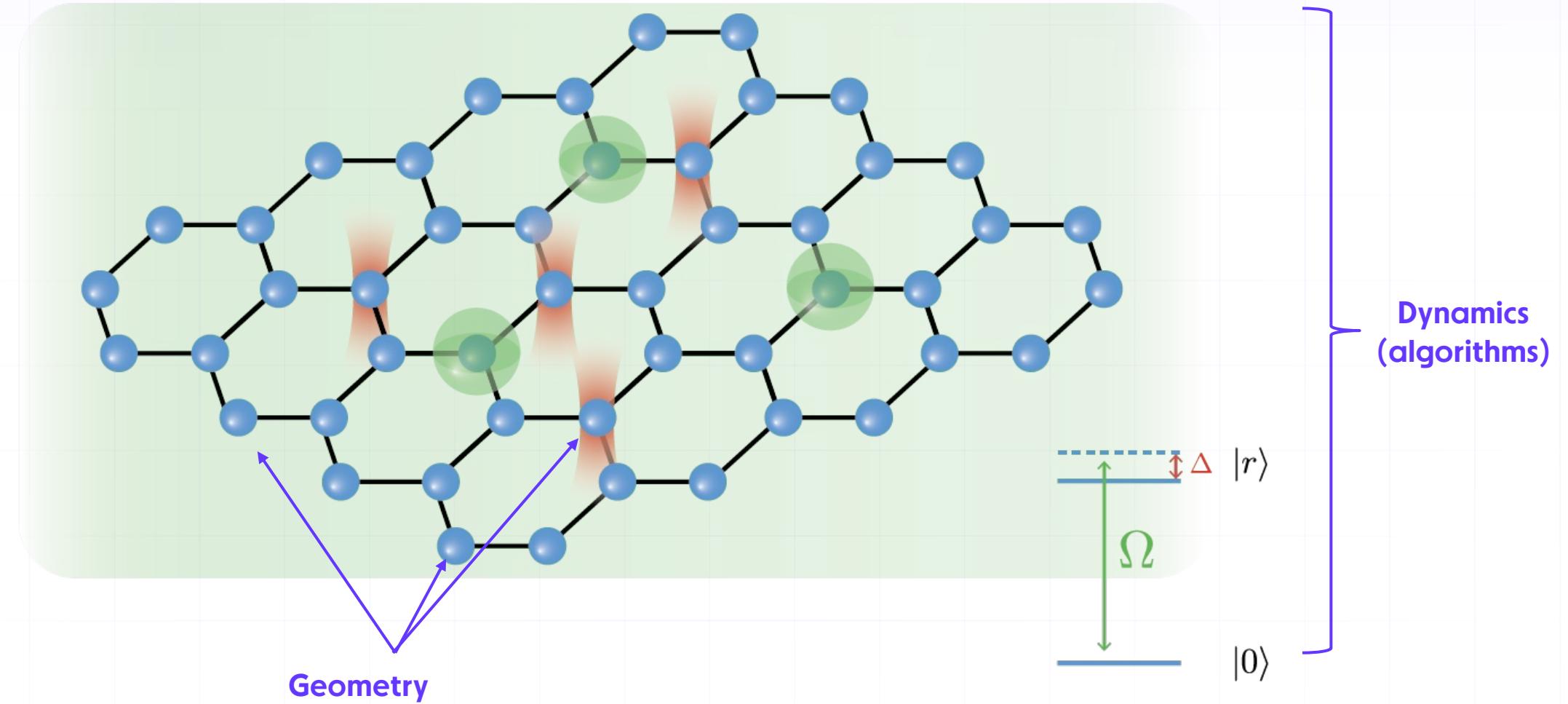
proc f

proc g

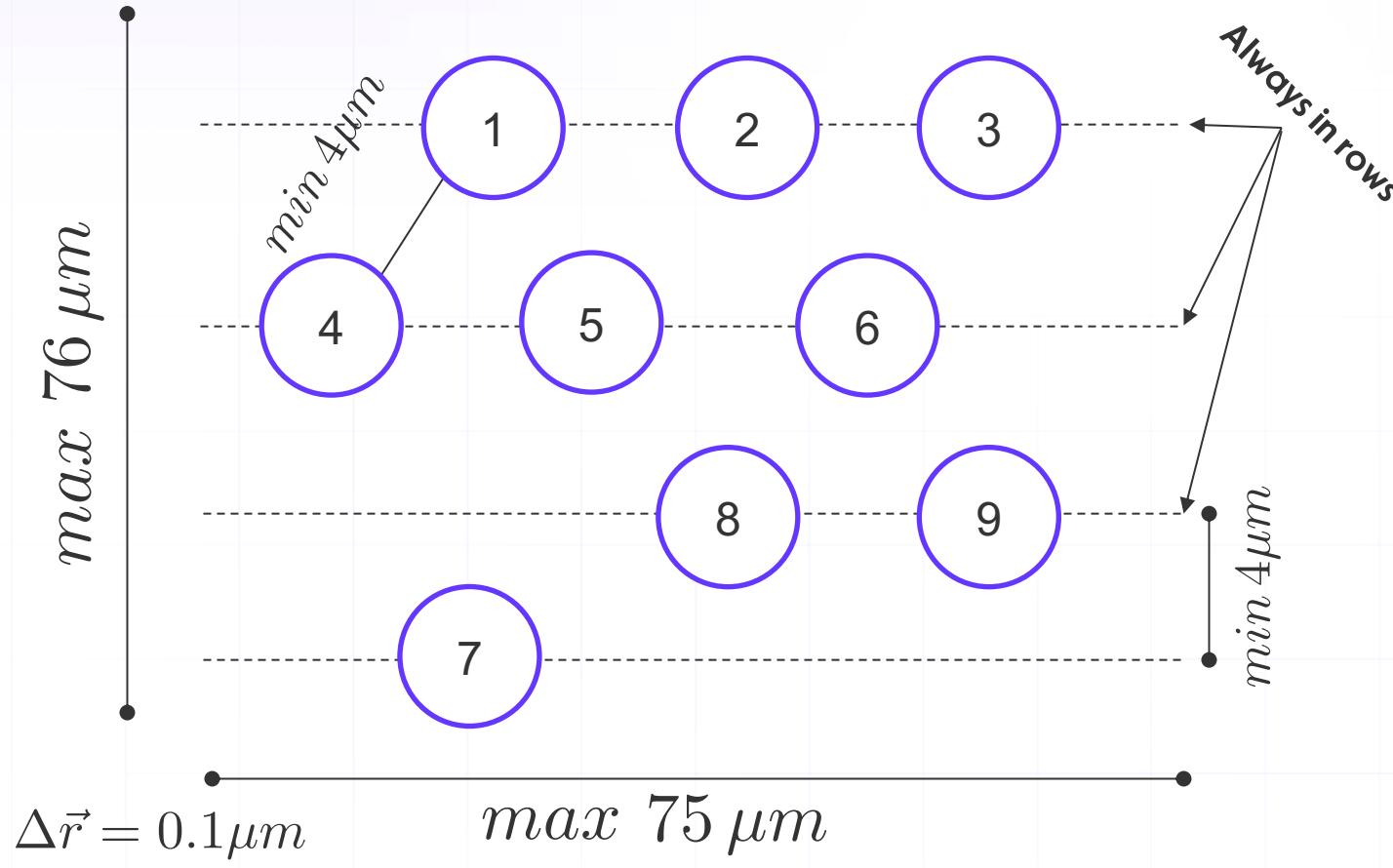
proc i



# 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:

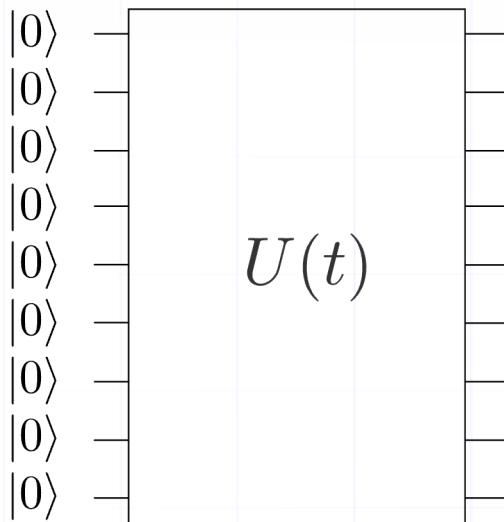
defining qubit positions on Bloqade

More details @

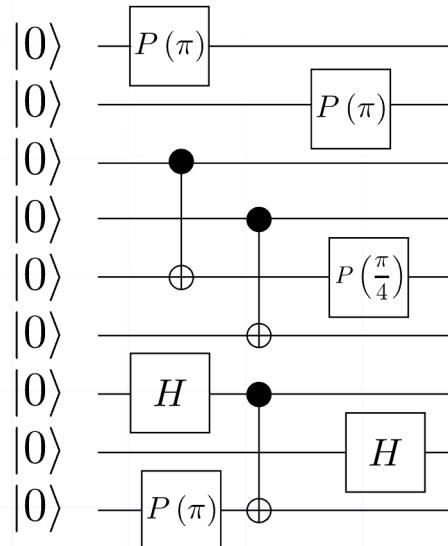
<https://queracomputing.github.io/Bloqade.jl/dev/capabilities/>

# Information processing: Analog computing

Analog operation



Digital operation



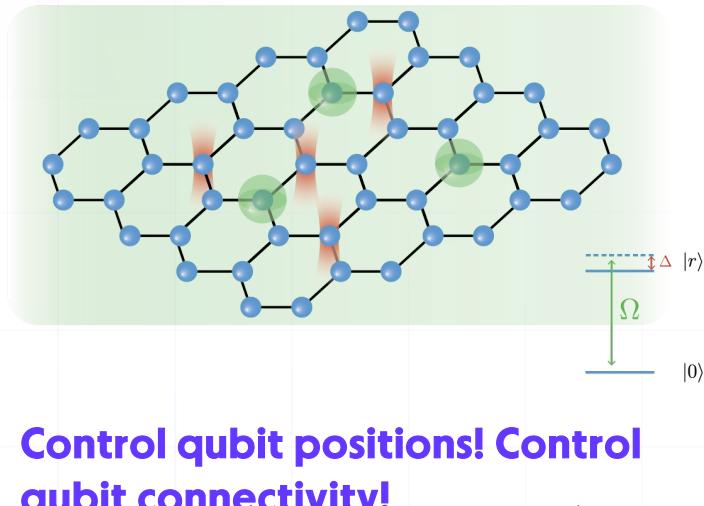
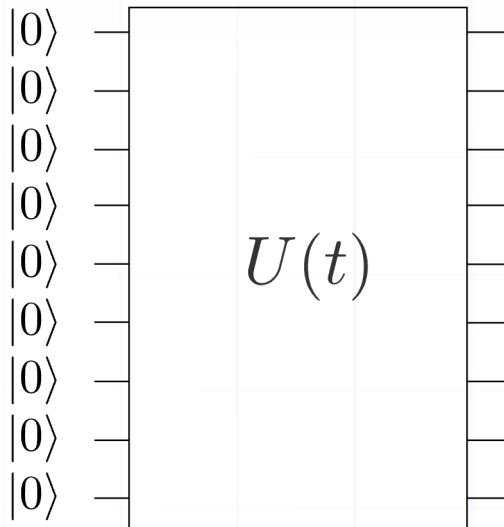
Designed for the early stage of maturity of the quantum computing resources of today...

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

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

# Field Programmable Qubit Arrays (FPQAs)

Analog operation



**Control qubit positions! Control  
qubit connectivity!**

⇒ Many possibilities!

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

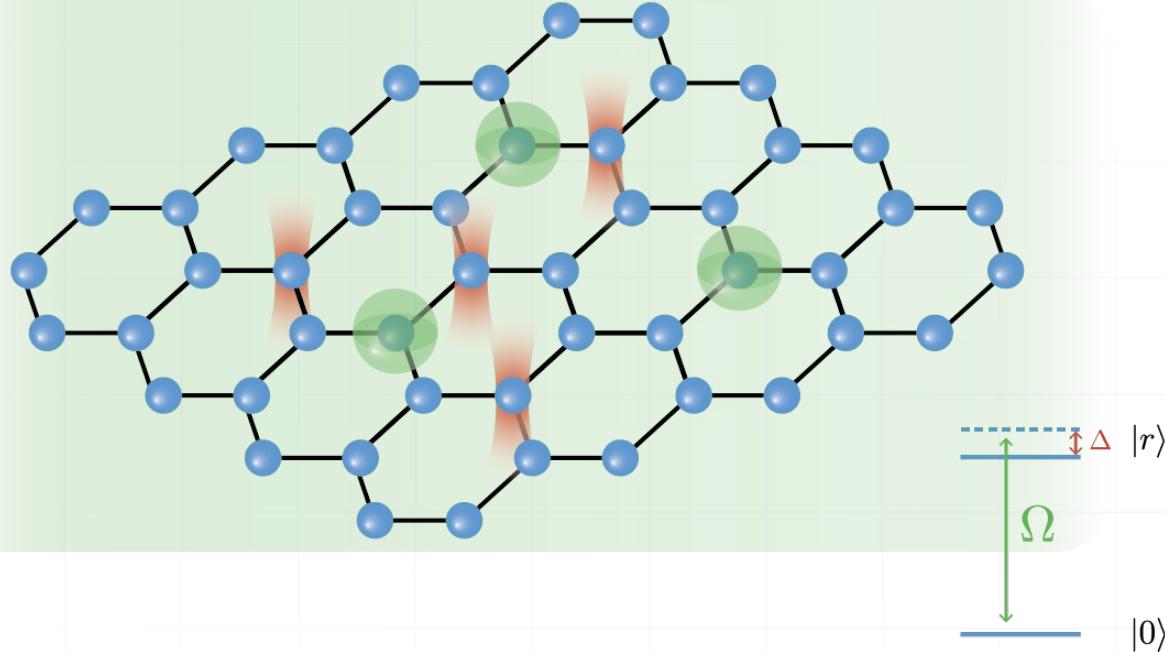
More on analog processors:  
[Nature](#) volume 607, p. 667–676 (2022)

# Algorithm = time evolution

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

# Analog quantum dynamics control

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

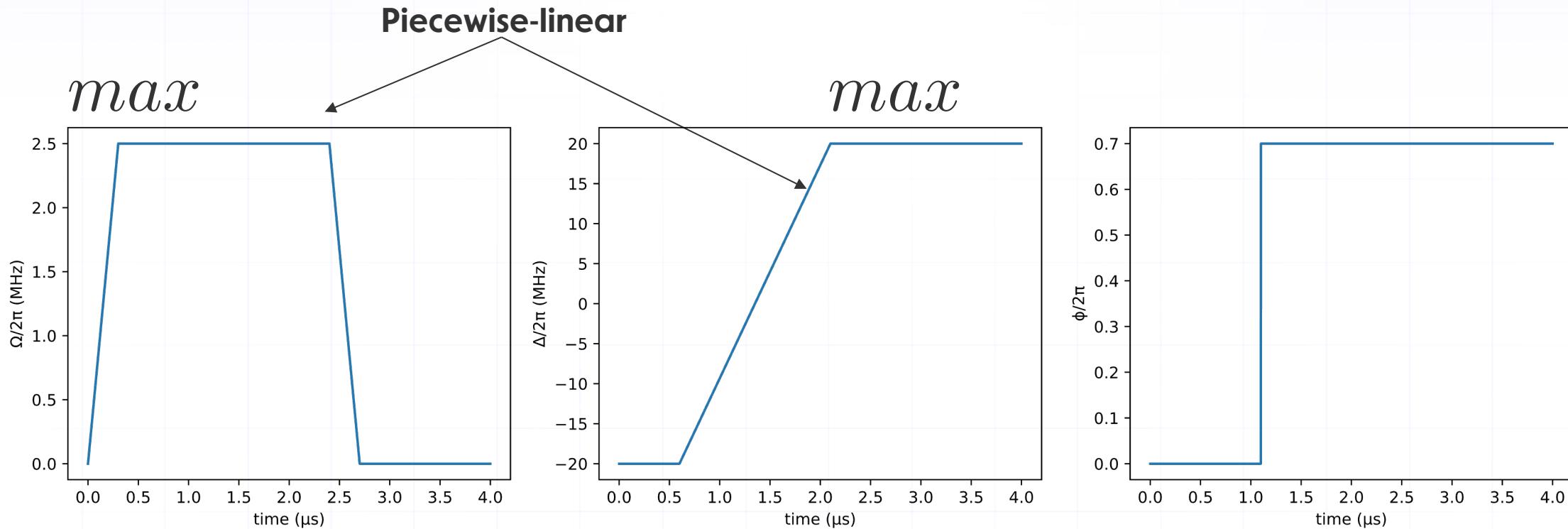


$$n_i = 1 * |r_i\rangle\langle r_i| + 0 * |g_i\rangle\langle g_i|$$

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

# Hardware constraints: dynamics

Activity: Encoding waveforms on Bloqade

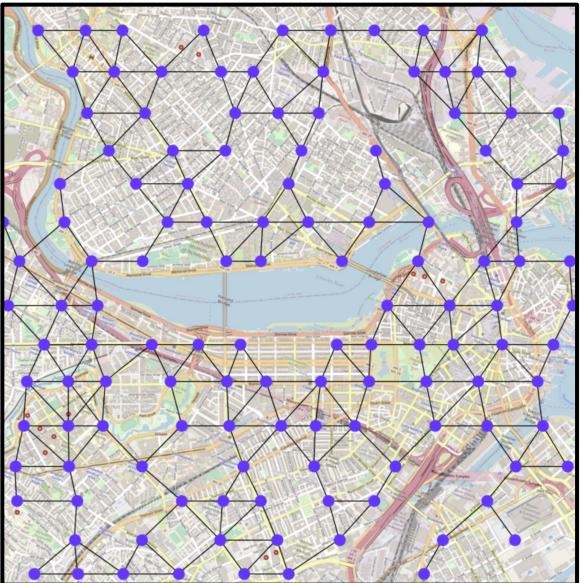


$$t_{max} = 4 \mu s$$

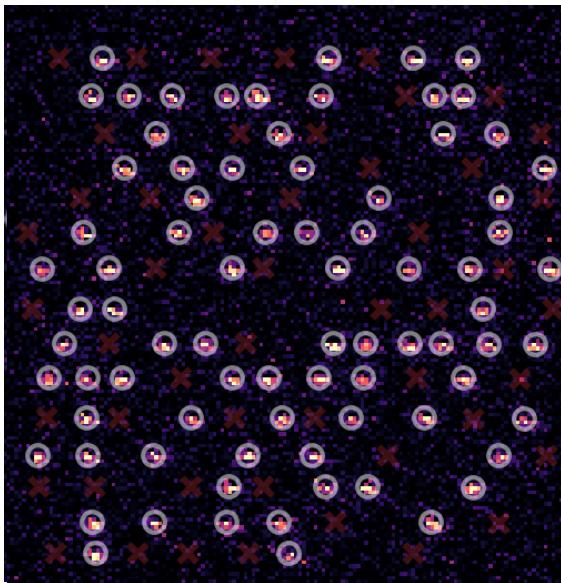
Piecewise-constant

# FPQA = Efficient Problem Encoding

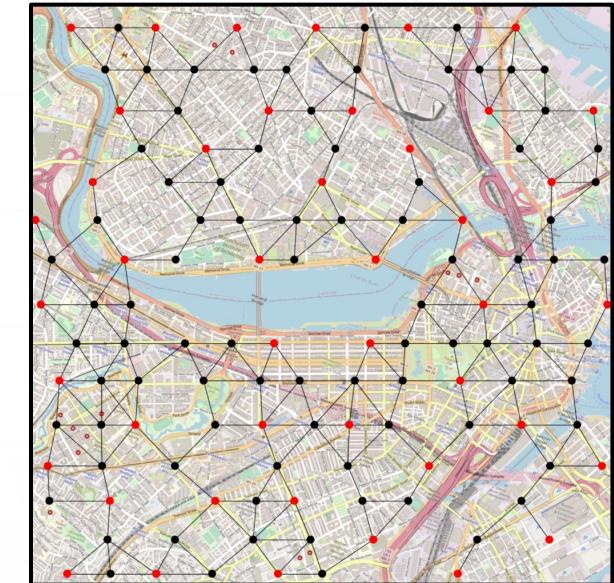
Choose possible locations



Create an atomic twin

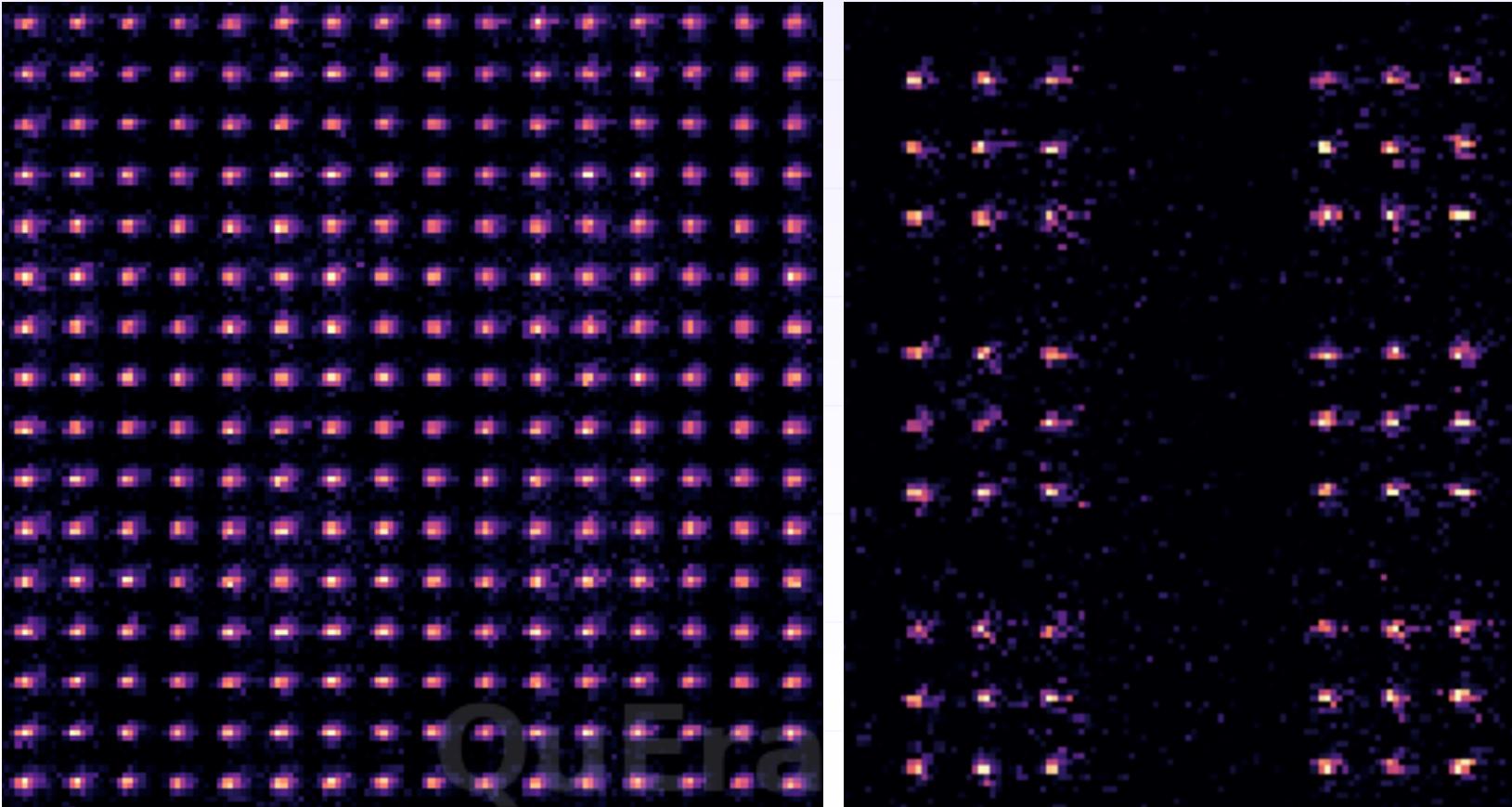


Excite atoms to find answer!



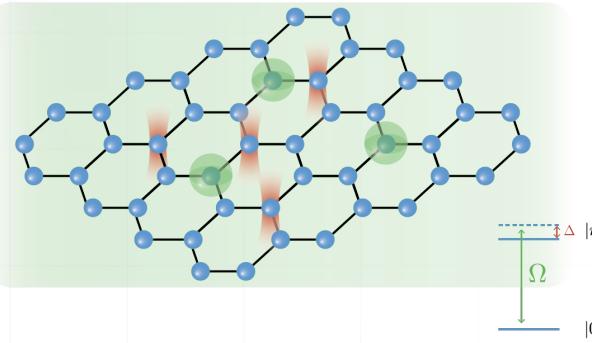
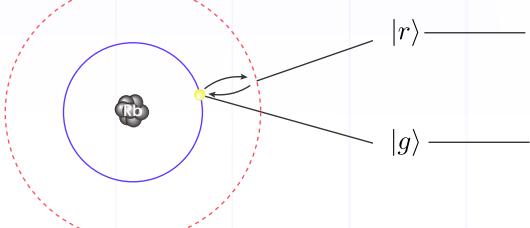
How to optimally cover Boston with coffee shops?

# FPQA = Parallelization

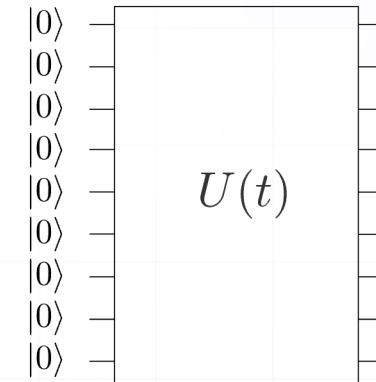


# Summary

## Architecture

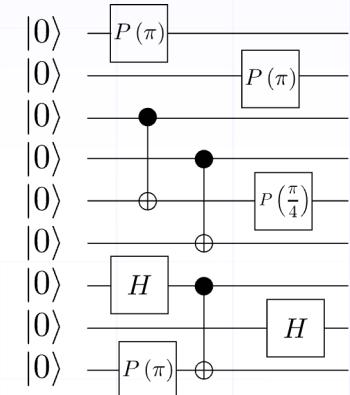


## Analog operation

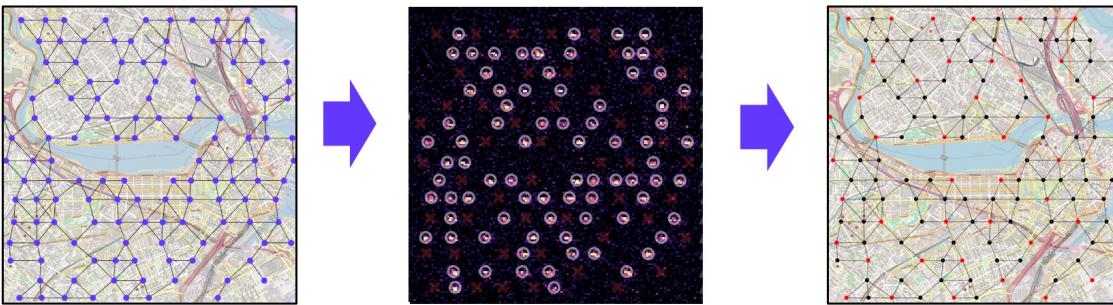


$U(t)$

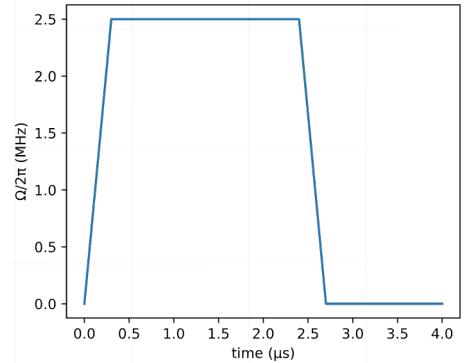
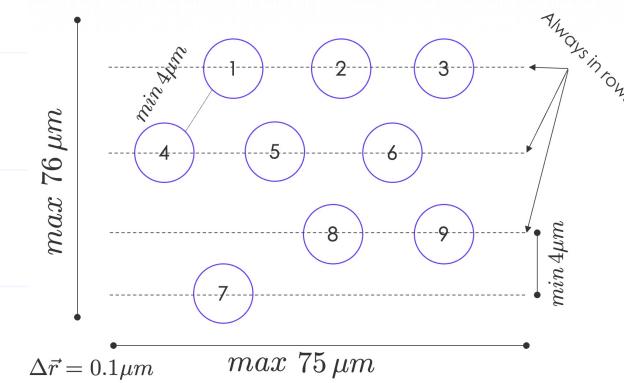
## Digital operation



## FPQA paradigm



## Hardware constraints



# Learning objectives

**Now you are 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**
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