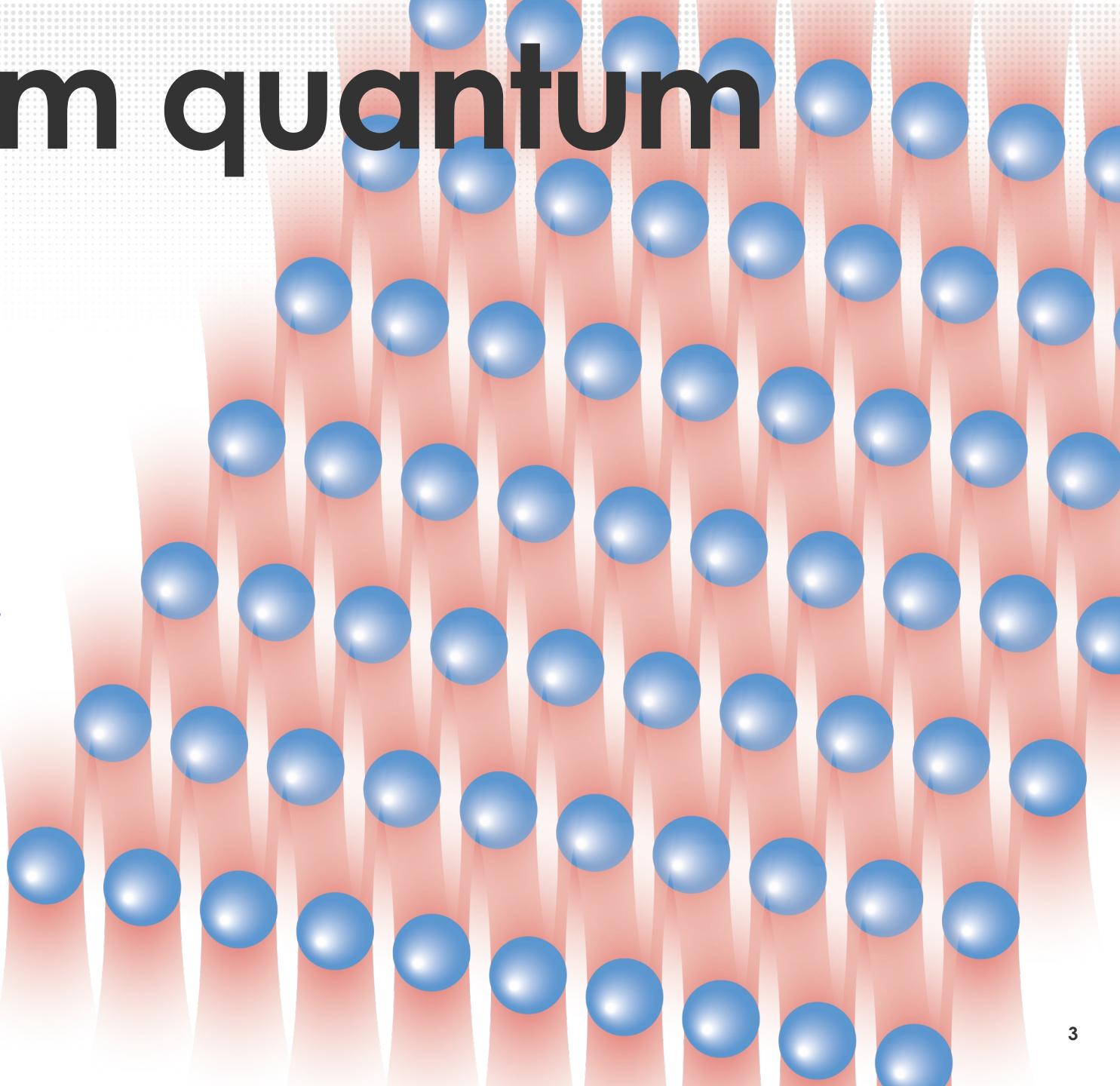


SESSION I: BASICS

Neutral-atom quantum processor

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

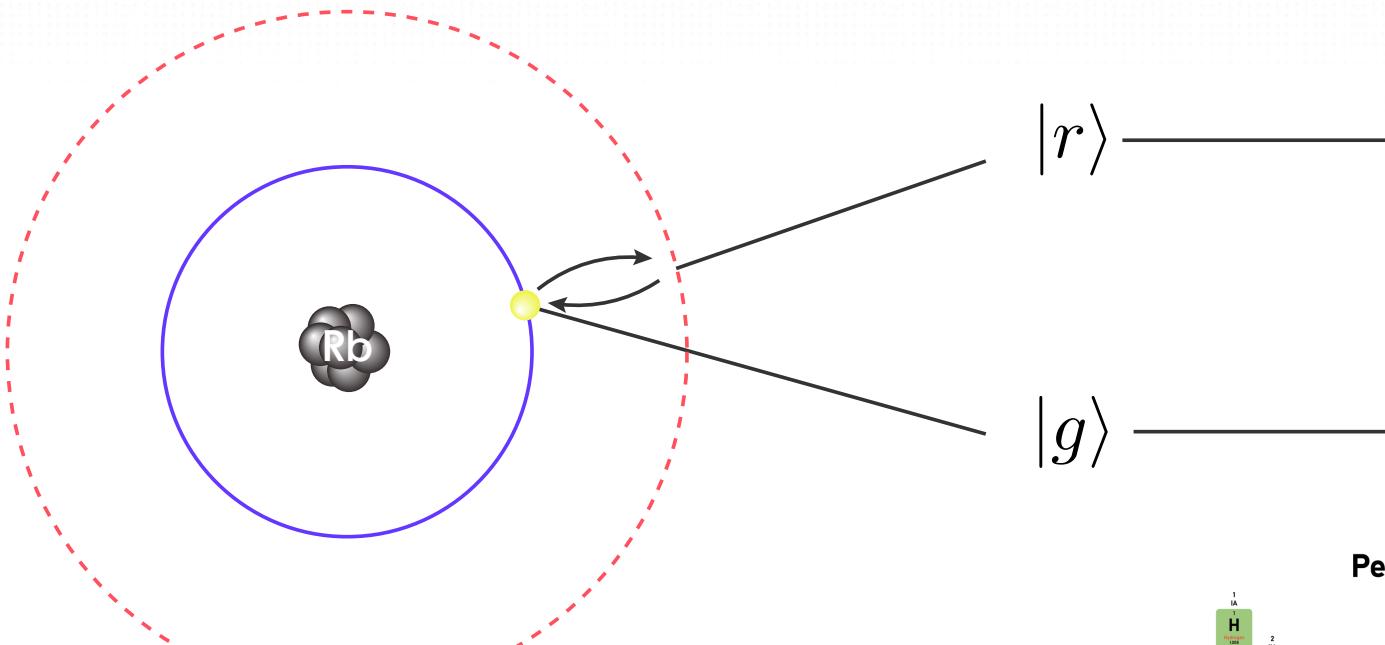


Learning objectives

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

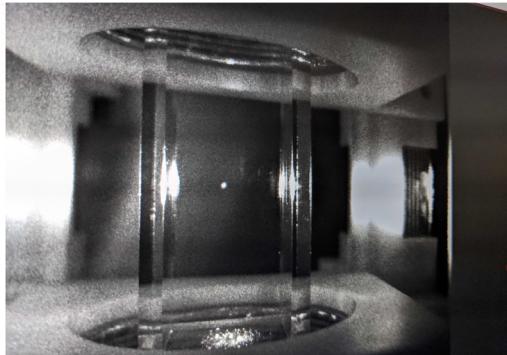


Periodic Table of the Elements

Periodic Table of the Elements																	
		Atomic Number →															
		Symbol →															
1	IA	2	IIA	3	IIIA	4	IIIB	5	IVB	6	VIB	7	VIIB	8	VIII	9	VIIIA
H	Li	Be	Mg	Na	Al	Sc	Ti	V	Cr	Mn	Fe	Ni	Co	Zn	Al	C	He
1	3	4	12	13	13	21	22	23	24	25	26	27	28	29	31	6	18
Hydrogen	Lithium	Boron	Magnesium	Sodium	Aluminum	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Nickel	Copper	Zinc	Silicon	Carbon	Helium
Gas	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Gaseous						
10	VA	11	IB	12	IIIB	13	IVB	14	VIB	15	VIIB	16	VIII	17	VIIIA	18	VIIIA
Ne	Ar	Br	Kr	Xe	Og												
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Ca	Sc	Ti	V	Cr	Mn	Fe	Ni	Co	Zn	Al	Si	P	S	Cl	Ar	He	
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Sodium	Scandium	Titanium	Vanadium	Chromium	Manganese	Iron	Nickel	Copper	Zinc	Aluminum	Silicon	Phosphorus	Sulfur	Chlorine	Argon	Helium	
Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	Solid	
39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Y	Zr	Nb	Ta	Ru	Rh	Pd	Ag	Cd	Sn	Tl	Pb	Bi	Po	At	Rn	He	
Actinides	Transition metals	Post-transition metals															
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
Hf	Ta	Ta	Re	Os	Ir	Pt	Ag	Cd	Sn	Tl	Pb	Bi	Po	At	Rn	He	
Actinides	Transition metals	Post-transition metals															
75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
W	Re	Osmium	Ruthenium	Rhenium	Rhenium	Rhenium	Ruthenium	Rhenium	Rhenium								
Actinides	Transition metals	Post-transition metals															
93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110
Fr	Rf	Ds	Sg	Bh	Hs	Mt	Rg	Cn	Nh	Ts	Mc	Lv	Fr	Mc	Lu	Fr	Mc
Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	Actinides	

The routine

Load MOT in 20-40ms



Load 60% of traps

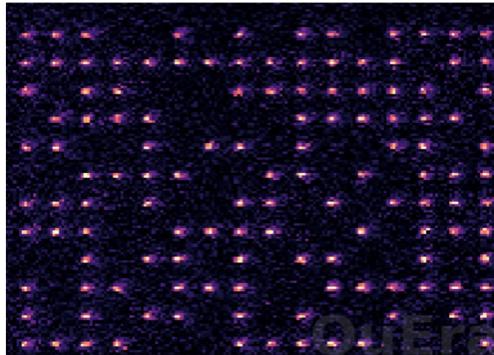
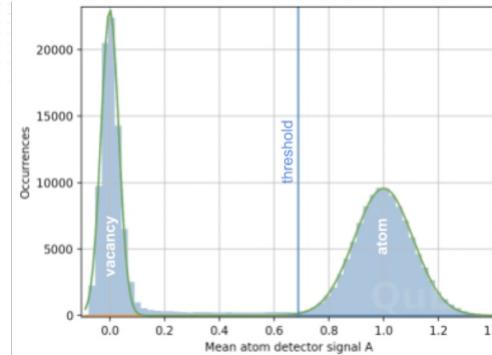
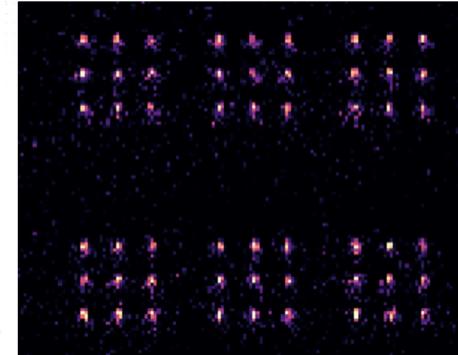


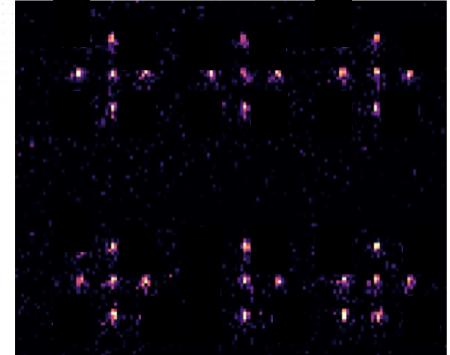
Image in 5ms



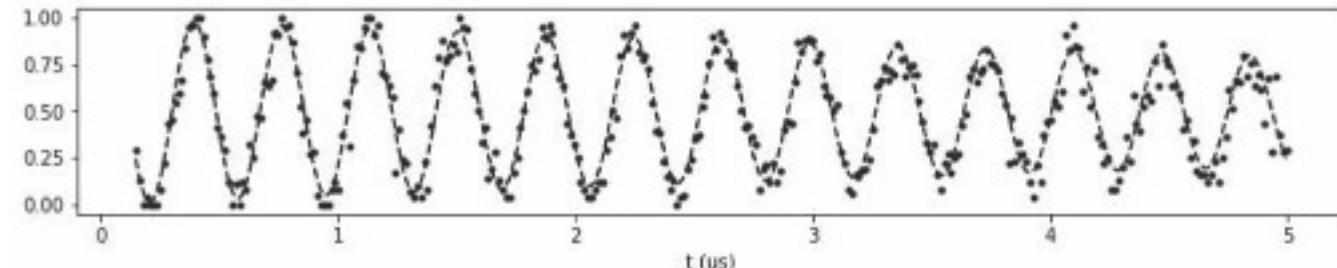
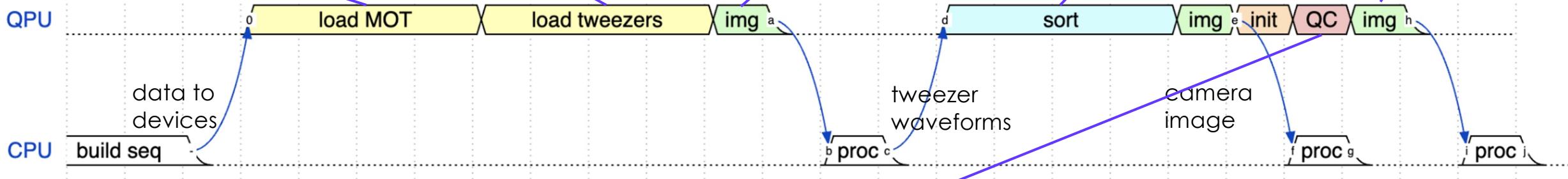
Sorting in ~30 ms



Results

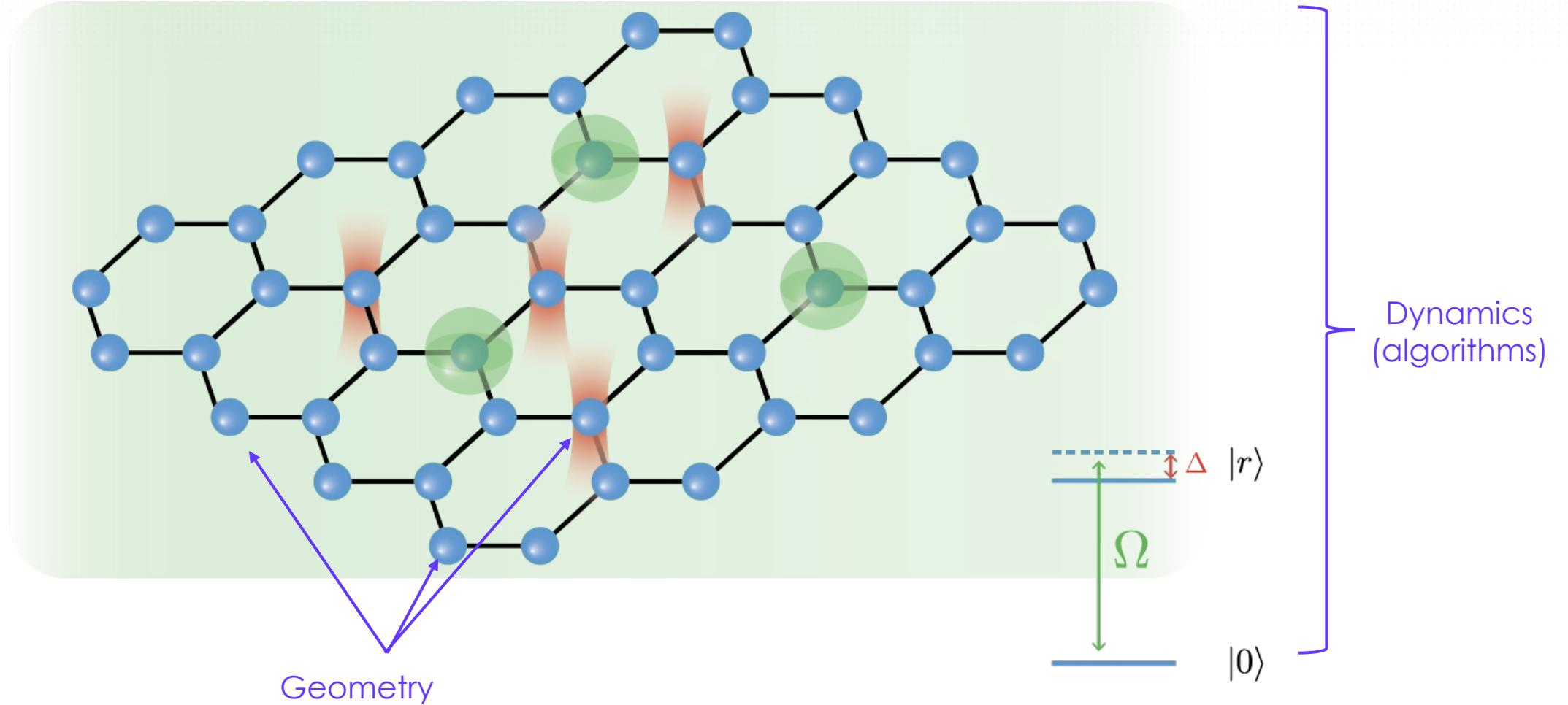


QPU

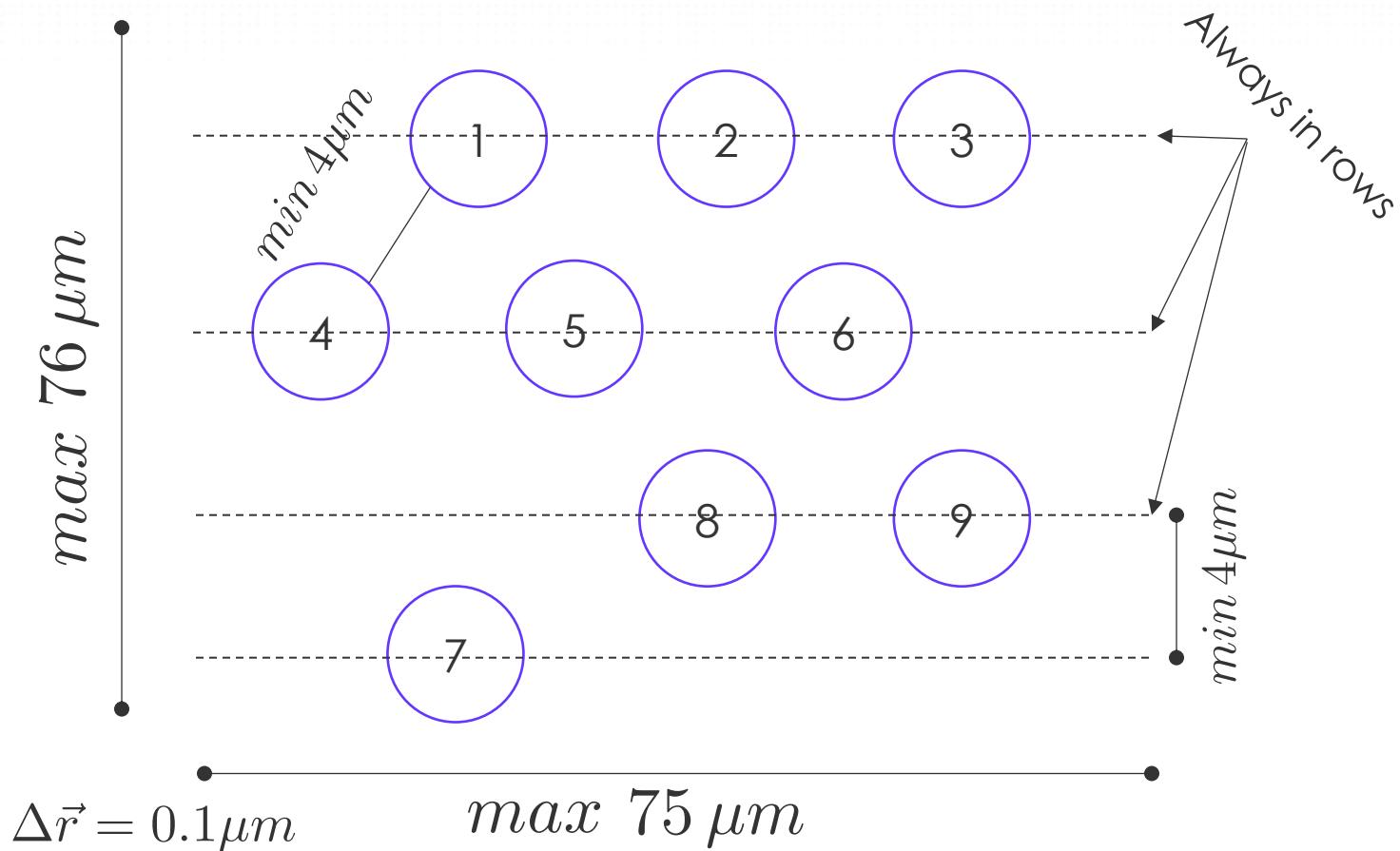


| QUESa >

A neutral-atom quantum processor



Hardware constraints: Geometry

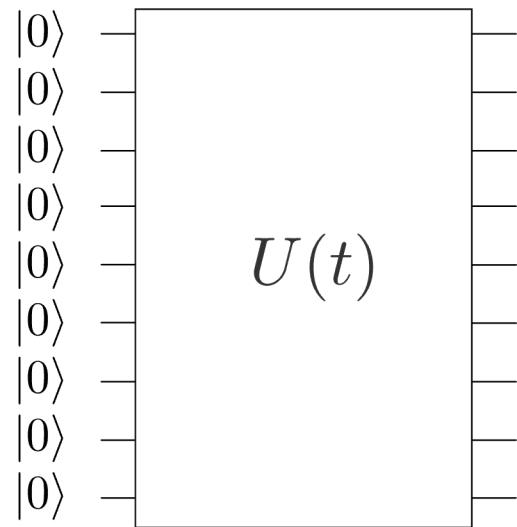


Activity 1: Think-pair-share. What do you think is the origin of each of these constraints?

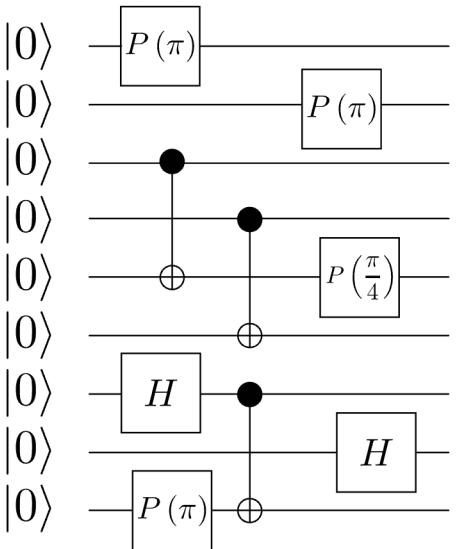
Activity 2: defining qubit positions on Bloqade

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

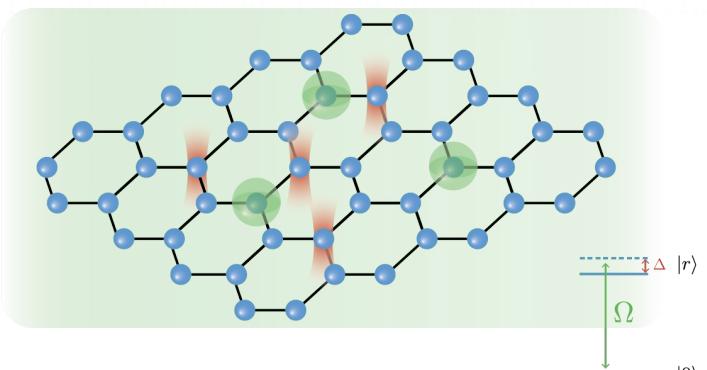
More on analog processors:
[Nature](#) volume 607, p. 667–676 (2022)

Field Programmable Qubit Arrays (FPQAs)

Analog operation

$$|0\rangle \quad |0\rangle \quad |0\rangle$$

$U(t)$



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

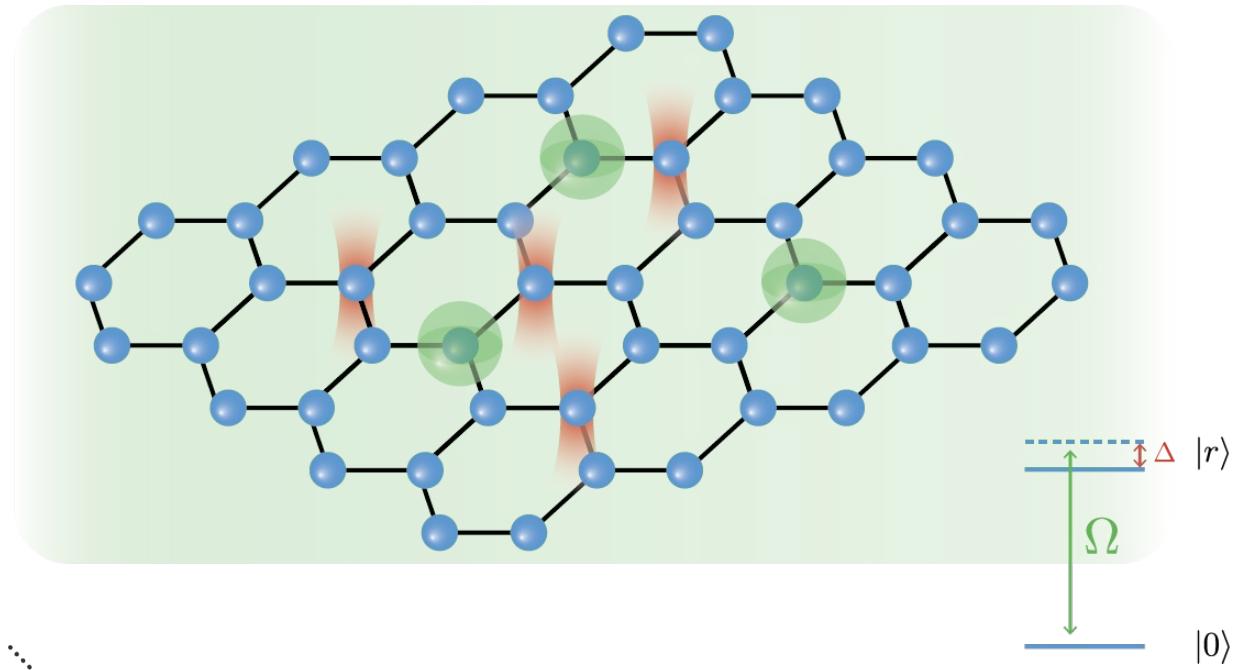
More on analog processors:
[Nature](#) volume 607, p. 667–676 (2022)

Algorithm = time evolution

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

Analog quantum dynamics control

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



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

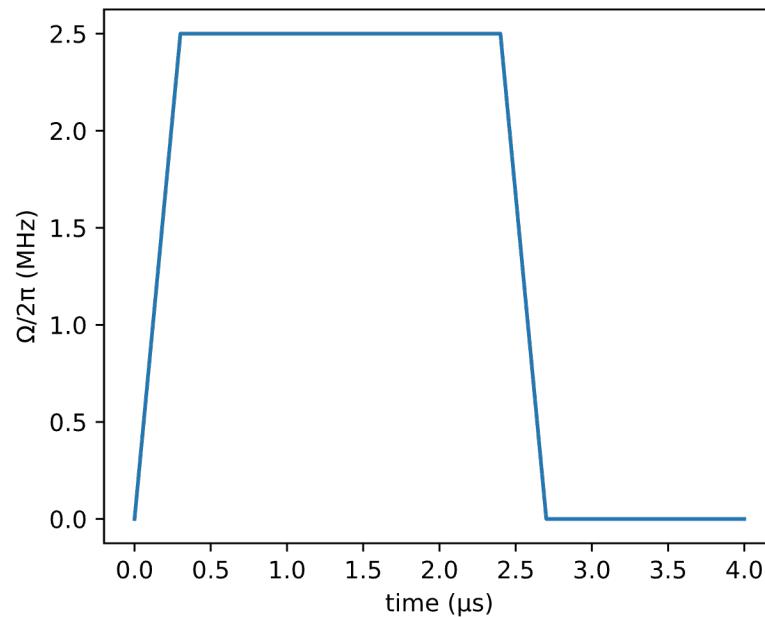
$$V_{ij} \sim d_{ij}^{-6}$$

Hardware constraints: dynamics

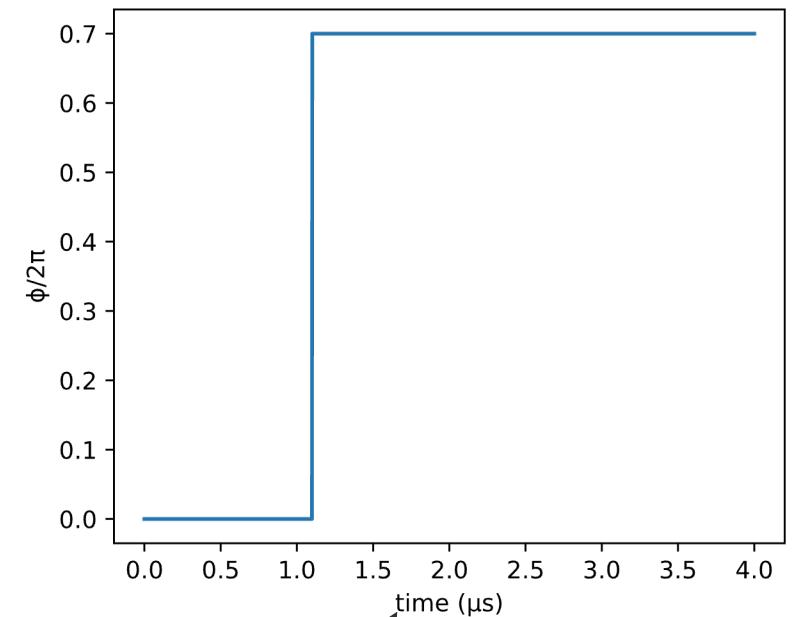
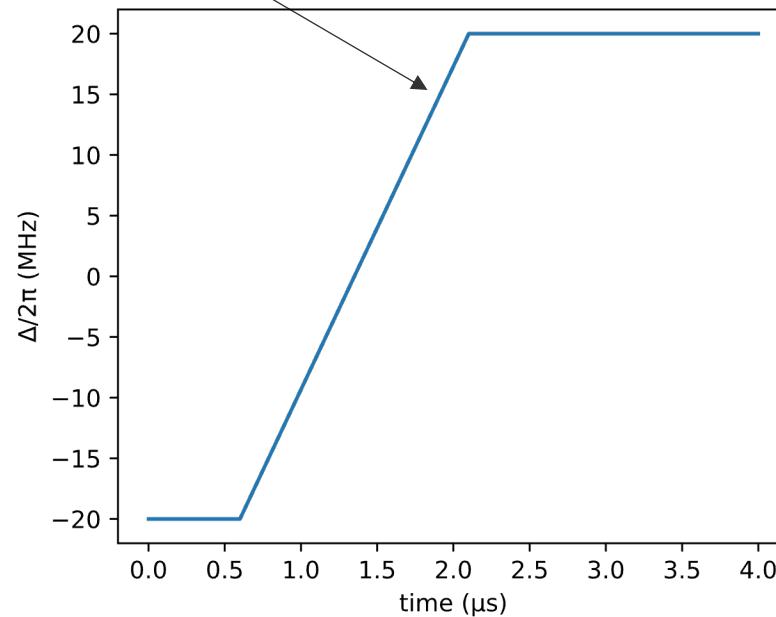
Activity: encoding waveforms on Bloqade

Piecewise-linear

max



max



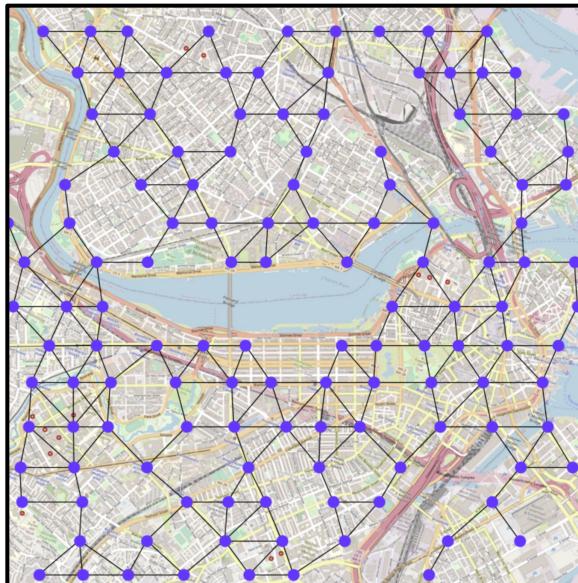
(QUREa)

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

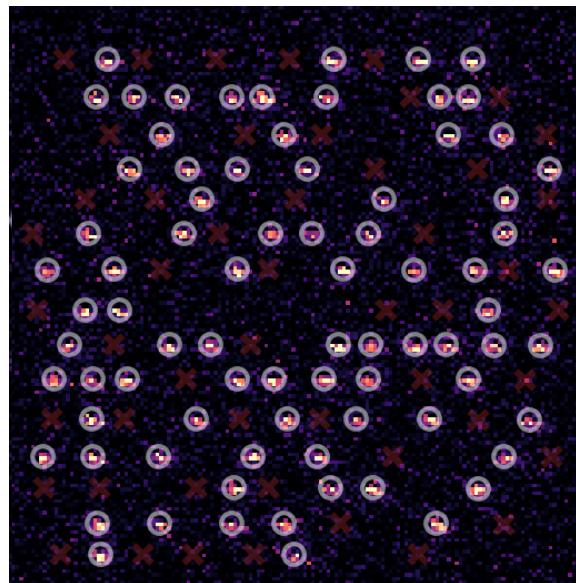
Piecewise-constant

FPQA = Efficient Problem Encoding

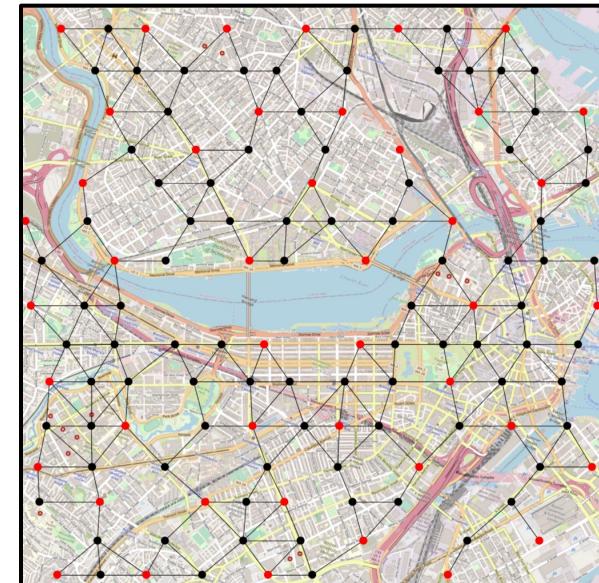
Choose possible locations



Create an atomic twin

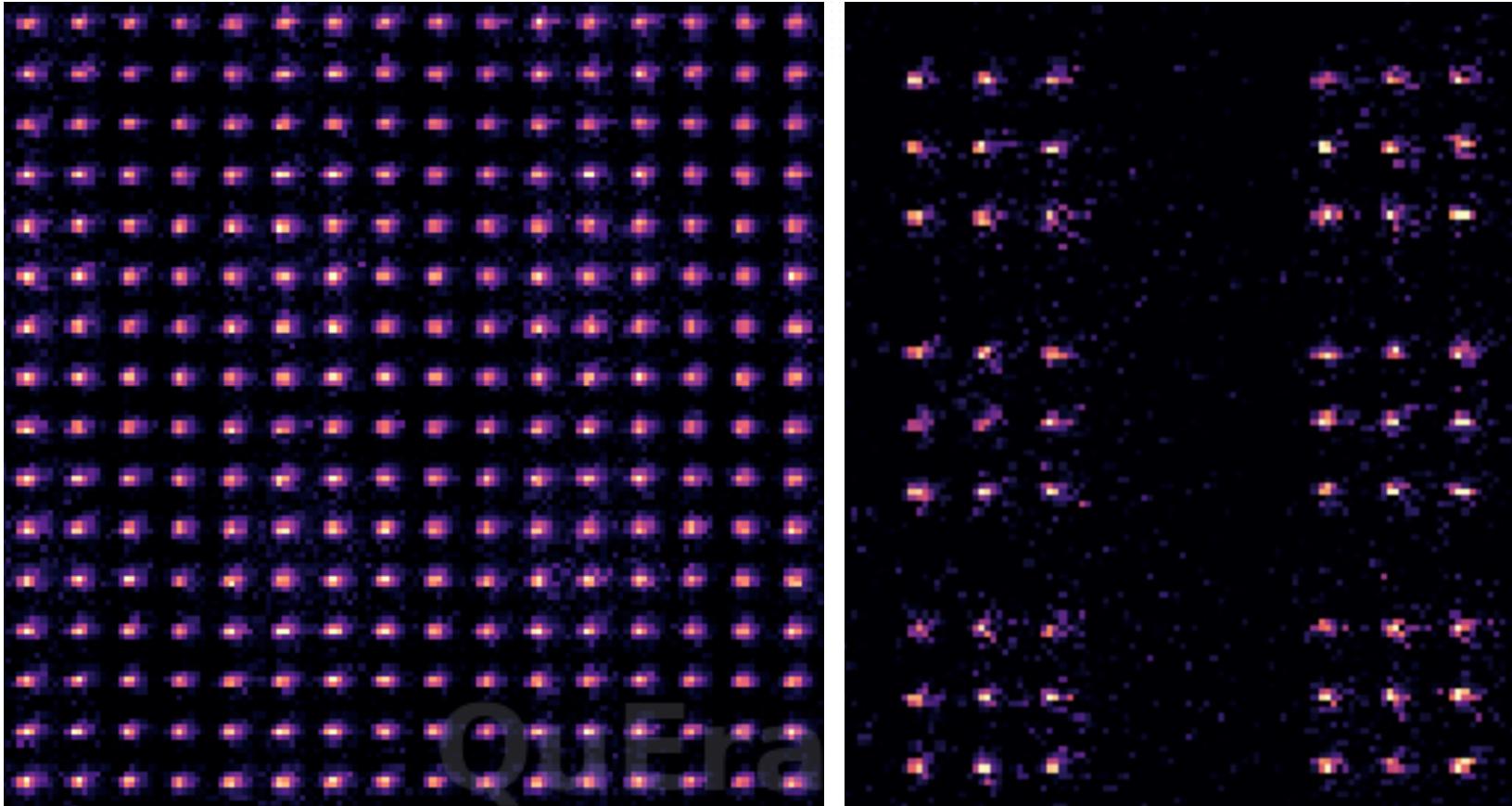


Excite atoms to find answer!

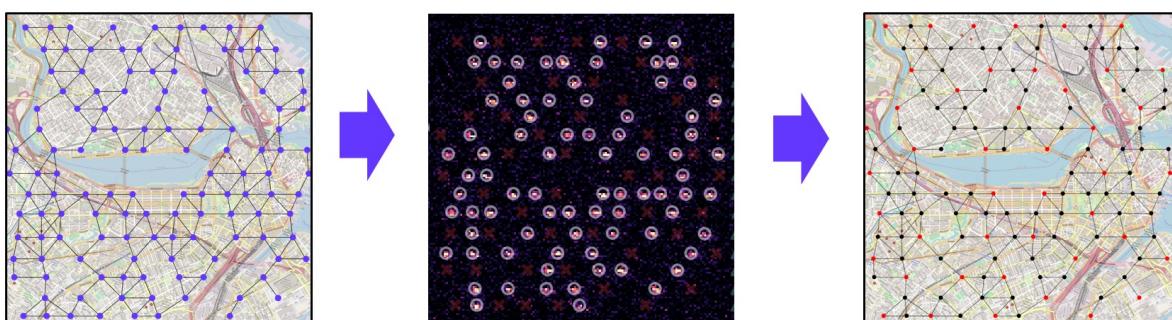
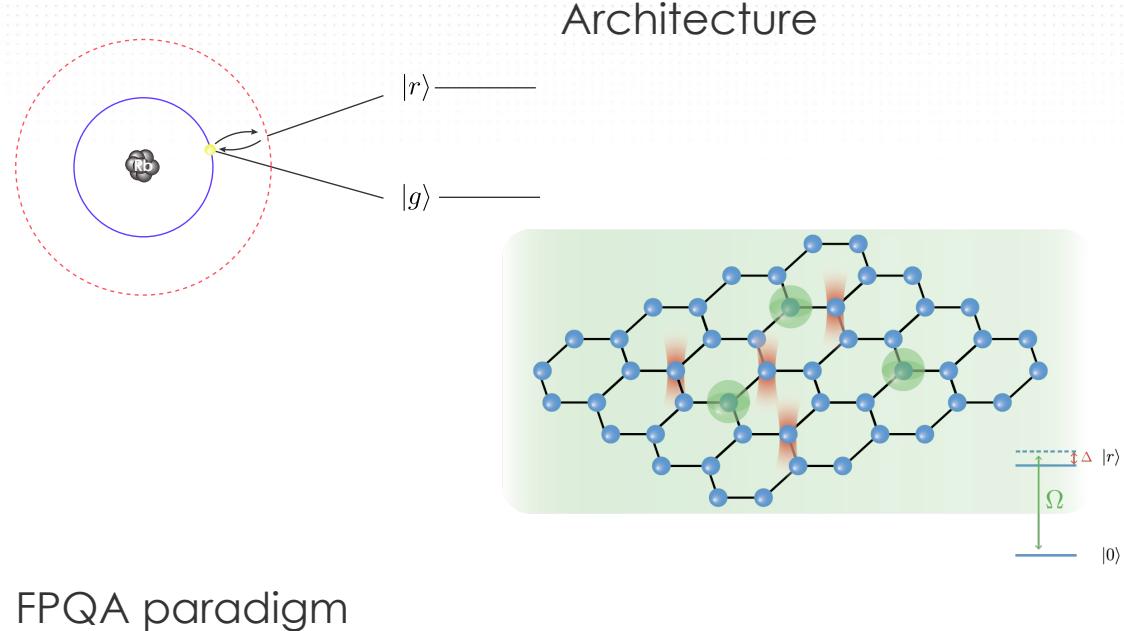


How to optimally cover Boston with coffee shops?

FPQA = Parallelization

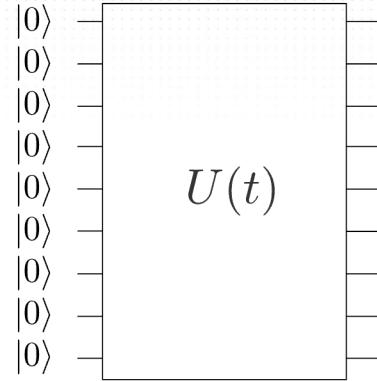


Summary

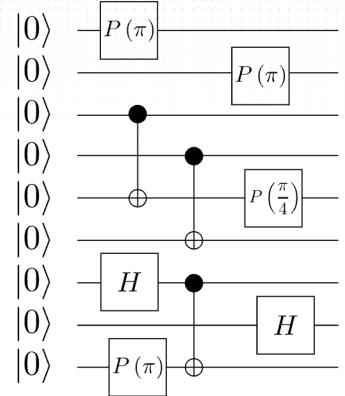


〈QUEFa〉

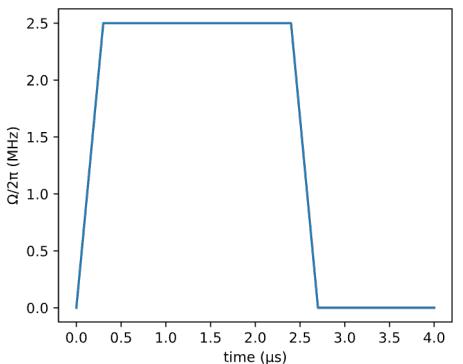
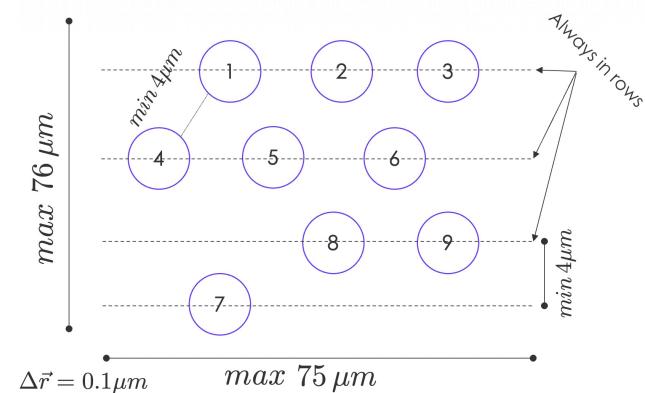
Analog operation



Digital operation



Hardware constraints



Learning objectives

Now you are able to:

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