QUANTUM SIMULATORS

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TYPES OF QUANTUM HARDWARES

	Leading technologies in NISQ era[1]		Candidate technologies beyond NISQ		
Qubit type or technology	**Superconducting[2]**	**Trapped ion**	**Photonic**	**Silicon-based[3]**	**Topological[8]**
Description of qubit encoding	Two-level system of a superconducting circuit	Electron spin direction of ionized atoms in vacuum	Occupation of a waveguide pair of single photons	Nuclear or electron spin or charge of doped P atoms in Si	Majorana particles in a nanowire
Physical qubits[4,5]	IBM: 20, Rigetti: 19, Alibaba: 11, Google: 9	Lab environment: AQT[6]: 20, IonQ: 14	**6×3[9]**	**2**	target: 1 in 2018
Qubit lifetime	**~50–100 µs**	**~50 s**	**~150 µs**	**~1–10 s**	target ~100 s
Gate fidelity[7]	**~99.4%**	**~99.9%**	**~98%**	**~90%**	target ~99.9999%
Gate operation time	**~10–50 ns**	**~3-50 µs**	**~1 ns**	**~1–10 ns**	–
Connectivity	Nearest neighbors	All-to-all	To be demonstrated	Nearest neighbor	–
Scalability	No major road-blocks near-term	Scaling beyond one trap (>50 qb)	Single photon sources and detection	Novel technology potentially high scalability	?
Maturity or technology readiness level	TRL[10] 5	TRL 4	TRL 3	TRL 3	TRL 1
Key properties	Cryogenic operation Fast gating Silicon technology	Improves with cryogenic temperatures Long qubit lifetime Vacuum operation	Room temperature Fast gating Modular design	Cryogenic operation Fast gating Atomic-scale size	Estimated: Long lifetime High fidelities

FUNCTIONS OF A QUANTUM SIMULATOR

Quantum simulators are software programs that run on classical computers and act as the target machine, making it possible to run and test quantum programs in an environment that predicts how qubits will react to different operations.

The quantum simulator is responsible for providing implementations of quantum operations for an algorithm.

This includes primitive operations such as H, CNOT, and Measure, as well as qubit management and tracking.

The Quantum Development Kit includes different classes of quantum simulators representing different ways of simulating the same quantum algorithm.

AVAILABLE SIMULATORS

- IBM’s Qiskit
- Google’s Cirq
- Amazon’s AWS Bracket
- Microsoft’s Q# and Azure Quantum
- Rigetti’s Forest
- Xanadu’s Pennylane

SOFTWARE COMPARISON

Simulators	Company	Supported Softwares	Hardwares
Qiskit	IBM	Python library	Superconducting Qubit
Cirq and Tensorflow Quantum	Google	Python library	Superconducting Qubit
AWS Bracket	Amazon	IonQ, Rigetti, D-Wave	Only a cloud provider to other hardwares
Q# and Azure Quantum	Microsoft	Q#	Topological Qubit
Rigetti / PyQuil / Forest SDK	Rigetti Computing	Python	Superconducting Qubit
Strawberry fields	Xanadu	Python library	Silicon quantum Photonic chips
Pennylane	Xanadu	Cross-platform python library	Supports Qiskit, Amazon Bracket, Strawberry fields, Cirq, Qulacs, AQT, Honeywell, Microsoft QDK, Rigetti Forest, IonQ, Orquestra, ProjectQ

HARDWARE COMPARISON

Manufacturer	**Platform**	**Cloud access**	**Max # qubits**	**Gate fidelity (1-qubit, 2-qubit)**
IBM	Superconducting	IBM Quantum Experience (Open access)	15 (Melbourne)	99.97%, 99.16% (Santiago)
IonQ	Trapped Ions	Microsoft Azure or Amazon Bracket	11	99.50%, 97.50%
QuTech	Silicon	Quantum Inspire	2 (Spin2-QPU)	$\approx$ 99%, $\approx$ 90%
Google	Superconducting	Google Quantum AI	53 (Sycamore)	99.85%, 99.35%
Rigetti	Superconducting	Rigetti Quantum Cloud	31 (Aspen-8)	99.8%, 95.9%
Honeywell	Trapped Ions	Microsoft Azure or Amazon Bracket	10 (H1)	99.97%, 99.5%

CROSS-PLATFORM QUANTUM SIMULATORS

- **Pennylane:** A cross-platform Python library for differentiable programming of quantum computers.

LITERATURE REVIEW

1. Overview and Comparison of Gate Level Quantum Software Platforms, Ryan LaRose
2. Quantum computing hardware in the cloud: Should a computational chemist care? Alessandro Rossi, Paul G. Baity, Vera M. Schafer, and Martin Weides
3. “What To Look For In A Quantum Machine Learning Framework” – link
4. “Trapped Ion, Superconducting, and Photonic” - link

THANK YOU