Opportunities in Quantum Software

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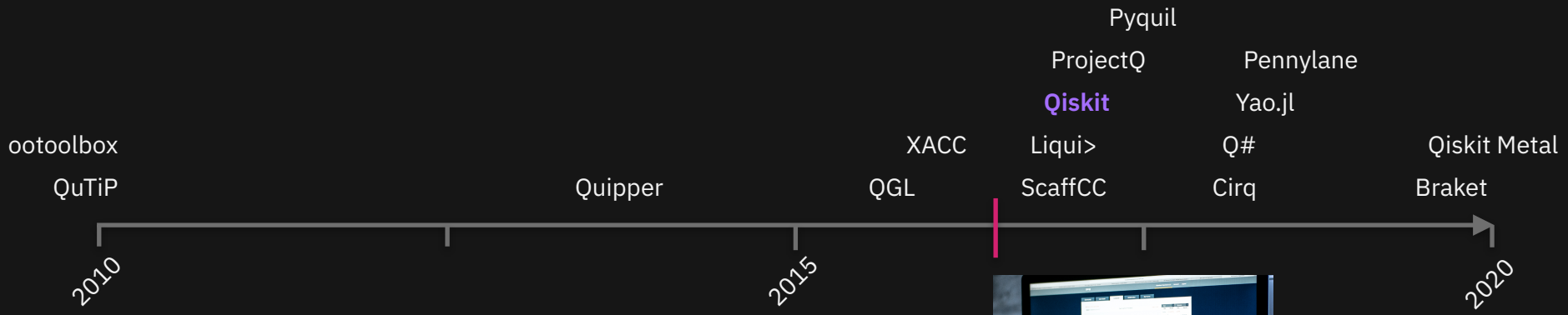
A brief history of quantum software

IBM **Quantum**



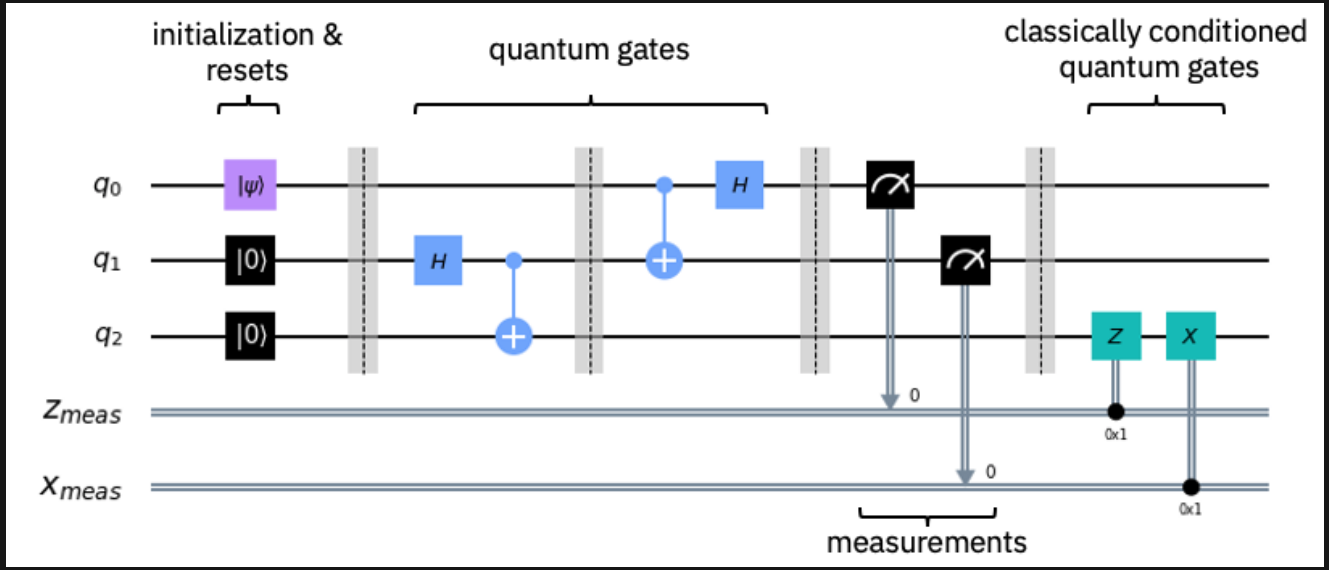
The early days of quantum software were not easy:

“This does not further the advancement of science” - PRA editor

“This is more of an educational topic” - Korea NRF reviewer

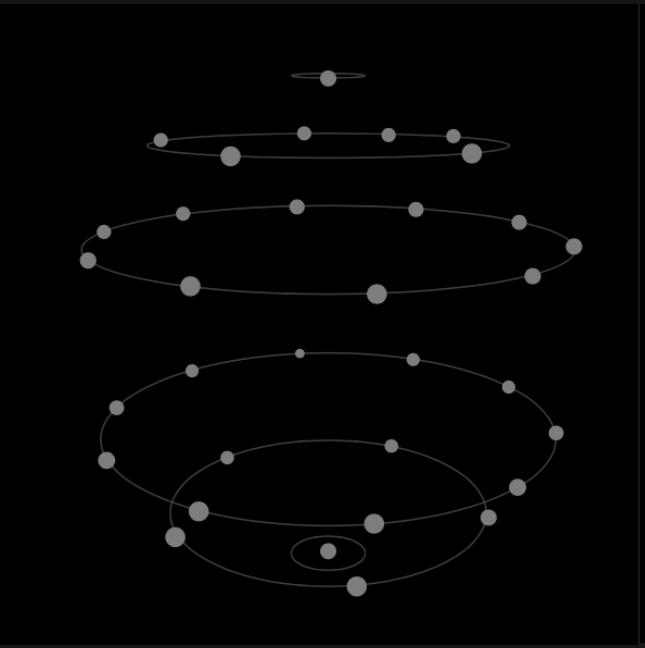
May 4, 2016: IBM Quantum Experience

Quantum circuits

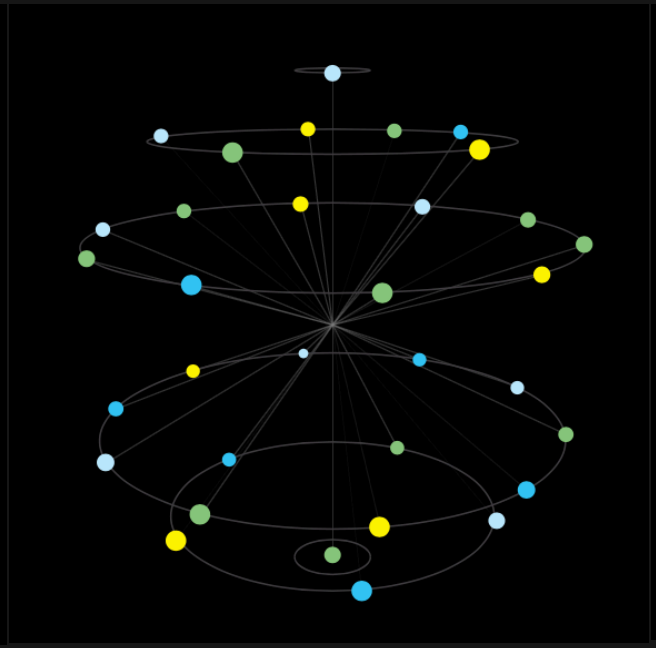


The building block of quantum computation.

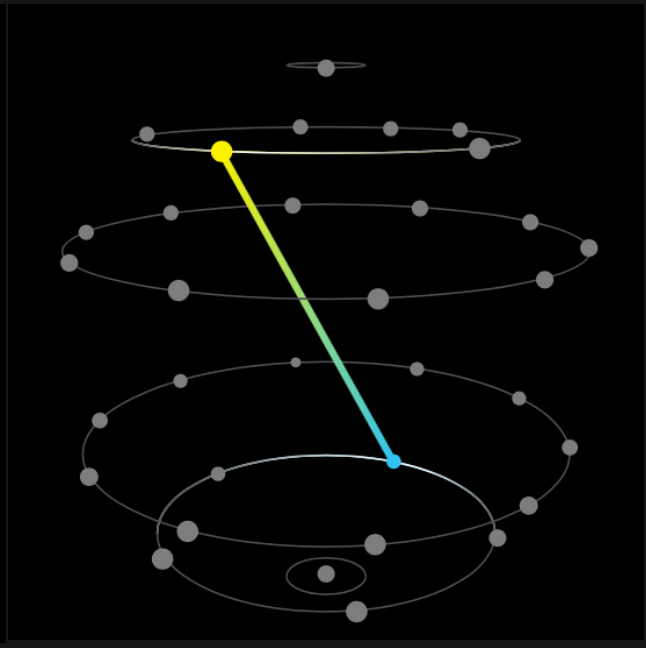
Quantum algorithms (vastly simplified)



Create superposition of all 2^n states.



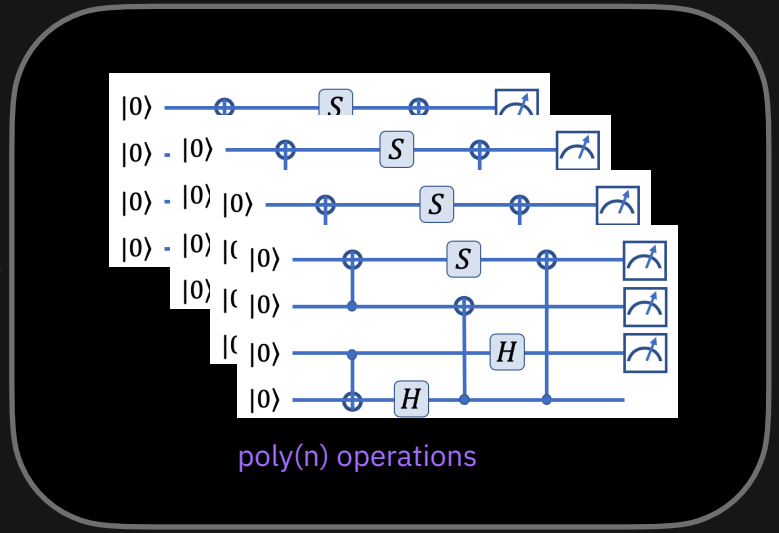
Encode the problem into the phases of the states.



Use interference to bring states back to solution of few outcomes.

Quantum applications

Execute on quantum hardware



Classical computation needed to generate quantum circuit description.

\+

near-time classical computing resources

Quantum hardware

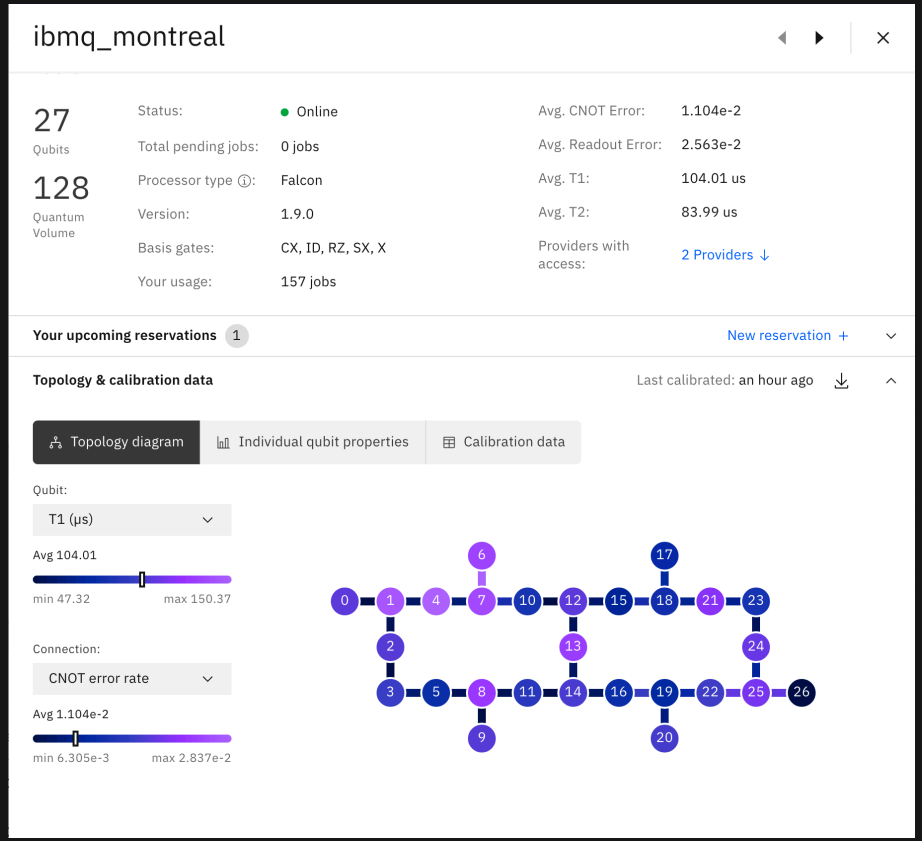
Systems with ~ 100 available online via the cloud.

Error rates approaching 10^{-3} for two-qubit gates.

Systems now beyond the computation power of classical simulation methods.

No fault tolerance in the near-term.

Can we demonstrate advantage over classical compute capabilities for one or more problem instances on a noisy quantum system?



Quantum problems

Modeling Nature	Mathematics	?
Quantum chemistry	Shor’s algorithm	**Plenty of room for advancements**
Material science	Grover’s algorithm	
High-energy physics	Linear systems	
	Optimization	
	Machine learning	

= heuristic algorithms

- Model developers

- Algorithm developers

- Kernel developers

Quantum software needed at all levels

Quantum circuits: The kernel developer

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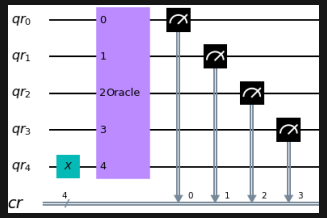
High-fidelity quantum experiments require advanced quantum circuit compilation routines.

Input circuit



Compiler (Terra)

do-while

conditional

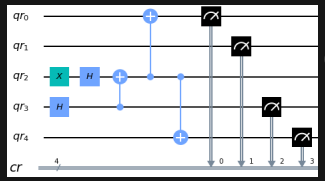
Pass A (unroll) → Pass B (swap) → Pass C (depth check) → Pass D (merge)

Transpiler

Pass A (as soon as possible) → Pass B (dynamical decoupling) → Pass C (optimal control)

Scheduler

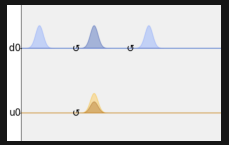
Synthesis Tools | Gate Library | Pulse Library | Device Properties



OpenQASM

OpenPulse

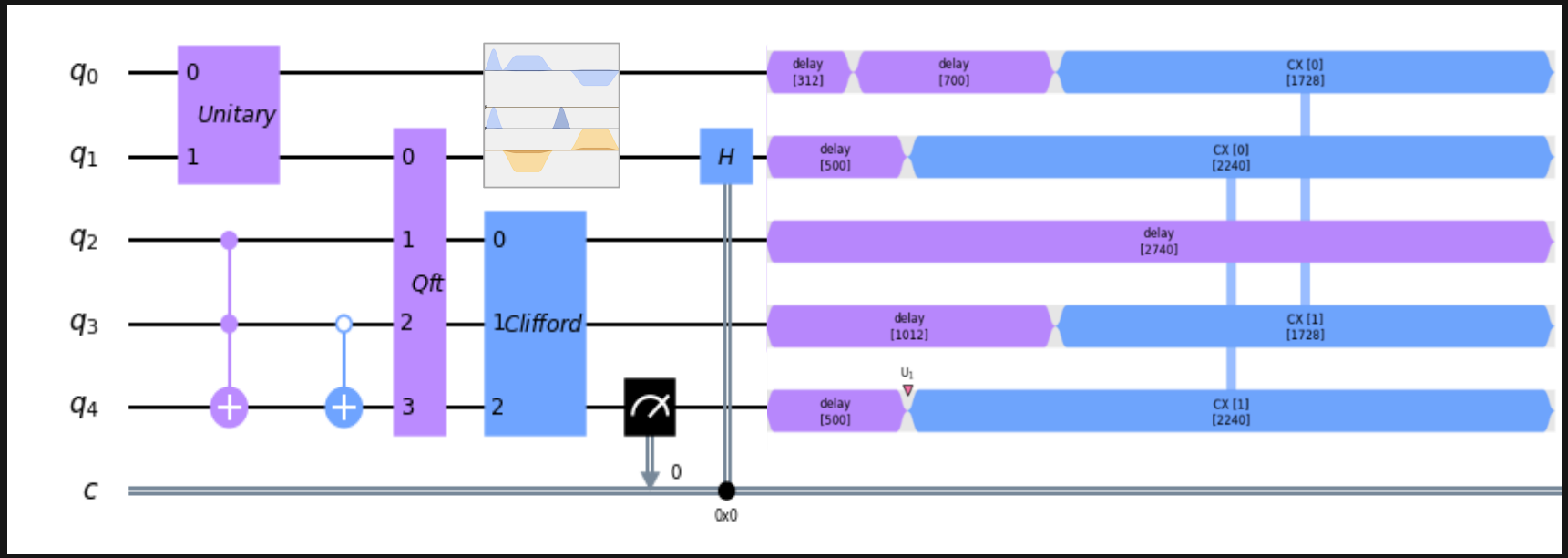
Optimized Schedule(s)



Quantum circuits: The kernel developer

IBM **Quantum**

Near-term systems require understanding of underlying physics at the pulse-level.



Algorithm developers

Apply domain-specific knowledge to transform a problem of interest into something a quantum system can execute.

Typically leverage existing classical computing toolchains for problem description.

Solution methods are typically heuristics with unknown metrics for determining advantage over classical compute.

This is where much of the action is today.

Variational quantum eigensolver (VQE)

(1) Express problem as Hamiltonian in terms of Pauli operators.

$$H = \sum_{\alpha} h_{\alpha}\sigma_{\alpha}$$

(2) Determine parameterized trial solution $|\psi(\vec{\theta}_i)\rangle$.

(3) Measure energy via expectation values.

$$\langle\psi(\vec{\theta}_k)|H|\psi(\vec{\theta}_k)\rangle$$

(4) Iterate until solution is found.

■ = domain specific

Model developers


```
# describe the problem
qubo = QuadraticProgram()
qubo.binary_var('x')
qubo.binary_var('y')
qubo.binary_var('z')
qubo.minimize(linear=[1, -2, 3], quadratic={('x', 'y'): 1,
                                            ('x', 'z'): -1,
                                            ('y', 'z'): 2})
```

```
# choose a solver
qaoa = MinimumEigenOptimizer(QAOA(backend))

# solve it
result = qaoa.solve(qubo)
```

Abstract away quantum circuits and algorithms for use by non-experts.

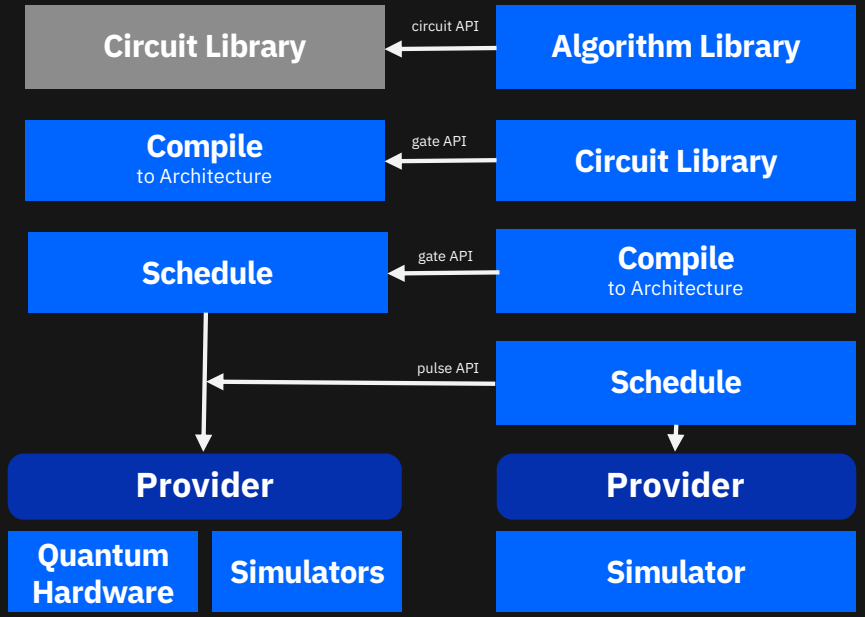
Let users use the tools they are familiar with.

Take advantage of the underlying stack to create full-featured local and cloud-based applications.

This is still very early and experimental (which means it is interesting!).

Qiskit: The power of open science

No matter what your interest, Qiskit has a place for you to learn and extend the quantum computing landscape.



Quantum Developer, Quantum Researcher

Quantum Information Scientist

Physicist

Physicist

Depth of Quantum skills

Thank You