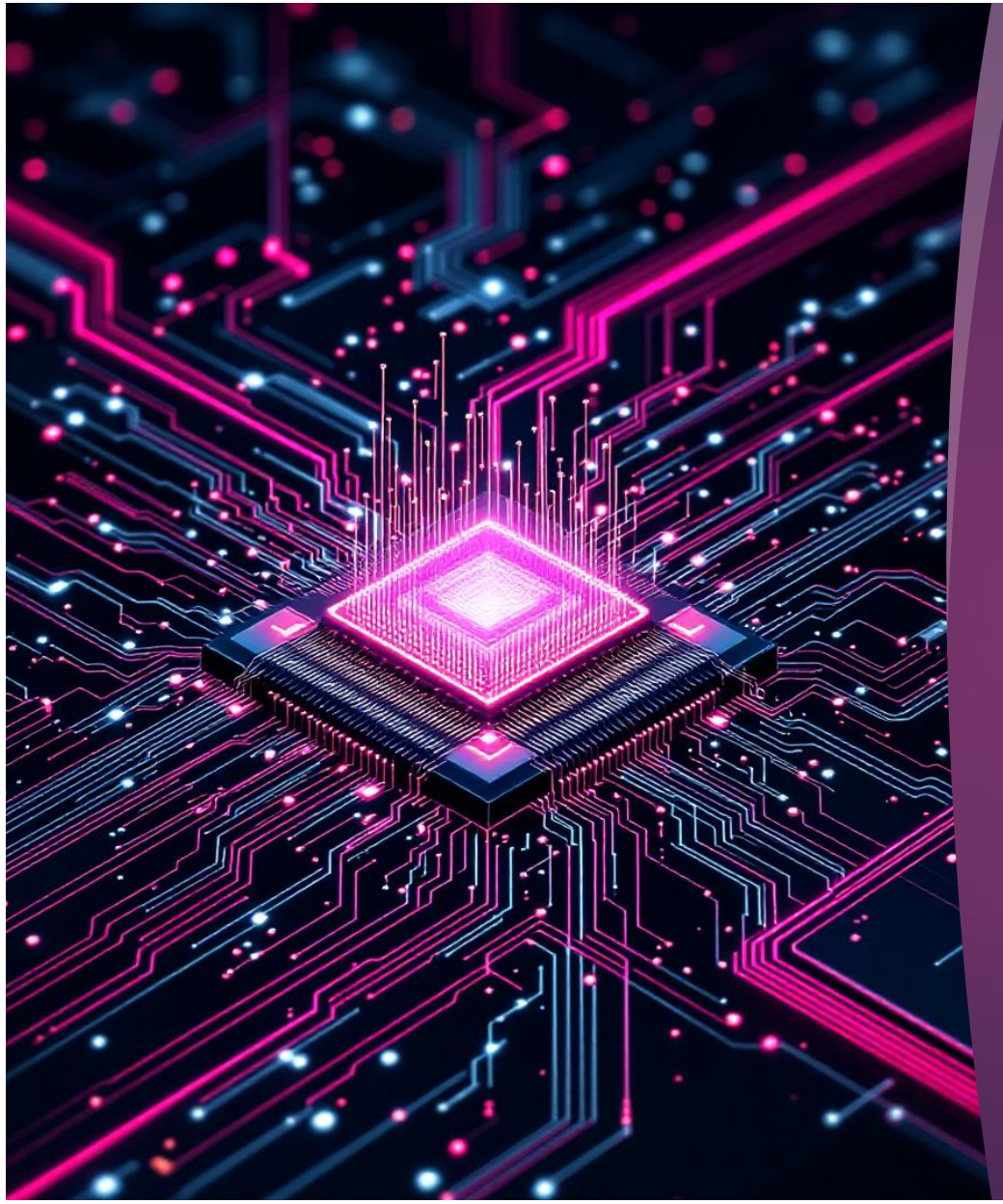


Quantum-Centric Supercomputing

BRIDGING QUANTUM & CLASSICAL WORLDS

The Exponential Scaling Challenge

Exponential Growth

- Quantum state space: 2^N basis states
- Classical resources scale exponentially

The Universe Barrier

- 270 qubits = $2^{270} \approx 10^{81}$ states
- More states than atoms in the universe

Practical Impact

- Chemistry & materials problems hit this wall quickly
- Classical storage becomes impossible

This isn't a hardware limitation; it's a fundamental mathematical barrier for classical computers

Why Quantum Hardware Provides Natural Advantage

Classical Computing

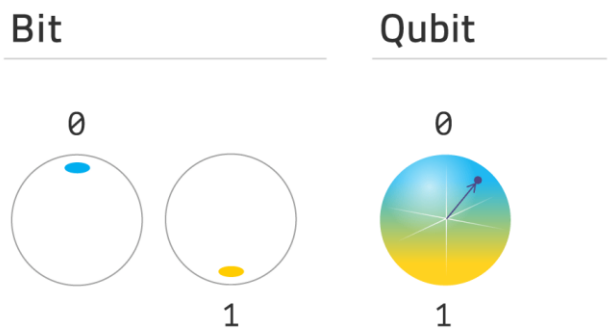
Bits: 0 or 1

Sequential processing of definite states

Quantum Computing

Qubits: Superposition & entanglement

Natural quantum mechanical rules



Adapted from 1QBit

Current Quantum Processor Constraints

Limited Qubit Count

- ~150-200 qubits available on leading systems

Noisy Operations

- Pre-error correction era ("NISQ"); errors accumulate
- Limited to ~5,000 gates before decoherence

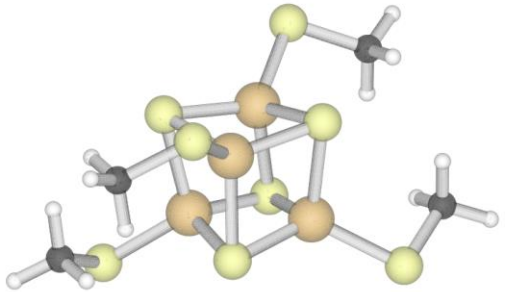
Incomplete Workflows

- Cannot run end-to-end algorithms alone

Real Example – Fe_4S_4 Cluster

Biological electron transfer protein simulation

- Requires 6.7M Pauli operator measurements
- Chemical accuracy demands exceed quantum-only capability
- Perfect case for hybrid approach



Fe_4S_4 on **72** qubits (TZP-DKH basis set): **6.7M** Pauli operators

10^{-10} precision on each operator for milliHartree precision

Each circuit must be executed **10^{20}** times

Runtime at 10µs/circuit ~**3M years**

Adapted from IBM Corporation

Classical can't handle exponential scaling.

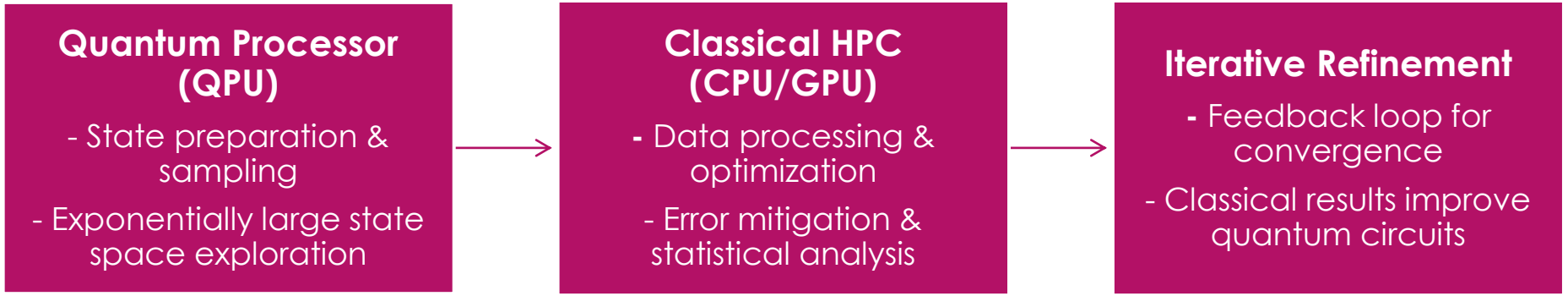
Quantum isn't mature enough for complete algorithms.

Quantum-centric supercomputing bridges this gap.

Quantum-Centric Architecture

Division of Labour

Each system performs what it does best - collaborative computing at scale



Core Principle: Task allocation - quantum hardware for exponentially hard quantum sampling, classical hardware for data processing, linear algebra, and optimization.

Demonstrated Performance: Real Results

Fe_4S_4 on 72 qubits (TZP-DKH basis set): 6.7M Pauli Operators

~ 3M years of computational time

VQE estimation at 10μs/circuit

- Pre-fault tolerant

~ 2 Hours to solution

Subspace estimation at 10μs/circuit

- Quantum-Centric supercomputing

N_2 Dissociation
Chemical bond breaking analysis

Protein Clusters
Iron-sulfur biological systems

Phase Transitions
Materials science applications

Active users: Cleveland Clinic (drug discovery), Lockheed Martin (aerospace materials)

Current State & Timeline

Not waiting for perfect quantum computers; using imperfect quantum hardware productively now

2023

Quantum utility achieved ✓

Demonstrated in Nature publication

2024-2025

We are here

Operational chemistry applications

2026-2027

Quantum advantage predicted

Best solution for targeted problems

Key Insight: Hybrid computing enables utility-scale applications *decades before* full quantum error correction

Quantum AND Classical

Collaborative Computing

Integration

Not replacement; collaborative partners

Operational Today

Not theoretical; practical applications running

Path to Advantage

Enabling what neither achieves alone