JUNIQ Benchmark Suite: A Decade of Application Benchmarks on Quantum Computers

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***Abstract*—As quantum computing hardware rapidly evolves, traditional metrics like gate fidelity and Quantum Volume are insufficient for predicting real-world utility. Researchers and industry users need objective, application-centric benchmarks to gauge when quantum processors will be ready for practical tasks. We present the JUNIQ Benchmark Suite (JBS), a comprehensive collection of application-driven benchmark problems and an open-source framework. JBS hosts an extensive repository of empirical performance data collected over more than a decade (2016–2026) across over 30 analog and digital quantum processing units (QPUs), tracking quantum technology readiness over successive hardware generations.**

***Index Terms*—Quantum computing, Benchmarking, Quantum processing units (QPU), Quantum computing applications, Reproducibility, Open science.**

I. Introduction

A quantum processor might excel at synthetic benchmarks yet struggle with real-world problems in combinatorial optimization, machine learning, or physical simulations. Standard metrics such as Quantum Volume or single-gate error rates often fail to capture the practical utility of these devices for scientific and industrial applications. Furthermore, the lack of standardized, reproducible benchmarking infrastructure makes it difficult for independent researchers to validate performance claims or track technology readiness levels (TRL) over long timescales.

Vendor-specific benchmarks can be biased toward showcasing hardware strengths while downpaying weaknesses, leaving users unable to assess when hardware is ready for domain-specific deployment. To address this, we introduce the JUNIQ Benchmark Suite (JBS), an application-centric, open-source benchmarking framework that objectively measures progress across hardware generations.

II. Approach and Novel Contributions

JBS is built for long-term evaluation, holding a decade of historical benchmark dataset tracking performance from early QPU prototypes (e.g., IBM Q Experience in 2016 and D-Wave 2000Q in 2017) across 30+ processors to state-of-the-art systems such as D-Wave Advantage2. Our primary contributions include:

A. Application-Centric Benchmarking

We shift focus from abstract hardware metrics to real-world application problems, evaluating QPUs based on solution quality, success probability, and scaling behavior across relevant domains.

B. Infrastructure for Reproducibility

A major barrier to credible benchmarking is software dependency drift. JBS introduces a standardized workflow via a CLI infrastructure toolchain that enforces a four-step lifecycle for every benchmark: **Init** → **Generate** → **Verify** → **Benchmark**. Integrated with continuous integration (CI) pipelines, this workflow guarantees that problem instances created today remain fully reproducible years later regardless of underlying software updates.

C. Open Science by Design

JBS is a vendor-agnostic initiative provided by an independent research lab to the community. Standardized templates and tooling are provided to lower the barrier for researchers to contribute new problem instances, fostering a transparent ecosystem where hardware vendors and users can define practical success.

III. Benchmark Suite Overview

The suite encompasses over 15 benchmark problems spanning diverse domains:

- **Hardware Diagnostics:** *Effective Qubit Temperature* (thermalization distribution analysis) and *Rabi Oscillation* (single-qubit control and decoherence).
- **Machine Learning & Sensing:** *Quantum Support Vector Machines (QSVM)* for classification in biological sequence analysis and remote sensing.
- **Optimization & Logistics:** *Travelling Salesman Problem (TSP)*, *Tail Assignment* (airline routing), *Garden Optimization*, *Weighted MaxCut*, *Knapsack Problem*, and *2-Satisfiability (2-SAT)*.
- **Quantum Simulation & Physics:** *Maximum Independent Set (MIS)* on Unit Disk Graphs, *Domain Wall Benchmark*, *False Vacuum Decay*, *GHZ State Preparation*, *Factoring*, and *Singlet State Characterization* (testing closeness to quantum theory).

IV. Long-Term Progress Tracking

Having systematically evaluated identical benchmark problems across a decade of empirical data (2016–2026), JBS

provides concrete evidence on hardware maturation. This includes comparative studies on over 30 analog quantum annealers, digital gate-based QPUs (AQT, IBM, IQM, Quantinuum, IonQ), and neutral atom architectures, establishing transparent benchmarks for practical quantum technology readiness.

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