

2026年度北海道大学情報基盤センター萌芽型共同研究成果報告書

1. 研究類型 A)計算資源利用型

2. 研究課題名 Implementation of a differentiable large-scale tensor network contraction framework

3. 研究期間 2025年7月18日～2026年3月31日

4. 研究代表者

氏名	所属機関・部局名	職名	備考
SUN ZHUN	東北大学 言語 AI 研究センター	特任准教授	

5. 研究分担者

氏名	所属機関・部局名	職名・学年	備考
棟朝 雅晴	北海道大学 情報基盤センター	教授	

6. 共同研究の成果

Results of Joint Research

1. **Overview and Achievement of Research Objectives** Through this collaborative research, we successfully developed **tneq_qc**, an open-source software framework for differentiable large-scale tensor network contraction (TNC). This directly fulfills the primary

research purpose outlined in our application: integrating state-of-the-art TNC techniques with robust automatic differentiation (AD) capabilities to overcome the computational bottlenecks in quantum many-body simulations and machine learning.

2. Specific Research Content and Methodology

In alignment with our four-phase research plan, the following technical milestones were achieved:

- **Framework Architecture (Phase 1 & 2):** We implemented a modular, layered architecture consisting of a Model Layer (for ASCII-based graph specification), a Strategy Layer (for optimized pathfinding), and a Backend Layer. This design allows for seamless switching between numerical backends such as PyTorch and JAX while maintaining a unified interface for differentiable execution.
- **Differentiable Operations and Scalability (Phase 3):** The framework supports end-to-end backpropagation through tensor contractions. To address scalability, we developed a distributed execution stack that partitions tensor network cores across multiple workers, using hierarchical reductions to combine results.
- **Benchmarking and Validation (Phase 4):** We validated the framework through diverse tasks, including image reconstruction using the MNIST dataset and quantum tensor network (QTN) equation matching.

3. Significance and Importance The significance of this research lies in bridging the gap between physics-oriented libraries (which lack AD support) and ML-oriented frameworks (which lack TNC-specific optimizations). `tneq_qc` provides a practical platform for "quantum-inspired machine learning" by treating core tensors as trainable parameters. Furthermore, our distributed benchmarks demonstrate that the framework is not only a performance optimizer but also a critical memory-management tool for large-scale models. For instance, at 145 qubits with a physical dimension of 16, distributed execution reduced peak memory usage by approximately 40% (from 17.1 GB to 10.2 GB).

4. Research Outcomes (Performance Metrics)

The following table summarizes the performance gains achieved through the distributed execution module developed during this project:

Qubits	Execution Mode	Avg. Step Time	Peak Memory (RSS)	Speedup	Memory Saving
97	Standalone	38.34 s	3229 MB	-	-
97	2-Process Dist.	9.32 s	2348 MB	4.1x	-27%
145	Standalone	61.01 s	4531 MB	-	-
145	2-Process Dist.	16.64 s	3157 MB	3.7x	-30%

(Data derived from distributed benchmarks on CPU gloo backend)

5. Publication and Presentation Records

The results of this joint research have been compiled into a formal research paper and submitted for peer review:

- **Paper Title:** *tneq_qc: Tensor Network Engine toward Quantum: Yet Another Software But More Flexible, Learnable, and Distributable.*
- **Preprint:** Available on arXiv (<https://arxiv.org/abs/2605.00140>). This manuscripts will be submitted to The 9th Workshop on Tractable Probabilistic Modeling (UAI 2026) and ICML 2026 Workshop on AI for Physics.
- **Open Source Contribution:** The source code developed through this project is hosted at <https://github.com/minogame/tneq-qc>.