Mehdi Soleimanifar

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Overview

- Postdoctoral researcher with a background in theoretical physics and quantum computing, currently transitioning into AI research.
- Interested in developing and applying AI systems with broad reasoning capabilities to accelerate progress in science and technology.
- Experienced in designing, analyzing, and validating machine learning algorithms for complex, high-dimensional scientific problems.

Education and Employment

Ph.D. in Theoretical Physics, Massachusetts Institute of Technology 2016-2022
Thesis: Efficiently Learning, Testing, and Simulating Quantum Many-Body Systems
Advisor: Aram Harrow

Postdoctoral Researcher, California Institute of Technology 08/2022-Present
hosted by: John Preskill and Urmila Mahadev

AI/ML Research Experience

- **Simplified AlphaEvolve: LLM-Guided Heuristic Discovery:** Implemented a lightweight version of Google DeepMind's AlphaEvolve to show how LLMs can iteratively invent and refine heuristics within a population-based search. Achieved competitive performance on the NP-hard bin packing problem using modest computational resources (e.g., GPT-4.1-nano), demonstrating the potential of LLM-guided search to produce novel algorithmic solutions. **Code** | **Technical Report**
- **LLM Steering of Pre-Trained RL Agents Toward Out-of-Distribution Goals:** Built a system where a pretrained RL policy (using DreamerV3) is intermittently paused and guided by an LLM that issues high-level action sequences to accomplish out-of-distribution goals. In the Crafter environment, this setup enabled the agent to perform complex tasks such as bridge and tunnel construction without retraining. Achieved 91% success on new tasks while maintaining performance on original game objectives through optimized intervention timing. **Code** | **Technical Report**
- **Tiny Labs: Interactive Benchmark for AI-Driven Scientific Discovery:** Developed TinyLabs, a lightweight framework for generating interactive benchmarking environments to evaluate LLMs on scientific reasoning across selectable domains (e.g., genomics, climate modeling, economics). The framework supports systematic assessment of pattern recognition, causal inference, and hypothesis generation. **Code** | **Technical Report**
- **Quantum System Learning:** Designed, implemented, and validated sample-efficient algorithms for learning quantum many-body systems, exponentially reducing sample complexity compared to traditional methods while maintaining performance guarantees for system reconstruction and property extraction. **Article 1 (Nature Physics)** | **Article 2 (Nature Physics)** | **Article 3**
- **Publications & Impact:** Publications in flagship computer science and physics venues including Nature Physics, PRL, FOCS, STOC, and SODA

Skills

Machine Learning & Artificial Intelligence: Large language model evaluation, fine-tuning, and prompt engineering; reinforcement learning (Policy Gradient, PPO, GRPO, RLHF); neural architectures (Transformers, GRU, RNN, MLP); experiment tracking with Weights & Biases and TensorBoard.

Algorithm Design & Optimization: Sample-efficient learning methods, complexity and performance analysis, specialized simulation algorithms for physical systems, heuristic search design, and integration of ML with scientific computing.

Programming & Experimental Infrastructure: Python; PyTorch, NumPy, SciPy, Hugging Face Transformers, TRL, Gymnasium; distributed training on HPC clusters (H100/A100 GPUs) using SLURM; Git-based version control; reproducible workflows.

Research & Collaboration: Cross-disciplinary project leadership, mentoring, peer-reviewed publications, conference presentations, and scientific writing.

Selected Publications

* *Indicates alphabetical order and equal contribution.*

1. A. Anshu*, S. Arunachalam*, T. Kuwahara*, M. Soleimanifar*. *Sample-Efficient Learning of Interacting Quantum Systems*. Nature Physics 17, 931–935 (2021); also in the proceedings of FOCS 2020, pp 685-691.

2. H. Huang*, J. Preskill*, M. Soleimanifar*. *Certifying Almost All Quantum States with Few Single-Qubit Measurements*. To appear in Nature Physics; also in the proceedings of FOCS 2024, pp 1202-07.

3. A. Anshu*, A. Harrow*, M. Soleimanifar*. *Entanglement Spread Area Law in Gapped Ground States*. Nature Physics 18, 1362–1366 (2022).

4. T. Yang*, M. Soleimanifar*, T. Bergamaschi, J. Preskill. *When Can Classical Neural Networks Represent Quantum States? arXiv:2410.23152*.

5. M. Soleimanifar*, J. Wright*. *Testing Matrix Product States*, in proceedings of SODA 2022, pp 1679–1701.

6. A. Ramkumar, M. Soleimanifar, *Mixing Time of Quantum Gibbs Sampling for Random Sparse Hamiltonians*. To appear in proceedings of TQC 2025.

Selected Awards

- AWS Quantum Postdoctoral Scholarship, Caltech (2022-2025)
- Quantum Innovator in Computer Science and Mathematics, IQC Waterloo (2022)
- IBM Prize for Excellent Contributed Talk, Physics of Computation Conference (2021)
- Buechner Graduate Teaching Prize, MIT (2020)
- Presidential Fellowship for Graduate Studies, MIT (2016-2017)

Professional Activities

- **Program Committee Member:** QIP 2025, TQC 2025
- **Journal & Conference Reviewer:** Nature Physics, Nature Communications, PRL, PRX Quantum, Physical Review A, SIAM Journal on Computing, Quantum, STOC, FOCS, QIP, ESA, ICALP, TQC, ITCS

Selected Talks

- When Can Classical Neural Networks Represent Quantum States? AWS–Chan Meeting, Caltech (2024)
- Machine Learning Models of Quantum States, Google Quantum-CS Seminar (2024)
- Sample-Efficient Learning of Quantum Many-Body Systems, FOCS (2020)
- New Features of Interacting Quantum Systems and Algorithmic Applications, IQC Waterloo (2022)