Quantum Information Technologies: a New Frontier for Visualization

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Challenge: *Quantum Information Science (QIS) technologies introduce a fundamental shift in computing paradigm*
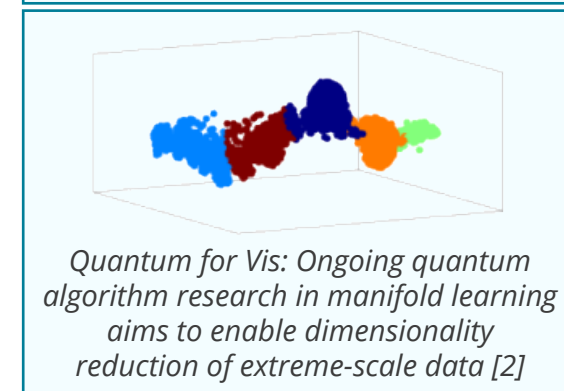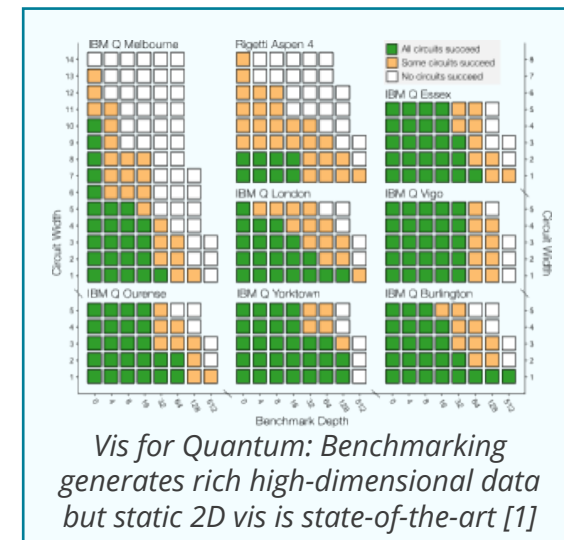
- *Vis for Quantum:* near-term systems are akin to noisy experiments
  - Generate massive data that must be harnessed for control, optimization, and verification
  - Shift from binary, deterministic regime to probabilistic based on qubits
  - Data is discrete, high-dimensional (exponential in # of qubits), stochastic, underlying non-Markovian dynamical system
  - Parametrized high-dimensional probability distributions
- *Quantum for Vis:* Nascent research on vis tools enabled by processing data using quantum computers

Opportunities: *Strategic engagement between Vis & QIS communities*

- Immediate: R&D to enable QIS community to extract insights from benchmarking data
  - Explore high-dimensional data interactively
- Near-term: Co-design algorithms/tools to visualize quantum-enabled science
  - Analyze functions of distributions: variational optimization, adaptive execution, and verification
- Long-term: Explore unique directions for visualization enabled by quantum computing hardware
  - Extend research in quantum manifold learning to extract insights from extreme-scale data

Timeliness: *QIS is a national technology and strategic priority*

- National Quantum Initiative Act
- DOE SC investments across program offices & in large interdisciplinary QIS research centers
- ASCR investments in quantum testbeds, algorithms, networking, & software stack research

Potential for impact: *broadly enabling DOE science capabilities currently out of reach to high performance computing*

Vis for Quantum: Benchmarking generates rich high-dimensional data but static 2D vis is state-of-the-art [1]

Quantum for Vis: Ongoing quantum algorithm research in manifold learning aims to enable dimensionality reduction of extreme-scale data [2]

[1] T. Proctor, K. Rudinger, K. Young, E. Nielsen, and R. Blume-Kohout, "Measuring the Capabilities of Quantum Computers," (2008) http://arxiv.org/abs/2008.11294
[2] A. Kumar and M. Sarovar, "Manifold Learning via Quantum Dynamics," (2022) https://arxiv.org/pdf/2112.11161.pdf