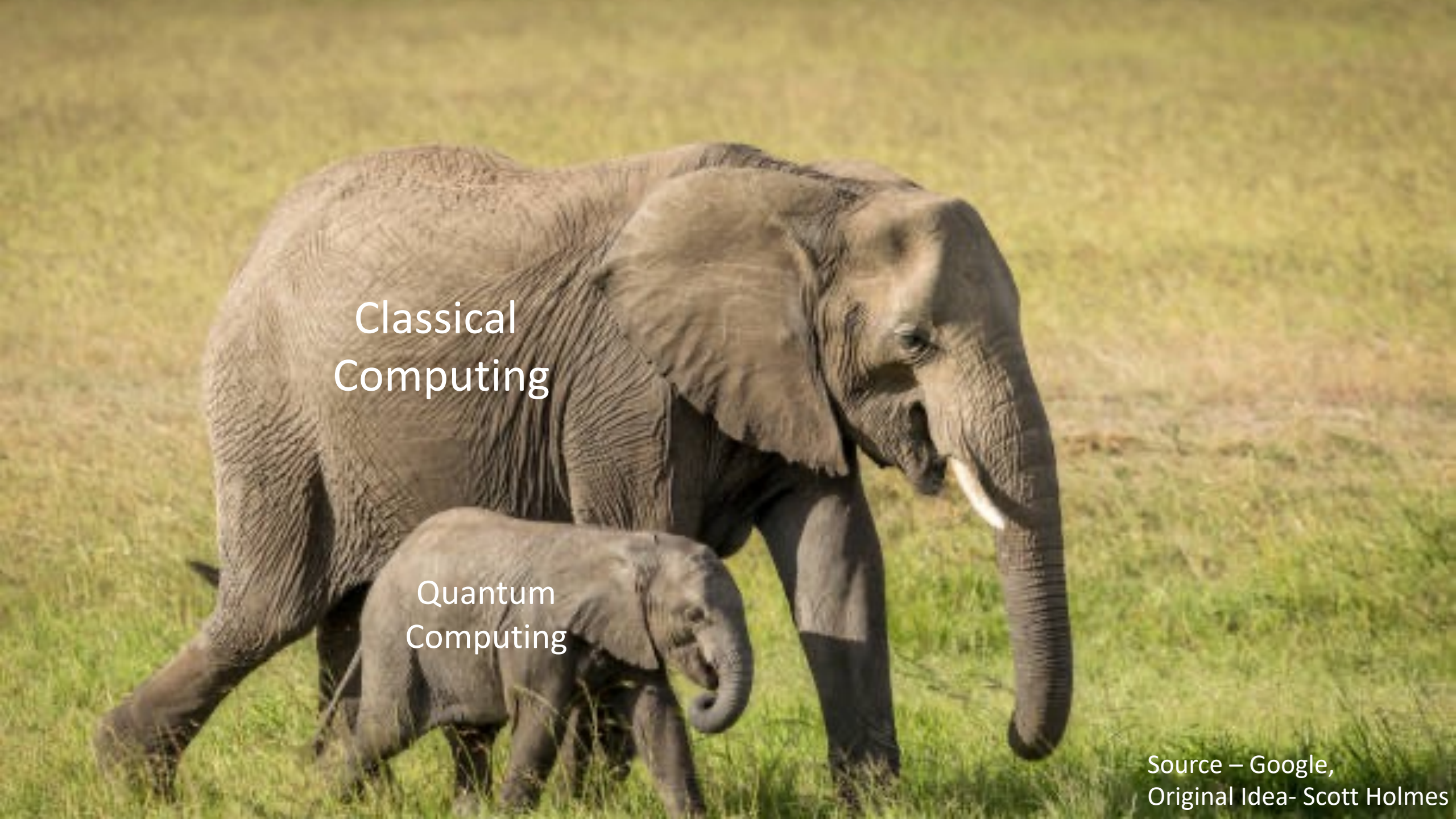
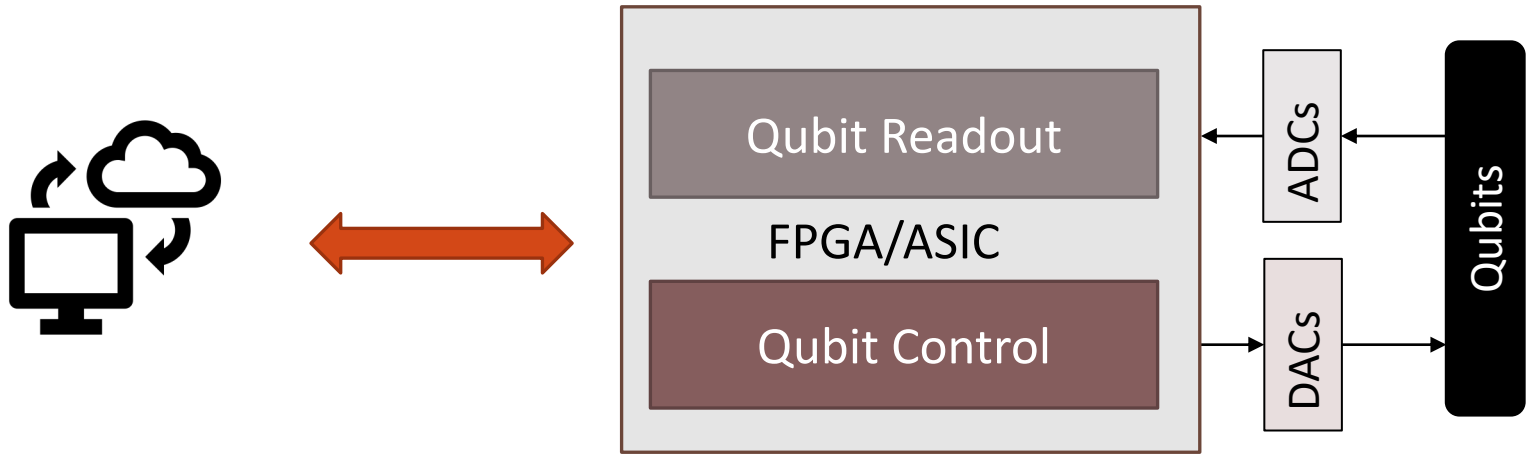


Source – Google,
Original Idea- Scott Holmes

Hybrid Quantum-Classical Systems: Architectures, Resource Management, and Security (Part-2)

Swamit Tannu

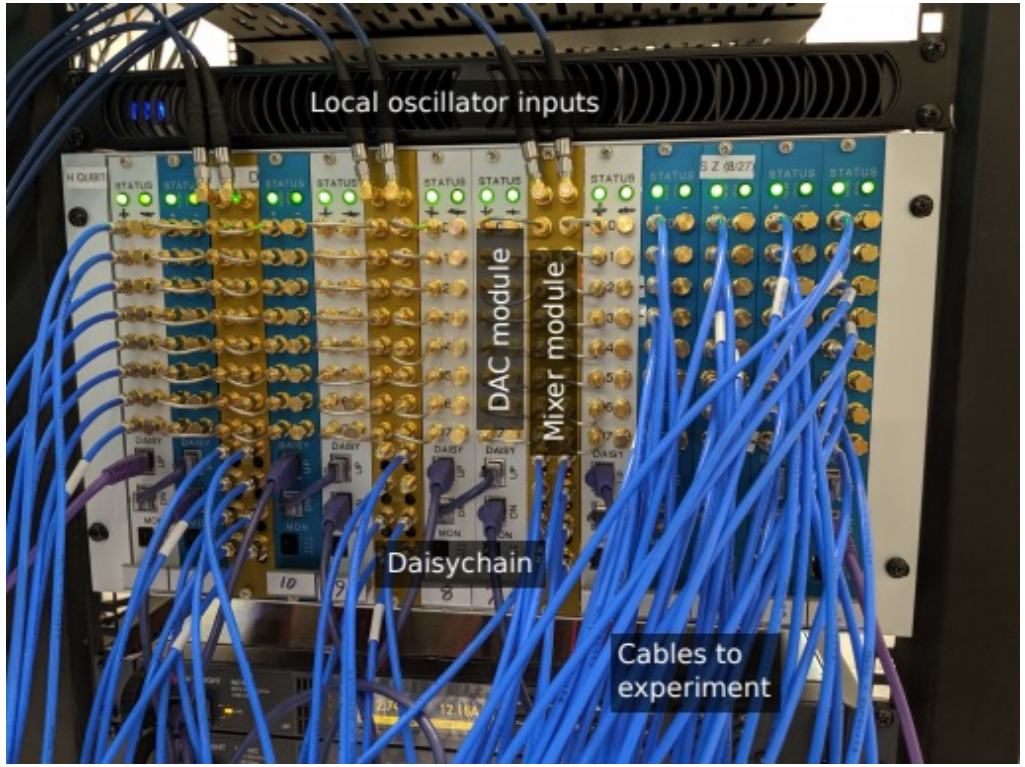
Quantum Control Hardware



Qubit Control: Responsible for manipulating the state of the qubits

Qubit Readout: Responsible for measuring the state of the qubits (0/1)

Control Hardware is Expensive



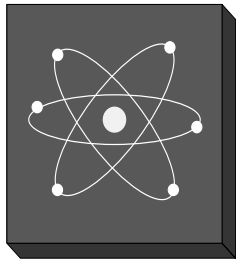
Control hardware for Google Sycamore

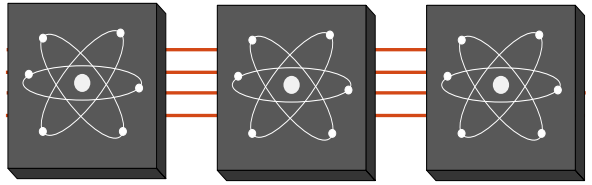
Number of qubits	53
Number of FPGAs	30+
Number of DACs	200+
Number of mixers	50+
Number of cables	200+

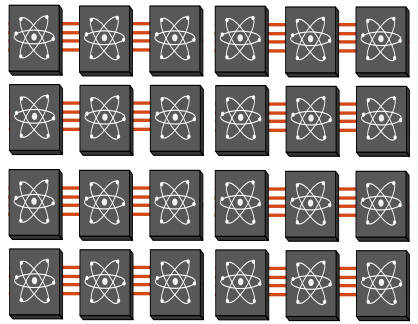
Mitigate Hardware Errors

Scale Control Architecture

New Materials, Devices, …







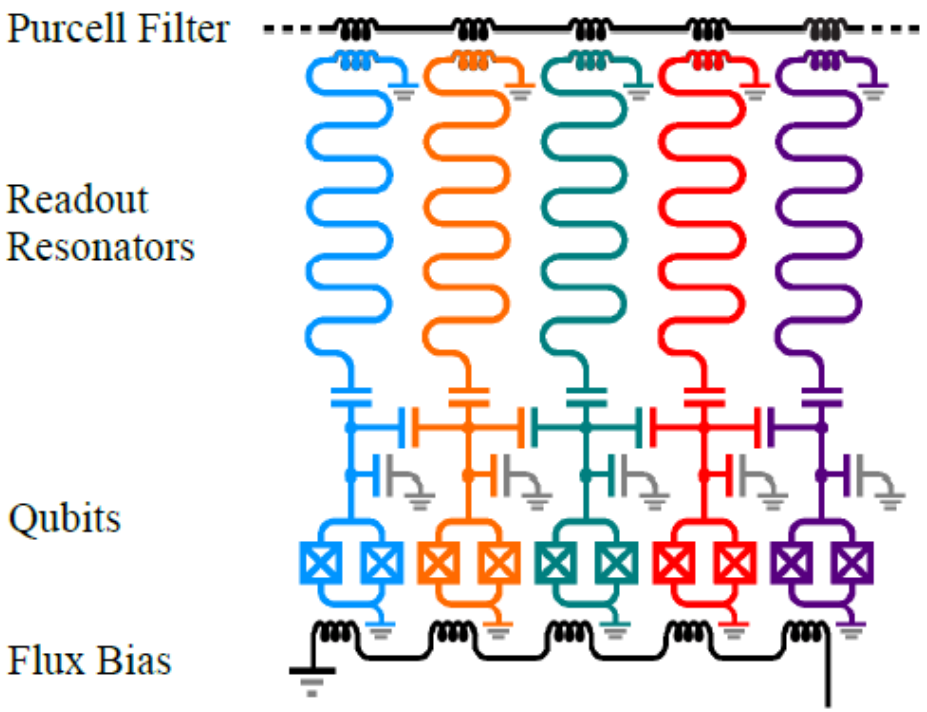
Current NISQ (100+ Qubits)

Near Future NISQ (1000 Qubits)

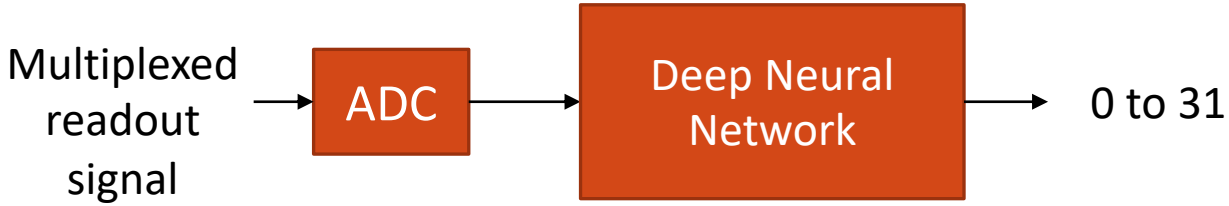
Dream (1,000,000 Qubits)

Goal: $700 per qubit

Qubit Readout for Transmon



5 frequency-multiplexed superconducting qubits[1]



>½ million parameters!

Deep Neural Networks are great!

Up to 10x reduction in readout crosstalk

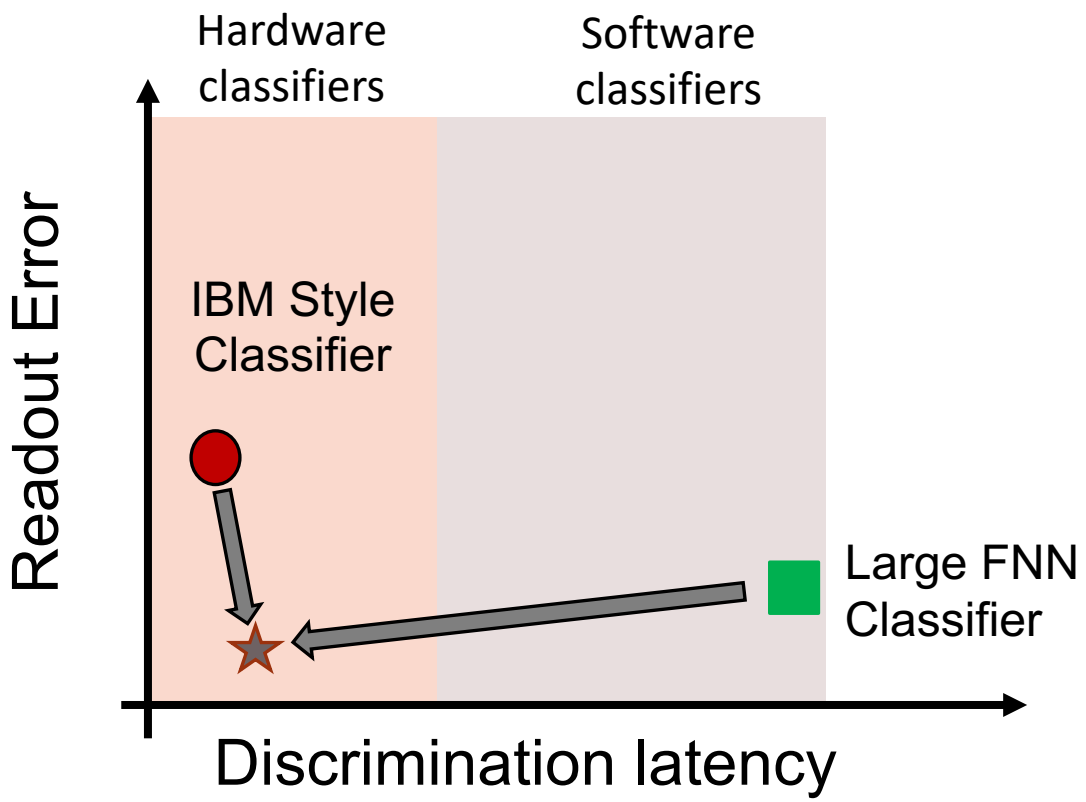
But they are slow and costly..

[1]Lienhard, Benjamin, et al. "Deep-neural-network discrimination of multiplexed superconducting-qubit states." *Physical Review Applied* 17.1 (2022): 014024.

Goal: Make Readout Cost Effective

Retain crosstalk mitigation advantages offered by neural networks

Reduce hardware cost and complexity



Efficient Machine Learning Systems for High-Fidelity Qubit Readout (ISCA'23)

SATVIK MAURYA

CHAITHANYA NAIK MUDE

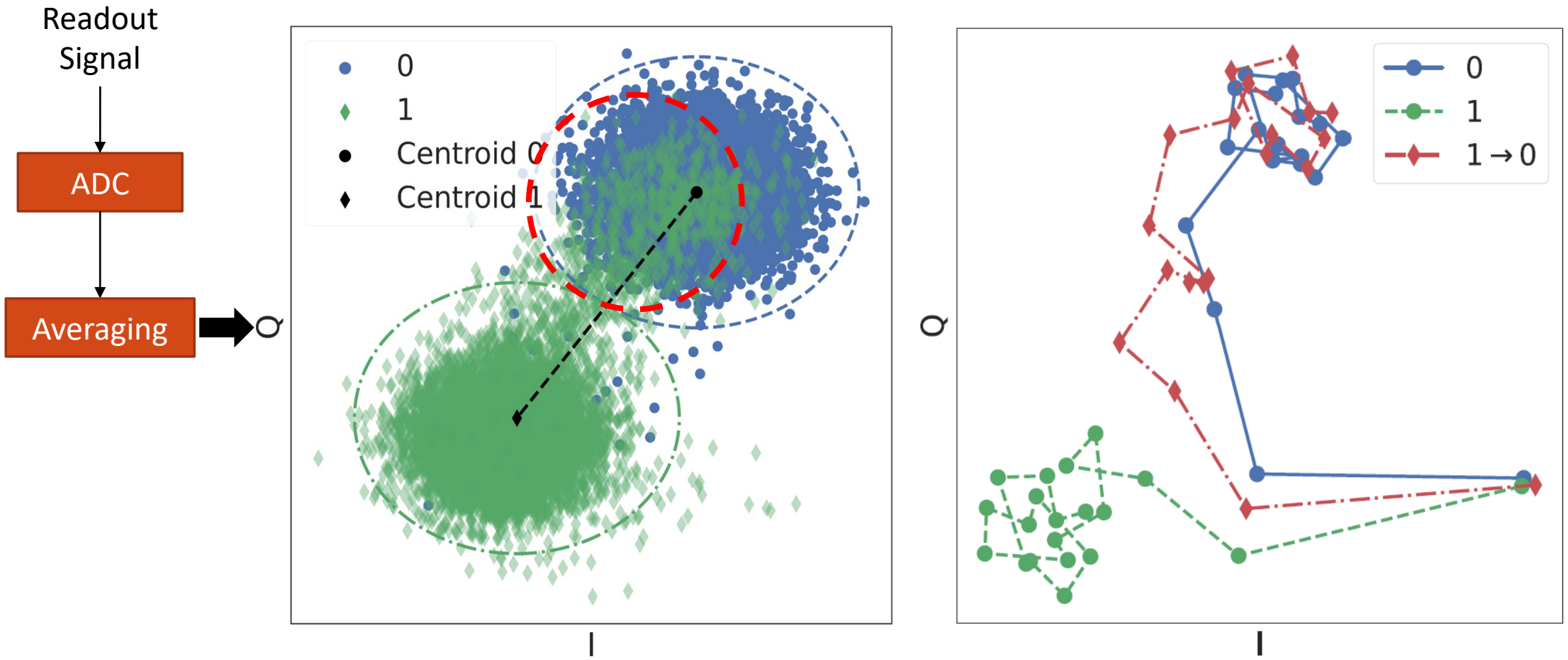
WILLIAM D. OLIVER

BENJAMIN LIENHARD

SWAMIT TANNU

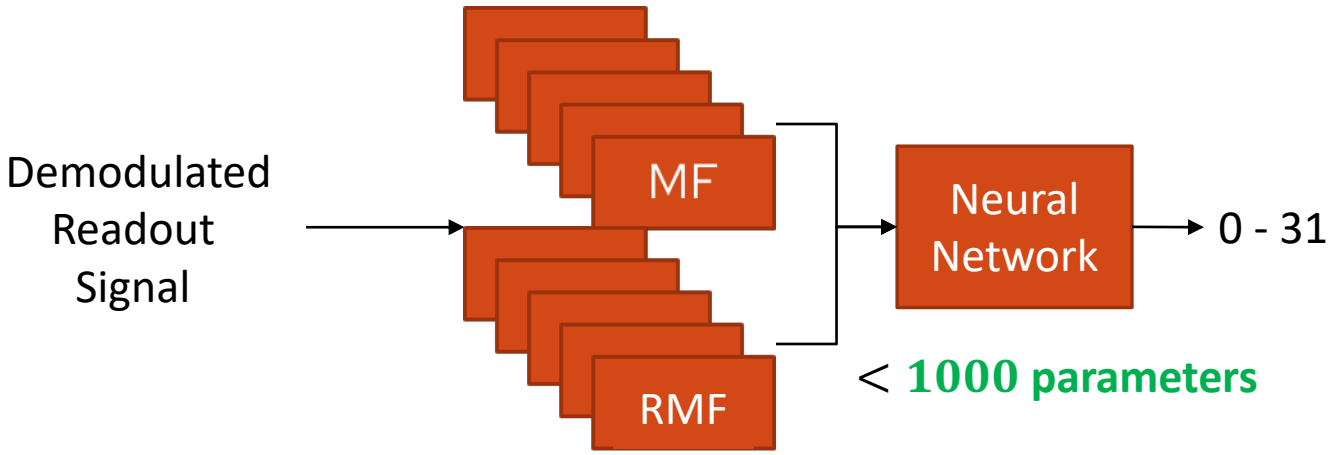
UNIVERSITY OF WISCONSIN-MADISON

Detecting Relaxations



Combining Matched Filters

Use traces corresponding to relaxations for training Relaxation Matched Filters (RMF).

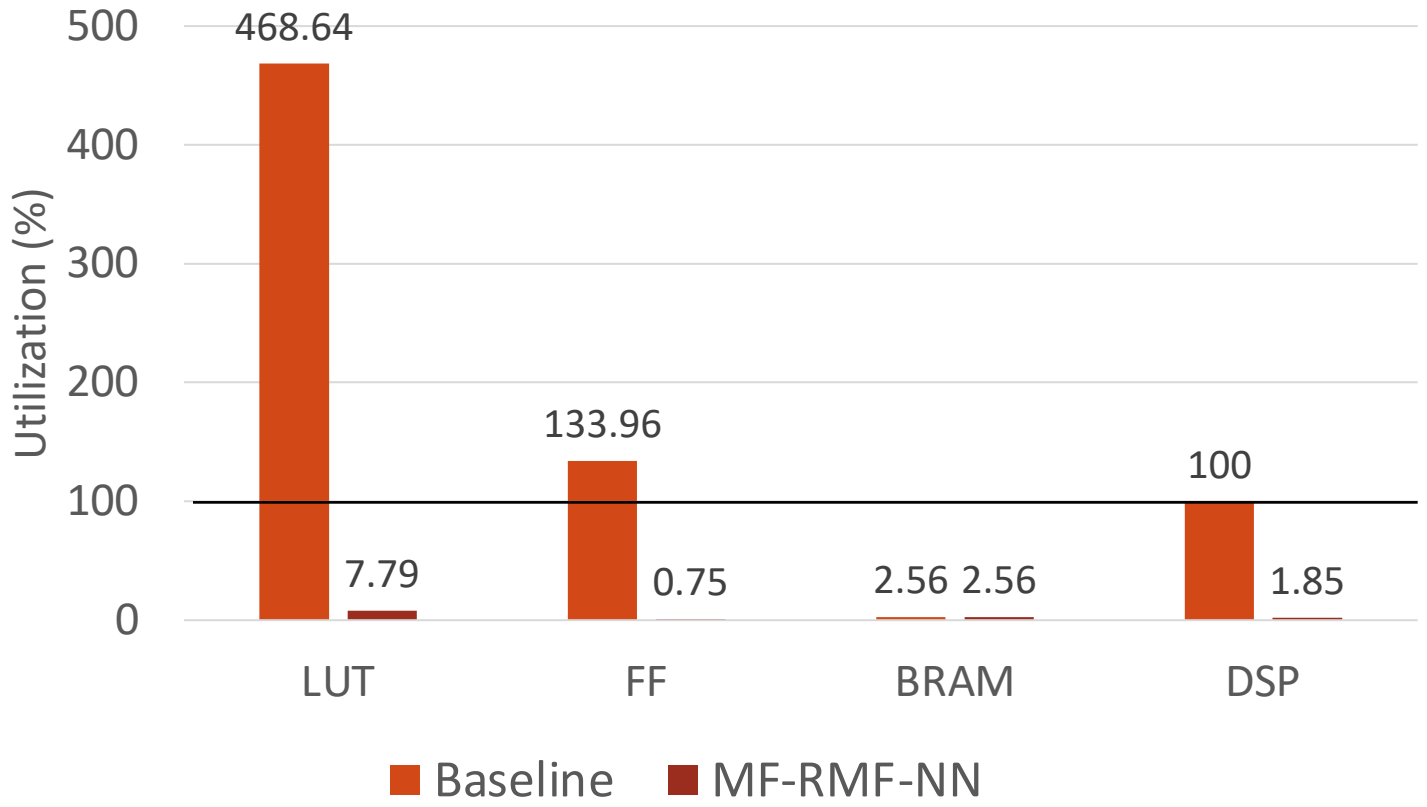


MF-RMF-NN

	Baseline[1]	Our
Qubit 1	0.969	0.985
Qubit 2	0.753	0.754
Qubit 3	0.943	0.966
Qubit 4	0.946	0.962
Qubit 5	0.97	0.989
$\mathcal{F}_{5Q}$	0.9122	0.9266

[1]Lienhard, Benjamin, et al. "Deep-neural-network discrimination of multiplexed superconducting-qubit states." *Physical Review Applied* 17.1 (2022): 014024.

Hardware Utilization



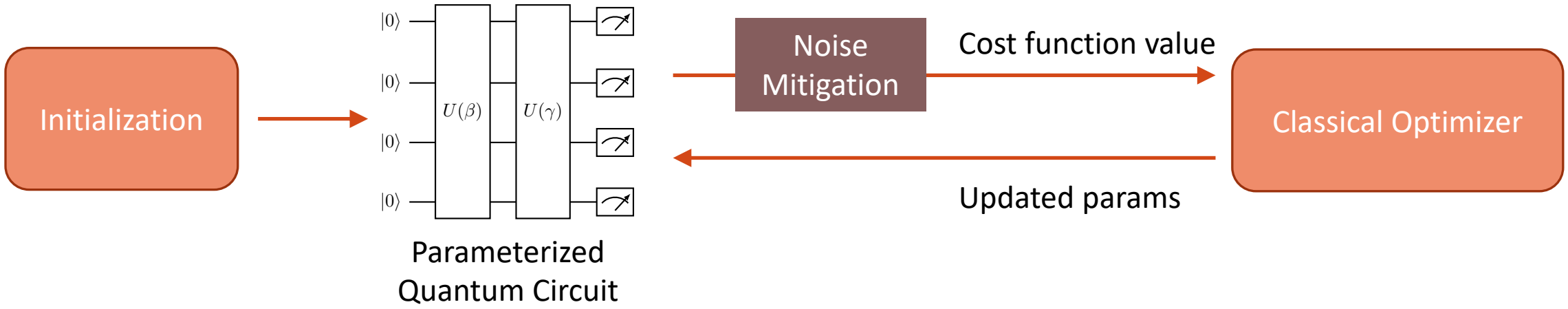
To read **five qubits**, baseline needs more resources than what we have on the FPGA, we can read **fifty qubits** with one FPGA

Lienhard, Benjamin, et al. "Deep-neural-network discrimination of multiplexed superconducting-qubit states." *Physical Review Applied* 17.1 (2022): 014024.

Software developers spend 35-50 percent of their time validating and debugging software. The cost of debugging, testing, and verification is estimated to account for 50-75 percent of the total budget of software development projects, amounting to more than $100 billion annually

Source: The Debugging Mindset: Understanding the psychology of learning strategies leads to effective problem-solving skills

Even if they work VQAs can be hard to monetize



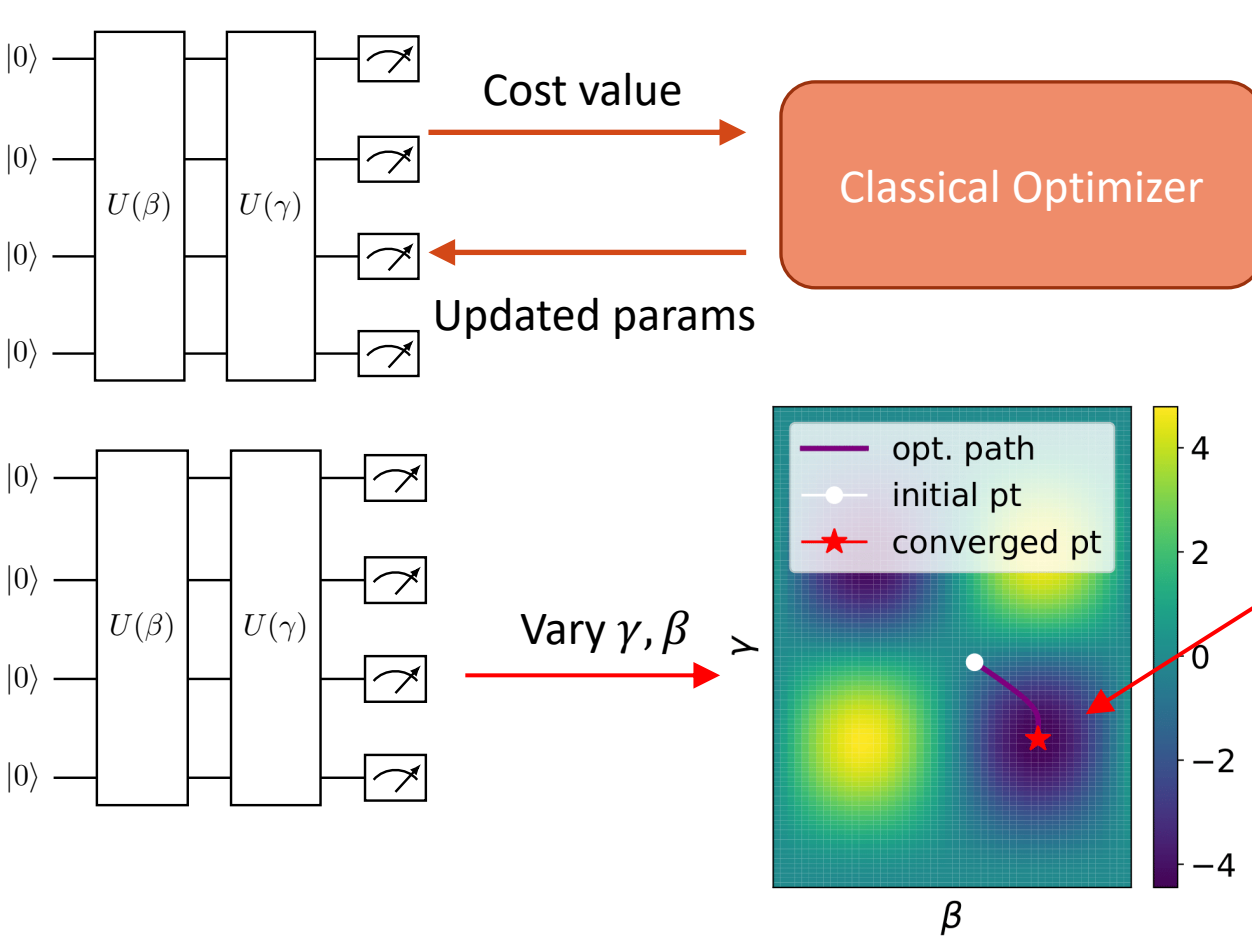
Running a Variational Quantum Algorithm (VQA) successfully needs:

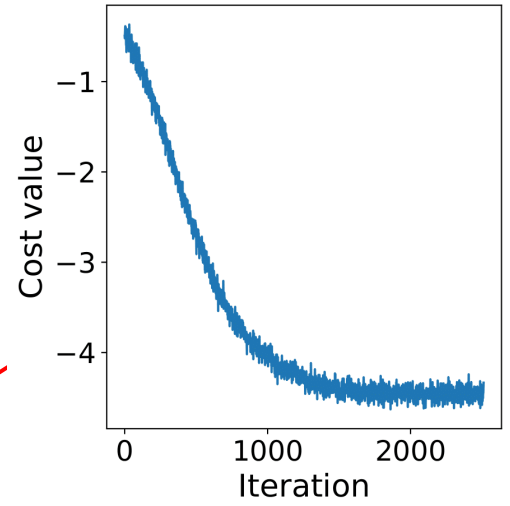
(1) Right initialization for circuit parameters

(2) Appropriate noise mitigation methods

(3) Suitable classical optimizer configurations

VQA landscapes can help





- Little information
- Want to have a **bird's eye view** instead of just the **optimization path**

High Performance Debugging for Variational Quantum Algorithms using Compressed Sensing (ISCA'23)

TIANYI HAO*

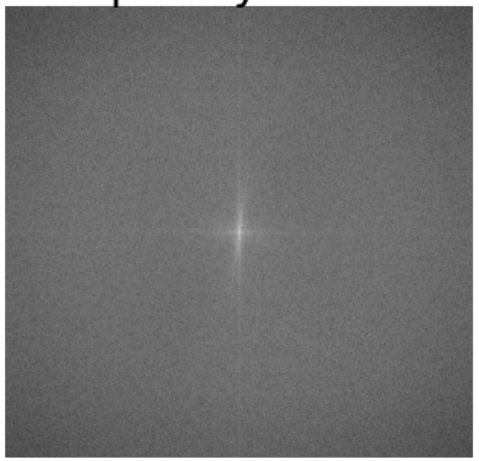
KUN LIU*

SWAMIT TANNU

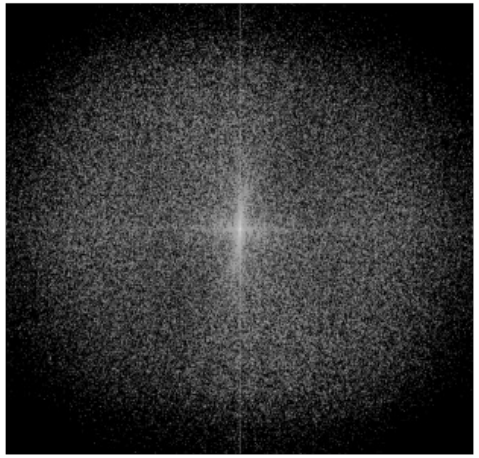
Compressed Sensing

original

frequency domain



truncated

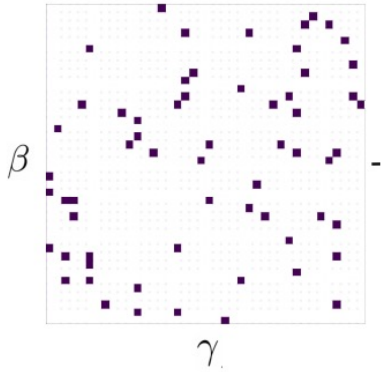


reconstructed

Candès, E.J., Romberg, J.K. and Tao, T. (2006), Stable signal recovery from incomplete and inaccurate measurements. *Comm. Pure Appl. Math.,* 59: 1207-1223. https://doi.org/10.1002/cpa.20124

OSCAR: cOmpressed Sensing based Cost lAndscape Reconstruction

1. Pick small number of β, γ randomly



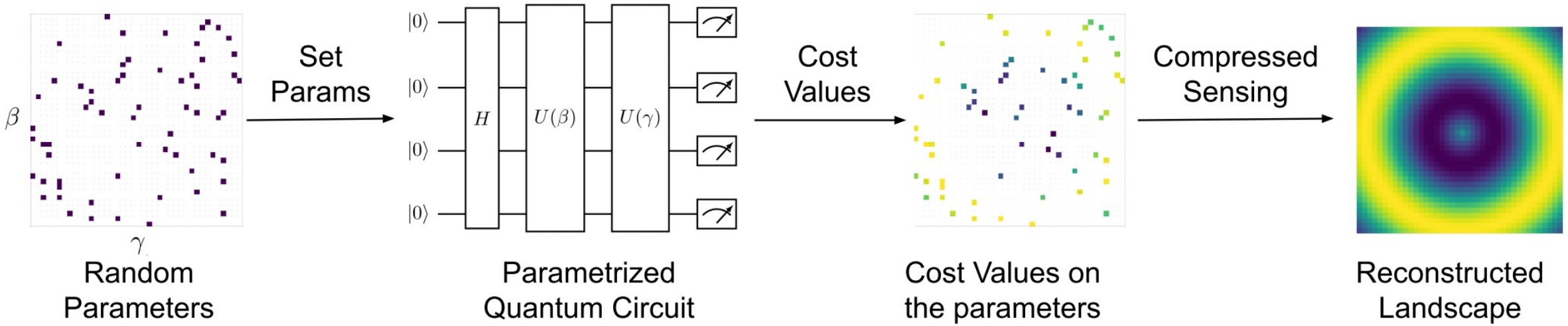
2. Run circuit with randomly selected β,γ pairs

3. Generate sampled landscape

4. Reconstruct Landscape

With 5%-10% of samples, we can reconstruct the full landscape

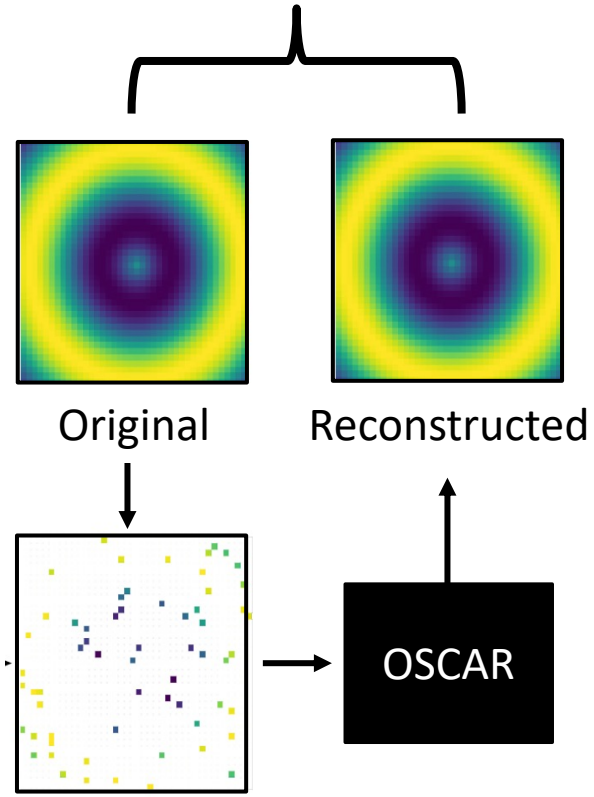
Parallel Reconstruction of Landscape



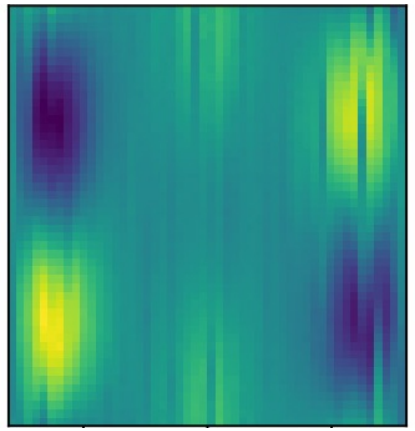
Random parameters are independent → Embarrassingly Parallel

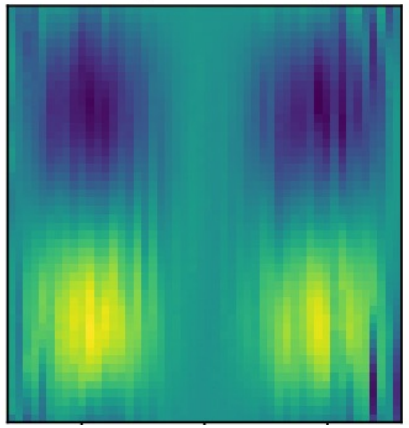
Evaluating Efficacy of Landscape Reconstruction

Compare, calculate similarity

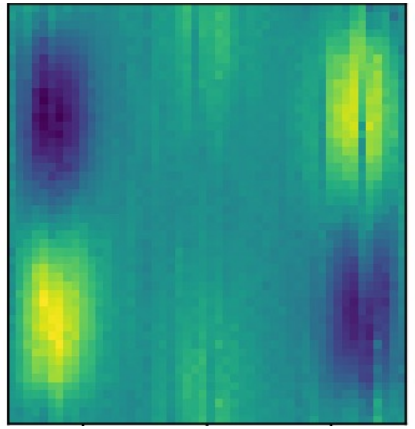


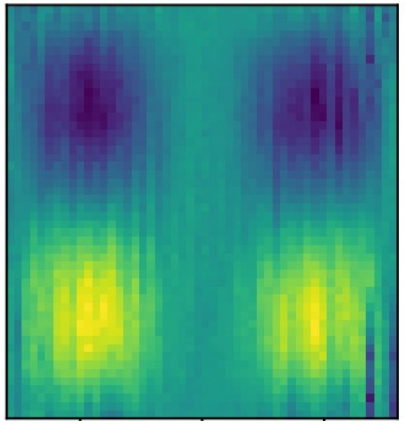
Original landscapes on Google Sycamore:





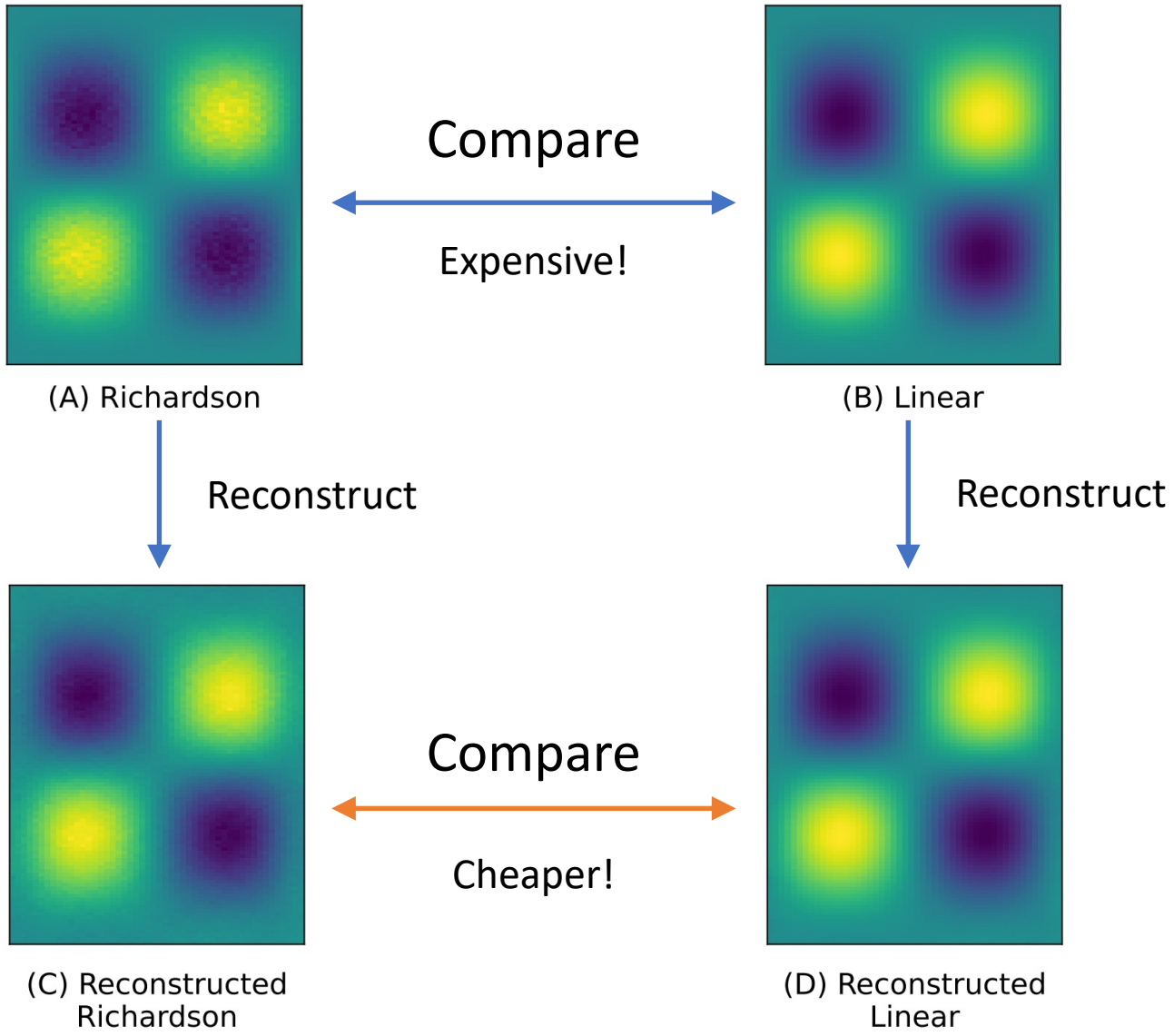
Reconstructed landscapes:





OSCAR can efficiently and accurately reconstruct cost landscapes

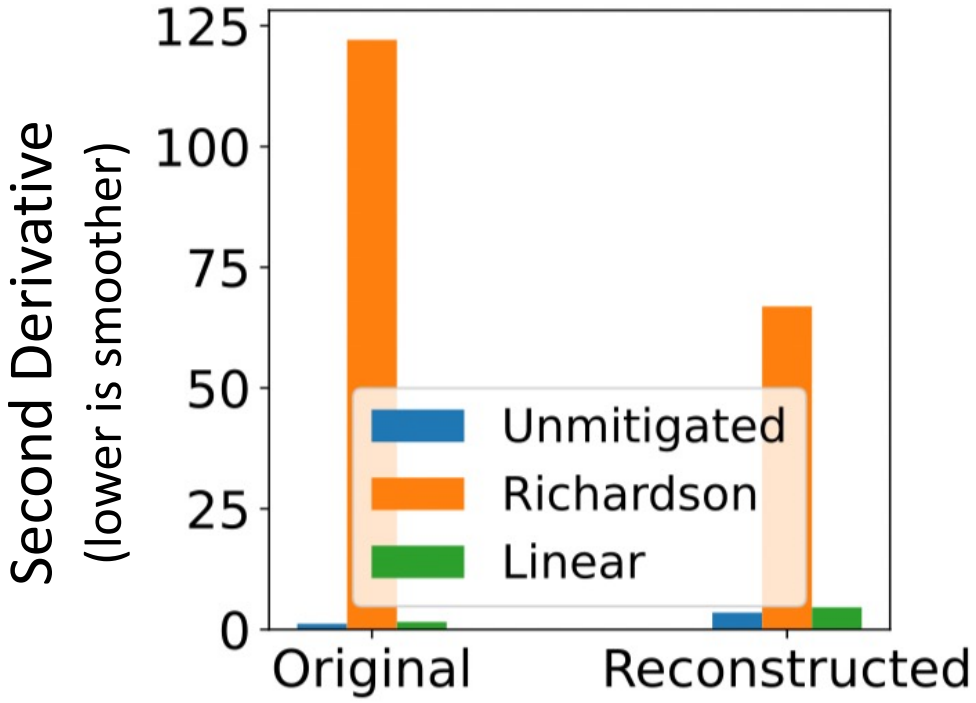
Use Case – Help benchmark efficacy of noise mitigation

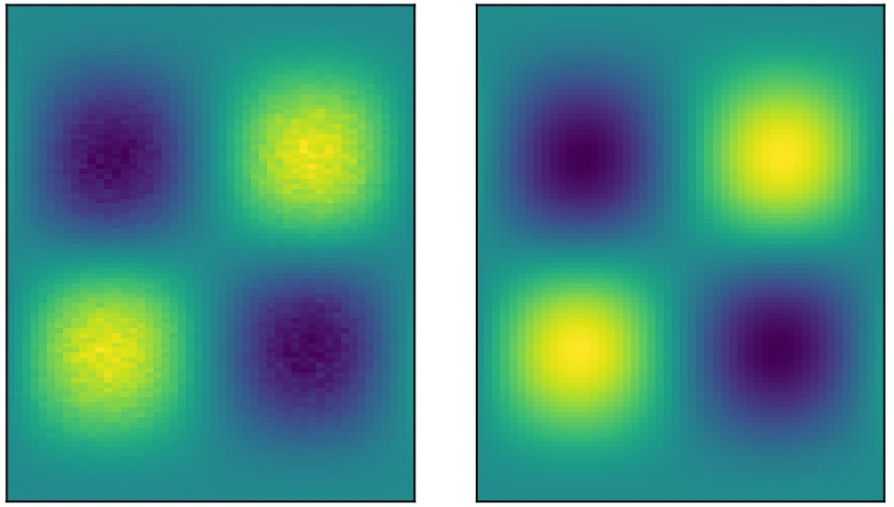


Richardson and Linear: two mitigation methods

Reconstructed landscapes preserve features of the original ones

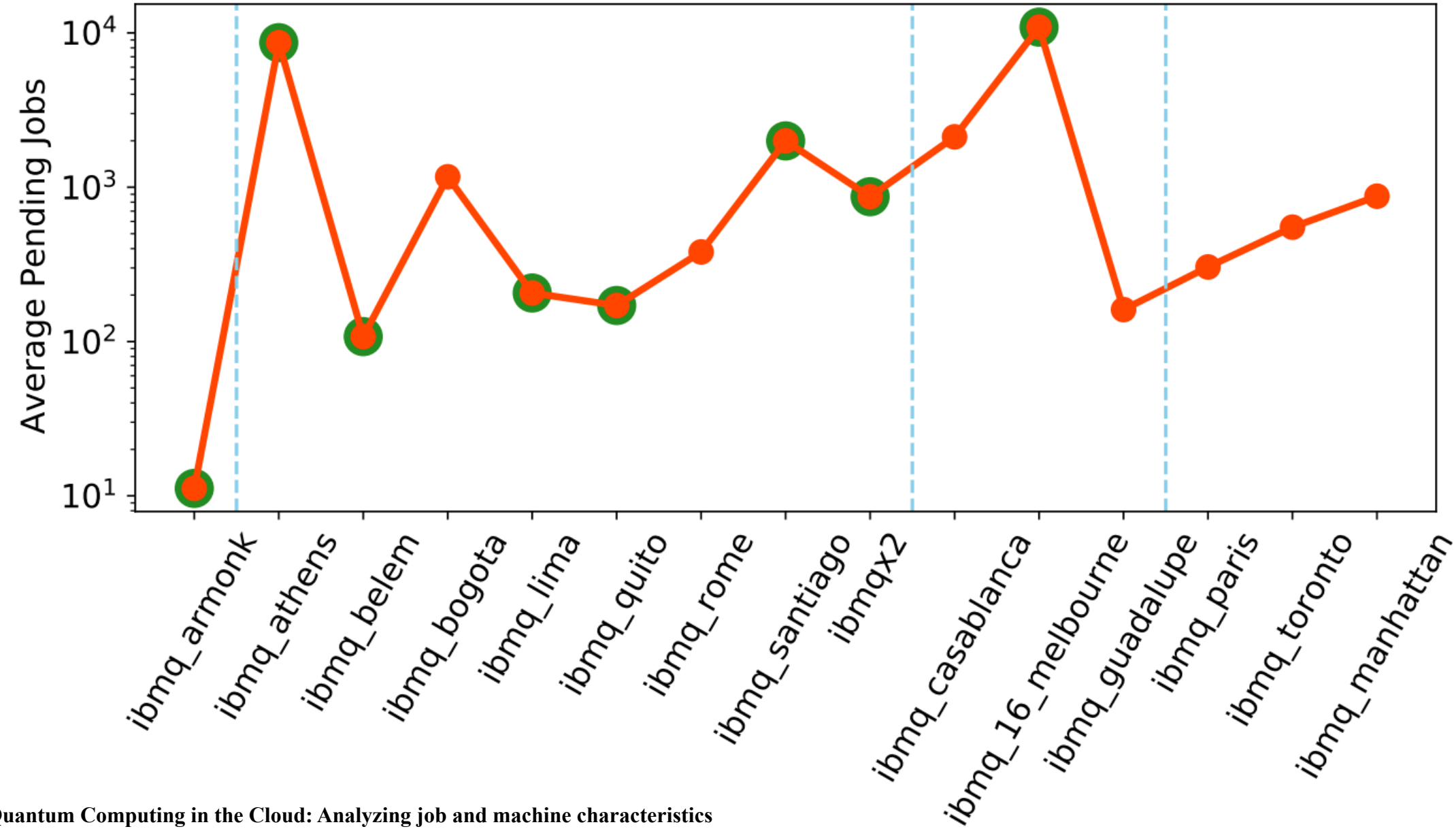
Recon. landscapes preserve features of the original's





(A) Richardson (B) Linear

- Share the similar pattern
- Match the actual case

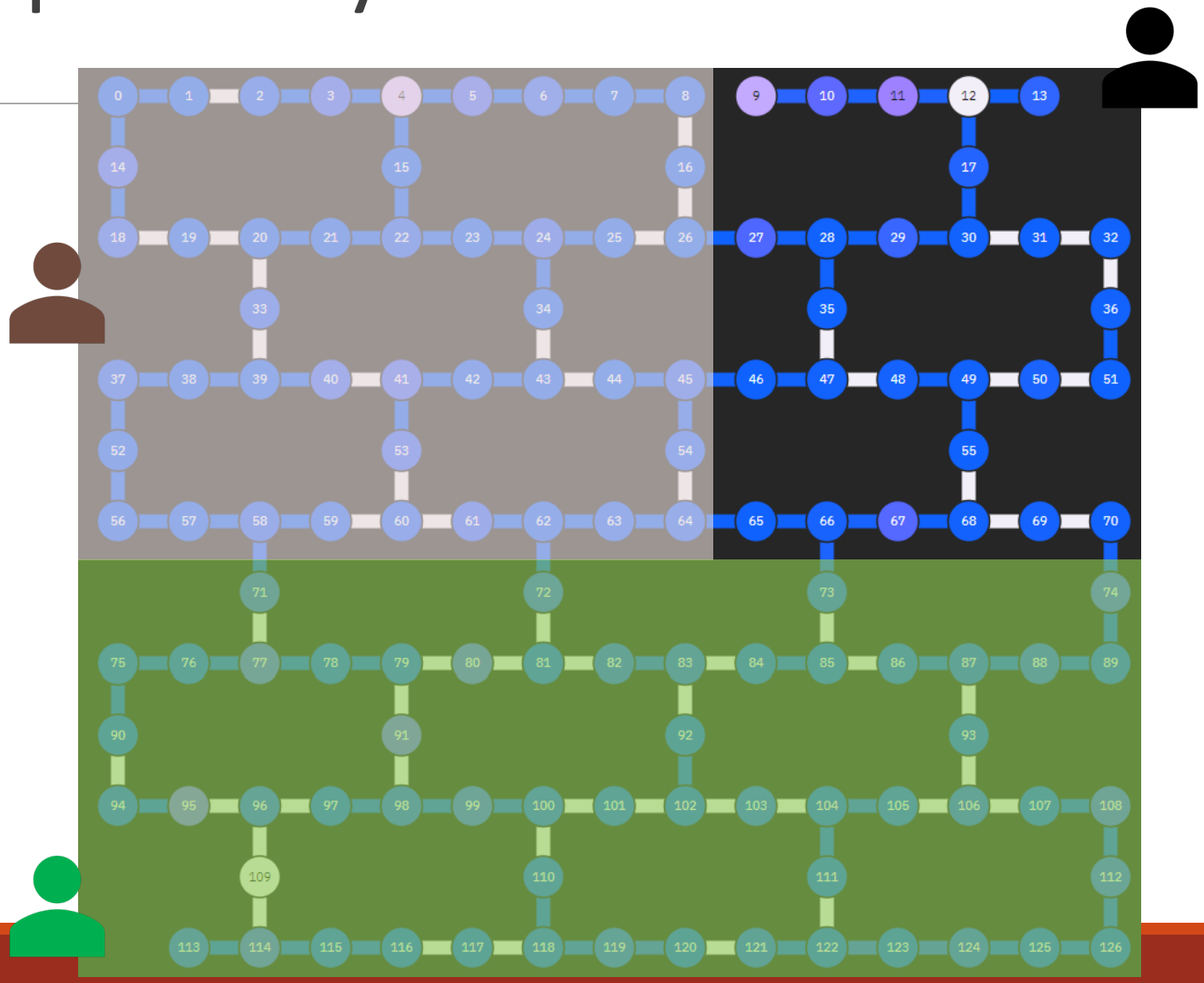


Source- Quantum Computing in the Cloud: Analyzing job and machine characteristics

Underutilized Quantum Computers Result in Large Queuing Delays

Multiprogramming: Opportunity

Partition the quantum resources enable multiprogramming to improve utilization and reduce cost



PayPal was founded in 1998, in 2000, it lost $6 million, or $1,900 an hour, to fraud at a time when its revenue was less than $5 million

Multiprogramming: Security Risks

Speculated Risks : DoS, learning output state, steal circuits, compiler optimizations, etc.

“Quantum Intellectual Property” can become target