

NQCC SparQ Access User Showcase

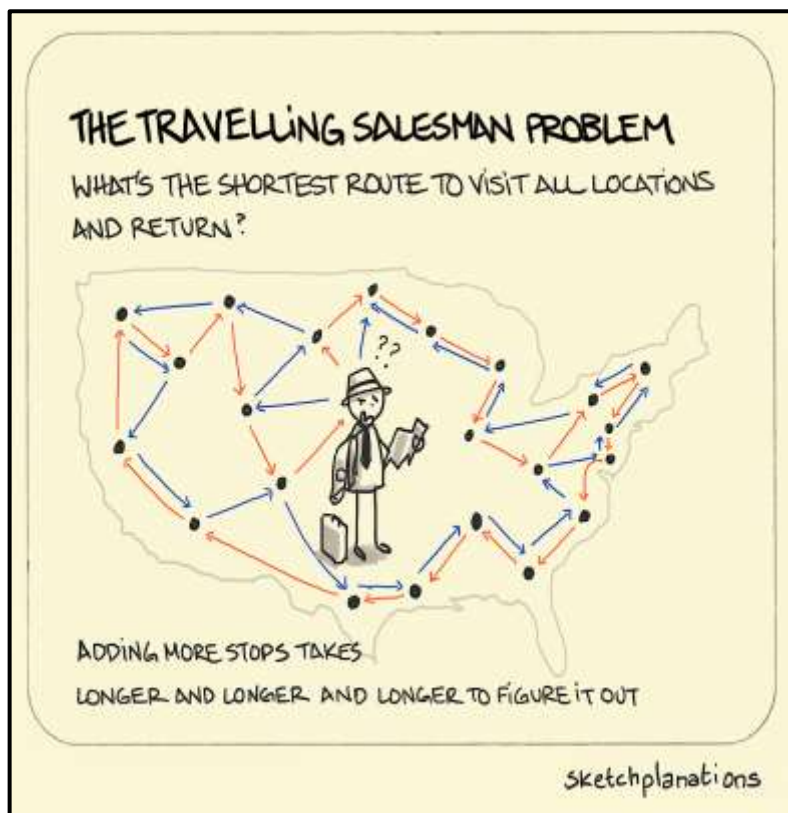
Solving larger Travelling Salesman Problem networks

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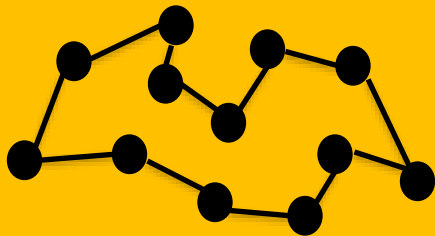
Solving larger Travelling Salesman Problem networks with a penalty-free Variational Quantum Algorithm

Daniel Goldsmith, Xing Liang, Dimitrios
Makris and Hongwei Wu

<https://arxiv.org/abs/2512.06523>

The travelling salesman problem has been studied on with Rigetti quantum hardware funded by the NQCC

Size: Our penalty free formulation needs **fewer qubits**



Only **49 qubits** are needed for a **17 location networks**: a QUBO formulation would need over 250.

Time: Faster run times from SPSA and caching classical result evaluation



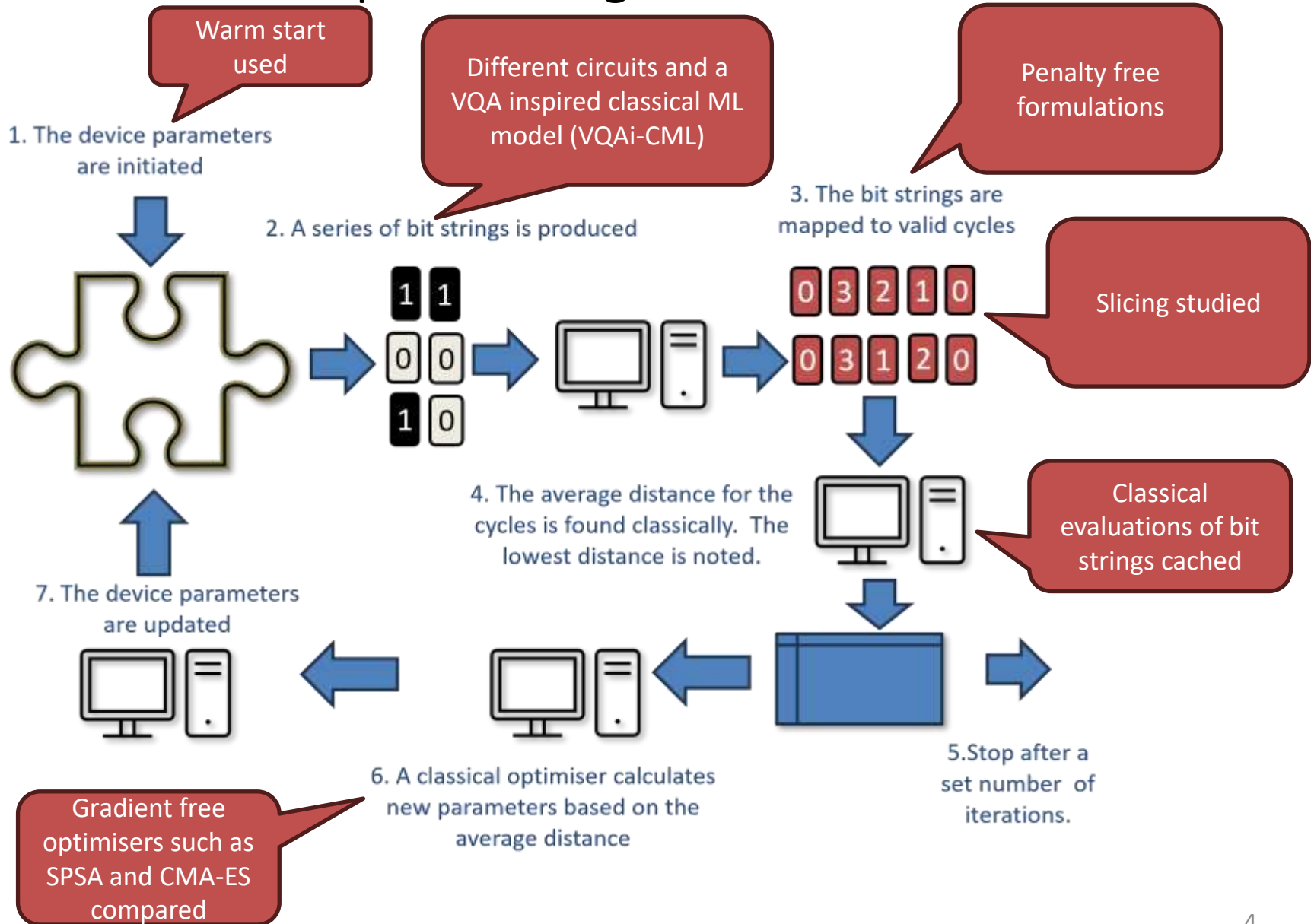
For example, run-times reduced from **over nine minutes to seven seconds** for an eight-location network.

Largest network solved to date on quantum hardware



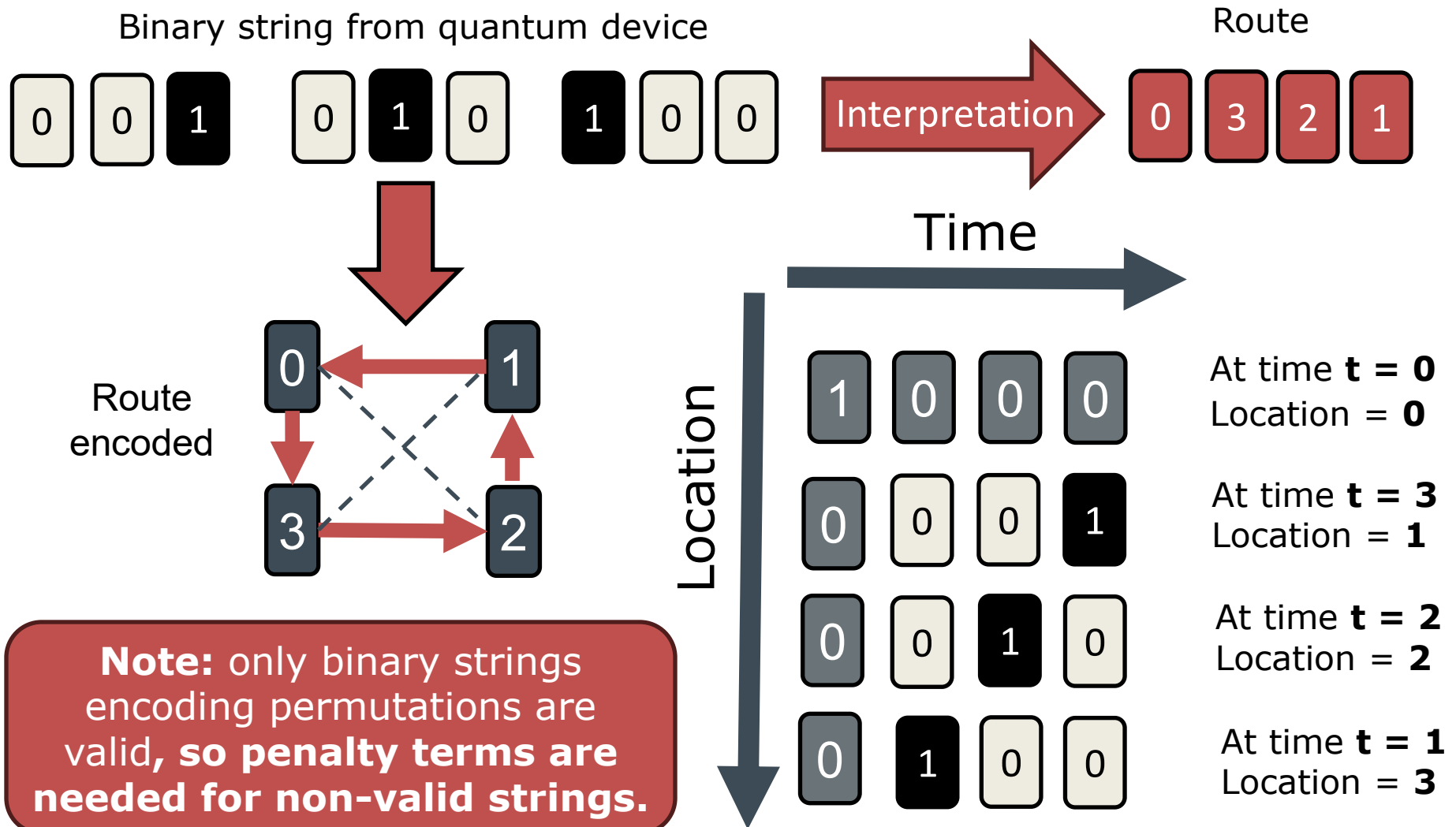
Solution quality of 95.3% **for a 17 location networks** run on the Rigetti Cepheus with a warm start, compare with 12 locations for D-Wave, 8 for circuit model

A variational quantum algorithm has been studied



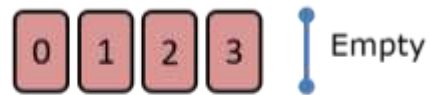
QUBO AGAINST PENALTY FREE FORMULATIONS

The QUBO interpretation of a binary string as a route with the One Hot scheme

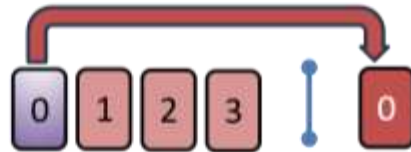




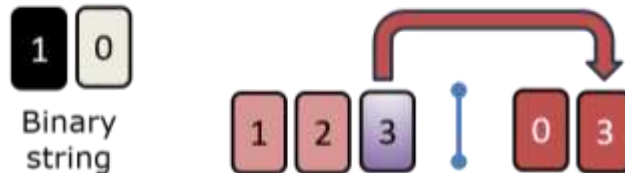
Step 0 – initial list created.



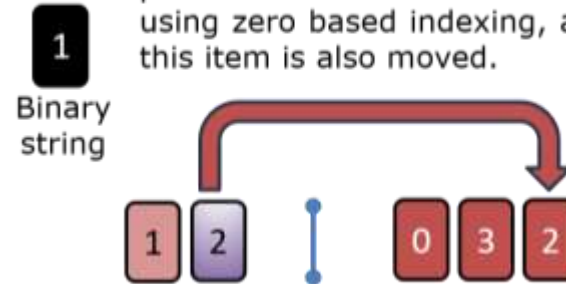
Step 1 – The zeroth item is moved, as without loss of generality, the route can always start with zero:



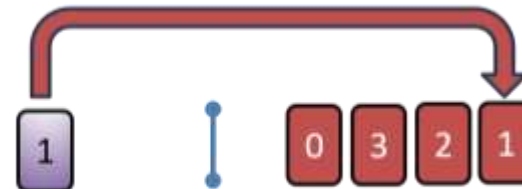
Step 2 – 10_2 is regarded as a pointer to the third item using zero based indexing, and this item is moved to the re-ordered list:



Step 3 – 1_2 is regarded as a pointer to the second item using zero based indexing, and this item is also moved.



Step 4 – The final item is moved to complete the sequence.

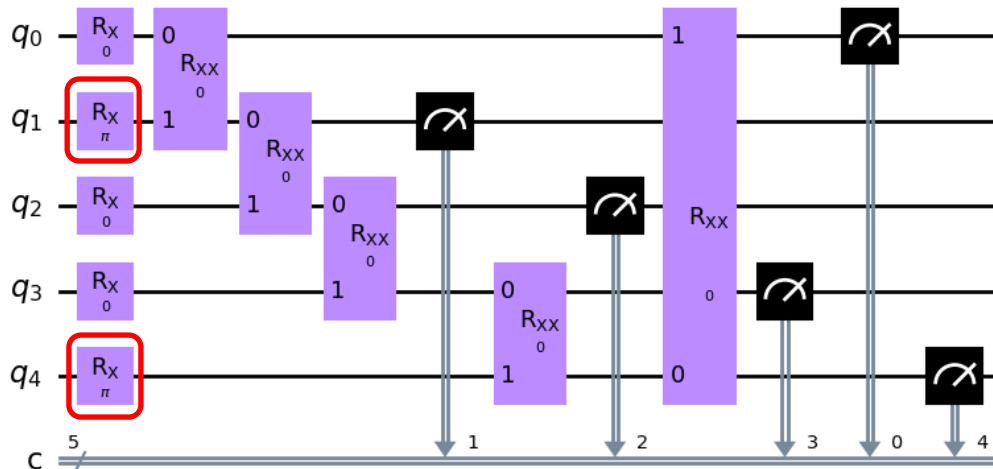


Our penalty free formulation uses fewer qubits than the QUBO model

The diagram shows how the bit string 101 is used to construct a valid cycle

QUANTUM CIRCUITS AND WARM STARTS

This example circuit supports a warm start



Shallow quantum circuits with an entanglement ring are used. Limited gate connectivity is needed so the circuit is suitable for NISQ-era devices.

In a warm start, a greedy heuristic calculates a nearest neighbour path, and this is used to set gate rotations.

Here the bit string calculated is $[1, 0, 0, 1, 0]$ and the gate rotations are set accordingly (note Qiskit sign convention)

WORKING WITH RIGETTI ON AWS BRAKET

Many thanks to NQCC SparQ for giving access to Rigetti devices on AWS!



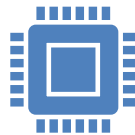
AWS notebook environment: easy to use, and many good example.



Gate set: For Rigetti – Cepheus, RX, RY and CZ gates can be used – needed to transpile circuit to this gate set.

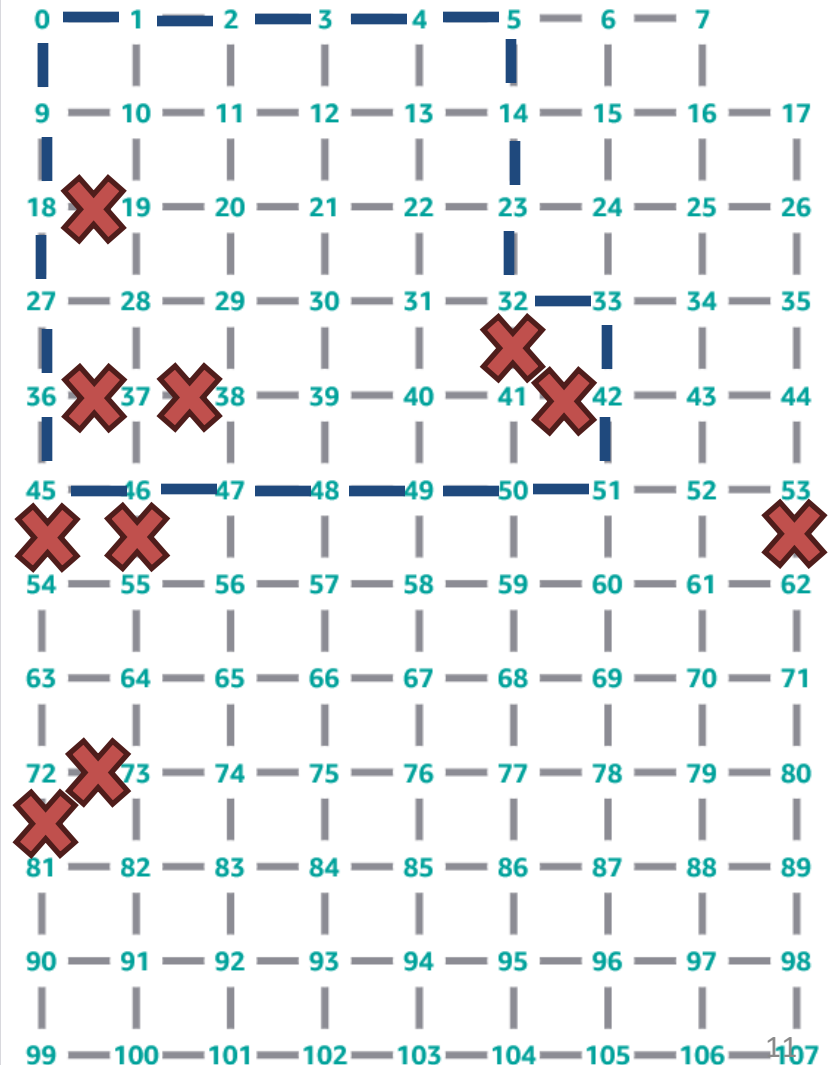


Rigetti qubit connectivity: entanglement loops need to avoid couplers where the error rate is 50%. Wrote code to check loop fidelity and connectivity.



Hybrid mode: Good for variational circuits since a combined quantum / classical job is run.

Entanglement loops avoid couplers with errors



OPTIMISERS

Optimisers are studied using Nevergrad

Optimiser	Description
NGOpt	Hand-crafted optimiser selection wizard provided by Nevergrad.
OnePlusOne	Simple evolutionary algorithm with a new “offspring” selected by mutating the candidate solution and retained if successful. If the mutation is succesful the mutation strength (σ) is increased.
TBPSA	Test-Based Population Size Adaptation: Generates, evaluates and compares a sample of test points, and updates best estimate. Adjusts population size based on noisiness of results.
CMA-ES	Covariance Matrix Adaptation Evolution Strategy: Samples candidate solutions from a multivariate normal distribution and adapts the mean and covariance matrix.
PSO	Particle Swarm Optimisation: Tracks candidate solutions (swarm of particles) and updates position and velocity based on each particle and the swarm best solution.

Optimisers (cont.)

Optimiser	Description
DE	<u>Differential Evolution</u> : Creates mutated vectors, randomly combines with the trial vectors (cross-over) and selects the best of the trial and mutated vector.
TwoPointsDE	<u>Differential Evolution</u> As DE, expect that cross-over is for parameters between two <u>indices</u> in the parameter vector.
SQP	Sequential Quadratic Programming : Replaces objective with a quadratic approximation.
SPSA	Simultaneous Perturbation Stochastic Approximation : Our version with hyper-parameters exposed.
Q-SPSA	Quantum SPSA : Inspired by Nevergrad, only evaluate one classical cost function per iteration, with hyper-parameters exposed.

Parameter shift is often used to optimise quantum circuits: however, two cost evaluations are needed for each parameter, and this can be very expensive.

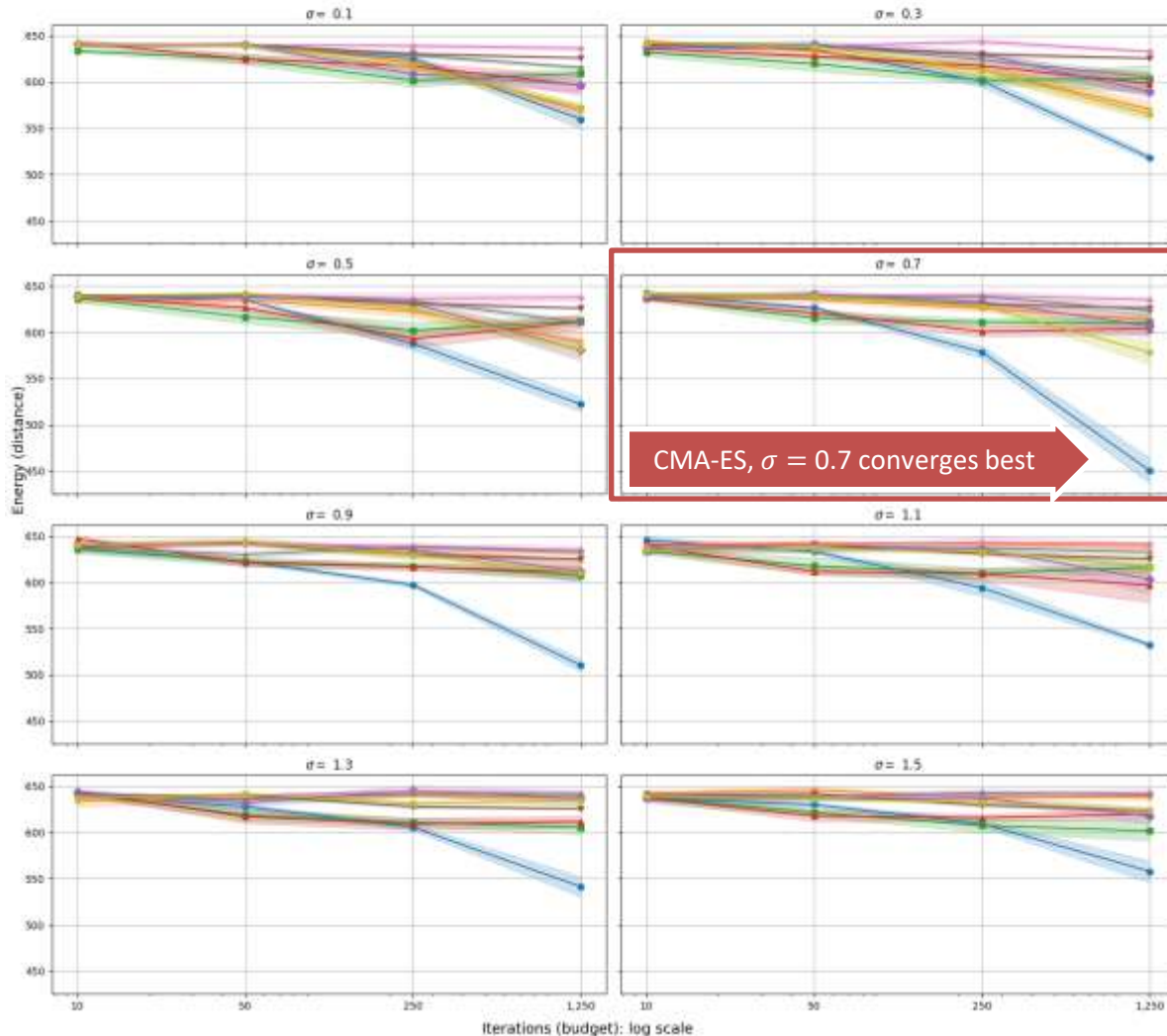
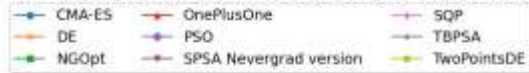
RESULTS

Caching and optimisation reduced run time

	SPSA	Parameter shift
No caching	37 seconds	585 seconds
Caching	7 seconds	217 seconds

Results are shown for an example network of eight locations. A bespoke variant of LRU cache is used.

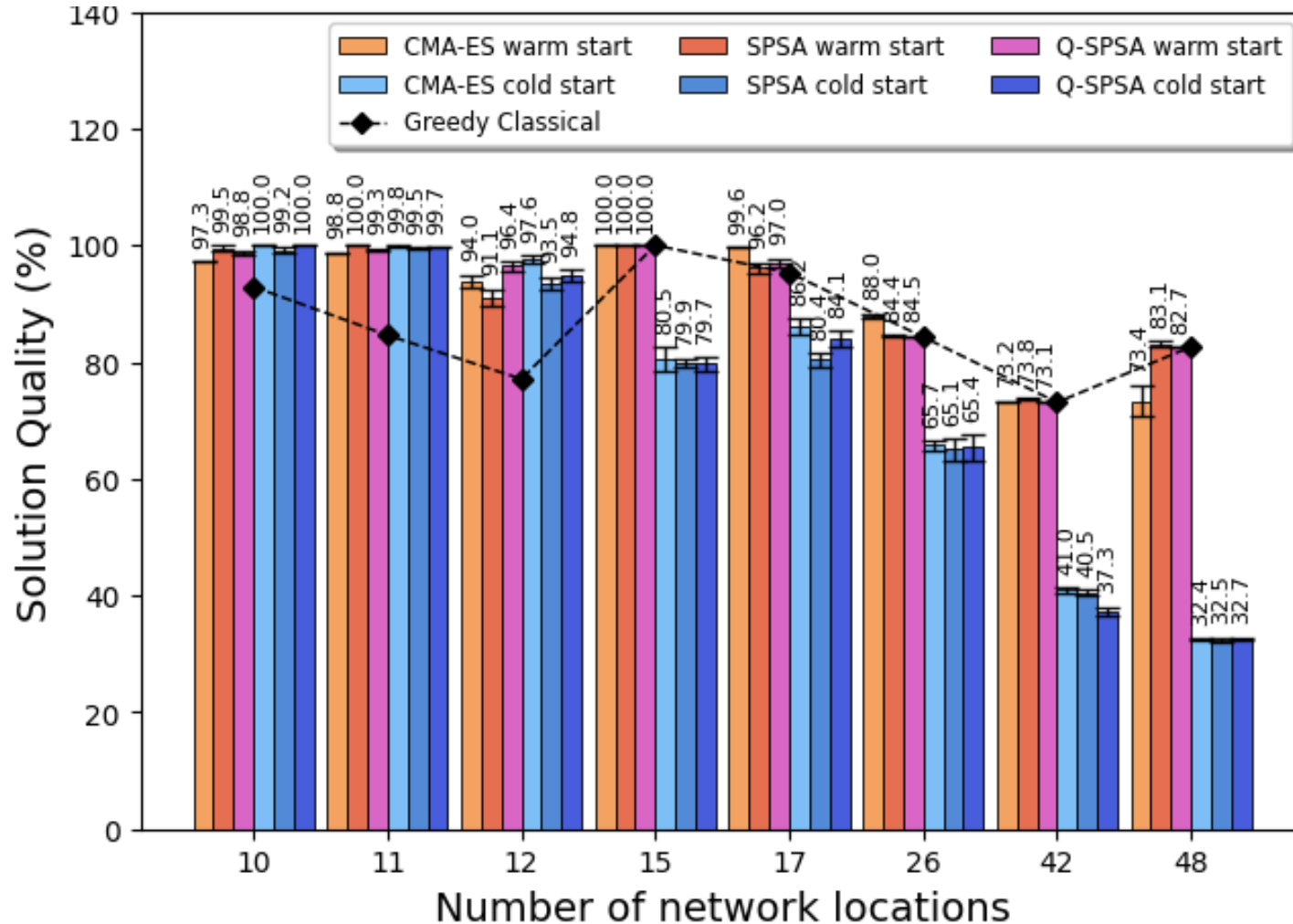
Optimizer Performance by Sigma with Estimated Uncertainty for 12 Locations and 1024 Shots



CMA-ES converges best to lower cost solutions

- Nevergrad only exposed one hyper-parameter so we coded our versions of:
 - SPSA (3 classical evaluations per shot) and
 - Q-SPSA (one classical evaluation per shot) were coded and compared.

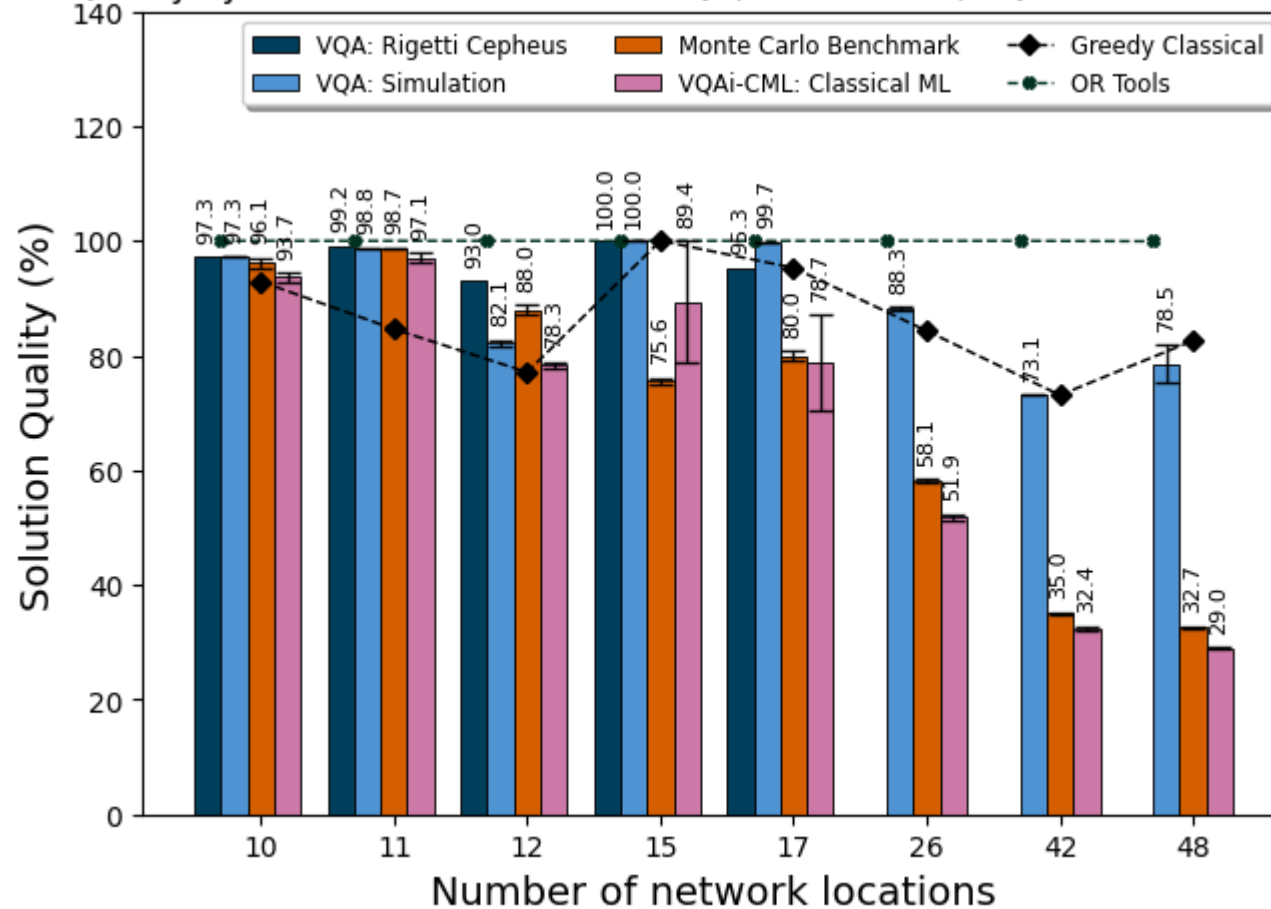
Comparison of optimisers and warm starts against cold starts



- CMA-ES seems to slightly outperform SPSA.

- If the greedy heuristic finds a good warm start, then warm starts can be beneficial.

Solution Quality by Number of Locations for VQA, Monte Carlo, VQAI-CML and Greedy methods



Summary of results: a hot start VQA out-performs greedy classical, Monte Carlo and the VQAI-CML model, but not the strong Google OR Tools classical optimiser

Acknowledgements

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Conclusions

- We have shown high-quality solutions in:
 - simulation for up to 48 locations, and
 - Rigetti quantum hardware for up to 17 locations
- Existing studies in the circuit model paradigm are for eight or fewer locations, with sub-optimal results
- Although aimed at NISQ devices, **penalty-free encoding, gradient free optimisers** and **warm starts** are likely to be relevant for fault tolerant hardware.

