Noise Aware Single Shot Error Mitigation with Coherent Pauli Checks

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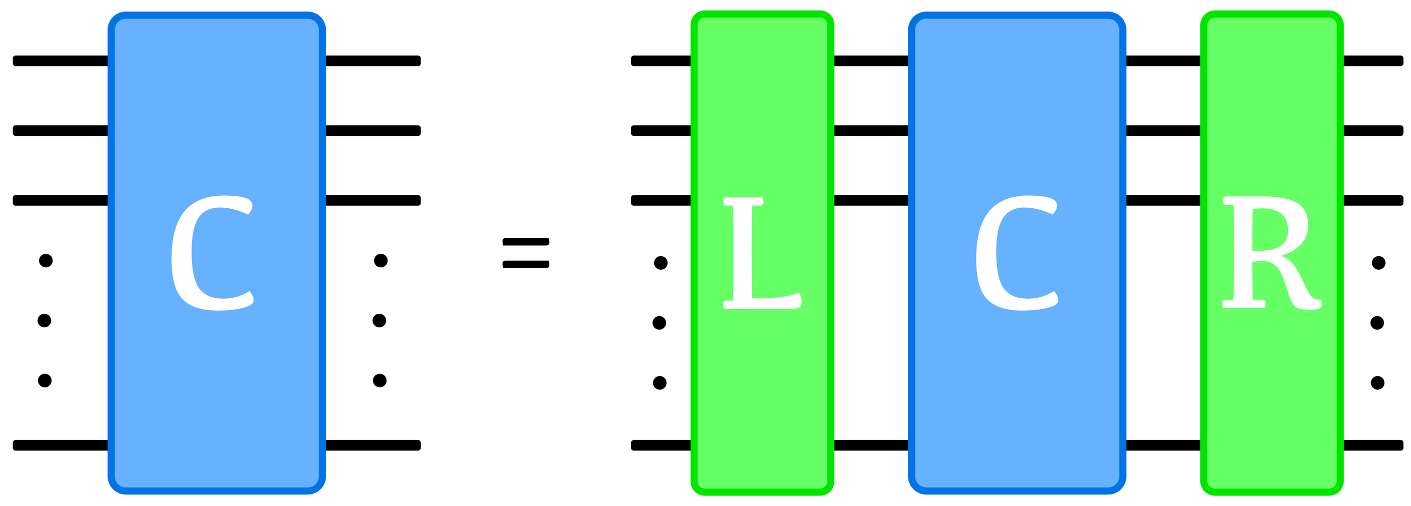
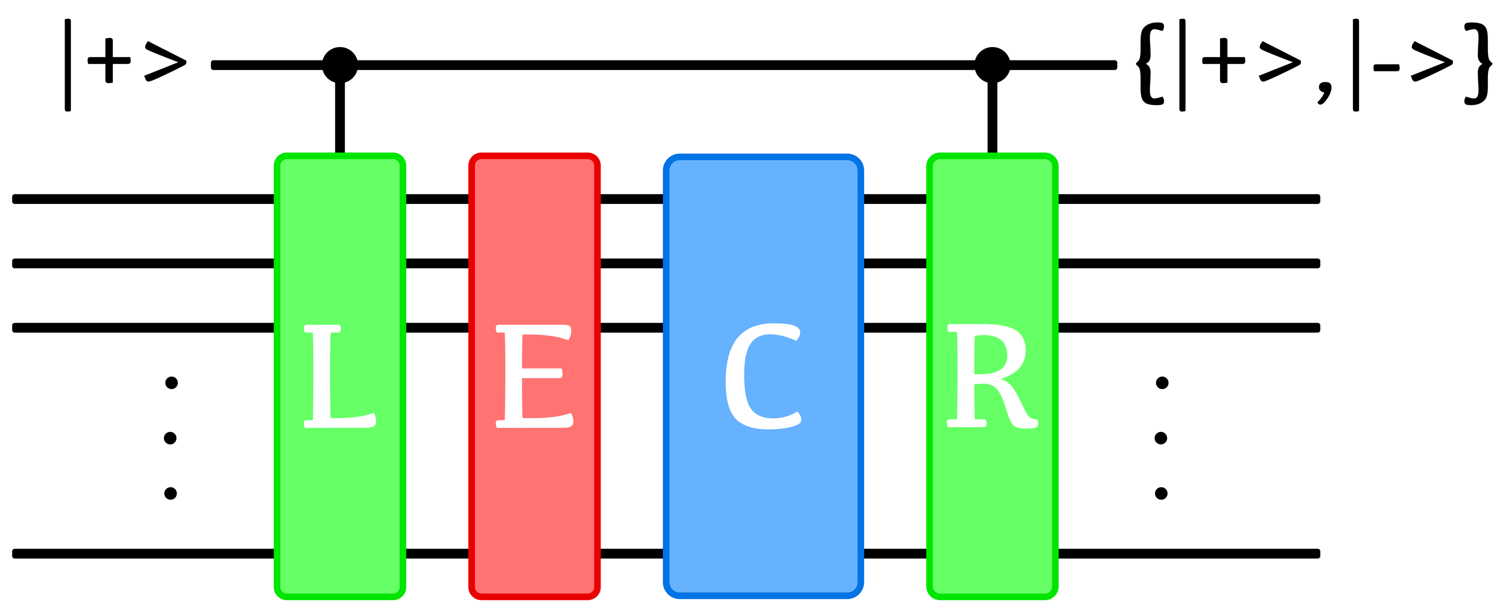
Elements of the Clifford group normalise the Pauli group. Hence for a Clifford 'C' and Pauli 'L', a Pauli 'R' can be found with:

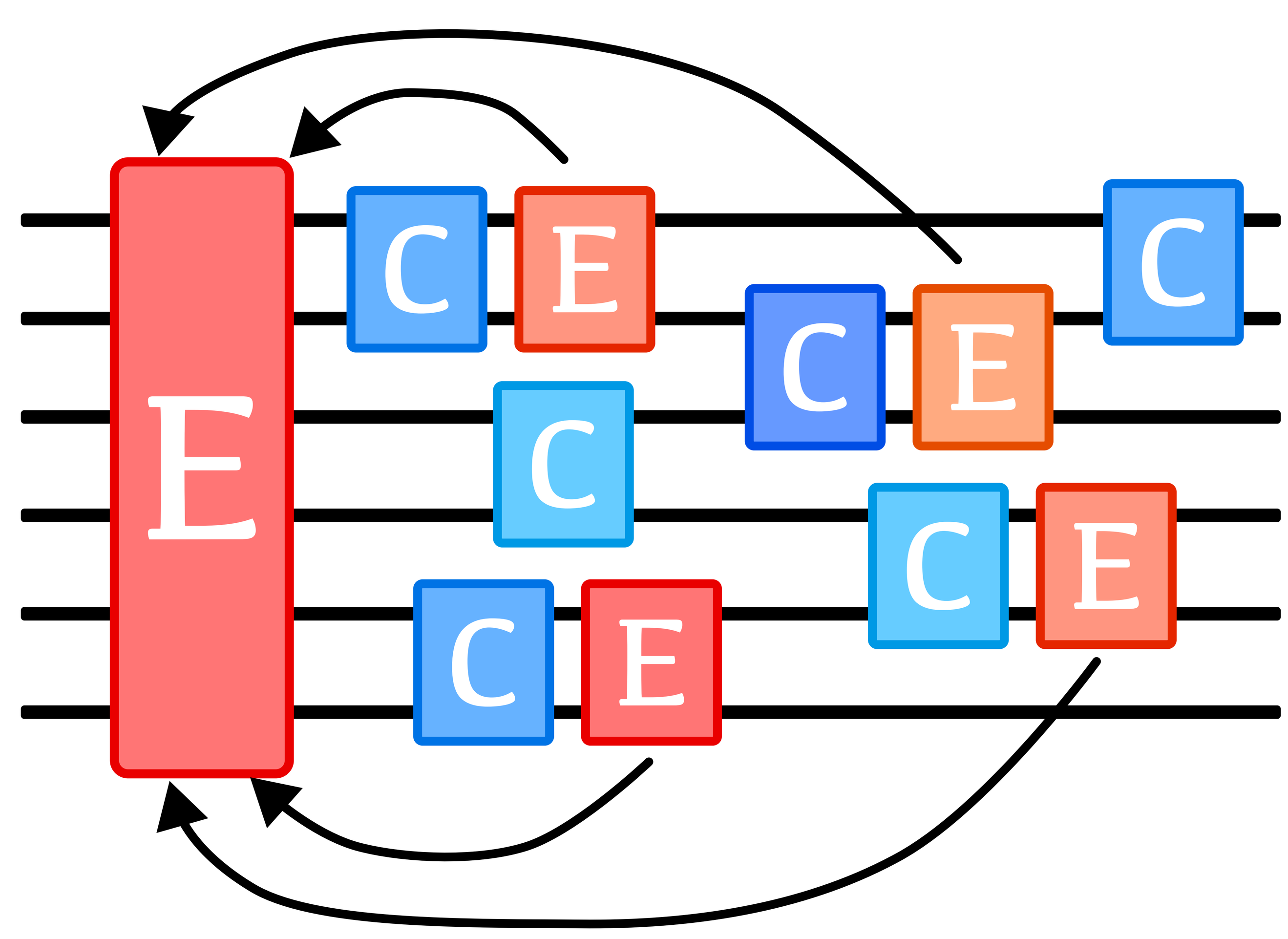


Suppose a Pauli error 'E' occurs on C. If E anti-commutes with L, an ancilla qubit can detect the resulting phase flip.



If E is uniformly distributed, and L is picked uniformly at random, 50% of errors are detected. This technique is called Coherent Pauli Checks (CPC); see "Single-shot error mitigation by coherent Pauli checks"

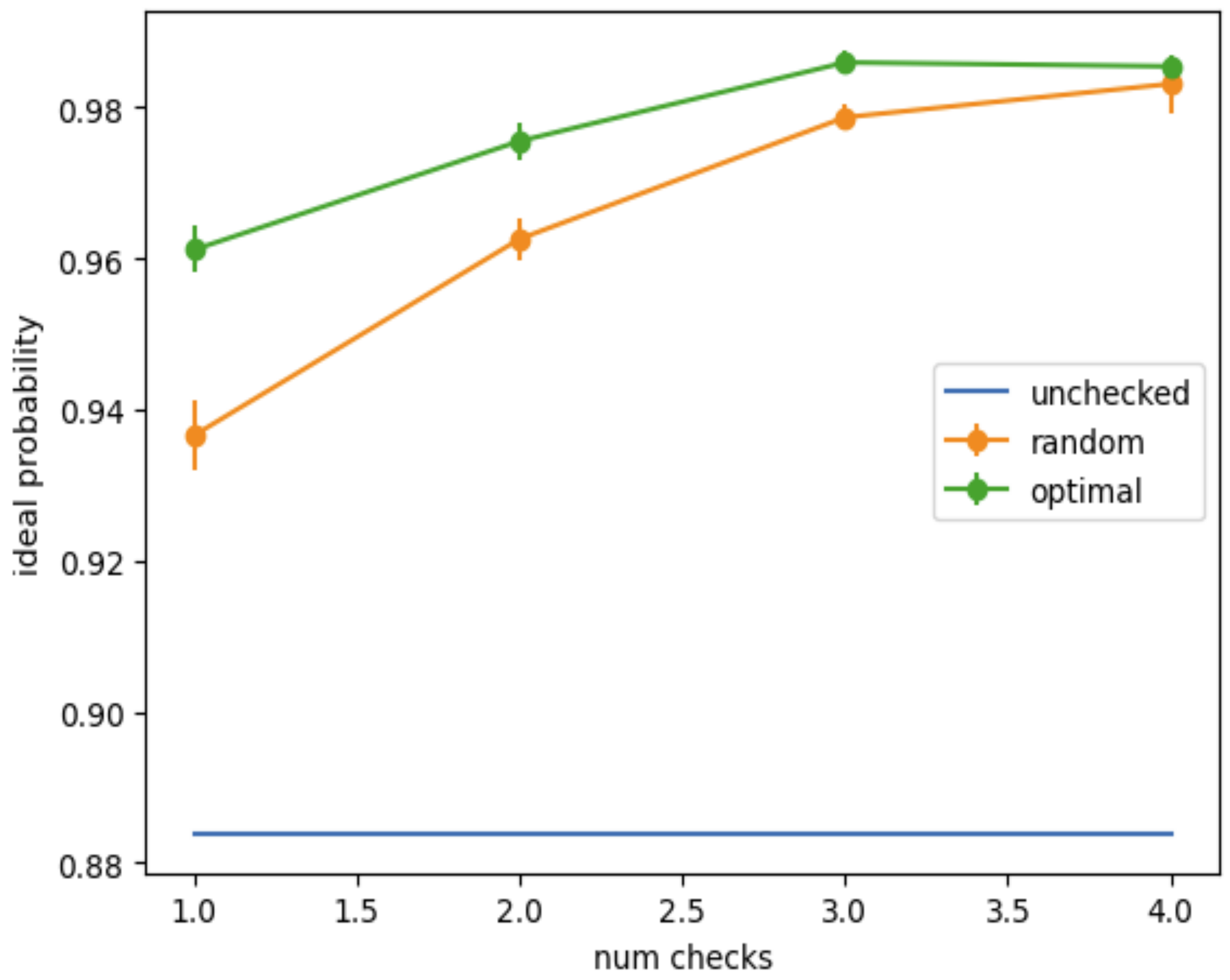
Here we present some ideas for a more nuanced utilisation of CPC. Suppose, as is typical for QPU providers, that we have characterised errors on 2-qubit Clifford gates. We take a Monte Carlo sampling approach to characterising errors on the entire circuit by; breaking up Clifford circuits into their constituents parts, repeatedly sampling 2-qubit errors, and pushing them to the start of the circuit.



This is efficient as we are working with Pauli and Clifford operators, and informs us of the relative likelihood of errors acting on the whole circuit.

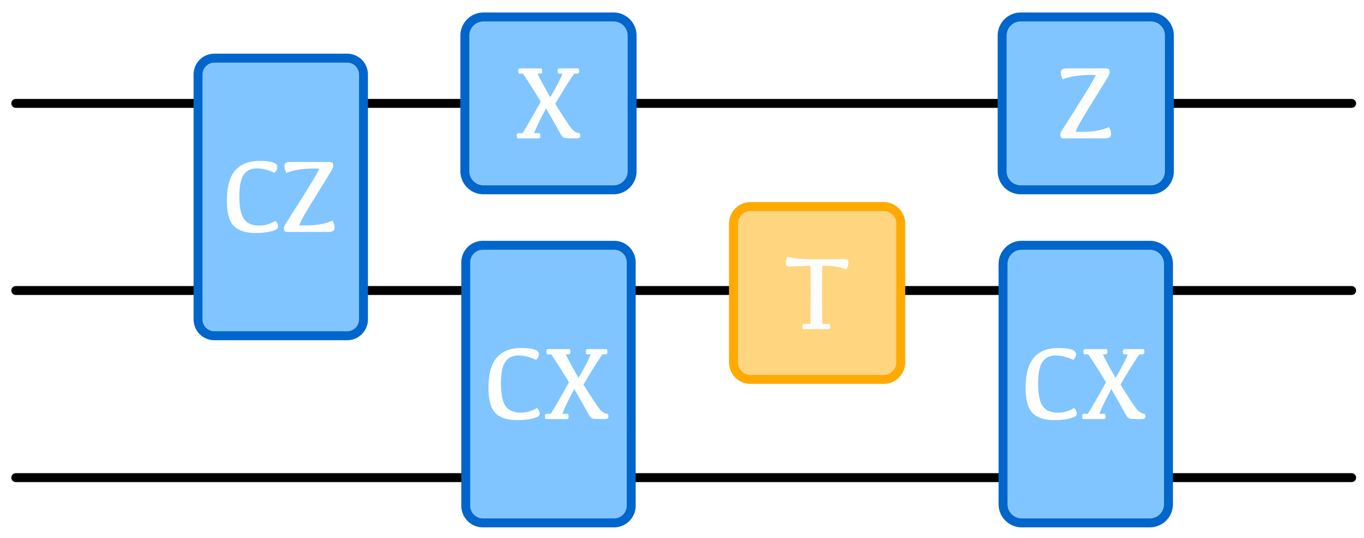
We can use this information to pick L to anti-commute with the largest fraction of errors occuring in the circuit, increasing the error detection rate. We refer to this scheme as Noise Aware Pauli Checks (NAPC).

We compare NAPC (optimal Pauli selection) and CPC (random Pauli selection) on a structured circuit with a single known output bitstring in the ideal case. We use an emulator of the Quantinuum H1 machine, which simulates a rich model of errors including, but not limited to, 2 qubit Pauli errors.

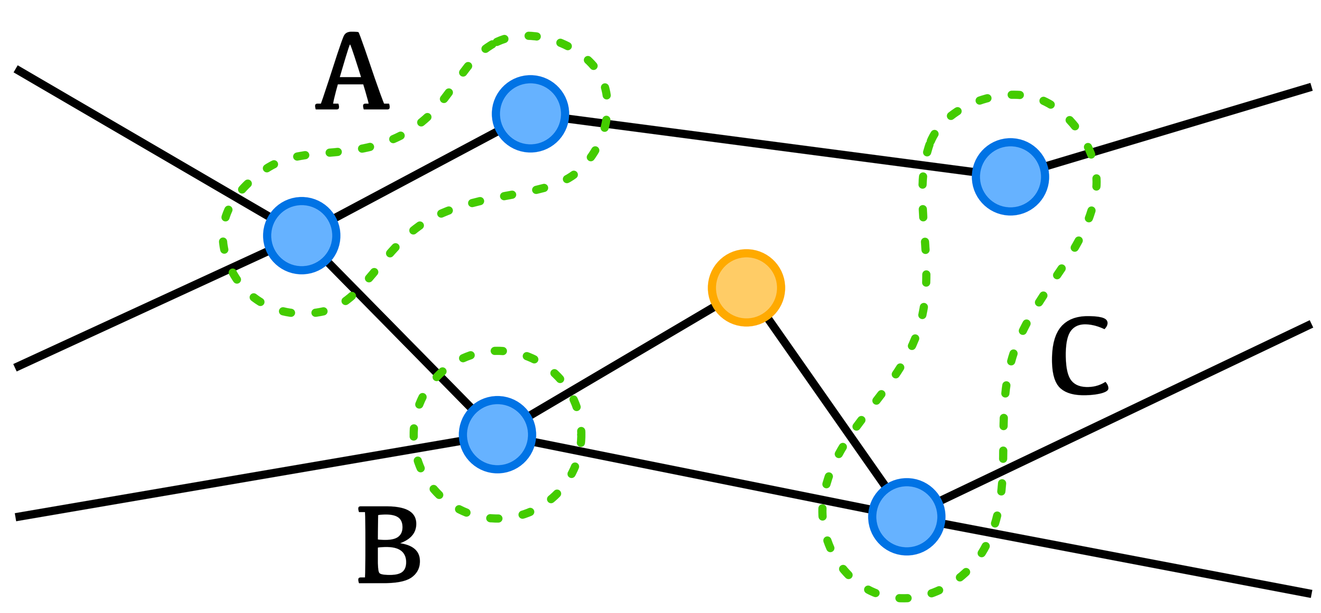


Adding more checks increases the set of errors which can be detected, increasing the ideal output probability towards the target value of 1.

Pauli Checks work only for Clifford circuits, or to protect Clifford subcircuits within a larger circuit. How then should we find Clifford subcircuits?



Imagine the circuit as a coloured graph, with Clifford nodes clustered into subgraphs. Subgraphs should be convex, to define valid circuits, and monochromatic.



Subgraphs can be merged when the merged subgraph is convex. Convexity can be checked efficiently by checking paths between the subgraphs to be merged. A and B can be merged, but not B and C.

As Pauli Checks themseves add errors, we merge subgraphs to minimise the total number of subgraphs; minimising the number of Clifford subcircuits which need protecting.

NAPC, and tools for Clifford subcircuit finding, are available in Qermit -> www.qerm.it. For support experimenting with NAPC contact daniel.mills@quantinuum.com