#14 Benchmarking noisy CX gates with QEC

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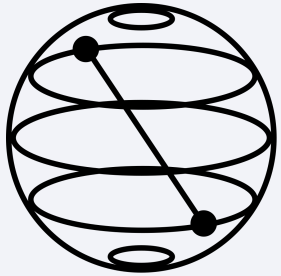
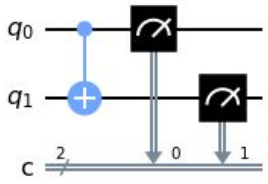
Mentor: James Wootton



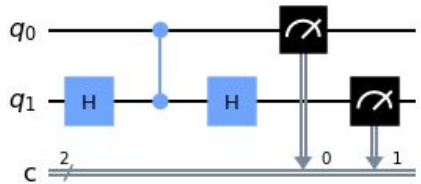
Some CNOT gate versions

We have tested these CNOT gates under some noisy different scenarios:

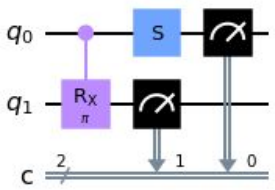
- Bitflip channel
- Depolarizing channel
- Bitflip/Depolarizing channel + coherent errors



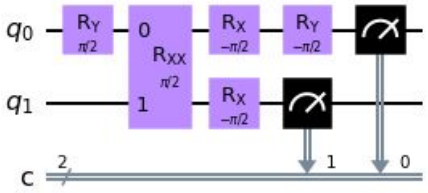
Standard



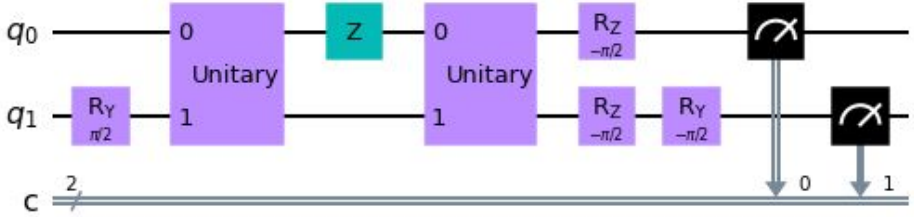
Hadamard + CZ



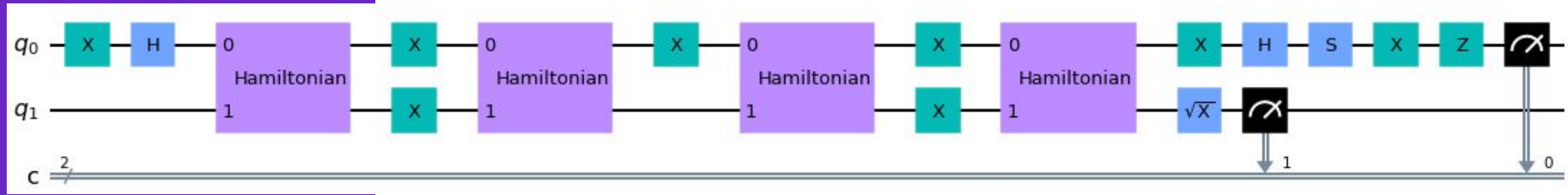
Controlled-RX + S



Molmer-Sorensen



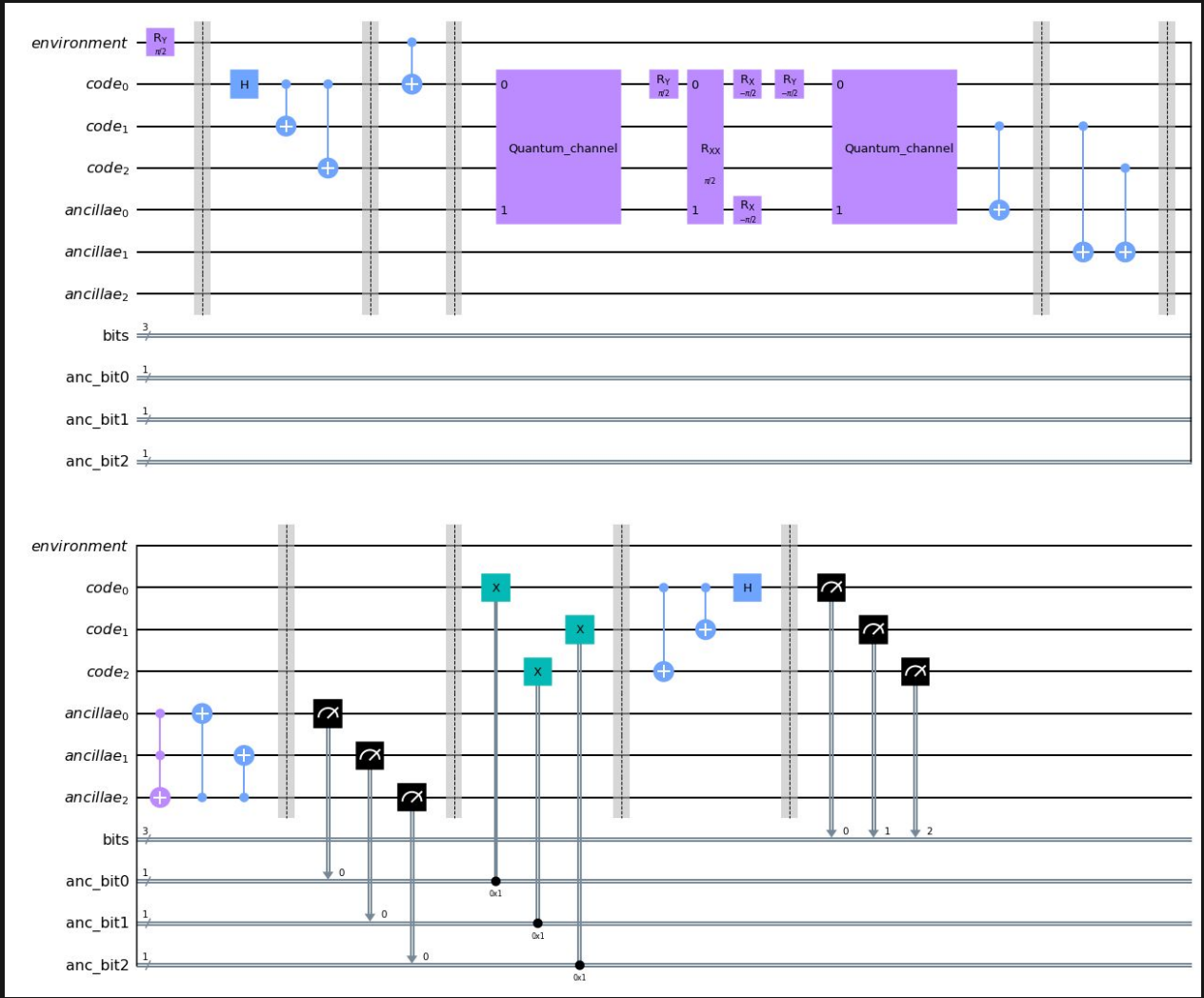
Square root of SWAP CNOT



$$H' = \frac{J_{12}}{2}|\gamma_x|^2\left(\sigma_{\mathrm{x}}^{(1)}\sigma_{\mathrm{x}}^{(2)} + \sigma_{\mathrm{y}}^{(1)}\sigma_{\mathrm{y}}^{(2)}\right) + E_z(\sigma_{\mathrm{z}}^{(1)} + \sigma_{\mathrm{z}}^{(2)})$$

Floating gate CNOT

arXiv:1808.03927v2



Repetition code

[[3,1,3]] code with an imperfect Molmer-Sorensen CNOT gate (Bitflip version)

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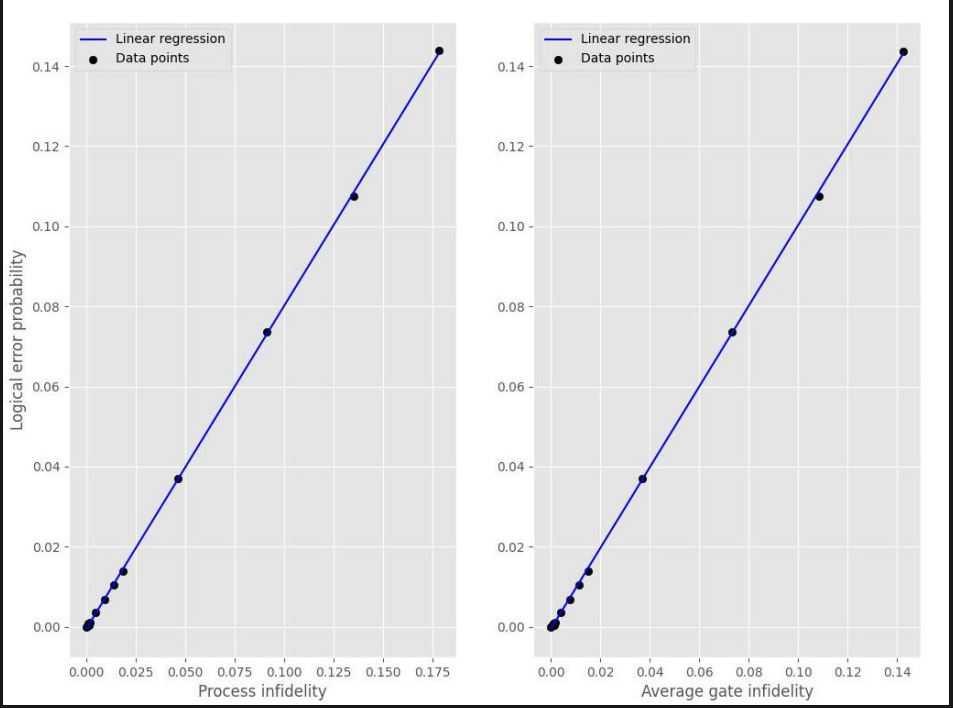
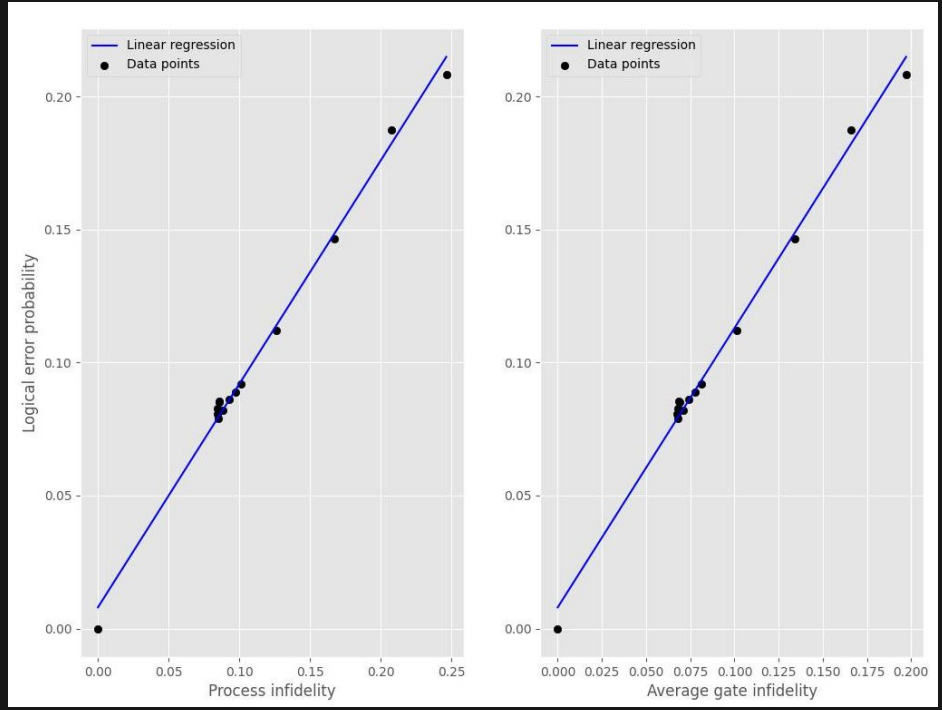
Molmer-Sorensen CNOT gate
Depolarizing channel (left) vs Depolarizing channel + coherent errors (right)





Source: https://github.com/jvscursulim/cnot-benchmark/tree/main/figures

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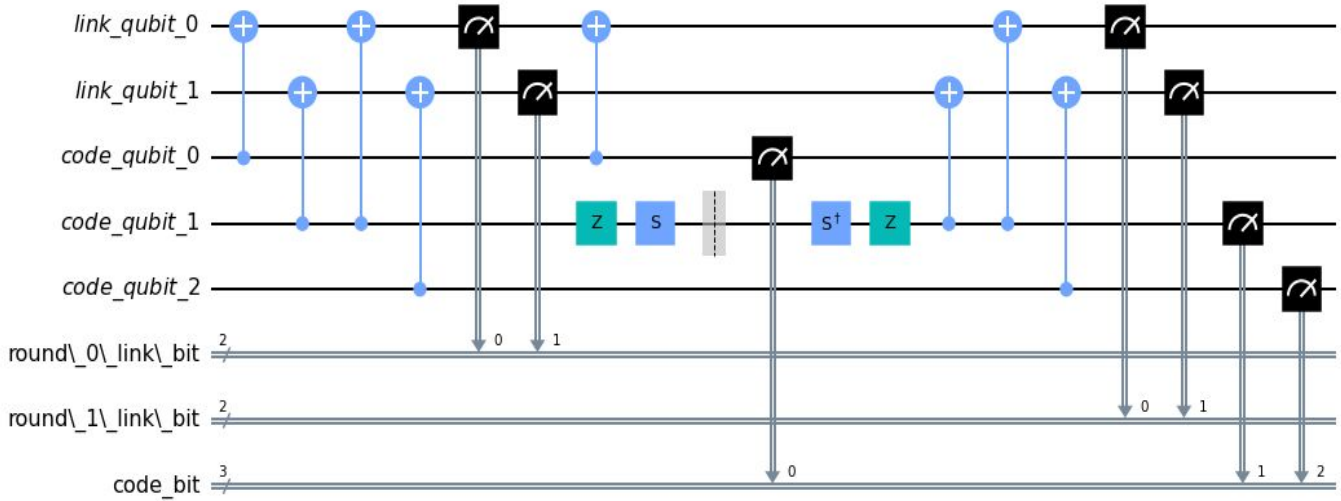
Randomized Benchmarking

We tried using Randomized Benchmarking to get an idea about the performance of the CX gate.

Studied the combined effect of the RB and the QEC approach, and tried to find out how it causes the reduction i n the SPAM errors

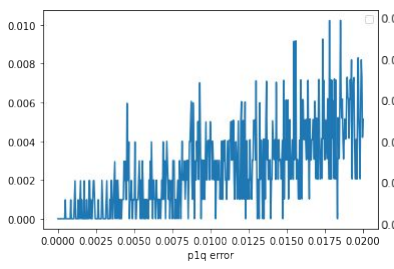


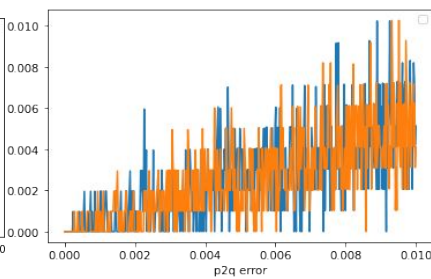

```
p
```

```
{'0': 0.037109375, '1': 0.0244140625}
```

```
noisy_p
```

```
{'0': 0.003092783505154639, '1': 0.0020597322348094743}
```





Bonus: Grover's algorithm applied on parity check equations

Grover's algorithm can be used to find out the solutions of modulo 2 equations, for instance: https://github.com/qiskit-community/IBMQuantumChallenge2020/blob/main/exercises/week-2/ex_2a_en.ipynb)

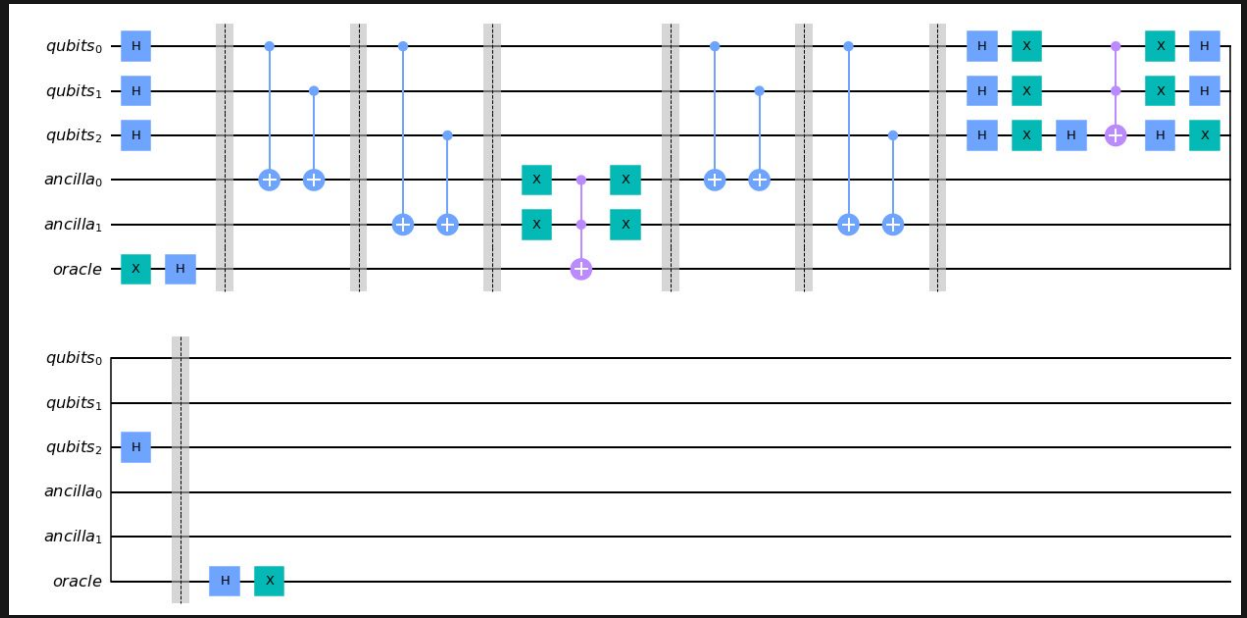
$$H\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} = Hx^{\mathrm{tr}} = 0$$

$$Hx^T = 0$$

$$\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$x_1 + x_2 = 0$$

$$x_1 + x_3 = 0$$




```
{'[3,1,3]': {'code_distance': 3, 'codewords': ['000', '111']}}
```

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Delivarables

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- A GitHub repository where you can find the code to run the experiments and all the data that we collected in our experiments.
  CNOT Benchmark: https://github.com/jvscursulim/cnot-benchmark
  *If you have a CNOT candidate and want to test it, we would like to invite you to use the tools we created.

- During the studies about error correction, we find out an interesting application of Grover's algorithm on the problem of determining the distance of an error correction code.
  GitHub repository:
  https://github.com/jvscursulim/using_grover_algorithm_to_findout_the_distance_of_a_classical_error_correcting_code

Thank you!!!