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Detecting Crosstalk and Drift in Quantum Information Processors

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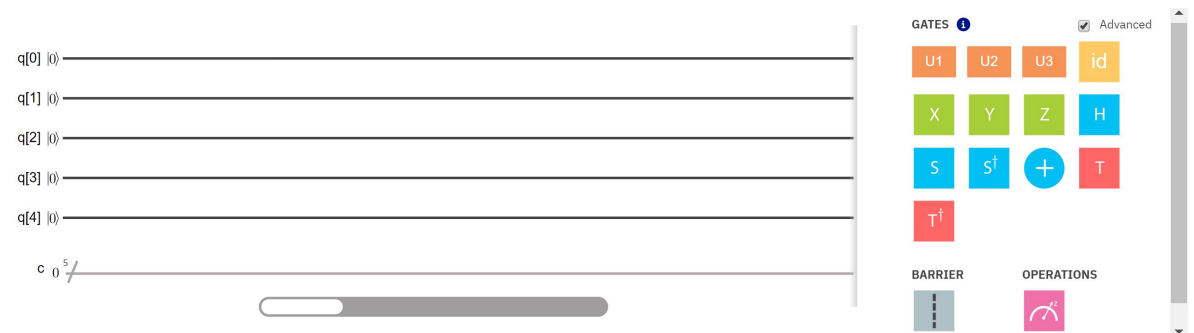^Sandia National Laboratories, kmrudin@sandia.gov

Purpose

- Context Dependence
  - Crosstalk (spatial)
  - Drift (temporal)
  - Sandia

- IBM's Quantum Experience
  - Publicly-Accessible
  - 2 5 Qubit systems
  - 1 16 Qubit System

Definitions

- Gate Sequence: Consecutive Operation of Gates comprising an experiment. Assigned a bias parameter.

- Bias Parameter: the bias of a gate sequence outcome, which is being estimated

- Assumption: Bias Parameters are stationary and Markovian.

- Null hypothesis: The same gate sequence in two different contexts have the same bias parameter

Statistics

- Likelihood score – probability of a bias parameter returning received results: $\mathcal{L}(q|N, h) = q^h (1-q)^{N-h}$

- Maximum Likelihood score– Maximum Score of a bias parameter, *P*:

- $\mathcal{L}_P = \dfrac{h_P}{N_P}^{h_P} (1 - \dfrac{h_P}{N_P})^{N_P - h_P}$

- Likelihood scores A, B and C where:

- A is created for a gate sequence in one context, B is in a different context. C is composite score, created under the assumption that the biases in the different contexts are the same

- $\lambda = -2\log \dfrac{\mathcal{L}_C}{\mathcal{L}_A \mathcal{L}_B}$

Statistics

- Assumption: Number of trials, *N*, is 'large enough'
  - λ follows χ_k^2 distribution, $k = 1$
  - Model violation:
  - $N_\sigma = \frac{\lambda - k}{\sqrt{2k}}$
- Aggregate Log-Likelihood statistic also created for entire collections of gate sequences, here 50
- $\lambda = -2 \sum_{i=1}^{50} \log \frac{\mathcal{L}_{C_i}}{\mathcal{L}_{A_i} \mathcal{L}_{B_i}}$
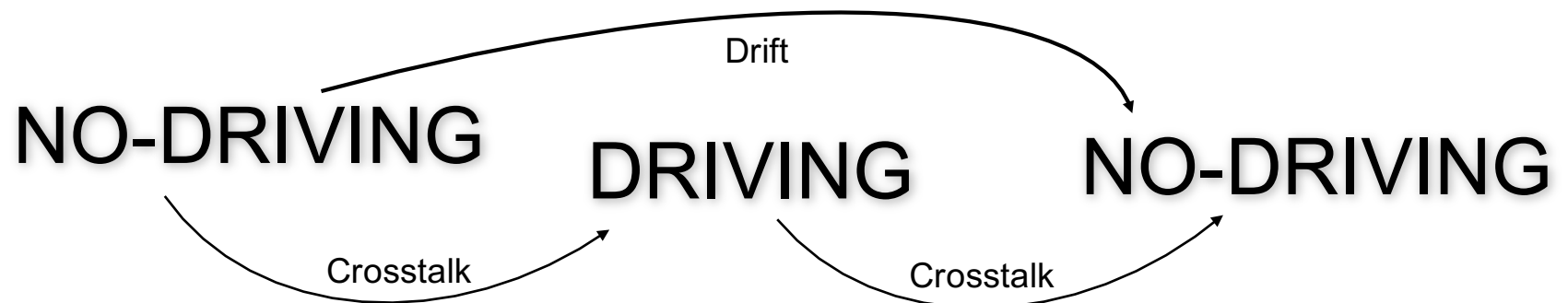
Experiment

- Experiments contained enough gate sequences to be tomographically complete (about 50)
- Gates from $\{H, I, S\}$, gate sequences were GST gate sequences
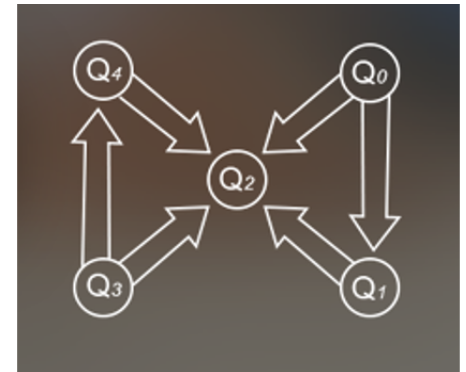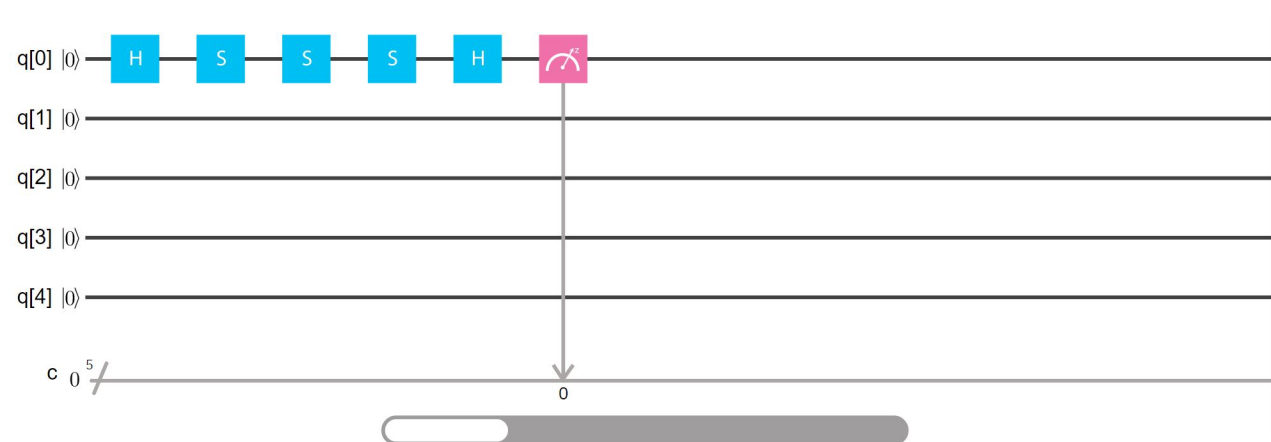
Experiment

- Three gate sets per experiment: 'No-Driving', 'Driving' and 'No-Driving'
- Reason: tests for crosstalk cannot be interwoven
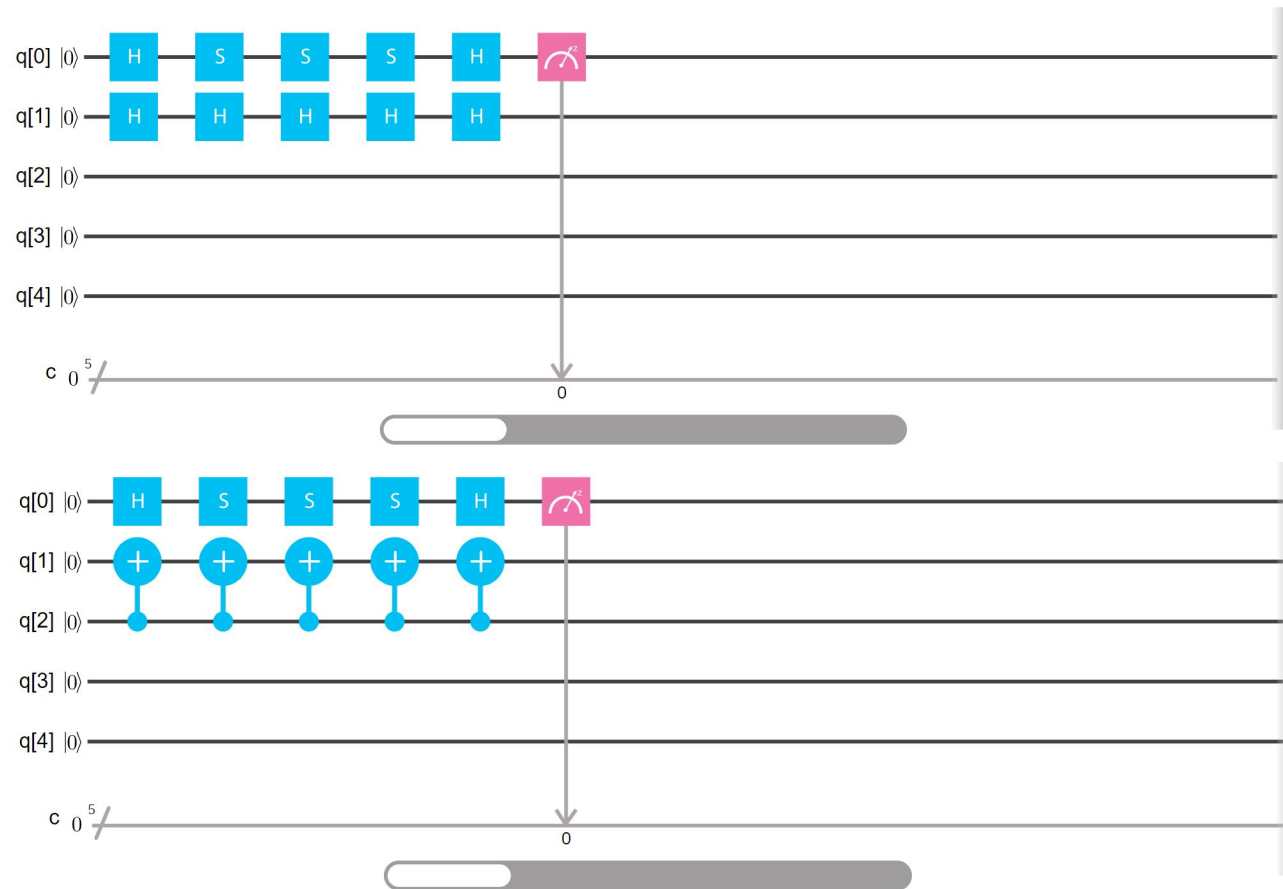
No Driving

Spectator Qubit – Qubit being operated on by gate string
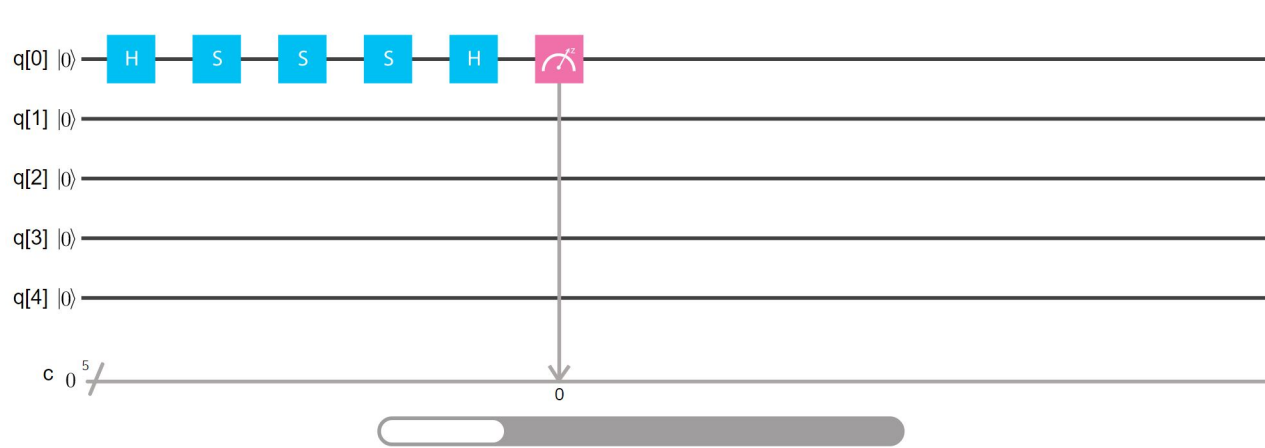(experiences crosstalk)

Driving

Driver Qubit – Qubit being operated on during 'Driving Run' (creates crosstalk)
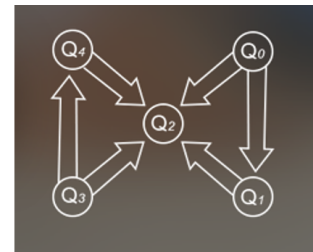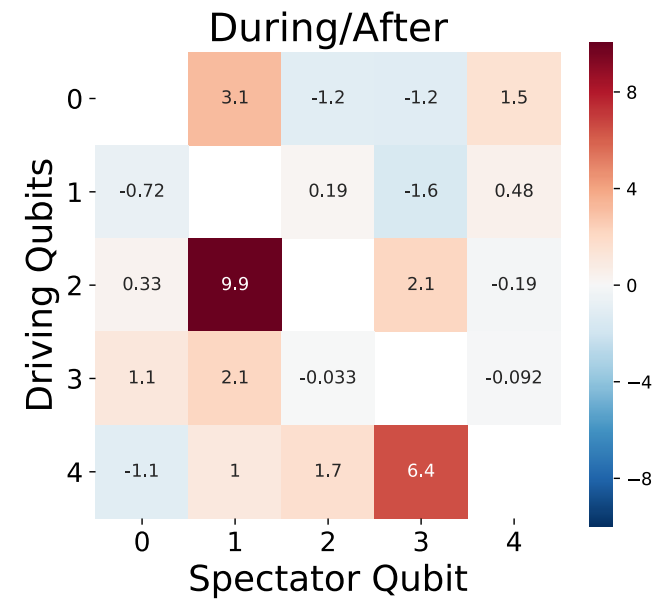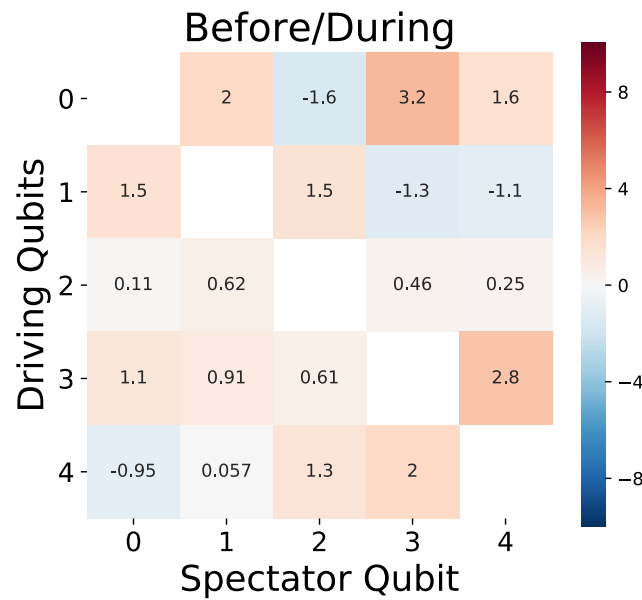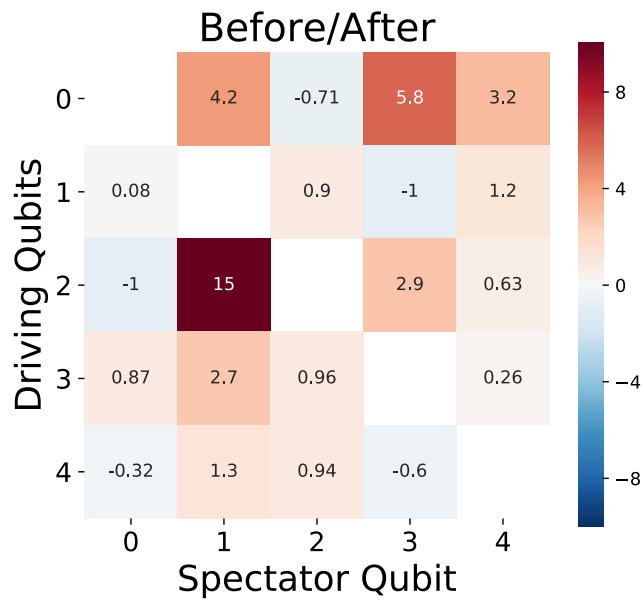
1 Driver: H or S
2 Drivers: $CNOT$

No Driving

Results: S Driving Gate

Model violation (N_σ)

Results: H Driving Gate

Model violation (N_σ)

Before/After

Before/During
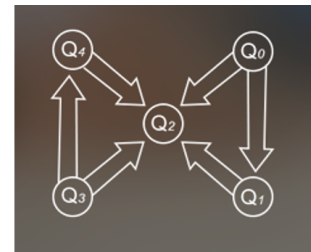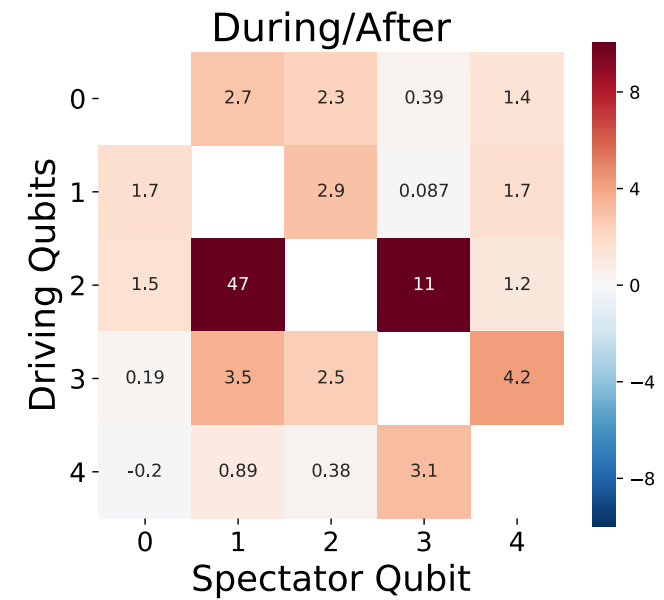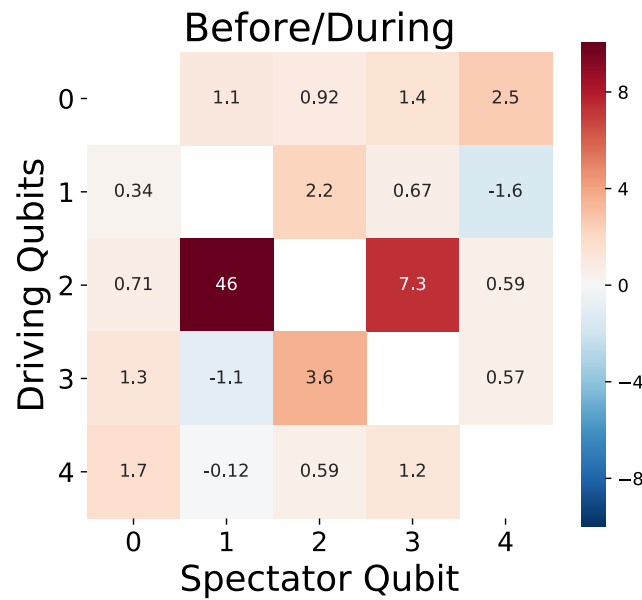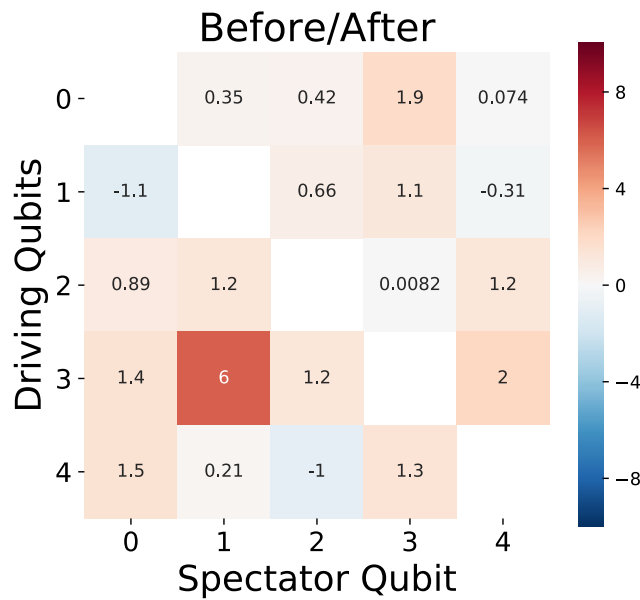
During/After

Results: CNOT Driving Gate

Model violation (N_σ)

Before/After

Driving Qubits \ Spectator Qubit	0	1	2	3	4
(0, 1)			-0.85	2	-0.4
(0, 2)		4.1		1.7	-0.23
(1, 2)	-0.98			1.7	0.77
(3, 2)	3	-1.6			1.5
(3, 4)	1.6	1.9	-0.39		
(4, 2)	3.3	-0.028		0.045	

Before/During

Driving Qubits \ Spectator Qubit	0	1	2	3	4
(0, 1)			2.7e+02	22	3.2e+02
(0, 2)		1.9		87	1.2e+02
(1, 2)	7.9			80	5.1
(3, 2)	60	1.1e+02			1.2e+02
(3, 4)	1.1e+03	12	2.9e+02		
(4, 2)	1.7e+02	5.5		40	

During/After

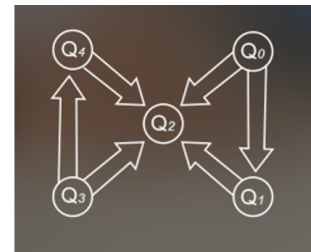| Driving Qubits \ Spectator Qubit	0	1	2	3	4
(0, 1)			2.6e+02	21	3.2e+02
(0, 2)		1.8		76	1.2e+02
(1, 2)	4.4			78	6.9
(3, 2)	55	1.2e+02			1.3e+02
(3, 4)	1.1e+03	13	2.9e+02		
(4, 2)	2e+02	-0.019		35	

Conclusion

- Protocol developed at Sandia
  - 50 Gate Sequences tested on IBM's Quantum Experience
  - Statistical analysis tested created λ from received results
  - λ follows $\chi^2_{k=1}$ distribution if null hypothesis is true
  - Excess log-likelihood determined model violations
- Quantum Noise:
  - Context Dependence
    - Crosstalk
    - Drift
  - $CNOT$ operations created a high amount of crosstalk