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Practical 2-qubit Gate Set Tomography

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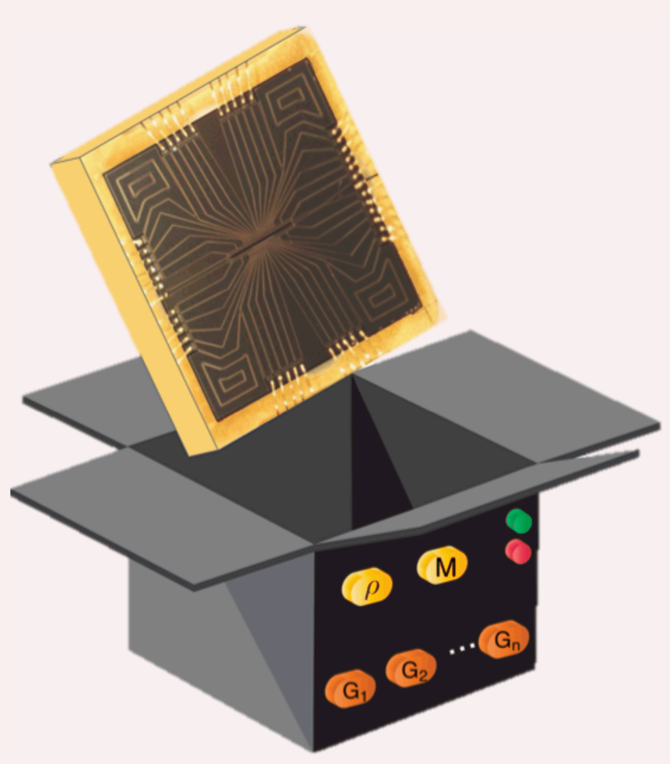
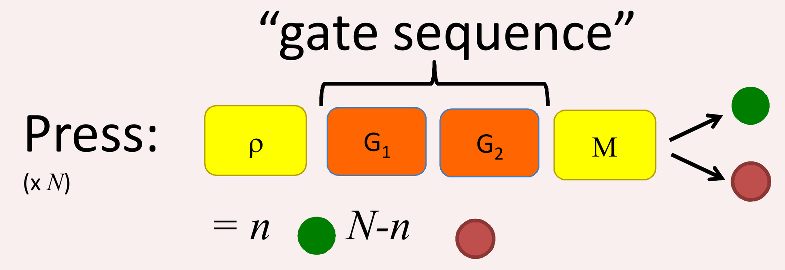
Gate Set Tomography (GST) Overview

1. Experiment treated as a black box



2. You perform certain gate sequences



In particular, the sequences:

$$\rho \; F_i \; (g_k)^R \; F_j \; M$$

where: $F_i = G_{i_1} \cdots G_{i_f}$ "fiducials"

$g_k = G_{i_1} G_{i_2} \cdots G_{i_g}$ "germs"

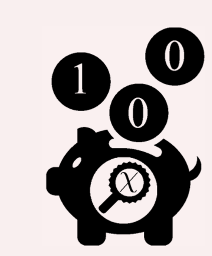
3. GST machinery optimizes a likelihood to give you the set of (Markovian) gates which best fit your data.

$N =$ number of times each experiment is repeated.

$f_i =$ frequency of i-th gate sequence (from data)

$p_i =$ probability of i-th gate sequence (from model)

$$\log L = \sum_i N f_i \log(p_i)$$



Problem: 2-qubit GST requires much more computation

Differences between 2-qubit and 1-qubit GST:

	# germs g_k	# fiducial pairs F_i F_j	# parameters
1-qubit GST	11	16	23
2-qubit GST	71	160	1263

Roughly 100x more experiments and 1000x more compute time.

Solution: Optimizations & Modifications to GST

Weighted Gauge Optimization

When optimizing the gauge degrees of freedom, preference can be given to gates which are expected to be closer to the ideal (usually the single-qubit gates).

Gauge Transformation

$$\langle\langle E| \rightarrow \langle\langle E|B$$

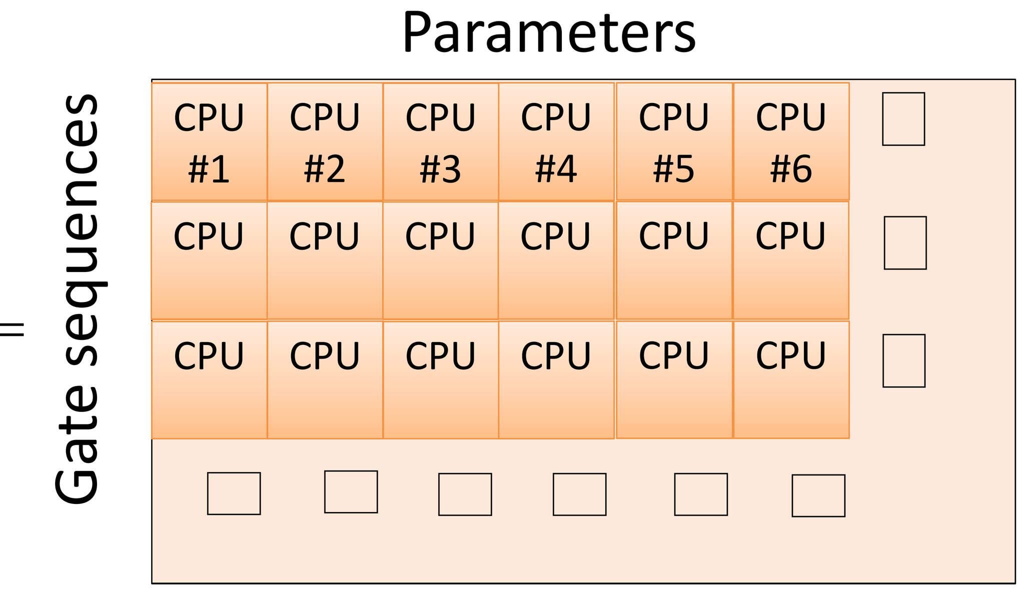
$$|\rho\rangle\rangle \rightarrow B^{-1}|\rho\rangle\rangle$$

$$G_k \rightarrow B^{-1} G_k B$$

Distribution over multiple processors

Jacobian used in log-likelihood optimization

$$\frac{d \log L}{d \text{ Parameters}} =$$



Automated Germ and Fiducial Selection

Selection of fiducial and germ sequences has been automated, enabling the use of GST with arbitrary desired (2-qubit) gates.

$$\{g_k\} \quad \{F_i\} \quad \{F_j\}$$

For fiducial selection,

$$\text{Gram}_{ij} = \langle\langle \rho | F_i F_j | M \rangle\rangle$$

Must be full-rank (fiducial selection). For germ selection, we require the scaled Jacobian

$$\nabla^{(L)}_{g_k} \equiv \frac{\partial (g_k)^L}{\partial \vec{G}}$$

to have n singular values which grow with the germ-power-length L, where n = # of gateset parameters.

Fiducial Pair Reduction

In order to reduce the total number of gate sequences (speeding up both data taking and GST run time), a subset of all fiducial pairs F_i F_j are found which still amplify all gate set parameters.

$$\rho \; F_i \; (g_k)^R \; F_j \; M$$

E.g., only analyze above sequences with pairs:

	F_1	F_2	F_3	F_4
F_5	✓	✗	✓	✗
F_6	✗	✓	✗	✗
F_7	✗	✓	✗	✗

- Leads to **10-20x** fewer sequences (& shorter run time).
- **Works on nice Markovian data.**
- **Fragile** when using non-Markovian data.

Summary

- 2-qubit GST requires **significantly more experiments and computation resources** than 1-qubit GST.
- Current improvements allow **2-qubit GST to be performed in several hours** on a single core.
- **A work in progress**, with many ideas still to be implemented and tested.

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