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Model-based characterization on 10 qubits.

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Background

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- Quantum processors offer promising speedups, but we need lots of qubits and a very low “error rate”.
- Todays processors ~10-100 qubits, and are implement noisy operations.
- Our goal: understand the performance and what limits the performance of today’s quantum processors.
- This talk focuses on ~10-qubit sized processors

Characterization of quantum processors

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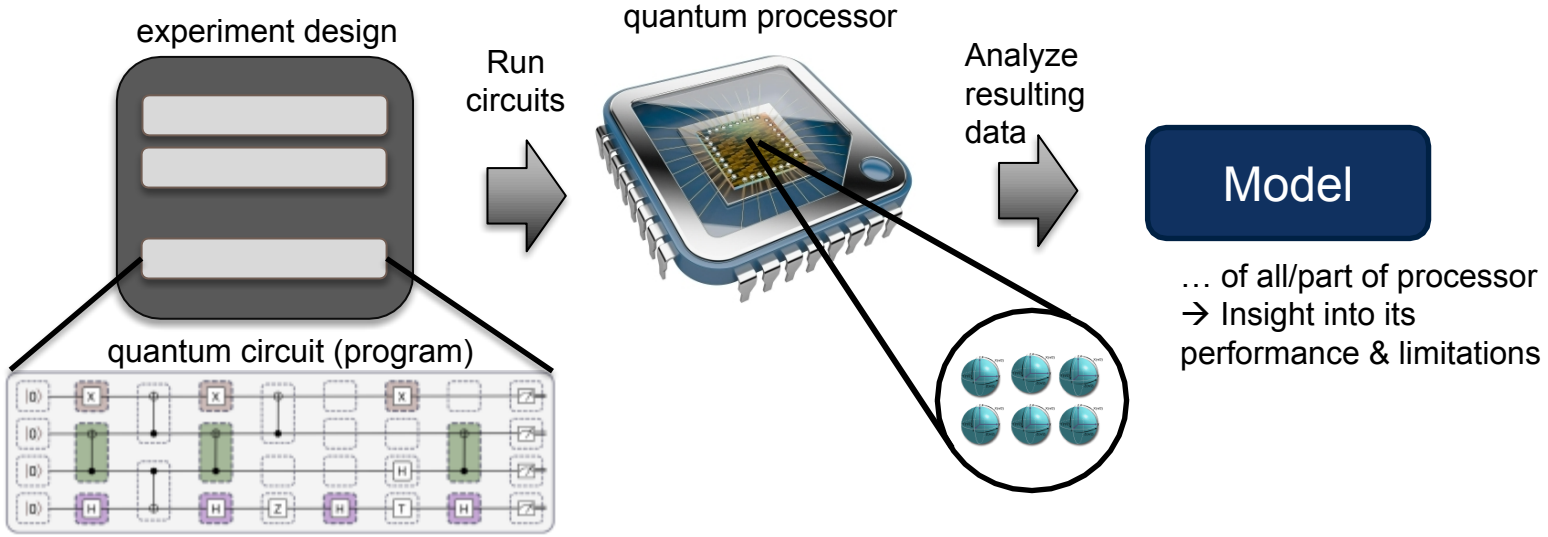
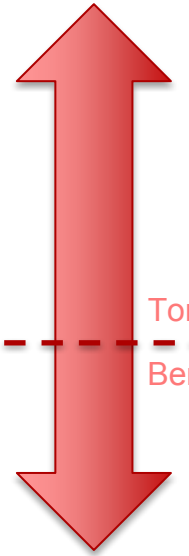
We characterize a processor by running ***characterization protocols***:



Models

Characterization protocol → Model, but there's a spectrum…

More complex
Harder to analyze



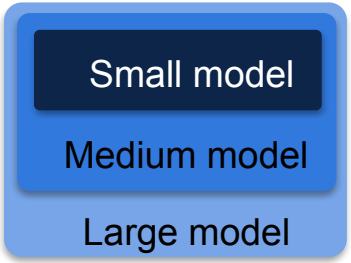
Model of…	Predicts…	Max. # qubits
physical Hamiltonian	results of arbitrary control waveforms	~2
individual gates	**results of arbitrary circuits**	**2-10 ?**
Tomography / Benchmarking		
average* error rate	average* performance	many

Less complex
Easier to analyze

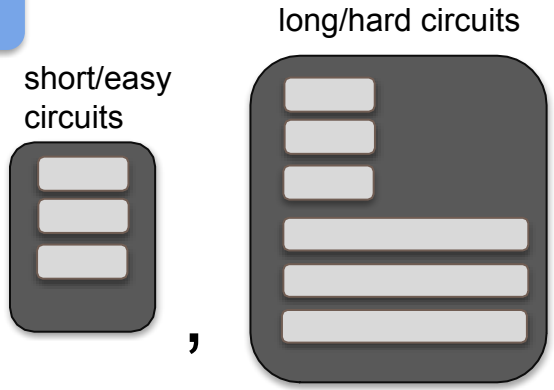
- Focus on gate-level models; ask - how far can we go?
- Develop algorithm that varies model & experiment design complexity

Model-testing framework

- Ingredients:
  - Nested (parameterized) models



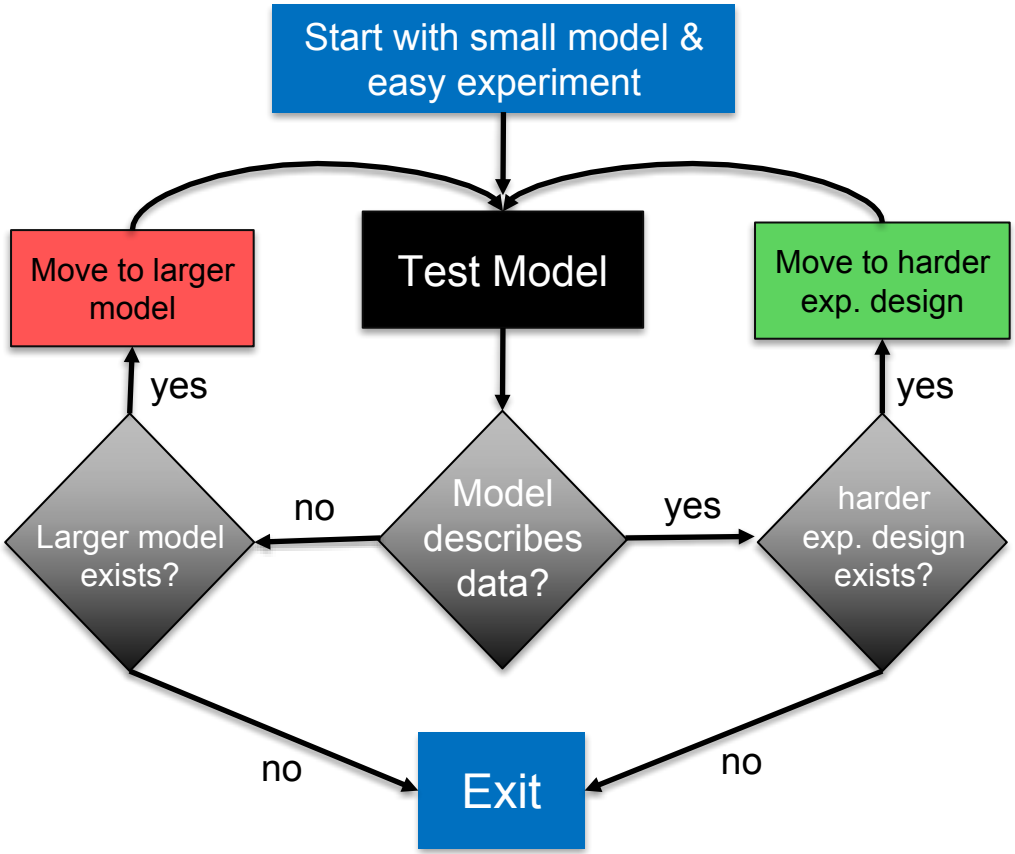
  - Test suites (experiment designs) of different hardness/complexity

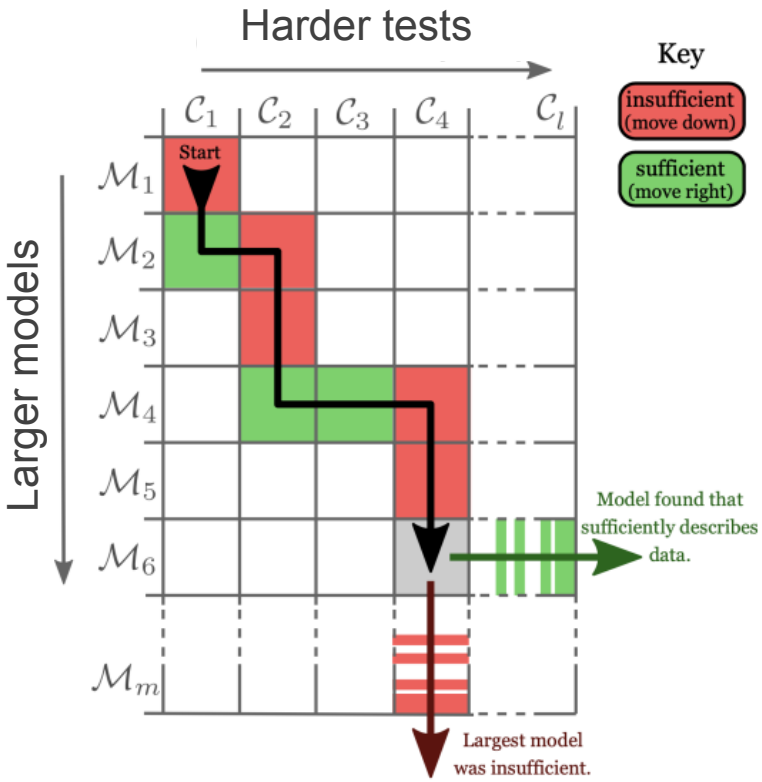


  - Ability to fit model to data
  - Ability to quantify whether a model is “good”, i.e. whether it describes the data sufficiently well

www.pygsti.info

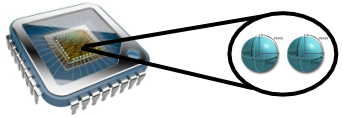
The algorithm





Arxiv reference

2-qubit example



Simulated coherent + Pauli-stochastic errors

120 RB circuits

+240 periodic circuits

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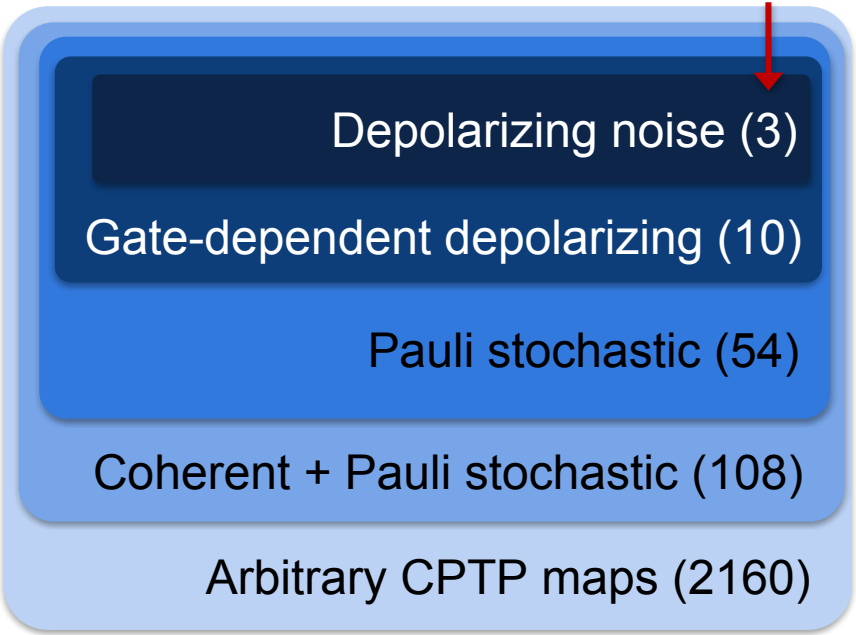
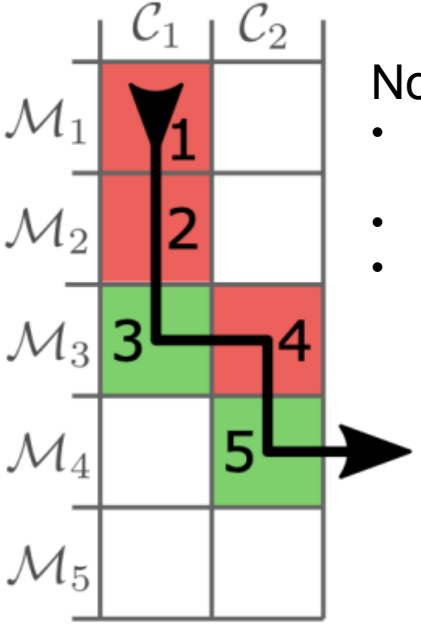
parameters





Notes:

- Accept/reject based on wildcard error. [cite]
- CPTP model unnecessary
- Periodic circuits reveal coherent noise

Scaling to more qubits

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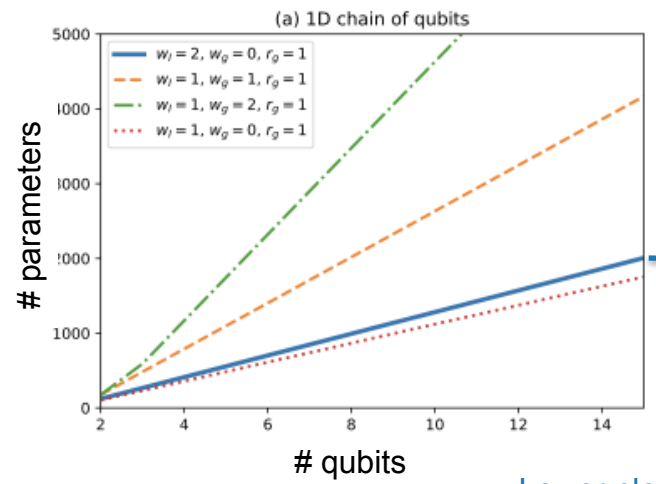
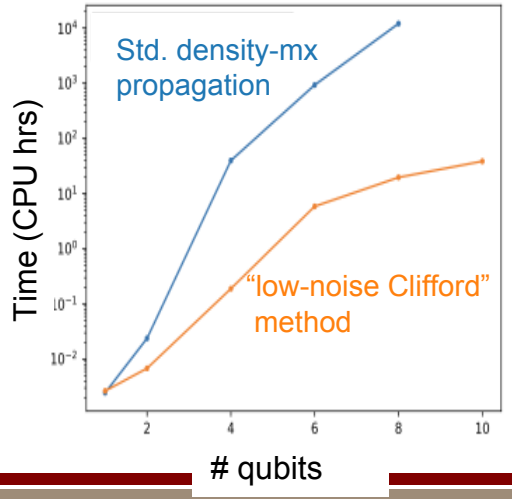
- "Efficient" gate-level models constrain error **weight**, **type**, and **support**
  - Linear parameter-count scaling w/#qubits
  - 10 qubits; 500 to 10000 parameters

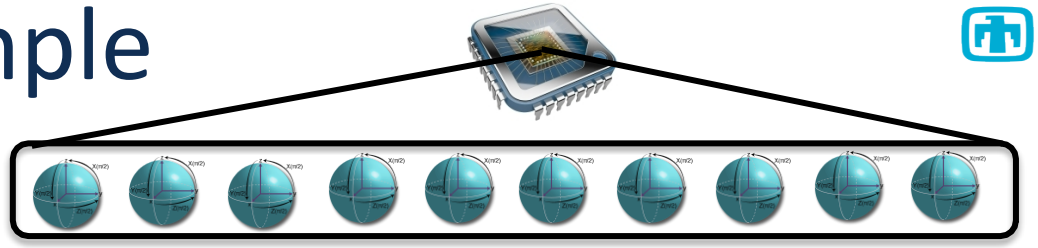


- Simulation becomes bottleneck
  - Clever methods for low-noise Clifford operations can scale better than typical exponential.
  - 10 qubits; takes ~1 hour on ~50 procs to fit "coherent + Pauli stochastic" model.



Lower plot gives timing for this model

10-qubit example



10-qubit linear chain:

Simulated coherent + Pauli-stochastic errors

(weight <= 2, geometrically local)

371 process tomography circuits

+252 periodic circuits

parameters

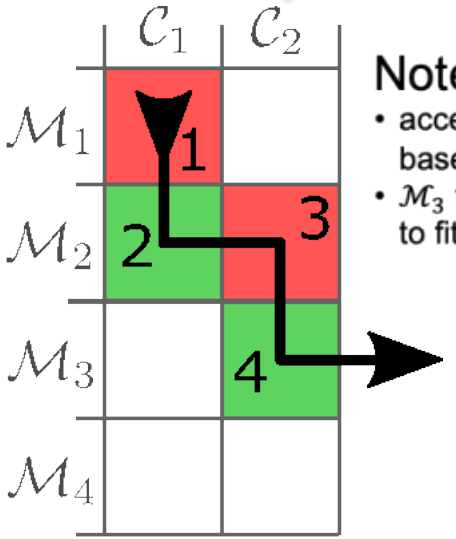
"Efficient"models:
- At most weight-2 errors
- nearest-neighbors

Gate-dependent depolarizing (177)

Pauli stochastic (873)

Coherent + Pauli stochastic (1746)

Arbitrary CPTP maps (~ 3×10^{13})



Notes:
- accept/reject based on $N_\sigma < 3$
- $\mathcal{M}_3$ takes ~ 1hr to fit (32 cores)

Summary

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- We presented a simple characterization method that
  - incorporates multiple models & experimental test suites
  - is extensible to O(10) qubit systems using *gate-level* models.
- Multiple models allow trade-offs:
  - Model & experiment complexity **vs.** amount of error modeled & resources required
- Future: characterizing ~100-qubit processors
  - Look at less complex (higher-level) models, e.g. average performance
  - Look at integrating patches of smaller gate-level characterizations