Quantum Gate Pattern Pattern Recognition and Circuit Optimization for Scientific Applications

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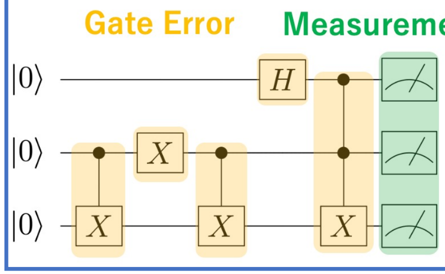
AQCEL : Software for Optimization of Quantum Circuits developed by ICEPP and LBNL

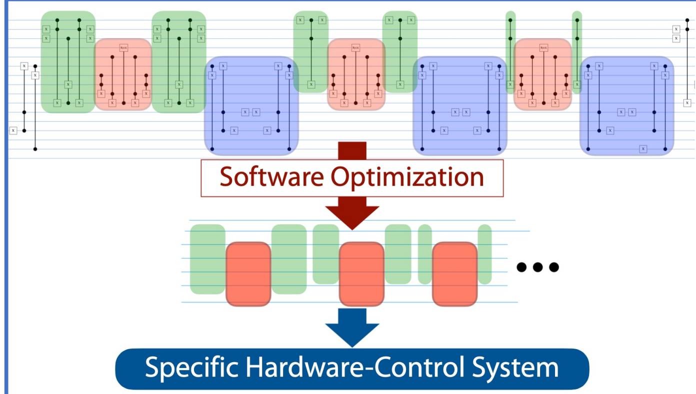
Background

Current Quantum computers are influenced by noise, which are called NISQ (Noisy Intermediate Scale Quantum Computer) devices. There are three main strategies to improve the performance of NISQ.



1. Error Mitigation
2. **Gate Reduction**
3. **Pulse Control**

AQCEL



1. Remove Unnecessary Controlled Operations
2. Remove Adjacent Gates Pairs
3. Recognize Recurring Sets of Gates (RSG)
4. *Optimize Pulse Controls of RSGs (Future)*

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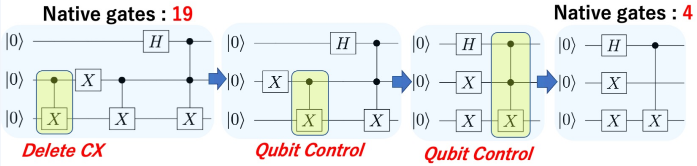
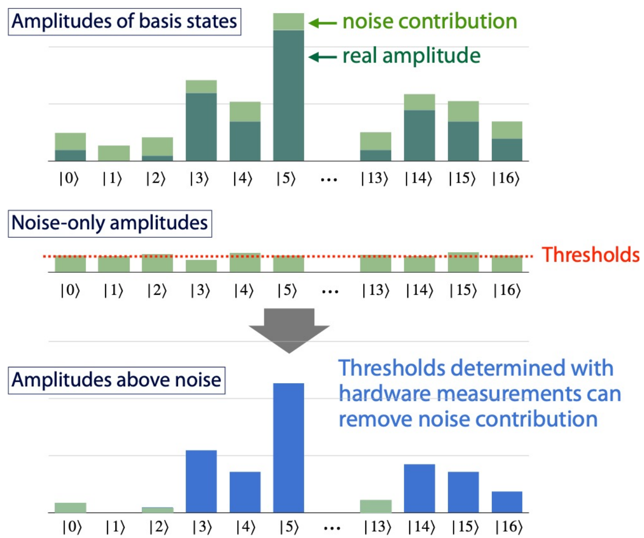
arXiv : 2102.10008
Github : UTokyo-ICEPP/aqcel



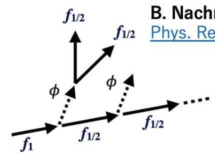
	First CX	Second CX	CCX
Quantum State	$\|000>$	$\|010>$	$\frac{1}{\sqrt{2}}\|011> + \frac{1}{\sqrt{2}}\|111>$
Bit Strings	'0'	'1'	'01', '11'
Optimization	*Delete CX*	*Delete Qubit Control*	*Delete second Qubit Control*

	Measurement of Bitstrings	Removing Unnecessary Controlled Operations	RSG Recognition
Classical Simulation	$O(nN2^n)$	$O(nN)$	$O(N^{N_{\text{thr}}})$
Quantum Computer	$O(Mn^2N^2)$	×	×

For the identification of basis states using a classical simulation, it requires the exponential computational cost. If we measure controlled qubits repeatedly using a quantum computer, the cost is polynomial. However, it contains noise contributions which needs to be removed by thresholds.

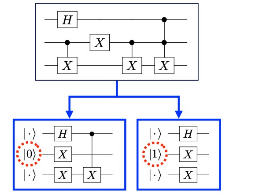


Results



B. Nachman *et al.* Phys. Rev. Lett. **126**, 062001 (2021)

- 2 types of Fermions and 1 type of Boson
- Boson Emission and Splitting
- Interference due to flavor changes

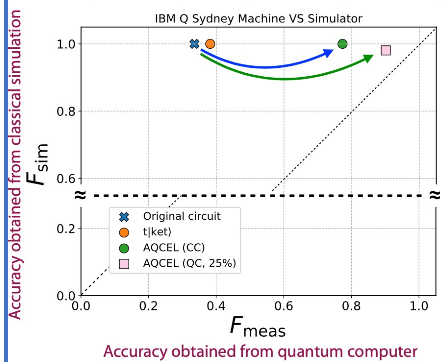


Circuit designed with generic initial states (*a la* parton shower algorithm) can be simplified when specific initial state is given

Emission/Splitting possibilities using Sudakov Factor
- Quantum circuit designed for all initial states (f_1, f_2, Φ)
- Many redundant controlled operations for a specific initial state

#Gates	Original	t|ket⟩	AQCEL (Classical)	AQCEL (Quantum)
CNOT	527	616	178 (34%)	64 (12%)
$U_{1,2,3}$	362	331	102 (28%)	24 (7%)
All	889	947	280 (31%)	88 (10%)

AQCEL reduced gate counts significantly including CNOT gates.
→How about the accuracy of optimization?



Classical fidelity F

$$F = \sum_k \sqrt{p_k^{\text{orig}} p_k^{\text{opt}}}$$

Classically : it maintains the accuracy of the circuit.
QC measurements : It loses a little accuracy, but sometimes improves the performance on QC more.

Discussion

- We developed AQCEL that can remove redundant controlled operations and recognize RSGs.
- AQCEL reduced the gate counts of a quantum parton shower algorithm and improved the performance on QC.
- We are exploring the optimization of pulse controls of RSGs