Poster ID:01

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Research and Development toward Practical Quantum Computing

General Background

Introduction

- The process rule for transistors used in classical computers is about to reach 1 nm(10 atoms size).
- The 1nm process rule reaches the quantum world, and the process rule will eventually reach its physical size limits.

New computational technologies are needed...

Quantum Computers as a New Computational Technology

Current Quantum Computer

- The quantum computer used in the demonstration experiment is called NISQ.
- This NISQ contains errors due to noise and produces calculation results containing errors.
- A fault-tolerant quantum computer with quantum error correction will be developed in the future.

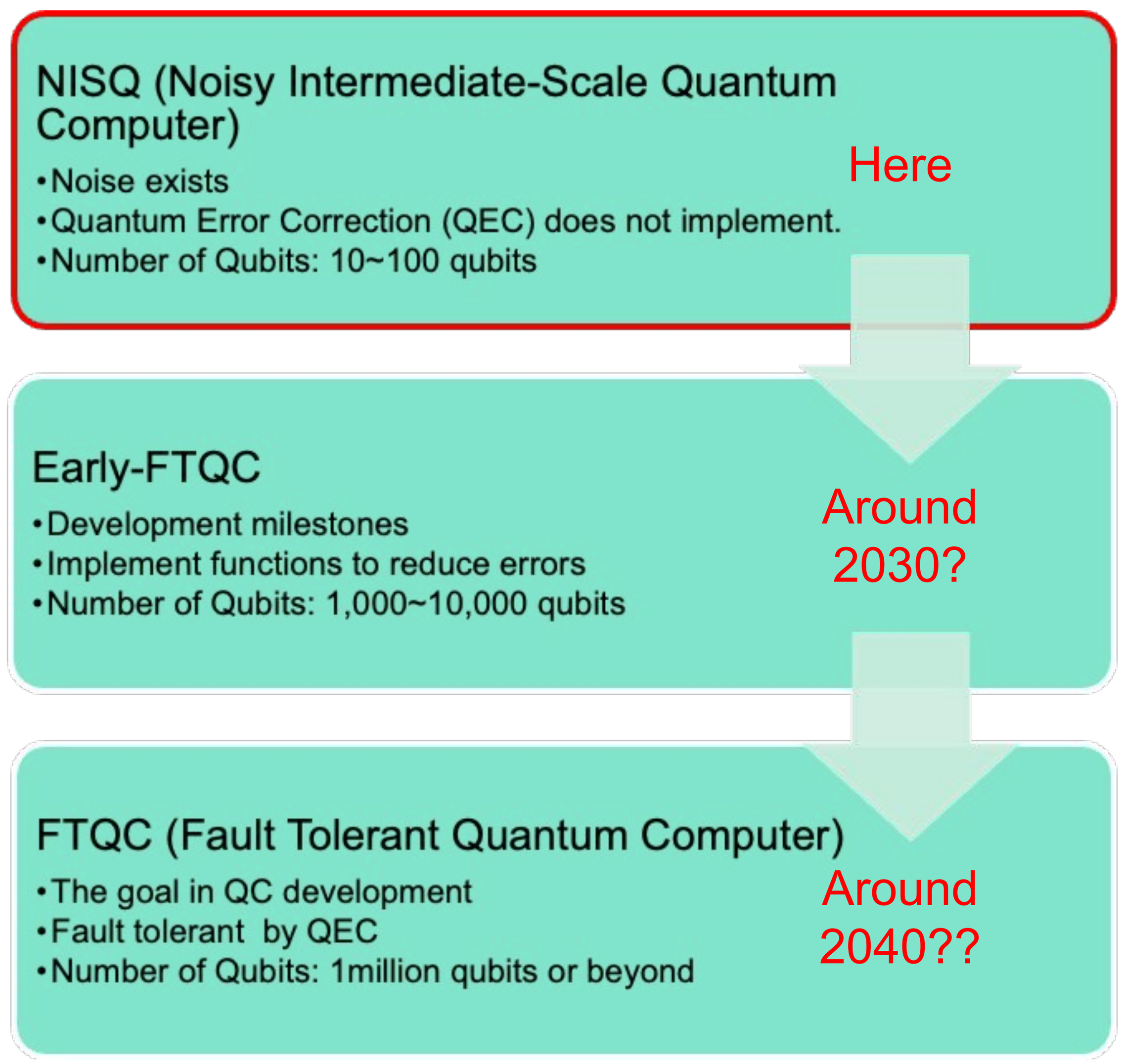


Fig.1: Development Phase and Features of QCs

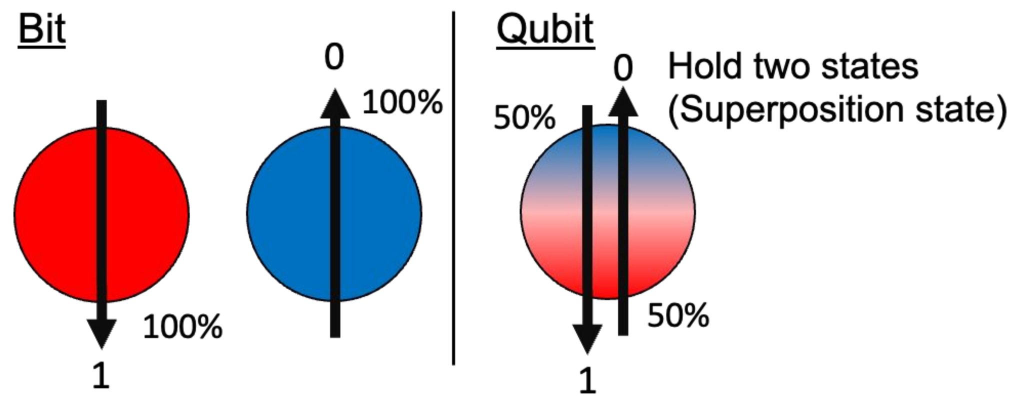


Fig.2: Bit vs. Qubit

Fig.3: Benefits by Practical QCs

Research Targets

Quantum Algorithms

Motivation & Goal

- A quantum algorithm solves a problem using a quantum computer, and many quantum algorithms are proposed.
- We focus on Grover's algorithm[2], which can search data with quadratic acceleration of linear search.
- NISQ does not implement quantum error correction and many qubits, so the utility of Grover's algorithm is limited.

We want to use Grover's algorithm usefully with NISQ…

- The goal is to reduce the computation time of existing Grover's algorithm so that Grover's algorithm is useful on NISQ.

Expected Results

- This research can be used for realistic scale data search in the future.
- Larger data can be searched.

Methodology

- Devise theoretical calculations and verify them using a quantum circuit simulator called *Qiskit*[3].

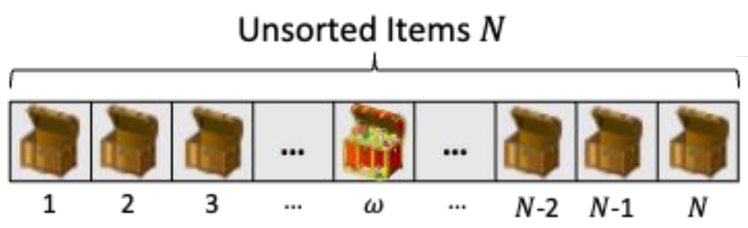


Fig.5: Grover's algorithm searches for unstructured data with $O(\sqrt{N})$

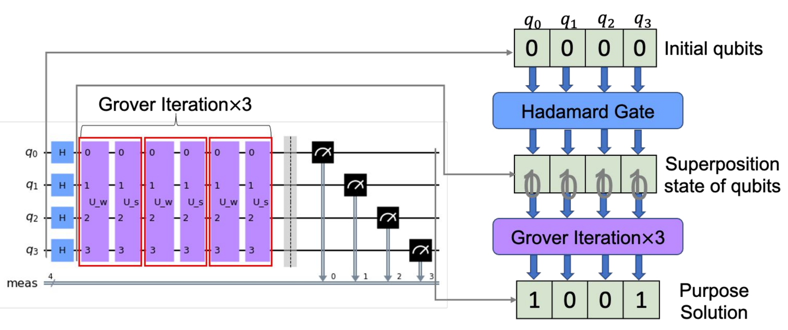


Fig.6: Quantum Circuit of Grover's Algorithm using *Qiskit*

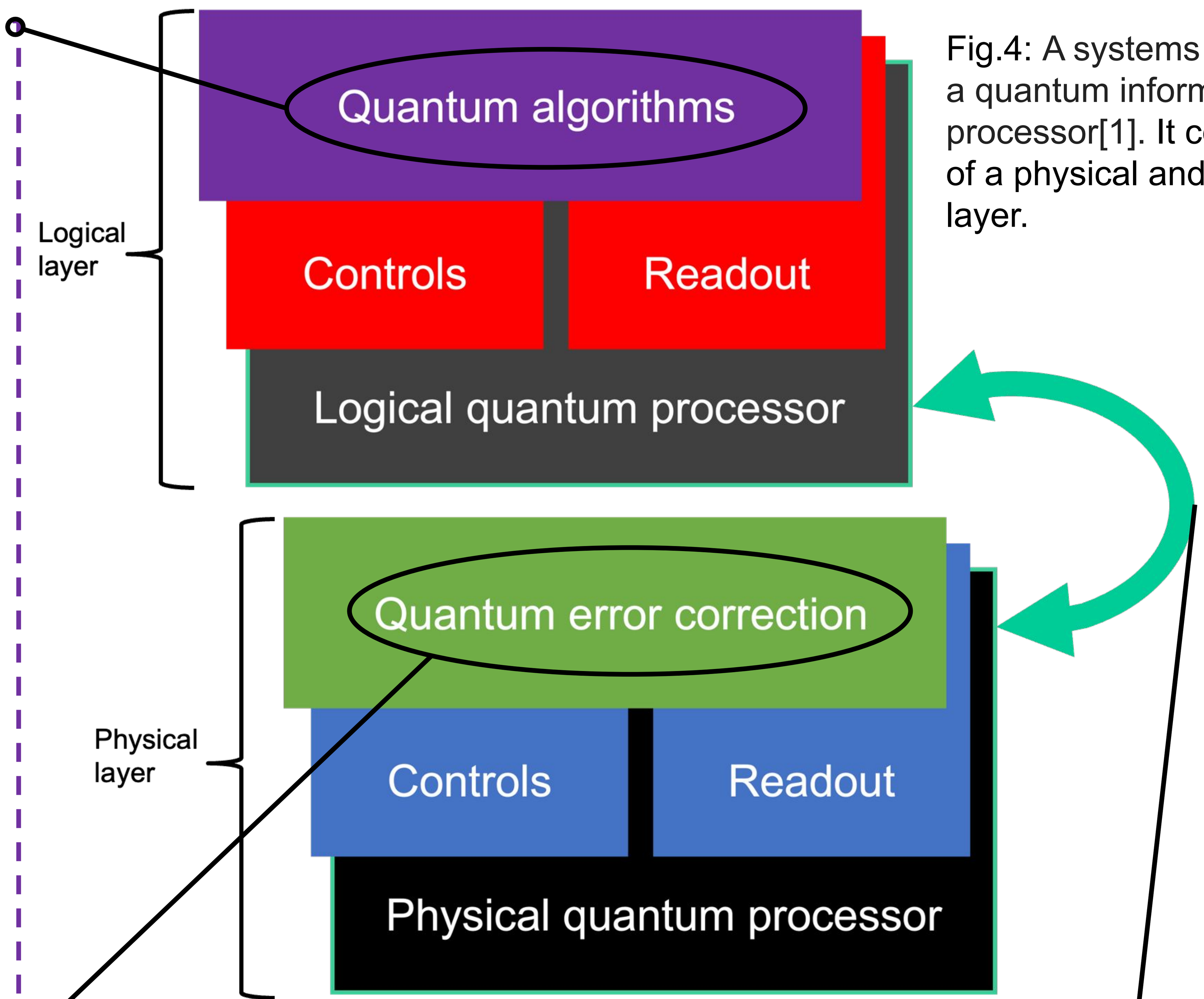


Fig.4: A systems view of a quantum information processor[1]. It consists of a physical and logical layer.

Quantum Error Correction

Motivation & Goal

- Quantum error correction corrects bit flip and phase flip (Fig.7) due to noise by encoding with redundancy (Fig.8).
- To implement quantum error correction, a large number of qubits are required, where NISQ can not handle.

We want to reduce errors in NISQ…

- The goal is to mitigate noises and reduce errors in NISQ(This research field is called *quantum error mitigation* (QEM) [4]).

Expected Results

- This research helps promote the development of Early-FTQC.
- QEC and QEM can coexist.
- Better results for quantum algorithms.

Methodology

- Post-processing of calculation results by statistical processing using classical computer.

Bit flip : $|0\rangle \xrightarrow{\text{Noise}} |1\rangle$

Phase flip: $|0\rangle \xrightarrow{\text{Noise}} -|0\rangle$

Fig.7: Bit flip and Phase flip

QEC: Encoding

$|0\rangle \rightarrow |000\rangle$

$|1\rangle \rightarrow |111\rangle$

Fig.8: Encoding with redundancy

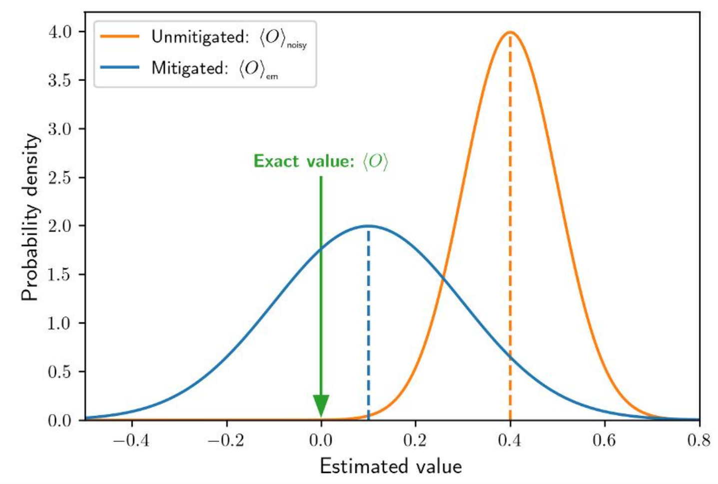


Fig.9: Noise mitigated and unmitigated using a classical computer[4]

Physical & Logical Quantum Processor

Motivation & Goal

- A logical quantum processor, which is virtual qubits needed to execute quantum algorithms, maps to a physical quantum processor, which is composed of "physical" qubits.
- *Qiskit* has several mapping methods available, and the best method is adopted based on the results of the execution of these methods.

Qiskit performs calculations for many mapping methods, which increase the computational cost and take time to compile…

- The goal is to devise more efficient mapping methods.

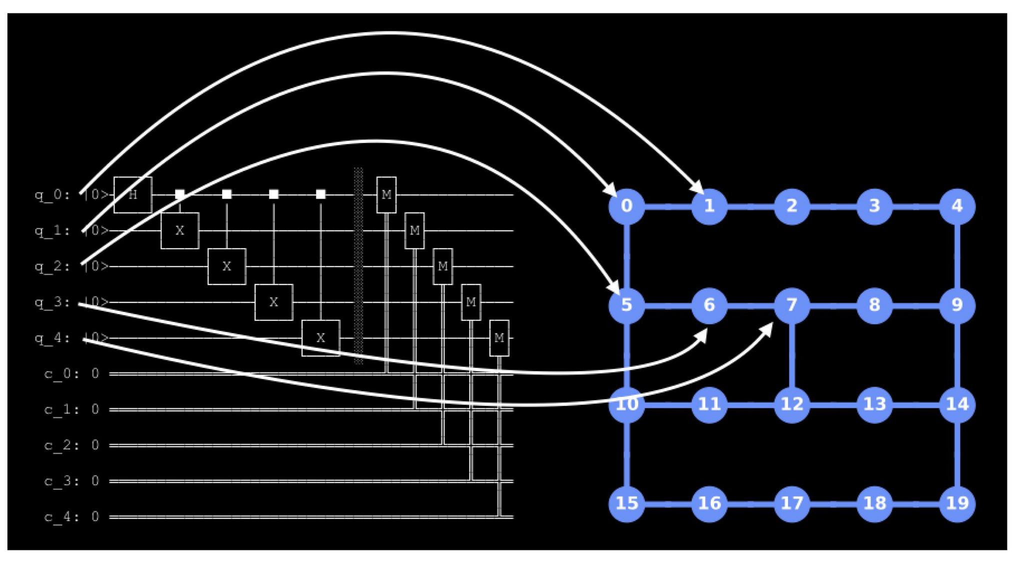
Expected Results

- The *Qiskit* map and my development have similar performance.
- The time cost of compiling quantum circuit is reduced.

Methodology

- In terms of the topology of the physical quantum processor, a more efficient mapping method is considered and simulated using Qiskit.

Fig.10: Mapping from logical quantum processor to physical quantum processor[5]. We need to map these virtual qubits in a one-to-one correspondence to the "physical" qubits in an actual quantum device.



Reference

[1] Gambetta, Jay M., Jerry M. Chow, and Matthias Steffen. "Building logical qubits in a superconducting quantum computing system." *npj quantum information* 3.1 (2017): 2.
[2] Grover, Lov K. "A fast quantum mechanical algorithm for database search." *Proceedings of the twenty-eighth annual ACM symposium on Theory of computing.* 1996.
[3] Qiskit, https://qiskit.org/ [last accessed 16 September 2023]
[4] Qiskit, https://qiskit.org/ecosystem/ibm-runtime/locale/ja_JP/tutorials/Error-Suppression-and-Error-Mitigation.html [last accessed 16 September 2023]
[5] Qiskit, https://qiskit.org/documentation/apidoc/transpiler.html [last accessed 16 September 2023]