High Fidelity Qubit Mapping for IBM Q

2nd International Workshop on Quantum Compilation

Keio University Quantum Computing Center

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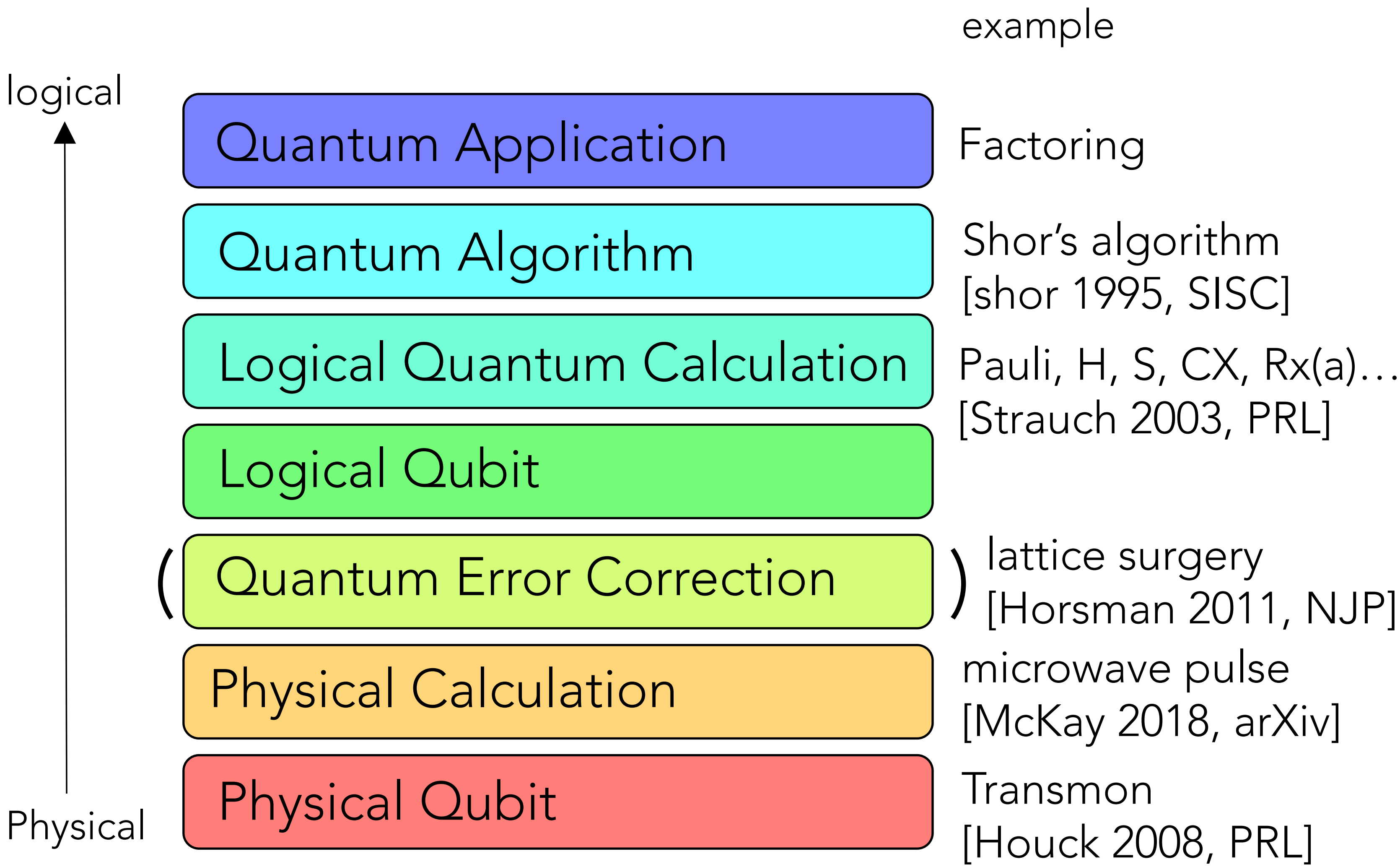
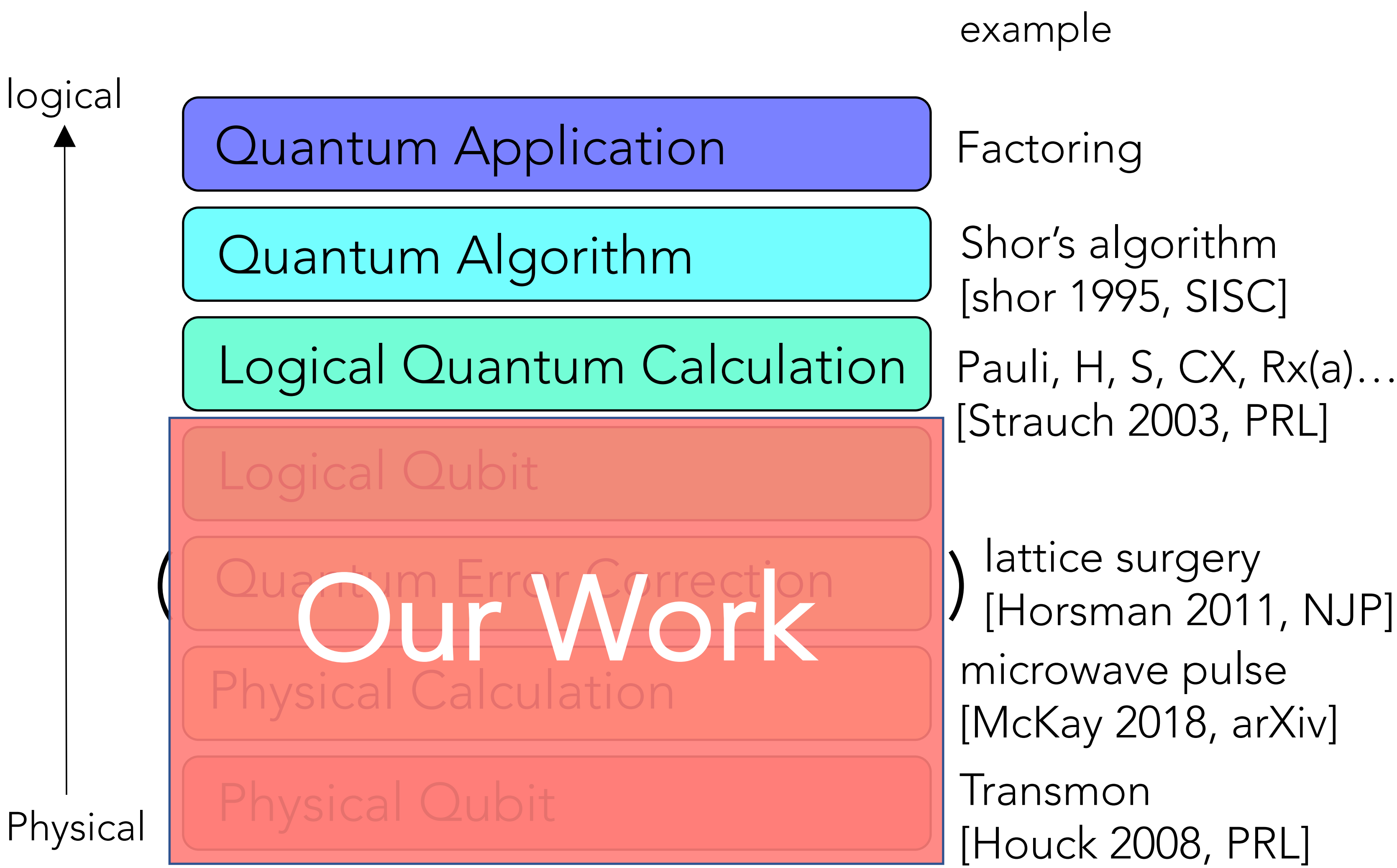
Quantum Computer Architecture



Quantum Computer Architecture

Quantum Computer Architecture

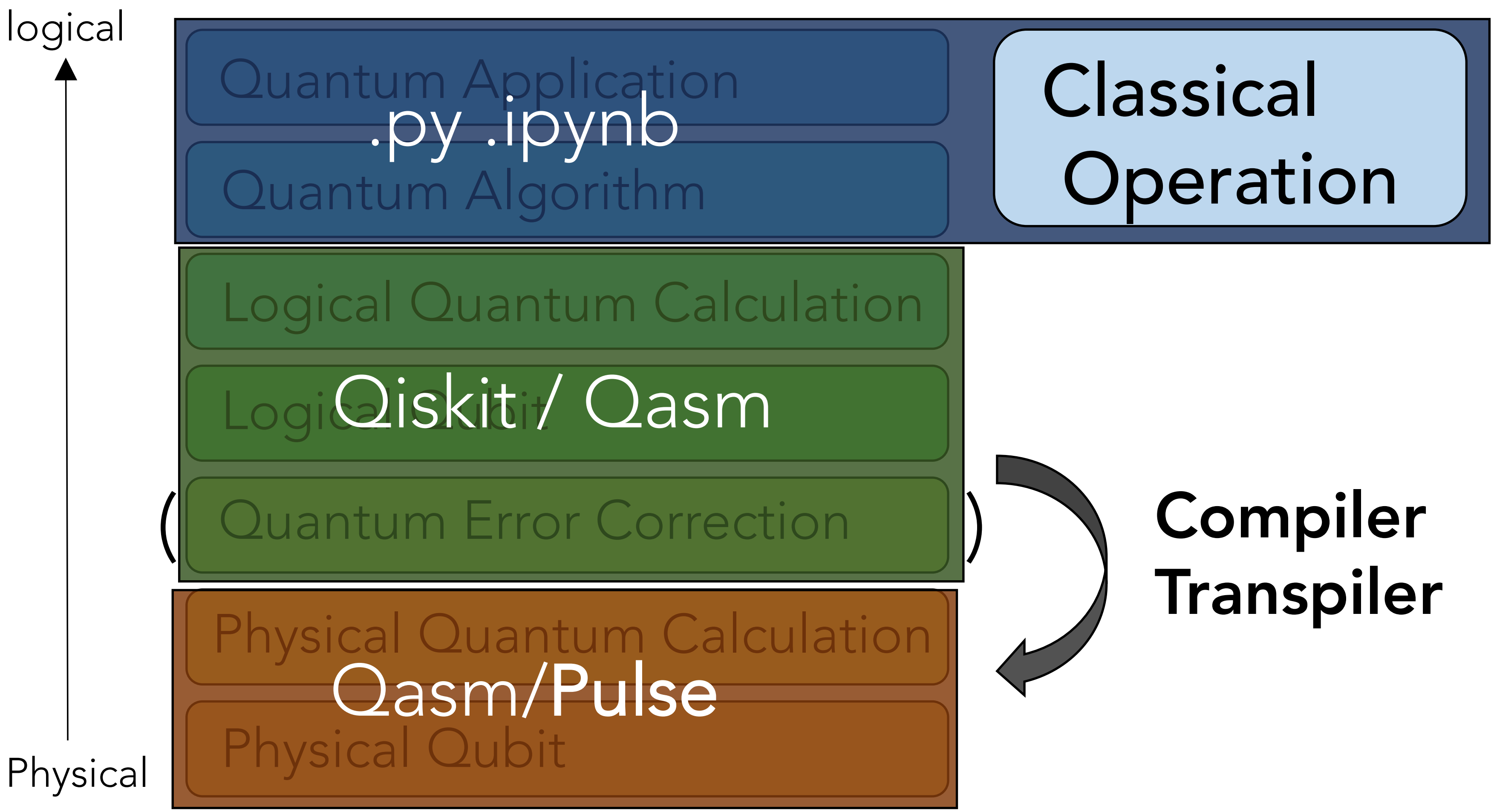


Quantum Computer Architecture

Function of Compilation

- **Optimize** Quantum Circuit
  - gate disassembly & assembly ex) Solovay-Kitaev [**Dawson 2005, arXiv**]
  - decrease T-Depth
- Quantum Error Correction (post NISQ?)
- Quantum Distributed Computation (post NISQ?)
- Convert logical quantum circuit into physical quantum circuit.
  - Qubit Mapping

Existing Architecture (IBMQ Qiskit)



Definition of NISQ

Noisy

- ibmq20_tokyo [IBMQ 2018]
  - Gate error($\mathbf{10^{-3}}$): 1.83
  - Bi-Qubit Gate error($\mathbf{10^{-2}}$): 8.06 (IBMQ16)
  - Readout error($\mathbf{10^{-2}}$): 8.58
- Error rate of each qubit is unequal

Intermediate-Scale

- # of Qubits in a processor: about $10 \sim 10^3$

Definition of problem

Compare analytic **simple error model** with the **reality of the machine.**

Enable **error aware compilation.**

The Story

1. Characterize the machine
2. Create an **estimation of circuit success probability**
3. Compare to the reality of the machine
4. (incorporate into compilation process; Pan et al., later this morning)

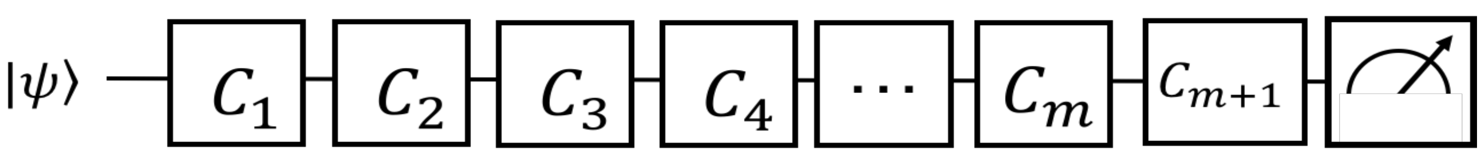
Randomized Benchmarking (RB)

Get $\overline{F^{ave}}$(Average Gate Set Fidelity)
[Knill 2007, PRA]

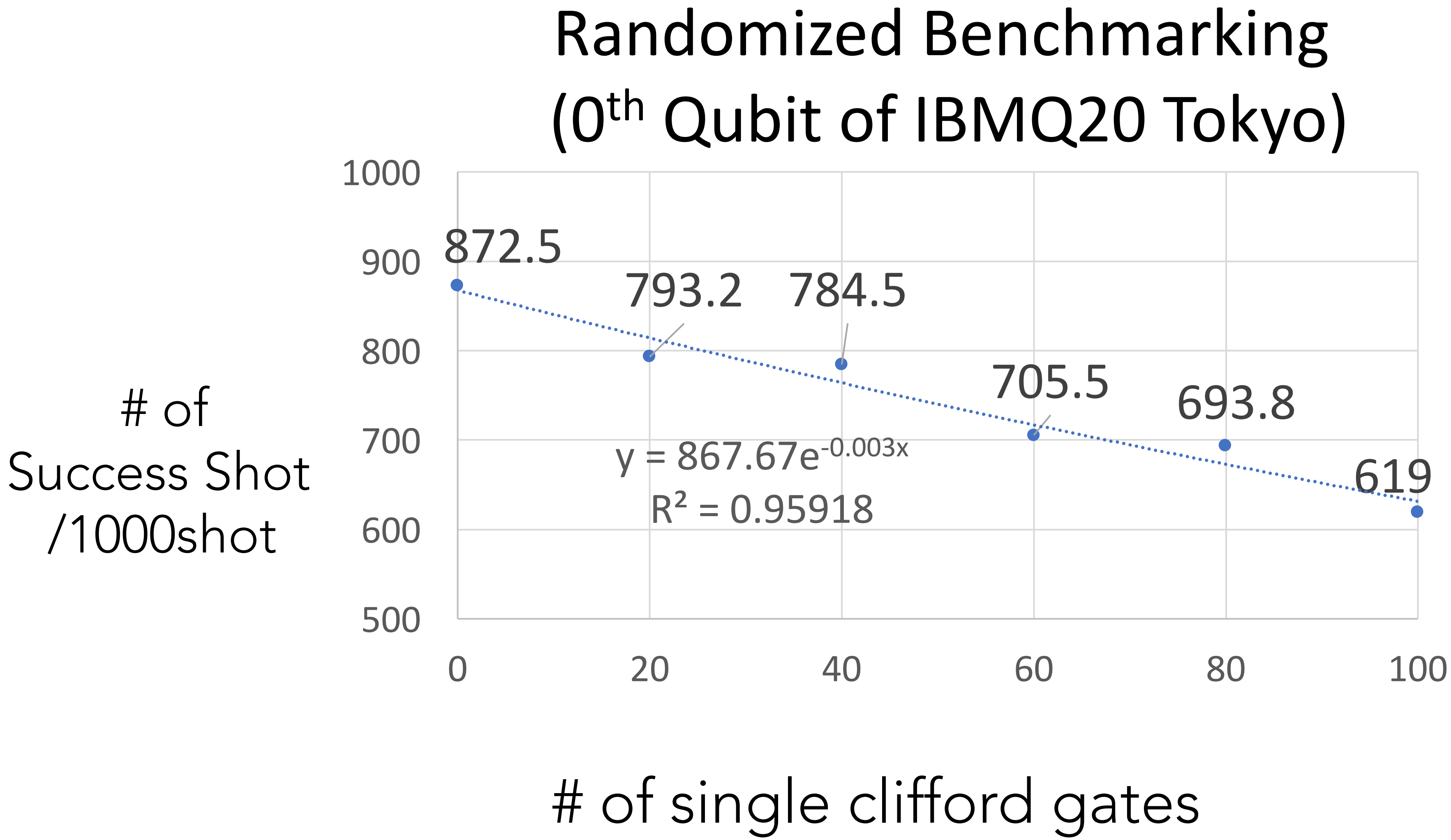
- Can be used as a cost function

$$Clifford\ gate : C_n = \{U : UP_nU^\dagger = P_m\}$$

$$C_{m+1} = \left(\prod_{i=1}^{m} C_i\right)^\dagger$$

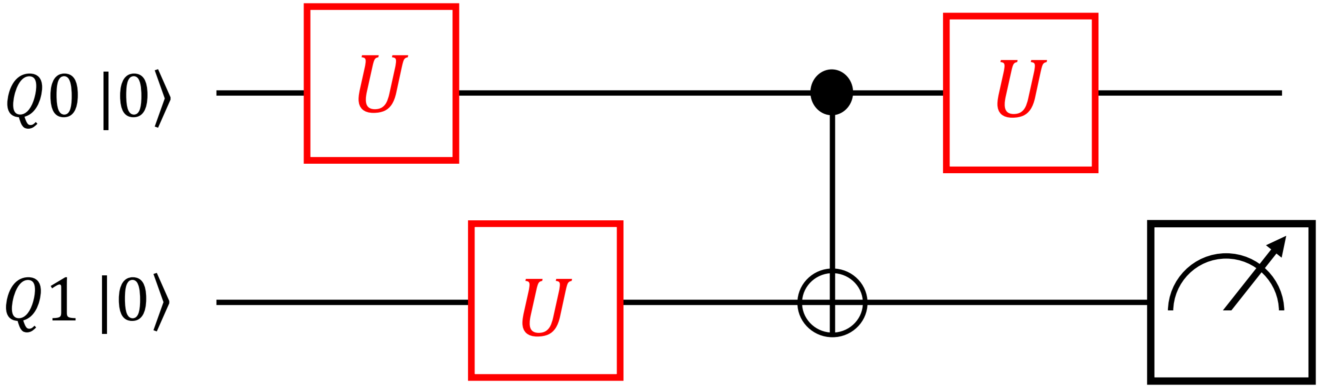


RB on IBMQ


Randomized Benchmarking
(0th Qubit of IBMQ20 Tokyo)
1000
900
800
700
600
500
0
20
40
60
80
100
872.5
793.2
784.5
705.5
693.8
619
y = 867.67e-0.003x
R² = 0.95918
# of
Success Shot
/1000shot
# of single clifford gates

Error model

1. G(single qubit gate error)
2. B(bi-qubit gate error)
3. SPAM(state preparation and measurement)



Error model

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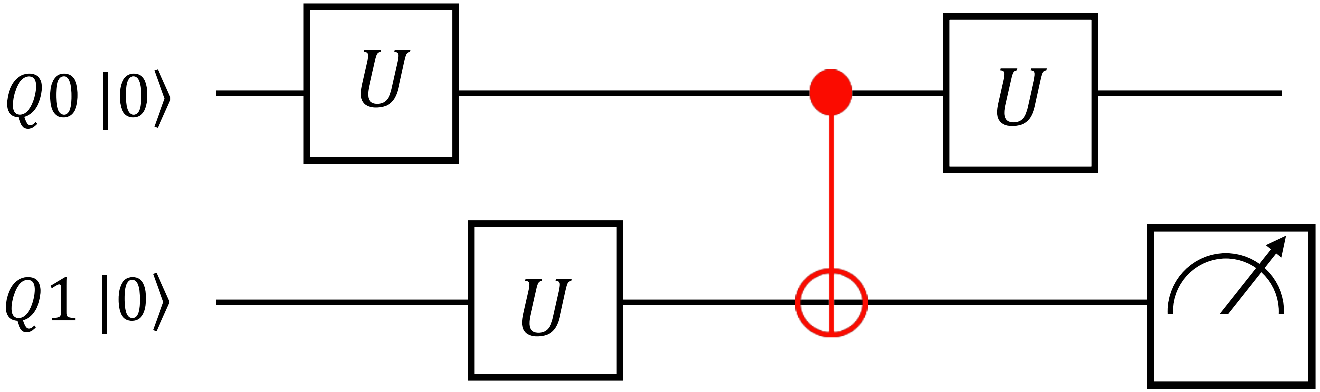

Error model

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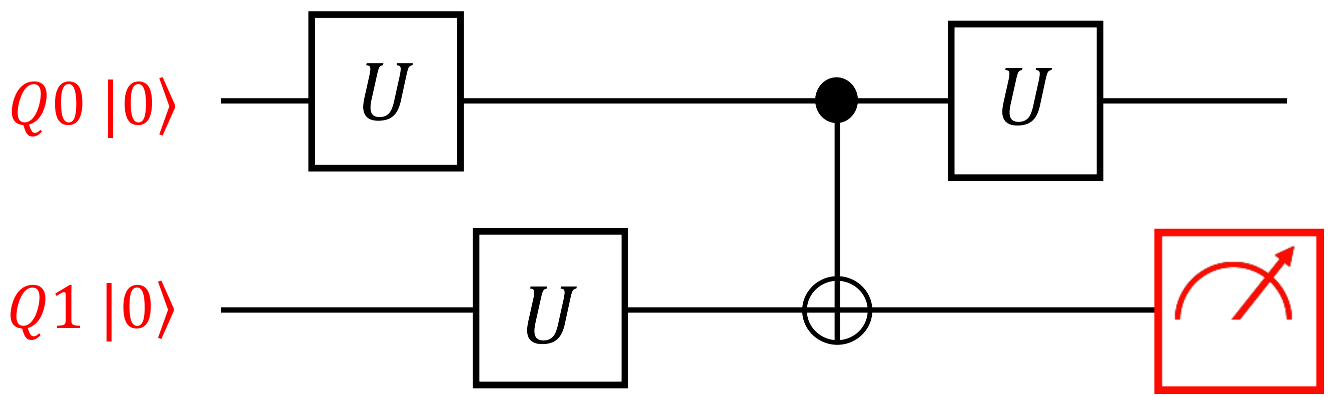


For IBMQ20 G<<B<SPAM

Success Probability

$$S_{est} = \prod_i (1 - \varepsilon_i)$$

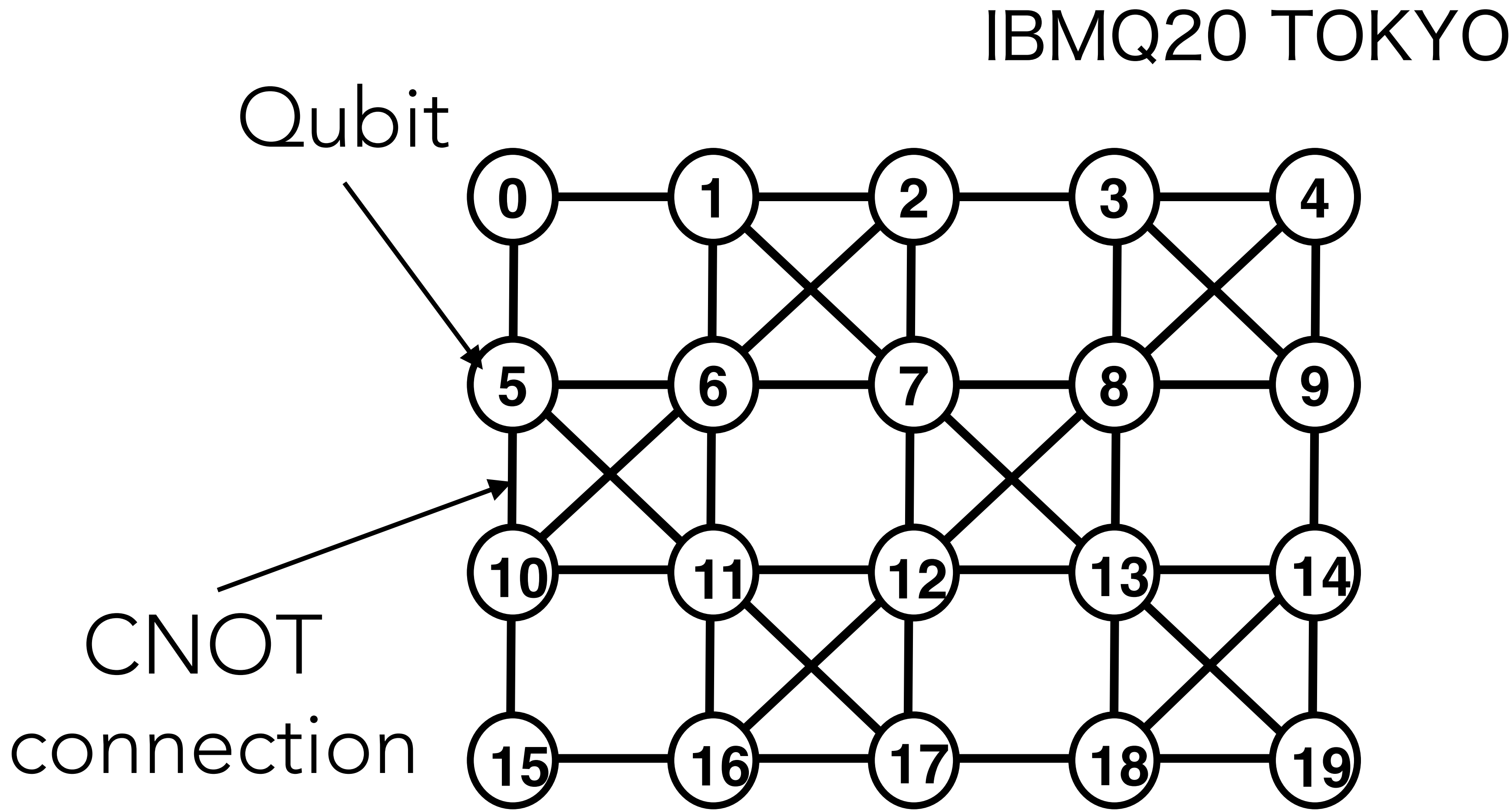
ε_i : the error rates(G, B, SPAM)

S_{act} $(Fidelity)$

Compare!!

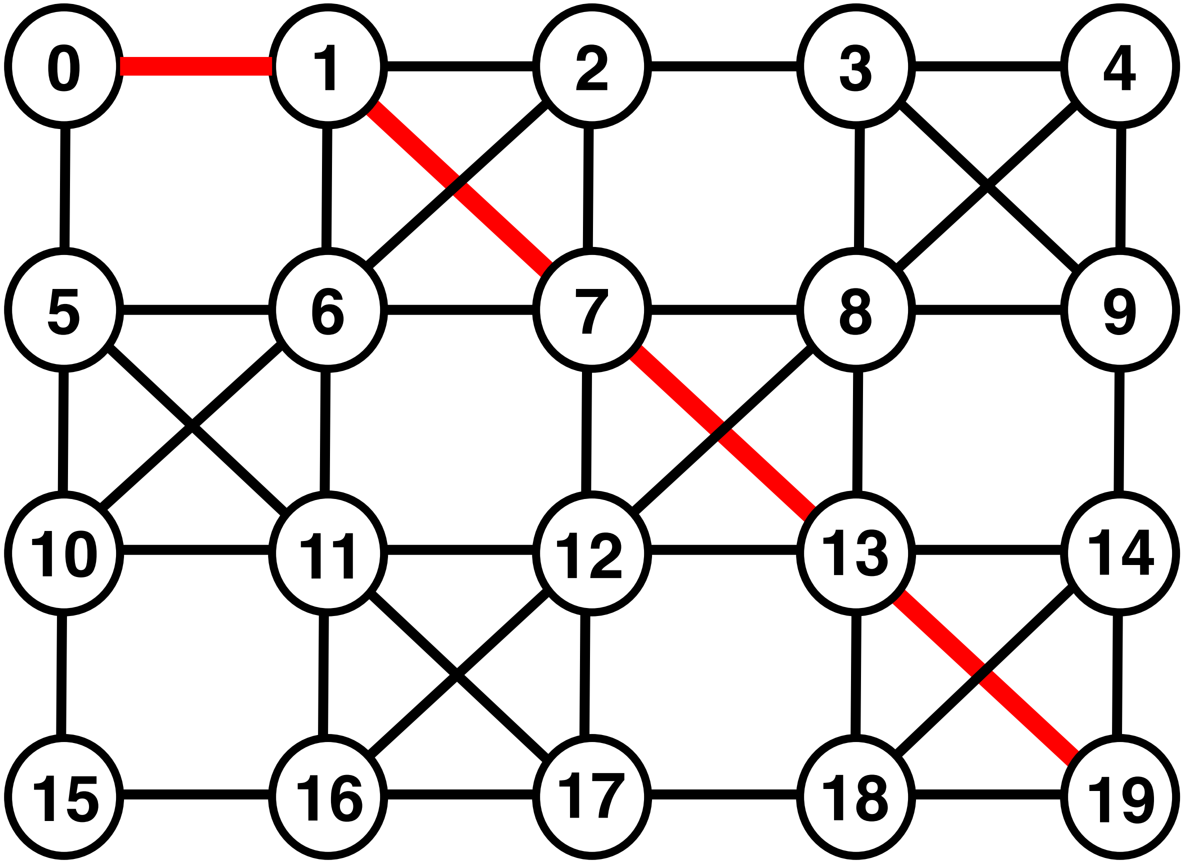
Problem 1 : Path Selection

an example of grid architecture



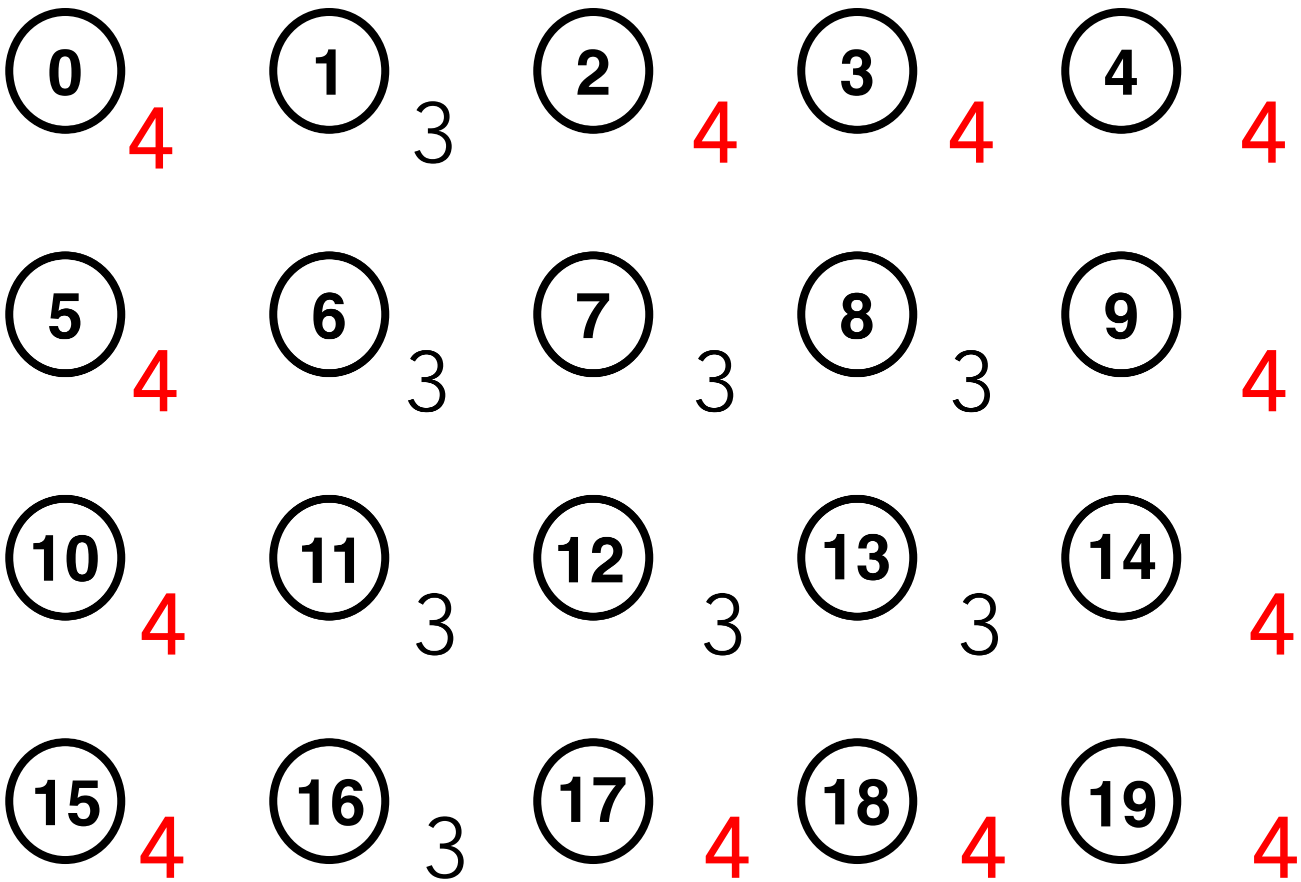
Scale of the Problem

one of the longest “shortest path”
in IBMQ20 TOKYO



Eccentricity

Max distance to another qubit



Eccentricity

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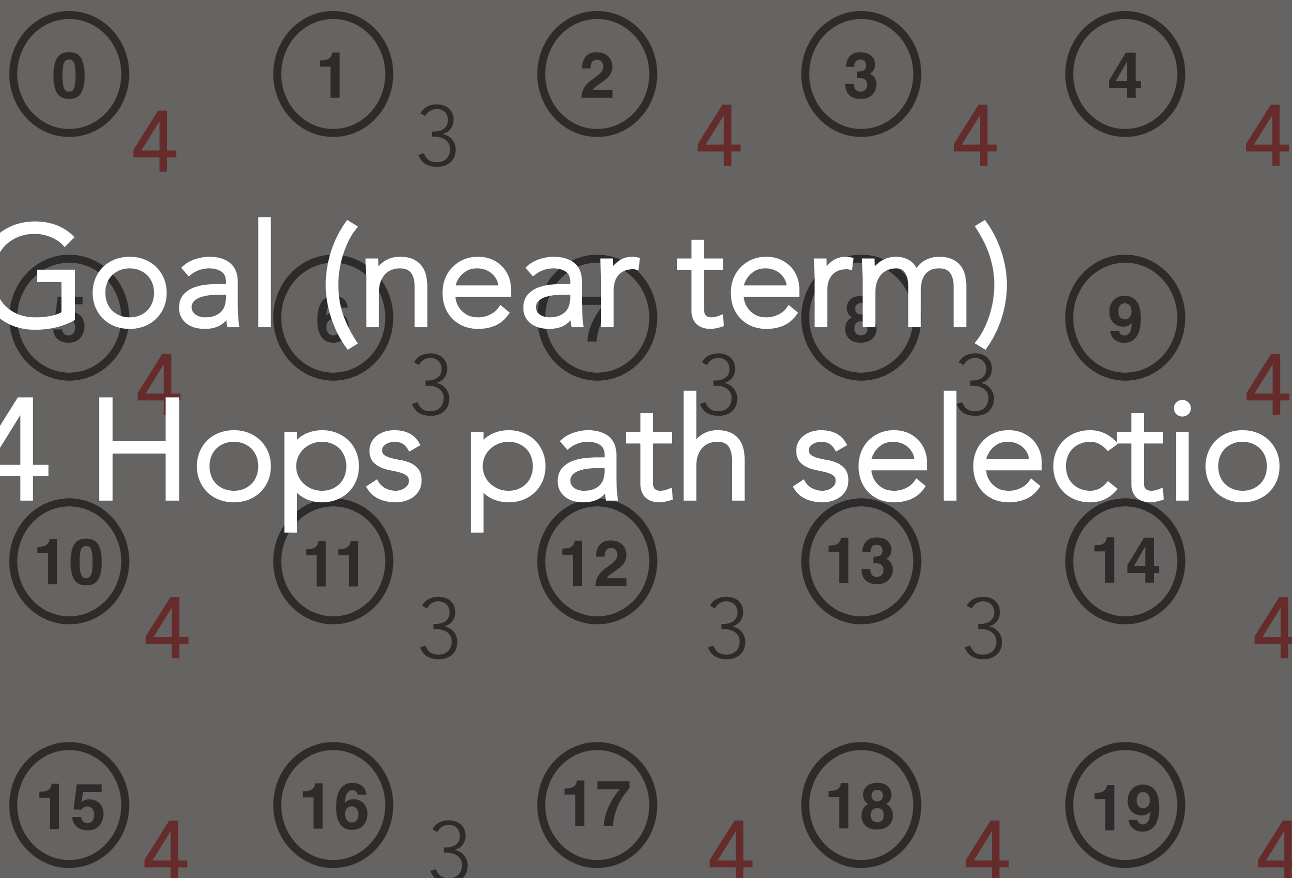
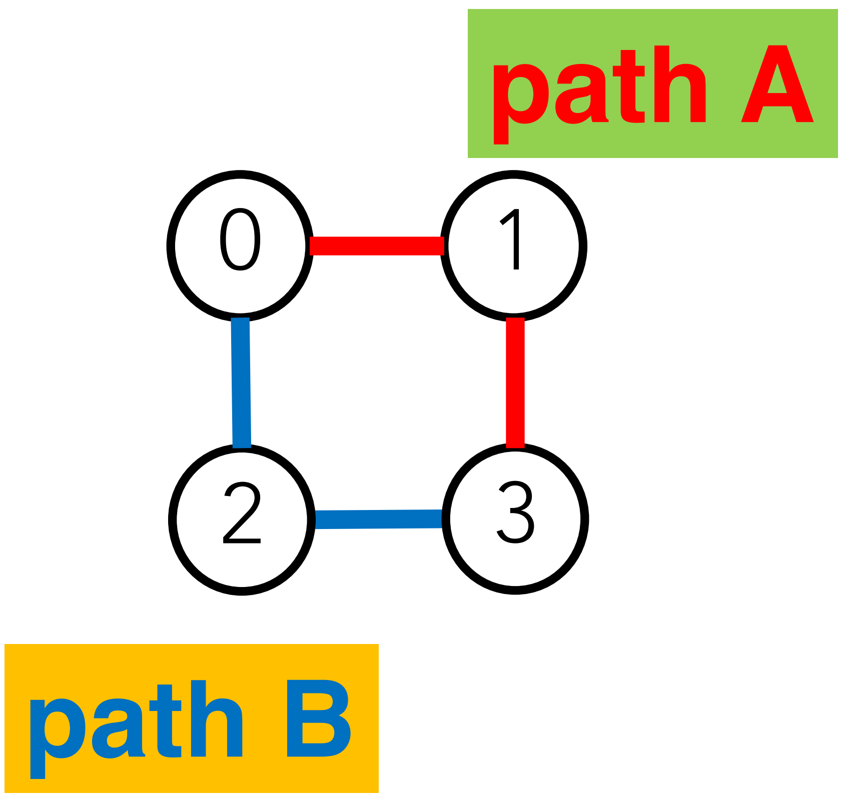


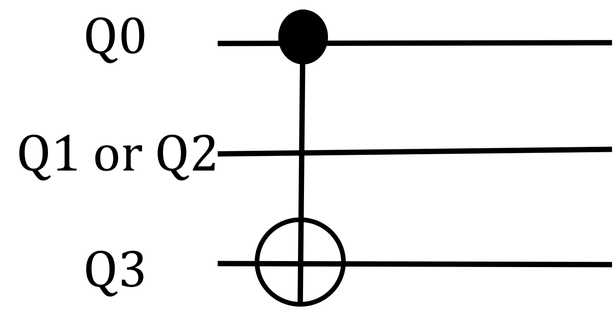
Goal (near term)

4 Hops path selection

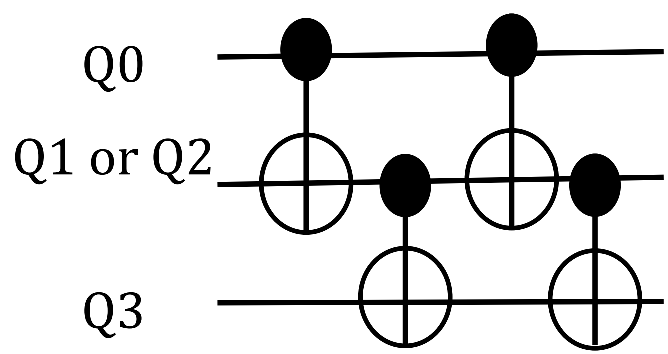
2 Hops Path Selection



Logical Circuit
(written by programmers)



Implementation



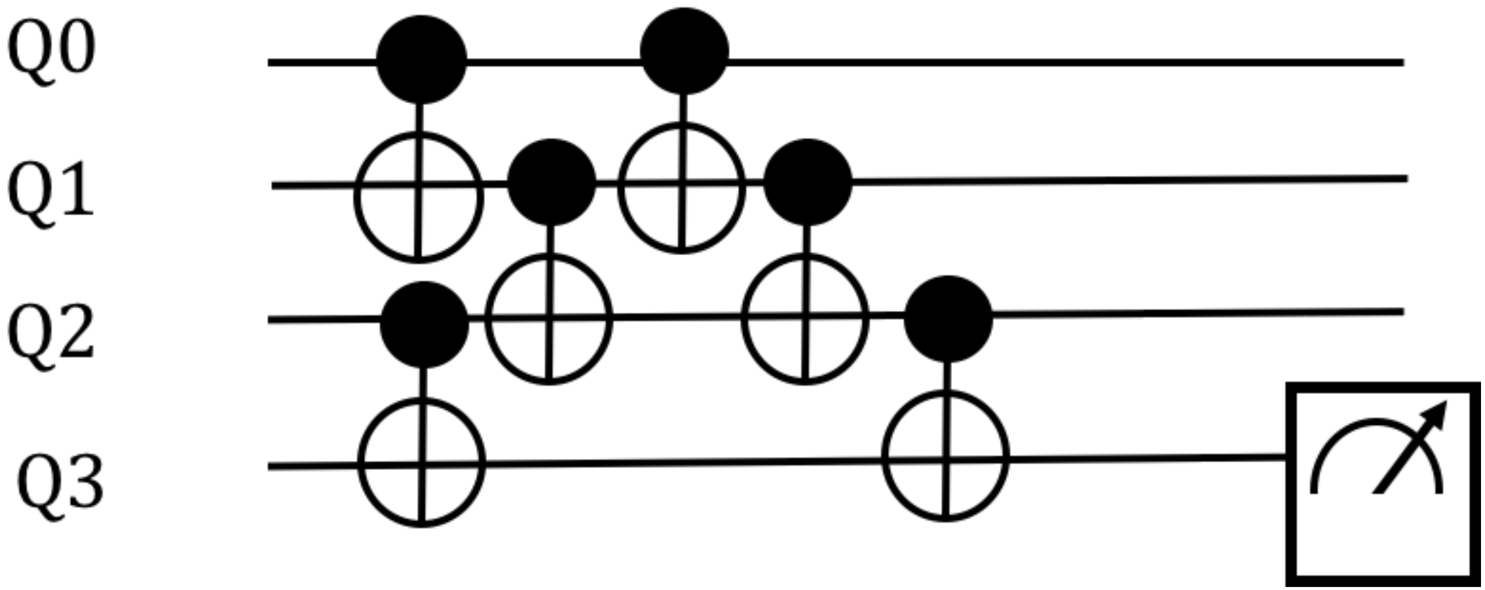
2 Hops Path Selection

Succeeded in **70.0%**

of All 3-hops paths in IBMQ20 Tokyo

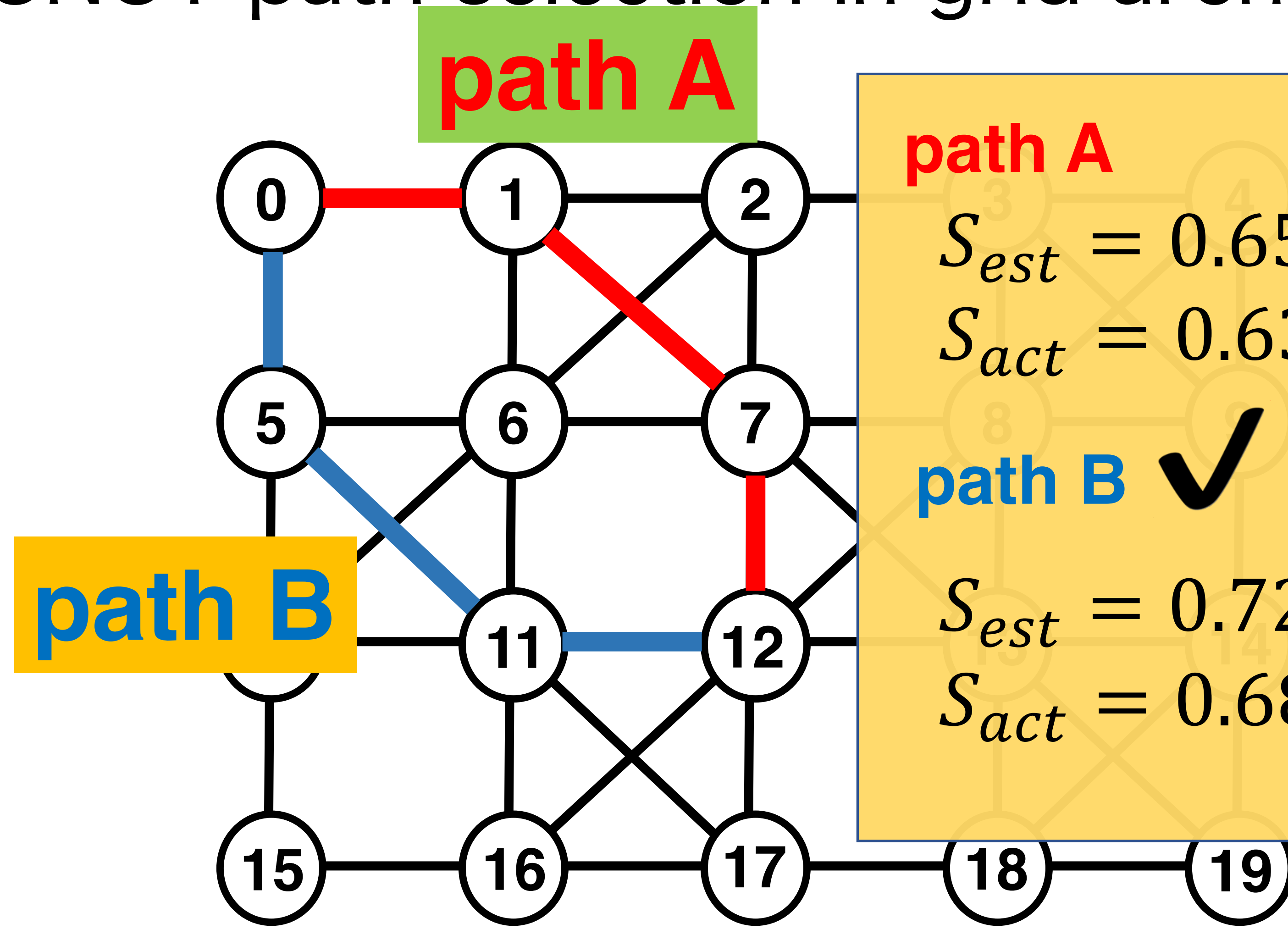
3 Hops Circuit

Circuit for the Benchmarking 3-hops path



3 Hops Circuit

CNOT path selection in grid architecture



path A

$$S_{est} = 0.655$$
$$S_{act} = 0.635$$

path B ✓

$$S_{est} = 0.7227$$
$$S_{act} = 0.683$$

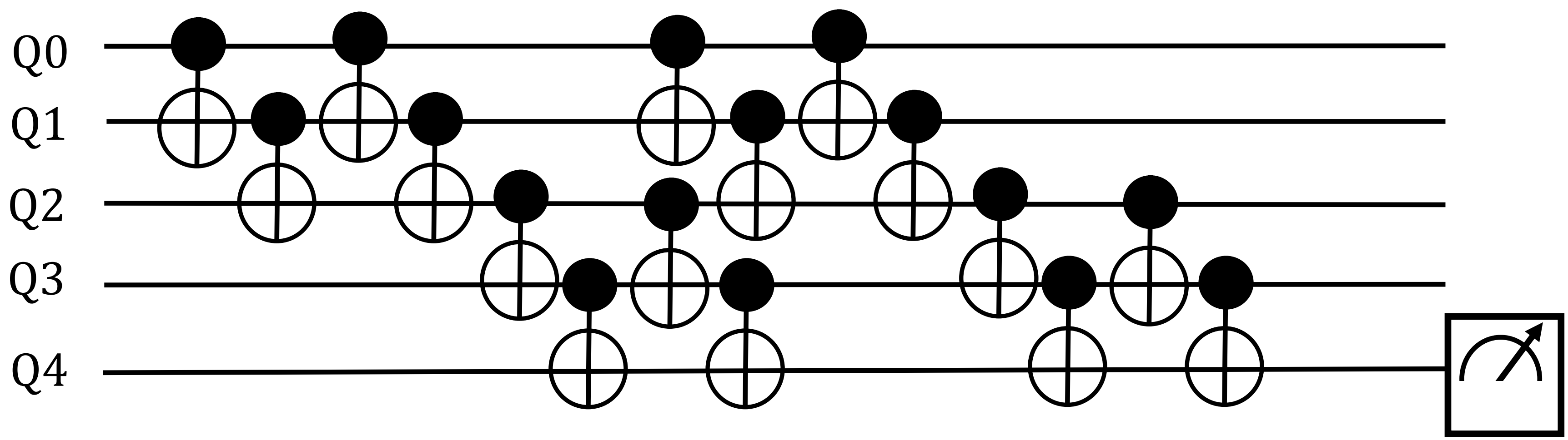
3 Hops Path Selection

CNOT path selection in grid architecture

Succeeded in **66.6%**
of All 3-hops paths in IBMQ20 Tokyo

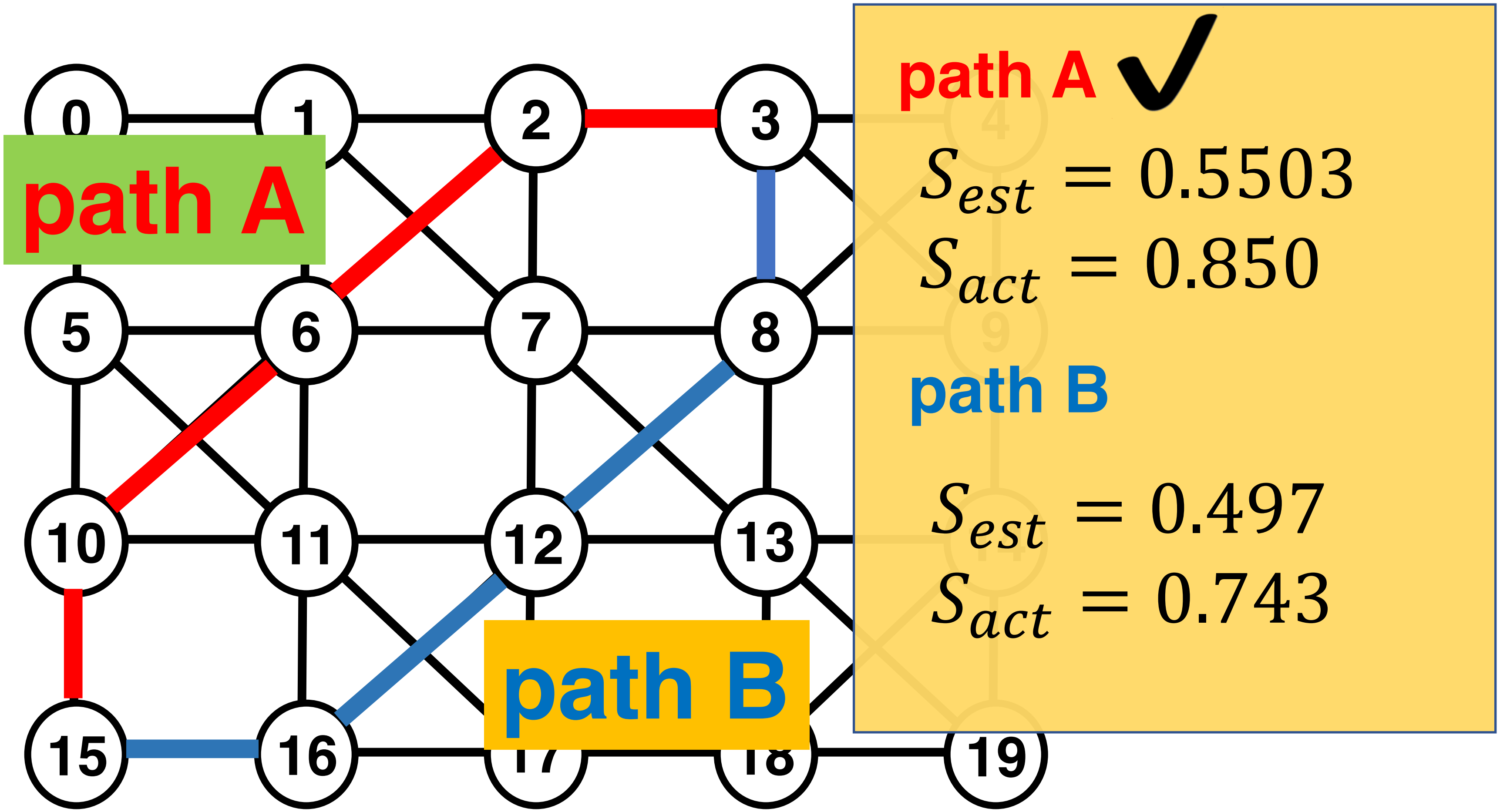
4 Hops Circuit

Circuit for the Benchmarking 4-hops path



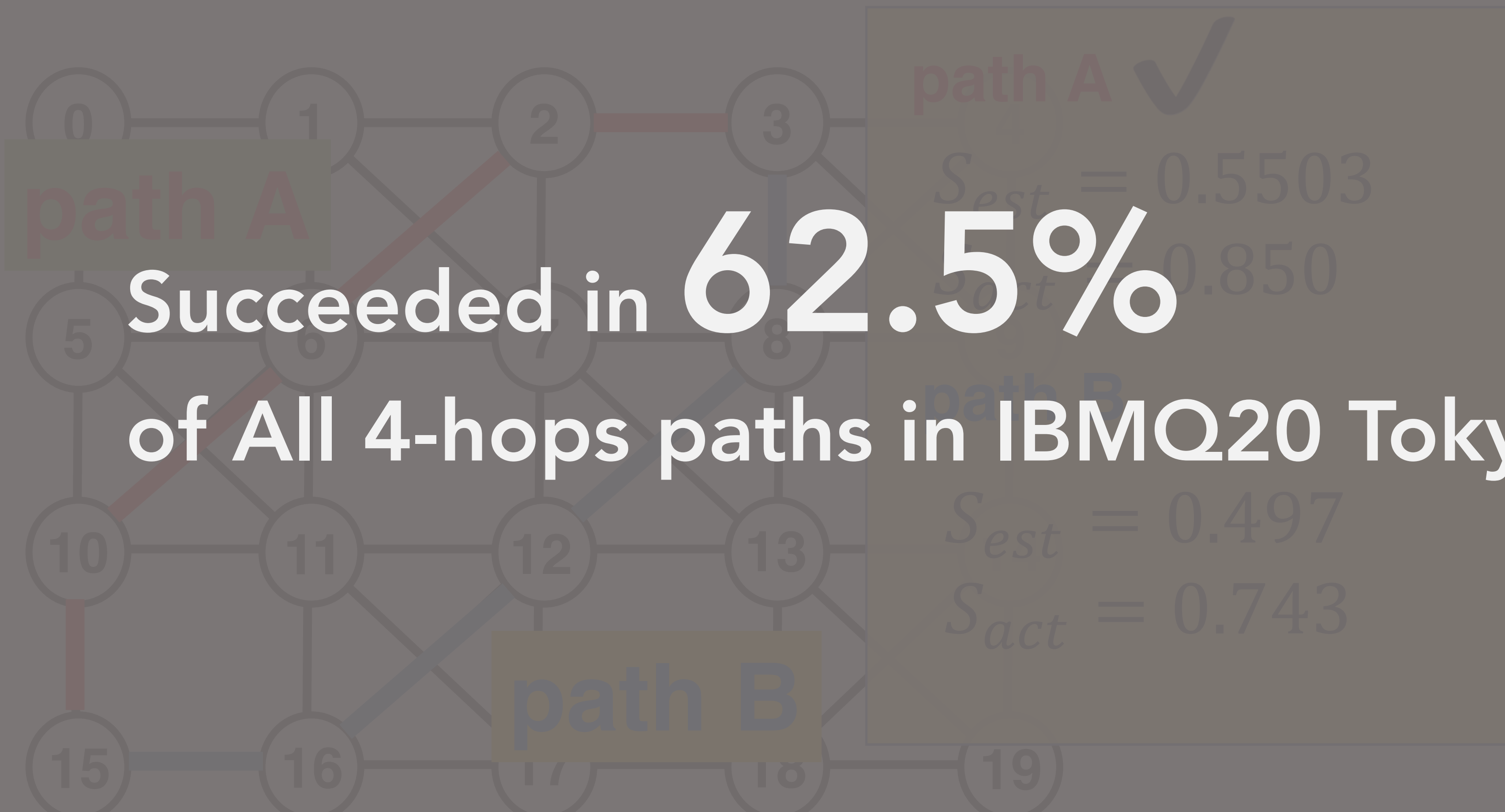
4 Hops Path Selection

CNOT path selection in grid architecture



4 hops path

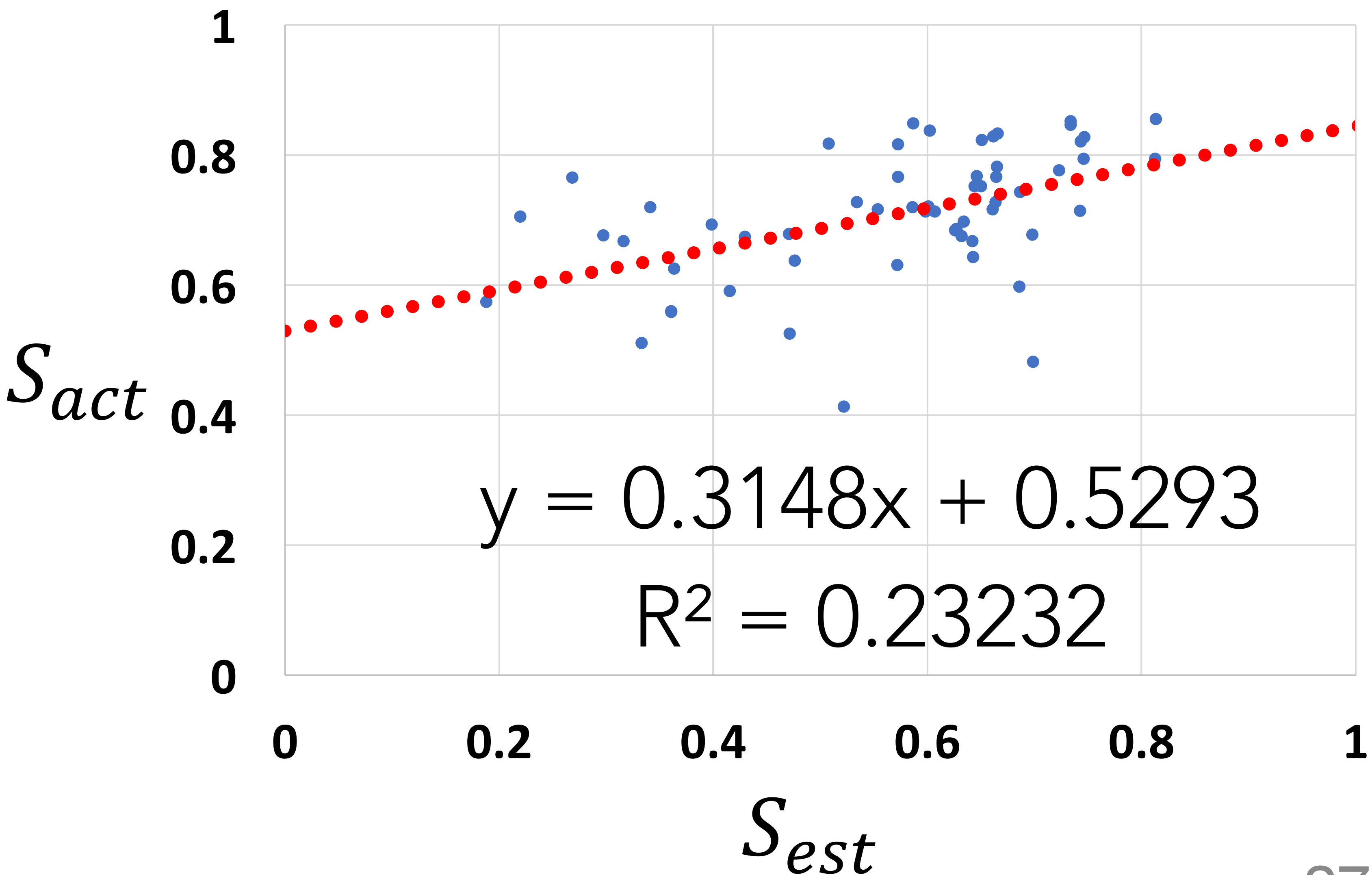
CNOT path selection in grid architecture



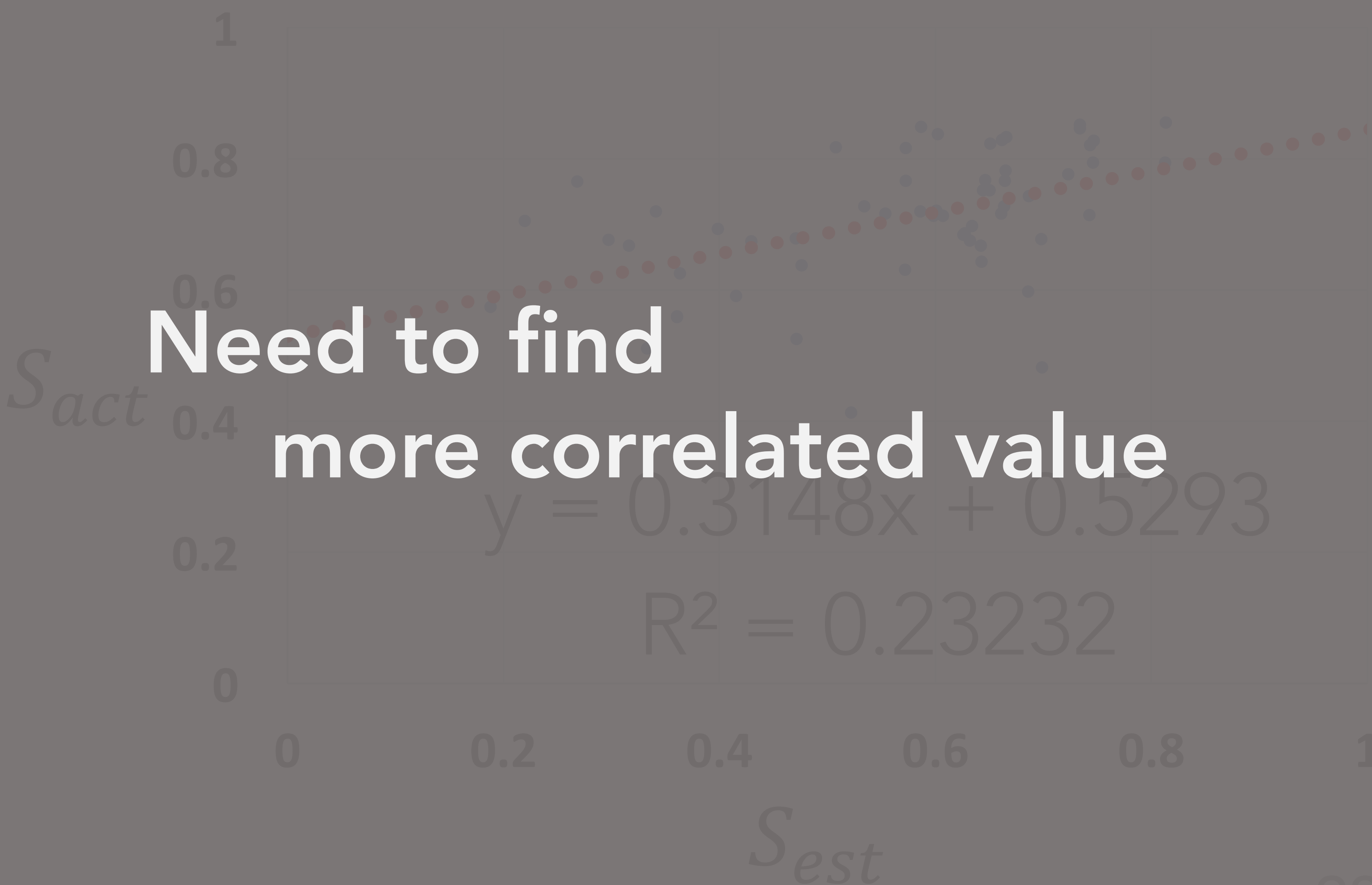
Succeeded in 62.5%

of All 4-hops paths in IBMQ20 Tokyo

Correlation Between S_{est} and S_{act}

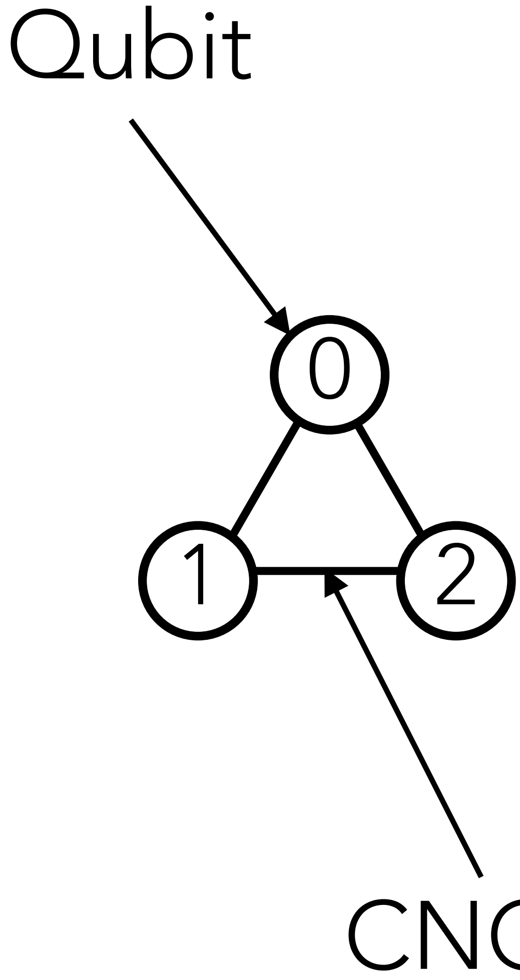


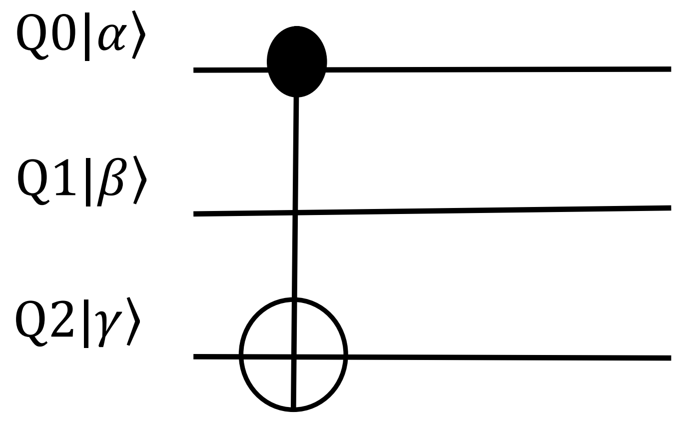
Correlation Between S_{est} and S_{act}



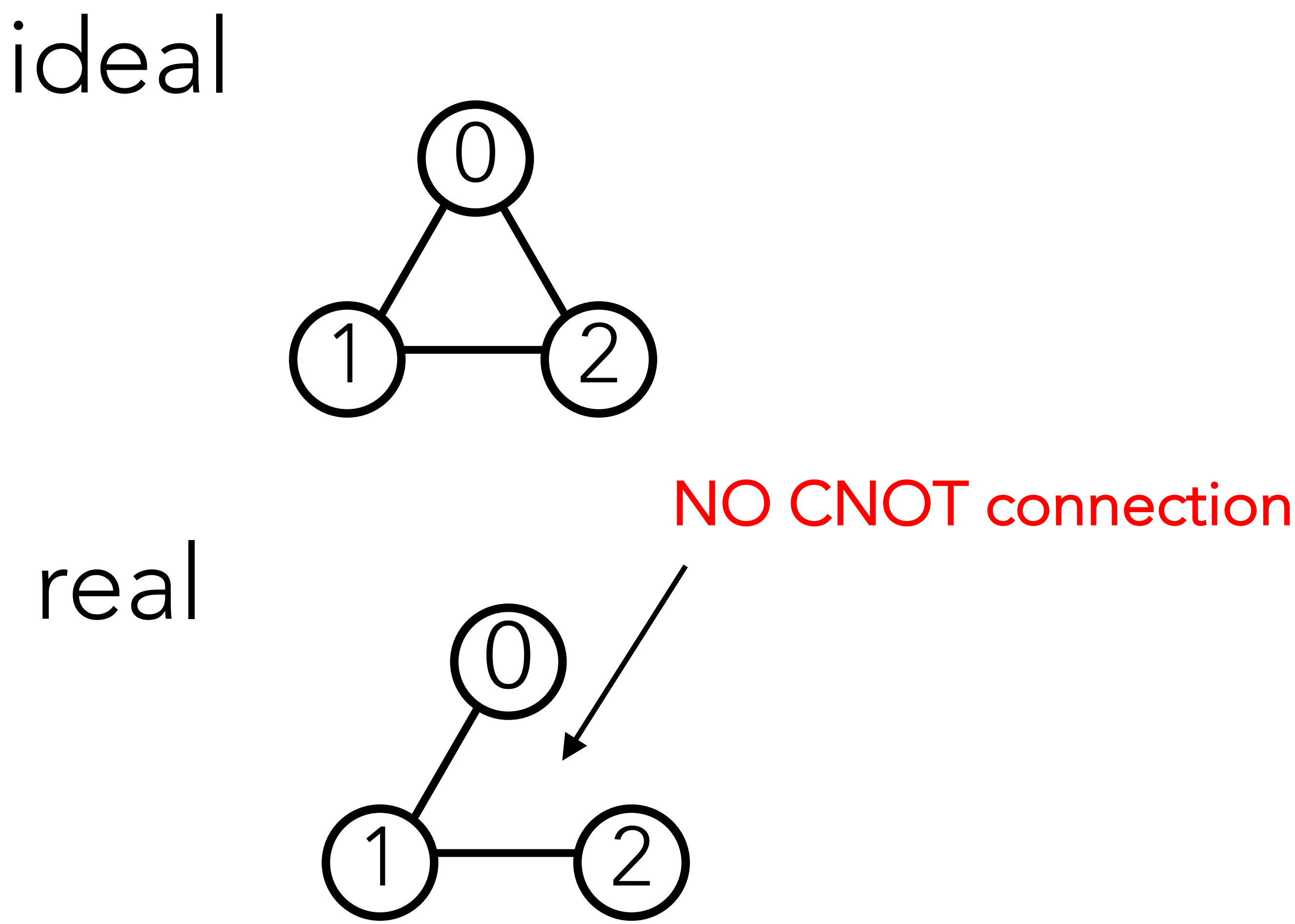
Need to find more correlated value

Problem2 : Three body Problem

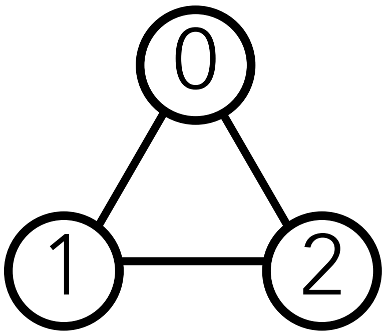


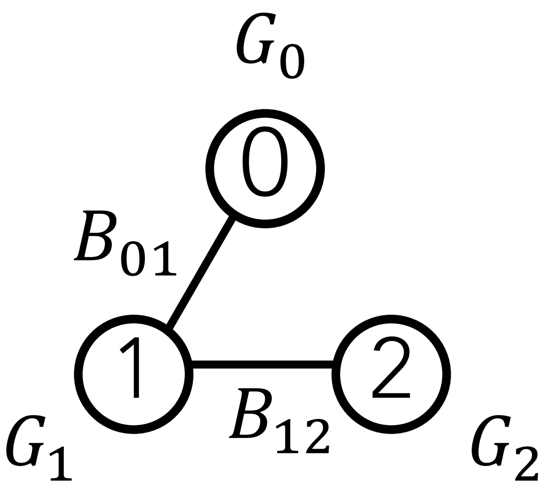


Equivalent Circuits for Circuit A



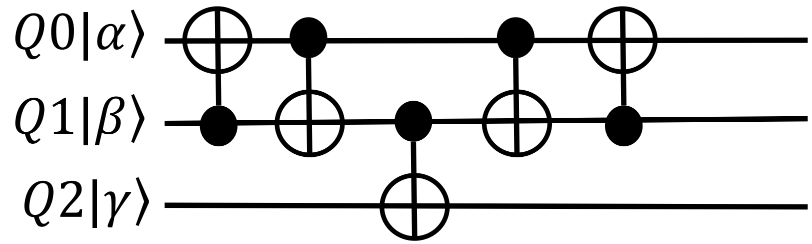
Equivalent Circuits for Circuit A



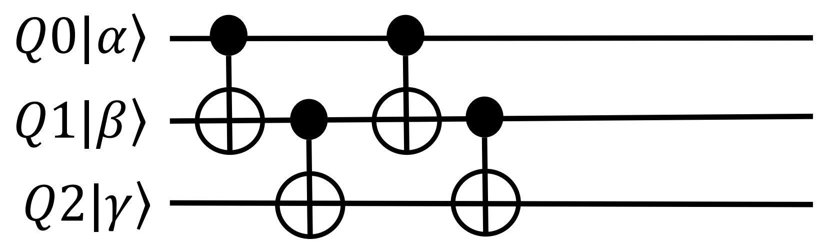


Value of Errors

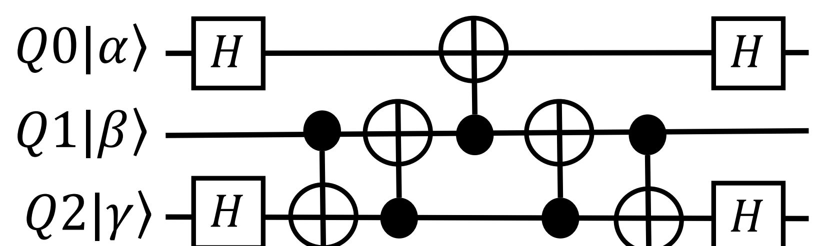
Circuit B



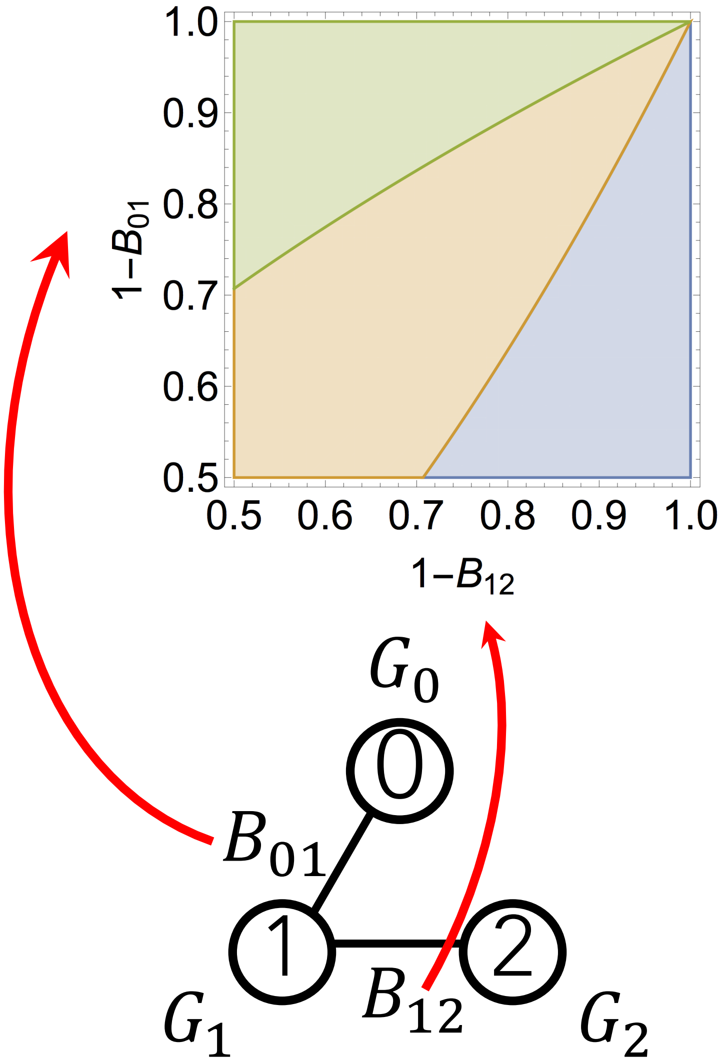
Circuit C



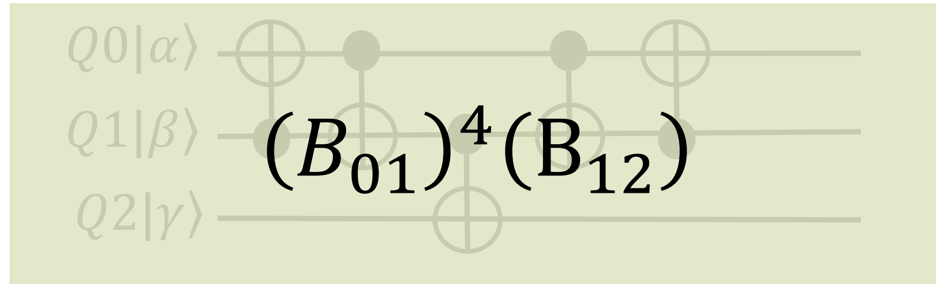
Circuit D



Error of each circuits

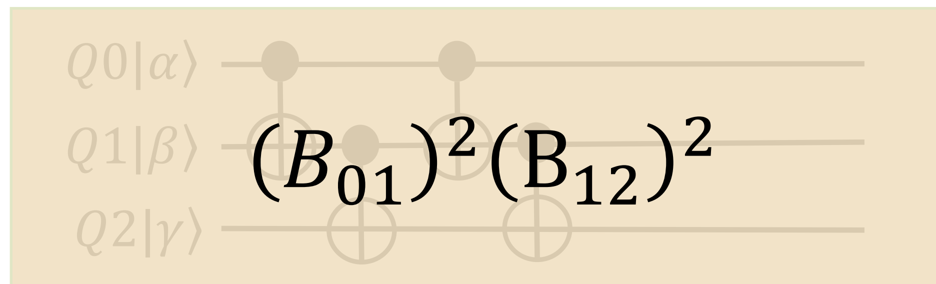


Circuit B



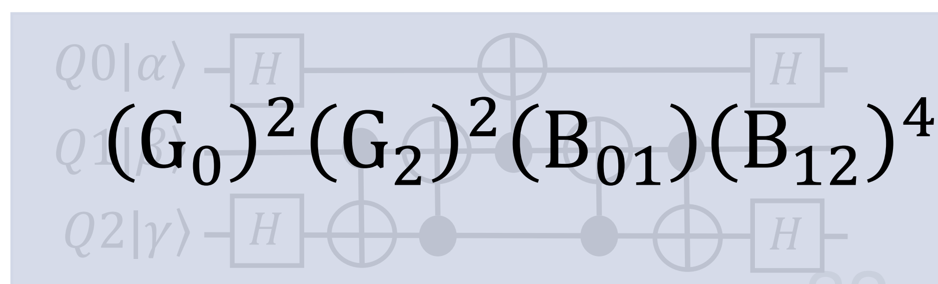
$(B_{01})^4(\mathrm{B}_{12})$

Circuit C



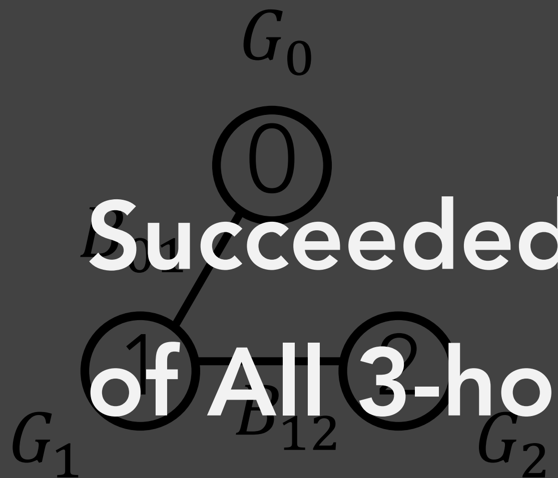
$(B_{01})^2(\mathrm{B}_{12})^2$

Circuit D



$(\mathrm{G}_0)^2(\mathrm{G}_2)^2(\mathrm{B}_{01})(\mathrm{B}_{12})^4$

Three body problem



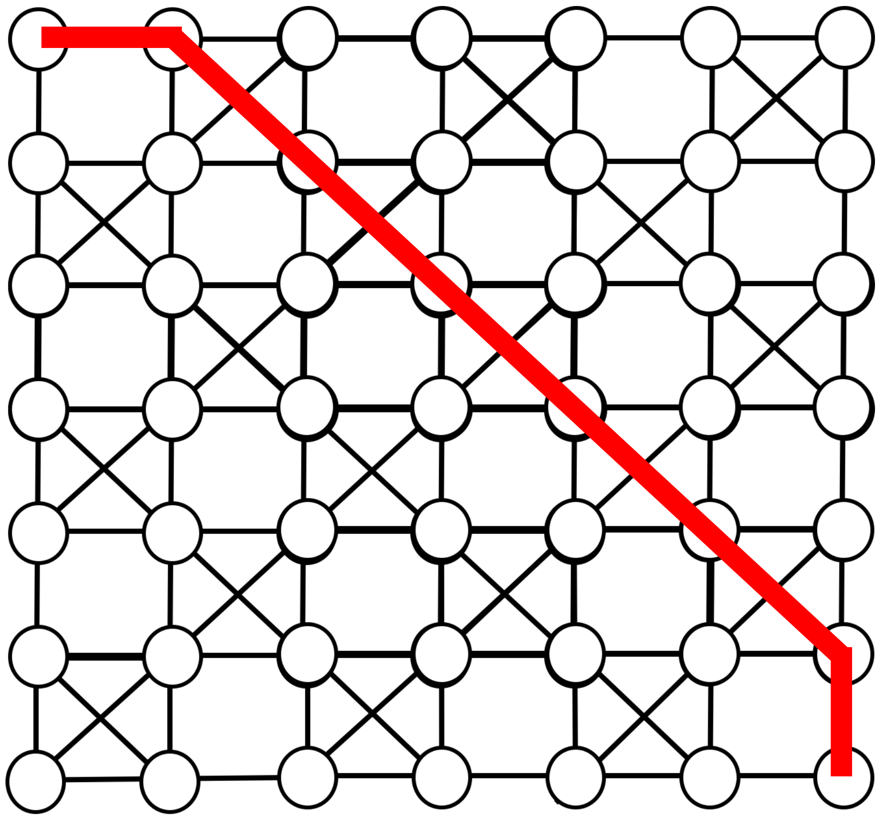
Succeeded in 40.0%
of All 3-hops paths in IBMQ20 Tokyo

数式を入力します。

Conclusion

- S_{est} is useful for 2-4 hops path selection.
- Using single parameter (e.g. output of RB) is not good enough to estimate long CNOT path S_{est} of quantum circuit.
- We need more sophisticated error model.

Future work



7hops path?

near 50 qubit device?

Future work

Use Other Error Model

- more physical
  - T1, T2 & time for execute gate
  - leakage
  - crosstalk

  - Divide
    - Decoherence
    - Dephasing
    - Unitary

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Thanks for Listening !