Appendix

- Quantum Supremacy
- Quantum Fourier transformation
- Quantum Teleportation
- Error-tolerable quantum computing
- Quantum Random numbers

A1. Quantum supremacy

- Speed of Computation

Quantum computer >> Ordinary computer

In 2015, Google and NASA reported that D-Wave quantum computer works 10^6 faster than a regular computer chip !

In 2019, Google publishes the quantum supremacy claim. Nature, vol. 574, no. 7779, Oct. 2019, pp. 461+

In 2020, University of Science and Technology of China (中国科学技術大学) announced they realized Quantum supremacy by 「九章」 (Jiuzhang). 九章2号 was announced (2020)

A2. Quantum Fourier Transform using Qiskit

https://qiskit.org/textbook/ja/ch-algorithms/quantum-fourier-transform.html

目からうろこの

フーリエ変換

フーリエからシュレーディンガーまで

<u>What is Qiskit ? </u> https://ja.wikipedia.org/wiki/Qiskit

池田 直

量子フーリエ変換

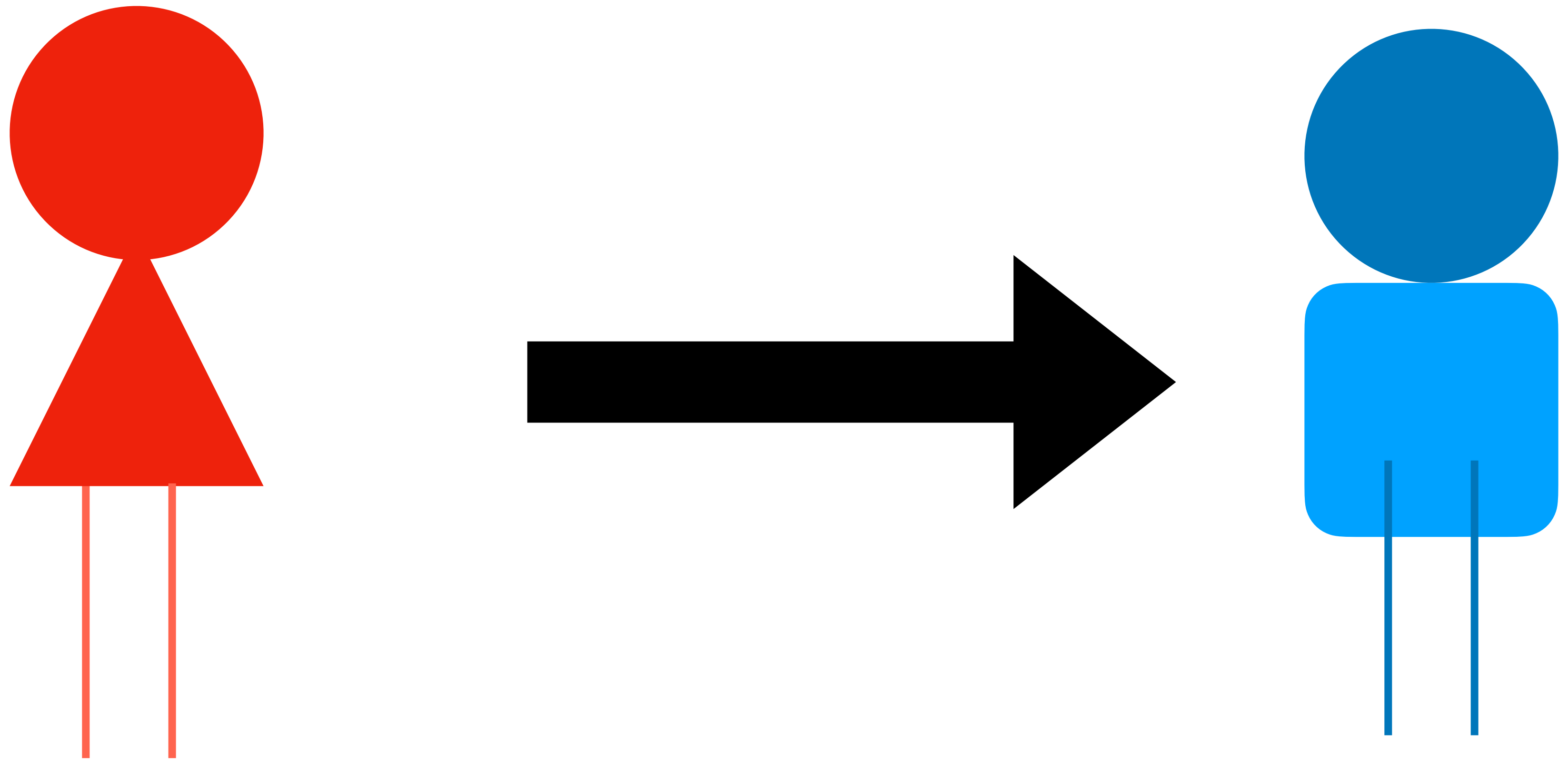
このチュートリアルでは、量子フーリエ変換（QFT）の紹介と、回路の導出、Qiskitを使用した実装を紹介します。実装においては、シミュレーターと5量子ビットデバイスでQFTを実行する方法を示します。

目次

https://qiskit.org/textbook/ja/ch-algorithms/quantum-fourier-transform.html

A3. Quantum Teleportation

Alice



Bob

Alice will transmit the state of a qubit, Q

Receiver

Alice's qubit

Bob's qubit

Assist qubit

1. Alice has a qubit, **Q** with state |Ψ>.
   Alice wishes to transmit the state Ψ >
   to Bob
2. Alice starts with two additional qubits, which we label R and S.
   S will be sent to Bob, and the other will stay with Alice.
3. Alice prepares an entangle state with qubits R and S.
4. Alice sends quibit S to Bob
5. Alice perform a measurement
   on her original qubit Q and half of R

A4. Error-tolerable quantum computing
(誤り耐性量子計算)

- 1995, Shor et al shows that quantum error correction is possible, in spite of the no-cloning theorem.

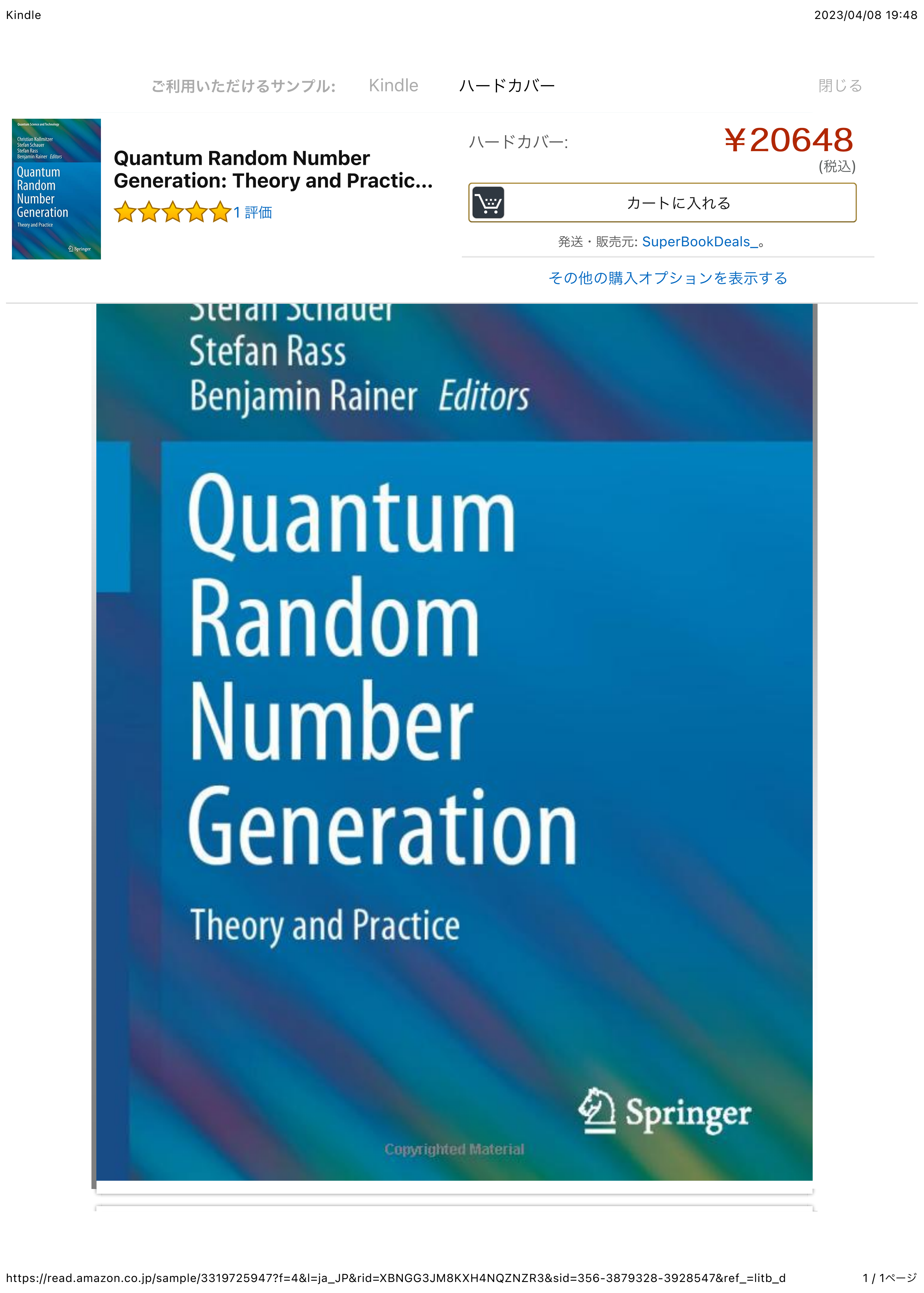
No-cloning theorem: (量子複製不可能定理)

The theorem forbids the creation of identical copies of an arbitrary unknown quantum state.

W. Wootters and W. Zurek,
"A Single Quantum Cannot be Cloned" Nature 299: 802–803.
D. Dieks,
"Communication by EPR devices" Physics Letters A 92: 271

A5. Quantum Random Number Generators

- Important for Monte Carlo simulations
- But old pseudo-random number such as “Linear congruential method”, “Mersenne twister” are not enough ?
- If Quantum computers run very fast, we need lots of Random numbers …



A6.Comparison of R/D among Japan, US, Europe, China

from JST CRDS “R/D and industry trends”

	Japan	US	Europe	China
Hardware				
Basic research	◎ →	◎ →	◎ →	○ →
Application research	○ →	◎ →	◎ →	○ ↗
Software				
Basic research	○ →	◎ ↗	◎ ↗	○ ↗
Application research	○ →	◎ ↗	○ ↗	○ ↗

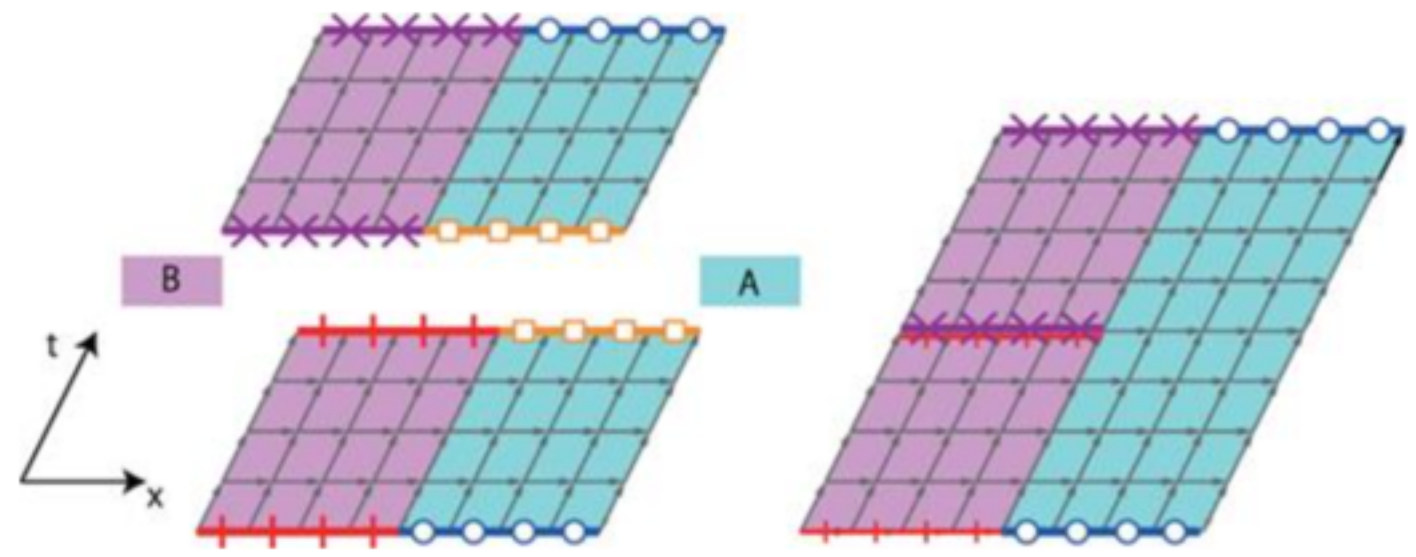
Entropy

Entropy is important quantity.

$$S_A = -\mathrm{Tr}\,\rho_A \, ln\, \rho_A$$

But it is non-trivial to calculate it on the Lattice.

Fig. 1.



In the previous analysis, we got reasonable results.
But we suffered from large errors especially near the phase transition point.
Simulations with the renormalization-group improved action will improve this situation.

Quantum annealing

Developped by D-Wave Systems

1. Backgroud
   - In 2013　IT consumed around 10 % of the world power generation

     Big IT companied construct their data-center at cool areas, for reducing power for the cooling

   - Quantum anneaaling machines using the super-conductivity quantum bits is around 20kW:

     corresponding ca. 50 houses in Japan

     (in case of Super computer, K, around 300,000 houses)

What is Quantum Annealing
(D-Wave System Documentation documentation.pdf)

What is Quantum Annealing?

This section explains what quantum annealing is and how it works, and introduces the underlying quantum physics that governs its behavior. For more in-depth information on quantum annealing in D-Wave quantum computers, see QPU Solver Datasheet.

Applicable Problems

Quantum annealing processors naturally return low-energy solutions; some applications require the real minimum energy (optimization problems) and others require good low-energy samples (probabilistic sampling problems).

What is Quantum Annealing (contin.)

Intuitive explanation by D-Wave in youtube
https://youtu.be/zvfkXjzzYOo

D-Wave company page:

Big Difficulty of Quantum Computers

Quantum Computers will run much faster than super-computers.

But **Noise problem !**

Noise due to decoherence and other quantum noise

For the perfect coherence, the system should be perfectly isolated.	Noise from disturbances in Earth’s magnetic field, local radiation from Wi-Fi or mobile phones, cosmic rays, and even the influence that neighboring qubits

Quantum error correction is inevitable, but not so easy.