

論文 / 著書情報
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論文要旨

THESIS SUMMARY

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| 系・コース： Department of, Graduate major in | 物理学 物理学 | 系 コース | 申請学位 (専攻分野)： Academic Degree Requested | 博士 Doctor of | (理学) |
| 学生氏名： Student's Name | 西村 光嗣 | | 指導教員 (主)： Academic Supervisor(main) | 西森 秀稔 | |
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

In this thesis, we study the simulation of the Griffiths-McCoy singularity on a physical quantum annealer. Quantum annealing is a quantum algorithm that aims to solve combinatorial optimization by using quantum mechanics. This quantum algorithm is now gaining growing attention because of the physical realization of this algorithm which is often referred to as quantum annealer by a company named D-Wave Systems. Although at first it was unclear if this device really uses the quantum mechanics explicitly, it has now been confirmed that this D-Wave quantum annealer can exhibit data that obey quantum mechanics. Though this machine initially aimed at performing ideal quantum annealing, decoherence caused by environment noise also affects the performance of the quantum annealer significantly. Moreover, it has turned out that the measurement result from the D-Wave machine in some cases follows the Boltzmann distribution, leading to practical applications of the D-Wave device as a classical Boltzmann sampler. Recently, another approach of the use of the D-Wave machine, using the D-Wave machine not an optimizer but as a quantum simulator, starts to gain much attention. Initial research of the use of the D-Wave machine as a quantum simulator was done by Harris et al. where they showed experimentally that the D-Wave device can sample quantum thermal equilibrium states with particular annealing schedule. They also show that the D-Wave machine can simulate three-dimensional quantum Ising spin glass. Another example is by King et al. where they show that the D-Wave machine also exhibits the established physical phenomena, Kosterlitz-Thouless transition. Although these physical phenomena can be simulated by using the quantum Monte Carlo method on conventional classical computers in principle, it is still of great significance to demonstrate them on the D-Wave machine because of the following reasons. First, the calculation process between the quantum annealer and quantum Monte Carlo method is intrinsically different. The quantum annealer generates a real quantum state inside the apparatus and outputs the result by measuring the magnetic flux of each qubit, whereas the quantum Monte Carlo method is one of stochastic simulations on classical computers. It can be said that the quantum annealer can be regarded as a device for large-scale real physics experiments with programmable parameters. Simulation on the D-Wave machine corresponds to a realization of physical phenomena that are predicted by numerical computations. Second, the calculation time of the quantum annealer is much faster than that of classical computers. An annealing process inside the device typically takes several microseconds where the quantum Monte Carlo method on the classical computer requires, even with a small number of Monte Carlo steps, at least several seconds.

Motivated by these studies, we show another example of the quantum simulation, quantum simulation of the Griffiths-McCoy singularity, on the D-Wave device. The Griffiths-McCoy singularity can be characterized as a kind of singularity which occurs in a paramagnetic phase on a percolated quantum Ising system and has been studied especially by using numerical computations. Since the previous studies of the use of the D-Wave machine as a quantum simulator mainly focused on the simulation of a global phase transition of the quantum Ising system, this study will give a first example of the use of the D-Wave quantum annealer as a quantum simulator which is different from exhibiting a global phase transition. Note that, though we have emphasized only the use of the D-Wave quantum annealer, the method we use in the thesis can be applied not only to the D-Wave machine but also to the same type of quantum annealer which is expected to be constructed by other organizations shortly.

We first investigated this physical phenomenon by using quantum Monte Carlo simulation on a large-scale computing and confirmed that the model we deal with does exhibit the Griffiths-McCoy singularity. We explored the property of phase transitions and critical exponents using finite-size scaling analysis and then focused on the behavior of the Griffiths-McCoy singularity. We confirmed that the divergence of nonlinear susceptibility induced by the Griffiths-McCoy singularity can be observed by the quantum Monte Carlo numerical calculation.

Next, we demonstrate the simulation of the same model on the D-Wave device. By measuring magnetizations and susceptibilities, we observed a clear sign of phase transition and the phase transition point from the D-Wave machine. We next investigated the Griffiths-McCoy singularity from the histogram of the susceptibilities and confirmed that the result is qualitatively the same as one from the quantum Monte Carlo method. This result means that the D-Wave device can capture the Griffiths-McCoy singularity, which is the first example of the demonstration of this physical phenomenon. This research sheds an important light on demonstrating physical phenomena on a real programmable quantum device, not a simulation on a conventional digital computer.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

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