【Grant-in-Aid for Transformative Research Areas（A）】

Foundation of "Machine Learning Physics" --- Revolutionary Transformation of Fundamental Physics by A New Field Integrating Machine Learning and Physics （Machine Learning Physics）

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Research Area Information	Number of Research Area : 22A202 Keywords : Fundamental physics, Machine learning	Project Period (FY) : 2022-2026

Purpose and Background of the Research

●Outline of the Research

In physics, which has traditionally progressed through both experiment and theory, the search for theoretical principles and mathematics and the development of experiments through technological advances have revealed new aspects of the universe and matter. In computational science, which has contributed to both, the recent technological innovation of machine learning has brought about social innnovation. We have therefore created the field of ”machine learning physics" to integrate machine learning, data science methods, network science, etc., with theoretical methods in physics to discover new laws and explore new materials, which are fundamental issues in fundamental physics. We will integrate particle, condensed matter, gravity, and computational physics with machine learning from the viewpoints of mathematics, statistics, and topology to create a new area ”machine learning physics".

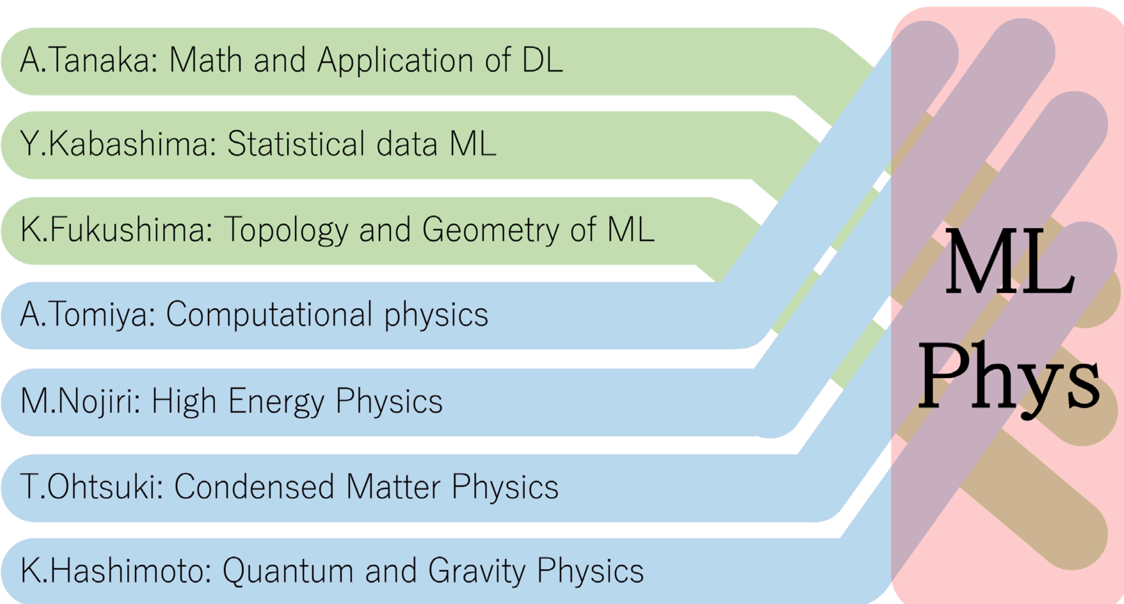

Fig.1 The structure of the research area to merge Machine Learning (ML) and Physics (Phys)

● From research papers to the formation of the research area

The researchers participating in this research area pioneered the application of machine learning to physics by publishing their methods around 2016-2017. These pioneering studies span a wide range of physics, including computational physics, particle physics, nuclear physics, condensed matter physics, quantum gravity theory, and statistical mechanics. Since they are also the basis for subsequent trends, this area was formed as a group that can create the field of machine learning and physics in Japan.

●The basis exists to form "machine learning physics" area

The online community "Deep Learning and Physics (DLAP)," which was initiated in 2020 by the head investigator with the main members of the area, Tanaka, Tomiya, and Nagai, had over 1,000 researchers and students registered by summer 2021, and is holding research talks, discussions, and intensive lectures every other week. This area has received support from this community, and the creation of an active research area has been long awaited. This community is characterized by the fact that it also functions as an educational organization, including many young people such as university and graduate students, and the birth of this area, was the best timing.

The formation of this community was a bottom-up process that took place through the organization of numerous national and international workshops. In June 2017, the head investigator organized DLAP, the first workshop in Japan, and this field was initiated, followed by a JPSJ symposium in 2019, and DLAP2019, the first international workshop. We have also authored several textbooks on machine learning and physics, paving the way for many young researchers in Japan to participate in this area.

Expected Research Achievements

●Combining Physics and Machine Learning to Solve Problems in Fundamental Physics

Physics is originally the study of discovering new laws and phenomena governing the universe and pioneering new materials by finding laws from data to understand the behavior of phenomena. Especially in quantum physics, which governs the microscopic scale, the modern era has seen the development of a variety of experimental techniques that have made it possible to verify the laws. The development of machine learning provides new algorithms that mechanically extract features from vast amounts of data and optimize them in this mutually verifying relationship between theory and experimental data. Applying the methods developed in machine learning to the fundamental problems of fundamental physics will open a new breakthrough to the remaining difficult problems in physics and create a new field of "machine learning physics" that will revolutionize existing physics.

- Acceleration of quantum configuration generation in computational physics.
- Improvement of the detection sensitivity of large accelerator experiments and refinement of corresponding theories in particle physics.
- Quantum complex regime in condensed matter physics, elucidation of quantum fluctuation and quantum entanglement.
- Elucidation of the mechanism of the holographic emergence of the space-time.

●Developing methods to solve physics problems through the new area that takes advantage of the affinity between machine learning and physics

Based on the apparent affinity between the mathematical structure of machine learning and that of physics, it is an urgent task to match the natural history of neural networks, which have evolved to solve diverse problems, with the multi-scale problems of physics. We promote physics-based research on machine learning and to apply it to fundamental problems in basic physics.

- Mathematical elucidation of the mechanism of deep learning using domain knowledge of physics and classification of methods to deal with the problem.
- Overcoming the problem of computational difficulty in machine learning by statistical mechanics/developing the frameworks
- Development of a physics-friendly neural network learning method using topological geometry.

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