Preface

The recent Nobel Prizes in natural sciences illustrate how machine learning techniques have rapidly advanced in recent years and become indispensable in many fields of physics. At the same time, the fundamental concepts of physics have been instrumental in the development of machine learning techniques, leading to a synergistic relationship where machine learning and physics advance hand in hand.

Many-body quantum systems are one of the most challenging problems in condensed matter physics and in other areas such as nuclear physics. Neural networks effectively represent wave functions in many-body systems and have been increasingly applied for the detection of phase transitions. In addition, Monte Carlo sampling and molecular dynamics simulations have been dramatically accelerated by machine learning techniques, while physical concepts such as the Langevin equation and symmetries have inspired significant developments in machine learning.

This Special Topics presents 11 review articles that explore exciting intersections between physics and machine learning. The issue is divided into two parts: the first focuses on the application of machine learning to physics, while the second examines the use of physics concepts to advance machine learning techniques.

The first section begins with a review by Nomura and Imada, which discusses the use of restricted Boltzmann machines to represent many-body wave functions. Bayo, Çivitcioğlu, Webb, Honecker, and Römer use percolation as a case study to explore the properties of deep neural networks. Mochizuki and Miyajima review image recognition techniques applied to the study of the Berezinskii-Kosterlitz-Thouless transitions. Nakamura uses magnetic properties as an illustrative example to comprehensively review Gaussian process regression, a machine-learning technique that does not rely on neural networks. Further, machine-learning techniques are promising for analyzing experimental data. Yamaji reviews the application of neural networks in self-energy spectroscopy. Tomiya examines the acceleration of QCD Monte Carlo simulations through machine learning. Transformer models, which are the core of recent advancements in large-language models, are gaining attention in physics. Hammad and Nojiri review the applications of transformers in high-energy physics.

The second part focuses on the application of physics to machine learning. Hirono introduces the diffusion model, which is widely used in image, audio, and video generation, emphasizing its similarity to the diffusion process described by the Langevin equation. Tanaka reviews the diffusion model from probabilistic and group theoretical perspectives. Kamata and Fukushima expand on this by connecting the diffusion model to the stochastic quantization. Finally, Takahashi reviews statistical physics (replica method) approaches to the problem of variable selection in machine learning, thereby bridging the two disciplines.

This Special Topic highlights the vibrant interplay between machine learning and physics, offering readers a comprehensive view of how these fields drive each other. The editors thank the authors for their exciting and enlightening articles.

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