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4-D Langevin trajectory analysis using machine learning/機械学習を用いたランジュバン軌道解析

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Nuclear fission serves as the most fundamental physics phenomenon underlying nuclear energy. It is quite a complex process of large-amplitude collective motion of finite quantal systems, which produces a huge energy of around 200 MeV/fission, and fission neutrons, which are used to sustain chain reactions, and over 1,000 kinds of fission products are produced. Understanding nuclear fission is also essential in describing the nucleosynthesis in the cosmos since fission recycling is believed to occur in r-process sites. The mass distribution of fission products in the actinide region is known to be characterized by 2 asymmetric peaks, and it turns to a sharply symmetric shape for nuclei heavier than ^{257}Fm while it is mildly symmetric for pre-actinide nuclei. This change in the mass distributions between the dominance of the asymmetric and symmetric distributions gives us an important clue to understanding how fission proceeds. Even though there is a long history of research on the fission mechanisms, the essential mechanisms are still a big mystery, and many studies are necessary to understand them from both experimental and theoretical approaches.
On the theoretical side, a large number of macroscopic, macro-microscopic, and microscopic theories have been proposed to describe nuclear fission. As dynamical theories, time-dependent density functional theories have been recognized to be the most advanced method. However, the calculations start outside the barrier in this kind of calculation since trajectories do not come out if these calculations are started from the ground state or the second-minimum of the potential energy surface inside the saddle point. In this approach, therefore, we cannot understand how the system overcomes the barriers after forming a compound nucleus. On the other hand, the Langevin approach, where the nuclear fission is treated as a Brownian motion of nuclear shape degree-of-freedom, can describe the dynamical process of the system starting from the ground state or the second minimum.
The purpose of this study is to elucidate the basic mechanism of nuclear fission, namely, how a compound nucleus overcomes the barrier and how it leads to population of symmetric or asymmetric fission fragments. For this sake, we calculate fission trajectories in the 4-dimensional Langevin model[1] and analyze the trajectories as time-sequential data by using a Long Short-Term Memory (LSTM) method of Recursive Neutral Network (RNN). The time-series data used for training are preprocessed and labeled by time steps, the atomic number Z and the mass number A of a fissioning nuclide, event numbers, values of four collective variables, and corresponding momenta. Then, classification of symmetric or asymmetric fission is performed using multiple all-coupled layers. This presentation will report a progress of this study and preliminary results.

[1] C. Ishizuka, M. D. Usang, F. A. Ivanyuk, J. A. Maruhn, K. Nishio, and S. Chiba, Phys. Rev. C 96, 064616 (2017).

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