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Active deep learning for single-particle beam dynamics studies

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The dynamic aperture is defined as the region of phase space where the particle motion in circular particle accelerators remains bounded over a fixed and large number of turns. Understanding the key features of this concept offers insight into non-linear beam dynamics and factors affecting beam lifetime in accelerators, which are pivotal for the operation of machines like the CERN Large Hadron Collider (LHC) and the design of future ones, such as the Future Circular Collider (FCC). However, dynamic aperture calculation conventionally involves computationally intensive numerical simulations that track large sets of initial conditions distributed in phase space over multiple turns around the accelerator circumference. This study aims to identify an optimal accelerator parameter set that includes, e.g. betatron tunes, chromaticities, and Landau octupole strengths, which improves the dynamic aperture. This goal is achieved by using a deep neural network model that predicts the dynamic aperture limits using LHC data from numerical simulations. To enhance its performance, we have integrated this model into an innovative Active Learning framework. This framework not only facilitates the retraining and updating of the model but also enables efficient data generation through intelligent sampling.

The framework includes error estimation for predictions and interfaces with traditional simulation tools to correct high errors, improving the model by retraining with the new data.

The results obtained so far demonstrate that the Active Learning framework enables rapid scanning of LHC ring configuration parameters while maintaining the accuracy of dynamic aperture calculations, thereby improving the global efficiency of the non-linear beam dynamics simulations for circular particle accelerators.

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