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Efficient generation of synthetic datasets for magnetic confinement fusion

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We present three case studies demonstrating the minimisation or elimination of human intervention from the process of generating data sets with relevance to different problems in tokamak fusion experiment design and control.

The design of new tokamaks, optimisation of plasma scenarios and construction of real-time control systems in tokamaks require a comprehensive and often expensive exploration of plasma and coil configurations over a high-dimensional parameter space. We present a Markov chain Monte Carlo algorithm to produce large libraries of forward Grad-Shafranov solutions without the need for user intervention. The algorithm minimises the resources dedicated to exploring unsuitable equilibria by assigning a score to points in the parameter space based on the properties of the corresponding plasma configurations. New configurations are sampled based on ratios of scores. This allows the circumvention of problematic profiles or numerical issues in the integration of the Grad-Shafranov equation, a smooth emulation of classic-control matrices, and parameter optimisation towards equilibria with desirable properties (e.g., high flux expansion factor).

Investigating tokamak scrape-off layer and divertor processes for the purposes of machine design and experiment analysis typically requires employing numerical models, which span a broad range of fidelity, completeness and computational expensiveness. These models (such as UEDGE, SOLPS, Hermes, etc.) typically require significant oversight by the operator and are prone to crashes that can be difficult to diagnose. In this work, we report on methods developed to enable the automated creation of large-scale data sets using the code SD1D, including strategies for deployment on HPC systems with minimal resource waste, automated convergence checking, and parameter space exploration.

Finally, we present an active learning pipeline to sample parameter spaces of dynamical systems with possible chaotic solutions, with an application to turbulence simulations. Given a set of simulations and an emulator, the emulated root-mean-square field amplitude yields a prior distribution from which to draw the next simulation parameters, which are then ranked by the uncertainty of the emulator. The prior distribution privileges simulations that are expected to develop a chaotic solution. This approach keeps the computation of expensive simulations to a minimum, while also populating their parameter space efficiently and enabling uncertainty quantification on derived quantities.

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