Surrogate Modelling of the Tritium Breeding Ratio

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The tritium breeding ratio (TBR) is an essential quantity for the design of modern and next-generation Tokamak nuclear fusion reactors. Representing the ratio between tritium fuel generated in breeding blankets and fuel consumed during reactor runtime, the TBR depends on reactor geometry and material properties in a complex manner. In this work, we explored the training of surrogate models to produce a cheap but high-quality approximation for a Monte Carlo TBR model in use at the UK Atomic Energy Authority.

Having implemented and deployed our sampling software on a high performance cluster, we used the MC TBR model to generate over $9 \cdot 10^5$ datapoints for training and test purposes. On this set, we investigated possibilities for dimensional reduction using Principal Component Analysis, Kriging and autoencoders, and concluded that no straightforward reduction was possible without significant information loss. We reviewed 9 families of surrogate models for potential applicability, benchmarked their behaviour as a function of training set size and tuned their hyperparameters via Bayesian Optimisation.

Here we present the performance and scaling properties of these models, the fastest of which, an artificial neural network, demonstrated $R^2 = 0.985$ and a mean prediction time of $0.898\,\mu\text{s}$, representing a relative speedup of $8 \cdot 10^6$ with respect to the expensive MC TBR model. While this surrogate was trained on a set of size $5 \cdot 10^5$, we demonstrated that comparable results can also be achieved using only 10^4 datapoints. We further present a novel adaptive sampling algorithm, Quality-Adaptive Surrogate Sampling, capable of interfacing with any of the individually studied surrogates. Our preliminary testing on a toy TBR theory has demonstrated the efficacy of this algorithm for accelerating the surrogate modelling process.

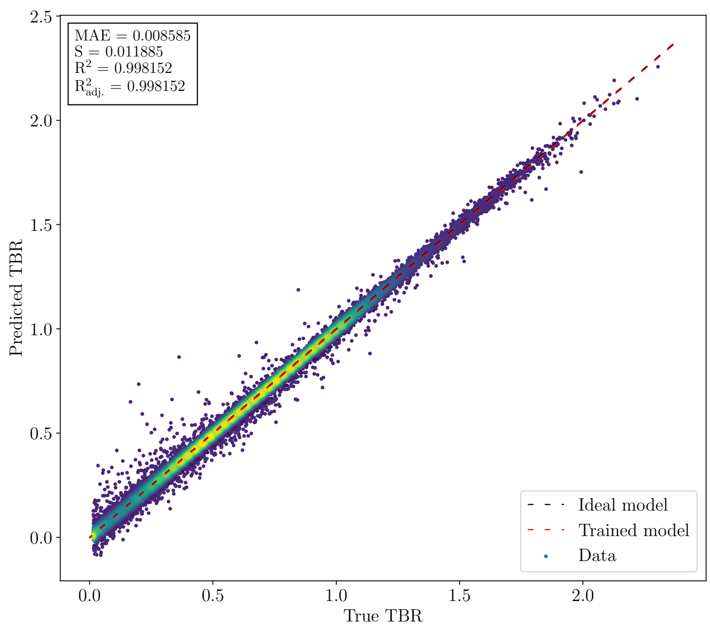

Figure 1: Regression performance of the most accurate evaluated surrogate (artificial neural network), viewed as true vs. predicted TBR on a test set of a selected cross-validation fold (out of 5). Points are coloured by density.