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Deep Learning Acceleration of Progress in Fusion Research

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Accelerated progress in delivering accurate predictions in science and industry have been accomplished by engaging advanced statistical methods featuring artificial intelligence/deep learning/machine learning (AI/DL/ML) that have enabled data-driven discovery in key scientific applications areas including the quest to deliver Fusion Energy. An especially time-urgent and challenging problem facing the development of a fusion energy reactor is the need to reliably predict and avoid large-scale major disruptions in MFE (magnetic fusion energy) tokamak systems such as the EUROFUSION Joint European Torus (JET) today and ITER with targeted first plasma by 2026 in France.

Modern AI/DL/ML methods deployed with the aid of powerful high-performance computing (HPC) capabilities have enabled new avenues of data-driven advances in key scientific applications areas for plasma physics. An especially formidable associated problem involves the prediction and control of large-scale major disruptions in tokamak systems – the most prominent of which is the EUROFUSION Joint European Torus (JET) today which recently established a new record for a DT plasma of 5 seconds confinement time and the ITER burning plasma experiments which are scheduled to begin in 2028. A key challenge is to deliver significantly improved methods of prediction to provide advanced warning for disruption avoidance/mitigation strategies which must be effectively applied before critical damage can be done to ITER.

This plenary talk describes (as illustrated in Figure 1) advances in the deployment of deep learning recurrent and convolutional neural networks in Princeton's Deep Learning Code -- "FRNN" – that has enabled the rapid analysis of large complex time-dependent datasets on supercomputing systems which have accelerated progress in predicting tokamak disruptions with unprecedented accuracy and speed[1]. This represented the first adaptable predictive DL software trained on leadership class HPC systems to deliver accurate predictions for disruptions across different tokamak devices (DIII-D in the US and JET in the UK) – with the unique capability to carry out efficient "transfer learning" via training on a large data base from one experiment (i.e., DIII-D) and be able to accurately predict disruption onset on an unseen device (i.e., JET). Moreover, in recent advances, the FRNN inference engine has been deployed in a real-time plasma control system on the DIII-D tokamak facility in San Diego, California [2]. This can be expected to lead to exciting avenues for moving from passive disruption prediction to active control with the introduction of an innovative deep-learning-based surrogate model ("SGTC") capable of carrying out first-principles global simulations as a "real-time simulator[3] ." Associated interactions with actuators in the plasma control system holds potential for effectively improving the "plasma state" with subsequent optimization for fusion reactors.

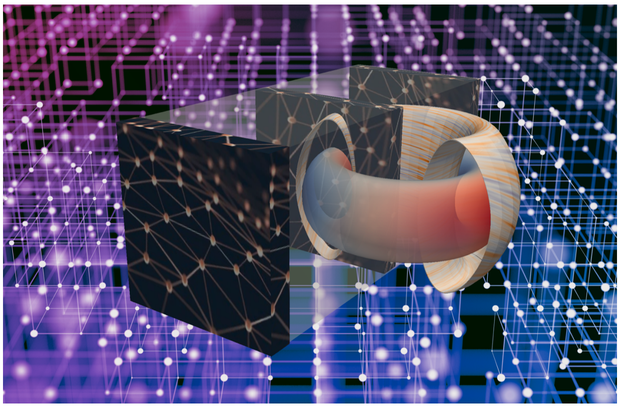

Figure 1. Artificial intelligence/deep learning statistical methods bring new technology to accelerate progress in fusion research, e.g., Princeton's Fusion Recurrent Neural Network code (FRNN) employed convolutional & recurrent neural network components using high-performance computing for training and integration of spatial and temporal data to predict tokamak plasma disruptions; "Predicting Disruptive Instabilities in Controlled Fusion Plasmas through Deep Learning" NATURE: DOI: 10.1038/s41586-019-1116-4)

References

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[3] Dong, Ge et al., "Deep Learning-based Surrogate Model for First-principles Global Simulations of Fusion Plasmas,' Nuclear Fusion 61 126061 (2021).