Empirically Trained Diagnostic Systems (ETDS)

*A **ReNew** research suggestion white paper*

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Background

UNICON's recent participation in the *Small Business Innovation Research* (**SBIR**) programs at the DOD and DOE has inspired us to envision how very large and fast artificial neural networks could be constructed. We believe that our technology [1] allows us to employ very large neural networks in a way that enables a concept we call "***exhaustive learning***" to be applied for the benefit of certain types of complex and slow computational problems. We recently developed a paper [2] for the DOD that described our concept of exhaustive-learning in some detail and it also described some ways it could be used to effectively address massive-data type problems. This ReNeW paper *focuses on* the utilization of exhaustive-learning methods as the basis for certain types of diagnostic solutions potentially important to ITER and the larger fusion energy community.

1 The Problem – The Potential Need For Empirically Trained Diagnostic Systems

Within the last few years we have come to better understand certain needs within the DOE fusion energy community. We understand that the community has been pursuing activities that are significantly focused on high-energy tokamak reactor science. Such scientific exploration demands experimentation. High-energy tokamak experimentation inherently comes with the significant risk that abnormal and unsafe operating conditions will be encountered at the system or subsystem level. Given the high energies involved with such experimentation abnormal events can result in costly damage to equipment or loss of life. Therefore, effective diagnostic systems are highly valuable in such an environment. As scientific efforts progress physics-based models will likely be developed that describe the proper operation of various system components. These models can be used as a guide for the development of real-time diagnostic systems that ensure the safe operation of system components. However, such models generally require experimentation, data collection, data analysis, and time to develop, test, and verify. This ReNeW paper *focuses on* the how we might develop complex and useful diagnostic/monitoring systems before such physics-based models can be developed.

Given the state of the US economy and the strong desire of our political leaders to make rapid progress on clean energy projects there exists the possibility that DOE leadership may be under considerable pressure to consider certain types of *shortcuts* when developing effective fusion energy systems. As an example, complex subsystems may be constructed and operated under schedule and funding constraints where proper behavior can only be observed and empirically verified by DOE scientists in a general way. Therefore, a thorough analysis of proper system behavior may not be initially possible and the development of verified physics-based behavioral models must be performed later. This then leads to an important question: ***How do we develop effective diagnostic/monitoring systems in this situation?***

Of course, we want to operate high-energy experimental systems as safely as possible and we would prefer to have diagnostic systems that are based upon verified models; however, DOE managers and experiment operators may be under pressure to continue to "make progress" and continue experimentation without such verified models. In fact, substantial experimentation may be required to even develop such models. This situation suggests that a reasonable course of action might be to develop diagnostic systems that are based on fast/fuzzy pattern recognition systems that can be trained using empirically collected data to recognize "*normal*" system behavior; such a system could then provide real-time diagnostic alerts when "*abynormal*" operating conditions are observed. It is possible that an entire class of such diagnostic systems might be useful as a stopgap measure to enhance experimental safety until appropriate physics-based models are developed and verified. *In summary, we believe that there is likely a need for fast and effective empirically trained diagnostic systems that can be used to enhance the safety of experiments such as ITER, DIII-D, and others within the fusion energy community.*

2 Technical Requirements For A Solution

Given the high-energies involved in operating modern tokamak reactors we envision that almost every diagnostic/monitoring system will have challenging real-time requirements. Additionally, because complex systems generally exhibit complex behaviors any associated diagnostic/monitoring systems will likely require large amounts of data to be processed in real time in order to determine whether the system being monitored is operating in a safe manner. Therefore, it appears that the requirements for an effective solution are that such diagnostic systems must:

- **(a)** Be able to process potentially large amounts of experiment related data in real-time,
- **(b)** Be capable of learning vast amounts of ***normal*** operational behavioral data,

(c) Be capable of ***generalizing*** when recognizing whether current (unknown) operational data is "***close to***" previously learned operational data that was previously verified by some means,

(d) Be capable of rapidly processing the data provided and provide results indicating ***normality*** or ***abnormality***,

(e) Be capable of generating alerts that indicate that ***abnormal*** or ***unsafe*** operating conditions are present.

3 Elements Of Research Thrusts Needed To Provide The Solution

3.1 A Brief Overview Of The Method Proposed

The basic premise behind this proposal is that fast/fuzzy pattern recognition systems have the inherent capability to generalize upon the data that they learn. Through generalization these fast/fuzzy pattern recognition capabilities allow future operating parameter data to be compared with previously learned data in a way that allows us to quickly determine whether current operating parameters are ***close enough*** to previously learned data to be considered ***normal*** and hence it is presumed to be within a ***safe*** operating region. If the pattern recognition system returns a response that indicates "***not seen before***", then we can reasonably conclude that the system is operating in unrecognized operating parameter territory and we might reasonably conclude that either (a) the system is operating in unsafe conditions, (b) some algorithm should be applied to assess risk, or (c) human intervention is likely required to make a determination regarding the safety of the system. In summary, we believe that it is possible to exploit the ***anomaly detection*** capabilities of fast/fuzzy pattern recognition systems to develop effective diagnostic/monitoring systems.

3.2 Research Thrusts Needed To Develop Effective Tools

Looking forward across the spectrum of potential needs for ITER and the larger DOE fusion energy community we believe that various opportunities exist for the application of advanced pattern recognition methods as the basis for unusual computational solutions to address important technical challenges. The need for experimentally trained diagnostic systems is certainly one such technical challenge. The following list of research thrusts is provided for consideration:

A. **Experimentally Trained Diagnostic Systems (ETDS):** One research thrust suggested (the focus of this paper) is the study of advanced pattern recognition methods as the basis for experimentally trained diagnostic systems. As described in the <u>Theme I Panel Priorities</u> list [3] the DOE currently recognizes an ***urgent need*** for various types of diagnostic systems. As mentioned earlier, diagnostic systems based on verified physics-based models would be preferred; however, when new systems are developed it may take some time before physics-based models are developed and verified. An effective method to develop and *temporarily* deploy a complex diagnostic system that has been trained using empirically collected data would likely allow high-energy experiments to be repeatedly operated with enhanced safety. Additionally, because a baseline for "safe" operation would be learned through training, the subsystem involved can likely be operated with less scientific and technical (human) oversight. This would allow key scientists and technicians more flexibility to focus on true problem areas and not on routine subsystem monitoring issues.

   We understand that one important need for complex real-time diagnostic systems is for the detection of off-normal events; particularly the detection of tokamak instability detection/prediction. If a new reactor is brought online where a **<u>verified</u>** physics-based model is not yet available, a method to effectively implement ETDS will likely provide an important capability for the fusion community. There are potentially a large number of other applications for similar types of ETDS.

Organizational issues: Given the fact that the solution enabling methods described in this section originate within the private sector we suggest that the DOE draw upon and partner with private sector resources in a significant way to accelerate the research and development of advanced systems to meet the urgent needs of the fusion energy community.

4 Anticipated Research Outcome

Should the DOE OFES look favorably on the research thrust topics listed above, this section presents a forward looking ***and admittedly optimistic*** view of what types of tools might be developed as a result of the research and development efforts proposed.

(a) **ETDS:** Given a significant and successful R&D effort we believe that effective ETDS can be developed that are based on advanced fast/fuzzy pattern recognition methods. We believe that such tools will allow high-energy experiments to be conducted with enhanced safety and less technical oversight. Tokamak instability monitoring is one potentially beneficial application area. Numerous others likely exist.

5 References

[1] *CogniMax® pattern recognition technology;* COGNIMAX is a trademark of UNICON Inc.

[2] CADARET, P., "*What Is Exhaustive-Learning?*" (WIEL). Available within the DTIC IR&D collection (www.dtic.mil) with document accession number is 08241207

[3] **Theme I Panel priorities** recently observed:

Theme I Panel	Topics for Burning Plasma Theme	EPAct Report	ITER Research Plan v1	ITER/ITPA High Priority
	Diagnostics			Urgent
Off-normal Events	Disruption/VDE/runaway mitigation	II.B	2.2.3	Urgent