Fermilab Laboratory Directed Research and Development, LDRD

Preliminary Proposal

Project Title: Signal Processing with Recurrent Neural Networks
Principal Investigator: Jason Bono

Supervisor/Line Management Approval: ___________________________________ ___________
Date

Lead Division/Sector/Center Approval: ___________________________________ ____________
Date

Project Summary (~150 words): Project objectives, novelty, relation to mission.

The primary goal is to outperform, in accuracy and precision, traditional frequency extraction techniques, for certain signal types, through the use of simulations to train a Recurrent Neural Network (RNN). The use case here is the frequency extraction of signals from NMR probes in magnetic fields with gradients. In this circumstance, the finite volume of the probe causes complex envelope and baseline evolution, which makes fitting unstable and inaccurate. The fundamental frequency itself drifts, making things worse. Fourier methods loose precision from the frequency drift and from noise. The g-2 techniques are state-of-the-art, but suffer from limitations. They are analytic and are informed by simulation, but project the high dimensionality of the simulation space onto a low one. This works well under restricted conditions that may not hold. A sufficiently trained RNN could capture more of the simulation space and do a better job.

The second goal extends on the primary one. Beyond obtaining a mono-frequency that gives the average field, one can use the temporal structure of the NMR signal to extract information on the spacial structure of the field. Physically, such a mapping exists, but its increase in complexity is very large. The idea is to use machine learning techniques that can handle the complexity of the map and to utilize it. This way, the complex signal structure becomes an advantage rather than a disadvantage.

Achieving both goals will improve the precision and accuracy of the g-2 result by improving the field measurements. Beyond g-2, the project would provide a general and unique tool to aid in precision measurements of magnetic field where low gradients are not possible to achieve. There are two transferable deliverables. One is a probe-specific, already-trained model that could be used out of the box for its corresponding probes. Another would be the raw ingredients needed to build such a model for any probe, including the model architecture that needs to be trained and the simulation package that needs to be tuned and run to generate custom training data. The solenoid field measurements in Mu2e, for example, could use the toolkit.

Project Work Plan (~200 words): Overview description the work to be performed, timescale, and approximate financial/personnel resources required.

One part of this project is generating data, which will be done by continuing a simulation effort that is already mature. The existing simulations model the probes response to magnetic fields. The user inputs a magnetic field and gets a signal in return. Under restricted conditions, a few hundred signals may be sufficient to train and validate the RNN for average field determination (equivalent to frequency extraction). Under realistic conditions, it may take thousands of signals to train the RNN. The secondary goal, wherein the RNN also returns field gradients, may require hundreds of thousands of signals, which would take a few hours of computing time to generate.

Training and validating the RNN will be more computationally demanding than signal generation and will likely require HPC resources available at Fermilab, and possibly require additional resources such as Google Cloud.

I estimate that to achieve all goals, roughly 50% of my time will need to be spent over the next 18 months. To help get started, roughly 80 hours of consulting from Fermilab employees in the Machine Intelligence Group would be needed over the course of a few months. In addition, 40% of a graduate student's or post-doc's time over the 18 months would be helpful.

Comments or Questions (optional).

As far as I know, the use of RNNs to extract frequency in the case of NMR signals has not yet been done, but similar successful projects have been carried out in audio processing. Using the NMR temporal structure to determine field spacial structure has not yet been done—likely because it has not yet been needed. As particle physics experiments go to higher precision, it is reasonable to suspect that such information will be needed and g-2 is one of the first examples.