Computationally Efficient High Resolution Muon Tomography through use of RNN, LSTM and Image Segmentation (IS) Techniques

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1 Project Background

Muon Tomography is a technique that utilizes muon scattering and muon absorption to generate images of large target objects such as buildings, volcanoes, and ancient archaeological structures [4]. Slow rates of successful muon events needed for efficient tomography makes the operation time for Muon Telescopes tediously long and generates copious amounts of data in the process. Most of this data is not of interest to the operator and is discarded. Such premature data processing means that important information about muon spectrum are not being utlized, thereby resulting in substandard tomograms. Furthermore, these resultant tomograms are usually limited to the resolution determined by the hardware configuration of the telescope [5]; The lack of advancments in software techniques to resolve such problems has made this issue worse. This motivates the need for some intelligent data processing regimes that make use of the great volume of data generated without compromising operating time and system resources. Moreover, application of Machine Learning techniques such as RNN, LSTM, and IS should be utilized to mitigate the influence of hardware capabilities that traditionally act as a limiting factor on the resolution.

Our group at Texas Tech University has been working on Muon Tomography for the past 4 years (See a *Symmetry* Article on our work). Last year, we have developed a portable prototype telescope that was capable of generating images at a resolution of 50 milliradians [1]. Presently, we are working on a next generation telescope to achieve 100 times finer resolution by recycling most of the hardware from the previous prototype with the aid of better software. The sequential emission file generated by the telescope makes it an ideal candidate for training RNNs which would recast the problem of predicting ”next hits” as a regression problem[2, 3]. Such a schema can be made further robust by using LSTMs to contextualize the entire data frame, thus, providing an additional constraint on the training regime for the RNNs. Image Segmentation is finally used to generate pixel map and extract shape information of target object to add the final constraint layer for RNN training regime.

2 Project Proposal

The primary goal of this project would be to publish a computationally efficient python package that implements the aforementioned Machine Learning techniques to generate robust and high resolution tomograms from muon telescope datasets. The software architecture would be designed prioritizing high parallelization, whenever admissible, to reduce run time of analysis. I also aim to implement a thread balancing scheme through the use of LSTM networks to determine regions of interest a priori as a part of the calibration process of the telescope which would help diminish the effects of non-uniformity of stochastic scattered muon hits. Following this initial objective, I will develop an

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additional python package that would extend the functionality from the previous package to cover the functional requirements of general tomography. Throughout this project I will be learning more about Machine Learning, Tomography and Parallel Computing, I aim to analyze the various techniques recommended in literature and report on their efficacy in regards to the benefits it provides to our original goal. This project would be carried out at the Advanded Detector Particle Laboratory at Texas Tech University under the supervision of Dr. Akchurin.

3 Deliverables

- Creation of a comprehensive dedicated Muon Imaging Framework leveraging popular tools in ML
- Development of a well documented python package with easy to use API with implementations of RNN, LSTM and IS for applications in general tomography regimes
- Final report on a study of parallelized ML schemes for faster and more efficient training of Neural Networks

4 Timeline

I would be taking the least amount of hours in my Undergraduate career ever in Fall 2021 since I am graduating and hence I can devote most of my time to ensure successful completion of the project.

- **Week 1:** Project setup; Implementation of *input data agnostic* framework for training RNNs and LSTMs (using TensorFlow) done seperately.
- **Week 2-3:** Combine the various training frameworks into a parallelized/distributed set up; Design testbed for verifying effictiveness of multithreading and cohesiveness of various ML components.
- **Week 4-5:** Train the comprehensive regime on simulated ”ideal” muon data for calibration and conduct thorough unit validation tests; Generate tomograms and compare with base case.
- **Week 6:** Train the program on prerecorded ”real” muon data; Start implementation of IS to extract pixel map and shape information; Merge the IS functionality into the regular operation of the telescope.
- **Week 7-8:** Study the performance of IS in the tomogram generation process; Implement the thread balancing scheme; Calibrate and train all the different parts of the software together.
- **Week 9-10:** Start testing performance of comprehensive system in on field real time operation using the prototype detector; Create wrappers for core functionality; Finish Code Documentation and Tutorials.
- **Week 11:** Create new package for general tomography.
- **Week 12:** Submit both packages to Python Package Index (PyPI); Finilaze and polish the manuscript for the study.
- **Week 13:** Prepare final report with findings.

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5 Student Background

I am a senior Applied Physics and Mathematics major with a Computer Science minor from Texas Tech University. I have been working with the Advanced Particle Detector Laboratory at Texas Tech University for the past two years on various Muon Tomography projects - *developing Monte Carlo simulations using Geant4 to test experimental data integrity, designing custom Printed Circuit Boards (PCBs) for more efficient read out electronics, assisting with mechanical and electronic assembly of two different prototype Muon Telescopes, conducting statistical and image analysis on measured datasets*. Presently, I am studying and implementing Machine Learning techniques for Muon Tomography. In addition to my work with the High Energy Physics group, I have also worked on developing simulation and analysis software for Autonomous Vehicle systems (see CV for more details), parallelized calibration framework for traffic flow simulation software (see CV for more details) and contributed to various Open Source Quantum Computing projects. The proposed project will allow me to apply my knowledge of software design, machine learning and data analysis to solve one involved problem and would serve as an excellent segway as I start my PhD journey in the Spring of 2021.

References

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