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Image content understanding in the future massive Liquid Argon Time Projection Chambers

Liquid Argon Time Projection Chamber (LArTPC) detector technology is the tool for neutrino physics studies, with the ultimate and ambitious goal of building the 40kt DUNE detecor (Deep Underground Neutrino Detector), to be placed on the neutrino beam by 2026 (ref. 1). LArTPC is all about imaging the particle interactions in high resolution and large volumes.

LArTPC detector technology is present on the neutrino market for many decades, however the techniques of processing the LArTPC data are still under very active development and offer a large unexplored field of possible approaches. Today's jump in the availability of parallel processing hardware and the progress on the neural network processing open an obvious direction for the LArTPC data analysis development. Our team, after development one of the major currently used solutions in 3D reconstruction (ref. 2), is now convinced that research should be pushed in this direction and combine machine learning with algorithmic solutions that are already developed for LArTPC's.

The idea is far beyond simple application of the newly available machine learning toolkits. Any approach attempted in LArTPC realm needs many layers of pattern and context recognition in order to make the interpretation of images useful for physics analysis. Briefly summarizing: interesting interaction needs to be localized among tracks of background particles, large- and small-scale features have to be recognized in order to find the primary interaction point and understand species and energies of outgoing particles, all of that under the strict control of systematic uncertainties which are the priority for the DUNE experiment. Finally and the most importantly for the image processing challenge: events in the images do not follow regular shape templates; the interpretation has to be done on a high level of abstraction.
Challenge in the machine learning based approach to the analysis of LArTPC images comes also with the huge volume of data. Even though the expected experimental data amount for DUNE is manageable already today (order of PB), data sets larger by many orders of magnitude are foreseen in the R&D process towards formulation of efficient image content recognition. Today's technical limitations result with simplicity of algorithms for deep convolutional neural networks (CNN) training, while much more advanced algorithms do exists for the standard, multi-layer perceptrons; such methods should become available for CNN with the hardware developments.

The proposed research in our vision should become competitive in applications beyond the physics data analysis. The perfect example is the medical image recognition, such as reconstruction and interpretation of vascular trees or mammograms, often very similar to the LArTPC images in the signal to noise quality, resolution and even the object shapes. We also note an important synergy between medical and physics data processing: in both cases the understanding and control over systematic properties of algorithms are extremely important factors.

Let us close the abstract with two remarks about very distant in time events. We are now standing at the beginning of the exciting research, with the first proof of concept. However the future of LArTPC's is the 3D readout replacing multiple 2D projections, vastly improving the potential of the particle interactions imaging, and opening new challenges for analysis techniques.

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Fig.1. Neutrino event among cosmic muons in the MicroBooNE LArTPC detector (source: http://www-microboone.fnal.gov/first-neutrinos). Each event in LArTPC is to be reconstructed and interpreted from two or three such 2D projections made at different angles.

References:

1. DUNE Collaboration, *Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE) Conceptual Design Report Volume 1: The LBNF and DUNE Projects*, ArXiv 1601.05471, 2016
2. ICARUS Collaboration, *Precise 3D track reconstruction algorithm for the ICARUS T600 liquid argon time projection chamber detector*, AHEP 260820, 2013, see also the up-to-date shape on: http://larsoft.org/list/

Summary

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