A machine-learning based raw waveform ROI Finder in LArSoft

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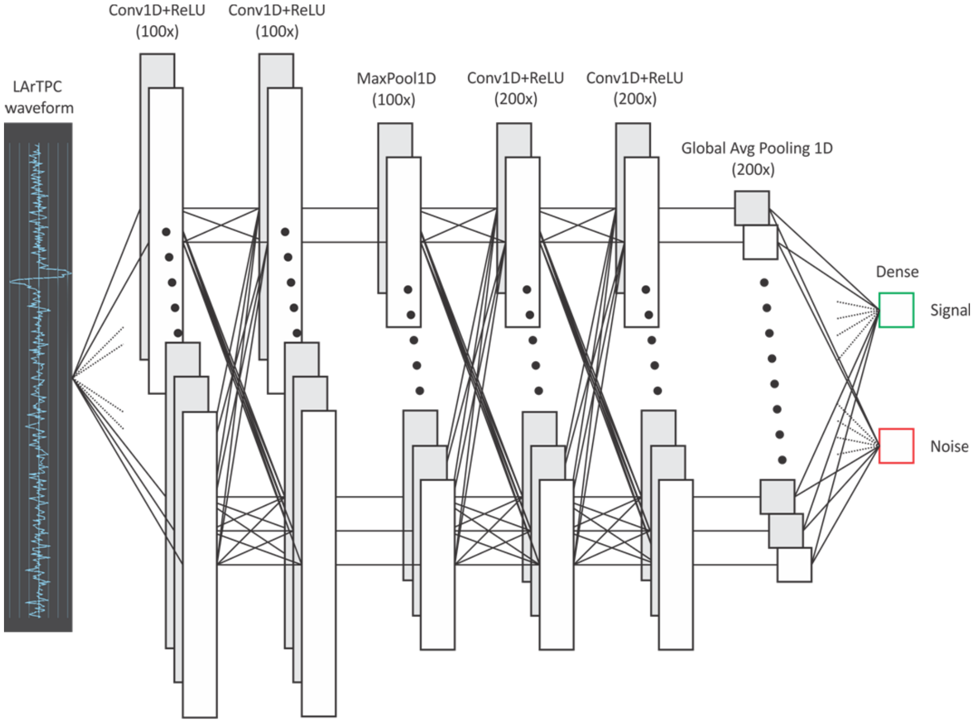
Introduction

- Motivation:
  - 10k's of wires in a typical LArTPC-based neutrino experiment
  - potential problem considering amount of data from all these channels that need to go through the computationally intensive signal processing algorithms (fft deconvolution, etc.) typically used by neutrino experiments to find signals
  - serious challenge for experiments that have to deal with huge backgrounds
  - or those that are interested in extracting small signals from low-energy phenomena
- Approach:
  - use modern deep learning (DL) methods
  - DL nothing new and now commonly used in neutrino experiments, but these algorithms tend to deal with higher-level reconstructed objects
  - in fact, some now investigating use of DL on raw LArTPC data, but these still tend to look at data across planes or multiple wires to form 2D images
  - common notion that Deep Neural Nets (DNNs only effective if data presented as pictures, images or in 2D form
  - no such constraint for DNNs, and in this talk, we describe our novel approach of using simple 1D-CNNs to look directly at raw temporal waveforms from single LArTPC wires

Initial Attempt

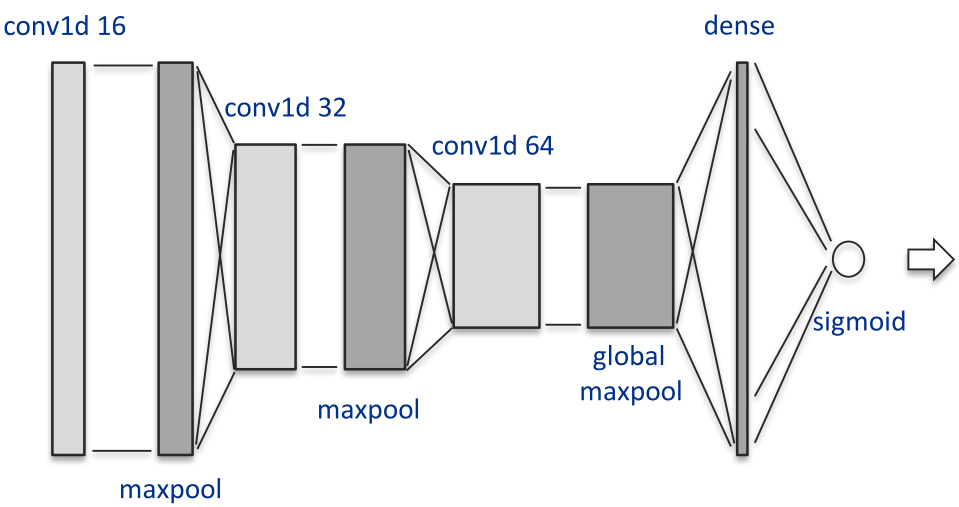
- Began this effort about a year ago with David Ruth (Fermilab TRAC-program teacher/intern) where we adapted 1DCNNs used to analyze cell phone accelerometer data to the analysis LArTPC waveforms:

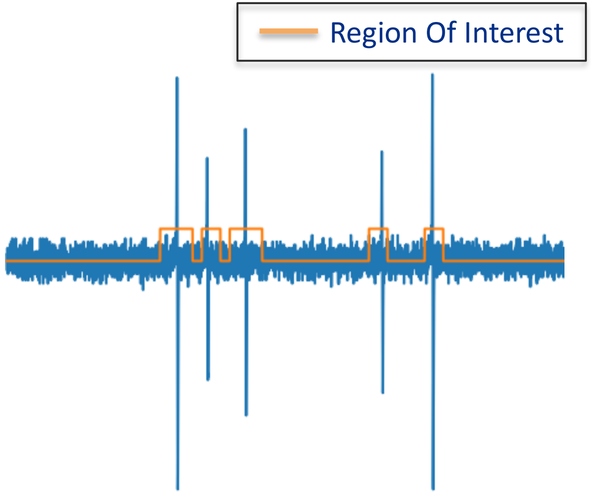
Applied this to simulated DUNE data samples with promising results in signal/noise discrimination



Further Development & Current Model

- Based on the promising results, we continued developing the idea and model with Lorenzo Uboldi (Fermilab Italian Students Summer program)
- Two major developments:
  - Significantly simplified the 1DCNN model we had used initially
  - Extended the technique to the identification of the Region Of Interest (ROI) in the waveform

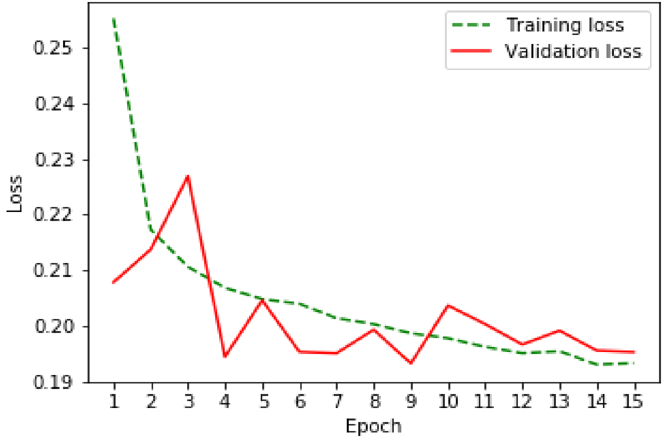


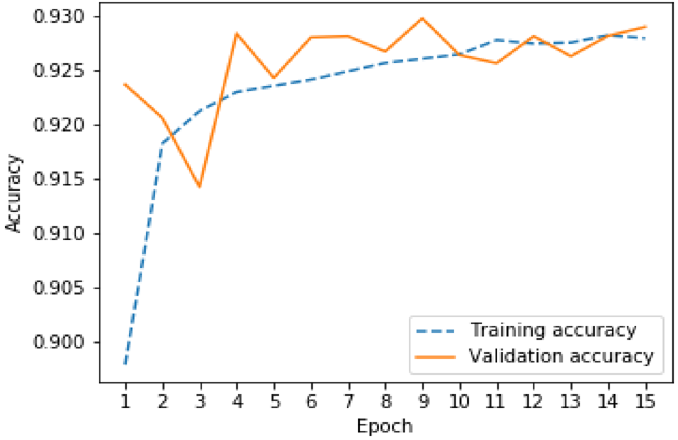


Training and Validation on simulated ProtoDUNE samples

From Lorenzo

- Trained on 112k samples, validation set 28k samples
- Half signal and half noise waveforms
- Binary cross entropy loss with adam optimizer
- 15 epochs, batch size 64 optimized for learning convergence
- Very fast: 6 minutes on a Nvidia GTX1060

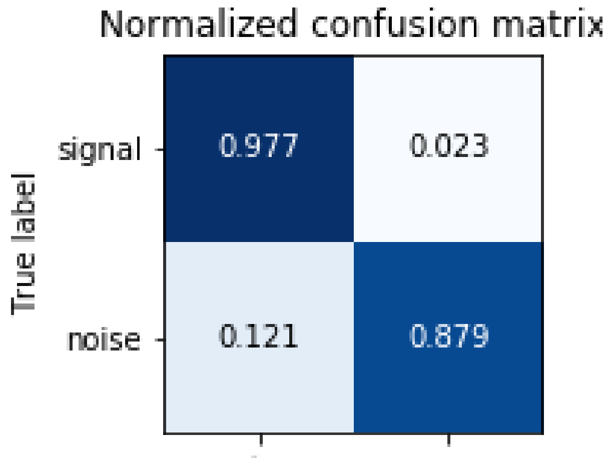


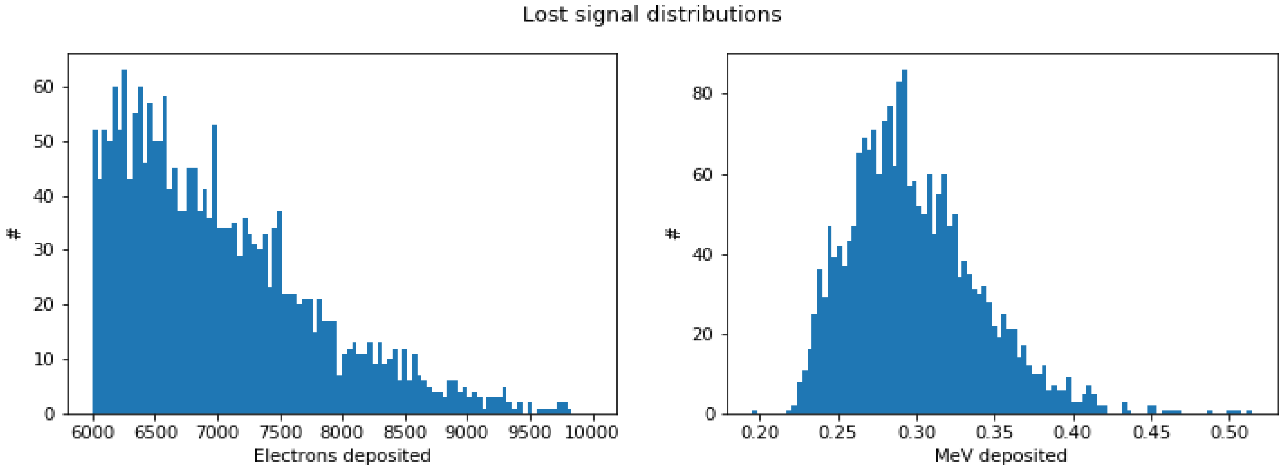


Testing Results on ProtoDUNE samples

From Lorenzo

- Test set with 35k examples
- 1.8 seconds on Nvidia GTX1060
- Test accuracy 0.93

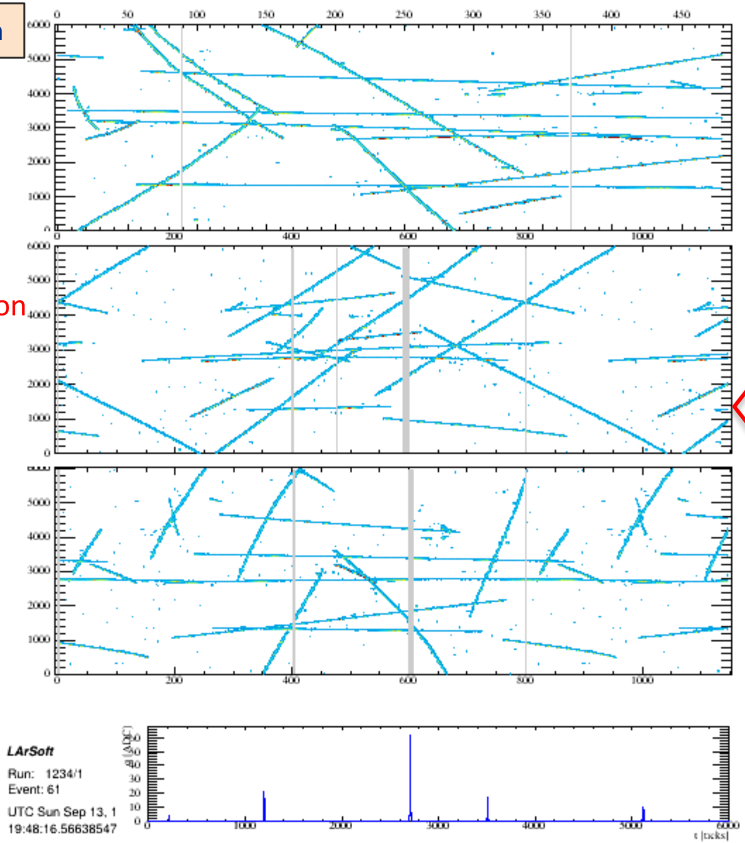


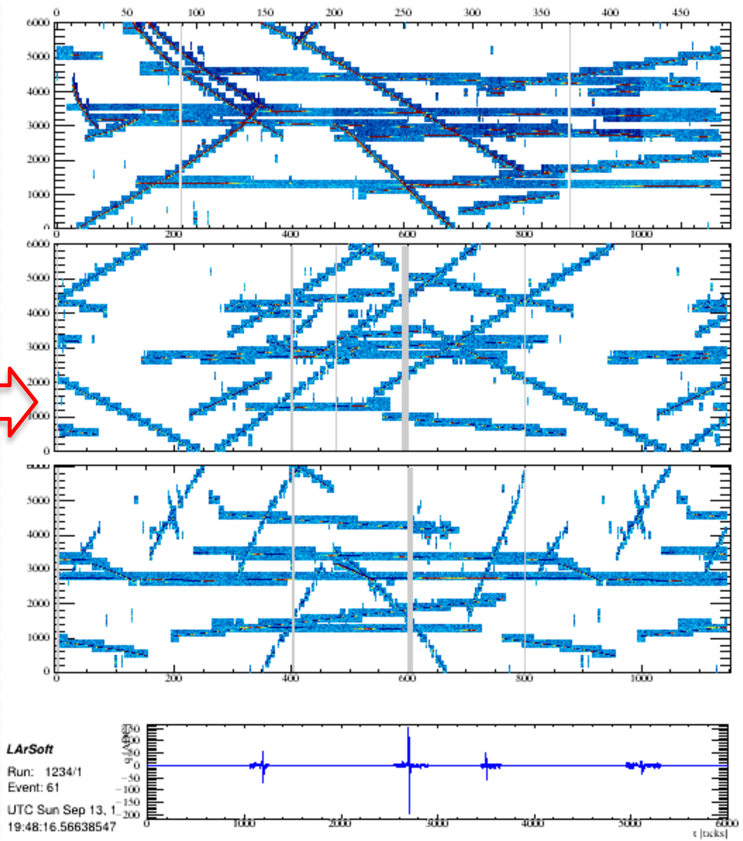


Trained model applied to simulated ProtoDUNE samples

From Tingjun

Deconvolution based ROIs



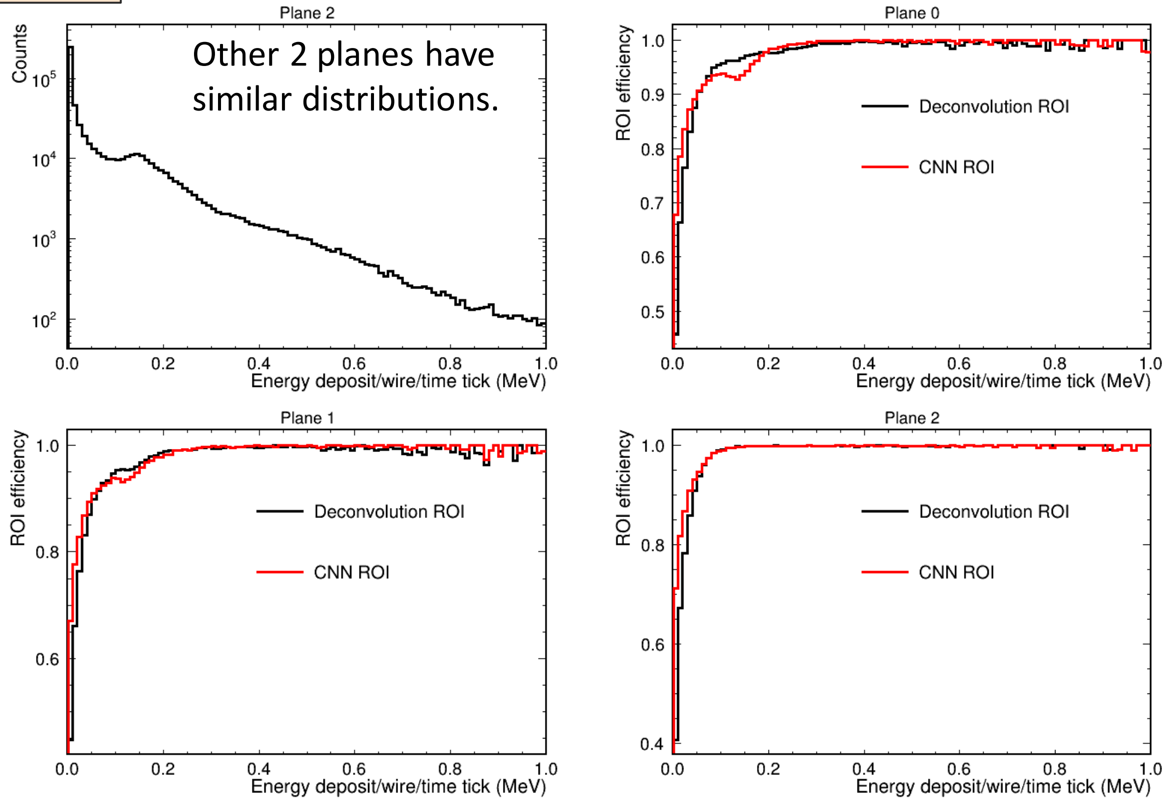


1D CNN based ROIs

Efficiencies determined from simulated ProtoDUNE samples

From Tingjun

Efficiency of ROI finding algorithms



Other 2 planes have similar distributions.

Two components in the energy distribution: radiological backgrounds (^{39}Ar etc.) at low energy and muons at high energy.

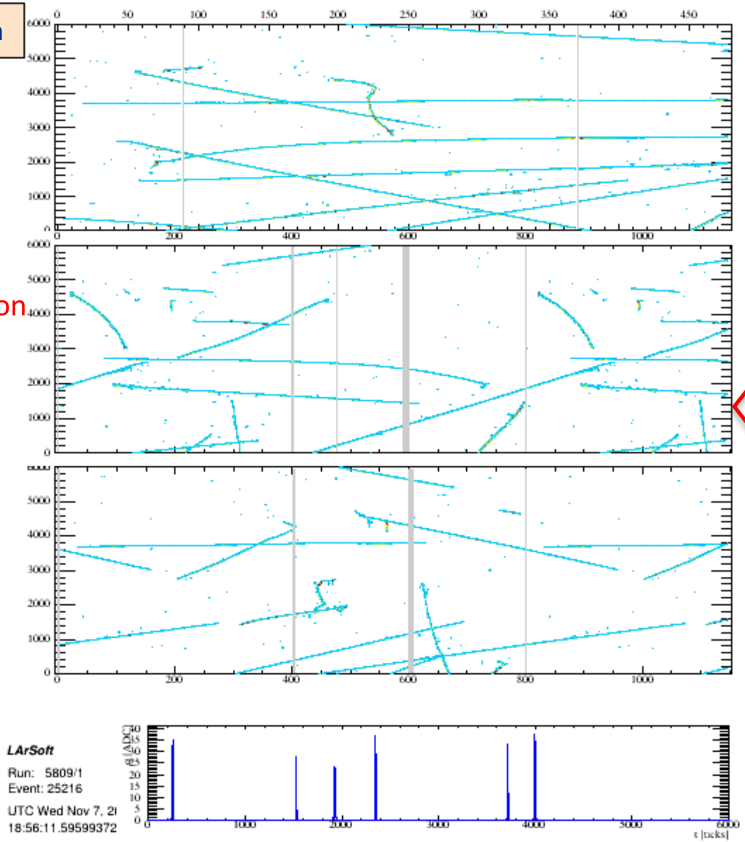
CNN based ROI finder gives comparable results versus the deconvolution based ROI finder.

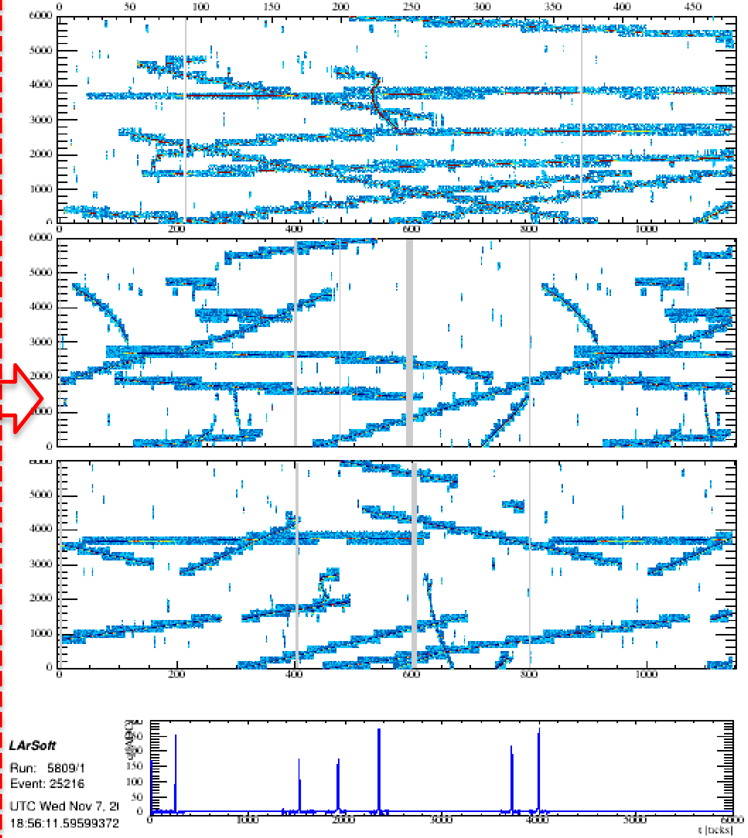
CNN based ROI has a fixed size, so it is not a direct comparison.

Trained model applied to real ProtoDUNE data

From Tingjun

Deconvolution based ROIs



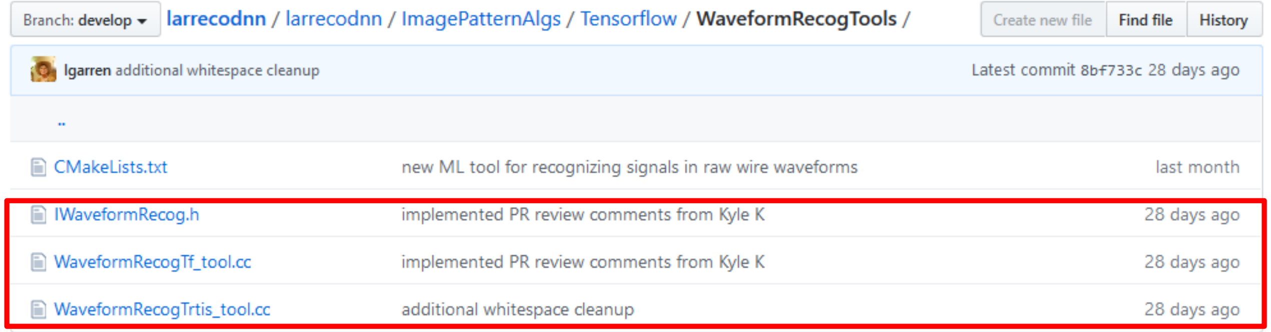


1D CNN based ROIs

Significance of ProtoDUNE studies

- Main takeaways from previous two slides
  - Certainly, traditional deconvolution based ROI finder does a better job in localizing the signal
  - Main point, however, is that the CNN-based tool approximates the results very well by dealing directly with unprocessed raw waveforms, without relying on the computationally demanding algorithms in the typical LArTPC signal processing pipeline
  - Implications:
    - Offline use: can be implemented in early stages of offline reconstruction as a very effective filter or sophisticated zero-suppression algorithm, so later stages can implement more sophisticated signal processing on much less data
    - Online use: simple CNN architecture can be implemented in hardware and deployed in front-end boards for intelligent filtering or as a trigger
  - Also important to note preliminary nature of results, algorithm is likely not optimal yet and can be further improved

LArSoft Tool and Module



larrecodnn / larrecodnn / ImagePatternAlgs / Tensorflow / **WaveformRecogTools** /

lgarren additional whitespace cleanup — Latest commit 8bf733c 28 days ago

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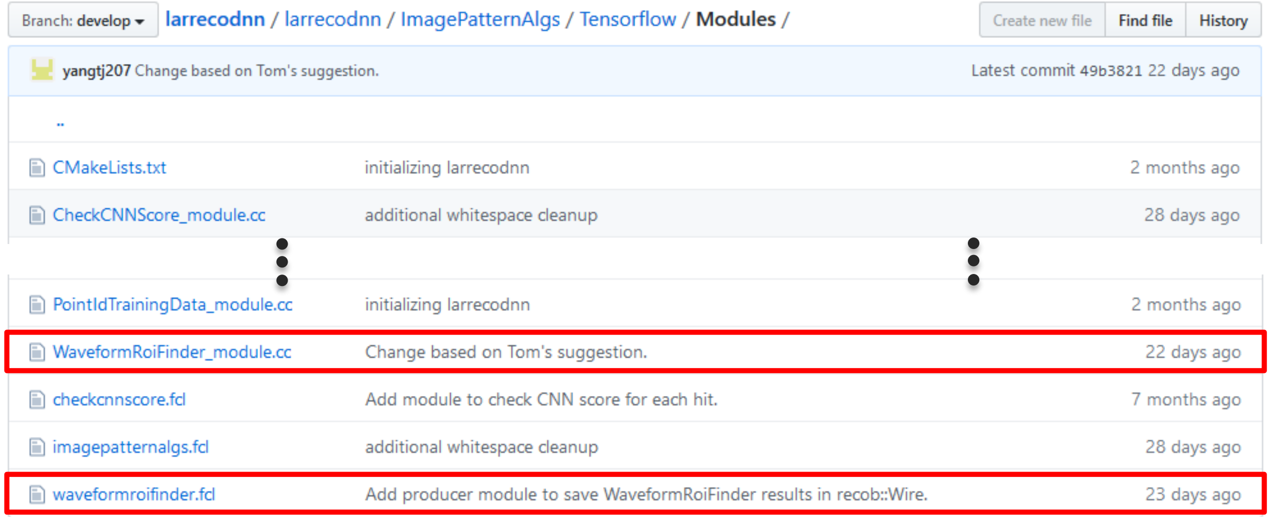
CMakeLists.txt	new ML tool for recognizing signals in raw wire waveforms	last month
IWaveformRecog.h	implemented PR review comments from Kyle K	28 days ago
WaveformRecogTf_tool.cc	implemented PR review comments from Kyle K	28 days ago
WaveformRecogTrtis_tool.cc	additional whitespace cleanup	28 days ago



larrecodnn / larrecodnn / ImagePatternAlgs / Tensorflow / **Modules** /

yangtj207 Change based on Tom's suggestion. — Latest commit 49b3821 22 days ago

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CMakeLists.txt	initializing larrecodnn	2 months ago
CheckCNNScore_module.cc	additional whitespace cleanup	28 days ago
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PointIdTrainingData_module.cc	initializing larrecodnn	2 months ago
WaveformRoiFinder_module.cc	Change based on Tom's suggestion.	22 days ago
checkcnnscore.fcl	Add module to check CNN score for each hit.	7 months ago
imagepatternalgs.fcl	additional whitespace cleanup	28 days ago
waveformroifinder.fcl	Add producer module to save WaveformRoiFinder results in recob::Wire.	23 days ago

Conclusion

- Shown that DL techniques can be applied to single LArTPC wires not only to discriminate signal from noise waveforms but also to localize the signals within the waveform
- Deployed a new tool and module in LArSoft that performs this functionality
- Tested the tool/module on real ProtoDUNE data with very encouraging results
- Implications for intelligent offline and online filtering applications
- Next steps:
  - More studies to characterize performance of algorithm
  - Optimize the algorithm further for performance and computational speed
  - Started looking at Argoneut data, looking into to developing better noise model so the model can be trained effectively
  - Look into possible hardware implementation for online applications

End