Online triggering with deep learning
AI for particle imaging detector

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Particle Imaging Detectors: LArTPCs

Data taking
2015-2021

Data taking starts 2023

Timeline ~ 2030

Data taking
2022-2027
The Crux of LArTPCs: Next Gen Particle Imaging Detectors

- Excellent particle imaging detector
- mm scale spatial resolution
- Light signal by PMTs

Current generation LArTPCs

Diagram showing charged particles and waveform signals:
- Sense Wires U, V, Y
- Time (Drift Direction)
- Wire (Beam Direction)

Color corresponds to deposited charge:
- Protons
- Electron shower

Fermilab
LArTPC Images:

LArTPC - a sneak peek into the world of neutrinos

showers

ν

18 cm

LArTPC - a sneak peek into the world of neutrinos

Event Reconstruction

Online/Real-time Triggering and Tagging

showers

track

track

Next Gen LArTPCs

Bigger Detectors → more neutrino interactions expected

Challenge - efficient, fast turnaround data processing to meet physics goals

1X ~ 5X ~ 500X

LAr Mass

Data rates

1X 5X ~100X

33 GB/s 45 GB/s 5 TB/s

μBooNE SBN Program DUNE

#channels
DUNE - Future Flagship Experiment @ Fermilab

● World’s largest multi kiloton LArTPC detector

● One of the major physics goals
  ○ study rare (off-beam) events at Far Detector

Expected data rate ~1.15 TB/s/ 10kT

Requirement: efficient and continuous data processing
DUNE - Future Flagship Experiment @ Fermilab

- World’s largest multi kiloton LArTPC detector
- One of the major physics goals
  - study rare (off-beam) events at Far Detector
- Requirement: efficient and continuous data processing

“For in this new era, the neutrinos bring it’s trigger, the key to everything” - Chatgpt
ML based Trigger Algorithm

- Parallel trig. algorithm: Identify $\nu$ & $\nu$-like interactions

Shower - electron, photon, michel, delta

Track - Muons, Pions (MIP) or Protons (HIP)

Other - Low energy blips
Dataset Info:


- Simulated neutrino interactions, overlaid on top of cosmic ray data

- Goal: develop a TPC-data based ML algorithm
  - Use wire waveform information from opendata

- Training logistics -
  - Crop image around highest pixel value
  - 512 X 512 pixel maps as input
  - Samples
    - Trained on ~34,000 events
    - Validation ~ 4,000 events
    - Test sample ~ 4,000 events

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**MicroBooNE Public Data Sets: a Collaborative Tool for LArTPC Software Development**

Giuseppe Cerati, Track 8
Semantic Segmentation Ingredients:

- Cropping around highest pixel value
- Corresponding pixel truth map

Pixel-level object recognition - Classify every pixel into pre-defined semantics (labels)
Network Architecture:

- Sparse images → < 1%
- NVIDIA - Minkowski Engine
- Training on Nvidia A100, Elastic Analysis Facility at Fermilab
- Test on CPU

Sparse approach → less matrix multiplication → better timing and memory usage → well suited for trigger algorithm
Network Architecture:

- Depth = 5 (downsample steps)
- Filters = 64
- Kernel Size = 3X3
- Cross Entropy Loss Function
- Class imbalance
  - Class wise loss weighting
- ADAM optimizer
- Learning Rate = 1e-4
- Output 512 X 512 with 3 channels per pixel encoding a probability (SoftMax classifier)
Network Prediction:

ADC Values  Ground truth  Predicted image

Overall accuracy of the network  85%
The performance tests were done on an Intel core i7-8750H CPU 2.2 GHz.

<table>
<thead>
<tr>
<th>Network Used</th>
<th>Memory Usage</th>
<th>Inference time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparse approach</td>
<td>0.3 GB</td>
<td>~0.23 s</td>
</tr>
<tr>
<td>Dense approach</td>
<td>2 GB</td>
<td>~3 s</td>
</tr>
</tbody>
</table>
Summary:

- Promising results in terms of timing and memory usage for a trigger algorithm
- Further classification among shower
  - Target: Identify EM showers in low energy region
  - Potential for calibration purposes
    - Using Michel electrons
- Future possibility includes triggering on some of the on-beam activities
- Possibility to use ML tools on specialized hardware such as FPGA (power efficient)
TPC Based Trigger System R&D

- Excellent opportunity at MicroBooNE for R&D
- Modify the readout system at MicroBooNE to test DUNE trigger design

NU: externally triggered data stream, not sensitive to Supernova events

SN: Continuous readout, Regions of Interest (ROI) - waveform over certain threshold

Trigger Primitives:
- SN ROI Summary
  - Amplitude
  - Integral
  - Time over threshold

External Trigger
1.6 ms

NU Stream

SN Stream

ADC Counts

Time Ticks
Thank you!

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